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The OPERA experiment

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Summary. — OPERA is a long baseline neutrino experiment, designed to search for $\nu_\mu \to \nu_\tau$ oscillation through the direct observation of ν_τ in the almost pure CNGS ν_μ beam produced at CERN and detected at LNGS, the large underground Gran Sasso National Laboratory 732 km away from CERN. The detector construction was completed at the beginning of 2008 and the data taking started in Summer 2008. In five years of data taking, the experiment is expected to collect about 10 to 15 ν_τ interactions. We discuss the performance of the detector, the event analysis flow and the physics potential as well as the preliminary results obtained in the 2008 run.

PACS 14.60.Pq – Neutrino mass and mixing.
PACS 13.15.+g – Neutrino interactions.
PACS 14.60.Lm – Ordinary neutrinos (ν_e, ν_μ, ν_τ).
PACS 29.40.Gx – Tracking and position-sensitive detectors.

1. – Introduction

In the last decades, the mixing of neutrino flavour states and the consequent flavour oscillations hypothesis have been confirmed by several experiments performed with different neutrino sources in disappearance mode [1]. A final proof in the atmospheric sector will be set by studying the $\nu_\mu \to \nu_\tau$ oscillation channel in appearance mode.

The Oscillation Project with Emulsion tRacking Apparatus (OPERA) [2] was designed to provide an unambiguous evidence for $\nu_\mu \to \nu_\tau$ oscillation in the atmospheric sector through the direct observation of ν_τ in an almost pure ν_μ beam.

The CERN Neutrinos to Gran Sasso (CNGS) [3] high-energy neutrino beam ($\langle E_{\nu_\mu} \rangle \simeq$ 17 GeV) is produced at CERN and delivered at LNGS where the OPERA detector is located. It has been designed in order to maximize the number of ν_τ CC interactions in the target. Contaminations by other neutrino flavours are negligible ($\sim 2.1\%$ for $\overline{\nu}_\mu$, below 1% for $\nu_e + \overline{\nu}_e$, $\mathcal{O}(10^{-6})$ for prompt ν_τ). A nominal beam intensity of 4.5×10^{19} p.o.t. per year is expected for five years' run. Accordingly, we expect about 4500 ν_μ charged and neutral current events per year.

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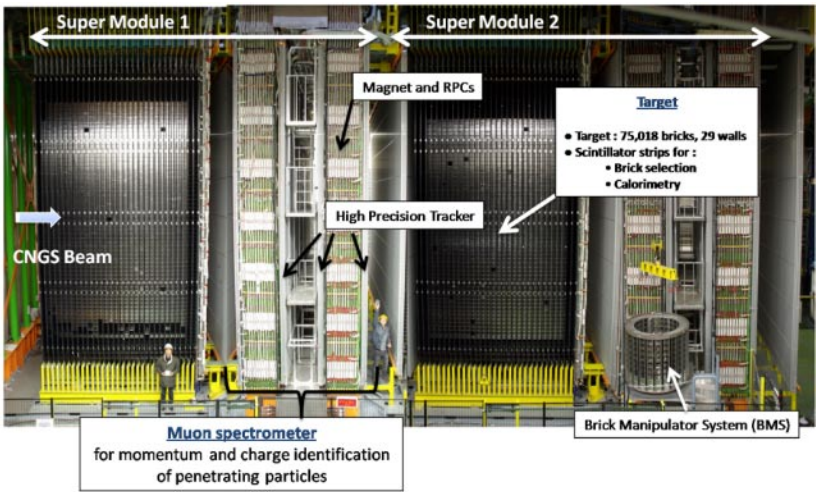

Fig. 1. – View of the OPERA detector.

If the $\nu_\mu \to \nu_\tau$ oscillation hypothesis is confirmed, the number of tau events observed in the OPERA detector after 5 years of data taking is expected to be 10 with a background of 0.75 events for a $\Delta m^2_{23} = 2.5 \times 10^{-3}\,\mathrm{eV}^2$ at full mixing.

2. – The OPERA detector

The OPERA hybrid apparatus consists of two identical Super Modules (SM1 and SM2) as shown in fig. 1. Each Super Module is composed of a target section and a muon spectrometer.

Each target section (~ 625 tons) is organized in 31 vertical "walls", transverse to the beam direction. Every wall is filled with 3328 "bricks" with an overall mass of 1.25 kton and is followed by double layers of scintillator planes acting as Target Trackers (TT) devoted to the location of neutrino interactions occurred within the target.

The brick is the basic unit of the detector: it consists of 57 nuclear emulsion films interleaved with 1 mm thick lead plates, with a total length of 7.9 cm along the beam direction, transverse dimensions of $10.2 \times 12.8\,\mathrm{cm}^2$ and a total weight of 8.3 kg. An additional tightly packed doublet of emulsion films (Changeable Sheets, CS) is glued to the downstream face of each brick, in order to connect the electronic detectors predictions to the brick.

The spectrometers consist of active detectors and a dipolar magnet instrumented with planes of RPCs (Internal Tracker, IT) and drift tubes (Precision Tracker, PT). Tasks of the spectrometers are muon identification and charge measurement in order to minimize the background. The charge misidentification probability has been estimated to be of about 0.3% up to 50 GeV/c; the momentum resolution is about 20% in the same kinematical range.

The apparatus is equipped with an automatic machine (Brick Manipulator System, BMS), allowing the online removal of bricks from the detector, together with some ancillary facilities for the emulsions' handling and development. Dedicated European and Japanese Scanning Stations take care of the nuclear emulsions films measurement.

3. – The OPERA strategy

Every time a charged particle produced in a neutrino interaction occurred in a brick produces a signal in the TT, a brick finding algorithm is applied in order to select the brick which has the maximum probability to contain the neutrino interaction. Once this brick is removed from the target by the BMS, the corresponding CS doublet is detached from the brick and developed in a dedicated underground facility. The two emulsion films are then scanned in two scanning stations, one at LNGS, the other one in Japan. The measurement of emulsion films is performed through fast automated microscopes with a scanning speed greater than $20\,\mathrm{cm}^2/\mathrm{h}$, a tracking efficiency of about 90%, sub-micrometric position resolution and milliradian angular resolution.

If any track originating from the interaction is detected in the CS, the brick is exposed to cosmic rays (for alignment purposes) and then depacked. The emulsion films are developed and sent to the scanning laboratories of the Collaboration for event location studies and decay search analysis.

All tracks located in the CS are followed upstream through the brick (*scan-back*) until they stop. A general scanning (no angular preselection) is then performed in a volume around the stopping point(s) in order to reconstruct the vertex topology. The measured residuals between electronic detectors predictions and CS tracks are found to be of the order of cm. CS to brick connection is achieved with less than $100\,\mu\mathrm{m}$ position accuracy and with a slope accuracy of the order of 10 mrad.

4. – A first glance at the OPERA 2008 run

OPERA data taking (electronic detectors and target bricks installed) started in 2007 with a very short run, due to a fault of the CNGS facility. The 2008 run can be thus regarded as a milestone for the experiment.

From June to November 2008, 1.78×10^{19} p.o.t. were delivered by the CNGS [4]. OPERA collected 10122 events and among them 1663 interactions in the target region where 1723 were expected. The other events originated in the spectrometers, the supporting structures, the surrounding rock, the hall structure. All electronic detectors were operational and the live time of the data acquisition system exceeded 99%.

At the time of this presentation, the analysis of 2008 run data is still in progress. Under the two extreme hypotheses that none or all the events still under analysis will be found, the vertex location efficiency ranges in the intervals 90%–95% and 74%–83% for CC and NC, respectively. These preliminary estimates of the vertex location efficiency are in agreement with the Monte Carlo expectations of 90% and 80% for CC and NC events, respectively [4]. Among the located events, charm-like decay topologies are reconstructed, too. These kinds of topologies are very interesting for OPERA due to the fact that are similar to tau decay ones. One of these charm-like topologies is shown in fig. 2 (online display of the OPERA electronic detector and emulsion reconstruction).

A 4-prong primary vertex is observed originating at a depth of about $30\,\mu\mathrm{m}$ in the upstream lead plate. A secondary 3-prong decay vertex at $1150\,\mu\mathrm{m}$ from the primary vertex is reconstructed too. The muon track and the charm candidate one lie in a back-to-back configuration ($\Delta\phi \simeq 150°$). The momentum of the parent is estimated to be about $\sim 16\,\mathrm{GeV}/c$ while for daughter tracks the measured values are $p_1 = 2.4^{+1.3}_{-0.6}\,\mathrm{GeV}/c$, $p_2 = 1.3^{+0.4}_{-0.3}\,\mathrm{GeV}/c$ and $p_3 = 1.2^{+1.7}_{-0.4}\,\mathrm{GeV}/c$ (transverse momenta of about 610, 90 and $340\,\mathrm{MeV}/c$, total momentum: $4.8^{+2.2}_{-0.8}\,\mathrm{GeV}/c$), at the 90% CL.

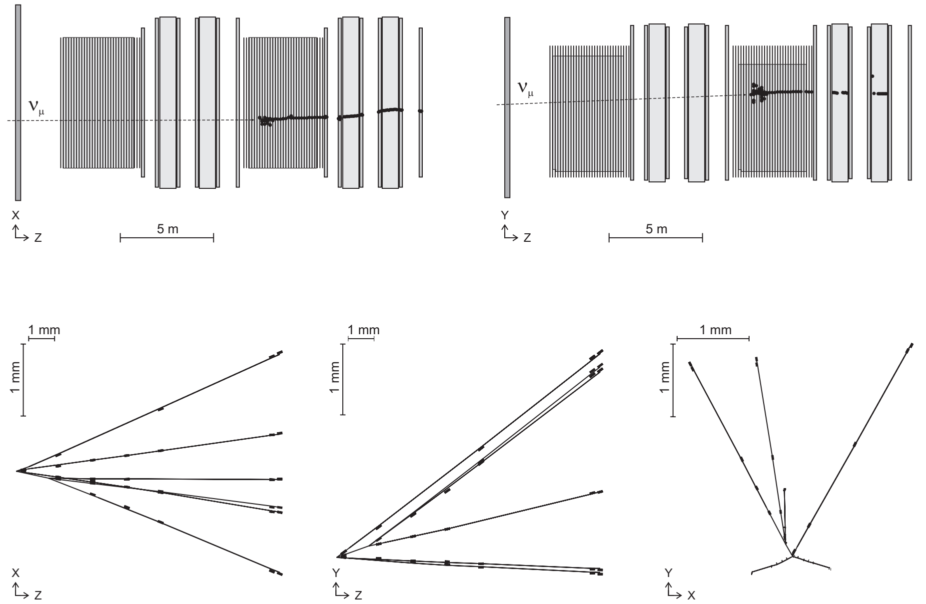

Fig. 2. – Event reconstruction in OPERA: a charm-like decay topology from 2008 run.

5. – Conclusions

The OPERA detector and its infrastructure successfully operated during 2008 CNGS run. The OPERA strategy has actually been validated over a subsample of the 1700 events inside the bricks. In the analysed data sample, events with a charm-like topology were found. With the 2009 run, statistics should be sufficient to observe less than three tau events and to precisely estimate OPERA efficiencies and backgrounds.

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