Emulsion analysis in the OPERA experiment

N. Naganawa on behalf of the OPERA collaboration

Fundamental Particle Physics Laboratory, Graduate School of Science of Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8602, Japan

Email: naganawa@flab.phys.nagoya-u.ac.jp

Abstract. OPERA is a unique experiment aimed at the first detection of $\nu_\tau$ appearance in a flux of $\nu_\mu$ due to the neutrino oscillation from $\nu_\mu$ to $\nu_\tau$. The CERN CNGS beam is the source of $\nu_\mu$. The detector is hybrid; it is composed of nuclear emulsion films and electronic detectors. It is located in the LNGS underground laboratory. The target consists of 150,000 Emulsion Cloud Chambers (ECC) bricks, which are stacks of interleaved emulsion films and lead plates. The $\nu_\tau$ charged current interactions will be detected by identifying the decay topology of the $\tau$ in the ECC bricks. The first run started in 2008. The experiment is currently in the phase of data taking and analysis. The experimental methods, the status and the summary of the results from the 2008 run are presented in this paper.

1. Introduction
OPERA [1] is a unique experiment aimed at the first direct observation of the appearance of $\nu_\tau$ caused by $\nu_\mu$ to $\nu_\tau$ oscillation by detecting the decay topology of the $\tau$ induced in the $\nu_\tau$ CC interactions. The CERN $\nu_\mu$ CNGS beam has an average optimised energy of 17 GeV. The hybrid detector composed of nuclear emulsion films and electronic detectors is located 1400m underground in the LNGS laboratory, 730km away from CERN. The first physics run with a target partly filled started in spring 2008. The experiment is currently in the phase of its second year of data taking and of data analysis.

2. The OPERA detector
The OPERA detector [2] consists of two identical Super-Modules. Each consists of an instrumented target followed by a magnetic muon spectrometer. The targets, for a total mass of 1.25 kton, is composed of 150 000 units called hereafter “bricks” arranged in twice 31 walls. These are interleaved with pairs of planes of orthogonal plastic scintillator strips constituting the Target Tracker (TT) - see Figure 1.

Bricks are fabricated following the so-called Emulsion Cloud Chamber (ECC) technique: 57 nuclear emulsion films and 56 1-mm thick lead plates are stacked alternately (see Figures 2 and 3). This technique is adequate to recognise $\tau$ decay topologies as proven by the DONUT experiment [3].

An emulsion film is made of two layers of nuclear emulsion gel 44 $\mu$m thick deposited on each side of a 205 $\mu$m thick plastic base of $12.5 \times 9.9$ cm$^2$. A track of a minimum ionising particle is shown in Figure 4. The position resolution of the emulsion film is 0.3 micron. A brick weighs 8.3 kg and its thickness, 7.5 cm, corresponds to about 10 radiation lengths. With this structure, it is also possible to measure momentum by Multiple Coulomb Scattering [4] and identify electrons and measure their energy by counting the number of track segments in the electromagnetic showers [5].
A pair of emulsion films called the Changeable Sheets (CS) is packed into a thin box glued on the downstream face of each brick. The films can be removed and if necessary replaced without opening the brick. They serve as interface between the TT and the brick.

![Figure 1. The OPERA detector.](image)

![Figure 2. An ECC brick and its structure.](image)

![Figure 3. OPERA emulsion films and lead plates.](image)

![Figure 4. The microscopic image of a track of a M.I.P. The linear sequence of black dots along the blue arrow is the track of a M.I.P. in a developed emulsion film.](image)

**3. Localisation of the neutrino interaction vertices in the ECC bricks**

From the tracks reconstruction in the TT, the brick with the highest probability to contain the interaction vertex is identified and removed from the target by an automaton. The CS is developed underground and scanned at either LNGS and or in Japan. If tracks from the neutrino interaction are found in the CS, the films of the corresponding brick are developed, scanned and analysed. The tracks in the CS are extrapolated to the most downstream film of the brick and searched for. They are then followed upstream until they disappear. A volume scan of about 1 cm$^3$ around the point of disappearance is performed. Tracks emerging from a single point are extracted from the data. This localises the position of the vertex inside the brick.

In case tracks belonging to the event are not found in the CS, the brick is equipped with a new pair of CS and reinserted into the target. The next most probable brick is then removed and its CS are analysed.
4. Separation of the vertices of the neutrino interaction and of the $\tau$ decay

The histogram in red in Figure 6 shows the minimum distance between pairs of tracks from neutrino interactions in lead plates computed from the data recorded in the emulsion films immediately downstream of the vertex plate. Only tracks with a momentum larger than 1 GeV/c are considered.

The uncertainty of the position of vertices in the lead plates results from Multiple Coulomb Scattering, the angular resolution and the position resolution of the tracks. The blue histogram shows the Monte Carlo simulation of the distribution of the impact parameter (IP) of the decay daughters of $\tau$ produced in CC $\nu_\tau$ interactions. The comparison between the two plots demonstrates that the vertices of the neutrino interaction and of the $\tau$ decay are separable. The 1 mm thickness of the lead plates does not affect significantly the $\tau$ decay search. This is confirmed by the detection of several charm decay candidates with topologies similar to that of $\tau$ decays. An example of such event is shown in Figure 6.

5. Summary of the run status and future prospects

During the run of 2008 [6], the CNGS provided $1.782 \times 10^{19}$ protons on target (p.o.t.) and 1690 neutrino events have been registered in the OPERA target. This corresponds to an expectation of 0.7 detected $\nu_\tau$ CC interactions for $\Delta m^2 = 2.43 \times 10^{-3}$ eV$^2$ and full mixing. Up to now, 746 vertices of neutrino interactions have been localised in the bricks. No $\tau$ candidate has been detected yet. However, several charm decay candidates have been observed, in particular charged charm decays into one and three prongs with topologies similar to $\tau$ decay topologies.

It is verified from the data that the lead plates are thin enough and the spatial resolution of the films is good enough to allow efficiently separating the vertices of the neutrino interaction and the $\tau$ decay.

For the 2009 run which has started on June 1, we requested $4.5 \times 10^{19}$ p.o.t. About 2.5 $\nu_\tau$ CC interactions would then be expected to be detected at the end of this run.

References
[1] Guler M et al. 2000 CERN/SPSC 2000-028, SPSC/P318, LNGS P25/2000
[2] Acquafredda R et al. 2009 JINST 4 P04018
[3] Kodama K et al. 2001 Phys. Lett. B 504 218
[4] Park B D et al. 2007 Nucl. Instrum. Meth. A 574
[5] Toshito T et al. 2003 Rev. Sci. Instrum. 74 53-56
[6] Agafonova N et al. 2009 JINST 4 P06020