Status of OPERA experiment

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IReS – Strasbourg
on behalf of the OPERA Collaboration

IV INTERNATIONAL CONFERENCE
on NON-ACCELERATOR NEW PHYSICS
Dubna, Russia, June 23-28, 2003

- Physics Goal
- CNGS Beam and OPERA detector Status
- Detector Construction
- Physics Performance
- Conclusions
OPERA Collaboration

Belgium
IIHE(ULB-VUB) Brussels

Bulgaria
Sofia University

China
IHEP Beijing
Shandong University

Croatia
Zagreb University

France
LAPP Annecy
IPNL Lyon
LAL Orsay
IRES Strasbourg

Germany
Berlin Humboldt University
Hagen
Hamburg University
Münster University
Rostock University

Israel
Technion Haifa

Italy
Bari,
LNF Frascati,
LNGS,
Padova,
Salerno

Japan
Aichi,
Kobe,
Utsunomiya

Russia
INR Moscow,
JINR Dubna,

Switzerland
Bern,

Turkey
METU Ankara

36 groups
~165 physicists

M. Dracos
Physics Goal

• Direct search for $\nu_\mu \rightarrow \nu_\tau$ oscillations by looking at the appearance of $\nu_\tau$ in a pure $\nu_\mu$ beam.

• Search for the subdominant $\nu_\mu \rightarrow \nu_e$ oscillations.
CNGS Beam

High energy long baseline $\nu_\mu$ beam

$\langle E_\nu \rangle \sim 17$ GeV ($E_{CM} >> m_\tau$), $L = 732$ km
Well adapted neutrino beam for $\nu_\tau$ appearance

$4.5 \times 10^{19}$ p.o.t/year
(7.6 $\times 10^{19}$ in dedicated mode)
(proton energy = 400 GeV)

Sensitivity to $\Delta m^2 = 1.6 - 4.0 \times 10^{-3}$ eV$^2$

23 June 2003  NANP'03
Project on schedule: beam in May 2006

Civil engineering almost completed, end of works foreseen by end of June.

CNGS upgrade financed and well under way (increase the intensity by a factor of 1.46).
OPERA Experiment Layout in the Underground lab

L'AQUILA  CERN  OPERA

TERAMO  Borexino
**OPERA Detector**

2 Supermodules: 206,336 bricks (1766 tons)

- $\nu$ target and $\tau$ decay detector
- 2x31 target walls: alternated Pb/emulsion “bricks” walls and planes of orthogonal scintillator strips

A “hybrid” experiment

- $\mu$ spectrometer
- Magnetised Iron Dipoles
- Drift tubes and RPCs
OPERA Detection sequence

**Target Trackers**

**Pb/Em. target**

**μ spectrometer**

**ν**

8 m

**Extract selected brick**

**Pb/Em. brick**

**ν_τ**

DONUT real event

**Basic “cell”**

**Pb**

**Emulsion**

1 mm

**Electronic detectors**

→ select ν interaction brick

→ μ ID, charge and p

**Emulsion analysis**

→ vertex search

→ decay search
e/γ ID, kinematics
Why Emulsions?

Emulsions

- ~15 grains/50 µm
- Emulsion “grains”
- track segment
- High spatial resolution is necessary

Emulsions

\[ \sigma_{\theta x} \sim 5 \text{ mrad} \]
\[ \sigma_x \sim 0.5 \mu \text{m} \]

decay “kink”

>25 mrad

\[ e, \mu, h \]

\[ \nu_e, \nu_\tau, \nu_\mu \]

NANP'03
The Vacuum sucker Vehicle (VV)

Pb/emulsion brick

changeable sheet to reduce scanning load

skates

brick size tests

robot
Automatic emulsion scanning

A: Vacuum holder (on the microscope)
B: Emulsion handling system
C: Emulsion changing system

5x5 mm²

Performance of S-UTS system: 40 cm²/hr

M. Dracos

23 June 2003

NANP'03
Main goal: Find the right brick to extract

Hamamatsu
MA-PMT
(64 channels)
3x3 cm²

62 walls (496 modules)
7.5x7.5 m²

23 June 2003
Target Tracker

Coextruded scintillating strips (7 m) under production by ACRYSH (Kharkov)

Coextrusion line: scintillator: polystyrene+PTP+POPOP
external layer: polystyrene+TiO$_2$

Number of photoelectrons versus the distance from PMT's.
$N_{pe} > 6$ p.e. in the worst position
~100 detection efficiency

Kuraray WLS fibres

AMCRYSH
Target Tracker

First Target Tracker wall
Drift tube spectrometer trackers

- **Required features for 25% momentum resolution:**
  - space resolution (0.5 mm), high detection efficiency, multi-hit capability, no toxic and flammable gas
- **Tube:** vertical \( \varnothing = 38 \text{ mm} \), length 8 m, wire \( \varnothing = 50 \text{ \(\mu\)m} \)
- **Plane:** 4 staggered layers, each with 168 tubes
- **Channels:** 4032 / spectrometer
- **Readout:** ATLAS and HERAb (discriminator/ADC)
- **Design:** simplified version of the ATLAS tubes (tube thickness 0.4 \(\rightarrow\) 0.85 mm, wire positioning precision 50 \(\rightarrow\) 100 \(\mu\)m)

**Profit from ATLAS experience**
Spectrometers

Full scale prototype magnet
Constructed and tested at Frascati

Total Fe weight
~ 1 kton

12 Fe slabs in total

Fe (5 cm)

RPC

B = 1.55 T

8.2 m

slabs

base

coil

M. Dracos
Magnet Installation

LNGS Hall C
RPCs

- Bakelite RPCs,
- Produced by General Tecnica,
- 21 RPCs (2.91x1.14 m²)/plane,
- 2x11 planes/magnet (~3000 m²),
- Horizontal strip pitch: 3.5 cm,
- Vertical strip pitch: 2.6 cm,
- Mechanical and electrical tests.
Simulated event

$\nu_\tau$ interaction with $\tau \rightarrow \mu$

Hit visualization

Scintillators

emulsions

Drift tubes

SRPC

XRPC

brick
## Physics Performance

<table>
<thead>
<tr>
<th>Evts/day</th>
<th>Shared mode</th>
<th>Dedicated mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.5 (10^{19}) pot/year</td>
<td>7.6 (10^{19}) pot/year</td>
</tr>
<tr>
<td>NC</td>
<td>10.96</td>
<td>18.52</td>
</tr>
<tr>
<td>CC DIS</td>
<td>31.42</td>
<td>53.10</td>
</tr>
<tr>
<td>CC QE+RES</td>
<td>4.07</td>
<td>6.38</td>
</tr>
<tr>
<td>Total</td>
<td>46.45</td>
<td>78.5</td>
</tr>
</tbody>
</table>

### Event Rate

- Scanning power must follow:
  - target mass 1766 tons
  - 1 year : 200 days
  - shared:
    - 46452 x 0.895 evts in 5 years
  - dedicated:
    - 78504 x 0.831 evts in 5 years
Possible improvements

- Changeable Sheet: increase efficiency by 10-15%
  - CS reduce scanning load by a factor 2
  - More trials in brick finding
  - Higher brick finding efficiency -> higher $\tau$ yield

- $dE/dx$: background reduction by about 40%
  - Charm background events have low momentum muons not identified
  - A large fraction stops in the target region and is identified through the $dE/dx$

- Better use of spectrometer: reduce the background in $\mu$ channel by about a factor 30%
Physics Performance

Expected number of events $\nu_\mu \rightarrow \nu_\tau$

<table>
<thead>
<tr>
<th></th>
<th>signal $(\Delta m^2 = 1.8 \times 10^{-3} \text{eV}^2)$</th>
<th>signal $(\Delta m^2 = 2.5 \times 10^{-3} \text{eV}^2)$</th>
<th>signal $(\Delta m^2 = 4.0 \times 10^{-3} \text{eV}^2)$</th>
<th>Back</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Design</td>
<td>9.0</td>
<td>17.2</td>
<td>43.8</td>
<td>1.06</td>
</tr>
<tr>
<td>With possible</td>
<td>10.3</td>
<td>19.8</td>
<td>50.4</td>
<td>0.67</td>
</tr>
<tr>
<td>improvements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **full mixing**
- **5 years run @ 6.76x10^{19} \text{pot / year}**

Aim at the evidence of $\nu_\tau$ appearance after a few years of data taking
Probability of $\geq n\sigma$ significance for different $\Delta m^2$

<table>
<thead>
<tr>
<th>$\Delta m^2$(eV$^2$)</th>
<th>3 years (20.3x $10^{19}$ pot)</th>
<th>5 years (33.8x $10^{19}$ pot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_{3\sigma}(%)$</td>
<td>$P_{4\sigma}$</td>
</tr>
<tr>
<td>1.8x $10^{-3}$</td>
<td>77.2(91.1)</td>
<td>46.8(68.2)</td>
</tr>
<tr>
<td>2.2x $10^{-3}$</td>
<td>94.9(98.9)</td>
<td>80.5(93.0)</td>
</tr>
<tr>
<td><strong>2.5x $10^{-3}$</strong></td>
<td><strong>98.9(99.9)</strong></td>
<td><strong>93.9(98.6)</strong></td>
</tr>
<tr>
<td>3.0x $10^{-3}$</td>
<td>100(100)</td>
<td>99.6(100)</td>
</tr>
<tr>
<td>4.0x $10^{-3}$</td>
<td>100(100)</td>
<td>100(100)</td>
</tr>
</tbody>
</table>

Best fit of SK + K2K is $Dm^2 = (2.6\pm0.4)$ eV$^2$ Fogli et al. hep-ph/0303064 (the number in parenthesis are obtained assuming possible improvements).
By fitting simultaneously the $E_e$, missing $p_T$ and $E_{vis}$ distributions: sensitivity ~ 90%

Limits at 90% C.L. on $\sin^2 2\theta_{13}$ and $\theta_{13}$
($\Delta m^2_{23}=2.5\times10^{-3}$ eV$^2$; $\sin^2 \theta_{23}=1$)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\sin^2 2\theta_{13}$</th>
<th>$\theta_{13}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHOOZ</td>
<td>&lt; 0.14</td>
<td>&lt; 11°</td>
</tr>
<tr>
<td>MINOS</td>
<td>&lt; 0.06</td>
<td>&lt; 7.1°</td>
</tr>
<tr>
<td>ICARUS 5 yr</td>
<td>&lt; 0.03</td>
<td>&lt; 5.8°</td>
</tr>
<tr>
<td>OPERA 5 yr</td>
<td>&lt; 0.05</td>
<td>&lt; 7.1°</td>
</tr>
<tr>
<td>CNGS 5 yr</td>
<td>&lt; 0.025</td>
<td>&lt; 4.5°</td>
</tr>
<tr>
<td>JHF 5 yr</td>
<td>&lt; 0.006</td>
<td>&lt; 2.5°</td>
</tr>
</tbody>
</table>
## Schedule for Installation

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>343</td>
<td>INSTALLATION IN LNGS HALL C</td>
<td>144.71 w</td>
<td>Mon 2/10/03</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>344</td>
<td>C R &amp; ELECTRONIC ROOM</td>
<td>13.46 w</td>
<td>Fri 1/14/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>350</td>
<td>BAM</td>
<td>71.5 w</td>
<td>Fri 1/28/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>354</td>
<td>SPECTROMETERS (2 MAGNETS &amp; RPC's)</td>
<td>94.65 w</td>
<td>Mon 2/10/03</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>355</td>
<td>Preliminary working</td>
<td>15 w</td>
<td>Mon 2/10/03</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>356</td>
<td>Veto plane</td>
<td>24 w</td>
<td>Thu 4/3/03</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>357</td>
<td>Magnet 1</td>
<td>41.95 w</td>
<td>Fri 5/30/03</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>384</td>
<td>Magnet 2</td>
<td>79.65 w</td>
<td>Fri 5/30/03</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>411</td>
<td>TARGET WALLS + TARGET TRACKERS</td>
<td>65.9 w</td>
<td>Fri 6/4/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>412</td>
<td>SM1</td>
<td>30.4 w</td>
<td>Fri 6/4/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>489</td>
<td>SM2</td>
<td>35.5 w</td>
<td>Wed 1/19/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>568</td>
<td>XPC's &amp; PRECISION TRACKERS</td>
<td>86.76 w</td>
<td>Mon 4/5/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>567</td>
<td>XPC 1</td>
<td>42.26 w</td>
<td>Mon 4/5/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>570</td>
<td>Precision tracker 1</td>
<td>77.16 w</td>
<td>Mon 4/5/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>603</td>
<td>XPC 2</td>
<td>40.06 w</td>
<td>Fri 1/14/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>606</td>
<td>Precision tracker 2</td>
<td>77.76 w</td>
<td>Fri 6/11/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>639</td>
<td>CABLEING (detector to control room)</td>
<td>2 w</td>
<td>Thu 4/21/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>642</td>
<td>MANIPULATORS</td>
<td>59.06 w</td>
<td>Fri 10/29/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>643</td>
<td>SM1</td>
<td>33.56 w</td>
<td>Fri 10/29/04</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>649</td>
<td>SM2</td>
<td>10 w</td>
<td>Thu 10/27/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>653</td>
<td>COMMISSIONNING</td>
<td>13.6 w</td>
<td>Mon 10/24/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>656</td>
<td>ECC BRICK MANUFACTURING WITH BAM</td>
<td>43 w</td>
<td>Mon 7/11/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>658</td>
<td>WALL FILLING</td>
<td>47.5 w</td>
<td>Mon 7/11/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>659</td>
<td>filling SM1 (2b/min 8h/day) = 960 bricks</td>
<td>22 w</td>
<td>Mon 1/11/05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>660</td>
<td>filling SM2 (2b/min 8h/day)</td>
<td>22 w</td>
<td>Fri 1/20/06</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>661</td>
<td>FULL DETECTOR COMPLETED</td>
<td>0 d</td>
<td>Fri 6/30/06</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

23 June 2003
Conclusions

Achieved

- Studies and construction of full scale prototypes,
- Detector design,
- Progress in automatic emulsion scanning in Europe and Japan,
- \( \tau \) detection efficiency improved since CNGS approval.

Detector construction and installation

- OPERA detector installation already started,
- Detector (and CNGS beam !) will be ready by June 2006

Important Physics Program

- First evidence of \( \nu_\mu - \nu_\tau \) appearance in few years data taking,
- In a five year run: 17.2 signal (SK best fit) and 1.06 background events,
- Studies to improve efficiency ( \( \rightarrow 19.8 \) events and background ( \( \rightarrow 0.67 \)),
- Significant measurement of \( \theta_{13} \).

Very low background is the key issue