Status and results from the OPERA experiment

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Abstract. The OPERA experiment is aiming at the first direct detection of neutrino oscillations in appearance mode through the study of the $\nu_\mu \to \nu_\tau$ channel. The OPERA detector is placed in the CNGS long baseline ν_μ beam 730 km away from the neutrino source. The analysis of a sub-sample of the data taken in the 2008-2009 runs was completed. After a brief description of the beam and the experimental setup, we report on event analysis and on a first candidate event, its background estimation and statistical significance.

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INTRODUCTION

The atmospheric neutrino oscillations have been studied by many experiments [1] [2] [3]. However, the direct observation of flavour transition in appearance mode has never been done. OPERA is aiming at the first direct detection of $\nu_\mu \to \nu_\tau$ oscillations in appearance mode. Lead plates and emulsion films are used as target and detector, satisfying the requirements for the ν_τ appearance: a large target mass and a very high spatial accuracy to detect the short-lived τ lepton decay ($c\tau = 87\mu$m), The observation of neutrino interactions in the OPERA detector have already been presented [4]. In this document, we report on event analysis and on a first candidate event, its background estimation and statistical significance.

THE CNGS BEAM AND THE OPERA DETECTOR

OPERA is exposed to the CNGS long baseline ν_μ beam from CERN to LNGS, 730 km away. The average ν_μ energy is 17 GeV in order to maximise the number of ν_τ CC interactions. In terms of interactons, the $\bar{\nu_\mu}$ contamination is 2.1% and the ν_e and $\bar{\nu}_e$ contaminations are lower than 1%, while the number of prompt ν_τ is negligible. The expected interactions for 22.5×10^{19} pot (nominal pot in 5 years) are about 24000 events. About 10 τ decays are expected to be observed.

OPERA is a hybrid detector made of two identical super modules consisting of a target section made of ECC bricks, of a scintillator tracker detector, and of a muon spectrometer. An ECC brick consists of 57 emulsion films interleaved with 1 mm thick lead plates. An OPERA film has 2 emulsion layers of 44 μm thickness poured on a 205 μm plastic base. In order to reduce the emulsion scanning load, removable pairs of emulsion films called Changeable Sheets (CS) have been used as interfaces between the scintillator tracker and the ECC bricks.

EVENT ANALYSIS

Bricks predicted to contain a neutrino interaction by the electronic detectors are removed from the target wall and the CS is detached from the brick and developed underground, then analyzed to validate the brick. After a brick has been validated, its emulsion films are developed and dispatched to the various scanning laboratories. All tracks measured in the CS are followed back until they are not found. The stopping point is considered as either a primary or a secondary vertex, then the vertex is confirmed by scanning a volume with 1 cm^2 $\times$ 15 films, 5 upstream and 10 downstream of the stopping point. A further analysis called decay search procedure is applied to located vertices to detect possible decay or interaction topologies. When secondary vertices are found in the event, a kinematical analysis is performed using track angles and momenta.

Momenta of charged particles can be measured in ECC using the angular deviations of tracks by Multiple Coulomb Scattering (MCS) in lead [5]. This method gives a momentum resolution better than 22% for particles with momenta lower than 6 GeV/c, passing through a brick. For higher momentum, the position deviations are used for the measurement. The resolution is better than 33% for particles with momenta lower than 12 GeV/c, passing through a brick. Momenta of muons reaching the spectrometer are measured with a resolution of 20% up to 30 GeV/c.

The analysis of a sub-sample of 1088 events of the neutrino data taken in the 2008-2009 runs was completed, corresponding to 1.89×10^{19} pot.

Charmed particles have similar lifetimes and decay topologies if charged, so the detection of charm decays is used to check the τ efficiency. In the sample of ν_μ CC interactions, 20 charm decays have been observed that survived all the cuts, in agreement with expectations from a MC study, 16.0 ± 2.9. Out of them 3 have a 1-prong topology where 0.8 ± 0.2 are expected. The background for the total charm sample is about 2 events.

Several ν_e-induced events have also been observed.

THE FIRST ν_τ CANDIDATE EVENT

The decay search procedure yielded one candidate event satisfying the selection criteria for the ν_τ interaction search ([6]). The cuts are the same as those defined in the experimental proposal ([7],[8]). The event is displayed in Figures 1 and 2.

The selection criteria are that there is no tracks compatible with a muon or an electron, the secondary vertex and the primary vertex survive the cuts shown in Table 1.

TABLE 1. Kinematical variables

Variable	Measured	Selection criteria
Kink angle (mrad)	42 ± 2	>20
Decay length (μm)	1335 ± 35	Within 2 plates
P daughter (GeV/c)	12^{+6}_{-3}	>2
P_T daughter (MeV/c)	470^{+230}_{-120}	>300 (γ attached)
Missing P_T (MeV/c)	570^{+320}_{-170}	<1000
Angle Φ (deg)	173 ± 2	>90

The primary vertex consists of seven tracks of which one track has a kink. Two electromagnetic showers caused by γ rays have been detected and they are compatible with pointing to the secondary vertex.

The invariant mass of the two detected γ rays yields a mass consistent with the π^0 mass, $(120 \pm 20(stat.) \pm 35(syst.))MeV/c^2$. Then, the invariant mass of the $\pi^-\gamma\gamma$ system has a value compatible with that of the ρ (770), $(640^{+125}_{-80}(stat.)^{+100}_{-90}(syst.))MeV/c^2$. The ρ appears in about 25% of the τ decays.

BACKGROUND ESTIMATION AND STATISTICAL SIGNIFICANCE

The secondary vertex is compatible with the decay of $\tau \rightarrow h^-(n\pi^0)\nu_\tau$. The main background sources to this channel are

- the decays of charmed particles produced in ν_μ CC interactions where the primary muon is not identified.
- the 1-prong interactions of primary hadrons produced in ν_μ CC interactions where the primary muon is not identified or in ν_μ NC interactions.

The charm background produced in the ν_μ interactions in the analysed sample is 0.007±0.004 events, that produced in the ν_e interactions is less than 10^{-3} events.

The background from hadron interactions has been evaluated with a FLUKA based MC code, updated with respect to the proposal simulations. The kink probability to occur in 2 mm lead integrated over the ν_μ NC hadronic spectrum yield a background probability of $(1.9 \pm 0.1) \times 10^{-4}$/NC. This probability decreases to $(3.8 \pm 0.2) \times 10^{-5}$/ NC taking into account the cuts on the event global kinematics. This leads to a total of 0.011±0.006 events when misclassified CC events are included.

The cross-checks of the 1-prong hadron background estimation have been performed. The tracks of hadrons from a sub-sample of neutrino interactions have been followed far from the primary vertex to search decay-like interactions. A total length of 9 m has been measured and no event has been found in the signal region (Figure 3). This corresponds to a probability over 2 mm lead smaller than 1.54×10^{-3} at 90% C.L. Within the low statistics, the P_T distribution agrees with the simulation.

We observed 1 event in the 1-prong hadron τ decay channel, with a background expectation 0.018±0.007 (syst.). The probability to observe 1 event due to a background fluctuation is 1.8% (2.36σ). As all τ decay modes were included in the search (1-prong μ, 1-prong e, 1-prong hadron, 3-prong hadron), the total background becomes 0.045±0.023 (syst.), the probability to observe 1 event due to a background fluctuation becomes 4.5% (2.01σ).

CONCLUSIONS

Data taking in the CNGS beam is going smoothly. The analysis of a sub-sample of the neutrino data taken in the 2008-2009 runs was completed, corresponding to 1.89×10^{19} pot out of 22.5×10^{19} proposed pot. Decay topologies due to charmed particles have been observed in good agreement with expectations, as well as several events induced by ν_e present as a contamination in the ν_μ beam. One muonless event showing a τ to 1-prong hadronic decay topology has been detected. It is the first ν_τ candidate event in OPERA, with a statistical significance of 2.36σ (1-prong hadronic decay mode) and 2.01σ (all decay modes). Analysis of the 2008+2009

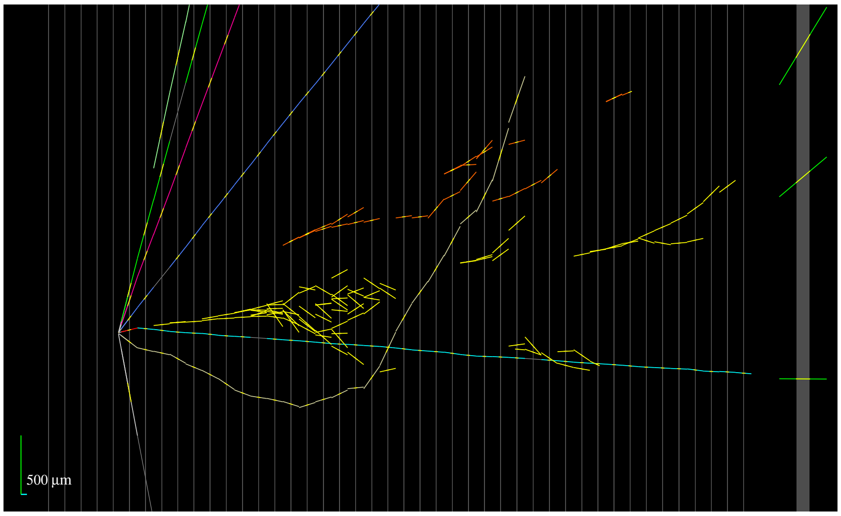

FIGURE 1. Display of the ν_τ candidate event.

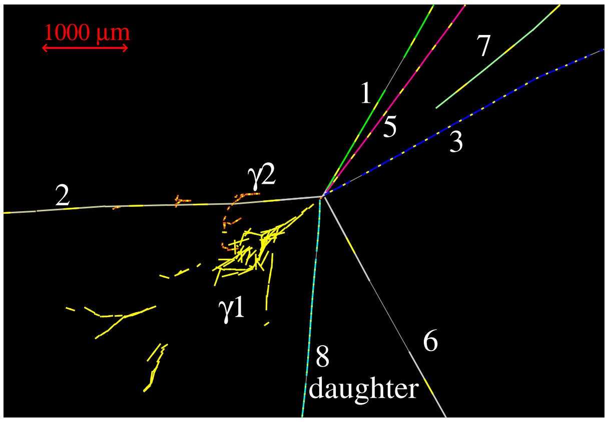

FIGURE 2. Display of the ν_τ candidate event (beam view).

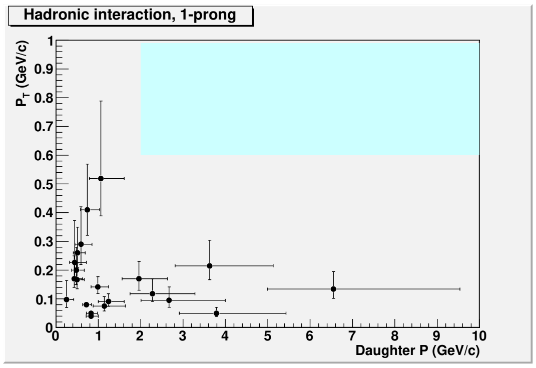

FIGURE 3. P-P_T plot of the hadronic interactions found in the reference sample. No event found in the signal region (blue region).

full sample will be completed early next year. Analysis of 2010 events is being performed in parallel.

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