The OPERA experiment and the first events from the CNGS neutrino beam

Cécile Jollet for the OPERA collaboration
Institut Pluridisciplinaire Hubert Curien - ULP-IN2P3, Strasbourg, France
E-mail: cecile.jollet@ires.in2p3.fr

Abstract

The aim of the OPERA experiment is to provide unambiguous evidence for the $\nu_\mu \leftrightarrow \nu_\tau$ oscillation by looking at the appearance of $\nu_\tau$ in a pure $\nu_\mu$ beam. The detector is located on the high-energy, long-baseline CERN to LNGS beam (CNGS) 730 km away from the neutrino source. The apparatus consists of a target made of lead/emulsion-films bricks complemented by electronic detectors. The neutrino interaction inside the bricks is tagged using the electronic trackers. In August 2006, a short CNGS run was successfully performed and a first sample of neutrino events was collected. Experiment description and results from the first CNGS run are reported in details.

1 Introduction

The “appearance” long baseline neutrino experiment OPERA [1] has been motivated by the atmospheric neutrino disappearance. Given the distance of 730 km between the neutrino source (at CERN) and the detector (in the Gran Sasso underground laboratory), the CNGS beam was designed in order to maximise the number of $\nu_\tau$ charged current interactions detectable at Gran Sasso. To be sensitive in the oscillation parameter region delimited mainly by the Super-Kamiokande results [2], the average energy of the CNGS beam is about 17 GeV. With the CERN SPS accelerator operating in a shared mode, $4.5 \times 10^{19}$ protons on target (pot) will be delivered per year, and 2900/kton/year $\nu_\mu$ charged current interactions are expected at Gran Sasso. If the $\nu_\mu \leftrightarrow \nu_\tau$ oscillation hypothesis is confirmed, the number of $\tau$’s produced via charged current interaction at Gran Sasso should be of the order of 16/kton/year for $\Delta m^2=2.4\times10^{-3}$ eV$^2$ at full mixing.

2 The OPERA detector and experimental strategy

The principle is to detect the $\tau$ leptons produced by $\nu_\tau$ interactions. According to the mean life time of the $\tau$ lepton, an unambiguous signature of its presence is the detection of its decay topology in one prong (electron, muon, hadron) or in three-prongs. Consequently, the photographic emulsions having an accuracy better than 1 $\mu$m are used for the charged track detection. Moreover, in order to increase the number of $\nu_\tau$ interactions, lead is used as target. The detection principle is depicted in Figure 1. Each track segment is reconstructed using 15 to 20 visible grains produced by the charged particles. The spatial resolution is 0.21 $\mu$m while the angular resolution is 2.1 mrad. On the reconstructed events, the decay kink search is performed as well as the energy reconstruction of electromagnetic showers and the determination of momenta of charged particles by multiple scattering.

The detector is made of two identical supermodules each one consisting of a target followed by a muon spectrometer. The schematic view is given in Figure 2. Each target combines “passive” elements such as emulsions with electronic detectors.

2.1 Target Bricks

The base component of the detector is the target brick. Each brick is made of a sandwich of 56 1 mm thick lead sheets interleaved with 57 emulsion layers. The dimensions of each brick are $12.8 \times 7.5 \times 10.3$ cm$^3$ and the weight is 8.3 kg. The bricks are contained in a 6.7 m high wall made of steel. The target mass will reach 1.35 kton, consequently 154700 bricks will be installed into 62 walls. The production is carried out by a dedicated apparatus called Brick Assembly Machine installed in Gran Sasso. It is a chain of different stations (for piling, pressing, wrapping) using robots operating in dark rooms with controlled environment. The goal is to construct 936 bricks/day in order to finish the filling by April 2008.

© 2008 IOP Publishing Ltd
2.2 Electronic Detectors

The main role of the Target Tracker (TT) [3] is to localize the right brick to extract. Each wall of the TT will provide in 2D the position of the brick. It is composed of X and Y planes of plastic scintillator strips (6.8 m × 2.6 cm × 1 cm). A particle crossing the strips will create blue scintillation light. A wavelength shifting fiber glued in a groove made in the center of the strip will absorb the blue light, reemit it in green wavelength and then propagate the light up to the extremities of the fiber. Each TT wall is divided into 4 horizontal modules and 4 vertical modules. Each module is made of 64 scintillator strips, and the 64 fibers are connected to a multianode Hamamatsu photomultiplier tube at both strip ends. For a particle at the minimum of ionization, at least 5 photoelectrons are detected permitting to reach a detection efficiency of 99% which will provide the trigger of the experiment.

When the brick is selected, a robot called BMS (Brick Manipulator System) will extract it. The emulsions are developed and scanned with automatic microscopes [4] [5] having a scanning speed of 20 cm²/h.

The aim of the muon spectrometer is to measure precisely the charge and the momentum of the muon and provide an efficient muon tagging. It is composed of an inner tracker and a precision tracker [6]. The magnet of the inner tracker delivers a magnetic field of 1.55 T. Each wall of the magnet is made of 12 iron slabs interleaved with RPC’s (Resistive Plates Counters). While the RPC’s give the range of the muons, the precision tracker measure precisely their momentum. It is made of drift tubes covering an area of 8 × 8 m². Drift tubes stations are placed in front, in the middle, and behind each dipole magnet.

The precision on the momentum measurement is lower than 20% for momentum lower than 50 GeV. Combining the muon spectrometer data with the TT information, the muon identification probability is around 95%.

2.3 Physics performance

The expected results are compiled in Table 1. They are given for a full mixing, after 5 years of data taking and for an intensity of 4.5 × 10¹⁹ pot per year. The detection efficiency is given for the studied τ decay channels and the number of expected events is given for two values of Δm². At 90% Confidence Level, the OPERA experiment will test all the region of the parameters given by Super-Kamiokande.

3 First CNGS neutrino events

The first CNGS run took place in August 2006 [7]. The beam intensity was 70% of the nominal one, the total integrated intensity was 7.6 × 10¹⁷ pot in 121 hours of run, and no bricks were yet inserted into the target. The chosen SPS cycle was 16.8 seconds, and the CNGS proton beam was extracted in two 10.5
$\epsilon$ short pulses separated by 50 ms.

The events were selected by a comparison of their absolute timestamps with respect to the beam time information with a measured resolution of about 100 ns. Doing this time selection, 319 beam events were collected and examples of two reconstructed events are shown in Figure 3.

The angular distribution with respect to the horizontal axis observed for the sample of single-track events is shown in Figure 4 and compared with simulated cosmic ray muons. Beam-induced events appear as a peak around the horizontal direction. A gaussian fit yields an inclination of $3.4^{\pm}0.3^\circ$ in agreement with the expected value of $3.3^\circ$.

Another CNGS run with real bricks was foreseen in October 2006, but a serious leak problem in the water cooling circuit of the CNGS reflector caused the early stop of the run. An integrated intensity of $0.6^{\times}10^{17}$ pot was collected and only 29 neutrino-induced events were registered. Anyway, the TT to brick connection has been studied using cosmic rays and a good agreement has been found.

### 4 Conclusions and perspectives

The first detection of neutrino events from the long baseline CNGS neutrino beam has been performed by OPERA. 319 neutrino-induced events were collected for an integrated intensity of $7.6^{\times}10^{17}$ pot in agreement with the expectations. The reconstructed zenith-angle distributions and the time structure of the events demonstrate the capability of the electronic detectors, build up during the last three years, to reach the experiment goals. The next CNGS run begins the 18th of September and it will last 6 weeks, 70% of the nominal intensity will be delivered and the target mass will be around 600 tons. The OPERA detector faces the last effort of brick production and insertion and the detector is ready for the next phase which is the observation of neutrino interactions inside bricks.
Figure 4: Angular distribution of beam-induced and cosmic-muon events taken with the electronic detectors. The histogram indicates the predictions from cosmic-ray simulations. The inset shows the angular distribution of on-time beam events.

References

[1] M. Guler et al. [OPERA and collaboration], CERN-SPSC-2000-028.
[2] Y. Fukuda et al., Phys. Rev. Lett. 81 (1998) 1562.
[3] A. Adam et al., Nucl. Instr. Meth A577 (2007) 523.
[4] L. Arrabito et al., Nucl. Instr. Meth. A568 (2005) 261.
[5] S. Aoki et al., Nucl. Instr. Meth B51 (1990) 466.
[6] R. Zimmermann et al., Nucl. Instr. Meth. A555 (2005) 435.
[7] R. Acquafredda et al., New Journal of Physics 8 2006 303.