Oscillation appearance with an Emulsion tRacking Apparatus

Outline

- Neutrino oscillation
- OPERA experiment
- Detection of the tau neutrino
- OPERA detector

Neutrino oscillation

- Experimental indication of oscillation
  - Atmospheric Neutrinos: Super-Kamiokande, confirmed by accelerator neutrinos (K2K)
  - Solar Neutrinos: Homestake and successors, confirmed by reactor neutrinos (Kamland)
- Assume that:
  - There are two neutrinos (simpler)
  - The weak flavor eigenstates are not the same as the mass eigenstates

A classic quantum-mechanical two state system:

$$\begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \cos\Theta & \sin\Theta \\ -\sin\Theta & \cos\Theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

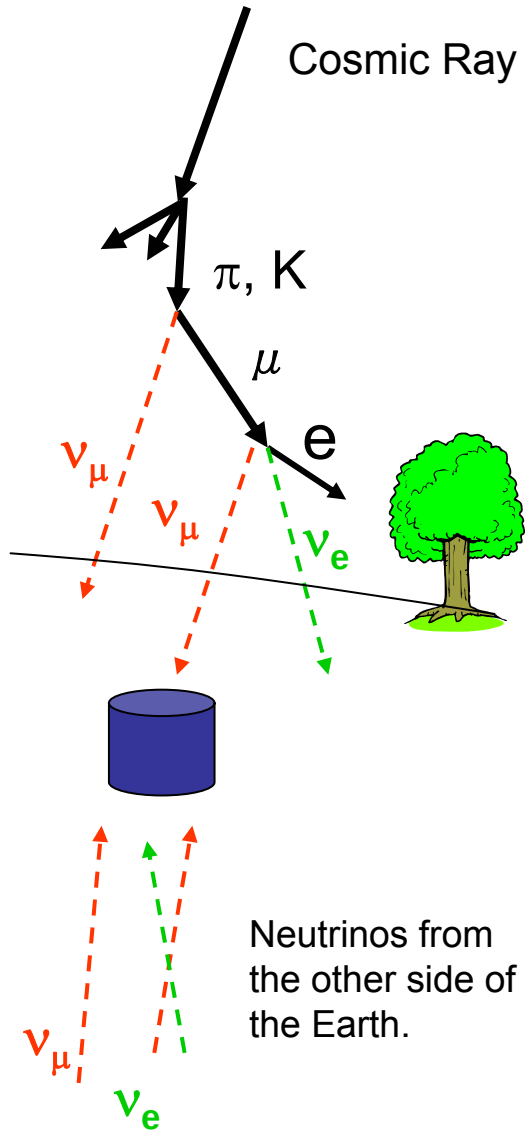
Neutrino oscillation

Solving and plugging in sensible units leads to the probability of finding tau-neutrinos if neutrino was created as an muon neutrino:

$$P\left(\nu_\mu \rightarrow \nu_\tau\right) = \sin^2 2\Theta \sin^2\left(1{,}27\Delta m^2 \frac{L[km]}{E[GeV]}\right)$$

Pedictions from Super-Kamiokande

- Evidence for oscillation in atmospheric neutrinos
  - Difference in the flux of up/down going neutrinos



Neutrino oscillation

- Observed L/E distribution constrain neutrino oscillation parameters:

$$1{,}5\cdot10^{-3} < \Delta m^2 < 3{,}4\cdot10^{-3} eV^2$$

$$\sin^2 2\Theta > 0{,}92$$

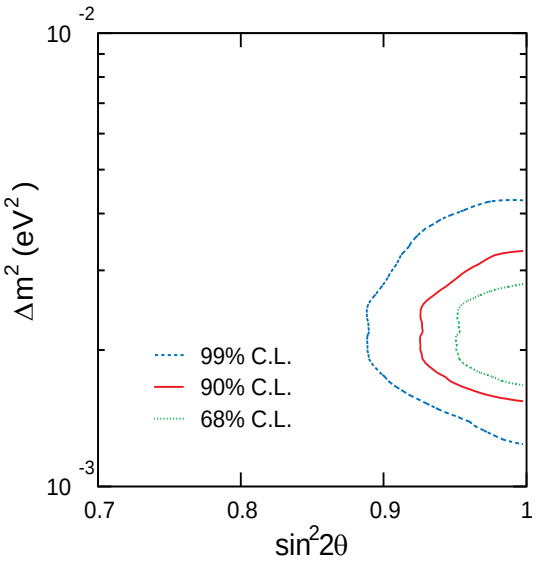
SK (25.01.05)

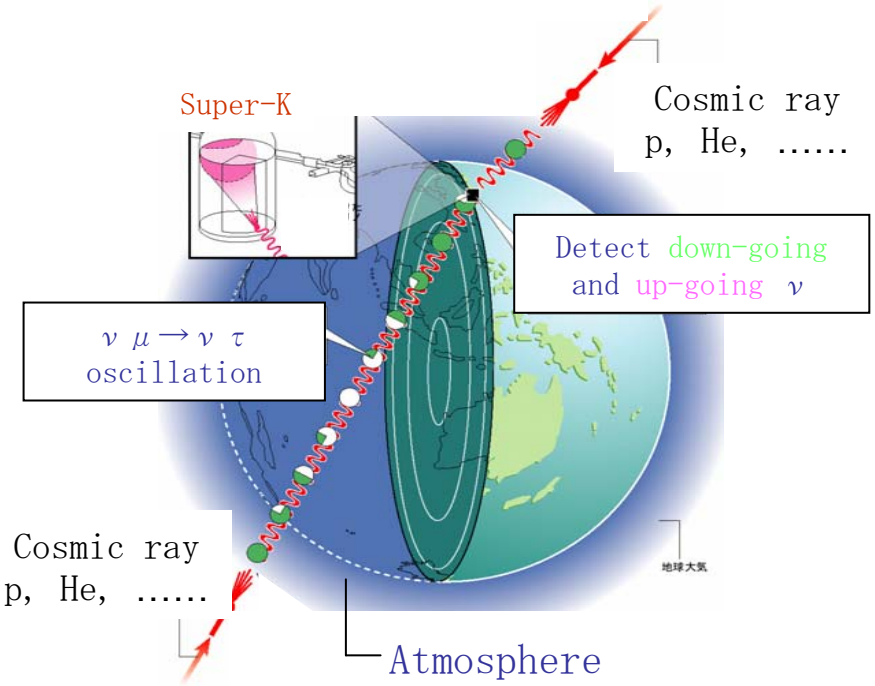
Best fit:

$$\Delta m^2 = 2{,}8\cdot10^{-3} eV^2$$

$$\sin^2 2\Theta > 1.0$$

K2K (11.09.04)





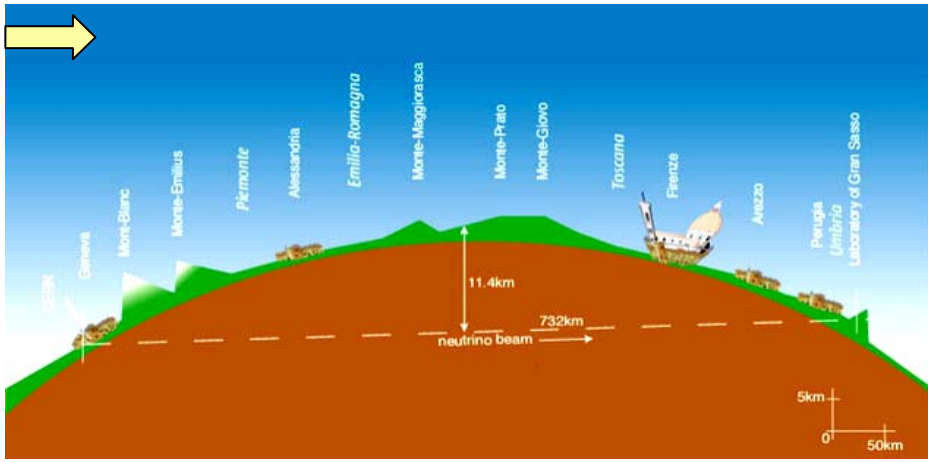
OPERA will search for tau neutrino appearance originating from $\nu_\mu \leftrightarrow \nu_\tau$ oscillation in the parameter region predicted form SK

The aim of OPERA

- Long baseline Experiment
- Detection of a tau neutrinos from oscillation of muon neutrinos: Appearance experiment
- Combined with other experiments more precise measurement of the mixing angle Θ_{23} and the mass difference Δm_{23}, Θ_{13} (limits)

CNGS Project

- CERN SPS provides neutrino beam to Gran Sasso



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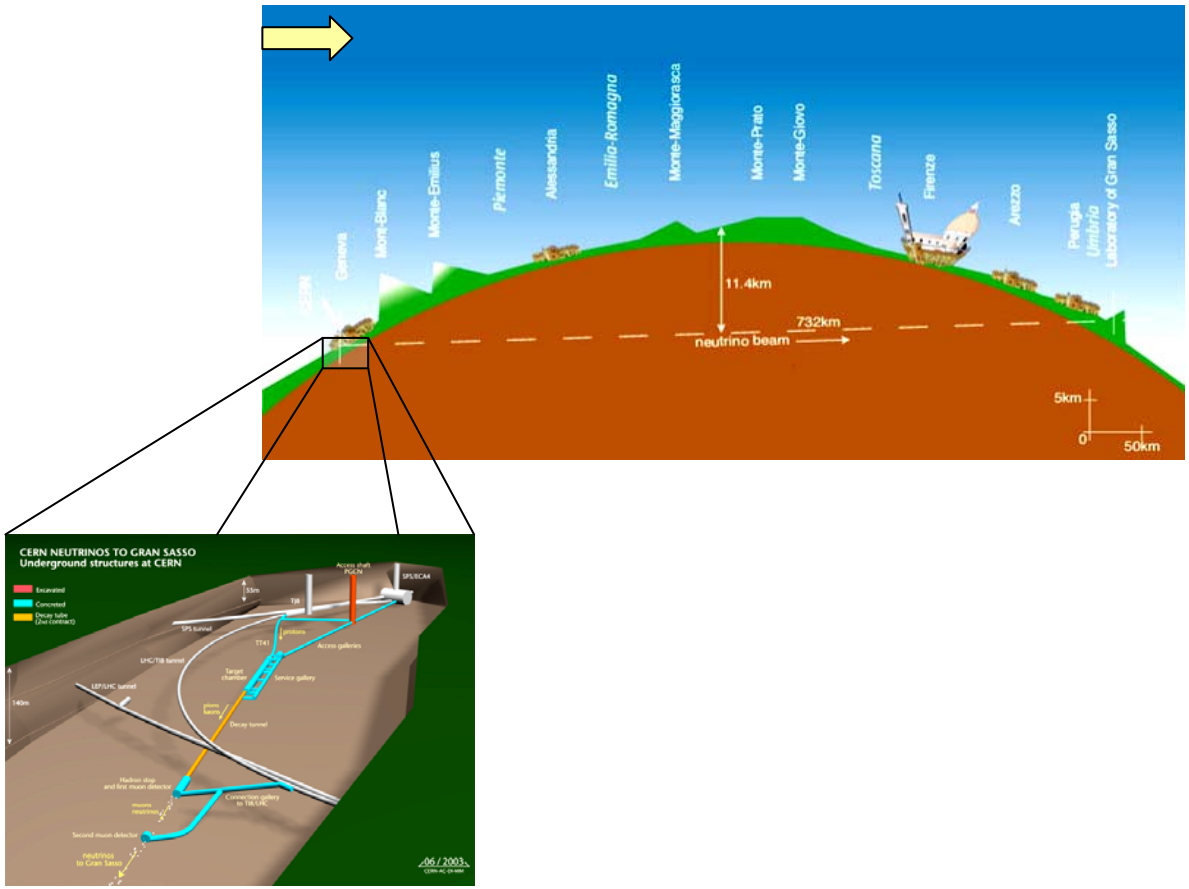

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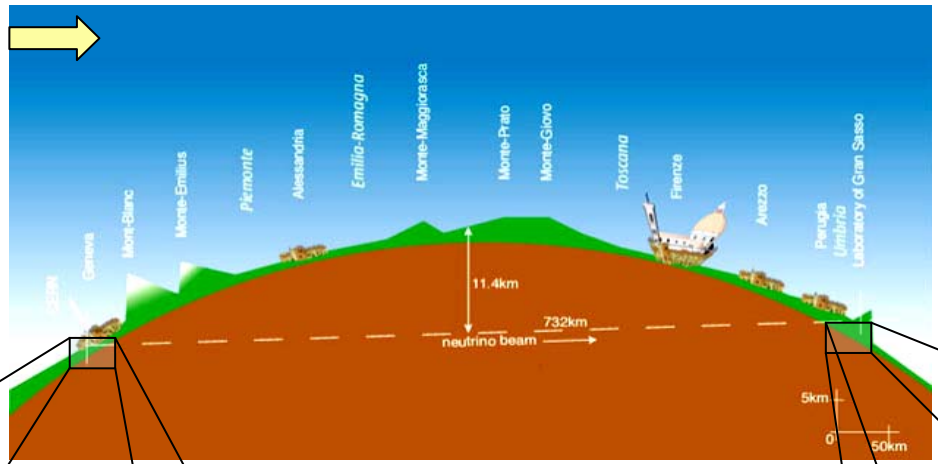
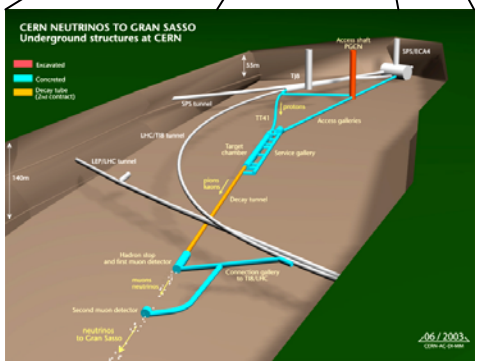
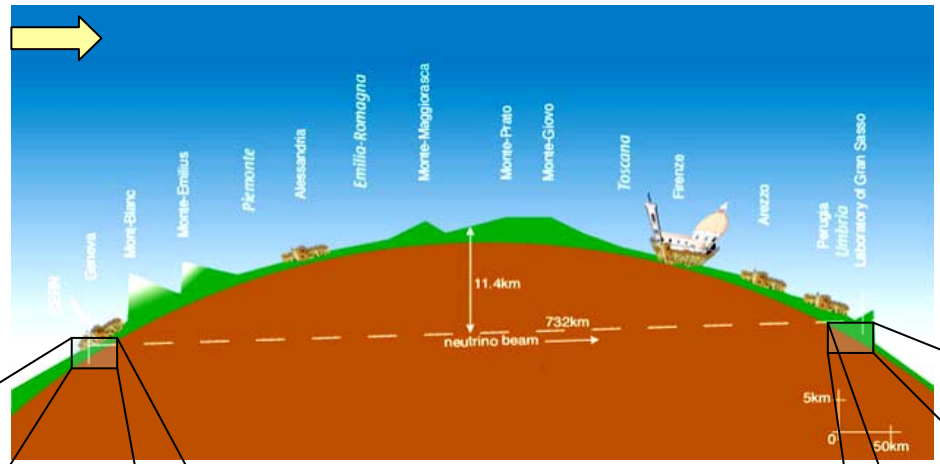


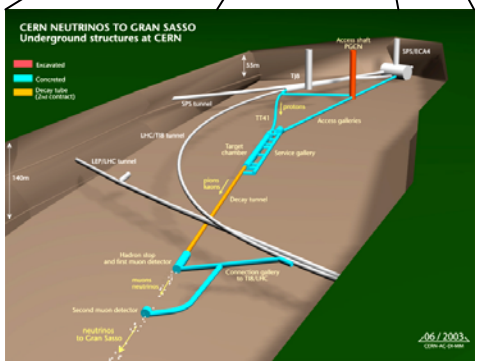


CNGS Project

- CERN SPS provides neutrino beam to Gran Sasso

$\langle E\nu_\mu \rangle$	**17 GeV**
$(\bar{\nu}_e + \nu_e)/\nu_\mu$	**0.87%**
$\bar{\nu}_\mu / \nu_\mu$	**2.1%**
ν_τ **prompt**	**negligible**





CNGS Project

Oscillation probability for:

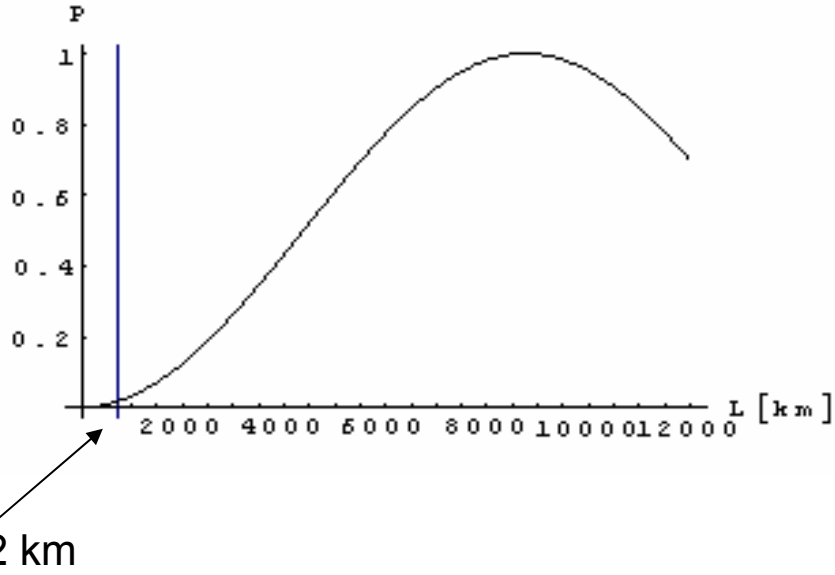
$\Delta m^2 = 2{,}8 \cdot 10^{-3} eV^2.$

$E = 17 GeV$

$\sin^2 2\Theta = 1.0$

Advantage: above tau production threshold

Disadvantage: bad rate of ν_τ



MINOS	E=1GeV	L=730km	P=0.79
K2K	E=1GeV	L=250km	P=0.41

Detection of the tau neutrino

- Detection of the tau neutrino through the decay of the tau lepton
- Like DONUT who discovered 2000 first the tau neutrino in an ECC brick

$$\nu_\mu \xrightarrow{\text{oscillation}} \nu_\tau + N \rightarrow \tau^- + X$$

$\tau^- \rightarrow \mu^- + \nu_\tau + \bar{\nu}_\mu$	BR: 17,4%
$\tau^- \rightarrow h^- + \nu_\tau + n\pi^0$	50%
$\tau^- \rightarrow e^- + \nu_\tau + \bar{\nu}_e$	17,8%

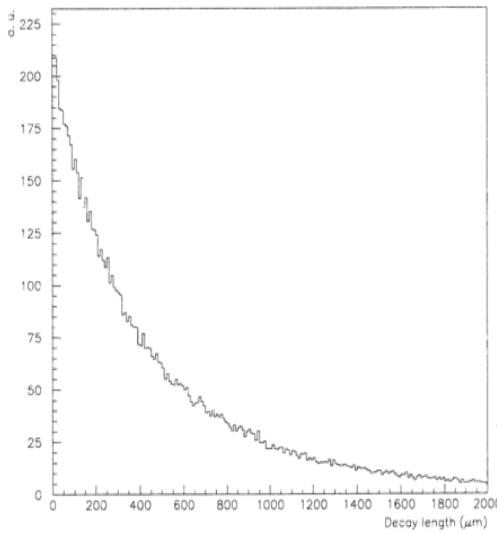
<u>detection of tau lepton by decay products:</u>

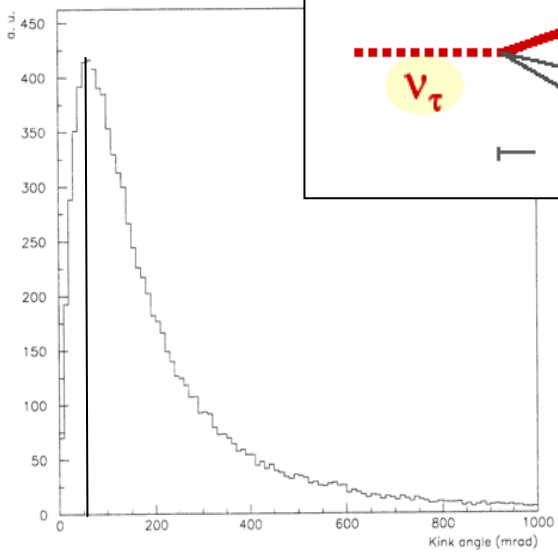
→ muon: long tracks (muon spectrometer)
→ hadron: hadronic showers
→ electron: electromagnetic showers

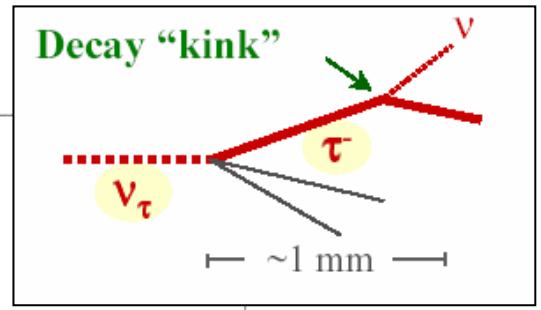
Detection of the tau neutrino

- Topology of the tau decay:

  ~0,6 mm long tracks with a characteristic decay kink

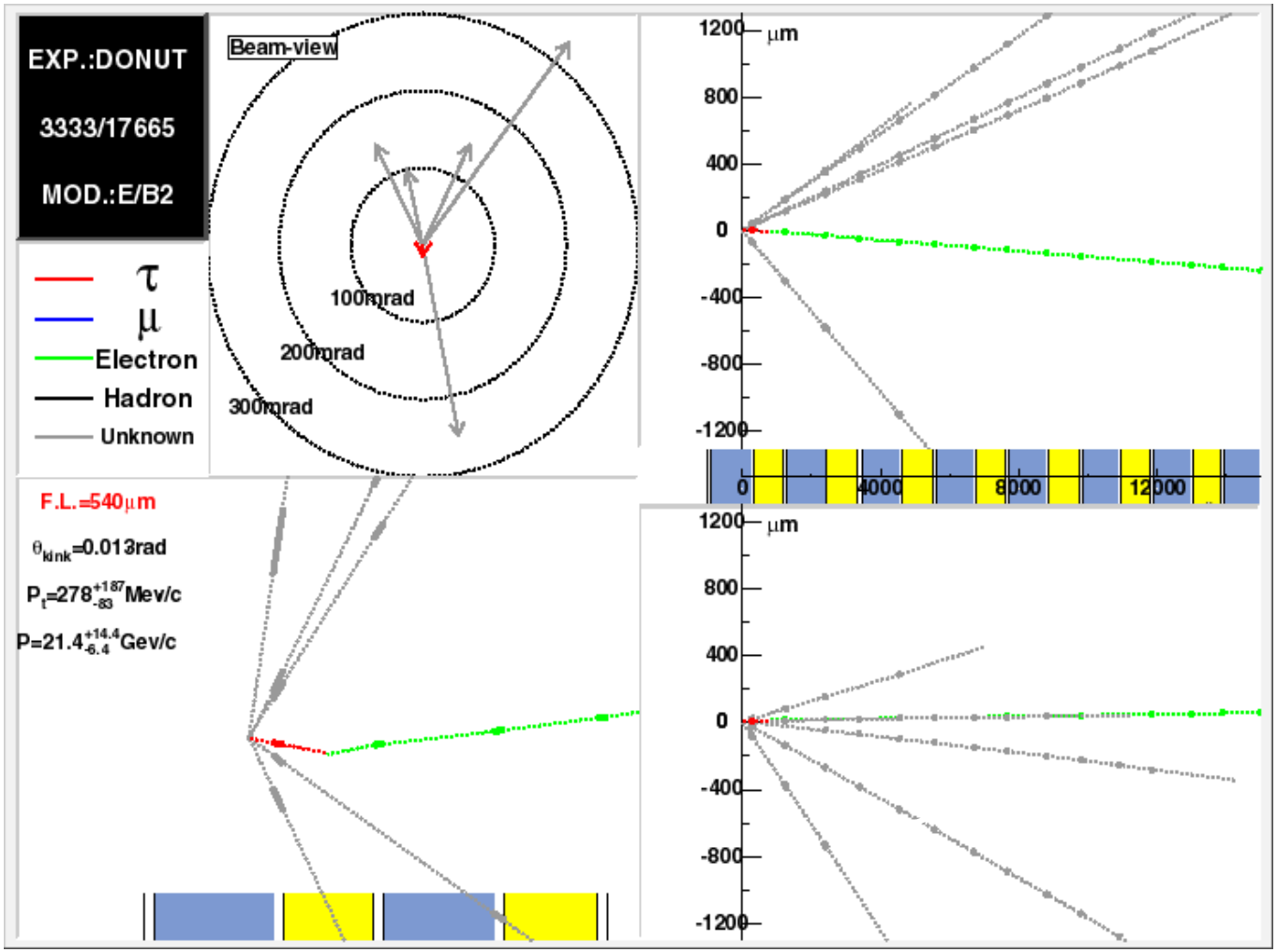




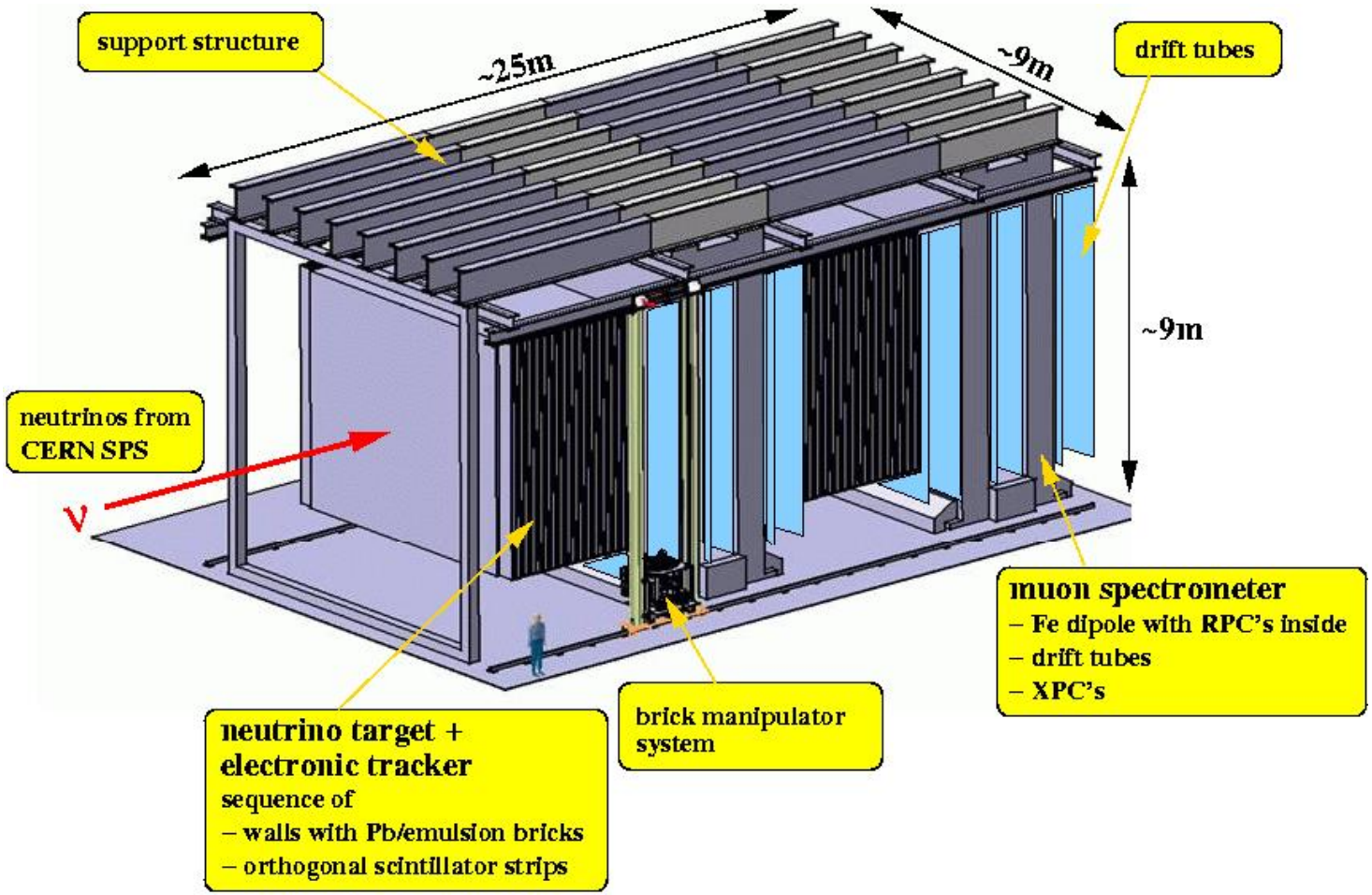


~50 mrad

DONUT pictures



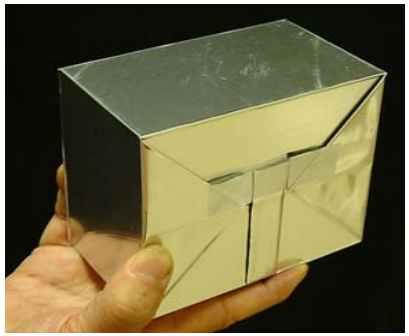
The OPERA Detector



Neutrino Detector

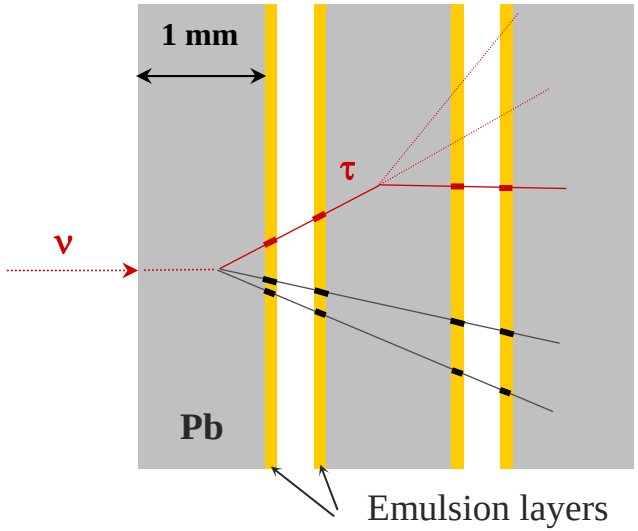
Basic unit is the Emulsion Cloud Chamber (ECC) brick

- About 230000 bricks compose the target ~1,8kt
- ECC assembled in walls
- ~3264 brinks per wall
- 24 walls
- Mechanical packing

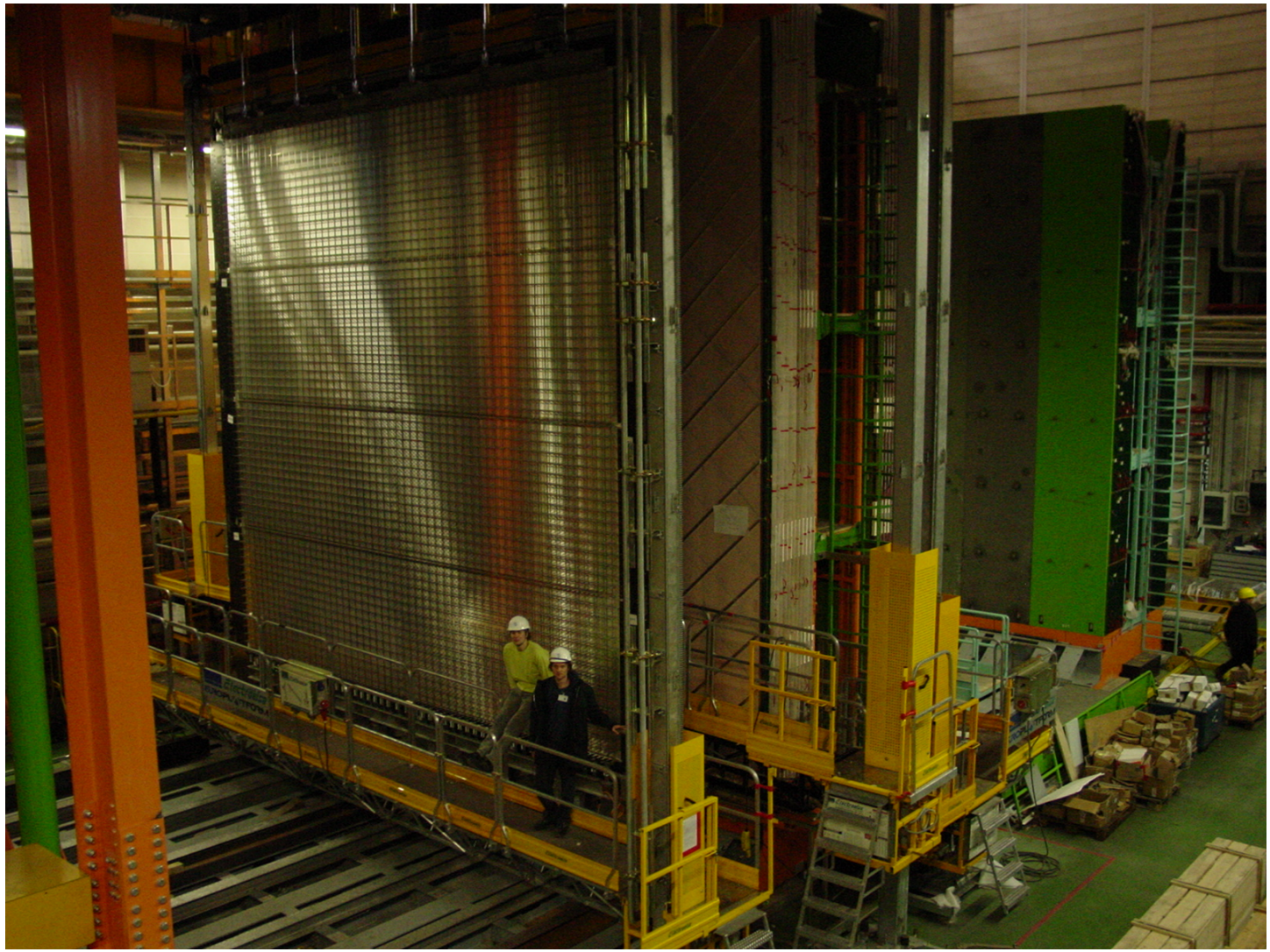


ECC consists of 56 Pb sheets and 56 emulsion layers

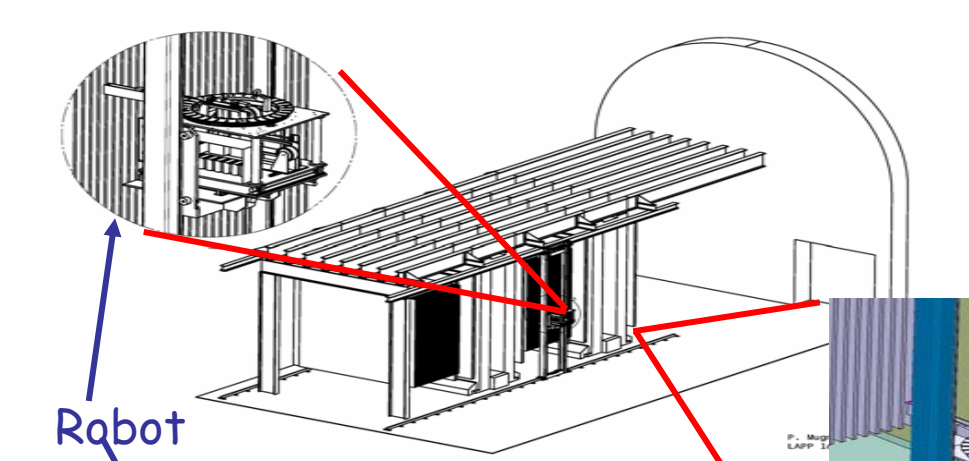
- Determination :
  - of the decay kink
  - of the vertex
  - momentum charged particles (multiple scattering)
- Resolution:
  - Angular resolution ~ 2,1 mrad
  - Position resolution: 0,3 μm



Neutrino Detector

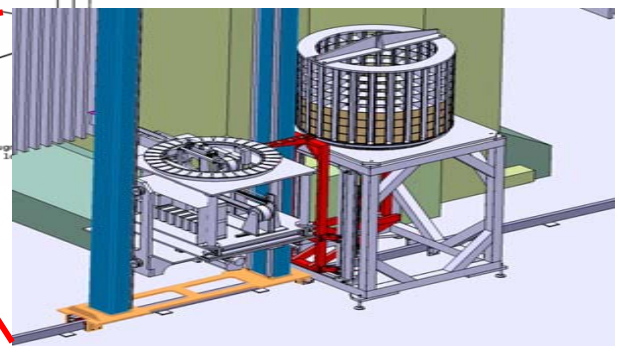


Brick Manipulator System



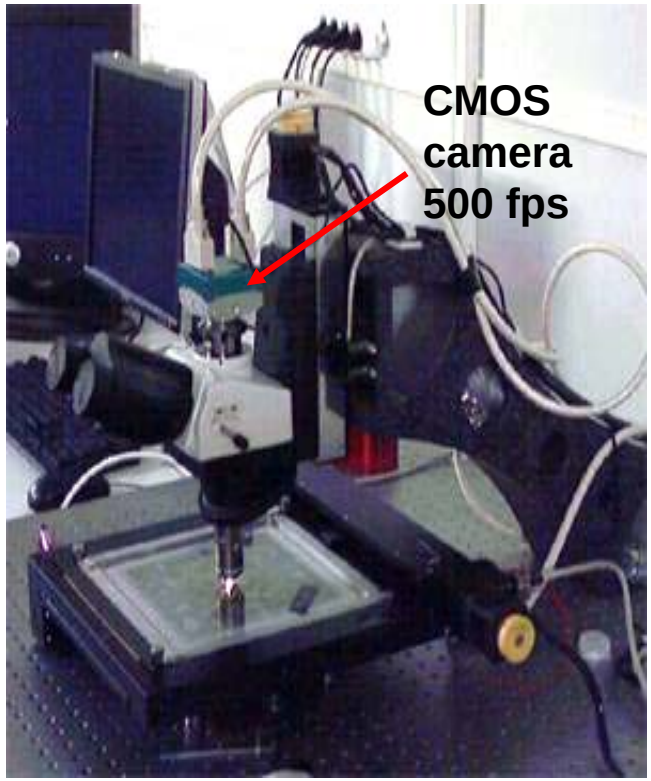
Robot

Loading station

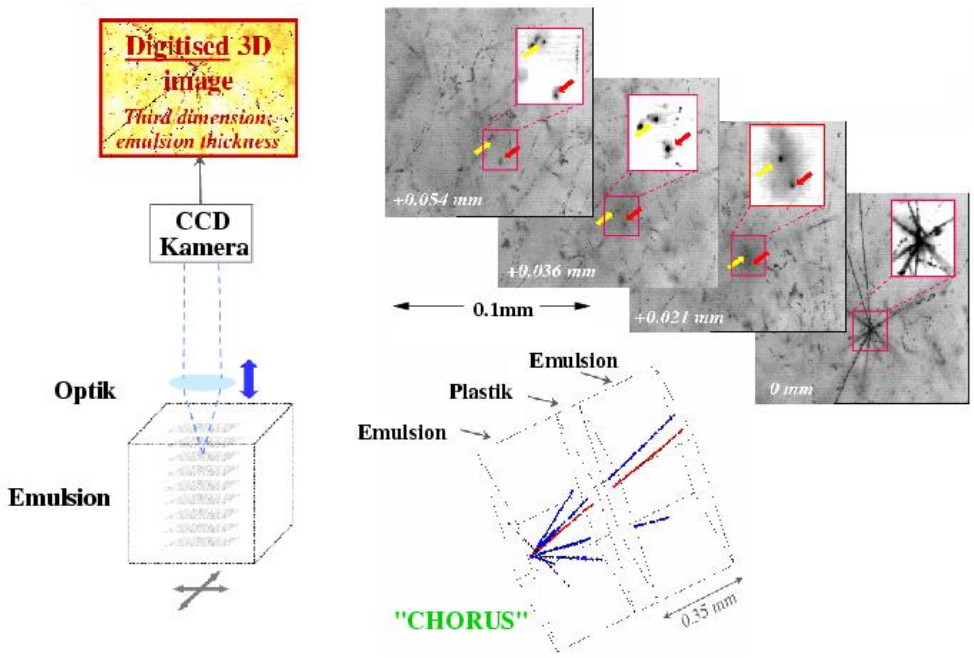


The Vacuum sucker Vehicle (VV)

Scanning of the emulsion



Final version of the european system ready and working at 20 cm^2/hour (15 stations under installation)



Kinematic analysis

- Momentum measurement through multiple scattering in the PB plate
- Distribution of the scattering angel app. Gaussian with RMS:

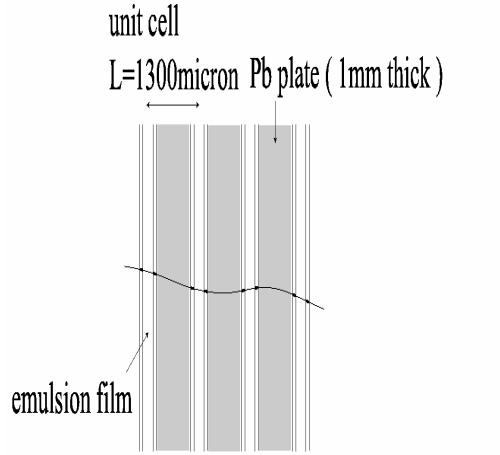
$$\Theta_0 = \frac{13{,}6 MeV/c}{p\beta}\sqrt{X}$$

- Two different methods:
  - Angular method
  - Coordinate method

Kinematic analysis

Angular method

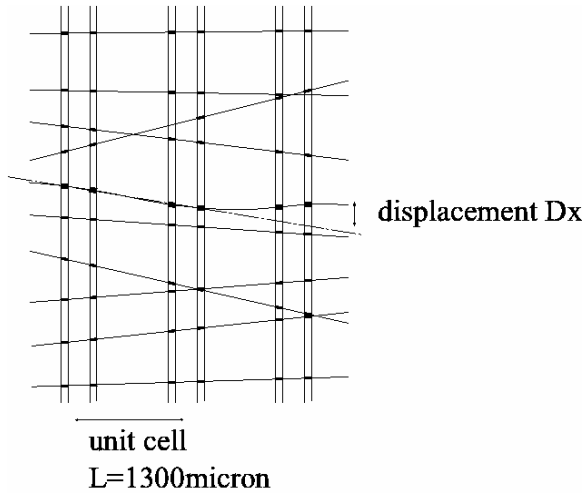
- Measure of the angle by taking the difference of angles in two consecutive emulsion films
- P_{max} = 10.0GeV due to the angular resolution



Coordinate method

- Emulsion are aligned through cosmic rays
- More sensitive to high momenta
- Pmax = 16,7GeV

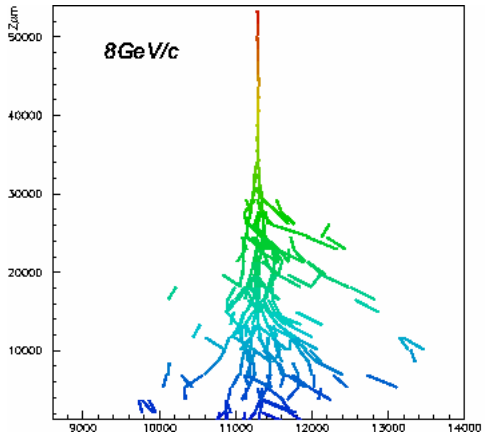
$$\Theta_0 = \frac{Dx}{L}$$

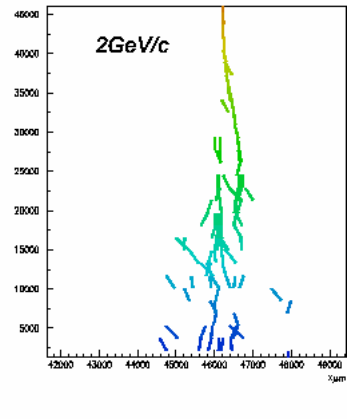


Kinematic analysis

Shower analysis

- Electron tracks develops into a shower
- Energy determined before the shower starts (multiple scattering) and by counting the number of electrons when the shower develops





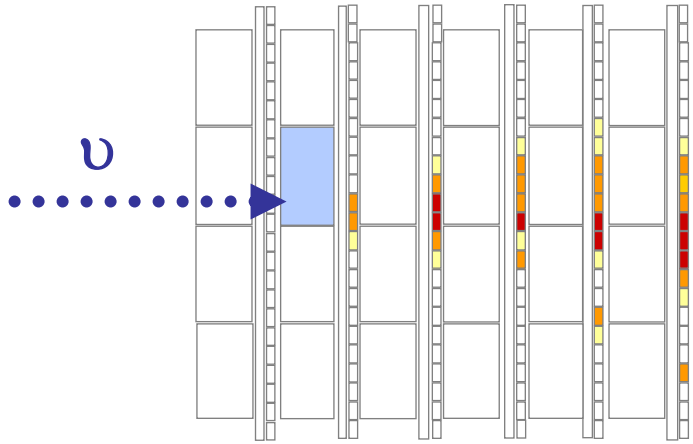
Electron/Hadron identification

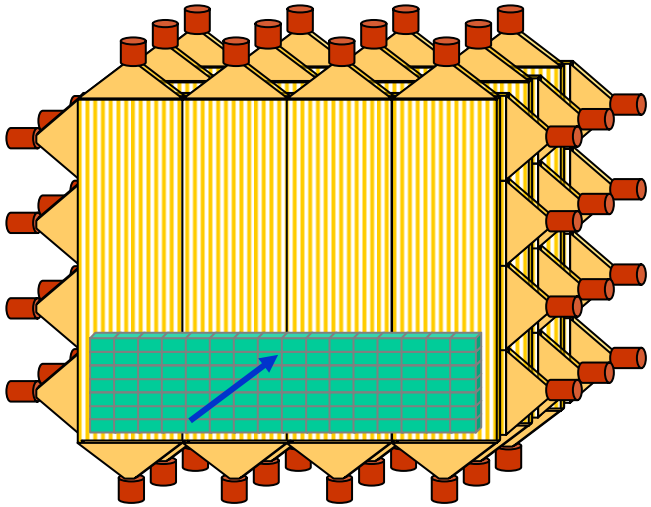
- Energy loss different for electron- / hadronic showers:
  - Electrons: bremsstrahlung
    $E(x)=E0e\ (-x/X0)$
  - Hadrons: ionization losses
    $E(x)=E0(1-(dE/dx)x)$

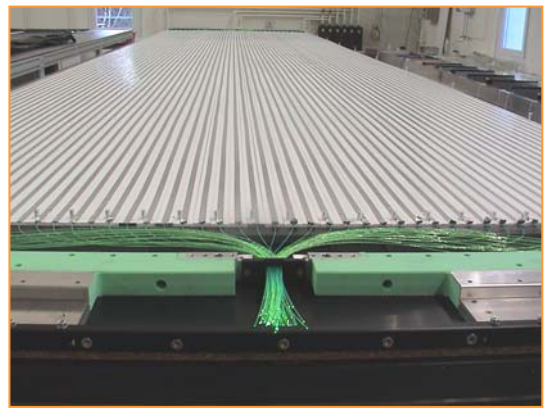
Target tracker

How to find the interaction brick?

- Between the walls with the ECC bricks are layers of scintillator strips (target tracker)
- Interaction trigger
- Brick identification
- Myon tracking

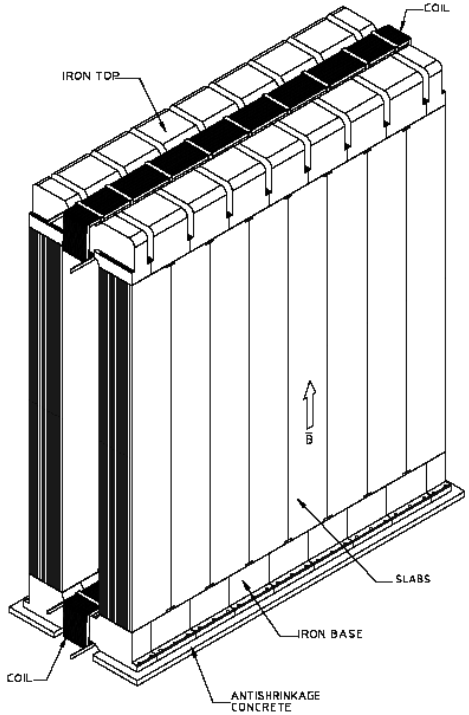


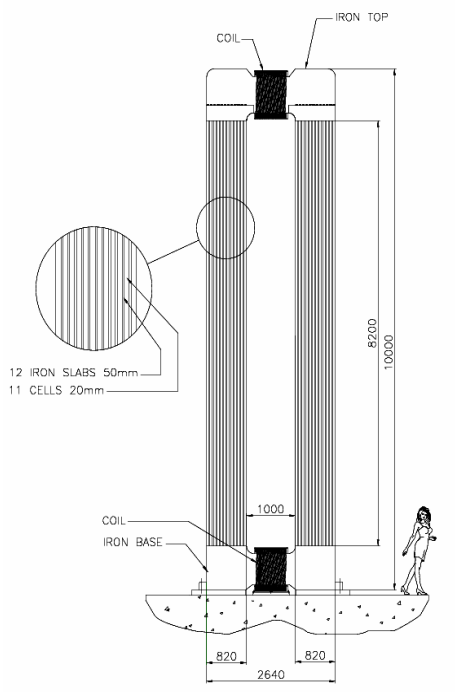




Spectrometer

- Dipolar magnet with 1,55 T, 0,9 kt
- Located in the back of the ECC target
- 12 Fe slaps per magnet side with resistive plate chambers (RPC) inside the gap



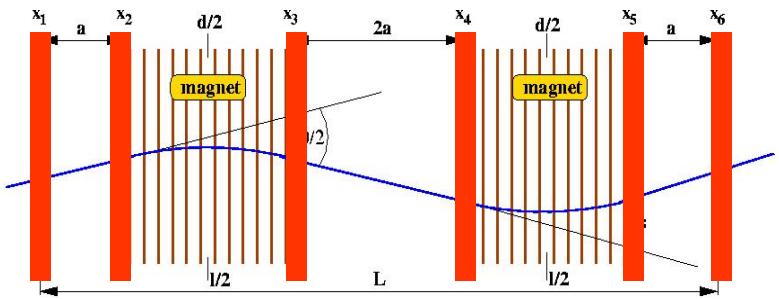


Spectrometer

Spectrometer

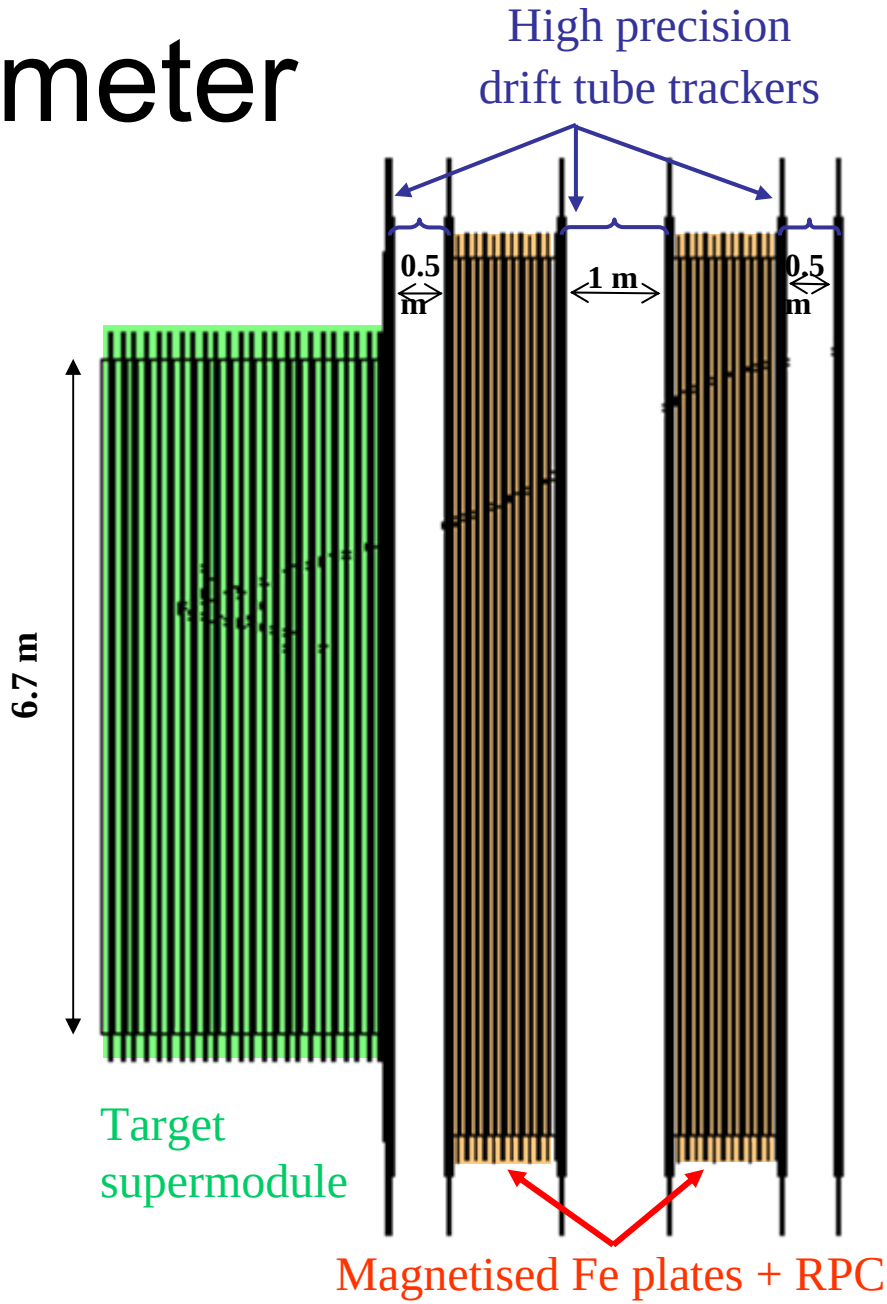
High precision drift tubes

- Measures the coordinate of the muon track before, inside and behind each dipole magnet



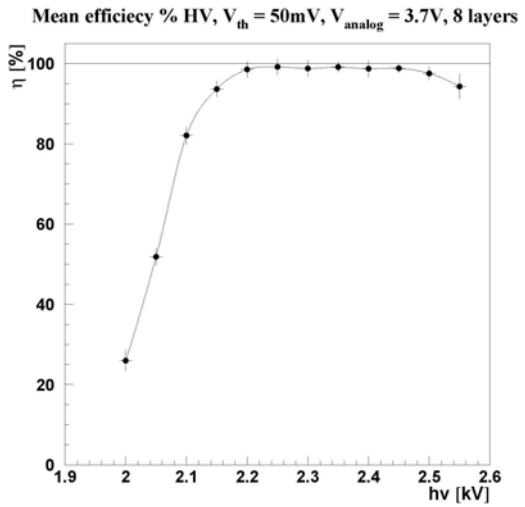
Spectrometer

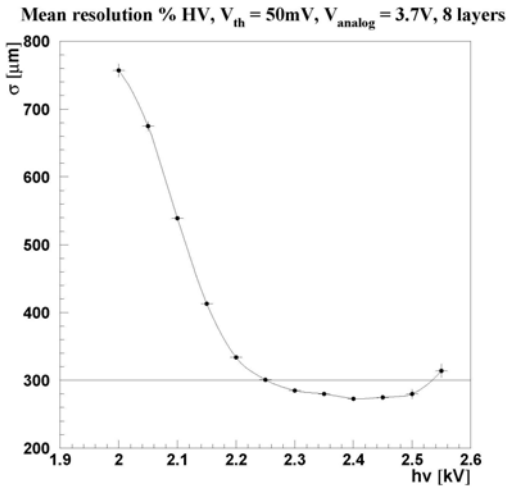
- Aimed to reconstruct the charge and momentum of the muon sign
- Veto for background events



Precision Tracker

- Resolution: < 0,3 mm, high efficiency





Precision Tracker

Neutrino interactions

SPS operation at CERN:

- 200 days/year
- 4,5 x 10^{19} pot/year
- 5 years run
- 1,8 kt average target mass

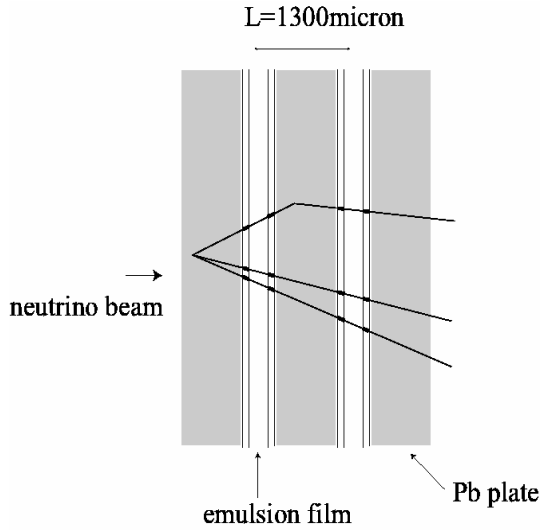
Expected interactions:

- ~33000 muon neutrino CC + NC interactions
- ~120 tau neutrino CC interactions
  at $\Delta m^2 = 2.4 \times 10^{-3}\ eV^2$ *and full mixing*

Physics performance

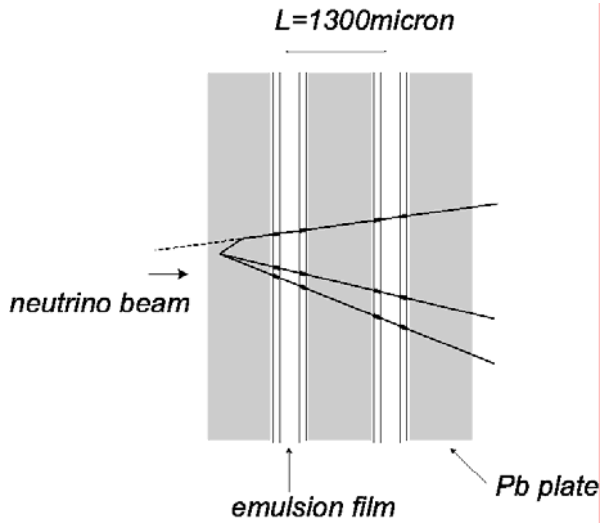
Efficiency for the tau neutrino detection

- Includes:
  - Brick finding eff: target tracker efficiency
  - Geometrical eff: losses through edge effects in the bricks
  - Vertex finding eff: relates to the scanning facility, alignment of the emulsions
  - Eff to identify a fake lepton at primary vertex: i.e. hadron identified as a electron (muon)
  - Short and long decays



Decay mode	DIS long	QE long	DIS short	Overall*
$\tau \rightarrow e$	3.0	2.6	1.3	3.7
$\tau \rightarrow \mu$	2.7	2.8	-	2.7
$\tau \rightarrow h$	2.2	2.8	-	2.3
Total	8.0	8.3	1.3	8.7

* Weighted sum of DIS and QE events

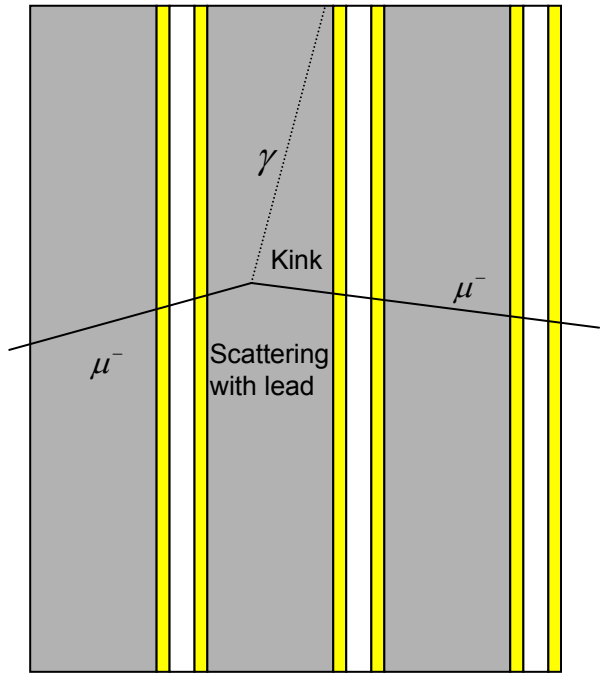


Background

Every event which looks like the tau topology is background

Sources for background

- Charmed particles produced in muon neutrino NC/CC interactions: charmed mesons lifetime ~like the taus
- Muon scattering
- Hadronic reinteractions

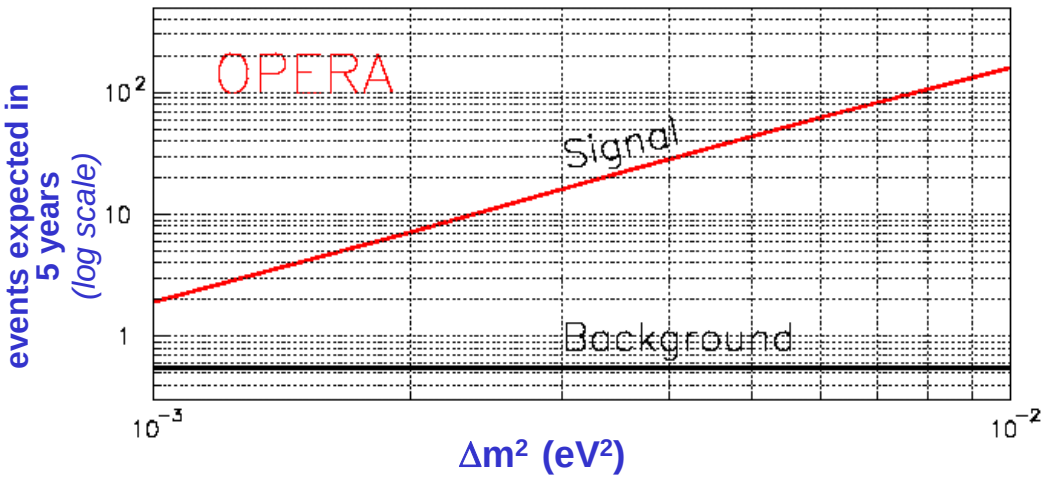


	$\tau \to e$	$\tau \to \mu$	$\tau \to h$	Total
Long decays: Charm production	0.15	0.03	0.15	0.33
Long decays: ν_e CC and π^0	0.01	-	-	0.01
Long decays: Large μ scattering	-	0.10	-	0.10
Long decays: Hadron reinteractions with kink topology	-	-	0.10	0.10
Long decays: Total	0.16	0.13	0.25	0.54
Short decays: Charm production	0.03	-	-	0.03
Short decays: ν_e CC and π^0	« 0.01	-	-	« 0.01
Short decays: Total	0.03	-	-	0.03
Total	0.19	0.13	0.25	0.57

Expected events

- Full mixing
- 5 years data tacking
- Average target mass ~1,8kt

				ν_τ events
τ decay	Δm^2 (10^{-3} eV^2)			**b.g.**
	1.5	3.2	5.0	
e	1.7	7.7	18.5	0.19
μ	1.3	5.7	13.8	0.13
h	1.1	4.9	11.8	0.25
Total	**4.1**	**18.3**	**44.1**	**0.57**



Summary

- OPERA searches for tau neutrino appearance from a muon neutrino beam
- Within the parameter region predicted from SK
- Detection through tau decay in emulsions
- More precise measurement of Δm_{23} and Θ_{23}
- Due to electron detection probability: measurement of Θ_{13}