Searching for neutrino oscillations with OPERA

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Abstract. The OPERA experiment will search for neutrino oscillations using a muon neutrino beam and a hybrid emulsion-scintillator detector. Basic principles, current status and expected performance of the experiment are discussed.

1 Motivation

Results from Super-Kamiokande [1] and K2K [2] together with those of CHOOZ [3] gained strong evidence in favor of the $\nu_\mu \rightarrow \nu_\tau$ scenario for the atmospheric neutrino anomaly. OPERA intends to confirm this result by observing the appearance of $\nu_\tau$ in a $\nu_\mu$ beam. As a byproduct of the experiment, a significant improvement of the current CHOOZ limit [3] on $\theta_{13}$ is expected.

2 Experimental strategy

OPERA will use the CNGS (CERN Neutrinos to Gran Sasso) $\nu_\mu$ beam. The detector will be placed in the Gran Sasso underground laboratory in Italy, 735 km away from the source.

The detection of $\nu_\tau$ will be based on direct observation of $\tau$ decay topologies. Since $\tau$ decay length under experimental conditions is very short (of order of 1 mm), a detector with a very high spatial resolution is required. This will be accomplished by using nuclear emulsions.

The OPERA emulsions films consist of two 40 $\mu$m emulsion layers separated by a 200 $\mu$m plastic base. The emulsions are sandwiched with 1 mm lead sheets, according to the so-called emulsion cloud chamber (ECC) technique. The basic unit of the OPERA detector, a brick, contains 57 emulsion films and 56 lead plates. The brick dimensions are $10.2 \times 12.7 \times 7.5$ cm and the weight is 8.6 kg. The overall weight of the OPERA detector will be 1.7 kton.

In order to identify the location of the bricks containing the neutrino interaction point, brick layers are interspaced with electronic detectors. The Target Tracker (TT) planes consist of horizontal and vertical plastic scintillator strips read out by 64-channel PMTs. The DAQ of TT defines the trigger for the brick extraction for analysis.

The OPERA detector will be organized into two large sections ("supermodules") of 31 brick and TT planes. Each supermodule will be followed by a muon spectrometer for $\mu$ identification, momentum and charge measurement and charm background reduction. Each muon spectrometer is composed of a 1.55 T dipolar magnet, 22 RPC layers and 6 sections of drift tubes.

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Once the interaction candidate brick(s) is (are) identified, its (their) extraction will be handled by two designated robots called BMS ("brick manipulation system"). After extraction, the brick is exposed to cosmic rays for film alignment, and then disassembled. The emulsions are developed on-site and then sent to participating laboratories for scanning. After scanning, particle tracks are analyzed and the event is reconstructed using momentum information from multiple Coulomb scattering and readouts of the TT and the muon spectrometers.

3 Installation of the experiment

3.1 Neutrino Beam

The CNGS project has successfully completed the civil engineering stage as well as the installation of hadron shop, decay tube and general services. Currently, installation of the proton beamline, target, horn, deflector and shielding is underway. The commissioning is expected in Spring 2006.

3.2 Spectrometers

The magnets for both muon spectrometers are now in place. Installation of detectors for the spectrometers is in progress. The 4 downstream RPC planes of the first supermodule are already taking cosmics data.

3.3 Target modules

All required TT modules have been produced and are now delivered to Gran Sasso on a ready-to-install basis. As of September 2005, about 2/3 of TT and brick walls for the first supermodule are installed. It is expected that by November 2005 all TT installations for the first supermodule will be completed. The brick assembly machine (BAM) is expected to be fully commissioned by December 2005 and should start producing lead-emulsion bricks in January 2006. Brick filling of the first supermodule should start in January 2006 and continue until the expected CNGS beam arrival in July 2006. After that, while taking data with one supermodule, the collaboration will continue to fill the second supermodule with bricks.

4 Emulsion scanning

The OPERA scanning system uses many ideas and approaches that originated during development of the automatic scanning system for CHORUS. The total surface of OPERA emulsions is, however, more than 170,000 m², as compared to 500 m² for CHORUS [4]. Such a high scanning load requires innovations in
Figure 1: Schematic view of the OPERA detector.

Figure 2: Construction of the OPERA detector (June 2005). The neutrino beam will come from the left.
both scanning hardware and analysis algorithms, which have been successfully implemented in OPERA computer-controlled scanning stations.

Thanks to these innovations, the scanning speed has been increased more than by a factor of 20 with respect to the previous systems and reached over 20 cm$^2$ per hour. Online 3D reconstruction of particle tracks is performed with a sub-micron precision and efficiency better than 95%.

Scanning systems installed in Europe and Japan are now operational and are analyzing data from various test beams. A sample reconstructed event from a CERN 10 GeV pion test beam is shown in Figure 3.

The overall scanning capacity of the collaboration is estimated around 30 bricks per day, which fulfills the requirements of the experiment.

5 Expected event and background rates

The overall efficiency of $\tau$-decay observation in OPERA was calculated to be 9.1%. This figure is based on both short and long decays of $\tau \to e$, $\tau \to \mu$ and $\tau \to h$ channels. A possibility of inclusion of the $\tau \to 3h$ channel with potential improvement in efficiency by about 1% is being investigated. Finally, a recent
Table 1: Expected number of observed signal and background events in 5 years of running for nominal calculations and envisaged improvements of efficiency and background reduction.

| $\Delta m^2 (10^{-3} \text{eV}^2)$ | Signal (1.9 2.4 3.0) | BG (0.7 1.0 0.8) |
|------------------------------------|----------------------|------------------|
| Nominal                            | 6.6 10.5 16.4        | 0.7              |
| Improved eff.                      | 8.0 12.8 19.9        | 1.0              |
| + BG reduction                     | 8.0 12.8 19.9        | 0.8              |

study shows a possibility of a 10% improvement in brick finding efficiency.

The event rate of OPERA strongly depends on the oscillation parameters. Calculations for several values of $\Delta m^2_{\text{atm}}$ (corresponding to the central value of Super-Kamiokande best fit and the limits of the 90% confidence interval) are presented in Table 1.

The main sources of background are charm decays, hadron re-interactions and large angle $\mu$ scattering. Algorithms employing $\text{dE/dx}$ information for improved $\pi/\mu$ separation are currently being developed. It is expected that they would reduce charm background by about 40% (down to about 0.28 event). The result of recalculation of the large angle $\mu$ scattering background including nucleon form factors is 5 times lower than the upper limit from the CHORUS measurement used earlier.

6 Conclusions

The CNGS and the OPERA detector construction are progressing and the experiment should be ready to take data in August 2006. Based on Super-Kamiokande best fit for $\Delta m^2_{\text{atm}}$, OPERA should see in 5 years about 12.8 $\tau$ events. The background is expected on the level of 1 event. An ongoing effort to improve the efficiency and to further suppress the background may improve these figures.

References

[1] Super-Kamiokande Collaboration, Phys. Rev. D 71, 112005 (2005).
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