High precision reconstruction of electromagnetic showers in the nuclear emulsions of the OPERA experiment

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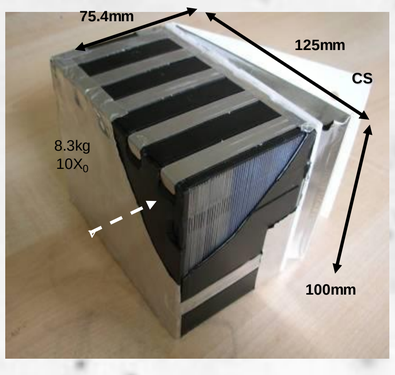
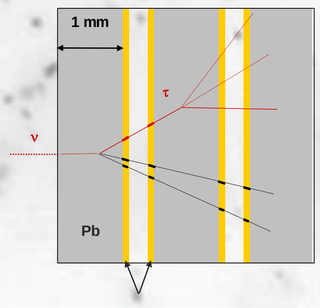
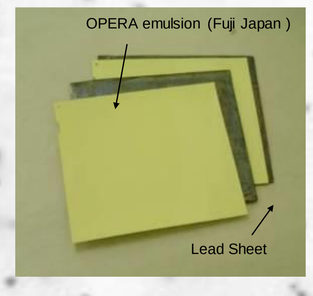
OPERA Emulsion Cloud Chamber



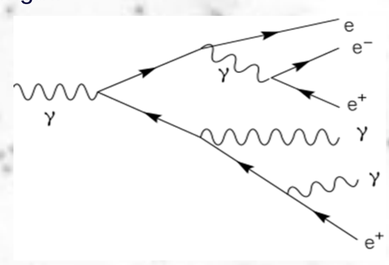


2 emulsion layers (42 μm)
200 μm plastic base



OPERA experiment observed $\nu_\mu \rightarrow \nu_\tau$ oscillation detecting ν_τ production from a ν_μ beam[1]
ν_τ interactions and tau lepton decays were reconstructed in compact detectors composed by 57 emulsion plates and 56 lead plates (ECC) [2]

Electromagnetic Showers play an important role in the reconstruction of neutrino interactions.
The decay channel $\tau^- \rightarrow e^- \nu_e \nu_\tau$ has a branching ratio of 17%, showers originating from γ photons and π^0 are to be taken into account to study the topology and the energy of the incoming neutrino.
EM shower energy is linked to track multiplicity at interaction vertex by the ***Heitler*** model. Each electron (positron) is expected to emit a ***bremsstrahlung photon*** in one ***radiation length (X_0)***, each photon is expected to convert into an electron-positron pair in the same length.



It is possible to evaluate a depth X_{max} where tracks multiplicity is maximum, being E_C the critical energy in emulsion-lead cells.

$$X_0 = \frac{(716.4 g.cm^{-2})A}{Z(Z+1)\ln(\frac{287}{\sqrt{Z}})} \qquad X_{max} = \frac{X_0 \ln \frac{E_0}{E_c}}{\ln 2}$$

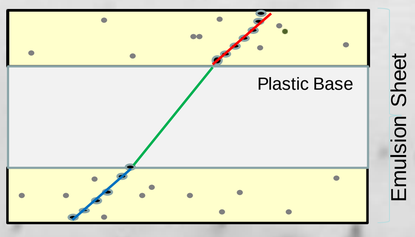
The track multiplicity measured at X_{max} is used to evaluate the energy E_0 of the primary particle as follows:

$$N(X_{MAX}) = {}^{E_0}/_{E_C}$$

When measuring tracks in ***OPERA ECC*** however, due to the large background and to the presence of lead plates, the electron-positron reconstruction efficiency decreases with energy.
A new tool was developed in the framework of **automatic emulsion scanning techniques**. The ***FOG*** tool performs detailed emulsion data acquisition and automatic 3D track reconstruction on accurate tomographic images.
FOG demonstrated a track reconstruction efficiency close to 100% and a purity close to 95%. The track spatial resolution is 0.1μm and the angular resolution is 1mrad.

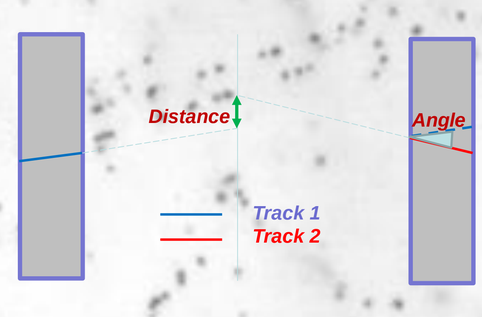
Silver grains in a single-layer emulsion image

3D track reconstructed by summing up 80 images taken in emulsion with 1μm vertical pitch

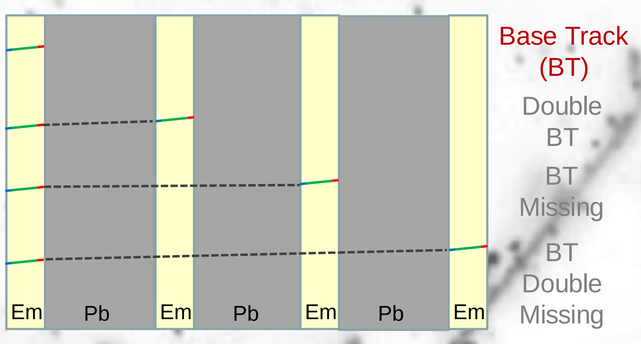


EM shower tracks reconstruction

Volumes in the ECC are finely scanned with ***FOG*** and tracks are reconstructed. Afterwards shower search is performed. The ***link*** between two tracks is established setting the threshold for two quantities: the ***angle*** between the two tracks and the ***distance*** between the two intersections of the tracks with the plane in the middle.



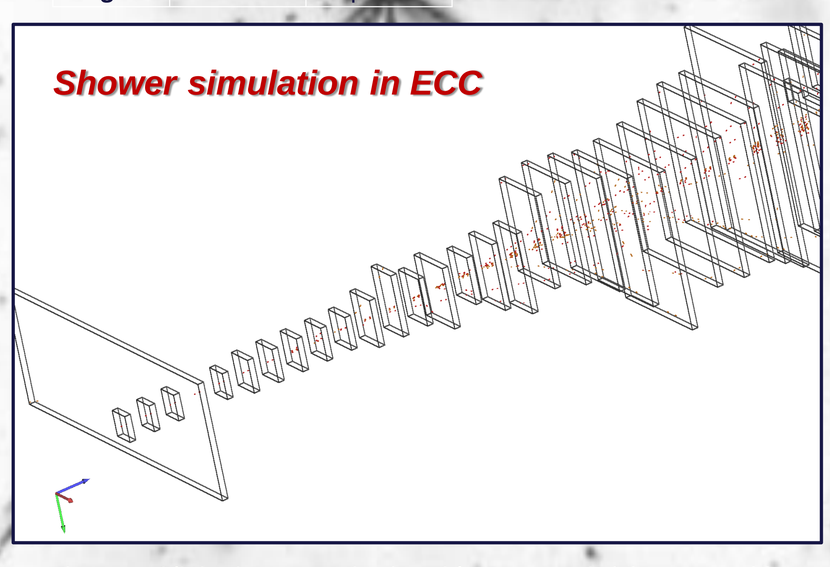
The set of *volume tracks* is further refined by linking the tracks of two adjacent emulsion plates. The link is performed also between two emulsion plates separated by one or two lead plates (efficiency recovery procedure).



Threshold values for linking parameters were defined by means of a ***Montecarlo*** study over a set of $\nu_\mu \rightarrow \nu_e$ events generated by ***Geant 4*** in the OPERA EMUREC standard framework. Three sets of thresholds were applied and compared :

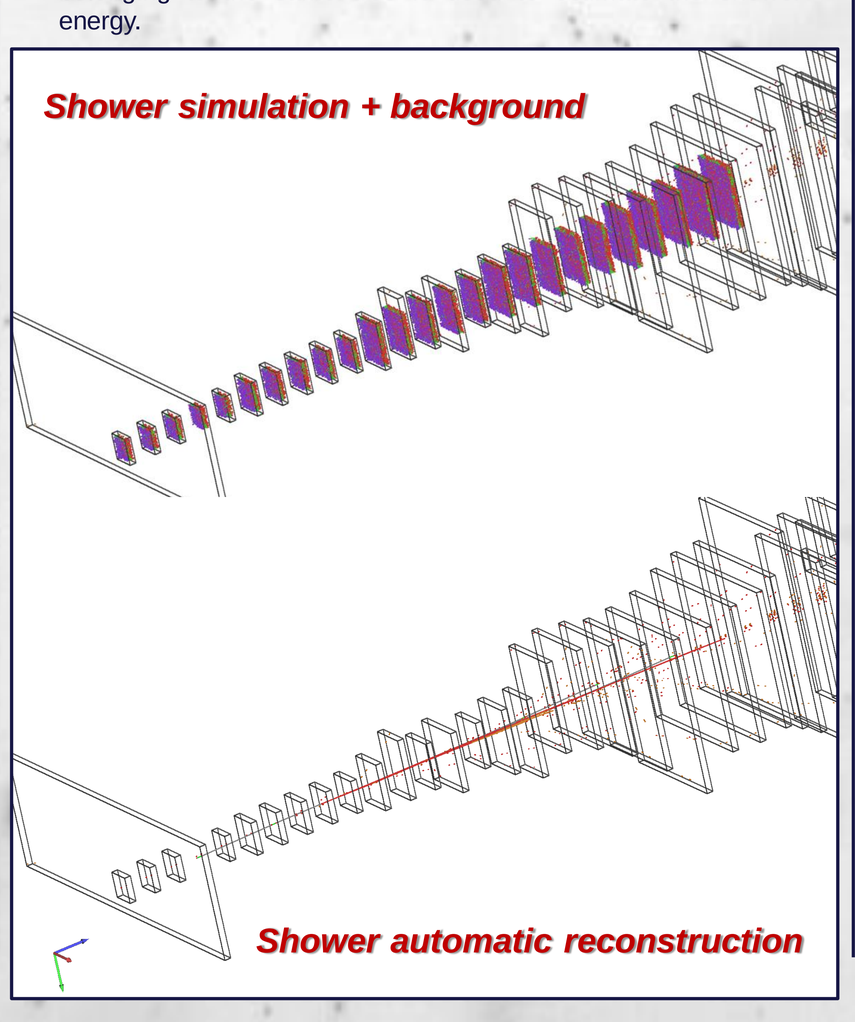
Small	0.040 rad	40 μm
Medium	0.050 rad	50 μm
Large	0.060 rad	60 μm

Shower simulation in ECC



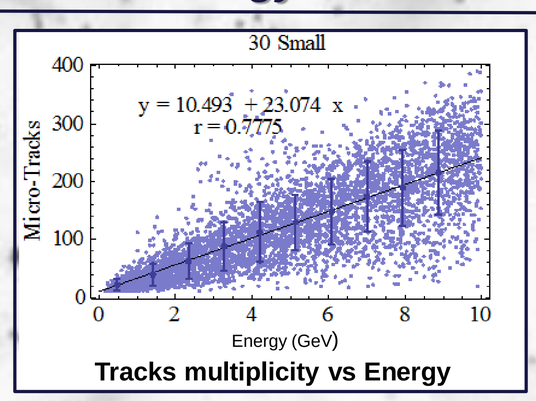
The set of linked Basetracks (Double Basetracks) is spanned by an iterative process which collects all the basetracks which share at least one link, in a tree. The multiplicity of microtracks belonging to the same tree is used to estimate the shower energy.

Shower simulation + background

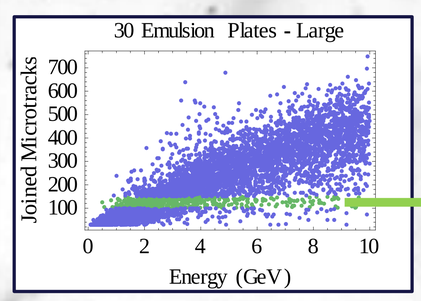


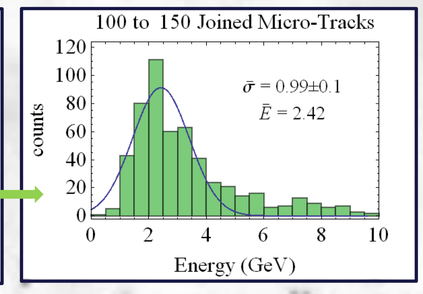
Shower automatic reconstruction

Shower energy evaluation

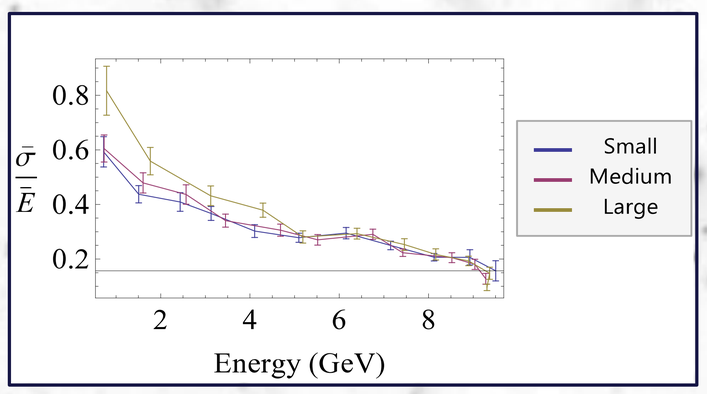


Tracks multiplicity vs Energy



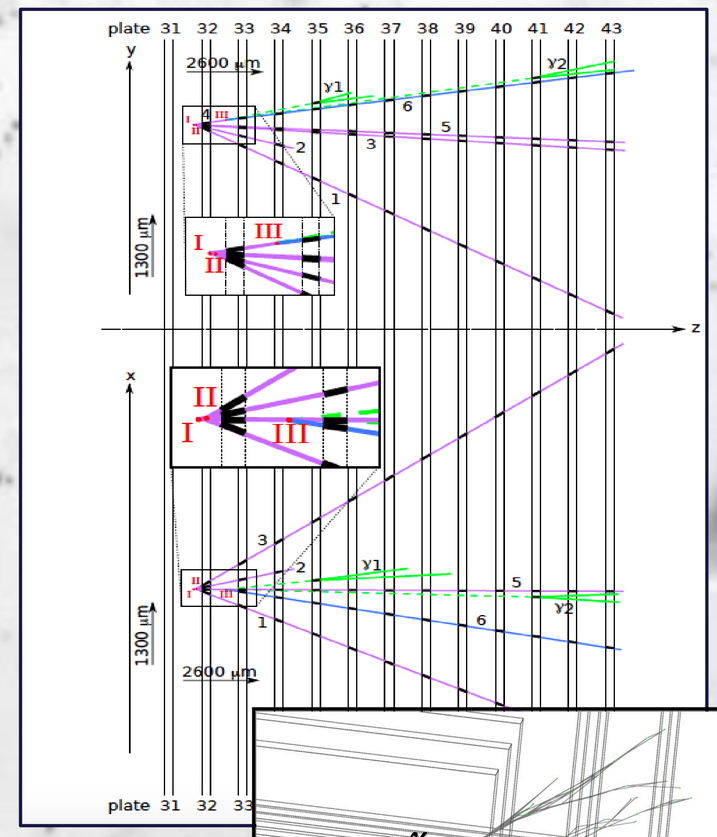


Selecting an in interval in the multiplicity we can have an estimation of the energy



Conclusions

- ✓ This is **a completely new procedure** based on images acquired with 1μm pitch tomography. This allows enhanced 3D accuracy in the reconstruction of tracks
- ✓ This procedure showed stability with respect of background tracks density and has an **efficiency of 98%** (in realistic background conditions) for showers with energy greater than 1GeV
- ✓ **This algorithm was used to evaluate shower energies in an interesting event with double vertex topology detected by OPERA [3]**
- ✓ Shower energy evaluation **improves the ability to study Tau lepton decay in the electronic channel**



γ_1 (7.2 ± 1.7) GeV:
γ_2 (5.3 ± 2.2) GeV

References

1. ***PRL*** 115 (2015) 121802
2. ***NIM*** *A556 (2006) 80-86*
3. ***EPS-HEP*** 2017 "More results from OPERA experiment"