



The OPERA experiment

Why the CNGS neutrino beam?

The CNGS beam

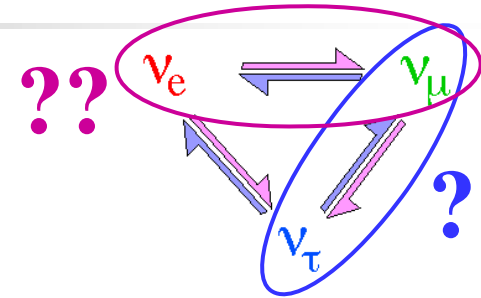
The OPERA detector

Sensitivity to oscillations

Conclusion

Discover the source of the atmospheric ν_μ "deficit"

$n_m \leftrightarrow n_t$ oscillations?

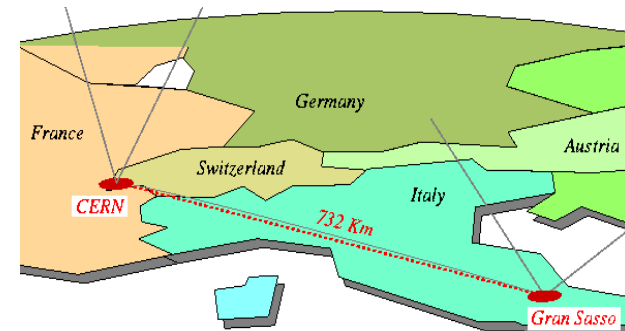


The proof: "appearance" of ν_τ in a ν_μ beam

$n_m \dots \dots \dots n_t$

High energy, long baseline ν beam

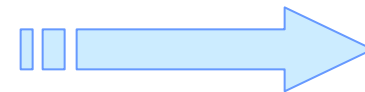
($E_{CM} \gg m_t$ $L \sim 1000$ km)



Detection of τ leptons

Sensitivity to $\Delta m^2 = 1.6-4.0 \times 10^{-3} eV^2$

High background rejection and $M_{target} = O(1$ kton)



CNGS Overview

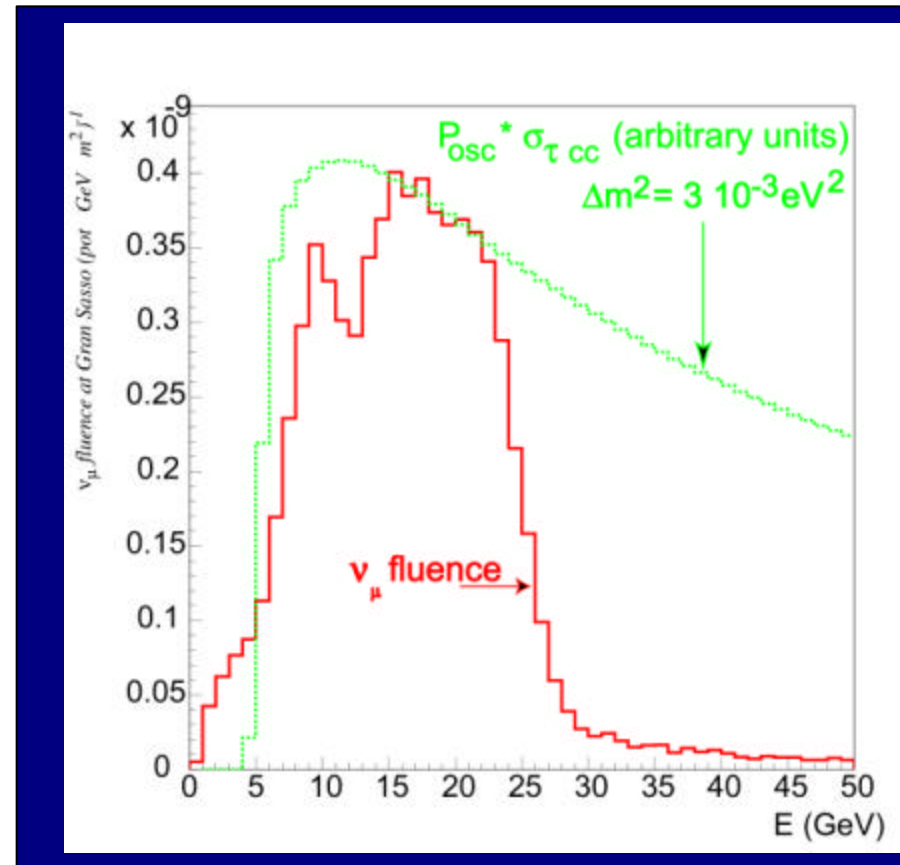
Expected Performance

cf. "Addendum" of 1999:

- priority to LBL n_t appearance -
- SBL experiment "out"
- > result: "lower energy" beam -
more compact layout of
target / horn / reflector

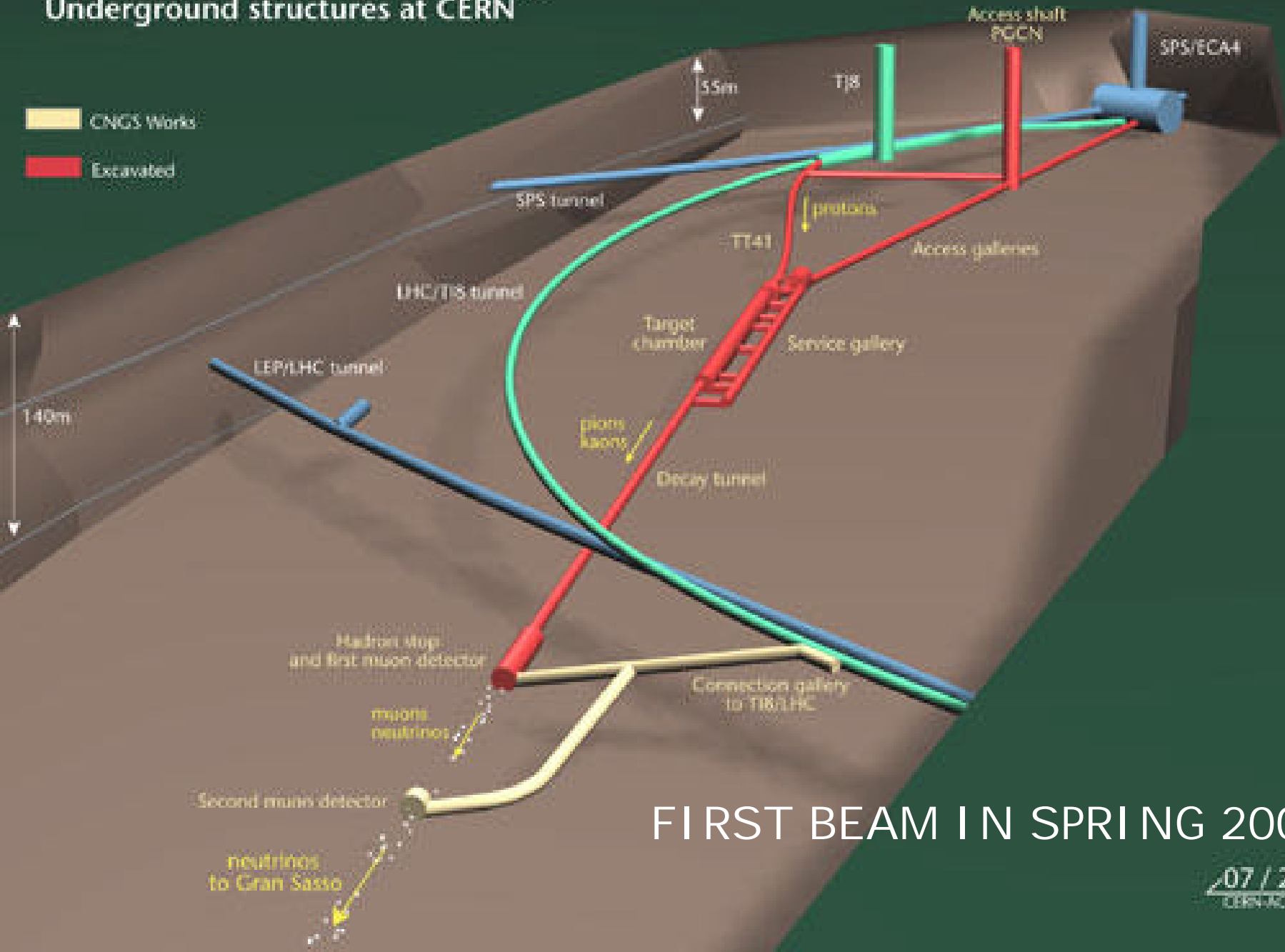
cf. "Note" of Dec. 2000:

- > higher current in reflector
- > space after target for monitor



CERN NEUTRINOS TO GRAN SASSO

Underground structures at CERN



FIRST BEAM IN SPRING 2006



The CNGS and the expected number of events in OPERA

Nominal ν beam (Nov. 2000)

Shared SPS operation

200 days/year

4.5×10^{19} pot / year

Average ν_μ energy 17 GeV

5 year run

1.65 kton average target
mass

(accounting for mass reduction with
time, due to brick removal for analysis)

Expected interactions

$\sim 30000 n_m \text{ NC+CC}$

$\sim 120 n_t \text{ CC}$

at $\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$ and full mixing



Limiting factor for θ_{13} search:

$\nu_e + \text{anti-}\nu_e$ beam contamination $\sim 0.87\%$



COLLABORATION

Belgium

IIHE(ULB- VUB) Brussels

China

IHEP Beijing, Shandong

Croatia

Zagreb

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

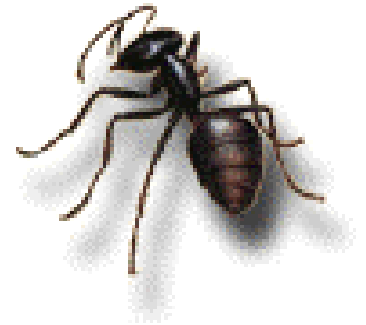
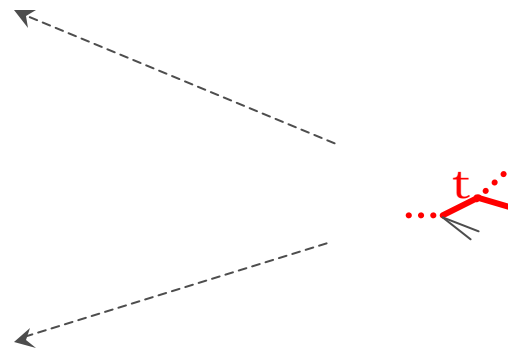
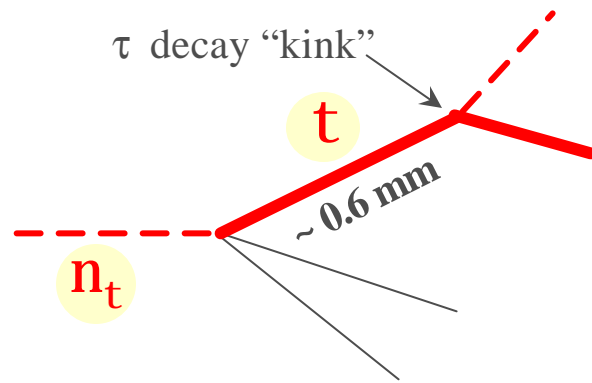
35 groups
~ 170 physicists



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To identify τ leptons, "see" their decay topology



The challenge

n oscillation \otimes massive target AND decay topology \otimes micron resolution



Lead - nuclear emulsion sandwich
"Emulsion Cloud Chamber", in brief "ECC"

The Emulsion Cloud Chamber (ECC)

- Emulsions for tracking, passive material as target

↳ < mm space res.

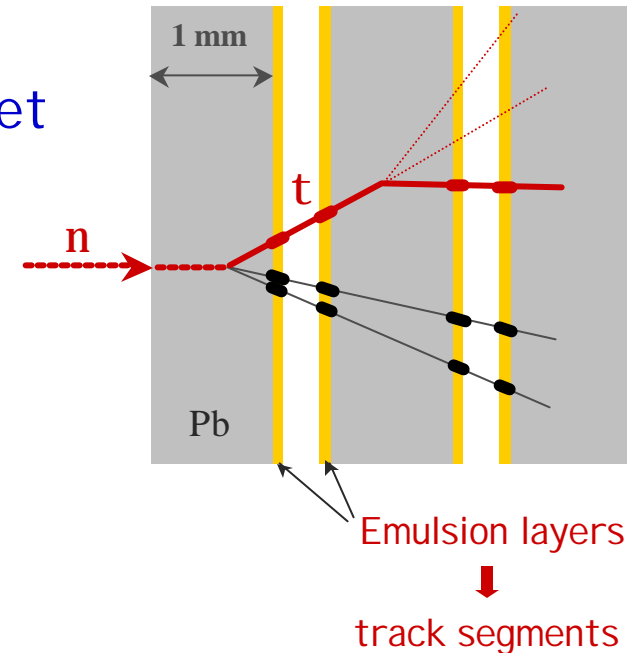
↳ mass

- Established technique

- charmed "X-particle" first observed in cosmic rays (1971)
- DONUT/FNAL beam-dump experiment: ν_τ observed (2000)

$$Dm^2 = O(10^{-3} \text{ eV}^2) \quad \textcircled{R} \quad M_{\text{target}} \sim 2 \text{ kton}$$

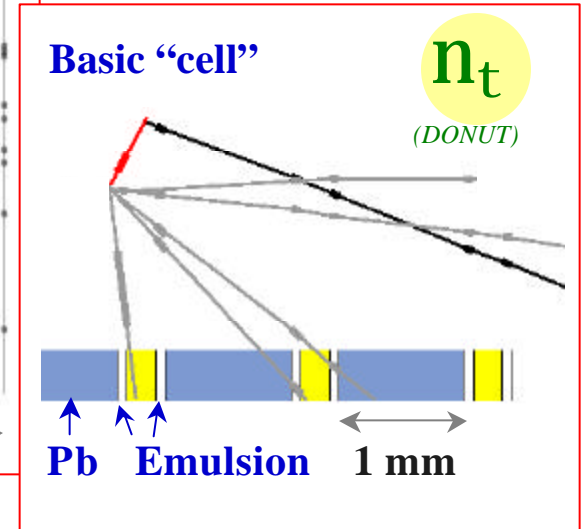
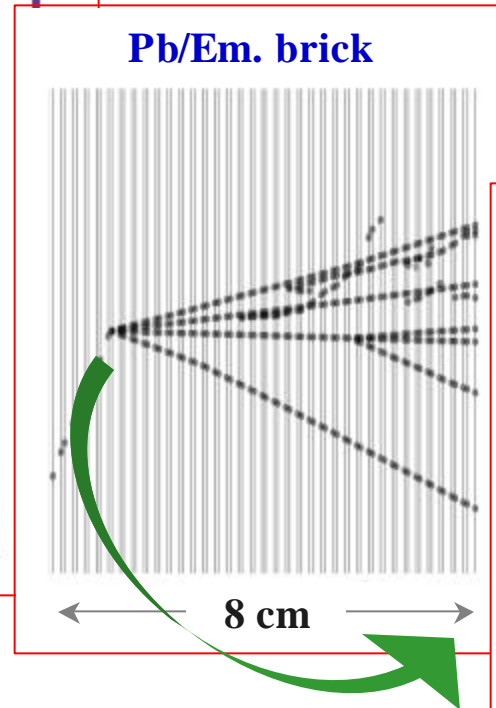
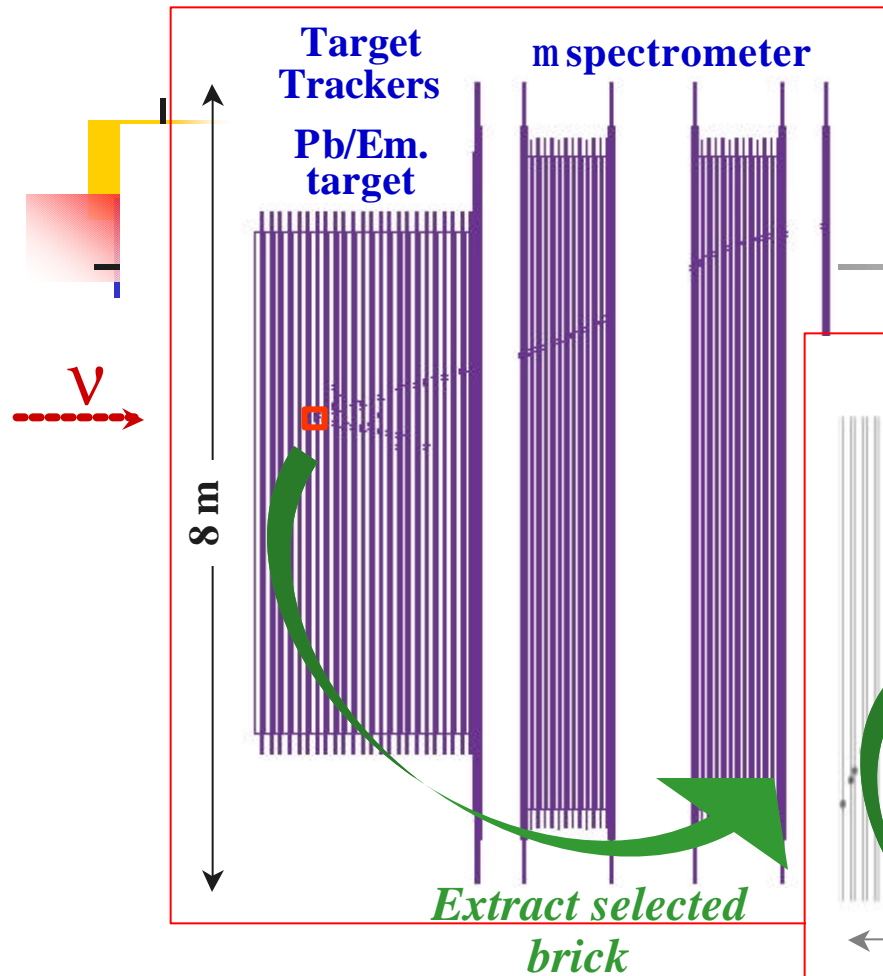
modular structure ("bricks"): basic performance is preserved
large detector → sensitivity, complexity
required: "industrial" emulsions, fast automatic scanning



Experience with emulsions and/or ν_τ searches :
E531, CHORUS, NOMAD and DONUT



A "hybrid"
experiment
at work



Electronic detectors

- select n interaction brick
- m ID, charge and p

Emulsion analysis

- Ⓡ vertex search
- decay search
- e/g ID, kinematics

Cell structure; exploited τ decay channels and topologies

➤ “Long” decays

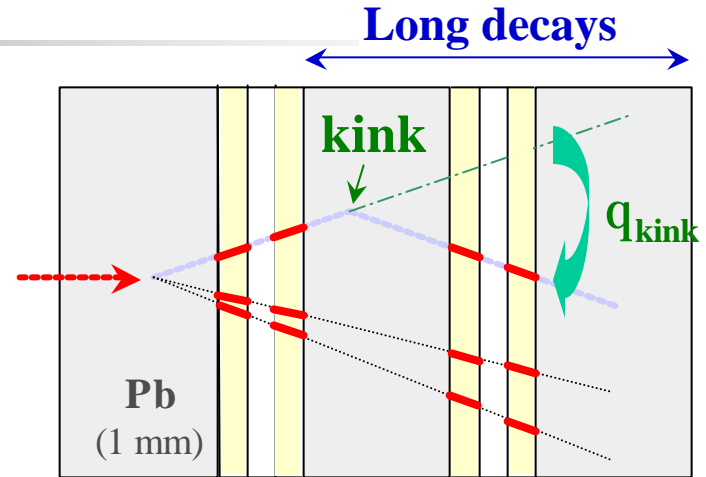
kink angle $q_{\text{kink}} > 20 \text{ mrad}$

t ⊗ e Progr. Rep. 1999

t ⊗ m Progr. Rep. 1999

t ⊗ h (np⁰) Proposal 2000

+ r search Status Rep. 2001

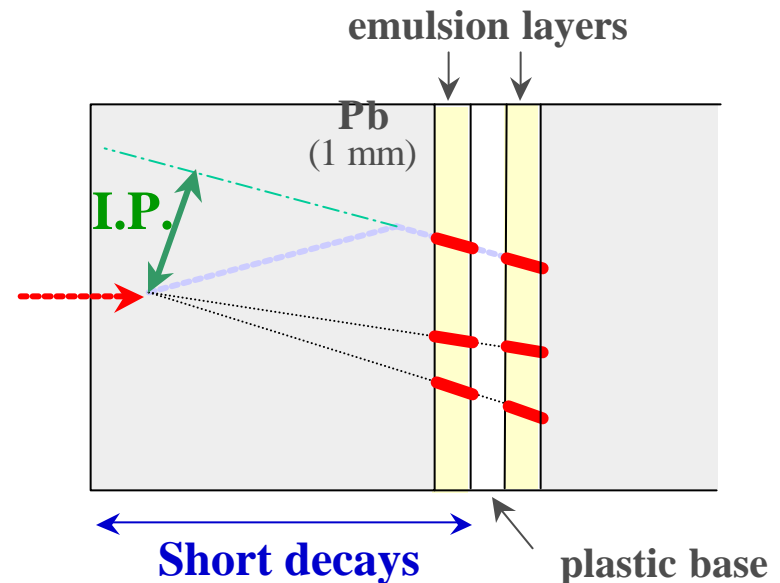


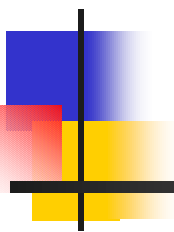
➤ “Short” decays

impact parameter I.P. > 5 to 20 mm

t ⊗ e Proposal 2000

t ⊗ m Status Rep. 2001





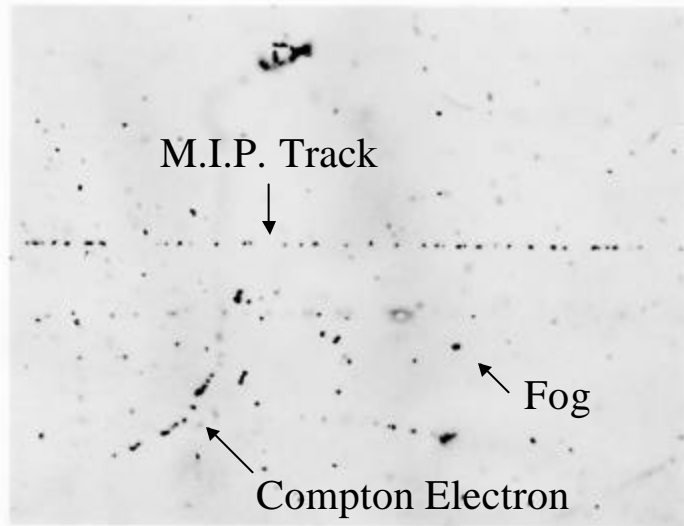
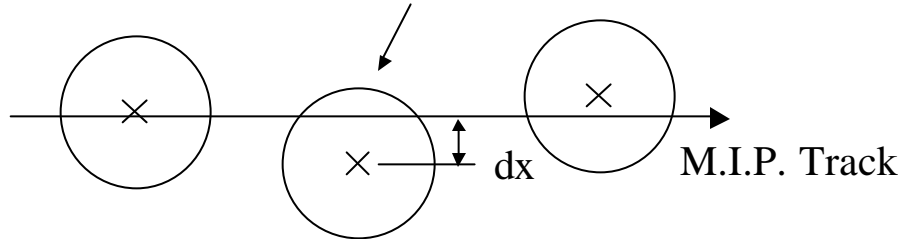
An overview of test results obtained with emulsions

OPERA performance has been
evaluated by using not only Monte
Carlo, but it is based on test results
with real data

Intrinsic space resolution in tracking with emulsion

Cross sectional view of an emulsion layer

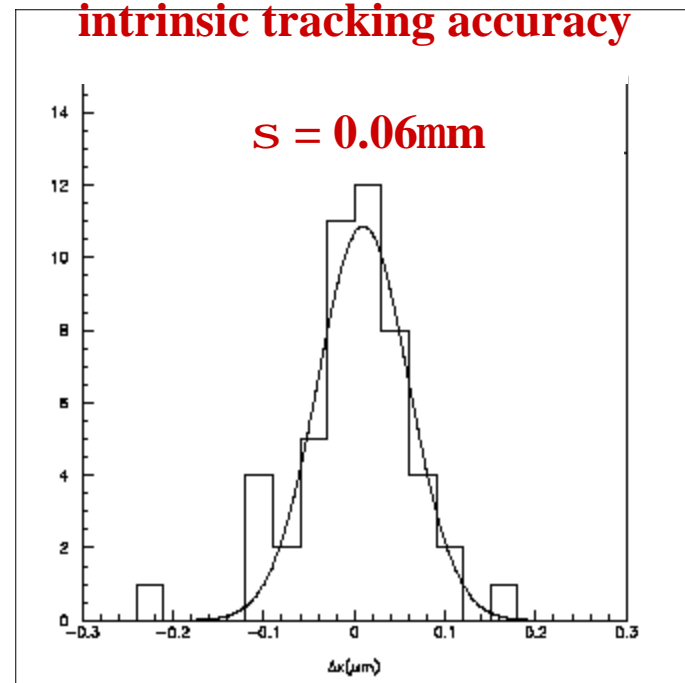
Ag grain after development



100 mm

~ 30 grains / 100 mm
grain diameter ~ 0.6 mm

intrinsic tracking accuracy



Routinely we have $\delta x \sim 0.3 \mu\text{m}$

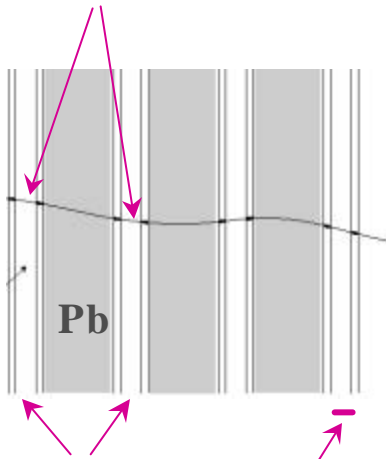
Momentum measurement from Multiple Coulomb Scattering

(allows additional b.g. rejection by kinematic criteria)

Angular method

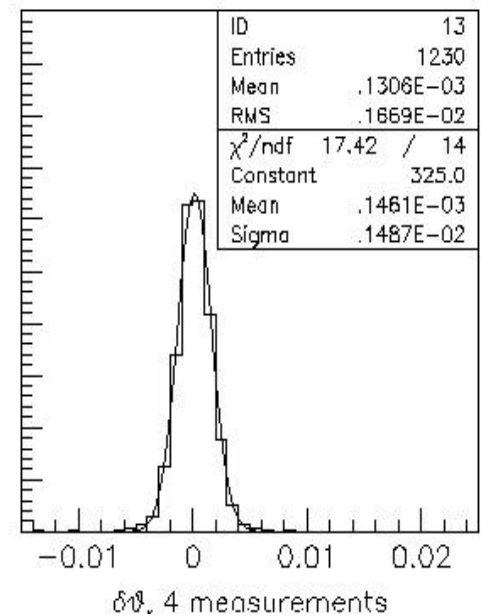
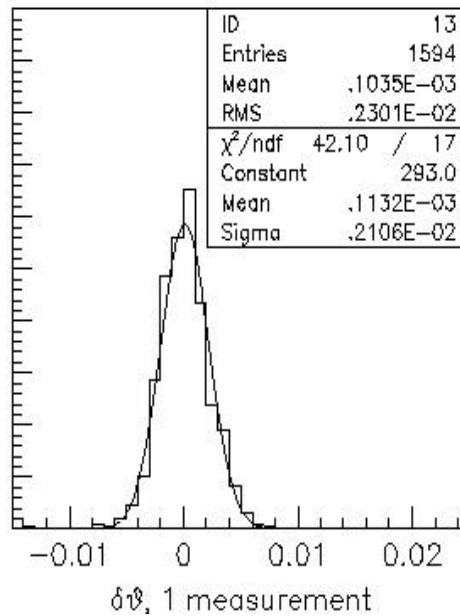
{ Not relying on alignment of emulsion films
 Relying on parallelism of Pb plates and emulsion films

Angle difference



Film with emulsion layer on both sides of a plastic base

Plastic base thickness:
lever arm for angle measurement

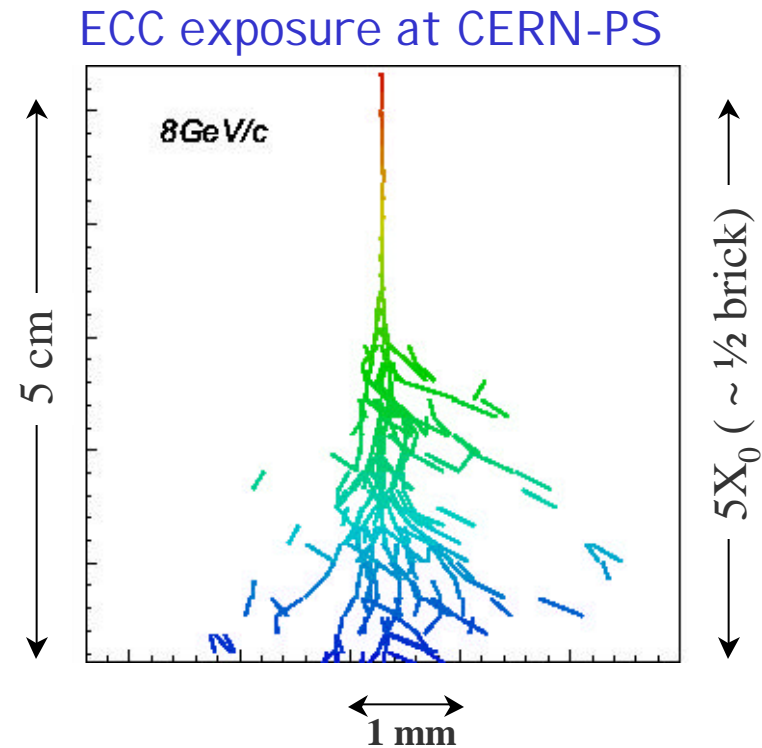


With intrinsic resolution 10.0 GeV/c

(max p measured with $\Delta p/p < 0.2$ after $5X_0$)

Electron identification and energy measurement (1)

- Electron identification close the Pb critical energy
- Performance estimated by reproducing the full chain:
 - Fuji-emulsions stored for about 2 months
 - Emulsion refreshing at the Nagoya University
 - Transportation of packed emulsions to CERN
 - Test exposure at the PS beam (mixture of e and π , C upstream of the ECC)
 - Emulsion developed soon after the beam exposure
 - Scanning and analysis





Electron identification and energy measurement (2)

I dentification

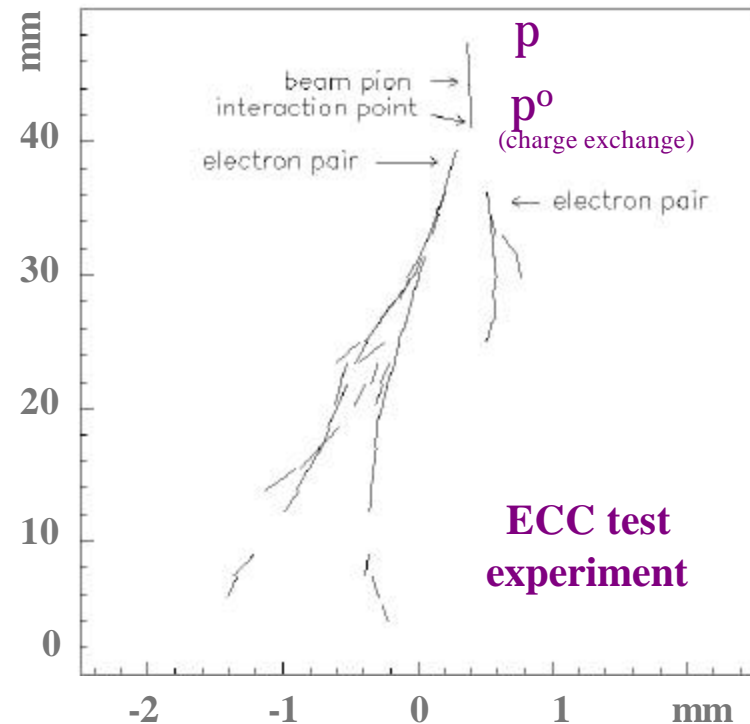
- Method based on shower identification and on MCS of the track
- e/π ratio is measured with Cerenkov and ECC (good agreement)
 - ECC 1.42 ± 0.17 Cerenkov 1.46 ± 0.11 at 2GeV
 - ECC 0.41 ± 0.05 Cerenkov 0.32 ± 0.03 at 4GeV
- $\varepsilon_e = 88$ (91) % at 2 (4) GeV (in agreement with MC)

Energy

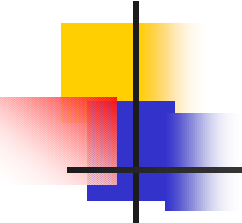
- Measured by counting the number of track segments into a cone along the electron track
- Multiple Coulomb Scattering before showering
- Resolution $\sim 20\%$

γ/π^0 reconstruction

- γ s assigned to primary or to decay vertex depending on Impact Parameter
- γ s assigned to the decay vertex
 - improved $p_{t \text{ decay}}$ resolution (charged+neutral)
 - looser cut and higher efficiency
- γ s assigned to the primary vertex
 - improved missing p_t resolution



π^0 mass reconstruction also possible ($\Delta m \sim 30\%$), but not used in the following analysis



Summary of the event reconstruction with OPERA

- High precision tracking ($\delta x < 1 \mu\text{m}$ $\delta \theta < 1 \text{mrad}$)
 - Kink decay topology
 - Electron and γ/π^0 identification
- Energy measurement
 - Multiple Coulomb Scattering
 - Track counting (calorimetric measurement)
- Ionization (dE/dx measurement)
 - π/μ separation (not discussed here)
 - e/π^0 separation



Topological and kinematical analysis event by event

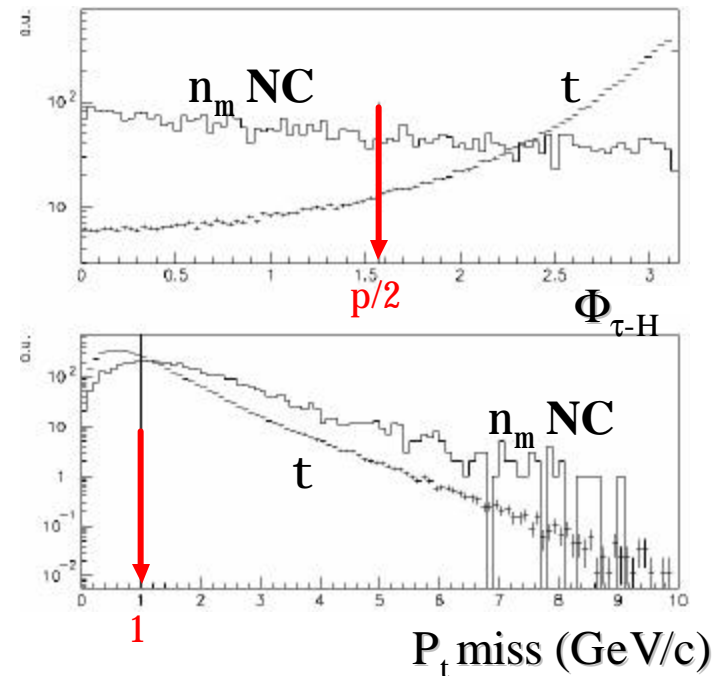
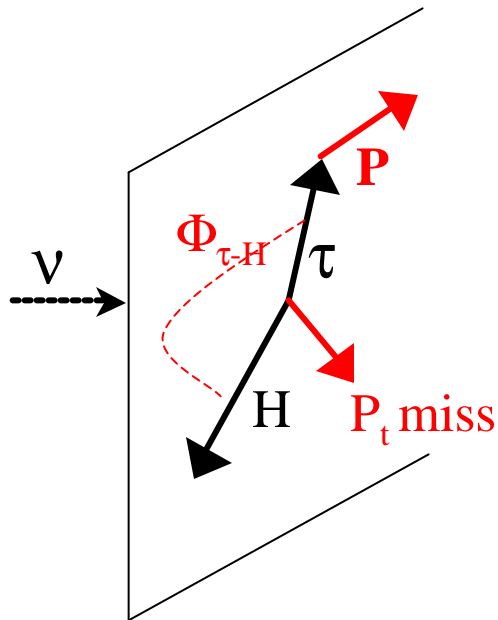


Backgrounds for the $\nu_{\mu} \rightarrow \nu_{\tau}$ search

- Charm production
 - Cross-section and charmed fractions based on neutrino data
- Large angle μ scattering
 - Rate of μ scattering off lead estimated by using
 - MC simulation including nuclear form factors (cross-checked with NOMAD data)
 - data from 7.3 GeV/c μ scattering off copper
 - μ scanned in the CHORUS emulsions
 - Scattering off lead of μ ($p = 6-10$ GeV/c) experimentally studied by the Collaboration. Results in agreement with expectations
- Hadron reinteractions with kink topology
 - the present estimate is based on a FLUKA simulation
 - consistent with preliminary results from dedicated experiments

Global kinematics for $\tau \rightarrow h$

(for events with a τ decay candidate)



In these plots the improvements from γ detection are not taken into account

Expected number of events

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

	signal ($\Delta m^2 = 1.6 \times 10^{-3} \text{ eV}^2$)	signal ($\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$)	signal ($\Delta m^2 = 4.0 \times 10^{-3} \text{ eV}^2$)	background
2001 Status Report	4.9	11.8	30.0	0.74
Final Design	4.3	10.3	26.3	0.65

Room for improvements:

- dE/dx : background 0.65 \rightarrow 0.41
- Changeable Sheet : increase efficiency by 10-15 %
- Beam intensity increase by 30-50 %



Aim at evidence of ν_τ appearance after a few years of data taking



Probability of $\geq n\sigma$ significance for different Δm^2

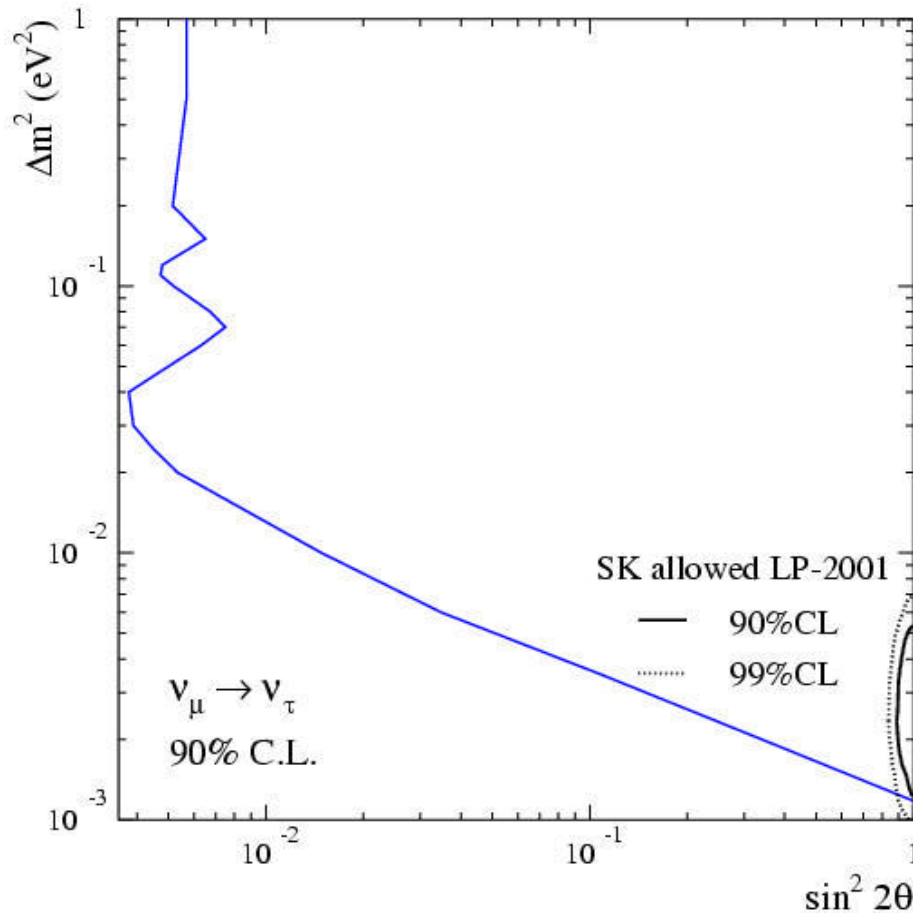
(5 year run, nominal Φ flux)

$Dm^2(eV^2)$	P_{3s}	P_{4s}
$1.6 \cdot 10^{-3}$	78%	44%
$1.8 \cdot 10^{-3}$	89%	64%
$2.0 \cdot 10^{-3}$	95%	79%
$2.2 \cdot 10^{-3}$	98%	91%
$2.4 \cdot 10^{-3}$	99%	95%

Obtained with old numbers!

There is room for improvements

Exclusion plot in the absence of a signal



90 % CL upper limit
obtained on average by a
large ensemble of
experiments

$$\Delta m^2 < 1.2 \times 10^{-3} \text{ eV}^2 \text{ at full mixing}$$

$$\sin^2(2\theta) < 5.7 \times 10^{-3} \text{ at large } \Delta m^2$$

Gives an indication of the
sensitivity ... but of course
we expect to see a signal

Uncertainties on background ($\pm 33\%$) and on efficiencies ($\pm 15\%$)
accounted for here and in the following



Backgrounds for the $\nu_\mu \rightarrow \nu_e$ search

- π^0 identified as electrons produced in ν_μ NC and ν_μ CC with the μ not identified
- ν_e beam contamination
- $\tau \rightarrow e$ from $\nu_\mu \rightarrow \nu_\tau$ oscillations

In the following we assume a three family mixing scenario with $\theta_{23}=45^\circ$

$\nu_\mu \rightarrow \nu_e$: selection efficiencies

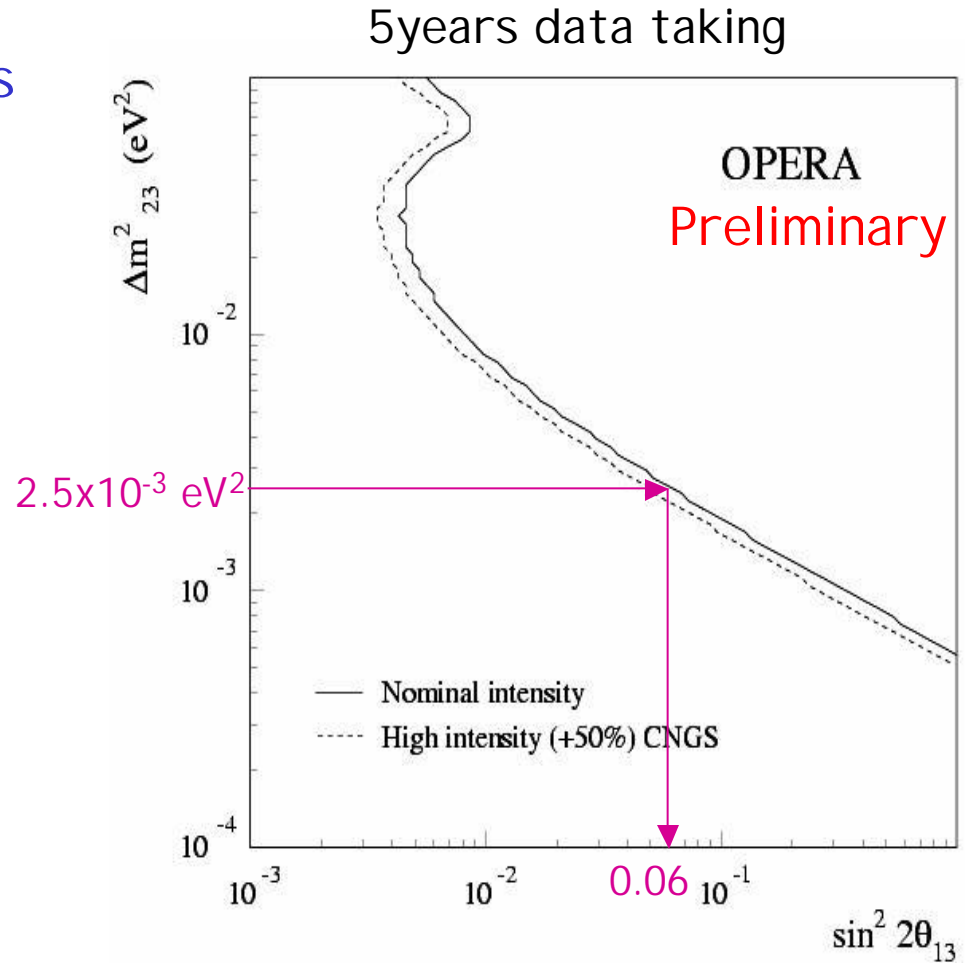
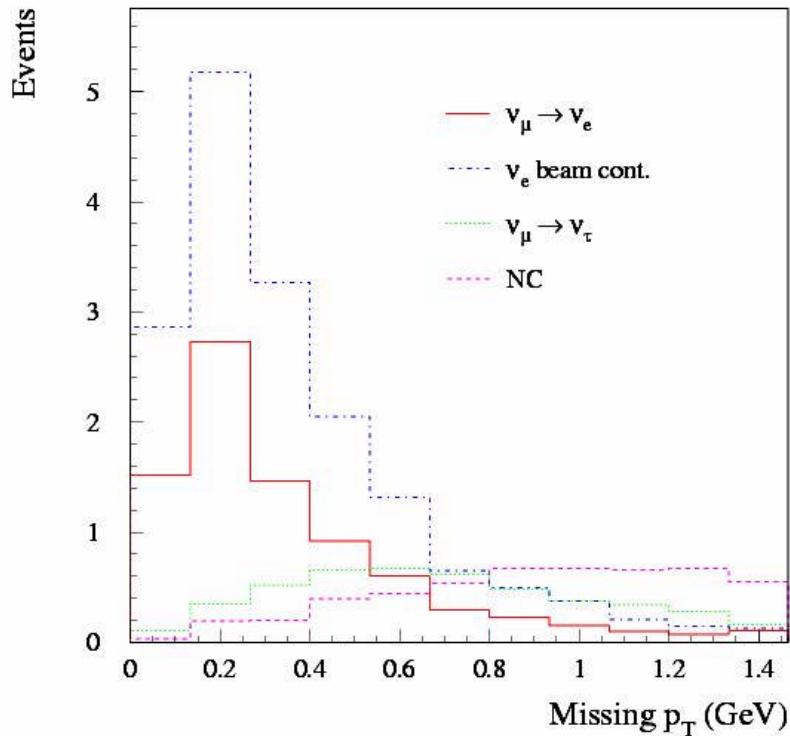
	signal	$\tau \rightarrow e$	ν_μ CC	ν_μ NC	ν_e CC beam	
Location eff.	ξ	0.53	0.053	0.52	0.48	0.53
Total eff.	ε	0.31	0.032	0.34×10^{-4}	7.0×10^{-4}	0.082

Expected signal and background assuming 5 years data taking with the nominal CNGS beam and $\Delta m_{23}^2 = 2.5 \times 10^{-3} \text{ eV}^2$, $\sin^2 2\theta_{23} = 1$

θ_{13}	signal	$\tau \rightarrow e$	ν_μ CC	ν_μ NC	ν_e CC beam
9°	9.3	4.5	1.0	5.2	18
8°	7.4	4.5	1.0	5.2	18
7°	5.8	4.6	1.0	5.2	18
5°	3.0	4.6	1.0	5.2	18
3°	1.2	4.7	1.0	5.2	18

OPERA sensitivity to θ_{13}

By fitting simultaneously the E_e , missing p_T and E_{vis} distributions we got the sensitivity at 90%

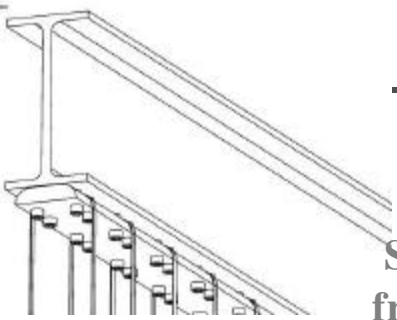




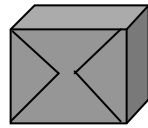
Status of the construction

The support structure for the "brick walls"

Tests of full scale prototypes



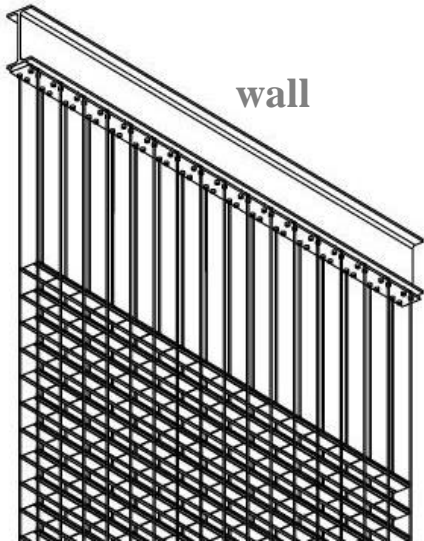
Suspension
from the top



Bricks inserted
from the side

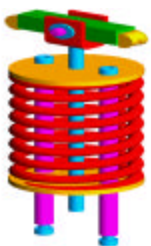


Height ~ 6.7 m



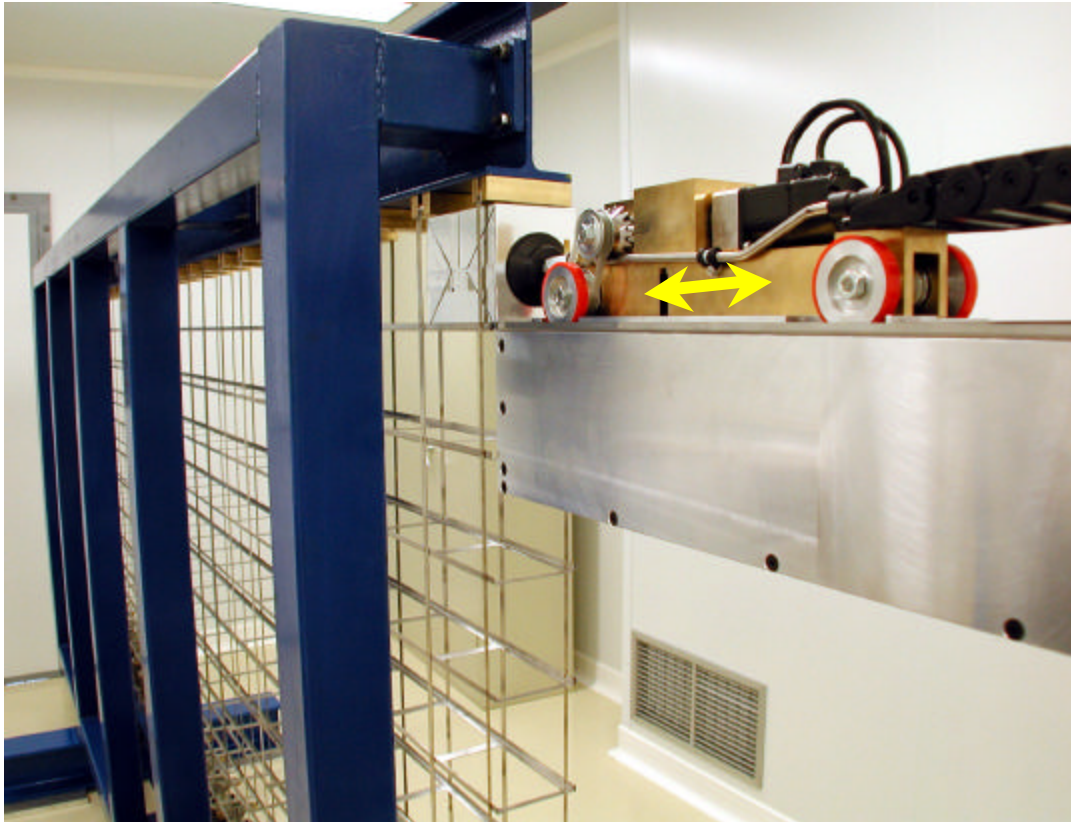
wall

Tensioning
from the
bottom

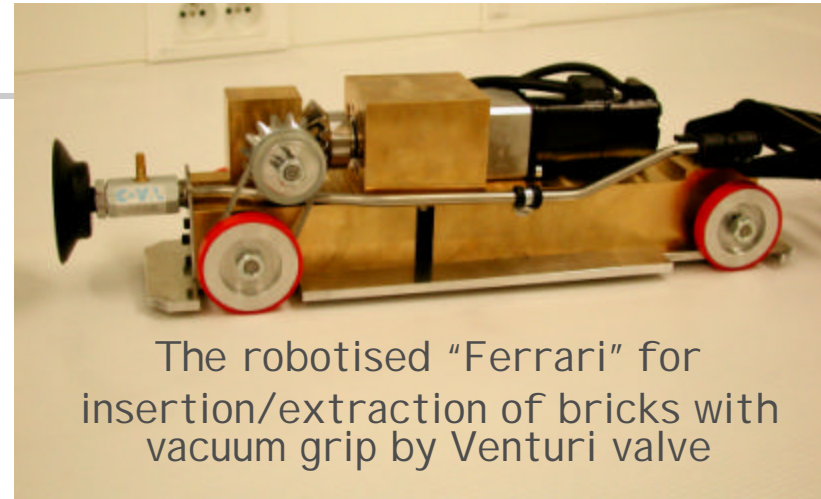


Brick loading test

The Brick Manipulator System (BMS) prototype: a lot of fun for children and adults !



Tests with the prototype wall



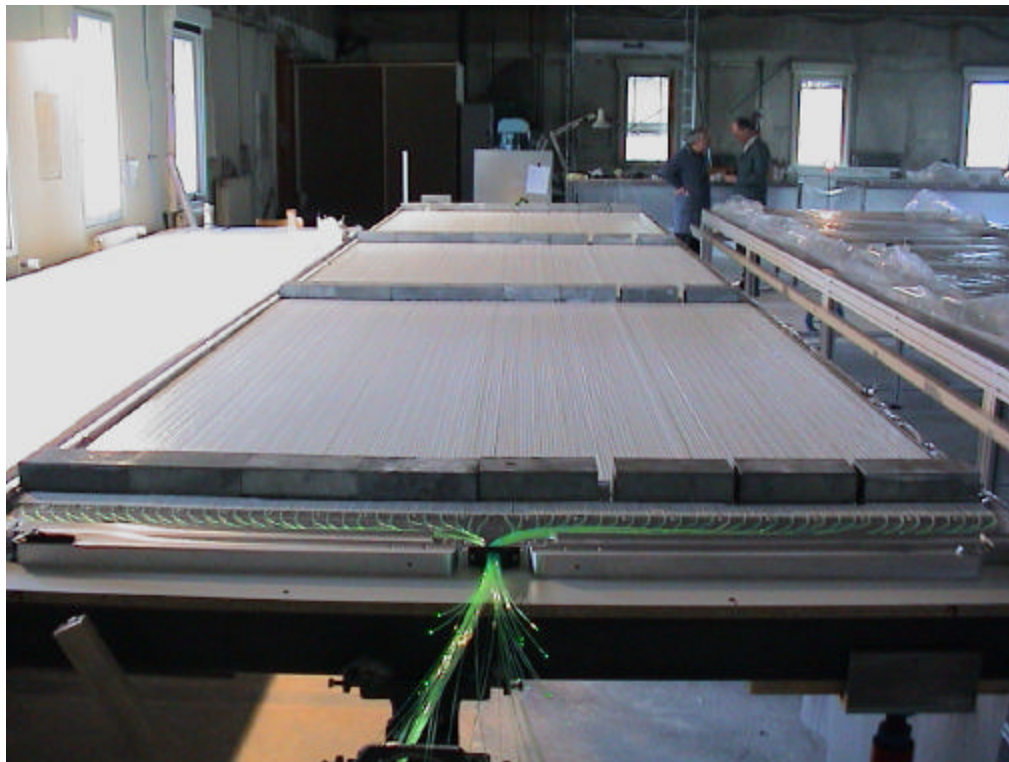
The robotised "Ferrari" for
insertion/extraction of bricks with
vacuum grip by Venturi valve



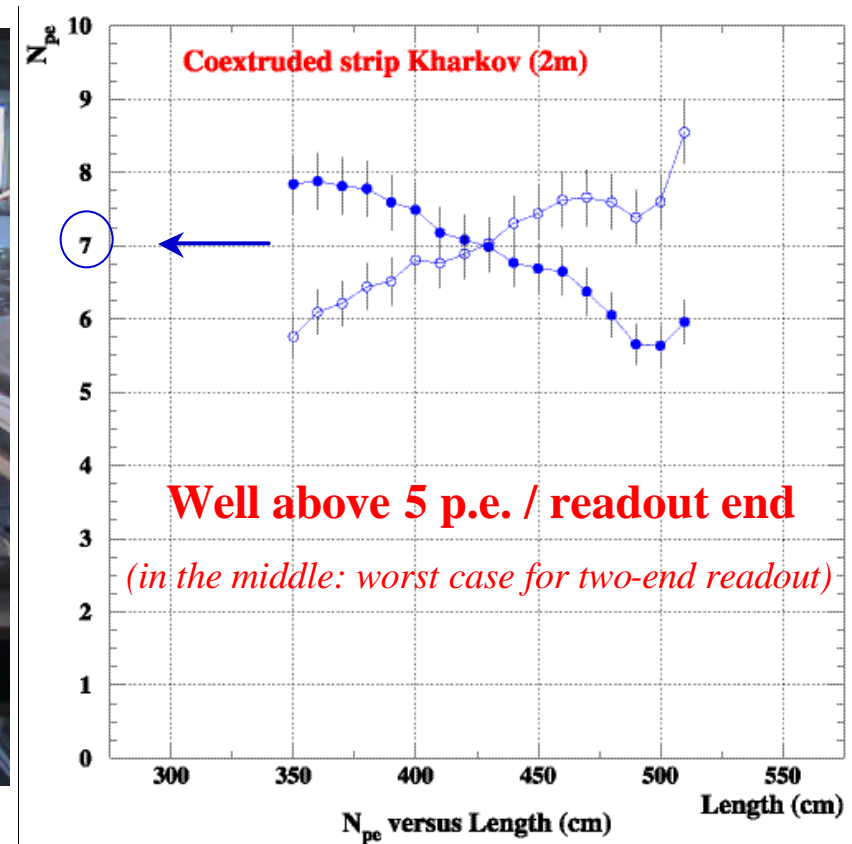
"Carousel" brick dispensing
and storage system

Target Tracker: plastic scintillators

- 64 strips of 6.7 m length, 2.6 cm width, 1 cm thickness
- Readout by wavelength shifting optical fibres in co-extruded grooves
- Co-extruded TiO_2 coating

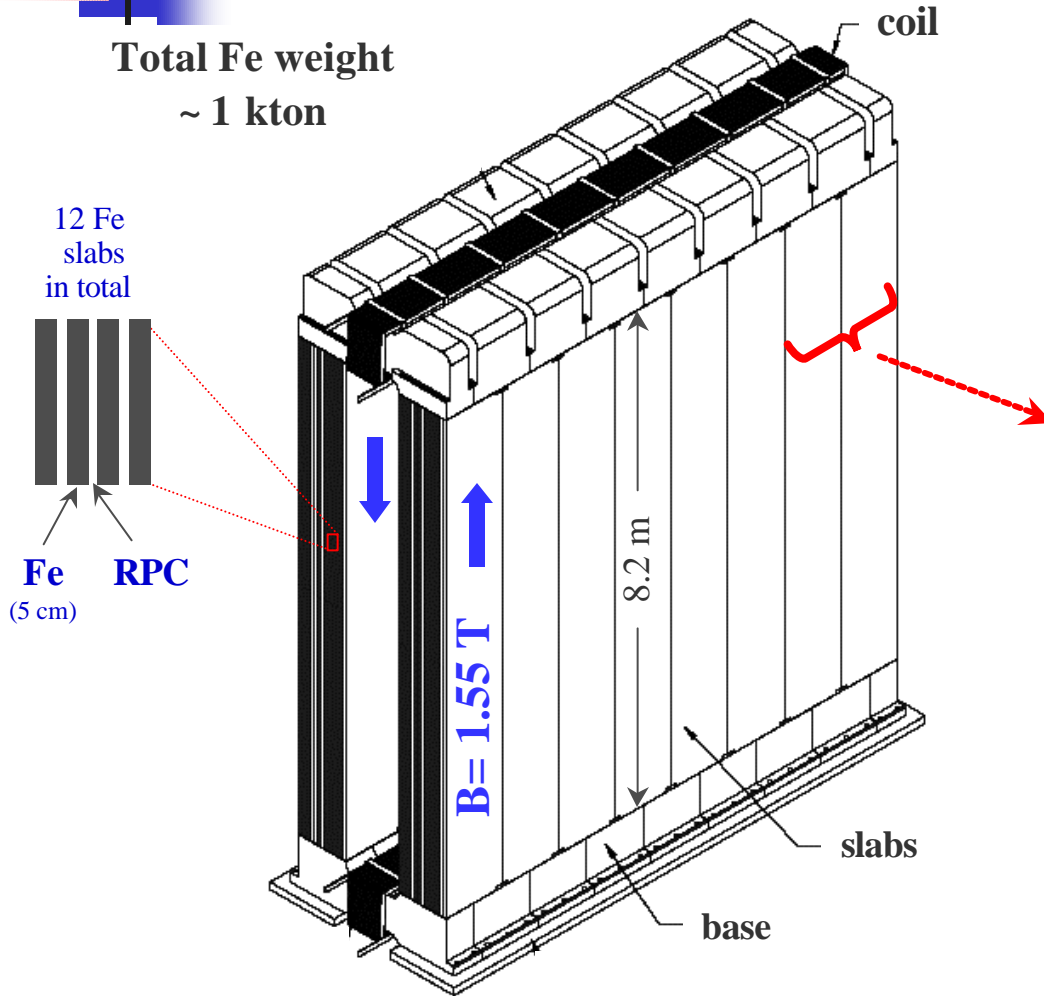


Full scale prototype module

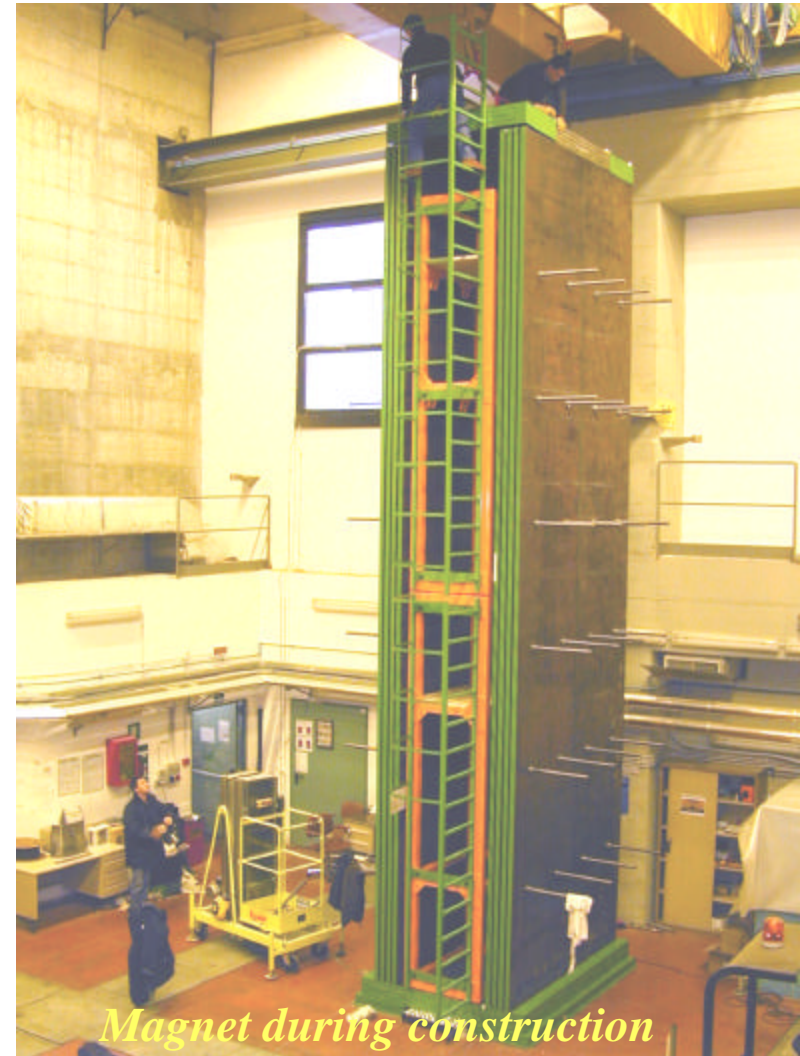


Dipolar magnet

RPCs inside gaps: muon identification , shower energy
Drift Tubes: muon momentum



Full scale prototype of magnet section constructed and tested



Iron in tendering-ordering phase

Magnet during construction



Conclusion

- Construction of CNGS is well underway. The tunnel excavation is complete. The remaining construction work is on schedule (Beam starts by mid 2006)
- The OPERA experiment will permit
 - An unambiguous direct evidence of τ appearance in a ν_μ beam
 - A measurement of Δm^2 at 20-30%
 - Extend sensitivity for small $\nu_\mu \rightarrow \nu_e$ mixings (competitive with other experiments)
- The construction of the detector is in progress and it is planned to be completed by mid 2006
- The OPERA concept has been demonstrated to be very appealing also for future oscillation physics at the Neutrino Factory (A.Donini, D.Meloni, P.Migliozzi hep-ph/0206034)