CNGS experimental program: OPERA and ICARUS

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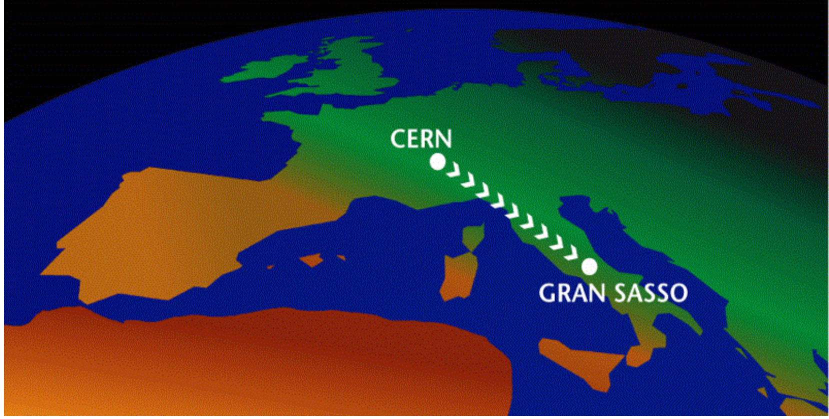
LAPP, Annecy

- Introduction
- CNGS beam-line
- OPERA experiment
- ICARUS experiment
- Conclusion

NNN05
Aussois, April 8th 2005

CNGS program:



In the CERN high energy ν_μ beam (CNGS):

• search for ν_τ appearance at the Gran Sasso laboratory (732 km from CERN)

→ Answer unambiguously on the origin of the ν oscillations observed at the atmospheric Δm^2 scale

• search for $\nu_\mu \rightarrow \nu_e$ and put new constraints on θ_{13}

Most recent atmospheric results:

Super-Kamiokande : (hep-ex/0501064):

Best fit: $\Delta m^2 = 2.1\ 10^{-3}\ eV^{-2}$ and $\sin^2 2\theta = 1.0$

$1.5 < \Delta m^2 < 3.4 \times 10^{-3}\ eV^2$ at 90% CL

SK L/E analysis : PRL 93 (2004) 101801:

Best fit: $\Delta m^2 = 2.4\ 10^{-3}\ eV^{-2}$ and $\sin^2 2\theta = 1.0$

$1.9 < \Delta m^2 < 3.0 \times 10^{-3}\ eV^2$ at 90% CL

CNGS: beam optimized for ν_τ appearance

For 1 year of CNGS operation in shared mode:

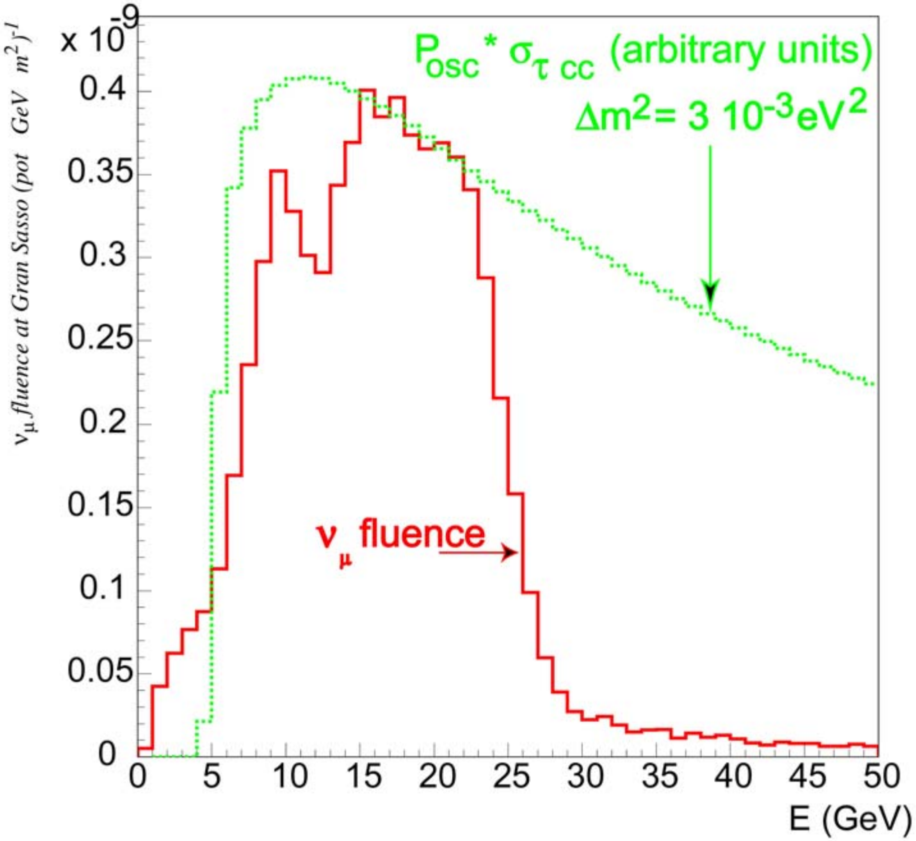
200 days/year ; ε = **55%**

4.5 x 10^{19} pot/year

ν_μ CC / kton	**2900**
ν_μ NC / kton	**875**
$\langle E \rangle_\nu$ (GeV)	**17**
$(\nu_e + \overline{\nu_e}) / \nu_\mu$	**0.85 %**
$\overline{\nu_\mu} / \nu_\mu$	**2.1 %**
ν_τ prompt	**negligible**

→ OPERA: ~ 30 evts/day

"Off-peak":

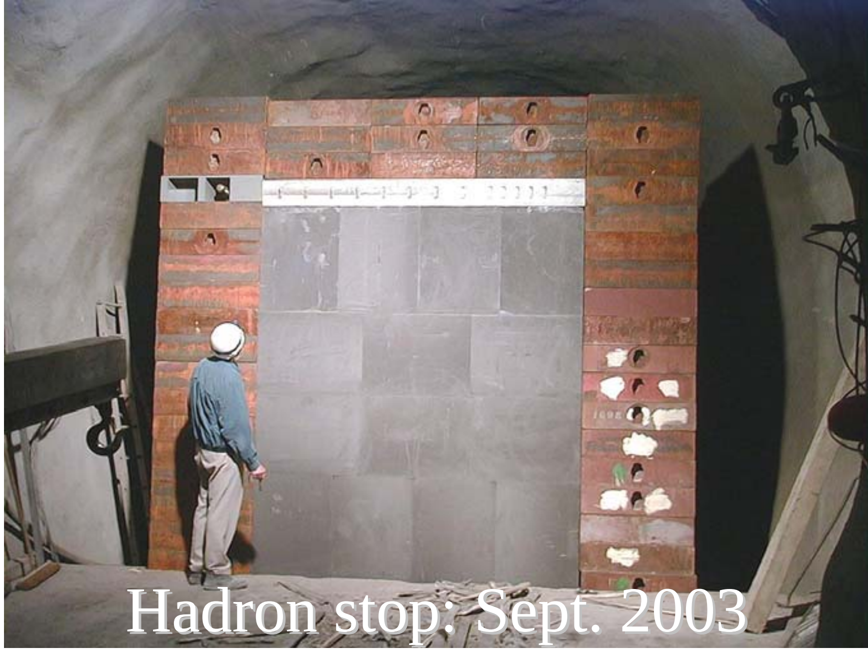


For Δm^2=2.4x10^{-3} and maximal mixing

expect 16 ν_τ CC/kton/year at Gran Sasso

Status of the project:

- Civil engineering is completed (June 2003)
- Hadron stopper and decay tube installed (June 2004)
- Installation of the services going on until June 2005



Hadron stop: Sept. 2003

Target chamber: June 2003

Decay tube: 998 m vacuum tested April 2004

- Proton beam and target chamber installation: second semester 2005

Inner Conductor of the Horn

June 2003 at LAL

with the Outer Conductor

April 2004 at CERN

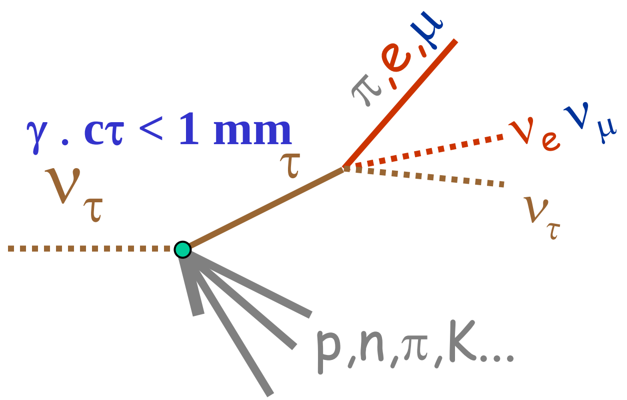
Inner Conductor of the Reflector

Delivered to CERN Feb. 2005

Work to complete by CERN

→ First beam to Gran Sasso in spring 2006

Experimental signature for ν_τ appearance:



τ decay modes:

$\mu^- \; \nu_\tau \; \bar{\nu}_\mu$	BR 17.4 %
$h^- \; \nu_\tau \; n\pi^o$	49.5 %
$e^- \; \nu_\tau \; \bar{\nu}_e$	17.8 %
$\pi^+ \pi^- \pi^- \; \nu_\tau \; n\pi^o$	15.2 %

→ detect and identify the ν_τ CC events

OPERA: direct observation of τ decay topology

requires nuclear emulsions: ~ μm granularity

ICARUS: ν_τ CC events identified through kinematic criteria

requires particle-ID, momentum and angular resolution

large electronic bubble chamber capabilities: ~ mm granularity

Reject efficiently main topological background: charm production

prompt μ at primary vertex

wrong sign assignment at secondary vertex

pt imbalance criteria

150 evts/kton/year

Gran Sasso National Laboratory: (Italy, 120 km from Rome)

Underground laboratory:

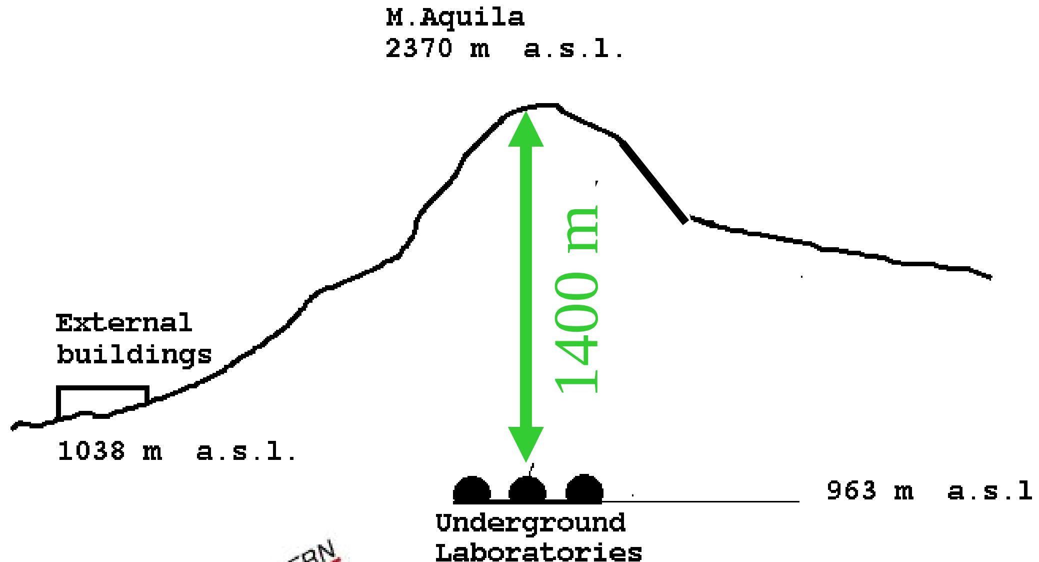
good cosmic ray shielding

1 cosmic/m^2/hr

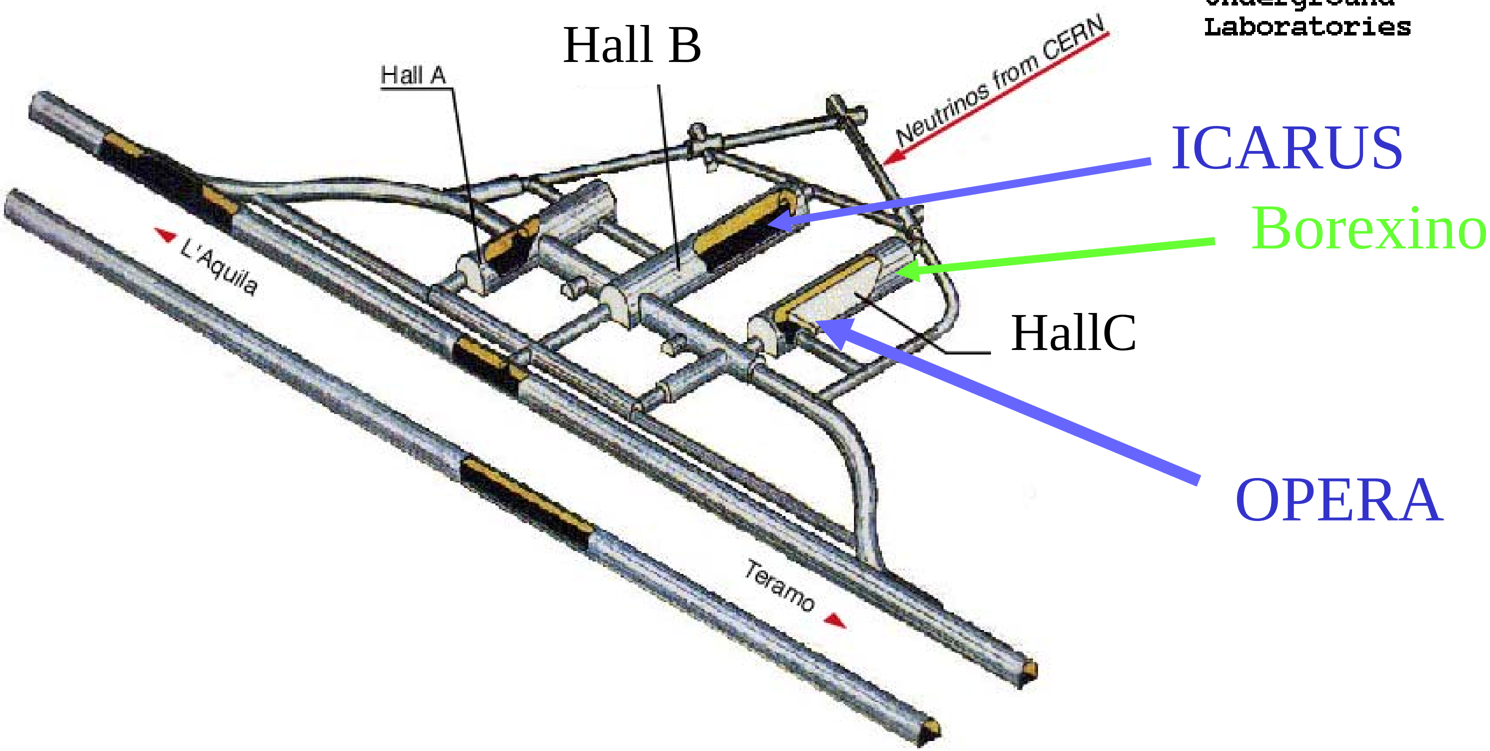
3 large experimental halls

(100m x 18m x 18m)

directed towards CERN



3800 mwe



OPERA

COLLABORATION

Belgium
IIHE(ULB-VUB) Brussels

Bulgaria
Sofia University

China
IHEP Beijing, Shandong

Croatia
Zagreb University

France
LAPP Annecy, IPNL Lyon, LAL Orsay, IRES Strasbourg

Germany
Berlin, Hagen, Hamburg, Münster, Rostock

Israel
Technion Haifa

Italy
Bari, Bologna, LNF Frascati, L'Aquila, LNGS, Naples, Padova, Rome, Salerno

Japan
Aichi, Toho, Kobe, Nagoya, Utsunomiya

Russia
INR Moscow, ITEP Moscow, JINR Dubna, Obninsk

Switzerland
Bern, Neuchâtel

Turkey
METU Ankara

- July 2000:
  Experiment proposal
- May 2003
  Start construction
- Summer 2006
  First beam expected

36 groups
~ 165 physicists

Newcomer in 2005:
Tunis group

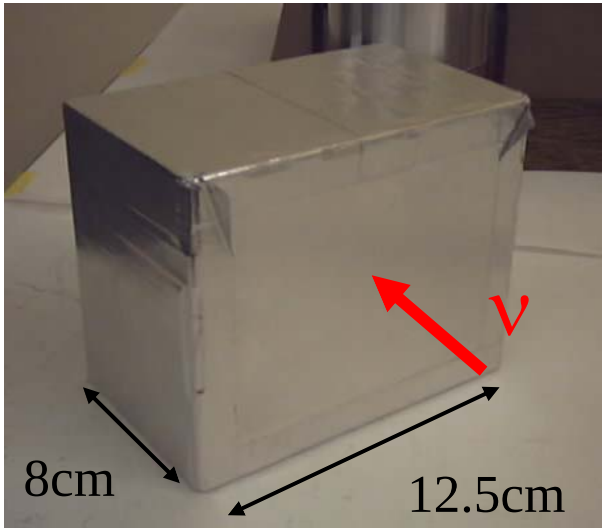
OPERA: CERN experiment CNGS1

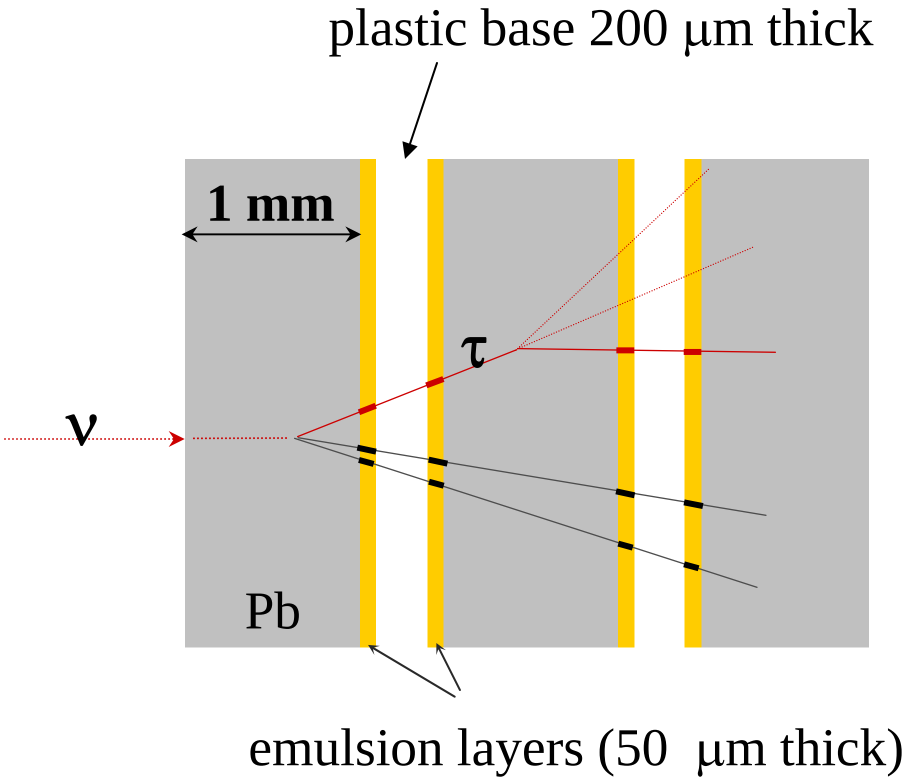
direct ν_τ observation by DONUT in 2000

use photographic emulsions

alternate emulsion films with lead sheets (ECC concept)

Modular detector: basic unit brick



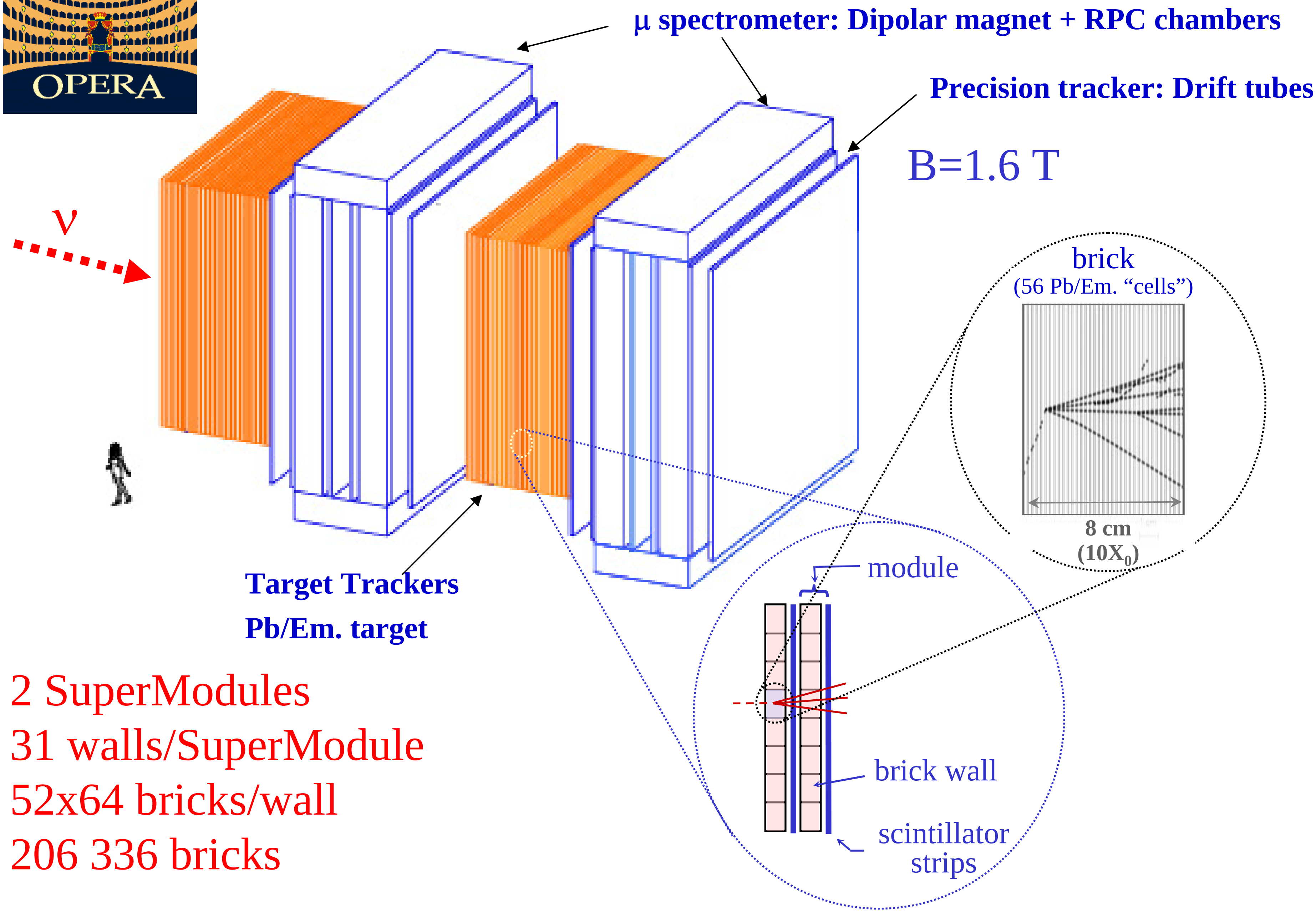


$10X_0$
56 Pb sheets (1mm)
57 FUJI emulsion films
1 changeable sheet

σ(angle) = 2.1 mrad
σ (position) = 0.21 μm

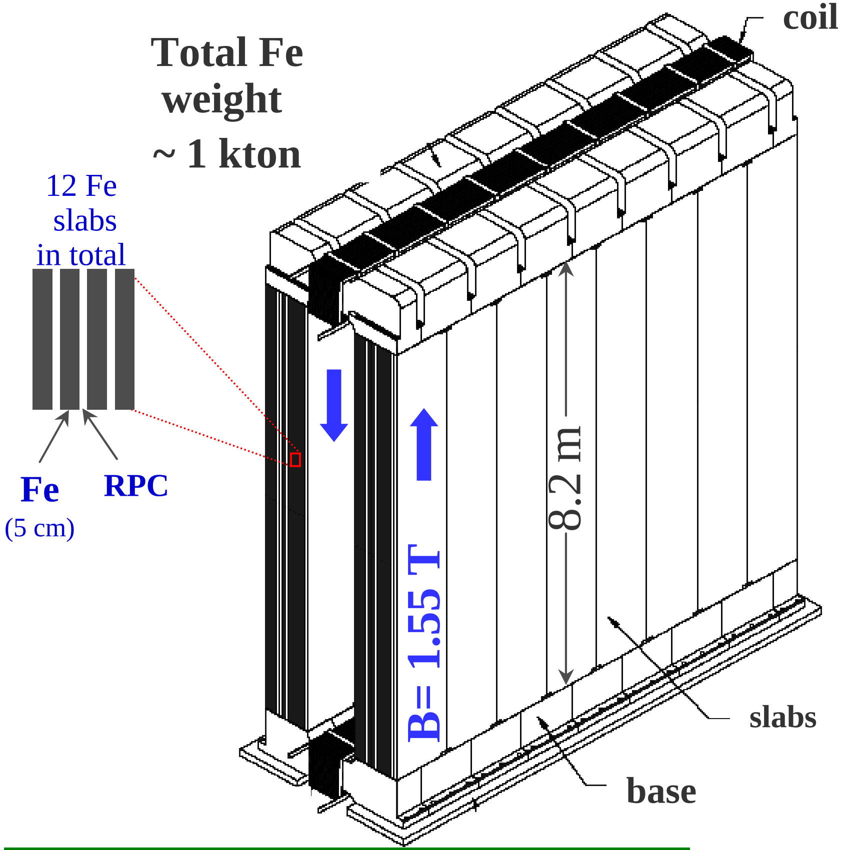
206 336 bricks are needed → target mass: 1.8 ktons

1.8 kton detector at Gran Sasso (Hall C)



- 2 SuperModules
- 31 walls/SuperModule
- 52x64 bricks/wall
- 206 336 bricks

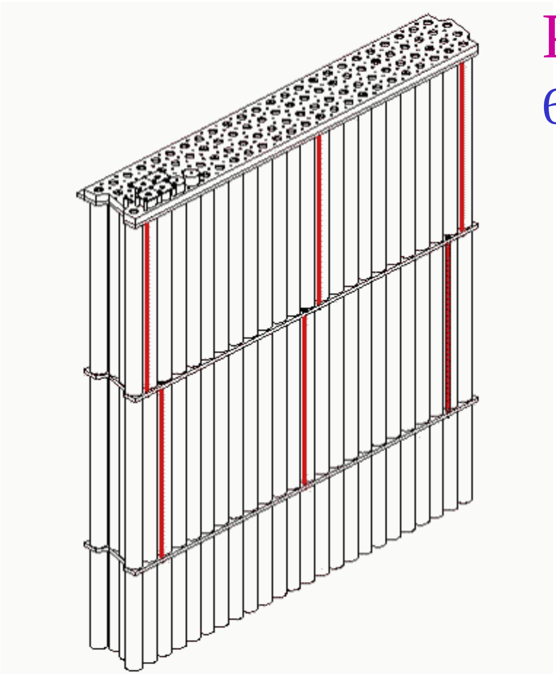
Muon spectrometer



installation started: may 2003

Bakelite RPC:

22 planes of 21 chambers
2.9 m x 1.1m
copper strips



Precision tracker

6 planes of drift tubes

- **Tube :** vertical , ϕ = 38 mm, length 8 m , wire ϕ = 50 μm
- **Plane:** 4 staggered layers, each with 168 tubes
- efficiency: 99.1%
- resolution: < 300 μm

$$\varepsilon^{miss}_{charge} \approx (0.1 \div 0.3)\%$$

$\Delta p/p$ < 20% for p<50 GeV

μId > 95%
(with Target Tracker)

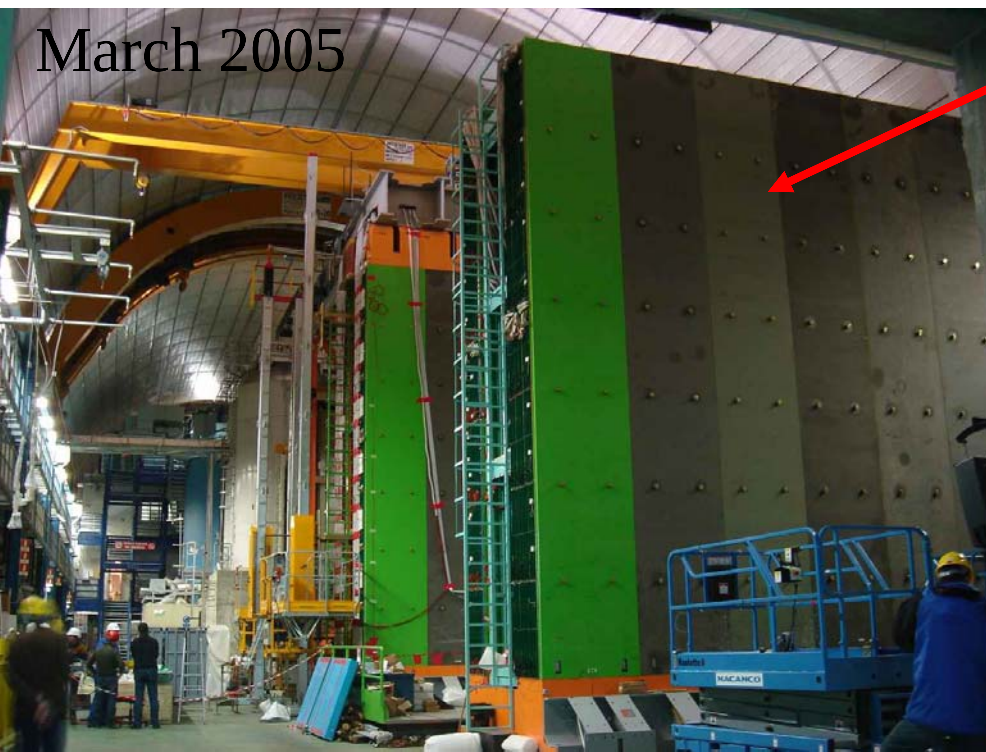
Magnet SM1 completed June 2004

Precision tracker:

Mass production started in January 2005

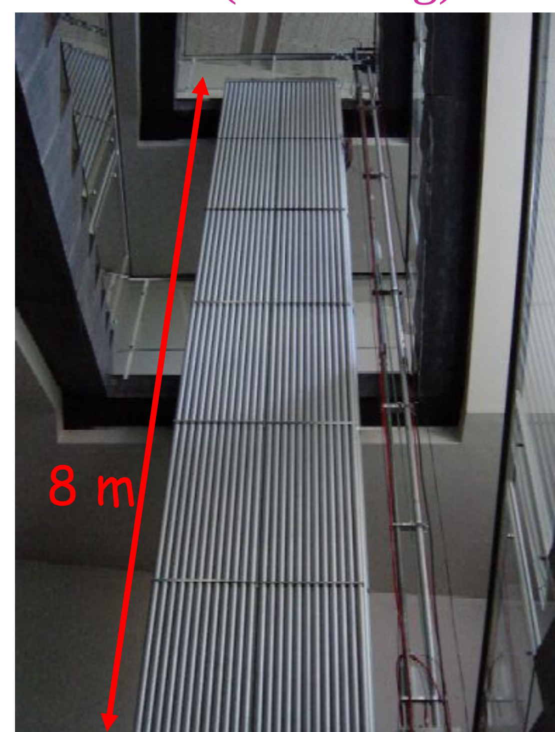
Installation: 48 modules in April 2005

48 modules in August 2005



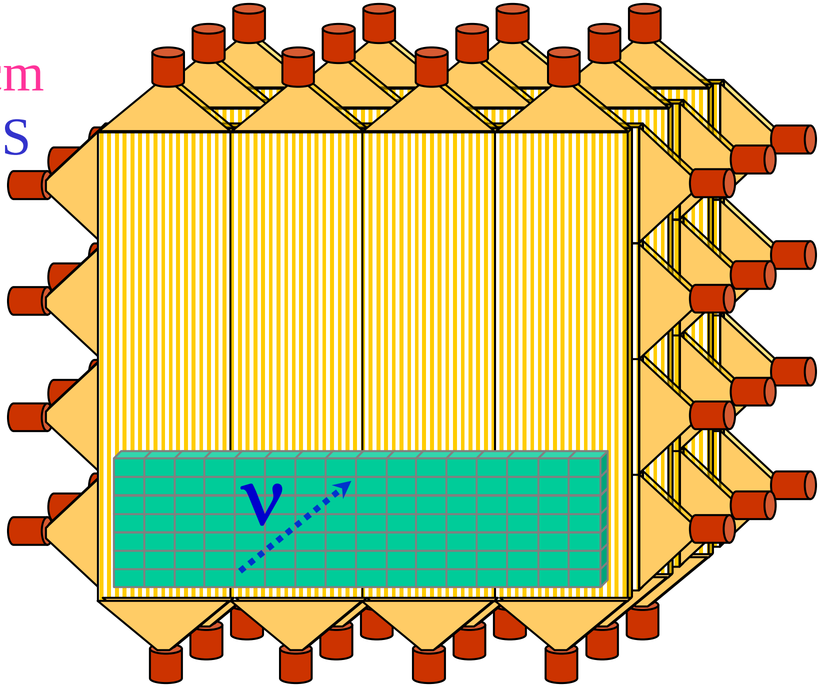
Magnet SM2 completed March 2005

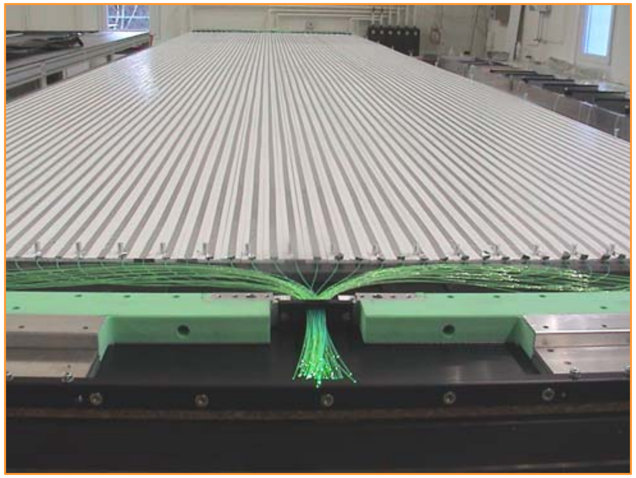
full size prototype module (Hamburg)



Target tracker:

- Plastic scintillator strips: 6.7 m x 2.5 cm x 1 cm
- AMCRYS-H (Kharkov) readout by Kuraray WLS optical fibres + Hamamatsu PMT 64 channels
- X and Y planes of 256 strips

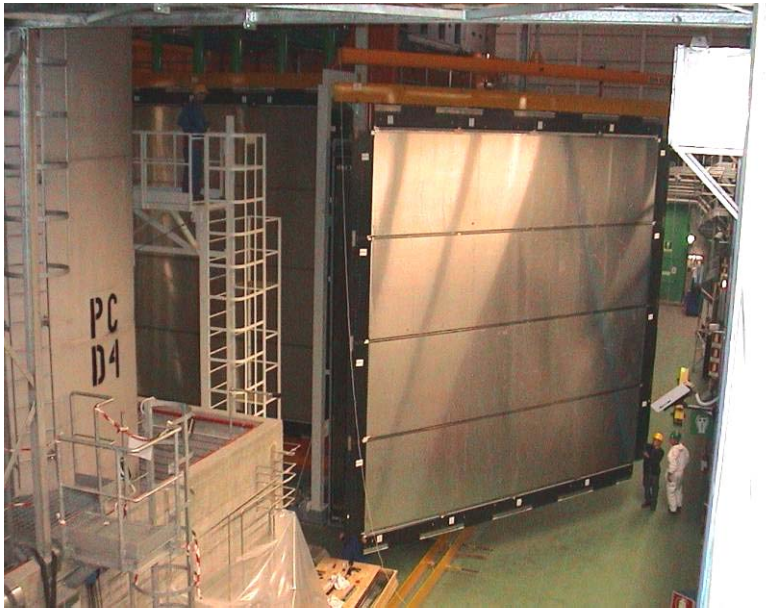




Module assembly in Strasbourg (IRES): > 60%

- Target Tracker tasks :
  - trigger (ε > 99%)
  - brick finding: ε_{brick} = 70-80%
  - initiate muon tagging

Commissioning of the electronics (FE chips LAL) and DAQ (IPNL) at LNGS in progress



- Mechanical Structure Extended, completed for SM1 August 2004
- Target Section SM1 startedSept 2004

OPERA Hall C : september 04

Target walls: mass production going on.
Rate: 2 half-walls/week

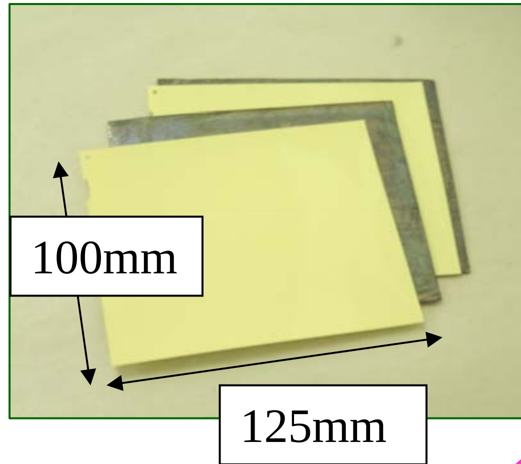
December 04: first brick wall installed in Hall C

- Installation procedure needs optimisation
- Target installation paused
- Some modifications in support structure foreseen
- Target Installation should resume beginning of May 2005

The Bricks:

Germany

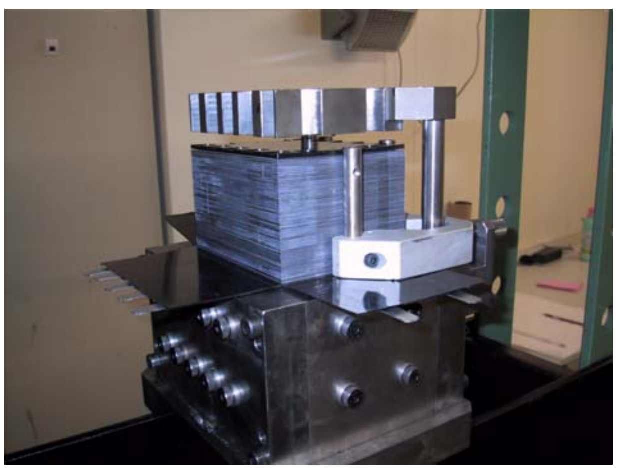
LEAD
Low radioactivity lead
(Boliden) Pb +2.5 % Sb
12 million plates

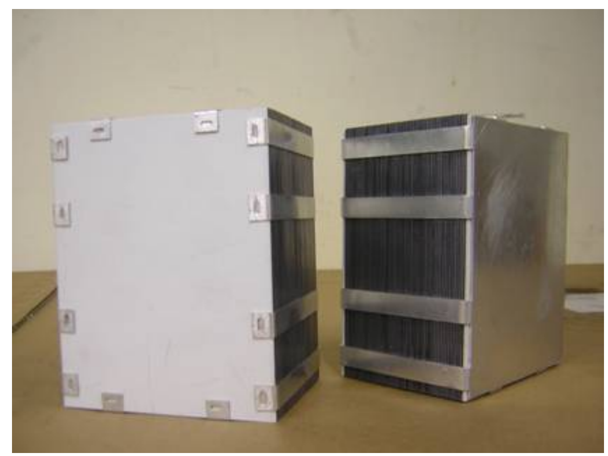


Japan

Emulsion films
12 million sheets

Italy

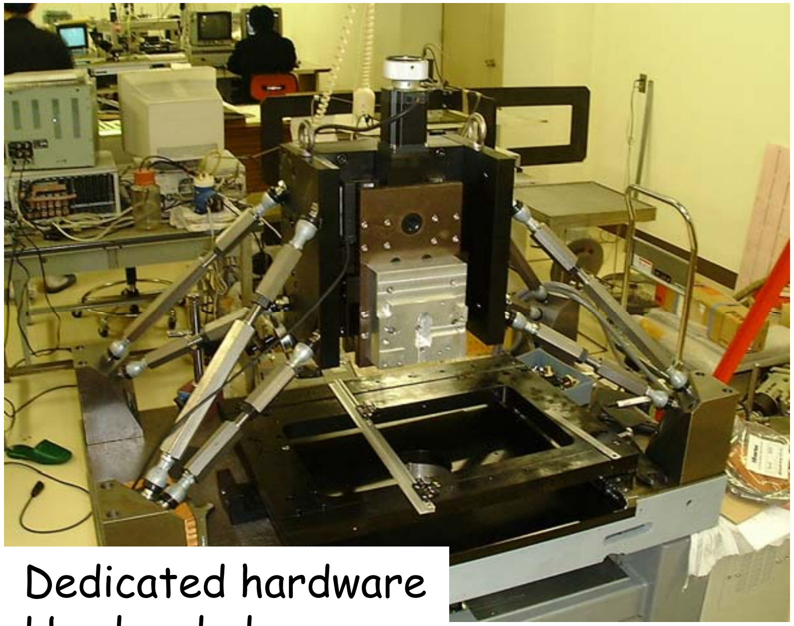




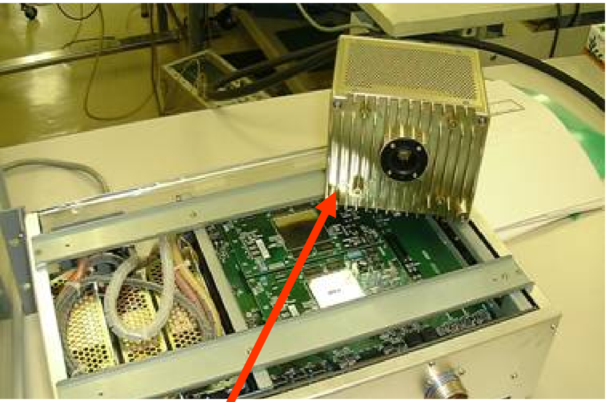
In Gran Sasso underground area: automatic Piling and packaging
2 bricks/mn → 1 year production

Automatic Scanning: Nagoya and Europe R&D efforts

S-UTS prototype at Nagoya



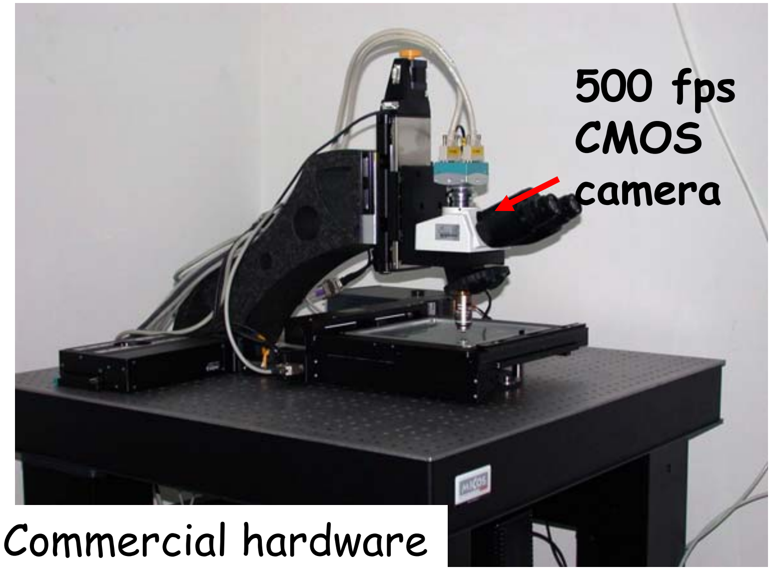
Dedicated hardware
Hard coded



- Fast CCD camera (3 k frames/sec)
- Continuous movement of the X-Y stage

European station

Bari, Bern, Bologna, Lyon, Napoli, Neuchatel, Roma, Salerno



Commercial hardware
Software algorithms

15 microscopes working

Scanning speed ~ 20 cm^2/h/side

Single side microtrack finding efficiency ~ 95%

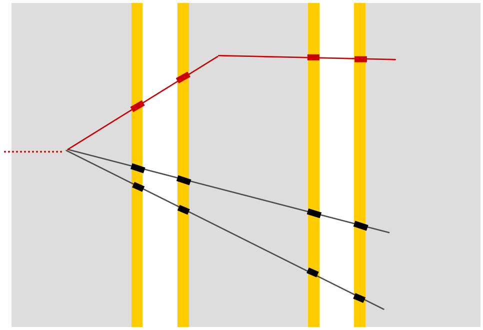
Sheet-to-sheet alignment (8 GeV/c πs) ~ 0.5 μm

Angular resolution ~ 2 mrad

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

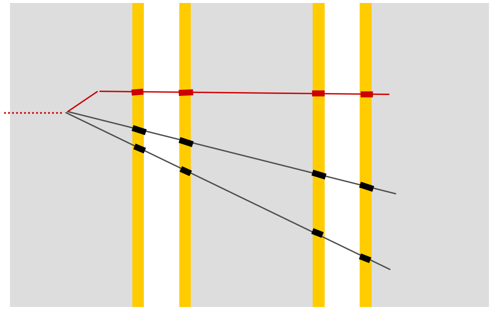
Exploited τ decay channels

$\tau \rightarrow$ e " long decays "
$\tau \rightarrow \mu$ " long decays "
$\tau \rightarrow$ h " long decays "
ε.BR = 2.8-3.5%



kink angle θ_{kink} > 20 mrad

$\tau \rightarrow$ e " short decays "
$\tau \rightarrow \mu$ " short decays "
ε.BR = 0.7-1%



impact parameter I.P. > 5 to 20 μm

Recently added: **$\tau \rightarrow$ 3h long and short decays**

Main backgrounds:

- charm decays (64%)
- large angle μ scattering (13%)
- hadron reinteractions (23%)

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

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

- New Brick finding strategy: eff. gain +10%
- Including the $\tau \rightarrow$ **3 prongs** (ε.BR = 1.0%): eff. gain +10%

channel	Signal (Δm^2 (eV^2))			ε.BR	Background
	$1.9\ 10^{-3}$	$2.4\ 10^{-3}$	$3.0\ 10^{-3}$		
e	2.7	4.3	6.7	3.7%	0.23
μ	2.2	3.6	5.6	3.1%	0.23
h	2.4	3.8	5.9	3.3%	0.32
3h	0.7	1.1	1.7	1.0%	0.22
total	8.0	12.8	19.9	11.1%	1.00

Improvements under study

- Reduction of the number of background events (~30%):
  - ❑ improve π/μ id. (low p) using dE/dx vs range: reduce the charm background
  - ❑ New measurement of the large angle μ scattering
  - ❑ New estimates of the hadronic background using Chorus data

The ICARUS Collaboration

ICARUS experiment jointly approved by INFN and CERN

– CNGS2 (April 2003)

- Explicit search for ν oscillations at the CNGS neutrino beam

25 INSTITUTIONS, 150 PHYSICISTS

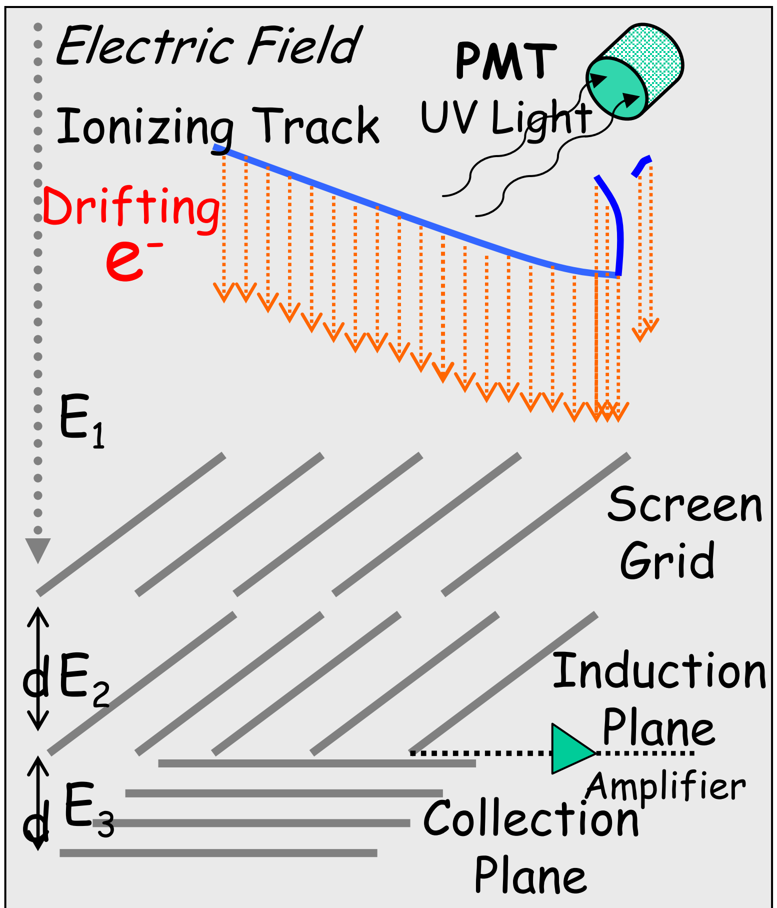
ITALY: **L'Aquila, LNF, LNGS, Milano, Napoli, Padova, Pavia, Pisa, CNR Torino, Pol. Milano.**
SWITZERLAND: **ETHZ Zürich.**
CHINA: **Academia Sinica Beijing.**
POLAND: **Univ. of Silesia Katowice, Univ. of Mining and Metallurgy Krakow, Inst. of Nucl. Phys. Krakow, Jagellonian Univ. Krakow, Univ. of Technology Krakow, A.Soltan Inst. for Nucl. Studies Warszawa, Warsaw Univ., Wroclaw Univ.**
USA: **UCLA Los Angeles.**
SPAIN: **Univ. of Granada, Madrid**
RUSSIA: **INR Moscow**

Physics program: CNGS,
solar and atm. ν,
Supernova ν,
proton decay

ICARUS:

Principle: 3D imaging in a large volume Liquid Argon TPC

- very pure LAr (<0.1ppb) → electrons can drift over large distances (>1.5 m)
- scintillation light for t_0
- 3 wire planes at 0,+60,-60^o with 3mm pitch
- → 3D reconstruction with high resolution

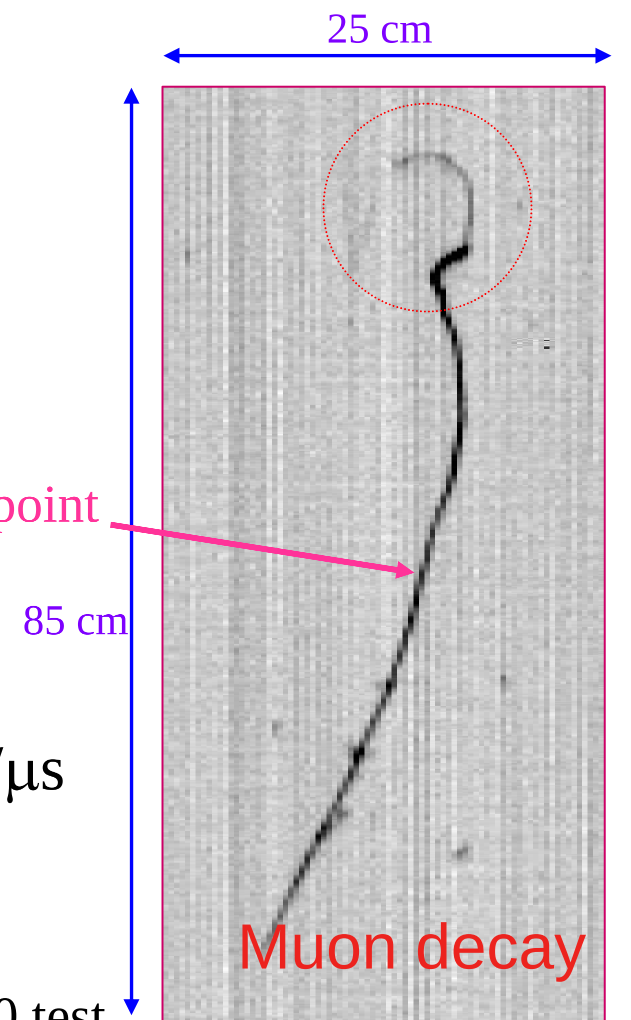


σ_z=150μm

σ_{xy}=1mm

Energy deposition measured for each point (400 ns sampling)

V_{drift}=1.56mm/μs @ 0.5kV/cm

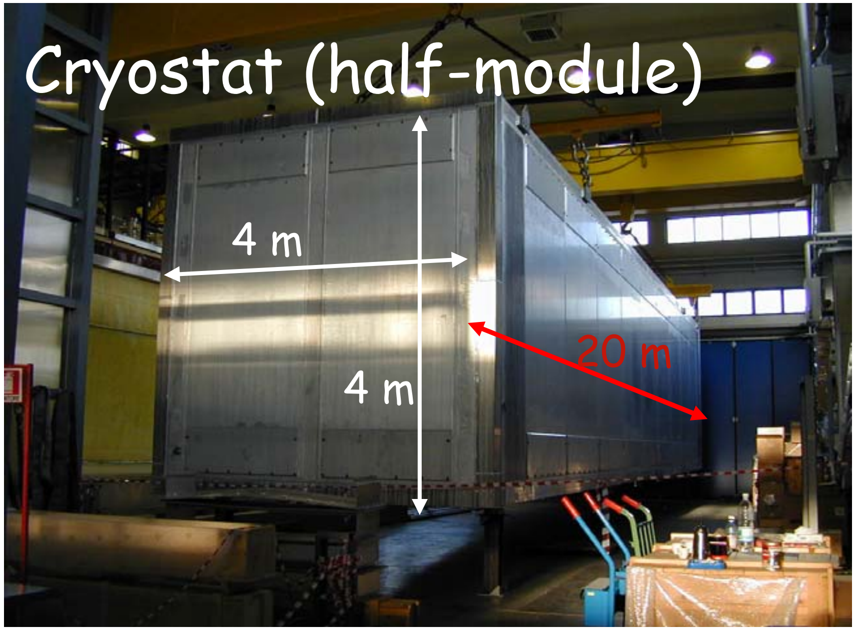


T600 test

Run 960, Event 4 Collection Left

ICARUS design: multi kton device in modular structure

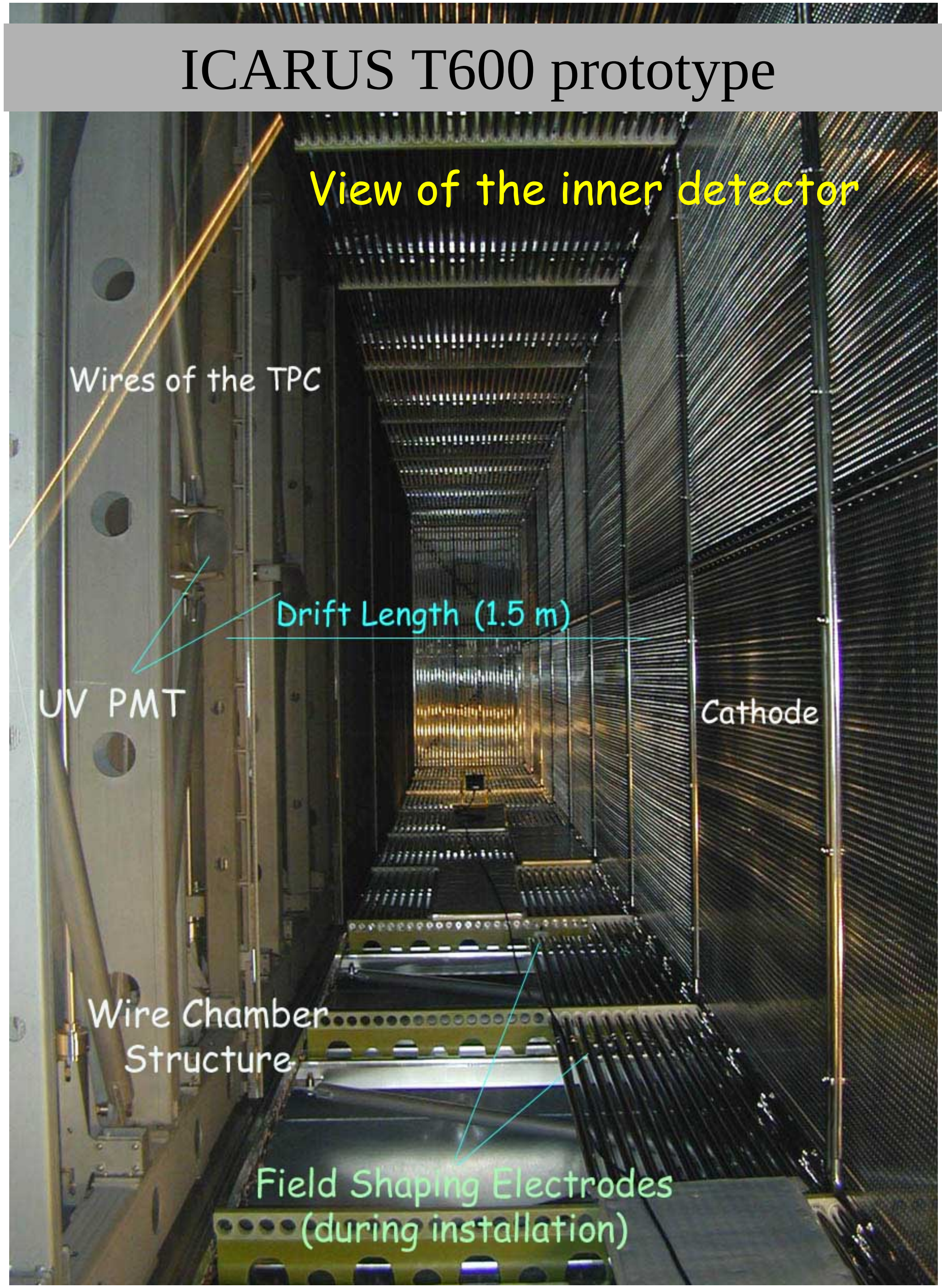
Smallest detector unit: 300 tons (T600 half-module)



1st half T600 succesfully tested during 2001 in Pavia

Validate the technology for these large scales

ICARUS T600 prototype



Detector performance:

EM and hadronic showers are identified and fully sampled

Total energy obtained from charge integration

➡ Excellent calorimeter with very good E resolution

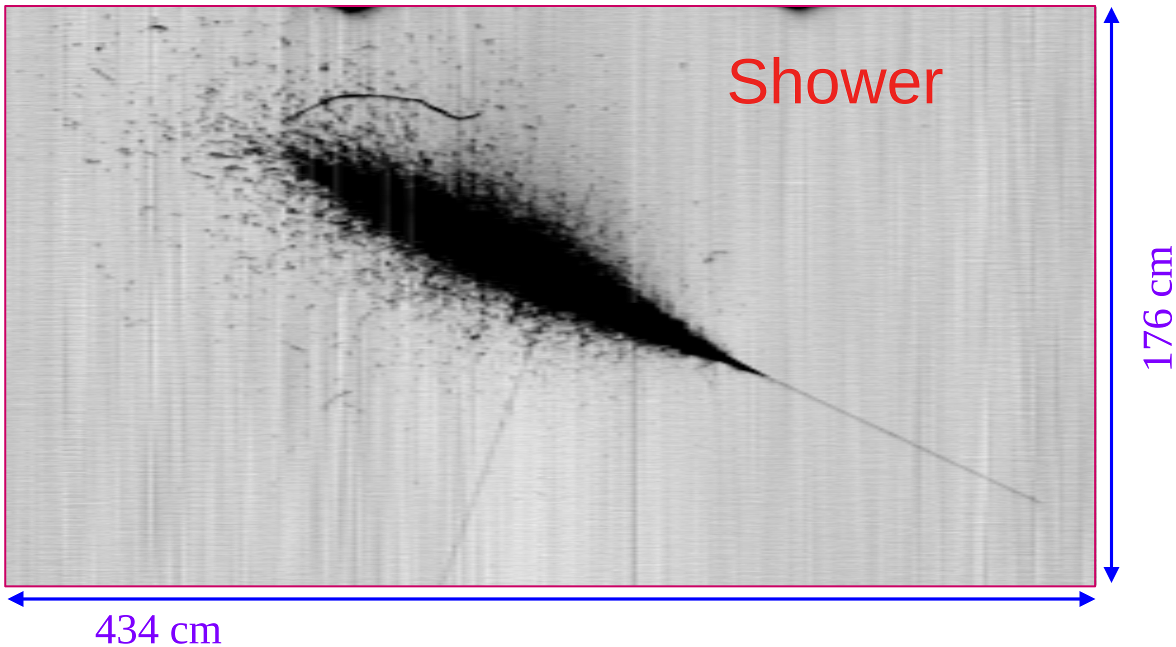
EM showers:

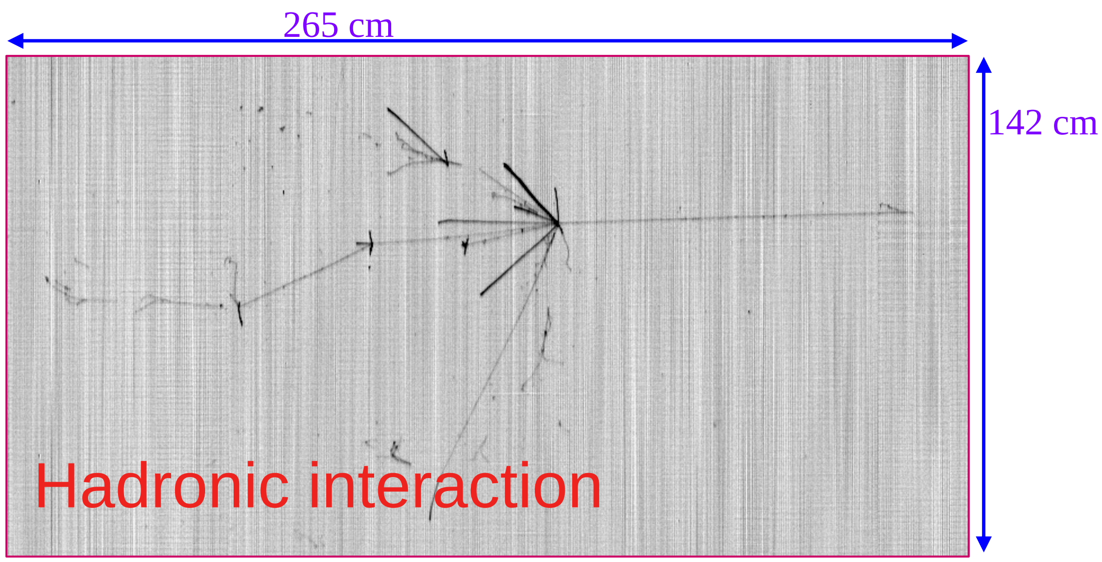
$$\frac{\sigma(E)}{E} = \frac{3\%}{\sqrt{E}} + 1\%$$

Hadronic showers:

$$\frac{\sigma(E)}{E} \approx \frac{17\%}{\sqrt{E}}$$

Pictures from T600 technical run:



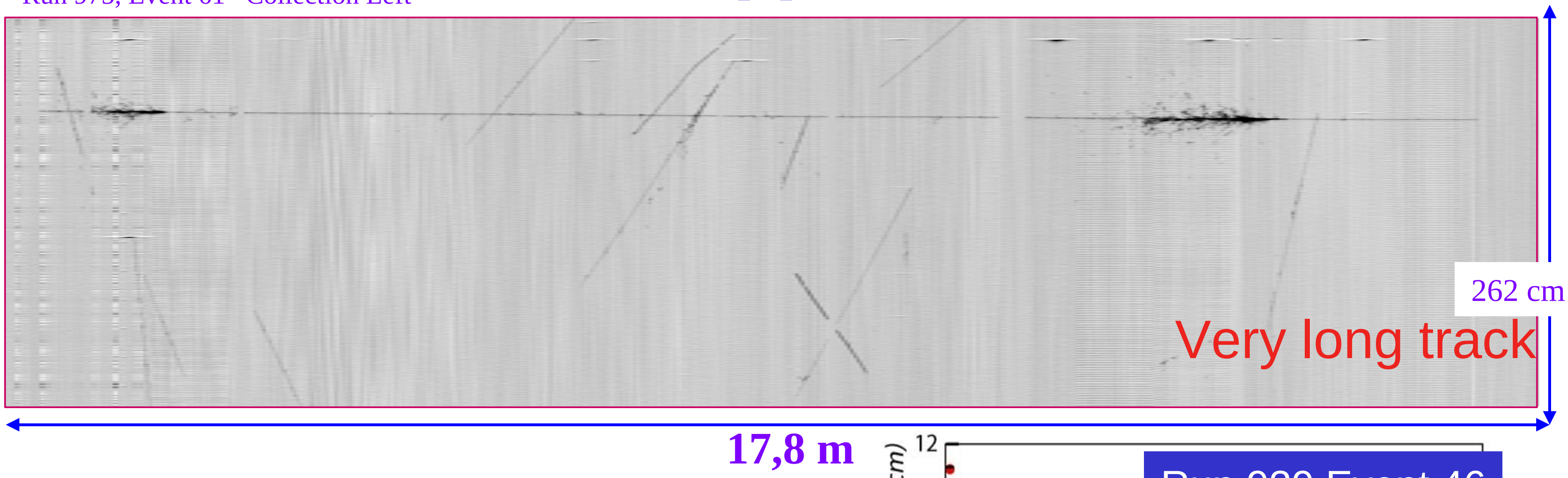


Run 308, Event 160 Collection Left

Detector performance:

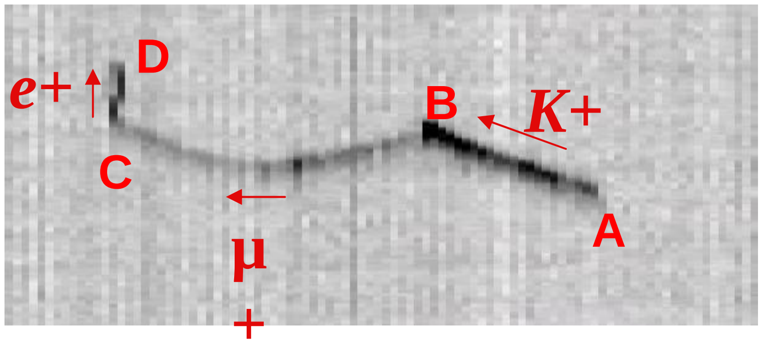
μ momentum measurement by MCS
Δp/p=20% at 10 GeV

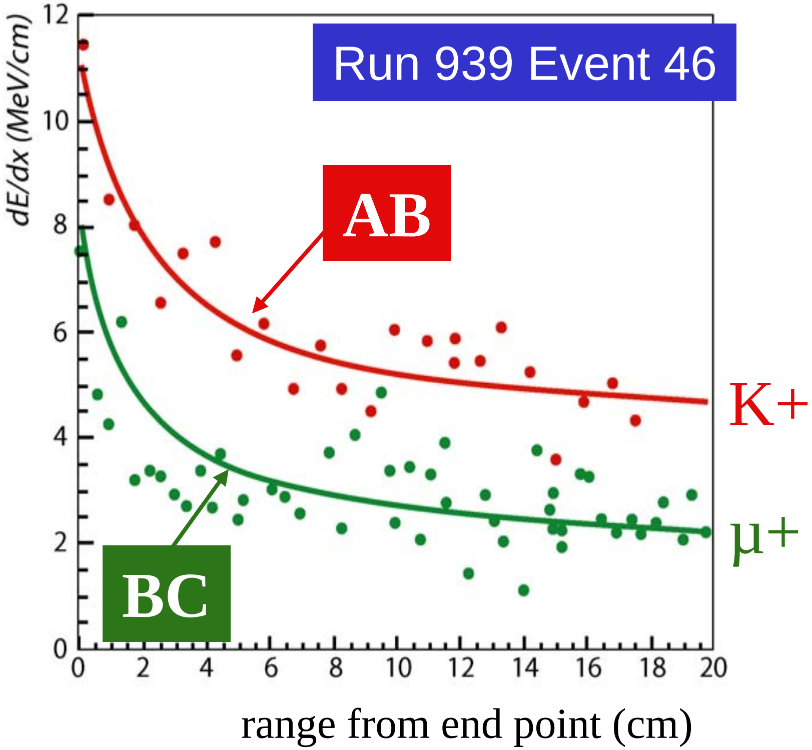
Run 975, Event 61   Collection Left



Particle identification:
by means of dE/dx vs range

$$K^+[AB] \rightarrow \mu^+[BC] \rightarrow e^+[CD]$$



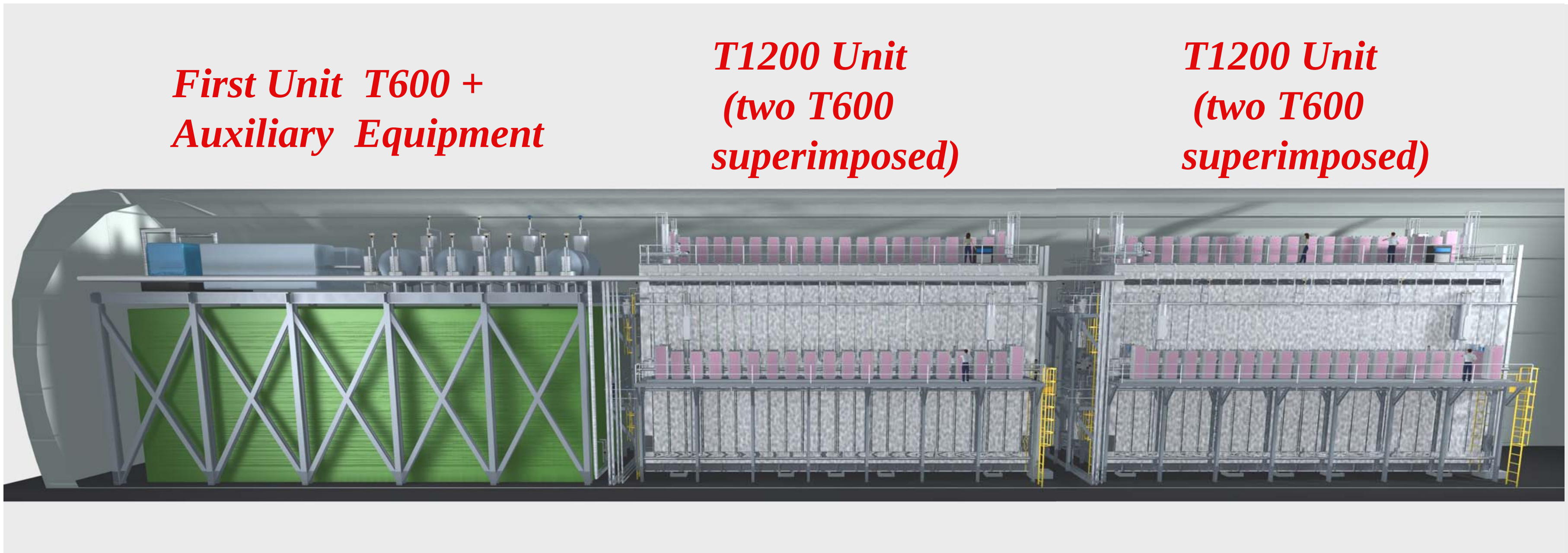


ICARUS in Gran Sasso (Hall B)

gradual mass increase

Cloning T600 module to reach a sensitive mass of 2.35ktons

ν



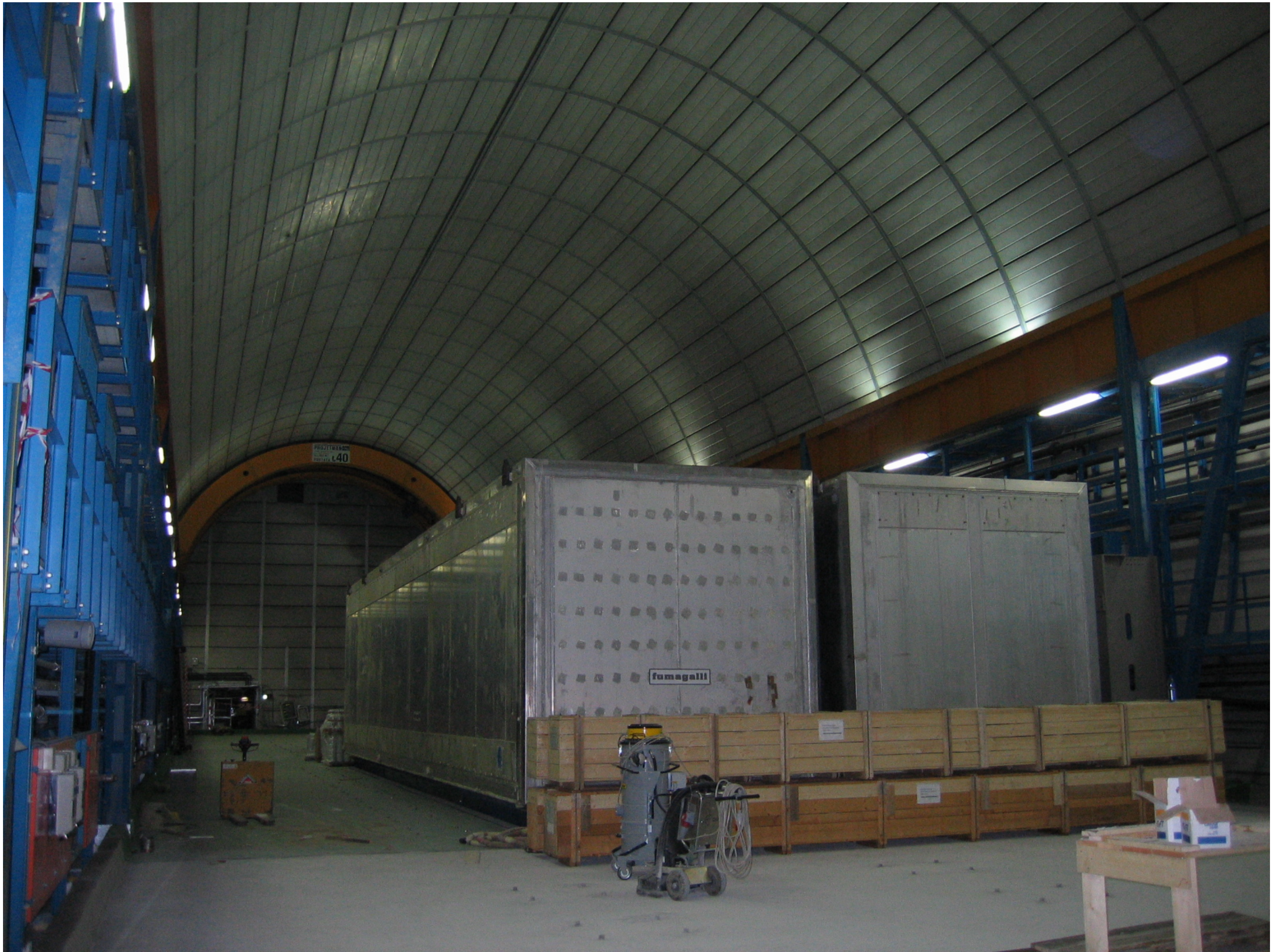
transported to LNGS:
to be installed in 2005
Should be completed by autumn 2006

money available for tendering of cryostats, inner mechanics and readout electronics:
Should be completed by end of 2007

Not yet included in infrastructure design but ultimate goal:
T3000+muon spectrometer

Numbers quoted: 1 year of T600 + 4 years of T1800

T600 in Hall B: March 2005

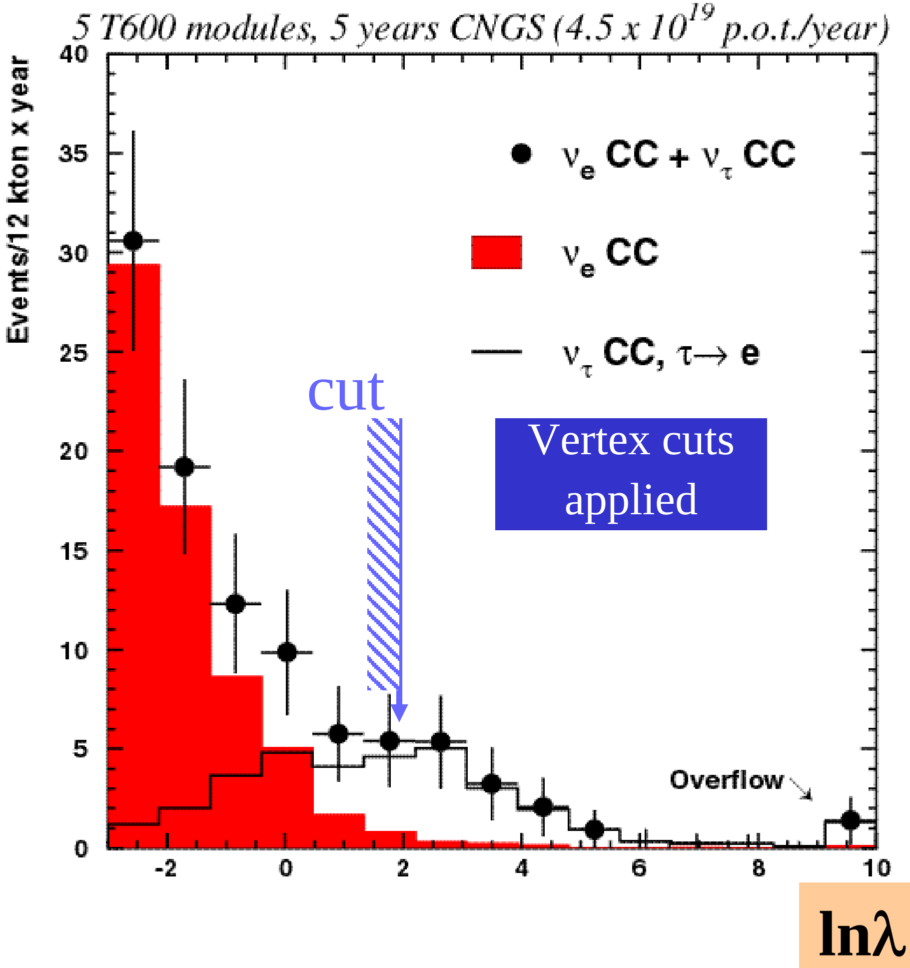


ICARUS: $\nu_\mu \rightarrow \nu_\tau$ search

golden channel: $\tau \rightarrow e\nu_e\nu_\tau$

Kinematical suppression of the background: ν_eCC from beam

- Analysis based on 3 dimensional likelihood
  - **$E_{visible}$,**
  - **P_T^{miss},**
  - **$\rho_l \equiv P_T^{lep}/(P_T^{lep}+P_T^{had}+P_T^{miss})$**
  - **<u>Exploit correlation between variables</u>**
  - Two functions built:
    - L_S ([Evisible, $\mathbf{P_T^{miss}}$, ρ_l]) (signal)
    - L_B ([Evisible, $\mathbf{P_T^{miss}}$, ρ_l]) (ν_e CC background)
  - Discrimination given by



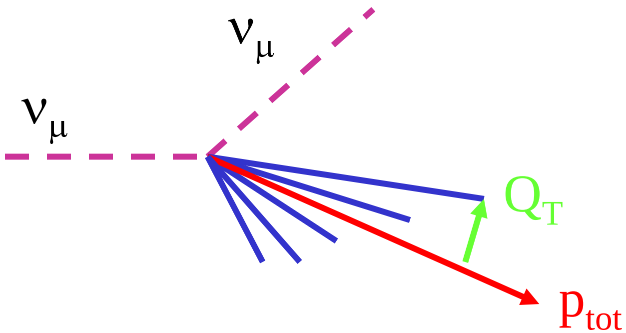
$$\ln\lambda \equiv L([\text{Evisible}, \mathbf{P_T^{miss}}, \rho_l]) = L_S / L_B$$

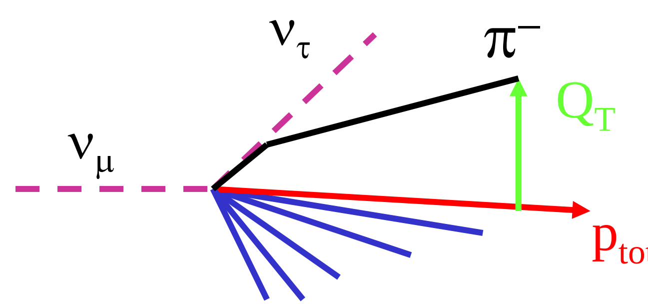
ICARUS: $\nu_\mu \rightarrow \nu_\tau$ search

other channel: $\tau \rightarrow \rho\nu_\tau$ with $\rho^- \rightarrow \pi^-\pi^o$

main background: ν_μ NC $\rightarrow$ missing p_t

use isolation criteria: Q_T





T1800 detector (1 year 0.47 kton+4 years 1.4 kton active LAr)

channel	Signal (Δm^2 (eV^2))			ε.BR	Background
	$1.6\ 10^{-3}$	$2.5\ 10^{-3}$	$3.0\ 10^{-3}$		
e	1.9	4.7	6.8	4.4%	0.3
ρ DIS	0.3	0.8	1.1	0.8%	<0.1
ρ QE	0.3	0.7	1.0	0.7%	<0.1
total	2.5	6.2	8.9	5.9%	0.3

5 years: 2.25×10^{20} pot

$\nu_\mu \to \nu_e$ search: at CNGS

Assuming $\Delta m_{12}^2 << \Delta m_{23}^2 = \Delta m_{13}^2 = \Delta m^2$, in the 3 flavour ν oscillation framework

$P(\nu_\mu \to \nu_\tau) = \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2(1.27\, \Delta m^2\, L/E)$

$P(\nu_\mu \to \nu_e) = \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2(1.27\, \Delta m^2\, L/E)$ ← subleading transition

• look for an excess of ν_e CC events and take into account $\nu_\mu \to \nu_\tau$, $\tau \to e \nu_\tau \nu_e$

expected signal and background

5 years: 2.25×10^{20} pot

OPERA

θ_{13} (deg)	$\sin^2 2\theta_{13}$	Signal $\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\tau$, $\tau \to e\nu_\tau\nu_e$	ν_μ CC	ν_μ NC	ν_e CC
9	0.095	9.3	4.5	1.0	5.2	18
7	0.058	5.8	4.6	1.0	5.2	18
5	0.030	3.0	4.6	1.0	5.2	18

ICARUS T1800

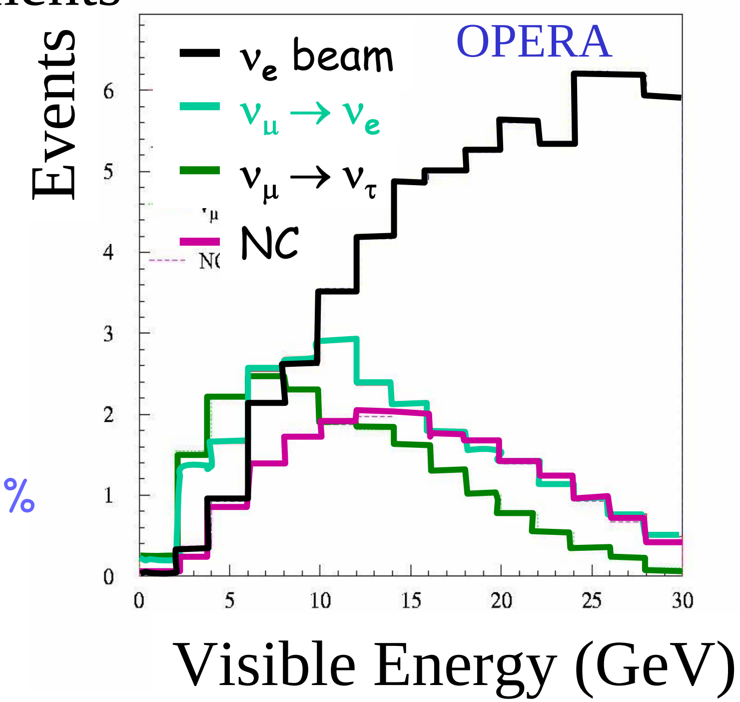
θ_{13} (deg)	$\sin^2 2\theta_{13}$	ν_e CC	$\nu_\mu \to \nu_\tau$, $\tau \to e\nu_\tau\nu_e$	Signal $\nu_\mu \to \nu_e$
9.2	1.000	45	14	18
8	0.076	45	14	13
6	0.030	45	14	8

$\nu_\mu \to \nu_e$ Similar approach in both experiments

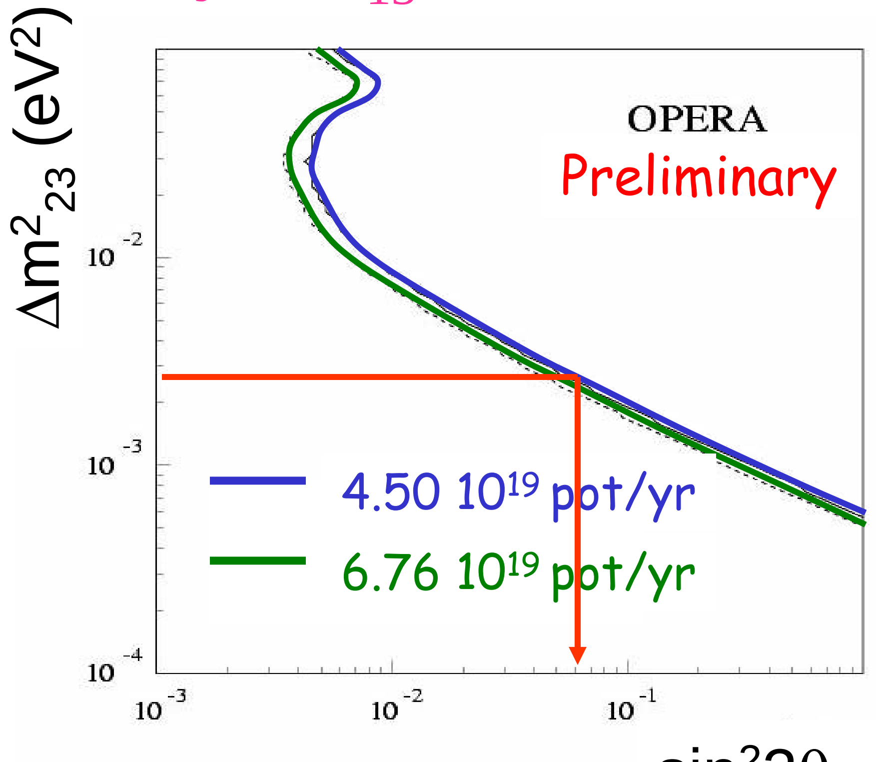
Fit oscillation components simultaneously → $\sin^2 2\theta_{13}$

Both oscillations distort E_{vis} at low energy

use E_{vis}, P_T^{miss}, E_{el}



sensitivity to θ_{13} syst. ν_e contamination up to 10%



Limits at 90% CL for $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 full mixing

	$\sin^2 2\theta_{13}$	θ_{13}
CHOOZ	**<0.14**	**11^0**
ICARUS	**<0.07**	**7.7^0**
OPERA	**<0.06**	**7.1^0**

Conclusions

CNGS beam: on schedule → expect to start in June 2006

OPERA: construction and installation is progressing

→ should be ready to record ν events in 2006

ICARUS: successful demonstration of the principle withT600

Hall B: T600 in 2006 + T1200 version completed end 2007

Physics with CNGS:

$\nu_\mu \to \nu_\tau$:

- first evidence for ν_τ appearance signal after a few years
- expect 20 τ events after 5 years with very small background at $\Delta m^2 \sim 2.4\ 10^{-3}\ eV^2$

$\nu_\mu \to \nu_e$:

- high detector capabilities to explore this channel
- θ_{13} limit down to 6^0
- sensistivity on θ_{13} with a dependence on δ_{CP} different from T2K

The End