The CNGS program status and Physics potential

Thanks to K.Elsener, A.Rubbia, P.Strolin, the CNGS, OPERA and ICARUS colleagues

And apologies to Boticelli…..

CNGS beam optimized for appearance

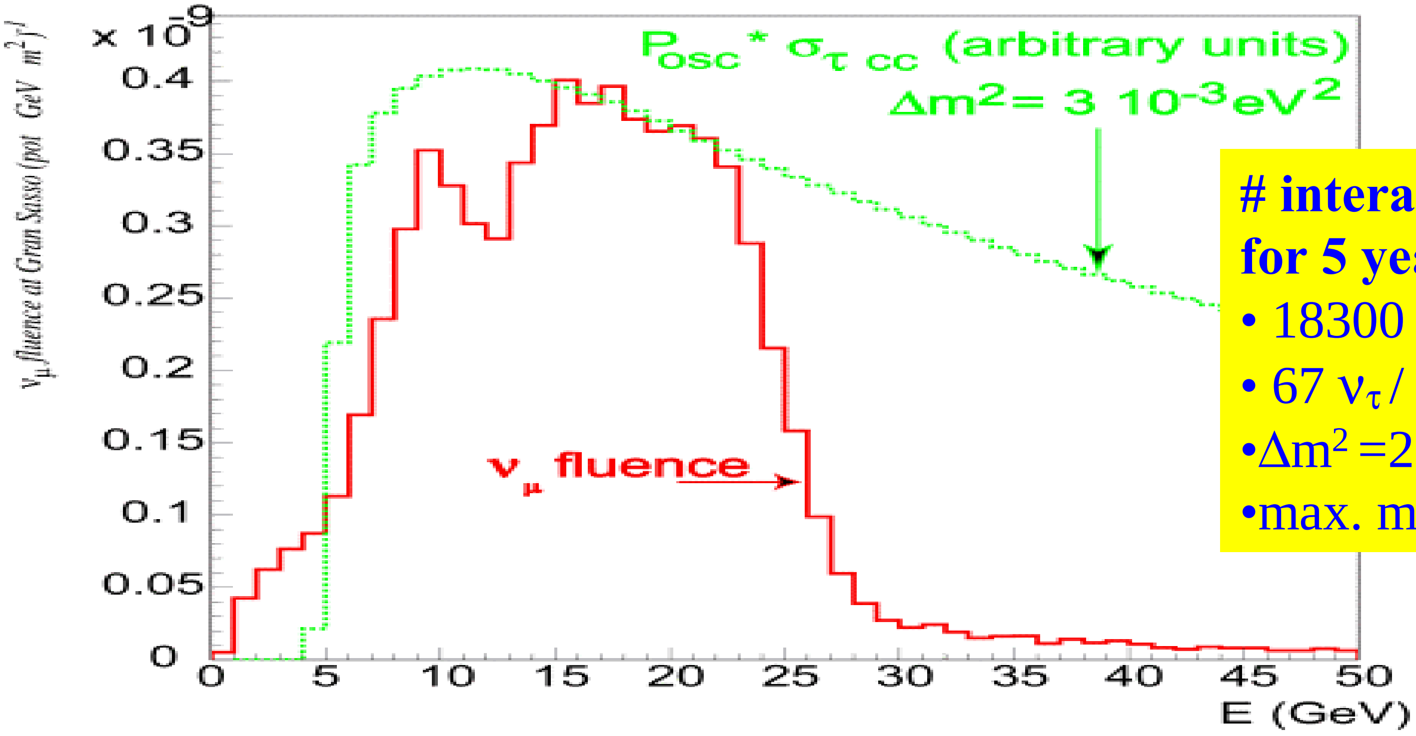
CNGS Program Status and Physics Potential
Nu2002 Munchen

Shared SPS operation

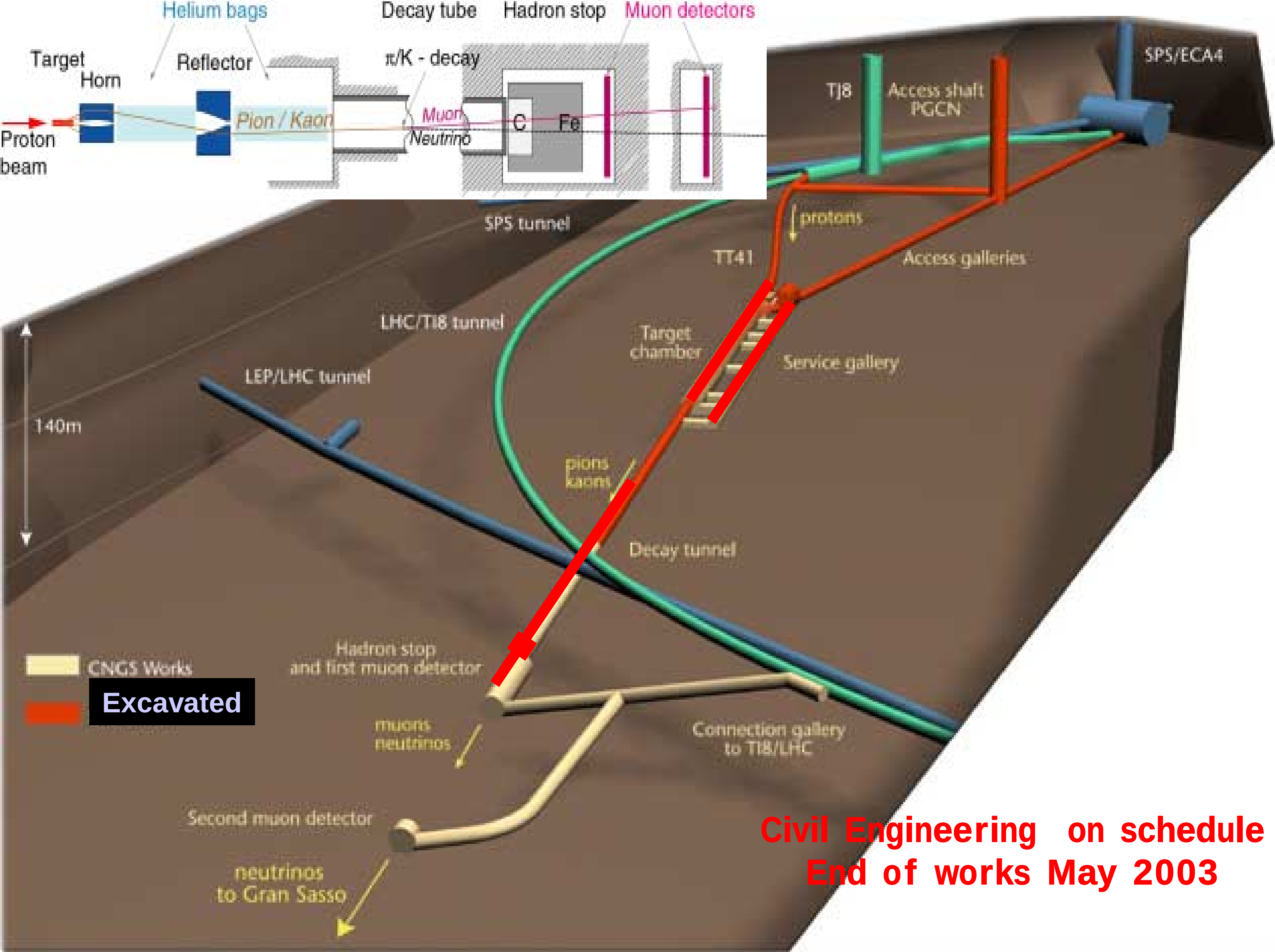
200 days/year

$4.5x10^{19}$ pot / year

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



 # interactions ν for 5 years :
- 18300 NC+CC / kt
- 67 ν_τ / kt
- $\Delta m^2 = 2.4x10^{-3}\ eV^2$
- max. mixing


Helium bags
Decay tube
Hadron stop
Muon detectors
Target
Horn
Reflector
π/K - decay
Pion / Kaon
Muon
Neutrino
C
Fe
Proton beam
SPS/ECA4
TJ8
Access shaft PGCN
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target chamber
Service gallery
LEP/LHC tunnel
140m
pions kaons
Decay tunnel
Hadron stop and first muon detector
CNGS Works
Excavated
muons neutrinos
Connection gallery to TI8/LHC
Second muon detector
neutrinos to Gran Sasso
Civil Engineering on schedule
End of works May 2003

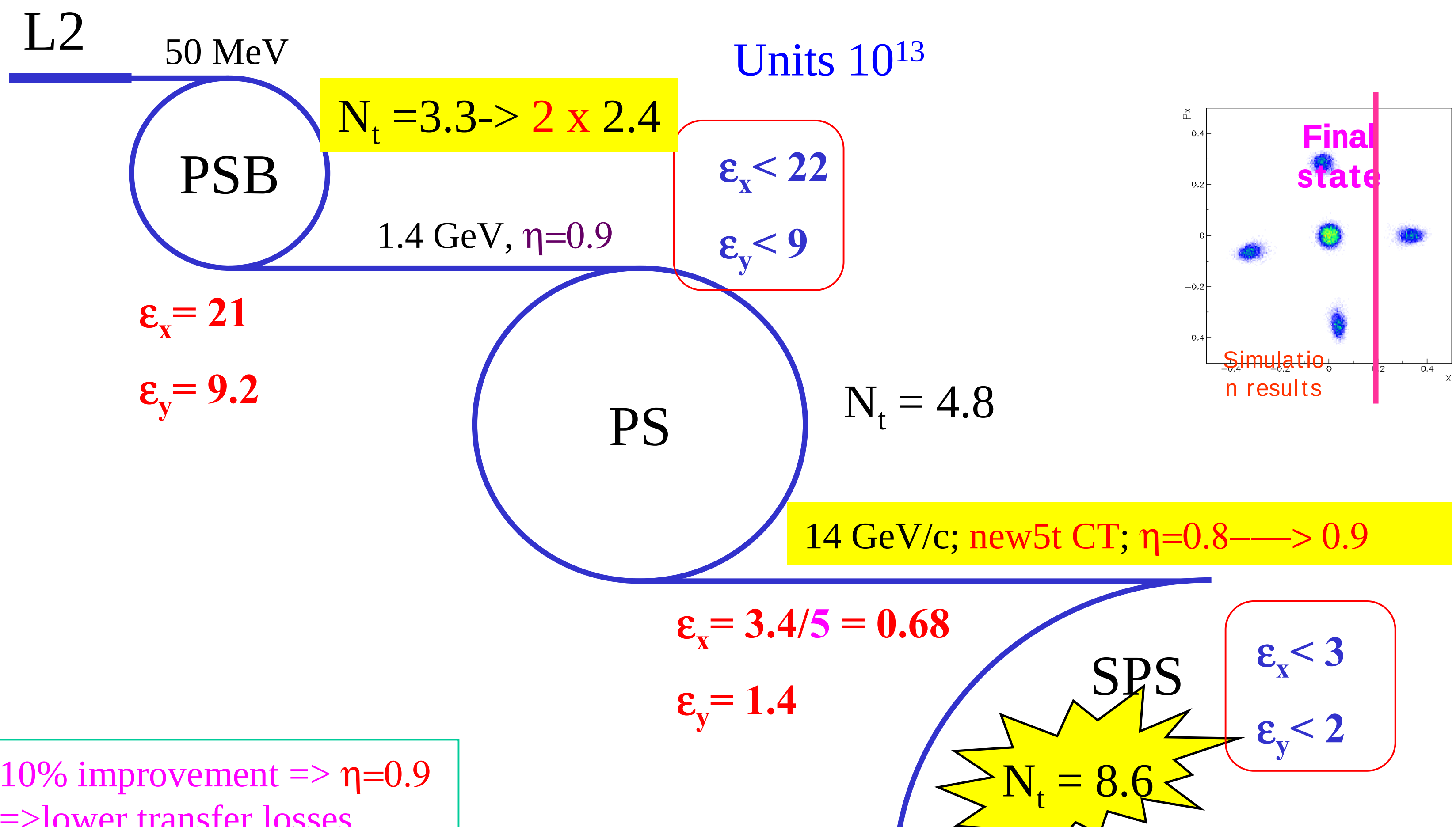
CNGS : schedule

re-scheduling presently under way

June 2006 (?)

Reevalution: Cost 71 -> 77.6 MCHF
Manpower 60-> 80 manyears

New ideas on the beam side (R.Cappi et al.)



10% improvement => η=0.9
=>lower transfer losses,
better matching, etc.

filling time = 2.4s

ψ_p = 8.6/7.2 = **1.19** **G = 1.49**

ψ_p = 8.6/6.6 = **1.30** if PSB@.6s **G = 1.63**

A gain of 30 to 50% in flux expected at minimal cost <2 MCHF

2 ways of detecting τ appearance

ν_μ ..... ν_τ $\rightarrow$ τ^- + X

oscillation — CC interaction

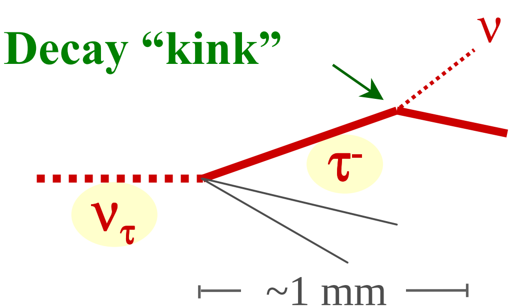
μ^- ν_τ $\bar{\nu}_\mu$	BR 18 %
h^- ν_τ $n\pi^o$	50 %
e^- ν_τ $\bar{\nu}_e$	18 %
π^+ π^- π^- ν_τ $n\pi^o$	14%

OPERA: Observation of the decay topology of τ *(à la CHORUS)*

In photographic emulsion

(~ **μm** granularity)

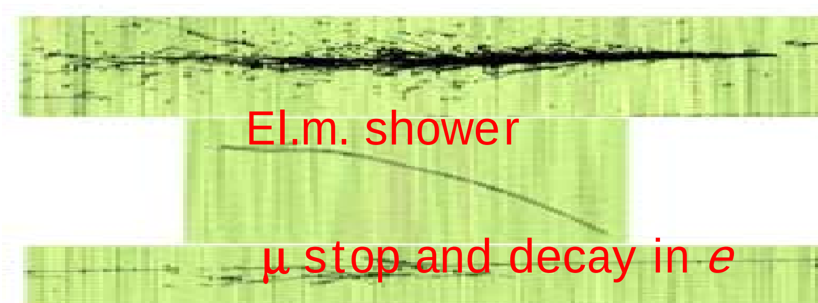
A digital Cloud chamber



ICARUS: detailed TPC image in liquid argon and kinematic criteria *(à la NOMAD)*

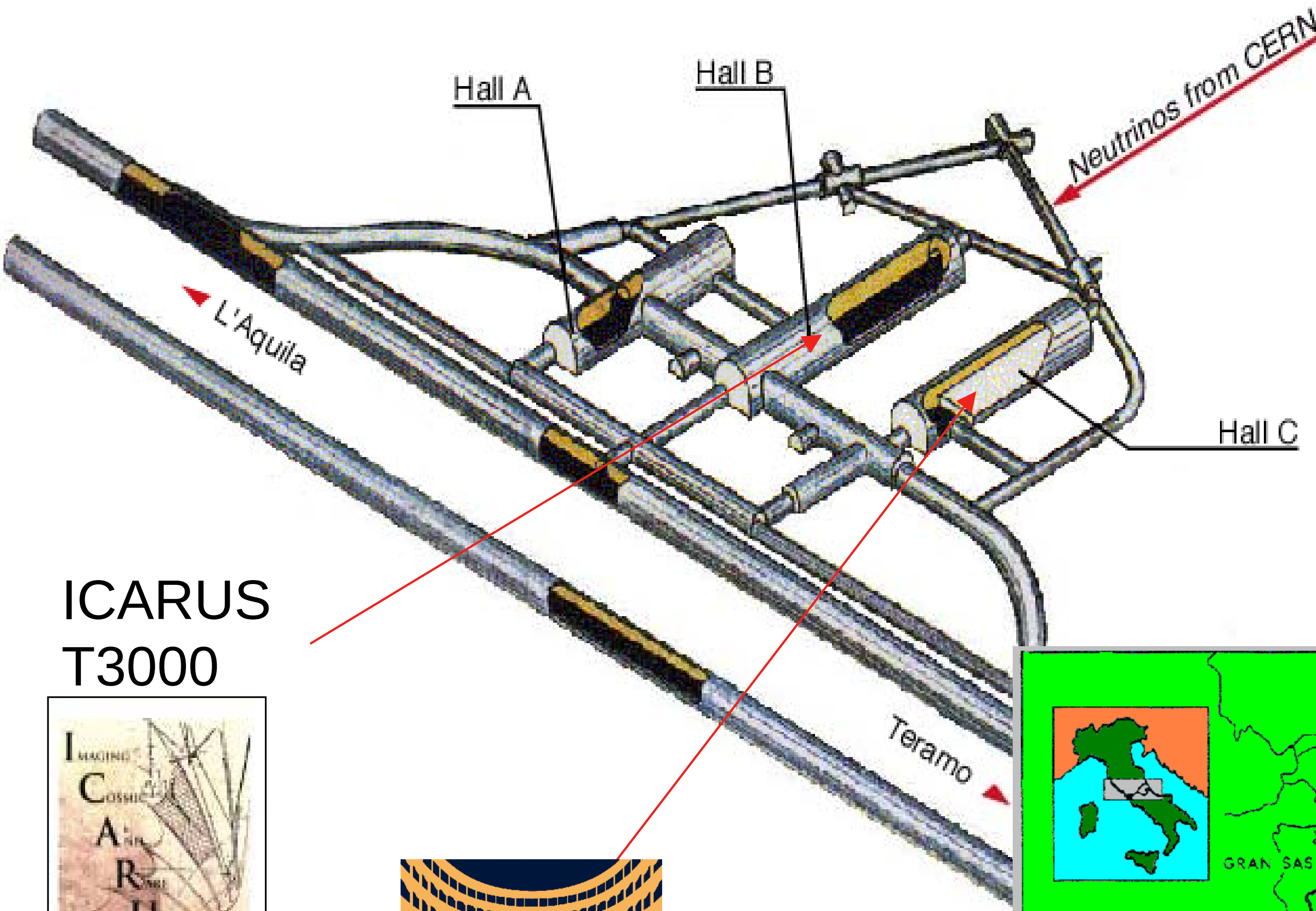
(~ **mm** granularity)

A digital Bubble chamber



But also: ν_μ ... ν_e $\rightarrow$ e^- + X

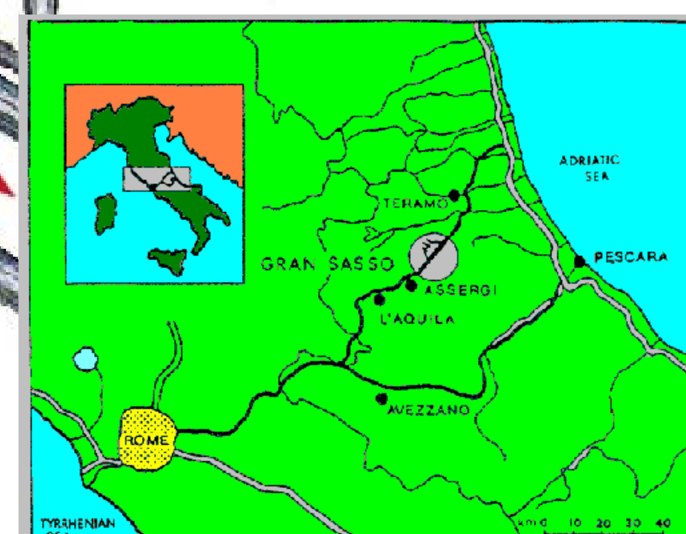
LNGS Laboratory and the 2 detectors



ICARUS
T3000

Imaging Cosmic And Rare Underground Signals

OPERA



OPERA

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, Naples, Padova, Rome, Salerno

Japan
Aichi, Toho, Kobe, Nagoya, Utsunomiya

JINR Dubna

Russia
INR Moscow, ITEP Moscow, JINR Dubna, Obninsk

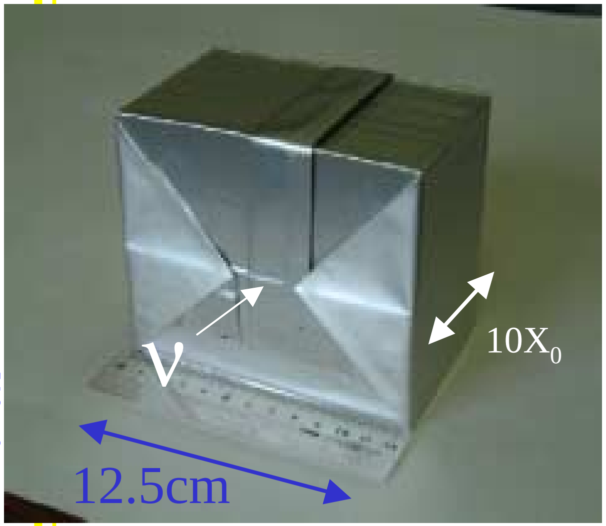
Switzerland
Bern, Neuchâtel

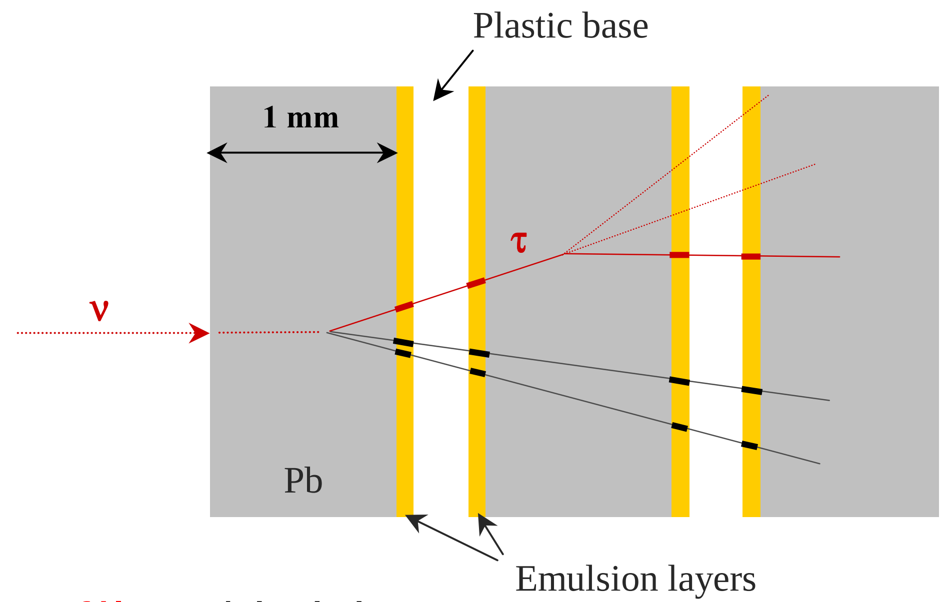
Turkey
METU Ankara

34 groups
~ 170 physicists

OPERA =CNGS1
Approved

The smallest OPERA element

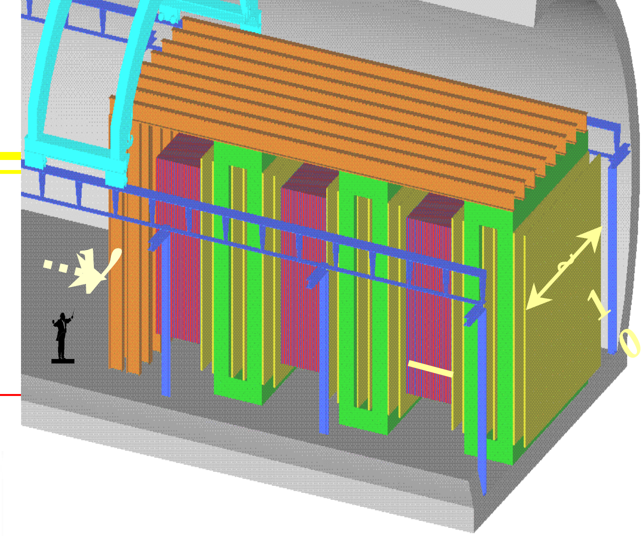


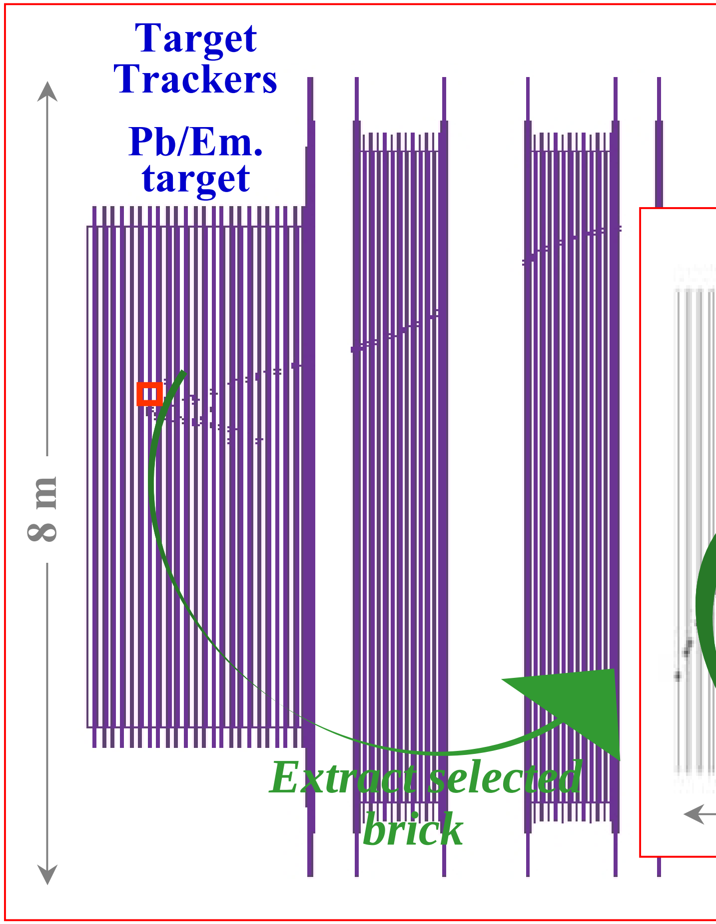


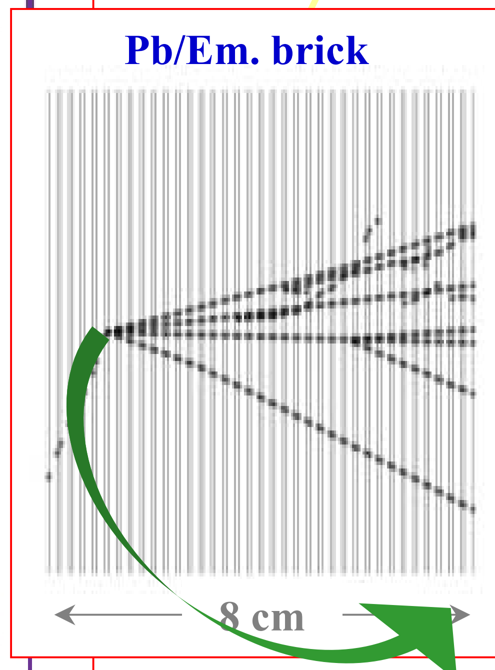
56 emulsion films / brick

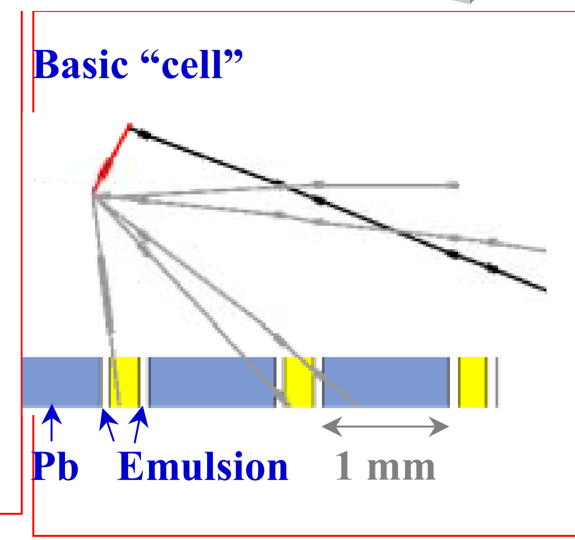
- To the full detector:
  2 supermodules
  31 walls / supermodule
  52 x 64 bricks /wall
  200 000 bricks

CNGS1: OPERA a hybrid detector









Electronic detector

→ finds the brique of ν interaction

→ μ ID, charge et p

Emulsion analysis

→ vertex

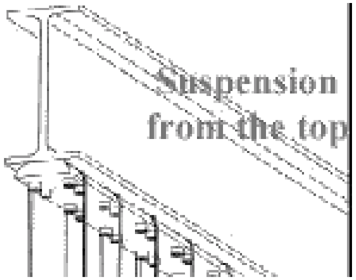
→ decay kink

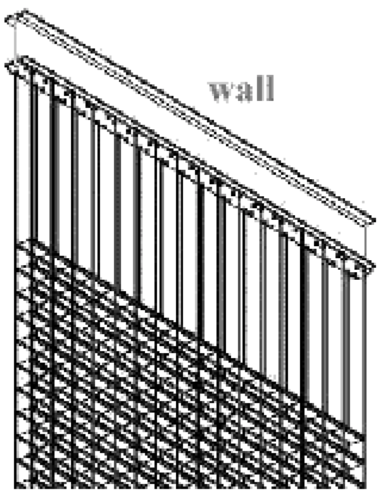
→ e/γ ID,

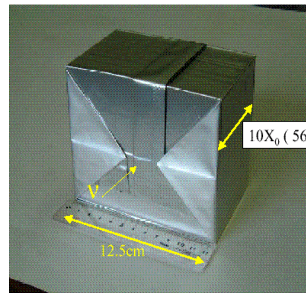
multiple scattering, kinématics

OPERA

Brick wall



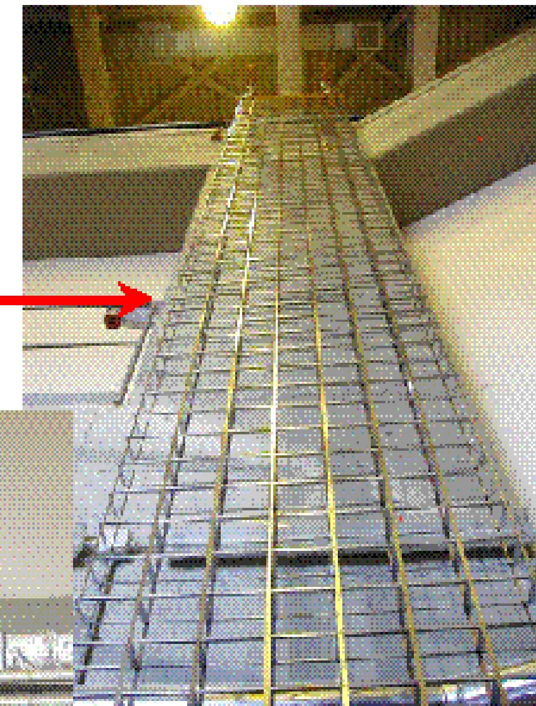




235k bricks
for 3 supermodules

loading test

Bricks inserted
from the side



Tensioning
from the bottom

Tests of full scale wall prototypes and components
(Frascati and Naples)

CNGS Program Status and Physics Potential
Nu2002 Munchen

The Brick Manipulator System (BMS) prototype at LAPP Annecy

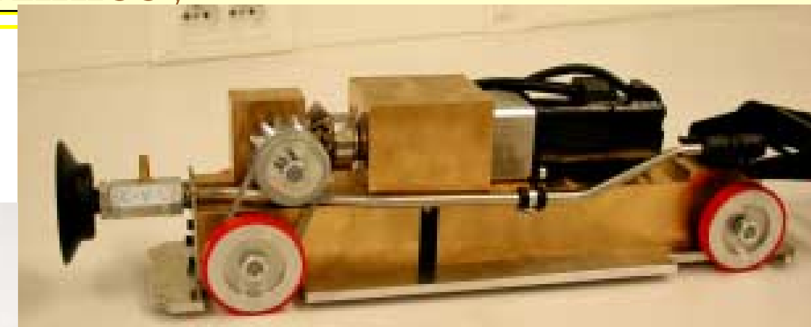
Fill the brick walls

200,000 bricks / 1 year

Tests with the prototype wall from Frascati-Napoli

Extract bricks with ν interactions

~ 40 bricks / day

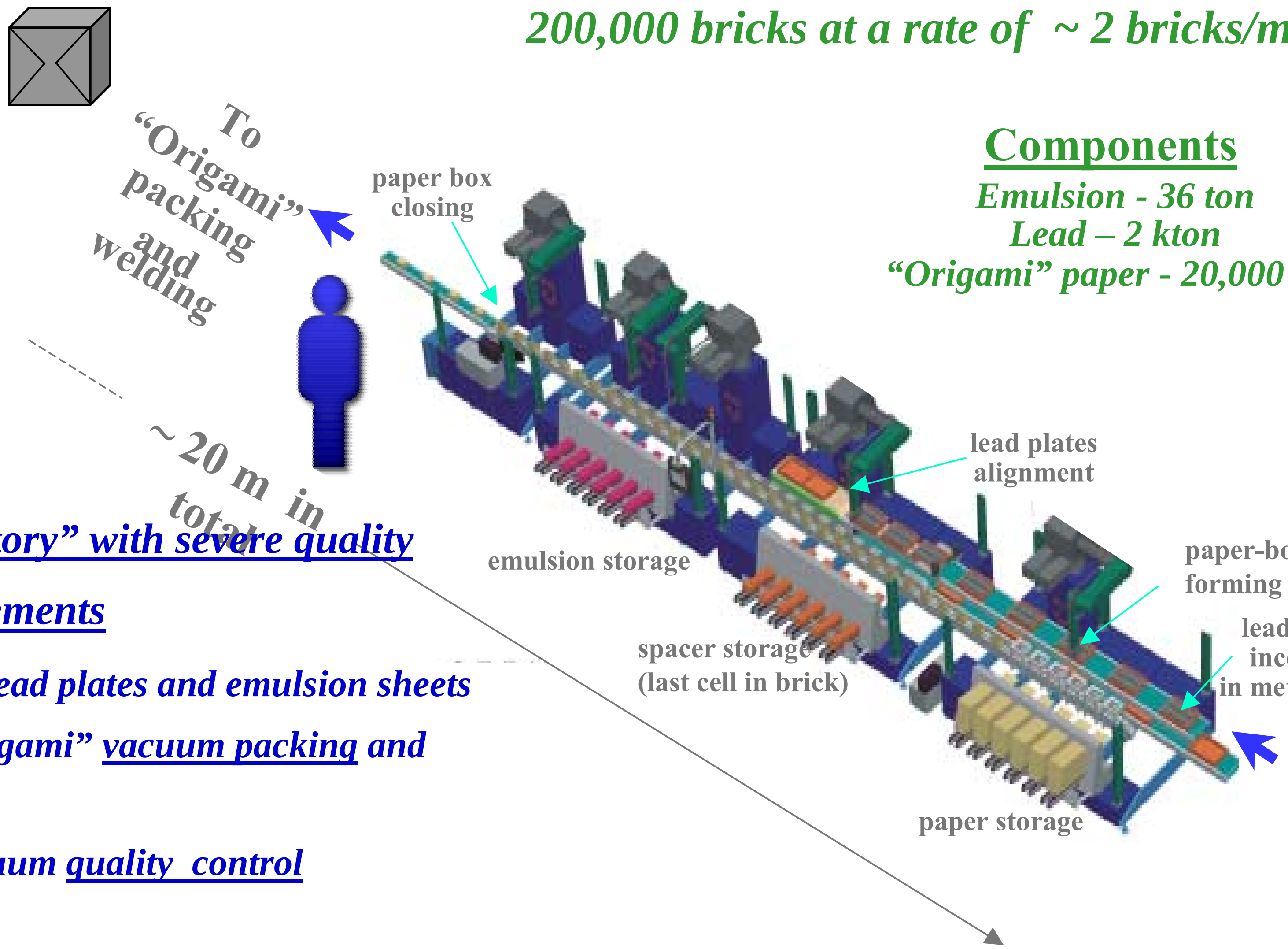


The robotised “Ferrari” for insertion/extraction of bricks with vacuum grip by Venturi valve

“Carousel” brick dispensing and storage system

Brick assembly machine (BAM)

27 million lead plates + emulsion sheets
200,000 bricks at a rate of ~ 2 bricks/minute



Components

Emulsion - 36 ton
Lead – 2 kton
"Origami" paper - 20,000 m^2

A "factory" with severe quality requirements

- ***Stack lead plates and emulsion sheets***

2) *"Origami" vacuum packing and welding*

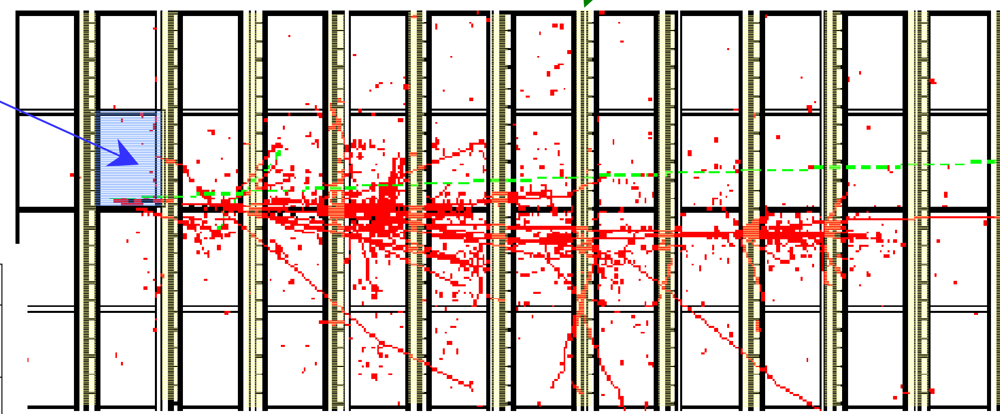
3) *Vacuum quality control*

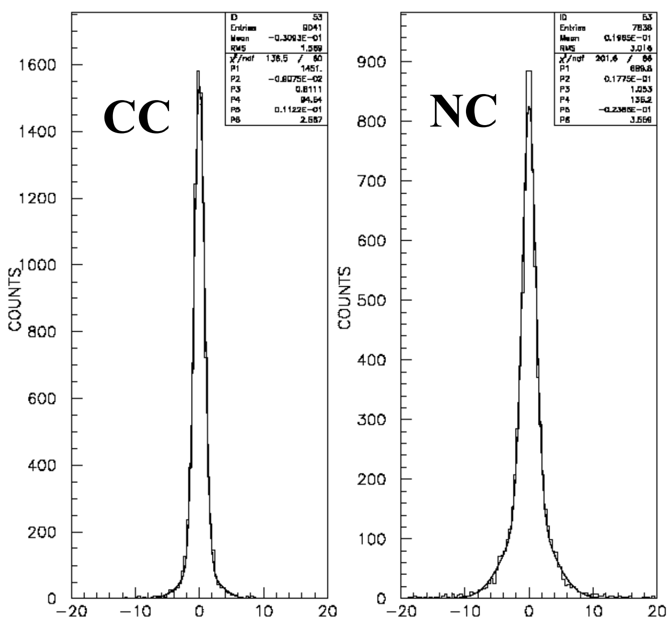
Electronic detectors to select bricks with ν interactions

(plastic scintillator strips)

- Target Tracker tasks :
  - select bricks efficiently
  - initiate muon tagging
-

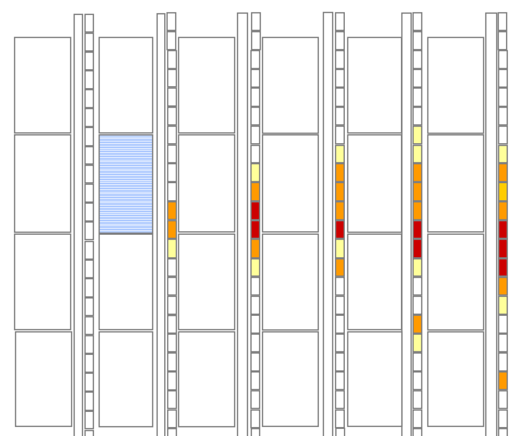
Sampling by Target Tracker planes (X,Y)





$x_{true} - x_{rec}$ (cm)

σ = 1.5 cm CC
3.0 cm NC



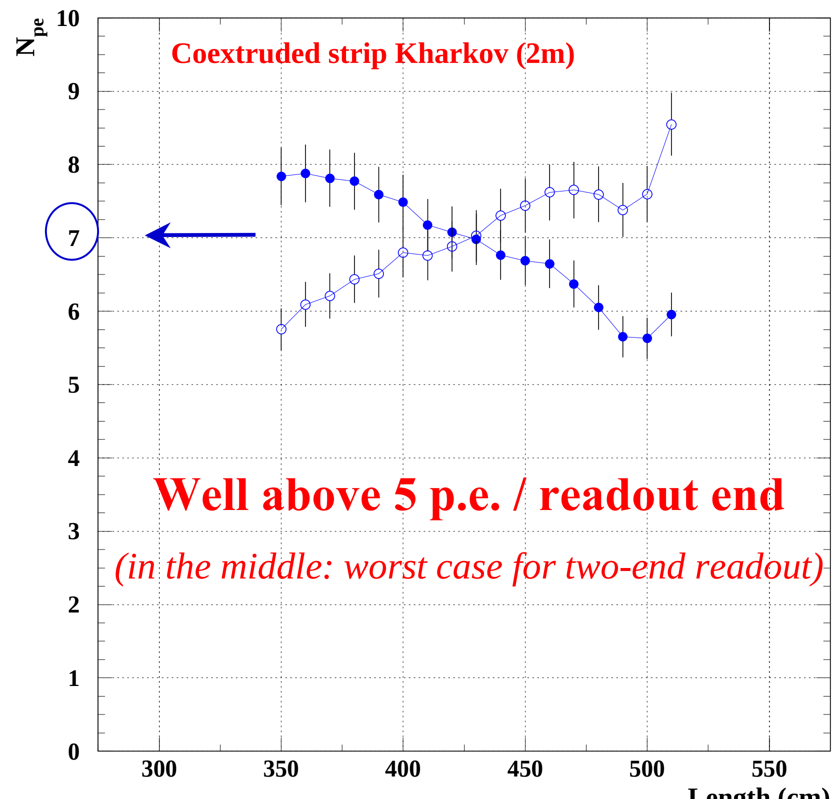
Event as seen by the Target Tracker

p.h.
0 max

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
- Tests of co-extruded strips from Amcrys-H (Kharkov), Pol.Hi.Tech and Chemo Technique
- Co-extruded TiO_2 coating
- Contacts for assembly of modules by industry

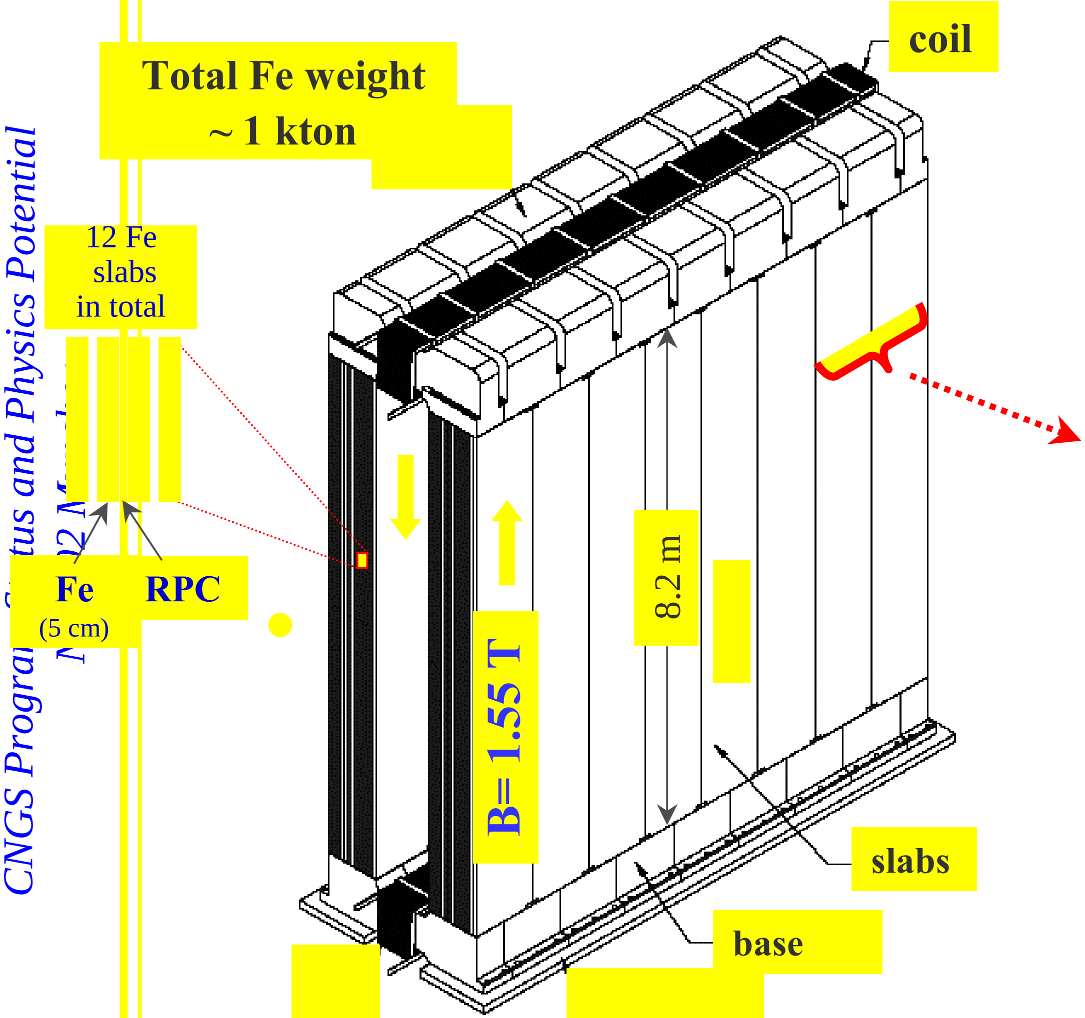
Full scale prototype module *(Strasbourg)*



N_{pe} versus Length (cm)

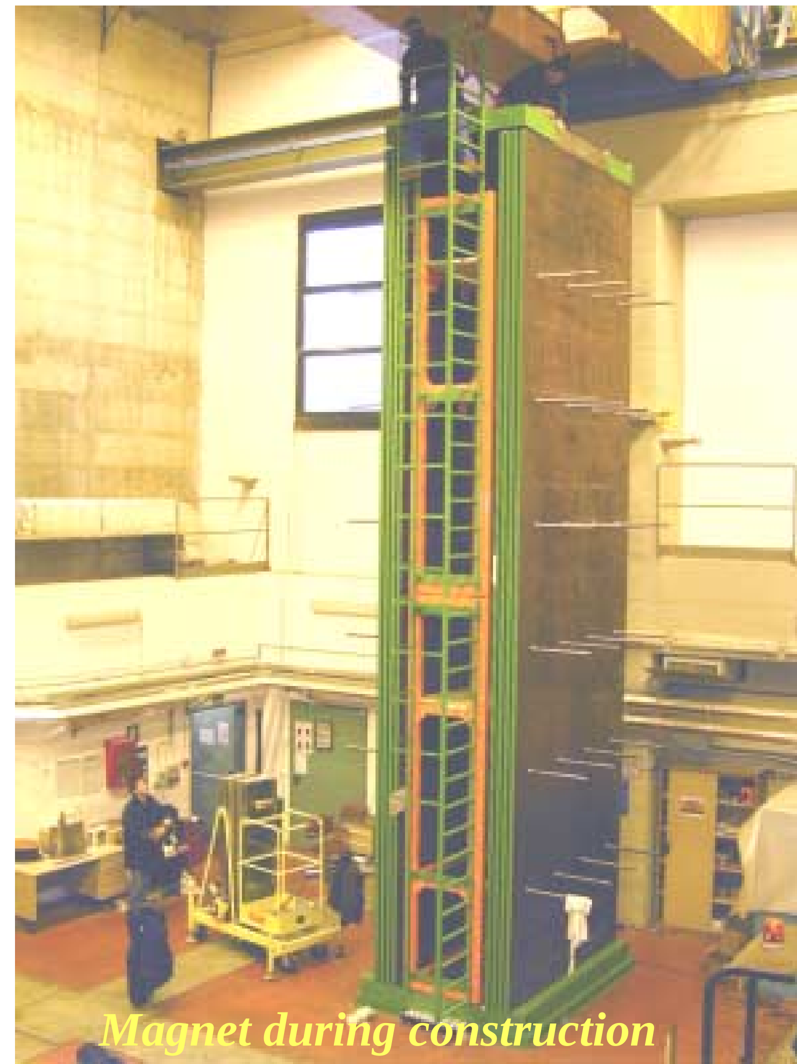
Dipolar magnet

- *RPCs inside gaps: __muon identification__ , shower energy*
- *Drift Tubes: muon momentum*



Iron in tendering-ordering phase

Full scale prototype of magnet section constructed and tested at Frascati



New facts after approval

• **"Changeable** (emulsion) **Sheets" added to detector**	**Reduced scanning load**
• **Perspective of higher beam intensity** (x 1.3-1.5 at moderate cost, …..)	**Larger ν_τ yield** (CS help scanning)
• **Detector compatible with Hall B-C → Hall C**	**Installation problems (→ 6 m delay)** **but Hall C wider (→optimise det.)**
• **CERN financial crisis**	**CERN group withdrawn**: - reallocate its responsibilities - face reduced funding

Simplify the detector

Maintain (… improve) sensitivity to oscillations

Hall C wider than Hall B

Two spectrometers instead of three
(with no change in mechanical design)

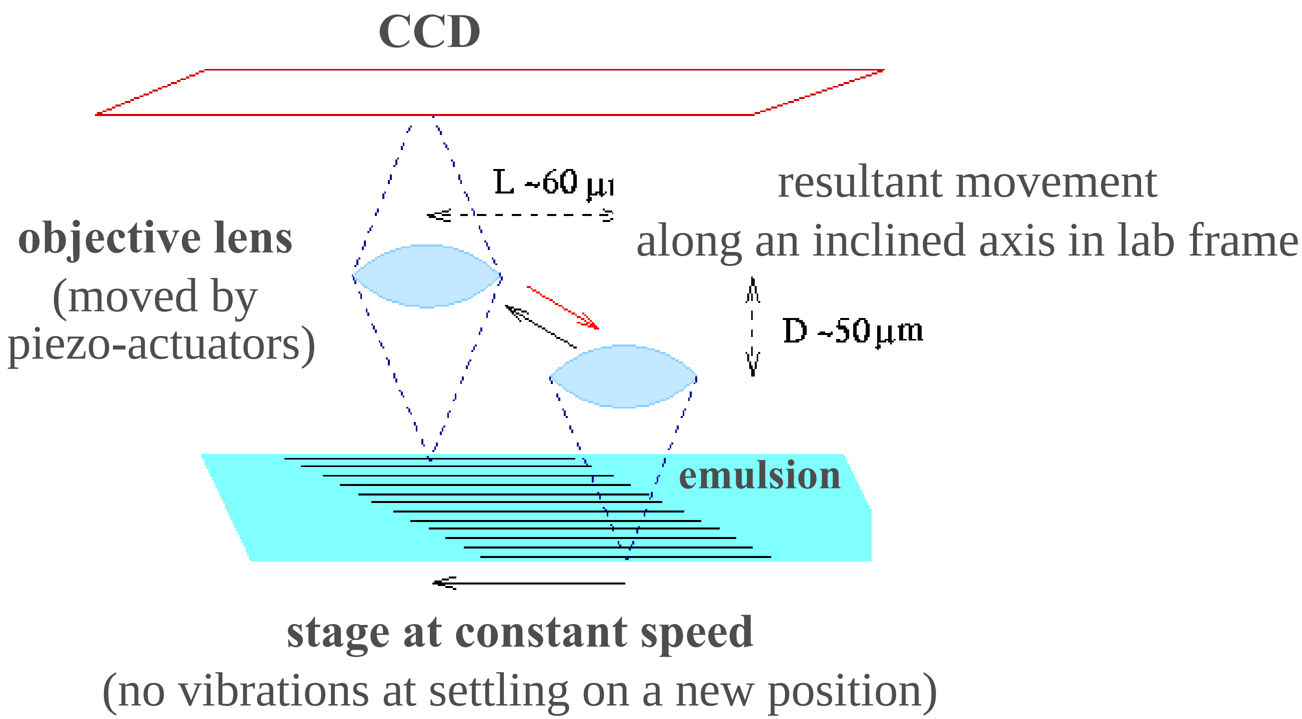
- **Hall C wider than Hall B (+ 3 m): easier sliding in of Target Trackers**
- **24 → 31 target planes / spectrometer**
- **<u>3</u> → <u>2 spectrometers</u>, target mass practically unchanged (–12.5 %): detector simplification, ~ 3.4 M€ saving on lead and electronic detectors**

  Add ~ 1.5 kton inert structure to damp seismic vibrations.
- **Perspective of +50% beam intensity increase at moderate cost: more attractive to compensate –12.5% reduction of target mass**

Schedule for installation in Hall C → detector ready in 2006

Automatic scanning in Nagoya : the new mechanical concept

(take images without stopping the stage, to increase the speed)



Objective and stage movements <u>have to be synchronised</u>

Goal for OPERA : **~20 cm^2 / hour / syst.**

ALSO Development of automatic scanning in Europe

"Sysal" system operating in Salerno

R&D in Bari, Bern, Bologna, Lyon, Münster, Napoli, Roma, Salerno

Design philosophy

Optics with large view

hence
no critical mechanics

Commercial components

(in continuous development)

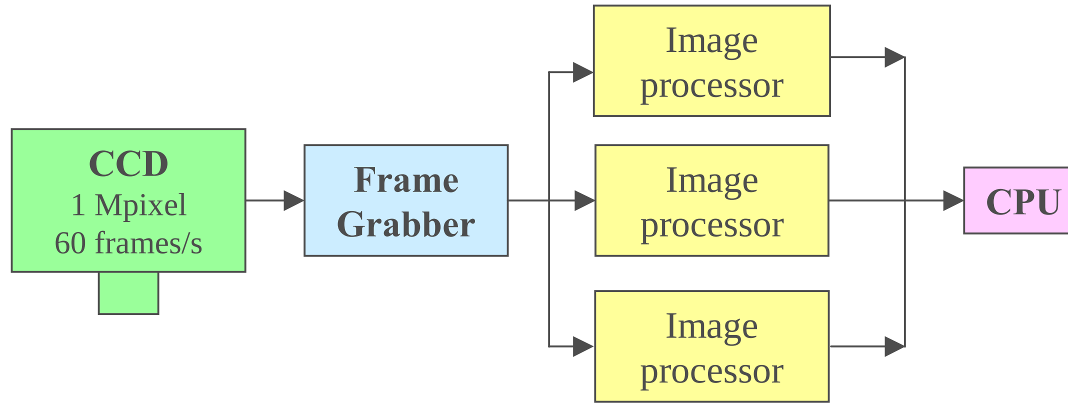
Software approach

⬇

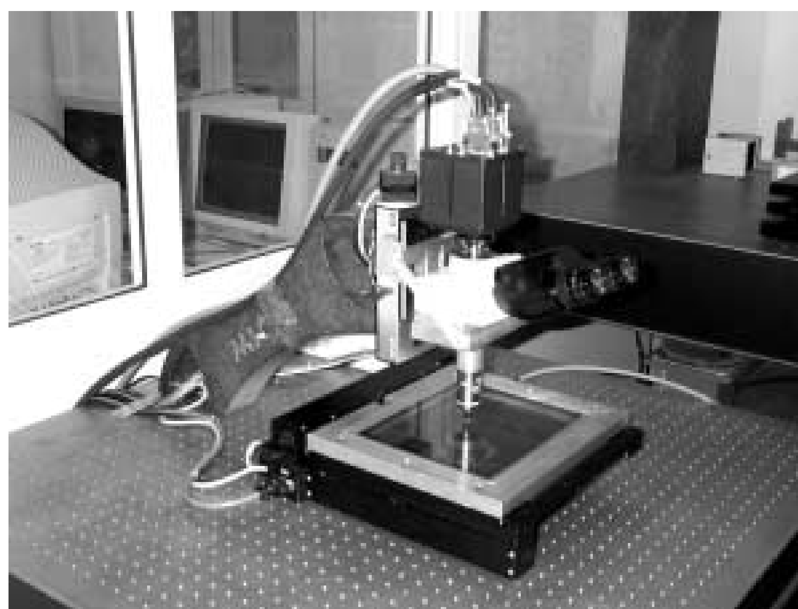
Excellent performance
with present technology
10 cm^2/hour

⬇

Aim
20 cm^2/hour



Parallel processing



50 x magnification

330 x 330 μm^2 view

Change of view
with <80 ms settling time

R&D:

CMOS sensor: x2 frames/s

Oil immersion → dry objectives

4 Mpixel sensors ?

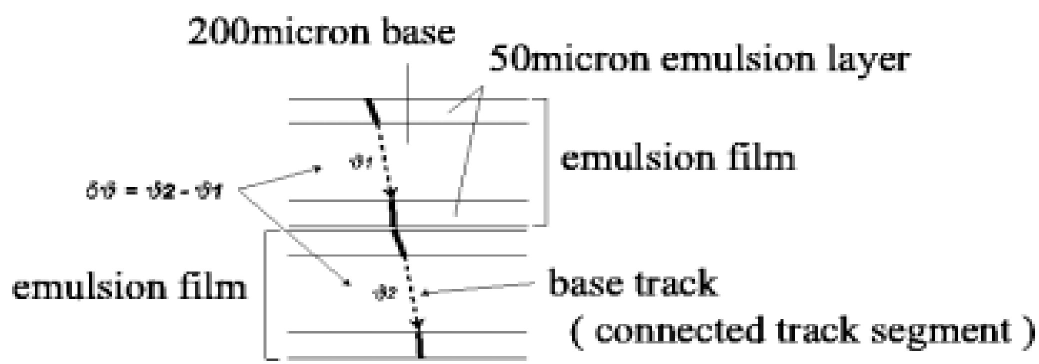
Intrinsic space resolution in tracking with emulsion

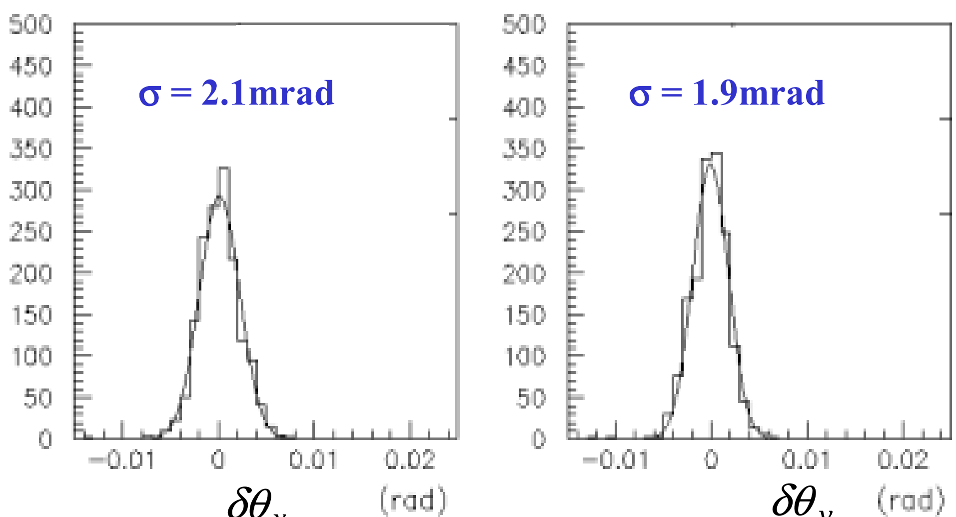
Base track resolution

(limited by digitisation error in image processing)

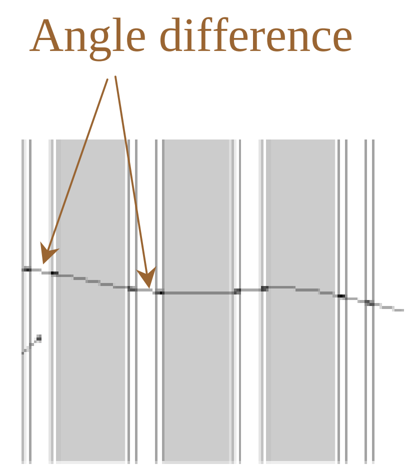
σ (angle) = 2.1 mrad

σ (position) = 0.21 μm





$$\frac{\delta\theta_x}{\sqrt{2}} \qquad \frac{\delta\theta_y}{\sqrt{2}}$$



Momentum measurement by MCS: max p measured with $\Delta p/p < 0.2$ after $5X_0$

Electron identification and energy measurement

- Requires low density of background tracks: emulsion “refreshment” after production

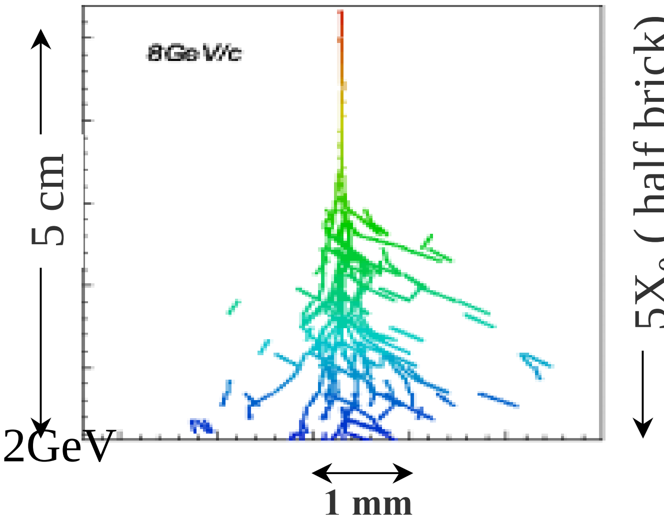
- Performance estimated by reproducing the full chain

•ID Method based on

•Showering and MCS of the track

•e/π measured with Cerenkov/ ECC

•Beam Tests ECC 1.42±0.17 /Cerenkov 1.46±0.11 at 2GeV

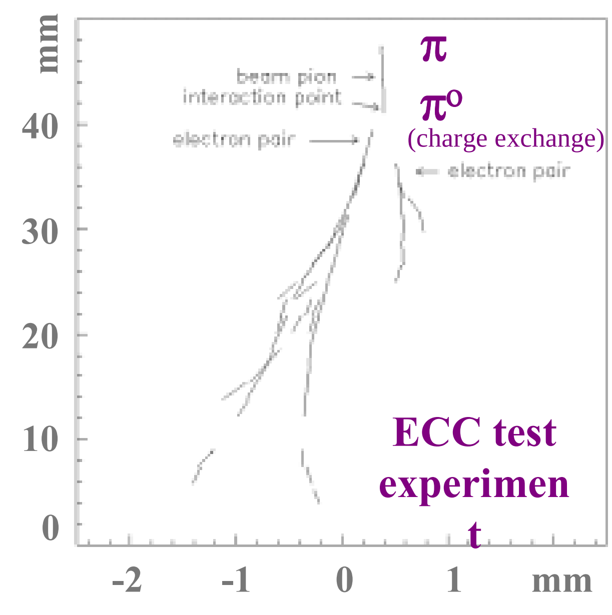


•MC: ε_e = 88 (91) % , π mis-ID 6% (4%) at 2 (4) GeV

•Energy measured by counting the number of track segments into a cone along the electron track

$$\frac{\sigma}{E} = \frac{40\ \%}{\sqrt{E}}$$

π0 ID ->

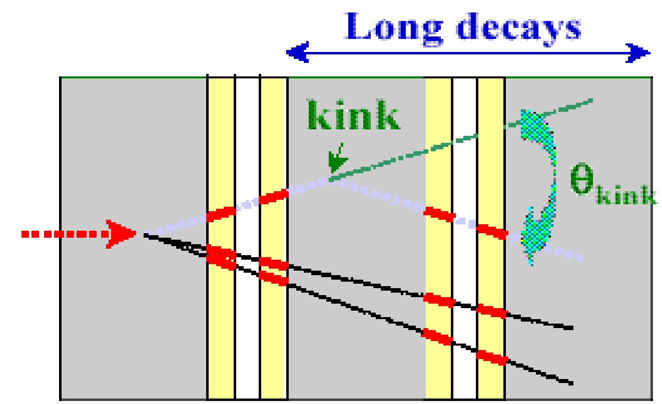


Decay channels

➢ **"Long" decays**

kink angle $\theta_{kink} > 20$ mrad

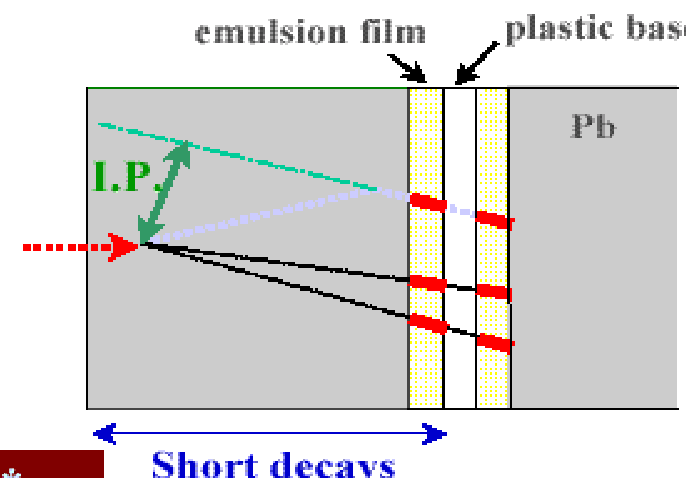
$\tau \rightarrow e$	Progr. Rep.	1999
$\tau \rightarrow \mu$	Progr. Rep.	1999
$\tau \rightarrow h\ (n\pi^0)$	Proposal	2000
$+\ \rho$ search		**2001**



➢ **"Short" decays**

impact parameter I.P. > 5 to 20 μm

$\tau \rightarrow e$	Proposal	2000
$\tau \rightarrow \mu$		**2001**

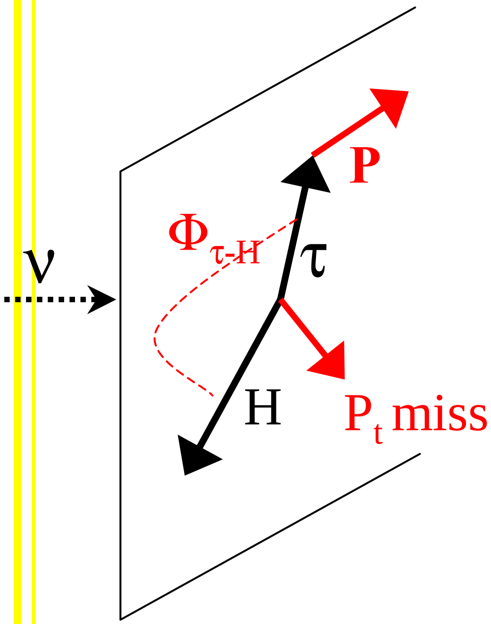


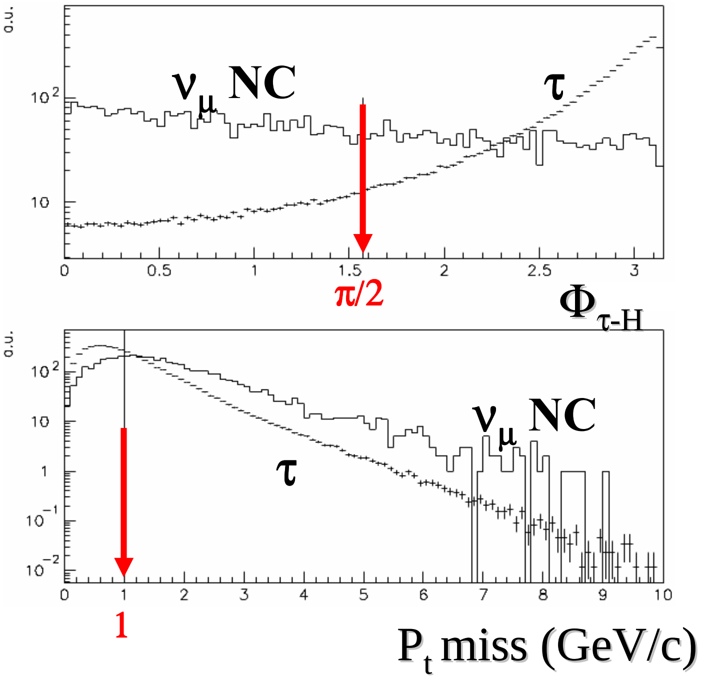
	DIS long	*QE long*	*DIS short*	*Overall**
$\tau \rightarrow e$	2.7	2.3	1.3	3.4
$\tau \rightarrow \mu$	2.4	2.5	0.7	2.8
$\tau \rightarrow h$	2.8	3.5	-	2.9
Total	8.0	8.3	1.3	9.1 (8.7)

(proposal)

Global kinematics for $\tau \rightarrow h$

(for events with a τ decay candidate)





	OPERA $\nu_\mu NC$	NOMAD $\nu_\mu NC$	OPERA $\tau \rightarrow h$	NOMAD $\tau \rightarrow h$
ε_{kin} @1^{ry} vtx	0.20	2.0x10^{-6}	0.65	0.021
P_t kink > 0.6 GeV/c	8.4x10^{-5}	-	0.28	-
Total	1.7x10^{-5}	2.0x10^{-6}	0.18	0.021

Primary role of the observation of the τ decay topology

Expected background events

(5 year run with 1.8 kton average target mass)

		$\tau \to e$	$\tau \to \mu$	$\tau \to h$	*Total*
LONG DECAYS	*Charm production*	0.14	0.03	0.14	0.31 ←
	ν_e *CC and* π^0	0.01	-	-	0.01
	Large angle μ *scattering*		0.10	-	0.10
	Hadron reinteractions	-	-	0.10	0.10
	ν_μ CC		0.06		0.06
	ν_μ NC		0.10		0.10
	Total	**0.15**	**0.29**	**0.24**	**0.67**
SHORT DECAYS	*Charm production*	0.03	0.02	-	0.05
	Large angle μ *scattering*	-	0.02	-	0.02
	ν_e *CC and* π^0	« 0.01	-	-	« 0.01
	Total	**0.03**	**0.04**	-	**0.07**
	Total	**0.18**	**0.33**	**0.24**	**0.75**

Experiment's sensitivity specially depends on the background (Poisson statistics)

Further tools for background reduction are under study

(e.g. μ-π discrimination by dE/dx at the end of the range, on candidate events)

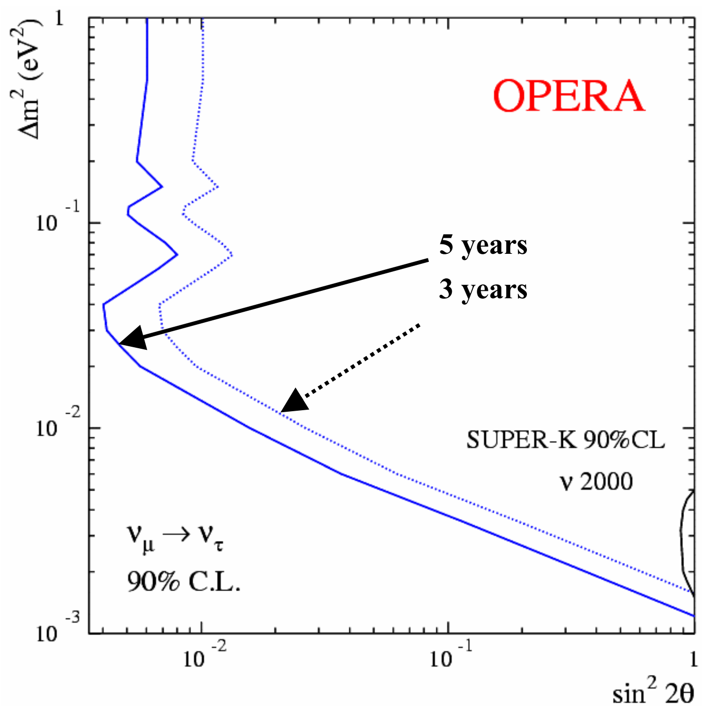
Sensitivity $\nu_\mu \rightarrow \nu_\tau$

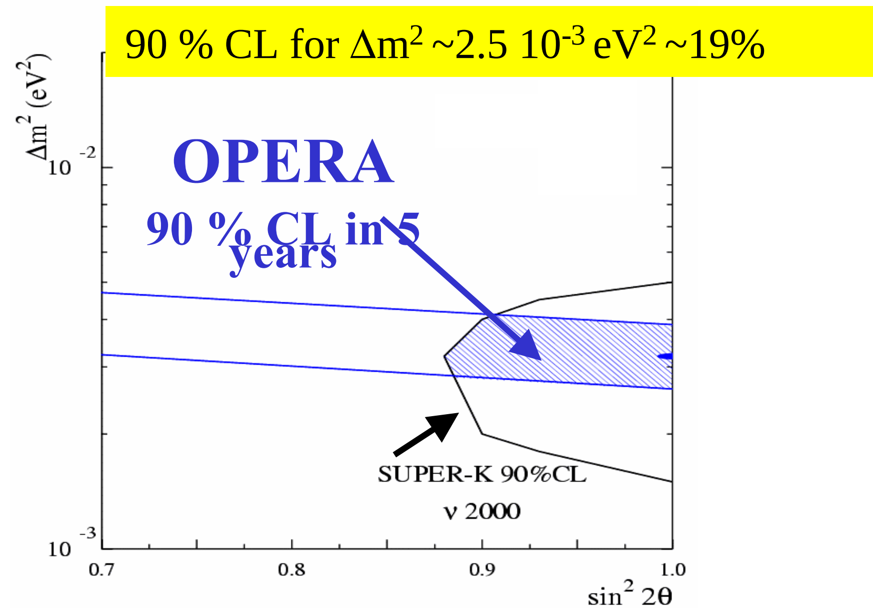
5x1.8=9 Kt years

2.25 10^{20} p.o.t.

- Prob of 3σ significance for $\Delta m^2 = 2.5\ 10^{-3}\ eV^2$: ~ 99%

Decay mode	Signal 1.2*10–3	Signal 2.4*10-3	Signal 5.4*10-3	Bkgnd.
$\tau \rightarrow e$ long	0.8	3.1	15.4	0.15
$\tau \rightarrow \mu$ long	0.7	2.9	14.5	0.29
$\tau \rightarrow h$ long	0.9	3.4	16.8	0.24
$\tau \rightarrow e$ short	0.2	0.9	4.5	0.03
$\tau \rightarrow \mu$ short	0.1	0.5	2.3	0.04
Total	2.7	10.8	53.5	0.75





Uncertainties on background (±33%) and on efficiencies (±15%) accounted for

Expected number of events with Hall C detector

Δm^2 from Super-K / MACRO best fit and S-K 90% CL limits; full mixing; 5 year run)

	signal ($\Delta m^2 = 1.3 \times 10^{-3}$ eV^2)	signal ($\Delta m^2 = 2.5 \times 10^{-3}$ eV^2)	signal ($\Delta m^2 = 4.0 \times 10^{-3}$ eV^2)	background
Status Report				
CNGS	**4.9**	**11.8**	**30.0**	**0.74**
Hall C detector				
CNGS x (1 ÷ 1.5)	**4.3 ÷ 6.4**	**10.3 ÷ 15.5**	**26.3 ÷ 39.4**	**0.65 ÷ 0.97**
CNGS x (1 ÷ 1.5) + dE/dx	**4.4 ÷ 6.6**	**10.6 ÷ 15.8**	**26.8 ÷ 40.2**	**0.41 ÷ 0.62**

dE/dx : preliminary results with μ/π separation and background rejection on the basis of specific ionisation at the end of the range, by special measurements on candidate events.

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

For ν_μ-ν_e oscillation: profit of the excellent e-identification capabilities of the lead-emulsion bric
(1999 Progress Report + current study)

The ICARUS Collaboration

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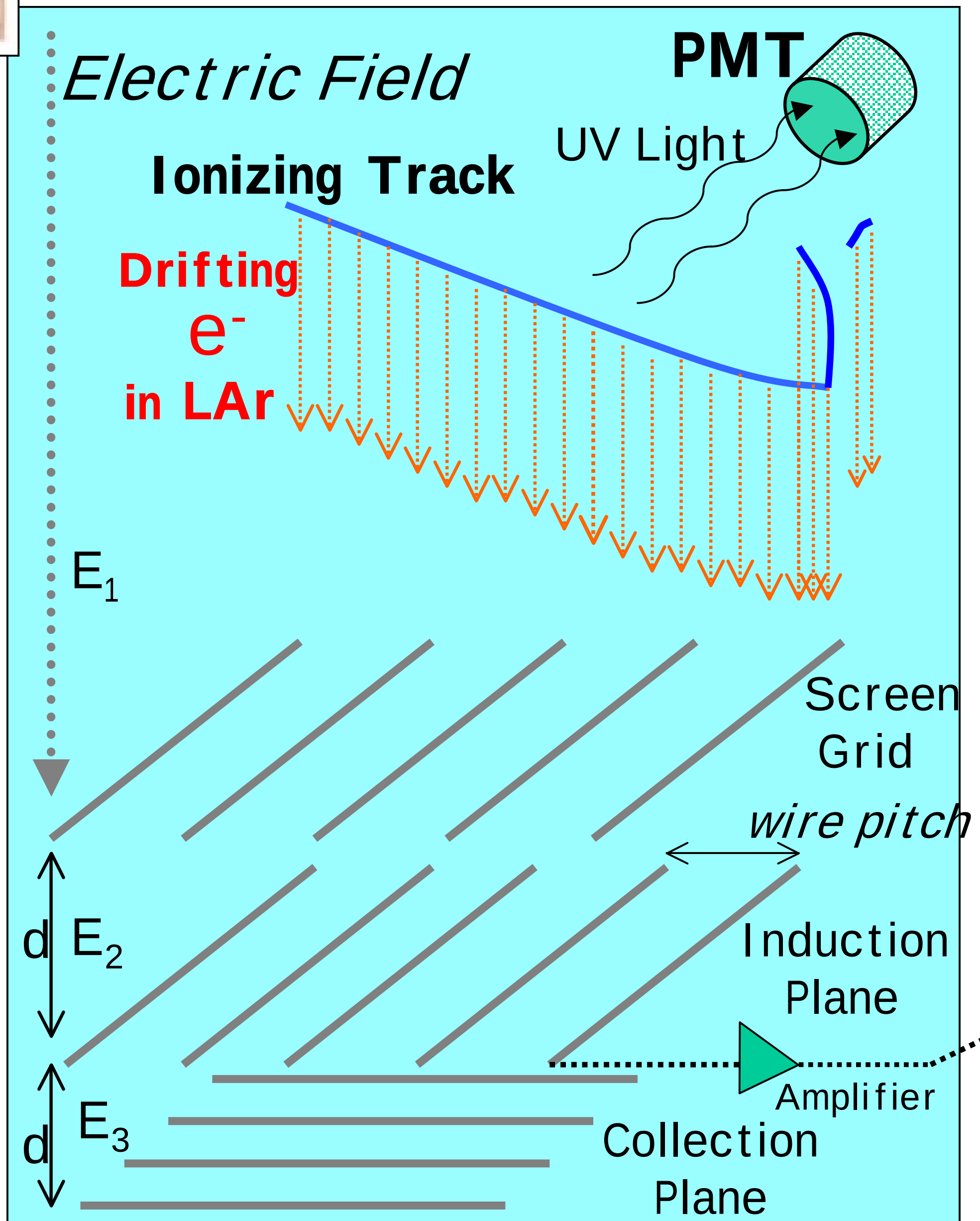
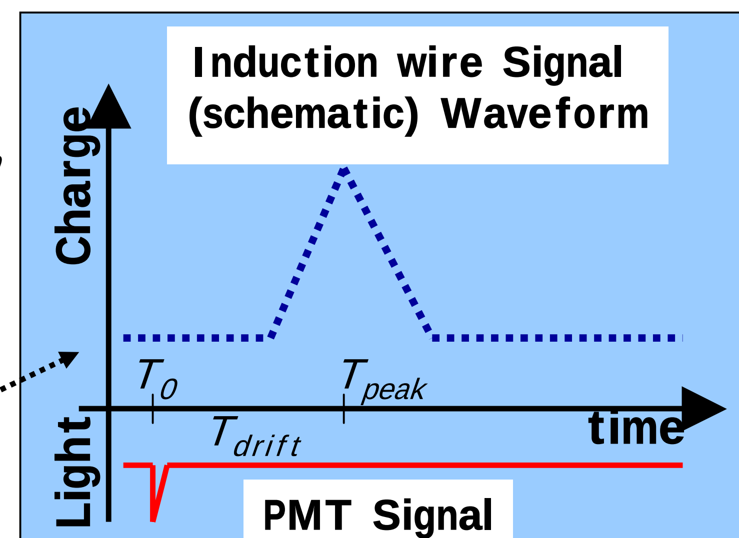
This is an "open" collaboration: new teams welcome !

ICARUS

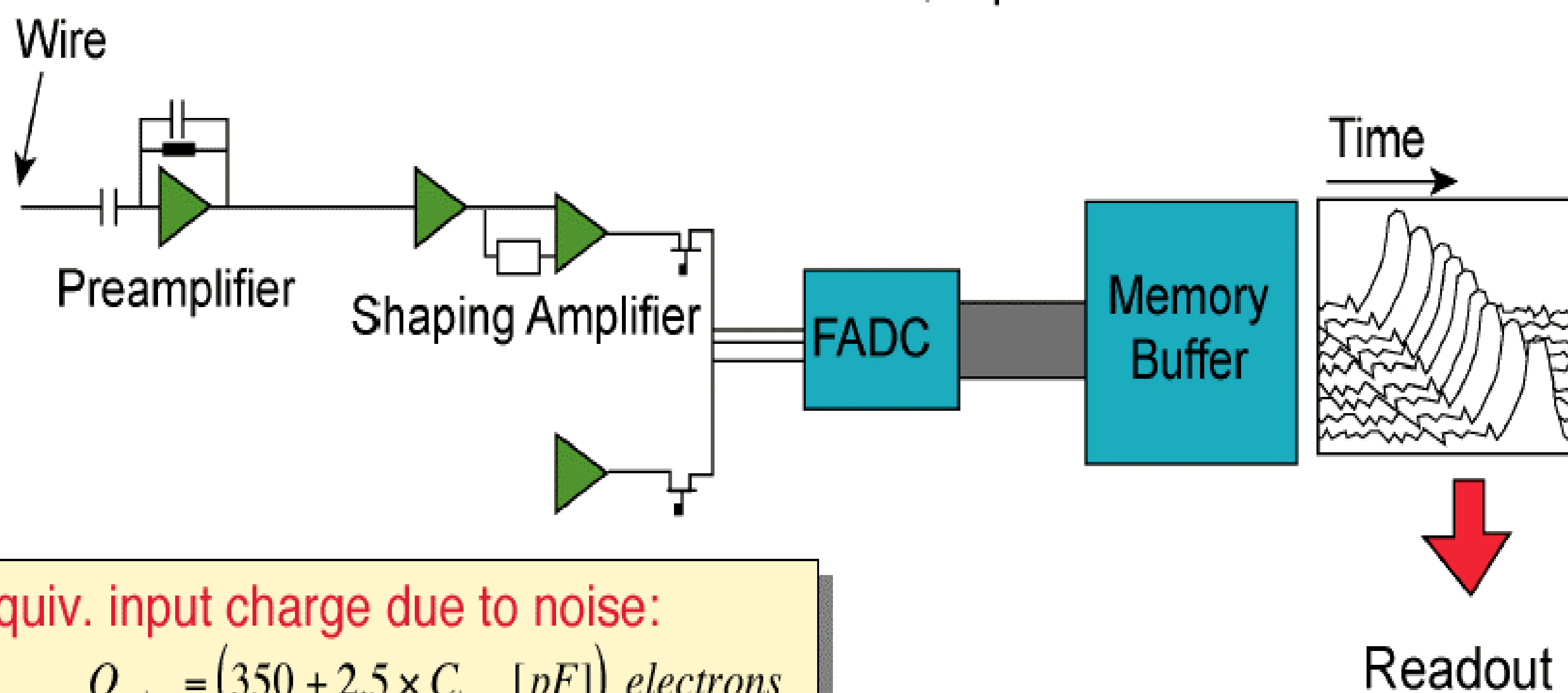


Liquid argon TPC
R&D since late 80's
Drift times > 3 ms (10ms soa)
Low noise electronics
Providing the t=0, scintillation light, optimisaion vs collected drift charge (1 kV/cm)
Resolution 1 mm xy, 0.15mm z
MCS 20% @ 10 GeV



Method of signal recording

- The collected charge is sensed by a ultra-low noise, FET charge sensitive pre-amplifier.
- The signal waveform from individual wires, after being further amplified, filtered and digitized, is continuously stored on a circular memory buffer.
  - ➥ The chamber is continuously sensitive
  - ➥ The *event* is contained in a time window, equal to the maximum drift time.



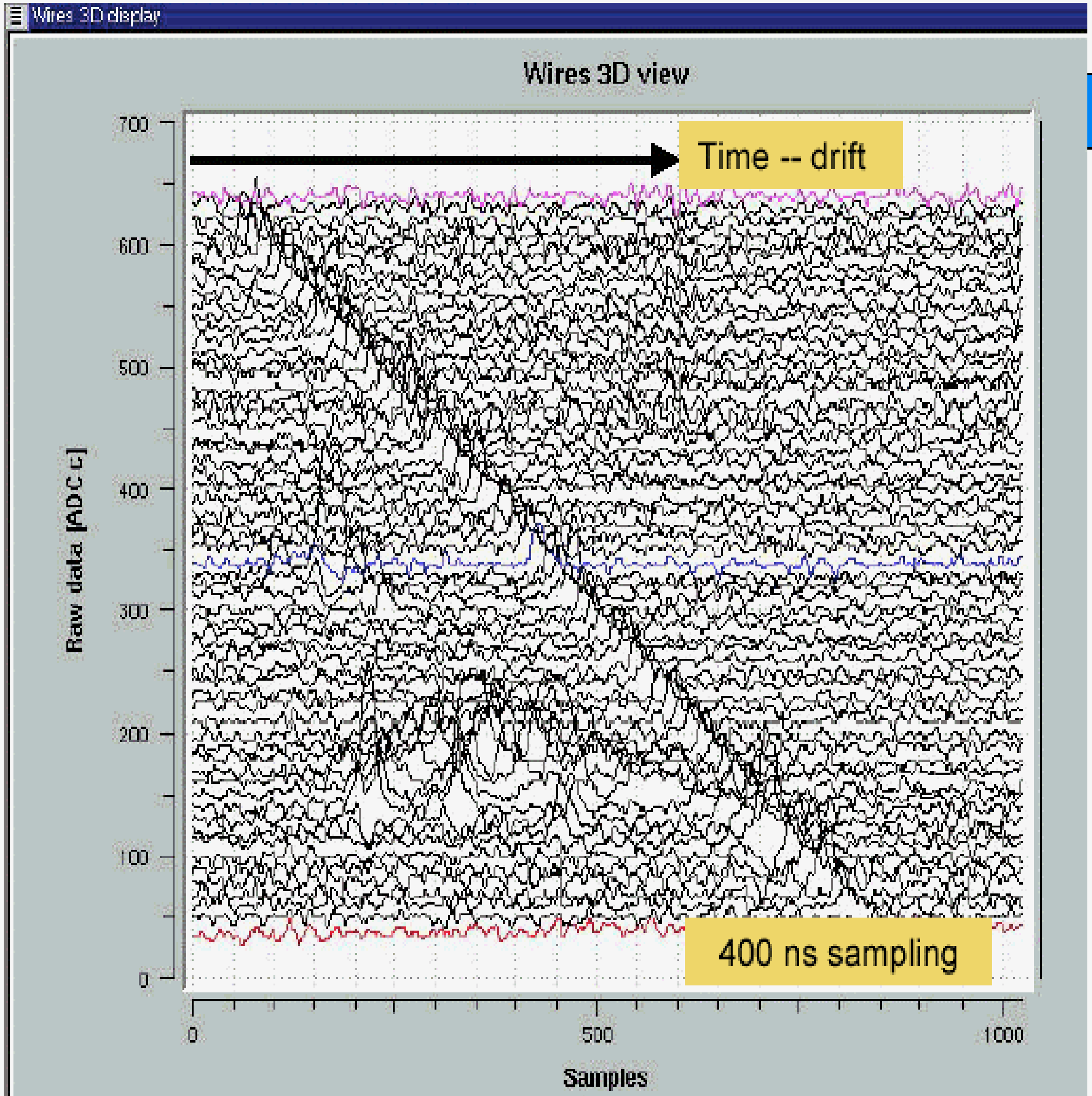
Equiv. input charge due to noise:

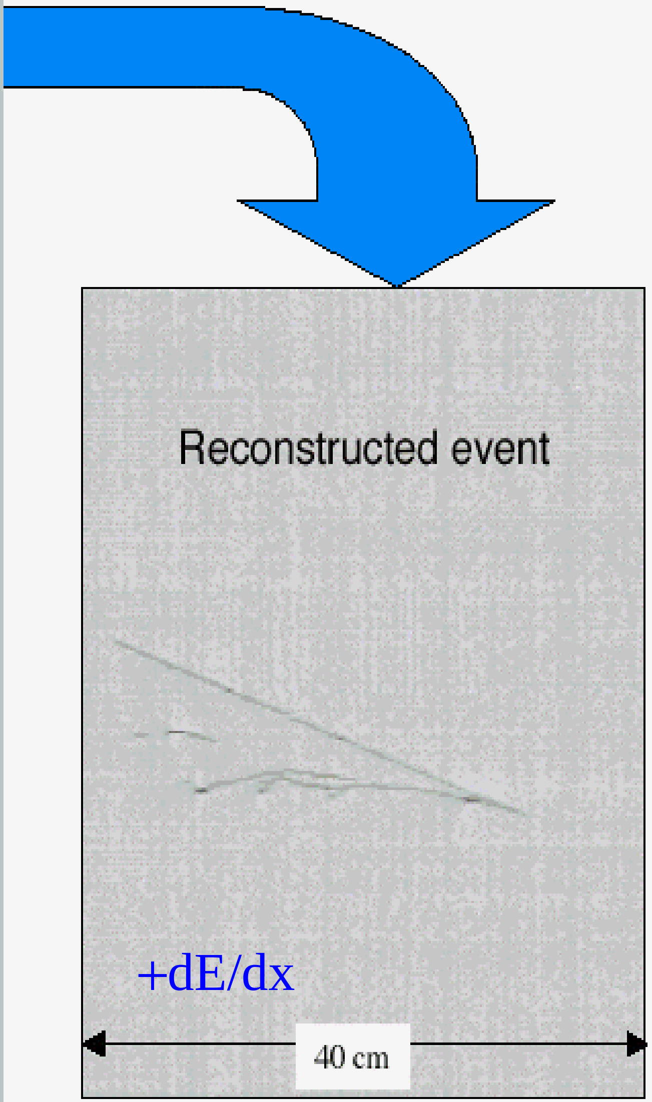
$$Q_{noise} = \left(350 + 2.5 \times C_{input}[pF]\right)\ electrons$$

Principle of signal recording

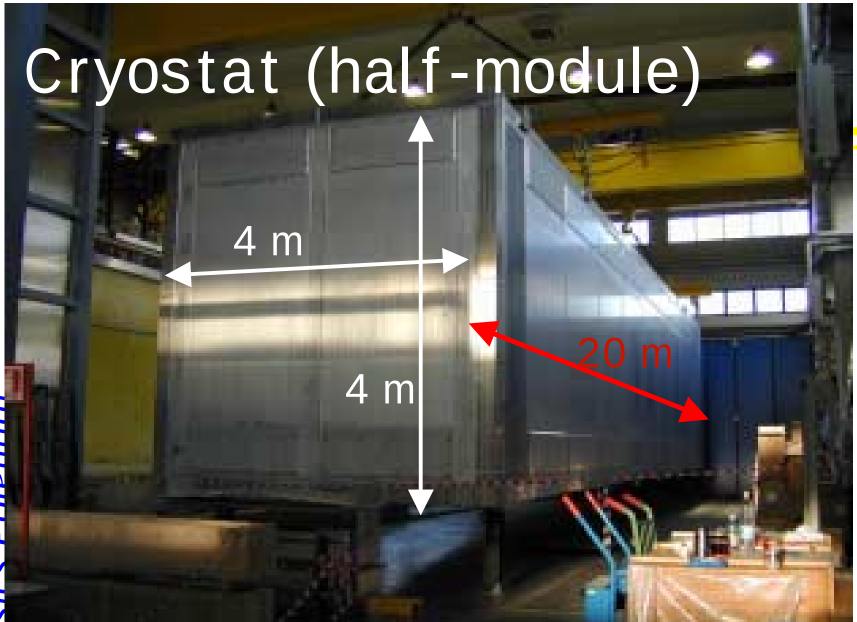
Real Event from a 15 ton LAr Detector

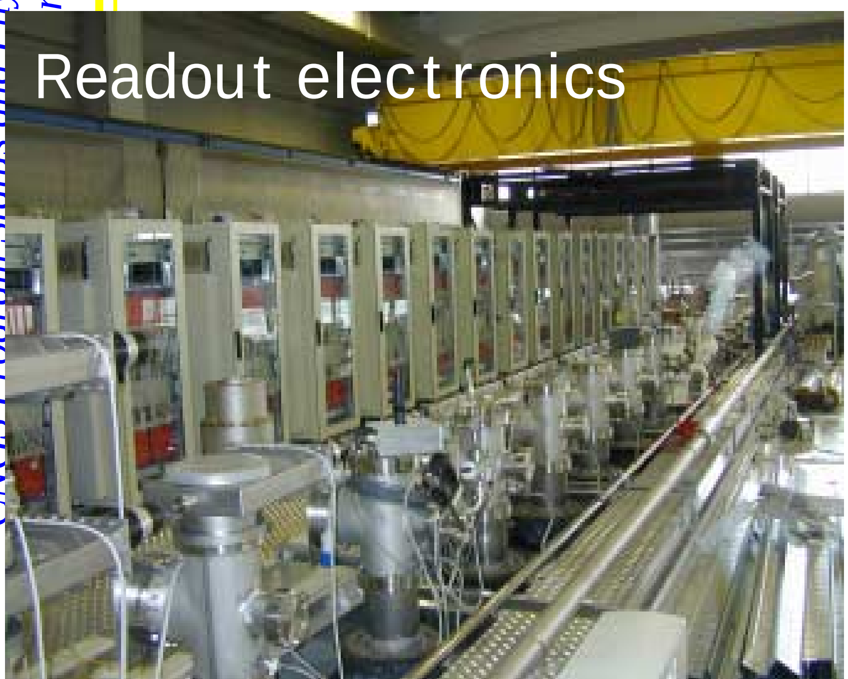
Raw Data

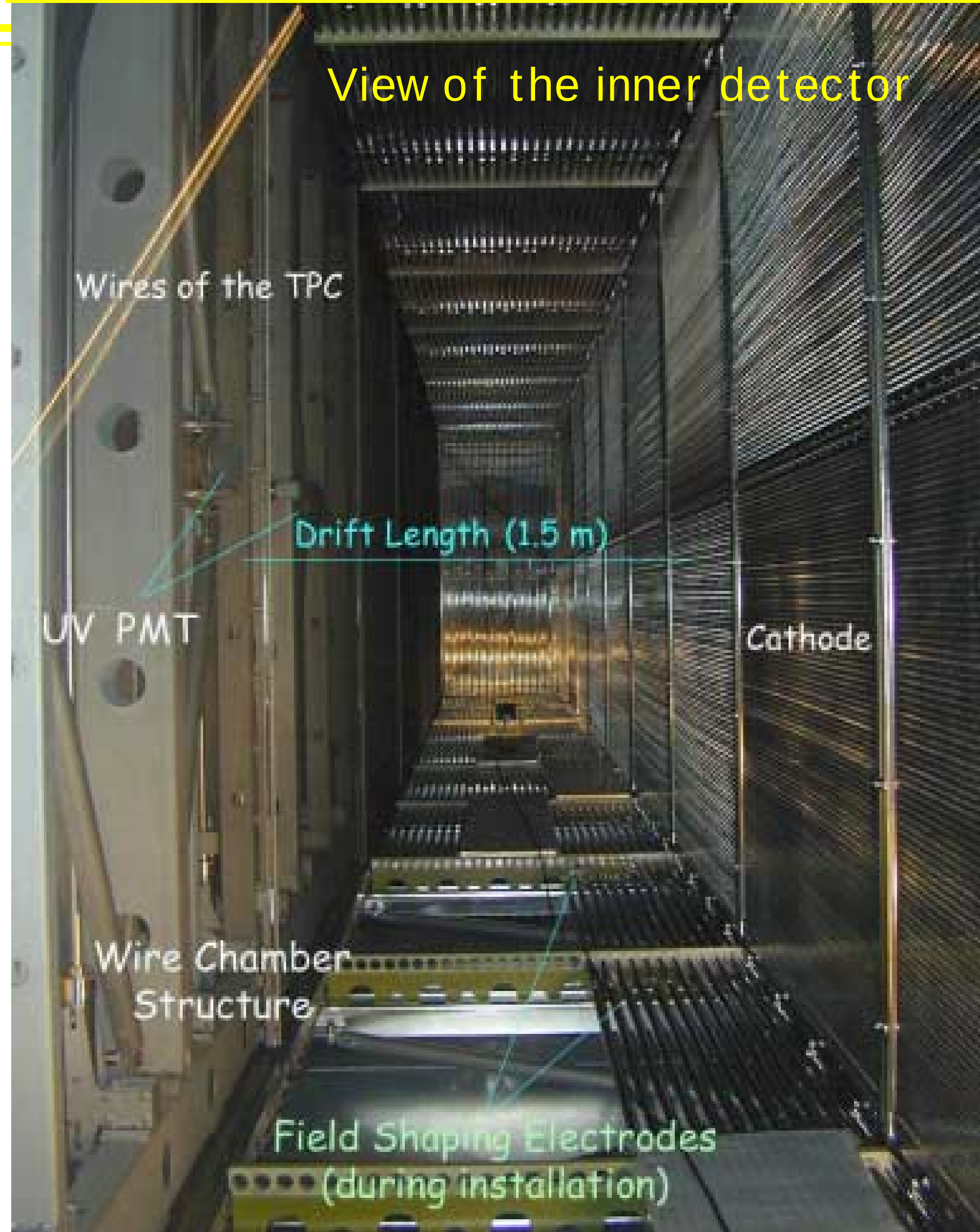




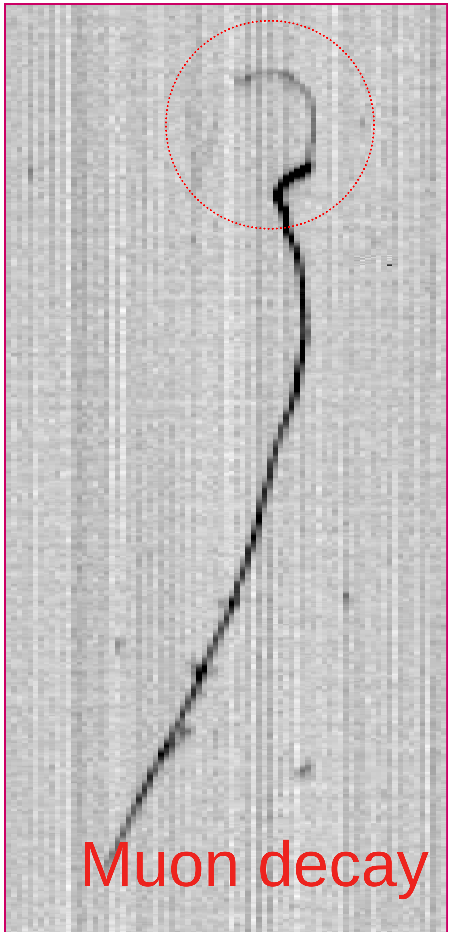
ICARUS T300 prototype





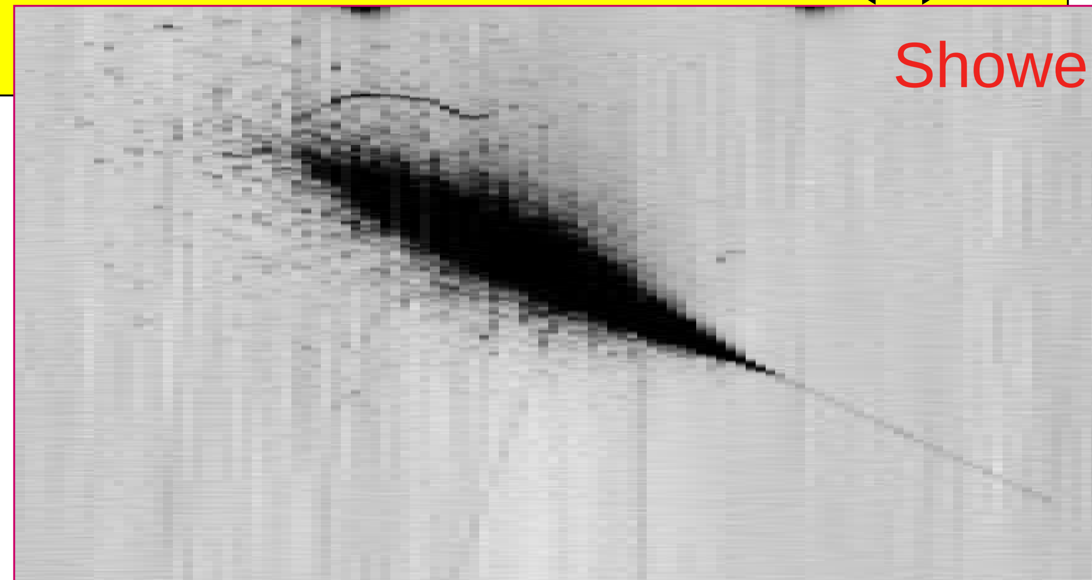


Electronic bubble chamber (I)



85 cm

Run 960, Event 4   Collection Left



176 cm

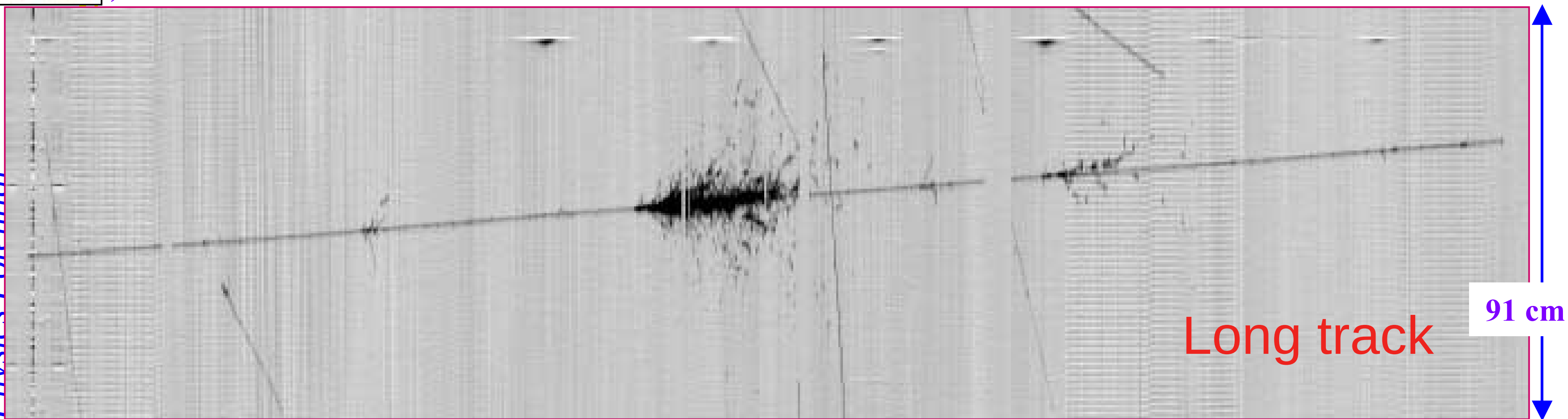
434 cm

265 cm

142 cm

Run 308, Event 160   Collection Left

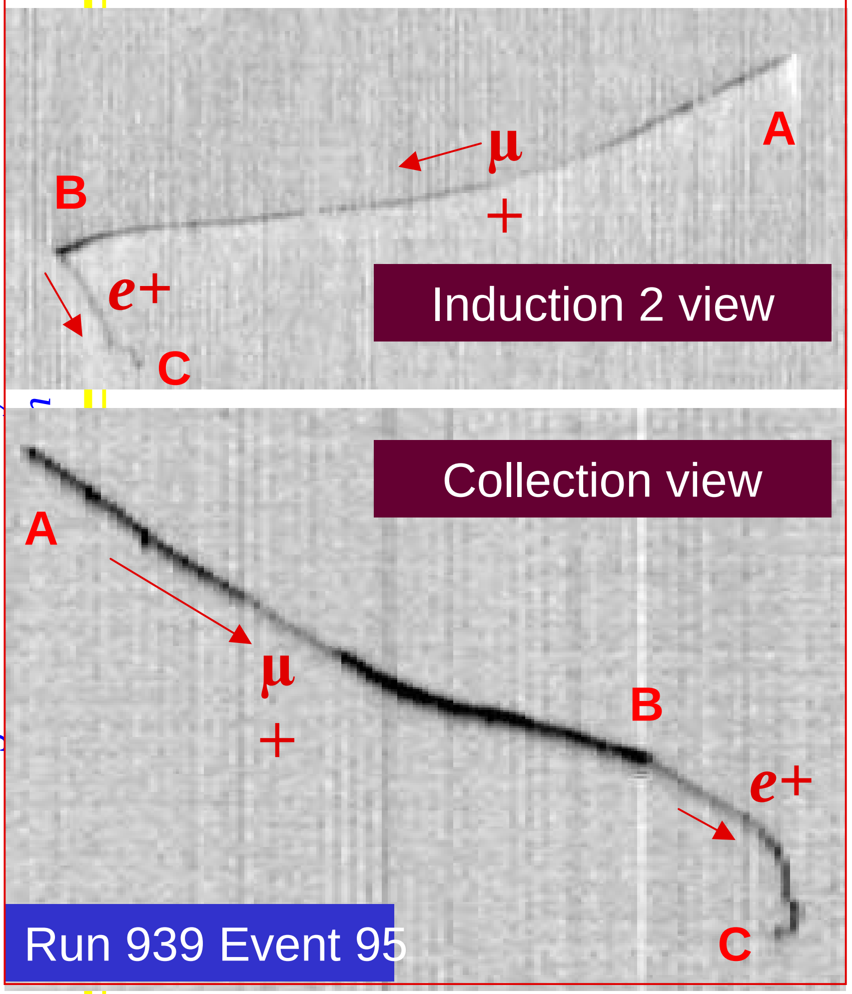
Electronic bubble chamber (II)



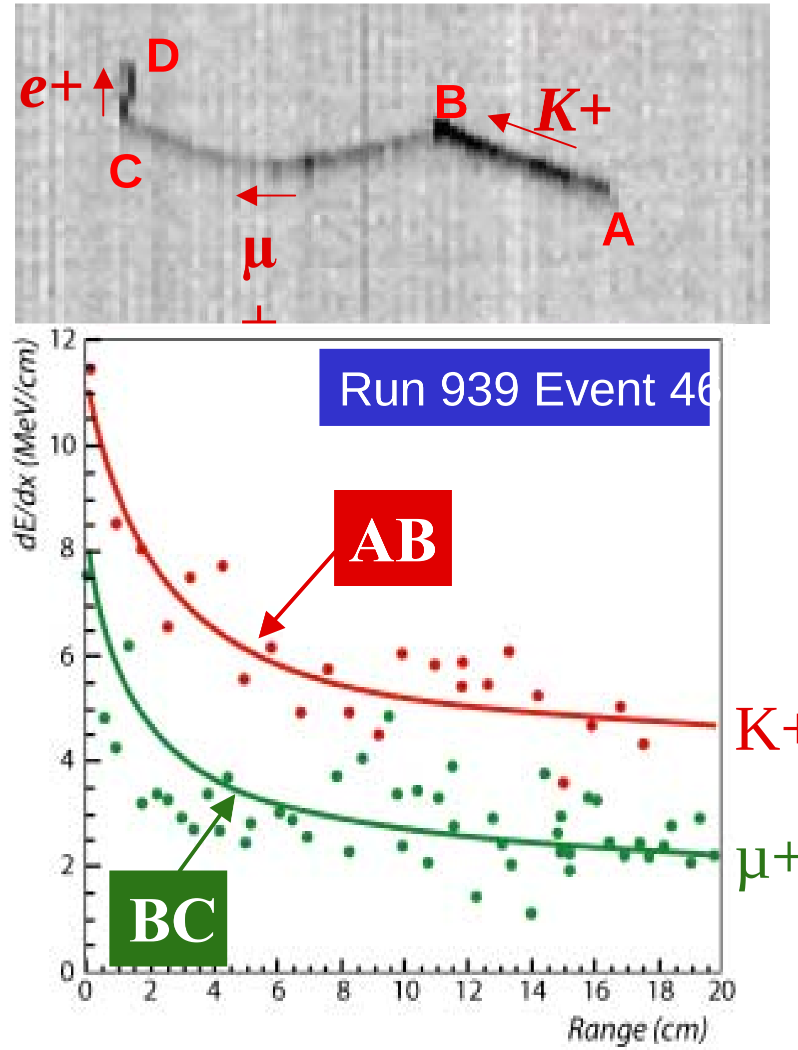
Run 975, Event 61 Collection Left

Particle identification

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



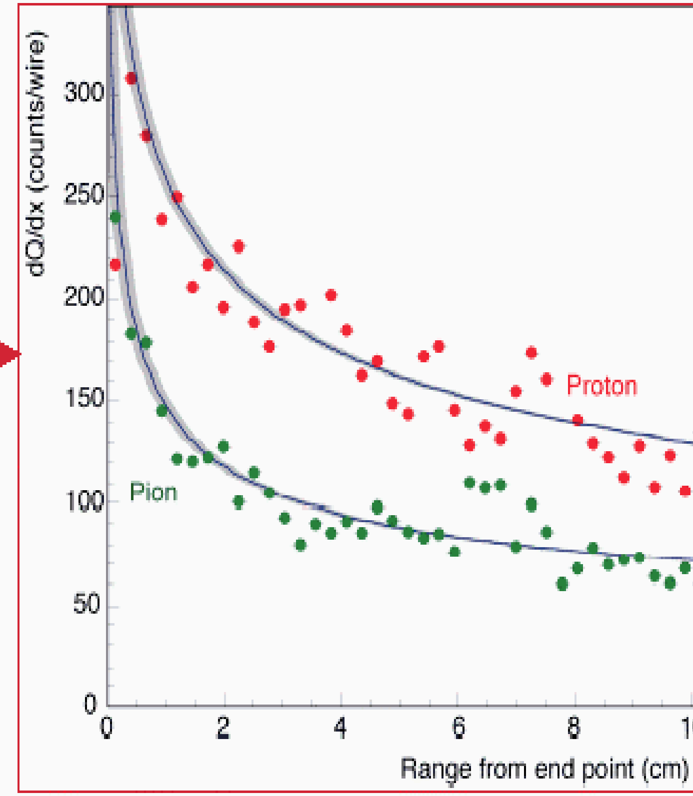
$K^+[AB] \rightarrow \mu^+[BC] \rightarrow e^+[CD]$



CNGS Program Status and Physics Potential

Detector's performance (cont.)

- Measurement of local energy deposition:
  - ➥ Electron / gamma separation (3mm)
  - ➥ Particle ID by means of dE/dx vs range measurement



- Total energy reconstruction of the events from charge integration ➔ excellent calorimeter with high accuracy for contained events

RESOLUTIONS

Low energy electrons:	$\sigma(E)/E = 7\% / \sqrt{E(MeV)}$
Electromagn. showers:	$\sigma(E)/E = 3\% / \sqrt{E(GeV)}$
Hadronic showers (pure LAr):	$\sigma(E)/E = 16\% / \sqrt{E(GeV)} + 1\%$
Hadronic showers (+TMG):	$\sigma(E)/E = 12\% / \sqrt{E(GeV)} + 0.2\%$

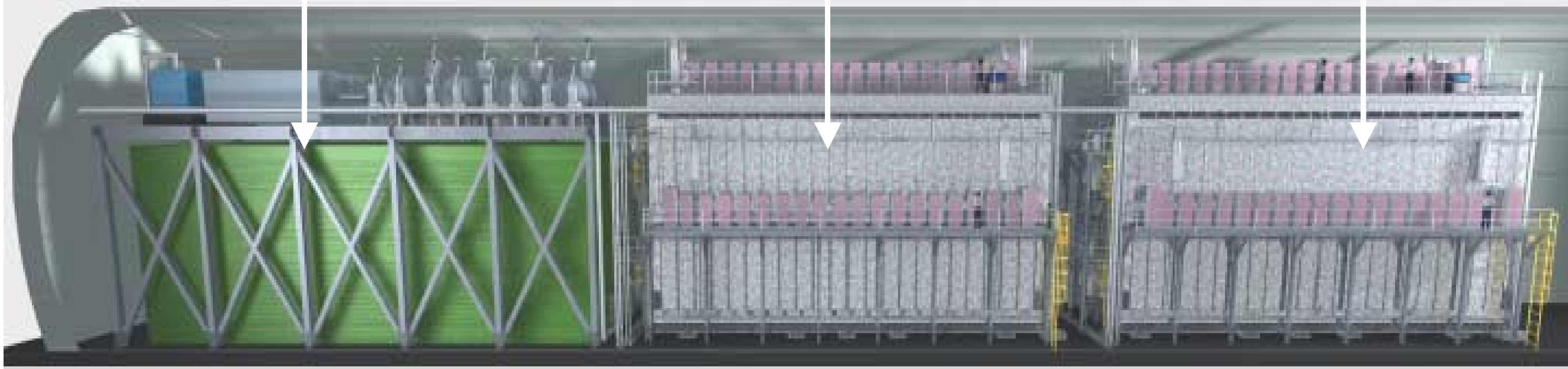
ICARUS T3000 (proposed)

T3000 Detector in Hall B of LNGS (cloning of T600)

First Unit T600 + Auxiliary Equipment

T1200 Unit (two T600 superimposed)

T1200 Unit (two T600 superimposed)



Improved statistics for:

≈ 70 Metres

Future extension to additional modules

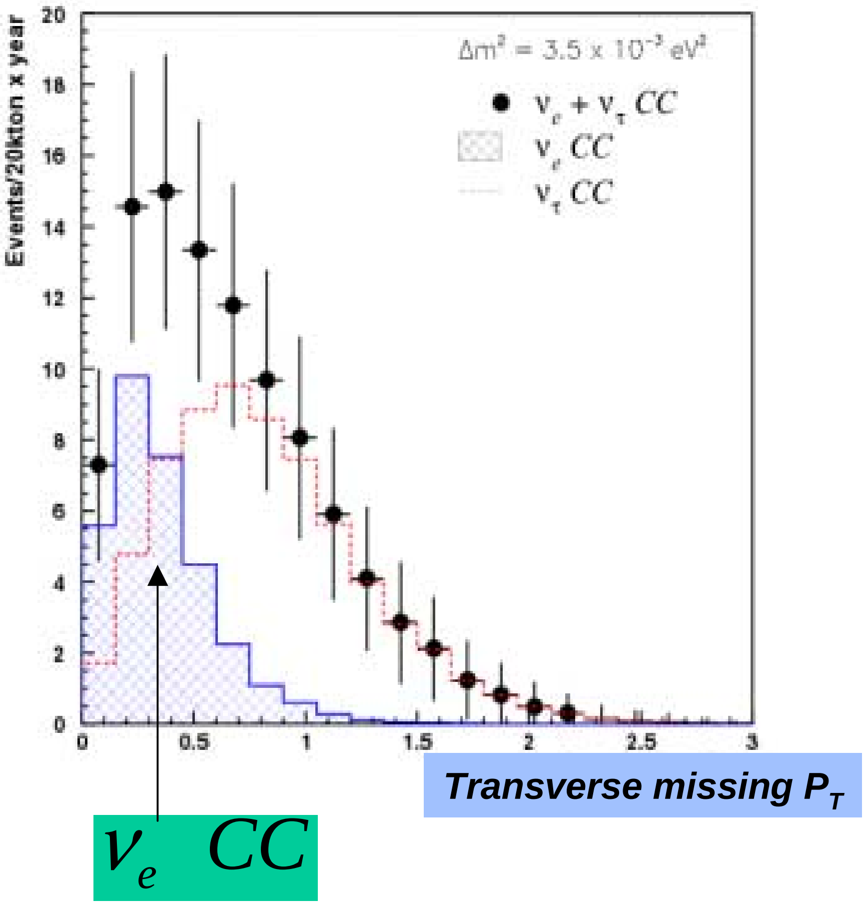
1. **Solar neutrinos**
2. **Atmospheric neutrinos**
3. **Supernova neutrinos**
4. **CERN-NGS neutrinos**
5. **Proton decay**

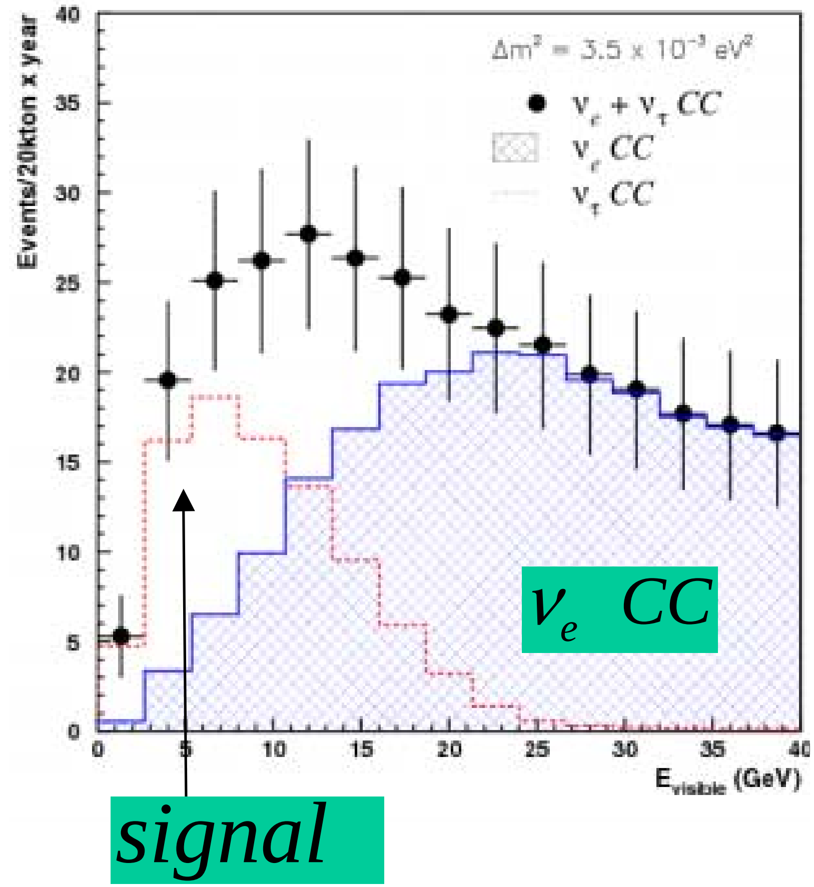
T600: installed in LNGS in 2003

T3000: operational by summer 2006

ICARUS $\nu_\mu \rightarrow \nu_\tau$

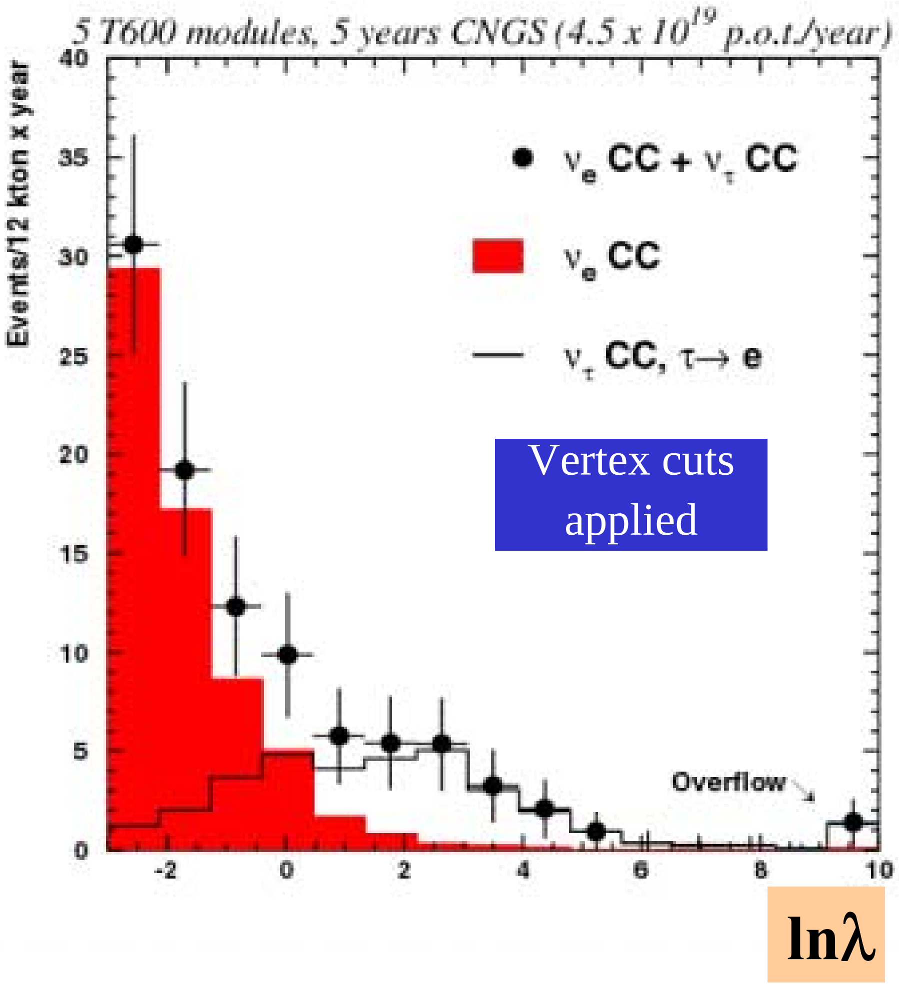
Golden channel $\tau \rightarrow e$ (good e/π^0 separation) but also ($\tau \rightarrow \rho$)





$\tau \rightarrow e$ search: 3D likelihood

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



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

$\nu_\mu \rightarrow \nu_\tau$ appearance search summary

ICARUS T3000 detector

(2.35 kton active LAr)

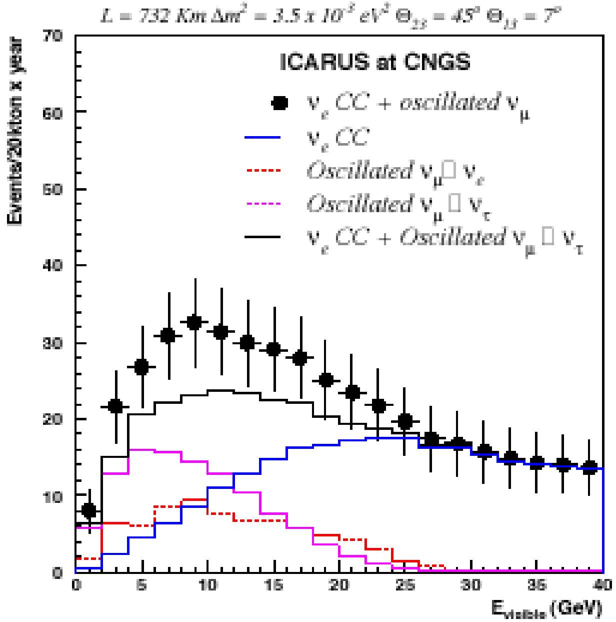
5 year CNGS "shared" running

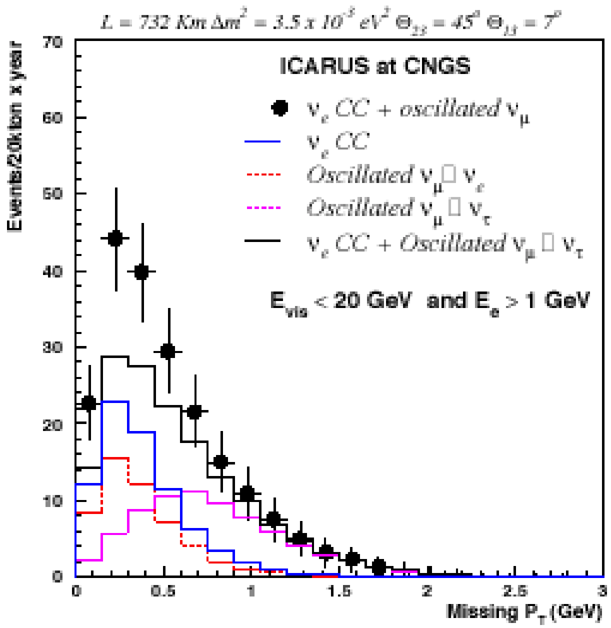
(2.25 x 10^{20} p.o.t.)

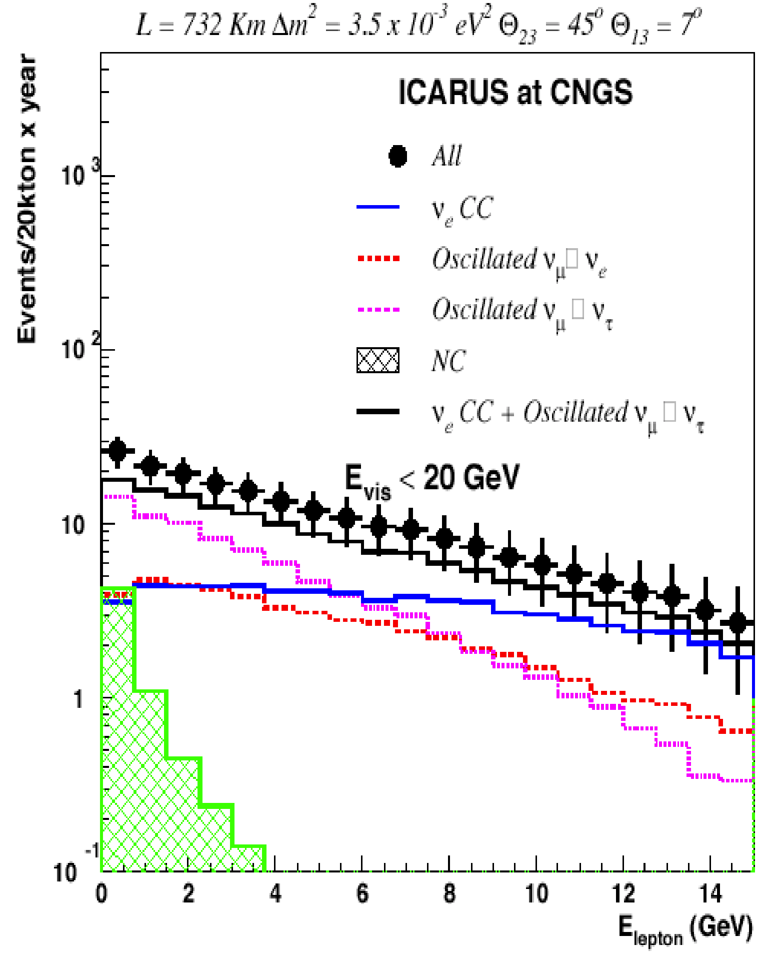
τ decay mode	Signal $\Delta m^2 =$ 1.6×10^{-3} eV^2	Signal $\Delta m^2 =$ 2.5×10^{-3} eV^2	Signal $\Delta m^2 =$ 3.0×10^{-3} eV^2	Signal $\Delta m^2 =$ 4.0×10^{-3} eV^2	BG
$\tau \to e$	3.7	9	13	23	0.7
$\tau \to \rho$ DIS	0.6	1.5	2.2	3.9	< 0.1
$\tau \to \rho$ QE	0.6	1.4	2.0	3.6	< 0.1
Total	**4.9**	**11.9**	**17.2**	**30.5**	**0.7**

Super-Kamiokande: $1.6 < \Delta m^2 < 4.0$ at 90% C.L.

SAME SENSITIVITY AS OPERA







Electron appearance
Full 3 flavour analysis

ICARUS $\nu_\mu \rightarrow \nu_e$

Oscillations $\nu_\mu \rightarrow \nu_e$: => θ_{13} (8 years shared or 5 dedicated)

Cuts: Fiducial, $E_e > 1$ GeV, $E_{vis} < 20$ GeV

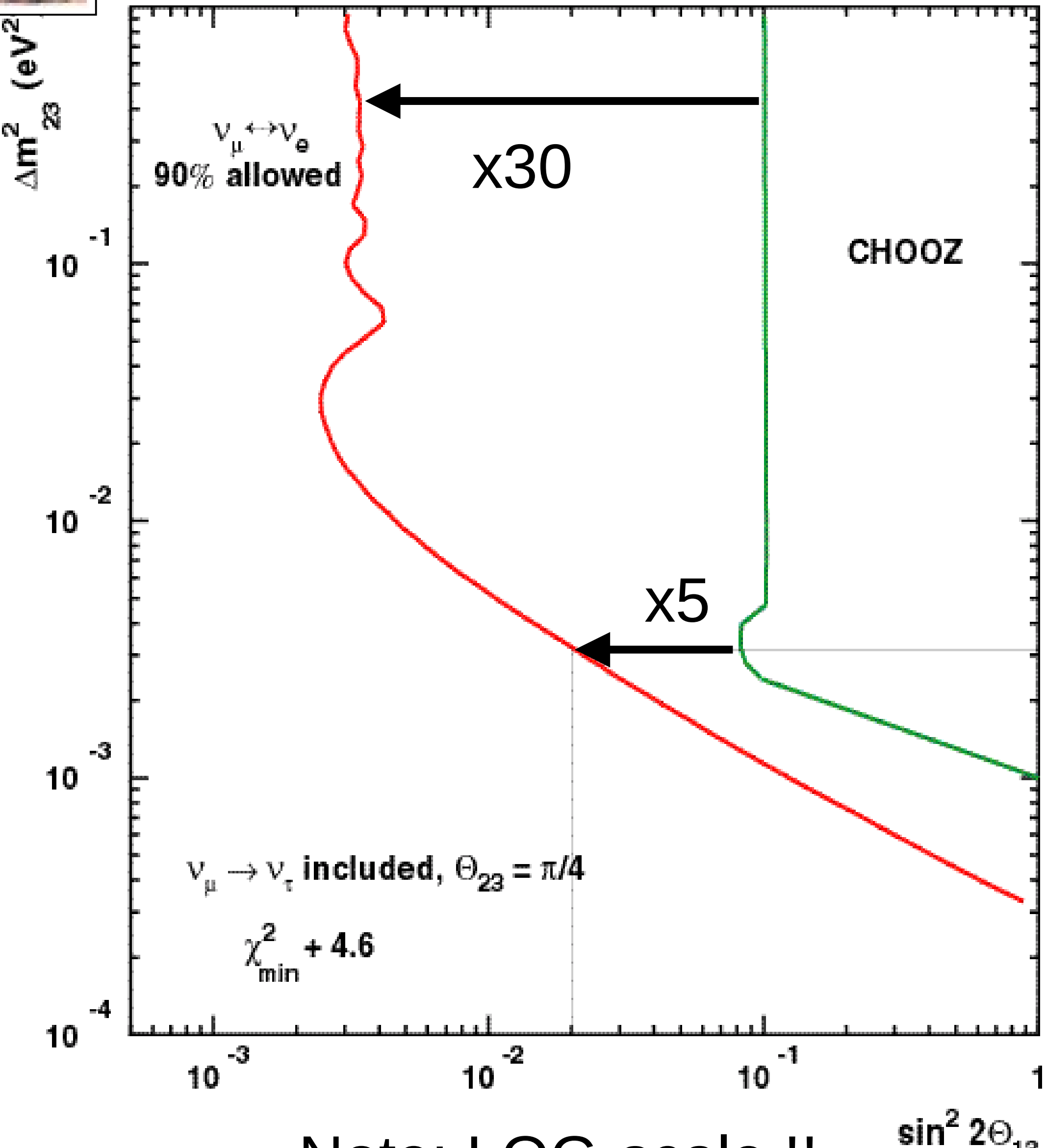
$\Delta m^2_{23} = 3.5 \times 10^{-3}$ eV^2, $\theta_{23} = 45^o$

θ_{13} (degrees)	$\sin^2 2\theta_{13}$	ν_e CC	$\nu_\mu \rightarrow \nu_\tau$ $\tau \rightarrow e$	$\nu_\mu \rightarrow \nu_e$	Total	Statistical significance
9	0.095	79	74	84	237	6.8σ
8	0.076	79	75	67	221	5.4σ
7	0.058	79	76	51	206	4.1σ
5	0.030	79	77	26	182	2.1σ
3	0.011	79	77	10	166	0.8σ

$$P(\nu_\mu \rightarrow \nu_\tau) = \cos^4 \theta_{13} \sin^2 2\theta_{23} \Delta^2_{32}$$

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta_{13} \sin^2 \theta_{23} \Delta^2_{32}$$

Expected sensitivity to θ_{13}



Note: LOG-scale !!

ICARUS
5 years dedicated SPS
2.35 kton fid. mass

Sensitivity assuming both $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_e$ at the same Δm^2 (three family mixing)

$$\sin^2 2\theta_{13} > 2 \times 10^{-2}$$

$$for \;\; \Delta m^2_{32} = 3 \times 10^{-3} eV^2$$

Θ_{13} limit from 9 to 5^0

Conclusions

- BEAM
  - CNGS beam on schedule, small overscost, can be ready by 2006
  - a 30-50% increase in luminosity at low cost possible
- EXPERIMENT STATUS
  - OPERA quickly adapted the detector to Hall C, and the loss of the CERN group, with negligible loss in sensitivity. Detailed schedule showing that they can be ready by 2006
  - ICARUS has demonstrated brilliantly the principle, and is proposing a T3000 detector in Hall B, installing T600 in 2003 . T3000 could be ready by 2006.
- PHYSICS
  - ICARUS/OPERA will collect of the order of 25-30 τ appearance events in 5 years with negligible background @ $\Delta m^2 \sim 2.5\ 10^{-3}$ eV^2 permitting a determination of Δm^2 with a precision of 10%
  - The ν_e appearance channel is there practically for free, both detectors are high grained. The systematics of the ν_e component in the beam main background. Activity in both detectors to evaluate precisely the optimal sensitivity in the ν_e appearance channel, giving access to θ_{13}