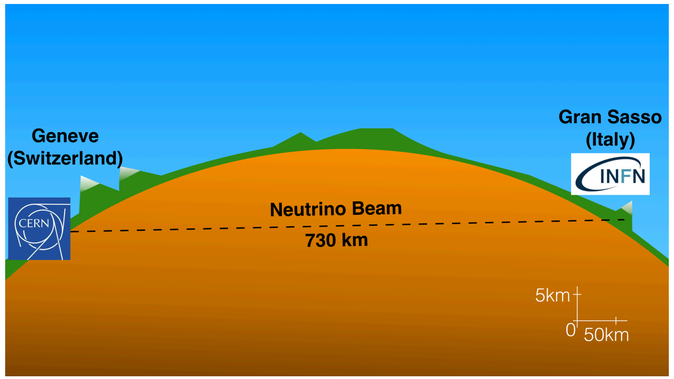
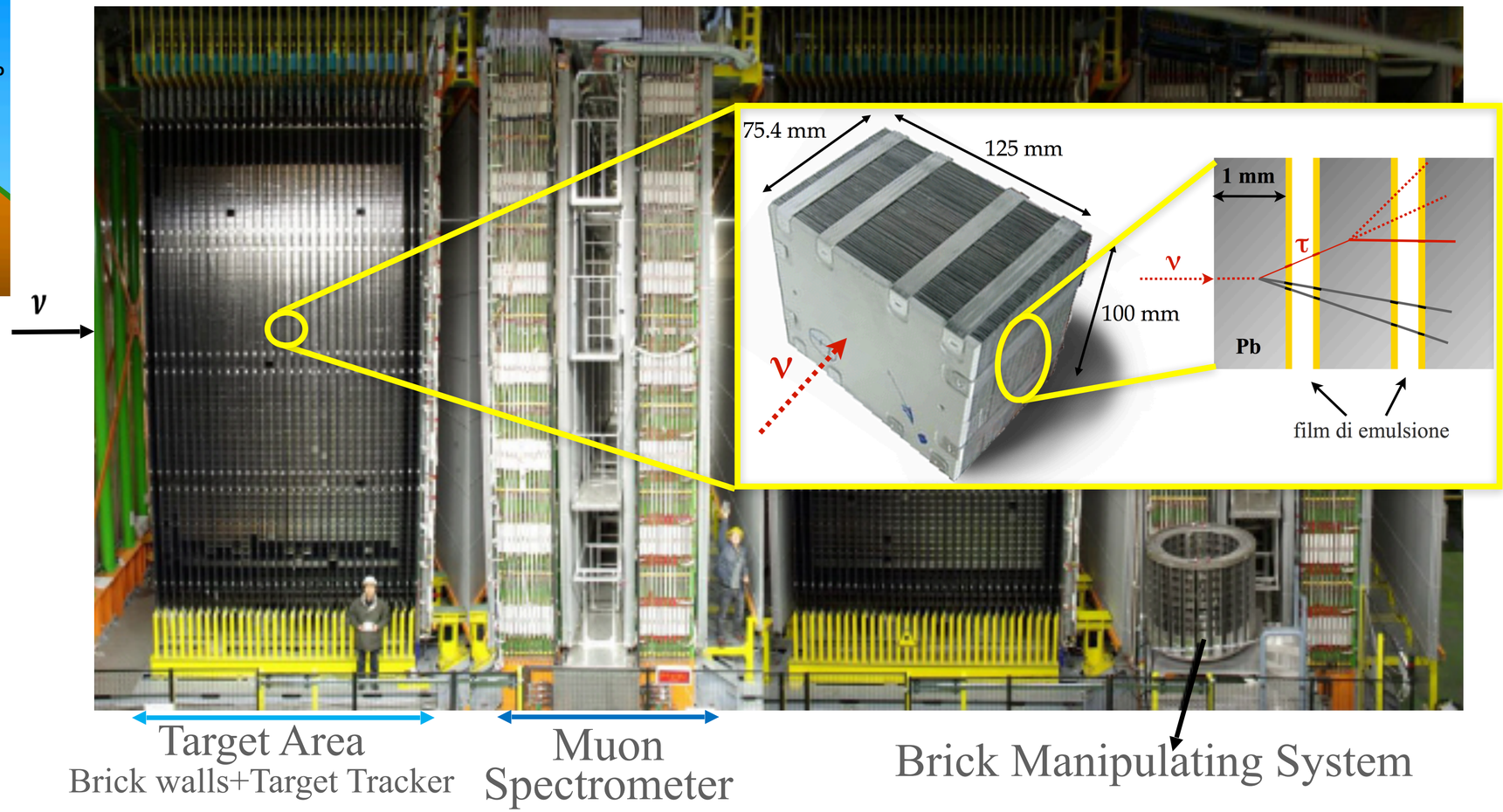
The OPERA experiment

The OPERA experiment (Oscillation Project with Emulsion tRacking Apparatus) designed to directly observe, for the first time in APPEARANCE MODE, the $\nu_\mu \rightarrow \nu_\tau$ oscillation in a pure ν_μ beam

Video of the lecturer



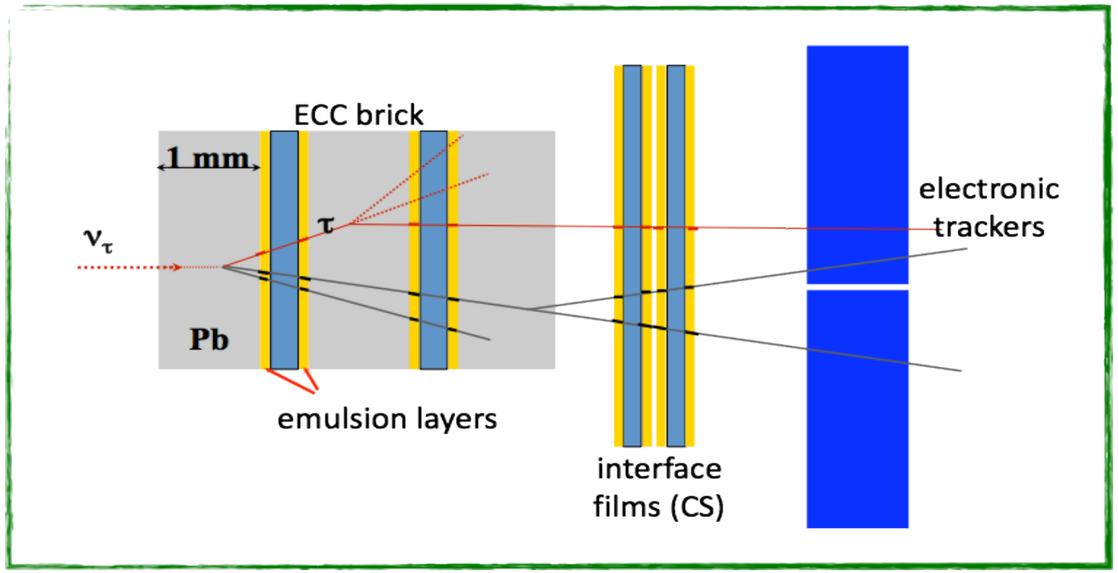
- High density and 1.2 kton target mass for statistics
- Underground location: Gran Sasso Laboratory (10^6 reduction of cosmic ray flux)



The OPERA experiment

The largest ever emulsion detector (110000 m^2 of emulsion films)

Video of the lecturer

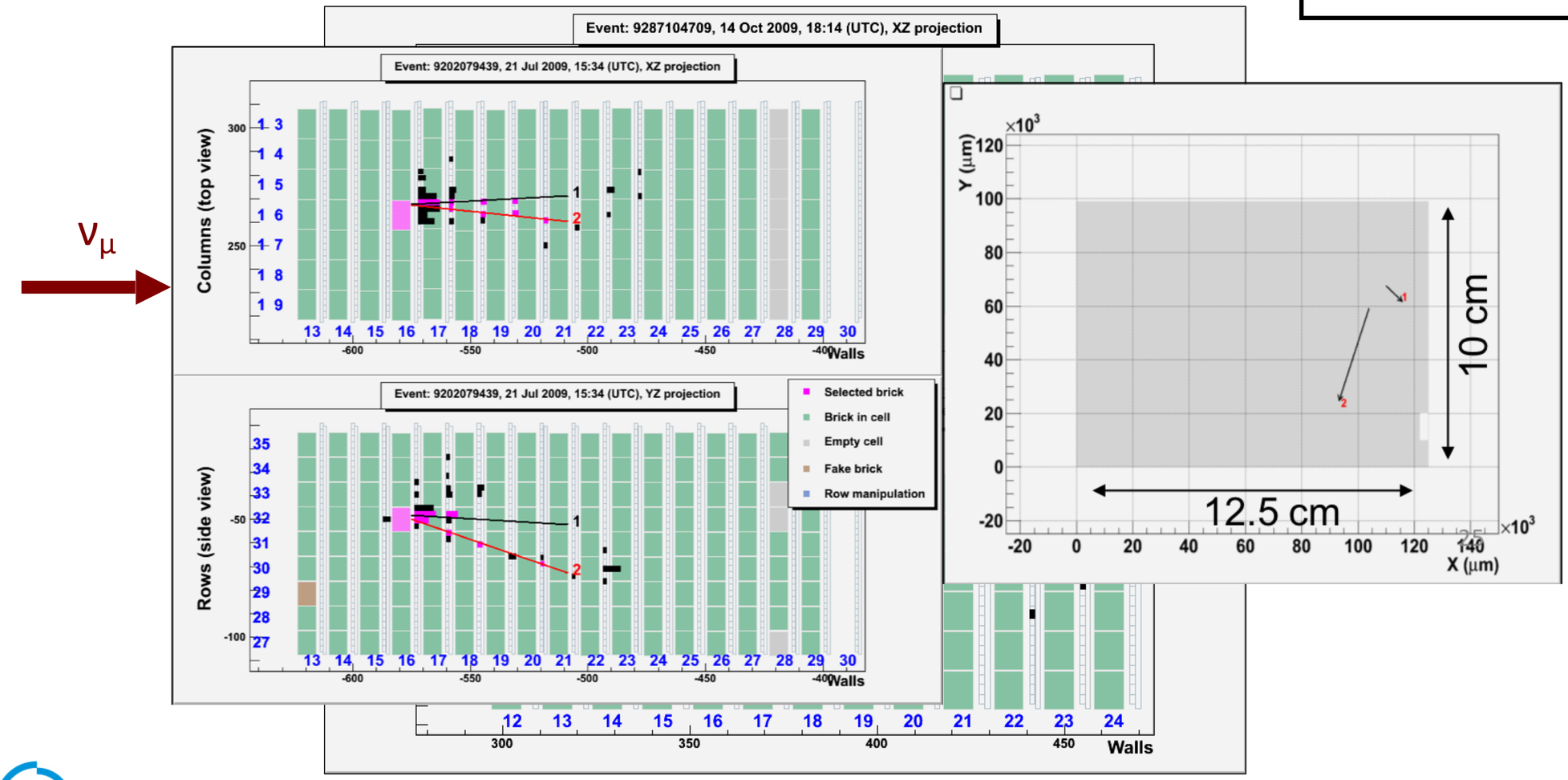


- Small neutrino cross-section and beam divergence: massive active target (~ 1.2 kton target with 30 ton emulsions)
- Detect τ-lepton production and decay: micrometric space resolution
- Electronic detectors to provide the“time stamp”, preselect the interaction brick and reconstruct μ charge/ momentum

Interface emulsion films

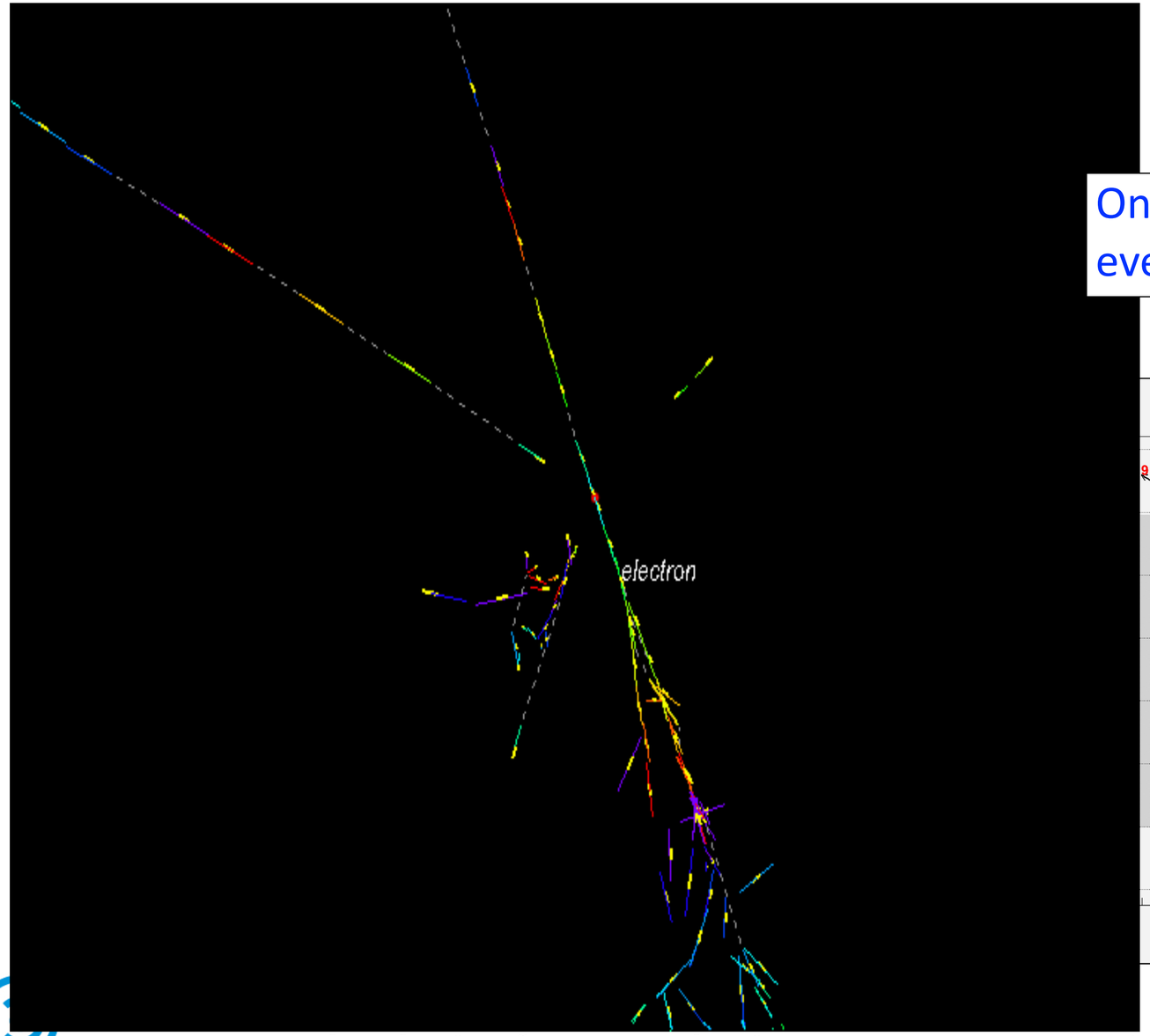
Video of the lecturer

High signal/noise ratio for event trigger and scanning time reduction

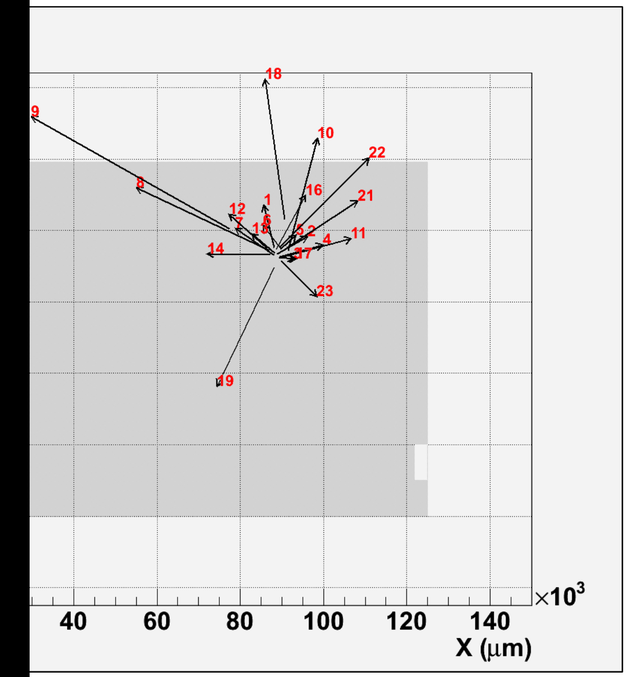


Interface emulsion films

Video of the lecturer



One of the electron neutrino events reconstructed

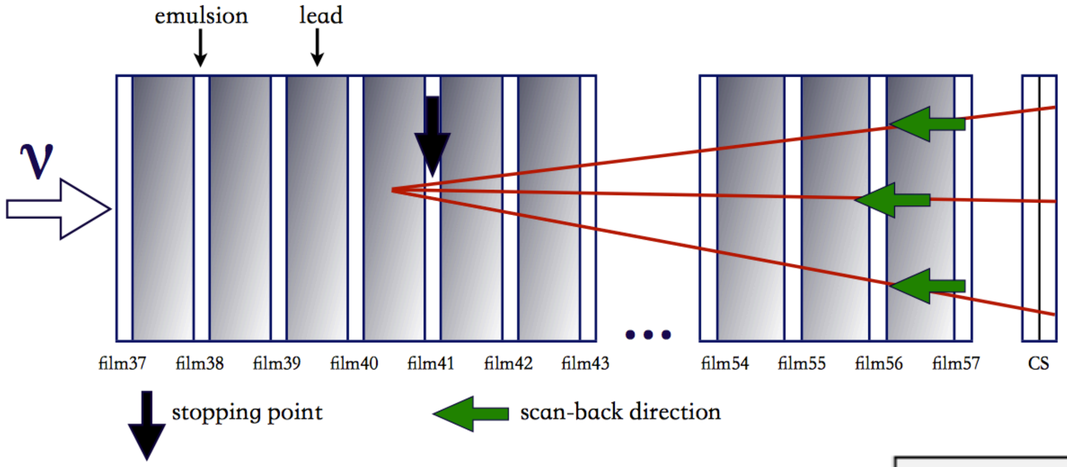


Track follow-up and vertex finding

Video of the lecturer

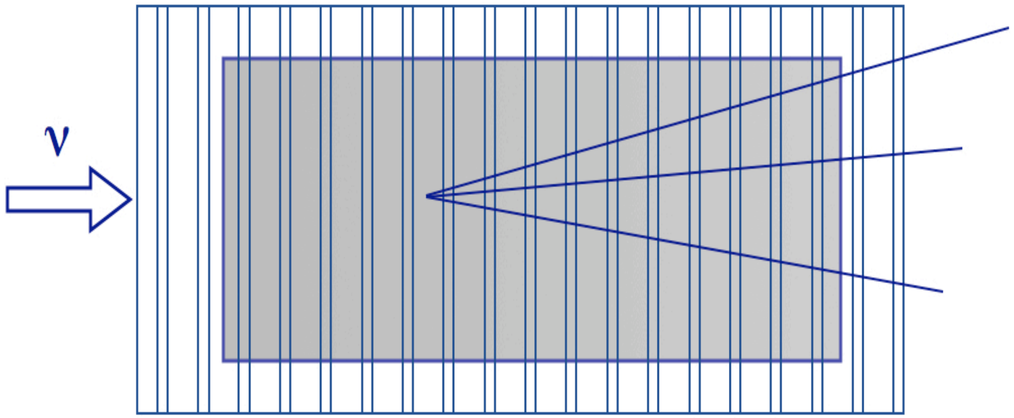
Track follow-up film by film:

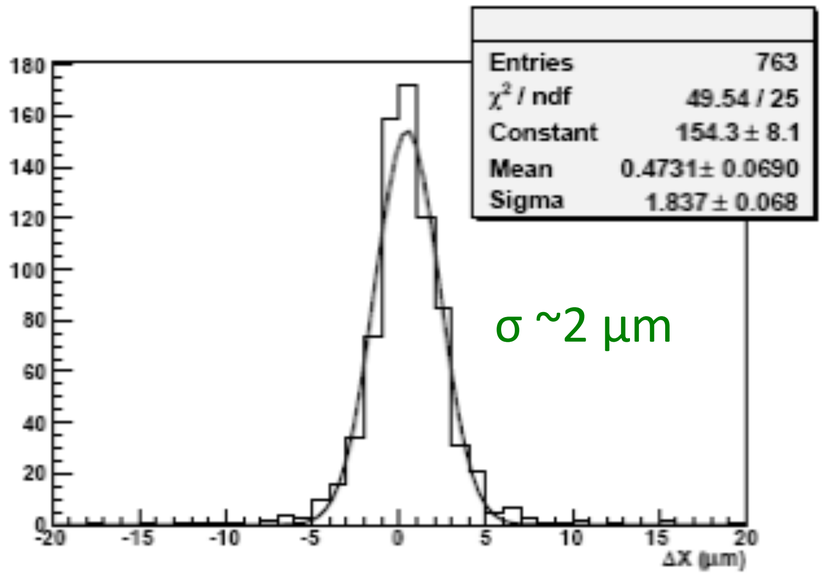
- Brick exposure at the surface laboratory to cosmic-rays for alignment
- Definition of the stopping point



Volume scan:

- ~2 cm^3 around the stopping point



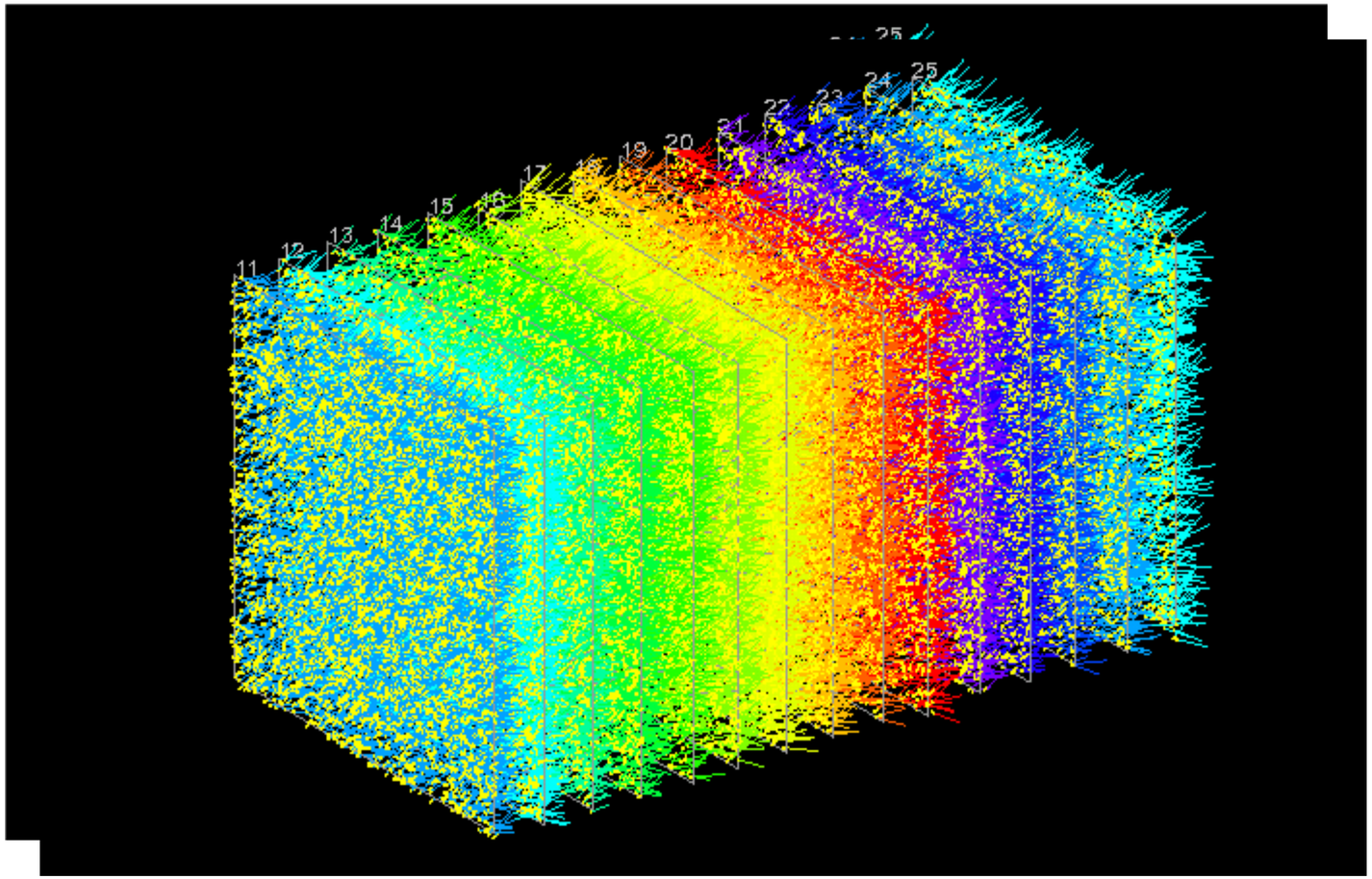


Location of neutrino interactions

Emulsions give 3D vector data, with micrometric precision

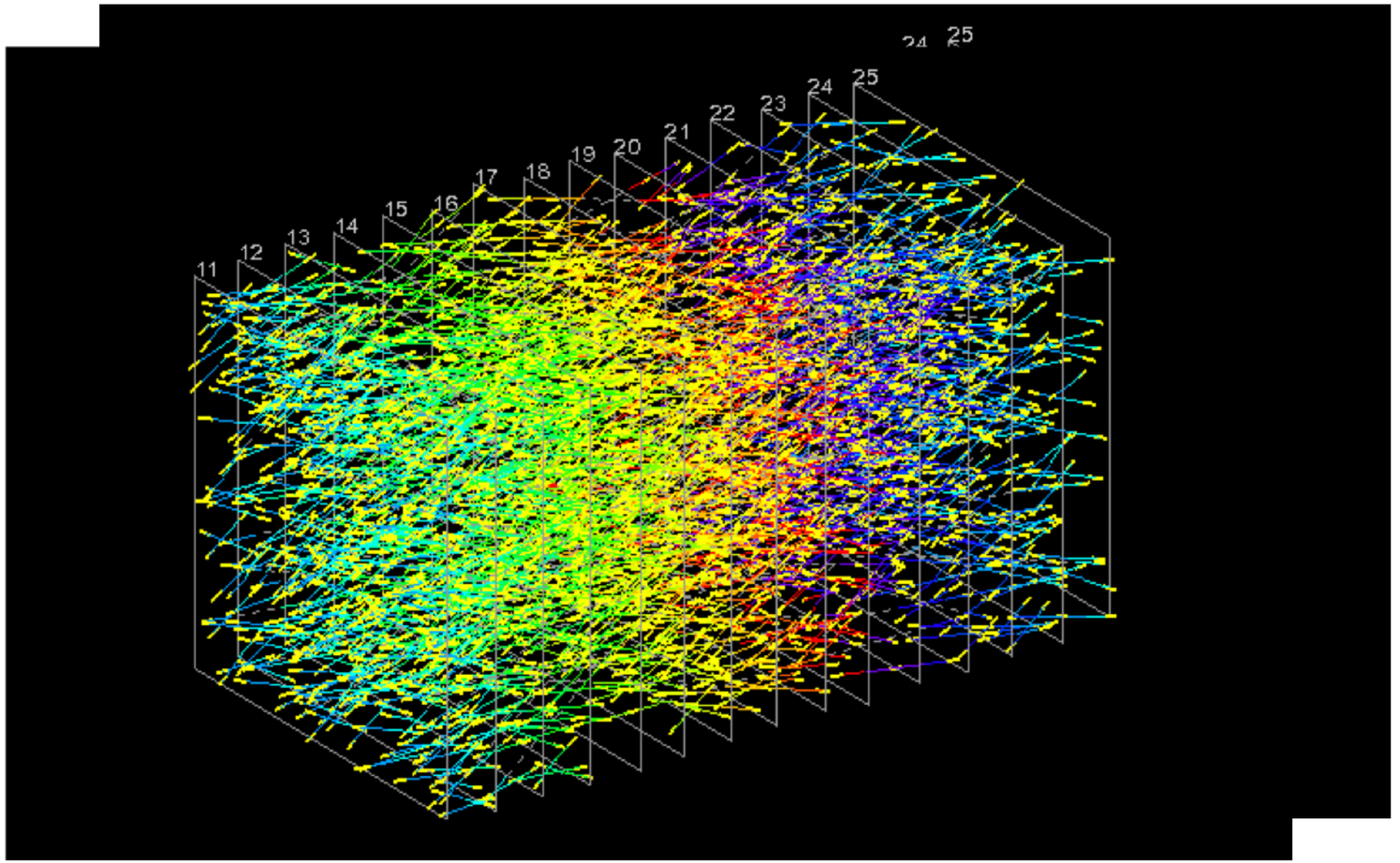
The frames correspond to the scanning area. Yellow short lines → measured tracks. Other colored → interpolation or extrapolation.

Video of the lecturer



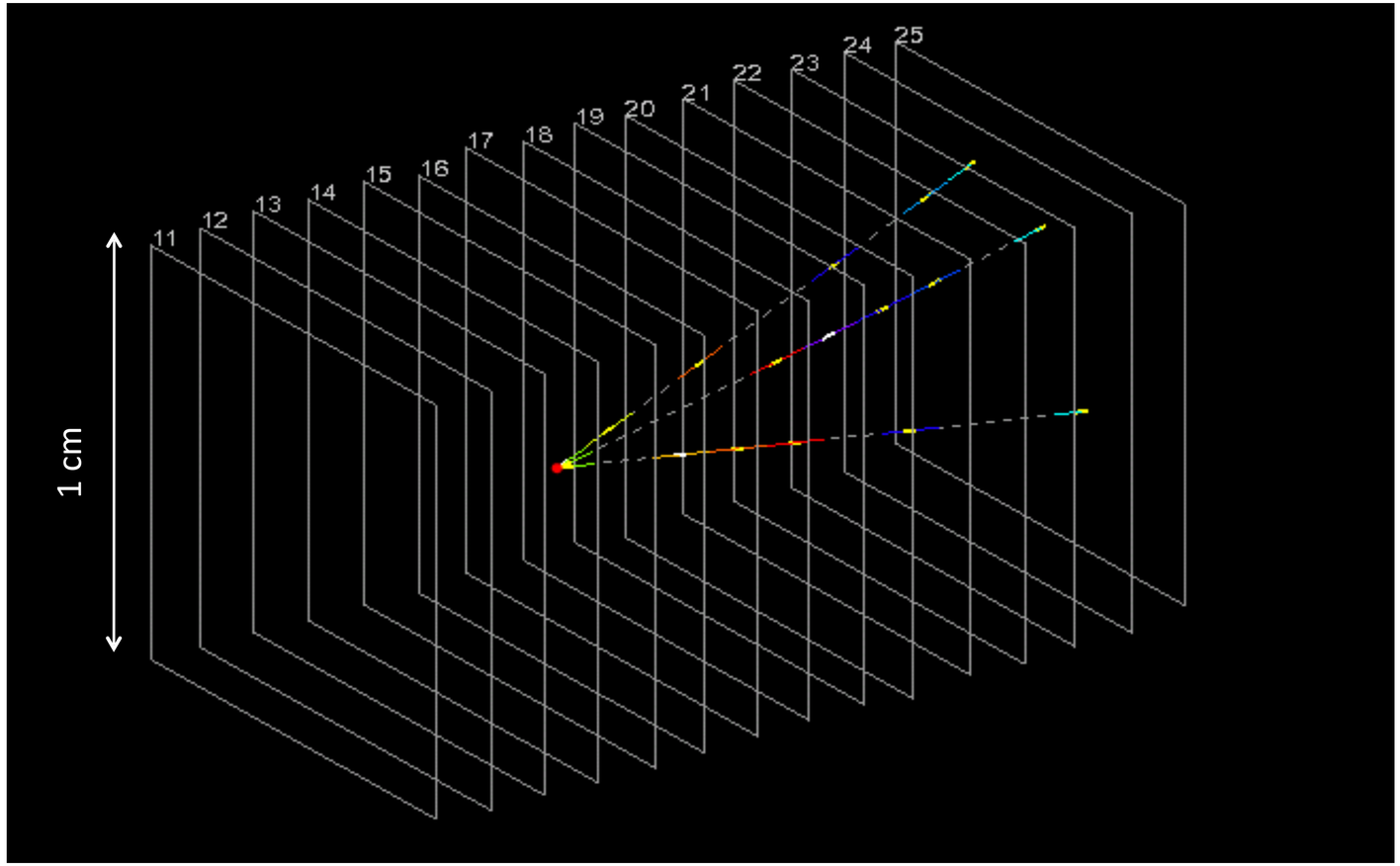
Location of neutrino interactions

Video of the lecturer

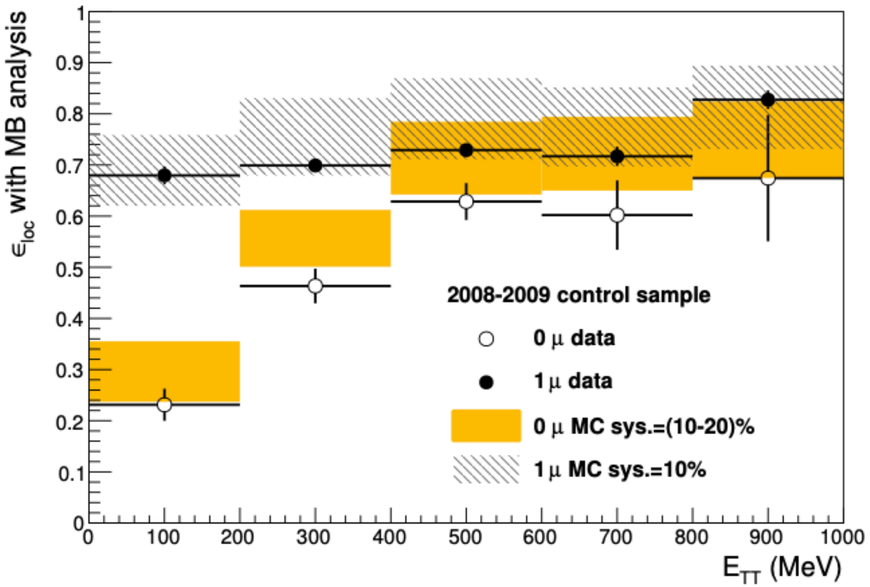


Location of neutrino interactions

Video of the lecturer



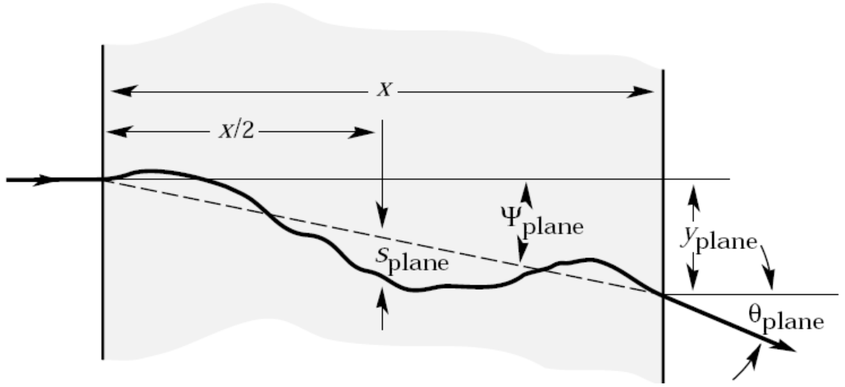
Event location efficiency versus energy

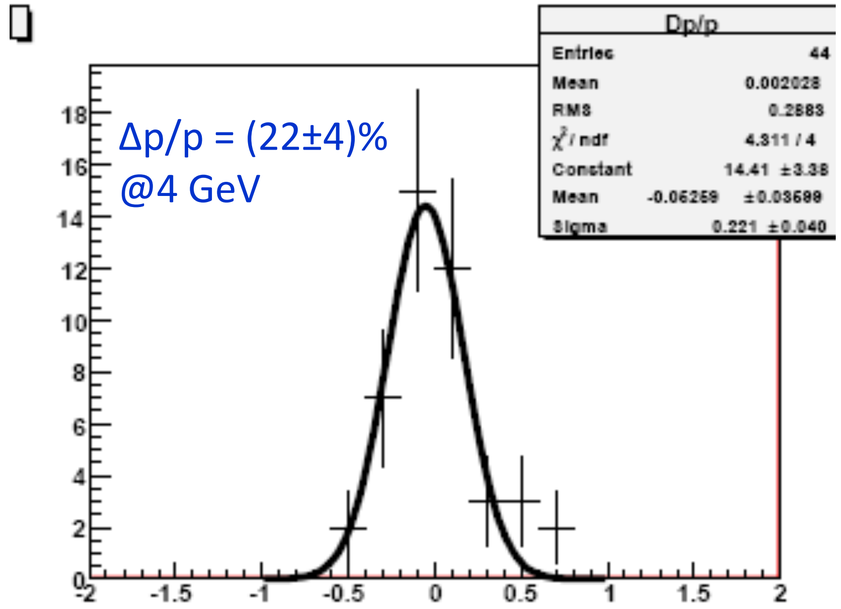


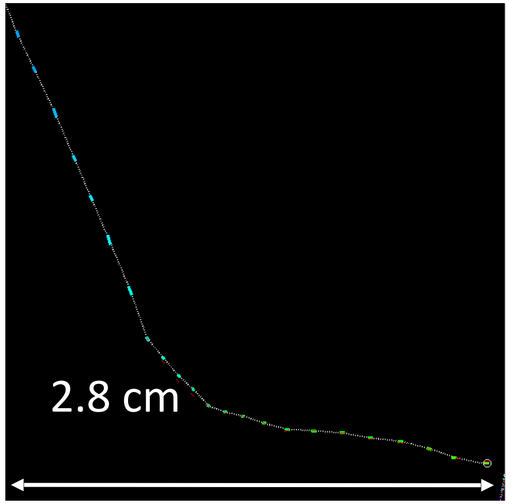
JHEP 11 (2013) 036

Momentum measurement by the multiple Coulomb Scattering

Video of the lecturer



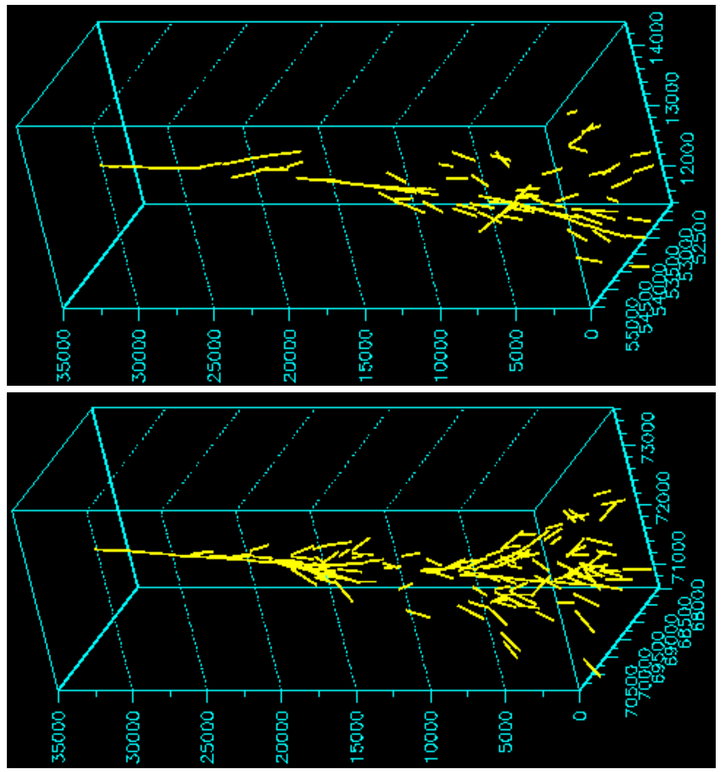


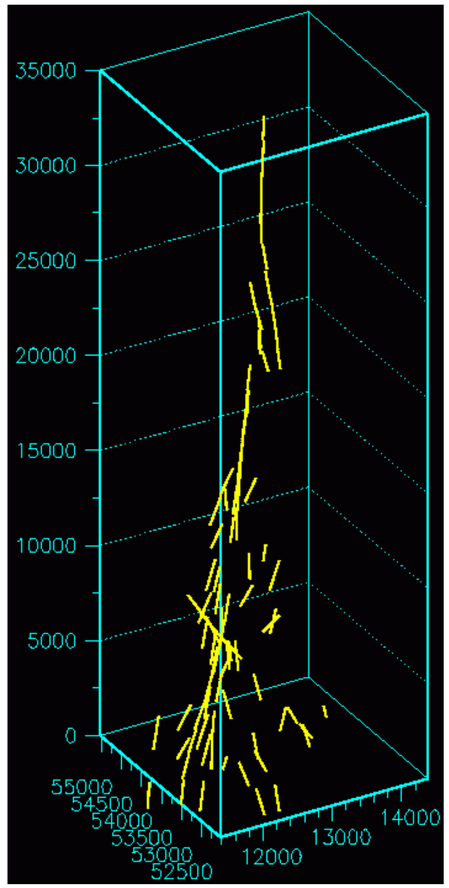


$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\left[1 + 0.038 \ln(x/X_0)\right]$$

High sampling calorimeter with >5 active layers per X_0

Video of the lecturer





5 X_0

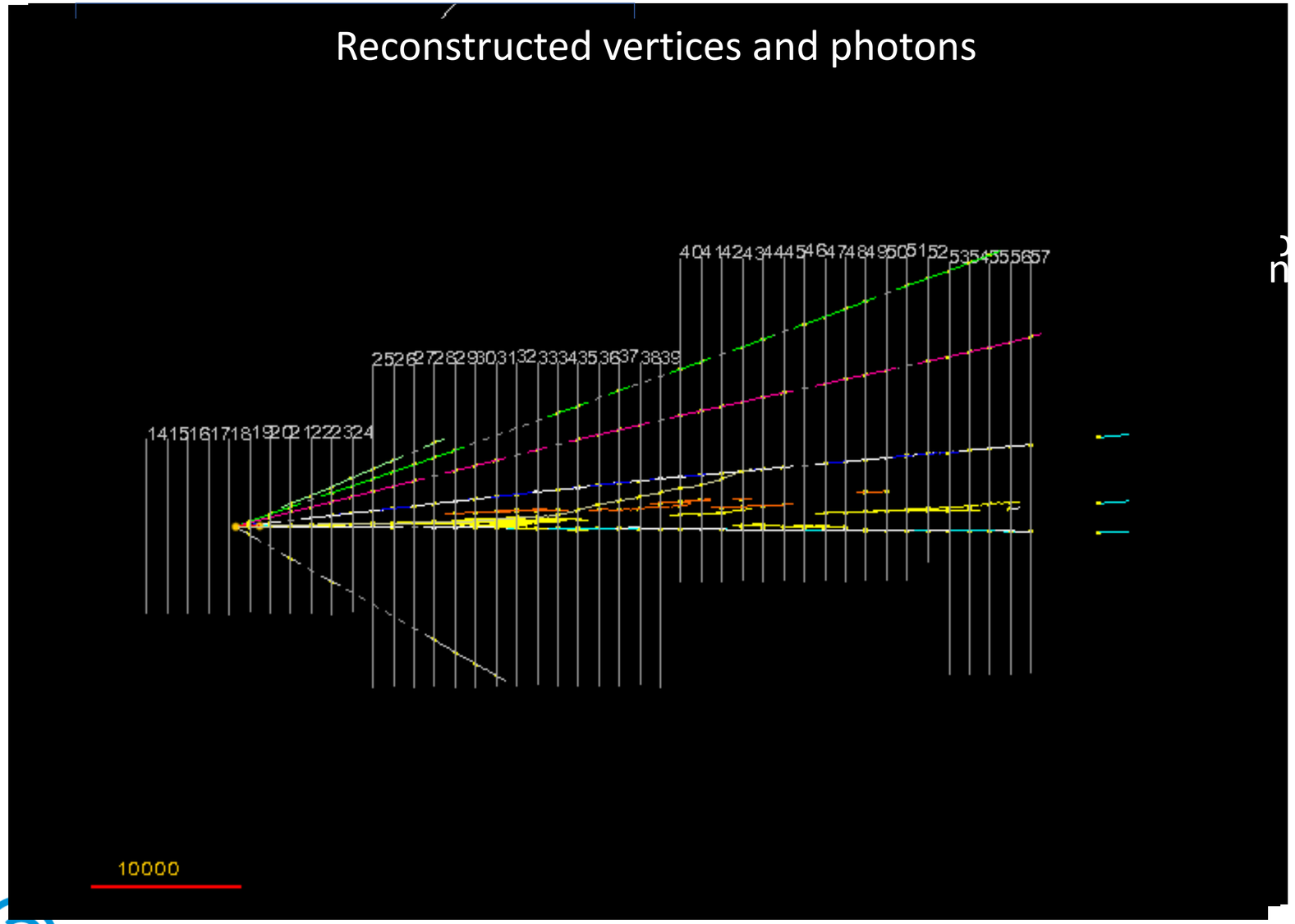
$$\frac{\Delta E}{E} \sim \frac{0.2}{\sqrt{E}}$$

depending on the X^0 and electron threshold

Energy measurement with a calorimetric approach

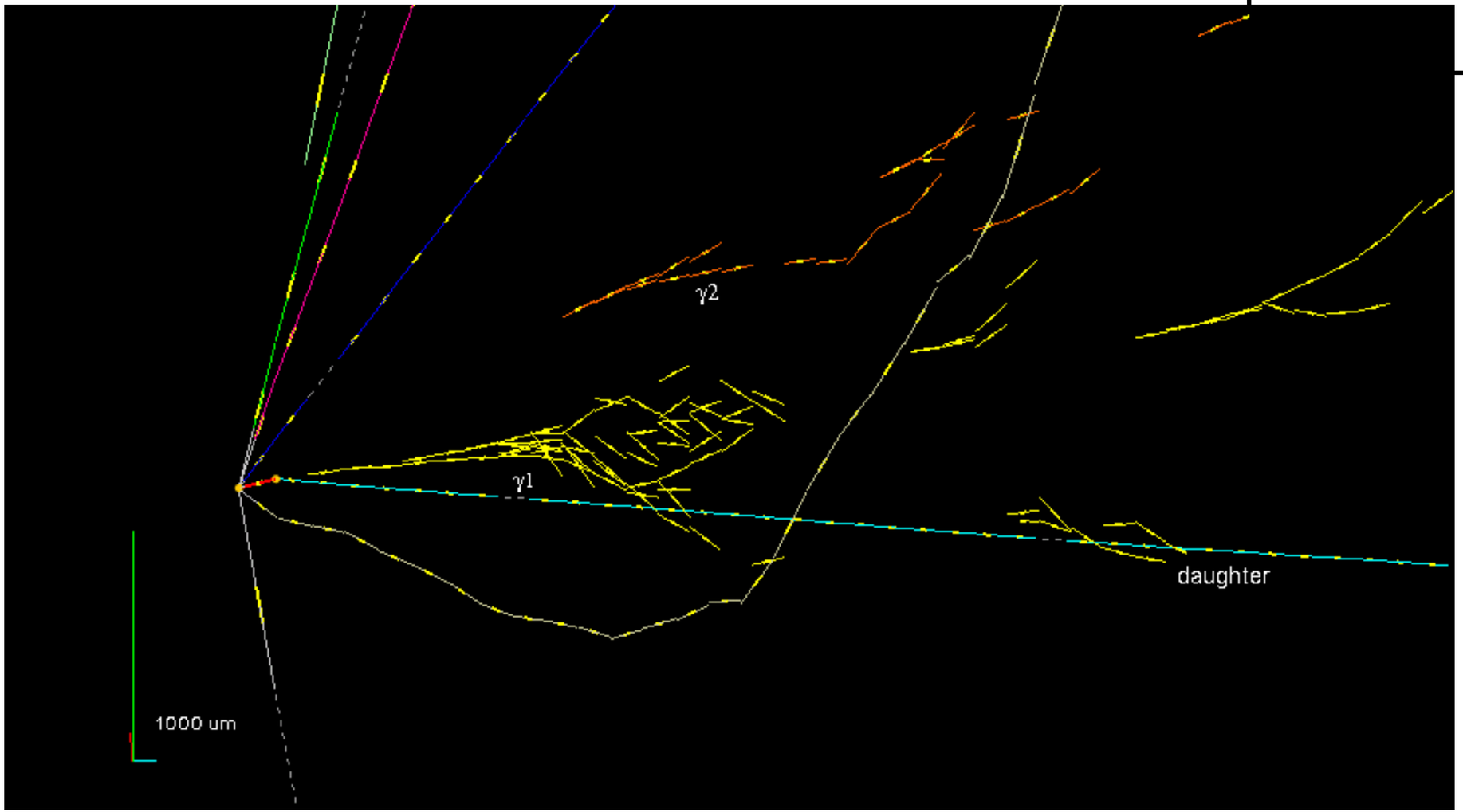
The first tau neutrino candidate

Video of the lecturer



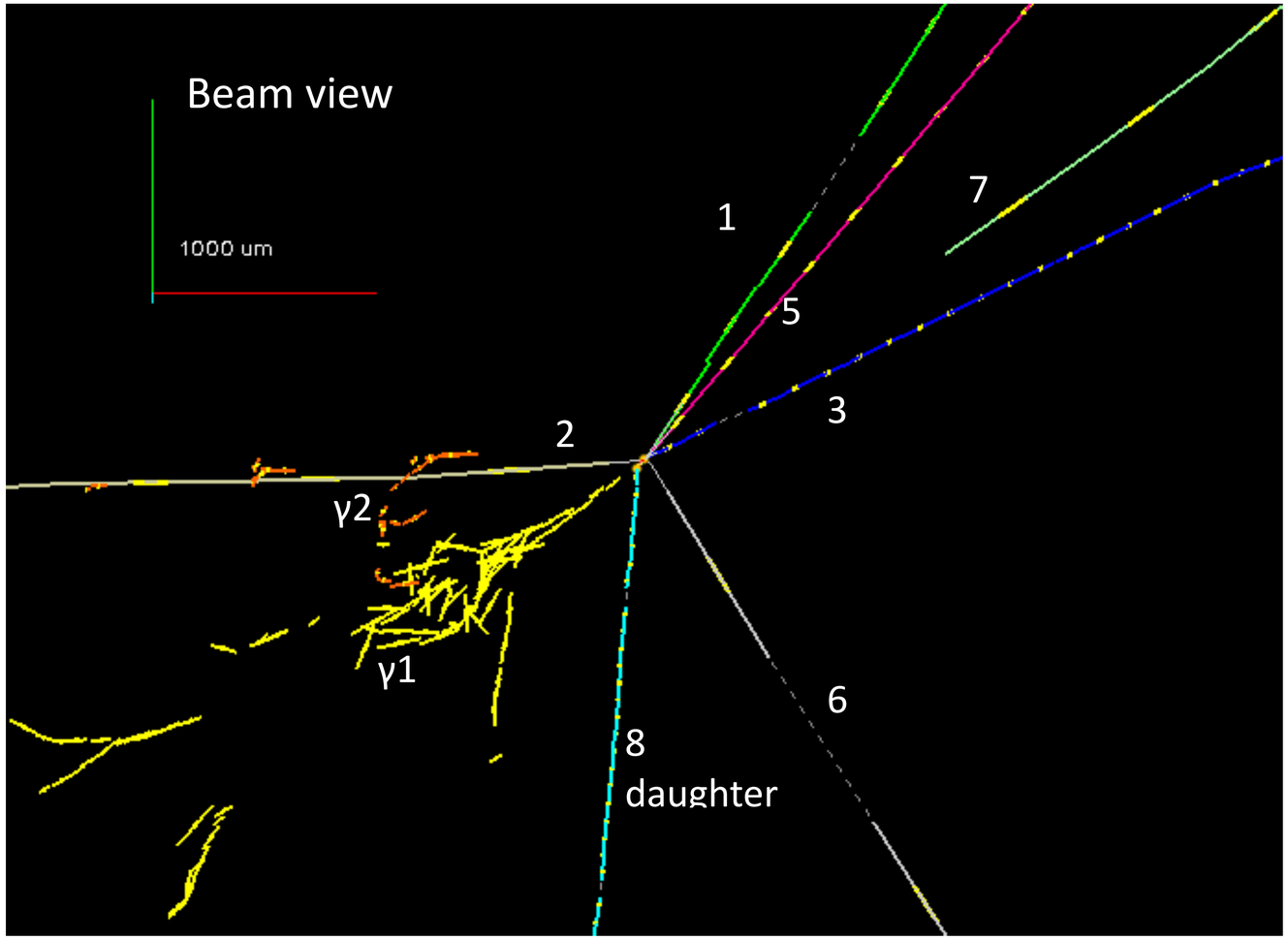
The first tau neutrino candidate

Video of the lecturer



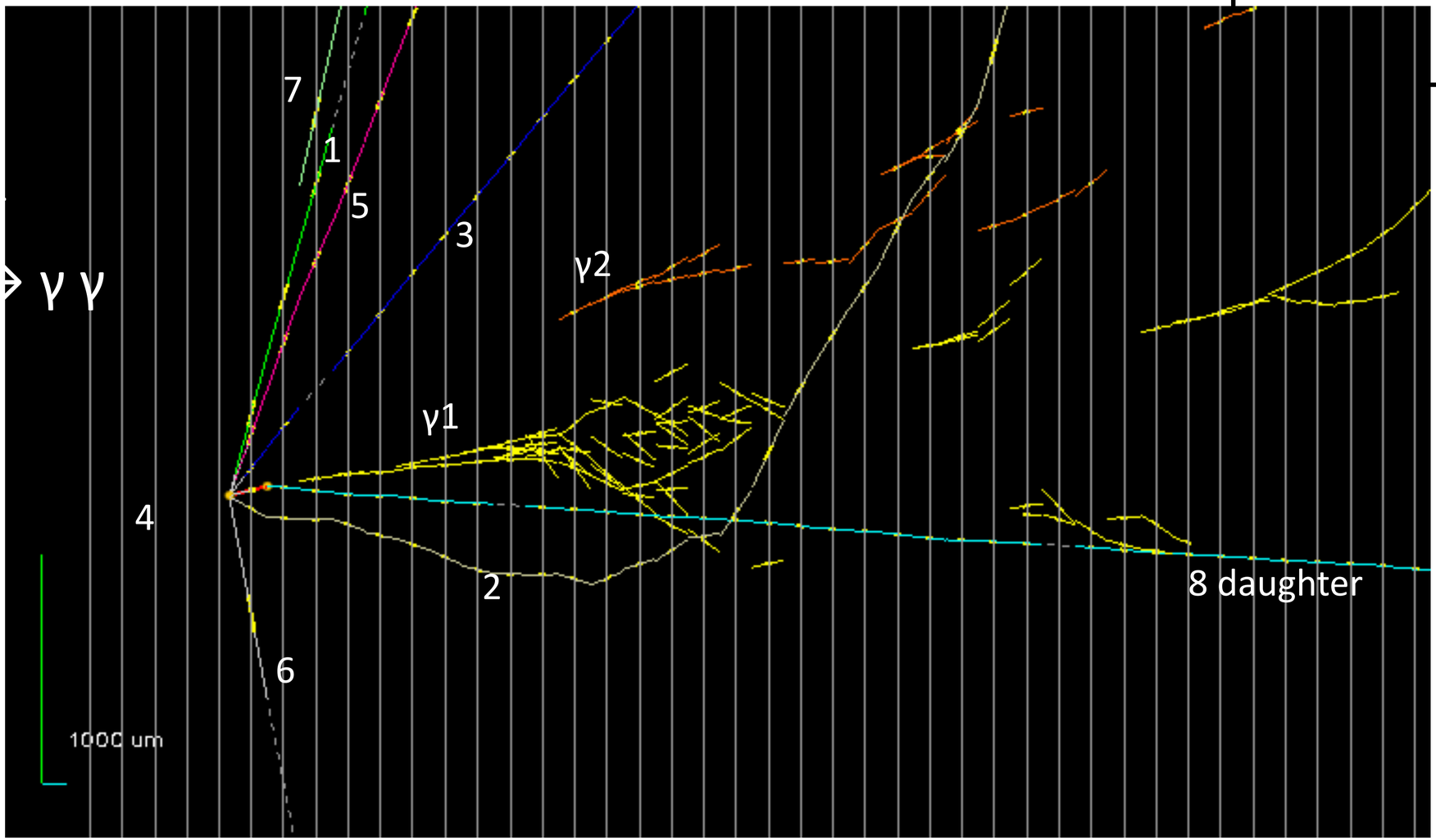
The first tau neutrino candidate

Video of the lecturer



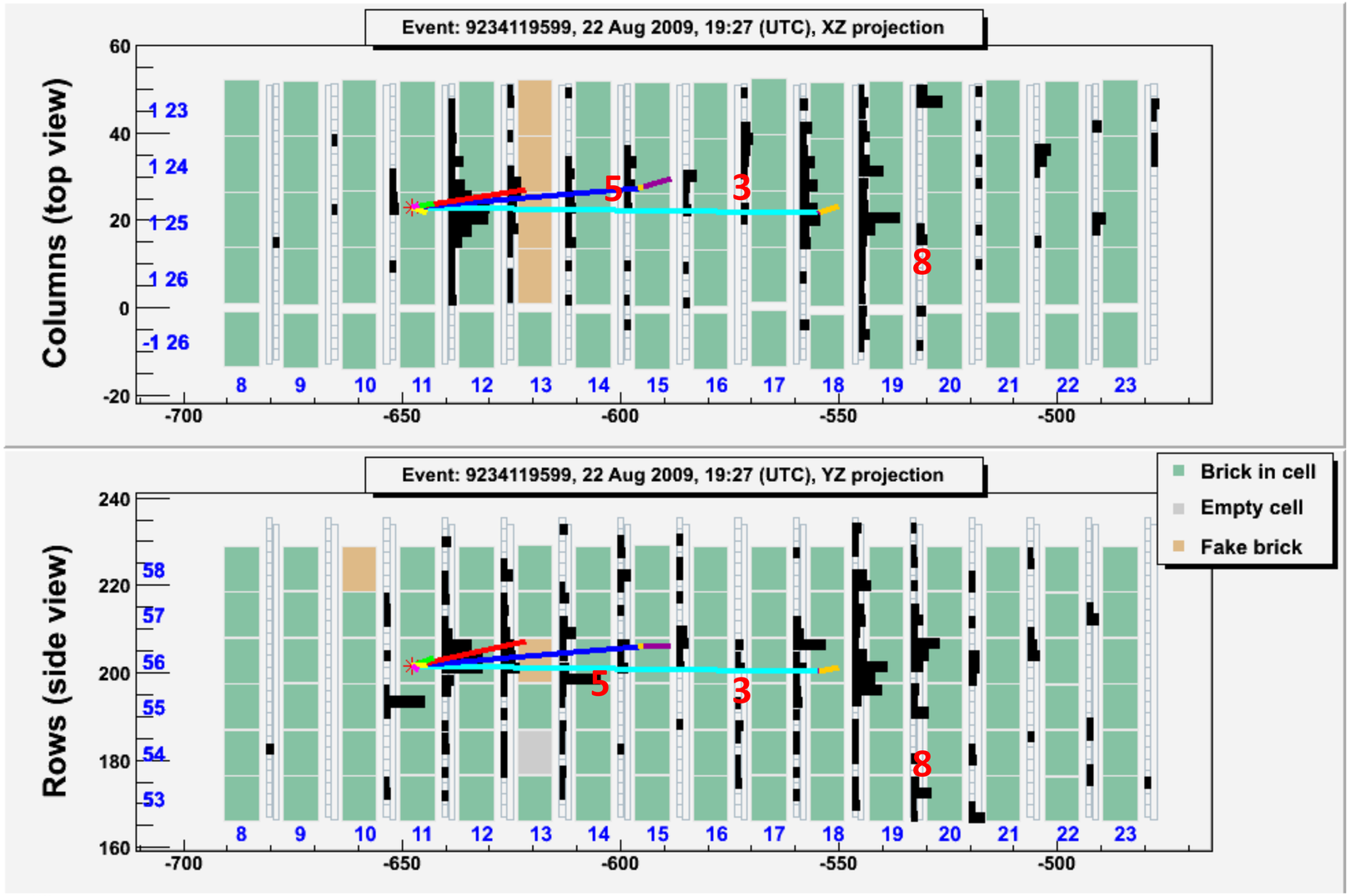
The first tau neutrino candidate

Video of the lecturer



Particle identification by following the track along its path

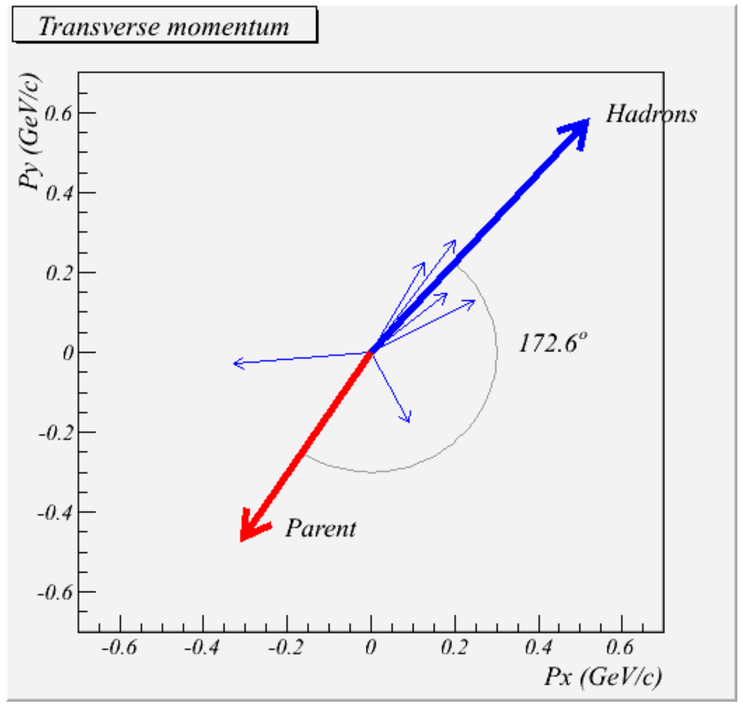
Assess the muon/hadron nature of the particle



Video of the lecturer

Kinematical variables measured in emulsion

Video of the lecturer



Variable	Measured value
kink (mrad)	**41 ± 2**
decay length (μm)	**1335 ± 35**
P daughter (GeV/c)	**$12\ ^{+6}_{-3}$**
Pt (MeV/c)	**$470\ ^{+230}_{-120}$**
missing Pt (MeV/c)	**$570\ ^{+320}_{-170}$**
φ (deg)	**173 ± 2**

OPERA final results

Video of the lecturer

PRL 115, 121802 (2015) PHYSICAL REVIEW LETTERS week ending 18 SEPTEMBER 2015

Discovery of τ Neutrino Appearance in the CNGS Neutrino Beam with the OPERA Experiment

PHYSICAL REVIEW LETTERS 120, 211801 (2018)

Editors' Suggestion Featured in Physics

Final Results of the OPERA Experiment on ν_τ Appearance in the CNGS Neutrino Beam

10 events observed, discovery with 6.1 sigma significance

First measurement of Δm^2 in appearance mode

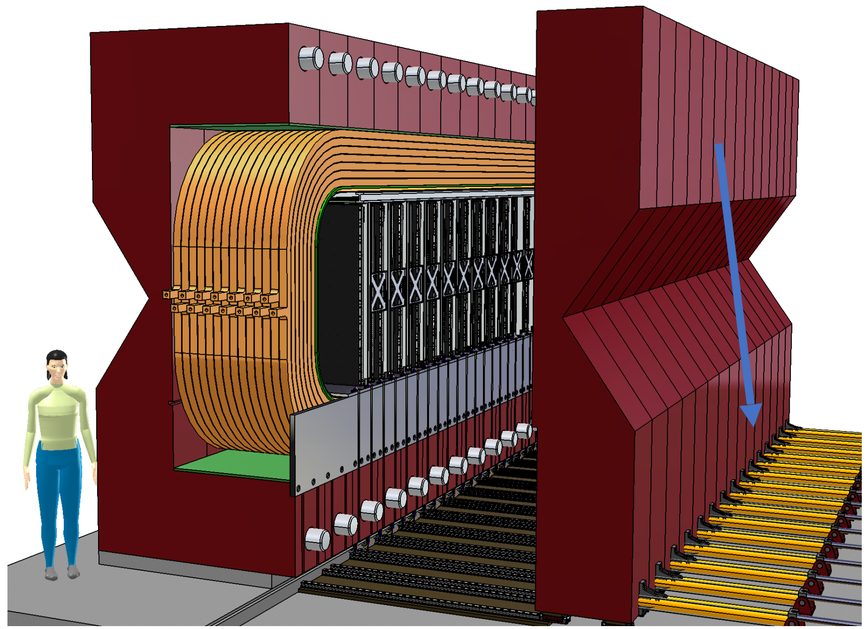
First cross-section measurement

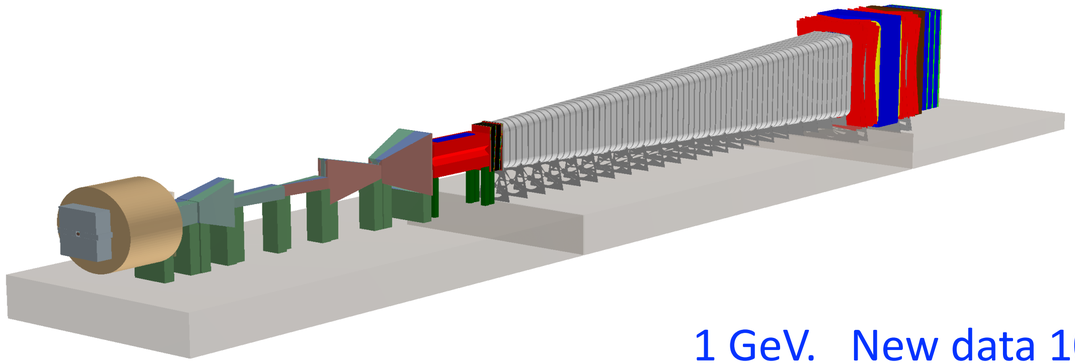
First direct observation of the leptonic number of ν_τ

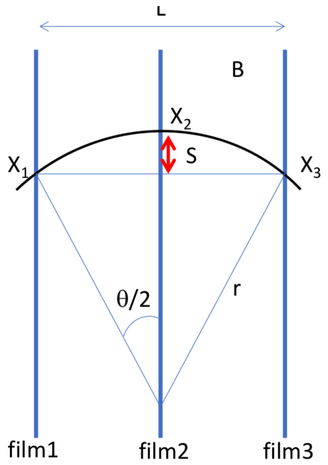
Neutrino detector in SHiP based on nuclear emulsions

Video of the lecturer

~7300 m² of films
placed in magnetic field
to be fully analysed







1 GeV. New data 10 GeV

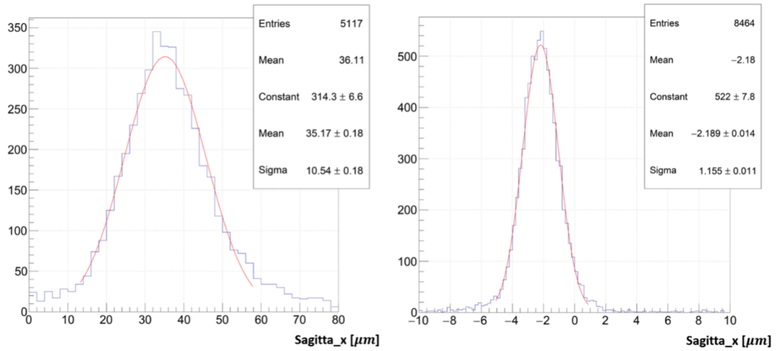


Figure 7: Measured sagitta along the x axis for 1 and 10 GeV/c pions.

NIM A592 (2008) 56-62

Compact Emulsion Spectrometer

QUIZ - 2

- Explain how to distinguish the 3 neutrino types and why a hybrid detector with an emulsion-based neutrino target can accomplish this task

- The OPERA experiment was using a hybrid technology, combining emulsion with electronic detectors. Electronic trackers provided particle trajectories with centimetre accuracy. What is the method used to connect those tracks to the corresponding ones reconstructed in the emulsion to finally achieve the micrometric resolution?