Kinematical analysis with the Emulsion Cloud Chamber in the OPERA experiment

F. Di Capua on behalf of the OPERA Collaboration
INFN, Napoli, Italy

Abstract

The OPERA experiment aims at measuring for the first time neutrino oscillation in appearance mode through the detection of ν_τ in an almost pure ν_μ beam produced at CERN SPS (CNGS), 730 km far from the detector. The ν_τ appearance signal is identified through the measurement of the decay daughter particles of the τ lepton produced in CC ν_τ interactions. Since the short-lived τ particle has, at the energy of the beam, an average decay length shorter than a 1 mm, a micrometric detection resolution is needed. The OPERA apparatus is hybrid, using nuclear emulsion as high precision tracker and electronic detectors for the time stamp, event localization in the target and muon reconstruction. The Emulsion Cloud Chamber technique fulfils the requirement of a microscopic resolution together with a large target mass. The kinematical analysis allowed by this technique is described.

1 The ECC in the OPERA experiment

The short-lived τ lepton ($c\tau$ = 87.11 μm) is identified by its characteristic decay topologies either in one prong (electron, muon or hadron) or in three-prongs; its short track is measured in a target made of 1 mm thick lead plates (target mass and absorber material) interspaced with nuclear emulsion films (high-accuracy tracking devices). The films are made of two 45 μm emulsion layers on each side of a plastic base of 200 μm. This detector is historically called Emulsion Cloud Chamber (ECC).

OPERA has a modular target with units (called bricks) consisting of 57 emulsion films [1] interleaved with 56 lead plates. The transverse dimensions are 12.8×10.2 cm^2 and the thickness along the beam z direction is 7.9 cm (about 10 radiation lengths). The weight is 8.3 kg. The OPERA experiment contains 150000 bricks in total.

The scanning of emulsion films is performed with two different types of automatic microscopes: the European Scanning System (ESS) [2, 3] and the Japanese S-UTS [4]. Microscope systems have comparable performances ensuring a scanning speed two orders of magnitude greater than that of the systems used in the recent. The spatial and angular resolution is of the order of $\sim$1 μm and 1 mrad, respectively.

In order to reduce the emulsion scanning load, interface films (Changeable Sheets, CS [5]), between the electronic detectors and the bricks are used. They consist of tightly-packed emulsion film doublets, glued on the downstream face of each brick. CS doublets are removable without opening the brick. All tracks measured in the CS are sought in the most downstream films of the brick and followed back until they disappear in three consecutive films. The stopping point is considered as the signature either for a primary or a secondary vertex. The existence of the vertex is then confirmed by scanning a volume of about 2 cm^3 around the stopping point.

2 Topological and kinematical analysis

The ECC allows a very precise position determination of the primary neutrino interaction vertex. The track impact parameter distribution of the reconstructed tracks with respect to the reconstructed vertex position is shown in Figure 1.

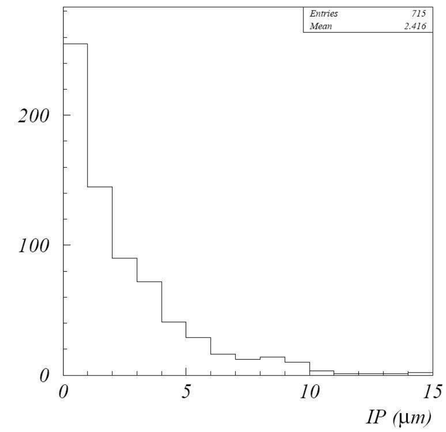

Fig. 1: Impact parameter distribution of the tracks in OPERA neutrino events with respect to the reconstructed vertices.

As expected, the impact parameter distribution is peaked at zero with a mean value of 2.4 μm. The few entries above 10 μm are identified to be due to low energy particle tracks.

A kinematical characterization of the neutrino interaction is also possible in ECC. The relevant aspects will be discussed in the following.

2.1 Momentum measurement

An estimation of charged particle momenta is possible by detecting the deviations of the particle trajectory from a straight line due to multiple coulomb scattering (MCS). In fact the distribution of track slope differences after crossing a fixed amount of lead plates is peaked at zero with a shape which can be approximated by a Gaussian with a standard deviation given by

$$\theta_0 = \frac{13.6\text{MeV}}{pc\beta}\sqrt{\frac{x}{X_0}}\left(1 + 0.038\ln(\frac{x}{X_0})\right). \quad (1)$$

The angular resolution of the emulsions allows the momentum measurement of charged particles ranging from hundreds MeV to a few GeV. It corresponds to the momentum range of the secondary hadrons produced in OPERA neutrino interactions. By using dedicated test beam with pion of known momentum, a momentum resolution from 20% to 40% for pion momentum from 1 GeV/c to 8 GeV/c has been achieved with this method.

2.2 Electron identification

The ECC allows an excellent electromagnetic shower identification, hence the separation of electrons and pions. An electron quickly develops an electromagnetic shower in lead. The total number of tracks, as well as the different longitudinal and transverse profile of the shower can be used for particle identification. On the other hand the MCS angle presents a different longitudinal profile for electrons and pions: going through a material the energy remains almost constant for pions while it exponentially decreases for electrons. By using a Neural Network method an electron identification efficiency of 90% with a π contamination less than 1% has been obtained at energies greater than 2 GeV. For $E = 1GeV$ the electron identification efficiency is 80% with a π contamination of 1% [6]. By counting the segments of the shower, as it is done in a calorimeter, a measurement of electron energy is possible.

The good shower reconstruction capability can be also used for π_0 identification. By reconstructing the two separate showers from $\pi_0 \rightarrow \gamma\gamma$ decay, the invariant mass of the π_0 can be measured with a resolution of 30%. In Fig.2, the display of an OPERA neutrino interaction reconstructed in ECC is shown: six showers are reconstructed in the event, four of them are due to π_0's produced at primary vertex, the other two origin from a π_0 produced at secondary hadronic interaction.

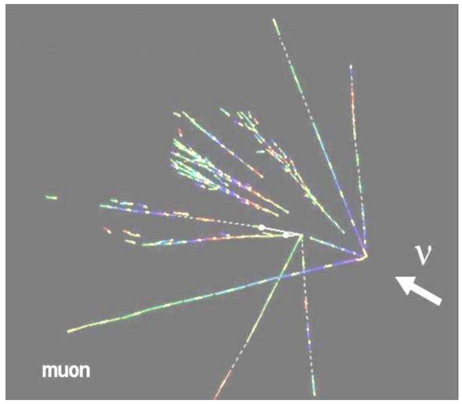

Fig. 2: A neutrino interaction reconstructed in ECC with a secondary hadron interaction. Six electromagnetic showers have been reconstructed in the event: four of them from the primary and two from a secondary vertex.

3 Charm events

Charmed hadrons produced in neutrino interactions decay with a flight path similar to the one of the τ lepton. The capability of the ECC in the detection of short-lived particles is demonstrated with the detection of first charm events in the OPERA experiment. Fig.3 shows the display of two neutrino interactions where a charmed hadron is produced. On the left side a D^0 decay in four charged particles is shown, the flight length of the D^0 is about 300 μm; the angle between the muon and D^0 direction in the transverse plane is $173°$. On the righ a charged charm decay in single prong is shown, the flight length is about 3 mm, the angle between the muon and the charm direction in the transverse plane is $165°$.

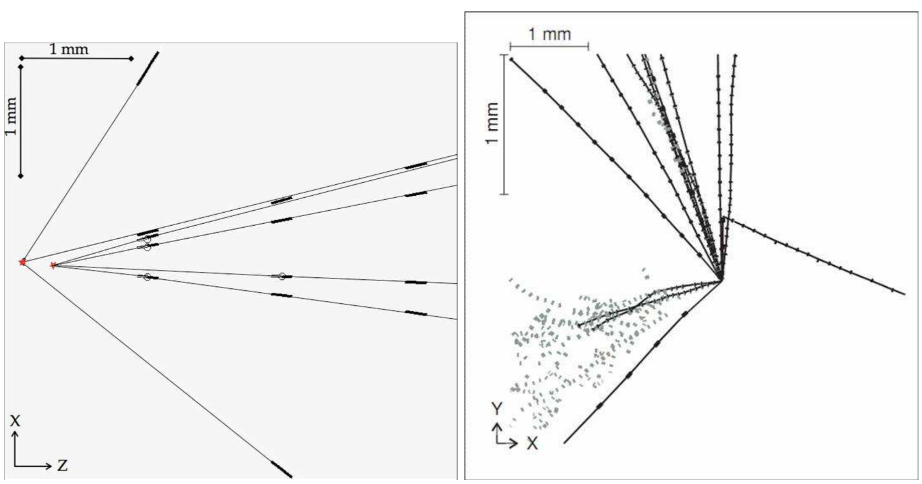

Fig. 3: Left: D^0 decay in four charged particles. Right: Charged charm decay in one prong.

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