Operation of and results from OPERA

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The Swiss participation in OPERA

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2 INSTITUTIONS, 17 PHYSICISTS

(OPERA: 35 institutions, ~200 physicists)

* previously forming the Neuchatel group, moved to Bern in August

CHIPP Plenary meeting

C. Pistillo - Bern Univ.
OPERA is designed for the direct observation of $\nu_\tau$ appearance in a pure $\nu_\mu$ beam in order to provide a final confirmation of neutrino oscillations in the atmospheric sector.

\[
P(\nu_\mu \rightarrow \nu_\tau) \equiv \sin^2(2\theta_{23})\cos^4(\theta_{13})\sin^2\left(\frac{1.27\Delta m_{31}^2 L (\text{Km})}{E(\text{GeV})}\right)
\]

**best fit:**

\[
\Delta m_{31}^2 = \begin{cases} 
-2.37 \pm 0.15 \times 10^{-3} \text{ eV}^2 & \text{(inverted hierarchy)} \\
+2.46 \pm 0.15 \times 10^{-3} \text{ eV}^2 & \text{(normal hierarchy)}
\end{cases}
\]

\[
\theta_{23} = 42.3^{+5.1}_{-3.3}
\]
The Cern Neutrino to Gran Sasso (CNGS) beam

L = 730 km; 
\langle E_{\nu\mu} \rangle = 17 \text{ GeV} 

\bar{\nu}e + \nu e / \nu \mu = 0.7\% 
\bar{\nu} \mu / \nu \mu = 2\%
Detection of the $\nu_\tau$ appearance signal

Two conflicting requirements:
- Large mass $\Rightarrow$ low Xsection
- High spatial resolution $\Rightarrow$ signal selection, background rejection
The OPERA target

The OPERA target is composed of ~150000 bricks
OPERA: a hybrid detector

Spectrometer: XPC, HPT, RPC, magnet

Veto plane (RPC)

Target and Target Tracker

SM1

0.68 kton

SM2

0.68 kton
Brick handling

Brick Manipulator System

Xray machine

- Brick extraction
- XRay exposure (local reference frame)
Chemical plant for emulsion development

A dedicated building @ LNGS
Automated emulsion analysis

Fully unattended emulsion scanning.

40 microscopes in OPERA

LHEP Bern: Swiss Scanning Station with 5 microscopes. ~10 physicist from Bern and ETH Zürich involved.

Goal: analyze ~ 20% of the total OPERA bricks statistics (700/1000 brick/year).
Strategy for event analysis

Event: 218184565, 6 Jul 2008, 03:27 (UTC), YZ projection

Brick finding information: Super module 1

<table>
<thead>
<tr>
<th>BrickId</th>
<th>Wall</th>
<th>Side</th>
<th>Column</th>
<th>Row</th>
<th>Prob</th>
<th>CS x</th>
<th>CS y</th>
<th>Muon track parameters: Mu-</th>
</tr>
</thead>
<tbody>
<tr>
<td>brick 1</td>
<td>1036429</td>
<td>17</td>
<td>1</td>
<td>9</td>
<td>33</td>
<td>0.59</td>
<td>6.3</td>
<td>15.6</td>
</tr>
<tr>
<td>brick 2</td>
<td>1036448</td>
<td>17</td>
<td>1</td>
<td>9</td>
<td>32</td>
<td>0.37</td>
<td>5.3</td>
<td>128.9</td>
</tr>
<tr>
<td>brick 3</td>
<td>1067422</td>
<td>16</td>
<td>1</td>
<td>9</td>
<td>32</td>
<td>0.02</td>
<td>46.0</td>
<td>117.9</td>
</tr>
</tbody>
</table>

Selected brick
Brick in cell
Empty cell
Status of the experiment data taking

**May 2006:** electronic detectors commissioning

**Aug 2006:** technical run, \(0.76 \times 10^{18}\) pot collected

319 interactions in the rock, mechanical structure and iron of the spectrometer

**Oct 2006:** start of brick production

**Oct 2007:** pilot physics run (\(~40\%\) target) \(0.82 \times 10^{18}\) pot

first 38 neutrino events in the target

**Jun 2008:** OPERA detector filled and fully commissioned, 146000 bricks inserted (150000 by end 2008)

**Jun 2008:** Start first OPERA production run

**Sep 2008:** \(5.6 \times 10^{18}\) pot and \(~500\) neutrino events in the target
Event 178969961: $\nu_\mu$ CC interaction

SIDE VIEW (Vertical projection)

19 m

8 m

43 mm

5 prongs

$\langle IP \rangle = 9 \mu m$

Electromagnetic shower pointing to the vertex ($\gamma$ conversion)
Event 183545620 located in Bern – first (only) $\nu_e$ candidate

**Em. Shower**

$E = 4.7 \pm 1.3$ GeV

**Neutrino vertex**

$\text{IP} \approx 3 \mu$m
Event 180718369: a charm candidate

Flight length: 3247.2 μm
θ_{kink}: 0.204 rad
P_{\text{daughter}}: 3.9 (+1.7 -0.9) GeV
P_T: 796 MeV (> 606 MeV )

Clear kink topology + EM shower

Two e. m. showers pointing to vertex
OPERA $\nu_\tau$ observation probability

OPERA 10-15 event 0.8 BG (5 full CNGS years)

- 3 $\sigma$ sensitivity
- 4 $\sigma$ sensitivity

SK 90% CL (L/E analysis) MINOS
The 2008 OPERA run

**Expectations:**
127 days for the CNGS
2.3 x 10^{19} p.o.t

**Current situation (Aug 31th):**
After 68 days: 5.6 x 10^{18} p.o.t
~45% of what originally expected

**Prospects: Protons on Target 2008**

<table>
<thead>
<tr>
<th>Total number of interactions</th>
<th>2660</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_\mu$ CC events</td>
<td>2000</td>
</tr>
<tr>
<td>$\nu_\mu$ NC events</td>
<td>600</td>
</tr>
<tr>
<td>$\nu_e/\bar{\nu}_e$ events</td>
<td>17</td>
</tr>
<tr>
<td>Charm decay</td>
<td>84</td>
</tr>
<tr>
<td>Tau candidate (@2.5 x 10^{-3} eV²)</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Past activities of the Swiss researchers

- conceptual design
- proposal
- CNGS beam design and optimization
- construction of the Target Tracker
- lead production monitoring
- development of European microscopes
- emulsion film robot
- test beams
- physics analysis
- …
Responsibilities of the Swiss researchers

Management of the experiment:
A. Ereditato (spokesperson), U. Moser (member of publication committee)

Emulsion scanning:
Largest scanning team in Europe (~10 physicist) and ~20% brick scanning at LHEP

Data Analysis responsibilities:
Electron identification, shower reconstruction, $\pi^0$ detection and $\tau$ search in $\tau \rightarrow e$ channel

Other Analysis activities:
Strategies for neutrino interaction vertex location for muon-less events
Determination of neutrino energy spectrum
Charm event studies
PhD thesis in progress:

J. Knüsel (LHEP): low momentum muon identification

C. Lazzaro (ETHZ): determination of the CNGS neutrino energy spectrum from CC events reconstructed with the electronic detectors

F. Meisel (LHEP): measurement of the $\nu_e$ contamination of the CNGS beam

T. Strauss (ETHZ): neutrino induced charmed particle decays
Conclusions

- The whole detector is fully commissioned
- The concept of the OPERA detector is experimentally validated

The first physics run started in June
- After 68 days $5.6 \times 10^{18}$ p.o.t have been collected
- ~500 neutrino interactions have been triggered by electronic detectors and are being analyzed in the scanning laboratories

Interesting topologies detected (charmed particle decay, prompt $\nu_e$) We just miss the tau! Chance to observe the first $\nu_\tau$ candidate event with 2008 run?
BACKUP SLIDES
### τ search: Backgrounds

#### Charm production in CC, common to the 3 channels

- $\nu_{\mu,e} \rightarrow \mu,e^{-}$
- $D^+ \rightarrow \mu^+,e^+$

#### Lead: Bck. to $\tau \rightarrow \mu$

- Coulombian large angle scattering of muons in $e^+h^+$
- Same decay topology as $\tau$

#### Good muon identification is fundamental

#### Expected number of background events after 5 years running with nominal beam:

<table>
<thead>
<tr>
<th>Channel</th>
<th>$T\rightarrow e$</th>
<th>$T\rightarrow \mu$</th>
<th>$T\rightarrow h$</th>
<th>$T\rightarrow 3h$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charm background</td>
<td>.173</td>
<td>.008</td>
<td>.134</td>
<td>.181</td>
<td>.496</td>
</tr>
<tr>
<td>Large angle $\mu$ scattering</td>
<td>.096</td>
<td></td>
<td></td>
<td></td>
<td>.096</td>
</tr>
<tr>
<td>Hadronic background</td>
<td>.077</td>
<td>.095</td>
<td></td>
<td></td>
<td>.172</td>
</tr>
<tr>
<td>Total per channel</td>
<td>.173</td>
<td>.181</td>
<td>.229</td>
<td>.181</td>
<td>.764</td>
</tr>
</tbody>
</table>
$\nu_\mu \rightarrow \nu_e$ oscillation search

<table>
<thead>
<tr>
<th>$\Theta_{13}$</th>
<th>SIGNAL</th>
<th>$\nu_e$ beam</th>
<th>$\tau \rightarrow e$</th>
<th>$\nu_\mu$ NC</th>
<th>$\nu_\mu$ CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>9°</td>
<td>9.3</td>
<td>18</td>
<td>4.5</td>
<td>5.2</td>
<td>1.0</td>
</tr>
<tr>
<td>7°</td>
<td>5.8</td>
<td>18</td>
<td>4.5</td>
<td>5.2</td>
<td>1.0</td>
</tr>
<tr>
<td>5°</td>
<td>3.0</td>
<td>18</td>
<td>4.6</td>
<td>5.2</td>
<td>1.0</td>
</tr>
</tbody>
</table>

$\Delta m_{23}^2 = 2.5 \times 10^{-3} \text{ eV}^2 \quad \Theta_{23} = 45^\circ$

nominal CNGS beam 5 years

Combined fit of $E_e$, $E_{vis}$, (pt)$_{miss}$ to improve S/B ratio

90% C.L. limits on $\sin^2(2\Theta_{13})$ and $\Theta_{13}$:

$\sin^2(2\Theta_{13}) < 0.05 \quad \Theta_{13} < 7.1^\circ$