12 September 2007, draft 3.0

DOUBLE CHOOZ

TECHNICAL DESIGN REPORT

EDMS ID : I-010643 – DRAFT V3.0

Authors (to be completed):

J.C. Anjos , F. Ardellier, A.F. Barbosa, , JC Barriere, J. Beltramelli, E. Bludcher, NS Bowden, C. Buck, J. Busenitz, E. Casiimiro , S. Cazaux, E. Calvo, M Cerrada,, Y. Endou C. Fernandez, T. Hara, Y. Fukuda, H. Furuta, H. de Kerret, I. Gil Botella, M. Goeger-Neff, P. Guillouet, T. Haruna, F.X. Hartmann, T. Horiuchi, G. Horton-Smith, Y. Kamyshkov, T. Kawasaki, E. Kemp, D. Kryn, M. Kuze,T. Lachenmaier, C. Lane, T. Lasserre, H. Lima Jr , T. Matsubara, F. Meigner, G. Mention, H. Miyata, M.Motoki, Y. Nagasaka , H.Ota C. Palomares, P. Pfahler, P. Perrin, B. Reinhold, D. Reyna, I. Rodriguez, Y.Sakamoto, L. Scola, R. Svoboda, F. Suekane, T. Sumiyoshi, T. Sumiyoshi , Y.Tabata ,N. Tamura, H. Tanaka,F. Toral, F. Valdivia, A. Verdugo, D. Vincent, G. Yamasaki,A. Yoshino ….

CONTENTS

1. Introduction

The Technical Design Report (TDR) for Double-Chooz project is intended to fulfil with several purposes:

- It gives the technical details to allow a practical realisation of the components necessary to construct detectors. The physics requirements can be found in the Double Chooz proposal (hep-ex/0606025).
- It will be an internal documentation tool for communication within the collaboration, and it describes the components of the detectors and their interfaces. It is useful for the following purposes :
    - Defining the components / objects of the detectors
    - Describing the details of interfaces between components
    - Identifying missing components
    - Following the progress in the implementation of the detector: tests of components, assembly protocols.

    Some items will be with a ‘draft status’ and will be updated during the project progresses.

The detectors components are defined in a Product Breakdown Structure (PBS) described in the management chapter.

The TDR will be divided in several chapters grouped according to the organisational breakdown structure of Double Chooz collaboration, with its division in tasks and responsibilities.

In a first time, the document will only **deal with the far detector**.

Each chapter describing the detectors components will be independent from the others.

In a first time, the TDR will deal only with the far detector architecture. The architecture of the near detector will be identical to the far detector until the Buffer area. This change could be the consequences of the localisation and the civil engineering of the near laboratory.

The project of detector realisation will be presented and also how it will be managed.

The constraints for the development and the detector construction will be presented.

Then you will find a description of all components and then the specific system protocol to reach the performances will be exposed.

2. Overview of the detectors

The Double Chooz detection is based on two almost identical detectors located at the Chooz EDF nuclear power plant.

- The far detector is located in an existing lab (called Neutrino Lab) at 1,05 km from the two nuclear cores of Chooz.
- The near detector will be installed in an underground laboratory to build located at around 300 meters from nuclear cores.

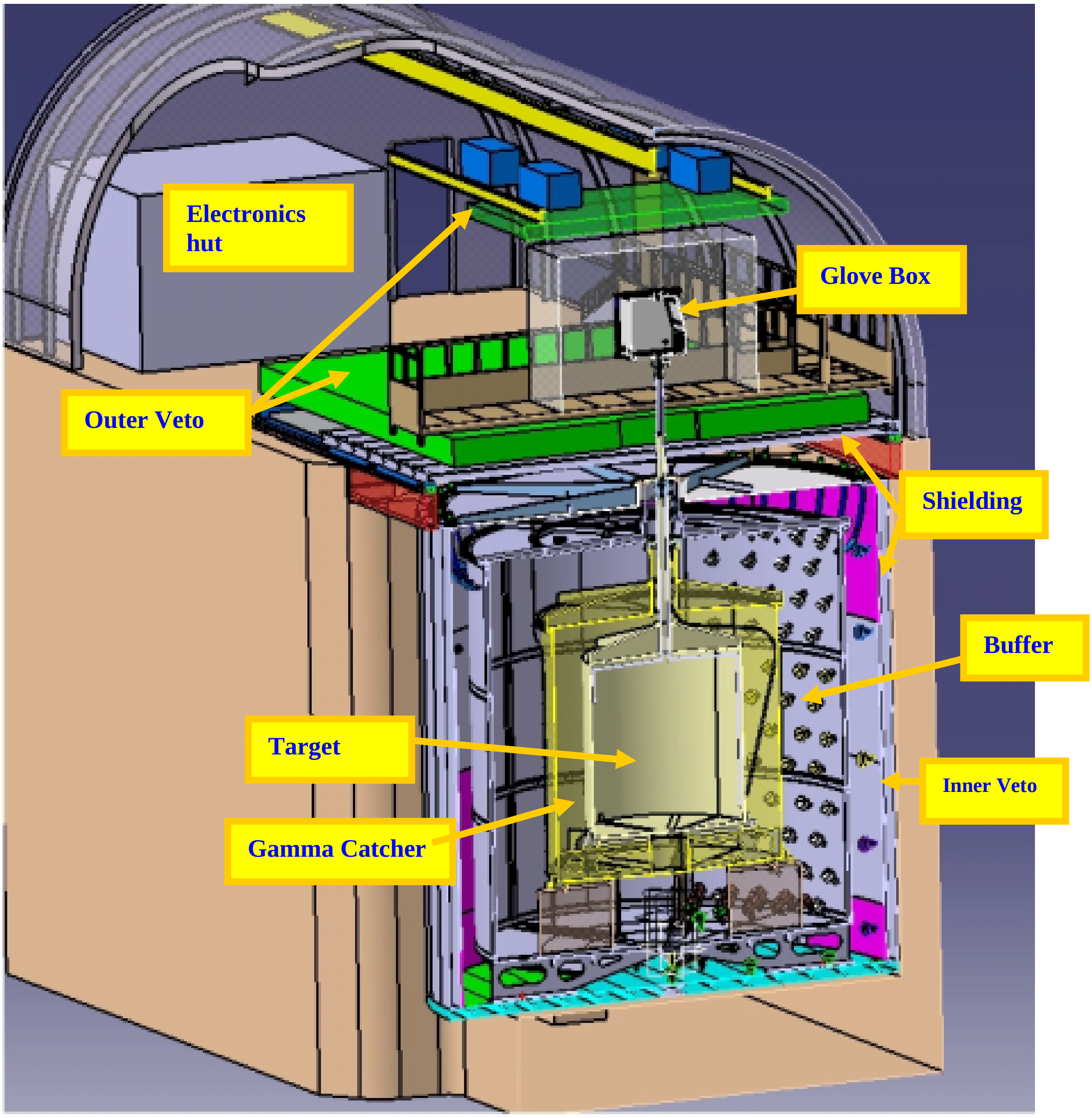


Figure 1: layout of the far detector

Each Double Chooz detector will be made of 6 distinct areas with the main following functions:

- **Area I : Fiducial volume = Target**
    - 10.3 m^3 of LS doped with Gd (0,1%) embedded in an tight acrylic vessel which is totally transparent to photons. This volume is the heart of the detector where neutrinos interactions are counted. The height level of liquid in the target chimney will be 5 cm below the Inner Veto top lid.
    - Calibration systems will be deployed periodically into the target, allowing to check the stability of the system.

- **Area II : positron and neutrons calorimeter volume = Gamma Catcher**
    - 22.6 m^3 of LS used as calorimeter (which allow to measure the energy spectrum of antineutrinos) embedded into tight acrylics vessel transparent to photons. The Gamma Catcher thickness is 55 cm. The height level of the liquid in the Gamma Catcher chimney will be 5 cm below the Inner Veto top lid.
    - Calibration systems will allow deploying radioactive sources through a guide tube device.

- **Area III : Buffer**

Its aim is to protect the Target and the Gamma Catcher from residual radioactivity due to photomultipliers and other steel parts but also from natural radioactivity coming from rocks surrounding the detectors.
It is made of:

- A thickness of 105 cm of mineral oil embedded into a stainless steel vessel which is supporting 390 PMTs (+10) and their bases. The height level of mineral oil in the Buffer chimney will be until 5 cm below the Inner Veto top lid.
- Calibration systems for Target & Gamma Catcher; laser LED driven calibration light transportation stability measurement in Target, Gamma Catcher and Buffer.

- **Area IV : Inner VETO for muons**

Its aim is to detect muons which pass through the and also muons which are stopped in the detector. The associated events will be cut off-line.
It is made of:

- A thickness of 50 cm of LS embedded in a tight and reflective steel vessel. The height level will be at around 5 cm the Inner Veto top lid.
- 72 photomultipliers tubes
- A thermal control system for the management of temperature differences between detectors.

- **Area V : Shielding against radioactivity of the surrounding rock**

It is made of 15 cm of steel for far detector and could change for the near detector. Background will be different in both detectors. There is therefore no need to keep the same design for the shielding.

- **Area VI : Outer Veto**

This element of detector will increase the rejection of muon backgrounds. This will be used to help identifying muons which could cause neutrons or other cosmogenic background and allow them to eliminate from the data set.
Outer Veto will be made of plastic scintillator beams (2 or 4 layers) read by photomultiplier tubes. It will be different between far and near detectors.

Electronics and acquisition

Photomultiplier connections

The photomultipliers of Double Chooz are connected to the external of the detectors with one single coaxial cable per photomultiplier. Each cable carries the high voltage to the voltage divider of the photomultiplier and carries the signal out of the anode. At the border of the detector, the signal is decoupled from the high voltage by a capacitor. The signal is then propagated to the *Front-end Electronics* by another coaxial cable.

Front-end electronics

The Front-end Electronics serves several purposes:

1. amplifying the signal to match the input range of the digitizers,
2. removing the signal distortion due to the capacitive decoupling of the signal and the high voltage,
3. clipping properly the signal when it exceeds the dynamic range of the electronic chain, to protect downstream devices and grant fast recovery after saturation,
4. keeping the baseline stable,
5. providing partial and total analog sums to feed the trigger.

For the Near Detector, all this must be achieved with a rate of 1 kHz of cosmic rays in the Inner Veto, one third of which also crosses the Target.

Waveform Digitizers

The signal of each photomultipliers goes through the Front-end Electronics and then to *Waveform Digitizers*. These are 8-bit, 500 MSPS (Mega Sample Per Second) flash-ADCs writing to a dual-port memory with a smart address management, so as to allow continuous digitization and read out and zero dead-time.

Trigger and Data Aquisition

The running principle of the DAQ (Data AcQuisition) of Double-Chooz is to keep a continuous record of the signals of the photomultipliers during long periods of time (~days), like with hundreds of digital oscilloscope channels with a 2 ns sampling period. Since this would lead to an unsustainable data flow if data was not compressed, the data flow is reduced in two steps:

1. The *First Level Trigger*, implemented in hardware, eliminates all data except around pulses of energy above a given threshold in the Target or the Inner Veto, thus defining events;
2. The *Second Level Trigger*, implemented in software, identifies in real time the event type and executes the data compression appropriate to this type.

3. ORGANISATION OF THE PROJECT

3.1.Management

The organisation of the project is based on a Technical Breakdown Structure which is approved by the collaborators.

In a first phase, the detector has been divided into components and defined in a PBS (Product Breakdown Structure.

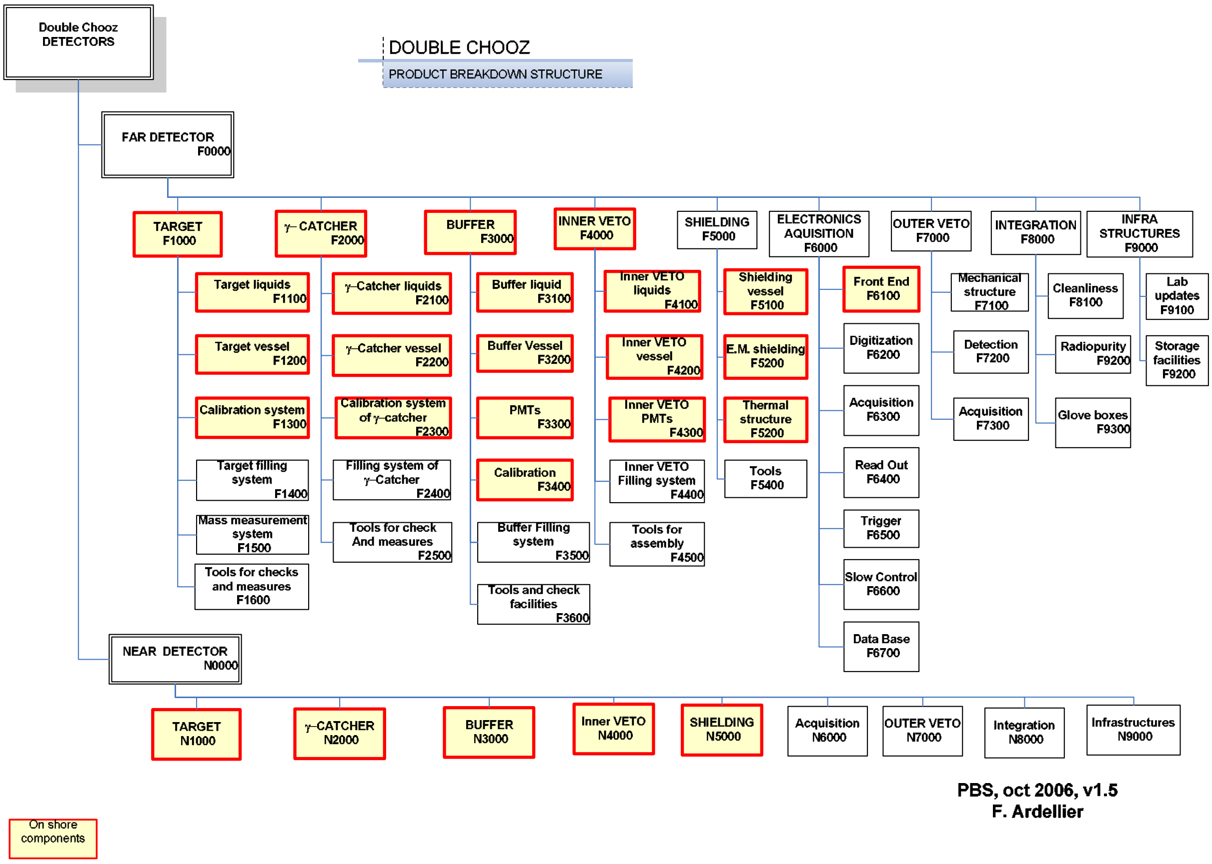


Figure 2 : Product Breakdown Structure of the Double Chooz project

From this breakdown structure, 2 types of components have been distinguished:

- On board components or embedded components: components without access after their assembly in the detector because they are immersed into liquids. The maintainability will be heavy.

- Conventional components : access and maintainability is possible during operating phase

3.2. General strategy

The second step was to defined coherent batches of tasks. Then the organisation of the project is based on the organisational Breakdown Structure with its division into subsystems which represents tasks and responsibilities.

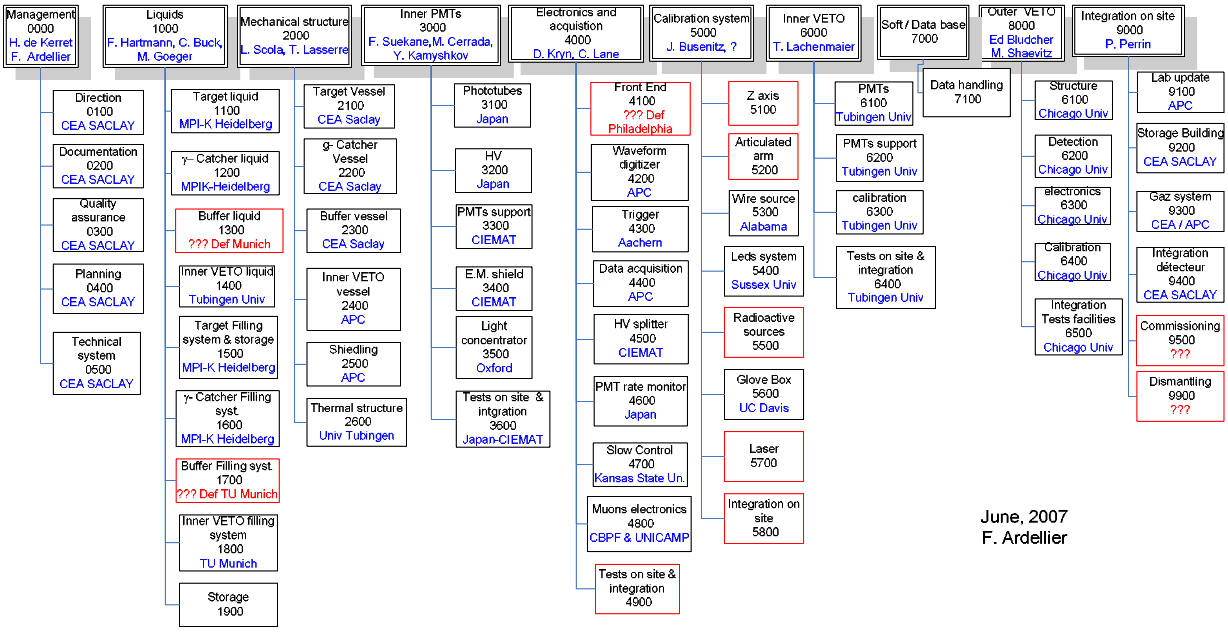


Figure 3 : Technical Breakdown Structure

Each Sub-system identified has got at least two leaders

Red squares are not totally under responsibility of an identified institute.

The tasks responsibilities associated to a subsystem consist in

- the development,
- the realisation,
- the tests, and the installation on site of the component(s) for both detectors.
- The dismantling has also to be considered as soon as possible.

Missions of the susbsytem leader are on the one hand the coordination of its system, on the other the reporting of the status (schedule and technique) to the direction of the direction of the project.

The subsystem leaders meet during Technical Boards which is composed of around .

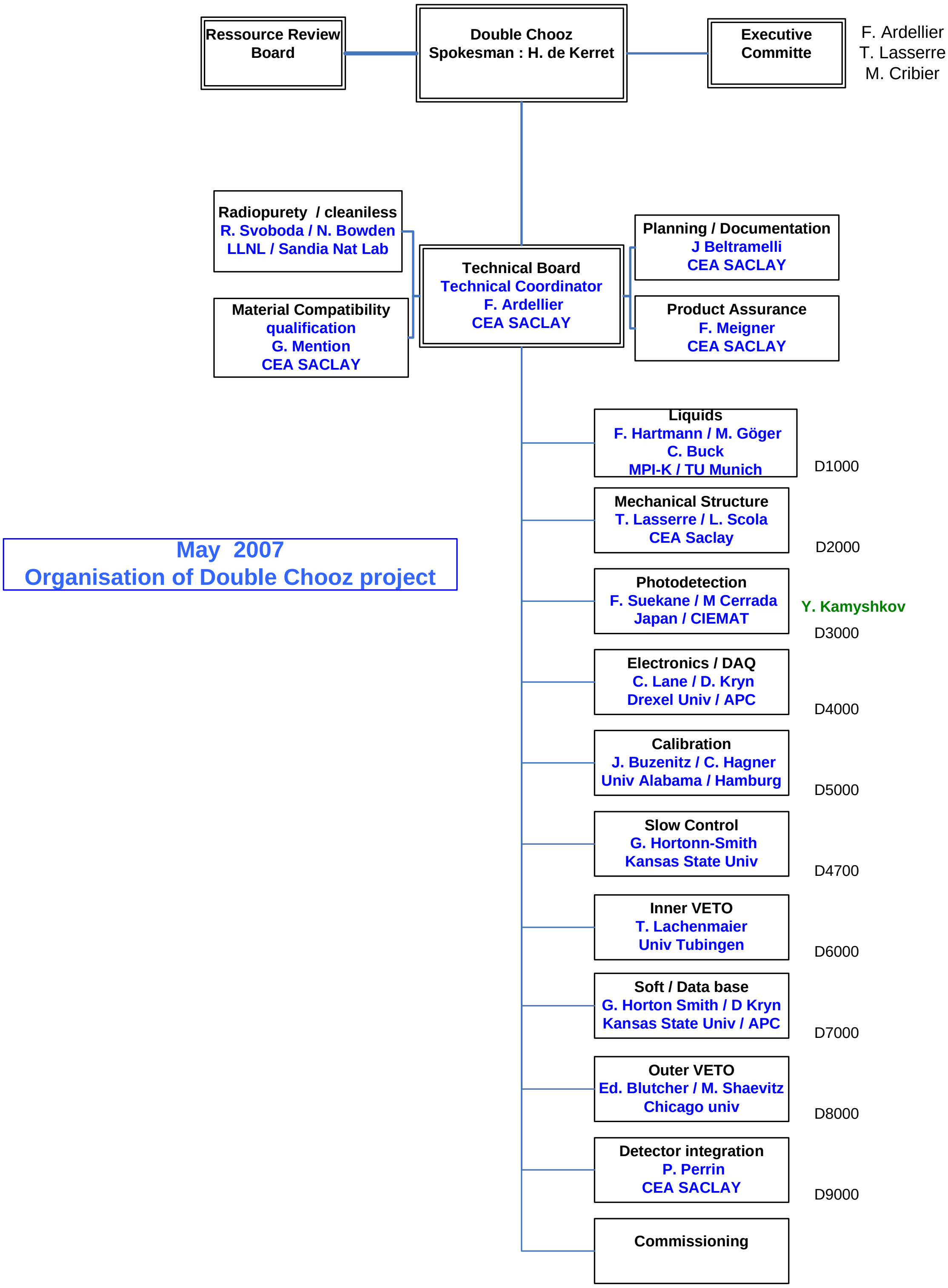


Figure 4 : permanents members of the Double Chooz Technical Board

Technical Boards are planned at least during collaboration meetings and, more often if needed.
Permanent members of technical boards:

- Spokesman
- Each subsystem group leader
- Experts if needed

3.3. Project control requirements

The purpose of the part is to specify the management information required from each subsystem:

- **Project Breakdown Structure** which is done in order to clarify the instrument, the scope of the work and the responsibilities involved. It could be made of :
  - The Product Tree (PT) to breakdown detectors into its components both hardware (and software?)
  - The Work Breakdown Structure (WBS) to define the scope of the work and the responsibilities involved

- **Technical Design Report** which :
  - defined all the interfaces (mechanical, thermal, electrical, chemical ...) between subsystems and
  - present the development plan of detectors realisation

- **Participation to the following reviews** :
  - Kick Off meeting : (june 2006)
  - Conceptual Design Review : (october 2006)
  - Technical Design Report (→ June 2007)

During this review, all sub system is able to show the correlation between the specification and the final file for production.
Interfaces will be checked during this review and coherence of the detectors has to be verified.

  - Integration Readiness Review for far detector (January 2008)
  - Integration Readiness Review for near detector
  - Commissioning / reception of the far detector (beginning of 2009)
  - Commissioning / reception of the near detector (????)

3.4. Communication inside the technical board

The supports of the Double Chooz communication scheme could be described as below:

- Collaboration meetings
- After the 1st TDR edition, monthly progress reports are required to manage and update the schedule→ they had to be sent to the technical coordinator (Florence Ardellier) and will be discussed by phone
- Video conferences for dedicated technical exchanges
- Reviews to validate the coherence of the system

Document of reference:

- Proposal for a management plan of Double Chooz technical group v3.0 :
  - Author : F. Ardellier / EDMS Id I-004658

4. SYSTEM ASPECTS

4.1. Technical constraints for development

- This chapter will deal with the main constraints which pilot the development of Double-Chooz instruments. Those are coming from the requirements exposed in the Double Chooz Proposal (hep-ex/0606025). It could be summed up as following:

- Near & Far detectors must be identical within a knowledge of 0.2 % for both of them until the Buffer area. This assumes the relative normalization systematic of 0.6%. Consequently the following topics have to be kept in mind during the detector development and construction :
    - high stability of the systems during 5 years
    - reproducibility and total control of manufacturing processes
    - allowing the possibility for liquid recirculation
    - allowing the possibility to change the acrylics vessels
    - total control of the magnetic field around the PMTs for both detectors
    - total control of the target liquid quantity knowledge.

- Low background experiment
    - material choice and implementation must be done keeping in mind the low background constraints
    - cleanliness has to be managed from the beginning until the operating phase
    -
- No access to numerous components
    - Development like embedded components (product assurance)
    -
- Development in a tight schedule
    - Use a maximum of approved technologies
    - Use existing infrastructures as much as possible

- Construction of detectors on a nuclear power plant
    - Safety rules and security regulation to respect

4.2. Stability of the system

Each detector is made of 5 tight vessels filled with different liquids. This has to be stable (at 1%) during 5 years that means that on the one hand each material introduces in the liquid does not disturb the liquid performances and on the other hand the liquids must not affect the materials

→ Material compatibility has to be proven for each component in contact (even gaseous) with liquids (see material compatibility chapter).

→ Absence of dust in the liquid must be managed

The intrinsic properties of liquids must also be stable during at least 5 years. (see liquids chapter).

4.3.Management of a 'low background experiment'

Double Chooz detectors are located in underground laboratories to be shielded against cosmologic particles.
Nevertheless it is important to control all material closed to the detectors Target and more generally in the detector. Simulations have been done and requirements for each part/area of the detector could be found in the proposal.

All material has to be selected taking into account their Co^{60}, U^{238}/Th^{232}, and ^{40}K natural rates which have to fit with requirements. Then they will be tested. Moreover, the process chosen for detector construction have also to be tested (see radio purity assess chapter).

4.4.Reproducibility of the detectors

To assume the constraints of reproducibility, all components and assemblies have to be identical between both detectors that mean a total control of material, process and life profile of each component. This will be managed with tools issued of product assurance.

4.5.Policy of embedded components

At high level of breakdown structure, two different categories have been identified for detectors development:

- Embedded components made of all the items in the shaft: vessels, liquids, permanent calibration systems, PMTs (included bases and cables), magnetic shields, light concentrators (to be confirmed). All those components are not accessible after detector filling phase.

- Standard components made of electronics / DAQ, filling systems, calibration facilities

Product Assurance Plan is developed with a higher severity for embedded components since no access or modification could be foresee after installation of the detector.
Reliability has to be considered since the conception phase and justified in the TDR.

4.6.Safety and security rules on site

Detectors will be built on the site of a French nuclear power plant. Safety and security rules must be respected and have to be considered from the conception phase.

The Double Chooz installation, called chemical & radioactive ICPE (Installation Classée pour la Protection de l'Environnement) file has to be accepted and recorded at the Préfecture des Ardennes before the start of the construction.

The main critical components for this file are:

- liquids composition → safety data sheets of the mixtures and risk analysis for filling system are required

- calibration systems and management of sources on site
- mechanics assembly on site → heavy components to transport in a tight area and human work in a shaft for steel welding.
- Fire risks has to be analysed and some solutions have to be described to prove the ability to answer to a fire incident.

During the construction phase, a person in charge of the building site will be identified and will constitute the link between the EDF power plant and research teams: this person is Patrick Perrin from Saclay lab. He will help the collaborators for the administrative and logistics aspects. Its missions are described in the 'detector integration' chapter.

4.7.Description of the environment: use of existing infrastructures

The far detector will be built in an existing lab where a shaft is available to welcome the detector. Nowadays the environmental conditions in the lab are a temperature around 15°C (+/- 1°C) all the year and 100% of relative humidity. A dedicated ventilation device has been installed for Double Chooz application.
To respect the radio purity requirements of Double-Chooz, some other dedicated facilities like clean tents, will be installed (see cleanliness chapter).
Some measurements are planned to be done in the lab in order to assess the radioactive rate of the lab dusts.

Permanent handling facilities available in the lab are:

- One directional crane with a capacity of 5 tons passing by the middle of the shaft and with the hook located at 3.5 meters from the floor.
- 2 parallel beams (also parallel to the main crane) which could be equipped with 2 tons cranes for each.

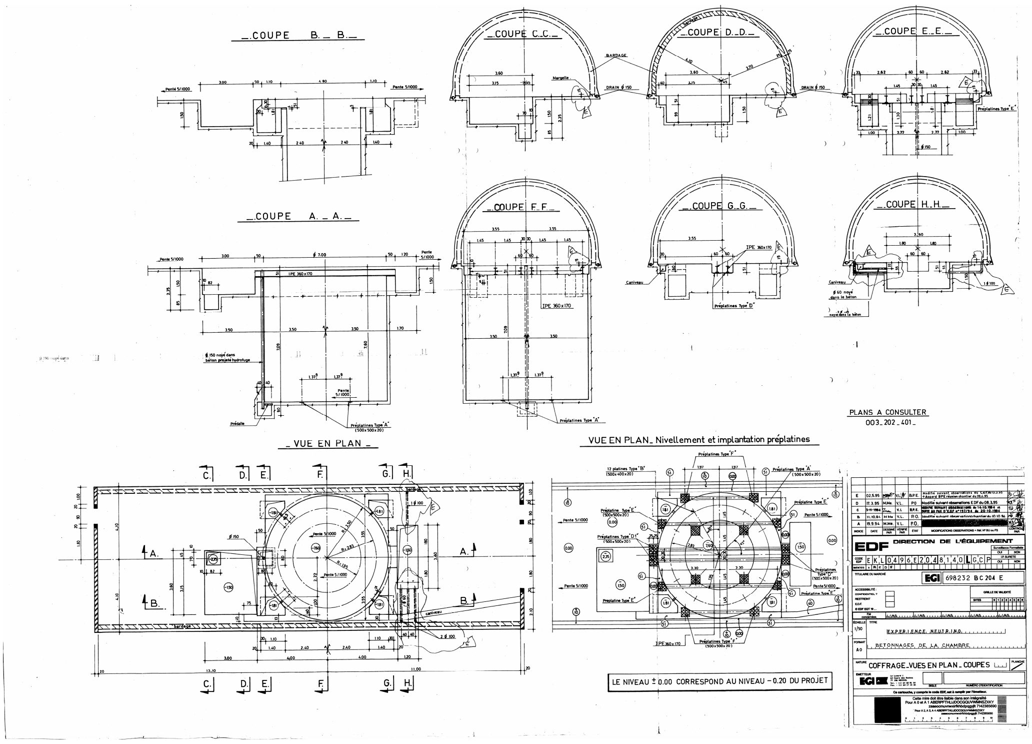


Figure 5 : view of the Neutrino lab

No industrial water is available in the laboratory.

<u>Electrical interface:</u>

A electrical casket is available at the lab entrance with the following characteristics :
- 35 kA at 220 Volts
- 25 kA at 380 Volts

4.7.1. Access tunnel to the Neutrino lab

The access tunnel is around 150 meters long with a mean slope of 10% from the main entrance until the lab entrance. Its shape is more or less like a cut cylinder with a radius around 3.8 meters.
The dimensions of the lab and access tunnel are fixed and could not change.

Moreover, the lab is an emergency exit for another EDF building site. That means an extra safety footbridge must be available every time in the lab.

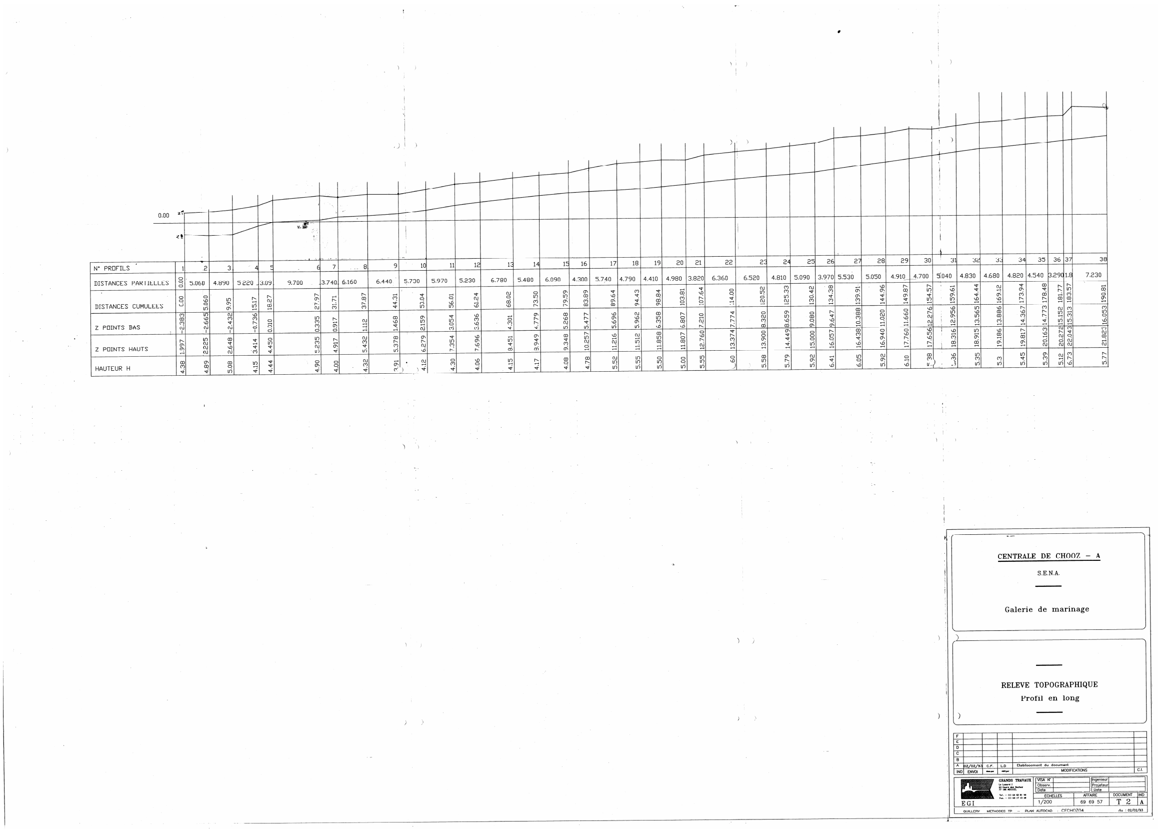


Figure 6 : Topography of the access tunnel

A dummy has been built in august 2005 to make the test of the handling through the tunnel. Consequently, the maximum diameter of pieces allowed to go through is 3.5 meters. Dedicated facilities have to be developing for transportation of heavy or big pieces.

Figure 7 : View of the GC dummy through the access tunnel

4.7.2. Liquids storage building

Another available building, called "liquids transfer building" is located at ~15 meters from the tunnel entrance. All the liquids containers will sit in this building. Before the installation of the storage tanks it has to be refurbished: ventilation, spill-tray, civil engineering for tubing, heaters…

4.8.Schedule

The development of the Double Chooz detectors has to be done in a tight schedule because of the experiment concurrence like DayaBay, Reno…
The goal is to take data with the far detector at the beginning of 2009, and at the end of 2010 with both detectors.

The development plan will be made to obtain a detector of quality in this schedule.

The master planning of Double Chooz is made of the schedule of the detector assembly on site. It is coordinated by Saclay people who introduce and manage inputs data provided by each subsystem leader.

An optimisation in the sequences has to be studied to reduce as much as possible the delays.

You will find hereafter a planning for the far detector integration updated in august 2007.

N°	Responsible	Task	Duration	Start	End	Marge libre
58		**FAR DETECTOR (FD) - ASSEMBLY ON SITE**	**57,2 sms**	**Jeu 17/04/08**	**Mer 22/07/09**	**58,6 sms**
59	APC	Shielding assembling_FD	11 sms	Jeu 17/04/08	Mer 02/07/08	0 sm
60	APC/TUBINGEN	Veto mechanic + Cleaning_FD	8 sms	Jeu 03/07/08	Mer 27/08/08	0 sm
61	CEA	Buffer vessels integration + Veto PMTs integratio	6 sms	Jeu 28/08/08	Mer 08/10/08	0 sm
62	CEA	Clear area assembly_FD	2 sms	Jeu 25/09/08	Mer 08/10/08	0 sm
63	APC	DAQ Installation	20 sms	Jeu 09/10/08	Mer 25/02/09	94 sms
64	JAPAN / CIEMAT /	PMTs buffer integration_FD	8 sms	Jeu 09/10/08	Mer 03/12/08	0 sm
65	CEA	Acrylics vessels integration_FD	7 sms	Jeu 04/12/08	Mer 21/01/09	0 sm
66	USA-Alabama	Calibration systems integration_FD	2 sms	Jeu 22/01/09	Mer 04/02/09	0 sm
67	CEA / APC	Buffer & Veto closing_FD	1 sm	Jeu 05/02/09	Mer 11/02/09	0 sm
68	HEID./MUNICH	Tubbing junction + Cleaning/Flushing_FD	4 sms	Jeu 22/01/09	Mer 18/02/09	0 sm
69	HEID./MUNICH	Filling_FD	3 sms	Jeu 19/02/09	Mer 11/03/09	0 sm
70		Preliminary Far detector Commissioning_FD	1 sm	Jeu 12/03/09	Mer 18/03/09	0 sm
71	APC	Detector closing (Upper shielding)_FD	2 sms	Jeu 19/03/09	Mer 01/04/09	0 sm
72	USA-Chicago	lower Outer veto assembling _FD	4 sms	Jeu 02/04/09	Mer 29/04/09	0 sm
73	USA-Davis	Glove box assembling _FD	2 sms	Jeu 30/04/09	Mer 13/05/09	0 sm
74	USA-Chicago	Upper Outer veto assembling _FD	2 sms	Jeu 14/05/09	Mer 27/05/09	0 sm
75		Final Far detector Commissioning_FD	8 sms	Jeu 28/05/09	Mer 22/07/09	73 sms

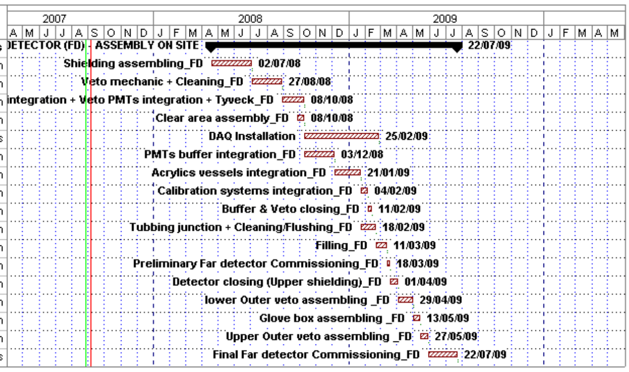


Figure 8 : Far detector assembly on site schedule

The schedule shows the start of the assembly on site (shielding) at the beginning of 2008 and the first data could be available in march 2009.

Before this step, the Neutrino Laboratory has to be adapted to Double Chooz application; this work is taken in charge in France.

To reach this planning, milestones for the orders and their arrival on site of each detectors components are the following:

COMPONENT	ORDER DEADLINE	RECEPTION AT CHOOZ DEADLINE	OPERATING MODE delivery deadline
Shielding	September 2007	1st March 2008	January 2008
Inner Veto vessel	October 2007	1st July 2008	May 2008
Inner Veto PMTs	To be defined	1st September 2008	June 2008
Buffer vessel	October 2007	15th August 2008	June 2008
Inner PMTs	PMTs : November 2007		
	HV supply : April 2008	4th October 2008	July 2008
Electronics & DAQ	ADC, FEE : December 2007	4th October 2008	July 2008
Slow control	December 2007	4th October 2008	July 2008
Calibration systems	Design frozen in October 2007	10th December 2008	October 2008
Acrylics vessels	November 2007	1st december 2008	October 2008
Liquids	October 2007	1st September 2008	June 2008
Detector Fluid Operating System	December 2007	1st February 2008	December 2007
Component Fluid System	December 2007		
Outer Veto	To be defined	March 2009	January 2009
Glove Box		End of april 2009	January 2009

Figure 9 : deadline of each subsystem

5. Development plan

The construction of the experiment is piloted by the tight schedule. Consequently there are only a few places for new technologies and approved systems (which answer to requirements) are preferred.

The major new development is the heart of the detector with the Target. Its performance and stability inside the system has to be proven before the construction of the far detector. Consequently, the master development plan of the project has foreseen a technological Mock-Up scaled 1:1

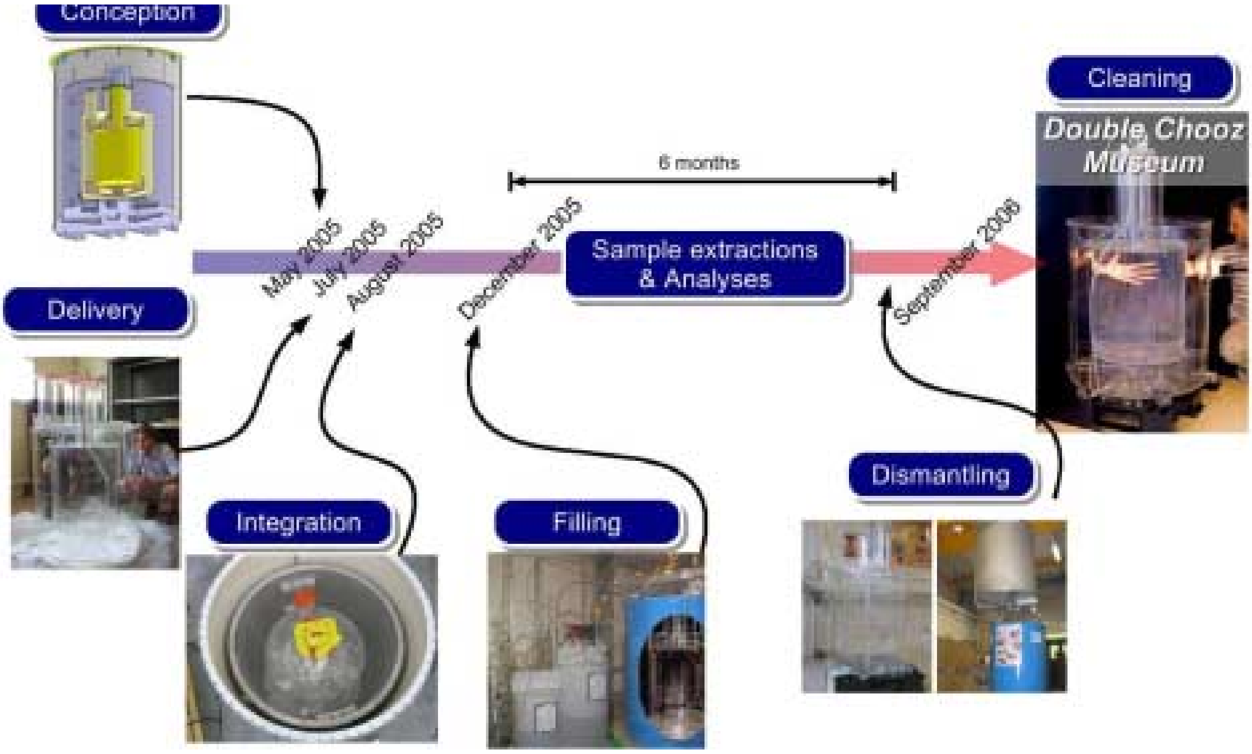
5.1. Phase of feasibility

5.1.1. Liquids

The baseline composition of Nu target liquid has been selected after several receipts made by MPI-K Heidelberg and Gran-Sasso lab have been tested.
A reporting has been presented at all collaboration meetings.

5.1.2. The 1/5th scale mock-up of the detector:

A 1/5th scale mock-up prototype of the final detector design has been realized in order to validate several technical aspects as well as interfaces between subsystems. On the material compatibility point of view, this mock-up allowed us to test acrylic vessels and gluing compatibility with large scale amounts of liquid scintillators. The inner volume of this mock-up contained about 110 L of Gd doped liquid scintillator. We did not test the final scintillator recipe at that time since it was not yet available on the 100 L production scale. Smaller acrylic vessels with a capacity of approximately 30 L are also available for long-term/large scale stability and material compatibility testing. As a result of these tests, no clear degradation of the liquid scintillator transparency has been observed over 6 months of data taking. These mock-up tests were stopped after an overpressure unglued the top lid of the target acrylic vessel while operating. Target and γ-catcher volumes were then no more safely separated. In order to avoid such a fatal fate for the final detector, overpressure control and safety valves will be used on the design of the final fluid/gas handling system.



A technical note (*EDMS Id* I-008430) is available to present all the anomalies detected during the mock-up cycle of life.

5.2. *Phase of design*

5.2.1. Mock up of the chimneys (scaled 1:1)

The motivation of this mock-up is to prove the efficiency of the chimney areas which required obvious flexibility to allow the calibration without inducing any constraints on the vessels.

The system design of the detector is going on taking into account the return of experiment of the mock-up and the others similar experiments. The first mock up showed the difficulty for the design and the reliability for the chimneys mounting.

A concept with several bellows has been proposed but it very difficult to qualify it with simulations. Moreover, up to now, the integration of calibration systems (wire source) is not totally defined.

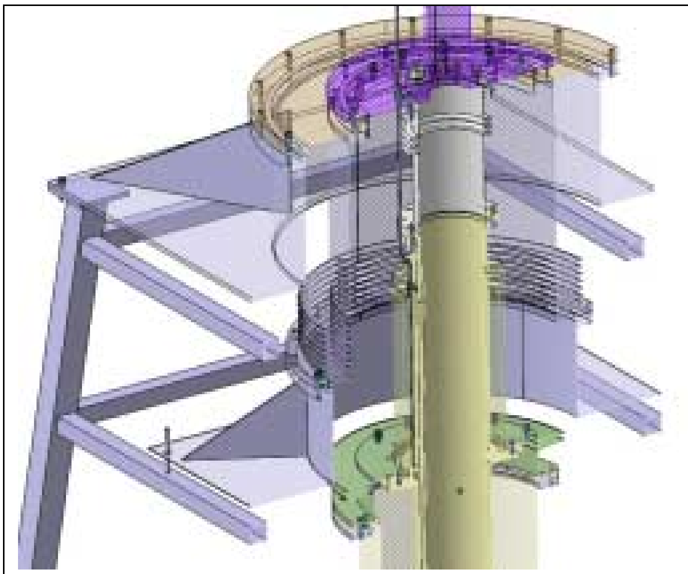
That is why a mock up of the acrylics chimneys is planned in the middle of 2007.

Its aim is to prove:

- The feasibility for the mounting of chimneys on site
- The feasibility for the mounting of the filling tubes paths in the chimneys
- The reliability of the system.

This mock up will also allow testing the assembly of wire source system and the interface with the glove box.

The chimneys will be made in PMMA GS-233 and the bellows will be made like for the real detector. If it is qualified, the bellows will be furbished to the far detector.



Design studies for the chimneys mock up

Views of the assemblied chimneys mock up (scaled 1/1)

Figure 10 : views of the Chimneys mock up (scaled 1:1)

5.2.2. Neutrino laboratory mock up (scaled 1:20)

The study of the integration on site shows the difficulty of the logistic on site and the conflict of space and no obvious solution is appeared.
To go ahead in the development, a mock up scaled 1:20 has been built. The idea is to use it with all the components needed on site to find an optimisation.

Figure 11 : View of the Double Chooz far detector in its lab scaled 1:20

This mock up showed the necessity to remove the target storage tanks from the Neutrino laboratory after the filling phase. This operation will authorize to have and Outer Veto plan of 14 m X 7m.

The next steps are:

- To define the cable paths and their optimisation
- To try to find a way to manage the Buffer and Inner Veto top lid during the assembly on site.

5.2.3. Nu Target Liquid optimisation

See Liquids and Fluid component system: chapter 7

5.2.4. Choice of PMTs

See Inner PMTs and Inner Veto chapters : chapter 8 & chapter 12

5.2.5. Electronics prototypes

See electronics & DAQ : chapter 10.

5.3. Realisation phase & spare strategy

Each component is provided on site by the institute in charge of it. The material/component entering in the lab would is identified and coupled with a technical data sheet.

The detector realisation phase is going to start on site on March 2007 for the far detector. Before this date, infrastructures have to be updated and adapted to the Double Chooz constraints.

An Integration Readiness Review is planned in December to validate all the definition files and check all the interfaces before the realisation.

The spare strategy is based on the fact to allow (for the embedded components) the possibility to:

- Recirculation of target liquid if it involves
- Change the acrylics vessels if the stability of the system is damaged
- To remove the corresponding PMTs in one detector if some problem occurs on the other.

To answer to those requirements, it has been decided to produce:

- 1 batches of Acrylics vessels spare
- 1 batch of Nu Target liquids spare
- 10 % of spare for the other liquids
- 10% of PMTs spares
- A pre production batch for electronics cards
-

6. TRANSVERSAL ACTIVITIES OF DOUBLE CHOOZ PROJECT

6.1. Material Compatibility

6.1.1. Material compatibility requirements

Double Chooz detectors will use four separated volumes, each of them filled with a different liquid (see the liquid section for specifications). These liquids are choosen for their good optical transparency for light transportation around 430 nm (related to the PMT efficiencies). From the inner to the outer, these four volumes are:

The detector response depends on the light transportation between the interaction point (in the two inner volumes) and the detection point (the PMTs). Therefore, the stability of detector optical properties over time is of upmost importance to keep detection systematic uncertainties, a key point of the experiment, at their lowest levels. Not all the volumes have the same constraint levels. While the γ-catcher, buffer and veto volumes are well known liquids with low deterioration risks, the target volume, an R&D liquid, requires a special care. Dedicated measurements have been carried out on the intrinsic time stability of the target volume liquid.

A material compatibility activity, in Saclay, has been performed to guarentee that materials inside the detectors, as well as the ones occasionally introduced into it, will not alter the optical properties of the liquids.

6.1.2. Material compatibility test protocols

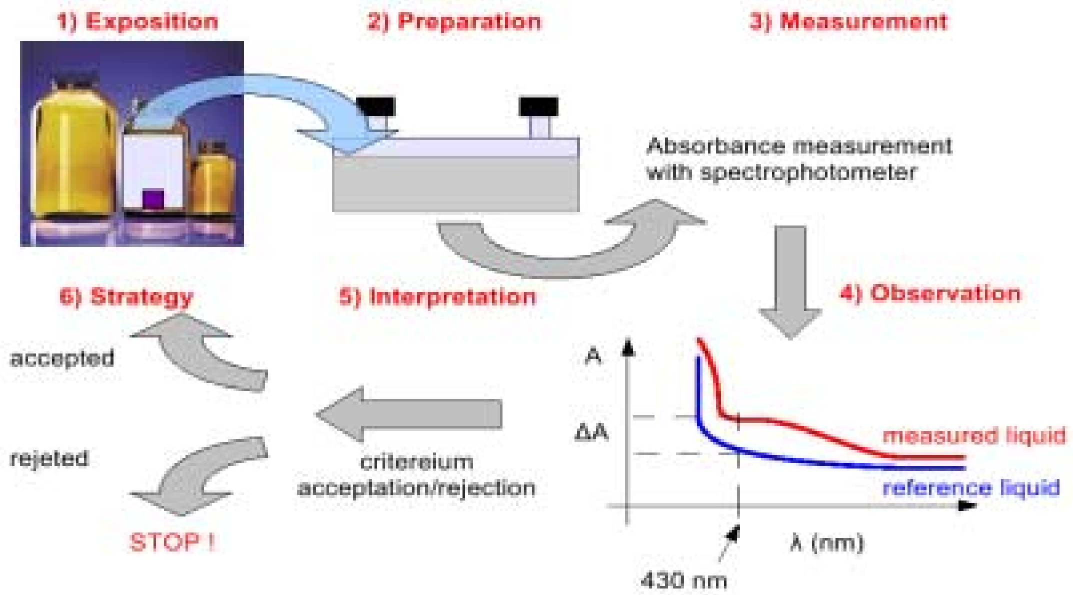


Figure 13: Material compatibility protocol.

A first stage, in the material comptibility works, was the development of a dedicated certification protocol. The main ideas of the measurements are described on Figure 12. This protocol has been defined, tested and written in June 2006. It includes six basic steps:

- The exposition phase: the previously cleaned material is put in contact with the liquid in a dedicated bottle, tightly closed, and under Nitrogen atmosphere. A reference sample of the liquid is also kept in an other bottle on the preparation day. An exposure time is then fixed for that sample.
- The bottles are opened, and 80 mL of the liquid is extracted to be measured in dedicated 10 cm long quartz cells. These cells follow a specific cleaning protocol (EDMS reference I-010979) before and after each filling.
- The optical transparency measurement is then carried out with a spectrophotometer over the full range between 300 nm to 800 nm.
- Absorbance measurements are then stored into files sorted by the measurement dates, and a short observation commentary is written in the laboratory book. The cell content is then placed again inside initial bottle for a further measurement.
- Two basic comparisons are then directly performed:
  - a comparison between the liquid samples with and without the material (the reference sample), measured on the same day.
  - a comparison with past measured samples, category by category: references with references, liquids in contact with materials with the same liquid put in contact with the same material earlier.

  These two basic comparisons ensure that intrinsic liquid deterioration of the liquids can not be taken for liquid deterioration induced by the material contact.
- Up to now, a basic yes/no answer was given to the acceptance/rejection criterium of the material compatibility tests. The level of acceptance/rejection is then linked to the sensitivity of the method. According to the previous studies, a liquid absorbance difference at the level of 10^{-3} may be seen on a 10 cm long cell. This yields a sensitivity at the order of 43 m attenuation length effect. Following this precision, a preliminary acceptance or rejection of compatible materials was drawn.

6.1.3. Material compatibility certification tests

Material compatibility tests were made and will be made especially for the Gd-LS (target liquid). All materials in contact with the Gd-LS in the detector or the liquid handling systems have to be checked thoroughly. Since June 2006, five measurement campaigns, on Gd-LS, have been performed on different materials:

1. acrylic (GS 233): all three inner volumes, target, γ-catcher and buffer are in contact with acrylic vessels, therefore the material compatibility of the respective liquids with the acrylic (GS 233) used in the experiment is crucial.
2. acrylic glue (Acryfix 190): with the same level of constraint, the glue used to stick acrylic pieces together has to be compatible with the three liquids.
3. Stainless steel (304 L) which could be used for an articulated callibration arm and for some parts of the target chimney, in contact with the target liquid either in liquid or in vapor phases (see for instance the Glove Box section). Also the buffer liquid will be in permanent contact with the stainless steel vessel and the stiffeners.
4. Delrin: a strong plastic proposed as a solution to encapsulate radioactive sources for detector calibrations. This Delrin would enter in contact with the target liquid through the fish-line calibration device.
5. Viton: used for the gloves of the glove box on top of the detector, to manipulate calibration devices before moving them through the chimney toward the center of the detector. They are among the most chemically resistive type of glove for the user protection.

Among these materials, acrylic (and glue) compatibility is of upmost importance. For this, the compatibility of several PXE/dodecane mixtures and Gd-scintillator versions with single and two piece acrylic samples was tested at the Rœhm company, in Germany, at the Mines de Douay, in France, as well as in CEA Saclay. Two aspects of the chemical compatibilities have been addressed:

- the liquid optical properties stability over time, whose tests were performed in Saclay.
- the acrylics mechanical behaviour with and without contact with liquids, whose tests were performed in the three above mentionned laboratories.

These measurements confirmed the improving compatibility with increasing dodecane concentrations. The PXE/dodecane ratio of 20 to 80 by volume mentioned above seems to be the best compromise providing sufficient material compatibility and scintillator light yield. The PXE concentration in the target scintillator could be lowered to about 15 % to improve the safety margin, since the overall loss of light would not only be a few percent (light output decreases, but transparency of oil is better than that of PXE). No clear deterioration of acrylics mechanical properties have been observed through liquid exposed acrylic samples and non-exposed ones.

6.1.4. The 1/5th scale mock-up of the detector:

A 1/5th scale mock-up prototype of the final detector design has been realized in order to validate several technical aspects as well as interfaces between subsystems. On the material compatibility point of view, this mock-up allowed us to test acrylic vessels and gluing compatibility with large scale amounts of liquid scintillators. The inner volume of this mock-up contained about 110 L of Gd doped liquid scintillator. We did not test the final scintillator recipe at that time since it was not yet available on the 100 L production scale. Smaller acrylic vessels with a capacity of approximately 30 L are also available for long-term/large scale stability and material compatibility testing. As a result of these tests, no clear degradation of the liquid scintillator transparency has been observed over 6 months of data taking. These mock-up tests were stopped after an overpressure unglued the top lid of the target acrylic vessel while operating. Target and γ-catcher volumes were then no more safely separated. In order to avoid such a fatal fate for the final detector, overpressure control and safety valves will be used on the design of the final fluid/gas handling system.

6.1.5. Currently tested materials:

There are also other materials in contact with the scintillators during the detector operating time (calibration system), handling and purification. Steel (304 L) surfaces should be avoided for the target scintillator following the preliminary acceptance/rejection criteria. This system is expected to be surface reactive in contact with steel and the stability of the scintillator could be affected. In the production and synthesis of the 110 L of Gd-CBX scintillator for the mock-up only PFA, PTFE, PP, PE and glass was used. Only such materials should be used for the final Double Chooz systems as well. Permanent stainless steel pieces should be Teflon coated in order to completely avoid any contact with the target liquid scintillator (top part of the target chimney), even with liquid scintillator vapor (but not yet tested).

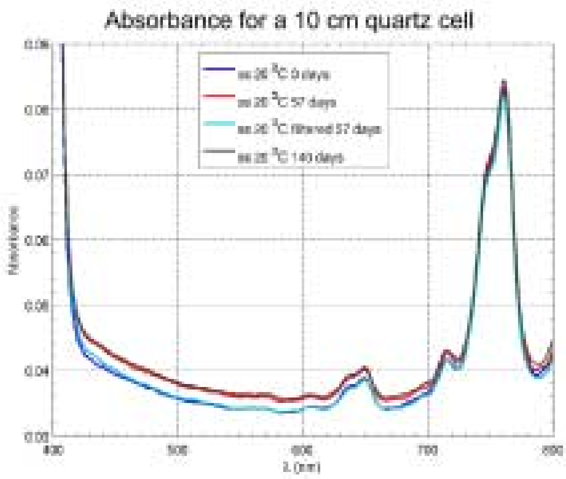


Illustration 1: Target LS in contact with stainless steel 304 L at 20 Celsius degrees.

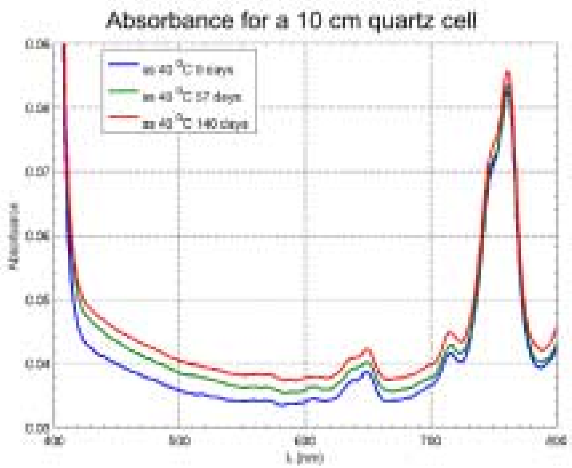


Illustration 2: Target LS in contact with stainless steel 304 L at 40 Celsius degrees.

Temporary stainless steel pieces (articulated calibration arm for instance) could in principle still be accepted, but this will requires extended tests and a better designed acceptance/rejection criterium to compute the safety margin coefficient. Works on this point are currently ongoing.

Delrin and Viton samples have been tested also. They seem to be incompatible using the preliminary acceptance/rejection criterium.

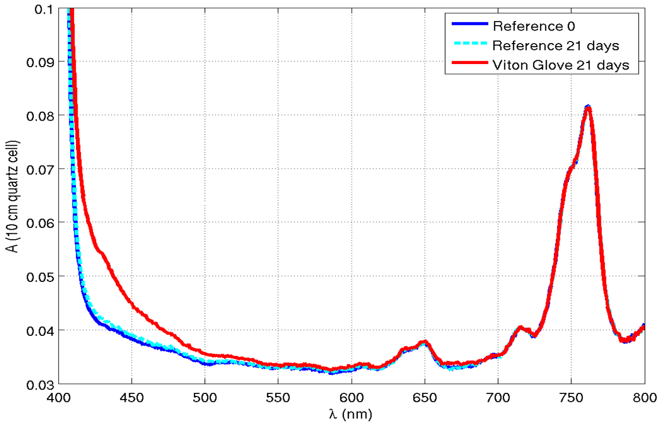


Illustration 3: Target LS in contact with Viton glove at 20 Celsius degrees. This exposition has been performed in liquid phase contact.

Further studies are however required to draw a final conclusion on these two materials, since not so much other possibilities are foreseen. Delrin will be indeed a temporary material used for calibration sources encapsulation, and contact with liquid could be for a short time. Viton gloves will be permanently on top of the detector inside the glove box. Direct liquid scintillator contact could be avoided by cleaning gloves after each handling (mineral oil,...), and liquid scintillator vapor contact could be also reduced through nitrogen flushing of the glove box.

Among all the materials which have been tested, in some measurements strong overall offsets over the whole spectrum (300 nm to 800 nm) have been noticed with no clear material association. The most significant difference of absorbance were observed at the level of $6\ 10^{-3}$ (7 m attenuation length) for the references and $1.5\ 10^{-2}$ (2.3 m attenuation length) for the materials. Filtering the samples removed this offset. This observation could be due to the particular version of the liquid scintillator used for the tests. Other tests with the final version of the target liquid scintillator have to be performed again in order to check this point, since in the final detector, no filtering of the full detector in one time will be possible after the filling.

Degradation speeds in day^{-1}

N.B.: A 20 m on the L_{att} effect yields an average ~2% effect on energy scale in the detector

	20 °C	40 °C	Exposed S/V (m⁻¹)	Detector scale S/V (m⁻¹)	Scaling factor	Time (days)	Effective Latt (in m) @ 20 °C	Effective Latt (in m) @ 40 °C
References	4E-4	2E-5						
Acrylics	6E-6	6E-5	11.0	6.68	6.1E-1	365	75.2	7.5
Glue	7E-5	2E-5	0.7	0.04	5.5E-2	365	70.5	246.9
Stainless steel	7E-5	3E-5	5.0	0.02	3.9E-3	10	>> 200	>> 200
Delrin	7E-4	1E-4	5.0	0.0005	9.7E-5	10	>> 200	>> 200

Illustration 4: Summary table of degradation speed on the absorbance and typical S/V ratio for exposed samples and detector scale materials. This table exposes the preliminary results from the measurements performed on years 2006-2007. Is also illustrated in this table the effective attenuation length of the degradation observed rescaled for the detector. Note that on average a 20 m effect on the attenuation length leads to a near 2 % effect on the energy scale in the detector.

Other tests on γ-catcher and buffer liquids are currently ongoing. These tests are foreseen to be less subject to any deterioration observation. The most stringent constaint comes from the cleaning of the surfaces to avoid dust particles inside the detector. Pieces of γ-catcher calibration device are thus beeing tested. In the buffer, coated optical fiber which will be used for LED laser calibration is also currently checked.

6.2.Cleanliness

6.2.1. Cleanliness Plan:

The cleanliness plan has the dual goals of:

- Ensuring that dust contamination in the detector does not contribute more than 1 Hz to the singles rate in the gamma catcher or target above 0.7 MeV.
- Not seriously impacting or delaying detector construction, or increasing costs unnecessarily.

A study based on the experience of the Sudbury Neutrino Observatory, particle size distribution in typical airborne dust, and measurements of U/Th/K in Chooz rock has been completed and is described below. Based on this study, estimates are made on the amount of dust deposited in the target or gamma catcher, buffer, or inner veto that would result in a singles rate of 0.3 Hz in each volume. Then, using the most conservative value of the dust settling rate reported by SNO and an estimate of the time each volume would be open, the maximum allowed dust concentration in the air is determined. This dust limit then determines the clean room class required for each phase of construction. Recommendations for achieving these standards are made.

6.2.2. Specific Activity of Chooz Rock:

Airborne dust in the underground laboratory is assumed to be from the surrounding rock. The radiopurity of this rock was determined by the original Chooz experiment to be:

- ^{238}U 2000 ppb
- ^{232}Th 5000 ppb
- natural K 14,000 ppm

The rock is assumed to be in secular equilibrium, which is a conservative assumption in that radon daughters may diffuse out of the rock and leave the hall.

The relevant specific activity of the dust depends on the ability of alpha decay to produce triggers in the detector. Due to the short range of the alpha particles, they will not be able to penetrate the scintillator filled volumes from outside the gamma catcher. The same is true for betas. This means that in the buffer and inner veto only relatively high energy gamma rays will be important. In this case, the gamma rays from ^{40}K, ^{208}Tl, and ^{214}Bi are used to determine the effect of the dust.

For the target and gamma catcher regions, the betas from these high Q decays are also included. In addition, alpha activity is estimated using the know spectrum of alphas from the uranium and thorium chains, and a very conservative energy-independent quenching factor (QF) of 5 is used to determine whether an alpha will trigger the detector above 0.7 MeV or not. This is quite conservative as most scintillators have a factor above 5.

Natural potassium is 0.0117% by weight ^{40}K, which decays by both beta and electron capture (EC). The EC branch (10.7%) goes almost 100% to the first excited state of ^{40}Ar, which immediately decays to the ground state by emitting a 1.46 MeV gamma ray. Given a half-life of 1.277 x 10^9 years, the potassium-induced specific activity **of Chooz rock** is therefore **0.045 Bq/g** if only the 1.46 MeV gamma is important.
If the decay is in the target or gamma catcher scintillator, then the energy of the beta decay must also be considered. Estimating that roughly half of the electrons from the ^{40}K beta spectrum are above 0.7 MeV, a specific activity of **0.23 Bq/g** is predicted. These two different specific activities are designated “far” and “near”, respectively. *Note that in practice, the actual beta spectrum is used in the simulation, along with that for ^{208}Tl and ^{214}Bi.*

The thorium chain far specific activity is estimated **as 0.0073 Bq/g** based on ^{208}Tl activity only. For all volumes, the decay of thallium is simulated, so this number is not used directly – but it does give some idea of the scale of the problem. Alphas from the thorium chain have the following energy distribution (MeV): 4.1, 5.5, 5.8, 6.4, 6.2(36%), 8.95(36%). A QF=5 means these would all be visible above 0.7 MeV. In addition, there are gammas from ^{228}Ac and ^{212}Bi, which increase the activity by roughly a factor of 0.66 above 0.7 MeV. Additional betas from ^{212}Po add an additional factor of about 0.32. The resultant near specific activity is then **0.23 Bq/g.**

In a similar fashion, the far activity from the uranium chain is estimated at **0.017 Bq/g** for far, and **0.40 Bq/g** for near. This estimate includes gammas from ^{234}Pa and ^{214}Pb with estimated factors of 1.0 and 0.02, plus an alpha spectrum (MeV) of: 4.3, 4.9, 4.8, 4.9, 5.6, 6.1, 7.8, and 5.4. For QF=5 these would all be visible above 0.7 MeV.

In summary, the total specific activity from ^{40}K/^{208}Tl/^{214}Bi due to beta and gamma activity is estimated as 0.23+0.027+0.051 = **0.31 Bq/g**. Alpha activity (QF=5) is estimated as 0.096+0.20 = **0.30 Bq/g**. Note: this is stongly QF dependent. If QF=10 it would be only about 0.0073+0.025 = **0.032 Bq/g**, an order of magnitude less.

6.2.3. Activity Deposition Rates:

SNO has unofficially reported a mass deposition rate of 1 μg/cm^2/month in areas of "high activity" in a mine laboratory, which had air quality of 2500 +/- 500. This number refers to the number of 0.5 micron or larger diameter particles per cubic foot, which corresponds to about 88,300 per cubic meter. Table 1 shows the particle size distribution for this standard. Thus the SNO number corresponds to somewhat worse than ISO class 6.

Assuming that the deposition rate is proportional to the airborne dust density, **Table 2** shows the calculated mass density, activity density, and activity deposition rate as a function of ISO clean room class. This table will be used to deduce the appropriate clean room standard in the next section.

diameter (microns)	**0.1**	**0.2**	**0.3**	**0.5**	**1**	**5**
class 1	10	2	1	0.4	0.08	0.003
2	100	24	10	4	0.8	0.03
3	1000	237	102	35	8	0.3
4	10000	2370	1020	352	83	3
5	100000	23700	10200	3520	832	29
6	1000000	237000	102000	35200	8320	293
7	10000000	2370000	1020000	352000	83200	2930
8	100000000	23700000	10200000	3520000	832000	29300
9	1000000000	237000000	102000000	35200000	8320000	293000

Table 1 ISO clean room standard airborne particulate size spectrum. The top number in each column refers to the particle diameter in microns.

ISO class	Mass density **μg/m3**	Deposition rate **Bq/m2/day**	activity density **Bq/m3**
1	7.812E-07	1.68E-09	7.81E-13
2	7.8568E-06	1.69E-08	7.86E-12
3	0.000077735	1.67E-07	7.77E-11
4	0.0007819	1.68E-06	7.82E-10
5	0.0076468	1.64E-05	7.65E-09
6	0.076993	1.65E-04	7.70E-08
7	0.76993	1.65E-03	7.70E-07
8	7.6993	1.65E-02	7.70E-06
9	76.993	1.65E-01	7.70E-05

Table *2 Based on ISO size spectrum and SNO "high activity" deposition rate, the mass and activity deposition rates are calculated assuming 1 Bq/g of specific activity for rock dust. The third column shows the airborne activity. This table can be scaled to the appropriate specific activity, exposure time, and surface area for the various construction phases*

6.2.4. Target and Gamma Catcher:

A simulation of 1 gram of rock dust in the target was done, which resulted in a specific activity above 0.7 MeV of **0.19 Bq/g** from ^{40}K/^{208}Tl/^{214}Bi, smaller than our estimate above. To this should be added the expected alpha activity, which we will conservatively take as **0.30 Bq/g**. Thus the activity deposition rates in **Table 2** must be multiplied by 0.49 to give the appropriate activity deposition rate for the target. The gamma catcher is assumed to have a similar constraint.

In addition, it can be seen that to have less than 0.3 Hz of activity added to the trigger rate by dust in the target, the total amount of dust must be kept to a level of less than 0.3/0.49 = **0.6 grams.** For a total surface area of 108 square meters[1] this corresponds to less than about 0.5 μg/cm^2. This corresponds to an amount just visible when wiping with a white glove, or 2(20) weeks exposure of SNO quality air at high(low) activity. *Thus it is extremely important that the acrylic vessels be completely sealed from the point of manufacture to installation in the detector*.

On site, the air inside the target and gamma catcher acrylic vessel (assuming a three month exposure time) needs to be kept to a deposition rate of 6×10^{-5} μg/cm^2/day or less[2]. **This corresponds to between ISO class 4 and class 5.**

[1] Using a target area of 26 m^2 and counting both sides, plus a gamma catcher inner area of 56 m^2
[2] = 0.3 Hz/(90)(108)(0.49)

Problems can be minimized by filtering the air inside the acrylic vessel while on site and unsealed, and to the best extent possible, not allowing lab air to mix with the recirculated air of the vessel. The length of time the vessel remains exposed to air should also be minimized.

6.2.5. Buffer Region:

In this region we no longer have to worry about alpha activity, even on the surface of the acrylic vessel. Therefore the estimate from the simulation can be used uncorrected. One gram of rock dust *distributed evenly* in the buffer region would correspond to an activity of about 0.004 Hz in the target and gamma catcher above 0.7 MeV. Therefore the total amount of dust allowed for a rate of 0.3 Hz is about 75 grams. For a 12 month exposure and a surface area of 146 m^2, this would correspond to a need for **ISO class 7**. This will change when the acrylic vessel is installed in the buffer tank.

Note that this also sets the scale for the cleaning of the PMT's. No more than about 0.1 g of dust per PMT can be allowed into the buffer (assuming 400 PMT's). Cleaning recommendations for the PMT's are discussed below.

Dust distributed on the outside surface of the gamma catcher is much more dangerous than dust distributed uniformly in the buffer. The relevant specific activity is then roughly half the specific gamma activity (not beta or alpha) above 0.7 MeV. This is estimated to be 0.06 Bq/g[3]. Assuming a three month exposure of the acrylic vessel exterior in the buffer vessel before filling, the inside air should be maintained at **ISO class 6** or better.

6.2.6. Inner Veto:

In this region we can use the distributed activity simulation, which predicts an effective activity of 0.006 mBq/g. In this case, the requirement is that no more than 50 kg of rock be distributed evenly inside! Thus the requirements on the inner veto will be dominated by the *transparency needs* of the project and not by radiopurity considerations. No ISO clean room standard is required, and cleanliness procedures will be based on past experience and common sense with a goal towards keeping the scintillator useable. In addition, keeping the exterior of the detector clean will contribute to keeping the central regions dust free by keeping rock dust from becoming airborne.

[3] This is the sum of the three high energy gamma specific activities divided by two.

6.2.7. Cleanliness plan during the installation on site

6.2.7.1. Phase 1: Shield and Veto Tank Installation

Description: Installation of steel shield pieces. Welding of veto tank pieces. Installation of buffer tank feet.

Access requirements: None

Facilities requirements: During installation of the shield there are no requirements on laboratory access or air standards other than those required for general health and safety.

Procedures: None

6.2.7.2. Phase 2: Initial Cleanup

Description: Prior to installation of the Inner Veto (IV) photomultiliers and buffer tank.

Access requirements: No eating or drinking (except water) in the pit area. Show covers required in the pit area. No smoking in the lab area. The “pit area” includes an area 1 meter from the edge of the pit.

Facilities requirements: Pit area roped off. Shoe covers available at entrance to pit. Bridge screened from pit with plastic shield to prevent dust from falling off the bridge into the pit. Source of DI water inside pit.

Procedures: In order to remove gross dust and suppress airborne particles, an initial cleaning should be done. This should consist of simply washing floors, walls, and other surfaces with mild soap and water. Special care should be taken in the ceiling areas above the pit. After washing, it may be appropriate to paint surfaces and equipment (such as the crane) to seal in dust where practical.

The interior of the veto tank should be cleaned with mild soap and water and then wiped down by hand with DI water alcohol and lint-free disposable cloth or paper. Special care should be given to welds and other areas where dust or welding debris may be. The goal is to reduce the effect on IV scintillator transparency in preparation for IV PMT installation.

6.2.7.3. Phase 3: Veto PMT Installation

Description: Installation of the Inner Veto PMT’s. Covering of pit area.

Access requirements: “Pit shoes” (clean sneakers left in a box at the edge of the pit), white tyvek coveralls, and “pit hats” (clean hard hats left in a shelf at the pit entrance) for workers in the pit area. Shoe covers while working in the general lab area.

Facilities requirements: Shoe covers available at lab entrance. Dress out area with white coverall, pit shoes, and pit hats available for workers entering the pit. Clear plastic tent over the pit top to prevent dust from ceiling.

Procedures: IV PMT's should arrive pre-cleaned in double plastic bags. The outer bag will be removed at the door of the lab. Inner bag removed prior to entering the pit area. PMT cables will be free of printing (or else printing removed by cleaning) and PMT metal/plastic housing cleaned with mild soap and DI water. Metal part of the housing wiped with alcohol and lint-free clothes or paper (do not get alcohol on acrylic windows).

Interior of cable conduits (if used) cleaned by flushing with mild soap and water and then by DI water.

After PMT's installed a final cleaning shall be done. After that, large plastic sheets should be draped over the PMT's and tank area. These sheets will be removed from the top *after* buffer tank installation. They should be made of flame resistant plastic, since they may come into contact with sparks from welding on the inside of the buffer tank.

6.2.7.4. Phase 4: Buffer Tank Installation

Description: Installation and welding of the buffer tank.

Access requirements: Pit area and lab access requirements are the same as phase 3.

Facilities requirements: Same as phase 3.

Procedures: The buffer tank pieces shall be pre-cleaned before welding in the area on the edge of the pit. The tank floor and each side ring piece will be cleaned after welding with mild soap and water, then isopropyl alcohol using lint=free cloth or paper.

During buffer tank welding the IV region shall be sealed with plastic sheet and the air in the IV kept dust-free. In addition, the buffer tank lib shall be cleaned in a similar fashion to the rest of the tank, and it shall be kept sealed in a plastic cover.

6.2.7.5. Phase 5: Setting Up a Clean Room in the Pit

Description: After tank welding, the pit area shall be prepared for gamma catcher installation. Cleanliness standard shall be ISO class 7 or better (roughly class 300,000 by the old standard).

Access requirements: Shoe covers or dedicated clean deck shoes. Clean hard hats and hair covers. Tyvek coveralls. "Sticky" pads at the entrance to the pit. Only use of certified tools allowed.

Facilities requirements: As in phase 3, plus air filters to maintain class 7 standards. Pit tent sealed at floor level, if possible, and should include outer veto area. Cover sheets should be removed from outer veto. Sticky pads at pit entrance. Tool chest for certified tools. Access to pit only by personnel trained in maintaining cleanliness standards.

Training signed off by on-site cleanliness manager. If practical, a particle dust counter should be installed to monitor airborne dust levels.

Procedures: Outer veto cover sheets should be removed before sealing tent over the IV area. Only the annulus ring need be covered now. Tools will be cleaned by cleaning with mild soap and DI water, and then wiped with alcohol. A certified tool box will store tools for use. Electronic equipment will be wiped down and stored in plastic bags. Scaffolding shall be cleaned.

6.2.7.6. Phase 6: PMT Installation

Description: Installation of PMT's.

Access requirements: As in phase 5. In addition, personnel access should be minimized to avoid spreading dust.

Facilities requirements: Scaffolding will be cleaned with mild soap and DI water before assembly in the buffer tank. As practical, the floor of the buffer tank will be covered with a removable plastic sheet to collect dust. Personnel handling PMT's should wear disposable latex gloves.

Procedures:

PMTs, magnetic shields, and mountings need to have less than 0.1 g of dust per assembly to avoid significantly contaminating the buffer. This should be done off-site if possible in a clean area by personnel dressed to the same standards as the pit. This includes:

(1) Cleaning of all metal fasteners (nuts, bolts, etc) by *individually* wiping with mild soap and water, followed by cleaning in an ultrasonic bath filled with DI water mixed with alcohol. This should remove oil from the manufacturing process. They should then be rinsed with DI water and stored in sealed plastic bags for use in the pit. These bags in turn should be placed in outer bags for delivery to the edge of the pit. There the bags should be removed and the inner clean bags taken into the pit.
(2) Acrylic pieces should wiped with mild soap and DI water, thoroughly rinsed, and individually certified clean by wiping in with a clean, white, lint free "kimwipe". They should also be double bagged for shipment to the site. The outer bag should be removed at the edge of the pit. Each mounting assembly should be inspected for cleanliness by the PMT installation supervisor before installation.
(3) Mumetal shields may be cleaned in a similar fashion to the acrylic mounts.
(4) The PMTs themselves should be individually wiped with alcohol to removed dust and oils. They should also be inspected and certified clean, then double bagged and delivered to the site.

Integration of the PMT with the shield and mount is probably best done at the edge of the pit in the clean room using the certified "clean tools". If this is not possible, then the integration area should be ISO class 6 or better and the PMT's assemblies should be delivered double bagged for installation in the pit.

Installation of PMT assemblies on the buffer tank lid will be accomplished by making the area under the id a temporary clean area. This can be done by putting a plastic cover on the deck, then sealing a plastic wall around the edge. The air inside should be filtered while PMT installation is taking place. Once PMTs are installed, the floor and walls may be removed, by the lid itself should remain sealed in plastic.

After PMT assembly is completed and scaffolding removed, the plastic covers should be removed from the pit bottom by carefully folding such as to not allow trapped dust to escape.

6.2.7.7. Phase 7: Gamma Catcher Installation

Description: The gamma catcher acrylic vessel will be cleaned, transported to the site and then through the access tunnel to the pit. It will then be rotated into the pit.

Access requirements: Same as phase 6. Gamma catcher installation will require the presence of the Cleanliness Manager (CM) on site to approve all procedures as regards keeping the tank and lid clean.

Facilities requirements: A particle counter should be used to certify the pit area as **ISO class 6** or better before gamma catcher installation begins.

Procedures: The interior of the gamma catcher needs to be cleaned at maintained at **ISO class 4** and kept that way from the time of manufacture to installation in the detector. The exterior should be kept at **ISO class 6** or better. All interior and exterior surfaces should be wiped with mild soap and DI water and then thoroughly rinsed with DI water. This should be done in a clean environment, preferably at the time of manufacture. The entire tank (and lid) should then be double plastic sealed for transport.

The steel tank holder and rotator assembly must be cleaned with mild soap and DI water. Bare stainless steel is preferable to painted carbon steel for these devices. Before use, they should be certified free of oil and dust by the CM.

The outer bag should be removed from the gamma catcher tank before rotating into the pit. After the outer bag is removed, the interior air of the tank should be filtered and kept at low humidity to avoid entraining or settling dust. After lowering into the pit, the inner bag may be removed, but the air quality should continue to be maintained by leaving the open top covered and continuing to condition the air to **ISO class 4.**

The acrylic cover should be cleaned and stored using similar standards to the tank.

6.2.7.8. Phase 8: Target Tank Installation

Description: The target tank is delivered to the site and installed. The lid of the gamma catcher tank is glued into place.

Access requirements: Same as for phase 7. The CM should be on site during target tank installation to ensure cleanliness of the tank, people, and installation equipment.

<u>Facilities requirements:</u> During the (short) time of installation, the pit air cleanliness should be improved to **ISO class 5** standards r better. After the gamma catcher lid is glued in place, this can be relaxed to **ISO class 6**.

<u>Procedures:</u> Both the interior and exterior of the tank should be maintained in an **ISO class 4** environment or better from the time of manufacture to installation in the pit. The acrylic may be cleaned with mild soap and DI water, followed by repeated DI rinse. The tank should be transported double-sealed into the lab in similar fashion to the gamma catcher. Again, the inner bag should be removed at the last possible minute before installation, and the interior should remain sealed and the interior air filtered and kept at low humidity to prevent dust from gathering inside.

The steel tank transport jig should be made of bare stainless steel if possible. This steel should be cleaned by wiping with mild soap and water, then alcohol, and then rinsed with DI water. It should be stored double bagged and certified clean by the CM before use.

After the gamma catcher lid is in place, cleanliness standards on the pit may be reduced as specified above. Gluing shall be done in an **ISO class 6** or better environment.

6.2.7.9. Phase 9: Top Installation and Detector Closeout

<u>Description:</u> Installation of the buffer tank lid and veto tank lid.

<u>Access requirements:</u> After the buffer tank lid is in place and before welding, pit air standards have to be maintained at **ISO class 7** or better. The CM need not be present for this work. In addition, after the buffer lid is in place no special cleanliness training is required to enter the pit area. Clean coverall, hat, and shoe covers must be worn until the veto tank lid is in place. After it is in place, only shoe covers, and disposable coveralls are required. After the veto tank lid is in place, only shoe covers are required.

<u>Facilities requirements:</u> A sufficiently large and fire-resistant tent must be used to protect the pit area from dust during the welding process. Every attempt should be made to filter the air around the site of welding in or to minimize airborne particles.

<u>Procedures:</u> The time that the pit is uncovered for buffer tank lid installation should be minimized. The tank top and IV region should be covered to prevent dust from entering, especially while welding is going on.

After buffer tank welding in complete, these cover sheets can be removed for veto tank lid installation. Again, the time the pit in uncovered while the veto tank is installed should be minimized. After the veto tank lid is in place (it doesn’t necessarily have to be welded), the pit tent can be removed and the air can cease being filtered.

It should be noted that the chimney needs to remain sealed and covered with plastic to prevent dust incursion.

6.2.7.10. Phase 10: Glove Box and Outer Veto Installation

Description: The Outer Veto (OV) and glove box (GB) are installed.

Access requirements: No special access requirements for OV installation. The GB area will have a portable soft-sided clean room installed, and special training will be required for access. Entry into the GB clean room will require shoe covers, clean disposable coveralls, hair cover, and latex gloves.

Facilities requirements: A soft-sided glove box at roughly **ISO class 7** will be installed over the GB area. The approach to the GB will have a "sticky pad" and show covers should be worn. A "dress out" area shall be established on the GB bridge. This could be a simple plastic floor cover with sticky pad, a plastic roof, and clean, sealable, plastic storage bins.

Procedures: The interior cleanliness requirements of the GB are covered in the TDR section on the GB. The GB assembly will be delivered to the site double bagged. The GB will be certified as clean by the CM before installation. The outer bag may be removed upon entry into the lab area, but the inner bag should not be removed until just immediately before installation.

The GB exterior will be cleaned using mild soap and water, followed by several rinses with Di water. Alcohol may be used to clean the welds and aluminum frame. This cleaning is preferably done off-site before shipping to the lab.

GB tools will be kept in the GB clean room and not used for other purposes.

6.3. Radiopurity monitoring

Radiopurity requirements are given in the Proposal document (hep-ex/060625, p59).

	Th, ppb	U, ppb	K-40, ppb
Target	0.000001	0.000001	0.000001
Acrylic	0.01	0.01	0.01
PMT	26	28	10
Catcher	0.000001	0.000001	0.000001
Buffer	0.000001	0.000001	0.000001
Veto	0.000001	0.000001	0.000001
Steel	3.3	2.3	0.54
Rock	5000	2000	1638

Table 21: Assumptions for calculation of singles rates.

To ensure that the ambitious sensitivity goal of the Double Chooz experiment is attained, great care must be taken to keep the background trigger rate at or below the design level of a few Hz. This in turn requires that great care be taken in material selection, so that the intrinsic radioactivity of detector components does not produce too high a background rate. We have been measuring the radioactivity of important materials to ensure that they will meet or exceed the required level of radiopurity.

Activity measurements requiring very high sensitivity have been made at the Oroville Low Background Counting Facility. This facility, operated by the Lawrence Berkeley National Laboratory, is located in the powerhouse of the Oroville Dam in Northern California, under 180 m of rock cover (~600 m.w.e.). It has three Ge spectrometers: a 115% n-type, an 80% p-type, and a 30% p-type. Sensitivities of 50 parts-per trillion (PPT) for U and daughters, 200 PPT for Th and daughters, and 100 parts-per-billion for K are realized at the Oroville site.

Activity measurements requiring less precision (such as PMT glass and steel) will be made in a new facility to be built by U.C. Davis with university funds. This facility will also be able to count large components (such as entire PMT's) to the required level of activity (~100 mBq above 1.4 MeV). The U.C. Davis counting system will be operated at CEA Saclay and Chooz during detector installation. In this way, a representative sampling of the actual detector components can be assayed before being built into the experiment.

6.3.1. UC Davis Portable Counting System

The Davis system consists of an ORTEC GEM80 80% HPGe detector in a OFHC copper enclosure with remote preamp, designed for low background use. It will be mounted in a 950 kg steel-coated, copper lined 10 cm thick lead shield mounted on a table above a 30 liter liquid nitrogen dewar. The readout system will include safety monitoring devices that shut the detector down in the event of loss of cooling to avoid damage to the crystal. The entire shield and detector will be covered on 5 sides by 12.5 cm thick plastic scintillator veto counter. This counter uses 10 2-inch PMT’s (2 to a panel) powered by a single HV power supply and read out via a NIM discriminator and logic unit.
Additional Detector Specifications:

- HPGe power requirements: TBD
- Muon veto power requirement: TBD
- Liquid Nitrogen usage: 30 liters/week

The system will be enclosed in a 1.85 x 2.45 meter soft-sided portable room. The room has vinyl walls, a filter and fan unite (see Figure 14 and Figure 15). It requires a smooth floor to be assembled, and at least 30 cm above the roof for the fan exhaust.

Additional Clean Room Specifications:

- Height: 241 cm (includes fan exhaust height)
- Light: 220 VAC/50 Hz 120 W (two of these)
- Fan/Filter Unit: noise 48 DBA, flow 18.2 m^3/minute, 220 VAC/50 Hz, 317 W at high speed, 170 W at low speed (one of these)

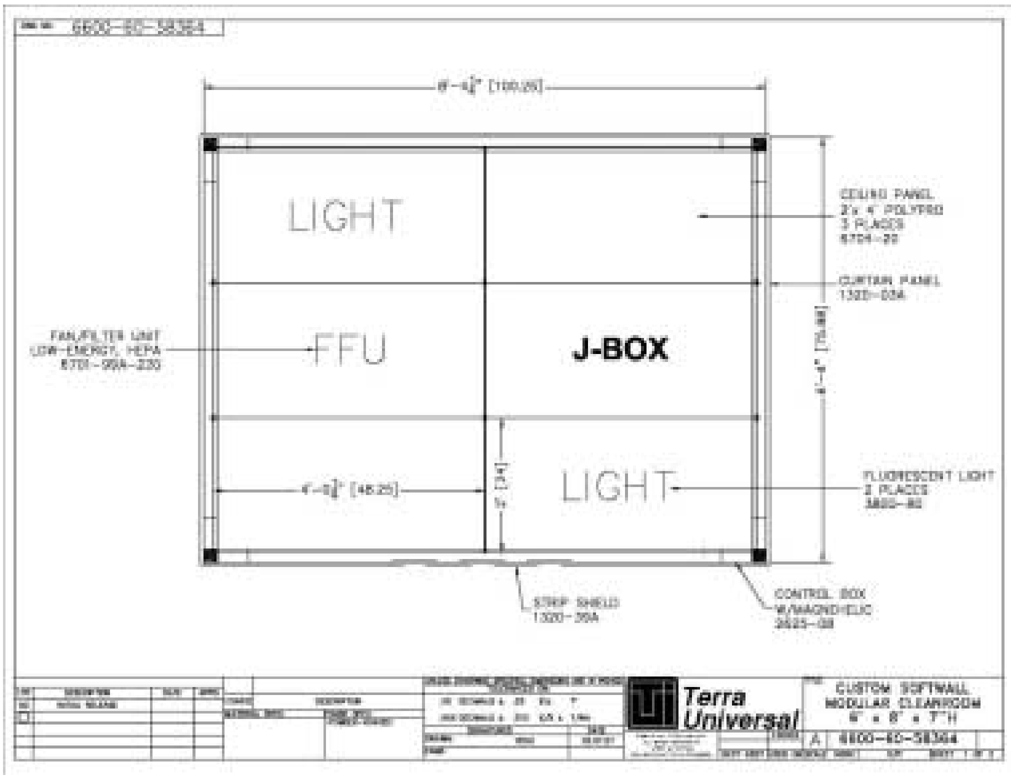


Figure 14: Footprint of the clean enclosure for the Davis counting facility

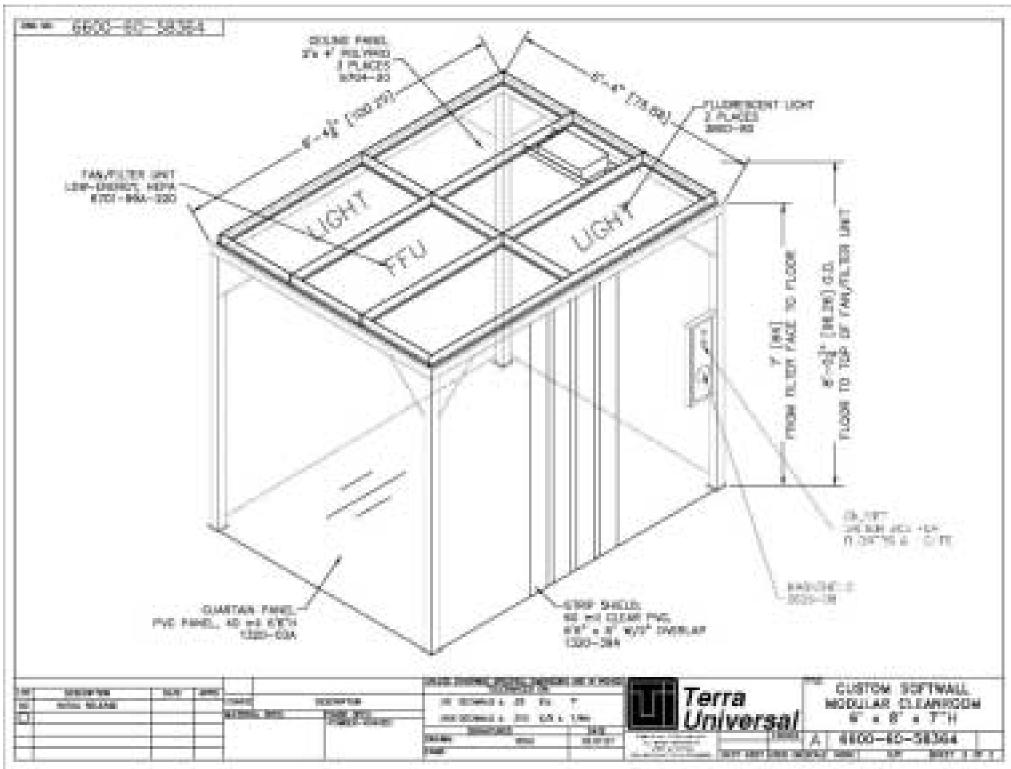


Figure 15: 3-D drawing of the enclosure. Note: as built the control box and entrance will be on the short side rather than the long one.

This system will initially be set up at Saclay in summer, 2007 for screening PMT's and other materials (such as buffer vessel welding rods). When space becomes available, the system will be moved to the Chooz Far Laboratory in order to shorten the screening time and further increase the sensitivity by moving deeper underground.

6.3.2. Radiopurity Monitoring during the design phase

Samples of all materials foreseen for use in the detectors will be radioassayed, just as they are being tested for chemical compatibility. This effort is underway, with samples of component materials and/or components being assayed in Europe and the US. Items assayed so far are listed in Table 1. Items that have been counted, with results not yet available are listed in Table 2. Items remaining to be assayed are given in Table 3.

Item, Counting Facility	**K (ppm)**	**U (ppb)**	**Th (ppb)**	**^{60}Co (mBq/kg)**
ETL, glass, manufacturer	64	30	30	-
ETL, glass, Alabama	85 ± 34	28 ± 7	26 ± 13	-
ETL, glass, MPIK	59	54	156	-
ETL, glass, LBNL	91 ± 5	45 ± 2	13 ± 1	-
Hamamatsu R5912, glass, Alabama	205 ± 60	81 ± 13	210 ± 30	-
Hamamatsu R5912, glass, LBNL	165 ± 8	78 ± 4	230 ± 12	-
Photonis, glass, LBNL	104 ± 9	180 ± 10	65 ± 6	-
ETL, dynode, manufacturer	109	35	12	-
Hamamatsu R1408, glass, LBNL	110 ± 5	620 ± 31	310 ± 15	-
Hamamatsu 10", glass, LBNL	220 ± 11	170 ± 8	350 ± 17	-
Hamamatsu 10", insulators, LBNL (*)	-	800	-	-
ETL, EP37 Epoxy, LBNL	< 4	< 1	< 3	-
ETL, Potted base, LBNL	< 1	3	< 5	-
ETL, tubular insulator, LBNL	60	110	< 30	-
ETL, Al2O3 insulator, LBNL	40	150	90	-
RG-303 coax	< 2	< 1	< 3	-
Buffer Tank Steel, ("Batch 1")	< 0.004	< 0.0003	0.008	11.8 ± 0.3
Buffer Tank Steel, ("Batch 2")	< 0.004	< 0.0002	0.002	7.8 ± 0.2

Table 1. Items assayed to date (* preliminary result).

Item
ETL, Dynode metal
ETL, socket
Hamamatsu R5912, insulators
Hamamatsu R5912, dynode metal
Hamamatsu R5912, socket
Hamamatsu 10", dynode metal

Table 2. Items counted, results forthcoming.

Item	Responsible
Optical Fiber	Sussex
PMT mount	Madrid
PMT mu metal	Madrid
Source Guide tube	Alabama
Magnetic monitor	KSU
Welding Rods	Saclay
Hamamatsu PMT base and potting	Davis
Outer shield steel	Davis

Table 3. Items remaining to be assayed during design phase.

Based on the above results, and assuming we will use the 10" Hamamatsu PMT's the expected background contributions above 1 MeV are estimated as follows:

- Rock: 1-2 Hz
- Acrylic vessel: <0.3 Hz
- Buffer Tank: 0.28-1.6 Hz
- Veto Tank and Shield: 0.16-2.8 Hz
- PMT's: 8 Hz

The spread indicates the spread in the measured values and/or from measurements in the literature. Thus the goal is to ensure that materials used in detector construction are, as much as possible, in the lower part of the available range. In addition, we need to do *in situ* checks to catch major variations from the design values.

6.3.3. Radiopurity Monitoring during the production phase

As certain important detector components are being produced, assay of raw materials and/or a sampling of completed items will ensure that radiopurity requirements are being met. Examples include the assay of samples of buffer tank steel before acceptance from the manufacturer (completed), and assay of PMT glass before PMT production. This should also extend to other PMT hardware (mounts, shields, etc), since there are many of these items in close proximity to the active detector volume.

The guide tube production material should also be assayed in this way, since it will not be possible to assay the finished product due to its large size.

6.3.4. PMT production monitoring

During the production run for the ~ 1000 PMTs to be installed in the Double Chooz detectors the following radiopurity monitoring scheme will be implemented:

- **Glass batch check**
  Representative samples of the glass to be used in PMT production will be counted. It is desired that every different batch of glass used in DC PMT production be assayed. The exact PMT production sequence is not yet clear, i.e. whether all the glass for the DC PMTs will be acquired at once, or whether

different batches will be used as production progresses. In any event large (~1 Kg) samples will be used to ensure rapid counting.

- **Whole PMT assay**
  Once PMT production is underway, a sample of PMTs from each production batch of 100 will be sent to the UC Davis system for “whole body” counting. This will ensure that the PMT production process for that batch did not introduce unacceptable levels of contaminants. Given that each PMT batch takes one month to produce counting should be completed within this timeframe. Thus, if a problem is identified it can be rectified before production of the next PMT batch. We therefore propose that 4 PMTs from each batch be acceptance tested. Two of the first ten PMTs produced should be rapidly sent to the UC Davis system for testing prior to the completion of the batch. One PMT from the middle of the run (45-55) and one from the end (90-100) should also be sampled to ensure consistency across the batch. It is estimated that 1-3 days will be required per PMT for this activity check.

6.3.5. PMT hardware production monitoring

The same logic described for PMTs should also be applied to PMT hardware. This includes PMT mounts, fasteners used therein, and mu metal shields. Samples of material batches purchased for mount and shield production should be sent to Sandia/UC Davis for acceptance testing. Similarly, a sampling (5%) of completed items should also be sent for counting during construction so that any production process contaminant can be detected early.

6.3.6. Radiopurity Monitoring during the construction phase

The U.C. Davis counting system will be moved to CEA Saclay in late summer 2007, and then installed in the Chooz Far detector lab after installation of the buffer tank. Continuous and well organized use of this facility will allow for a representative sample of components destined for integration into the detectors to be tested immediately prior to that integration. Of course, samples of all components will have been previously tested. However, this approach will ensure that any components accidentally contaminated by improper handling, fabrication, or use of contaminated raw materials from production batches not previously assayed will be “caught” before being built into the detectors.

A preliminary list of the components to be assayed at Chooz is given in Table 4. As schedule information becomes available, this table will be populated, and priority in the order of counting will be assigned, so as not to delay construction. Dimension and mass information for each items must also be collected so that it can be determined whether items will fit in UCD system, and for how long they must be counted.

Before integration, all items will have to be certified by this onsite sampling, or by prior counting that demonstrates their radiopurity. Where feasible, onsite counting is to be preferred as it minimizes the opportunity for contamination after certification.

System	Component	No. to be installed	No. to be assayed	Date due at Chooz/Saclay	Installation Date
Target					
	Z-axis Cable	1	1	?	?
	Acrylic Glue	-	-	?	?
	Laser Fiber	1	1	?	?
Gamma Catcher					
	Acrylic Glue	-	-	?	?
Buffer					
	Welding Rods	50	50	?	?
	PMTs	400	50	?	?
	PMT mounts	400	25	?	?
	PMT mu-metal	400	25	?	?
	Fiber diffusers	20	5	?	?
Inner Veto					
	Welding Rods	50	50	?	?
	PMTs	100	10	?	?
	PMT mounts	100	5	?	?

Table 4. List of components that will be integrated into the Double Chooz Far detector. Also given are the size of the sample that will be assayed onsite, and the dates between which this must occur.

6.4. Product assurance

6.4.1. Generalities

Product Assurance is a discipline devoted to the study, planning and implementation of activities intended to assure that the design, controls, methods and techniques in a project result in satisfactory level of quality in a product. This discipline includes Quality Assurance, and reliability, availability, maintainability and safety.

The specificity of the project, environment (nuclear power plant), and scientific requirements (technical developments and configuration management) need the putting in operation of a Product Assurance system.

6.4.2. Product Assurance requirements

The Product Assurance system is described in the Product Assurance Plan (PAP) EDMS N° I-010753

The PAP describe :

- the applicable and reference documents
- the Product Assurance requirements in development
- the delivery documentation

The delivery documentation of each subsystem is described in :

- Delivrery documentation matrix
- the documents « Acceptance Data Package Requirements »

The examples of delivrable documents contents are described in templates.

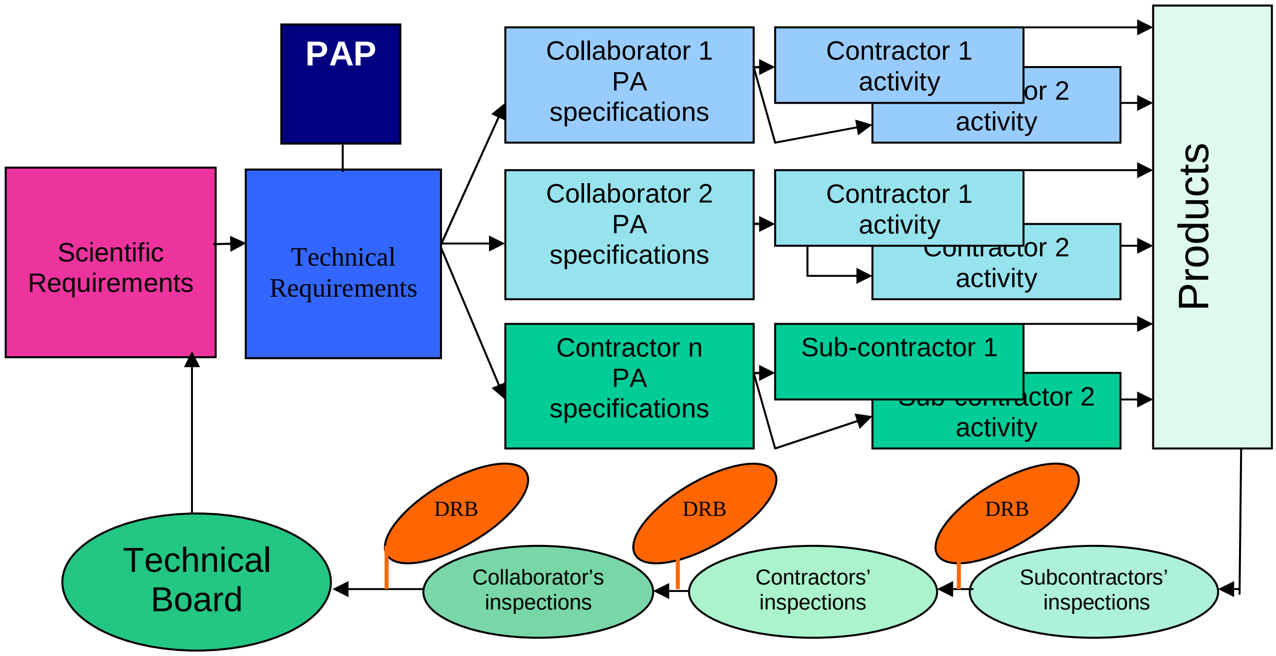


Figure 16 : Informations flow to garantee the products Quality

6.4.3. Organisation

The Product Assurance Manager has the responsibility of this activity in the project. For each subsystem a Local Product Assurance Manager has to be identified to control the project requirements application (material and associated documentation) and to inform the P.A. Manager of any major non-conformance or any major modification. The Local Product Assurance Manager is at each review (internal subsystem and project). These reviews are described in the flow chart (chapter 7)

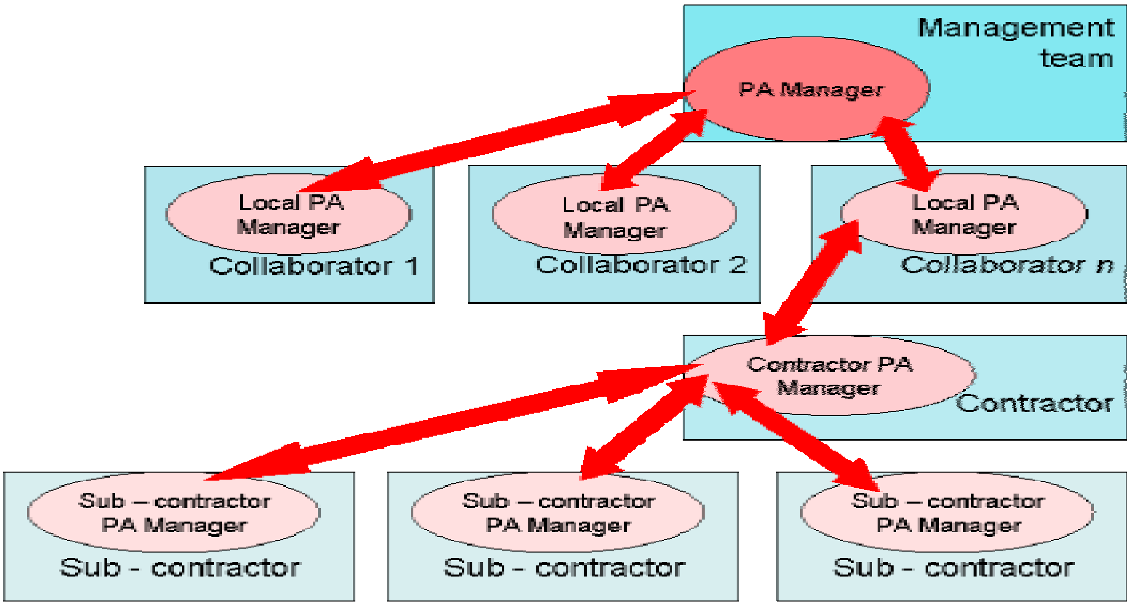


Figure 17 : Product assurance organisation

Names of the Subsystem Product assurance managers

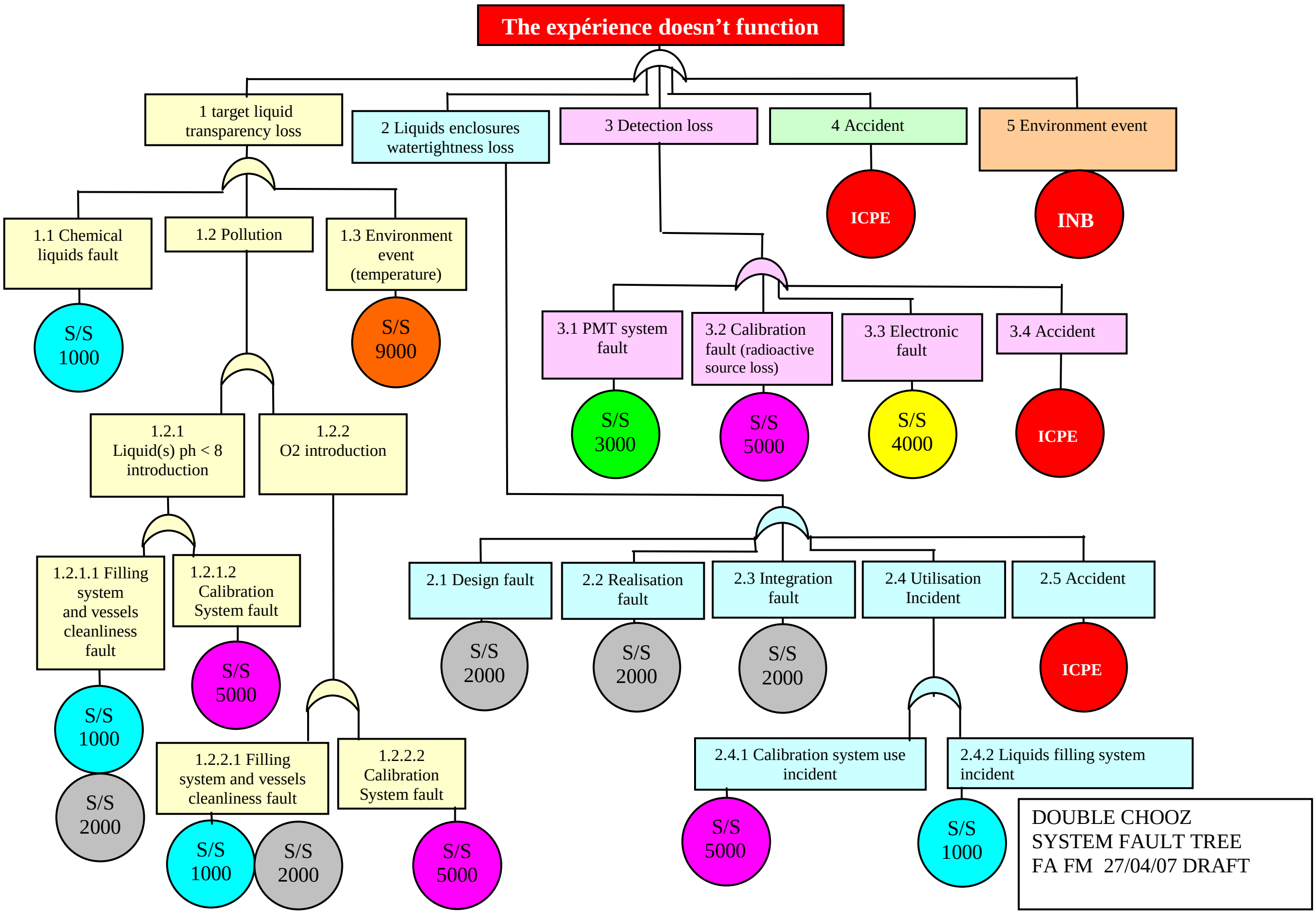
S/S Numbers	Subsystems	Names of the Subsystem Product assurance managers
	System	F Meigner CEA
1000	Liquids and filling system	Nobody
2000	Mechanical structures	M. Benallou APC - F. Meigner CEA
3000	Inner detector PMTs	Nobody
4000	Electronics and acquisition	M. Benallou APC
5000	Calibration system	Nobody
6000	Inner veto	Nobody
7000	Soft/data base	Nobody
8000	Outer veto	Nobody
9000	Integration on site	M. Benallou APC - F. Meigner CEA

Figure 18 : Subsystem Product assurance managers (July 2007)

6.4.4. System risk analysis

A system risk analysis have been made by the Project Manager and Product Assurance manager with a fault tree analysis.

The idea of the fault tree is to identify all the causes which will induce the loss of the detector.



Symbols	Descriptions	Symbols	Descriptions
	« AND » function	S/S 1000	Liquids fault
	« OR » function	S/S 2000	Mechanical Architecture fault
	Event	S/S 5000	Calibration fault
	Basic event of this analysis Must be detailed in subsystem analysis	S/S 9000	Detector Integration fault

Figure 19 : System risk analysis of detector

To be done chronologically

After this first system analysis, all the subsystems must do the same work.

All their fault identified at the bottom level are considered as feared event of their analysis

After the causes identification, a maximum of caution during the design, development and integration have to be considered to avoid it.

The bubbles represented on the diagram identify either the Safety files which discribe the caution means or the subsystem which have to deal with the risk cause identified.

The PA Manager can help the subsystems in this work.

6.4.5. Configuration management

The configuration management need to master the following activities :

a) Design control
b) The management of some lists (DML DPL DCL)
c) The management of the non conformances
d) The management of the change proposal

6.4.5.1. Design control

The design of every product has to be managed like ISO 9001 norm mind.
The main requirements are:

Drawings must be numbered
The issue must be explained by a non conformance and its number
The issue must be explained by a change proposal and its number
The drawings must have technical control
The drawings must have subsystem control
An interface drawing ID must be validated by the two subsystems in interface
An interface control drawing ICD must be completed after realisation with the metrology data before the delivery of the product

The first issue of a design is qualified « AS DESIGNED » file
The issue of a design after realisation and integration is qualified « AS BUILT » file

The life of the configuration is

AS DESIGNED + X non conformances +Y change proposals = AS BUILT file

6.4.5.2. The lists (DML DPL DCL)

DML : DML is a Declared Material List. All the materials must be recorded in a specific document. The form of this document is given by the Project.

DPL : DPL is a Declared Process List. All the process must be recorded in a specific document. The form of this document is given by the Project.

DCL : DCL is a Declared Components List. All the componentss must be recorded in a specific document.The form of this document is given by the Project.

6.4.5.3. Non conformance management

Every subsystems must manage a local system of non conformance. The non conformances are recorded in a specific document the « **N**on **C**onformance **R**eport » (NCR)

The non-conforme product must be identified « NON CONFORM »

There are two types of non conformance :

Minor NCR is a non conformance without interfaces impacts

Major NCR is a non conformance with interfaces impacts

A major NCR must be sent to the Product assurance manager of the Project to do a system analysis.

The major NCR list is a delivrable document

The minor NCR list is a consultable document

A template of NCR data sheet is provided in P.A.P. Annex

6.4.5.4. Change proposal management

Every subsystems must manage a local system of Change Proposal. The Change Proposal are recorded in a specific document the « Change Proposal **R**eport » (CPR)

There are two types of Change Proposal :

Minor CPR is a Change Proposal without interfaces impacts

Major CPR is a Change Proposal with interfaces impacts

A major CPR must be sent to the Product assurance manager of the Project to do a system analysis.

The major CPR list is a delivrable document

The minor CPR list is a consultable document

A template of CPR data sheet is provided in P.A.P. Annex

6.4.6. Safety

Safety is a discipline to provide for a system *a state in which the risk of harm (to persons) or damage is limited to an acceptable level (ISO 8402)*

At the system level the safety activities are managed by safety engineers under the P.A. Manager and Project Manager autority.

The main activities are the safety risk analysis. There are two types of Safety risk analysis

- **Subsystem** Safety risk analysis and **System** Safety risk analysis

6.4.6.1. Subsystem Safety risk analysis

Every subsystems have to manage a risk analysis of their activities. The output records of this analysis are the incoming information for the system safety risk analysis

Four subsystems have to provide the results to the P.A.Manager :

Liquids Mechanical Architecture Calibration Integration

It has been defined from fault tree (Figure

6.4.6.2. System Safety risk analysis

The system safety risk analysis is managed by The Project Manager, the Product Assurance Manager and the Safety engineer.

The tools used are : **MOSAR and MES (CEA tools)**

MOSAR *Méthode Organisée Systématique d'Analyse des Risques*
Organised, Systematic Risk Analysis Methodology

MES *Maîtrise par les Exploitants de la Sécurité*
Collective risk analysis (with operational people of the installation)

A MOSAR analysis (draft issue) with M.E.S tool was done by L. Latron and L. Béraud. (CEA Safety engineers)

–

6.4.6.3. ICPE File

This document have for goal to declare the experience to EDF and the French Safety Autorities.

ICPE *Installation Classée Pour l'Environnement*
Classified installation for environment

None of experiment construction activities can begin before French safety autorities agreement

The ICPE file is managed at Saclay ; it is labelled EDMS I- I-011134

6.4.7. Delivrable documentation

The delivrable documentation is defined in a matrix you could find in appendix 16.5

TECHNICAL DESCRIPTION OF DETECTOR COMPONENTS

7. Liquids and Fluid components system [1000]

Liquids
The main links between liquids detectors is the density. It has to respect a window of 1% within which lie all the densities of the four liquids. In addition, the light yield of the neutrino target (NU) and the gamma catcher (GC) are to be equal.

The density is maintained in a strategy that uses two liquids in NU region which tune the density and three liquids in the GC to tune the light yield. The density is matched in the Buffer region (BF) and Muon Veto (MU) also through the use of two liquids.

Liquids Architecture

Each liquid is a component of the Detector. The system that mates to the detector that handles the filling, recirculation, expansion etc. is called the Detector Fluid Operating System and is located solely in the underground Neutrino Lab. There is one DFOS and it handles all four liquids.

The component liquids are themselves sent to the DFOS via Component Fluid Systems. There are thus four component fluid systems: the NU, GC, BF and MU Fluid Systems. Each of the component fluid systems is comprised itself of the component trunk lines, component storage and/or transport tanks and a component fluid operating system. These systems are located in the outside Storage (or Far Detector Fluid) Building. In addition there are a number of auxialiary systems that support the Detector and Component Fluid Systems.

There are two special tanks that have a mobile feature. The Neutrino Target Weighing Tank (NWT) is located underground during filling or un-filling operations or is otherwise removed. The Neutrino Target Transport Tank (XPT) is used between the Storage Tank and the offsite MPIK Scintillator Hall Facility that was built especially for Double Chooz.

These are described further below.

7.1. Description of components

7.1.1. Target and gamma catcher liquids

The Double Chooz detector will have four separated volumes filled with different organic liquids. In the center there will be the neutrino target consisting of 10.3 m³ Gadolinium scintillator at 1 g/l Gd-loading. The base case target scintillator composition and some basic properties are listed below:

- Composition:
  - 80 Vol.% n-Dodecane ($C_{12}H_{26}$, CAS# 112-40-3, flash point: 71°C)
  - 20 Vol.% o-PXE ($C_{16}H_{18}$, CAS# 6196-95-8, flash point: 167°C)
  - 6 g/l PPO ($C_{15}H_{11}NO$, CAS# 92-71-7)
  - 4.5 g/l $Gd(thd)_3$ (CAS# 14768-15-1)
  - Tetrahydrofuran, CAS 109-99-9: 0.5 %
  - bis-MSB (CAS# 13280-61-0): 20 mg/l

- colorless clear organic liquid
- Flash point : 71.5 ± 1.5°C (ISO 3679)
- Density : 0.80 (20°C)
- Thermal expansion coefficient $\alpha = 1.1 \cdot 10^{-3}$ K
- Viscosity: 2.28 ± 0.02 mm²/s (20.7°C)

The base case composition is being adjusted through the use of precision measurements made with a new Compton Backscatter Instrument set-up at MPIK for this purpose. The scintillator light yield and rudimentay timing aspects are modelled in a light yield model especially created for Double Chooz. The model is used to establish the scintillator light operating region which is then followed up with fine tunings based on the precision measurements. It is anticipated that the composition will be finalized before October 2007.

The optical properties can be found in the technical performance subchapter below. A material safety data sheet for this scintillator mixture exists. The composition of the target mixture determines the density of all the liquids since they have to be the same within at least 1 % precision.

The target volume is surrounded by 22.6 m³ of Gamma-catcher liquid which is an organic liquid scintillator as well, but without Gd-loading. It contains similar solvents and fluors as the target, however, a third solvent (mineral oil) is needed in the mixture to adjust density and light yield:

- Composition
  - 46 Vol.% n-Dodecane
  - 50 Vol.% Oil (CAS# 8042-47-5, Shell Ondina 909)
  - 4 Vol.% o-PXE
  - 2 g/l PPO
  - Others (bis-MSB): < 0,1 %
- colorless clear organic liquid
- Flash point: > 71.5 ± 1.5°C (ISO 3679)
- Density : 0.80 (20°C)

The scintillators in the detector center are embedded in a transparent non-scintillating buffer with a volume of 114 m³. The demands on the buffer are fulfilled using an n-Dodecane oil mixture (details can be found in chapter 7.2.2). The scintillator of the inner muon veto is described in the veto chapter of this document.

7.1.2. Target and Gamma Catcher Fluid System

The target and gamma catcher fluid systems are comprised of the :

(a) trunk lines connecting the DFOS to the systems in the Storage Building
(b) GC and NU fluid operating systems
(c) GC transport / storage tanks and NU storage tanks

The trunk lines will connect to the NU and GC section of the DFOS system. (The DFOS system which insures safety of the detector is described below in a separate section.) For the case of the NU liquid the DFOS also connects to the NWT, which also serves as the intermediate buffer tank. All NU target systems are made of PVDF or equivalent. A separate intermediate buffer tank is planned for the GC liquid between the DFOS and the Trunk Lines.

In both cases, for the GC and the NU liquids, the intermediate buffer tanks buffer the pressure between the outside and underground locations to avoid an over pressure accident (see risk section below). This is planned despite the presense of expansion tanks for the NU and GC systems due to the smallness of the expansion tanks. For the case of the BF and MU systems the functions of the intermediate buffer tanks are accomplished in the DFOS via the expansion tanks due to the less risk of an overpressure accident due to the larger volumes involved.

Trunk Lines Subsystem.

The DFOS system will contain a section that mates to the trunk lines. The NU trunk line will consist of a PVDF or equivalent (PVDF/E) flexible hose of ¾ inch. It will be contained within a PVC pipe of 1.5 inch. The PVC pipe will contain tell-tale drains at T sections of importance in testing. The PVC containment pipe will contain a continuous flow of low pressure nitrogen from the blanketing systems.

The GC trunk lines will be constructed similar to the lines for the case of the NU target except the inner tubing will be made of electropolished stainless steel sections. Each section will be VCR connected with connections in the vicinity of T sections containing tell-tale drains.

Fluid Operating Systems.

The fluid operating systems for the NU and GC will be similar except the NU system is PVDF/E while the GC is electropolished stainless steel.

Each system will contain a pressure operated fluoroware positive displacement pump that will constantly fill a pressurizer tank, connected in a negative feedback arrangement to eliminate the hazards associated with computer control. The pressurizer will maintain the upper pressure header at a fixed operating pressure. Some droop is included for feedback control. Each header (low and high pressure) service a manifold connection. The manifold connections support the interconnections. Each system is made as a module off-site and pre-cleaned. The module upon arrival at the site will be bolted to the floor for safety. The interconnections between the modules manifold and the various loads will thus be made.

The fluid operating systems will through their manifolds connect to the tanks of the liquid flushing system (LFS), the storage tanks and the trunk lines.

Storage Tanks (and in some cases Transport Tanks)

The target scintillator will be produced in 4 PVDF tanks each of them holding a volume of 6000 liters. These tanks can only be operated inside buildings or halls in a temperature range of 5 – 30°C. On the top of the tank there are 4 connections each equipped with manual operating valves. Two of the connections end at the top of the tank and will be used for filling and as a vent; the other two are equipped with ¾'' tubes going to the bottom of the tank, one for emptying and one for gas bubbling. The maximum overpressure will be 400 mbar. This allows to empty the tank without any pump just by applying some overpressure. A spill tray mounted to a steel frame around the tank has the capacity to hold the liquid of a full tank in case of a leak. The footprint of the tank is 2.1 x 2.1 m² at a height of 2.6 m. A blind flanged bottom outlet will just be used for tank cleaning.

Two of these tanks will be used for the storage of the neutrino target for the Far Detector.

These tanks cannot be used for transportation of the target scintillator from Heidelberg to Chooz. Therefore certified tank (XPT) for transportation mounted in a 10 foot Iso-frame (l x w x h = 2.99m x 2.44 m x 2,59m) was designed. It is a 6000 liter stainless steel container with an inner PVDF coating. Also here all materials in contact with the liquid are fluorpolymers to assure material compatibility. The allowed pressure range is from -0.4 to + 4 bars. Filling and emptying is done from the top. Finally, there will be a PVDF tank inside the neutrino lab with a volume of 11000 liters, so it can hold the whole target volume.

For the gamma-catcher liquid stainless steel tanks can be used for mixing and transportation. The scintillator mixing in Heidelberg will be done using three 20 foot Iso-Containers that are certified for intermodal transportation of the liquid as well. Each of the containers has a capacity of 24 m³ and can hold a complete gamma-catcher volume. The tare weight is about 4 tons per tank. The pressure range in the tank can vary from 0.21 to 4 bar and each tank is equipped with a safety valves and burst disks to prevent overpressure accidents. The tank has four 2'' connections on top for filling and emptying. Also here the bottom outlet will be blind flanged when the tank is filled with the scintillator. One full Iso-Containers will be placed in the storage building in front of the neutrino lab to fill the intermediate tank in the neutrino lab with the gamma-catcher liquid.

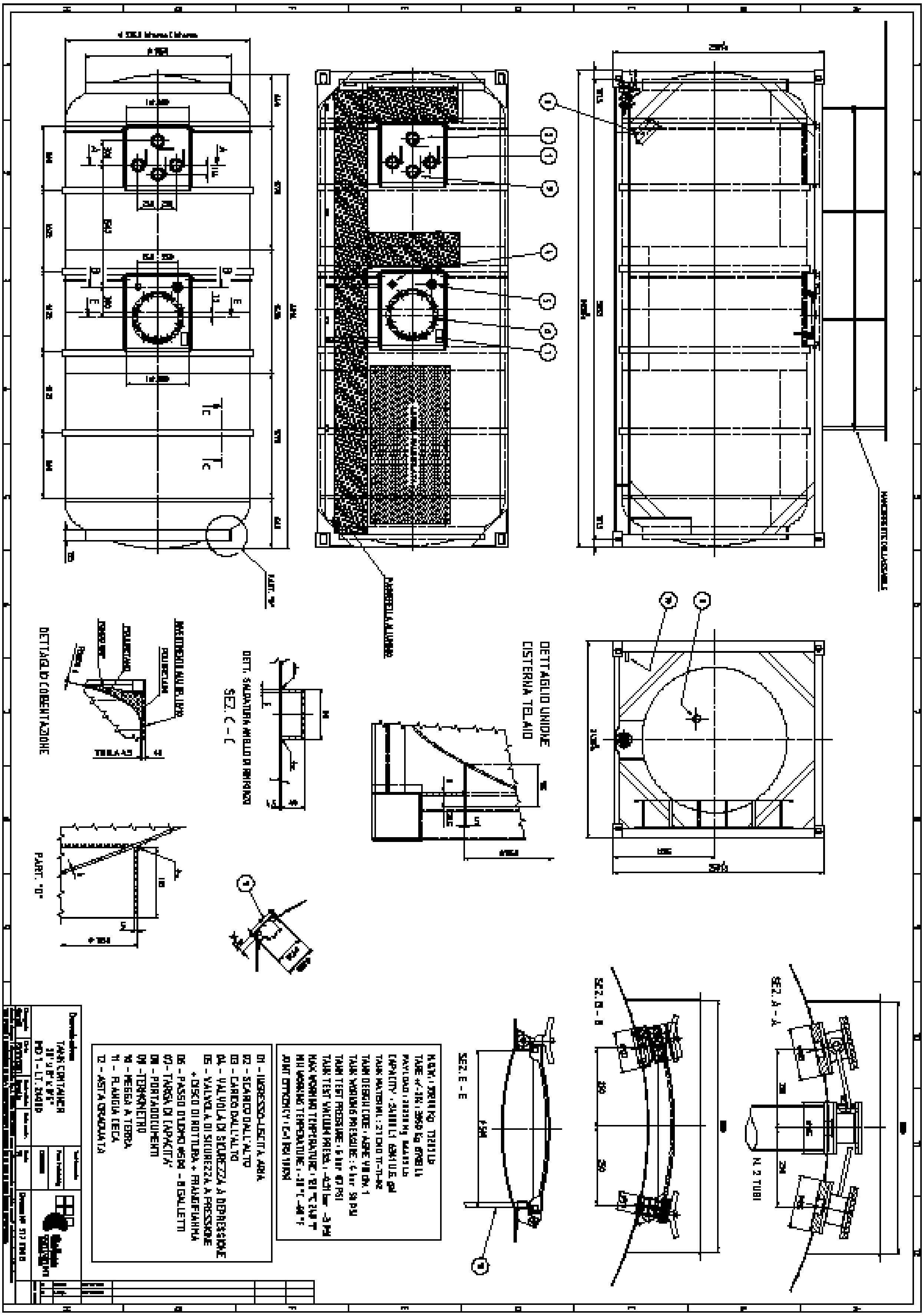


Figure 20 : ***Drawing of Iso-Container used for transport and mixing of the gamma-catcher scintillator.***

7.1.3. Buffer and Muon Veto

Deliverables:

- Liquids: scintillator for the inner muon veto (MU), Buffer liquid (BF)
- Component Fluid System in the Storage Hall for receipt, storage and mixture of liquids
- Detector Fluid System in the underground lab
- Level control during filling, and level regulation system of the different detector volumes

7.1.4. Component Fluid System (storage and mixing MU and Buffer fluids)

- The component fluid systems go into a dedicated building already existing close to the entrance to the neutrino lab (distance to the detector ~ 150 m, height difference ~ 14m)

- The liquids will be stored in 6 single-walled stainless steel tanks:
  Tank specifications: material: stainless steel 1.4301 (AISI304)
  size: diameter 2.6 m (MU), 2.8 m (BF)
  height: 7.6 m (MU), 7.9 m (BF)
  total volume: 35 m^3 (MU), 43 m^3 (BF)
  working overpressure: 0.9 bar
  maximum overpressure: 1.3 bar

- All fluids will be stored and handled under nitrogen atmosphere. Air driven teflon pumps will be used for circulation/ displacement of the liquids. For the mixing and filling operations, a liquid nitrogen supply is required.

- All tubing is made out of stainless steel, connections are made by orbital welding or VCR connectors. Liquid lines are 1'' diameter, high pressure nitrogen lines (HPN) are 1/4'', low pressure nitrogen (LPN) lines 1/2'' or ¼''. The low pressure vent (LPV) is ¾''. Tanks and tubing will be leak-checked after installation.

- **Delivery of liquids**: the liquids components will arrive from the supplier by truck. Truck unloading will go into an isotank (supplied by Heidelberg) located in front of the storage building, and from there via overpressure or pumping into the storage tanks.
  The top inlet of the storage tanks will be used to avoid a potentially dangerous backflow.

- **Mixing of liquids**: The scintillator and buffer mixture will be prepared on site by pump circulation and/or nitrogen flushing. The fluor and wavelength shifter will arrive on site already as pre-mixed master-solution (preparation in Heidelberg or Munich).

- A sketch of the storage area is attached.

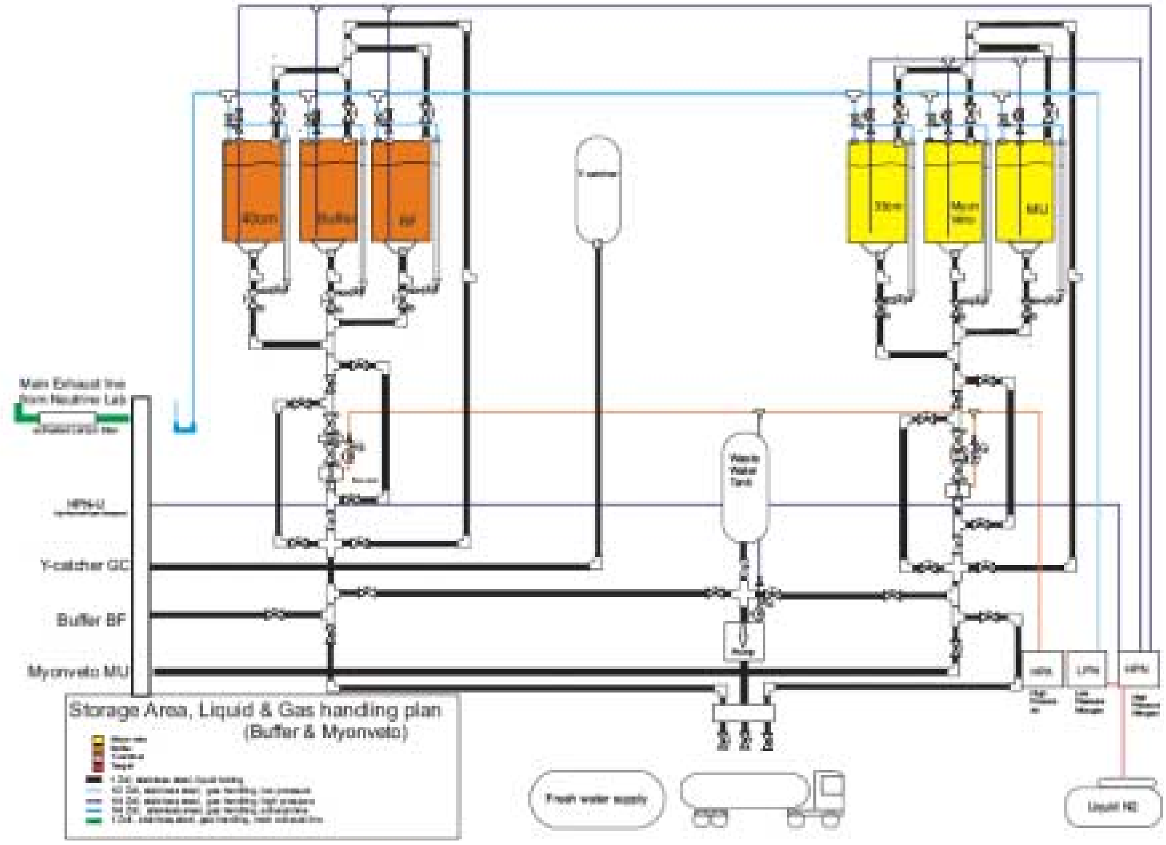


Figure 21 : Buffer & Muon storage area

7.2.Liquids

7.2.1. Liquids: Target & Gamma-Catcher

7.2.1.1. Scintillator description and backup options

The compositions of the various scintillator volumes were listed above. The target scintillator solvent was chosen looking partly at scientific and partly at safety aspects. Scientific arguments were stability, low reactivity, material compatibility with the acrylic, light yield and number of protons in the detector target. Good overall performance for both solvents in the target (PXE and Dodecane) was already found in other low background neutrino experiments. Furthermore, these solvents are preferable compared to other scintillator options as regards safety. The flash point is above 70°C in all the volumes and the hazard class was kept low for all the chemicals used (see safety data sheets).

As a backup option in case the PXE/dodecane cannot be used, we envisage to switch to linear alkylbenzene (LAB, CAS# 67774-74-7, flash point: 140°C) as scintillator solvent in the target. Also the LAB is not classified as dangerous substance. Additionally, oil would have to be used in the other volumes. The density of about 0.86 would have to be matched using high density mineral oils in the buffer.

We prefer a PXE/dodecane mixture as scintillator solvent for several reasons. These solvents were used in other low background neutrino experiments (dodecane in KamLand, PXE in the CTF at Gran Sasso). Therefore, radiopurity and stable performance in large underground detectors were already demonstrated for these solvents whereas the LAB solution would be something completely new in the field needing additional R & D. Furthermore, it would be harder to match density and light ield in the gamma-catcher in a LAB solution. If pure LAB is used in the target a proper high density oil would be needed for the precision adjustments. Such oils exist, however they typically have high viscosities and melting points. Finally, the LAB is not as well defined chemically as the PXE/dodecane mixture, since the LAB contains many different molecules and isomers. The optical properties of LAB are similar as for PXE/Dodecane as shown in the table below (attenuation length).

	PXE/Dodecane (20/80)	LAB
Density	0.80	0.86
Light yield (% pure PXE)	81 ± 2	81 ± 2
Attenuation length (> 430 nm)	> 20 m	> 20 m
Molecular weight	210 (PXE) + 170 ($C_{12}H_{26}$)	241 (average!)
Flash point	> 71°C	140°C
Refractive index	1.45 (589 nm)	1.48
Dyn. Viscosity [mm²/s]	2.3	6.6

Comparison of selected relevant properties between an ortho-PXE/Dodecane mixture (20/80 by volume) and linear alkyl benzene (Petrelab 550). The lower limit for the attenuation length is given for the pure solvents without any fluors or Gd. Light yield numbers were measured using 6 g/l PPO and 20 mg/l bis-MSB.

To improve the neutron detection efficiency the rare earth Gadolinium (Gd) has to be added to the target scintillator. Since the Gd itself would not dissolve in the organic liquid we form an organometallic compound to get the material in solution. The main requirements on this compound are chemical stability and purity, therefore we chose Gd-beta-diketonates (Gd-BDK) as metal complex. These molecules are known for there stability and they can be purified by sublimation. Several of these Gd-BDK molecules were tested and best overall performance showed tris(2,2,6,6-tetra-methyl-3,5-heptanedionato)gadolinium (III). The stability in solution was demonstrated over time periods of several years and the optical as well as the radiochemical purity was found to be within the strict requirements of the experiment.

As for the scintillator solvent we also have a backup option for the Gd-material. A Gd-carboxylate scintillator version was produced and tested in contact with acrylic in the Double Chooz detector mockup. This scintillator version also meets the basic requirements of the Double Chooz experiment, however, purification of radioimpurities and prevention of “polymerization” effects at low temperature would require further investigations.

The gamma-catcher composition was chosen to fulfil two basic demands: matching of the scintillator light yield (scientific) and matching of liquid densities (mechanical) in the inner two volumes. To adjust the light yield properly the aromatic fraction (PXE concentration) has to be changed in the scintillator. To keep simultaneously the density constant a third solvent (the medical white oil Shell Ondina 909) enters. This oil has high transparency in the UV and optical region, low reactivity, a low aromatic fraction and a reasonable viscosity.

Technical performances to reach :

- ***Stability of the liquid***:
  Stability tests of target scintillator samples containing $Gd(thd)_3$ are running since more than two years in two institutes (MPIK Heidelberg and CEA Saclay) and only small or no degradation was observed. Accelerated aging tests at 40°C and at increased Gd-concentrations (factor 5) are also performed.
  Concerning the gamma-catcher liquid stable performance of unloaded PXE based scintillators was already found in previous neutrino experiments as well as in the Double Chooz detector mockup and is not regarded as crucial.

- ***Optical transmission:***
  The goal is a transparency of more than 5 m above a wavelength of 430 nm in both scintillators. The final attenuation length depends on the purity level of the final liquids. The transparency of scintillator samples were measured in Heidelberg and in Saclay and attenuation lengths of more than 6 m were found in most test samples of target and GC mixtures. Even slightly higher values are obtained in the gamma-catcher scintillator. In the LAB option similar numbers were measured by UV/Vis spectroscopy as for PXE based scintillators. A typical UV/Vis spectrum for a target scintillator mixture is shown below.

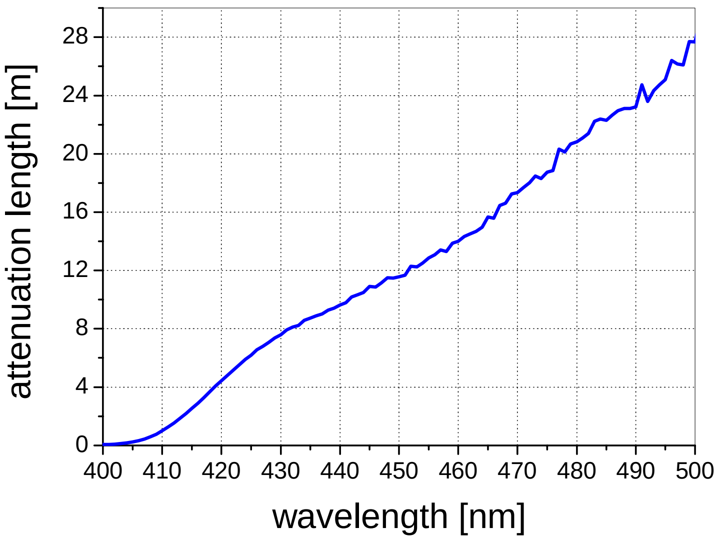


Figure 22 : ***Attenuation length of a target scintillator mixture (1 g/l Gd + fluors) measured by UV/Vis spectroscopy in a 10cm cell. The scintillator emission spectrum peaks around 420 nm. At this wavelength and slightly below the dominant absorption comes from the secondary wavelength shifter bis-MSB and most absorbed photons will be reemitted.***

Light yield

The light yield of the target scintillator was measured using the Compton backscattering peak of a ^{137}Cs-source. It was found to be 47% of BC-505 a common standard with a specified light output of 80% compared to anthracene. Anthracene has a light yield of 17400 photons/MeV. These numbers translate to a light yield of about 6500 photons/MeV fulfilling the requirements of the experiment. The reduced light yield compared to BC-505 is partly due to quenching effects of the Gd-complex, partly due to the admixture of the non-fluorescent dodecane in the scintillator and partly due to the reduced light yield of a pure PXE scintillator compared to the standard.
The light yield in the gamma-catcher has to match the one in the target. This is done by modelling the energy transfer rates and light yield properties in such a scintillator mixture. The regulation is done by adapting the aromatic fraction and the fluor concentration in the gamma-catcher liquid.

Temperature:

The optical stability of the Gd-scintillator was successfully tested at room temperature (20°C). Some degradation, mainly in the UV-region, was observed at an elevated temperature of 40°C. The detector presumably operates at about 15°C. This slightly reduced temperature should not effect the degradation rate, however it is important to make sure that no Gd comes out of solution. Therefore stability tests are also performed at 7°C in a fridge. No polymerization or particle formation was observed over the measuring period of more than a year.

Density:

The density of all liquids have to be the same within 1% precision. The density will be adjusted by choosing the proper ratio between a heavy and a light solvent component. The PXE concentration in the target was chosen to optimize material compatibility with the acrylic vessel and light yield properties. This PXE concentration in the target fixes the density in all volumes to about 0.80. Each volume has a component with densities above and below that number allowing precision density adjustments by changing solvent ratios.

Radiopurity:

The radiopurity of the Gd-compound is tested in the worlds most sensitive low background gamma-ray detector complex, the GeMPI 1/2/3 detectors at LNGS, Italy. It was found to be in an acceptable range. Below the activities for the ^{238}U and ^{228}Th chains as well as the ^{40}K activity in the first batches of the Gd-complex are listed:

Nuclide		Act $_{b\#1}$ [mBq/kg] Sample: 2.395 kg	Act $_{b\#2}$ [mBq/kg] Sample: 2.65 kg	Act $_{b\#1}$ [mBq/kg] Sample: 3.184 kg
Ra-226		< 14	< 8.6	< 14
Ra-226 (Rn-222)		< 1.0	< 0.46	< 0.45
Pa-234m		< 15	< 25	< 19
U-235		< 0.71	< 0.6	< 0.59
Ra-228		< 0.49	< 0.57	< 0.7
Th-228	2614 keV	1.5 ± 0.4	1.1 ± 0.3	< 0.19
	583 keV			< 0.41
K-40		8 ± 2	32 ± 3	12 ± 2

Figure 23 : ***Activities in the Gd-complex for several isotopes determined by γ-spectroscopy in the GeMPI detector at LNGS, Italy.***

Looking at the results and experiences of other low background neutrino experiments, no major contributions of the solvents are expected. The primary fluor PPO typically contains ^{40}K to some extend, but purification methods can be applied before usage in the experiment, if needed.

Refractive index:

A wavelength dependent precision measurement of the refractive index was performed for a target and a gamma-catcher mixture using LEDs at 8 different wavelengths. Temperature was controlled and kept stable at 18°C during the measurements.

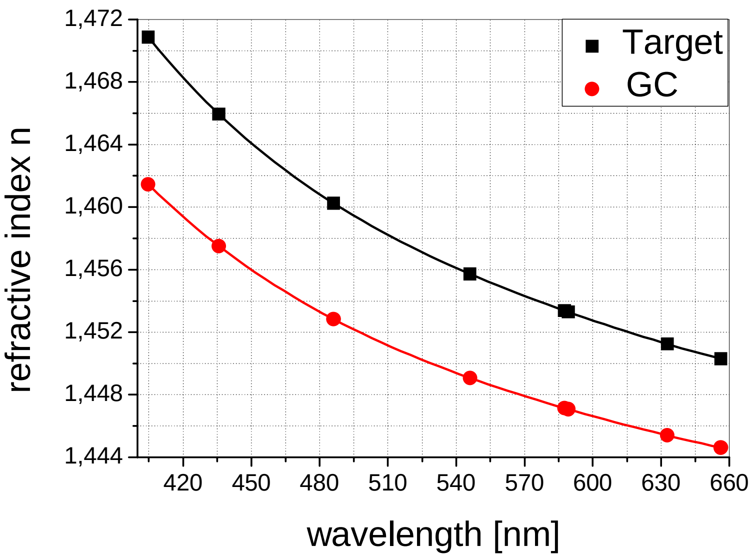


Figure 24 : ***Wavelength dependent refractive index at 18°C for a target and gamma-catcher solution. Values in between the data points are extrapolated using a polynomial fit.***

7.2.1.2. Chemical Interfaces:

To guarantee scintillator stability proper handling of the liquid is mandatory. This requires careful control over temperature, contacting materials, blanket, etc.. The scintillator has to be kept under nitrogen atmosphere during all operations and during the measurement. In the target liquid the blanket should be closed (no continous nitrogen flushing). The tolerable temperature range for the Gd-scintillator is 15 – 25°C.

All materials other than acrylic in contact with the target Gd-scintillator (e.g. the calibration system) either in the liquid or in the gas phase have to be fluorpolymers as PVDF, PFA or PTFE. Otherwise the optical stability of the scintillator is no more assured. For the gamma-catcher liquid stainless steel surfaces are allowed.

7.2.1.3. Operations and requirements on site

The target liquid will arrive in Chooz in a certified transport container. This container will be unloaded twice into two PVDF tanks that will be installed empty into the storage building. A pipe will run from the storage building to the neutrino lab to fill an intermediate tank. Each of the four liquid volumes will have its own intermediate tank. For detector filling the Gd-scintillator is moved to a dedicated filling tank (weight monitored) inside the neutrino lab. The weighing tank will be needed in the far detector lab during the filling phase only and can be reused for the near detector filling. The dimensions of all the tanks are given above in the description of deliverables. There will be a pipe connection to a liquid nitrogen plant outside the neutrino lab to keep a nitrogen blanket in the system.

The storage tank for the gamma-catcher is also in the storage building outside the neutrino lab along with the tanks of the buffer and veto liquids. A crane in the storage building is needed at least once to unload the Iso-Container from the truck and to put it in the right position. This could be done using an empty tank (ca. 4 t) that is then filled out of a second Iso-container outside using a temporary connection. Steel pipes will connect the tanks in the storage building the intermediate tanks in the neutrino lab. The detector filling will be done out of these buffer tanks which could act as expansion tanks to control the liquid levels.

7.2.1.4. Target volume measurement

For the Double Chooz experiment, the volume of both targets has to be known with an uncertainty around 0.1%.

In 2005, prospections have been made for different methods to ensure accurate volume measurements. Two different ways were tested: MPI-Heidelberg suggested to use Ph-metry and showed that the volume determination can reach 0.2% of uncertainty.

CEA-DAPNIA proposes a second method: the weight measurement :for the experiment, the idea is to weight an intermediate vessel before and after the filling of the target. The difference between the two measurements gives the weight of liquid introduced in the detector. In order to reduce the systematics, the same intermediate vessel, equipped with the weight sensors has to be used for both far and near detectors.

Some tests have been done at Saclay on the weight sensors. First, the check of repeatability by weighting a 1.5 ton mass 20 times. The standard deviation was 0.15kg.

Then, a cross-check was done between a flow-meter and the weight sensors filling a 2 cubic meter stainless-steel vessel. The flow meter datasheet indicates a global accuracy of 0.5% which can be reduced to 0.3% with local calibration. (This calibration uses a weight measurement). After the calibration of the flow-meter and several trials with both sensors, we obtained compatibles values of volume with a □ of 0.12%. This test doesn't prove the absolute accuracy of the weight measurement but only shows that this method can be trustful.

At the beginning of 2006 a simple method was studied to ensure the local value of gravity is quite the same on far and near sites. To achieve that, we accurately weighted a 100 g standard in gravity known sites around Chooz and in the experiment sites. Despite shifts on measurements the conclusion is the variations of gravity are below 3.10-5 between far and near site.

The future of this work package is an absolute calibration of the weight sensor at Laboratoire National d'Essais in Paris before their first run at Chooz or Heidelberg.

The study of the measurement vessel is in charge of MPI-Heidelberg.

The mechanical interfaces for the weight sensors is specified at Saclay, which will pay the bill. On its side, Saclay team has to study and realize a trailor with the possibility to adjust the horizontality of the interface plates. When these items will be realized, it is reasonable to plan a scale 1/1 test at Heidelberg.

7.2.1.5. Risks and safety precautions

Safety data sheets are available for each component in the liquids. The flash point of a full target scintillator mixture was measured by the PTB (Physikalisch Technische Bundesanstalt) to be at 71,5 ± 0,5°C. The PTB also estimated the ignition point (200°C) and the explosion limits. Glove tests were made by the company KCL with pure n-dodecane as well as for the full scintillator mixture. Nitril and Viton gloves were found to be suitable.

Procedures and operating instructions will be worked out and all activities will be documented. Liquids will be pumped and stored in a closed system under a N_2 blanket and all tanks are connected to a vent system. Therefore no exposure to liquids or scintillator vapours is expected in the neutrino lab. Nevertheless, suitable protective clothing (proper gloves, goggles, safety shoes) have to be used in case of any leakage or spill. A proper adsorber to remove minor spills is provided. The tightness and functionality of the system will be tested before operation.

The target tanks used for storage on site will have spill trays in case of unexpected liquid losses. Loading and emptying of the transport and storage tanks happens from the top to avoid tank drainage in case of a broken connection and the bottom outlets of these tanks are equipped with a blind flange for safety reasons. Safety valves will be installed to prevent overpressure accidents.

Intermediate tanks in the neutrino lab are used to reduce the liquid pressure due to the height difference of storage building and neutrino lab. After these intermediate tanks are filled the big tanks in the storage area are isolated by closing the valves in between. In such a procedure only limited amounts of liquid (volume of intermediate tank) would be affected by an accident during the detector filling.

Only authorized people (filling team) are allowed to participate in the detector filling. Each time liquids are moved at least two people of the filling team will be present to control the correct performance of the system.

Fluid and Storage Subsystems

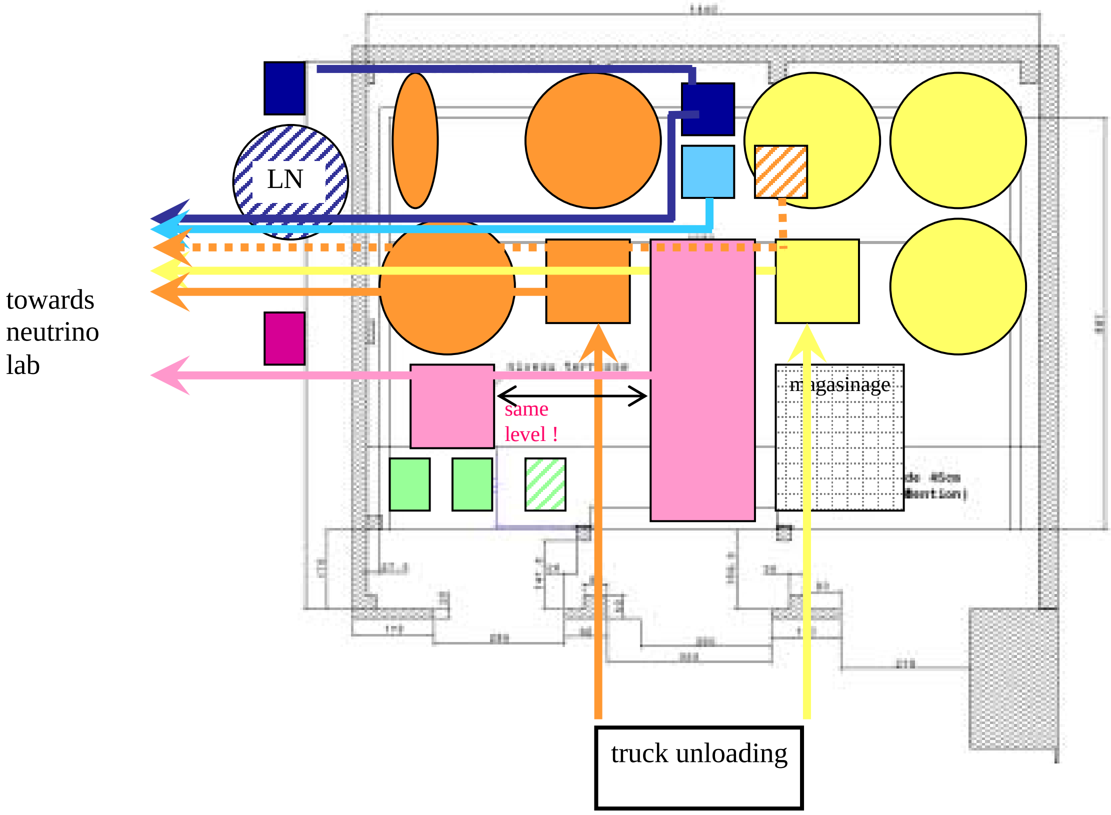


Figure 25 : Storage Building at Chooz: general layout of subsystem locations. This system has since been proposed to be changed and that will be finalized at the meeting. Meanwhile we are working on updating this drawing during th week of Sep 3 2007.

Legend :

Red = Target
Pink = Gamma Catcher
Yellow = Inner Muon Veto
Orange = Buffer
Green = water

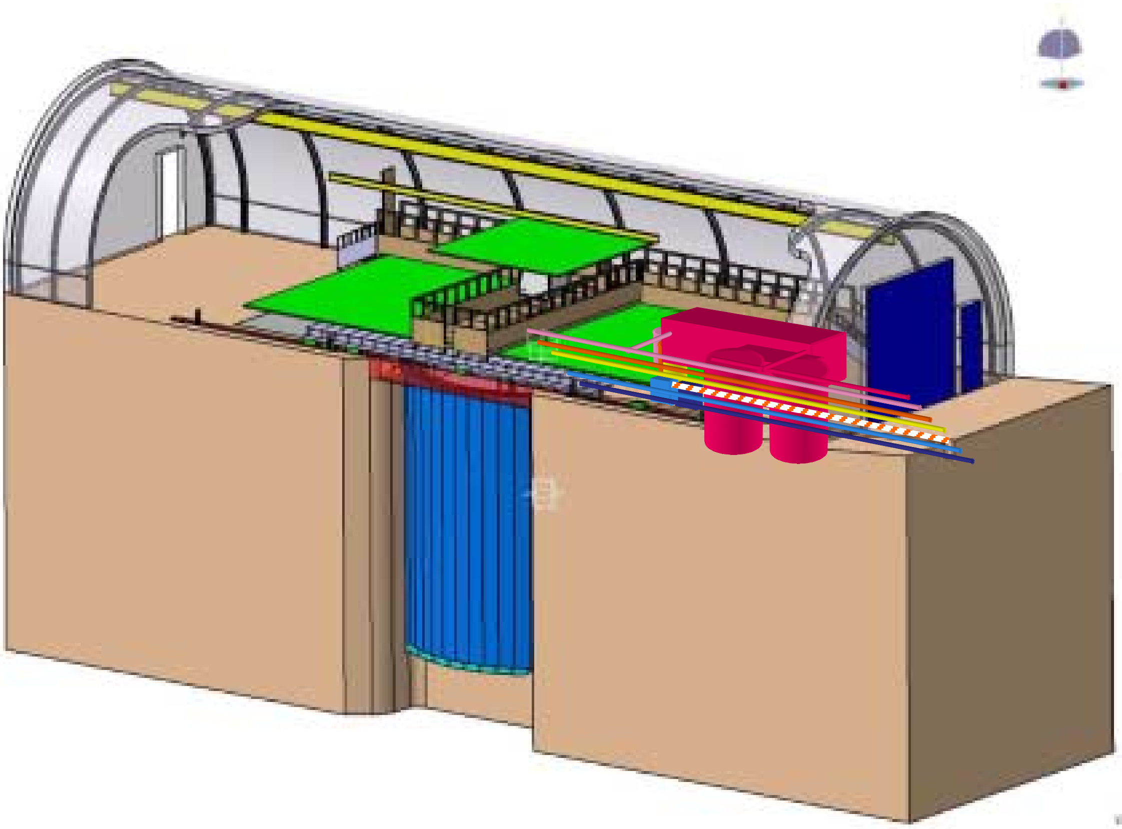


Figure 26 : Nu Target, G-Catcher and Trunk Lines in the Nu Lab

It is now proposed to change this and this and a new drawing is in progress.

A dedicated appendix (appendix 1) gives all the sketches for Neutrino target and Gamma Catcher filling system and handling liquid on site

7.2.1.6. Schedule & development plan for Neutrino target and Gamma Catcher (assuming loading 30Sep2008)

- Chemicals:
  - $Gd(thd)_3$:
    - Production already started
    - December 2007: Delivery of full amount (both detectors) of purified material
  - Liquids:
    - Summer 2007: Fix compositions and supplier
    - Beginning 2008: Delivery and purification of liquids
    - Spring 2008: Scintillator mixing
    - Summer 2008: Transportation to Chooz
    - Autumn 2008: Filling
- Storage tanks:
  - Target:

        - The target transport and storage tanks are already ordered
        - October 2007: Delivery storage tanks
        - March 2008: Delivery transport tank
      - Gamma-catcher: Delivery of Iso-Containers used for storage and transport of unloaded scintillator in September 2007
  - Pumping system:
      - Summer 2007: Design system
      - Autumn: Construction/assembly
      - Spring 2008: System operational

7.2.2. Liquids: Buffer & Inner muon Veto

- The **Muon Veto (MU)** consists of about 87 m^3 of liquid scintillator.

- Requirements of the scintillator are:
    - high transparency,
    - high light yield,
    - density matching that of the target scintillator,
    - long term stability
    - chemical compatibility with the materials used in the detector (stainless steel, reflective surface coating (TBD), Tyvek, cables, PMT encapsulations etc.)

- The primary choice for the scintillator is based on 40% LAB (linear alkylbenzene), mixed with 60 % tetradecane (C14H30) to match the density, with wavelength shifters (PPO, bisMSB). Optical properties and chemical compatibility studies for this scintillator are currently under study. LAB has been studied e.g. by the SNO+ and Daya Bay collaboration with very promising results. Material safety data sheets for the liquids are attached.

- A backup option for the liquid scintillator would be a mixture of 80% dodecane/ 20%PXE (phenyl-xylyl-ethane) with wavelength shifters (PPO, bisMSB). The exact mixing ratio depends on the density of the target scintillator. This scintillator has been studied in laboratory measurements for optical properties as light yield, attenuation length. Material safety data sheets are attached.

- The **Buffer (BF)** consists of 114 m^3 of fluid.
- Requirements are:
  - density match with the inner volumes
  - optical transparency
  - no scintillation
  - long term stability
  - chemical compatibility with the materials in contact (stainless steel, acrylics, PMTs, cables etc.)

- Primary choice is a mixture of tetradecane and mineral white oil (Shell Ondina 909)

- Properties of the liquids:

  Tetradecane: density: 0.76 g/cm^3
  flash point 99 °C

no transport regulations

LAB: density: 0.86 g/cm^3
flash point 140 °C
no transport regulations

Ondina 909: density: 0.83 g/cm^3
flash point 125 °C
no transport regulations

7.3. Filling system : Detector Fluid Operating System (DFOS)

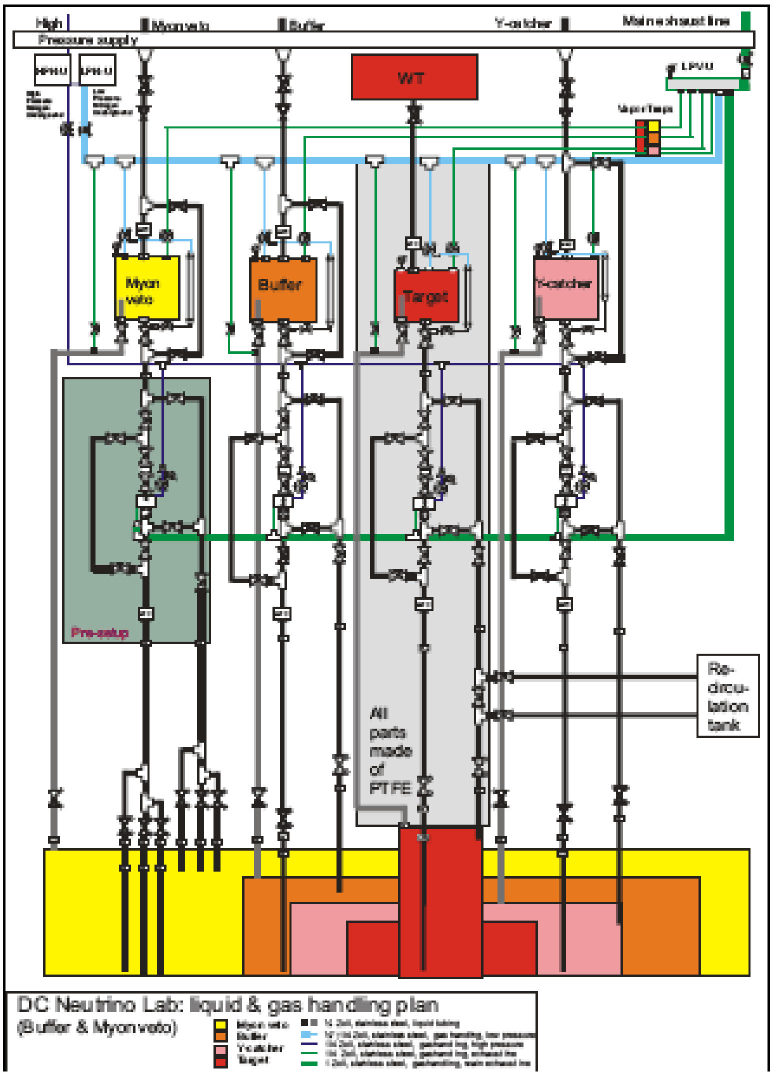


Figure 27 : Liquid and gas handling system in Neutrino lab

TO BE COMPLETED (T.U.Munich)

7.3.1. Detector Fluid system

- The system in then neutrino lab used for filling the detector volumes, regulating the liquid levels etc. is called **Detector Fluid System**. This system should be located in close vicinity of the detector. It consists of 3 intermediate tanks (max. 1 m^3 each) for veto, buffer and gamma-catcher, to decouple the filling system from the storage area plus the weighing tank for the neutrino target, pumps, flow meters, etc. A P&I diagram of the filling system is attached.

- The intermediate tanks will be made of stainless steel, with a maximum overpressure of 3 bar. They will be equipped with safety valves to ensure that no dangerous overpressure is reached. Each tank has a top inlet for the liquid from the storage area, a bottom outlet for detector filling. Load cells and level monitors will be used to control the filling level of these intermediate tanks.

- All tubing for the liquids (except for the target scintillator) will be made of stainless steel to avoid problems of electrostatic discharges and to ensure tightness. The pipes will be welded together where possible. Connections will be done via VCR standard (metal sealing). Tanks and tubing will be leak-checked after installation.

- Pressure driven teflon pumps will be used for the filling and unfilling of the detector. For each detector volume a separate pump is needed. An option is to fill the detector via gravity, but pumps will be needed for the unfilling. The flow control will be done using flow meters in each filling line.

- Gas system: a low pressure nitrogen atmosphere has to be maintained in all detector and tank volumes during the filling. A connection to the liquid nitrogen supply outside the neutrino lab is needed. Gas lines will be made of stainless steel (1/4’’ or ½’’), the low pressure vent bringing the gas outside the tunnel will be made out of PVC.

- All volumes will be filled through tubes going to the bottom of each volume to avoid splashes (problems of electrical discharges, disturbance of level measurement)

- Interfaces:
  Several feedthroughs are needed through the veto and buffer vessels (see sketch).
  Veto:
    - 6 1/2’’ pipes for filling, unfilling and eventual circulation of liquids.
      3 of the pipes go to the bottom of the veto tank
      3 of them end about 20 cm below the top lid.
    - 1 ½” pipe for nitrogen venting during filling
    - 1 8 cm-flange on outer ring (similar to the PMT cable feedthroughs) for feedthrough of level measurement

  Buffer vessel:
    - 1 1/2” pipe for filling from outside of veto vessel, going to the bottom of the buffer tank
    - 2 ½” pipes for nitrogen going through the buffer chimney
    - 1 8 cm flange for level measurement on buffer chimney

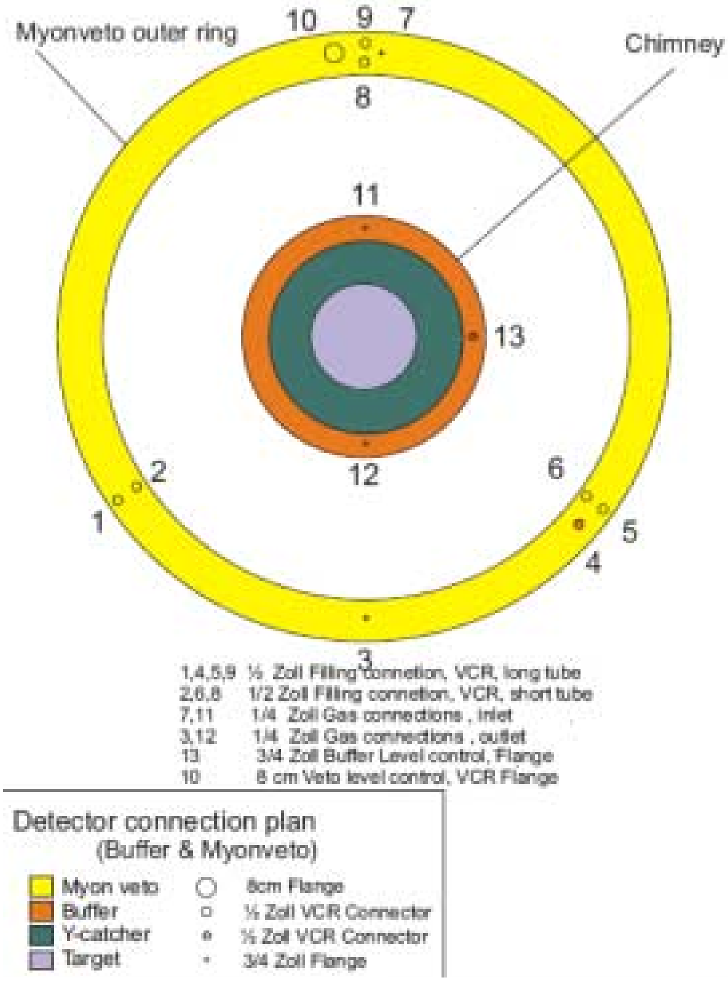


Figure 28 : Top view , July, 2007

7.3.2. Level measurements

7.3.2.1. Sub-system description

The Level Regulation System consists of an expansion tank, a Pump, and a level measurement System, which are used to level all volume changes of the detector-liquid its self. It allows the liquid to expand or lessen. Within 30mm (of the expansion tank) of liquid height the system is self regulating. If the liquid level changes above this value(30mm) the system has to be regulated either by controlling systems or human interaction. Which one is used depends on risk analysis.

- The controlling system consists of a pump which is electronically connected to a level height measurement system. If the level reaches certain values the pump starts and rises a lowering liquid level. A rising level is tolerated up to +30 mm, above that liquid has to be removed from the expansion tank.
- Human interaction: Adding or emptying the expansion tank with an 15L movable extra tank connected to the expansion tank.

Moreover to correct the level in one tank the aim is to keep the liquid levels in all four expansions tanks equal.

- To minimize the relative different heights between all the tanks we use the technique of communication gas bladders. Four communicating gas bladders for the expansion tanks. The non-flexible bladders are filled with Nitrogen and have a fixed volume ca. 25% of expansion tank volume.

7.3.2.2. Technical specifications applicable to the sub-systems

The intermediate & expansion tank are made of stainless steel, with a window for optical level control. The volume of each tank is adjusted to the volume that is needed to fill the detector 1.5cm in height. Volumens in Liter/cm ca:(MU:330L-BF:240L-GC:100L- NU:50L)
Level measurement System is AP-47 a „Keyence“ Sensor
The used pump is still unspecified

7.3.2.3. Interfaces (mechanical, electronics, software, logistics…)

Non

7.3.2.4. Development plan

System has to be tested, prototyping at best. Still under investigation

7.3.2.5. Remaining technical difficulties and associated development plan

The height of the tanks is given by the detector filling height above the top lid. This can cause problems realizing a useful tank. If the Muonveto tank can not stand an over pressure high enough the tank fit not into the available space or the are to big to fit under the outer veto.

7.3.2.6. Risk management

In case of dysfunction, detector highly endangered, risk of destruction by differential pressure off different liquid levels.

7.3.2.7. - Assembly and disassembly of the detector

System is pre assembled and just put in to place when arriving at the lab.

7.3.2.8. - Reference documents of the subsystem.

Pictures available and will be shown at Collaboration meeting in Oxford, 2007

7.3.3. Level regulation

7.3.3.1. Sub system description

The level measurement system consists of 3 measuring devices for each Liquid level. This means 12 in total, for one detector module. This measurement systems should be independent from each other, easy to handle, made of harmless materials (PTFE or eq.), strongly reliable, fail safe, small in size, interfere at least as possible with other systems (shadowing) and controlled and readout from above

- Two devices are measuring the pressure of the liquid height. They measuring the compressed gas (N2) in a Tube that runs along the z-Axis of the Detector.
  -One is able to cover the whole detector height of 7m by an accuracy of 1.5cm
  -The Second covers a range of 20 cm with an accuracy of 0.5mm
- One device is measuring the position of the liquid level, by using a contact sensor which is based on total light reflection. This measurement is made from the top lid and therefore independent to the pressure measurement.
  - This method will use optical fibers with liquid sensing tips (internal reflection in the tip, if no liquid is present; no internal reflection in presence of liquid). We plan to use 3 of these fibers coupled together with a distance of 5 mm for each volume. This means that we can always locate the liquid level within 1 cm. These fibres are completely made out of PVDF. As they enter only few mm in the liquid, these should be used for the continuous level monitoring after the filling (could be switched on once per day). Guiding tubes (perforated teflon tubes) where the fibres can run through are needed for each volume, espacially for the gamma catcher and the buffer where no straight vertical lowering of the fibres is possible.

7.3.3.2. Technical specifications applicable to the subsystem

For pressure measurement a sensor of a company called “Keyence” is used namely:
AP-47 as very accurate Sensor with a dynamic range of 20cm , accuracy 0.5mm
AP-48 as Sensor over the whole detector height of 7m, accuracy 1.5 cm
For contact sensors Keyence sensor FU-93Z is used:
FU-93z a 15m meter long fiber optic that recognizes liquid contact by total internal reflection

7.3.3.3. Presentation of the main design choices and their preliminary justification.

Level measurement is mainly made with pressure sensors but also with a big variety of other measuring principles. We used pressure because of the good experience this techniques and as one of the little possibilities that hit the specifications.
The contact sensor is a good possibility to have very accurate and independent measuring system. (OTHER SYSTEM SETUPS ALREADY UNDER INVESTIGATION)

7.3.3.4. - Interfaces (mechanical, electronics, software, logistics,…);

Level measurement interferes with every system that deals with the chimney. Furthermore we need for BF and MU level measurement one 8cm feed through each.

7.3.3.5. - Development plan

Testing phase of Detectors already begun- Prototype setup necessary and will be done end 2007

7.3.3.6. - Remaining technical difficulties and associated development plan

Fiber optics will have to be handled with in the glove box, chimney architecture (gamma-catcher) is very difficult to handle.
Pressure Sensors: possible Setup found but search for better ones is ongoing.

7.3.3.7. - Risk management

In case of dysfunction, detector highly endangered, risk of destruction by differential pressure off different liquid levels.

7.3.3.8. - Assembly and disassembly of the detector

System can be set in place during integration of the tanks little changes (adding holders) have to be done on the tank walls. Except the guiding tubes all measuring devices can be removed at any time.

7.4. Safety considerations:

- Electrical Discharge: as the organic liquids are non-conductive, the problem of electrical charging of the fluids and eventual discharge has to be addressed. All steel tanks and tubes will be grounded.

- Inflammation or explosion: all liquids will be stored and handled under nitrogen atmosphere. No oxygen in contact with liquids. Vapours will be trapped before the gas is vented. Pumps will be air (or nitrogen) driven, no electrical pumps.

- Toxic vapours: vapours will be trapped before gas is vented.

7.5. Time schedule of operations

- Sep. 2007: final design of storage tanks, intermediate tanks
Sep. 2007: order storage tanks, intermediate tanks (delivery time ~ 5 months)
- Fall 2007: Design filling system, Level measurement
Fall 2007: order parts for storage and filling system
- Sep. 2007: final tests of liquids optical properties, material compatibility
Sep. 2007: order liquids
Jan. 2008: start mount storage area
Spring 2008: receive liquids
Summer 2008: mix scintillator, buffer liquids
mount filling system
Fall 2008 Detector filling

8. Mechanical Structure [2000]

8.1. Overview

The main functions of the mechanical structure of Double Chooz detector is to assume the integrity and stability of each region defined. A leak between regions could induce the end of the experiment. The mechanical structure would also assume the respect of the safety rules on a nuclear power plant.

The mechanical structure is manly made of cylinders imbricate in each others, supports of photo detectors and supports for calibration systems.

To respect radiopurity levels which imply a minimum of material, some constraints have to be respected during all the life of the detector.

The level of liquids is located a few centimetres above the top lid of detector. Expansion tanks are located out of the vessels. The most critical one is to respect less than 3 cm of liquid height differences between areas during filling and operating phases.

The lifecycle of the far detector could present a phase for acrylics vessels change; design must give the possibility to drain, to open the detector and to change the acrylics without failures.

The construction of the vessels will be made on site in the pit.

The reference drawing used for mechanical dimensions is presented hereafter and labelled: 71 E021 DML 000 000 PG.

A parameter booked for mechanical dimensions (I-005749 v.3) is available and stored in the EDMS data base.

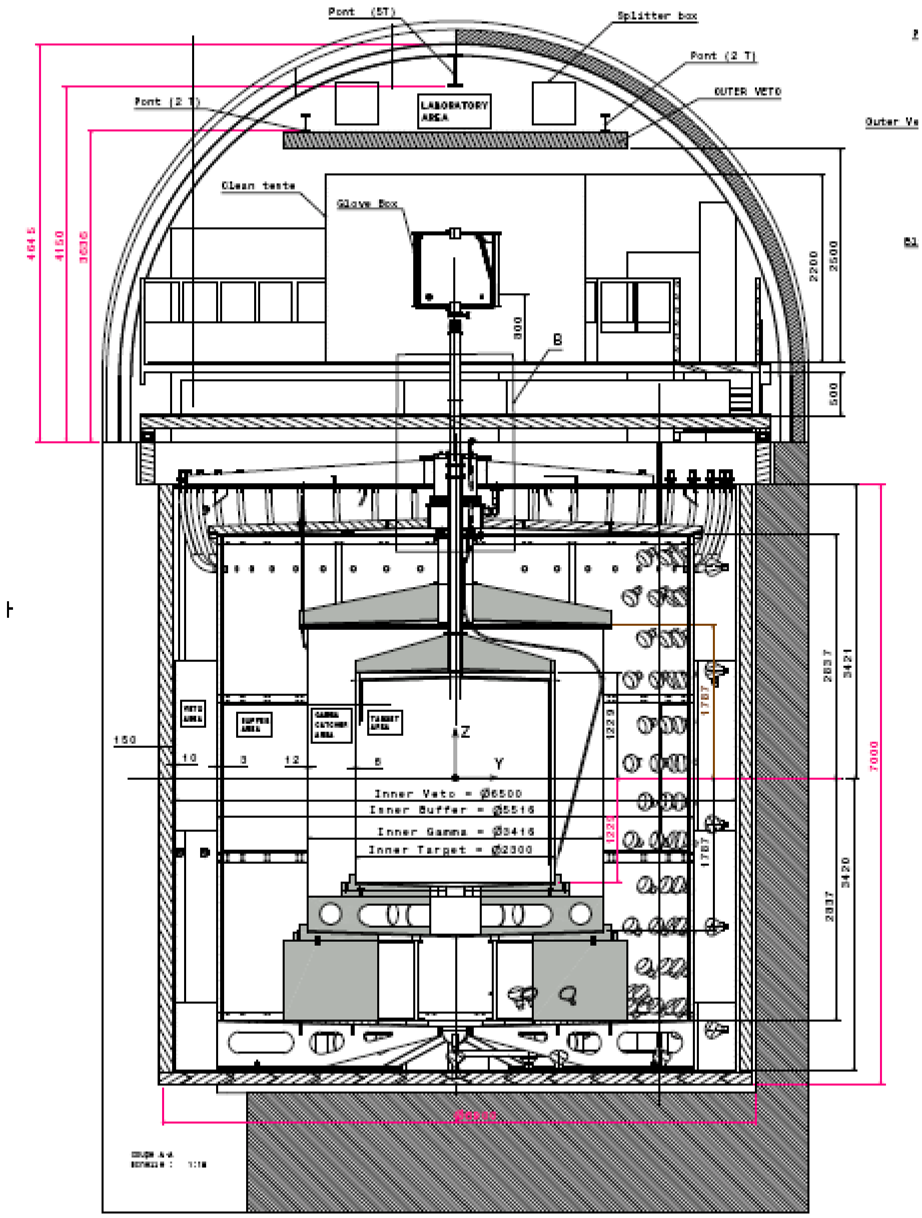


Figure 29 : cut view of the detector
Id : 71 E021 DML 000 000 PG

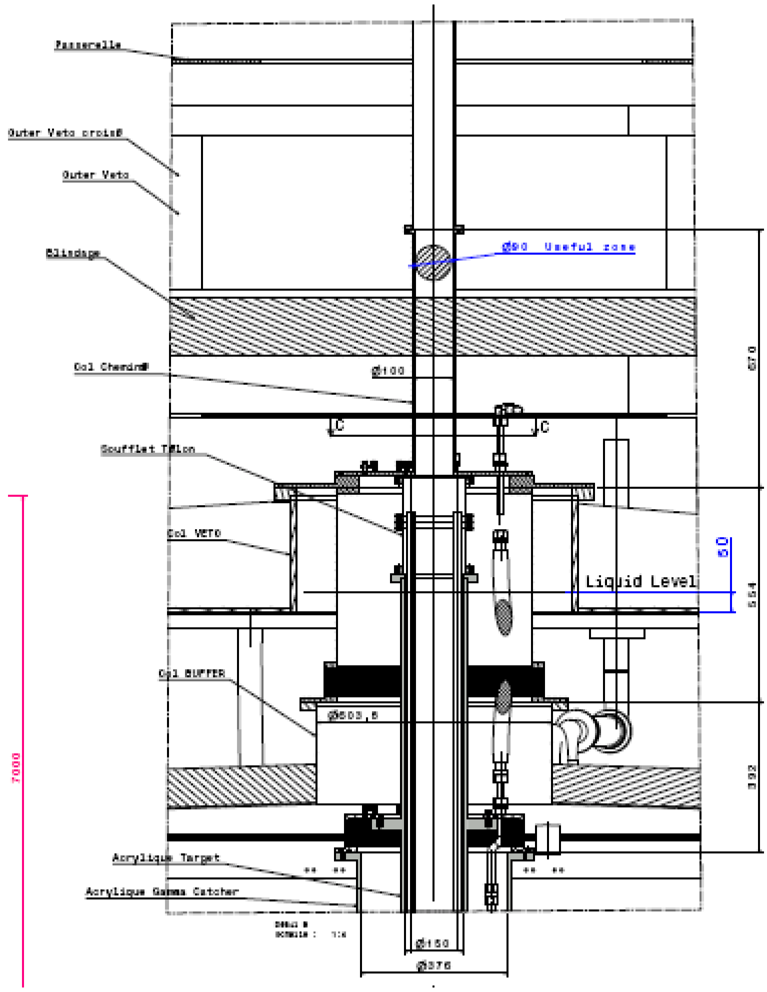


Figure 30 : zoom on the chimneys area design

The architecture above the detector (with Outer Veto, Glove Box, shielding and cable paths, expansion) is not yet totally defined; it will be discussed and define at Oxford meeting technical board (sept 2007)

8.2.Technical constraints

The choice of the design and material is essentially driven by the following constraints:

- respect of the radio purity thresholds (see Proposal document)
- choice of the assembly on site with only one crane with a capacity of 5 tons.
- The access tunnel dimensions (maximum size is 3.5 meters diameter)
- reliability of the system to assume two identical detectors
- stability of the system during 10 years in an aggressive environment (scintillators) and also during all the life profile of the piece
- chemical compatibility and stability with liquids contained in the vessels
- respect of a step below 3 cm between areas during the filling up phase and operating phase
- possibility to change the acrylics vessels
- respect of safety rules to work on nuclear power plant

8.3.Description of deliverables

The mechanical structure deliverables are the following:

- Shielding : a thickness of 150mm of steel which cover the pit
- Inner Veto vessel : external steel vessel containing the inner Veto (liquids and PMTs)
- Buffer vessel : stainless steel vessel containing the Buffer liquid, the Inner PMTs and calibrations
- Acrylics vessels : 2 independent and tight vessels contained doped scintillator in the Target and sintillator in the Gamma Catcher
- Containers for transport and storage to site: specific containers have to be developed and used for the transport to limit stresses and allow to keep the vessels under inert atmosphere.
- Tools and facilities for integration and tests on site : dedicated facilities and tools will be developed for the assembly in the pit and the check of the performances required (leaks, cleanliness…)

8.4.Shielding [2500]

The shielding tender has been granted to the ENDEL company end of August 2007. It will be installed at Chooz from April 2008.

8.4.1. Technical performances and tolerances

The shield thickness is 150 mm over 4 pi. It is divided in 3 parts: A top one, a lateral one, and the last one below the detector. The steel is S235JRG2 (old name : E24-2) or equivalent (E-36 for example).

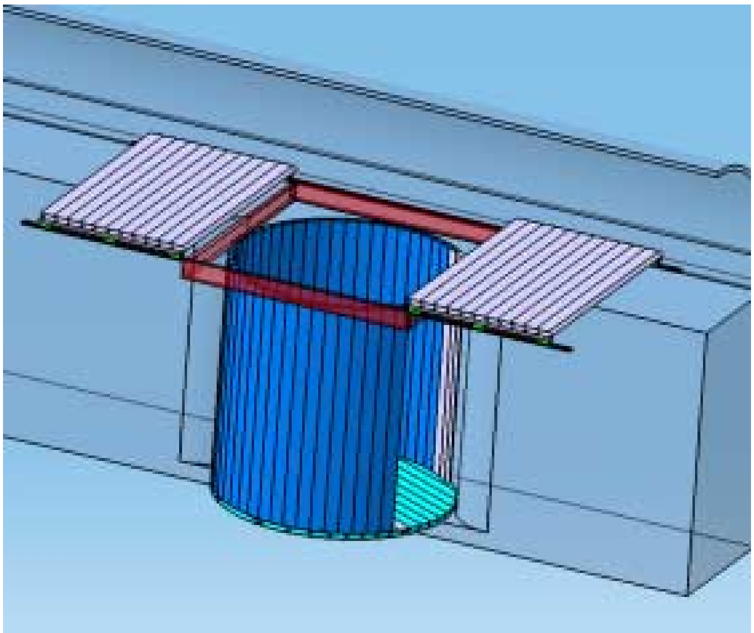


Figure 31 : Shielding overall view

The links between the shielding pieces will be a V shape, with an angle of 60 degrees. This chevron shape will allow a good tightness to radiations, since whatever may be the gamma ray incident angle the thickness of crossed materials will stay roughly constant. It makes the installation in the pit a lot easier: a gap as large as 1 cm can be accepted between neighbouring shielding pieces.

The lowest shielding is made of 14 pieces and one central piece acting as a key of the system.

The lateral shielding has 41 pieces which are similar between them. More over, there will be 1 piece and 2 halves as keys. Each of the 41 pieces is 50cm width and 7 m long.

The top shielding is made of 2 identical parts, each of them having 7 bars identical to the ones used in the lateral shielding (40cm width,7m long). The line between them is perpendicular to the lab axis:

- a fixed half shielding, on the nearest side of the lab entrance

- a movable one. It will be installed on rails, to allow the opening the top shielding by about one meter. This will provide access to the top lib of the veto tank and to the glove box implementation.

To avoid corrosion, the shielding will be protected by some coating or painting. The painting radioactivity has also to be measured (the upper limit is about 30 times higher than the steel).

8.4.2. Mechanical interfaces

The shielding's main interface is the Veto tank, which fits in as near as possible, taking in account a mounting tolerance. Due to this constraint, the veto tank radius will be fully defined only after the shielding installation.

The planarity requested from the shielding to bed the flat bottom of the veto tank is being studied.

Through the top shielding there will be:

- a central hole of 300mm diameter for the chimney
- two symmetric holes in this line between the 2 halves for the glove box supports
- the top shielding has to support the outer veto and move it during the shielding opening

8.4.3. Development plan & schedule

8.4.3.1. Control plan

Each bar will be marked at the factory, and its dimension controlled. The final shielding will be measured after installation.

8.4.3.2. Radiopurity

The 300 tons of steel necessary to build this shielding will be booked at the plant, trying to have steel with no radioactive material inside, few recycled steel, and mostly new minerals. It will be measured in at least two places before being eventually accepted by the experiment.

The allowed level is some 10-9g/g of Uranium and thorium, and 10-6 g/g of potassium. The Cobalt limit is 10 mBq/Kg. 10 kg samples will be delivered to APC lab to measure the radioactivity. The steel will be accepted after having fulfilled this requirement.

8.4.3.3. Demagnetisation

All shielding pieces will be measured to determine the residual magnetic field. The specs to reach is 100 milligauss. Each piece, which has been identified and marked by the supplier, will be demagnetized if necessary.

. It implies creating alternative cycles smaller and smaller inside each of the pieces. The 7m long pieces are introduced horizontally in a 8m solenoid. This test device will be assembled and tested at APC in the fall of 2007. the demagnetisation itself will done at Chooz, with the cooperation of the ENDEL company. A temporary hall will have to installed. This will be done within a delay of 6 weeks following the delivery of the shielding, hopefully with masked time: being onsite allow to demagnetize a bar and then install it.

From the measurements of residual magnetic field, the order of the installation of the iron pieces can be optimized. A final measurement will be made on site

.

8.4.3.4. Installation on site

The on site installation will be made by the contractor, who will provide all the needed tools. The experiment will have the possibility to keep the tools, so these will be studied to be possibly reused later on.

The top part of the shielding will be stored outside, and installed later on, when the detector will have been completed and filled. Its to surface will at about 30cm above the level zero (ground of the lab).

The pit is being reshaped, to make it a cylinder. A new concrete will be installed, to improve tightness against rock waters, and provide the bed for the lower shielding. This must be planar to +- 5mm. A measurement will be ordered to check it.

The first lateral bar will be fixed on the wall. The following ones will be linked to this one. A dedicated mechanics will hold the bar feet during this installation.

8.4.3.5. Tightness

The first inner barrier is provided by the main tank, described elsewhere in the TDR. The shielding itself will provide a second one. The tender asks to the contractor to make a tightness between the neighbouring plates by adding a gluing or tightening product.

8.4.3.6. Bridge

A bridge will go over the shielding to allow to cross over the detector, both for safety and for accessing to the working place around the glove box. This bridge will be a safety path for people working inside the old nuclear plant. The bridge will provide access to a platform 2.5 *2.5 meter surrounding the glove box on all sides, supported by two beams transverse to the lab axis.

This will be movable, to allow the shield installation. It will be only _m long at this step, and later on modified to increase it length.

In its final version, it must be 14m long, to go over the outer veto, and 90cm width. If needed, he could have a a supporting feet on the 2 beams supporting the platform (perpendicular to the lab axis).

-

8.5. Inner Veto vessel [2400]

8.5.1. Technical performances and tolerances

The tank is made of 2 parts : the tank itself, and the top lid. Both are in steel SR235JR or equivalent.

A note describing the tank computation has been written, and put under EDMS.

8.5.2. Dimensions

The tank inner diameter is 6500mm, and its thickness 10mm. The flat bottom, which is 10mm thick, sits directly on the shielding. The internal height will be 6840 mm

On the top lid is welded a flange rigidified by shoulder gussets. This flange is 40mm thick which is required to allow to have 80 M20 screws. The top lid has 42 holes of diameter 80 mm, which will provide the passage needed for the cables tubes for the cables (the collaboration has to freeze this number). To this has to be added the filling tubes. A total number of 52 holes have been booked.

The top lid is 10 mm thick for an outer diameter of 6230 mm A central chimney of diameter 710 mm and height 320 mm will allow the installation of the detector center. The lid is rigidified by stiffeners of thickness 10 mm linked to the central chimney.

8.5.2.1. Mass

The tank weight is 11.6 tons. The lid weight is 3.2 tons. The tank outer side will be painted to protect it. The inner side, including the lid, will be painted with a white 2-component epoxy painting. This will require a temperature (20 degrees) and humidity (60 %) control during the painting.

8.5.2.2. Welding.

The soldering will be arc welding, with a mass not to far of the welding point to reduce current able to create magnetic filed. It will be tested by penetrant testing.

8.5.3. safety constraints

The tank tightness is a component of the safety file.
A goretex gasket (PTFE) will be installed on the lid flange, and strongly tightened by the 80 M20 screws, to provide the requested tightness. The level of liquid will be higher than the gasket, to reach the expansion tank.

8.5.4. Mechanical interfaces

8.5.4.1. PMTs supports

The PM supports will be plugged on flat pieces equipped with pins and soldered to the tank. These flat pieces will be soldered before assembling the tank. 78 PM supports are expected, but the shift to IMB PMTs could require an increase of this number.

8.5.4.2. Buffer interface

The top lid leaves a diameter 6080 mm free to enter the buffer vessel. The buffer vessel will be supported by six legs and the fixation is made with pins.

8.5.4.3. Tubing

Several design of the tightness of the tubes to the top flange have been made. This is being studied between APC and Saclay.

8.5.5. Chemical interfaces

The white painting was used in the mockup with liquid scintillator. This test confirmed a good compatibility with the liquid.

8.5.6. Glove box supporting structure

The glove box will be installed on a frame, supported by 2 squared legs of 50 * 50 mm, on the line between the two shieling halves. The distance between them is 997.3 mm (947.3 internal distance).

8.5.7. Development plan

8.5.7.1. Radiopurity

The allowed level is some 10-9g/g of Uranium and thorium, and 10-6 g/g of potassium. The Cobalt limit is 10mBq/Kg.

Samples will be delivered to APC lab to measure the radioactivity (more than 1 kg, and up to 10 is needed). The steel will be accepted after having fulfilled this requirement.

8.5.7.2. On site assembly

The tank will be assembled on site. The components will be brought in the neutrino lab, with the constraint of the tunnel size. They will be soldered outside of the pit, to avoid creating any magnetic field in the already installed shielding. This will be done over the pit, thanks to dedicated tools (the pit could also be water filled, to use buoyancy to support the tank during the assembly). The tightness of the tank will be tested, before cleaning and painting

Painting

- External
  The components will be painted on the outer side at the factory, keeping the side free for soldering. After a full ring is completed, the welding will be tested, and painted, before lowering the tank.
- Internal

- Control
  - Soldering
  - The planeity of the Gasket support will be checked and improved if needed.

8.6. Buffer vessel [2300]

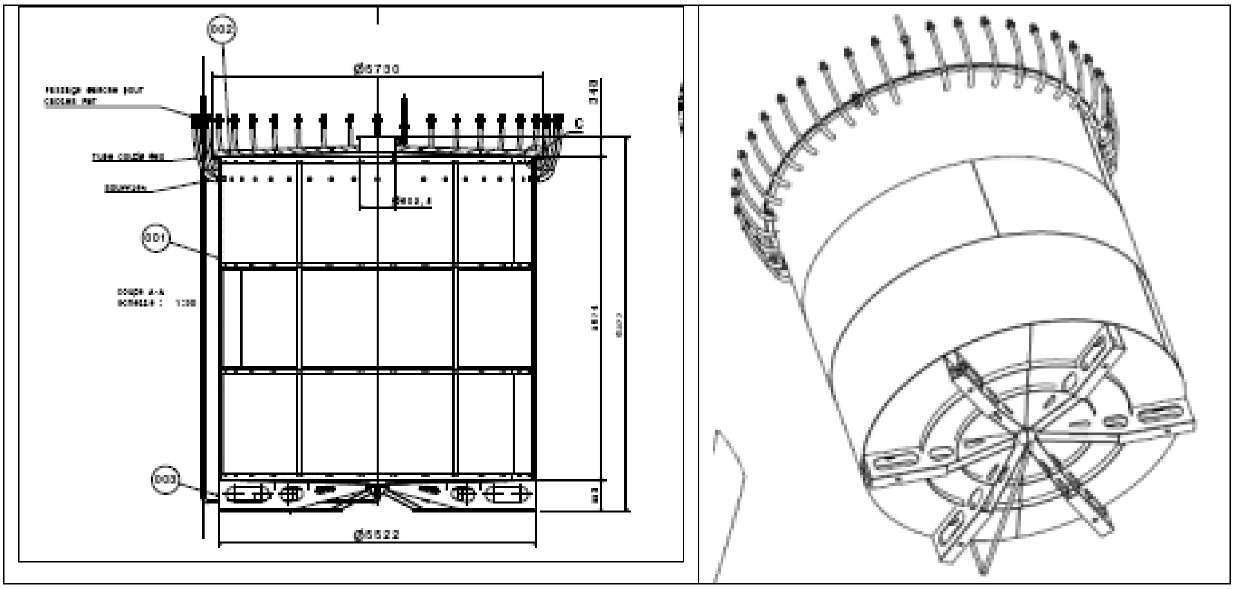


Figure 32: drawing of the Buffer vessel

Ref : 71 E021 DML 3110 000 PC (see appendix chapter)

Hereafter presents the technical performances to reach and tolerances of the Buffer vessel:

Inner diameter	5516 mm +/- TBDmm
Inner height	5674 mm +/- AD mm
Thickness	3 mm+/- AD mm
Material	304L
U rate/ Th (radioelement) g/g	< 10^{-9} g/ g
Cobalt rate (radioelement g/g)	< 20 mBq / Kg

Table 1 : Buffer technical performances.

The buffer will built up of a structure carrying and covered with a thickness skin to 3 mm

.

8.6.1. Mechanical interfaces (Interfaces drawing)

- Buffer Vessel / veto vessel : DAPNIA / APC

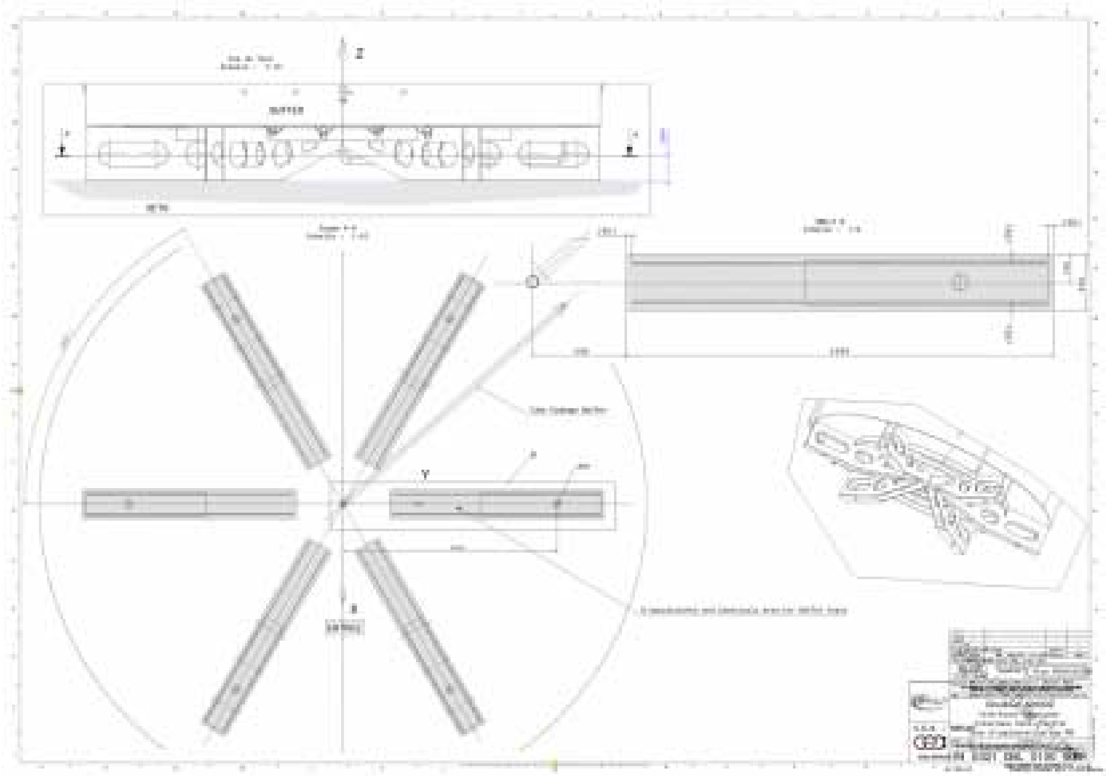


Figure 33 : Drawing of Interface Buffer / Veto.
71 E021 DML 0100 00PA (see appendix chapter)

- Buffer vessel / Phototubes mechanical support : DAPNIA / CIEMAT
  Add an engineering drawing

- Buffer vessel / cable path : DAPNIA / Japon

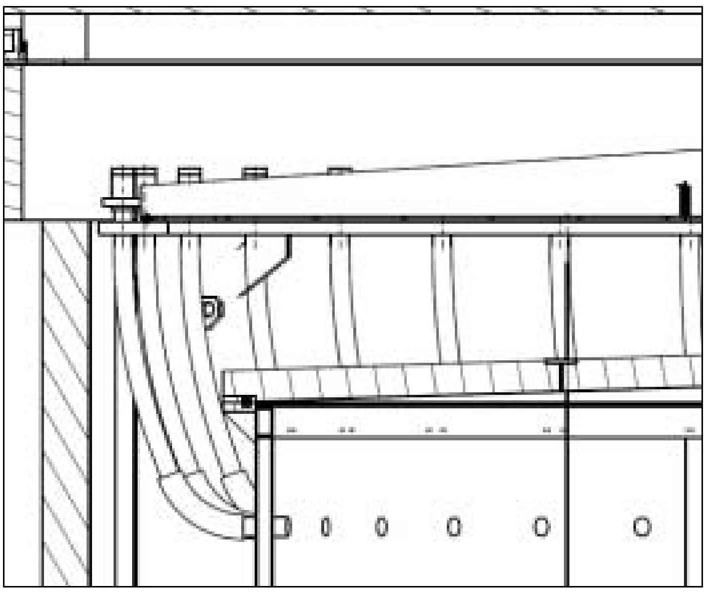


Figure 34 : View of guide tubes for Buffer PMTs cables

8.6.2. Chemical interfaces

- Buffer vessel / Buffer liquid : DAPNIA / Allemagne

8.6.3. Development plan & schedule

8.6.3.1. Simulation

The simulation defined a structure carrying and covered with a thickness skin to 3 mm. This is the result in the critical case: dead load.

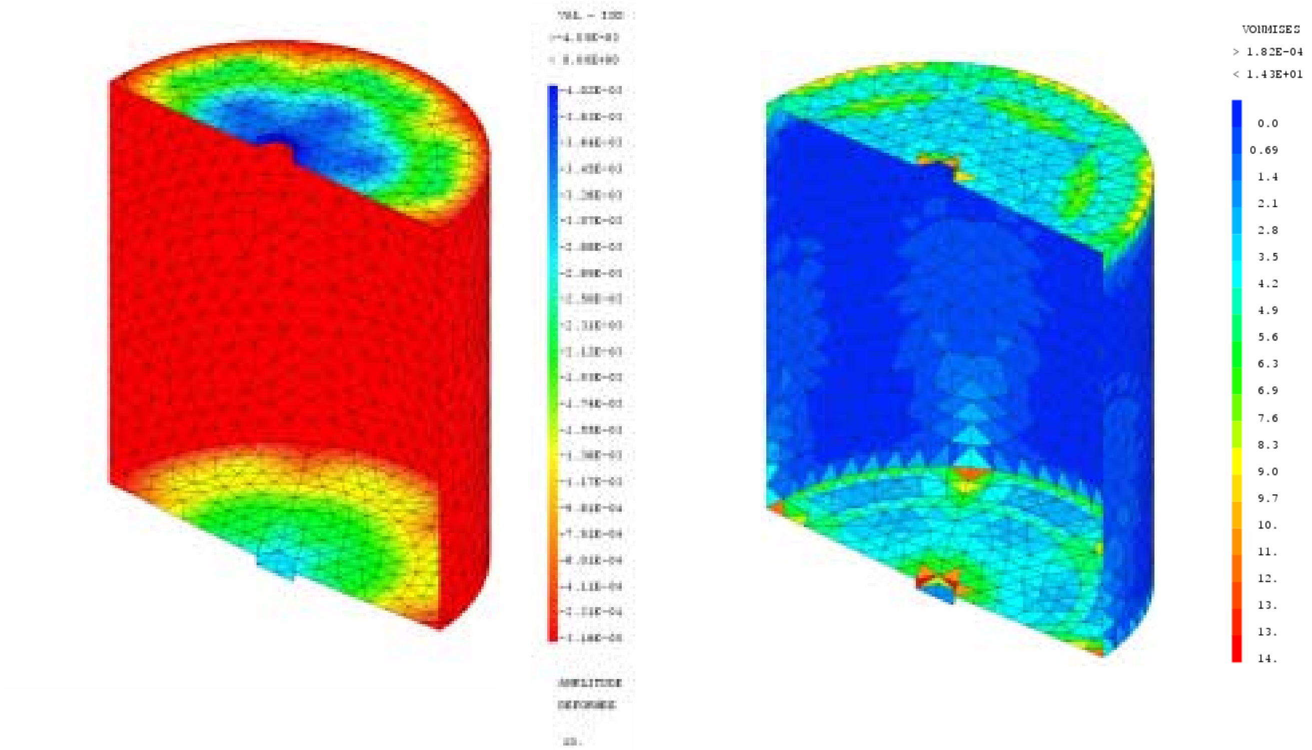


Figure 35 : Maximum displacement and Maximum Von Mises stresses.

The maximum displacement is 4.1 mm and the maximum Von Mises stresses is 14 MPa.

Mode n	Buckling load factor
1	2.9906
2	3.1389
3	3.1511

Table 2 : Buckling load factor.

The first mode of the buckling load is 3.

8.6.3.2. Preparation for Buffer assembly on site

Radiopurity monitoring

The selection of the stainless batch with radioelement rates compatible with the needs for the project is delicate. That's why the procurement of the stainless 304L sheet of 3 mm and the implementation in the factory is independent.
The stainless 304L sheet of thickness 3 mm and the channel section have been supplied. The control of the radiopurity level and the storage have be done. Sumary of the results is presented in the table 3 hereafter. A reporting is stored on EDMS data base (I-009556).

		Modane	**LNGS**	**Oroville**	
Lot #1	**^{60}Co**	13,6±2	17±2	5,5	mBq/kg
	^{238}U	0.5±0.2	0.24 +/- 0.09	< 0.1	10^{-9} g/g
	^{232}Th	0.5±0.1	1.10 +/- 0.2	< 0.1	10^{-9} g/g
	^{40}K	< 4.85	< 2.7	---	10^{-7} g/g
Lot #2	**^{60}Co**	11,2±2,5	9,4±1,2	12,6±1,2	mBq/kg
	^{238}U	< ?	0.20 +/- 0.08	< 0.2	10^{-9} g/g
	^{232}Th	< ?	0.58 +/- 0.03	< 0.6	10^{-9} g/g
	^{40}K	< 4.85	< 2.3	---	10^{-7} g/g

Table 3: summary of the measurements done

Preparation in industry

Then, the preform: bending and the preparation will be realized in the industry. A white mounting of the whole vessel is foreseen in industry before the transportation of halves rings on Double Chooz site.

8.6.3.3. Assembly on site

The vessels will be welded in the detector pit with a process to respect the radiopurity key.
The welding will be double, (the interior and the exterior of the buffer) and on the surface without contribution of element for the radiopurity. The tightness will be controlled in the experiment site by sweat or by radiography for local problem.
A phase of complete cleaning will be done before the assembly of the photomultipliers. A protocol of cleaning with diluted nitric acid and water is in the course of validation within collaboration.

The feet, the bottom and the half rings will be welded in the Neutrino lab, the structure will be positioned above the pit and the structure gone down until the level superior
The middle part will be welded: the first part ring, the second part ring and the inner stiffener. Then the structure will be gone down until the level superior. It is the same thing for the superior part. The structure will be gone done until the veto bottom and the tubes will be assembled and welded.
Then two half covers will be welded, positioned above the buffer and welded.

8.7. Acrylics vessels [2100 & 2200]

Target and Gamma Catcher vessels are two independent cylinders made with acrylics material. The detector vessels dimensions are obtained with the previously technical constraints and critical cases constraints of the vessel life: transport, filling up, dead load, density different.

The more severe constraint is to guaranty a gap during the filling up below 3 cm between the different vessels. The acrylic vessel will be made from acrylics (GS233 from Degussa) panels' assembly by gluing process (Acrifix 190 from Degussa) and then annealing.

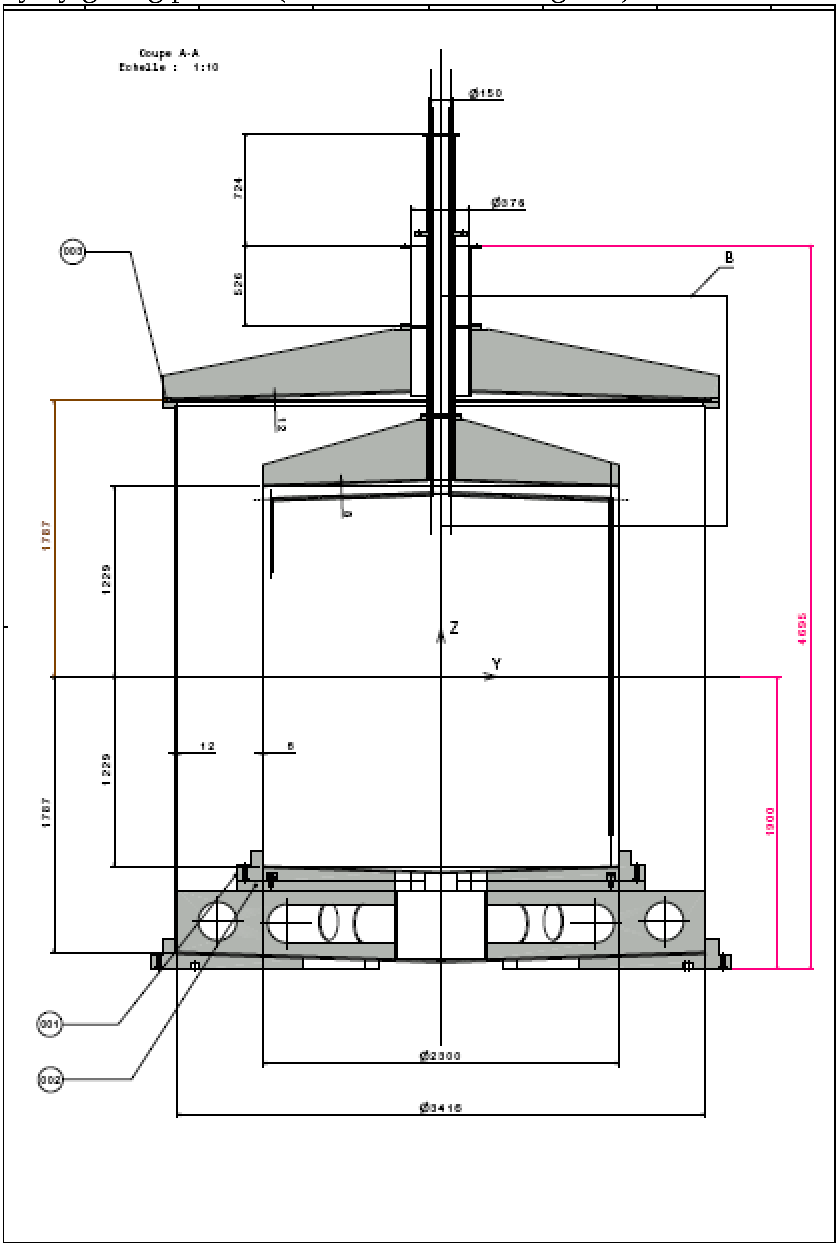
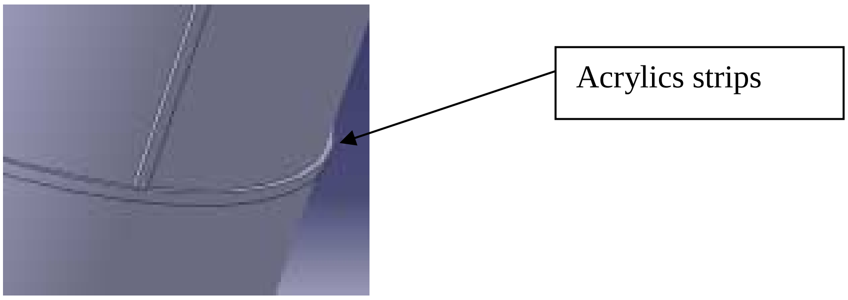


Figure 36 : Design view of the acrylics vessels
71 E021 DML 2100 000 PC (see appendix chapter)

Three target samples will be realised in parallel. The acrylic enclosures are considered like very fragile, so be careful during the transport and the handling. The transport and the storage acrylic vessels will be done under atmosphere nitrogenise. The simulation didn't take account of gluing, tensile test are made to define the gluing behaviour.
The failure stress of the acrylics GS233 is given at 82 MPa in literature. Mechanical tests have been done in labs (see after) and show, for Double Chooz application a failure stress of 12 MPa for glued parts.
To increase the mechanical safety factor, an overlap of a thin layer of acrylics will be added. Some mechanical tests (traction and flexion) have showed that the gain is around 60% (to be confirmed)



The simulations reports have been realized and are stored in EDMS data base. (EDMS I-006848). Their aim was to be sure to stay under a limit of 5 MPa whatever the configuration.

8.7.1. Target vessel [2100]

Main constraint for target vessels realization is the reproducibility and the knowledge of quantity of liquid inside.

The table 1 gives the performances to reach (and their tolerances) of the target vessel:

Inner diameter	2300 mm +/- 20mm absolute +/- 5 mm between the targets
Inner height	2458 mm +/- 20mm absolute +/- 5 mm between the targets
Thickness	8 mm +/- 0.5 mm
Optic transmission	T > 99.5 % between 420 et 600 nm T > 98 % @ 400 nm T > 50 % @ 390 nm
Material	Plexilass (Röhm) : GS233 (acrylic casted)
Mass	350 kg (+/- 10%)
U rate/ Th (radioelement) g/g	< 10^{-11} g/ g
K rate (radioelement) g/ g	< 10^{-8} g/ g

Table 3 : Target technical performances.

Mechanical interfaces (Interface drawing)

- Target vessel / Gamma catcher vessel: both vessels are provided by Saclay and the manufacture will be done in the same firm. A preliminary mounting will be done in the industry to check the interfaces

- Target vessel / Glove Box connection : DAPNIA / LLNL

- Target vessel / wire source : DAPNIA / LLNL

- Target vessel / filling system and level monitoring: DAPNIA / MPI-K Heidelberg. An Interface Drawing is available and approved y both parts (see above)

Chemical interfaces

- Target vessel / filling system and scintillating liquid : DAPNIA / Heidelberg. Material compatibility tests are going on to validate the interface (see material compatibility chapter)

8.7.2. Gamma Catcher vessel [2200]

Table 2 gives the technical performances to reach and tolerances of the gamma catcher vessel:

Inner diameter	3392 mm +/- 20mm
Inner height	3550 mm+/- 20mm
Thickness	12 mm +/- 0,5
Optic transmission	T > 99.5 % between 420 and 600 nm T > 98 % @ 400 nm T > 50 % @ 390 nm
Material	Plexilass (Röhm) : GS233 (acrylic casted)
Mass	1150 kg +/-10%
U rate/ Th (radioelement) g/g	$< 10^{-11}$ g/ g
K rate (radioelement) g/ g	$< 10^{-8}$ g/ g

Table 4 : Gamma catcher technical performances.

8.7.2.1. Mechanical interfaces

- o Gamma catcher vessel / buffer vessel: both vessels are provided by Saclay / DAPNIA. The interface between Buffer vessel anf Acrylics vessels is made of:
  - 6 acrylics legs located at the bottom of the Buffer vessel
  - A central chimney going through the the Buffer top lid.

o Gamma catcher vessel / calibration system : DAPNIA / University of Alabama The support tube of the wire source is studied, developed, provided and installed by Saclay. The development is done in closed collaboration with Univ of Alabama group. The wire source is provided by the Univ of Alabama. The protocol to use it is also the responsibility of the Univ of Alabama

- o Gamma catcher vessel / filling system : DAPNIA / MPI-K Heidelberg

The interface is defined by some holes in the acrylics vessels which will welcome the Teflon tubes / feedthrough provided by MPI-K Heidelberg.

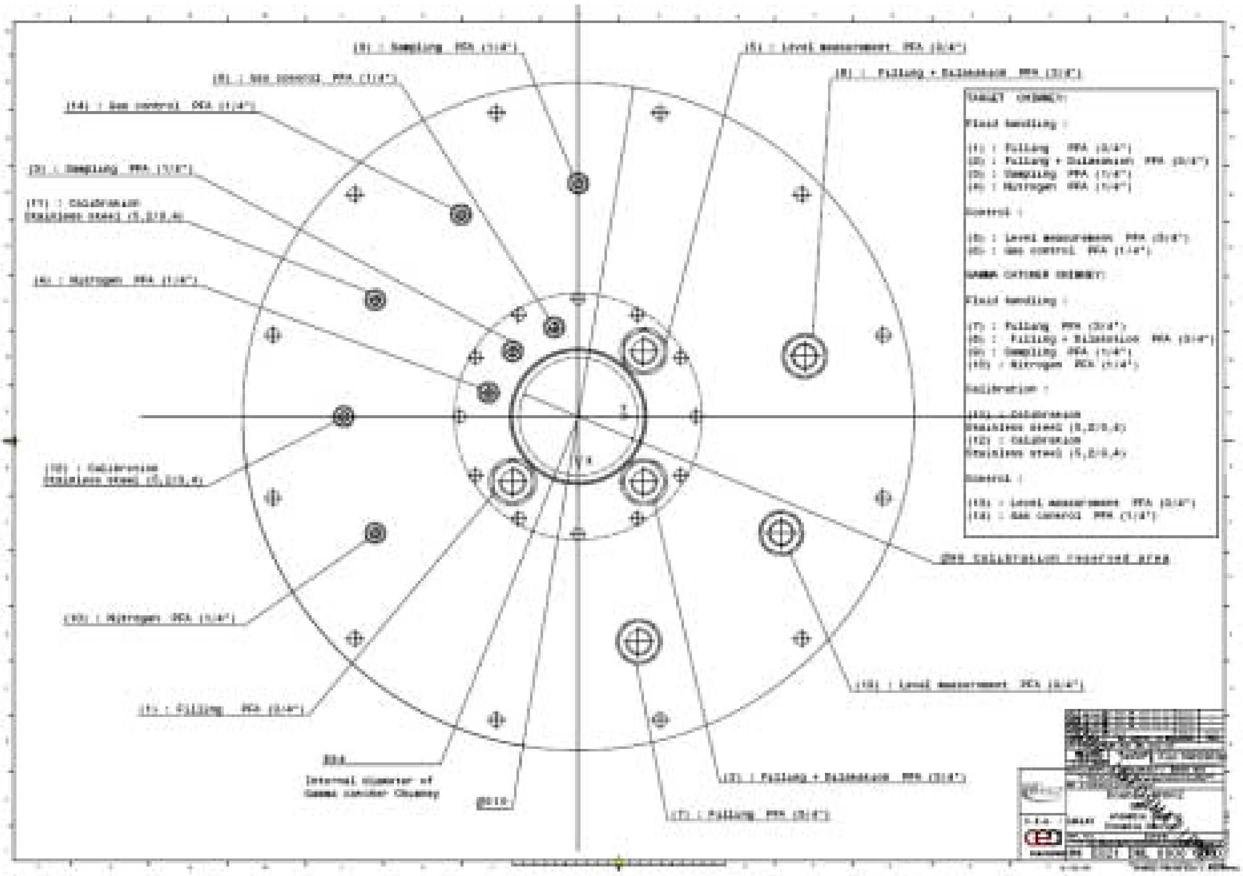


Figure 37 : Top view of the interface between acrylics vessels and Filling system

8.7.2.2. Chemical interfaces

Gamma catcher vessel / filling system and scintillating liquid : DAPNIA / Heidelberg

Material compatibility tests are going on to validate the interface (see material compatibility chapter)

8.7.3. Development plan

8.7.3.1. Simulations

Simulations have been realized to dimension and to study the acrylics vessels behaviour. This simulation have been done in critical cases : filling up, transport, density different, dead load. We found the maximum displacement is 1.62 mm and the maximum Von Mises stresses is 1.2 MPa.

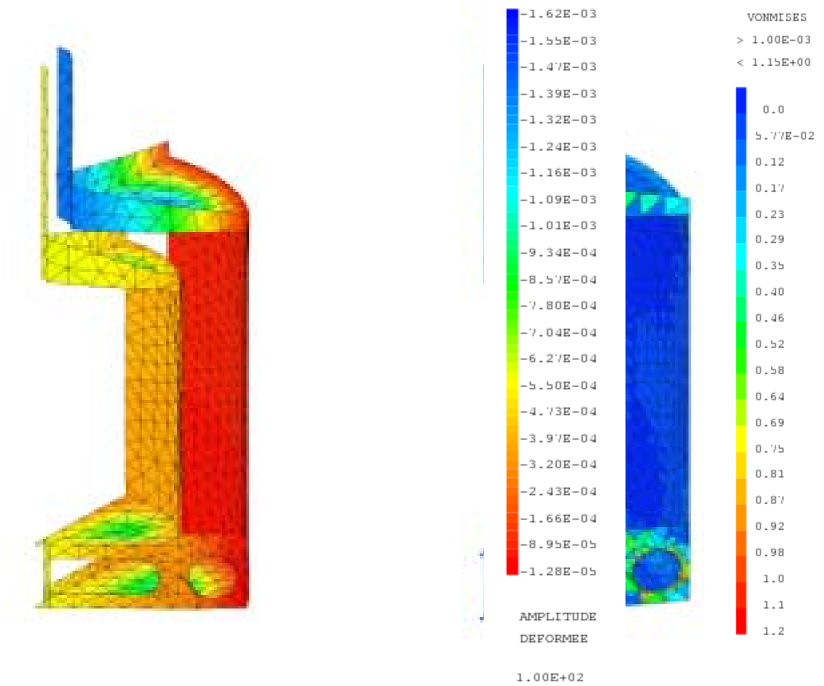


Figure 38: Maximum displacement and Maximum Von Mises stresses.

One specimen of the gamma catcher vessel will be realized in manufacture. Because the fragility of the structure during the transport, the gamma catcher top lid will be glued on site. This step implies the installation of a tent with a unit heater to obtain a temperature superior to 25°C and 40% of HR.

8.7.3.2. Mock up

A technological model 1/5 in dimensions has been realized with a thickness of 8 mm respecting the same materials

.

The main goals of this model were to :

- Check the materials compatibility
- Control the scintillation liquid (ageing)
- Evaluation of tiredness/ageing of the selected acrylic
- Select a manufacturing process with same thickness
- Definition of the annealing, cleaning, control protocols
- Mechanical assembly schedule
- Attachment unit
- Definition of the filling protocol and implantation detectors
- Validation of the interfaces

Figure 39 : Picture of the acrylics mock up, scaled 1/5.

This model gives us some teaching.

- The acrylic vessels manufactures don't allow mechanical adjustments better than 1 mm.
- The visual control of the joints seems sufficient to avoid the tightness.
- The Plexiglas filling tub and colour joint mustn't used.
- The acceptable overpressure on the acrylic vessels is 20 mbar.

The simulations didn't take account of gluing, tensile test are made to know the behaviour of the gluing. These tensile tests are realized at the Lab. "mines de Douai".
The main of these tensile tests is to determine the best technical gluing and the type of the joint. The failure stress with the best joint and gluing is 13.2 MPa. We must use the glue after mixing until ¼ hours.

Others tensile test will be done at Rhöm, the failure stress are 12 MPa.
These tests are allowed to take a security factor more important and to increase the gluing area with a thin strip.

A white assembling of the acrylic chimneys will be made because of the many interfaces: filling up, draining, level control, calibration system passing. A bad interfaces control can break the detector. This test will allow proving the feasibility, maybe to optimise ergonomics.

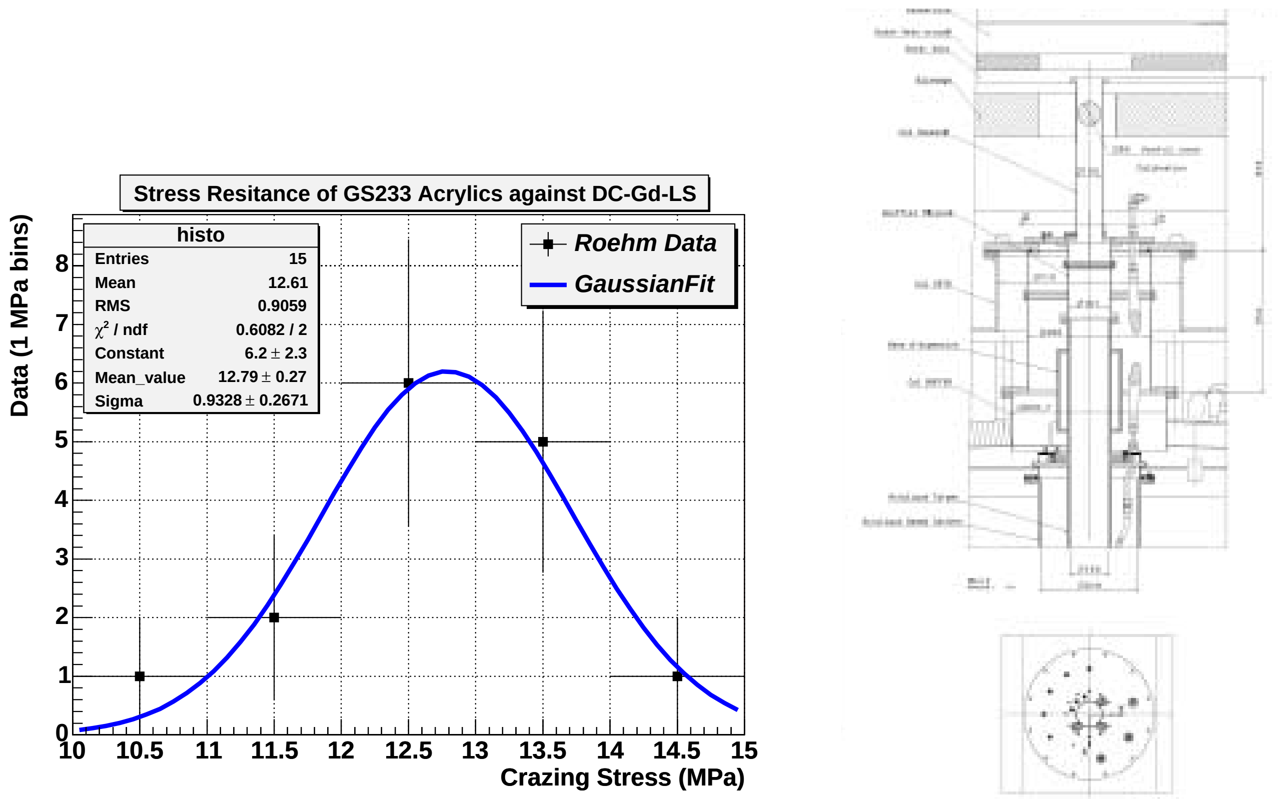


Figure 40 : Results of Rhöm tensile test and Drawing of chimney design.

To fit with the radiopurity requirements**,** Raw material will be check in Germanium detectors before construction in industry.

8.7.3.3. Model philosophy

The acrylics material will be a dedicated batch for 3 set of Target and Gamma Catcher vessels. Radiopurity assessments will be done before the start of the vessels manufacturing.

Target vessel

Three target vessels will be realized in the manufacturer. It allow to be ensured of a similarity manufacture and if necessary to have target vessels with the same ageing. The joints will be controlled in manufacture with a visual control.
The transport and the storage will be realized under atmosphere nitrogenises.

Gamma Catcher vessel

Gamma Catcher vessels will be manufactured step by step. First, the far detector specimen, then the near one and if needed, the spare will be built.

8.7.3.4. Assembly on site

Gamma Catcher Vessel

After the gamma catcher vessel transportation by truck with the handling tools, the tipper will be installed and the gamma catcher swivelled in the horizontal position.
Then the gamma catcher will be lift and installed on the crab to descent the tunnel. The gamma catcher will be positioned above the pit to be swivelled in the vertical position. In this delicate step, the higher level of PMTs mustn't be installed during the swivelling.
Before descending the gamma catcher to the pit, the handling tools must be separated and the gamma catcher down in the buffer. The support will be swivelled and extracted.To fix the gamma catcher in the buffer, we have a special tools and we tightening until screws clamping. Then the special tools and the ties rod will be extracted.
All the dedicated tools are realised by CIEMAT laboratory.

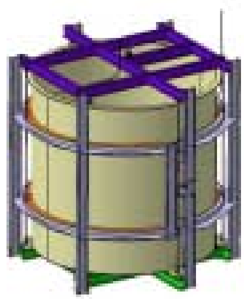
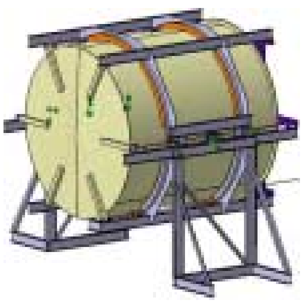


Figure 43 : Handling tools.



Gamma catcher Figure 41 : vessel swivelling.

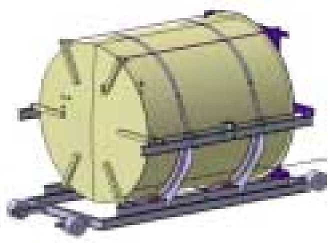


Figure 42 : Gamma catcher on the crab to descent the tunnel.

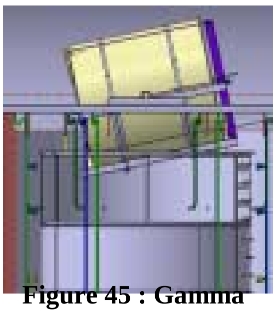


Figure 45 : Gamma catcher swivelling above the well.

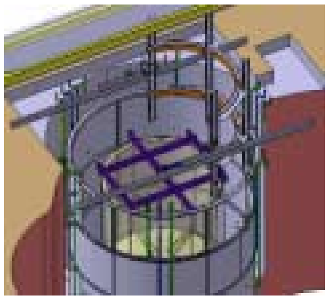


Figure 44 : Gamma catcher in the buffer and handling tools extraction.

Target vessel

The target will be made on the inferior frame, the handling tools will be installed on the target and the target vessel will be gone down in the tunnel on a rider pallet truck. The support will be extracted and the tie rod will be installed. Then target will be positioned above the gamma catcher to go down inside and the superior frame will be disassembled.

The target will be fixed in the gamma catcher. The screws tightening will be made until screws clamping with special tools. Then, the special tools and the ties rods will be extracted.

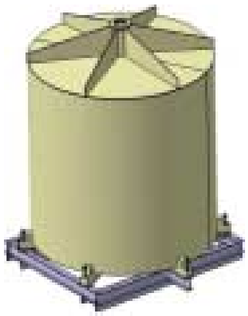


Figure 47 : Target construction on the inferior frame.

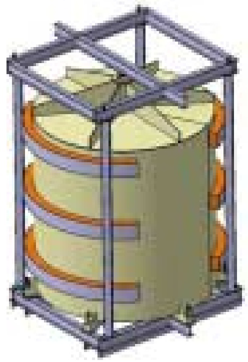


Figure 48 : Support installation.

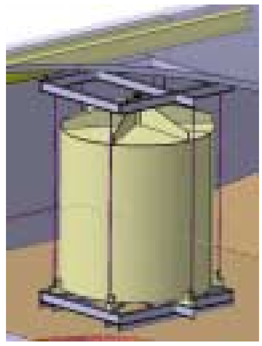


Figure 46 : Ties rod installation.

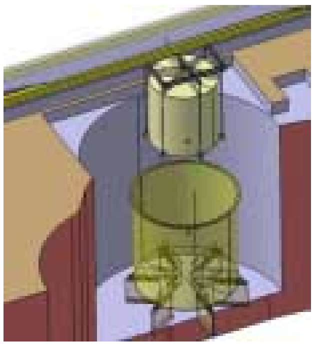


Figure 50 : Target vessel goes down.

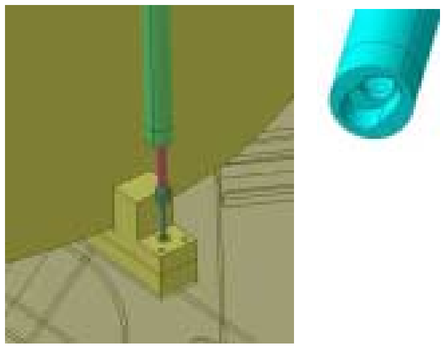


Figure 49 : Screws tightening with special tools.

Handling facilities

All the handling facilities usefull for acrylics vessels realisation in industry, transportation by truck and assembly in the lab are being realised by CIEMAT lab.

They will be ready at the beginning of October 2007.

8.7.4. Schedule

The order of the acrylics vessels is planned in november 2007. The installation on site is totally dependant of the steel vessels and PMTs installation in the pit and it is foreseen in September 2008.

9. Inner detector PMTs [3000]

9.1. INNER DETECTOR PMTs [3000]

9.1.1. Overview

PMT system description:
The inner PMT system is one of the core parts of the Double Chooz detector, which detects scintillation light from the liquid scintillator and gives information about energy and the position of the signal.
In order to reduce systematic uncertainly of event selection, the energy resolution of significantly better than $10\%/\sqrt{E(MeV)}$ is required. It means that much more than 100pe/MeV of photoelectron yield is necessary. Because the light output of DC liquid scintillator is ~5,000photons/MeV, >2% of photon detection efficiency (=photo-coverage (PC) x quantum efficiency (QE)) is necessary. We are targeting to obtain at least 3% of photon detection efficiency, namely 25% of QE and 12% of PC.

Fig.-1 shows the DC-PMT system, which includes PMT, magnetic shield, light concentrator, support structure, HV supply, HV/signal splitter, PMT monitor and cables down to the front end electronics (FEE). The responsibilities of the PMT group are to purchase, test, assemble, install, tune and to do maintenance and PMT radioactivity control.

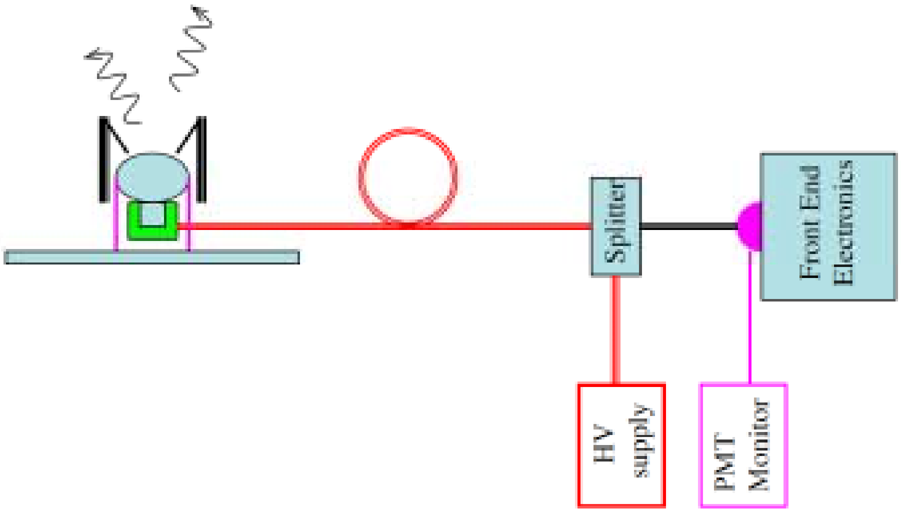


Figure 51 : Fig.-1, Schematics of inner PMT system

The PMT is immersed in the paraffin oil and special cares are taken with respect to compatibility with the oil. When empty, the gravity force of the PMT weight goes downward but when the oil is filled, the PMT experience a buoyancy force upward. The position of torque centers are also different. The support structure of the PMT is designed with these special conditions in mind. Arrangement of the PMT is also important issue to obtain uniform response and simulation studies are being performed. The Double Chooz far detector has thick iron shield in an outer layer and magnetic field at PMT positions is unpredictable and

the field cancellation by electric coils is not possible. Each PMT will have μ-metal cover to shield the magnetic field. A possibility to equip the PMT with a light concentrator is being investigated to increase the number of photoelectrons. PMT glass is one of the major background sources in the detector and low background glass is being investigated. HV supply is also responsibility of inner PMT group. The HV supply is being investigated in view of controllability as well as its electrical performances such as stability, noise level etc. One coaxial cable will be used both to supply HV and readout PMT signals. Therefore a HV/signal splitter circuit is necessary between HV supply, PMT and amplifier for PMT monitor. In order to monitor the PMT conditions in run time a PMT monitor will be equipped.
The manufactured PMTs will be delivered to Japan and acceptance test and HV tuning will be performed there. Then they are sent to France, where receiving check and assembling of PMT support, magnetic shield and possibly light concentrator take place. Then finally the PMTs are sent to DChooz experimental site and installed in the detector. After the installation, the final checking will be performed for the commissioning.

Schedule:
Fig.-2 shows the expected schedule of far detector PMT in case funding is available in October 2007.

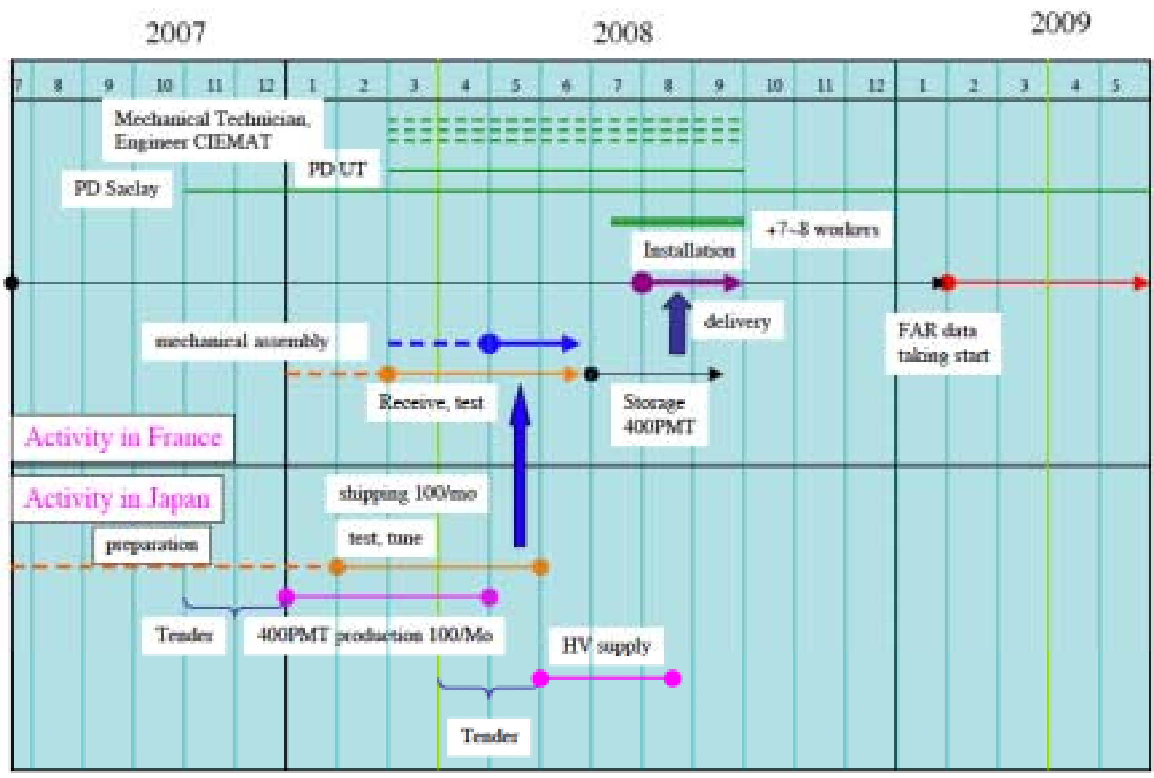


Figure 52 : Fig.-2, Inner PMT schedule

The tender will be opened in November. It will take two months to finish the tender process. From January 2008, 100 PMTs will be delivered from the manufacturer every month. It takes 4 months to produce all far detector PMTs. All the PMTs will be tested and HV tuned to obtain 10^7 gain in Japan. Then the PMTs are sent to France one month after its delivery. In France the receiving work starts from February and the PMTs will be tested again to check if there is any damage during the transportation. In the last two months, the support structure and magnetic shield and light concentrator are assembled to the PMT. The PMT installation in the buffer tank takes place from August to September 2008 and final testing and HV tuning takes place after that and the commissioning follows in winter 2009. The data taking by far detector start in winter of 2008. For near detector, PMTs similar process will be repeated by 1 year later.

9.2. Phototubes [3100]

9.2.1. Mechanical and electrical specifications

PMTs with larger diameter have advantages in terms of total cost because the number of necessary channels is inversely proportional to the square of the PMT diameter. On the other hand, the height of the PMT and the total mass of the PMT glass are larger for large diameter PMTs, which increase the background rate from radioactivity of the glasses. For the scale of Double Chooz detector, PMTs with ~10 inch diameter are optimum. There are two candidates for such PMTs. One is Hamamatsu Photonics K.K. (HPK) 10 inch PMT(R7081) and the other is Photonis 10.6 inch PMT(XP1804). Since HPK already has technology of low background and oil proof large area PMTs, there already be a lot of data available and the following description bases mainly on the HPK R7081 PMTs. Because quantum efficiency of HPK R7081 PMT is 25%, 390 of such PMT with current detector geometry are expected to yield 150pe/MeV or more. There are such effects that a good matching of refractive indices between oil and glass and reemission of the scintillation light in the liquid scintillator increase the number of p.e. in the actual operation. On the other hand, magnetic shield reduces p.e. and detailed simulation will be necessary to evaluate the final performance.
Fig.-3 shows the size and a picture of the HPK 10 inch PMT with its oil proof base and cable.

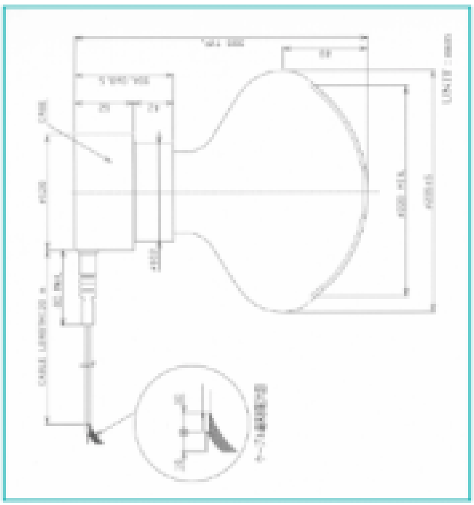


Figure 53 : Fig.-3 (a) Mechanical Size (b) Picture

The physical diameter of the glass is 259+-5mm and the length of the tube is 305mm max. The photo cathode area diameter is 220mm minimum. The average weight of glass part is 1.06kg and whole weight is 2.5kg typical. The glass is E-glass. The cathode material is bi-alkari with 25% QE at 420nm wavelength light. Fig.-4 shows its wavelength dependence of the QE. The QE spectrum matches well with bis-MSB light emission spectrum.

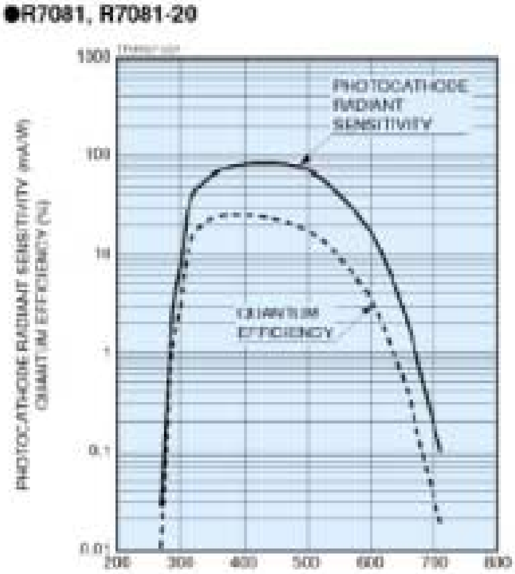


Figure 54 : Fig.-4 Quantum efficiency of HPK R7081

Fig.-5 shows the base circuit diagram. The circuit is based on IceCube type, which has better linearity and dynamic range than conventional circuit on catalog. The voltage ratio is same as IceCube PMT but the resistance is doubled to reduce the current to 1/2. The PMT is operated with plus HV to avoid the potential difference across the large tube glass in order to reduce the dark noise and increase the stability. The HV and signal transmit through one common cable and there is no DC decoupling capacitor in the base circuit. There is a backward termination resistor (R24) connected to the anode. It reduces the amplitude of the signal half but it quickly damps reflections of the signals caused by impedance miss matching which is an important feature to quickly recover from the very large muon signals.

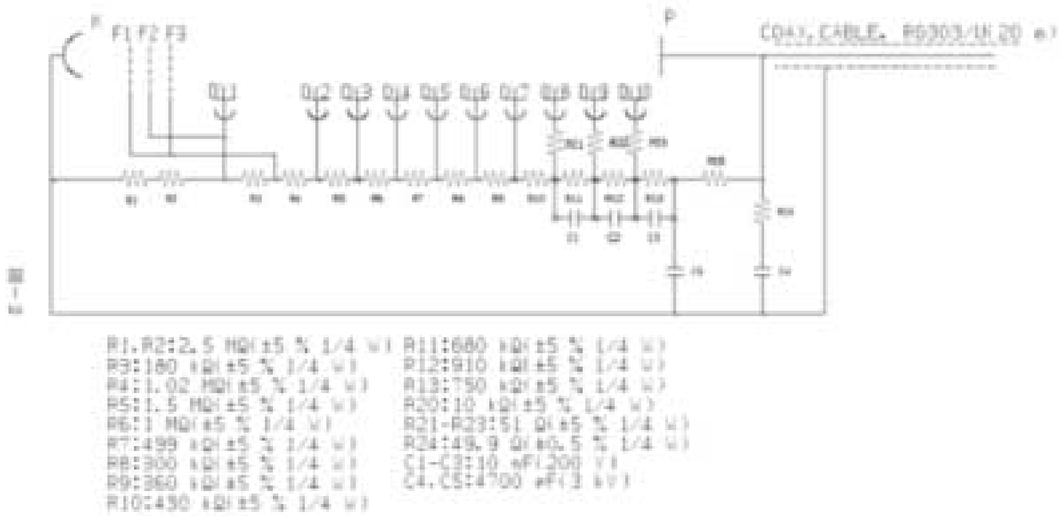


Figure 55 : Fig.-5, Base circuit diagram

The PMT base part is moulded by an epoxy glue which is covered by an acrylic housing. The cable is Teflon jacket cable with length 20m and specific impedance 50Ω (RG303). Table-1 shows main features of the cable with calculation of the performance for our case.

Impe-dance	Max Volt.	Attenu-ation	Weight	Conductor		Dielectric		Screen	Jacket	
□	kV_{rms}	dB/20m @100MHz	Kg/20m	Mat.	mm	Mat.	mm	mm	Mat.	mm
50+-2	2.5	2.6	0.9	StCuAg	0.95	PTFE	2.95	3.6	FEP	4.3

Table-1, Specifications of RG303/U cable

The cable outlet direction is set to random with 45 deg unit with respect to the dynode orientation in order to reduce the systematic area-variation of PMT response due to the variation of local magnetic field direction.

9.2.2. Chemical Interface

Fig.-6 shows the oil proof base for HPK large area PMT. The PMT base part is moulded by an epoxy glue. The purpose of this moulding is to protect possible degradation of electric parts and soldering due to the oil touching as well as to prevent contamination in oil by possible solution from the parts material and soldering.

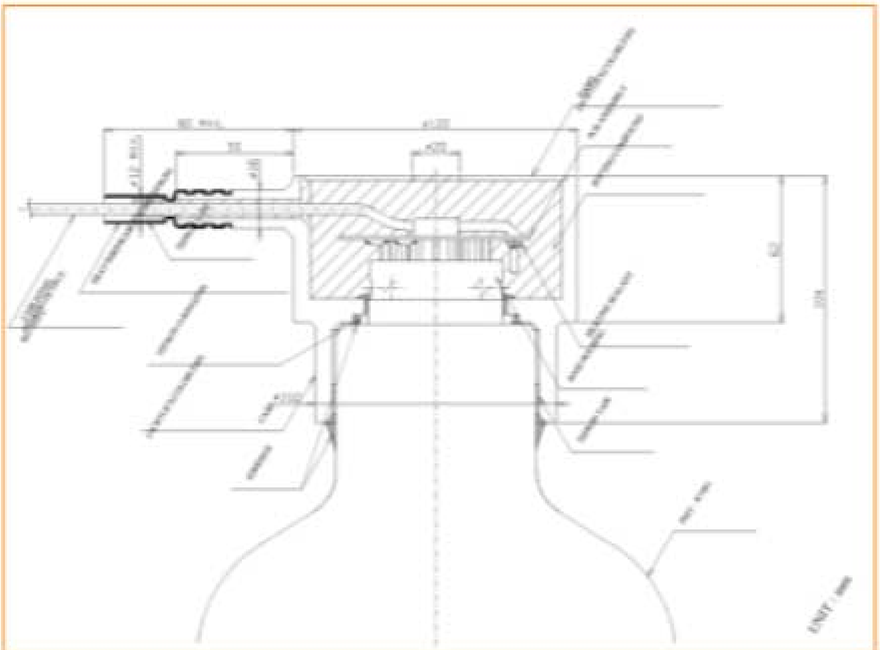


Figure 56 : Fig.-6, Oil proof PMT base.

This oil proof PMT base was developed for KamLAND experiment and has been reliably used for 6 years. The total failure rate of KamLAND 17 inch PMT is 1.4% so far. This base and cable structure and material is exactly same as KamLAND PMT. A sample PMT will be tested by soaking in a paraffine oil to see any bad effect on P/V ratio, TTS and dark rate. Figs.-7 show the data of one photoelectron peak and timing spread before and after the PMT is soaked in paraffin oil, which were measured by KamLAND during its R&D period. No degradation of the performance has been observed.

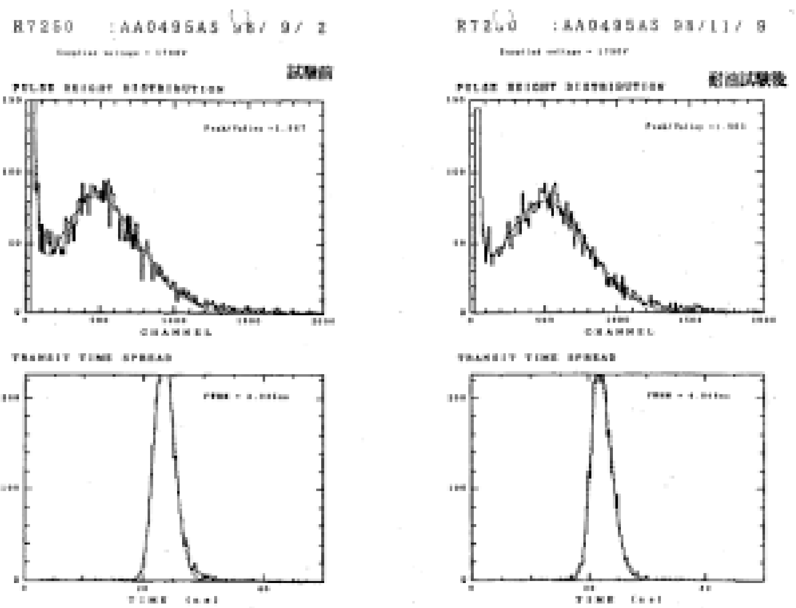


Figure 57 : Fig.-7 One photo electron peak (upper) and TTS(lower) for
Before soaking oil (Left) and after (Right) for KamLAND 20 inch PMT(R7250)

9.2.3. Electronic Specification

PMTs to detect the scintillation photons should have an excellent detection efficiency, a large active area, a low electronic noise, a wide dynamic range and so on. In order to cope with such demands, PMTs have to satisfy following conditions regarding an electronic aspect.

i) Supply high voltage (HV)

The PMT is going to be operated at a gain of $1x10^7$ in the normal operation. In order to suppress a dark current, it should be operated with a positive high voltage (supply positive HV to the anode while the photocathode is routed to ground). PMT should have a gain greater than $1x10^7$ at a voltage less than +2000V.

ii) High quantum efficiency (QE):

A peak QE should have greater than 22%. Since the blue light (400 nm) sensitivity is proportional to the quantum efficiency, we require more than 8 mA/lmF for this value. The QE is greater than 25% in average.

iii) Dark counts:

A counting rate at the threshold of 1/4 s.p.e. has to be less than 10,000 cps in order to suppress accidental triggers and energy offset in the PMT charge sum.

iv) Peak to Valley (P/V) ratio:

Since the number of photoelectrons observed by each PMT is not so large, the PMT has to have excellent detection efficiency for s.p.e.'s. Hence the P/V ratio depicted in table-2 has to be as large as possible. We require more than 2.3 for this value and typical value to be larger than 2.8.

v) Transit time spread (T.T.S.):

Timing resolution of the PMT is very important to reconstruct the positions of the signals. We require T.T.S. to be around 3.0 ns (FWHM) for s.p.e.'s from any active photocathode area.

vi) Other specifications:

Prepulse or after pulse may cause some correlated backgrounds, hence those should be suppressed as small as possible.

Table-2, PMT specifications

			Hamamatsu R7081-01	Photonis XP1804
Photocathode Diameter			10”	10.6”
Length (Max.)			300	294
Effective area (cm^2)			450	410
No. of stages			10	11
Dynode structure			Box line	Linear Focus
Cathode Sensitivity	Luminous Typ. (mA/lm)		80	60
	Blue Sensitivity Typ. (mA/lmF)		10 (@400nm)	10 (@400nm)
	QE at peak (%)		25	
Anode Sensitivity	Supply Voltage (V)		1500	1600
	Gain Typ.		$1x10^7$	$1x10^7$
	Dark Current (nA)	Typ.	50	30
		Max	700	100
	Dark Counts (cps)	Typ.	4000	3000
		Max	8000	15000
Peak to valley ratio Typ.			2.8	2.3
Transit Time Spread Typ. (FWHM) (ns)			2.9	2.4
Pulse Linearity ±2% deviation (mA)			20	150
Comparison by ANTARES [Ref.]	Peak to valley		2.8	2.7
	Transit Spread (ns)		3.0	2.0
	Dark Counts		910	9200
	Prepulses (%)		0.01	0.01
	Delayed Pulses (%)		3.6	4.7
	Afterpulses-1		1.0	3.2
	Afterpulses-2		18	3.8

In the table-2, important electronic specifications for R7081 of Hamamatsu Photonics and X1804 of Photonis are compared using the catalogue data and ANTARES data.
Both have similar performance, but R7081 has slightly larger active area with less materials and better P/V ratio and less dark counts.

9.2.4. Radio Activity of the Glass

The γ–rays from radio activities in PMT glass is considered to be a dominant source of the single background rate of the Double Chooz detector and the control of radiopurity of the PMT glass is an important issue. In order to investigate the method of radiopurity control, a number of PMT glass samples have been counted by various institutes. Fig.-8 summaries the results of such measurements.

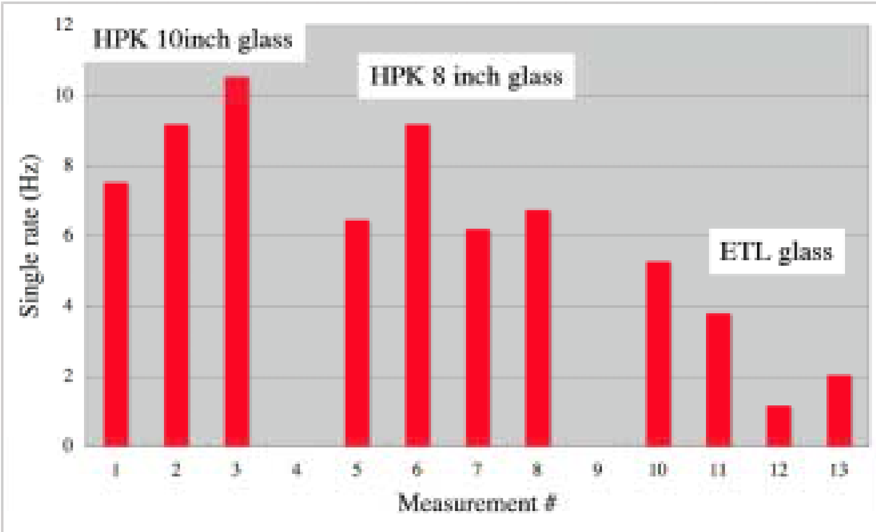


Figure 58 : Fig.-8 Glass activity measurement.

The single rate for new data are calculated using the formula:

$$n(E > 0.7MeV)[Hz] = 0.014A_{Th}[ppb] + 0.029A_U[ppb] + 0.082A_{^{40}K}[ppb]$$

and using 1.06kg of glass weight.

With the HPK 10 inch glass, the single rate for the threshold 0.7MeV in the gamma catcher is ~9Hz, resulting in the accidental background rate of 2/day assuming the neutron signal rate to be 0.023Hz and delayed coincidence window of 100μs. Fortunately, because the prompt signal is a positron signal, the event is localized and the background rejection by removing the outer skin of the -catcher can be safely performed. For example, if the prompt events with energy less than 3MeV which occur within 20cm from γ-catcher surface, are removed, the single rate will reduce to 1/3, while the loss of neutrino event is less than 0.1%. The accidental background will become 0.7/day, which is 1% of the neutrino signal and the background can be estimated precisely from the off-timing delayed coincidence rate.
How to control the radiopurity of the glass in the mass production phase is under intensive discussion with a manufacturer. The current plan is as follows, the manufacturer sends 2kg of glass sample for every batch (1month). The sample will be shipped to US for counting. If those measurements show unsatisfactory result, the production will be stopped to investigate he reason and to solve the problem. The requirement for the activity limit will be something like 10Hz equivalent single rate. The glass samples so far measured by us were sent to HPK for their own counting. The data will be used as the reference for screening the glass for the mass production.

9.2.5. Development plan

The development of the baseline PMT design is almost finished. In the current schedule, the tender will start in November 2007 and all the specifications will be fixed by then. Most of the parameters have already been determined. The remaining issue is to fix the method of radiopurity control. Negotiation with PMT companies will continue by then.

9.3.HV System [3200]

9.3.1. Description

A quality high voltage (HV) system will be specified and constructed for the near and far detectors of Double Chooz to provide clean, stable, monitored power for the PMTs. The major hardware subcomponents of this system are: a UPS to provide stable AC power, a multi-channel HV supply, and filtering to remove noise.

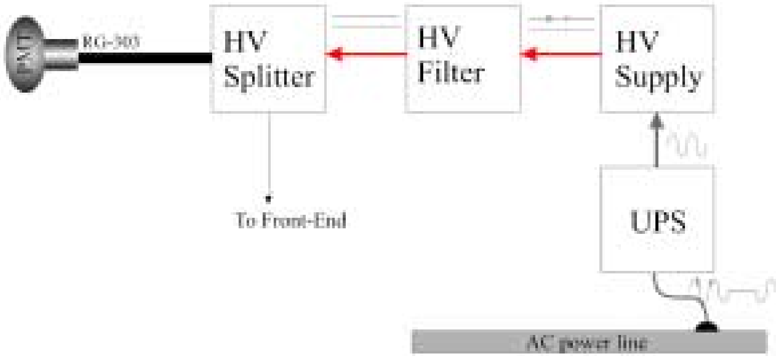


Figure 59 : Fig.-9. Block diagram of the High Voltage system,
showing the major subcomponents.

A single cable will be used for the connection between the PMT and the HV system and Front End Electronics (FEE) (see Fig.-9). Both HV and signal will be carried on the same RG-303 coaxial cable between HV splitter and PMT. HV Splitters will separate fast PMT response signal from the positive high voltage capacitive decoupling with RC~250 ns. Additional filtering is required between HV supply and HV Splitter to suppress possible voltage ripples and pick-up noise. The functions of signal-HV splitting and filtering will be combined in the passive HV filter units located at the exit from the detector and at a distance of ~ 20 m from the power supplies.
The baseline detector design calls for 390 channels of PMT inner high voltage for each of the near and far detectors. The baseline PMT design requires +2.5 kV DC at 0.3 mA per tube. This can easily be provided by many commercially available power supplies. Selection of a vendor will be made in light of the following specifications:

- Ripple and noise: the noise on the HV outputs under load needs to be below a level such that the effect on any signal is less than 0.1 mV peak-to-peak. To meet this requirement, some filtering external to the HV supply will be needed.

- Frequency spectrum of HV power supply AC noise on the HV DC level should not exceed 100 kHz (max internal switching power-supply conversion frequency) that can be a source of coherent noise in PMT system. For example, ground loop noise that potentially can be produced by the processor chips used by multi-channel HV controllers can generate noise in the frequency range of 100 MHz that will be difficult to filter from the PMT signal.

- Voltage set/monitor: resolution will be at the level of 1 V or better.

- Voltage limits: there must be a hardware provision that allows the setting of the maximum output voltage on a module or crate basis. This value shall be read back via software.

Software settable controls shall provide the ability to set software limits for the voltage settings.

- Current trip set/monitor: resolution must be 1 μA or better.
- Voltage ramp up/down: in the range of approximately 10 to 500 V/s, programmable.
- Operating temperature range: approximately 0° C to 40° C, dry atmosphere.
- Grounding: the HV outputs shall be floating, such that the crate ground is independent of the return for the HV channels.
- AC power supply: approximately 220 VAC, 50 Hz.
- Polarity: positive polarity modules are required.
- Communications: complete control of the HV system must be via a standard TCP/IP Ethernet connection. Provisions to control individual crates from either a front panel or a front panel connection must also be provided.
- Electrical connections: the HV connections must be through either standard SHV connectors or an HV certified multi-pin connector of proven reliability in this application.
- Stability: ±100 mV at a nominal setting of ~1,600 V for a period of 72 hours.

To date, the three primary candidate-vendors are CAEN, Universal Voltronics and ISEG, all of which have offerings that are potentially acceptable for Double Chooz. Table-3 compares some specifications of the HV modules of these manufacturer and Figs.-10 shows their appearances.

Interfaces

The usability of interface is an important element of HV systems. It will be taken into consideration when evaluating the system. One issue is how to incorporate HV control and monitoring schemes, such as ON/OFF, reading and showing the voltage and current monitor, etc., to main DC online schemes. These issues have to be discussed later when preparation of hardware has progressed.

	CAEN	Universal Voltronics	ISEG
Module	A1932A	Model 1461	EHQ20025P204
Crate/Controller	SY1527	Model 1458	ECHxxx
Max.V(V)	3K	3K	3K
Max. I (mA)	0.5	2.5	0.2
Ripple(mV p-p)	<30	<100	<10
Ch/module	48	12	32
Connector	Radiall 52 x1	SHV x12	REDEL32 x1
Ground	common	common	common
Rack size	8U x2	8U x3	6Ux2
Interface	Ethernet, RS232, HS-CANET	Ethernet RS232	Ethernet, CANbus
Monitor	V, I, T, etc..	V, I, etc.	V, T, etc.
Control	Power on/off V setting, etc.	Power on/off V setting	Power on/off
Program examples	Yes. (for all interfaces : WinXP, Linux2.4.22)	Yes. (for Ether. Linux(CLEO))	Yes.(for CANbus : Win9X, Me,NT) No (for Ether.)
Multi Channel User	SuperKamioka Borexino	KamLAND	
comment		Previously LeCroy	

Table-3, Specifictions of HV supplies

Figure 60 : Figs.-10, Appearances of HV supply system.

Universal Voltronics

Model-1458 Model-1461 (Left most module)

ISEG

ECHxxx EHQ20025P204

9.3.2. HV splitter

On their way from the PMTs to the Front-End Electronics, the PMT signals will first pass through HV passive splitters. Double Chooz will use a single cable for each PMT, carrying both the HV and the PMT signals, in order to minimize cost, dead volume in the detector, feedthrough area at the detector periphery, and ground-loop effects. The PMT signals are expected to be rather small ~ 4 mV, so noise must be kept well below the millivolt level. It is the primary job of the HV passive splitter to decouple the signals coming out of the PMTs from the HV supplies. In addition, the HV splitters will provide filtering of the HV to reduce low-frequency and pick-up noise that comes from the HV power supplies. Fig.-11 shows a schematic for one-channel passive HV splitter.

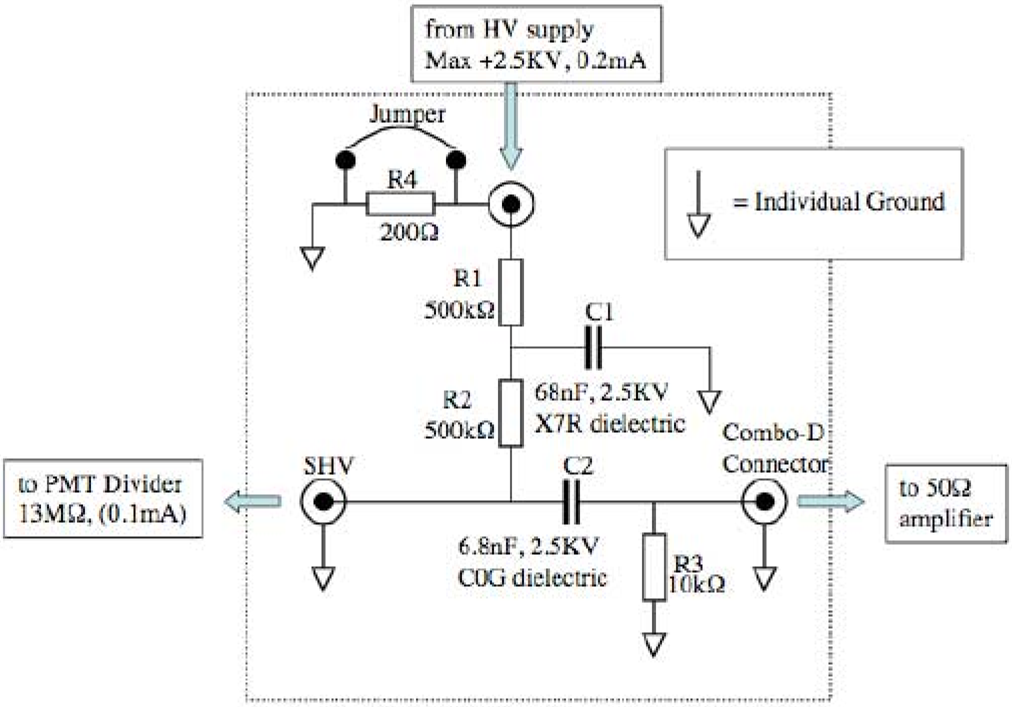


Figure 61 : Fig.-11. Schematic of a passive HV-splitter channel

Noise from the HV power supply, like ground-loop pickup, would be synchronous across many PMT channels (coherent noise). The summation of the PMT channels to produce energy triggers imposes additional strict requirements for the suppression of such noise in the HV distribution system. Thus, the role of noise filtering is essential for every individual HV splitter channel. R1 and C1 form the low pass filter with cut off frequency 5Hz for the noises from the HV supply, while C2 and input impedance of the amplifier (50Ω) form the high pass filter with cut off frequency 500KHz for the PMT signals. The C2 affects the shape of signal tail which is planned to be clipped in the front end electronics. Therefore, the capacitance of C2 has to be very stable with respect to temperature and applied voltage and C0G dielectric capacitor is chosen. Each channel has separate ground. Because the ground lines of front end electronics (FEE) are common and HV supply systems also have common grounds within the module, a ground isolation resistor is put in the HV ground to kill the possible ground loops. There will be ~0.2V of potential difference between the FEE ground and HV ground due to the ground isolation resistor. There will be ~100V of voltage drop at R1+R2 and the relation between the voltage of HV supply; V_0 and voltage actually applied to PMT: V_{PMT} is,

$$V_{PMT} = 0.927 \times V_0 .$$

Another concern is the possibility of cross-talk between the channels. In a detector of the Double Chooz design, one expects cross-talk not to be a serious concern: all of the PMTs are looking at the same events, and should have similar signals. There simply won't be cases of valid events where one PMT gets a large (muon-like) signal, while an adjacent PMT only gets single photoelectrons. The design of HV splitters will be done with an individual metal box for each channel. This will reduce the received EMI radiated from external sources and cross-talk between channels inside the splitter. Nevertheless, the cross-talk between channels has to be tested with the final cables length of PMT + splitter + cable to electronics because long cables going together a long path can also produce cross-talk between channels.

Prototypes of such splitter with simpler designs and smaller capacitors have been successfully used at PMT tests at UT, CIEMAT, and TMU. Design quality requirement for HV splitter should guarantee the detection of single photo-electrons (spe) with the PMT operating at the gain 10^7 with discrimination level of ~ 0.25 spe. Baseline noise (the width of pedestal) should be significantly less than 0.25 spe amplitude.

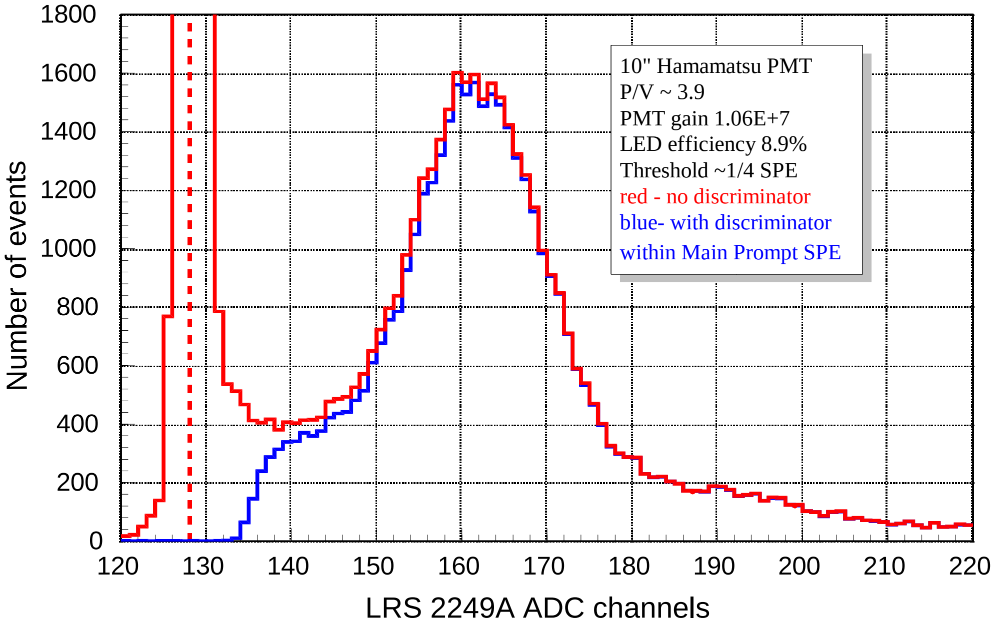


Figure 62 : Fig.-12. HV splitter quality should warranty detection of SPE as shown in this test of HV-splitter prototype

The individual HV-splitter boxes will be grouped in multi-channel modules that will be installed on the either sides of the experimental gallery close to the walls above the detector (see Fig.-13), to minimize the length of the expensive Teflon jacket PMT cables.

The number of channels per module and the precise position of the modules in the wall will be calculated to minimize the length of the cables and can depend also of the number of channels per HV power supply (48 for CAEN, 32 for ISEG or 12 for Universal Voltronics) if keeping a one to one relation between the power supply and the splitters module will reduce the number of cables and connectors. The cable routing outside the buffer must be known in order to perform the calculation of channels per module and the position of modules.

About 470 HV-splitters (390 inner PMTs and ~ 80 PMTs of IV system) need to be constructed and the responsible institution is CIEMAT.

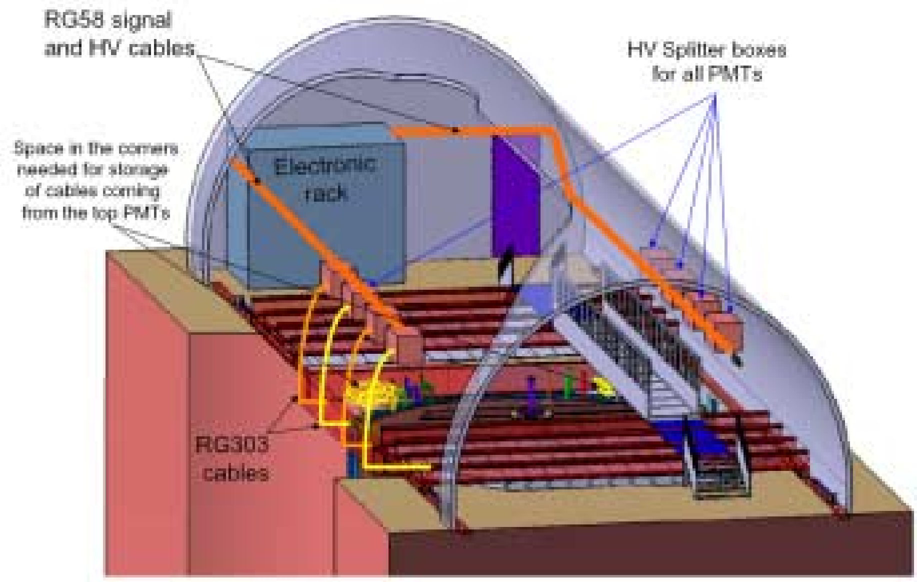


Figure 63 : Fig.-13. Location of HV splitters

Since the HV-splitters will be installed in the area without air-filtering and air-conditioning, splitters modules and individual boxes will be designed to avoid the entrance of humidity and special care will be given to the selection of components and particularly HV capacitors with long-term stable and temperature-independent characteristics.

HV-splitter design doesn't include the HV cables between the HV splitters and HV power supplies as well as signal cables from HV splitters to front-end electronics. These cables should be built and installed separately.

The individual splitters can be designed before the decision of the HV supply to be used but the splitters module must wait until the final decision of the HV supply if we want to keep the same connector and number of channels in both sides. Anyway, before the final design and production of the individual splitters, it will be convenient to test the individual splitter with the three options of HV power supplies to check the splitter performance filtering the HV supply noise.

The final design of the splitters module will be made after the decision of HV supply which is planned in June/2008. Meanwhile the individual splitters can be designed and tested with different power supplies.

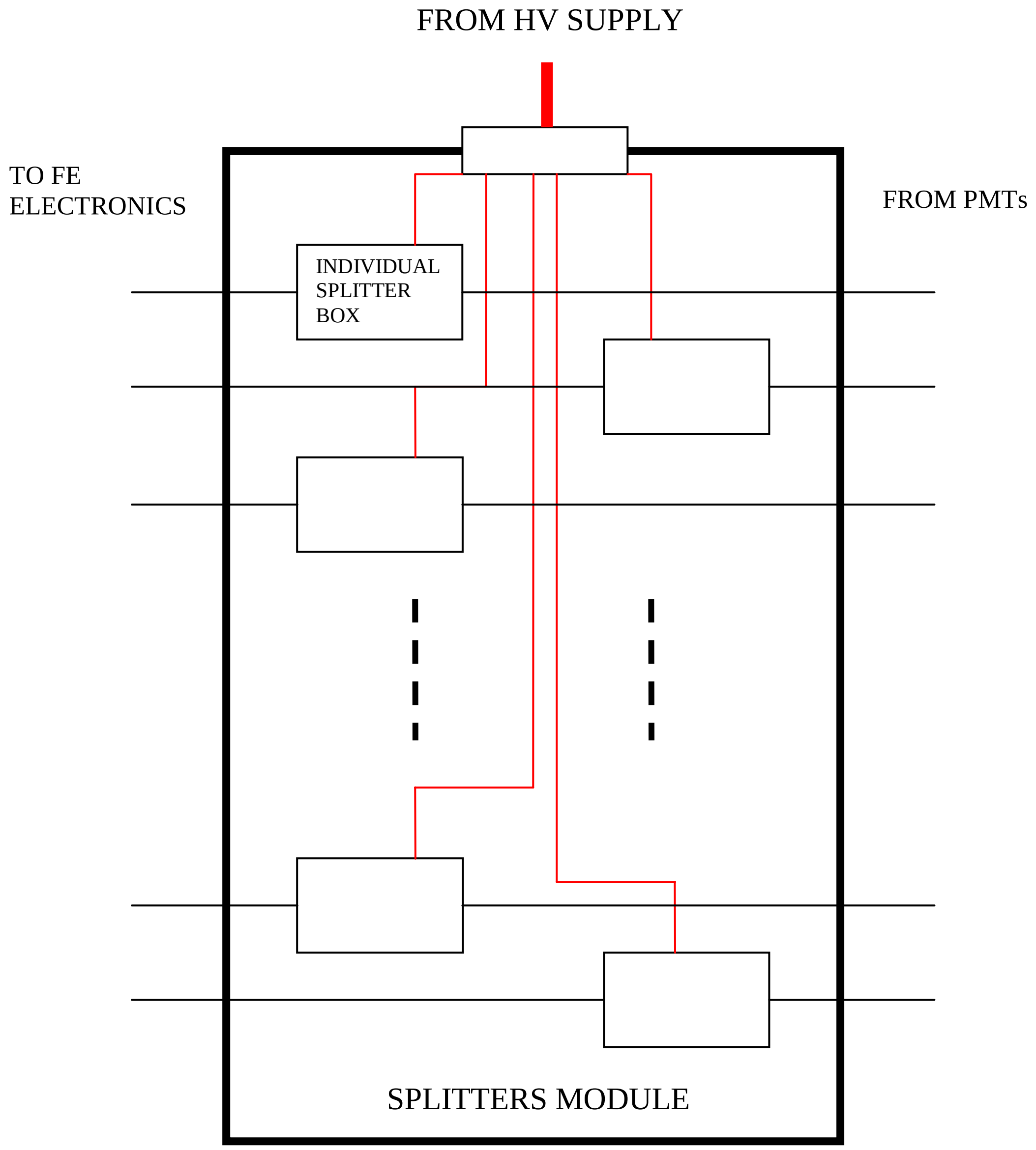


Figure 64 : Fig.-14 Diagram of HV splitters module.

9.3.3. PMT Rate Monitor

The stability of the Double Chooz detectors is of great importance to the overall physics result of the experiment. Indeed, it is necessary that the detectors be stable over time (after calibration) to better than 0.5 %. Stability at that level cannot be just assumed and needs to be subject to constant verification.

One of the most sensitive indications of stability for a scintillation detector is the rate of single photoelectrons from the PMTs. This rate is highly sensitive to changes in the PMT gain (whether caused by high voltage, magnetic fields, PMT aging or other effects), the scintillator efficiency and light attenuation, and changes in the electronics. If the single photoelectron rate is stable, it gives confidence that many critical parts of the detector are also stable.

Initially proposed idea of the Double Chooz trigger was based on the discrimination of the analog sum of the outputs of all PMTs. In this scheme the PMT rate monitors can be implemented provided that front-end amplifier modules will provide an independent analog output for every PMT channel as shown in Fig.-15.

Rate monitor can be designed as a custom-made VME module e.g. with 8 input channels per module, and should include in the design a discriminator with DAC-controllable threshold corresponding to PMT amplitude of ~ ¼ spe, a pulse width shaper, and a counter (per channel) that can be read and reset through the VME bus. Module can provide also digital output for complementary digital trigger processor forming a trigger signal based on hit sum rather than on analog sum information. Rate monitors information can be read by DAQ on a special requests (e.g. at the beginning or every run period) or at any time intervals during the run exposition and can be combined with GPS timing.

It is necessary to decide which institution will construct this system.

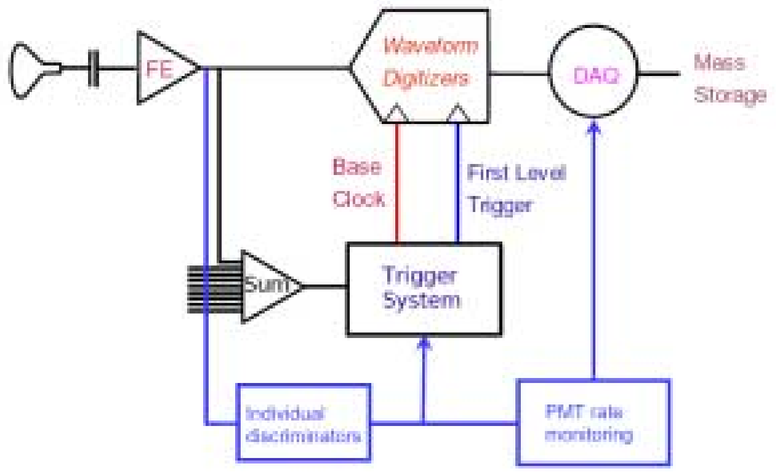


Figure 65 : Fig.-15. Schematic of a PMT Rate Monitor implementation

9.3.4. Development Plan

CAEN has agreed to lend a set of HV supply system to us for testing in August. We will measure the noise level, stability, control sequence, etc. by the system. In the current schedule, the tender for HV supply system will be open in April 2008 and we will decide the specifications by then. We have several sets of prototype HV splitter circuit and are using them for PMT tests and are experiencing the performance of the splitter. After the final vender of HV supply is decided by the tender, which takes place in June 2008, the final splitter box design will also be fixed and the mass production will start. The designing of the rate monitor is also going on. Which institute is responsible for the monitor is under discussion now. The HV supply is responsible of Japanese group and the Splitter production is responsible of CIEMAT group.

9.4. PMTs support [3300]

9.4.1. Technical performances and tolerances

Design requirements are:

- To support independently each PMT, taking into consideration all the conditions which will exist in the operation of the Double Chooz experiment. This mechanical structure should hold the PMT in two regions, a first one around the equator, and a second one at the oil-proof base. Materials to be used should be compatible with the oil, which will be present in the buffer, good from the radiopurity point of view (so to provide a negligible increase of single counting rate of PMT´s), and as light as possible.
- To be able to incorporate easily the mu-metal magnetic shielding, and a light concentrator.
- To position the centre of the PMTs with respect to the theoretical nominal location in the detector with a tolerance of 1 cm.
- To allow orientation of the PMTs so that they point to the centre of the detector, with a precision of less than 1º.

Our present proposal is shown in Fig.-16 (drawing with present baseline dimensions and a picture of our prototype assembled in one Hamamatsu 10” PMT). The system allows adjustments to cope with fabrication tolerances (up to a few millimetres) in the dimensions of the PMT´s.

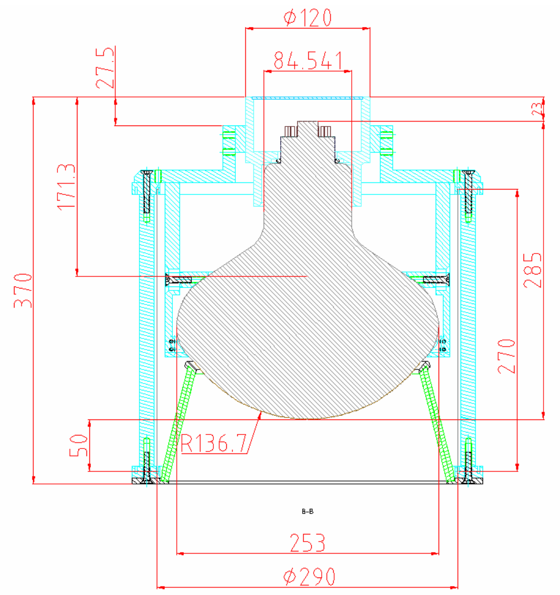


Figure 66 : Fig.-16: Drawing with present baseline dimensions and a picture of our prototype mechanical support assembled in one Hamamatsu 10” PMT.

As shown in the following figure (Fig.-17 left), one ring, and 4 vertical columns, each of them incorporating a top adjustable piece, provide the support at the level of the PMT equator. Material is acrylic. We are considering as an option that the top adjustable pieces are made of nylon or Teflon. Another option would be to have a second ring instead of these 4 top pieces. Fig.-17 right shows the clamp, also made in acrylics, to hold the PMT at the base level.

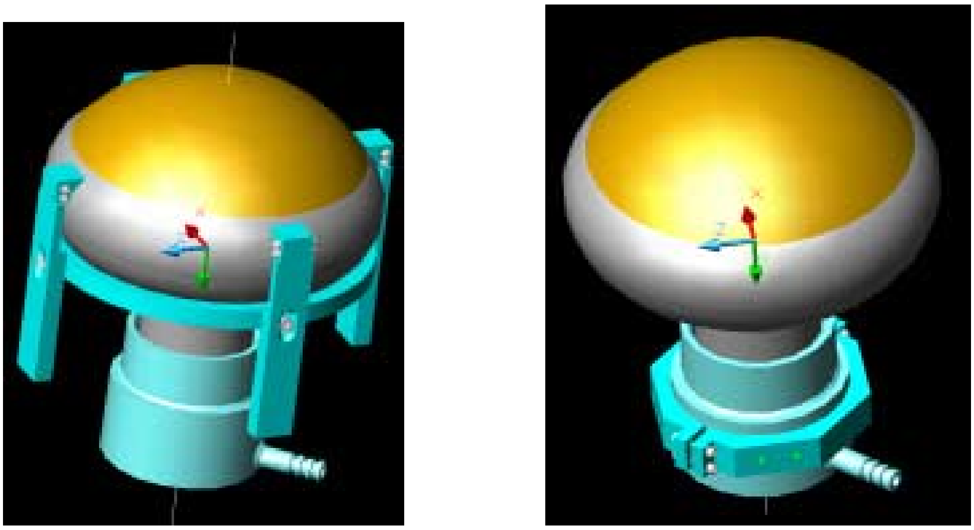


Figure 67 : Fig.-17: Sketch of the pieces holding the PMT at the equator (left) and at the base level (right).

Both supports are connected by intermediate L shape acrylic pieces acting as the main support of the PMT mechanical structure. On these pieces, the columns of the first support and the clamp of the second support are attached as shown in the next figure (Fig.-18).

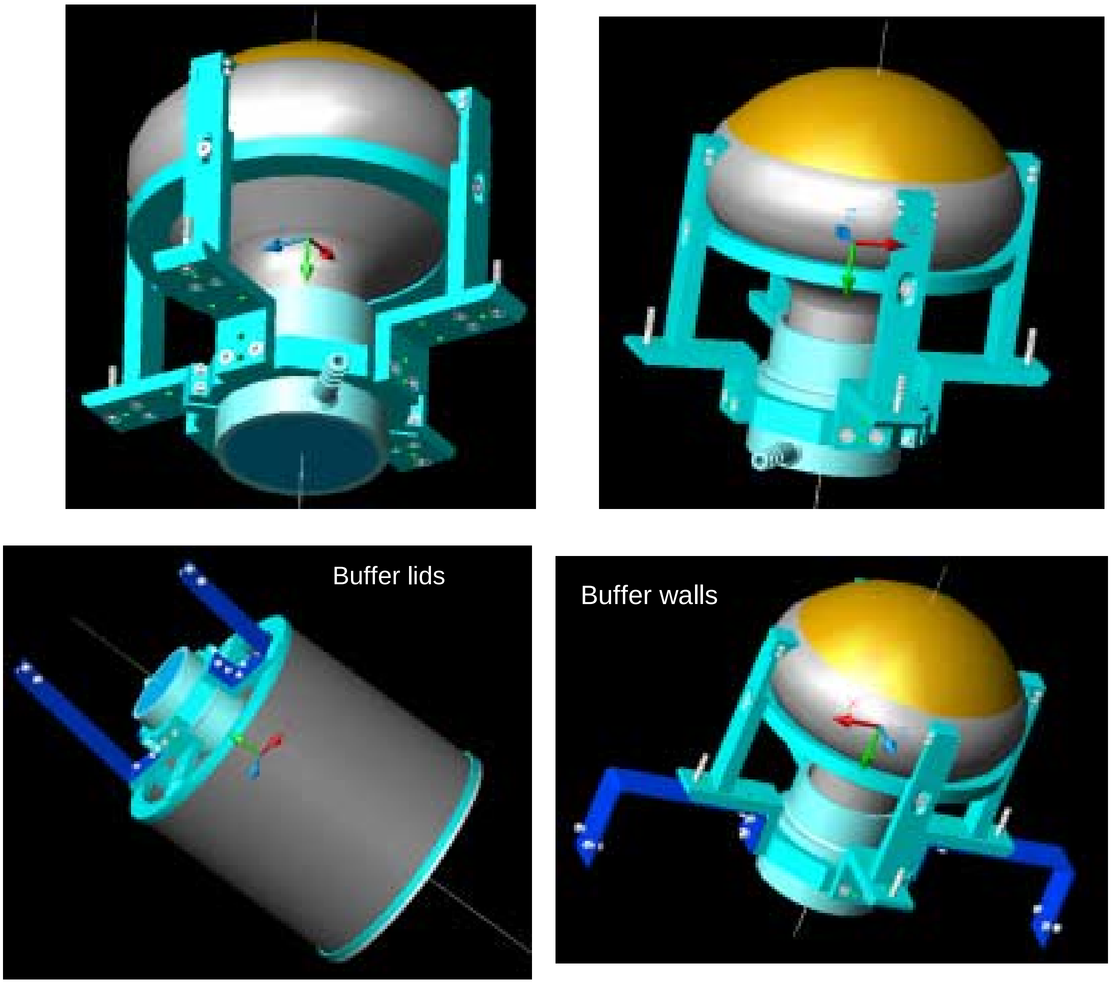


Figure 68 : Fig.-18: Assembled mechanical support system including L and U pieces

The PMT support structure is fixed to the buffer walls by intermediate U shape inox pieces (two per PMT). The shape of the U pieces (black blue) is different for PMTs at the side buffer walls and for PMT´s at the top and bottom lids (as also shown in Fig.-18).

Materials used:
As already mentioned we will use acrylic GS 233 (similar to the target and gamma catcher vessels) and inox 304L materials (similar to the buffer walls).

Estimated total weight:
The design is not yet optimized for making it as light as possible. At the present time it is in the range of 2 to 3 kg (acrylic pieces+ stainless steel pieces+ stainless steel screws)/PMT.

Radioactivity of materials:
The materials to be used will be tested, but no problems are expected since similar ones will be used in the buffer walls (stainless steel) and gamma-catcher (acrylic).

Compatibility of materials:
No problems are expected either concerning compatibility with oil in the buffer, for the same reasons as before. However, tests will also be made.

9.4.2. Mechanical Interfaces:

With the Buffer Vessel

The PMT support structures will be attached to stainless steel vertical L profiles on the cylindrical buffer wall, through the U stainless steel pieces, and to stainless steel ring structures on the buffer top and bottom lids, also through U stainless steel pieces (see below). The following figs show the basic distribution of the PMTs on the buffer. Total number is:

270 PMTs (cylindrical walls) +60 PMTs(top lid) +60 PMTs(bottom lid)=390 PMTs

There will be 9 rings in the side walls, each one with 30 tilted PMT´s pointing to the center of the detector. Three different configurations of holes in the U pieces will allow to achieve the 9 different orientation tilting angles in the PMTs of the side cylindrical buffer wall. The distribution of the PMT´s in the lids will have 4 rings (divided in 6 sectors) and will require 8 different shapes for the U pieces (see Figs.-19 and 20).

The final precise location of the PMT´s in the buffer walls is presently under study by Montecarlo simulations in order to improve the uniformity of the detector response. This means that there might be minor changes to the basic distribution shown in the next figures.

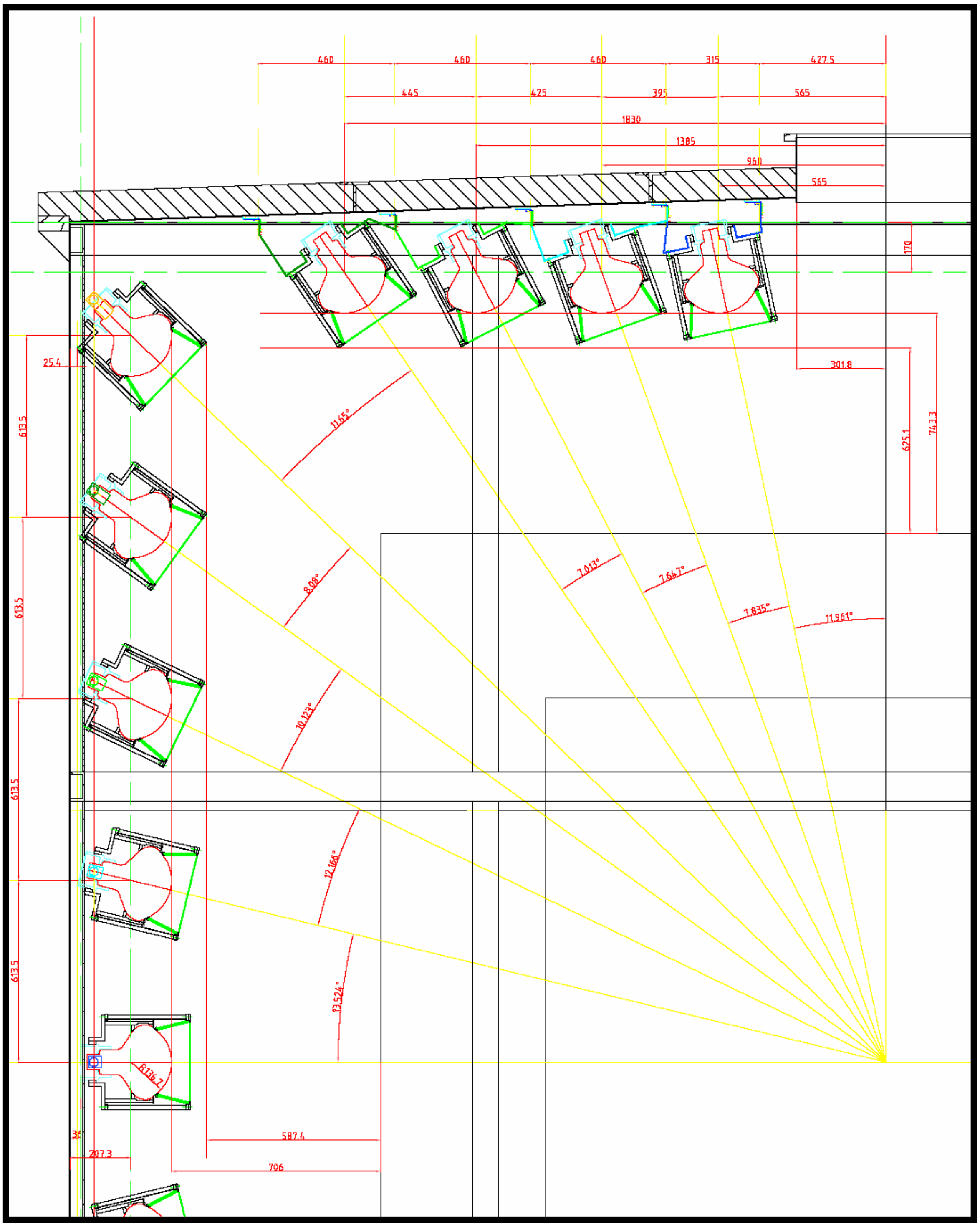


Figure 69 : Fig.-19: Distribution on PMT´s in the buffer walls

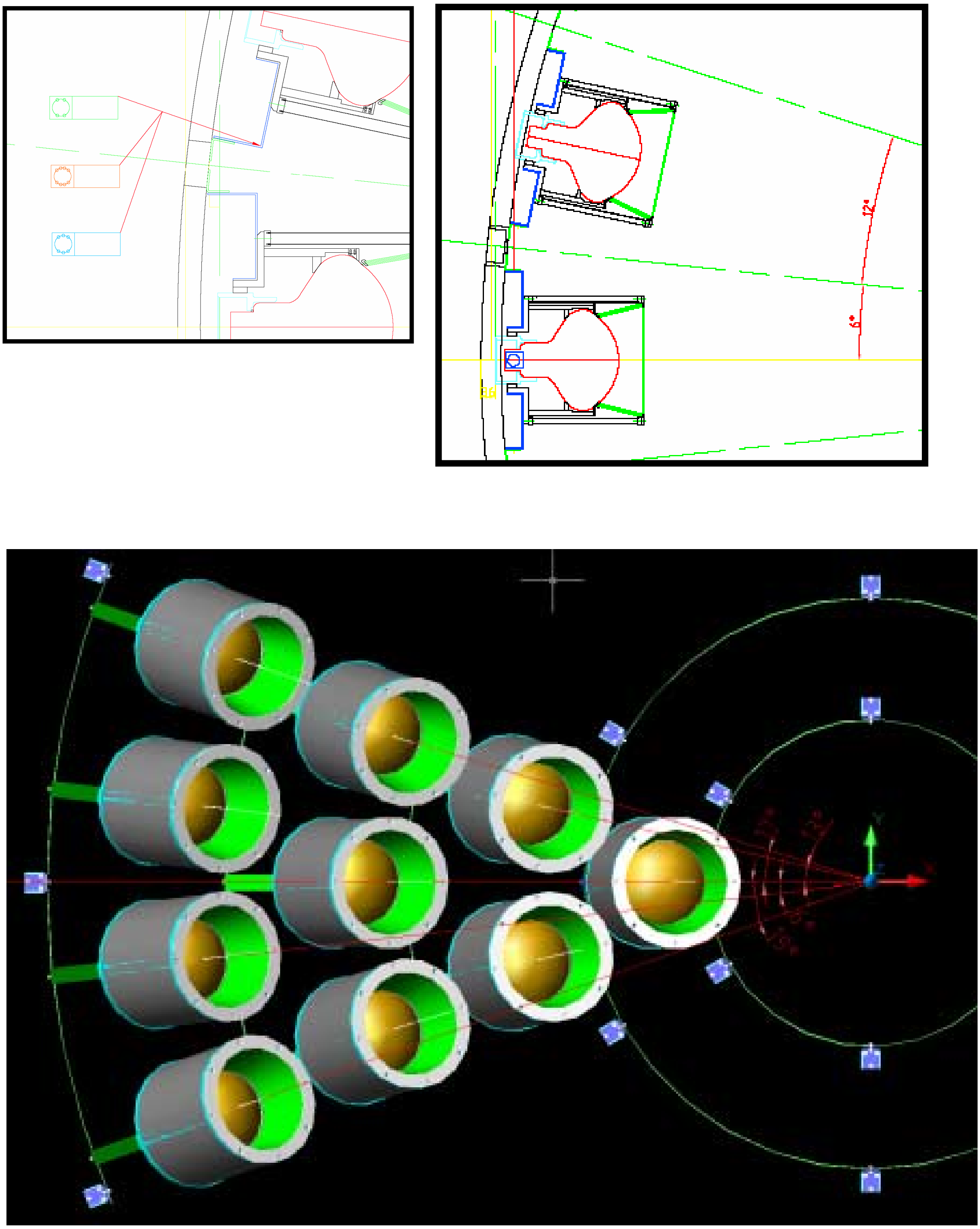


Figure 70 : Fig.-20: Distribution of the PMTs in the cylindrical walls, on the lids

The following figure (Fig.-21) shows the distribution of the L support profiles on the cylindrical area of the buffer. A total of (30+30) x 3=180 L profiles will be needed. The installation of these profiles will require M6 screwed holes in the U circumferential buffer profiles. This procedure is simpler than welding the L profiles, and allows adjusting later their position within a few mm if so required to compensate possible tolerances in the buffer fabrication. From the radiopurity point of view, stainless steel screws are also preferred to welding. Some special tooling might be required for the purpose of making these holes.

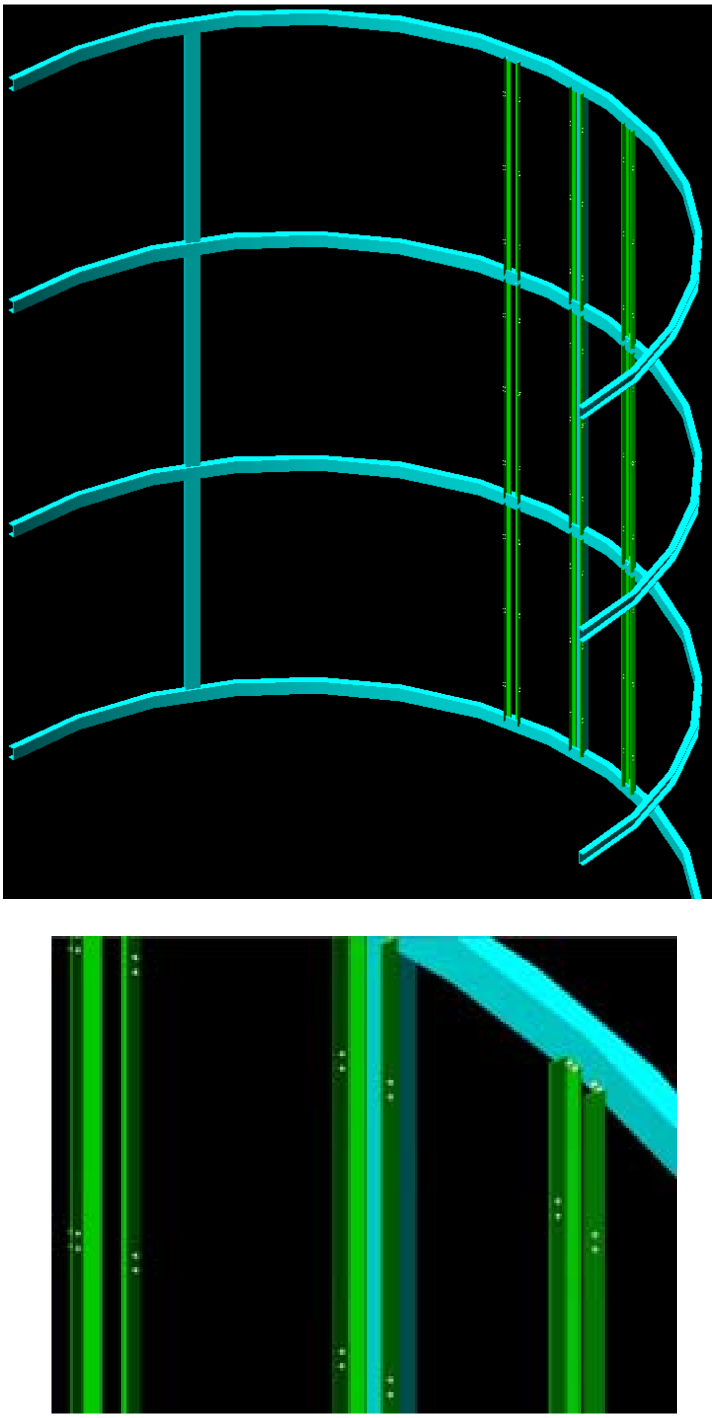


Figure 71 : Fig.-21: Rail distribution in the buffer cylindrical walls

Next figure (Fig.-22) shows the distribution of the support structure on the top and bottom lids of the buffer. Two complete central rings will be required, as sketched. And there should be additional 3 x 6 = 18 ring sectors. We believe that this could be made by welding 66+66=132 pieces (sky blue) on the buffer lids which could then be used to attach these required rings. Special tooling will likely be needed for this, and this should be studied.

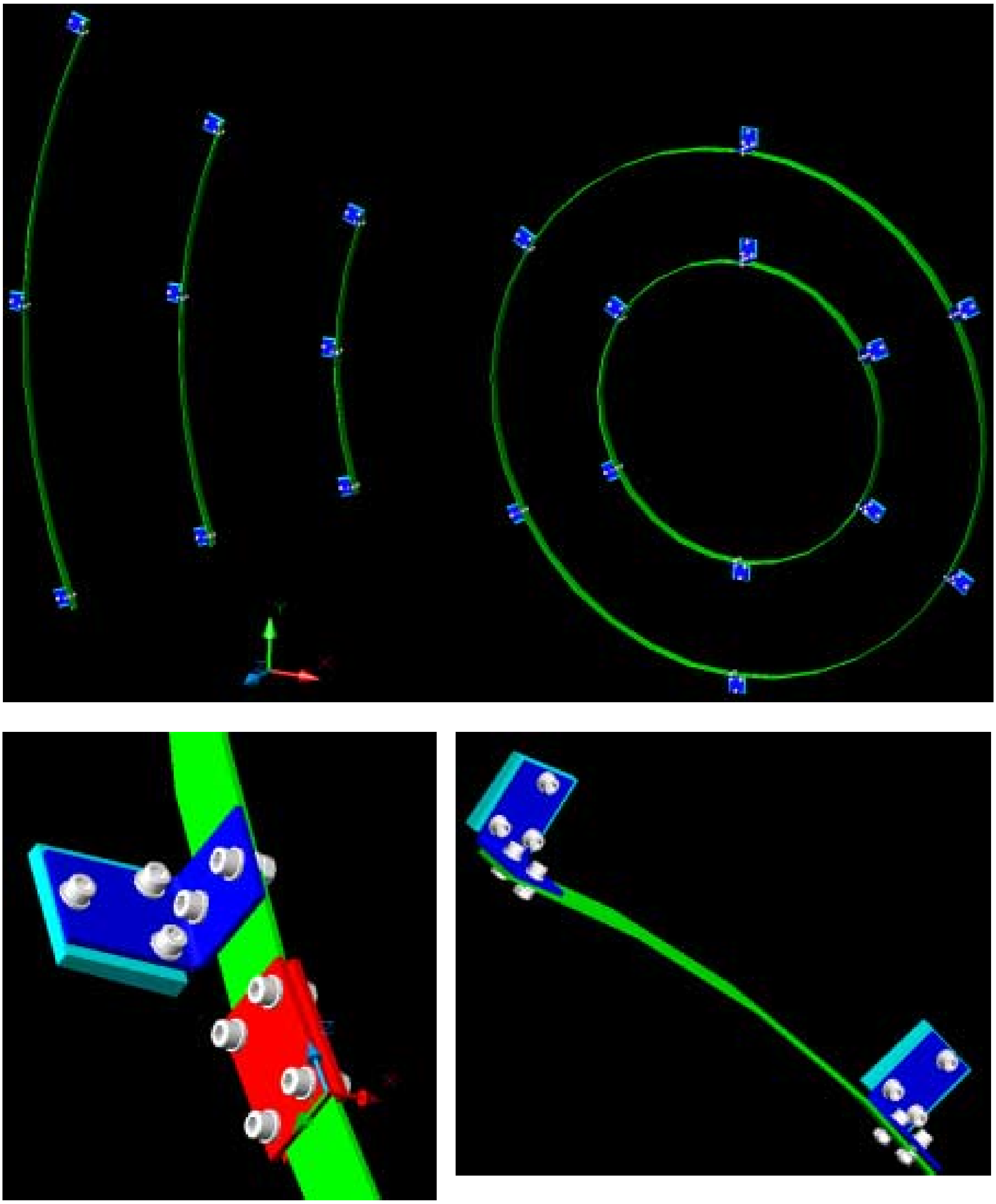


Figure 72 : Fig.-22: Rail distribution on the buffer lids

Next set of figures (Fig.-23) show the distribution for the 30 x 9 = 270 PMTs on the buffer cylindrical side walls.

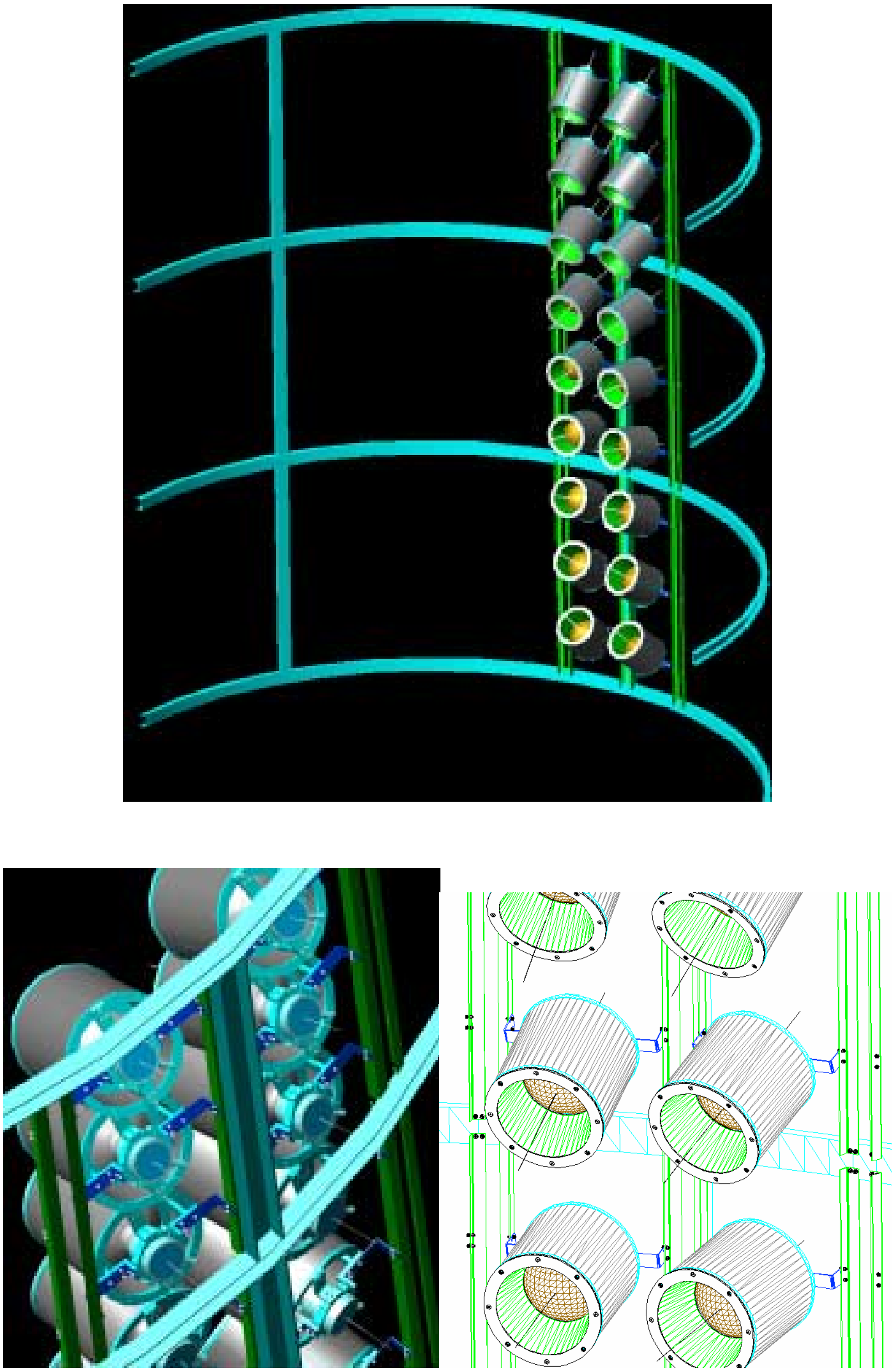


Figure 73 : Fig.-23: Sketch showing PMT´s positioned in the side buffer walls

And next set of figures (Fig.-24) show the distribution for the 60 + 60 = 120 PMTs on the lids.

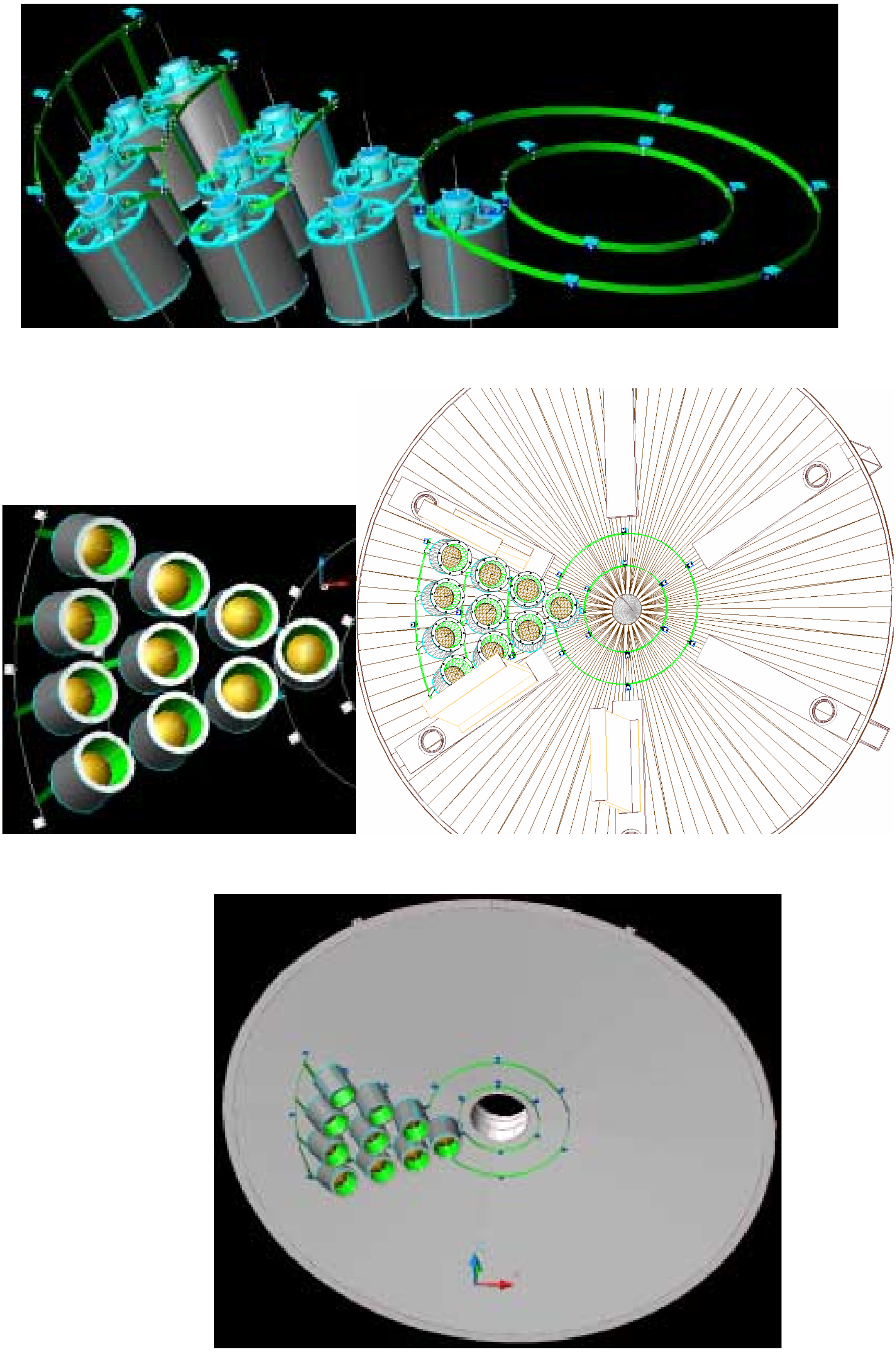


Figure 74 : Fig.-24: Sketch showing PMT´s on the buffer lids

With the Phototubes

These interfaces have been already described.

With the Magnetic shields

The mu-metal shields are attached directly to the main acrylic L pieces of the PMT support structure (see fig.-25). This attachment requires two rings and four columns as shown below. Material for rings and columns is also acrylics. A second layer of mu-metal could be incorporated if so required.

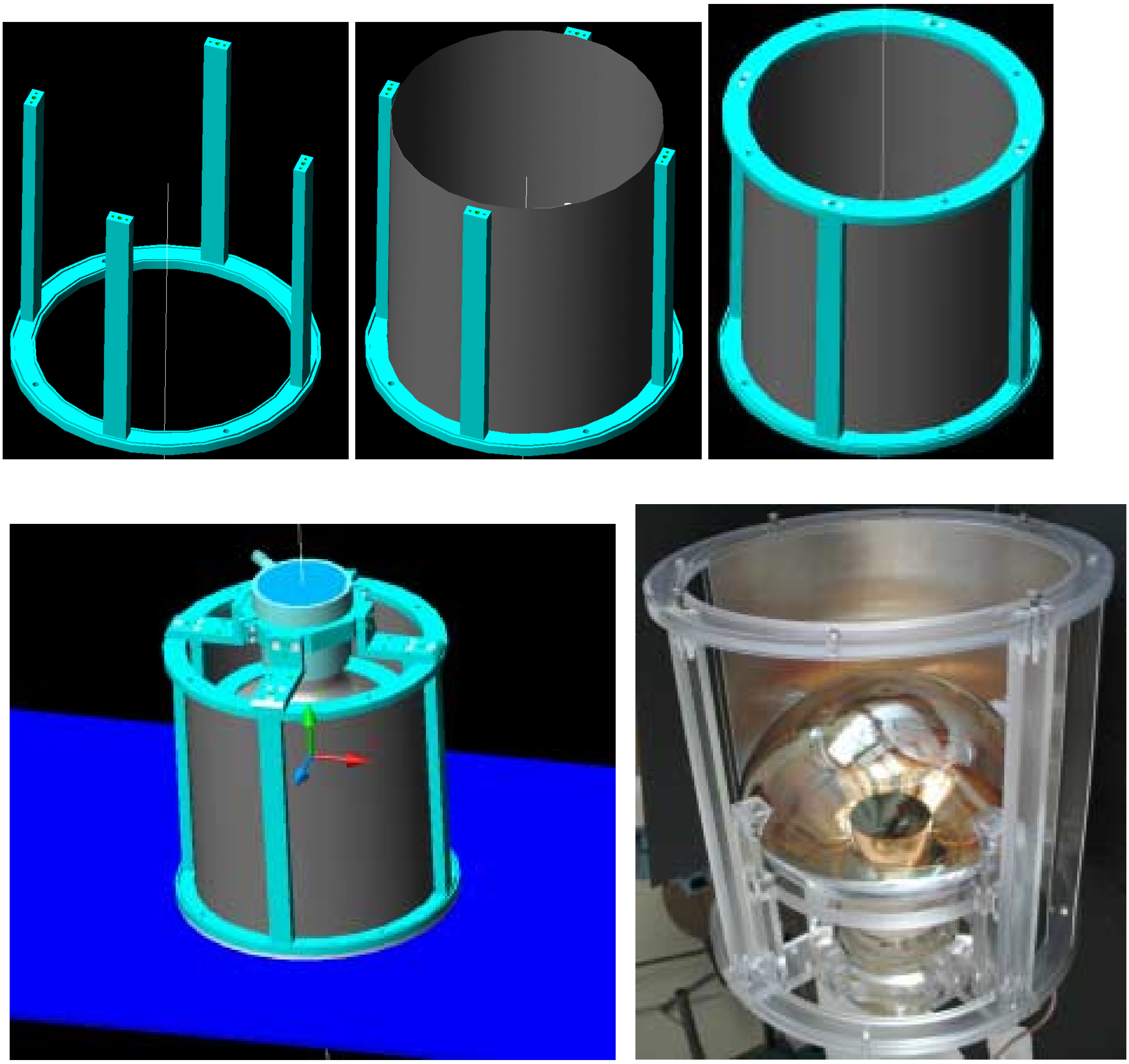


Figure 75 : Fig.-25: Sketch showing mu-metal shield attached to the mechanical support and a photo of our prototype

With the Light collector

It is attached directly to the top ring of the magnetic shield structure by four M6 screws. And it is also attached directly to the four columns (as shown in Fig.-26).

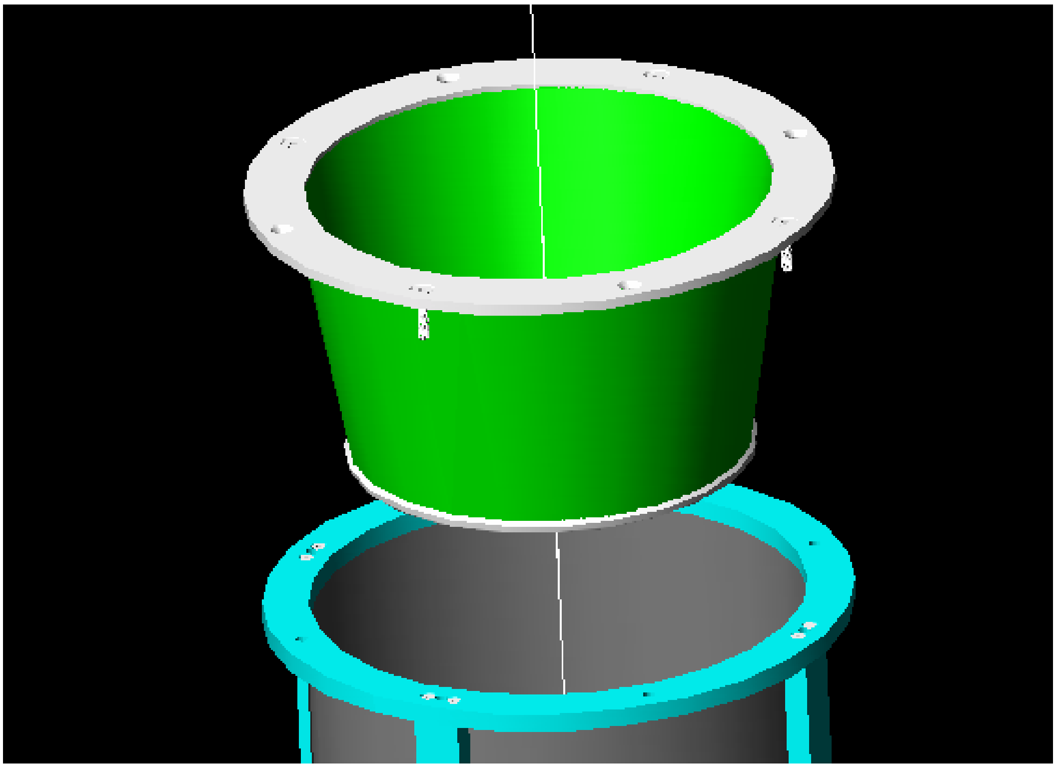


Figure 76 : Fig.-26: Sketch showing how the light concentrator would be integrated in the PMT support.

9.4.3. Chemical interfaces

Buffer liquid:

Although it will be tested, the compatibility of materials (inox and acrylic) can be considered as already proven.

9.4.4. Planning for production. Tentative schedule.

1. **Final design:** To be completed shortly after all pending issues have been defined. We expect this to happen after the TDR takes place at Chooz.
2. **Order of materials**: 4-6 weeks.
3. **Production at CIEMAT**: Our preliminary estimate is 4 months. We should evaluate the fabrication process aiming at an optimization of the production time. This process will also start shortly after the Chooz meeting, while we are waiting for the material delivery.
4. **Delivery to France**: 2 weeks.
5. **Mechanical assembly of PMTs**: This is foreseen to be made in France. The assembly procedure is explained in detail in another section of this document. The option of making some partial preassembly at CIEMAT is still under consideration. Starting time for the mechanical assembly in France will be decided once the final schedule of the experiment is more precisely known.

9.5. Magnetic shield [3400]

9.5.1. Technical performances and tolerances

As explained in section [2500], an external steel shield will cover sides, bottom and top of the detector. The steel pieces can be magnetized during their construction or manipulation and after their installation they can induced an extra B-field inside the detector to be added to the Earth magnetic field present in Chooz (B_x = 200.21 mG, B_y = -0.76 mG, B_z = 439.46 mG). To avoid this effect, the external shield pieces will be demagnetized and the magnetic field inside the detector after the complete shield installation will be measured, as already described. The goal of the demagnetization of the external steel shield will be to obtain a value of the B-field in the detector < 0.5 Gauss.

In order to be conservative, we will consider that the B-field in the PMT region can arrive up to ~1 Gauss in any direction, as a safety margin. We have checked and experimentally measured that the 10” PMTs to be used in Double Chooz are dramatically affected by B-fields much lower than 1 Gauss and the effect depends on the B-field direction with respect to the PMT.

Fig.-27 shows the variation of the Hamamatsu R7081 PMT response as a function of the external B-field. When a B-field of 500 mG is applied transversally to the PMT (X or Y axis) the PMT signal will be reduced between 20% and 60%. If the PMT is exposed to a B-field of ~1 Gauss in the transversal direction more than 80% of the signal is lost.

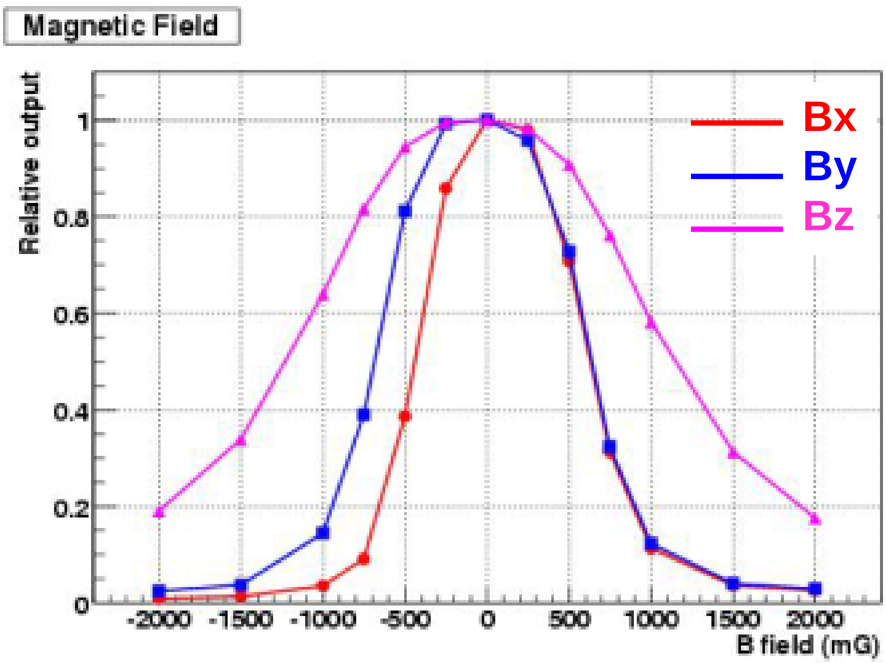


Figure 77 : Figure 27: Relative response of the Hamamatsu R7081 PMT as a function of the B-field applied in every PMT axis measured at CIEMAT laboratory.

The response of the two Double Chooz detectors located at different places must be identical. To assure that, we have to minimize all possible sources of disagreement such a difference in the effective B-field inside the detectors that can cause a different detector response. This problem cannot be solved by calibration. With the use of individual optimized PMT magnetic shields we will protect PMTs from any B-field influence in the range up to 1 Gauss.

The goal of our shielding is to keep more than 90% of the PMT signal in presence of an external B-field of 1 Gauss in any direction. The PMT shield will be a single layer cylinder with the characteristics summarized in table-4.

Material	Mu-metal from Meca Magnetic company
Construction	Cylinders will be spot welded and they will follow a heat treatment after construction at 1080ºC during 3 hours
Inner diameter	290 mm (± 1 mm)
Thickness of the layer	0.5 mm
Height of the cylinder	50 mm above the PMT top (~270 mm (± 1 mm) total height)
Estimated weight	~ 1.1 kg

Table-4: Characteristics of the proposed PMT magnetic shields.

The diameter has been chosen as the smallest one fitting inside the support structure. The height has been selected after a detailed study as a compromise between the shielding factor achieved and the loss of light collection. These dimensions can be slightly modified to fit in the final design of the PMT mechanical support. We are also considering the possibility of using "supermimphy" material instead of mu-metal. It will mainly depend on the radioactivity measurements of both materials.

The expected attenuation factor has been measured with a prototype of the same material as the proposed one, same layer thickness, 280mm diameter and 305mm height. Figs.-28 show the attenuation factor as a function of the B-field applied transversally to the cylinder. For 1 Gauss the shielding factor is ~37 in the center of the cylinder, which corresponds to 27 mG. The variation of this factor as a function of the longitudinal distance is shown in fig.-29. If we place the PMT at a distance of 5 cm from the end of the mu-metal cylinder, the photocathode area will be exposed at B-fields between 40-100 mG, i.e. ~10-25 attenuation factors.

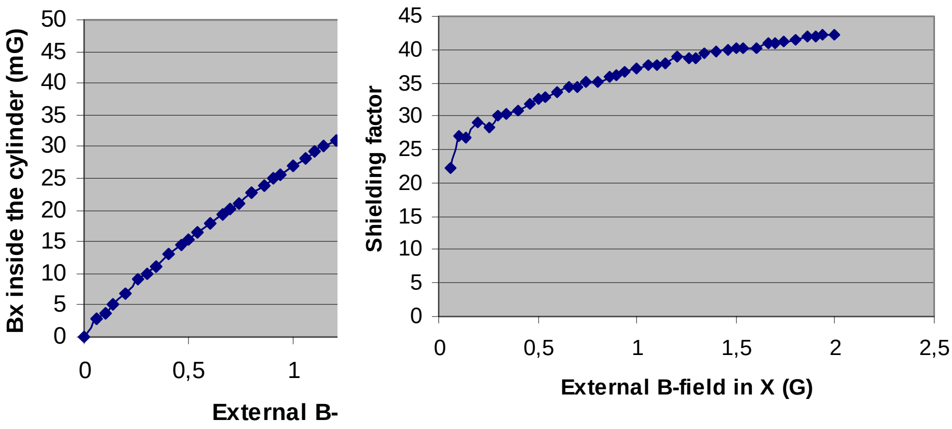


Figure 78 : Figure 28: Value of he B-field in the center of the mu-metal cylinder as a function of the external B-field applied perpendicularly to the cylinder (left) and the corresponding shielding factor (right).

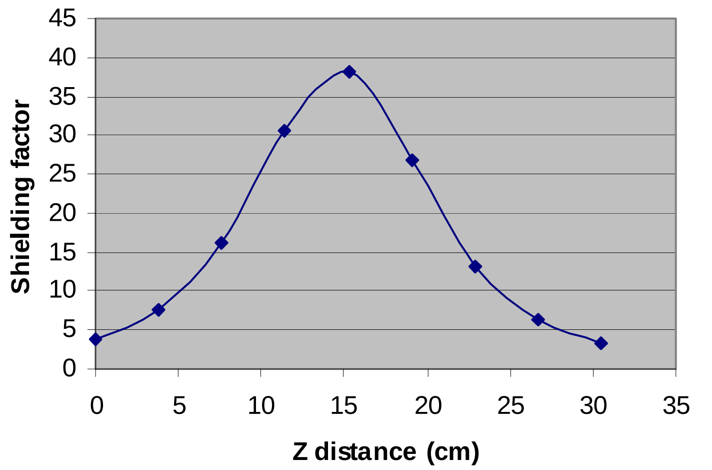


Figure 79 : Fig.-29: Variation of the attenuation factor as a function of the distance along the cylinder axis when an external field of 1 Gauss is applied perpendicularly to the cylinder. 0 cm corresponds to the top end of the cylinder.

The response of the R7051 PMT with this shield for different external B-field values has been measured and is presented in Fig.-30. The PMT top was placed at 5 cm below the top end of the cylinder. The loss of PMT signal with respect to 0 B-field is always less than 5% for 1 Gauss external B-field, proving that we achieve our requirements.

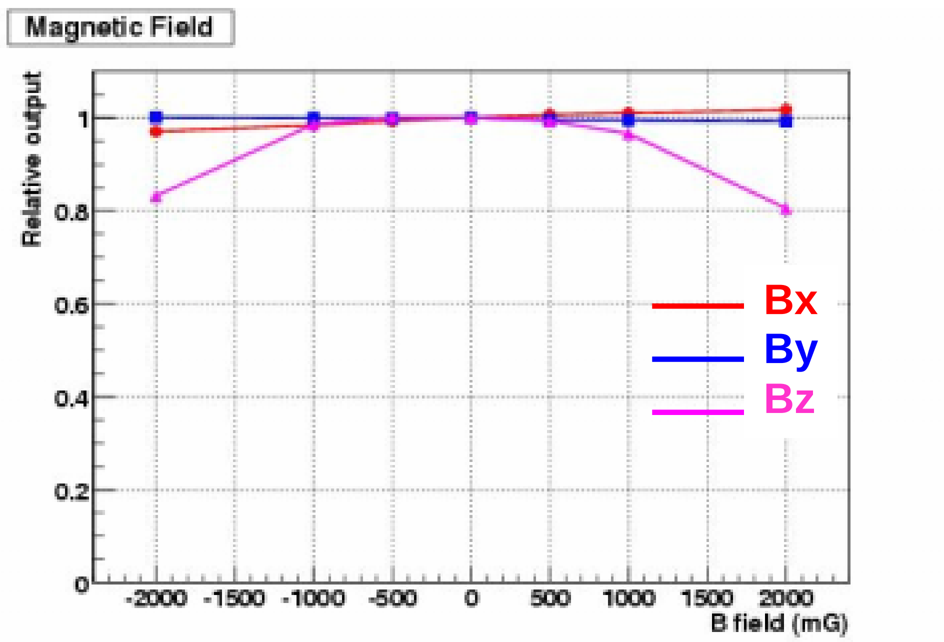


Figure 80 : Fig.-30: Relative response of the Hamamatsu R7081 PMT with mu-metal shield as a function of the B-field applied in every PMT axis.

9.5.2. Mechanical interfaces

PMTs supports

The mu-metal cylinder will be inserted in two acrylic rings placed at the top and bottom ends of the cylinder. Four acrylic columns between the two rings will provide rigidity to the system. The mu-metal layer support structure will be directly attached to the main acrylic L pieces of the PMT support.

Phototube

Mu-metal cylinders can be assembled independently of the PMT´s. Mechanical interface between both is provided by the PMT mechanical support structure.

Light concentrator

It is attached directly to the top ring of the magnetic shield structure.

A sketch of the PMT magnetic shield inserted in the PMT mechanical structure is shown in fig.-25 of the PMT support section.

9.5.3. Chemical interfaces

Buffer liquid

A test of compatibility between mu-metal and buffer oil is being performed. No major problems are expected.

9.5.4. Development plan

1. **Final design and material**: The current proposal has been already described. The final dimensions of the shield will be frozen once the whole PMT system is fixed. In order to choose the material (mu-metal or supermimphy), a test of radiopurity is being performed.
2. **Order of material**: 1-2 months
3. **Production at CIEMAT or by an external company**: ~3 months
4. **Quality tests:** a fraction of the mu-metal cylinders will be tested to verify the expected properties of the material. A dedicated set-up with 3 Helmholtz coils providing a 3D B-field up to 4 Gauss and a 3-axis magnetometer will be prepared for this purpose.
5. **Delivery to France**: 2 weeks
6. **PMT system assembly**: procedure already described in the PMT support structure section.

9.6. Light Concentrators

9.6.1. Motivation

The principle motivation for light concentrators is to dramatically increase the light collection of PMTs by up to ~70%, using an inexpensive and well-understood approach. This would lead to a 25-30% improvement in energy resolution, which would lead to an improved determination of energy scale and neutron window selection via use of the neutron peak. It would also improve the ability to achieve a “zero-threshold” trigger in the presence of radioactive backgrounds, which is a regime where changes in energy resolution can have a dramatic effect. The ability to study characteristics of spectral shape for various signal and background regions would also be enhanced. A similar level of resolution improvement is likely for event-by-event vertex reconstruction (as most algorithms tend to improve as roughly the square root of the light level). This could have important consequences for the identification of radioactive backgrounds and external neutrons as well as for studying various detector asymmetries and verifying calibration source positions via reconstruction. The overall increase in gathered light would also aid any pulse shape analysis of events.

9.6.2. Technical Performance

The basic concentrator shape proposed is similar to that of a truncated Winston Cone and is based on a scaling of the design used for SNO (fig.-26). The lower, inner radius of the concentrator (nearest the PMT) is set by the active photocathode area, over which the detection efficiency is sufficiently uniform. This, together with the desired angular acceptance, defines the basic shape of the concentrator needed to maximise the collection power uniformly over the acceptance and minimise any reflections back into the detector. The angular acceptance is thus designed to be relatively uniform as a function of angle, truncating fairly abruptly at approximately 50 degrees (fig.-27). This angle provides a reasonable compromise in terms of solid angle acceptance for the gamma-catcher given the cylindrical geometry (fig.-28).

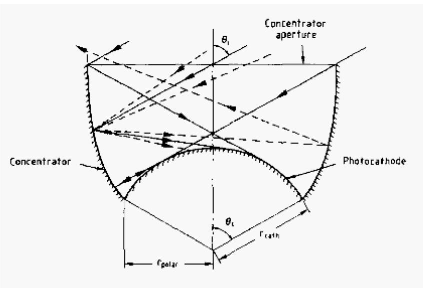


Figure 81 : Fig.-26: Basic optical design used for concentrators.

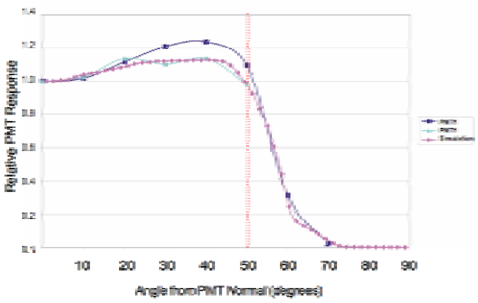


Figure 82 : Fig.-27: Angular acceptance measurements and calculation for SNO concentrator of same design

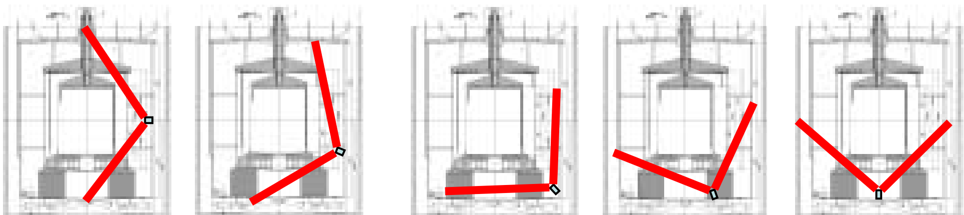


Figure 83 : Fig.-28: Approximate coverage of DC geometry for concentrator acceptance angle of 50 degrees

The DOGS package has been used to verify the predicted impact of such concentrators on light collection and energy resolution in the context of the Double Chooz geometry. This confirms the expected increase in light collection and the corresponding improvement to energy resolution, as shown in figure 29. These are in agreement with both analytical estimates and independent simulations. One side-effect is that the use of concentrators tends to accentuate the non-uniformity in total charge to some extent for events in different regions within the target volume. This is shown in figures 30a & 30b as a function of cylindrical radius r for different z displacements, as defined by the coloured lines. Dotted lines indicating the size of a ±5% variation are also given for scale. However, there are several ways in which very good uniformity can be restored in this volume through simple modifications of the energy estimator, such as by eliminating PMTs with large charge or by correcting the total charge based on a calculated charge asymmetry parameter (see figures 30c & 30d). Furthermore, detector uniformity is of most relevance near the edge of the target volume, where the size of any additional variation due to concentrators is much smaller. Therefore, this is not expected to have any significant negative effect on the neutrino signal, while the improved energy and spatial resolution will lead to clear improvements. For regions within the gamma-catcher, which will be principally used for better capturing the neutron signal, the uniformity is somewhat worse (for bare PMTs as well). Once more, simple corrections can be applied to recover very good uniformity. However, even without such corrections, this is not anticipated to affect the selection window for neutron identification in any significant way, as it will only lead to a slight broadening of the neutron signal for some fraction of the events.. Indeed, a much bigger effect here will be from the occasional photons not interacting in the gamma-catcher, thus giving arise to a 100% variation in visible energy deposition.

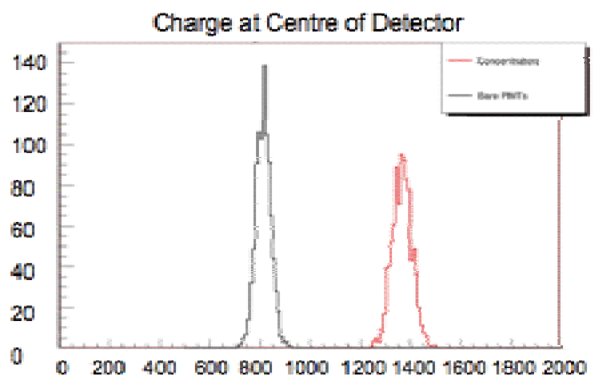


Figure 84 : Fig.-29: Histograms of summed charge for light generated by a 4 MeV electron at the centre of the Double Chooz detector, comparing cases both with and without concentrators.

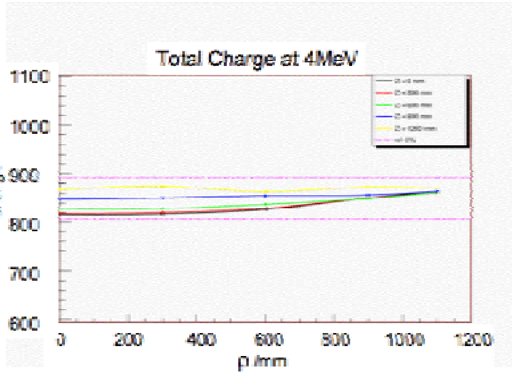


Figure 85 : Fig.-30a: Uniformity for bare PMTs to total, summed event charge as a function of position within target volume.

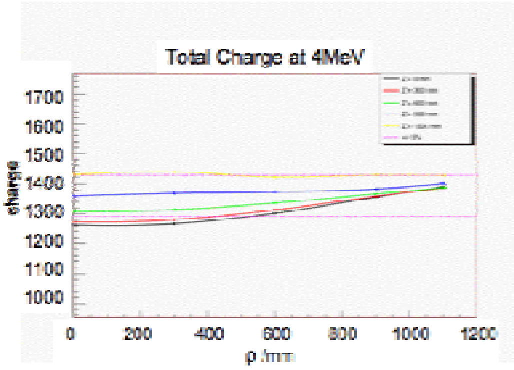


Fig.-30b: Uniformity with concentrators to total, summed event charge as a function of position within target volume.

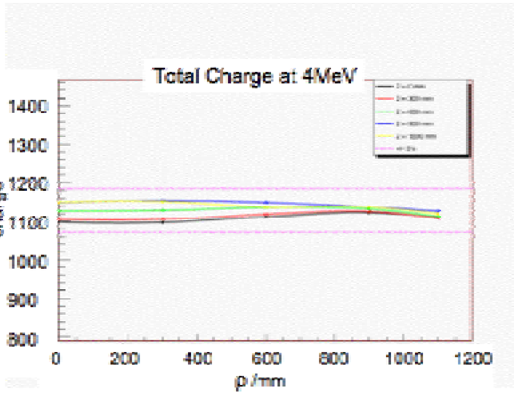


Fig.-30c: Uniformity with concentrators to summed event charge after subtracting the 5% of tubes with greatest charge.

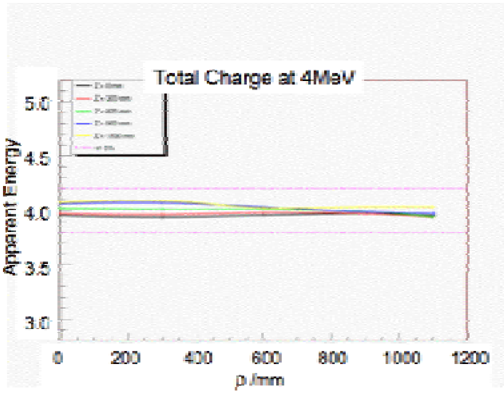


Fig.-30d: Uniformity with concentrators to total, summed event charge after correction using non-uniformity of event charges.

9.6.3. Mechanical Interface

The concentrator is being designed to fit inside the magnetic shield and is being integrated into the mechanical PMT support in cooperation with the Madrid group. The concentrator will have a non-reflective rim at the top (furthest from the PMT) of width 2 cm such that it can be fastened to the section of the PMT support structure which will also hold the magnetic shield (see fig.-31). A gap of approximately 5 mm will be present between the bottom section of the concentrator and the PMT surface to allow the flow of liquids and eliminate trapped air bubbles. Simulations indicate that such a gap will not noticeably affect concentrator performance and can be adjusted, if needs be, using additional spacers at the point of attachment below the rim.

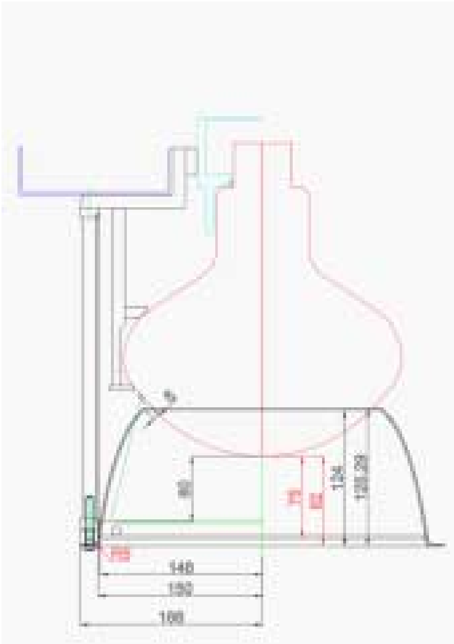


Figure 86 : Fig.-31: Mechanical interface of concentrator with PMT support/magnetic shield.

9.6.4. Chemical Interface

In order to minimize any possible interactions with the buffer liquid and the effect of any potential deterioration of the reflective surface with time, the intention is to seal the reflective surface in acrylic (with which the buffer liquid must already be compatible), thus avoiding physical contact of this surface with the liquid. Nonetheless, accelerated ageing tests are being, and will continue to be, carried out at Oxford on such possible constructions. In addition, samples will be sent to appropriate groups within Double Chooz in the near future for further tests as we better define these constructions and the specific materials of interest.

9.6.5. Development Plan

Two different approaches for encapsulating a reflective concentrator surface are currently being considered. Both involve the use of vacuum moulding to produce the basic concentrator shape using thin sheets of acrylic. The first is to produce two, nesting bowl shapes. The inner form is then back-aluminized and then inserted into the outer form, thus sandwiching the reflective layer. The two forms are then sealed together at the edges using appropriate acrylic glue, potentially together with separately machines acrylic rings at top and bottom, which match the concentrator diameters. A prototype for this approach has already been produced (fig.-32). The process of manufacturing this has led us to a better understanding of the necessary treatment of various interfaces and how to improve the mould production used for the acrylic forming. The resulting prototype has reasonable characteristics, though aspects of the production are labour-intensive and require particular care. However, we are confident that this approach could be made to work in principle.

Figure 87 : Fig.-32: Prototype concentrator for approach using two nested acrylic forms.

A second approach, on which we are now concentrating effort, involves the production of just a single back-coated form, with the reflective layer sealed by an acrylic-based protective epoxy that is sprayed on following aluminising. This would simplify production substantially. Accelerated ageing tests are currently under way to study the robustness of this approach and, so far, these tests look very promising, with no evidence of deterioration. A new vacuum mould was machined in Oxford and the resulting prototype concentrators look very encouraging. Final refinement of these is in progress.

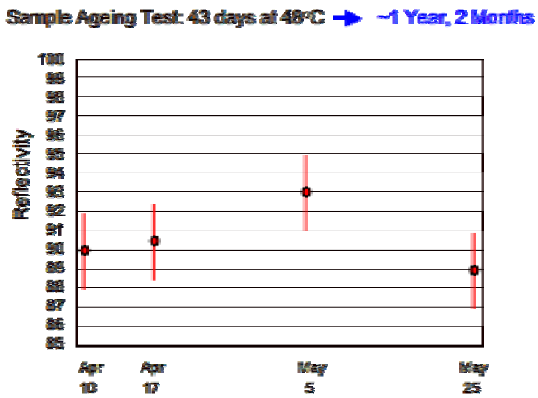


Figure 88 : Fig.-33: Results of preliminary accelerated aging tests on aluminium-coated samples

9.7.TEST, Delivery Assembly, Installation Scinarios

Fig.-2 shows detailed work schedule for the far detector, regarding the work for PMT test, delivery, mechanical assembly and installation, including planned man power. If the budget request is approved in October, the tender for PMT starts in November and the PMT production starts in January, 2008. 100PMT will be delivered to the test facility in Japan every month. It continues for 4 months. After the test and tuning the HV, the 100PMT will be shipped to France. The first batch of PMT will arrive at France in March 2008. In France the receiving test takes place at the rate of 100PMT/mo. The preparation for the accepting test will start in the fall 2007 by a PD hired by Saclay. The mechanical assembly of support structure, magnetic shield and light concentrator take place in May-June, 2008 along with the accepting tests. 400PMTs are once stored in a storage area and shipped to CHOOZ when the installation start in August. 2 months are expected for the installaion. Saclay also hires a PD for PMT group activity who stays in France and prepare the accepting tests. CIEMAT can send two mechanical technicians and one engineer to France when it is necessary. They will be mainly in charge of mechanical assembly of PMT and its preparation. UT will send a PD from the spring 2008 to be involved in testing and installation. When PMT installation starts in August, 2008, 13~14 workers will be necessary every day for two moths period. In these period, 6~8 additional shift workers are expected to come from various institutions. Thus man power is expected to be secured.

9.7.1. Testing and HV tuning in Japan

According to the current construction schedule, we will receive one hundred PMTs from a PMT vendor and following acceptance tests will be curried out in the Japanese institutes in parallel. The items for the acceptance tests are:

i) Obtain the HV value which gives $1x10^7$ gain and compare it with the value recommended by the vendor. This HV value is used as the nominal value.

ii) Measure the peak to valley ratio. This must be greater than 2.3.

iii) Measure dark counts at the threshold which is a quarter of the single photoelectron peak with the nominal HV value. This value should be less than 8000.

iv) Measure the transit time spread which is around 3ns (FWHM). For this measurement, we are going to use a pico-second laser pulser (< 60ps width) with a wavelength of 440±3nm (Advanced Laser Diode Systems Co.).

v) Pulse shape for a single photoelectron measured by an oscilloscope is stored.

vi) Uniformity of the response, which includes QE and collection efficiency, is measured by using rotating light sources. Fig.-34 show the system for this uniformity measurements.

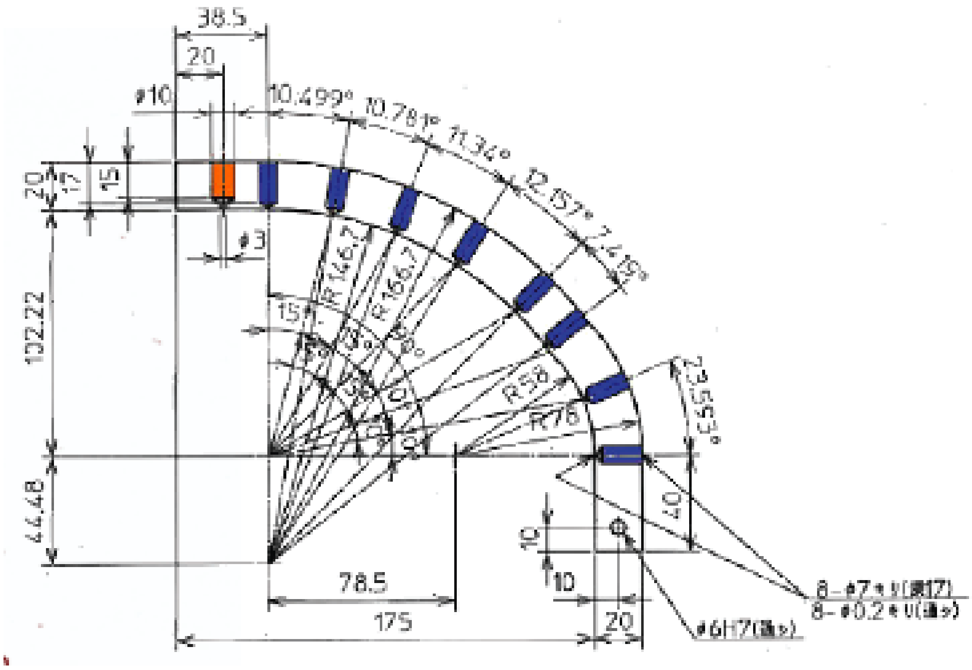


Figure 89 : Fig.-34, Uniformity measurement system.

Eight LEDs whose light intensities are adjusted to be equal (about 100 photoelectrons) are mounted on the arced arm made of black Derlin. The arm is fixed to the rotatable table. The table is rotated with a step of 15 degrees by a stepping motor. At each step the eight LEDs are flashed one after the other. Hence uniformity mapping with 8x24=192 points is curried out in less than one hour. The typical mapping result is shown in fig.-35. Stability of the LED (NSPB 500S: 465 nm) of Nichia Co. was tested and found to be stable within a few % for a day.

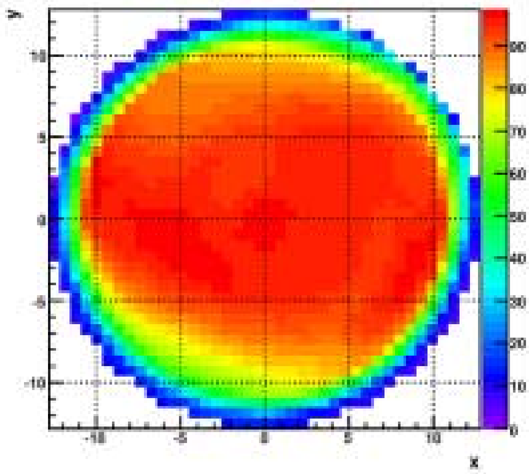


Figure 90 : Fig.-35 A sample of the uniformity measurement.

The PMT under the acceptance test is protected from geomagnetic field and stray field from the rotary table with two cylindrical μ-metals of 0.2 mmt PC (μ ~180,000) and 0.5 mmt PB (μ ~90,000). We have confirmed that this magnetic shield is enough to suppress the effect of magnetic filed less than a few %. The black box used for this acceptance test is shown in figs.-36.

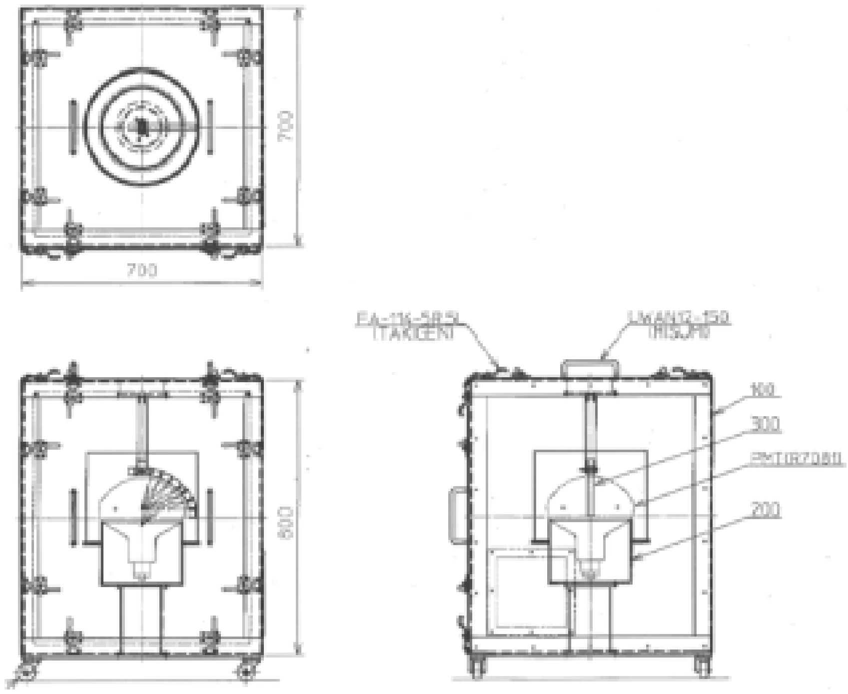


Figure 91 Fig.-36a The black box used for the acceptance test in Japan.

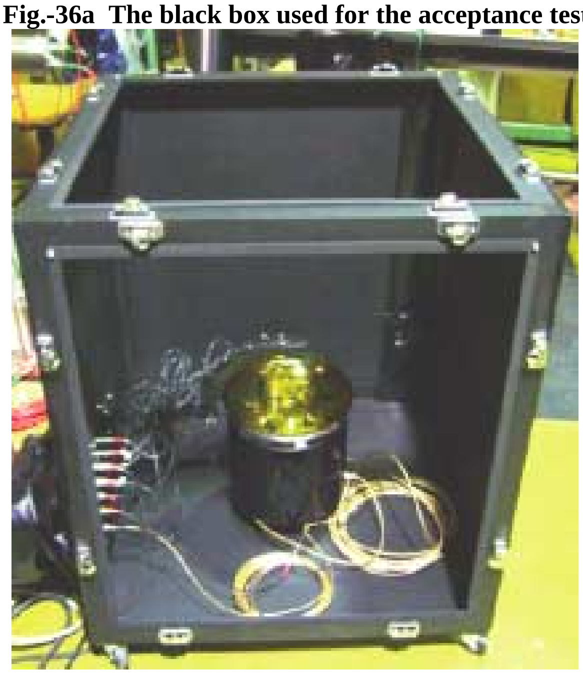


Fig.-36b Picture

The data obtained by this acceptance test are stored in a database for later use such as developing a realistic MC simulation and so on.

The work has to be performed under a clean environment and a vinyl house will be constructed in the testing room. Fig.-37 shows an example of such semi-clean room which was used when assembling the KamLAND PMTs. The vinyl used is anti-static type to prevent collecting the dusts.

Figure 92 : Fig.-37 Vinyl house used for KamLAND PMT mechanical assembly.

9.7.2. Shipping

The PMT will be delivered from manufacturer to the testing site with a carton, called 'Delivery Box', each contains 8 PMTs (Fig.-38). The size of the package is 130x120 x125H cm^3 and the weight is about 80kg including the PMTs. A PMT sits in a 'PMT Cradle' with a size of 35x35x40H cm^3. There are Styrofoam cushions in the Cradle and 5cm thick cushion bars on all the surfaces of the Cradle box. The cradle is put in an 'Inner Box' with a size of 46x46x51Hcm^3 and the Inner Box is contained in a 'PMT Box' with a size of 65x59x62Hcm^3. Between the Inner Box and PMT box are filled with heat insulator tips. The total weight of the PMT box is about 10kg including PMT with oil proof base and cable. 8PMT boxes are packed in the Delivery Box made with corrugated cardboard.

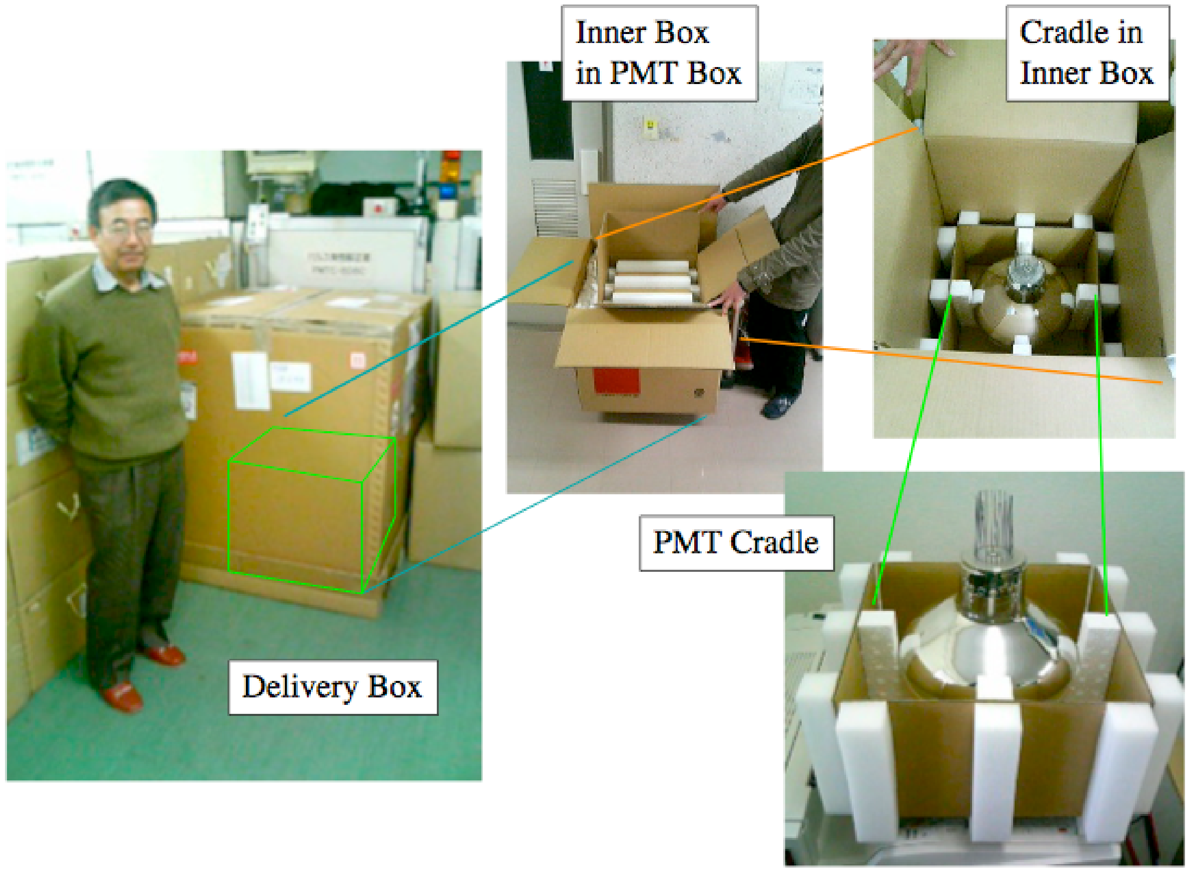


Figure 93 : Fig.-38 Package for PMT delivery

One concern was a sudden temperature change during the delivery, which may cause temperature non-uniformity on PMT and cause a stress between glass and epoxy glue due to the difference of heat expansion coefficient. A heat cycle tests were performed for the PMTs with oil proof base by HPK. The ambient temperature was quickly changed between -20 deg centigrade (degC) and 60 degC and the temperatures were kept for 3 hours. 5 cycle of the this temperature cycles were applied to 3 PMTs. Then the PMTs were kept at -20 degC for 96 hours. The PMT base was visually inspected (note that the epoxy is transparent) after the heat cycles and no change was observed. The one photo electron peak and dark rate were measured before and after the tests see if there is any degradation in electric performances. The result is shown in figs.-40 and 41 below. No degradation of the performances were observed.

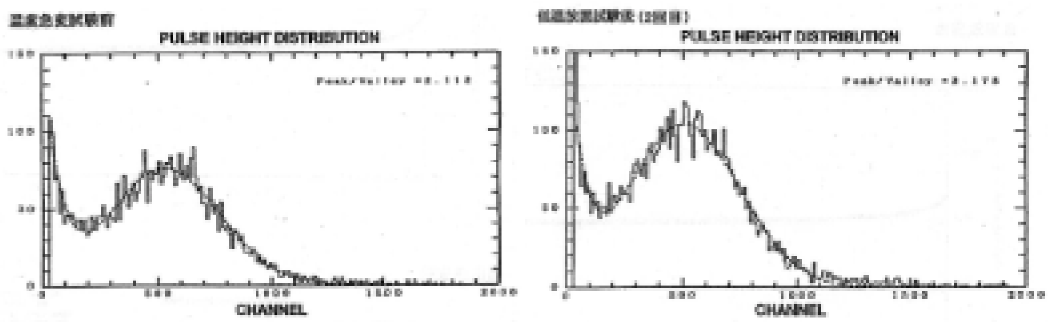


Figure 94 : Fig.-40 One photoelectron peak spectra before and after the temperature tests.

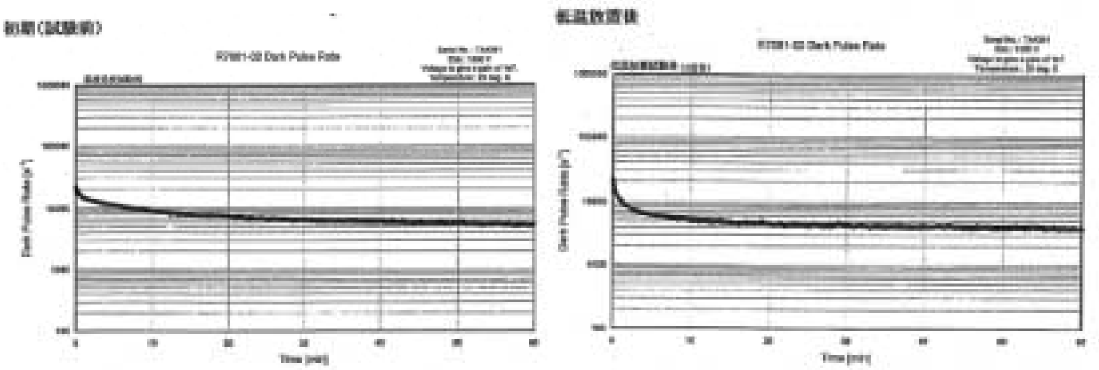


Figure 95 : Fig.-41 Dark hit rate before and after the temperature tests.

The PMT box is packed with heat insulator and the response to the ambient temperature change was measured. Two thermometer tips were put in the box and attached to the outside wall and the box were kept in a storage hut outside with no air conditioning. Fig.-42 shows the temperatures measured by the two thermometers for 4 days period.

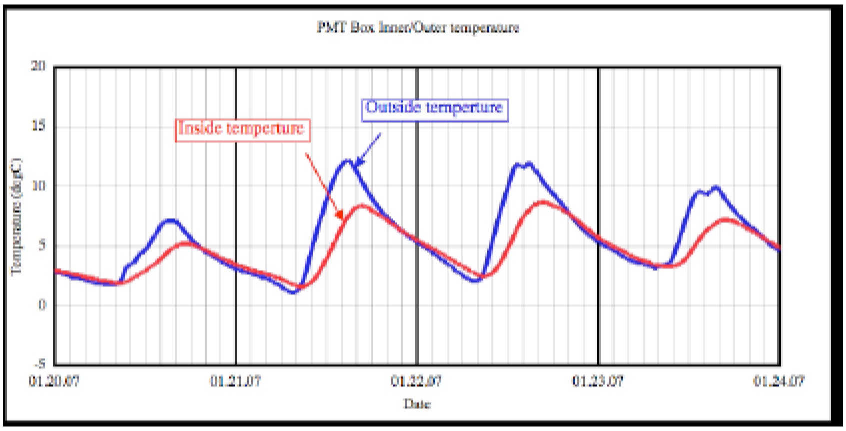


Figure 96 : Fig.-42 Temperatures of outside and inside the PMT Box.

The temperature inside the box shows about 1 hour delay with respect to the change of temperature outside. The delay is expected to become larger for delivery box because 8 PMT boxes are contained in the delivery box and only 3 faces out of 6 are exposed to outside through one more layer of card board. Even if there is a sudden temperature change outside the temperature change rate inside the box has time constant of >1hr which is long enough to equalize the temperature on PMT. From these tests and measurements, there is no danger expected due to temperature change.

The delivery box is also used to ship the PMTs by air from Japan to France after the HV setting and testing in Japan. The same box packages have been used in IceCube and Antares to carry thousands of 10 inch PMTs between Japan-USA and Japan- France. It is reported that this box is very reliable and they have not encountered problems with this. This fact ensures that mechanical vibration and shocks during delivery is tolerable level for the PMT. In France the PMTs are tested again and the support structure is attached. Then each PMT is cleaned and covered by a plastic bag and set in a contained. Then the PMT is delivered to Chooz site by trucks with air suspension for installation.

9.7.3. Testing in France

PMTs will be delivered from the vendor stored in a hard carton box in which eight PMTs are stored. Hence after the acceptance test in Japan all the PMTs will be transferred to France again stored in the same box. According to the current schedule, 100 PMTs will be shipped to France at the end of each month for 4 months period per detector.

In France acceptance tests, assembly of mechanical structure on PMT will be performed. In these tests we will not perform such detail tests done in Japan, instead, will perform tests to confirm that no damages during the transportation occurs. We are thinking about the following tests in France.

All PMTs are burned-in for more than 24 hours with a continuous flashing by LEDs at a gain of $1x10^7$ in order to reject an infant mortality. Eight PMTs are stored in a large black box as shown in Fig.-43 during this burned-in process and for the next tests. During the burned-in process, gain changes of PMTs are monitored continuously and if undergoes big changes, such as 10%, those PMTs will be rejected. After the burned-in test, we will measure the following things.

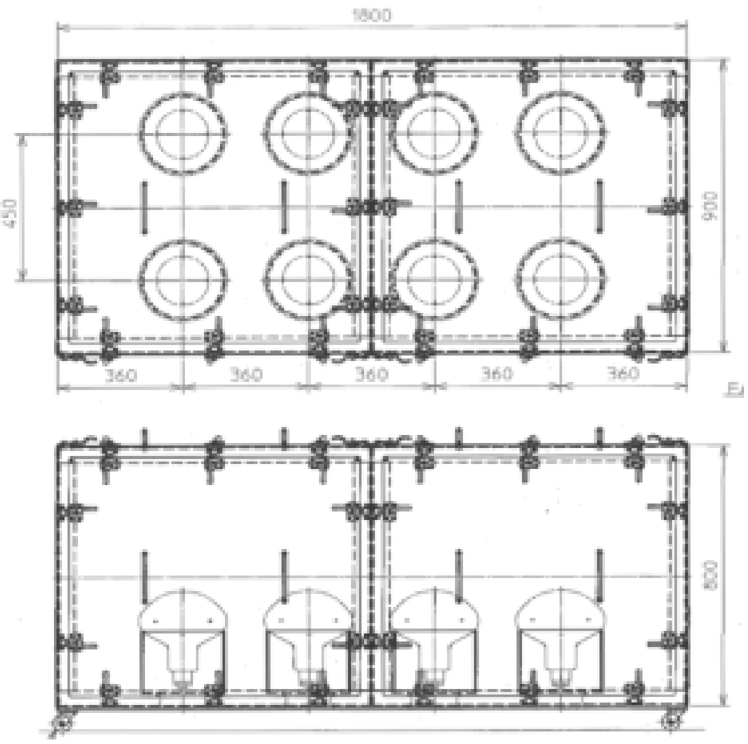


Figure 97 : Fig.-43a The black box used for the burned in process and other tests in France.

Figure 98 : Fig.-43b Picture.

i) Dark counts:

200m^2 of clean areas will be necessary for the tests, assembling and to storage 400PMTs. These area has to be kept clean to avoid dusts and a vinyl house with air conditioners will be constructed in the room. The workers will be required to put on clean suits in the area.
There are two candidates as the work place, one is at Saclay and the other is in Givet. The Saclay option has advantages that we can expect significant supports from the lab., such as mechanical and spatial, etc. and the work condition will be much better. It will be easier to keep the space during 2-year long construction period of both far and near detetctors. On the other hand, Givet option has advantages that the acceptance tests can be performed near the Chooz experimental site and possible damage of PMTs during the transportation will be minimum. Also the management of the PMT delivery to Chooz experimental site will be easier. The cost of staying will be cheaper in Givet than in Paris.

9.7.4. Mechanical Assembly of the PMTs

Mechanical technicians from CIEMAT will take care of this work which will be coordinated with the rest of PMT testing activities in France. Mechanical pieces will be sent from Madrid. Mu-metal cylinders will be also delivered there, and the same applies to the light concentrators in case the collaboration decides that we should have them installed. The mechanical assembly process includes several activities, some of them able to be done in parallel, as described next. Very simple tooling will be required in France for this assembly work. Prior to the mechanical assembly, a cleaning protocol (not yet developed in detail) will be applied to all the components, and the assembly procedure will also take into account all the considerations to ensure the proper conditions of the assembled system, from the point of view of cleanliness. Once assembled, the PMTs will be inserted in plastic bags. For the transport from the assembly place to the detector site we are planning to use the same packages used in the transport of PMT´s from Japan to France.

Appendix 2 is devoted to describe the mechanical assembly scheme we are presently considering:

A.- Sub-Assembly of the magnetic shield plus concentrator.

The whole process can be followed by looking at the series of sketches in figs.-44 and 45. A simple jig (red piece in the figs.-44 and 45), on top of an assembly table, will allow to position the four vertical acrylic columns. Then the bottom ring can be screwed. After this, we can put the structure upside down and insert the mu-metal cylinder in the bottom ring groove. The top ring can be installed, and on top of it the light concentrator can be attached. This subassembly is then completed.

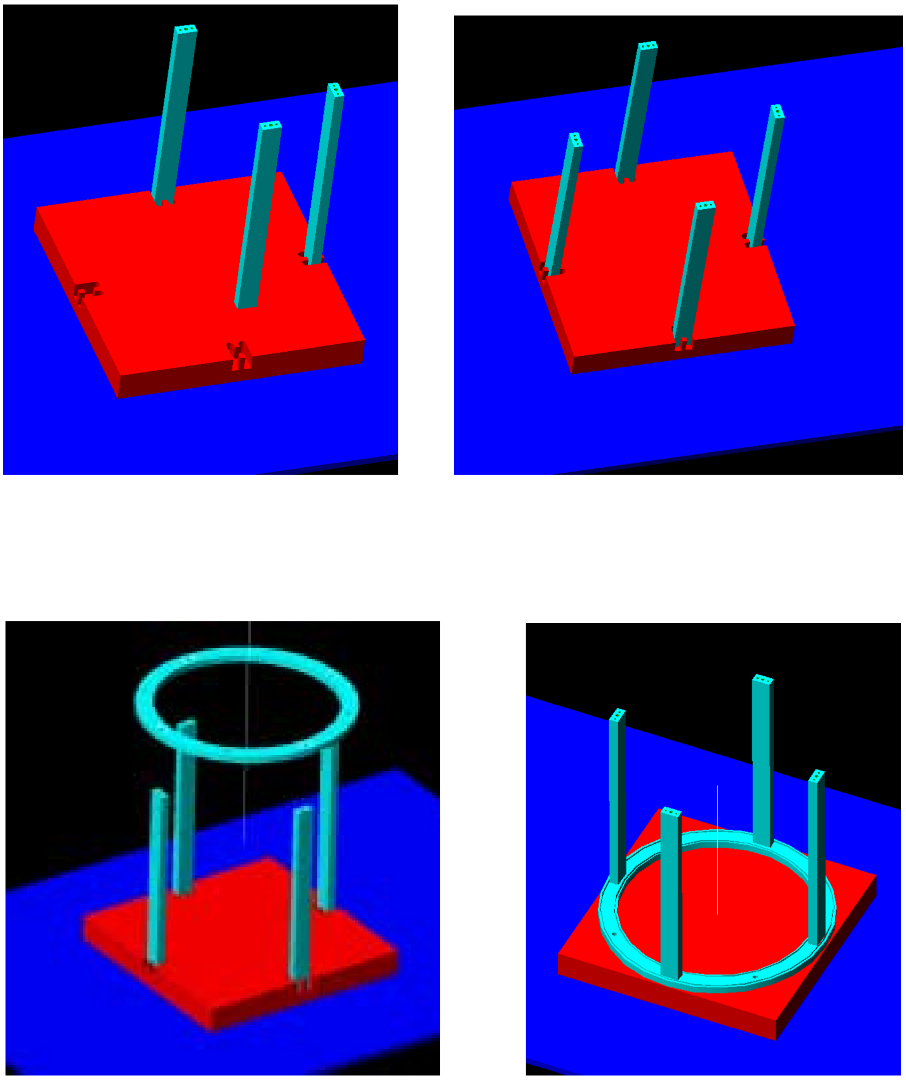


Figure 99 : Fig 44: Sequence of operations to be followed in sub-assembly A
(to be continued in Fig.-45)

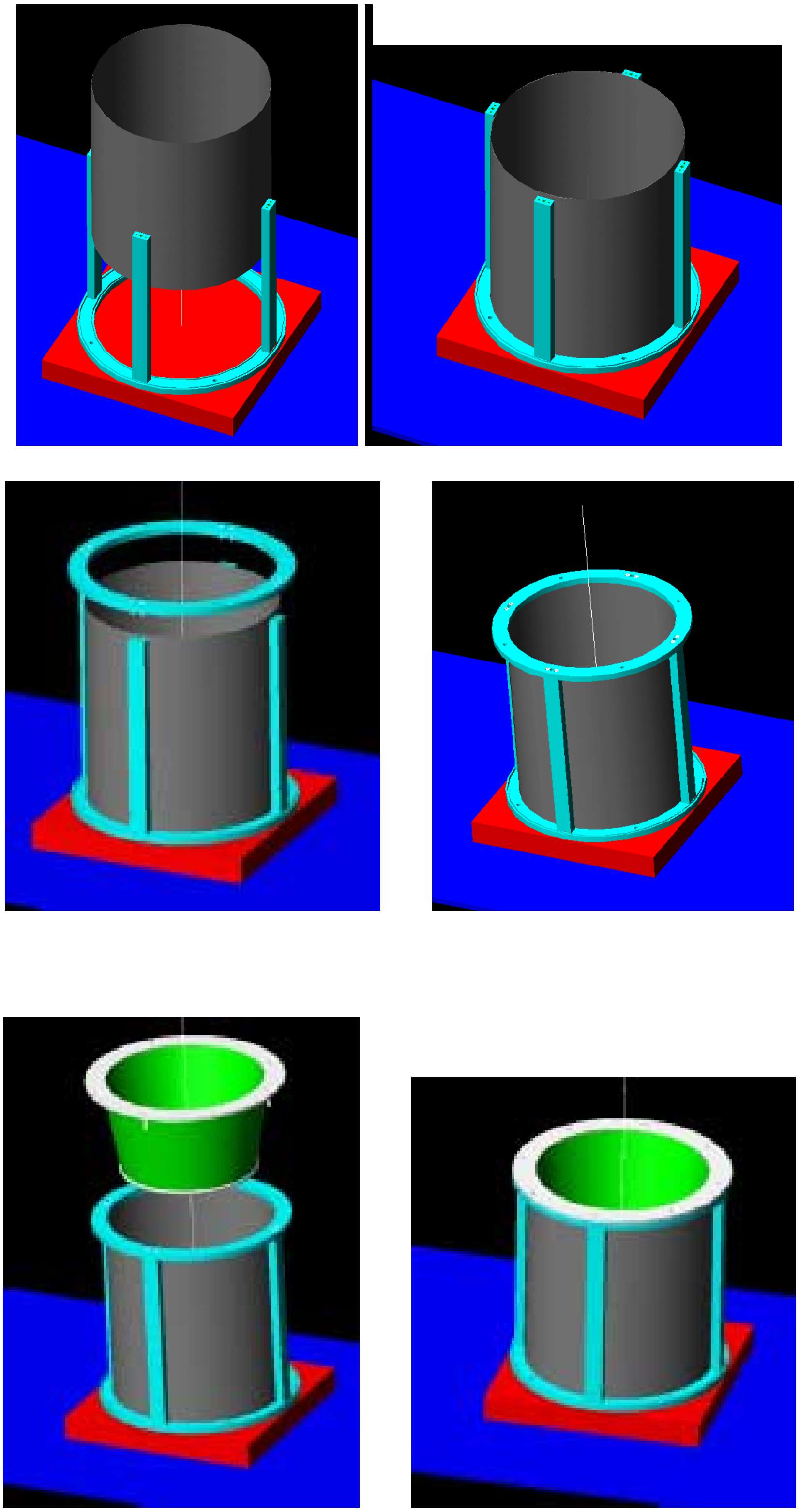


Figure 100 : Fig.-45: Sequence of operations to complete sub-assembly A

B.- Sub-Assembly of the clamp, L piece, column support of the circumferential fixation and the single support surfaces.

The sequence of operations is sketched in Fig.-46. Another “mounting jig” (red piece) is needed to allow the positioning of the different elements of this system and to optimize the operation time. First, L pieces are attached to the clamp. Then the two columns are mounted. And finally the top pieces are assembled on the columns, leaving loose the screws which should be used later for final adjustment when attaching this set to the PMT.

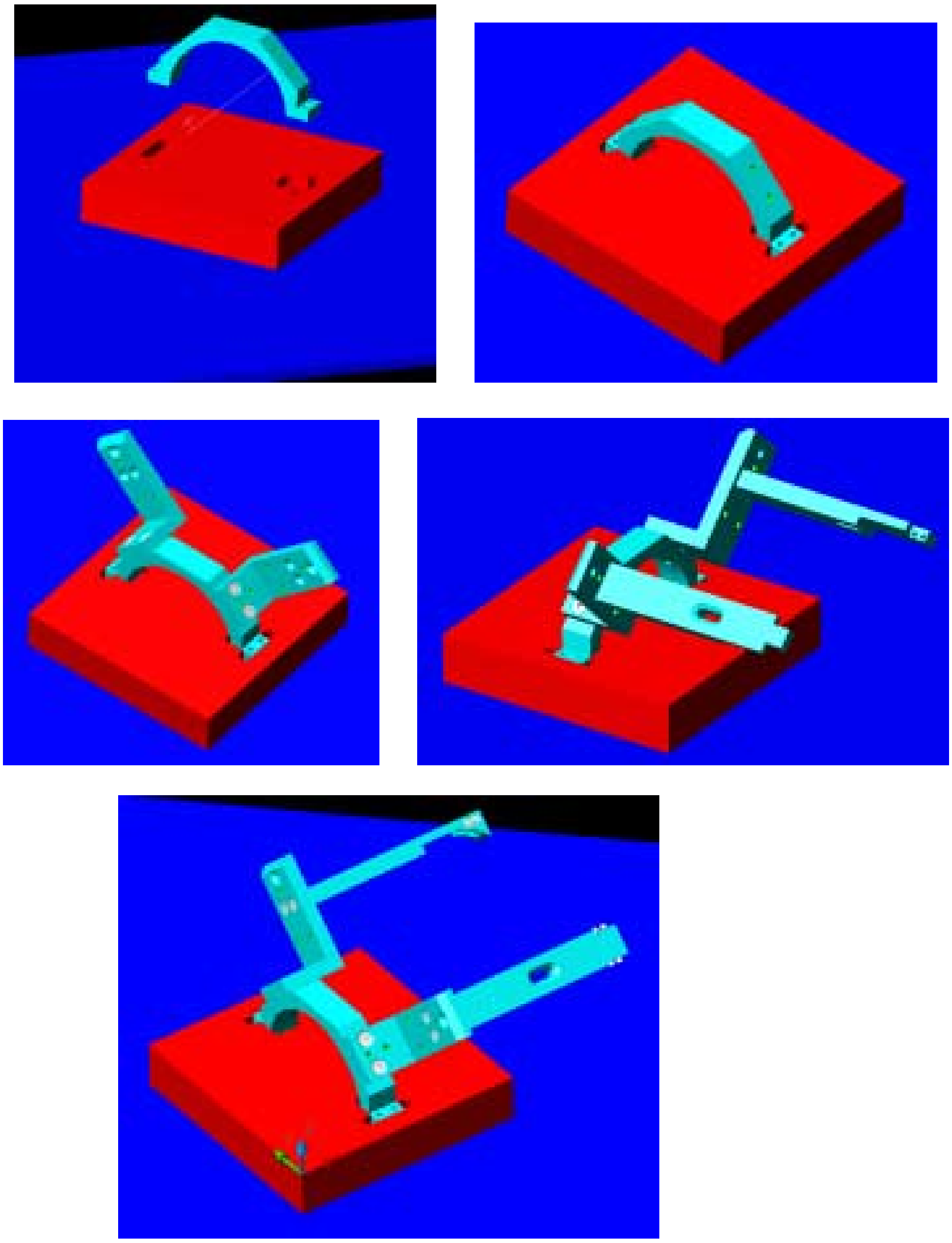


Figure 101 : Fig.-46: Sketch showing the process to be followed in sub-assembly B.

C.- Sub-Assembly of the main support of the PMT support structure.

We will use now another "mounting jig" (red piece) to attach the PMT to the mechanical structure. The base of the PMT is inserted in this jig as shown in the fig.-47. Previous to this, the support ring at the equator level should have been inserted all along the PMT cable and supported provisionally by a clamp to avoid interferences during the assembly process.

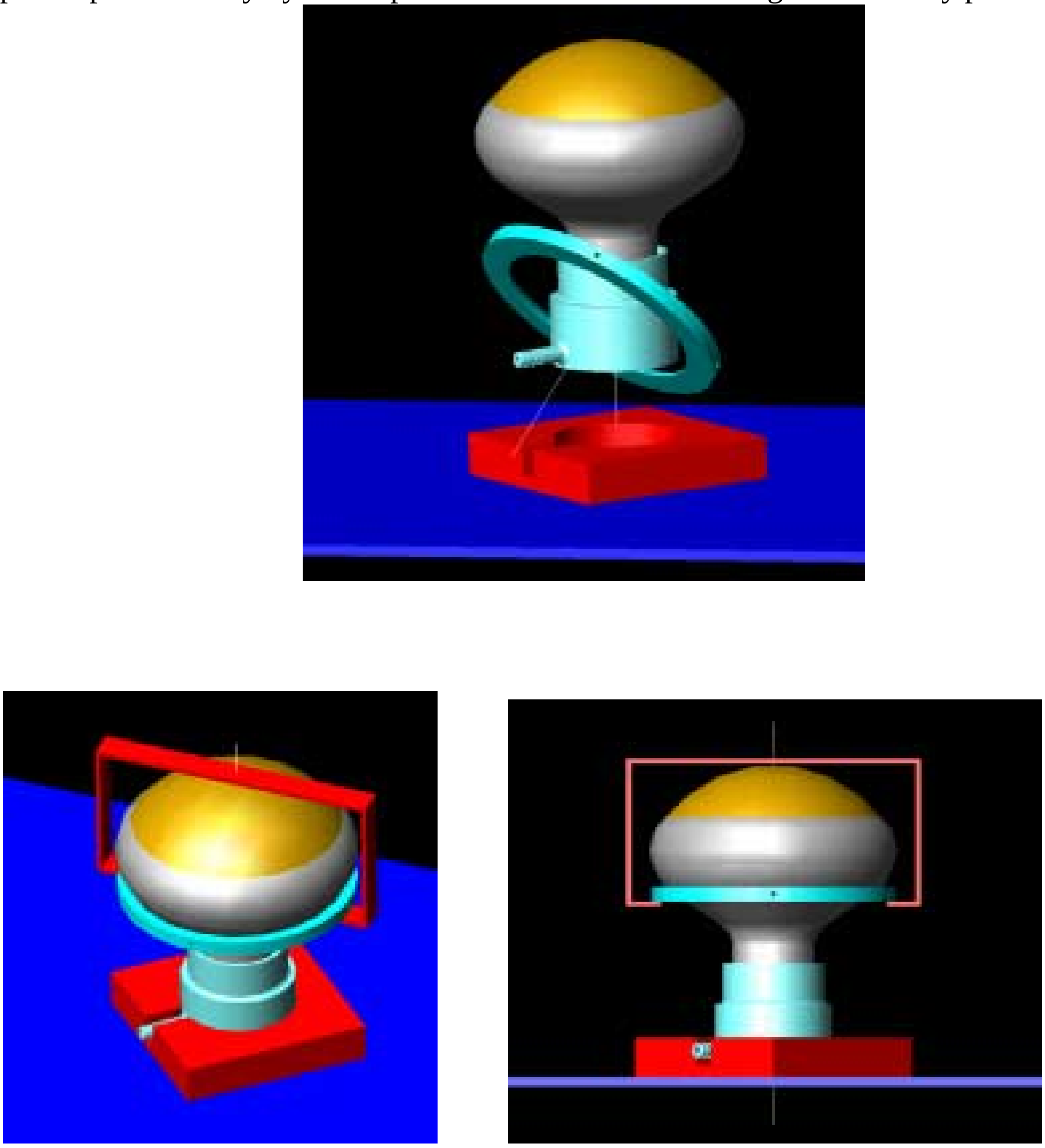


Figure 102 : Fig.-47: Initial phase of the assembly of the PMT to the mechanical support pieces

Then, the sub-assembly set, which was previously described in section "B", is placed in its position. This part has to be done carefully and only adjust all screws when the correct position has been achieved. At the end, the temporary clamp supporting the ring can be removed. This process can be seen in Fig.-48.

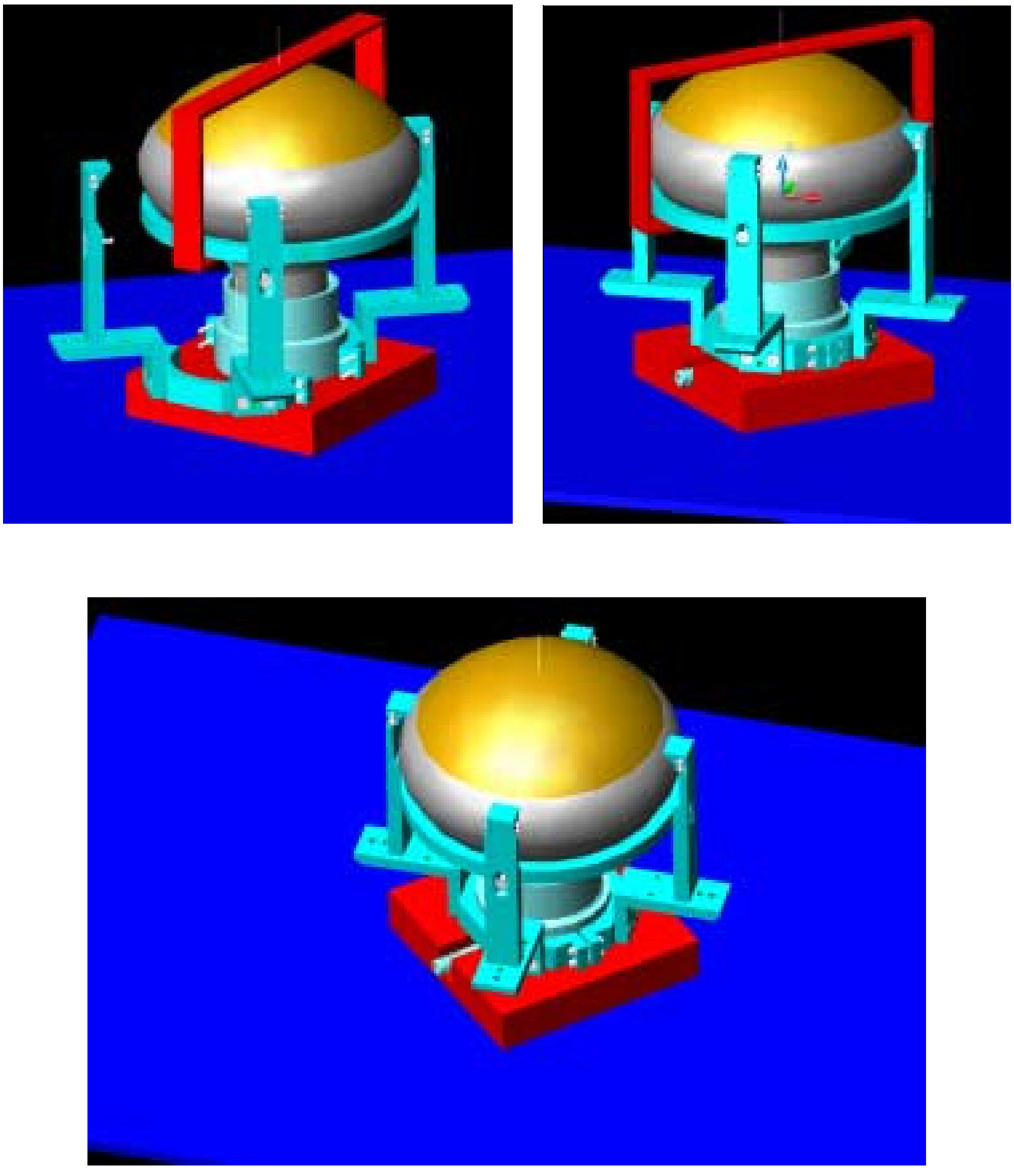


Figure 103 : Fig.-48: Completing the PMT fixation to the mechanical support system.

D.- Assembly of the complete PMT support structure.

The only thing left is to incorporate the sub-assembly set described in section A”. This subassembly is set on top of a table, with the concentrator side at the bottom as shown in fig.-49. Then the sub-assembly “C” is inserted from the top, with the right orientation to allow the final operation of fixing the last 4 screws.

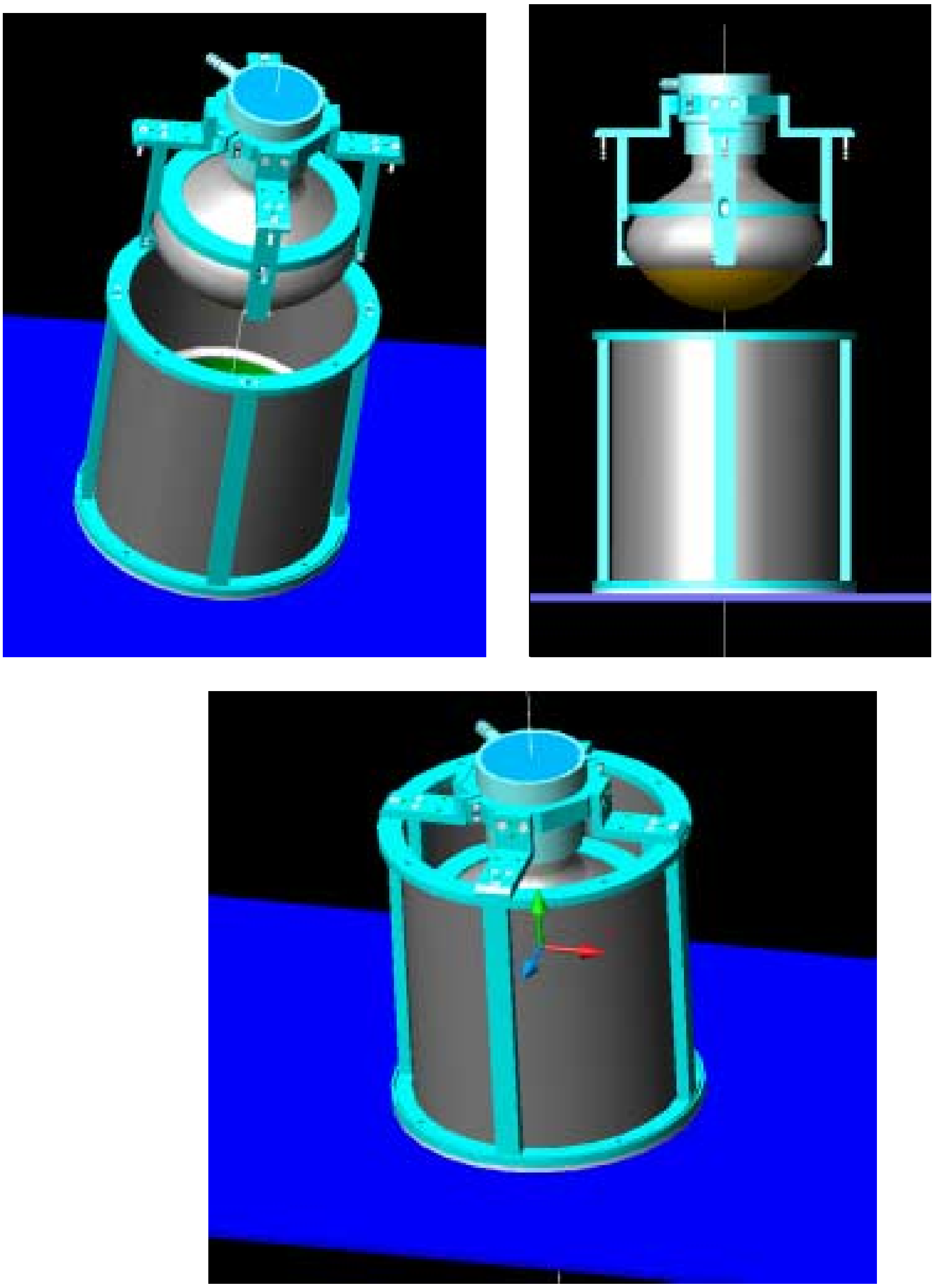


Figure 104 : Fig.-49: Final assembly to integrate the mu-metal shield and the light concentrator. After this, the PMT should be ready to be transported to the detector site.

Manpower needed :

We consider that 2 mechanical technicians will be able to perform this assembly work. Our present estimates of time needed to assemble one PMT are 30 minutes (after some training). This will amount to about one month and a half to assemble the 400 PMTs needed in one detector. Considering some preparatory work, and some contingency, the whole process will require a couple of months.

9.7.5. Cable routing and exit cable guide tubes

For 390 10-inch PMTs in the inner detector the following layout was proposed by CIEMAT. Bottom plane and top lid will have each 4 concentric rings of PMTs with 6 + 12 + 18 + 24 PMTs per ring correspondingly. Azimuthally PMTs will be arranged in 6 sectors (10 PMTs per sector) with structural ribs between the sectors. PMTs on the cylindrical wall of the detector will be arranged as 9 rings with 30 PMTs per ring (See Fig.-19). Vertical mounting ribs will be attached to the cylindrical wall of the buffer vessel to provide fixation support for PMTs (see Fig.-50 below: PMT mounting ribs). Space between these ribs can be used for cable routing inside the detector to the exit cable guide tubes on the top of the cylinder.

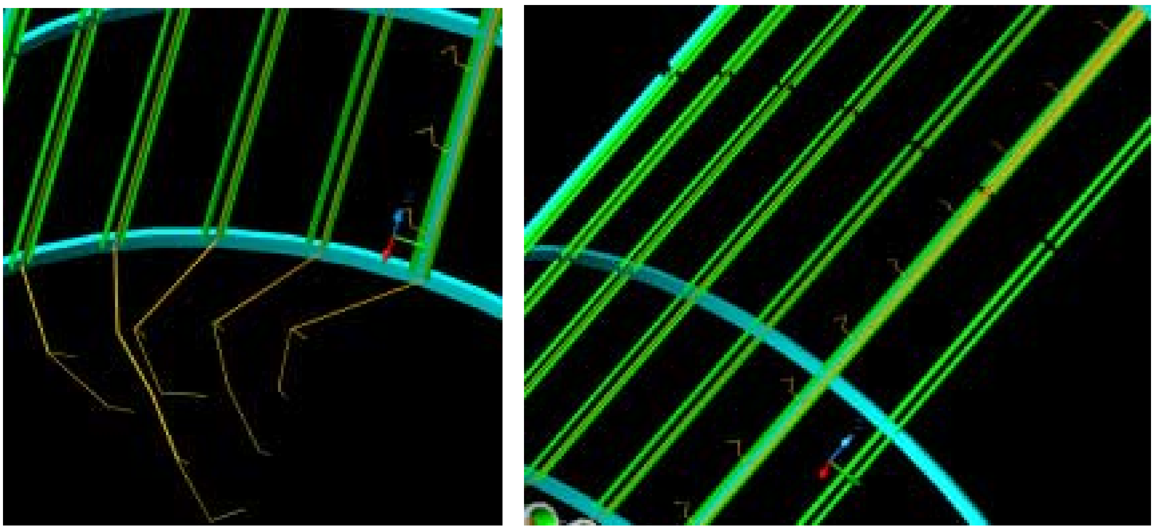


Figure 105 : Fig.-50

There will be the following inventory of the cables exiting the buffer volume:

- 390 PMT cables; RG-303/U with Teflon jackets of OD=4.32 mm (cross section = 0.147 cm^2).

 60 of these cables from top-lid PMTs will be exiting through 6 guide tubes mounted on the top lid of the buffer vessel. Remaining 330 cables (60 from the bottom plate and 270 from the cylindrical side) will exit the buffer vessel through 30 cable exit guide tubes welded to the upper part of the buffer vessel (See Fig.-51 and 52 below).

- 32 LED cables. Each cable consists of 3 coated optical fibers in the Teflon tube shroud with OD=8.0 mm (cross section = 0.503 cm^2). 6 LED cables are exiting through the top lid tubes; remaining 26 cables (6 from bottom plate and 20 from two rings of 10 LED on the side walls) are exiting through 30 guide tubes at the upper part of the buffer vessel.

- 12 slow monitor sensor cables. Each cable is multi-strand Teflon coated cable with OD = 10 mm (cross section = 0.785 cm^2). 3 sensors will be installed on the top lid, 3 sensors on the bottom plate and 6 distributed on the cylindrical wall.

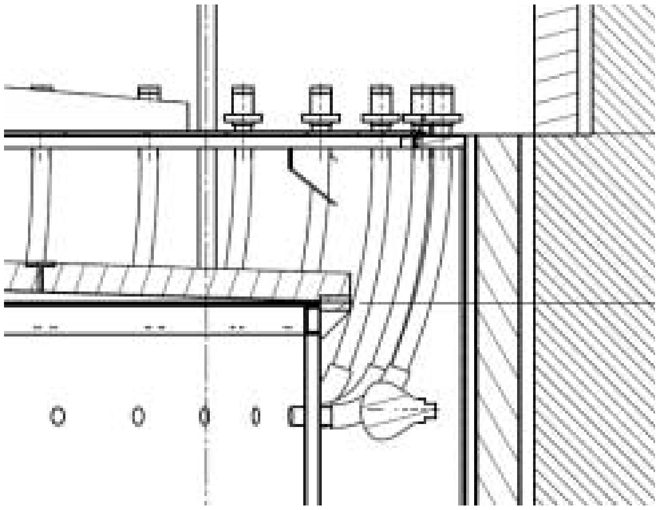


Figure 106 : Fig.-51. Side view of the cable exit guide tubes

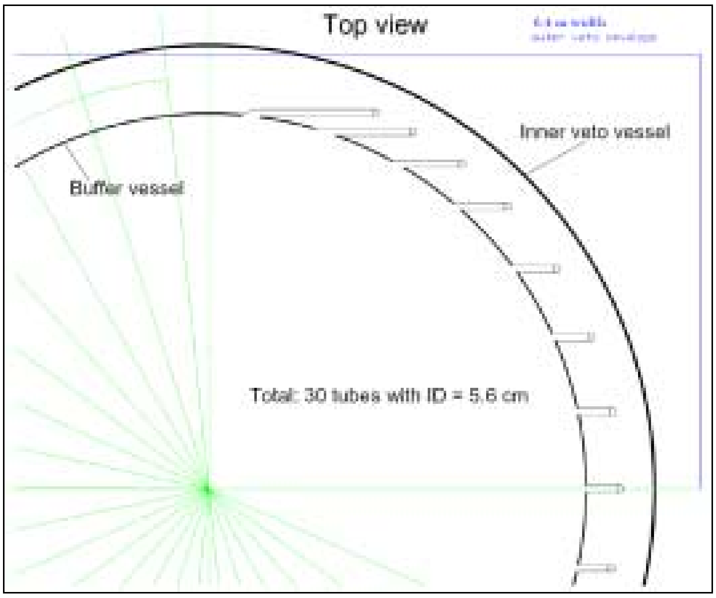


Figure 107 : Fig.-52, Top view of the cable exit guide tubes

Thus, the total number of cable exit tubes required for the buffer vessel is 36 (see Figs.-51 and 55): 6 tubes will be installed on the top lid of the buffer vessel and 30 on the upper part of the cylindrical wall. All the tubes will be made of SS with inner diameter 56 mm (cross section 24.63 cm^2). PMT, LED, and Sensor cables will be assembled in bundles before being pulled through the cable guide tubes.

Maximum number of cables in the bundle is 11 PMT cables + 1 LED cable + 1 Sensor cable. According to cable pulling tests performed at Tohoku University PMT cable in the bundle should be counted with the “safe” cross section area of 1.3 cm^2 per cable for convenient passing through the cable guide tube. Safe cross section for LED cable was estimated as 3 cm^2 and for Sensor cable as 4 cm^2. Thus, the safe cross section of the maximum-size bundle should be 21.3 cm^2 (less than cross section of the guide tube 24.63 cm^2). Final pulling test with prototype of the guide tube and maximum-size of the cable bundle will be required for procedure confirmation.

Guide tubes exiting buffer vessel should pass the inner veto volume with the shape allowing no straight muon track coming through the tube material without detection by the inner veto PMTs (see Figures above). After passing the inner veto upper lid the guide tube will be sealed in respect to the inner veto lid. Then cable bundle will be pulled through the Z-shaped siphon and siphon will be sealed to the guide tubes.

Cables of the Inner Veto PMT system will be exiting Inner Veto vessel through additional guide tubes. For 78 PMTs envisaged for the Inner Veto system 6 guide tubes should be sufficient.

9.7.6. Installation

Installation of inner PMT will be done from the same height-adjustable round platform that will be used for the welding of Inner Veto and Buffer vessels. The platform will be installed and removed by the crane.

Installation of PMTs (as well as of LED and Sensors) will start (see Fig.-53) from the bottom of the vessel. First 60 bottom plate and lowest raw of 30 side PMTs will be installed. Installation procedure at the bottom level will be challenging due to limited free space between the PMTs (See Fig.-53) and should be carefully planned in advance. Temporary PMT cable bundles will be laid in the cable guides formed by the PMT support ribs on the side wall of the buffer vessel and temporary fixed. Then the platform will be installed at the level slightly above the installed level of PMTs and the next rings of side PMTs will be installed before the height of the platform will be raised or adjusted. New cables will be added to the cable guides and fixed with acrylic lockers. Protective screen at the edge of platform should prevent dropping the tools and assembly materials on the lower level installed PMTs.

When 9 rings of PMT will be installed on the side wall of the buffer vessel all cables within one cable guide (maximum 13 cables =11 PMT cables + 1 sensor cable + 1 LED cable) will be tied to the bundle and pulled through the exit cable guide tubes to outside the detector. In this scenario it will be impossible to postpone the installation of the upper 9-th ring to after the installation of acrylic vessels, since the cable bundles will need to be pulled through the tubes before that. For that reason the diameter of the exit cable guide tubes probably should be further increased to allow pulling additional single PMT cable after the main bundle have been already installed.

Installation of the top-lid PMTs (as well as LEDs and Sensors) can be gone with buffer lid suspended in the gallery outside the pit. After installation of PMTs and routing the cables through the exit guide tubes top lid can be moved with crane to the top of the buffer vessel and sealed.

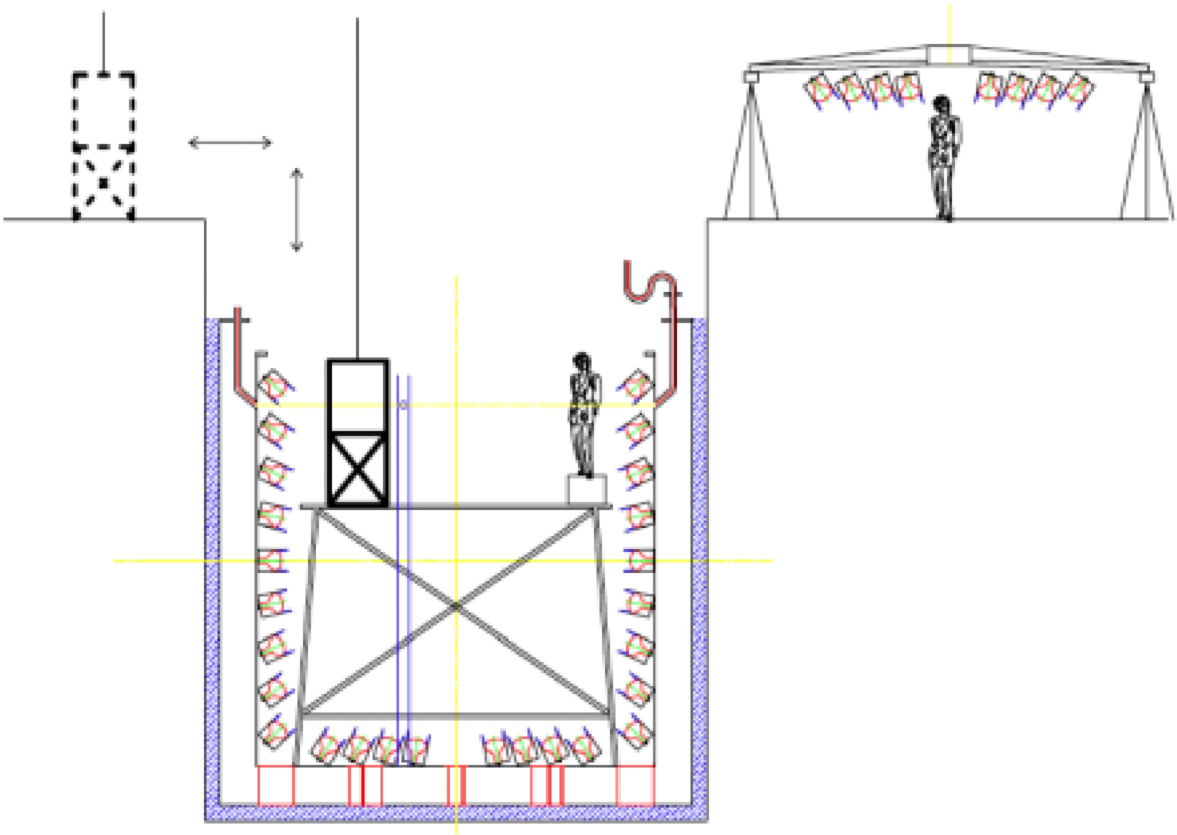


Figure 108 : Fig.-53, Schematic of PMT installation

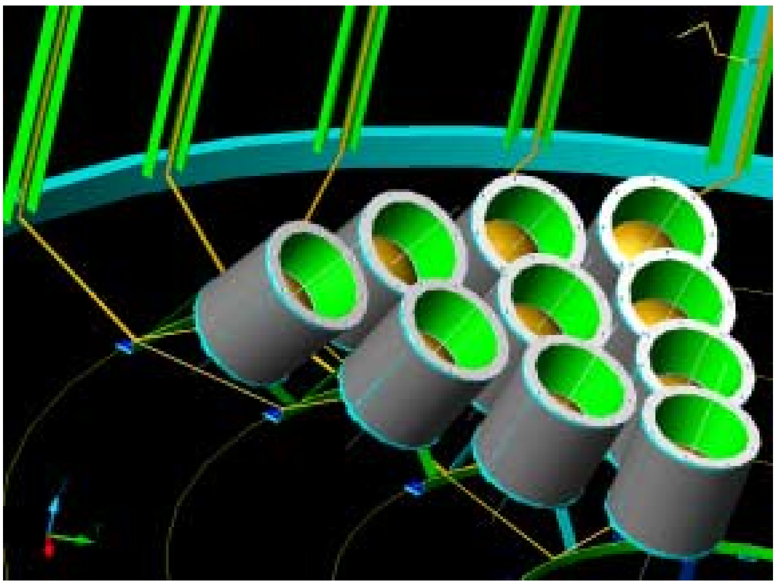


Figure 109 : Fig.-54. Tight space for assembly at the bottom plate of the buffer vessel

9.7.7. The optical treatment of PMT-PMT space.

There is an issue on how to treat the gap between PMTs. One idea is not to do anything special. In this case some fraction of scintillation lights are reflected by the inner wall of the stainless steel buffer tank and come in the PMTs at various places. Generally it will increase the number of photoelectrons and statistical energy resolution will improve. On the other hand, the uniformity is expected to be sacrificed and systematic error may become worse. Another idea is based on the concept that we will not detect indirect lights since they may introduce systematic uncertainty. Inner surface of the stainless steel tank will be covered by black sheets. Similar treatment is used in KamLAND (see the Fig.-55) and it makes the reliability of their data high. The material of the sheet is carbonized polyethylene terephthalate (PET) which are jointed by stainless steel staple.

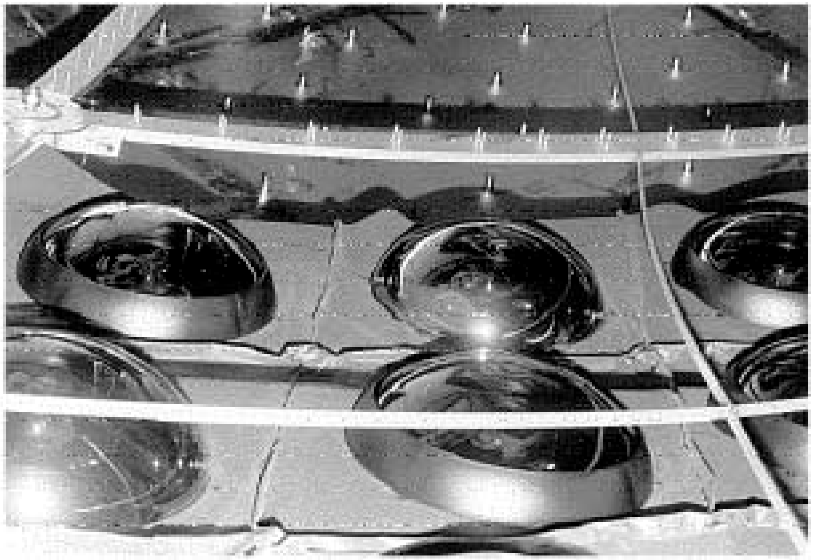


Figure 110 : Fig.-55 Black sheets between KamLAND PMTs.

There is a risk that a light flashes PMTs while the HV's are ON. The risk will be highest during testing the PMT on site because many other workers are supposed to be actively working around us. In order to prevent such accident, we will make a simple and reliable protocol to prevent to switch on the HV supply during light is exposing them and vise versa. Moreover, the current limit of the HV supply will be set low during the testing to minimize the damage in case if such accident should happen.

10. Electronics and acquisition [4000]

10.1. Overview of electronics

The electronics of DoubleChooz is made of four main subsystems (Fig. 1):

- The FrontEnd electronics, the role of which is to amplify and filter the signals from the photomultipliers and to provide an analog sum and partial sums to the Trigger subsystem,

- The Trigger subsystem, the role of which is to provide the other subsystems a common clock and the First Level Trigger signal. This first level signal is derived from analog inputs from the FrontEnd (total sum of the Target volume and partial sums of the Inner Veto) as well as logical inputs to receive artificial trigger sources,

- The Digitizers, mostly Waveform Digitizers, but also a few dedicated boards to collect data from the Trigger subsystem. The Waveform Digitizers have a resolution of 8 bits and a sampling period of 2ns. They are housed in 6U high VME boards with 8 channels per board. They are operated through the VMEbus.

- The DAQ system (VME crates and computers)

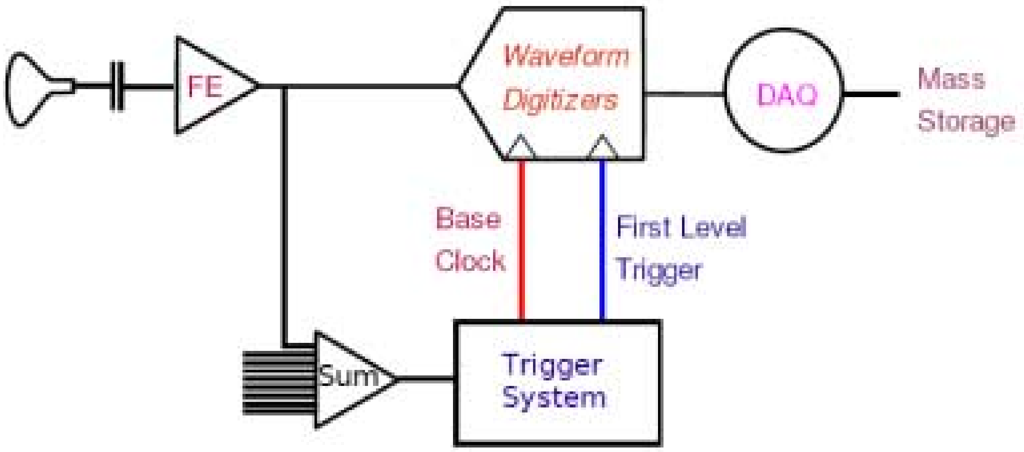


Figure 111 : ***Fig. 1: Simplified sketch of the electronics and Data acquisition***

10.2. Description of components

10.2.1. Analog Front-End

10.2.1.1. Functions

a. The overall functional block diagram is attached. 8 PMT inputs per front end card, plus calibration and digital control inputs, and 1-wire monitoring connections.

b. PMT input channels first go to a disable/calibration/termination block (using bistable signal relays) where they can be individually disabled or connected to a calibration input, and where the input signals are terminated into 50Ω 1% resistors

c. The signals are then (passively) split between `high gain' and `low gain' signal paths

d. On the high gain signal path, voltage gain of approximately 15 (may be changed by choice of resistors, will have some ~20% manual adjustment capability)

e. Pulse shaping correction for HV capacitive coupling, with time constant manually adjustable by ~30% . This is what is commonly known as'baseline restoration'.

f. Output drivers have dynamic range of ±3.5V minimum (typ. ±4V) into 50Ω

g. High-gain and low-gain channels also go to 8:1 analog fan-in (gain on each input manually adjustable over a small range) for output to the trigger, muon system, and other diagnostic systems.

h. DC offsets in amplifiers are corrected by active feedback using precision low gain opamps.

i. There is a separate analog fanin and stretcher on each front-end board, so that 8:1 signals can be converted to a 16:1 suitable for use by the L1 trigger and possible muon system trigger. This circuit will normally be used on every other board by the L1 trigger, with the remaining units available for use by the muon system.

j. The length of the pulse stretching is determined by a socketed (changeable) fixed delay line chip. The pulse stretcher is completely linear in operation, with no thresholding, so that the output pulse amplitude is linearly related to the input pulse summed charge.

k. Summary of inputs and outputs:

i. Eight PMT signal inputs, one calibration input, power, monitoring and control on the rear of the module, two analog inputs to the pulse stretcher on the front of the module.

ii. High gain: Two pairs of eight 1:1 signal outputs for WFD and PMT rate monitor, 8:1 summed outputs for the L1 trigger, possible PMT rate monitor use, and diagnostics. Low gain: one set of eight 1:1 outputs for the muon system, one 8:1 summed output for possible use by a muon trigger.

iii. Two front-panel inputs and one front-panel output for the linear pulse stretcher. The inputs are analog summed, with the output being of approximately fixed length (50-150ns) and amplitude proportional to the input pulse charge.

iv. 1-wire monitoring is planned for board temperature and supply voltages (after regulation, but there may be 2 positive and 2 negative regulators per board, plus ground, requiring at least five ADCs)

10.2.1.2. Physical packaging

a. VME form factor, 9U height for the front-end cards, single width modules.

b. Front-end channels will be needed for ID PMTs and for IV PMTs, a total of ~ 480 channels/detector, 60 front-end boards/detector, 3 full crates per detector.

c. Signal and calibration inputs on the back of the cards, outputs on the front.

d. The lower 3U of the VME crate will be used for a SUN-P3 backplane to distribute power (±6V, ground), monitoring and control signals. Pinout for the SUN-P3 commercial backplane attached. Rows A and C are used for power connections, Row B is `custom' and will be bussed across all cards in the crate. Pins B1-B5 are reserved for 1-wire monitoring.

10.2.1.3. Interfaces

a. Signal input and 1:1 outputs will use Combo-D 8W8 50Ω connectors (detailed specifications attached), with 8 signal connections per connector shell.

b. 8:1 outputs will be on a LEMO connectors, although this may be changed to Combo-D or other coax connectors if LEMO is too costly or too unreliable.

c. Stretcher inputs and outputs by LEMO or other similar coax connector.

d. Calibration signal inputs will be by LEMO connector

e. Control inputs will be active low open-collector TTL signals on the B row of the P3 backplane, with 8 data lines, 5 address lines and a strobe. The controls are "write only", with no data read back from the front-end modules, and with no bus activity during normal data-taking. Tentative bus assignment: pins B11-B24

10.2.1.4. Power consumption

a. Expected power consumption is less than 1.5kW per crate (~20 cards/crate, 2A of ±6V per board, with 50% safety margin)

b. The ±6V DC will be regulated to ±5V on each board using low-dropout power regulators

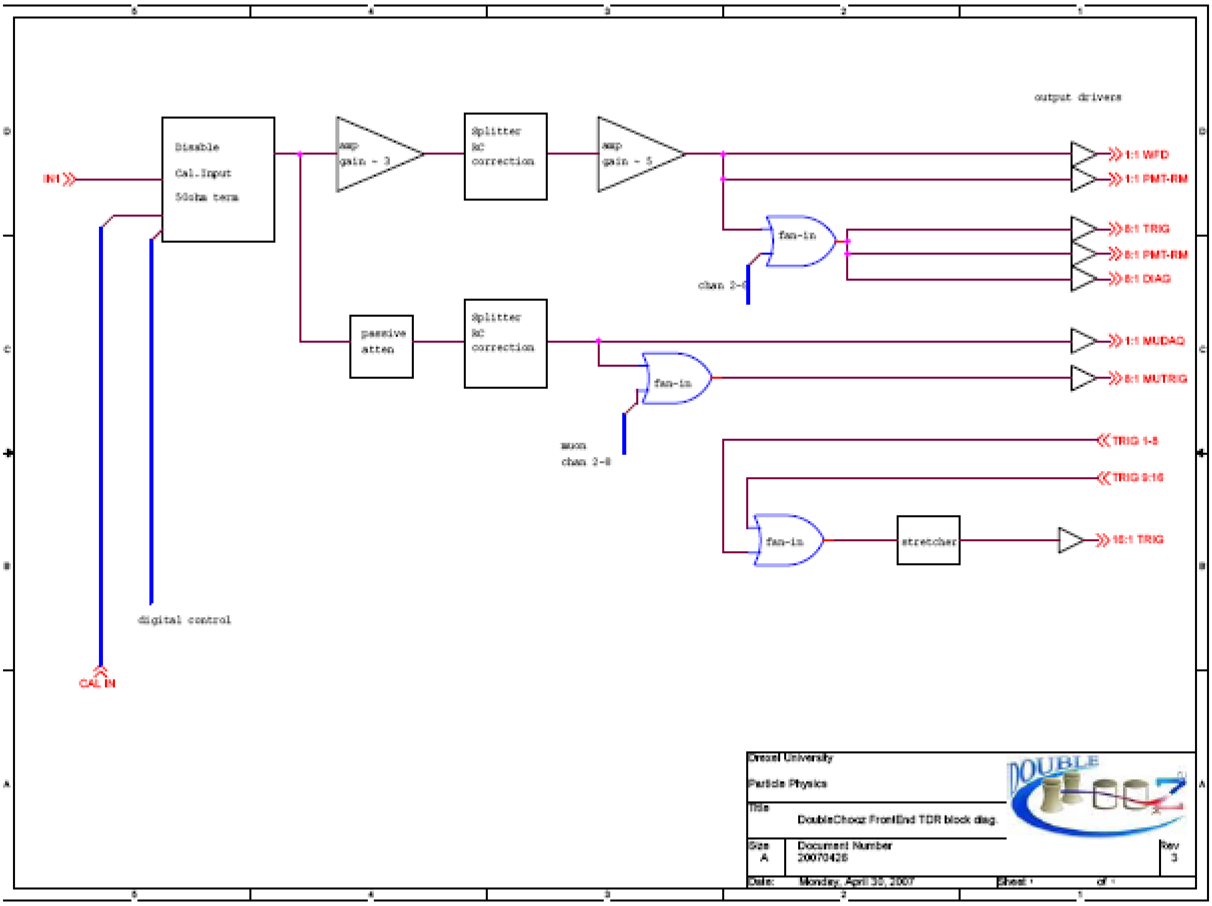


Figure 112 : Double Chooz FrontEnd TDR

10.2.2.Level 1 Trigger

10.2.2.1. Concepts

The trigger and timing system has to provide a highly efficient trigger to the Double Chooz experiment for neutrino events as well as for several types of background events. The trigger has to be reliable, i.e. trigger failures must be rare and easy detectable, and the trigger efficiency must be measurable with sub-percent precision. The trigger system will also distribute a common clock signal to the experiment and provide a time stamp for all events.

A two-stage trigger system is foreseen. The level-1 trigger is based on the analogue signals from the detector which are discriminated and analyzed in FPGAs (Field-Programmable Gate Arrays). A positive Level-1 decision triggers the readout of the detector. The readout is followed by a level-2 software trigger. It rejects further events before the data are written to tape.

This section covers the level-1 trigger only.

For level-2 see sect. ??.

There will be independent trigger systems for the far and near detector with independent clocks. The clocks will be synchronized between the two detector through either a cable connecting the two triggers or through GPS systems. The frequency of the clocks in both detectors must be identical. Synchronization of the phases is not required.

The trigger will receive input from the PMTs of the Inner Target and the Inner Veto. The signals of 10 PMTs will be presummed in the electronics of the Front-End modules (see sect. ??). The trigger only receives the signal sums. Input from the Outer Veto and the calibration systems can also be processed (for example from the laser system sec. ??). It is possible, but not foreseen, to apply veto conditions on the trigger level. Instead an event in the veto detectors will be read out as well as a neutrino candidate following it. It is left to the o_ine analysis to reject cosmogenic events. The signals of the groups of PMTs are discriminated individually to provide an approximate multiplicity of the event. In parallel the total signal sums from the inner target and inner veto are derived and discriminated on several levels.

The trigger will allow to apply conditions on the total energy and multiplicity and any combination of these. Special care will be taken to avoid the amplification of baseline-shifts, common-mode noise and saturation through the summation.

To keep the trigger conditions exible FPGAs will be used to apply the trigger conditions to the discriminated signals. For redundancy two independent Trigger Boards will be used for the Inner Target, each based on only half of the groups of PMTs. This guarantees that hardware failures do not result in the loss of events and can be easily detected.

A third Trigger Board1 will handle the Inner Veto and additional trigger inputs. A careful simulation will determine the initial trigger conditions. They can be adapted once experience with the real detector is available. The following list gives initial ideas on some of the necessary trigger conditions:

- **Inner Target Neutrino Trigger A**

Approximately 0.5 MeV energy threshold on the total energy in the Inner Target and at least 2 groups of PMTs above noise (to exclude single sparking PMTs from triggering). The trigger is based on the first half of PMTs only (groups A).

- **Inner Target Neutrino Trigger B**

Same as above, but based on the second half of PMTs (groups B).

- **Low Energy Neutrino Trigger A + B**

This neutrino is the same as above, but with a lower energy threshold. It's rate will be too high and therefore only 1 out of n events will create a real trigger. The energy threshold and n will be adjusted to the detector noise. This trigger allows to study the threshold behaviour of the main neutrino trigger.

- **Inner Target Muon Trigger A + B**

A muon will create a signal in the Inner Target that fires all groups of PMTs. The trigger will be based on multiplicity only.

- **Inner Veto Muon Trigger**

A trigger based on energy threshold and minimum multiplicity in the Inner Veto.

- **Inner Veto Low Energy**

A trigger on the Inner Veto with a lower threshold to study the trigger efficiencies. Scaled-down in rate as above

- **Random Trigger**

A trigger with an adjustable frequency triggering the readout at fixed time intervals. The events will be uncorrelated with any physics process in the detector (therefore random) and will allow to study detector noise.

_ ...

This list will become more concrete and finalized in the upcoming months.

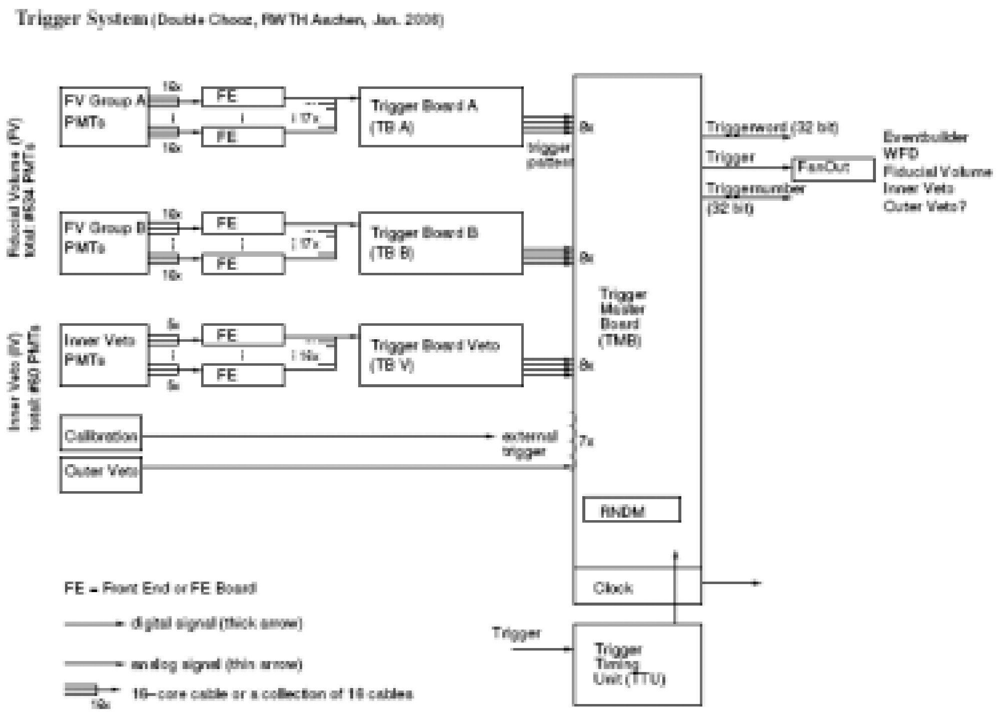


Figure 1: Schematic layout of the Trigger. From the PMTs in the detector on the left, output to the data acquisition on the right. The *Trigger Master Board (TMB)* is the interface to the outside world (not the *Trigger Board*).

Figure 113: schematic layout of the Trigger

10.2.2.2. Trigger System

A schematic view of the trigger is shown in fig. 1. Up to 16 PMTs are connected to a Frontend (FE) Board. The signal of each individual PMT goes to the Waveform Digitizers, for the Trigger all channels on one FE board are summed together, forming an analog sum signal, that goes into the Trigger Board. There will be three Trigger Boards for each detector. Two handling the Inner Target with half of the PMTs each and the third one handling the Inner Veto. On the Trigger Master Board a global trigger word is combined from the three Trigger Boards. The trigger decision is formed as a logic 'OR' of all triggers. Fan-Outs are needed, in order to distribute the signals to the Waveform Digitizers and other Subdetectors. See sec. 1.0.5 for details.

10.2.2.3. Input to the Trigger System

Each Trigger Board has 18 analog input channels, each of them being con-nected to one FE group. Each channel is discriminated on two different,

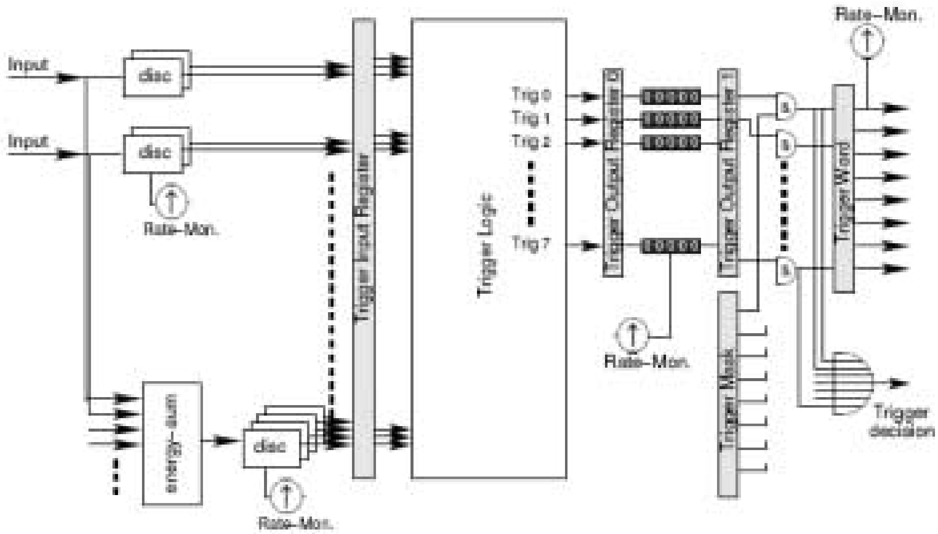


Figure 114 : Schematic layout of the Trigger Board. Input from the front-end electronics on the left, output to the Trigger Master Board on the right. Shaded rectangles are registers that will be read out.

The discriminators are labeled 'disc' programmable thresholds. The energy sum is derived and discriminated on four levels (see fig. 2). The same holds for the Inner Veto Trigger Board, though the thresholds and the logic on it will be different from the logic on the two *Inner Target Trigger Boards*.

The trigger logic is fully programmable and may combine any input signals. Up to 8 different triggers can be created in each board. The output of the trigger logic is stored in the output register 0. A scaler for each trigger allows to reduce its rate by accepting only every n.th trigger, where n is programmable. After down-scaling, the triggers are combined with a mask that allows to suppress individual triggers. The result is transmitted to the Trigger Master Board.

The Trigger Master Board has 4 LVDS[1] connectors. 3 of them are used for the 3 Trigger Boards, one is backup or free different applications in the future.
On the TMB the Triggerwords of the two Inner Target TBs are 'OR'ed and combined with the TB Triggerword of the Inner Veto TB.

[1]LVDS=Low Voltage Differential Signaling

Figure 115 : photograph of the Trigger Board (oct. 2006)

The TMB provides 7 digital inputs for external Trigger sources, 3 of which are reserved for Calibration Triggers. 4 of them can be used for additional applications. It provides also a Random Trigger, which allows to readout the detector independent of physics events. The global 32 bit Triggerword is created from the 7 External Trigger Sources, the Random Trigger and the three TB Triggerwords.

10.2.2.4. Output of the Triggersystem

The Trigger Master Board is the interface to the outside world. It provides:

- the 32 bit Triggerword
- the Event number (32 bit)
- the Trigger, which will be sent synchronous to the 62.5 MHz System Clock.

The Triggerword and the Event number have to be provided once per VME crate, the Trigger to every Waveform Digitizer. See sec. 5. for details.

Figure 116 : A picture of the recently (march 2007) assembled Trigger Master Board (some connectors still missing).

Monitoring

On each event status data is written into a FIFO, which is located inside the FPGA of its Trigger Board or Trigger Master Board. For each Trigger Board the status data consists of the status of the discriminators, together with the Input Rate counters of each post-discriminator channel (not the analog channel) and its event number. The status data for the TMB has still to be de_ned. The FIFO can be readout via VME, and the status data is thereby available for monitoring.

Clock and Timing

The trigger and timing system will provide a 62.5 MHz clock to the whole detector. For this purpose a free running oscillator will be placed on the Trigger Master Board to allow stand-alone running. A possibility to synchronize the clock to an external reference will be foreseen. With a cable connecting the Far and the Near Detector the two clocks could be synchronized. A separate timing module, the Trigger Timing Unit (see Fig.), is under discussion that receives the clock and an absolute time from the GPS system.
With such a timing module both detectors could be synchronized to GPS. It would also allow an absolute time stamp for each event, should this be necessary for physics. A potential application is the detection of neutrinos from super nova explosions and the correlation of the Double Chooz signal with other neutrino detectors and optical telescopes.

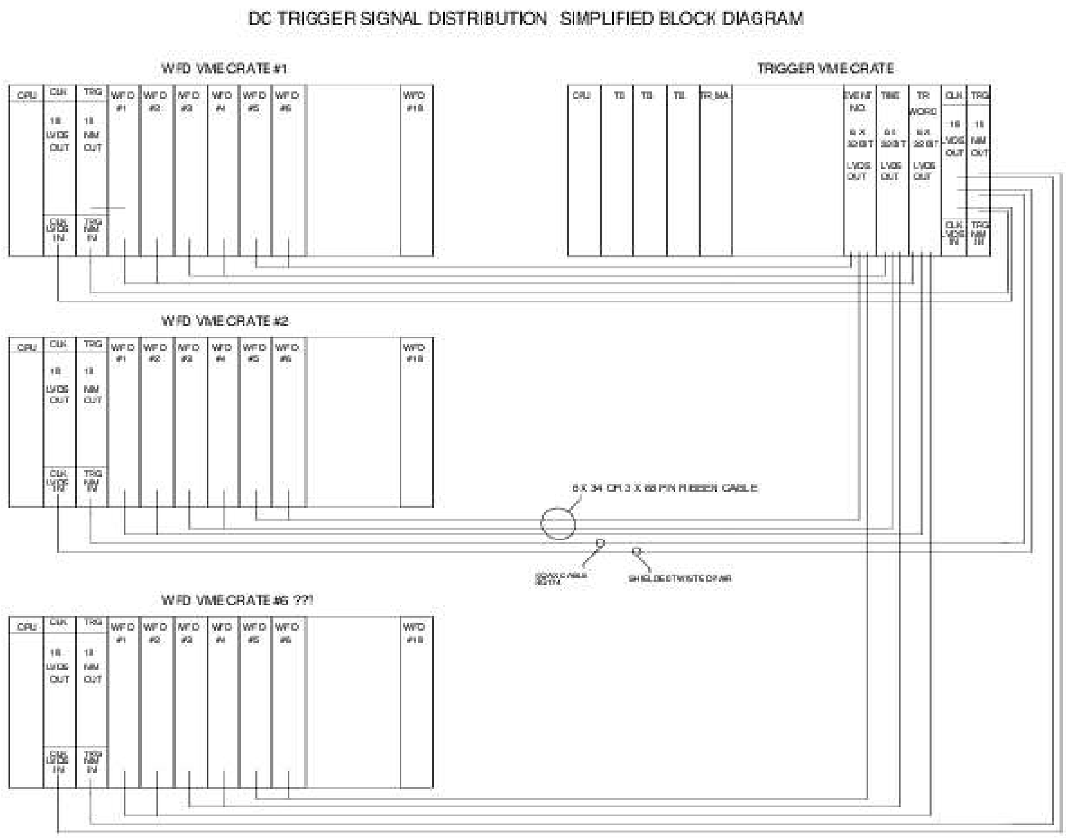


Figure 117 : Proposal for a DC Trigger Signal distribution, showing a simplified block diagram, with 6 Waveform Digitizer crates (while the actual number of crates is not yet fixed).

Busy Signal

The trigger will have a possibility to receive a busy signal from each subdetector should it not be ready for data taking. Triggers will only be created, if no busy signal is present. The trigger will monitor the busy signals. It will create an interrupt, if a subdetector does not remove its busy signal within a preset amount of time. The dead-time due to busy signals will be recorded.

10.2.2.5. Signal Distribution

Here a DC Trigger Signal distribution is proposed. An alternative scheme was discussed, where the Fan-Outs do not sit in the Waveform Digitizers' crates, but in a separate unit.
In this concept (see the simplified block diagram in fig. 1.0.5) three different types of Fan-out modules are needed:

- One for the NIM level Trigger signal: NIM Fan out 1 – 18
- One for the LVDS level Clock signal: LVDS Fan out 1 – 18
- One for the LVDS level Trigger Word and Event number: LVDS Fan-out 1-6(?) x 32 bit

The trigger and clock signals are needed by each Waveform Digitizer (WFD) so one Fan-Out module for each signal type should be plugged into each WFD VME crate to distribute the signals inside the WFD crate. The cables to distribute the clock inside the WFD crate may have different connectors on both ends. The same Fan-Out module types are installed inside the Trigger crate to provide the signals for the WFD crates.
The Trigger Word and the Event number are needed only once for every WFD crate, because of that the signal distribution can be done in the Trigger crate. In this case one 32 bit LVDS Fan-out module for each Data word s needed. The number of the outputs is dependent on the number of the FD crates. To connect the Fan out module and the 16 bit LVDS Data ports of the WFDs a spliced 68 lead or two 34 lead twisted 1.27 mm ribbon cables are needed. The table, listing details of cables and connectors will be part of a technical document related to the Trigger System.

10.2.2.6. List of Components

Near and Far Detector have each their own Trigger System, consisting of:

- 1 VME-controller Motorola MVME3100, it is identical or similar to the readout processors chosen for the Waveform Digitizers.
- 3 Trigger Boards: 2 for the Inner Target, 1 for the Inner Veto
- 1 Trigger Master Board
- 1 Trigger Timing Unit
- 1 VME Crate
- Fan-Outs, to distribute Trigger, Triggerword, Eventnumber, absolute timestamp (as provided by the Trigger Timing Unit), see sec. 1.0.5.

10.3. Waveform Digitizer

The Waveform Digitizer is the CAEN mdel V1721 which has a resolution of 8 bits and 2ns. This device, was developed in collaboration with APC.
It allows readout and digitization to occur simultaneously by the mean of large onboard memory and smart address management.

It houses 8 analog input channels with a dynamic range of 500mV. The input offset can be adjusted onboard within a range of ±1V, through VMEbus transfers.

Most logical operations of the board are clocked at 62.5MHz (16ns period). The digitization subsystem stores 8 Flash ADC samples every 16ns. The data is stored into and read from the onboard memory by blocks of 64 bits representing a time window of 16ns.

The memory is divided in 1024 pages of 1024 bytes, corresponding to 2048ns of record length.
The board is continuously digitizing and writing to one of these pages. On trigger, it simply switches to the next page.

A handshake mechanism allows the VME master and the onboard trigger logic to know which page is currently written and which pages are available for writing. An simple algorithm in the VME master can operate the board like an event FIFO.

The V1721 is capable of VME Block transfers, including 2eVME which provides a peak data flow of 160MB/s.

Fig 2. CAEN V1721

The 62.5MHz clock can be either generated internally or read from a dedicated front panel connector, allowing to synchronize several boards. When a trigger is detected, the time elapsed since the previous trigger is stored and made available to the VME bus. One such time is kept for every event. In addition, a dedicated input connector allows to provide 16bit word of data which is read on trigger and stored together with the time and an internal 16bit trigger counter.

The internal trigger counter and the time provide a mean for the DAQ to control the perfect synchronization of all the V1721 boards. More important, the time is the data which allows to check, online and offline, for coincidences between successive events.

10.3.1.1. Interfaces

The table below summarizes the interfaces of the V1721 Waveform Digitizers, with the FrontEnd for analog signals and with the Trigger system for logical signals.

Table 1: Waveform Digitizer interface with trigger system

Name	Direction	Format	WFD Connector
8 x Analog	in	[-1V,1V] [1]	MCX
Clock	in	LVDS	3 way male TYCO cod. 3-102203-4 AMP MODUII
Trigger	in	NIM	Lemo 00
Trigger Word	in	LVDS	PCB connector
Event Number	in	LVDS	PCB connector
Start	in [2]	NIM	Lemo 00
Stop	in [2]	NIM	Lemo 00
WFD Busy	out [2]	NIM	Lemo 00

[1] The amplitude of the signal is clipped when it exceeds a window of 510mV, but this window can be moved anywhere within the [-1V, 1V] range.

[2] Optional signal, non mandatory for the DAQ.

Connection with Front-End

The cables used to transport the analog signals from the Front-End are RG174 with a single Combo-D with 8 cables on the Front-End side and 8 MCX plugs on the Waveform Digitizer side.

Front-End side: combo sub-D 8w8 ref. Harting 09 69 410 0088
Waveform side: mcx ref. tyco 1-1337580

10.3.1.2. Readout Hardware

The read out hardware is made of several VME64x crates, each housing digitizer boards and a single board computer (SBC) capable of the most recent high bandwidth VME transactions, either MVME6100 or MVME3100 from Motorola Computer Group, and a single standalone microcomputer(PC). The SBCs and the PC are interconnected in a 1GB/s Ethernet network and the PC acts as a boot and disk server for the SBCs which are diskless.

Each SBC is in charge of reading the digitizers in it's own VME crate, performing the Second Level Trigger algorithm, formatting the data and transfering them to the PC. The PC controls the operations of the SBCs, assembles the events and writes them to mass storage.

10.4. DAQ model

The principle of the DAQ of Double Chooz is to keep a continuous record of the signals of the photomultipliers during long periods of time (~days), like with hundreds of digital oscilloscope channels with a 2ns sampling period. Since this would lead to an unsustainable data flow if data was not compressed, the data flow is reduced in two steps:

1. The First Level Trigger, implemented in hardware, eliminates all data except around pulses of energy above a given threshold in the Target or the Inner Veto, thus defining events;

2. The Second Level Trigger, implemented in software, identifies in real time the event type and executes the data compression apropriate to this type.

A prompt trigger is obtained from a simple discriminator, on one of the sums of PMTs signals, either total sum of Target volume, or partial sum of Inner Veto.

After synchronizing this trigger with the base clock, and then delaying it by aproximately 200ns, we obtain the First Level Trigger.

The Waveform Digitizers digitize continuously, writing into a rotating buffer able to store 2048ns of waveform. When the trigger signal is received, this buffer is put into a FIFO and digitizing continues into another buffer. The memory of the Waveform Digitizers is divided in 1024 such buffers. Since there is always one used to store the next event, the 1023 others constitute the FIFO. The events enter the FIFO instantly, on trigger. They get out on receipt of a command from the VMEbus, which is a single random access write. Unlike most FIFOs, the action of reading an element (event) and removing it from the FIFO are not the same. In our case, the whole content of the FIFO is permanently available through the VMEbus for reading. This allows the DAQ program to keep informed in real time of the contents of the FIFO.

The readout program reads the last 256ns of the events, which, given the 200ns delay of the First Level Trigger, provides a pulse shape with aproximately 56ns of baseline prior to the event and 200ns for the signal. Of course the signal does not start exactly in the same time on all channels due to differences in the time of propagation of the photons in the detector, but the differences fit easily within the given time window. All the records are made synchronous by synchronizing the intenal clocks of the Waveform Digitizers with the Base Clock delivered by the Trigger system. This allows to calculate offline the time differences between the pulses of different channels. The time difference between triggers is also recorded, giving the possibility to check offline for coincidences.

10.5. Muon Shower Monitor

10.5.1. Overview

Muons from cosmic rays are an important and copious background in reactor neutrino experiments, mainly for those not installed in deep underground facilities. Uncorrelated background, formed by coincident hits of cosmic muons and pulses from natural radioactivity, can be easily identified and removed by applying time cuts. However, correlated backgrounds formed by neutrons from muon-induced reactions require more sophisticated techniques for their recognition and effective suppression. The correlated backgrounds are generated either by spallation neutrons from muons interacting with the detector and the surrounding materials, or by the β-neutron de-excitation of long-lived isotopes produced by muon interactions on the scintillator carbon, mainly ^{9}Li and ^{8}He with half-lifes greater than 100 ms [i]. The β-neutron decays can produce pulses which mimic a genuine neutrino event and their long de-excitation times can introduce unacceptable dead-times if one uses a standard veto scheme. Since the expected rates for muons are of the order of 1000 Hz for the Near Detector and 30 Hz for the Far Detector a comprehensive study of muon interactions in the detector is necessary to better identify events related to β-neutron emitters and allow subtraction of this important component of background and improve the signal to background ratio.

The isotopes in excited states are most likely products of photonuclear reactions of the muons and their shower particles with the scintillator [ii]. Thus, a special care must be taken for muon events with high energy deposition. For instance, in KamLAND, showering muons represent ~ 1.5% of the muon flux and to get rid of this background a cut was applied on events with energy deposition greater than 3 GeV [iii]. Figure 118 : shows the integrated event rate expected for the Double Chooz Near Detector, calculated as a function of the minimum energy deposition [iv]. In addition, the isolated contribution of muons with momentum $p_\mu > 1$ TeV — expected to dominate the contribution of showering muons — is also shown. The rates were obtained from the muon flux parameterized by energy and angular dependence [v]. The energy deposition was calculated from muon tracks crossing the detector inner volume, within a sample of muon momenta $p_\mu < 4$ TeV at the detector. The muon energy deposition is based on calculations which include ionization, pair production, bremsstrahlung and inelastic scattering. From Figure 118 : it is possible to identify a selection criterion to identify likely showering events by imposing a threshold of deposited energy $E_c \geq$ 1.5 GeV. The predicted trigger rate of this selection would be
~ 0.1 Hz, corresponding to ~ 10^4 events per day.

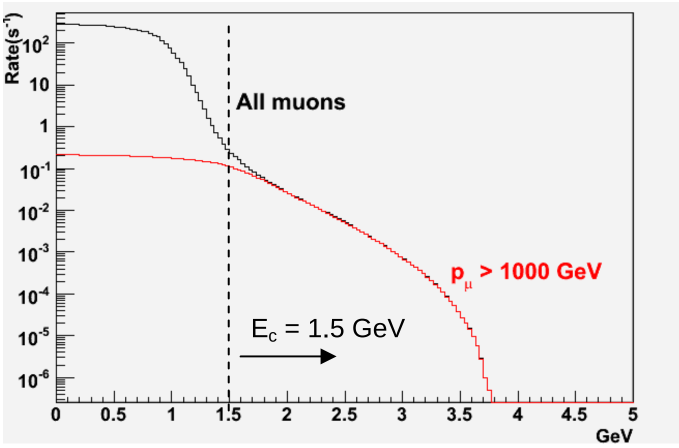


Figure 118 : Integrated rate for muon events as function of minimum energy deposition in scintillator [iv]. Black line: muons with $p_\mu < 4$ TeV (whole sample). Red Line: Component with $p_\mu > 1$ TeV. Dashed line: energy cut corresponding to minimum energy deposition for showering muon candidates.

10.5.2.Identification of showering muons

Since the expected neutrino signals are small (one p.e. to a few p.e. per PMT), the Central Detector PMT system is designed to operate at very high gain (~10^7). However, muon events produce a significantly larger signal in the PMT (hundreds more photoelectrons), requiring operation of the PMTs in a range above the linear response regime. Despite the non-linearity, PMT charge is still proportional to energy deposition, even to extremely large signals, as shown in **Erreur ! Source du renvoi introuvable.** and **Erreur ! Source du renvoi introuvable.**.

It should also be noted that lowering PMT gains to avoid PMT saturation would not be a better choice for estimating muon energy. As shown in the RCA PMT handbook [vi] the voltage dependence of the space charge current limit is $\propto V^{3/2}$, which means that the saturation level decreases with reductions in the HV applied to the PMTs.

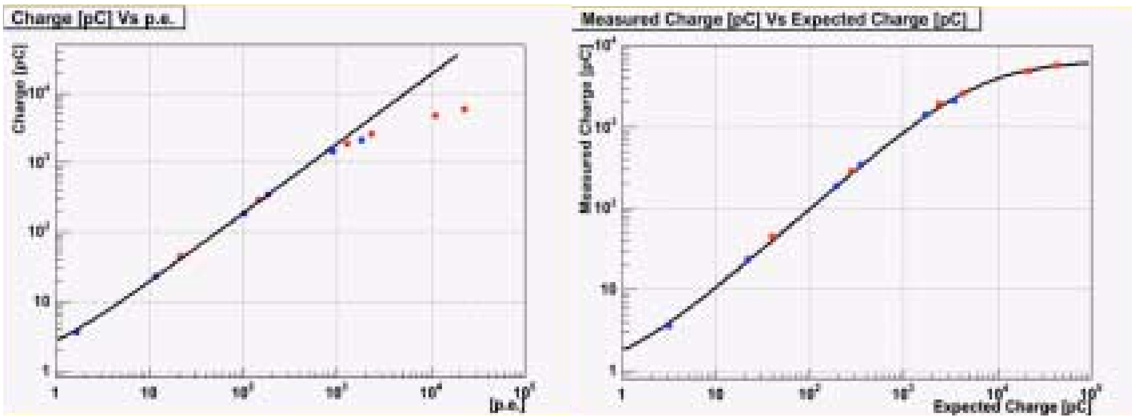


Figure 119 : Measurements of dynamic range of the ICECUBE PMTs (HAMAMATSU 10” PMT R7081-02). Left panel shows the deviation from linearity above 10^3 p.e. . Right panel shows the obtained fit describing a dependence on the PMT charge Q with number n of p.e. like $Q = (a+b.n)/(1+c.n)$. Details are located in reference [vii].

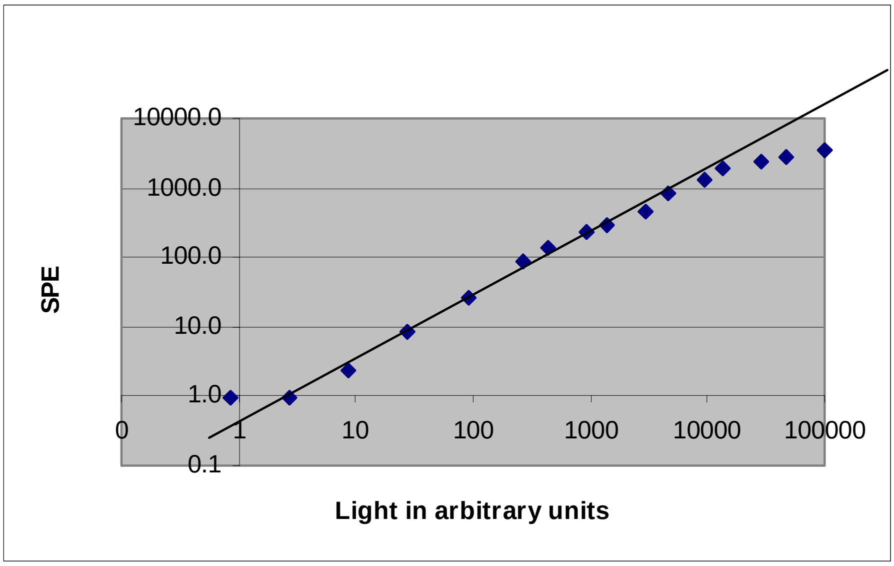


Figure 120: Measurements of R7081 PMT linearity done by the Double Chooz group of University of Tennessee [viii].

Other muon systems within the Double Chooz detector design, specifically the Outer and Inner Veto systems, can identify muon position and direction, but do not provide a measurement of their energy and cannot resolve showering muons. Furthermore, the amount of light yield from muon showers in scintillator is well above of the dynamic range of the primary electronics digitization. In order to measure muon energy and identify showering muon candidates, a muon shower monitor based on a dedicated electronics has been designed which is sensitive to high charge depositions within the central detector. In addition to pulse height information, the relative timing of the pulses will also be provided to allow muon tracking. The combined information will provide a crude estimation of the dE/dx of the muon which may improve the identification of background candidates even when the total energy deposited by the muon was relatively low. The PMT signals will be extracted from the attenuated output foreseen in the current Front-End Electronics design [ix] and the expected output data (integrated charge and timing information for PMTs) will be incorporated into the primary DAQ data stream.

10.5.3. System Description

10.5.3.1. PMT geometry

In the baseline design of the central detector there will be 390 installed PMTs: 60 PMTs on each lid plus 270 PMTs on the barrel wall, equally distributed in 9 rows. Since the muon energy deposition is large, only a very few PMT channels would be required to provide a good estimate of the total charge. As a result, the number of instrumented PMTs is driven by the requirements for adequate tracking. It has been estimated that this can be accomplished with the instrumentation of approximately 1/3 of the existing PMTs. To be as uniform as possible while keeping the 60^o symmetry of the whole detector the configuration shown in **Erreur ! Source du renvoi introuvable.** was chosen. In this configuration, the total number of PMTs for the muon shower monitor is 138, being 24 PMTs in each lid plus 90 in the barrel wall, 10 in each row.

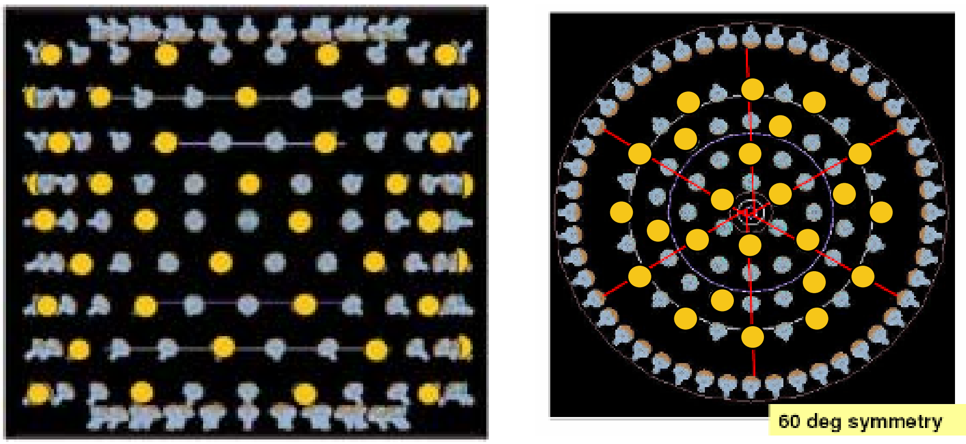


Figure 121 : PMT geometry of the muon shower monitor. Left panel shows the distribution scheme for 90 PMTs over the barrel wall (obs.: provisory draw, not in scale). Right panel is the distribution scheme for 24 PMTs on each lid (obs.: already fixed, no changes required in the draw).

Electronics

A dedicated electronics (MUon Shower Electronics – MUSE) will be developed for the measurements related to the showering muons. This system will provide three quantities in order to allow a detailed analysis of those events: the integrated charge over a reduced set of PMTs, precise timing between the PMT pulses and waveform sampling for special events and diagnostics. An overview of the MUSE is shown in the **Erreur ! Source du renvoi introuvable.**.

The integrated charge will be computed by digitally summing the individual charge from each PMT pulse. A pipeline analog-to-digital converter will continuously digitize the input pulses, delivering the samples to a Field Programmable Gate Array (FPGA), which computes the individual charge. An additional FPGA will compute the sum of all the individual charge information to form the integrated charge which should have an accuracy of a few percent.

In order to allow tracking of an event inside the central detector, Time-to-Digital Converters (TDCs) will be used to measure the relative time between the incoming PMT pulses. These TDCs will be operated in a START-STOP mode, measuring the time difference between a common START input and several STOP inputs. A reference signal delivered by the Double Chooz trigger system will provide the START for all the TDCs in the MUSE, while the STOP pulses will be generated by using on-board leading-edge discriminators.

Waveform sampling capability is also foreseen in the MUSE. This feature allows the digital storage of a complete PMT pulse for each muon event. It is expected that this information could be useful for further offline analysis of the underlying physics. Due to limitations on the current technology, this waveform sampling feature cannot be used at the full rate expected for all muon events. Therefore, the readout of the waveform will be requested only in special cases, defined either by means of an online trigger condition or an asynchronous (externally generated) input signal.

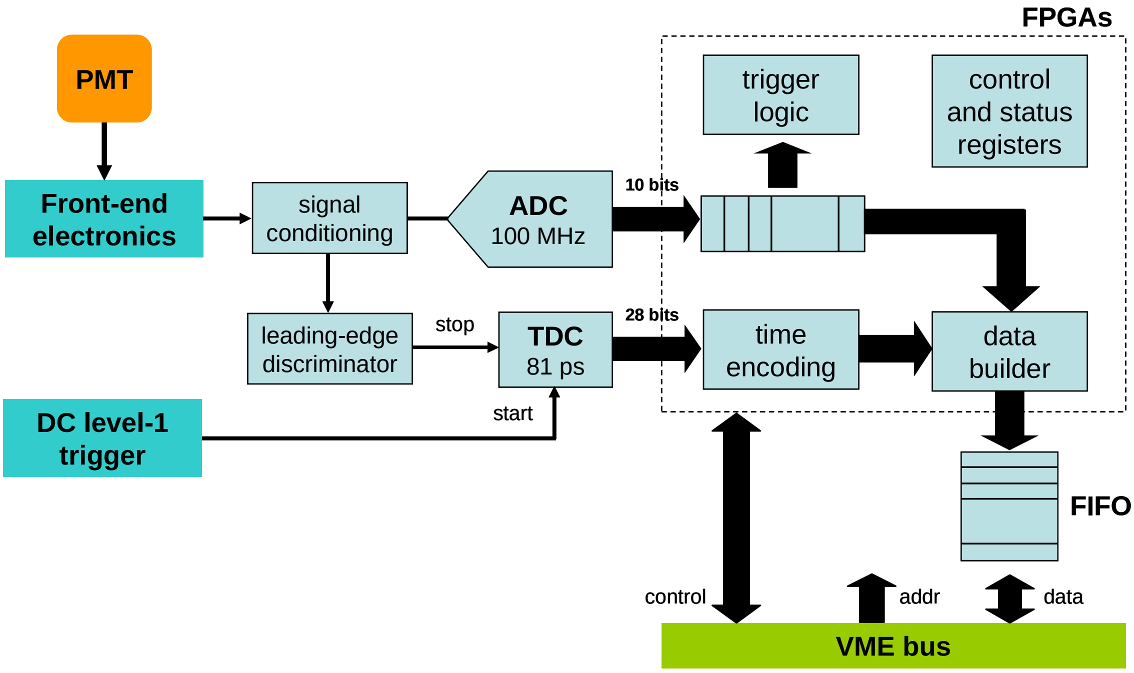


Figure 122 : Diagram of the showering muon electronics.

The MUSE modules will be constructed within the VME 6U standard. Each module will comprise eight analog channels (waveform digitizers) and eight time-difference channels. Each analog channel is composed of a signal conditioning circuit followed by a 10-bit pipeline ADC, operating at a sampling rate of 100 MHz. The time-to-digital conversion channel has a resolution of the order of 100 ps and an adjustable dynamic range. Besides the signal conditioning circuit, each analog input pulse will be applied to a fast leading-edge discriminator. The output of each discriminator will be used as the STOP signal for the TDC. A bank of FIFO (First In First Out) memories will act as a buffer for all the information (charge, time and waveform) generated in the MUSE module. All the functions related to control (registers), VME interface and digital signal processing (trigger, veto, etc) will be carried out by programmable logic implemented in high-performance FPGAs on the module. **Erreur ! Source du renvoi introuvable.** illustrates a preliminary mechanical view of one MUSE module, showing the principal devices.

Most of the activities in the MUSE modules will be synchronous with the 62.5 MHz clock provided by the trigger and timing system of Double Chooz. In order to receive this clock signal, and other control signals, a fan-out module is required to distribute the signals to the MUSE modules. Assuming a set of 138 PMTs to be used by the shower monitor (as presently defined) a total of 19 modules (1 fan-out module and 18 MUSE modules) is needed to build the system. Considering a commercial VME crate with 20 slots, the muon shower monitor will require only a single VME 6U crate.

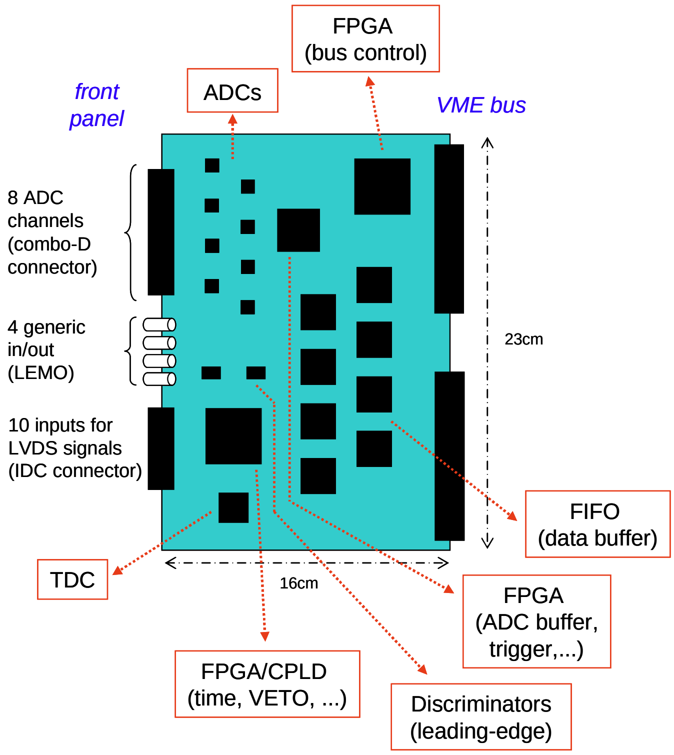


Figure 123 : Preliminary view of one MUSE main module**.**

For each event of interest (showering muon) in the central detector, the MUSE will store the following information per PMT:

STANDARD mode	WAVEFORM mode
integrated charge	integrated charge
relative time	relative time
-	digitized waveform

In **standard mode**, assuming one FIFO per channel, the data stored in one FIFO for a given event is organized as follow:

- *header*: one 32-bit word with a global identification (ID) of the PMT and other information
- *integrated charge*: one 32-bit word (floating-point format)
- *relative time*: one 32-bit word (floating-point format)

Assuming the system will monitor 138 PMTs, the total amount (T) of data stored for each event is:

$T = (3 \times 32 \text{ bits}) \times 138 \Rightarrow T \approx 1.7 \text{ kB}$

In **waveform mode**, again assuming one FIFO per channel, the data stored in one FIFO for a given event is organized as follow:

- *header*: one 32-bit word with a global identification (ID) of the PMT and other information
- *integrated charge*: one 32-bit word (floating-point format)
- *relative time*: one 32-bit word (floating-point format)
- *waveform*: seventeen 32-bit words (50 samples of the pulse at 100Hz sample rate)

Assuming 138 PMTs, the total amount (T) of data stored per event in waveform mode is:

$T = (20 \times 32 \text{ bits}) \times 138 \Rightarrow T \approx 11.0 \text{ kB}$

Since the muon electronics and the WFD share the same trigger source, and process information coming from the same detector, the MUSE DAQ software will send data for every event in the central detector. In most of the cases, the data will only contain a header stating that the event has not been processed because the minimum energy threshold that would characterize a showering muon event has not been reached. On the other hand, whenever an event is identified as a muon, besides the header, data concerning the integrated charge, the relative time, and the waveform (when requested) follow

It is worth noting that the MUSE modules will make use of state-of-the-art devices manufactured by worldwide-recognized companies. This policy reduces the overall cost, while keeping a reliable and high performance design. The modules will be developed and constructed in the UNICAMP and CBPF laboratories, including the fan-out custom module. The VME crate will be bought from regular vendors.

References

[1] Booth et al., Nucl. Phys. A119, 233 (1968); Abramov et al., Sov. J. Nucl. Phys. 23, 636, (1976); F. Ajenberg-Selove, Nucl. Phys. A490, 1, (1988).

[2] K.Zbiri, J.Martino, arXiv : hep-ph/0607179v2 21 Jul 2006.

[3] Toshiyuki Iwamoto, PhD thesis, Tohoku University, Japan, 2003.

[4] D. Reyna, Double Chooz Internal Document - PMT meeting, December/13/2006.

[5] D. Reyna, arXiv : hep-ph/0604145v2 Apr 2006.

[6] http://www.burle.com/cgi-bin/byteserver.pl/pdf/Photo.pdf , page 47.

[7] http://www.ppl.phys.chiba-u.jp/research/IceCube/pmt/dynamic/index.html

[8] B. Cheviz, Double Chooz Internal Document - PMT meeting, April/26/2007.

[9] see in this TDR, electronics chapter, the front-end boards description .

10.6. Slow control [4700]

version 2007/02/17
G. Horton-Smith
Kansas State University

10.6.1. Overview

The basic plan for the slow monitoring hardware is very simple: Dallas Semiconductor “1-Wire” chips connected with category 5e (CAT5e) wiring over long runs [1]. This hardware is fully described insection 2, including reliability tests and plans for packaging and encapsulation. Readout of the slow monitor data will be performed by a single computer at each lab, and data will be stored in a common PostgreSQL database [2]. Specifications and performance tests are described in section 3.

Interfaces with other systems and projects are outlined in section 4. The installation and commissioning plan is described in section 5. No significant safety issues exist in this system’s installation or operation, as explained in section 6. The schedule for purchasing, assembly, installation, and commissioning the system is given in section 7.

10.6.2. Hardware

10.6.2.1. Description

Quickly summarized, 1-Wire chips communicate using a shared “bus” of only 1 signal wire, plus a ground. The 1-Wire bus is an inverted-logic wired-OR arrangement, with pull-up current provided by the master and pull-down to logic-0 by the master or devices on the bus. Each 1-Wire chip has a unique 64-bit ID number lasered into it at the factory. (See Fig. 1.) The parts are very inexpensive and the bus emits very little EM radiation.
The chips can run in either “parasitic” or “powered” mode. In parasitic mode, the chips obtain their power from the signal wire when the bus is quiescent. Our plan is to run most of the chips in “powered” rather than “parasitic” mode for fastest network performance. Four conductors will be used in the CAT5e wiring for our “1-Wire” bus, corresponding to pins 1-4 on an RJ11 connector under the pin conventions
of the DS9490 USB–to–1-Wire adapter [3]. These pin assignments are shown in Table 1.

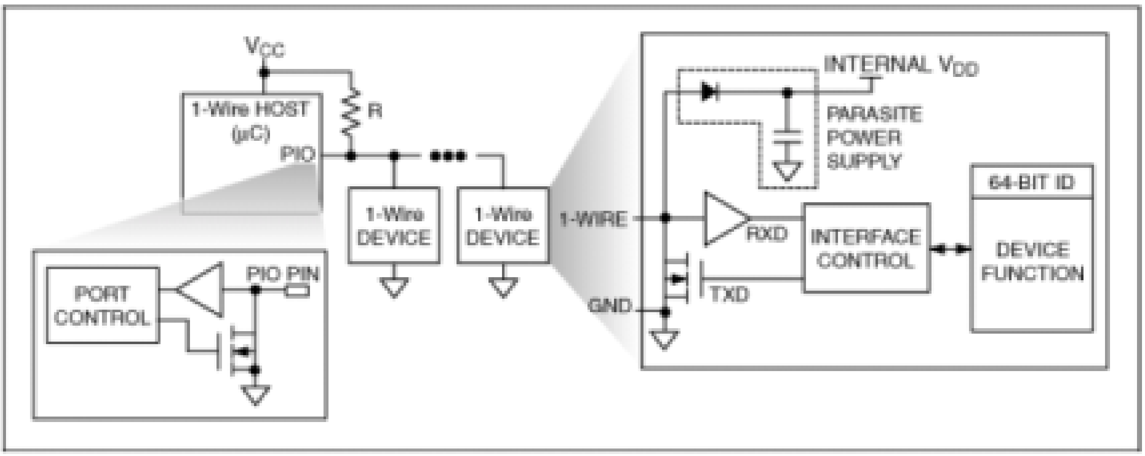


Figure 124 : ***Diagram showing 1-Wire bus, master, and devices. (From Dallas/Maxim*** *application note 3989.)*

Up to 548 1-Wire devices are foreseen (274 per lab), as detailed in Table 2. While in principle these could all be accommodated on a single network, we plan to have at least three separate networks in each lab, one for crate electronics monitoring, one for experimental hall monitoring, and one for detector monitoring, with branches in each network addressed through remotely-controllable 1-Wire “coupler” chips [5, 6]. (See Fig. 2.) Most individual modules will be connected via CAT5e cable, using standard RJ11 modular connections where needed. Chips used to monitor VME crate and card conditions will be built into the VME cards. The 1-Wire communication between cards will be through dedicated pins on the custom Double Chooz backplane, connected to the CAT5e 1-Wire network via a custom card containing a DS2409 coupler to avoid branches in the network..

Table 1: Pin assignments for RJ11 connector used for 1-Wire network, from [3].

Pin	Signal	Description
1	VDD	5VDC output
2	PWR GND	Power ground
3	OW	1-Wire Data
4	GND_OW	1-Wire Return
5-6	NC	No connection

Table 2: Slow monitor system device count.

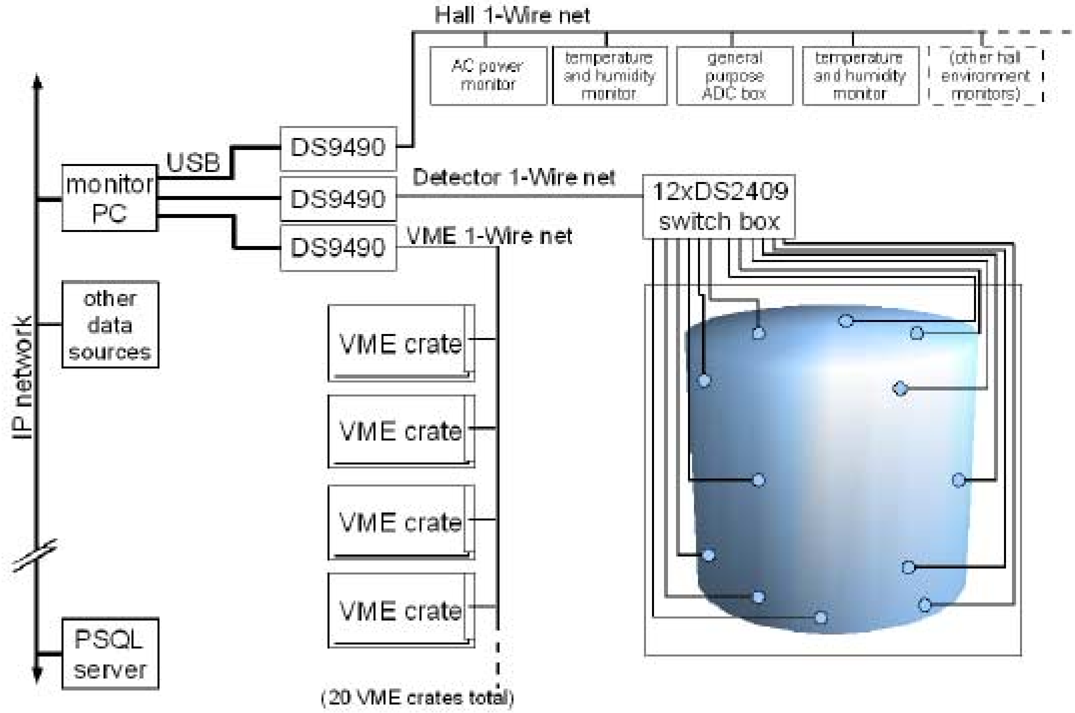


Figure 2: Monitor network topology.

10.6.3.Magnetic monitoring

Magnetic measurements will be made using units containing a Honeywell HMC 2003 three-axis magnetometer[7] read out by a 4-channel 1-Wire ADC chip; a schematic is shown in Fig. 3. The magnetometer has a sensitivity of 1 V/gauss; the practical range is -2 to +2 gauss. Honeywell claims an inherent sensitivity of 40 microgauss, corresponding to an output voltage precision of 40 microvolts. Dallas Semiconductor gives no noise specification for their ADC chips at all. Preliminary tests show RMS fluctuations of about 15 millivolts on the readout, well in excess of the digital resolution of the ADC. This is under investigation. Averaging 100 samples brings the RMS of the mean under 1.5 millivolts, corresponding to 1.5 milligauss (150 nT); averaging 2000 samples brings the RMS of the mean under 0.3 mV, corresponding to 300 microgauss (30 nT).

Ideally the magnetic monitors should be placed at the same distance from the walls as the equators of the PMTs. It would be possible to mount them directly on the PMT holders, but this is not optimal due to the distortion of the magnetic field by the PMT supports (and magnetic shielding, if any). Possibilities being discussed include attaching each monitor to a bar of acrylic spanning the space between two PMT holders or attaching the monitors to an acrylic bar directly bolted the L-shaped mounting rails on the buffer tank walls.

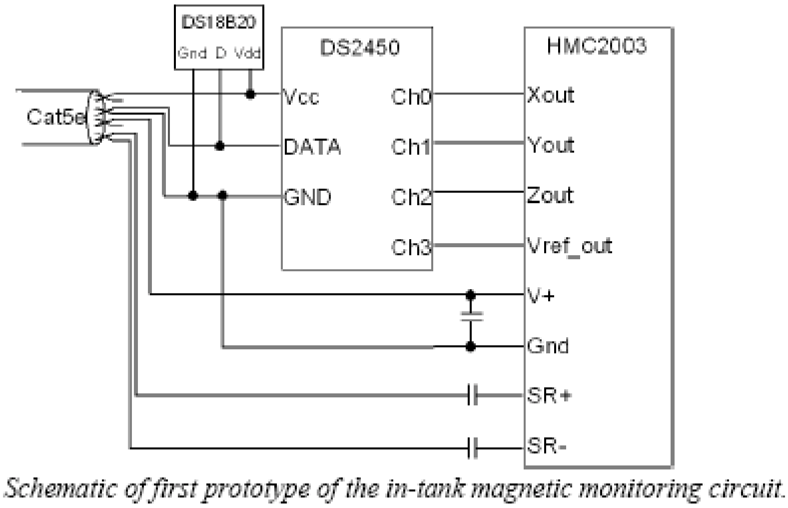


Figure 125 : schematic of first prototype of the in-tank magnetic monitoring circuit

10.6.4.Reliability tests

According to the manufacturer's reports and specifications, single-branch 1-Wire networks up to 300 m effective length will be reliable when some simple design guidelines are followed [1, 4]. Each 1-Wire chip adds 0.5 m of effective length to the network. Additional capacitance (e.g., from circuit board traces) adds one meter of length per 24 pF. In principle, we could instrument an entire lab on one branch.
As described above, our more conservative plan is to have at least three separate networks in each lab, with branches in each network addressed through remotely-controllable 1-Wire "coupler" chips [5, 6]. This improves reliability and eases diagnosis of any problems, and also lets any in-detector components be switched off during data taking if it proves necessary.

A few medium-scale tests with a dozen or so devices over 300 meters of CAT5e cable have been carried out. Undergraduate researcher Jim Black did many systematic tests in the summer of 2006, with encouraging results: see Jim's report and website [8]. Almost no devices failed except in their "infancy", suggesting that a simple burn-in test will be sufficient to weed out marginal chips. The few chips that did fail were victims of electrical surges that can be eliminated with improved electrical protection for devices at the end of long cable runs and use of libusb-based linux drivers for better control of voltage slew rates and error reporting.

Long-term reliability test of the hardware and software are on-going, with no apparent problem [9]. The prototype used for long-term testing includes the prototype magnetic monitoring unit shown in Fig. 3, and has been operating continuously for over two months with a readout frequency two orders of magnitude more frequent than intended in actual operation. A large-scale test with hundreds of devices will be carried out before the full system is bought.

10.6.5. Packaging and encapsulation

Transducer chips used to monitor the buffer region will be encapsulated in epoxy or acrylic certified by the appropriate detector subsystems groups as being oil-compatible and sufficiently radiopure. The current design calls for temperature and magnetic monitoring devices to be in one enclosure made of thermally conductive epoxy compound; in the event that this material proves unsuitable, it may benecessary to put the thermometers and magnetometers into separate packages. Chips used to monitor experimental hall environmental conditions will be packaged in modular boxes, and chips used to monitor VME crate and card conditions will be built into VME cards. The 1-Wire communication between cards will be through dedicated pins on the custom Double Chooz backplane, connected to the CAT5e 1-Wire network via a custom card.

10.6.6. Software

10.6.6.1. Low level readout

Dallas/Maxim provides Java software for readout of 1-Wire chips on Windows-based PCs. Although this might be sufficient, our experience suggests that better results will be obtained using libusb-based drivers on a Linux system for better control of voltage slew rates and error reporting [8]. Although this will entail a small amount of programming for each new type of device used, the benefits are considered worth the effort.

10.6.6.2. Database storage

We will sample store data for most channels at one minute intervals, maintain that data at full time resolution for at least one month, and then decimate the data to retain hourly averages for older data. A database storage structure has been devised that maintains quick access (less than 65 ms) to any single channel's history data independent of the number of channels or the time in history accessed, and equally importantly, keeps the single channel update time under 1 ms. This performance evaluation is based on tests done in March 2006 on a 2-year-old Linux server at Kansas State running PostgreSQL [2]. The database structure is shown in Table 3. The total storage requirements is less than 3.6 GiB for 5 years of data from 1000 channels.

Table 3: Double Chooz monitor database structure used for performance tests. The most important monitor history database tables are ChannelID *and* ReadoutHistory_N, *where* N *is a channel id number. The fields in each table are given below; the purpose of each table is indicated by its name.*

```
ChannelID:
 id   : integer      -- channel id code
 name : text         -- channel name
 unit : text         -- units of measurement

ReadoutHistory_N: (where N is a channel id number)
 time   : timestamp   -- time of readout
 value  : real        -- readout value at given time
 status : integer     -- status code

OneWireID:
 id             : integer   -- channel id code, same as in ChannelID
 owid           : integer   -- 1Wire device ID
 owsubch        : integer   -- 1Wire device channel number
 install_time   : timestamp
 uninstall_time : timestamp
```

10.6.6.3. Reliability tests

As mentioned above, a test was performed simulating the writing of 5 years worth of data to a database tovalidate the database design. In addition, on-going long term testing with actual data rates is being performed using a prototype system with a real thermometer, a real magnetometer-ADC combination, and several real external sources of data from computer-readable airport (METAR) weather condition reports in the vicinity of Manhattan, Kansas and Chooz, France [9]. As far as can be determined, the readout and storage system is reliable.

10.6.7.Interfaces

The critical interfaces are materials compatibility, radiopurity, penetrations of the vessel for in-tank monitors, electrical interfaces with the electronics crates, and computer support.

Materials compatibility: As mentioned previously, devices used to monitor temperature and magnetic field in the oil will be encapsulated in epoxy or acrylic. In addition, the cables to the devices will be in contact with the oil. These materials must be certified as compatible with the oil using procedures established by the responsible groups.

There has been some discussion of developing a device that could be deployed in the liquid scintillator (LS) by the calibration system to measure temperature, pressure, or other quantities in the target volume.
Any such device would be encapsulated in acrylic, possibly with epoxy seals, and would need to be fully certified for immersion in the LS. This is currently not considered a critical path item, and there is no schedule for its development.

Radiopurity: Although the mass of the in-tank devices is small, the devices will need to be counted before installation to be sure that they will not introduce unacceptable levels of radioactive background into the detector. Cable samples will also be counted.

Vessel penetrations: The cables to the devices in the oil need to penetrate the vessel in some way. The PMT group has agreed to pull the CAT 5e cables through the same cable paths as the PMT cabling. Note the US and Japanese members of the PMT group have experience pulling similar cables in KamLAND. (These cables were used for in-tank camera video and control signals, and were pulled through the same cable conduits as the PMT signal and HV cables.)

Electrical interfaces: The VME backplane lines to be used for the 1-Wire bus need to be identified before cards can be made. In addition, designing the 1-Wire circuit for the FE and WFD cards should be a shared responsibility between the slow monitor and electronics group, and populating the FE and WFD cards with 1-Wire chips should be fully within the electronics group's scope.

Computer support: Support is needed for a Linux-based slow control computer with available USB port at each lab, a server with PostgreSQL, and network connectivity between them.

10.6.8. Installation plan

Computer: A Linux-based computer with an available USB port must be installed and connected to the network in each experimental hall. This should be done in cooperation with the installation of computers for the DAQ system. For convenience, the computer should be located in the same area as the DAQ computers. If possible, this would be done at the same time as installation of the readout hardware; alternatively, a laptop can be done to commission the monitor hardware, with the permanent control computer installed later. Details will be finalized with the responsible parties at the time of hardware installation.

Experimental hall: It is assumed that the slow monitor CAT 5e cables can be strung in the same cable trays used for DAQ signals. The environmental sensors themselves are small and light enough that they can be securely affixed to walls or other existing structures by double-sided foam adhesive tape, light screws, or cable ties. Installation will be done on-site by Kansas State University personnel.

VME electronics: Installation will consist of plugging a board into each VME crate and attaching a cable. This installation can be done on-site by anyone in the electronics group at the time of electronics installation.

In-tank monitors: Installation of the monitors in the tank must be done during PMT installation. The installation procedure as currently envisioned is extremely simple: attach an acrylic bar securely to adjacent PMT supports, and attach the magnetic monitor package to the center of the acrylic bar.
Stainless steel nuts and bolts would be used to clamp acrylic pieces together to accomplish the fastening. The design and manufacture of the magnetic monitor mounts will be done at Kansas State University in consultation with the PMT group. Installation can be done on-site by the PMT installation crew, with KState personnel participating.

10.6.9. Safety issues

This system dissipates minimal heat and does not use any high voltages or currents, pressurized gas, moving parts, or dangerous chemicals. Installing the magnetic monitors in the tank will involve essentially the same activities as photomultiplier installation, but without any risks that may be associated with the vacuum tubes. Installing monitors around the lab may require use of a ladder and hand tools, requiring a normal level of physical dexterity and good judgment. In short, no special safety precautions are required for this system.

10.6.10. Schedule

The schedule for materials certification, design, purchasing, assembly, and installation for the monitoring system is shown in Figure 4.

In-tank monitors: The most critical point in the schedule is to have the in-tank monitoring packages for temperature and magnetic field ready before PMT installation begins in January 2008. Key milestones prior to installation are certification of the materials, finalization of the monitor package design, purchase of components, and assembly. The time between ordering and receiving parts for prototypes has been less than one week for all vendors, and all parts are single-vendor items; two months are allocated for obtaining all 12 magnetometers, ADCs, and thermometers for the full system. Electronic assembly and testing takes only a few hours per unit, and encapsulation will take less than a day, followed by a week of immersion for integrity testing, which may be done in parallel for all units. Material certification and design finalization can and should be completed by June 2007 in order to meet the technical board's schedule for preliminary readiness review. We thus have almost two months more time than we need to complete the in-tank parts of the monitoring system.

Experimental hall: The schedule for installation of the hall environmental monitors is flexible and may be guided by input from project leadership and other groups: later installation reduces the risk of inadvertant damage to the system during installation of other detector systems, while earlier installation gains the advantage of monitoring conditions during installation of other detector systems.

VME electronics: Ordering of the thermometer and ADC chips to be installed on individual WFD cards should be done in advance of WFD card production. The plan for this will be described in the electronics technical report. The custom cards containing the DS2409 "micro-net" switches plus ADCs and thermometers for overall crate monitoring (see section 2) are a K-State responsibility, with design and prototyping to be complete by June 2006, and assembly and delivery of 30 cards to be complete by December 2006. Installation of the VME crate electronics monitors will be coincident with VME electronics installation.

References

[1] "Guidelines for Reliable 1-Wire Networks", Dallas Semiconductor application note 148, Nov2001; http://www.maxim-ic.com/appnotes.cfm/appnote_number/148.
[2] PostgreSQL documentation may be found at http://www.postgresql.org.
[3] Data sheet for DS9490, Dallas Semiconductor, www.maxim-ic.com.
[4] Data sheet for DS2490, Dallas Semiconductor, www.maxim-ic.com.
[5] Data sheet for DS2409, Dallas Semiconductor, www.maxim-ic.com.
[6] "Advanced 1-Wire Network Driver", Dallas Semiconductor application note 244, May 2003; http://www.maxim-ic.com/appnotes.cfm/appnote_number/244.
[7] Data sheet for HMC 2003, "Three-Axis Magnetic Sensor Hybrid", Honeywell Solid State Electronics Center, revision 900151 02-04 Rev. E; http://www.magneticsensors.com/datasheets/hmc2003.pdf.
[8] J.E. Black, "How (not) to Fry a Thermometer: Testing a slow monitoring and recording system for the Double Chooz project", August 2006;

http://neutrino.phys.ksu.edu/~gahs/doublechooz/DC_SlowMRS/jeblack_1-wire-paper.pdf. See also http://www.phys.ksu.edu/~jeblack/.
[9] A limited web-based interface for looking at live data from the prototype test may be found at http://neutrino.phys.ksu.edu/~dchooz/monitor/plots.html.

Figure 126*: Monitoring subsystem schedule.*

	2007										2008
	3	4	5	6	7	8	9	10	11	12	1
In-tank:											
Electronics:	Order components		Assembly and testing								
Materials:	Materials certification										
Package:	Enclosure design				Full assembly and testing		Long term testing				Installation
Hall:											
All:				Order components		Full assembly and testing		Long term testing			Installation
VME:											
Crate mon:	Finalize design with electronics group			Order components		Full assembly and testing		Ship	(ready for installation ....)		
WFD cards:	Finalize design with electronics group			Order components and ship to Caen?					(ready for installation ....)		

Figure 4: Monitoring subsystem schedule.

11. Calibration systems [5000]

11.1. Overview

11.1.1.Main Goals

The main goals of the calibration system are

- to determine the relative ν_e detection efficiency between the near and far detectors to within 0.5%; and
- To determine the e+/γ energy scales to 1% and the n energy scale to 25% in each detector.

The relative detection efficiency is the ratio of the inverse beta decay detection efficiencies for the near and far detectors. The relative efficiency uncertainty budget, based on the experiment LOI [1], includes contributions from deadtime (0.25%), the cut on the delayed subevent energy (0.2%), and the cut on the time between the prompt and delayed subevents (0.1%). No other significant contributions to the uncertainty are anticipated.
The positron energy scale (which includes the annihilation gammas) and the neutron energy scale are to be determined within 1% and 25%, respectively, on an absolute scale for each detector. (Since the energy scales will be measured in the same way for each detector, the relative uncertainties in energy scale between the near and far detectors should be small compared to 1%.) This ensures that energy scale uncertainties will not negatively impact the experimental sensitivity. The neutron energy scale must be measured to help understand and subtract the fast neutron background.

11.1.2.Calibration System Features

The Double Chooz calibration system will include the following features in order to achieve the calibration goals stated above in a timely way.

1. Overlapping methods to determine calibration constants
2. Deployment of same sources in both detectors
3. Wide range of source deployment positions
4. Fixed sources for frequent monitoring
5. Detailed detector simulation of sources and calibration hardware
6. Well-developed algorithms for obtaining calibration constants from calibration data

11.1.3.Calibration Quantities and Sources

The basic quantities which the calibration system should directly probe may be delineated as follows:

1. The energy scale in each scintillator volume
2. Light transport across the regions and boundaries between the detector center and PMTs
3. PMT–by–PMT light collection (including quantum efficiency)
4. PMT–by–PMT gain
5. PMT–by–PMT timing
6. □ detection efficiency througout the target and gamma catcher
7. □detection efficiency throughout the target and gamma catcher
8. Detector deadtime

The calibration program must also provide the function of stability monitoring in order to provide interpolation of calibration measurements between detailed calibrations and to determine when the detector performance has changed to the extent that another detailed calibration is needed.
The calibration sources which will be used to measure these quantities and to carry out stability monitoring are sources, tagged and untagged n sources, and light flashers (LEDs and lasers). We will also take advantage of the cosmic background for detector calibration.
A breakdown of the calibration sources and the quantities they will be used to measure is shown in Figure 1.

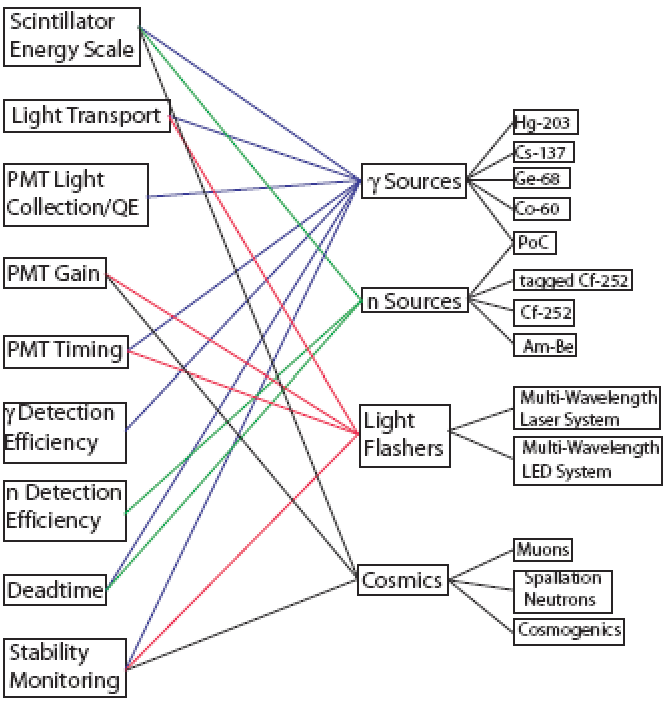


Figure 1:

Figure 127 Main topics to be addressed by calibration measurements and the sources to be mainly used in the measurements

11.1.4.Deployment Systems

The calibration sources will be deployed in a variety of ways, as schematically shown in Figure 3. All sources except the LEDs will be deployable on the target z–axis system. All γ sources and untagged η sources will be deployable throughout the target on the articulated arm and in the gamma catcher and buffer regions along guide tubes (wire source deployment systems). The LEDs will be fixed to the buffer wall. The deployment accuracy required is 1.5 cm for measurements of the energy scale. For measurements of the neutron detection efficiency, the accuracy is dependent on the source and distance to the target wall. As one example, for an Am–Be source, the distance between the source and the target wall must be known to within 1 mm if the source is nominally 5 cm from the wall, within 2 mm if the source is nominally 10 cm from the wall, etc. These results are obtained requiring that the product of the uncertainty in the deployment position and the magnitude of the slope of the efficiency be less than 0.25%. Figure ? shows the detection efficiency in the gamma catcher as a function of x for z = 0.

11.1.5. Calibration and Monitoring Plan

During detector commissioning, the PMT system will first be checked and debugged using LEDs. The PMT gains will then be set using the LEDs and/or the laser system. The final task of calibration for commissioning will be a global check using a neutron source deployed along the z–axis.
Once each detector is stable, a full initial calibration will be carried out deploying all sources in all regions. In the case of the near detector, which will come on–line some time later than the far detector, it will be considered to re–calibrate the far detector in synchronization with the near detector calibration.
Between periods of full calibration, the detector will be monitored using LEDs (nominally once/day) γ source deployments at a few positions along the z–axis and within the gamma catcher (nominally once/week), and naturally–occurring backgrounds (radioactivity and cosmics) in the normal data stream. A full or substantial calibration with radioactive sources and light flashers will be carried out whenever the performance of one of the detectors changes to the degree that previous calibrations and monitoring data no longer suffice to reconstruct the data and estimate efficiencies to the accuracy needed.

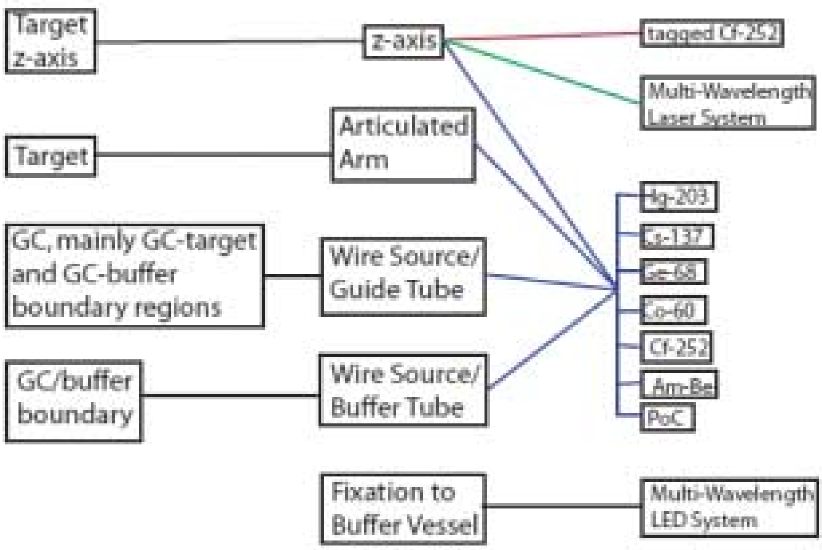


Figure 128 : Range of deployments for each deployment systems and the sources which they will be used to deploy

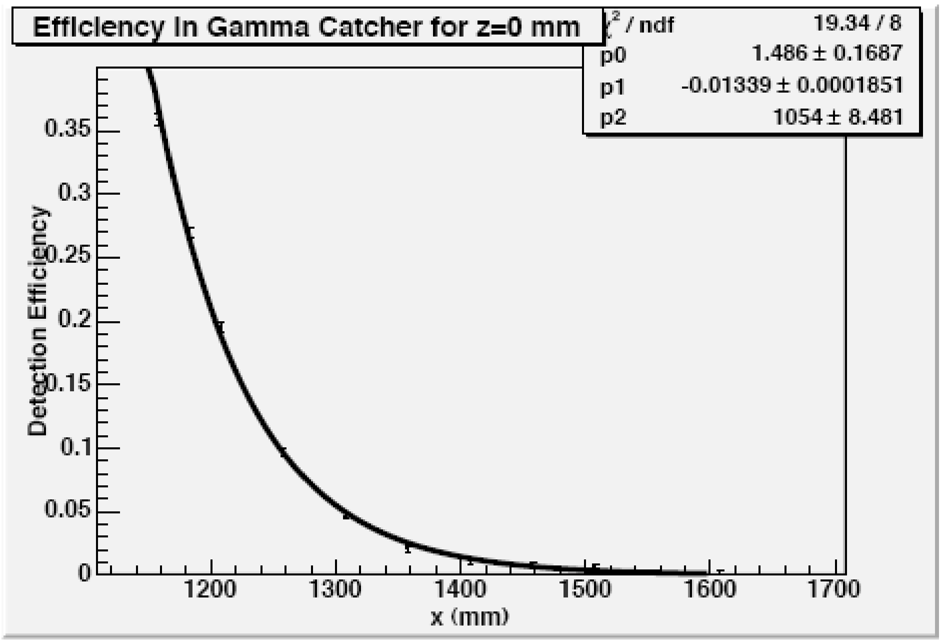


Figure 129: Neutron detection efficiency versus x for z = 0 in the gamma catcher. The curve is a simple exponential fit to the data.

11.2. Z-Axis System

11.2.1. Purpose

The purpose of the Z-Axis Deployment System (ZADS) is to deploy calibration sources into the target region along the vertical axis extending down from the chimney. The deployment systems utilized by the near and far detectors will be identical.
ZADS must be designed to accommodate gamma and untagged neutron sources. The laser and tagged neutron sources will be deployed manually, since their requirements are different and the frequency of deployment is expected to be much less. ZADS will be designed for daily use, even though such frequency may not be necessary in the end.

11.2.2.System specifications

The system must be capable of positioning sources with an uncertainty less than 1.5 cm. In practice it is likely that much better resolution can be achieved, however position resolution below the source size (typically a few mm) is not useful.
The materials and geometry of ZADS are chosen to minimize uncertainties in the corrections for shadowing and absorption. Each material used must be compatible with all elements of the detector environment to which it is exposed. The requirements are set such that direct exposure of stainless steel to the scintillator in the tank must be absolutely avoided, and that exposure of stainless steel to vapour must be minimized.
Furthermore, measures must be taken to protect the detector from radio-contamination. Therefore ZADS must operate in a nitrogen environment inside the glove box. In addition, the process of deploying the calibration system must not affect detector performance and the

setup of the calibration deployment system cannot be awkward or time-consuming, hence the system must be largely automated and must operate with the PMT's on. It is also desirable that EM noise be minimized during operation to reduce impact on data while the motor is running.

11.2.3.System concept

It is planned to have a simple motor and windlass scheme similar to that in KamLAND, where it has worked well. This consists of a stepper motor mounted inside the glovebox. The motor will be mounted in a custom-built housing to avoid contact with the scintillator vapor.
The shaft will extend out of the housing through a Teflon sleeve to turn a "fishing" reel. A shaft encoder in the housing will provide positive motor position indication. There may also be an additional shaft encoder on the reel to provide redundant backup and a "sanity check". Teflon-coated stainless-steel wire will be wound on the reel, pass through a pulley, and terminate with a weight and source attachment on the "business end". The line should be marked with position indicators (gold strips were used in KamLAND) to provide manual position indication to calibrate the encoders.
System control will be via a commercial software package run on a controller (or laptop) external to the glovebox. Cable positioning will be via a combination of the encoder and the use of visible fiducial marks on the cable itself. It may be useful to mount an IR camera inside the GB for observation of the deployment. In order to ease operation, the positioning software will accept target positions in either glove box (GB) or detector coordinates. The motor has an internal torque limiter to prevent potential damage to the detector vessel, wire or source attachment. In addition, the motor can be shutdown immediately by the operator via a panic button.
The sources will be mounted manually to the weight at the end of the cable with an inflexible and protected attachment. The mounting will be performed in a transfer box inside the glovebox with the deployment neck closed.

11.2.4.Potential dangers

Potential dangers are:

1. The weight attached to line has the potential to damage the target vessel should it come off during deployment. This must be absolutely prevented and tested thoroughly to verify reliability.

2. Loss of the source inside the detector would shut down data taking. There is no easy way to recover a lost source, and so this must also be absolutely prevented and thoroughly tested.

3. The ZADS must be physically incapable of hitting the bottom of the detector with the source.

4. The motor must be sealed as much as possible to prevent contact with scintillator due to compatibility considerations.

11.2.5.Major design considerations not yet resolved

1. what should be the mass of weight on end of line

2. how to connect sources to the line (including how to accomodate the same sources used in the wire driver)

3. software operating system (LabView or other)

4.size of line (should be very much over-designed)

11.2.6.Responsible institution

The z-axis system will be designed and built at Argonne National Lab, with equipment funds provided by U.C. Davis and/or LLNL.

11.3. Articulated Arm

11.3.1.Introduction

This section presents a conceptual design for an articulated arm source system for the target area of the Double CHOOZ experiment. This design is a first attempt at examining the design parameters and constraints on such a system. This initial design was driven by the requirement to minimize the material used in the system and the deflections of the system were a secondary concern. Also, at this time the amount of coverage that is needed within the target area is not known and this will greatly influence the design of the source system.

11.3.2.Description

The arm is basically a 3 bar linkage. It consists of the main support rod (12 mm diameter aluminum rod) which runs down the center of the target area. The source is deposited at the end of an arm that is a 6 mm diameter aluminum rod. The arm is hinged to the support rod.
A nylon cable (2 mm diameter) forms the third leg of the linkage and connects the arm to the support rod. A sliding sleeve on the main support rod supports the nylon cable. Figures 4, 5 and 6 below show the basic outline and reach of the system. By raising or lowering the sliding sleeve on the support rod it is possible to move the source through a range of positions. A cable (such as used on bicycle brakes) would be used to move the sleeve up and down. Also, by rotating the support rod about its axis it is possible to sweep 360 degrees with the source.

Range of motion
The arm can be rotated about the axis of the support rod to get 360 degrees coverage at any given position of the source. The entire target area can be covered by the source by lowering the support rod to various depths and varying the radial position of the source. However, the top of the cylindrical target area cannot be covered completely. It is difficult to reach the outer radius at the top of the cylindrical target area because the nylon cable runs into the top of the cylinder. The initial design of the arm had the nylon cable attached to the arm at 300 mm from the support rod. Whereas the chimney is not defined at this

time it was felt that a 600 mm diameter chimney was a possibility. If this were the case then it would be possible to recess the nylon cable into the chimney with the arm at 90 degree, thus allowing for full coverage of the target area. As discussed below, however, the deflections of the arm might dictate that the nylon cable be located further out along the arm. In this case it would not be possible to cover the outer radius of the target area at the top.

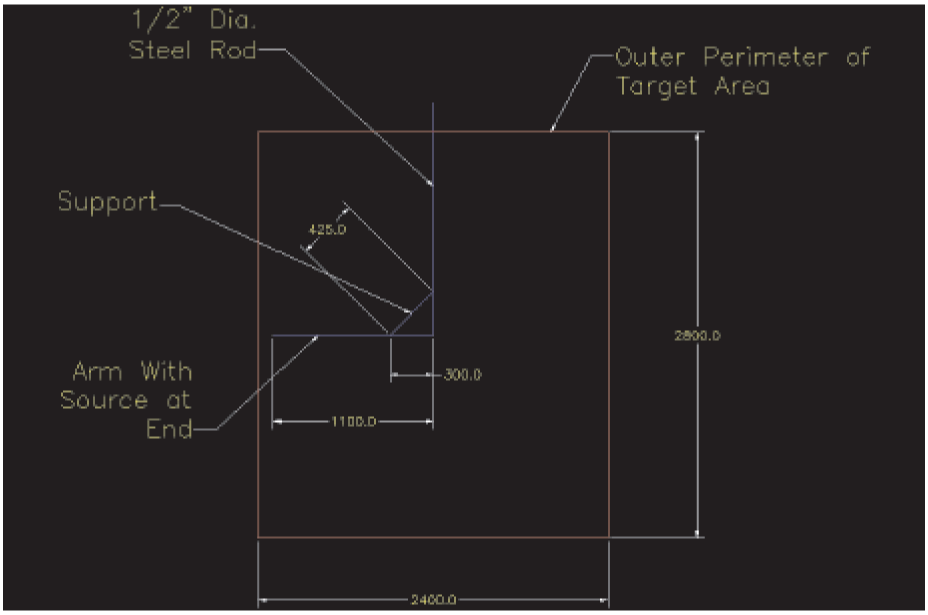


Figure 130 Basic dimensions of target area and articulated arm

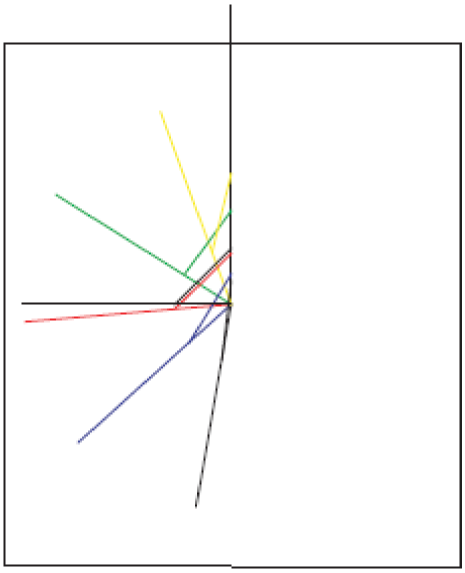


Figure 131 : Range of motion of the articulated arm

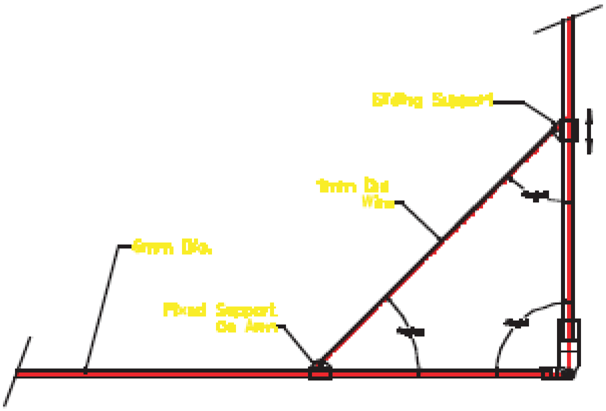


Figure 132 : Details of connections

<u>Deflections of Source</u>
The deflections of the source are due to two different affects. First, the sag of the arm and, second, the bending of the support rod due to the moment created by the weight of the arm offset from the axis of the support rod. A hand calculation (see Table 1.3.2)was done on several geometries to gain an initial understanding of the deflections. The weight of the source was neglected because it was felt that it was small compared to the weight of the structure.

Location of Nylon Cable (mm)	Counter Balance	Source Deflection (mm)	Rod or Tube
300	No	42	Rod
300	No	30	Tube
300	Yes	25	Rod
600	No	21	Rod
600	Yes	6.5	Rod

When the nylon cable is located 300 mm along the arm from the support rod and the length of the cable is 425 mm so that a 45 degree angle is formed between the cable and arm when the arm is at 90 degrees, the source sags 42 mm. When the nylon cable is moved further out along the arm to 600 mm while maintaining the 45 degree angle between the cable and arm the deflections drop to 21 mm.
Locating a counter balance as shown in Fig 7 can further reduce the deflections. This counter balance eliminates the deflections due to the bending of the support rod due to the overhanging weight of the arm. The problem with a counterbalance is that is introduces additional mass into the system. In the initial calculations a counter balance of 2.4kg was located 300 mm from the support rod. This counterbalance reduced the deflection of the source to 25 mm when the nylon cable was at 300 mm and down to 6.5 mm when the nylon cable was located at 600 mm.
A final calculation was done in which tubing was used for the structure rather than solid rods. Without a counterbalance and with the nylon cable at 300 mm along the arm the deflection of the source was 30 mm.

11.3.3.Conclusions

This section describes the design of an articulated arm for placing a radioactive source within the target area. The deflections of the structure can be significant. These deflections can be reduced in four ways:

- Increasing the diameter/size of the components of the structure
- Using a more efficient shape such as a tube instead of solid rods.
- Changing the position of the nylon cable
- Adding a counterbalance.

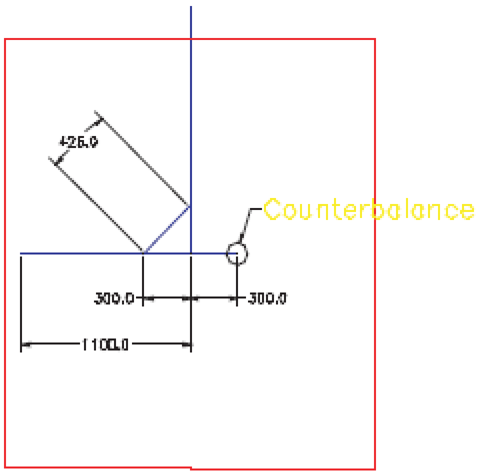


Figure 133 : Details of connections

11.4. Wire Source Deployment System

11.4.1.Hardware Components

The main hardware components are

1. Guide tube assembly, one per detector. In the gamma catcher itself, the assembly is a single formed tube supported by fixtures attached to the acrylic module walls and support ribs. Flexible tubing is used to route the guide tube path through and between boundaries leading up to the chimney exit into the clean area for the calibration deployment glovebox. A schematic of the guide tube path is shown in Fig 8.

2. Wire assembly with source connector at one end. The wire assembly is comprised of a fine gauge tube through which a wire is threaded. Several designs for the source connector are under test. Four wires will be fabricated, one for each detector and two spares.

3. Each detector will have a wire driver, comprised essentially of a wire spool, motor drives, encoders, and a computer interface. Three drivers will be built, one per detector and a spare.

4. Control PC, one per detector. The PC should be located in the glovebox clean room. The PC could be shared with other calibration systems.

5. Gas manifold, located in glovebox clean room, for purging the guide tube while system is not in use.

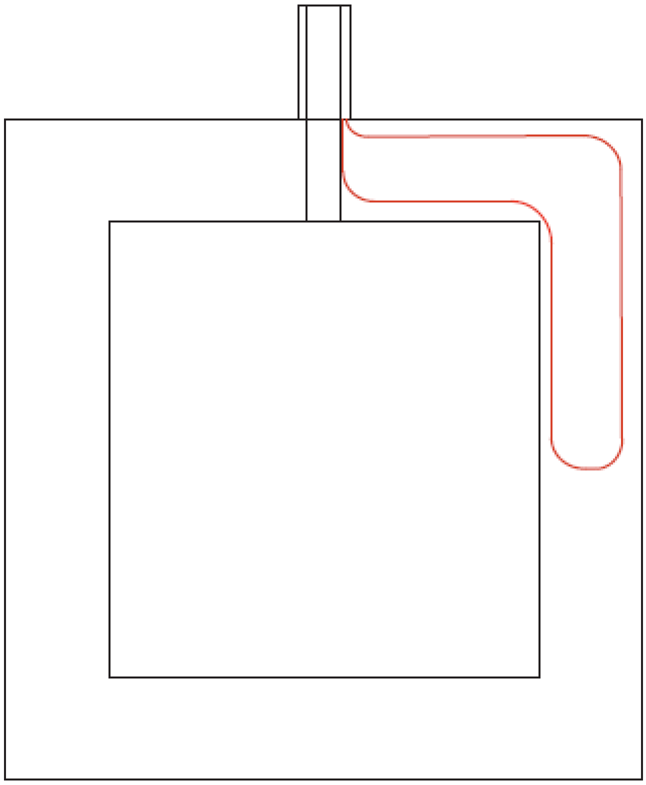


Figure 134 : Schematic of guide tube layout in the gamma catcher

11.4.2.Specifications

The main specifications for the wire source deployment system are as follows:

1. Guide tube path crosses representative regions of the gamma catcher.

2. Guide tube diameter is large enough to accomodate compound neutron sources, e.g. Am–Be and Po–C, without causing an undue amount of shadowing.

3. Guide tube double–ended for source recovery in case of wire failure.

4. Guide tube layout in gamma catcher known to 2 mm.

5. Uncertainty in absolute position of source along the length of the guide tube path is less than 1 cm and uncertainty in relative position is less than 3 mm.

6. Maximum force transmitted to wire by driver is 3 N.

7 Mechanical and chemical compatibility with acrylic and scintillator.

11.4.3.Interfaces

We list the other detector components which are impacted by the installation and operation of the wire source deployment system.

1. Acrylic module and chimney, to which the guide tube in the gamma catcher is attached.

2. Boundaries between the interior of the gamma catcher and the calibration glovebox clean area. The guide tube path must pass through and run through these boundaries.

3. Untagged gamma and neutron sources, which must be attached to the wire for deployment in the gamma catcher region.

4. Calibration glovebox clean area, in which the guide tube terminates and in which the wire driver, gas purge system, and calibration PC are mounted.

5. Power and network connections for wire driver and calibration PC used to control wire driver.

11.4.4.Compatibility tests

The following tests are required:

1. Check that acrylic immersed in LS does not fail under intermittent stresses of wire source driver. This test has been completed with results (to be) reported at the March 2007 collaboration meeting in Madrid.

2. Check chemical compatibility of SS304 tubing with gamma catcher scintillator. The test will be done by mechanics group using clean samples provided by the UA group.
To be done.

11.4.5.Design status

11.4.5.1. Guide tube assembly

Several prototype and compatibility tests must be completed before the design for the guide tube can be completed. These include

1. Measurement of wire driving forces required. Status: This test has been completed with the results reported in bama.ua.edu/ busenitz/dccal/chooz jun2006/guidetube.ppt.

2. Test of mechanical compatibility with acrylic. Status: This test has been completed with results (to be) reported at the Madrid meeting.

3. Check that guide tubes can be formed to required precision. Status: Completed with results reported in bama.ua.edu/ busenitz/dccal/wire report.pdf.

4. Test of compatibility of SS304 guide tube with gamma catcher scintillator. Status: To be done although no incompatibility is anticipated.

5. Feasibilty test for fabrication of minitature Am–Be source. The result of this test will have a strong influence on the diameter of guide tube. Status: Successful test of procedure using uranium oxide and beryllium. Awaiting delivery of americium oxide.

In addition, simulation studies are needed to optimize the guide tube path. It is expected that past simulation of gamma and neutron sources in the gamma catcher and ongoing studies on staged calibrations will provide adequate information on this question. Preliminary designs have been drawn up for fixing the guide tube to the acrylic module and how to route the guide tube path across and between boundaries. After discussion fo these designs with collaborator in the mechanics group, revisions will be made and prototype studies carried out as needed.

It is expected that the complete design for the guide tube assembly can be finalized in May 2007. The main source of uncertainty in the design schedule is the feasibility test for fabrication of miniature compound neutron sources, which depends on the schedule for delivery of americium oxide. It may be necessary to complete the design without the benefit of the results of this feasibility design, in which case the choice of guide tube diameter will have to be made to accomodate larger source diameters in case the feasibility test fails.

11.4.5.2. Wire

Two rounds of wire fatigue and wire–source interface tests has been completed with the results from the second round of studies (to be) reported at the Madrid meeting. The robustness of the wire and wire–source connection design has been demonstrated. The current design will be reviewed with collaborators and possibly iterated in minor respects. The design of the wire and wire–source interface will be finalized by the end of Summer 2007.

11.4.5.3. Wire Driver

We have a complete set of drawings for drivers built for Tevatron and LHC experiments. This design must be modified to allow the capability to deploy more than one source with a single driver.

The preliminary definition of the wire driver footprint in the calibration glovebox clean room will be carried out by June 2007. Modifications of the wire driver design for Double Chooz will begin by the end of Summer 2007 and will be completed (prototype tests included) by the end of Winter 2008.

11.4.5.4. Gas, Power, and Computer Control

The purge gas system will be designed in parallel with the guide tube assembly. The definition of the power and computer control will be carried out in parallel with design of wire driver.

11.4.6.Responsible Institution

The wire source deployment system will be built by the University of Alabama.

11.5. Radioactive Sources

11.5.1.Hardware Components

We categorize the radioactive sources as gamma sources or neutron sources. The gamma sources are primarily β–emitters, for which the β is essentially absorbed in the encapsulation.

The minimal set of gamma sources is Hg–203, Cs–137, Ge–68, and Co–60. The neutron sources emit neutrons, either as a result of fission (Cf–252) or as a result of (_,n) reactions (Am–Be, Po–C, etc.); the neutrons are usually accompanied by high–energy gammas. The minimal set of n sources will be untagged Cf–252 and Am–Be sources and one tagged Cf-252 source. Po–C is being considered as an additional source to provide further data for reduction of the systematics in calibration of the detector response to neutrons and for providing a high–energy gamma calibration point (6.1 MeV).

The gamma sources and untagged n sources are intended for use with all deployment systems, while according to present plans, the tagged Cf–252 source will be deployed only in the target along the z–axis. In principle, only one set of sources is needed for the experiment, but frequent use of some sources for detector monitoring may make it practical to build several sources each for 1–2 of the gamma emitters and one of the neutron emitters.

For relatively short–lived isotopes such as Hg–203, several sources will have to be sequentially fabricated over the course of the experiment.

11.5.2.Specifications

To reduce the risk of radio–contamination of the experiment, the sources must be doubly encapsulated except explicitly excepted. For mechanical robustness and maximum chemical compatibility, the outer encapsulation should be series 304 (ASME standard) stainless steel.

A protocol must be defined and rigorously applied for certifying the radio–integrity of the sources before they are allowed to be used. For universal deployment, the gamma sources and untagged n sources must lie within a cylindrical envelope a few mm in diamter and about 1 cm in length. The constraints on size will become more sharply defined once the guide tubes for the wire source deployment system are specified.

The activity of the sources will be as high as allowed by applicable safety regulations and DAQ capabilities in order to minimize the time required for calibration.

11.5.3.Interfaces and Auxiliary Facilities

The sources must be connectable to each of the relevant deployment systems. In the target, these are the z–axis system for all sources and the articulated arm for the gamma and untagged sources. Further, for deployment of sources in the target, an additional (temporary) layer of encapsulation may need to be added to isolate stainless steel from the

Gd–loaded scintillator. For deployment in the gamma catcher and buffer, the gamma and untagged n sources must be connectable to long wires.
Signal and power cables are needed for deployment of the tagged n source.
A clean area is needed near each detector for source storage and preparation. This room should be stocked with clean room clothing for workers and with chemicals and supplies for source cleaning. The area needed for storage and cleaning is estimated at 10 m2

11.5.4.Design Status

The design of the gamma and untagged n source capsules is driven mainly by requirements related to the wire source deployment system:

1. Several rounds of design and prototype tests have been carried out for the wire–capsule connection, resulting in a promising design in which a bolt, which is attached to the wire by a ring, is screwed into the capsule (Figure 9).

2. In parallel, a R&D program is underway to build miniature compound n sources, e.g. Am–Be, that can be deployed through small–diameter guide tubes.

3. Capsule design is expected to be completed by end of summer 2007 in parallel with final definition of the guide tubes and wires.

As already mentioned, additional requirements may have to be met to deploy sources in the target. Exploratory discussions with the z–axis deployment system group have begun. These requirements, if any, will be finalized in parallel with the design of the z–axis system.

Source activity limits are under investigation. These limits will be defined by the Chooz meeting in June 2007.

The above remarks on status apply mainly to the gamma sources and the untagged n sources. The design status of the tagged Cf–252 source is as follows. The initial design will be taken from the Chooz experiment, in which such a source was successfully used. What remains to be done is to confirm the compatibility of the source with the target scintillator, define how the source will interface to the target deployment systems, and lay out the power and signal interfaces. The design of this source should be completed in concert with the designs of the glovebox and z–axis system.

Figure 135 : Wire–capsule connection for the wire source deployment system

11.5.5.Responsible Institution

The untagged sources will be built by the University of Alabama. The tagged Cf–252 source will be built by the Kurchatov Institute.

11.6. Laser System

The laser calibration system measures the PMT gains, charge response funtions, optical medium properties, relative quantum efficiencies, PMT time offsets, and the effective speed of light.

11.6.1.Hardware Components

The main hardware components for the laser calibration system are:

1. Laser

2. Attenuation filters

3. Optical fiber

4. Fiber deployment reel

5. Optical diffuser

11.6.2.Specifications

The specifications for the laser calibration system are as follows:

• Dynamic range: the light level at any given PMT must cover a wide range of intensities, from much below the single photoelectron (PE) level, to just above saturation, i.e., O(100) PE.

• Narrow pulse timing: the intrinsic time width of the light pulse emerging from the laser must be small compared to the timing resolution of the PMTs (about τ = 1.5 ns for the 10-inch Hamamatsu PMTs) for all timing-related calibration measurements.

• Light output profile: for an accurate characterization of the optical properties of the medium/PMTs the angular distribution of the light emerging from the laser in the target volume should be well known (either isotropic – ideally, or well measured).

• Widely separated wavelenghts: two different laser wavelengths should be used in order to probe the response of the optical media and PMTs at different excitations. In particular, one wavelength should be in the UV in order to excite the scintillator, while a second one should be above the scintillator absorption limit, i.e., about λ> 440 nm.

• Deployment positions: these positions, assumed to be all along the z-axis of the detector, have to be known to an absolute accuracy of better than 10 cm, and a relative accuracy of better than 1 cm.

• Frequency: the repetition rate of the laser must be high enough to allow a full calibration of the detector PMTs in a reasonable amount of time, i.e., of the order of hours.

11.6.3.Interfaces

• DAQ signal
• External trigger
• Z-axis deployment system

11.6.4.Design Status

The primary candidate for the UV wavelength is currently the Spectra-Physics VSL-337 nitrogen laser, with a wavelength of Λ = 337.1 nm. It has a very narrow bandwidth (0.1 nm) and the pulse energy of 120 μJ is enough to deliver more than hundreds of PEs at all PMTs after significant attenuation filters. This laser is well suited for the PMT gain measurements and also for the PMT charge response functions, P(q; μ). On the other hand the pulse timing is quite wide (FWHM = 4 ns), which makes this laser inappropriate for any timing measurements. The maximum repetition rate of this laser is 20 Hz, which implies that the full gain calibration of the PMTs would take about 6 hours – assuming that a 1% gain measurement is sufficient. Since all of the UV light is absorbed by the scintillator no diffuser is needed in this configuration. However, a careful modelling of the shadowing effects induced by the bare fiber need to be understood and/or measured.

The second laser is a PicoQuant diode laser LDH-P-C-470(B) driven by the PicoQuant pulsed diode laser driver PDL-800 B. The pulse width is extremely narrow (FWHM = 50- 70 ps) and thus this laser is well-suited for all timing measurement. The repetition rate can go all the way up to 40MHz, while the amount of light can be directly adjusted from the driver unit. This laser will be using a diffuser flask.

11.6.5.Responsible Institution

The laser flasher systems will be built by the University of Alabama.

11.7. The Embedded LED Calibration System

11.7.1.Motivation

The purpose of the embedded LED system is to provide a permanent, non-intrusive tool that permits frequent calibration and monitoring of the whole detector. It will allow us to probe PMT gain, timing and charge linearity, as well as light-transport properties across the detector. As the system will be permanently installed and is foreseen to be used at least once per day, it will enable us to detect short-term variations, and will also inform the decision to carry out a full re-calibration of the detector.

The LED system will inject light into the detector at several well-known positions inside the buffer tank and the inner veto. LEDs are highly stable devices, with negligible pulse-to-pulse variation. Moreover, the system will contain no moving parts, and so should be both robust and reliable. It is expected to become a useful debugging tool. The systems at the near and the far detectors will be identical.

11.7.2.System Specification

The system should provide light sources at different wavelengths, as the optical properties of the detector are known to vary with wavelength. One of the LED wavelengths should be long enough not to excite the scintillator, so as to permit timing studies of the PMT readout. The light pulses from the sources should be short enough not to have a strong influence on the arrival times of the photons at the PMTs. The dynamic range of the light should cover a fraction of a p.e. up to a few hundred p.e., in order to allow charge-linearity calibrations. Each PMT should be usefully illuminated from at least two different light-injection points, so as to permit bootstrapping of the timing measurements, and also to provide redundancy.

As the LED system will be in frequent use, it must be possible to operate it during normal data taking. The data volumes produced must be compatible with the overall experiment requirement of no more than about 10 GB per day.

The components installed inside the detector vessels must be chemically compatible with the liquids in which they will be immersed, and must also comply with radiopurity requirements.

11.7.3.Hardware Components

For each detector, the LED system will consist of two rack-mounted electronics boxes (known as pulser boxes), optical fibres with suitable termination, and a PC for system control. The LEDs will reside in the pulser boxes, and the light will be fed from the LEDs to the lightinjection points inside the detector via the optical fibres; see Figure 1.7.3 below.

The pulser boxes will house, in addition to the LEDs themselves, their control and driver circuitry; PIN photodiodes and their driver and readout circuitry; a built-in power supply; and panel-mounted connectors for the optical fibres as well as for control and readout signals. There will be three LEDs of different wavelengths per light-injection point; the baseline choice of wavelengths is ca 385 nm, ca 425 nm and ca 470 nm. The light from each set of LEDs will pass an optical fan-in and illuminate the ends of two optical fibres (one of which is spare) and one PIN photodiode. The purpose of the PIN photodiode is to provide a reference light-level readout. The pulser boxes will, if feasible, be thermally insulated, in order to provide maximum operational stability for the LEDs.

The optical fibres will run from the pulser boxes in the electronics racks and terminate inside the detector. 32 light-injection points are currently foreseen for the inner detector. These are distributed in two staggered rings of ten points around the wall of the buffer cylinder, plus six points each at the top and the bottom of the buffer tank, as shown in Figure 1.7.3.
The number and distribution of light-injection points in the inner veto is under study.

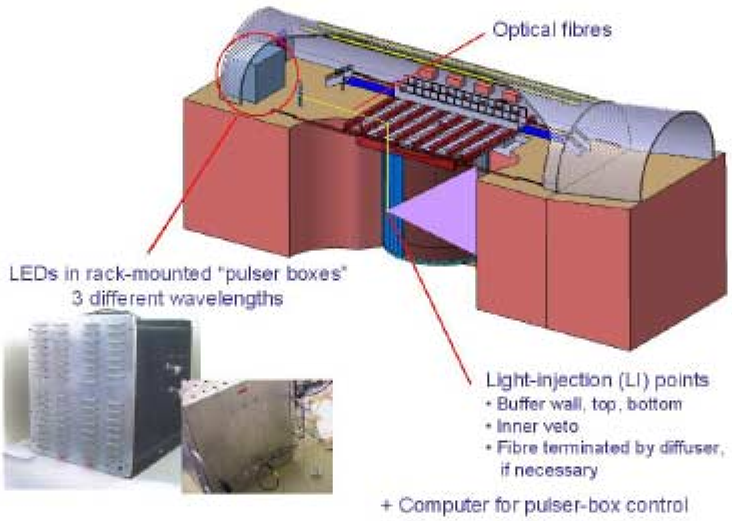


Figure 136 : The embedded LED system will consist of rack-mounted electronics boxes, known as pulser boxes, optical fibres with suitable termination, and a PC for system control. The LEDs will reside in the pulser boxes. The pulser box in the photos was designed for MINOS.

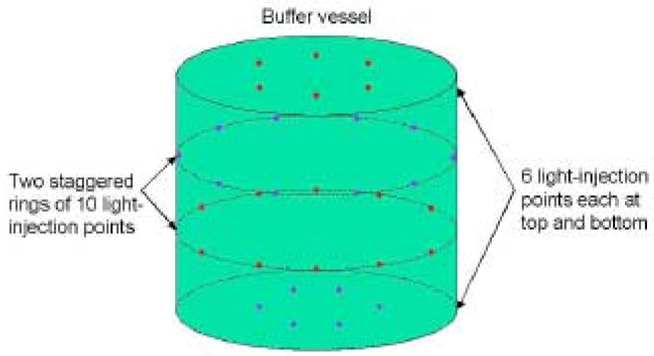


Figure 137 : Baseline configuration of the light-injection points is the buffer vessel. There will be two staggered rings of ten points around the buffer wall, and six points each at the top and the bottom of the buffer tank.

Furthermore, the option to install one or two “pencil-beam” light-injection points at the top of the buffer tank is being considered; these pencil-beam injection points would illuminate only the buffer oil, in order to help disentangle the optical properties of the different detector components.

If the requirement to have useful illumination by at least two light-injection points on each PMT makes it necessary, the fibre ends inside the detector will be terminated by some type of optical diffuser, in order to make the light beams more divergent. Otherwise, the termination will simply be the polished fibre end.

The control PC will run custom-written control software for the LED system, and will communicate with the pulser boxes as well as with the overall detector run-control system. The LEDs will be individually programmable in terms of light intensity (i.e., driver current), number of light flashes and flashing frequency.

Large parts of the design of the electronics and the mechanics of the pulser boxes will be recycled from the MINOS LED calibration system.

11.7.4.Interfaces

11.7.4.1. Mechanical Interfaces

The optical fibres will enter the detector via a subset of the stainless-steel guide tubes for the PMT cables. In the buffer tank, the termination points will be fixed to the PMT support structure. The details of how this will be done requires further study. The termination points in the inner veto have not yet been studied. In order to protect the fibres, the portion running inside the detector will be routed inside Teflon tubes (see Figure 1.7.4), which will be bundled with the PMT cables. The section between the exit of the guide tubes and the electronics racks will run inside black conduit.

11.7.4.2. Chemical Interfaces

The optical fibres, and their termination at the light-injection points inside the detectors, will be in contact with the buffer and inner-veto liquids, and must therefore be chemically compatible with these. The components of the termination at the light-injection points include the fibres themselves and the protective teflon tubes, as well as any components of the fixing to the PMT support structure. If diffusers are used, then these, as well as any optical glue or other attachment to the fibre end, must also be chemically compatible with the liquids.

11.7.4.3. Electrical Interfaces

The pulser boxes will fit into standard 19-inch electronics racks
and will require a standard connection each to mains voltage. Two slots of a height of 12.5U (ca 556 mm) in the racks of each detector site have been reserved for them. The pulser boxes will output a trigger signal tagging light-injection events. It will also deliver PIN photodiode readout signals. The definition of these signals will need to be agreed with the Electronics/DAQ group.

The communication between the pulser boxes and the control PC will be via a USB interface. An internet USB hub will be required if the PC is located too far away from the electronics racks to permit a direct USB connection. In addition to this, and a connection to mains power, the PC will require internet communication with the global run-control system, in order to permit fully automated light-injection sequences to be interspersed in the normal data taking. An interface between the run-control software and the control software of the LED system must be defined.

Figure 138 : The optical fibres will run inside protective teflon tubes in the detector

When the LED system is active, the control PC will deliver real-time information such as which LED is currently being flashed, LED light intensity and number of light flashes. This information should be integrated into the normal data stream, so that the PMT readout of light-injection events can be matched with the corresponding LED activity.

11.7.5.Compatibility Tests

All the components of the LED system residing inside the detectors must be chemically compatible with the liquids of the buffer and the inner veto. Samples of teflon tubing and of three different candidate fibres (polymer fibre with and without a flame-retardant jacket, and fused-silica (quartz) fibre) are currently being tested with buffer mineral oil at the University of Sussex, in order to investigate whether the optical properties of the fibres are affected by the oil. They must also be tested at Saclay in order to ensure that the optical properties of the buffer liquid are not affected by the LED-system components. Testing of the jacketed polymer fibre is under way, and samples of teflon tube and the other fibres have been sent for testing. No tests with inner-veto scintillator have been initiated yet (July 2007).

The components listed above must also be tested for radiopurity. A sample of jacketed polymerfibre is being tested at Sandia, and samples of teflon tube and the other fibres have been sent for testing.

11.7.6.Preliminary Risk Analysis

The embedded LED system poses no particular risks to other detector sub-systems, as long as chemical compatibility and radiopurity conditions are met. Regarding personal safety, there are no special precautions that need to be taken beyond those that will apply during installation in the pit and while handling electronics components in the racks.

11.7.7.Design Status

The design status as per July 2007 is delineated below.

1. The number and the distribution of the light-injection points in the buffer must be finalised. Determining this configuration has been identified as being on the critical path to ordering the buffer vessel, which must go out to tender in September 2007.

Finalising this design will require input from the following items:

(a) The embedded LED system must be simulated in DCGLG4sim, in order to test the configuration, so as to ensure that it gives sufficient light coverage on the PMTs, and to determine the exact positions of the light-injection points.

(b) The light-intensity profile of polymer fibre ends have been measured in preliminary lab tests. These measurements indicate that not the full numerical aperture of the fibre yields useful light-levels, and that some type of diffusers on the fibre ends, in order to increase beam divergence, may become necessary. More precise measurements are being prepared; in parallel with these tests, we are also preparing tests of different types of optical diffuser.

(c) The plan to route the optical fibres with the PMT cables through the stainlesssteel guide tubes is being tested. The fibres will be routed inside teflon tubes and bundled with the PMT cables. Tests at Sussex of this scheme have been successful;
Saclay have designed a new seal of the guide-tube exit and will leak-test this with sample teflon tubing shortly.

2. The calibration scheme and the configuration of LED light-injection points in the inner veto have not yet been studied.

3. The chemical compatibility and radiopurity tests discussed in Section 1.7.5 must be completed.

4. The choice of fibre technology – polymer or quartz – must be finalised. Polymer fibre is much less expensive, and more robust and easier to handle than quartz fibre. On the other hand, it has poorer transmission in the UV range. All tests completed so far indicate that polymer fibre would work well. The final input to the decision will come from the material compatibility tests. As these will take some time to complete, we currently plan to use polymer fibre, but will develop contingency plans in case we are forced to switch to quartz fibre.

5. A study of the desirability and feasibility of using pencil beams in the buffer tank has not yet been initiated. Such beams could be implemented with quartz fibres, which have a much smaller numerical aperture than polymer fibres

6. The attachment of the terminated fibre ends to the PMT support structures must be designed. Disucssions regarding the fixation to the buffer PMT support structure were

initiated with Madrid some months ago, and some preliminary design ideas outlined, but no work on this has been done since.

7. A baseline choice of wavelengths for the LEDs has been made, based upon studies reported at collaboration and calibration-group telephone meetings.

8. Design of the driver and control circuitry for the LEDs is largely done, but needs further testing. The circuitry for the PIN photodiode amplifier and readout are being designed, and will be tested shortly. Final design and testing of the pulser box circuitry will take place during the autumn.

9. A first design of the optical fan-ins to guide the light from the LEDs to the fibre ends and PIN photodiodes has been made, and is currently being tested. A final design is expected by early to mid-autumn.

10. The output signals and software interfaces discussed in Section 1.7.4 remain to be defined.

11. The mechanical design of the pulser boxes will be finalised when the design of the circuitry and the optical fan-ins have been completed and the output signals defined.

11.7.8.Responsible Institution

The embedded LED system will be designed and supplied by the University of Sussex.

11.8. Calibration Software

11.8.1.Overview

The calibration software effort can be divided into three general categories, calibration equipment operation software, analysis tools and simulation tools. Calibration equipment operation software will be required to operate the machinery that both moves a calibration source within a detector, and to operate that source once it is in position. Each procedure will have a different risk associated with its operation, consequently, a validation procedure will need to be defined for each one. Calibration experts will require a set of specialized software analysis tools to allow them to gain access to real time data on detector performance during a calibration. The act of calibrating a detector will, in nearly all cases, disrupt normal physics data taking, so the whole procedure must be performed efficiently to allow an expeditious return to normal operation with identical pre-calibration conditions. It is, therefore, very important that calibration experts have all possible relevant information at their disposal in real time. Finally, we cannot understand our detectors unless we have simulations that accurately model detector response to calibration sources. While responsibility will generally fall to the simulation group, the calibration groups will also have an input. We will need a set of event generators for every possible calibration source. Additionally, a physical model of the calibration source and it’s containment, as it would appear in the detector, will be required. In the following sections we will discuss the software that will be required in order to calibrate and monitor Double Chooz in a safe and efficient manner, while providing us with the calibration constants needed to understand detector efficiency and energy response of both detectors over time.

11.8.2. Calibration Tools

This section describes the software tools that will be needed to operate all the equipment necessary to calibrate the detectors. Some of this equipment will need to be moved around inside the detectors, and so will have the potential to cause damage if operated incorrectly. Other equipment will not have the potential to cause damage. Particular care will have to be taken with software that controls the operation of the former.

In order to reduce the disruption to the detectors and to minimize changes in their performance due to calibrations, wherever possible we will require remote operation of calibration devices so that PMTs will not have to be turned off when moving sources in and out of the detector or from place to place. Therefore, we will require independent hardware and software interlocks that have access to the calibration system status. The sorts of movements that are likely to happen are moving sources inside the gamma catcher through a source guide tube, z-axis or articulated arm operation. While the basic stepper motor position readings can be accessed by the hardware interlock, the software interlock may also perform more complex calculations, such as likely arm, cable and source positions, as well as likely future positions based on the current position and velocity. In both cases, if the calibration system/devices go out of an acceptable range, movement will stop. Additionally, the software should refuse to move calibration devices into a position or state that is likely to be dangerous.

We must also examine the question of whether or not it is worth designing a system to automate the placement of delicate sources within the detector (such as optical fibers or guide tube sources). Particularly in the case of a laser fiber, such a system may successfully provide positioning within a volume, but nevertheless be dangerous to the detector if fibers or wires become tangled or bent/stretched inappropriately. If we decide to build such a system a group must be assigned to the task as soon as possible, so that it can be built and rigorously tested/debugged before it's deployed in the detector.

Some calibration equipment (e.g. the laser, LED and triggered sources) may need its own software to operate. Assuming these devices are placed correctly and safely inside the detector volume, they should be designed so that they are incapable of damaging the detector. For example it should be impossible for the laser to operate at a luminosity that destroys PMTs. In that case the operational software of these devices may be written and tested by the individuals responsible for that device.

During a calibration run, the responsible people will need to have access to data to check how the detector is responding to the source. Examples of useful data are nsum, trigger rate, charge information and if possible a rudimentary vertex. Generation of this data should be automated wherever possible. The DAQ group will be responsible for the generation and accessibility of this data to the calibration experts.

Trigger settings and prescale settings used in past calibrations with the same source should be readily available. Whenever non default settings are chosen for a particular source, a warning should be issued before the run starts to alert the calibration expert(s) - who then must sign off on the new setting before starting. The DAQ group will be responsible for the interface in consultation with experts from calibration.

11.8.3. Analysis Tools

After the initial commissioning period of each detector, we will begin a calibration campaign aimed at extracting a set of calibration constants. The data should be analyzed as soon as possible so that the process of tuning simulations and analysis can begin. We will require the analysis tools to be available in time for the commissioning phase. Efforts are currently underway within the simulation and analysis groups to ensure that simulation data will be produced in the same format as real data before the campaign to test the analysis tools.

In addition to the generally available software available to access our database, the database and analysis groups will build a set of basic methods and tools with which we can plot the evolution of calibration constants in the database over time. One shouldn't need to know anything about the operation of database software in order to "see" or access detector calibration constants.

The database group has already developed a complete framework for the application of calibration constants (generated somehow) that the analysis can reach at any time. A likely scenario would be a database master server that will contain the latest complete version at all times, together with some number of slave servers available to analysis groups more locally. Access to the local group's favorite database server will be launched automatically from the analysis programs. It will also be possible to dump the database locally to any laptop for processing if necessary.

After the commissioning phase, calibration operations will settle into a period of detector monitoring. This will require a smaller subset of calibration sources to be deployed on a regular basis. The calibration group will decide in consultation with the analysis and simulation groups how often this will occur and which sources will be used. Also some automated generation of data via intermittent triggered sources or pedestal events during physics runs may also be used (note: the FADCs may not need pedestal event generation, it may be inferred from physics data runs - not decided yet). Background event rates will also be monitored from applying certain cuts to normal physics runs. Since such data would be generated automatically by radiation in the detector or from cosmogenic sources, it should be analyzed and the resulting data added to the database in a timely manner. The algorithms used in this analysis and the results obtained will probably be a point of discussion over a long period of time, however, clearly we would like to continuously monitor at least a subset of backgrounds from the commissioning phase onwards.

11.8.4. Simulations

Simulations will play an important role in the analysis of Double Chooz data. The relative antineutrino event efficiency of the two detectors needs to be known within 0.5while the absolute energy scale of both detectors needs to be known to within 1Additionally background event rates (after analysis cuts) must be calculated.
Calibration data alone cannot give us the likely detector response to antineutrino and background events. For example, neutron sources produce neutrons in the few MeV range, antineutrinos interacting via inverse beta decay produce n's in the few keV range. Additionally, antineutrinos produce positrons, calibration sources are generally gamma emitters.
Calibration effects such as shadowing and positional errors will also need to be accounted for. We need to estimate the target region energy response to positrons and the neutron capture

efficiency at low energies, with no shadowing. Simulations will be needed to estimate these important quantities (among others) at all positions in the detector.
Computer cluster time will be needed to run simulations of our calibration devices, backgrounds and antineutrino signal at a large number of positions in the detector. At IN2P3, software already exists to handle the division of (simulation) labor for this purpose. We also have funding at LLNL to set up a similar system on one of the available clusters.

The simulations will of course contain a constant set of elements that define the detector characteristics and a source specific set of characteristics. The detector characteristics can be divided into two sets, those characteristics that are consistent with most other scintillator detectors, and those characteristics unique to Double Chooz. A great deal of simulation code development has gone into the geant4 based programs called GLG4sim and DCGLG4sim. Basically, GLG4sim deals with the physical characteristics that Double Chooz has in common with other similar detectors, DCGLG4sim is Double Chooz specific. For each calibration source or type a “generator” will have to be written. This is essentially a program that outputs a list of particle events, listing particle types, multiplicities, positions relative to the detector, momentums and energies in a format that GLG4sim can understand. Additionally, in order to study shadowing and particle propagation effects, a model of the source geometry and physical characteristics will need to be added to the simulation. The following is a list of calibration tasks for which we will need an equivalent simulation and generator to compare, if we choose to calibrate with that source.

11.8.5. Generators Completed

1. AmBe source
i. Deployments along z axis in target
ii. Deployments throughout target - different shadowing due to different deployment device
iii. Deployments in gamma-catcher
iv. Can the 4.4 MeV gamma be used in AmBe calibrations? (as a check against simulations - yes)
v. Pulse shape identification of n elastic scattering?

2. 60Co deployments z axis, target, gamma catcher

3. 68Ge near e+ turn on threshold, z axis, target, gamma catcher

4. 252Cf tagged and untagged sources z-axis, target and gamma catcher

5.137Cs 0.66 MeV for near e+ turn on threshold, z-axis, target and gamma catcher

11.8.6. Generators Under Development

1. Muon spallation or initialized events
    i. n’s post muon
    ii. 12B beta decay
    iii. High energy, Michel electrons. Efficiency and energy calibration after high energy events

2. 337 nm Laser

i. Low gain PMT linearity
ii. Light transport in scintillator

3. 450nm laser, PMT timing offsets

11.8.7. Generators In Need of Development

1. Regular radioactive backgrounds monitoring
   i. Bi Po
   ii. K
   iii. Radon
   iv. ^{10}C and ^{11}C

2. ^{22}Na (e+ source)

3. ^{65}Zn

4. Trigger efficiency using LED light source

5. Trigger efficiency
i. Absolute: one gamma source of known activity
ii. Relative: other gamma energies

6. ^{203}Hg

7. Energy scale studies
   i. ^{10}C, ^{11}C give e+,

   ii. Alpha sources distributed inside the detector volume (from ^{232}Th or ^{222}Rn daughters)

11.8.8. Veto Calibrations

1. Inner veto trigger efficiency
   i. LED
   ii. Laser?
2. Correlated (due to neutrons) events in target and *outer* veto, but no inner veto
i. n elastic scatter in target/gamma catcher, pulse shape discrimination

3. Inner and outer veto trigger efficiency versus time after last muon

11.9. Preliminary Risk Assessment

11.9.1. General

We consider failures in the following main areas:

• Scope. What impact on achieving calibration goals in particular and experiment goals in general would the failure have?
• Schedule. How would the failure affect the experiment schedule for construction and operation?
• Budget. How would the failure affect the experiment budget? Included in this are the costs of recovery from the failure and modification of the system or construction of an alternate system.
• Health and safety. What are the potential effects on the health and safety of personnel from the failure?
• Environment. How could the failure affect the environment?
In addition to noting the possible failures, actions that will be taken to reduce the risk of failures are described.
The major part of risk assessment and mitigation below is organized by subsystem. Since it is common to many subsystems, however, the risk of materials incompatibility related to calibration will be considered in the first section for all subsystems.

11.9.2.Materials Incompatibility

Most of the calibration subsystems will have components which come into direct contact with one or more liquids (Gd–loaded scintillator, gamma catcher scintillator, buffer oil, inner veto scintillator) or the mechanical structures (target vessel, gamma catcher vessel, buffer vessel, steel vessel). Less direct contact, e.g. exposure of calibration components to vapors and tools which do not come in direct contact with a liquid but which are used on components which do, must also be considered. We broadly define materials compatibility, divide it into three classes, and describe each class below.

Chemical incompatibility can adversely affect the liquid and/or the calibration system. Adverse effects on the liquid include reduction in light yield, loss of transparency, and instability in Gd loading (target). Chemical incompatibility effects on the calibration subsystems could include distortion or reduction of light output, deterioration of seals, and weakening of mechanical components, which could lead to mechanical failure during calibration and contact between liquids and internal components which are chemically incompatible.

Mechanical incompatibility is comprised mainly of a calibration subsystem producing stresses on a mechanical structure which it cannot sustain. One important instance is the glovebox overloading the chimney stack; another is forces transmitted to the guidetube via the wire sources breaks a fixation point, allowing the tube to slip to an indefinite position, or cracks one of the acrylic vessels, allowing different liquids to be exchanged between volumes.

Radio–incompatibility refers to the phenomenon that radio-isotopes in the calibration components produce additional backgrounds for the experiment. There are three failure modes. First, calibration components which are permanently deployed in the detector are “hot” enough to produce significant background and/or radioactive surfactants deposited during processing are able to leach into the liquid. Second, radon and its daughters are carried into the target during deployments, producing backgrounds with strong time dependence. The third failure mode is leaky radioactive calibration sources, especially in the case of neutron sources which can produce correlated events.

It is clear that potential damage to scope, schedule, and budget due to materials incompatibility is great, and therefore measures must be taken to make the risk of this type of failure negligible. It is a risk to the construction schedule that a backlog could develop in identifying compatible materials and developing procedures f or preparing and cleaning materials.

Any material and process used in calibration must be certified as being chemically inert for the environment in which it is used and for the extent to which it is used. Central to certification is development of protocols for preparing and cleaning materials. Not only must a material be certified as chemically compatible for use after it has been prepared and cleaned in the prescribed way, but the preparation and cleaning protocol must be strictly applied to all components constructed from the material. Components which are intended to seal the incompatible interior of a device from its environment must be tested under pressures well exceeding those which will occur in the experiment. All calibration components which produce mechanical stresses on other elements of the experiment must demonstrate–under realistic conditions and before their design is finalized–that the stresses transmitted to the other parts of the experiment are well within the range of what can be tolerated. Finally, procedures will be adapted from previous low–background experiments to ensure adequate radio–cleanliness for all calibration materials and procedures and the radio–integrity of radioactive sources.

The quality assurance liaison for the calibration system will be responsible for documenting protocols for achieving materials compatibility and implementing the procedures for enforcing their use. Where reasonable, streamlined procedures and best–effort practices may be accepted in certifying material compatibility in order to deal with backlogs. No calibration device may be installed or deployed without the approval of the quality assurance liaison and the calibration group coordinators. Issues which cannot be resolved in the alibration group will be referred to the Executive Committee.

11.9.3. Glovebox

The purpose of the glovebox is to allow calibration devices to be inserted into the target while isolating the target from the outside environment. Calibration devices will be transferred in and out of the glovebox using an auxiliary gas lock (transfer box) and the glovebox will be isolated from the detector by at least one gate valve. The gas lock and glovebox will be purged with radon–free nitrogen gas.

The possible failure modes are overpressuring the glovebox, dropping something in the detector while the gate valve is open, opening the detector to the glovebox while the environment in the glovebox is contaminated, closing the gate valve while a calibration deployment is in progress, and forces from the glovebox overstressing the chimney stack. The potential damage ranges from mild (blowing out windows or seals if the glovebox is overpressured and no personnel are present) to very severe (damaging the chimney or acrylic vessel if the glovebox is open to the detector when it is overpressured or the window blowing out with personnel present). In the former case, experiment data taking could continue albeit with disruption in calibration activities; whereas in the latter case it may be necessary to replace the acrylic module, interrupting the experiment for a very long time and being very costly, or personnel may be seriously injured. Events such as dropping a radioactive source or a tool which is not compatible with the scintillator are also very dangerous, especially if there is no feasible and prepared plan for retrieving them.

It should be possible to purge the gas lock and glovebox independently with a relief valve for each. The pressure at which the relief valve opens should be chosen in consultation with the mechanics group. The pressures in the glovebox and gas lock must be available visually at all times and monitored electronically with a means for generating alarms if a pressure falls outside its normal range.

All objects introduced into the glovebox which are not attached to the deployment system must be tethered while the gate valve is open.

The glovebox is to be housed in a clean tent so that calibration devices can be removed from hermetic packaging and transferred to the glovebox without being exposed to dust.
Clean–room garb and safety–ware must be donned by the operators before entering the tent. The volume of the tent should be large compared to that of the glovebox to prevent oxygen starvation in case the glovebox blows out while personnel are present.

Oxygen monitors should be installed and at least a coarse calibration between oxygen and radon content should be obtained. The gate valve cannot be opened unless the oxygen content is sufficiently low and stable and the operation of the gas purging system is also stable.

The gate valve can be opened and closed only in limited circumstances. Interlocks are recommended in any case and mandatory if it is possible to open and close the gate valve remotely.

The glovebox must be supported independently and redundantly of the chimney stack.

Bellows or equivalent must be used to connect the glovebox to the chimney. The stiffness of the bellows and the glovebox support must be approved by the mechanics group.

While any kind of activity is going on in or around the glovebox, a trained glovebox operator must be on-site and at least visually monitoring the activity. All operations involving the glovebox must follow and mark a checklist. All collaborators working with the glovebox must be first trained and certified.

Funding is available to build the glovebox for the far detector. Funding to build the glovebox for the near detector is not available and so poses a risk to budget and schedule.
The glovebox is located on the exterior of the detector and is therefore does not enter the critical path for the experiment until late in the installation schedule.

11.9.4.Z–Axis Deployment System

The z–axis deployment system has the function of deploying, either manually or by motor drive, calibration sources in the target and chimney along the central axis of the experiment. The mechanisms for motor–driven deployment will be housed in the glovebox with electrical interfaces for power and control. It is expected that untagged radioactive sources and the central LED flasher will be deployed under motor control, while the tagged
Cf–252 source and the laser flasher will be deployed manually.

Possible failure modes include uncertainties in source deployment position which are greater than can be tolerated to calibrate the experiment to required precision, deployment of the source at positions that could damage the detector, e.g. hitting the bottom of the target or swinging into the side of the chimney, the calibration source detaching during deployment, and a spark from the drive motor igniting flammable vapors in the glovebox and chimney.

Failure in deployment accuracy cannot be tolerated. The requirements on deployment accuracy must be clearly met in the design and operational testing of the deployment system and by the accuracy which can be achieved in surveys of the experiment.

The other failure modes carry risk for adversely affecting the operations schedule and budget for the experiment. The possibility of igniting vapors in the glovebox also poses a risk to the safety of personnel.

The connection between the deployment system and sources must be redundant and tested across the range of stresses that could be expected during the experiment. If there is a detachment risk which cannot be made manifestly negligible, a means for recovery must be developed and demonstrated under realistic conditions.

Limit switches or the equivalent must be installed on all deployment mechanisms to ensure that no source enters a danger zone. Deployment speeds and procedures must be such that swinging of the source is minimized and well within the tolerable range of amplitude.

Any electrical device inside the glovebox which could produce sparks must be hermetically sealed.

Funding and manpower are available to carry out design and prototype studies on the z– axis deployment system. Funding is not yet available to build the final system and therefore there is budget risk associated to this system. The system enters the critical path late in the installation schedule of the detector.

11.9.5. Articulated Arm

The purpose of the articulated arm is to deployed calibration sources off the central axis in the target.

The articulated arm presently poses significant risk to the scope and schedule of the experiment because it is a challenging engineering task and there is no funding or manpower allocated to it. The risk is mitigated by the possibility that the articulated arm can be deployed at a later stage in the experiment and the glovebox design has provisions to ease retrofitting it for an articulated arm.

The articulated arm and the z–axis deployment system have failure modes in common. The articulated arm has one additional failure mode: the arm may get stuck during deployment so that it (and the source attached to it) cannot be retracted without (at the least) subjecting the acrylic module and chimney to severe stresses. Therefore, the risk of this failure must be made negligible by designing redundancy in how the articulated arm can be positioned for retraction.

11.9.6.Wire Source Deployment System

The purpose of the wire deployment system is to deploy untagged sources in the gamma catcher.

The significant failure modes are insufficient accuracy in positioning the source, a broken wire, source detachment inside the guide tube, and distribution of radon into the detector through the guide tube. Poor source positioning could lead to reduction in experiment scope or at least a prolongation of operational schedule to reach the design sensitivity. A broken wire or a detached source would affect the operational schedule at the least and reduce the experimental scope at the worst. Radon contamination, likely to be variable in level, would produce a time–dependent background in the experiment, complicating the analysis and thereby potentially prolonging the schedule or reducing the scope.

Errors in source positioning are to be controlled by design, careful fabrication of the guide tubes, and accurate surveys after guide tube installation.

The guide tube will be designed as a loop with each end terminated in the glovebox and/or with a inner plastic sleeve that can be retracted. Further, each wire, actually a tube, will be reinforced with a wire threading the tube so that the source can still be retracted even if the tube breaks from fatigue. With two ends accessible from the glovebox tent, a wire can be inserted in one end to push the source to the other end. With a plastic inner sleeve, the experiment can recover from a broken wire or detached source by retracting the plastic sleeve. Finally, the guide tube and wire–source assembly will be exercised repeatedly to simulate many deployment cycles to measure fatigue and other factors relevant to failure before finalizing the design.

The guide tube will be flushed with radon–free nitrogen. While deployment is in progress, the nitrogen will flow in the free end of the guide tube. When the system is not in use, the outlet end of the guide tube will be connected to a low–pressure bubbler. If a single–ended tube is used, a thin plastic tube carrying a nitrogren gas flow will be inserted to the end of the guide tube while the system is not in use.

There is funding and manpower to carry out design and prototype studies for the wire source deployment system and to fabricate the guide tube and its fixation. The guide tube enters the critical path of the experiment with the acrylic module and thus contributes a significant schedule risk. The remainder of the wire source deployment system, for which full funding is not yet available, enters the critical path of the experiment late in the installation schedule.

11.9.7.Radioactive Sources

The radioactive sources used in Double Chooz will be sealed and of relatively low activity but could still constitute a hazard to health and environment if not handled with proper care.

Though experiment collaborators are likely to be familiar with the basics of radiation safety, those collaborators who handle radioactive sources for calibration will receive training to review the basics of radiation safety and educate them about the specific sources being used for Double Chooz calibration.

Detailed procedures will be developed for handling and storing the sources between calibrations. These procedures will be made consistent with the applicable power plant and government regulations. To facilitate proper management of the radioactive sources, calibration sources built outside France will be entered into the inventory of one of the collaborating French institutes.

Apart from the tagged Cf–252 source, for which there is a commitment of resources to fully build the source, there is funding and manpower to carry out source development studies and to fabricate a subset of the neutron and gamma sources. Consequently, there is schedule and budget risk, which is mitigated by the fact that radioactive sources are relatively inexpensive and they enter the critical path of the experiment at the time of commissioning.

11.9.8. Laser Flasher

The laser flasher system uses pulsed laser light of different wavelengths. The laser and open optics segment of the system is mounted in a light–tight enclosure; the remainder of the system uses fiber optics. The operation of the laser flasher system does not pose a risk to personnel health and safety.

Manpower and funding is committed for design and prototype studies and to build a laser flasher system for the far detector. Schedule and budget risk therefore exists only for the near detector and this risk is somewhat mitigated by the fact that the laser flasher system enters the critical path of the detector at commissioning time.

11.9.9. Embedded LED System

See section on the embedded LED system for a preliminary risk assessment.

References

[1] F. Ardellier et al., Letter of Intent for Double-CHOOZ: a Search for the Mixing Angle Theta13, http://arxiv.org/abs/hep-ex/0405032

[2] P. Adamson et al., The MINOS light-injection calibration system, Nucl. Instr. and Meth. A 492 (2002) 325.

[3] P. Adamson et al., On the linearity of the MINOS light-injection calibration system, Nucl. Instr. and Meth. A 521 (2004) 361.

[4] E. Falk Harris, An Embedded LED System for Double Chooz, presentation at Double Chooz calibration meeting 29 November 2006, http://bama.ua.edu/_busenitz/dccal/led.pdf.

[5] E. Falk Harris, Sub-System Report: LED Calibration System, presentation at TDR preliminary review, 15 January 2007, http://minoserv.maps.susx.ac.uk/_efalk/dchooz/070115 tdr prelim review led system.pdf.

[6] E. Falk Harris, LED Calibration System Status Report, presentation at Double Chooz collaboration meeting, Madrid, 9 March 2007, http://minoserv.maps.susx.ac.uk/_efalk/dchooz/070309 dc collab mtg madrid led system.pdf.

[7] E. Falk Harris, LED Calibration System Update, presentation at Double Chooz collaboration meeting, Chooz, 30 May 2007, http://minoserv.maps.susx.ac.uk/_efalk/dchooz/070530 dc collab mtg chooz led system.pdf.

[8] S. Biller, DAQ Rate Requirements for Calibration Sources, internal document, 27 October 2006, http://bama.ua.edu/_busenitz/dccal/cal rate.ps.

11.10. Glove Box

11.10.1. Glove Box Requirements

Target calibration will require sources that are certified radiologically clean and a deployment environment that will be clean and under a dry nitrogen atmosphere. Thus it is necessary to have a glove box (GB) interface with associated clean room on the detector top. Assuming a specific activity of 0.5 Bq/g for dust suspended in the air (see the section on Cleanliness) then the requirements for the glove box interior can be estimated. Making the following assumptions:
• a deposition rate of 1 μg/cm2/month for 2500 suspended particles/m3. This is the SNO experience for an area with high activity. Low activity has an order of magnitude smaller deposition rate.
• the deposition rate scales as the concentration of suspended dust summed over all particle sizes and scaled to SNO at 0.5 μm.
• the suspended dust size spectrum corresponds to that given in ISO 14644-1
• half the deposited dust inside the glove box eventually ends up in the detector target.
Note: the area of the chimney is actually only ~1% of the area of the bottom of the glove box.
• over five years, the dust from the GB should not cause the singles rate in the target to increase by more than 1 Hz
Based on these very conservative assumptions, a class ISO 6 (roughly class 1,000 under the old standard) will suffice for the GB interior.1 For an external clean room , one can estimate the requirements based on the assumption that transferring equipment in/out of the GB might occur as frequently as twice/day. Under the following assumptions:
• airlock interior of roughly 1 ft3 (~0.11 m3)
• all the dust in the air lock air during transfer eventually ends up in the detector
• specific activity of 0.5 Bq/g
• over five years, air lock transfers should not cause the singles rate in the target to increase by more than 1 Hz.
An ISO 9 clean room (roughly class 1,000,000) would then be more than sufficient, leading to a deposited activity of only 0.02 Bq. The main purpose of an external clean room is therefore to prevent gross contamination and restrict access to the GB area.
Those components of the deployment system that come into direct contact with the target and/or γ-catcher scintillator will be checked for material compatibility. Components that will not come into direct contact with the scintillator, but that will be exposed to its vapors must also be tested. A procedure for vapor testing has not yet been worked out.
For the γ-catcher, deployment will be done via source tubes with a wire driver. This system will be set up and operated in the same clean room as the GB. This will be a system that can operate without the use of a GB, and again the clean room serves mainly to restrict access.
The volume of the GB must be large enough that sources can be easily manipulated and the deployment system can be assembled and disassembled safely and easily as needed. In addition, the GB must be connected to an N2 gas system and purged so that it has the same

atmosphere each time it is opened to the detector. The N2 system must supply dry, clean nitrogen at a cleanliness level of ISO class 6. The glovebox will be equipped with radon and oxygen monitors for flagging leaks and monitoring the progress of purging. While the detector interface is open to the detector, it must also be light tight. Feedthroughs for laser fibers and control and power cables must be hermetic to prevent air incursion. To bring sources into the detector interface, a transfer airlock is required: sources are placed into this box through an external door, then the box is purged, after which the operator opens an internal door and brings the source inside the detector interface. Figure 1 shows a general layout of the GB system.

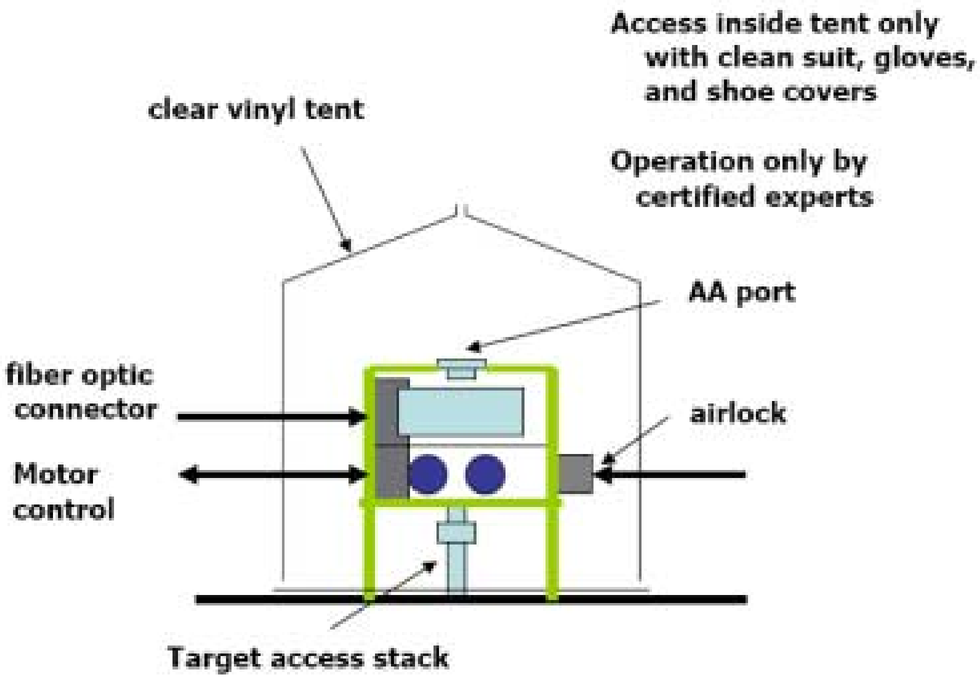


Figure 1: general layout of glove box system

[1] The area of the bottom of the GB is 0.7 m^2. An ISO 6 particle size spectrum, a specific activity of 0.5 Bq/g for dust, and a deposition rate of 1 μg/cm^2/month then leads to an activity deposition rate of 1.8 mBq/m^2/day. This corresponds to a total activity of (0.5)(0.0018)(0.7)(365)(5) = 1.1 Bq.

11.10.2. Glovebox Fabrication:

GB's are commercially available (see figure 2) that serve the needs of Double Chooz, however they will have to be modified for our particular requirements. A bottom access must be designed and constructed that will cap the top of the chimney. In addition, a "top hat" has to be made that will be tall enough to house the articulated arm. Internal hardware such as mounting brackets and bulkhead connectors must also be installed. A gate valve closing the GB off from the detector must be installed in the pipe stack that connects to the chimney. This valve must have a manual bypass for pressure equalization and also a differential pressure indicator.

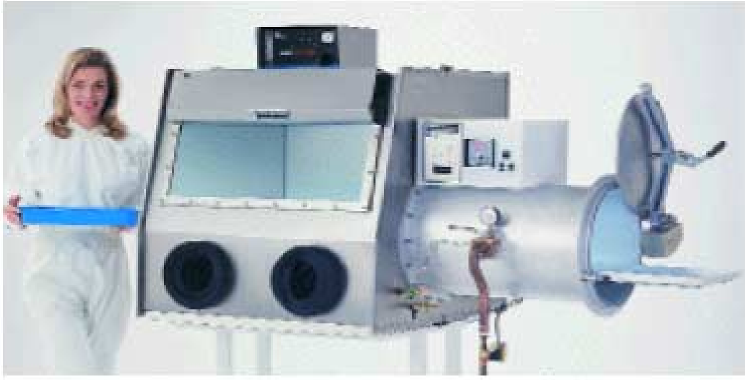


Figure 139 : TerraUniversal model 400 glove box.
The vaccum oven system is not needed for our application and will not be included in the system.

Sandia National Lab and the University of California, Davis are undertaking the design of the GB system, in close collaboration with Saclay collaborators, who are designing the chimney. U.C. Davis will construct and test the system. A commercial glove box has been ordered from TerraUniversal: Model 400 custom SS304 box with airlock, dual speed purge system, acrylic window, and viton seals and gaskets. The gloves have not been ordered as a material has not yet been selected.

Figure 3 shows the modifications that will be made to the commercial GB. An aluminum frame will be build to contain the GB so that it can be crane lifted into place and supported from the tank lid floor. On the top, a blanked off 6 inch CF 150 flange will allow access to the chimney from objects potentially larger than the GB size, e.g. an articulated arm deployment device. The bottom is connected to the chimney via a 4 inch CF 100 flange (see figure 4). The weight of the GB is supported through the frame, however, not the flange. A drain port is provided to remove significant excess scintillator.

Figure 5 shows the details of the frame connection to the port and GB enclosure. Connection is the same for both the top and bottom access ports. The half inch aluminium frame is bolted to a collar that is slipped over the CF flange. The collar is welded to the CF body on the exterior. The internal pressure seal is the weld of the CF spool to the GB enclosure from inside the GB.

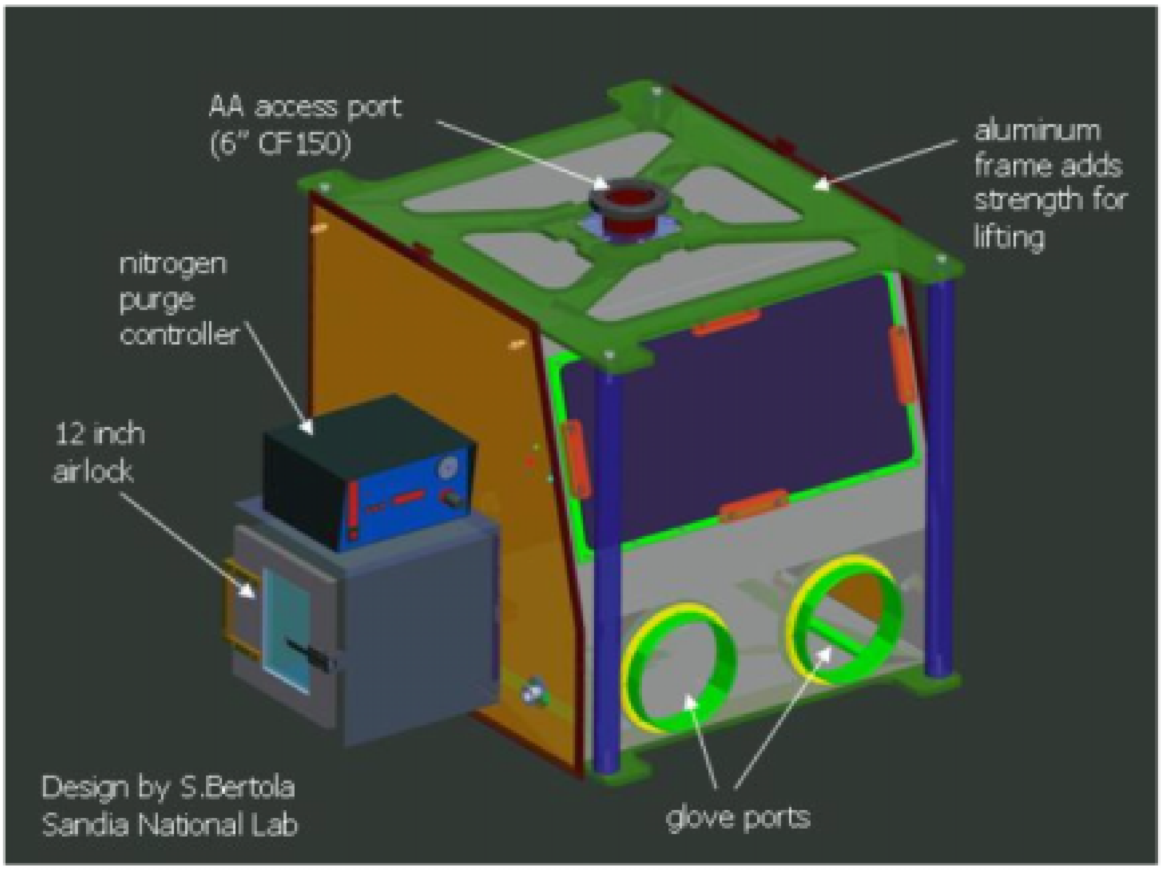


Figure 3: Sandia modifications for the Model 400 GB. The aluminum frame is for support and lifting. The black plastic window cover will exclude light during operation of the detector with the deployment port open. Also shown are bulkhead feedthrough ports for electrical and optical connections.

11.10.3. Material Compatibility:

Of great concern in this system is material compatibility with scintillator. All materials used in the GB body, seals, and viewports will be tested for such compatibility at Saclay.
Thus far, no material has been found for gloves and seals compatible with direct contact with the scintillator. Tests must be devised that test materials exposed only to vapors, or only for short periods of time to the scintillator. In addition, scintillator deposited in the GB must be prevented from returning into the detector.
The steel inside the GB and valve stack will be coated with Teflon to avoid problems with the scintillator reaction to stainless steel.

11.10.4. Clean Room:

Covering the glovebox will be a roughly 2m × 2m soft-sided clean room. This is essentially a rigid frame and roof supporting vinyl sides. HEPA filters will keep the interior dust-free.
As noted above, ISO 9 (class 1,000,000) is sufficient, so a major purpose of the clean room is only to prevent gross contamination and restrict access. Such portable clean rooms are commercially available products. It will be purchased and assembled on-site by U.C. Davis.

A similar clean room has already been purchased from TerraUniversal and assembled at U.C. Davis for use with the counter system.

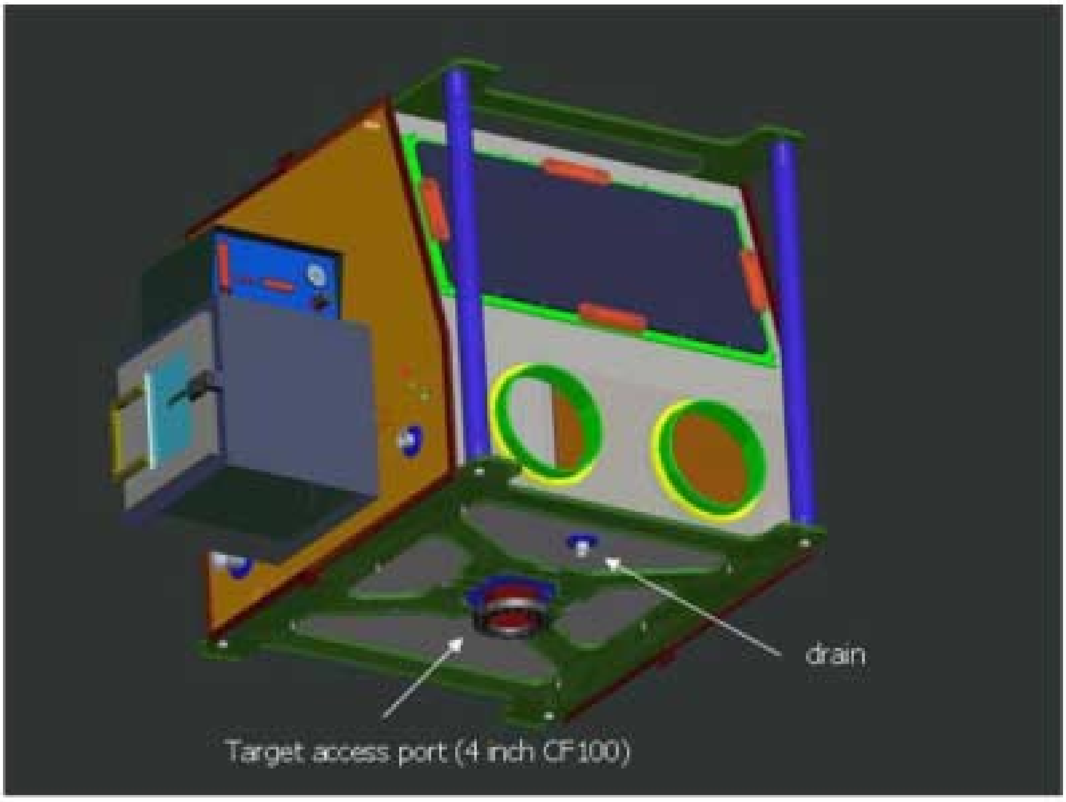


Figure 4: Bottom view of the GB showing the CF100 access flange and drain port.

Figure 140 : Figure 6 shows a conceptual design of the GB valve stack. The manually-operated gate valve opens to allow access to the target region. The pressure gauge and bypass allow pressure equalization before gate valve operation.

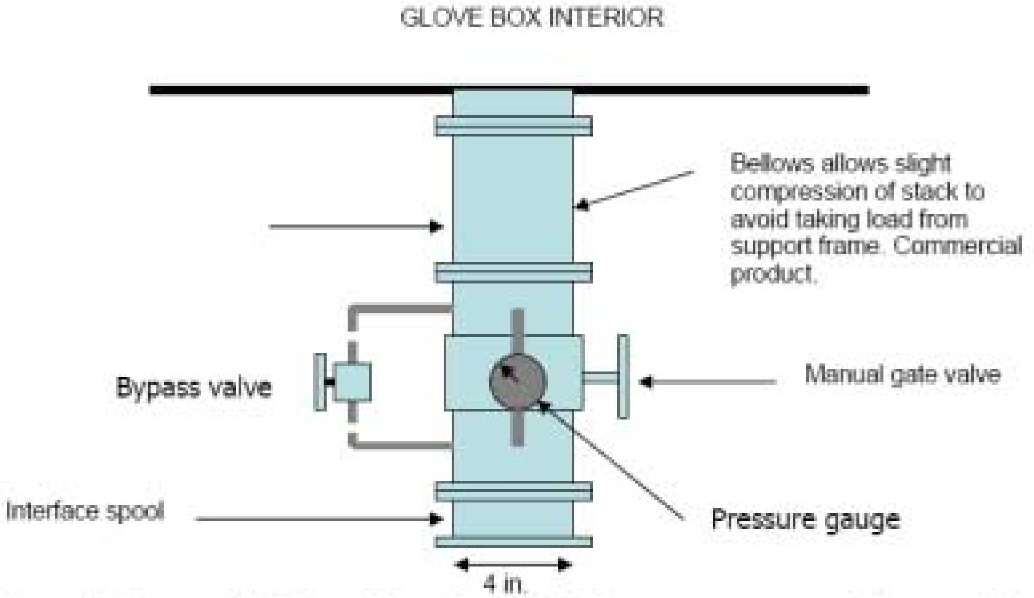


Figure 6: Conceptual design of the valve stack. The pressure gauge and bypass allow pressure equalization before opening the gate valve. The bellows ensures no thrust is applied to the chimney.

11.10.5. N2 Gas System:

This system requires clean, dry, radon-free nitrogen via 0.75 inch NPT fitting.
Input pressure should be 1-60 psi (0.007 to 0.4 MPa). Should be dust free to ISO 6 standards specified by ISO 14644-1.
During normal operation the purge system will not be running. While in high speed operation the flow can be as high as 20 SCFM. User settable.

11.10.6. Potential Hazards:

Potential hazards for the GB system are:
• Overpressure of the target via the nitrogen purge system. This is prevented by the Relief and Bleed (RB) valve, which lifts at less than 0.02 mbar pressure (0.005 inches water) plus any backpressure in the exhaust connection. This relief feature will be tested before installation.
• Pressure hammer caused by gate valve opening with significant differential pressure between the GB and target. This will be averted by procedure and training.
Only certified and trained personnel (plan is for three people only) will be allowed to operate the box. A checklist that includes pressure equalization via the bypass valve will be signed by the operator before opening the gate valve.
• Light leak into detector with gate valve open. This will be averted by procedure and training (as in the previous case). Operations checklist will include ensuring that photomultiplier HV is off when the gate valve is open and the GB window is not covered with a light-tight seal.

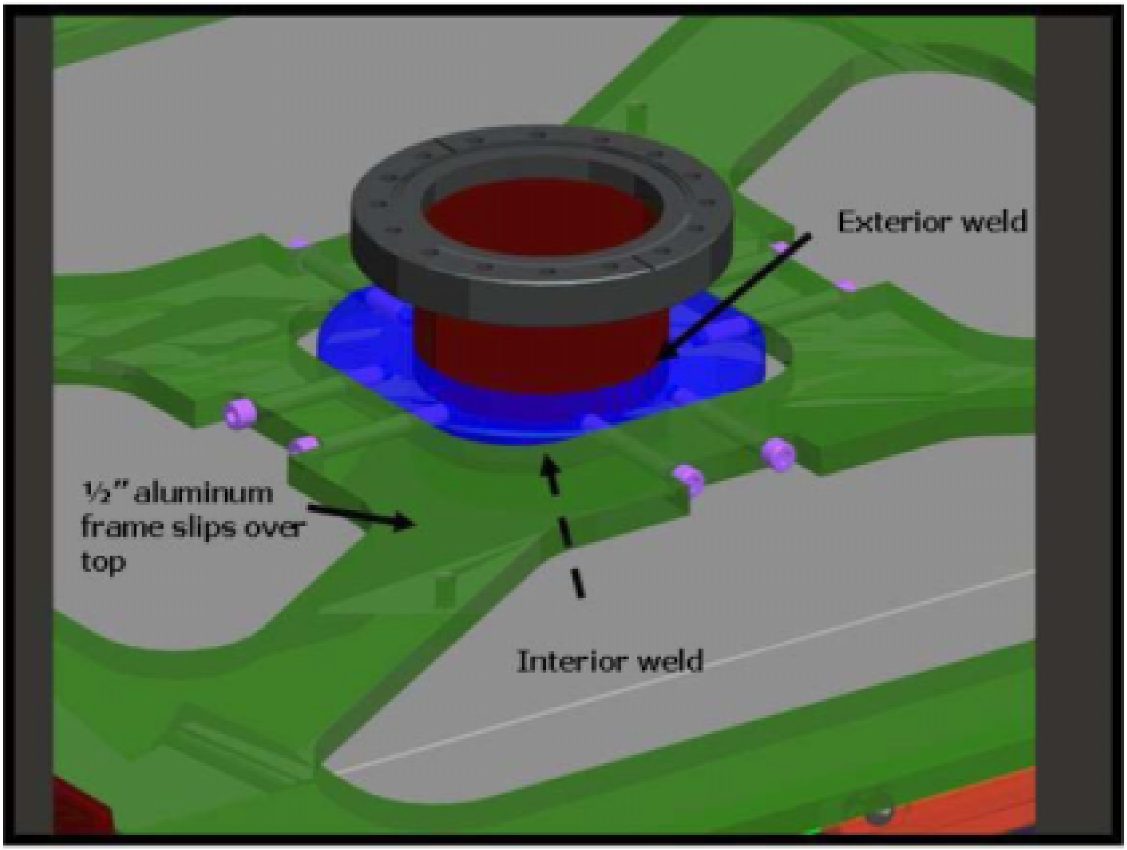


Figure 5: Detailed view of the frame connection to the port and GB.

11.10.7. Unresolved Issues:

1) Exact connection between RB valve and exhaust system not fully specified (Saclay and UC Davis)
2) Exact valve stack components not fully specified (UC Davis)
3) GB support from tank lid not designed (Saclay)
4) GB clean enclosure not fully specified (Saclay and UC Davis)
5) Funding of Near Detector GB system not settled (Far Detector funds are in hand). (US Groups)
6) Design of the interior of the glove box in not yet done (UC Davis and ANL)
7) Tests for o-ring and gasket materials in vapor have not yet been done (Saclay)

11.10.8. Schedule:

The commercial GB is now on order. Delivery is expected by the end of June, 2007. Modifications should be complete by December, 2007. It is anticipated that shipment to the Chooz site will be in summer, 2008 – or when appropriate.

12. Inner Veto [6000]

12.1. Inner VETO : Overview – general description

The purpose of the Inner Veto is to efficiently and reliably monitor and tag cosmic muons that possibly induce background events. A second purpose is to tag external fast neutrons that enter the detector. The veto volume is filled with organic liquid scintillator. Scintillation light is detected by PMTs that are attached to the floor and the walls of the veto vessel, on the top ring of the veto vessel as well as on the buffer vessel. The veto signals will be used to create two distinct veto trigger conditions - low and high energy veto trigger. In the baseline design, the number of PMTs is fixed to 78, completely encapsulated PMTs. The veto must be able to deal with ~ 1 kHz muon rate (in the near detector).

The Veto system includes the PMTs, PMT encapsulation, a single cable perm PMT for HV and signal, the support structure, Tyvek sheets for increasing the reflectivity of the surfaces, calibration devices and preparatory measures for temperature control of the detector(s). In the following, we describe the parts of the Inner Veto in more detail, their assembly and installation on site.

12.2. Dimensions

The dimensions and thickness of the cylindrical veto tank are defined in the corresponding chapter. The planning in this chapter is presented based on the following dimensions for the veto tank (see figure 1):

- Height (inner): z = 6840 mm with flat bottom
- Diameter (inner): ø = 6500 mm
- Thickness of the veto tank: t = 10 mm

- Buffer diameter (outer): ø = 5522 mm
- Buffer height (r=5522 mm, outer): h = 5680 mm
- Buffer height (r=0): h_{max}= 5846 mm (with 3% slope)
- Buffer thickness: t = 3 mm

- radial thickness (inner) of the veto volume: w = 489 mm
- top thickness (inner) of the veto volume: s_t = 500...583 mm
- bottom thickness (inner) of the veto volume: s_b = 500...583 mm

Radial thickness is uniformly w = 489 mm. The vertical position of the buffer vessel is chosen to reach equal veto thickness below and above the buffer vessel. Depending of the liquid level in the veto (see liquids chapter in this TDR), the active thickness (filled with scintillator) may differ (with a foreseen filling level which is 5 cm below the veto lid, this difference will also be 5 cm). The veto volume has to accommodate the steel support structure for the buffer and steel tubes attached to the buffer for cabling of the inner PMTs. It is also crossed centrally at the top by the chimney structure.

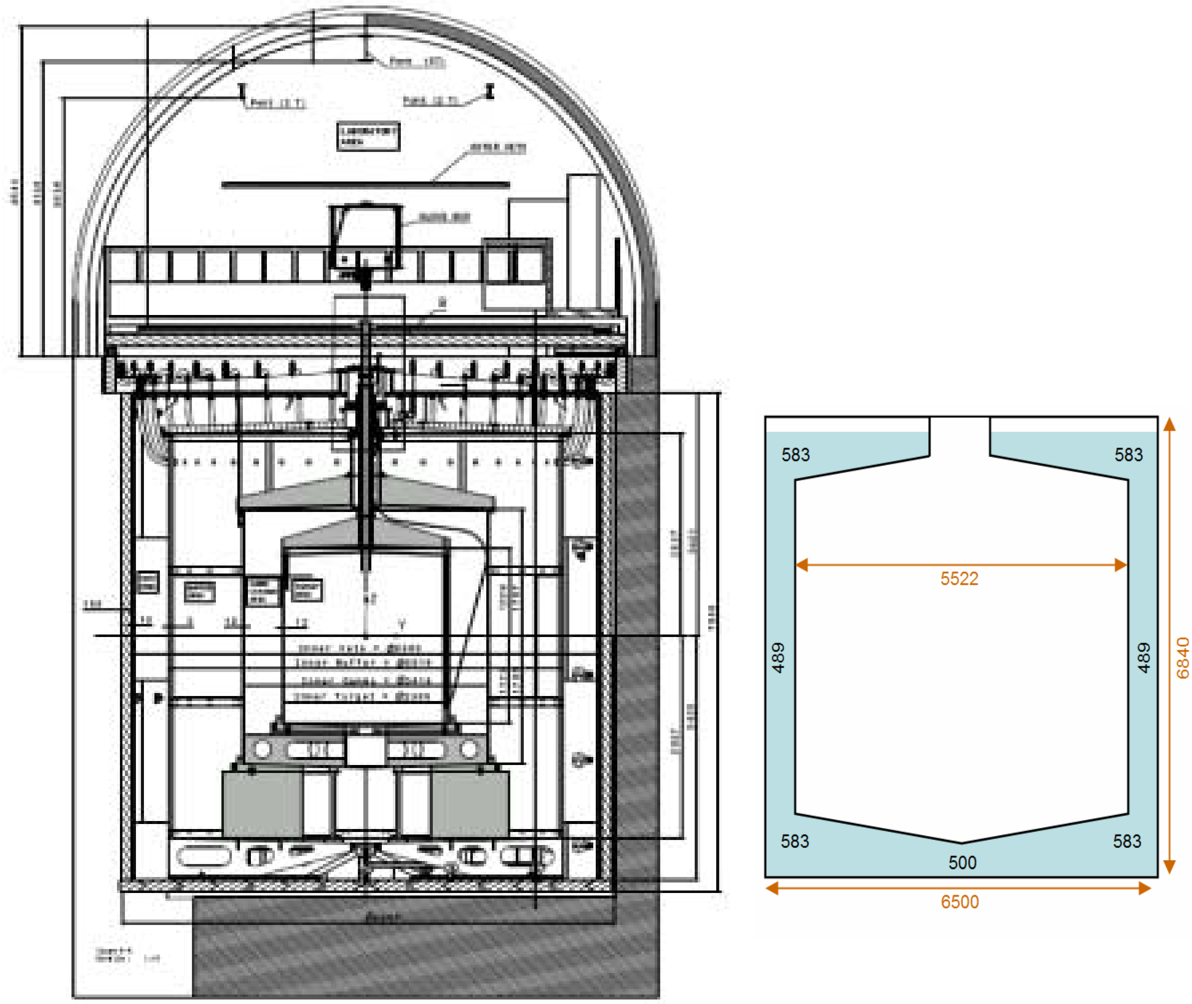


Figure 141 : Reference Drawing for the far detector, indicating the veto vessel dimensions and sketch of the relevant dimensions (in mm). (F. Ardellier 04.07.2007)

12.3. Surfaces

Our simulations have shown that coating the veto walls with white (TiO_2 including) paint and the buffer vessel walls with Tyvek foils increases the average light seen by PMTs for uniformly generated electron events by a factor of six compared to absorbing surfaces and three compared to stainless steel. The reflective cover extends the average time of hit by a factor of 2 compared to absorbing walls. Absorbing and stainless walls only differ by 20 %. The average number of hit PMTs increases as light is distributed farther through the detector.

While the steel veto vessel itself will be painted with TiO_2 -paint, the stainless steel buffer vessel cannot be painted. Therefore, Tyvek sheets have to be mounted on its outside. We plan to use Tyvek sheets of approx. 5640 mm length (the height of the buffer vessel minus 40 mm for mounting) and width of 1500 mm or less, depending on the spacing between the cabling tubes. Nylon ropes or stainless steel wires will be threaded through rings on the bottom edges of the the buffer vessel wall, and fixed at the reinforced corners of Tyvek sheets. Finally, the sheet can be hauled in place. Fixing the sheets on the top of the buffer vessel can be done in a similar way.

***Interface to buffer*:** to fix the Tyvek sheets on the buffer, small fittings (rings) are needed at the top and bottom edges of the buffer vessel. The position of these is determined by the pipes attached to the buffer and can be defined as soon as the final design of the cabling pipes is finished.

12.3.1. Items of the Inner Veto

78 PMTs (+spare), encapsulated as described below, with 20m cabling (TBD, RG-303 or similar), connector (TBD) to HV splitter boxes

- mechanical support structure to be mounted on platforms with welded screws as describe below for the PMTs of
  - inner top ring (12 PMTs)
  - outer top ring (12 PMTs)
  - side ring (12 PMTs)
  - outer bottom ring (24 PMTs)
  - inner bottom ring (18 PMTs)
- Tyvek sheets, pre-tailored with wires for attachment
- calibration LEDs with cabling, electronics
- temperature sensors with cabling
- heater modules with cabling

12.4. PMT Layout

PMT placement should optimize (1) redundancy and (2) uniformity of response, where (1) has priority. To this end, simulations were performed in the following way: electrons with fixed energy (1-5 MeV) were uniformly created in the Veto volume. Then, detector response maps were generated for number of hit PMTs and number of detected PEs. As expected, considerable non-uniformity is generated by the buffer support structure. Moreover, many partially separated volumes are created by its geometry. Accordingly, PMT coverage at the bottom was increased. As the support structure is stainless steel, painting is not possible. Assuming 40 % reflectivity for the surfaces, some shadowing effect, especially between the parallel walls of single support girders, could not be avoided.

In general, PMTs are arranged in rings with alternating up/down-orientation, in/out-orientation respectively. Mounted on top of the buffer vessel, there will be an **inner top ring** of 12 PMTs facing alterningly inwards and outwards. An **outer top ring** of 12 PMTs will be located close to the veto wall in the upper corner of the veto region. These PMTs can be mounted on the outer part of the veto top lid, if this is divided in inner and outer part. They face inward if they are at the same phi position as an inward facing PMT on the inner top ring, otherwise they look downward. Another 12 PMTs comprise the **side ring**. Orientation alters between up- and downfacing PMTs in such a way that PMTs at the same phi as a downward looking PMT on the outer top ring face downwards as well. The **outer bottom ring** consists of 24 PMTs, looking inwards where the corresponding side PMT looks down, or upwards where the side PMTis facing upward. Finally, the **inner bottom ring** includes 18 PMTs, facing inwards or outwards as determined by the outer bottom ring.

The position of the PMTs is defined by z-position and r-position of their reference point as defined in fig. 7, and their direction. A table of these data is the the specification the the *interfaces to inner veto vessel and buffer vessel*.

The resulting light collection with this PMT layout was simulated and the results are given in the following figures. Shown is the light collection (in p.e.s) for an energy deposit of 2 MeV at various positions in the veto volume.

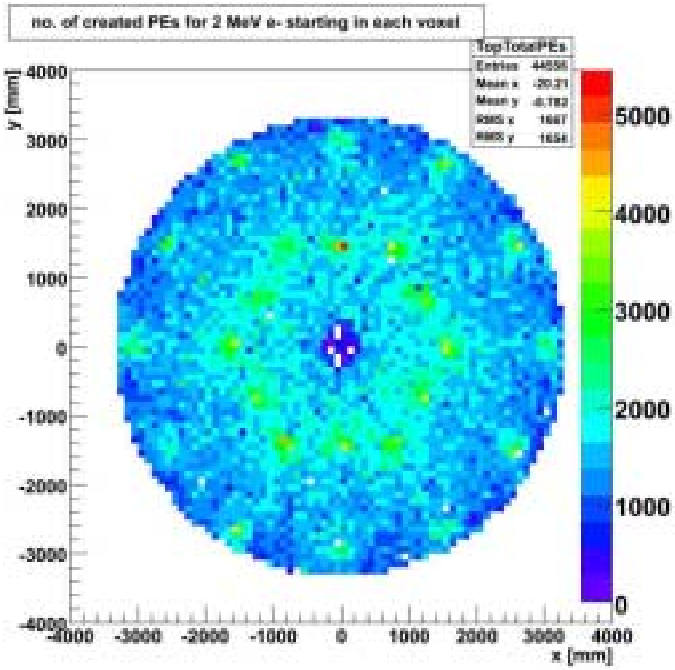


Figure 142 : Simulated light collection map for the top region (above the buffer).

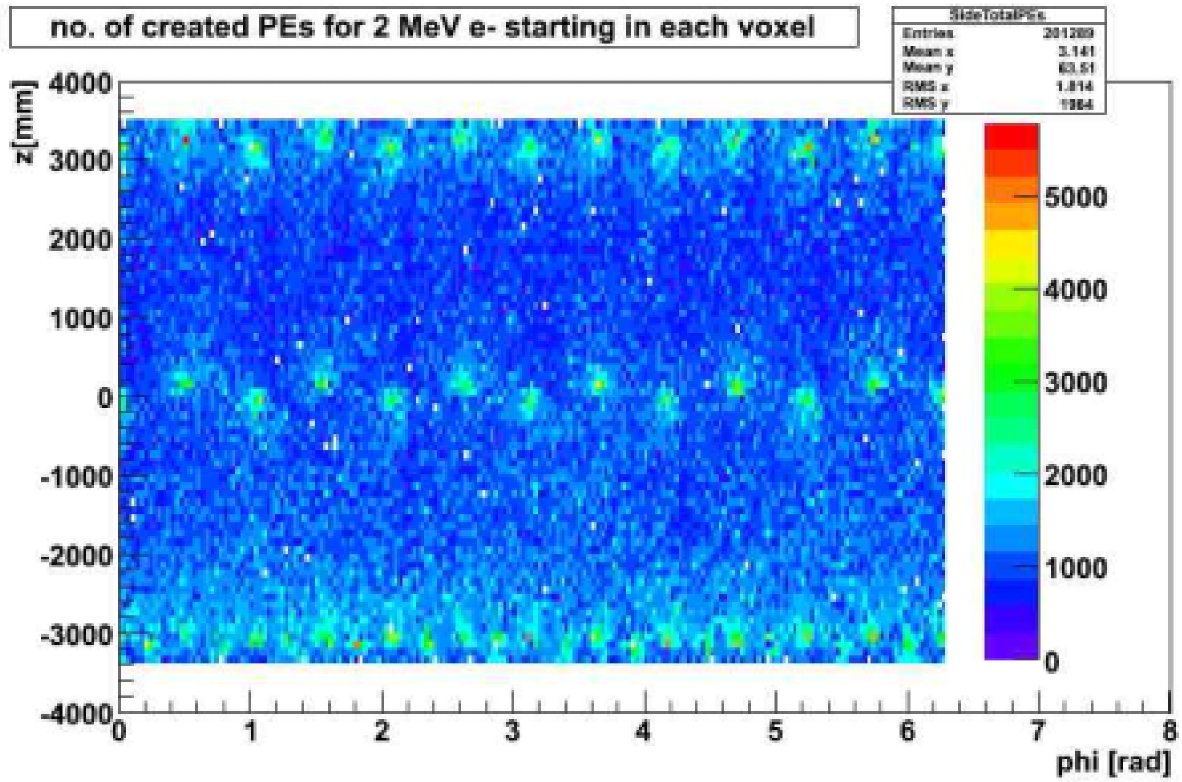


Figure 143 : Simulated light collection map for the side region (between buffer and veto vessel).

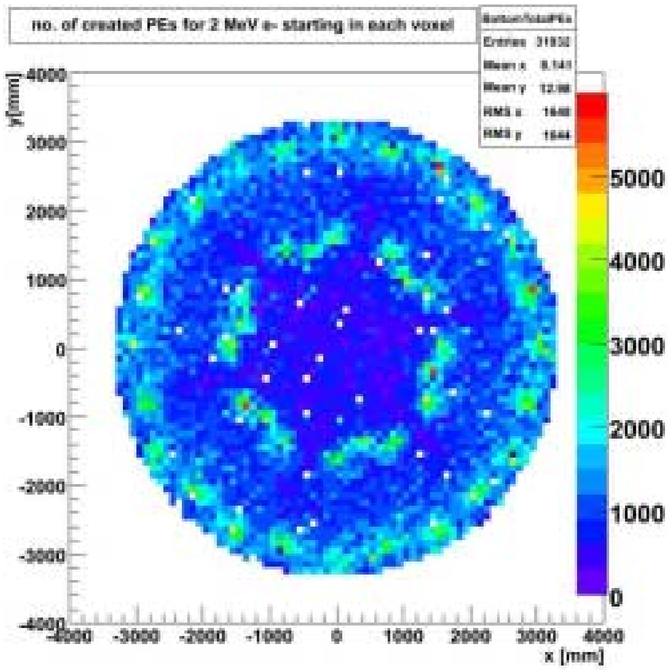


Figure 144 : Simulated light collection map for the bottom region (below the buffer), where the buffer support is creating shadow effects.

12.5. PMTs

Candidate PMTs under further consideration include (see also Inner Veto PMT talk in Madrid, B. Reinhold):

ETL 9354KB: 8 inch, baseline PMT for Double Chooz Vetos
Photonis XP-1806: 8 inch, alternative to ETL
Hamamatsu R-5912: 8 inch, alternative to ETL
Hamamatsu R-1408: old 8 inch tubes from IMB (and Super-K)

As the first three options have comparable tecnical specifications, price would be the driving criterion between these. The option of using old IMB tubes available from University of Calfornia, Irvine is under evaluation. The decision for the PMT candidate shall be based on criteria which are concretized by Monte Carlo Simulations on the trigger system and PMT measurements & comparison in Aachen. Criteria that have to be evaluated and met are:

- resolution: all three PMT types except the Hamamatsu R-1408 show good single p.e. resolution. Since light output is very high for crossing muons, this is not a critical point for muon detection. As a result of the MC studies, it was shown that the given exponential charge distribution of the R1408 allows also for neutron detection with an acceptable threshold and trigger condition.
- cathode efficiency: is it position dependent?
- acceptable dark rate
- radioactivity: contribution to gamma background
- failure probability: is it higher for the old batch of PMTs?
- performance in the magnetic environment near the shielding with a single layer mu-metal shielding

12.6. Processing and testing the PMTs

(It this part, it is assumed that new PMTs are used. The scenario for IMB PMTs is not sketched here).

1. The PMTs for the Inner Veto will be produced and undergo quality tests at the company, with inspection(s) involving people of the Double Chooz collaboration.
2. Shipment is to Tübingen. The Veto Group decided to do all tests and the encapsulation at the same site to avoid unnecessary transport.
3. PMTs undergo first tests (items: visual inspection, functionality, gain tuning, dark rate, single p.e. pulse shape)
4. Encapsulation: Tübingen has the expertise to do this (details see below).
5. Optical inspection, specification tests of the encapsulated PMTs.
6. Mechanical assembly of PMTs and support structure.
7. Packaging and transportation to Chooz.
8. Optical inspection and electrical tests on the Chooz site.
9. Installation of the Inner Veto PMTs in the veto vessel.
10. Electrical Tests and Comissioning of the Veto PMT system

12.7. Integration

The veto vessel itself will be welded together in place from two half-discs (bottom) and six half-cylinders (side walls) after the steel shield has been constructed in the pit. Steel bolts will be welded to the inside of the vessel to fix the encapsulated PMTs and cables in place. The surface of the veto vessel is painted with high reflectivity TiO_2 paint.

The strings for hoisting the Tyvek sheets are threaded through the lower guiding rings. Veto bottom temperature sensors and heater elements are installed and their cabling fixed to the walls. The bottom part of the veto vessel is protected by foils from dust and welding sparks. The middle third of the buffer vessel is welded on the lower third. Veto PMT installation is done for the side ring PMTs. Cables from bottom and side pmts are fixed to the wall up to half height of the vessel, followed by cleaning of the veto walls and moving of the protective foils upwards above the side PMTs. The top ring of the buffer vessel is welded in place. The inner detector is assembled in place.

The 36 tubes for the inner PMT cables are welded to the top third of the buffer wall, as are the top guiding rings for the Tyvek sheets. The buffer vessel is closed with the buffer lid, where stiffeners are welded to the lid. All surfaces are cleaned. The strings are threaded through the Tyvek sheets and the upper guiding rings. The Tyvek sheets are hoisted in place. The upper outer PMT ring is installed on the veto wall and the veto “crown”. All cabling is fixed to the wall up to the top of the veto vessel and led out through the appropriate tubes outside of the veto. The upper inner PMT ring is installed on the buffer lid, and their cabling led through the appropriate holes in the veto lid. As final step, the veto lid is closed.

12.7.1.PMT encapsulation and support structure

The PMTs will be encapsulated in a stainless steel encapsulation. The PMT glass is covered by a PET foil in this design, resulting in a completely closed device, filled with mineral oil.

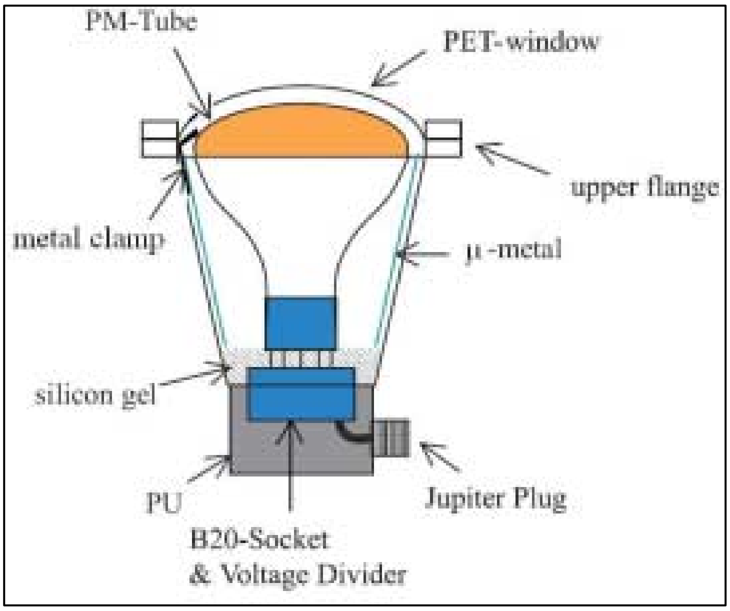


Figure 145 : Schematic view of the PMT encapsulation. The Jupiter plug will be replaced by a cable outlet of stainless steel and shrinking tubes.

Figure 146 : The encapsulation with cable outlet.

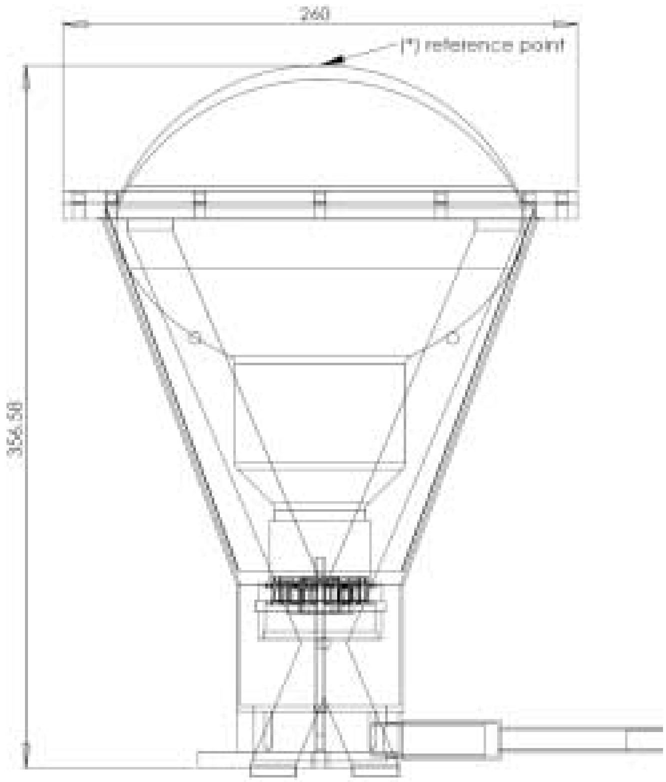


Figure 147 : Overall dimensions of the encapsulated PMT with reference point (*).

12.8. Interfaces with mechanics

The buffer vessel will be supported by six double-walled stainless-steel girders. Each girder wall is of trapezoid form, with the longer parallel side along the buffer bottom and the shorter parallel side along the veto bottom. The girder walls will contain three windows to allow for light propagation. In addition, there are two concentric rings of stainless steel with a height of half the available space, with radii of 1165 mm and 1770 mm respectively, attached to the bottom of the buffer vessel.

The inner PMT cables will be fed through the buffer walls and exit the detector at the top of the veto. As the buffer and veto vessels have to be completely separated, cabling tubes will be welded to the outside of the buffer vessel. Current design uses 30 tubes to the buffer wall close to the lid and 6 onto the buffer lid.

The cabling tubes are expected to be made of stainless steel as well. Simulations showed no shadowing effects regarding their radial positioning. However, it is important not to create straight paths for muons and neutrons unobserved by
the veto. It is therefore proposed to have a bend in each of the tubes (see inner PMT cabling section).

The mechanics group will need to know the number and size of cables for veto
PMTs and additional hardware installed in the veto and the desired place to feed
the cables through. The details of the construction process are to be discussed as well.

12.8.1.Support structure

Each PMT is equipped with an independent support structure, which holds the encapsulated PMT on the two ends: at the steel flange ring near the photocathode and at the opposite end near the encapsulated base. For material compatibility reasons, these support structures are made of stainless steel.

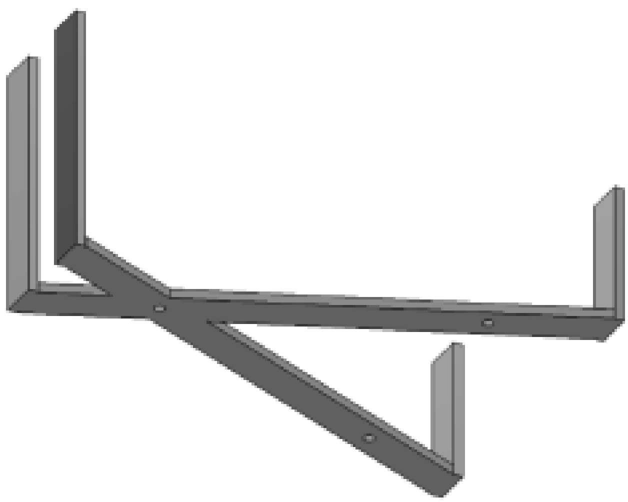


Figure 148 : Support structure and picture of a protoype for vertical looking PMTs.

With this support structure, the distance between the center of the PET foil (marked as reference point (*) in fig. 7) and the walls is either approx. 160 mm parallel to the PMT axis or approx. 400 mm in longitudinal direction.

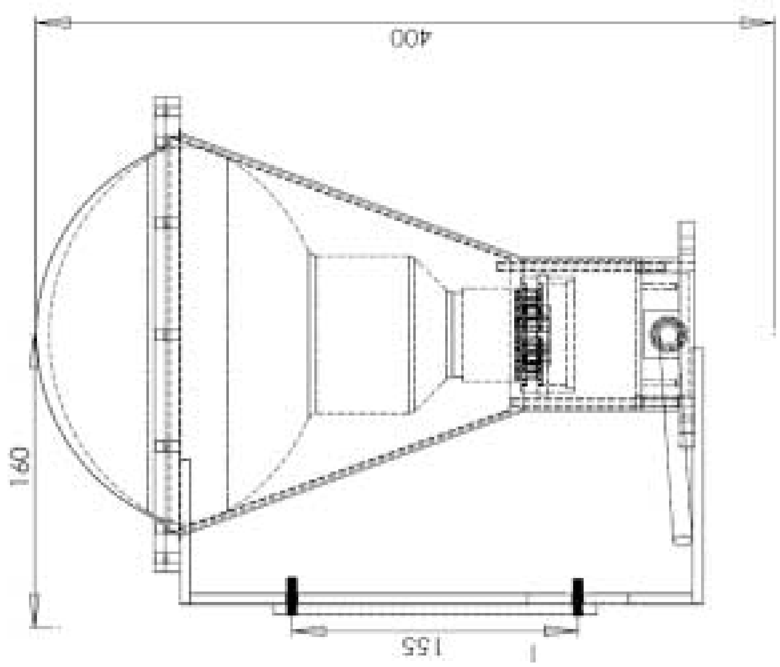


Figure 149 : PMT support structure attached to encapsulated PMT.

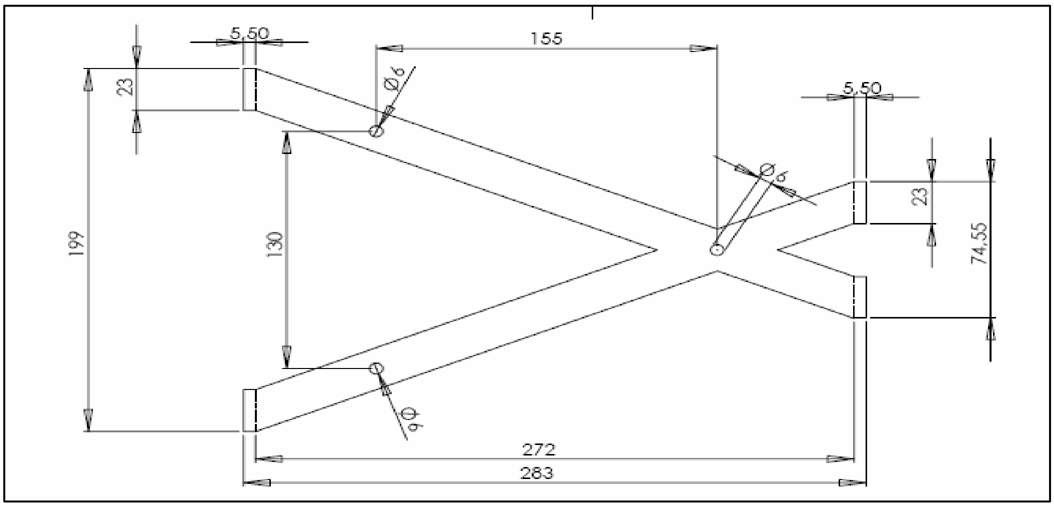


Fig. 9: Top view of the support structure with holes for the welded screws. The distance between the center of the holes is 155 mm in one direction and 130 mm in the other direction.

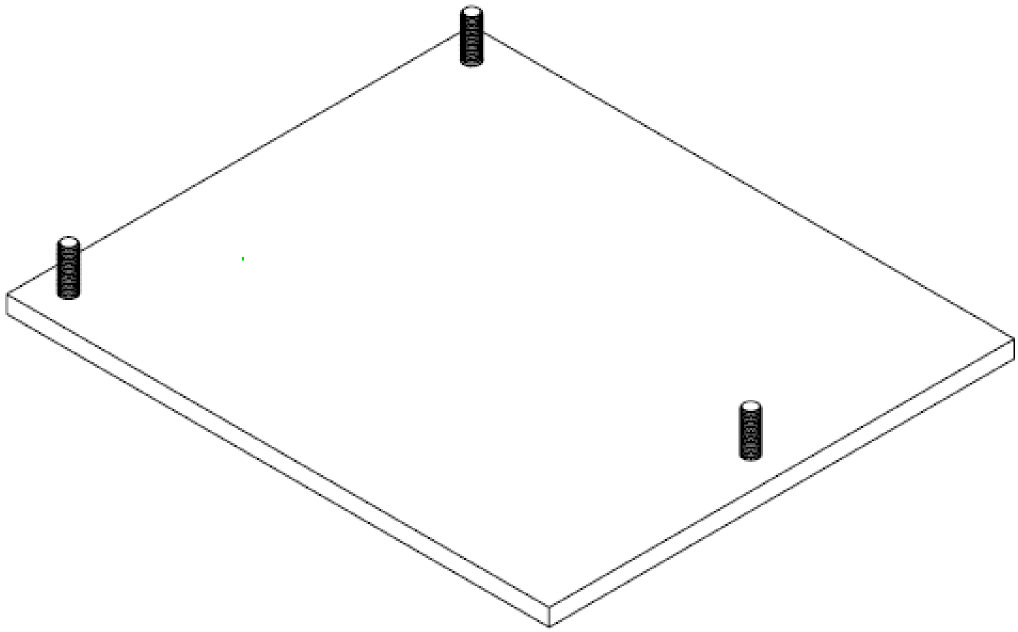


Figure 150 : Mounting plate with welded screws that can hold the PMT support structure.

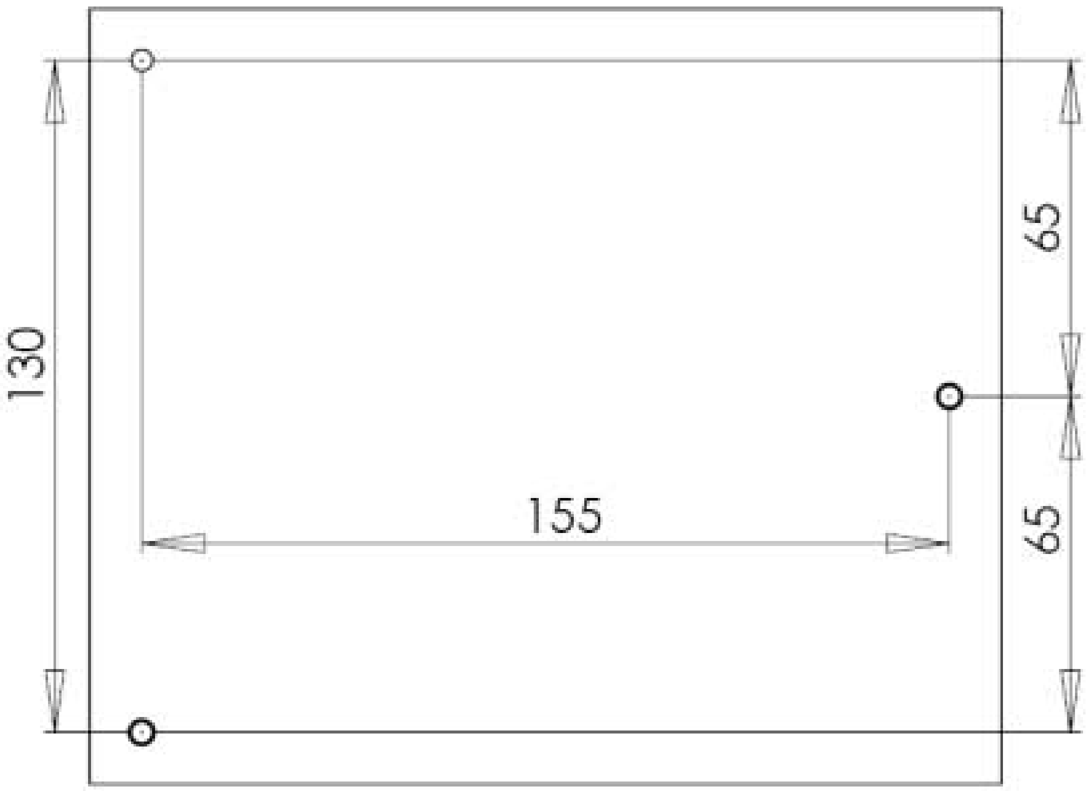
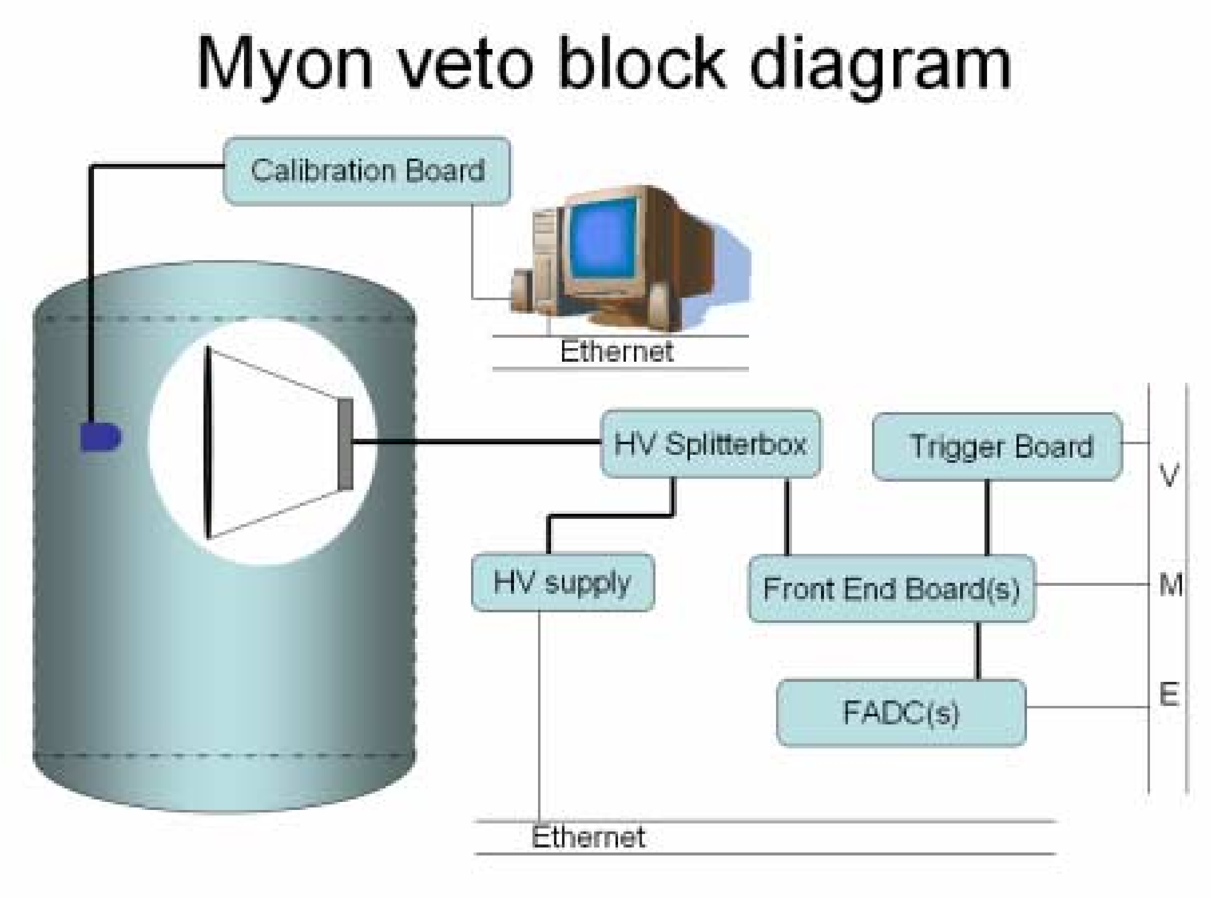


Figure 151 : Top view of the mounting plate with welded screws that can hold the PMT support structure. The distance between the center of the holes is 155 mm in one direction and 130 mm in the other direction.

12.9. Electronics

The 78 PMTs of the inner veto are connected to the DAQ system with single coaxial cables for both HV and signals which run inside the veto volume to the top and then outside of the detectors to the splitter boxes. The signal lines are then grouped by 5 or 6 for the FEE boards. The dynamic range of the veto signals has to be matched by the front end electronics. While simulations indicate signals ranging from a few PEs per PMT (neutron signals) up to O(10000) PEs per PMT, the PMT response to such signals is currently under study. The data to be specified includes signal amplitudes,
gain, FADC time window, shaping time constant and trigger conditions for event classification.

Calibration data generated by LED pulses should be flagged in the DAQ process, which means either the calibration system sends data to the trigger boards, or adds flags to the stored data for L3 (offline) trigger.



12.10. Calibration

Status: It is currently undecided, if the calibration hardware of the veto will be included in the overall calibration system or will be a separate system. For the latter design choice, a preliminary design exists which is discussed with the Calibration group in the time of the Oxford collaboration meeting. The aim is to have a useful interaction between those working on the inner detector calibration and those concerned with the inner veto to fix the design in October 2007.

13. Data Base / Soft [7000]

14. Outer Veto [8000]

TO BE UPDATED

14.1. Backgrounds and the Outer Veto

Understanding and subtracting background events is a key requirement for reactor experiments. The backgrounds that mimic the inverse beta decay signal may be separated into two categories: uncorrelated and correlated. Uncorrelated background events result from random coincidences between two different events, that together mimic the IBD signal. For example, a coincidence between a radioactive decay and a neutron produced by a cosmic ray muon could produce a fake signal event.
Fortunately, the level of these events can be measured easily by changing the required time coincidence window (*e.g.* by exchanging the required sequence for the positron-like and neutron-like signals).
Correlated backgrounds, in which both the positron and neutron-like signals result from the same parent particle, are more problematic. Three types of correlated backgrounds are considered:

- *Fast neutron.* Fast neutrons produced by cosmic ray muons can fake the IBD signal by elastically scattering in the Gamma Catcher or target volume and subsequently capturing on Gd. The recoil protons from the elastic scatter can mimic the prompt positron signal from inverse beta decay, followed by the delayed n+Gd capture signal.

- *Muon capture.* Muon capture, particularly on nuclei in dead material along the muon track, can produce fast neutrons that mimic the IBD signal as described above.

- 9*Li.* Spallation from cosmic ray muons can create 9Li inside the detector. About 50% of 9Li □decays produce a neutron that can capture on Gd, which along with the prompt signal from the □ mimics the IBD signal. The 178 ms half life makes these events difficult to veto without producing unacceptable dead time.

All of the background sources are associated with cosmic ray muons (even accidental back-grounds usually result from a coincidence between a radioactive decay and a muon-induced neutron). The muon flux at the near detector hall, protected by approximately 70 m.w.e. of rock overburden, is estimated to be 5.9×10^{-4} $cm^{-2}s^{-1}$ with a mean muon energy of 30 GeV; the far detector hall is protected by an average of 300 m.w.e. of rock, resulting in an estimated flux of 6.2X10^{-4} cm^{-2}s^{-1} with a mean muon energy of 61 GeV. These yield raw muon rates at the near (far) site of 5.9 (0.62) Hz per m2 of veto coverage. However, muons passing through the central target and gamma catcher deposit orders of magnitude more energy than IBD events and are easily identified. Most of the muons passing only through the mineral oil buffer will also produce significant Cerenkov light, and, thus, be identified and rejected. Table 1 summarizes the expected background levels in the near and far detectors after eliminating muons passing through the central detector. (Central detector muons have not been eliminated from the muon capture rates.) The total background rates in the near and far detectors are estimated to be 306 and 33 events/day, respectively. These rates result mainly from muon capture, against which the combined veto detectors should have excellent efficiency, as discussed below.

Even rejecting muons which have been tagged in the central detector, these are unacceptably high, because many background events are produced by muons that pass some distance away from the central detector.

Table 1: Background rates at the near and far detectors after eliminating muons hitting the central detector, but without using the inner or outer veto systems. (Central detector muons have not been eliminated from the muon capture rates.) Accidentals involving radioactive decays in the PMT glass and other detector material are shown separately.

Detector	Site		Background				
			Accidental			Correlated	
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.5 ± 0.8	2.0 ± 2.0	28	1.0 ± 0.5
(69 ν/d)	Far	bkg/ν	0.7%	2.2%	2.9%	40%	1.4%
Double Chooz		Rate (d^{-1})	5 ± 3	17 ± 9	9.1 ± 9.1	266	9 ± 5
(1012 ν/d)	Near	bkg/ν	0.5%	1.7%	0.8%	26%	0.9%

The Double Chooz experiment uses a two-part veto system to detect these \near-miss" muons: the inner veto, a 50 cm thick liquid scintillator detector that surrounds the three central detector volumes, and the outer veto, a large-area muon detector placed above the central detector which is the subject of this proposal.

The outer veto is intended both to reduce backgrounds associated with cosmic ray muons and to be a powerful tool in understanding the different background components and the performance of other elements of the Double Chooz detector. Its functions include:

- Reducing the fast neutron background at the near (far) detector by a factor of 5 (2) beyond what can be achieved with the inner veto alone.
- Measuring the efficiency of the inner veto.
- Selecting samples of cosmic muons hitting rock, steel shielding, support structures, etc. to study neutron backgrounds originating from these uninstrumented regions.
- Providing a tracked sample of muons to study 9Li background.

- Providing redundancy for the inner veto. For example, the outer veto will detect muons traveling down large vertical cable tubes in inner veto volume.

- Eliminating muon capture backgrounds in the steel shielding.

- Reducing accidental backgrounds associated with muons.

To perform these functions, the outer veto must tag muons with a high efficiency over the entire veto volume as well as provide tracking information for muons that pass in and around the central detector.
We have studied the benefit of different levels of coverage for the outer veto system. An ideal system would cover all sides of the detector and would surround significant additional passive shielding. Such a system would either veto muons producing neutron backgrounds, or provide enough shielding to attenuate neutrons produced by muons that did not hit the veto. In combination with the inner veto system, a large “umbrella-style" outer veto situated above the detector will provide much of this function at a significantly lower cost. A top-only design is also the only possibility for the existing far laboratory.
Figure 1 shows, for the near site, the reduction in the fast neutron rate into the Gamma Catcher and target regions as a function of the size of a square outer veto placed 1.1 m above the central detector. This study takes the proper surface distribution of cosmic ray muons as its input, and uses FLUKA to track the muons from the surface to the detector depth and produce neutrons. The rates shown are for muons that produce at least one neutron entering the Gamma Catcher volume. Muons passing through the central detector, which may be rejected without the veto systems, have already been excluded.
These curves assume 100% efficiency where coverage exists. The inner veto is expected to be fully efficient whenever the muon path length in scintillator exceeds 4 cm, less than 1/10 of the thickness of the inner veto. The outer veto efficiency, which will be discussed in the following section, should exceed 99%. Based on Fig. 1, the constraints of the detector hall, and dead time considerations we have decided on an outer veto size of 12.8 m *X* 12.8 m for the near detector and 6.4 m *X* 12.8 m for the far detector; the details of the outer veto design will be described Section 2.
At the near site, the muon rate hitting the outer veto system will be about 1 kHz, resulting in a 25% deadtime for a 250 μs veto; the muon rate at the far site outer veto will be only ~ 50 Hz, resulting in an order-of-magnitude smaller deadtime. As described in the Double Chooz full proposal [1], these deadtime rates will be monitored and measured using special electronic systems and are expected to only contribute a 0.25% systematic uncertainty in the near to far comparison.
The Venn diagram in Fig. 2 shows how the inner and outer veto systems complement each other to tag muons that produce neutrons which enter the Gamma Catcher and target regions. At the near site, 80% of these muons which are tagged by the inner veto will also be tagged by the outer veto; 92% of these muons which are tagged by the outer veto will also be tagged by the inner veto. Only 1.8% of muons producing potentially harmful neutrons will be missed by both systems.
Table 2 shows the background levels after rejecting muons crossing the inner veto or outer veto. The total background rate at the near site is 12 events/day (1% of the ν signal); at the far site it is 1.5 events/day (2.1% of the signal). At both sites, 9Li production is expected to be the dominant remaining background.
Compared to the background rates without the veto systems (Table 1), at the near (far) site the accidental rate is reduced by a factor of »10 (»5). The fast neutron rate at the near (far) site

is reduced by a factor of 60 (20). The difference between the near and far site reduction factors results solely from the reduced outer veto coverage at the far site, which is dictated by the size of the already existing far detector laboratory.
The muon capture rate at both sites is reduced by a factor of ~600. As 99% of the muon captures that produce a background event occur in the acrylic support structure and mineral oil buffer inside the central detector, the inner veto alone will tag these muons with a high efficiency, making the rate reduction at the near and far sites essentially the same. It should be noted that the outer veto will also have excellent e±ciency to tag these stopping muons, providing an important redundancy in the case of dead material in the top of the inner veto. The remaining 1% of muon captures which produce background occur in the steel shield, and are therefore tagged only by the outer veto, removing approximately 1 background event per day.

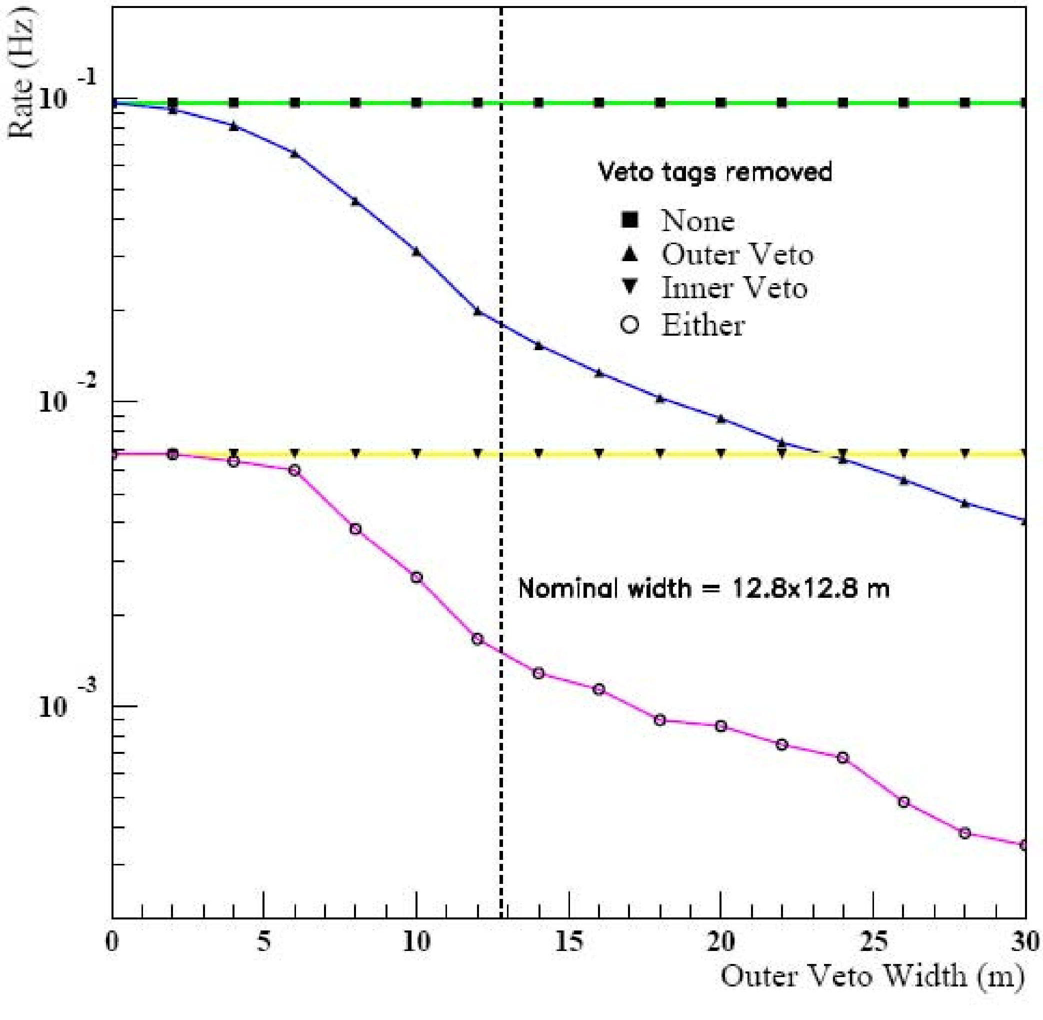


Figure 1: Rate of muon-produced fast neutrons reaching Gamma Catcher volume for top-only veto based on FLUKA.

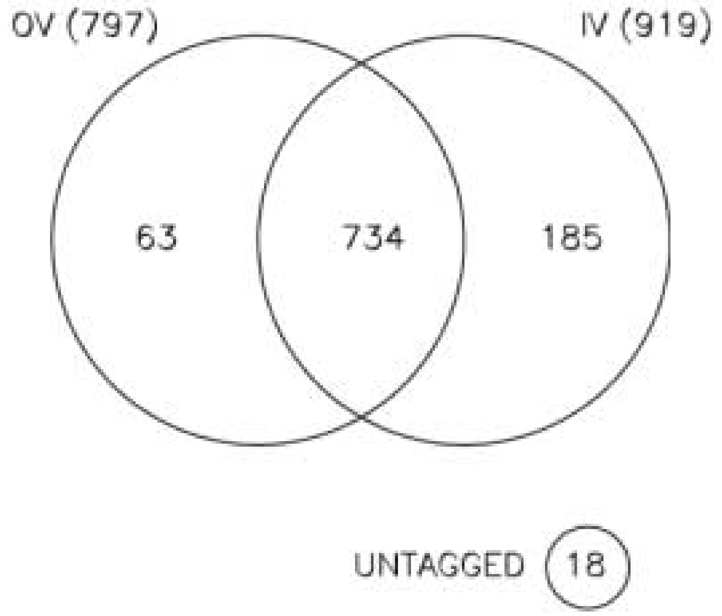


Figure 2: The number of muons (per 1000) producing neutrons which enter the Gamma Catcher and target volumes that are tagged by the inner veto (IV) and outer veto (OV) systems; the number of tags are shown in parentheses. Note that muons passing through the central detector volume are not included, because they can be identified without the veto systems. 18 events are not tagged by either system.

Table 2 also shows the expected systematic uncertainty for the background. Another key reason for the two veto systems is to assure the level of these systematic uncertainties by providingmeasurements and tagging for the backgrounds. In particular, the outer veto will allow one to track muons into different regions and assess the level of the various types of backgrounds. For example, although the 9Li background rates will likely not be reduced by the veto systems, we expect the veto systems, and the outer veto especially, to be an important tool in understanding the 9Li background level.

Table 2: Background rates at the near and far detectors after using all detector systems (central detector, inner veto, and outer veto) with 100% efficiency.

Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
Double Chooz		Rate (d^{-1})	0.1 ± 0.1	0.3 ± 0.2	0.11 ± 0.11	< 0.1	1.0 ± 0.5
(69 ν/d)	Far	bkg/ν	0.1%	0.4%	0.2%	$<$ 0.1%	1.4%
		systematics	<0.1%	<0.1%	0.2%	<0.1%	0.7%
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.7 ± 0.9	0.15 ± 0.15	0.4	9 ± 5
(1012 ν/d)	Near	bkg/ν	$<$ 0.1%	0.2%	$<$ 0.1%	$<$ 0.1%	0.9%
		systematics	<0.1%	<0.1%	<0.1%	<0.1%	0.5%

14.2. Outer Veto Design

As described in the previous section, the outer-veto system will be a large-area muon detector placed above the cylindrical Double-Chooz detectors. The outer veto will be made of 5 cm X 1 cm strips of scintillator formed into 6.4 m X 6.4 m planes. These modules will then be combined to form x and y layers of a supermodule that will cover an area of 6.4 m X 12.8m (12.8 m *X* 12.8m) at the far (near) detector site. The scintillator strips will be coextruded with a TiO2 reflective coating, similar to those used for the MINOS and OPERA experiments. Each strip will be 6.4 m long, and will have a 1.2 mm wavelength shifting ¯ber glued into a groove created during the extrusion process. Figure 3 shows a cross section of a strip.

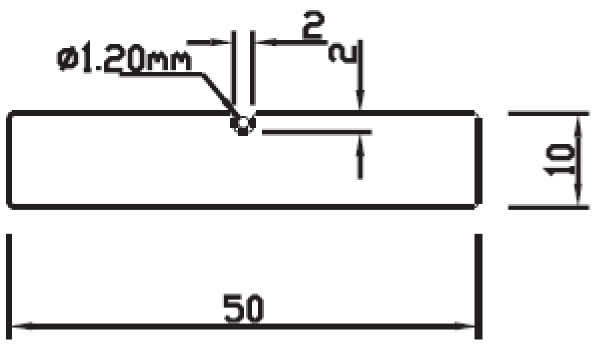


Figure 3: Cross section of scintillator extrusion. The nominal strip length is 6.4 m.

Modules will be built of two 32-strip layers of these strips, with each layer offset by 2.5 cm from the layer below. The resulting modules will be 1.6 m wide. Each 32 strip layer will be separately wrapped in a 0.02" Al skin that provides the light seal and strength for the module. The two 32-strip layers will then be attached to form a 64 strip module (see Fig. 4).

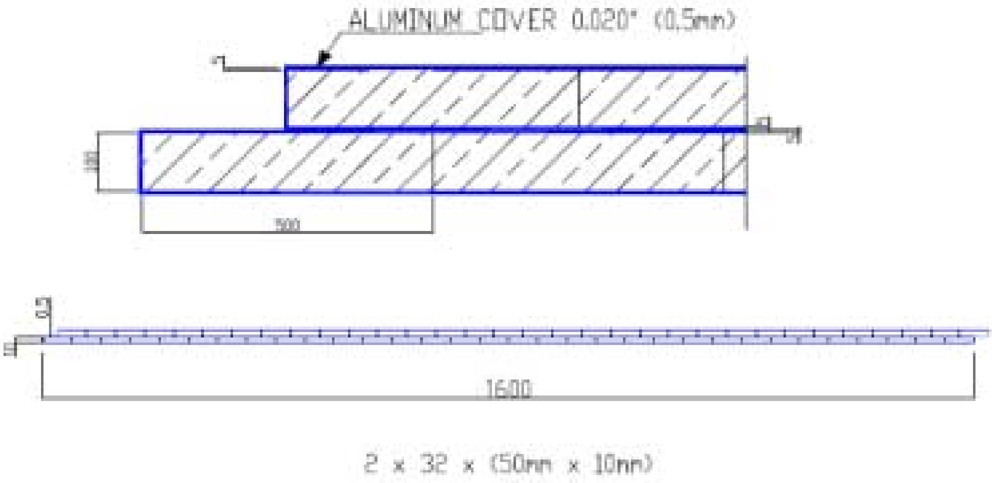


Figure 4: End view of 64-strip module. The detail shows the 0.02"Al skin surrounding each 32-strip layer

.

The 64 wavelength shifting fibers on each end will be coupled to a Hamamatsu M64 multianode photomultiplier tubes. Four of these 1.6 m wide modules will be combined to form a single 6.4 m X 6.4 m plane. Finally, a second 6.4 m square plane rotated by 90 degrees will be added. The resulting 6.4 m square plane with 4 layers of scintillator, shown in Fig. 5, is the basic unit used in the outer veto system.

Based on measurements by the MINOS collaboration, at the midpoint of a strip (i.e., 3.2 m from the end), a muon will result in about 4 photoelectrons. Using this estimate, a requirement of > 2 p.e. in at least one strip in each view will result in an efficiency greater than 99%.

The plans for the near and far detector are different because of the physical constraints of the existing far hall; the near hall will be constructed to accommodate the outer veto design. The near detector will use four 6.4 m square units surrounding the inner detector neck. An additional 6.4 m square unit will be installed above the “glovebox" to provide muon tracking over a limited region. (The glovebox will be used to introduce calibration sources into the central detector.) For the far detector, two of the 6.4 m square units will be installed on either side of the neck along the length of the tunnel. Small additional counters with single-ended readout will be added to cover the resulting gaps next to the neck. Finally, an additional ~ 5m square module will be added above the glove box for tracking; this tracking plane must be smaller because the tunnel roof is arched, reducing the space available above the detector.

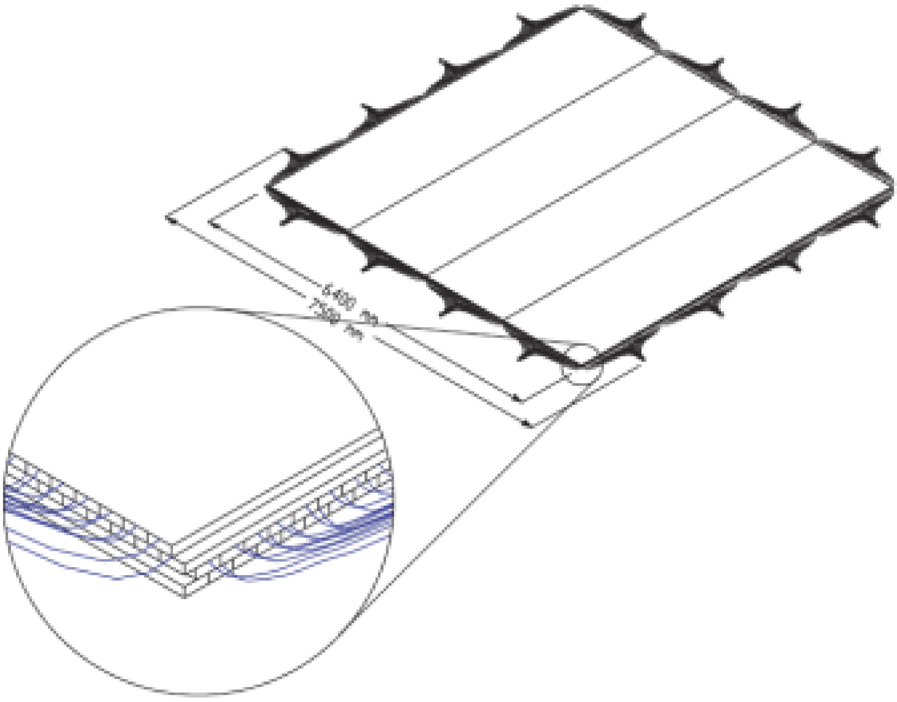


Figure 5: A complete 6.4 m square plane made up of 8 two-layer modules. The inset shows fibers leaving the 4 layers of strips.

14.2.1.Module Construction

Module construction will be done following procedures developed by the MINOS and OPERA collaborations. We estimate that construction of each 64 strip module will take 3 days using a full-time crew of 2 technicians and 4 undergraduate students.

The main steps in the construction are the following:

- 32 scintillator strips cut to the correct length will be glued into the bottom of an Al skin.
- After curing overnight in a vacuum bag, wavelength shifting fibers will be glued into the scintillator grooves and the fibers routed through plastic guides at the end of the module.
- After the glued fibers have cured overnight, the top of the Al container will be attached either by crimping or with glue.
- Two 32 strip modules made as described above will be glued to each other with a 2.5 cm offset.
- The 64 fibers on each end will be glued into a 64 fiber matrix that matches the M64 pixel layout.
- The fibers will be cut using the diamond-bit fly cutting station. At this stage, the module is ready for mounting M64s to the fiber matrix at each end.

Table 3 summarizes the cost for construction and testing of the scintillator modules; the costs for electronics and installation are given in the following sections.

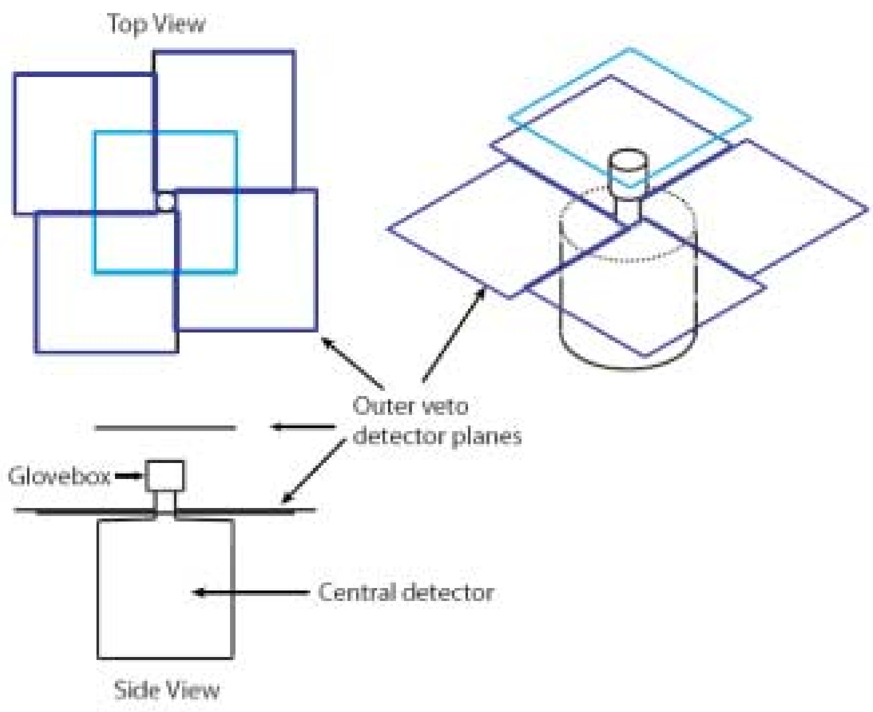


Figure 6: Outer veto layout for near hall. The design includes four 6.4 m square modules placed around the central detector neck, and a fifth 6.4 m square module placed above the "glovebox" to provide limited tracking.

At the site, the 64 strip modules will be attached to an Al support structure on rails;
we estimate $12k for each of the eight 6.4m square detector planes. Finally, the budget includes one full year of two technicians and 4 full-time equivalent undergraduates to complete the module assembly.

14.2.2.Electronics and Data Acquisition

The detector readout will require a total of 128 M64s, 80 at the near site and 48 at the far site.
The detector information needed for event reconstruction is the time and location of hits in the veto detector. Some analog information will also be useful to set thresholds.
We have designed a system in which the signals are discriminated and buffered locally to minimize cabling. Figure 8 shows a block diagram of the front-end electronics, which will be mounted on a small card behind each M64. Figure 9 shows the planned arrangement of a card mounted behind an M64.

[1]Although our nominal design assumes 1.2 mm diameter fibers, we have used the quote for 1.8 mm fiber. As we will be discussed in the section on prototypes, we will investigate whether an unglued 1.8 mm fiber (instead of a glued 1.2 mm fiber) gives sufficient light to ensure good efficiency; if so, the significant simplification in the assembly procedure will warrant the change. We've budgeted for the 1.8mm ¯ber to allow this possibility.

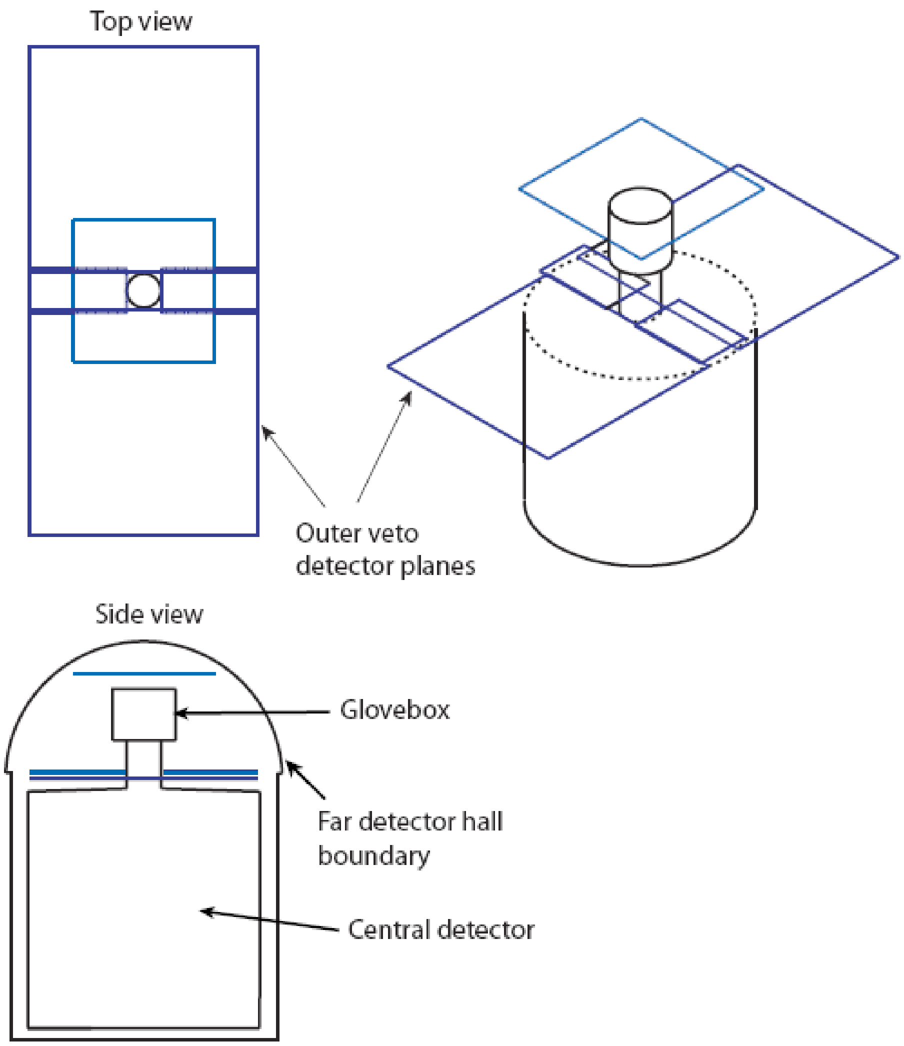


Figure 7: Outer veto layout for far hall. The design includes two 6.4 m square modules placed on either side of the central detector neck, and a fifth smaller module placed above the "glovebox" to provide limited tracking.

The 64 channels enter a MAROC2 custom integrated circuit, designed at LAL (Orsay) for the ATLAS luminosity monitor. This chip allows adjustment of the electronic gain of each of the 64 channels, which will be needed to correct for the expected factor of 3 pixel-to-pixel gain variation in the M64. The system will also apply three different discriminator thresholds for readout, thus, giving more detailed information for offine analysis. The chip also includes a multiplexed 12-bit ADC path that can be used for calibration, and a direct analog signal path, useful if an external trigger from the muon veto is ever required.

The output of the MAROC2 will be fed into an FPGA, also on the board. This FPGA will record the time of hits, buffer the data, provide control signals for the MAROC2, and provide a signal to the central system when data are present to be readout. A parallel to serial converter will be used to transfer data to central receiver boards when the FPGA is polled by the main system.

The system will use the Double Chooz distributed 62.5 MHz clock and time stamps to maintain synchronization with other detector elements. The outer veto data will be read out as a separate data stream of hits and times, and will be merged with the inner detector event records offine. The time offset between the inner and outer detector systems will be measured with cosmic ray muons.

The M64 price is based on a quote from Hamamatsu. We have included 150 M64s and readout cards providing 22 extra PMT units for spares and testing. For the clock distribution and VME system, we've included the requirements for the near and far readout, one spare component of each type, and also components for a single parallel readout system to be kept operating in the U.S. for tests. For example, the budget includes 4 VME crates: one for the near site, one for the far site, one spare, and one for a test setup in the U.S. The engineering and technician time are based on our estimates for the design, assembly, and testing of the readout system.

14.3. Quality Control

Quality control for different components of this very large system will be critical. Here, we mention only two elements of this testing:

- *M64 testing.*A test facility will be built to test and characterize each channel of the 64-channel Hamamatsu H7546 PMTs. The main goal of the test will be to measure the absolute gain of each channel, but several other characteristics such as cross talk and dark current will also be recorded.
- *Complete Module Testing.*We plan to test each completed module with its ¯nal electronics on a cosmic ray test stand for 12 hours. This test will allow us to verify the integrity of each

14.4. Prototype Construction

To finalize details of the design, construction, and module testing procedures, we will build two 64 strip prototype modules in early 2007[2]. The scintillator will be extruded at the Fermilab/NIU facility in December 2006. We will do extrusions with two different designs for the scintillator strips. One is the nominal design, in which 1.2 mm diameter wavelength shifting ¯bers will be glued into a groove (see Fg. 3). The other is a design with a central hole that will accommodate a 1.8 mm diameter fiber. If the larger fiber produces sufficient light without glue, this design would greatly simplify the module construction.
The prototype module construction will be completed during the spring of 2007. During the summer of 2007, we will collect data with these modules at the Double Chooz far detector hall.Measurements of the muon and singles rates in the hall will be extremely valuable in the final design of the electronics.

[2]This work is supported by an NSF supplement.

14.5. Detector Shipping and Installation

Complete 64-strip detector modules will be packed and loaded into 40 ft. intermodal containers for shipping to the Chooz site. Extensive studies done while shipping the MINOS modules demonstrated that no additional environmental controls are necessary.
We estimate that the near and far detector installations will each require two technicians for two months (i.e., a total of 8 technician months).

References

[1] \Double Chooz: A Search for the neutrino mixing angle theta(13)," Double Chooz Collaboration (F. Ardellier et al.), Jun 2006, 162pp, [arXiv:hep-ex/0606025].

15. Integration on site [9000]

The work package 'integration on site' deals with the coordination of the detectors construction on site. The construction of the detector in the Neutrino laboratory is made by each subsystem itself.
Integration refers to the assembly of detector on site and tests of the full systems during and after assembly. Written procedures are required on the one hand to obtain the authorisation (given by EDF) to work on site, and, on the other hand prepare all the facilities in time when needed.
A French people (P. Perrin from CEA-Saclay) will be in charge of the coordination of the assembly schedule on site, the acceptation / reception of delivered items. He will be permanent on site, and manage the space available, and the contact between EDF people and Double Chooz collaborators. He represents EDF on the site building site in front of the Double Chooz collaborators and he will be the 'spokesman of the building site' in front of EDF.

15.1. Terminology

The far site is made of:

- Neutrino lab : underground laboratory where the 'embedded detector' stays
- Building Liquid transfers building: building located at around 15 meters from the entrance of the neutrino lab tunnel, where containers will be stored.
- Area dedicated for truck unloads

15.2. Rules to work on site

Entrance authorization of each collaborator has to be prepared 2 months before the D-Day.

The technical work on site has to be planned two months before the start because a kick off meeting is planned with EDF people one month before to obtain the green light to start.
Following documentation has to be sent to the Detector Integration Leader on site :
-Flow chart of your building on site,
-Procedures of your tasks on site,
-Planning of realisation of works,
-Risks analysis and precautions taken compared to safety
    Example: to carry a helmet to work in the detector pit
- Environmental analysis and precautions taken compare to the environment
    Example: air extractor during soldering phase
- Authorization and accreditation of intervers

Dedicated handling tools and scaffold developed for the installation in the pit. They have to be certified as 'handling tools' before use on site.

The steps identified submitted to this protocol are:

- shielding installation
- Inner Veto vessel installation → mechanical structure paragraph
- Inner Veto PMTs installation → Inner Veto paragraph
- Buffer vessel installation → Mechanical structure paragraph
- Buffer PMTs installation → Inner PMTs paragraph
- Electronics installation → Electronics and DAQ paragraph

- Acrylics installation → Mechanical structure paragraph
- Tanks for liquids installation → Liquids and Filling system paragraph
- Tubing and filling system installation → Liquids and Filling system paragraph
- Glove Box installation → Calibration paragraph
- Outer Veto installation → Outer Veto paragraph

15.3. Scenario of detector integration

A ‘comics’ is being prepared by P Perrin to give all the steps for the detector assembly and tests. The inputs are provided by sub systems.

This chapter will describe the main step from the naked laboratory until the first data taking.

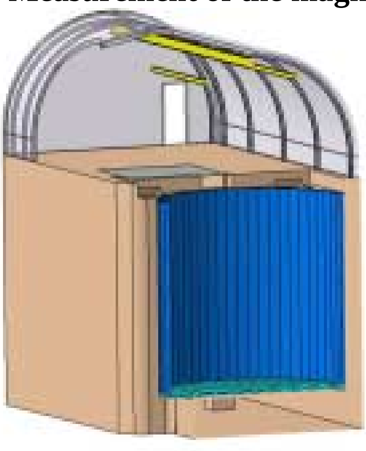
15.3.1.Infrastructure updates

To welcome the detector some modifications have been planned:

- civil engineering to give a better shape of the pit
- new ventilation system construction
- enlarging the entrance of the Neutrino laboratory
- Cleaning of the access tunnel
- Cleaning & drying of the laboratory
- Replacement of the footbridge
- Installation of a provisional door ‘type Manusouple’

15.3.2.Shielding assembly on site

- The beams to build the shielding have been demagnetized before their installation in the pit. Installation of the shield in the pit
- Check of the geometry
- **Measurement of the magnetic field**

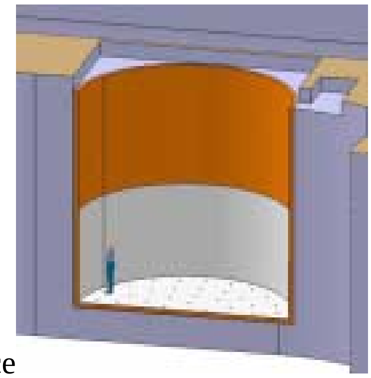


Tools and facilities:

- Movable platform for the tunnel
- Dedicated crane
- Scaffold

15.3.3.Inner VETO vessel installation in the pit

- Filling of the pit with water
- Welding of rings at the top of the pit
- Draining of the pit and descent of the vessel
- Check of the vessel tightness
- Closing of the vessel with the top lid



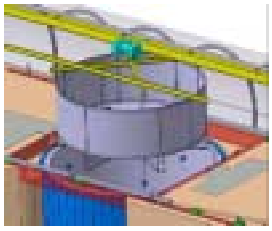
- Cleaning and white painting of the inner surface

Tools and facilities:

- movable platform for access tunnel
- dedicated crane
- scaffold

15.3.4.Inner VETO PMTs

- Installation of PMTs (see Inner Veto paragraph)
- Protection of installed PMTs



15.3.5.Buffer vessel installation

- Welding of the rings at the floor level
- Welding of the vessel at the top of the pit
- Closing of the vessel
- Check of the welding tightness
- Cleaning with a dedicated protocol (Nitric acid 10%)
- Installation of Tyveck foils on the external surface of the Buffer Vessel

Tools and facilities

- crane 5 tons
- gantry
- scaffold

15.3.6.Electronics installation

A dedicated electronics hut will be installed at the end of the laboratory. This hut will be mounted on site and equipped with air ventilation.
A first configuration study gives the layout here after :

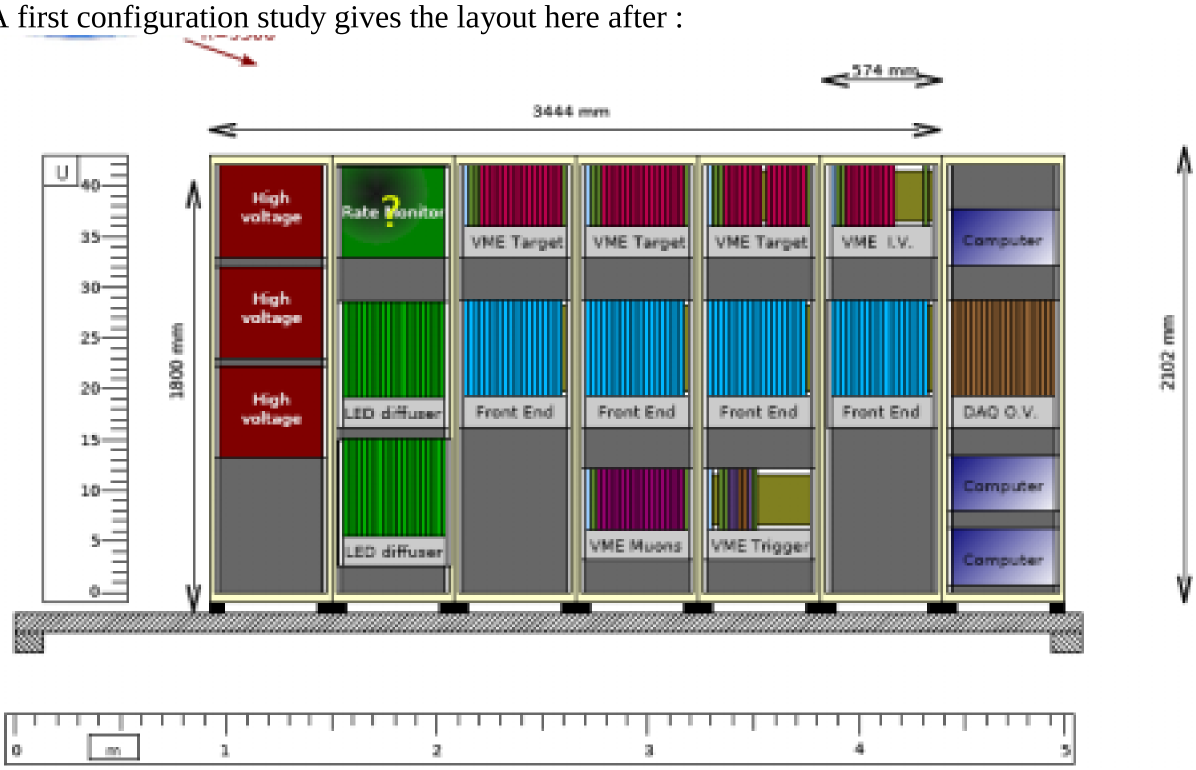


Figure 152 : optimised configuration in the electronics hut

The total amount of power dissipated in the electronics hut is around 10 kW.

15.3.7.PMTs of the Buffer

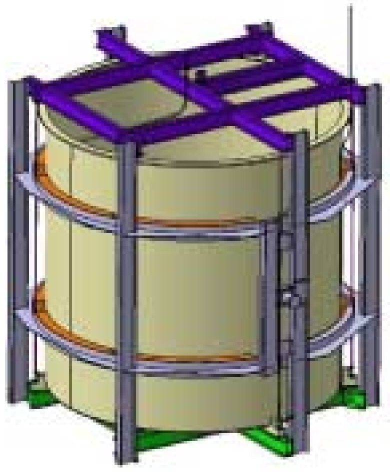
Before the integration of PMTS, a cleaning of the lab is planned and a dedicated clean area will be installed. A vinyl tent will be installed at the entrance of the Neutrino laboratory. From this step, the workers will have to put clean suits to in the Neutrino laboratory.

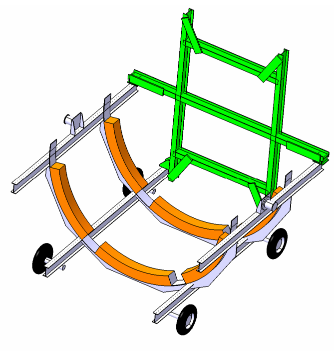
- The integration on site is very well defined in the PMT chapter
  - assembly of the PMTs equipped with magnetic shield, mechanical structure and light collector in the Buffer Vessel and the Top Lid
  - cables
  - cleaning
  - **first level tests with FEE and DAQ**

<u>Tools and facilities</u>
- scaffold
- crane

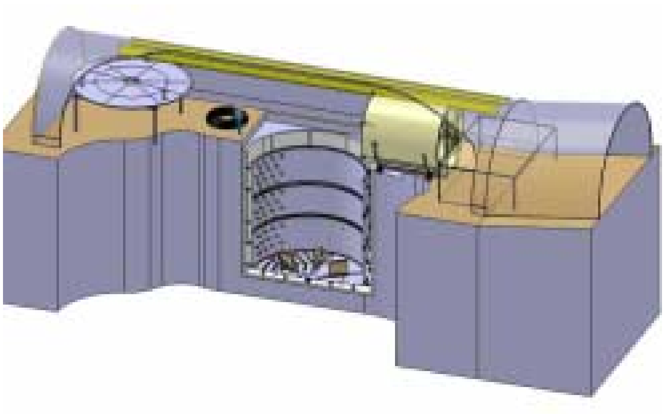
15.3.8.Acrylics vessels assembly

The Gamma Catcher and target vessels will arrive on site in dedicated tools which allows the keep the acrylics under nitrogen atmosphere and guaranty no stress during the transportation phases.





Dedicated tools for Gamma Catcher transport and installation (realisation made at CIEMAT)



- Installation of Gamma catcher is installed in the pit. Some PMTs will be removed to avoid collision between tools and PMTs during rotating phase.
- Installation of the Target vessel in the pit
- Gluing of the Gamma catcher top lid and acrylics chimneys under a vinyl tent to control the humidity and temperature during polymerisation

The mechanical structure chapter is describing deeply the installation phase on site.
The operation of installation will be driven by Patrick Perrin with 2 mechanical technicians from Saclay. The operation of gluing will be done by the firm in chare of the acrylics vessels production.

Facilities required

- Crane
- 2 lateral beams
- Dedicated tools
- Vinyl tent
- Aerotherm

15.3.9. Closure of the detector

- installation of the Buffer top lid equipped with its PMTs and cables
- Installation of the Inner Veto top Lid

15.3.10. Tanks and Tubing installation

To be completed

15.3.11. Glove Box installation

15.3.12. Filling of the detector

- Cleaning protocol to define
- Weighting devices to install
- Filling phase

Commissioning

To defined

15.3.13. Development plan

The main risks identified for the detector development and realisation are the following ones :

- use of a new doped LS for the target
- the mounting on an existing site;

After analysis and use of other experiment experience (Borexino, MiniBoone, Kamland), it was decided to answer to the following open topics:

- reliable process for acrylics vessels realisation
- Compatibility between the liquids and the vessels and others devices used.
- Definition of the interfaces inside the detector and also with filling system

The development plan for the detector realisation on site is made of three main steps:

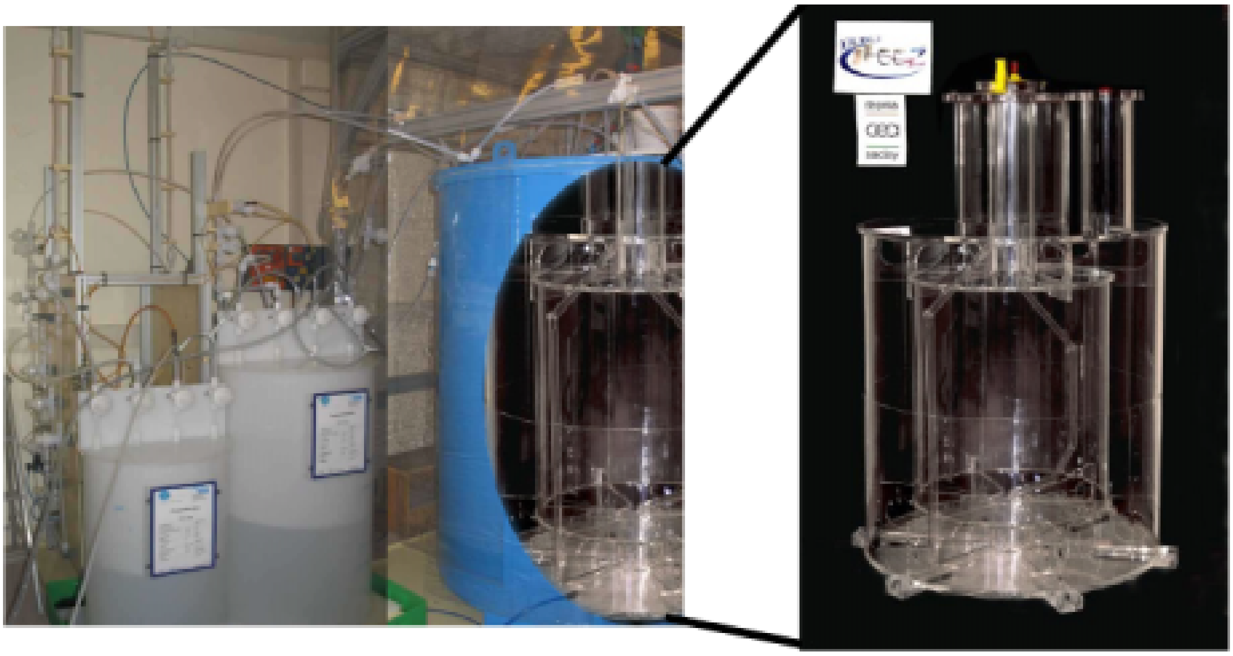
1. technological mock up of the detector scaled 1:5
2. chimneys mock up scaled 1:1
3. mock up of the far detector in the Neutrino lab scaled 1:20
4. realisation and spares

1. Mock up scaled 1:5

The technical goals of this mock up were to :
- validate design and process of realisation of acrylics vessels
- validate the mechanical solution
- validate a part of the detector integration scenario
- finalyse the definition of the interfaces and the assignment of responsabilities.

See chapter 5.2.2

Unfortunately, during the 6th extraction of samples, the target vessel was under overpressure statement and the gluing of the top was cracking.



View of the mock up.

What has been learnt with this model (see reporting EDMS I-XXXX):

Improvements
- Some technical solutions for the acrylics mechanics need revision → design has been updated
- Acrylics pipes at the interface with Teflon broke due to vibrations → all the acrylics pipes have to be replaced by Teflon pipes
- Some crazing appeared at the neck of the chimneys → a softer mechanical system has to be designed (use of bellows)
- The use of Viton joints (black) is forbidden because

- Tightness of the filling system is a crucial topic and its development and integration has to be carrying out with this constraints.
- The interfaces must be very well defined before the start of the realisation

Success

- The process of acrylics assembly has been qualified with the mock up realisation
- The coordination between groups and people is defined
- Protocol of cleaning and use have been defined
- The constraints for liquid handling have been well identified

1. Mock up scaled 1:1 of the chimneys

See chapter 5.2.1

The first mock up showed the difficulty for the design and the reliability for the chimneys mounting. A concept with several bellows has been proposed but it very difficult to qualify it with simulations.

Moreover, up to now, the integration of calibration systems (wire source) is not totally defined.

That is why a mock up of the acrylics chimneys is planned in the middle of 2007. Its aim is to prove:

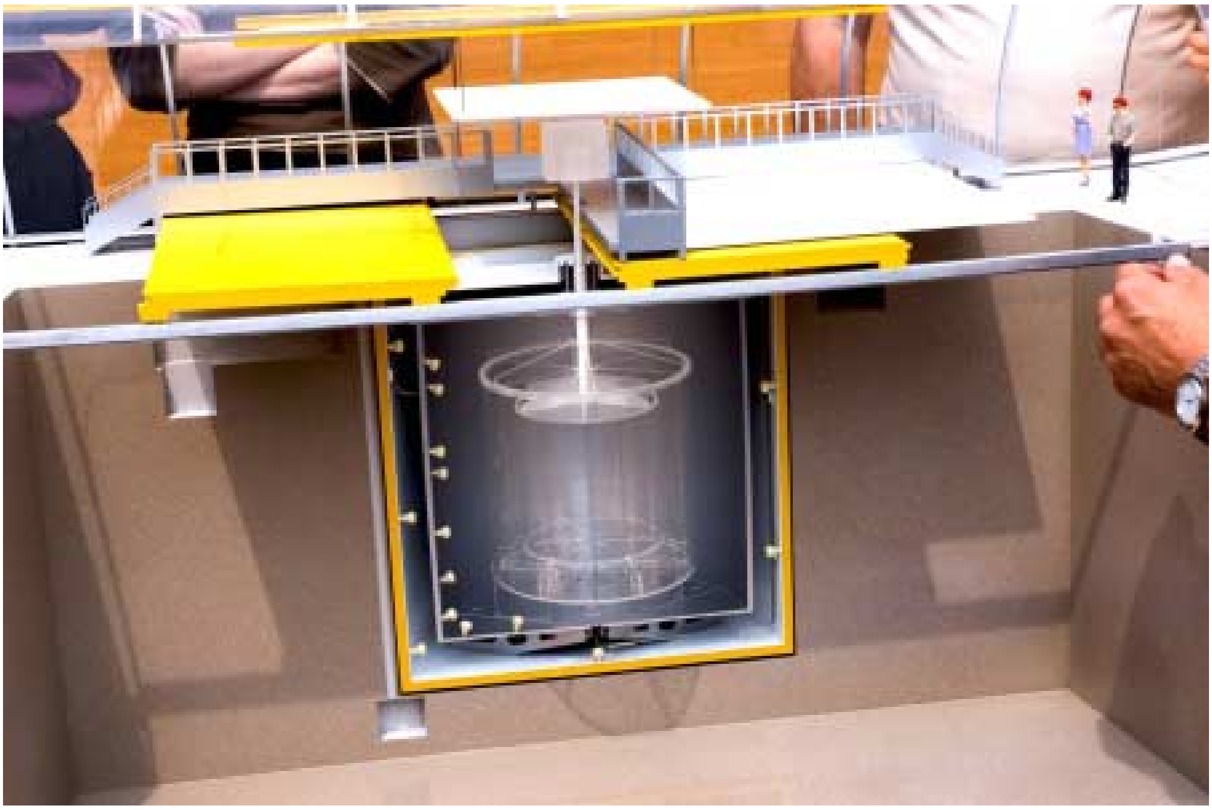
- The feasibility for the mounting of chimneys on site
- The feasibility for the mounting of the filling tubes paths in the chimneys
- The reliability of the system.

This mock up will also allow testing the assembly of wire source system and the interface with the glove box.

The chimneys will be made in PMMA GS-233 and the bellows will be made like for the real detector. If it is qualified, the bellows will be furbished to the far detector.

2. Mock up of the detector scaled 1:20

See Chapter 5.2.2
The study of the integration on site shows the difficulty of the logistic on site and the conflict of space.
No obvious solution is appeared.
To go ahead in the development, a mock up scaled 1:20 has been built. The idea is to use it with all the components needed on site to find an optimisation.



View of the mock up without electronics, fluid handling system, …

3. Realisation and spares

The design and assembly of the detector must consider the following possibilities:

- Change of the Target and Gamma Catcher liquid to guaranty the same liquid in both detectors→ recirculation system
- Change of the acrylic vessels if some involvement appeared when the near detector will be installed :

→ design of the Buffer and Inner Veto vessel keep the possibility to open the lid without dismantling the PMTs
→ operating mode :

- unfill the detector (4 volumes simultaneously)
- remove the Outer Veto upper part
- remove the left part of the top shielding
-

15.3.14. Tests plan on site

Before starting a step of component integration, some acceptance tests have to be done with the previous component installed.
Each component will have been tested before its arrival on site. A data sheet will accompany the component with its characteristics. This data sheet will be defined in the Product Assurance Plan.

The general test is not very well defined today. It is a proposal for framework.

Hereafter you will find some indispensable steps of tests:

- Measurements of the geometry
- Measurement of the magnetic field after the shielding installation
- Measurements of the geometry and tests of the inner Veto tightness
- Tests of Inner Veto PMTs after installation
- Dimensions measurements and tests of tightness of the Buffer vessel
- Measurements of magnetic field (to be confirmed)
- Test of Inner PMTs
- Tests of the tightness of the acrylics vessels
- Tests of the tightness of the tubing and filling system

16. APPENDIX

16.1.

[i] Booth et al., Nucl. Phys. A119, 233 (1968); Abramov et al., Sov. J. Nucl. Phys. 23, 636, (1976); F. Ajenberg-Selove, Nucl. Phys. A490, 1, (1988).
[ii] K.Zbiri, J.Martino, arXiv : hep-ph/0607179v2 21 Jul 2006.
[iii] Toshiyuki Iwamoto, PhD thesis, Tohoku University, Japan, 2003.
[iv] D. Reyna, Double Chooz Internal Document - PMT meeting, December/13/2006.
[v] D. Reyna, arXiv : hep-ph/0604145v2 Apr 2006.
[vi] http://www.burle.com/cgi-bin/byteserver.pl/pdf/Photo.pdf , page 47.
[vii] http://www.ppl.phys.chiba-u.jp/research/IceCube/pmt/dynamic/index.html
[viii] B. Cheviz, Double Chooz Internal Document - PMT meeting, April/26/2007.
[ix] see in this TDR, electronics chapter, the front-end boards description .