Overview of the Outer Muon System

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Correlated Muon Backgrounds

- **Spallation Neutrons**
  - Primarily of concern when the muon is not detected
    - Want to increase detectable volume for muons which hit the rock outside of the primary detector
  - From CHOOZ, ~10% background
    - Doubled target volume and additional neutron attenuation in mineral oil buffer reduce this as a concern for the Double Chooz far detector
  - Near detector will have much higher rate
    - Muon rate is x50 but signal rate is only x10

- **Muon Induced Radioactive Isotopes**
  - Primarily concerned with $^9$Li, $^{11}$Li, $^8$He
  - Evidence that these are related to high-energy “showering” muons
    - Want to detect a large dE/dx or high multiplicity for a muon which crosses the target volume
  - Implies that absolute rates are not significantly different between near and far detectors
    - Primarily a concern for the far detector
Goals for Outer Muon System

• Near Detector
  – Reduce untagged correlated neutron background to ~1%
    • $7 \times 10^{-5}$ Hz or ~6 ev/day
  – Large area coverage with >99% efficiency

• Far Detector
  – Determine track entry point
  – Sensitivity to showering/multiplicity
  – Need small granularity and fast response

• Additional
  – Cross-check efficiency of Inner Veto System
  – Need some 3 dimensional tracking
Detector Technology

- Wire Proportional Chambers with Ar/CO₂ gas
- Effective single layer efficiency of 97%
- A coincidence of 2/3 has 99.7% efficiency and reduces singles backgrounds
• System Block Diagram
  - Assumptions for Architecture:
    • Low Overall Trigger Rate
    • 100% Live Time (Low Trigger Rate)
    • Self-Trigger (Noise, CR)
  - Events are Tagged with Timestamps at Front End to Allow Processing Latency
  - Timestamps used for Event Reconstruction
• Front End
  - Amplifier/Discriminator made from discrete components
  - FPGA does timestamping and data processing
  - Can Self-Trigger, or Use External Trigger
  - One board for each module (24 detector channels)
  - Each data word = 24bit timestamp + 24 discriminator states
Simulation to Determine Coverage

- Use FLUKA to propagate muons from surface to near laboratory
- Record muon and neutron rates at various detector positions
- Save events in which at least one neutron entered the scintillator from outside
Surface Muon Distribution

For more info: hep-ph/0604145

\[ I(p_\mu, \theta) = \cos^3(\theta)I_v(p_\mu \cos \theta) \]
Near Lab Definition

Solution n°3
Détecteur semi-enterré
Voûte elliptique

Zone coupe-feu à traiter

Besoins en Energie : 150 kVA

Preliminary Outer Veto
### Some Basic Rates

#### Detected Muon Rates

<table>
<thead>
<tr>
<th>Category</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Veto</td>
<td>848 Hz</td>
</tr>
<tr>
<td>Inner Veto</td>
<td>658 Hz</td>
</tr>
<tr>
<td>Target + GC</td>
<td>314 Hz</td>
</tr>
</tbody>
</table>

#### Rate of Neutrons Entering Target + GC

<table>
<thead>
<tr>
<th>Category</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.340 Hz</td>
</tr>
<tr>
<td>Excluding Target Muon</td>
<td>0.104 Hz</td>
</tr>
<tr>
<td>Excluding Inner Veto</td>
<td>0.007 Hz</td>
</tr>
<tr>
<td>Excluding Outer Veto</td>
<td>0.001 Hz</td>
</tr>
</tbody>
</table>
### Untagged Neutron Rates for Various Detector Configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated cylinder (4.5m radius and 8m depth)</td>
<td>0.001 Hz</td>
</tr>
<tr>
<td>Top and Sides (5.2m radius and 5.2m depth)</td>
<td>0.0005 Hz</td>
</tr>
<tr>
<td>Top Only (7m radius)</td>
<td>0.0022 Hz</td>
</tr>
</tbody>
</table>

![Diagram of Rate vs. Outer Veto Dimensions](image)
Untagged Neutron Rates for Various Heights of a 7m Detector

<table>
<thead>
<tr>
<th>Height</th>
<th>Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal 1m above (3750)</td>
<td>0.0022 Hz</td>
</tr>
<tr>
<td>Top of Detector (3850)</td>
<td>0.0016 Hz</td>
</tr>
<tr>
<td>Top of Crane (3300)</td>
<td>0.004 Hz</td>
</tr>
</tbody>
</table>
A Single Module

3x8 2” tubes

6.9 m
A Panel

17 modules cover a 6.9m x 6.9m area

2 layers define a Panel
(34 total modules)
The Near Lab
Production Schedule

Module Production

Far Detector Installation

Near Detector Installation

Current Status
Summary

• Goals are achievable
  – Provides a factor 3-4 improvement over inner veto alone at near detector
  – Provides multiplicity and tracking at far detector
• Outer muon system was optimized for cost
  – $1.3M Mechanics, $1.0M Electronics
  – Other technologies are possible
• With top only construction, the outer muon system can be installed after the other systems, so the production schedule is not a significant constraint
Steel Shielding at Near Detector?

Rate for R<180 cm:
- With Steel: 1.74E+01 Hz
- With no Steel: 1.63E+02 Hz