INTRODUCTION

We know that in Nature there are three kinds of neutrinos and in particular atmospheric neutrinos show a deficit of ν_μ

This effect, found first by the SuperKamiokande and confirmed by many other experiments (for example by MACRO and K2K), has been deeply studied.

So, the disappearance of muon neutrinos seems doubtless stated .

Moreover, the experimental data agree very well with the hypothesis of $\nu_\mu \rightarrow \nu_\tau$ **oscillations.**
However, the experiments performed until now do not allow to observe the particle that should be produced in the oscillation: the ν_τ

In order to be sure that the oscillation $\nu_\mu \rightarrow \nu_\tau$ is the right explanation of the data, we need the direct observation of the ν_τ

…….. to “see” the ν_τ

The OPERA experiment

MTM Bologna, 17/6/ 2005

Physics motivations

Provide unambiguous evidence for

$\nu_\mu \rightarrow \nu_\tau$ oscillations

in the parameter region indicated by

atmospheric neutrino data

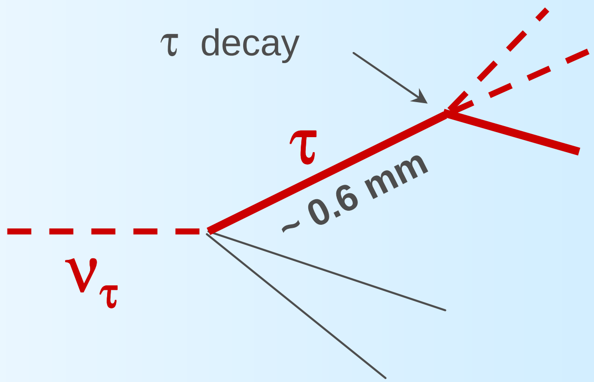
by searching for

ν_τ appearance

in the CNGS ν_μ beam

ν_τ appearance signature:

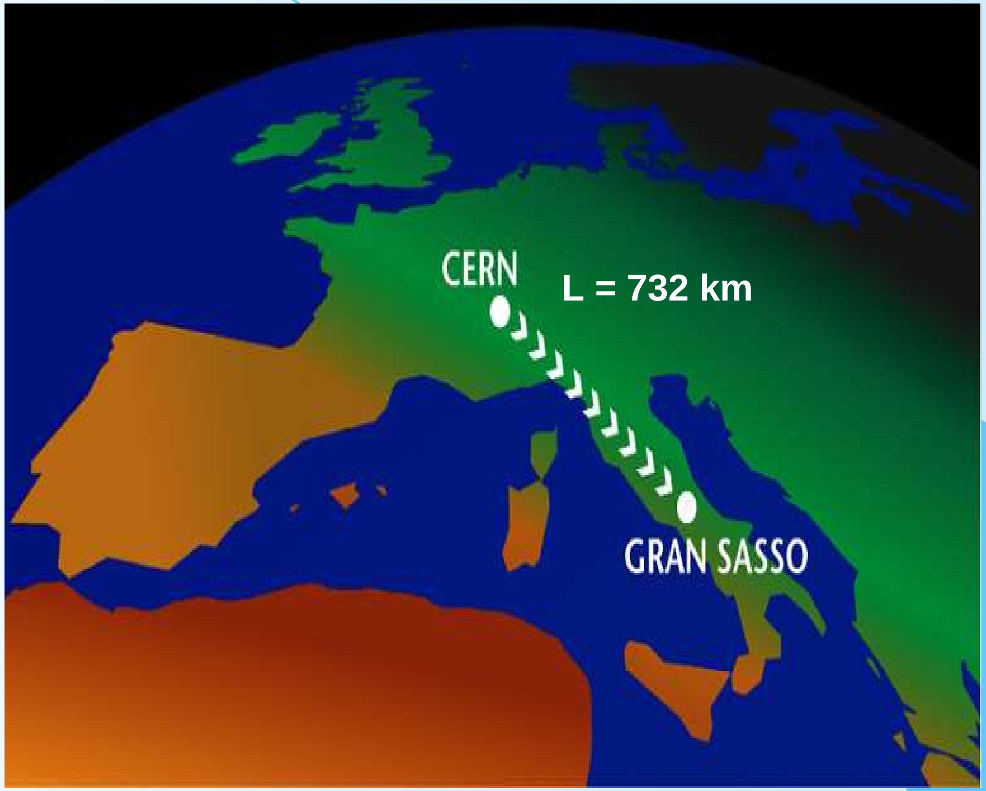
detection of ν_τ CC interactions and direct observation of τ decay topology



The CNGS Beam

Beam to LNGS in May 2006

$<E\nu_\mu>$	17 GeV
ν_τ prompt	negligible

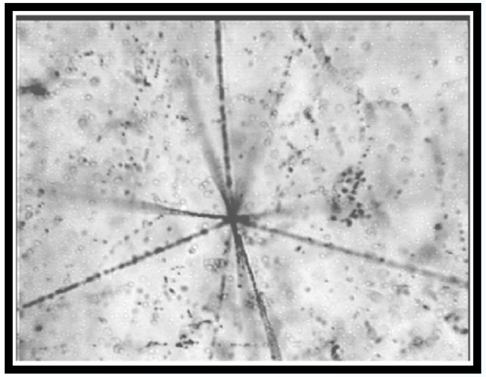


Expected ν_τ CC interactions/year: ~25
($\Delta m^2 = 2.4 \times 10^{-3}$ eV^2, maximal mixing)

The **O**scillation **P**roject with **E**mulsion t**R**acking **A**pparatus

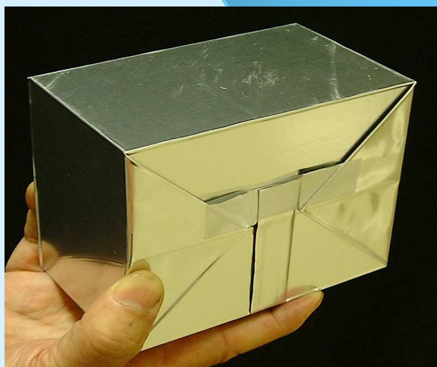
In order to detect the decays
of the τ particles produced in CC interactions
of ν_τ's from ν_μ oscillations

a high-resolution tracking detector is required



Nuclear emulsions

- 3D particle reconstruction
- Sub-micron spatial resolution
- High granularity (~300*hits*/mm)



Modular detector

basic unit (BRICK):
sequence of lead/emulsions

Detector structure

hybrid set-up:
visual + electronic detection techniques

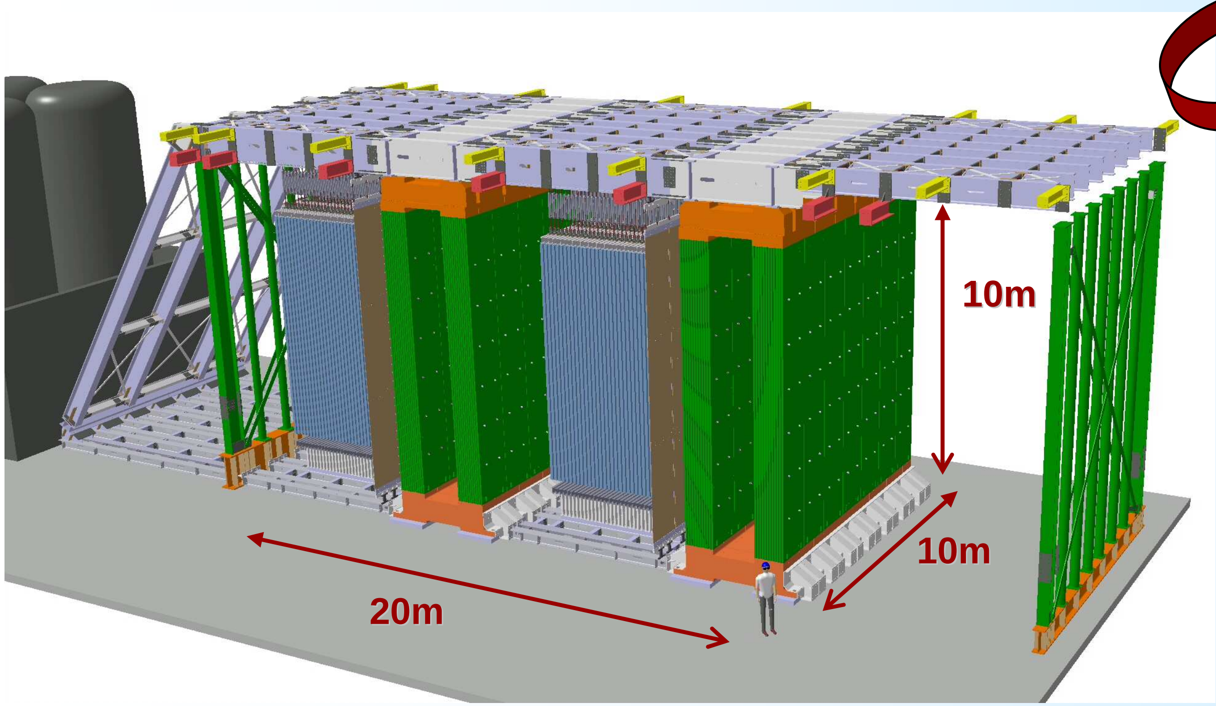
2 super-modules

muon spectrometer +

target walls

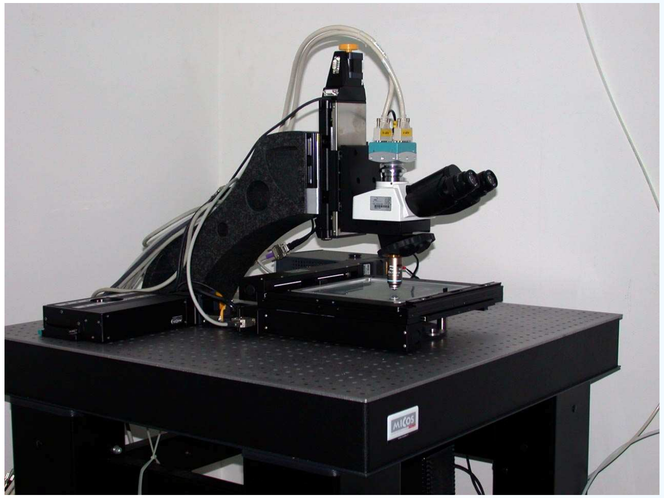
52x64 bricks

TOTAL > 220000 bricks

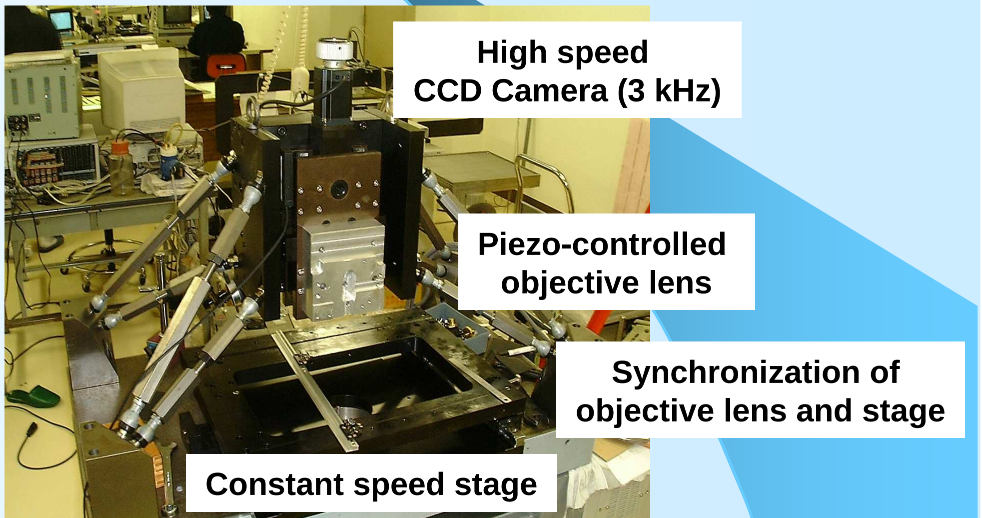


Automatic microscopes for emulsion scanning

European Scanning System
running in :
Bari, Bern, Bologna, Lyon,
Napoli, Neuchâtel, Roma, Salerno



S-UTS (Nagoya)



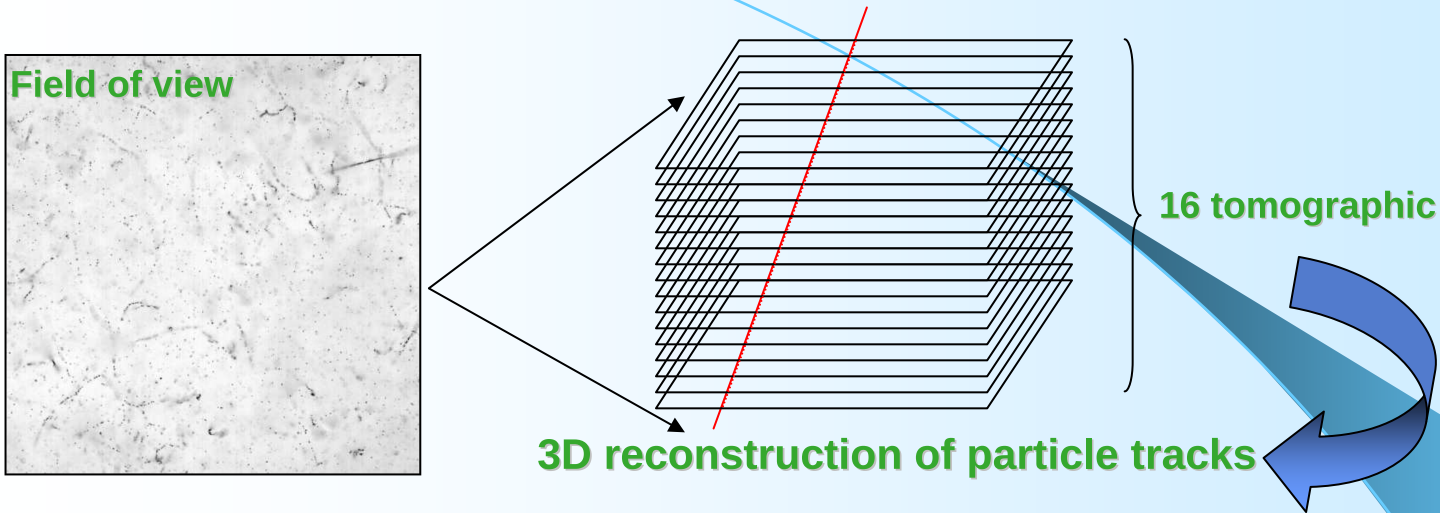
Scanning speed ~ 20 cm^2/h/side

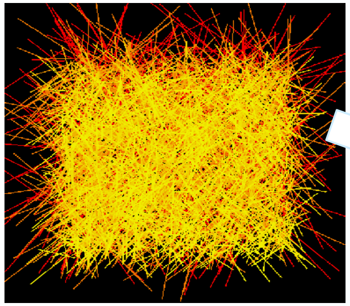
Single side track finding efficiency ~ 95%

Sheet-to-sheet alignment (8 GeV/c) ~ 0.5 μm

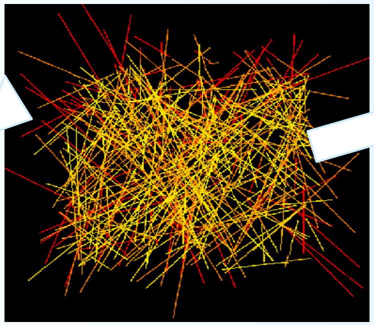
Angular resolution ~ 2 mrad

Automatic emulsion scanning

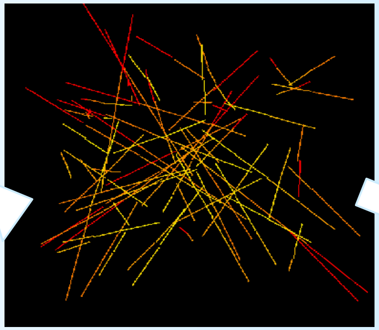




Track segments found in 8 consecutive plates

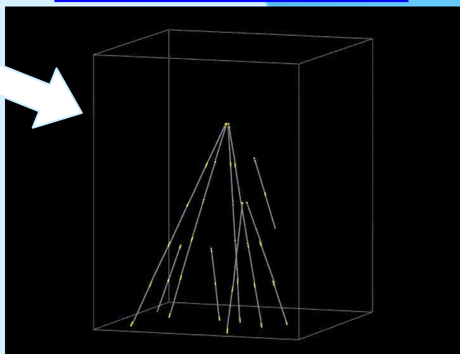


Connected tracks with >= 2 segments



Passing-through tracks rejection

Vertex reconstruction



Conclusions

OPERA

- A complex modular detector, using visual and electronic detection techniques, has been designed
- The detector construction and installation at LNGS are well underway
- Impressive progress in emulsion scanning automation has been achieved after challenging R&D

The OPERA experiment will start running in May 2006 to unambiguously confirm $\nu_\mu \rightarrow \nu_\tau$ oscillations

fine

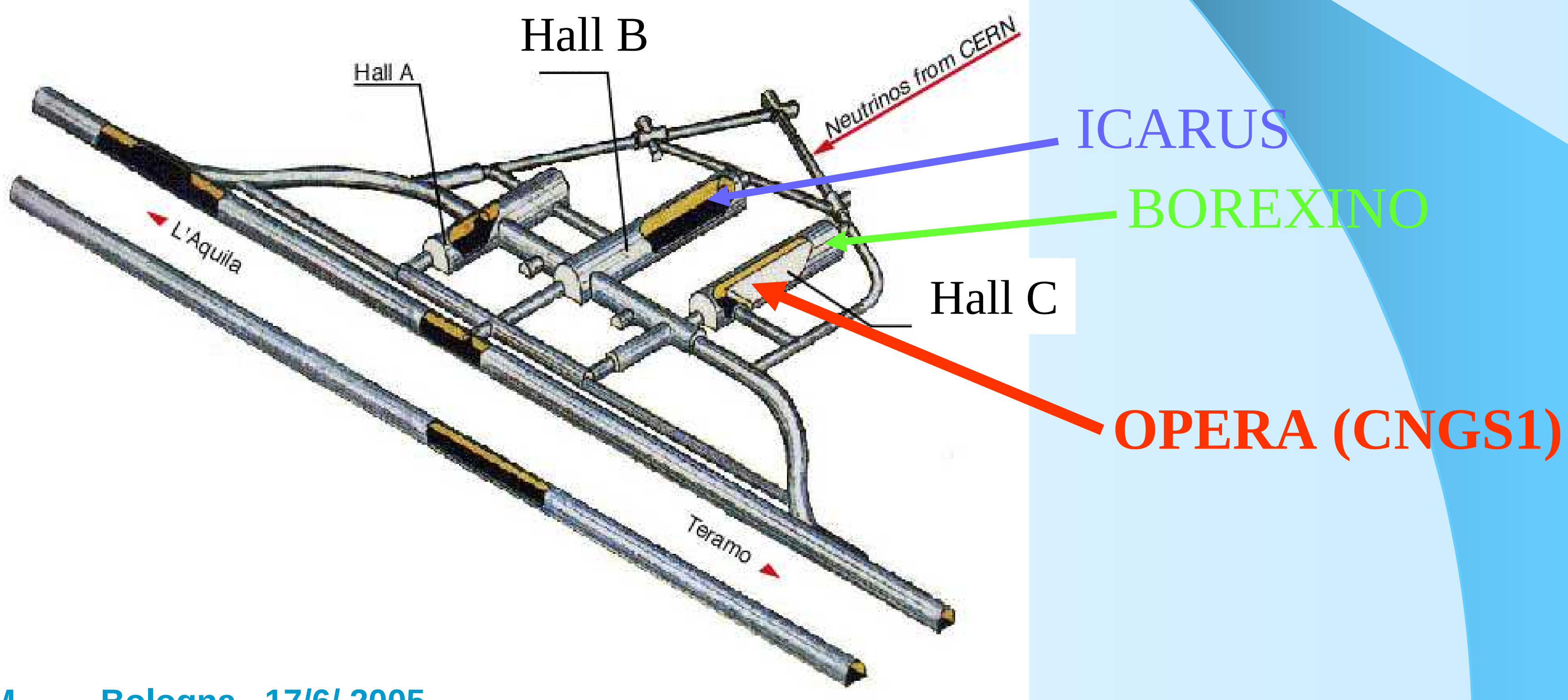
$\nu_\mu \rightarrow \nu_\tau$ oscillation search

τ decay channels	Signal			Background
	$\Delta m^2 = 1.9 \times 10^{-3}$ eV^2	$\Delta m^2 = 2.4 \times 10^{-3}$ eV^2	$\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	
ALL	8.0	12.8	19.9	1.0

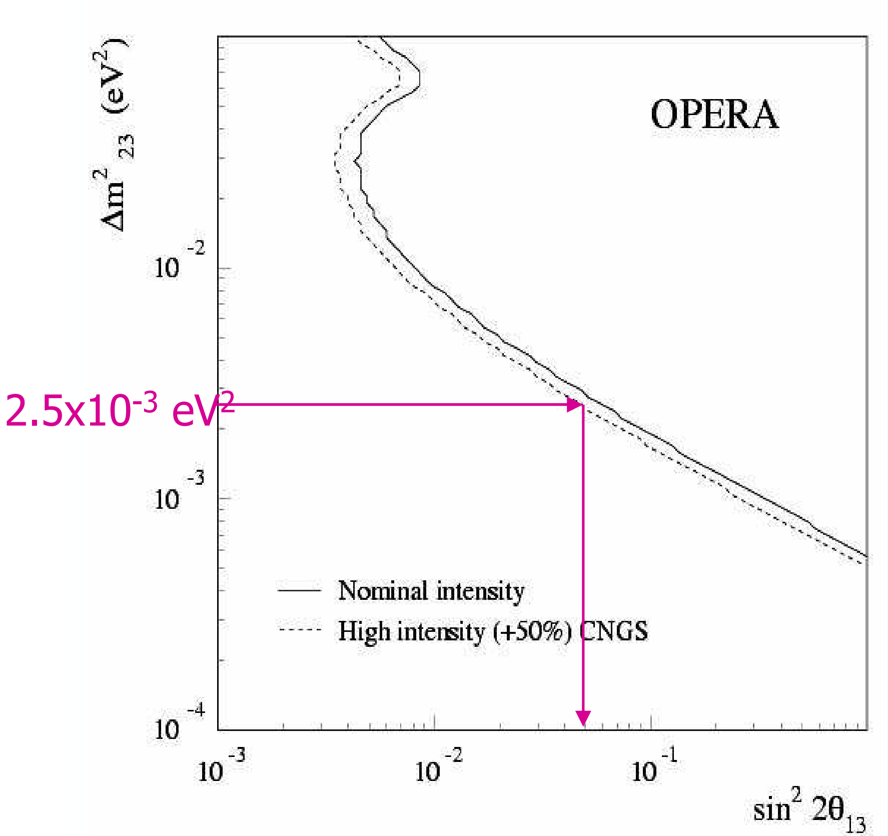
Main background sources:
charm production and decays
hadron re-interactions in lead
large-angle muon scattering in lead

LNGS – Gran Sasso National Laboratory

rock thickness 1400m (3800 m.w.e.)
cosmic muon flux: ~1/m²/h



$\nu_\mu \rightarrow \nu_e$ oscillation search



Δm_{23}^2 = 2.5 x 10^{-3} eV^2 Θ_{23} = 45°

nominal CNGS beam 5 years

Combined fit of E_e, E_{vis}, $(pt)_{miss}$

90% C.L. limits on $\sin^2(2\Theta_{13})$ and Θ_{13} :

$\sin^2(2\Theta_{13})<0.06$ $\Theta_{13} < 7.1°$

hep-ph/0210043

The OPERA Collaboration

Belgium
IIHE (ULB-VUB) Brussels
Bulgaria
Sofia
China
IHEP Beijing, Shandong
Croatia
IRB Zagreb
France
LAPP Annecy, IPNL Lyon, LAL Orsay, IRES Strasbourg
Germany
Berlin Humboldt, Hagen, Hamburg, Münster, Rostock
Israel
Technion Haifa
Italy
Bari, Bologna, LNF Frascati, L'Aquila, LNGS, Naples, Padova,
Rome La Sapienza, Salerno
Japan
Aichi, Kobe, Nagoya, Toho, Utsunomiya
Russia
INR Moscow, ITEP Moscow, JINR Dubna, Obninsk
Switzerland
Bern, Neuchâtel
Turkey
METU Ankara

OPERA

	Signal			Background
	$\Delta m^2 = 1.9 \times 10^{-3}$ eV^2	$\Delta m^2 = 2.4 \times 10^{-3}$ eV^2	$\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	
Old analysis	6.6 (10.0)	10.5 (15.8)	16.4 (24.6)	0.7 (1.1)
New analysis	8.0 (12.1)	12.8 (19.2)	19.9 (29.9)	1.0 (1.5)

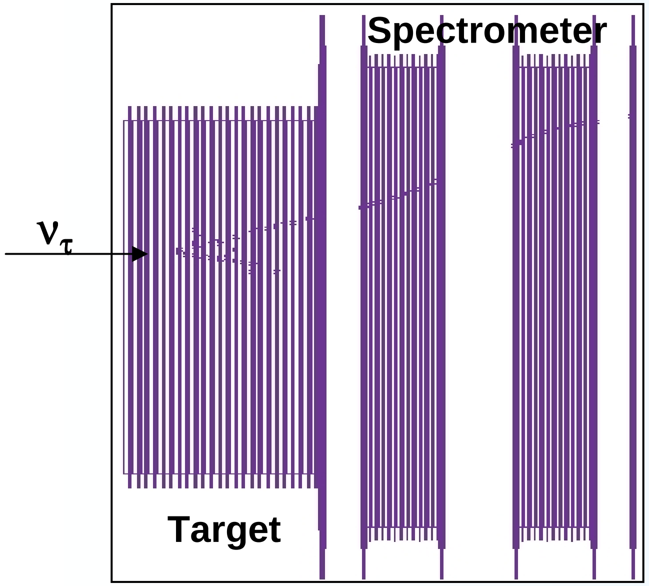
full mixing, 5 years run @ 4.5×10^{19} pot / year

(…) CNGS beam intensity increase (x 1.5)

Comments on background - possible improvements:

- **π/μ separation at low energy by dE/dx in emulsion** (charm background reduction)
- **extensive comparison of FLUKA with GEANT4/CHORUS data** (reduction of the uncertainty on hadron re-interaction calculations, based on FLUKA, 50% systematic error assumed)
- **experimental measurement of large-angle muon scattering**

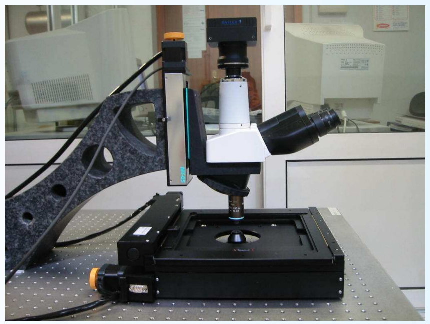
Experiment strategy



On-line analysis of electronic data

Brick identification and removal

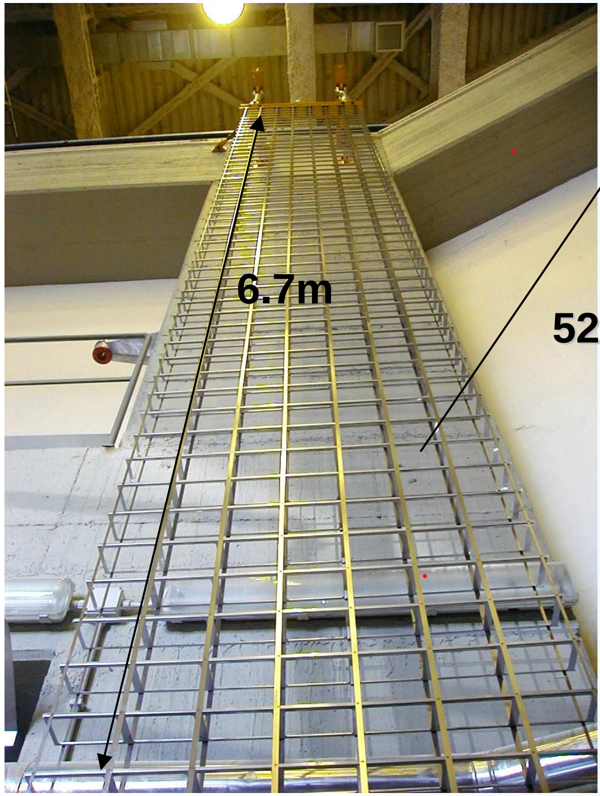
To the Scanning Stations - Laboratories



Emulsion analysis

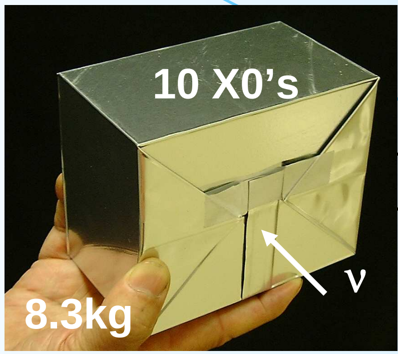
ν interaction vertex
τ decay kink
particle identification
and kinematics

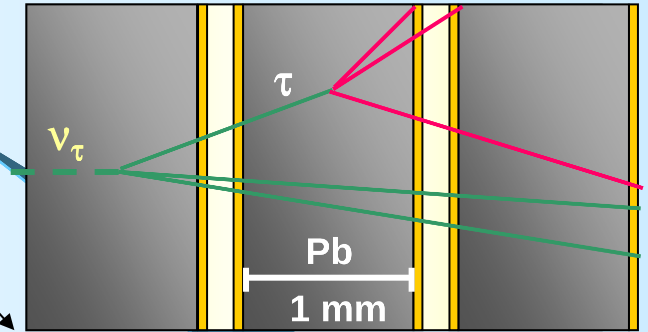
Lead – Emulsion Target



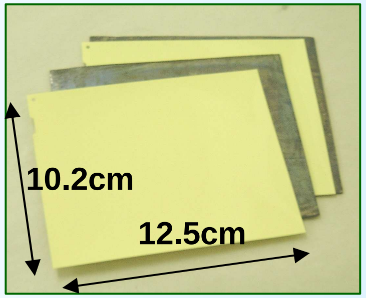
Wall prototype

52 x 64 bricks





BRICK: 57 emulsion foils +
56 interleaved Pb plates



2 emulsion layers
(44 μm thick)
glued onto a
200 μm plastic base

Emulsion films (Fuji)

mass production started in April '03
production rate ~8,000m^2/month
(206,336 brick ⇔ ~150,000m^2)

Lead plates (Pb + 2.5% Sb)

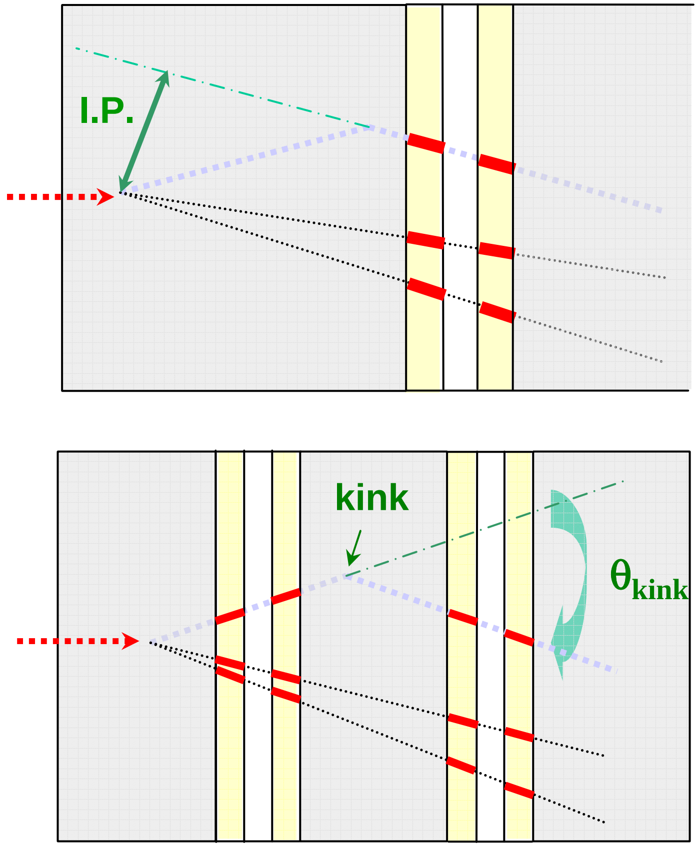
requirements:
low radioactivity level,
emulsion compatibility,
constant and uniform thickness

Total target mass : 1766 t

Detection of τ decays

short **decays:**
$\tau \to \mu$
$\tau \to e$

kink angle
$\vartheta_{kink} > 20$ **mrad**



long **decays:**
$\tau \to \mu$
$\tau \to e$
$\tau \to h$

impact parameter
I.P. > 5 ÷ 20 μm

New channel recently taken into account in the analysis: $\tau \to 3h$

Main background sources:
- **charm production and decays**
- **hadron re-interactions in lead**
- **large-angle muon scattering in lead**

τ detection efficiency

	DIS long	*QE long*	*DIS short*	*Overall**
$\tau \rightarrow e$	2.7	2.3	1.3	3.4
$\tau \rightarrow \mu$	2.4	2.5	0.7	2.8
$\tau \rightarrow h$	2.8	3.5	-	2.9
Total	8.0	8.3	1.3	9.1 %

* weighted sum on DIS and QE events

Recent improvements:

$\tau \rightarrow$ 3h now included in the analysis + updated brick finding algorithm

Step-by-step efficiencies, $\tau \to \mu$

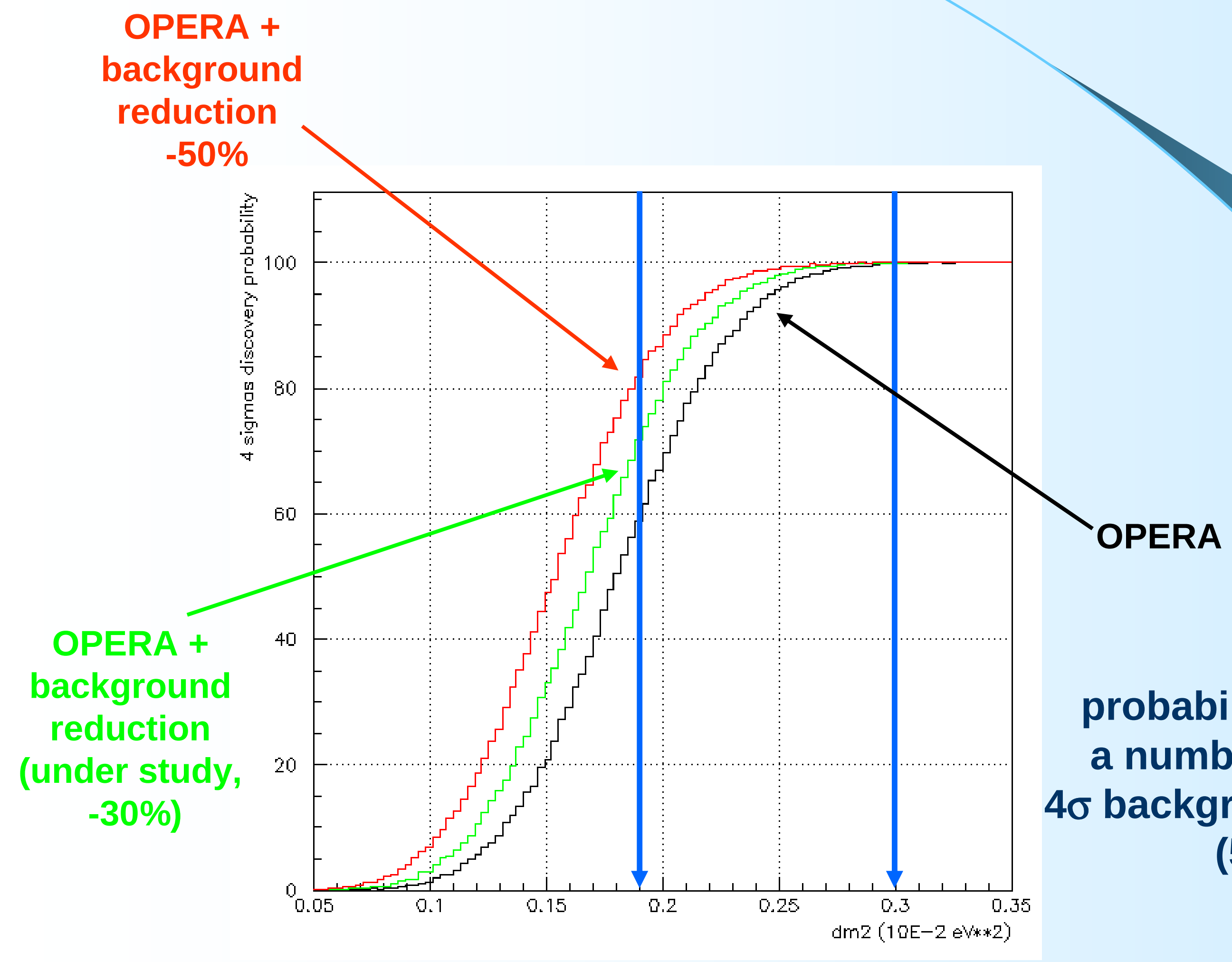
BR	Long dec.	Location	Kink+ kinematics	Id μ + ECC connection	Others
0.174	0.39	0.73	0.73	0.80	0.96

Application of the 3D chart

Extraction strategy:	$\tau \to \mu$	$\tau \to e$	$\tau \to h$	Additional fraction of extracted bricks
Only the Highest Prob. Brick (HPB)	73.5%	75.4%	64.2%	
HPB + second most probable brick (SMPB) if P1-P2<0.1	+1.0%	+3.0%	+4.7%	0.3%
HPB + SMPB if P1-P2<0.2	+2.0%	+5.0%	+6.9%	0.4%
HPB + SMPB if P1-P2<0.3	+2.8%	+5.8%	+8.2%	0.5%
HPB + SMPB (P2> 1%)	+8.1%	+9.7%	+12.0%	1.2%
Sequential extraction of all the bricks in the list (with P>1%)	+9.6%	+12.0%	+16.1%	1.9%
Net efficiency gain →	+7.7%	+ 10.1	+14.2%	

Minimal reduction of the target mass

$\nu_\mu \rightarrow \nu_\tau$ oscillations : OPERA sensitivity



probability to observe a number of events ≥ 4σ background fluctuation (5 years)

Particle separation by dE/dx

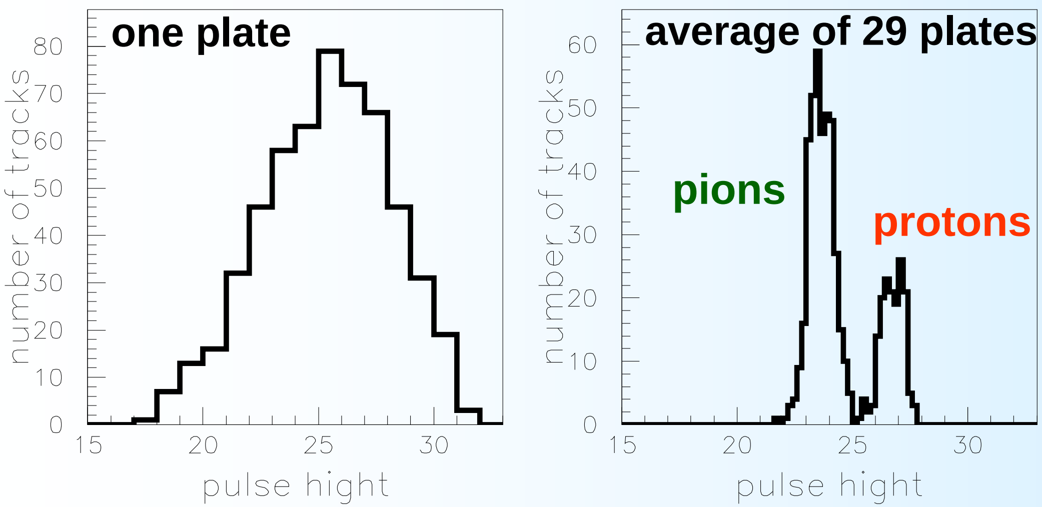
Grain density in emulsion is proportional to dE/dx

By measuring grain density as a function of the distance from the stopping point, particle identification can be performed.

Test exposure (KEK) : 1.2 GeV/c pions and protons, 29 plates

Calibration

IONISATION



MCS