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The OPERA experiment

Carlo Gustavino[*]

INFN, Laboratori Nazionali del Gran Sasso, Assergi, Italy

E-mail: Carlo.gustavino@lngs.infn.it

Abstract. OPERA is a neutrino oscillation experiment designed to perform a ν_τ appearance search in the future CNGS beam from CERN to Gran Sasso. The identification of the τ lepton produced by a CC ν_τ interaction is based on the use of the nuclear emulsion technique. The OPERA detector is presently under construction in the Gran Sasso underground laboratory, 730 km from CERN, and will receive its first neutrinos in 2006. The experimental technique is reviewed and the development of the project described. Foreseen performances in measuring ν_τ appearance and also in searching for ν_e appearance are discussed.

1. The OPERA detector principles

The CNGS (CERN Neutrinos to Gran Sasso) long baseline project is focused on the appearance of ν_τ in a ν_μ beam. Its objective is to prove explicitly the ν_μ–ν_τ nature of the atmospheric oscillation and to check the Δm^2 value in this channel. Searching for ν_τ–ν_e oscillations in this beam will also provide a window of opportunity to measure θ_{13} before the next generation of dedicated experiments. The OPERA experiment will be placed in the Gran Sasso underground laboratory, 730 km from CERN. The CNGS beam is a wide band neutrino beam optimized for ν_τ appearance with a mean neutrino energy of 17 GeV. The beam construction is well on schedule and first beams to Gran Sasso are expected in June 2006. With a foreseen intensity of $4.5 \cdot 10^{19}$ protons of 400 GeV on target per year (assuming 200 days of operation and 55% overall efficiency), the number of neutrino interactions expected in the 1.8 kton OPERA target is about 6200/year and the number of ν_τ CC interactions is 27/year (for $\Delta m^2 = 2.4 \cdot 10^{-3}$ eV^2).

The OPERA experiment is based on the direct observation of the ν_τ decay topology [1], by means of nuclear photographic emulsions. The detection of the τ decay kink in ν_τ CC events has been studied for the 1-prong ν_τ decay modes (85% total branching ratio) associating emulsion films for tracking with high Z plates as target. This technique was used in the ν_τ discovery by DONUT in 2000 [2]. The necessity to keep film alignment within a micron while achieving a target mass of 1800 tons leads to a highly modular target.

The basic target unit is a brick of 10.2 x 12.7 x 7.5 cm made of 56 lead plates (1 mm thick) and 57 emulsion films (about 200 000 bricks in total). The emulsion films are made of a plastic base with two emulsion layers of 45 μm. After emulsion film scanning performed by automated microscopes, charged tracks will be reconstructed allowing for vertex and decay kink finding. In addition, for low energy tracks, momentum measurement using multiple coulomb scattering in the lead plates and π/μ

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[*] On behalf of the OPERA Collaboration

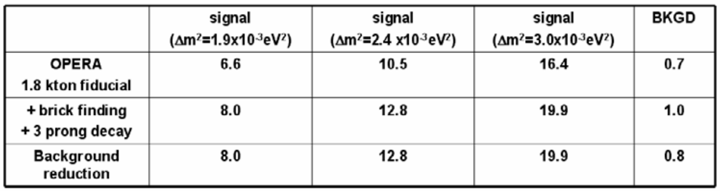
separation using dE/dx are possible. Electromagnetic showers developing in the 10 X_0 bricks can be measured, electrons identified and separated from γs and π^0s.

Interspersed between the target bricks stacked in vertical walls, electronic detectors allow to localize on line neutrino interactions and select the corresponding bricks. The Target Tracker (TT) planes consist of horizontal and vertical scintillator strips read out by 64-channel PMTs via WLS fibers, their DAQ electronic cards define the trigger.

There are two target blocks of 31 brick planes interleaved with 31 TT planes. To identify muons and measure their momentum and charge to fight charm background, each target block is followed by a spectrometer, composed of a dipolar magnet filled with 22 Resistive Plate chambers (RPC) planes and complemented by 6 sections of drift tubes for precision tracking through the magnetic field.

During data taking, the bricks tagged by electronic detectors will be daily extracted by two automated manipulators. The extracted bricks will be then properly exposed to cosmic ray near the surface to produce alignment tracks. After film development, scanning stations in Japan and in Europe will operate quasi on-line to fully complete data acquisition with vertex location and τ decay kink detection. For τ decay candidate events, further scanning measurements will be made to improve particle identification and momentum assignment.

Table 1. Background and expected signal (full mixing, 5 y of data taking, $4.5 \cdot 10^{19}$ p. o. t./year).



	signal ($\Delta m^2=1.9\mathrm{x}10^{-3}eV^2$)	signal ($\Delta m^2=2.4\ \mathrm{x}10^{-3}eV^2$)	signal ($\Delta m^2=3.0\mathrm{x}10^{-3}eV^2$)	BKGD
OPERA **1.8 kton fiducial**	6.6	10.5	16.4	0.7
+ brick finding **+ 3 prong decay**	8.0	12.8	19.9	1.0
Background reduction	8.0	12.8	19.9	0.8

2. Status of the OPERA construction

The installation of OPERA in Hall C of the Gran Sasso underground laboratory started in May 2003 with the construction of the spectrometers. The magnets, made of 5 cm thick iron slabs, are 10 m high and 9 m wide and weight about 1000 tons. The two magnets were completed in april 2005. Each magnet is equipped with 462 RPC, for a total active surface of 1540 m^2. Each spectrometer is complemented with six High Precision Tracker (HPT) planes. Each HPT plane is composed of four layers of staggered drift tubes, 8 m long and 38 mm diameter. Full height prototype measurements show an efficiency better than 99% and a resolution better than 0.3 mm when 0.5 mm. The installation of three out of six HPT of the first SuperModule (SM) has been recently completed. With HPT added, the expected Δp/p is better than 25%, the μ-ID efficiency is larger than 95% and the charge confusion is less than 0.3%.

The TT installation of the first SM, totaling 6000 m^2 of plastic scintillator strips, has been completed, as well as the electronics and cabling.

The bricks will be assembled by an automated machine at a rate 4800 bricks per week. The Brick Assembling Machine (BAM) has been prepared by an industrial company and will be commissioned at LNGS for the end of 2005. A Brick Manipulator System (BMS) will load the OPERA detector in parallel so that the target section of the first SM will be fully filled in July 2006 and the second one in December 2006. The lead plates, having a precision of 10 μm in thickness, are produced by an industrial manufacturer.

The emulsion films are developed by Fuji jointly with Nagoya University. Of the 13 millions films, 60% are produced. Film refreshing procedures to erase cosmic ray tracks are being applied in Tono mine (Japan) before shipping to Gran Sasso. R&D to speed up automatic scanning of emulsions to 20 cm^2 per hour or more has been achieved both in Japan and in Europe. The Japanese approach is based on dedicated hardware and hard coded algorithms, using continuous movement of the film stage and very fast CCD cameras (3000 frames per second). The European labs rely on software algorithms and on commercial hardware developing with the video PC market.

3. The OPERA physic performances

Efficiencies have been calculated for the various categories of τ decays. They include branching ratios together with losses in brick finding, kink finding, event selection, μ identification and connection. The total efficiency amounts to 9.1%, in considerable improvement from the time where only decays of τ to μ and electron were considered. The inclusion of the $\tau \rightarrow 3h$ decay mode could provide an additional 1.0% to the total efficiency. The main background sources are charmed decays, hadron re-interactions and large angle μ scattering. Possible improved π/μ separation using dE/dx in emulsions would reduce the charm background by 40%, down to 0.28 event/year. The large angle μ scattering background is an upper limit from past measurements and could be 5 times lower according to calculations including nuclear form factors. To evaluate the large angle muon background, a beam test has been recently done and the data analysis is in progress. Table 1 compares the total background to the expected signal (full mixing, 5 years of data taking, $4.5 \cdot 10^{19}$ protons on target/year). Figure 1 presents the 4σ discovery probability and the 90% CL sensitivity limit of OPERA. For the improvements described above, the OPERA discovery potential ranges from 80% to 100%.

The OPERA sensitivity has been also estimated in a search for ν_μ-ν_e appearance in the CNGS, looking for an excess of ν_e CC events [3]. The dominant background from the contamination in ν_e of the beam (0.8%) and contributions from ν_μ–ν_τ with $\tau \rightarrow e$ and from ν_μ NC and CC interactions, where muons are misidentified and π^0s are identified as electrons. The limit that can be obtained at 90% confidence level on θ_{13} is 7.1° (after 5 years with nominal beam) in significant improvement relative to the present CHOOZ limit [4].

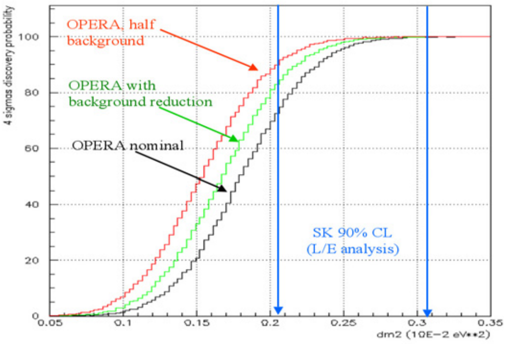


Figure 1. OPERA sensitivity limit and 4σ discovery probability as a function of Δm^2.

4. Conclusions

The CNGS beam is well on schedule. OPERA construction is on-going and should be ready to take data by 2006. Great progress has been accomplished towards a successful realization of the experiment. Work is continuing to improve the OPERA sensitivity by reducing the background and increasing the efficiency. The beam intensity upgrade will have the similar effect of securing the ν_τ appearance observation even for very low values of Δm^2.

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