Daniele Gibin

Universitá di Padova and Istituto Nazionale di Fisica Nucleare,

Sezione di Padova

"Physics Potential of CNGS"

- **Introduction.**
- **The CNGS project**
- **The physics programme of CNGS**
- **Conclusions**

Torino, April 15, 2004

Neutrino Oscillations

Neutrino oscillations depend from

- 3 mixing angles, $\theta_{12}, \theta_{23}, \theta_{13}$
- 2 mass differences: Δm^2_{12}, Δm^2_{23}
- 1 CP phase δ

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_3 \\ \nu_3 \end{pmatrix}$$

$$U(\theta_{12}, \theta_{23}, \theta_{13}, \delta) = \begin{pmatrix} c_{13}c_{12} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - s_{13}s_{23}c_{12}e^{i\delta} & c_{23}c_{12} - s_{13}s_{23}s_{12}e^{i\delta} & c_{13}s_{23} \\ s_{23}s_{12} - s_{13}c_{23}c_{12}e^{i\delta} & -s_{23}c_{12} - s_{13}c_{23}s_{12}e^{i\delta} & c_{13}c_{13} \end{pmatrix}$$

In vacuum:

$$P(\nu_\alpha \to \nu_\beta) = -4 \sum_{k>j} Re[W^{jk}_{\alpha\beta}] \sin^2 \frac{\Delta m^2_{jk} L}{4E_\nu} \pm 2 \sum_{k>j} Im[W^{jk}_{\alpha\beta}] \sin^2 \frac{\Delta m^2_{jk} L}{2E_\nu}$$

$\alpha = e, \mu, \tau$

$j = 1, 2, 3$

$W^{jk}_{\alpha\beta} = U_{\alpha j} U^*_{\beta j} U^*_{\alpha k} U_{\beta k}$

$$2\,\text{neutrinos}: \quad P(\nu_\alpha \to \nu_\beta) = \sin^2 2\theta \cdot \sin^2 (1.27 \Delta m^2_{\alpha\beta}[eV^2] L[km]/E[GeV])$$

Atmospheric Neutrino

New analysis Saji@noon2004

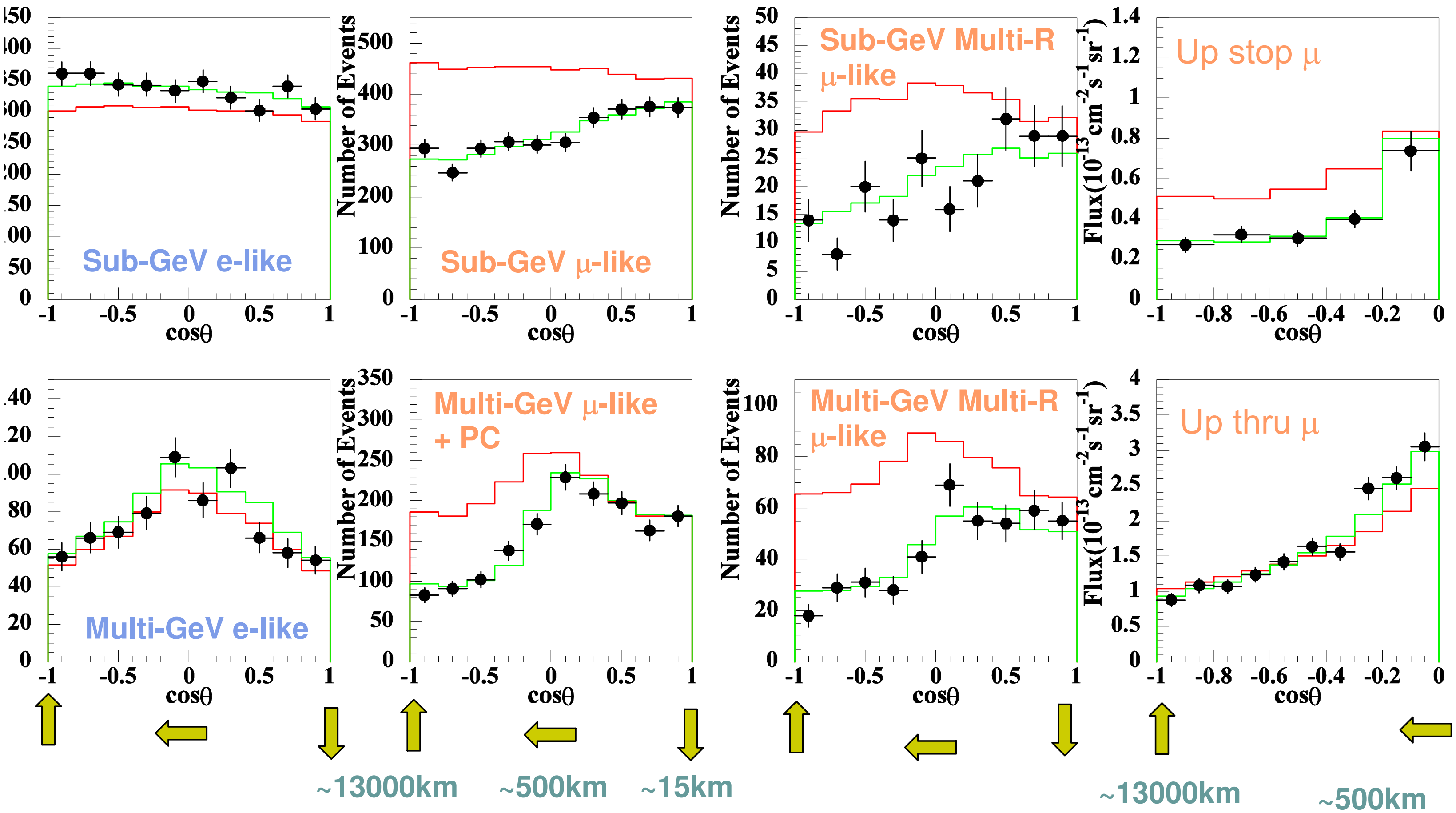
Zenith angle distributions

$\nu_\mu \leftrightarrow \nu_\tau$

2-flavor oscillations

Best fit $\sin^2 2\theta=1.0$, $\Delta m^2=2.0\times10^{-3}$ eV^2

Null oscillation



2 ν Oscillation Interpretation

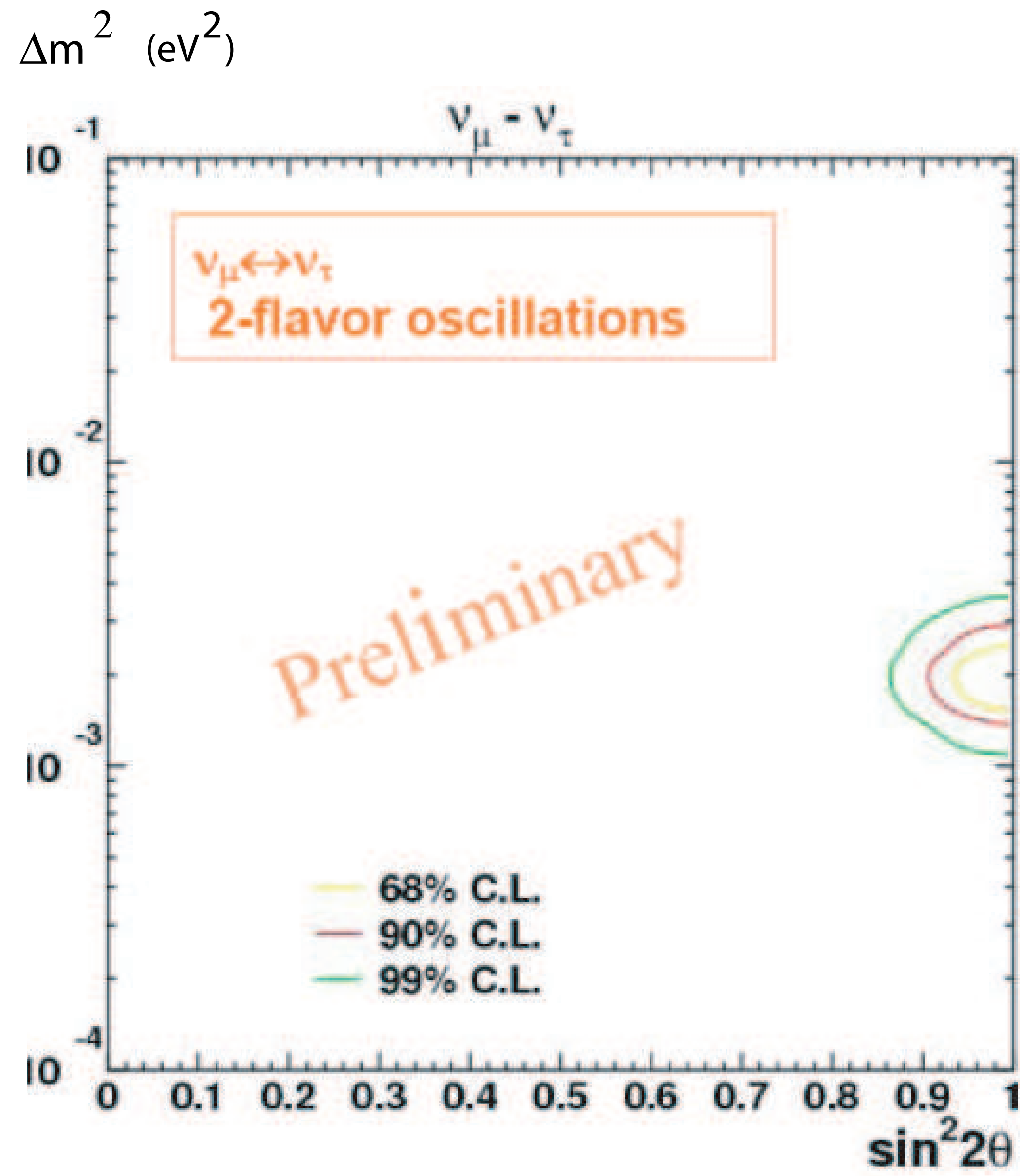
From Sanji@noon2004

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

Allowed region shifted!

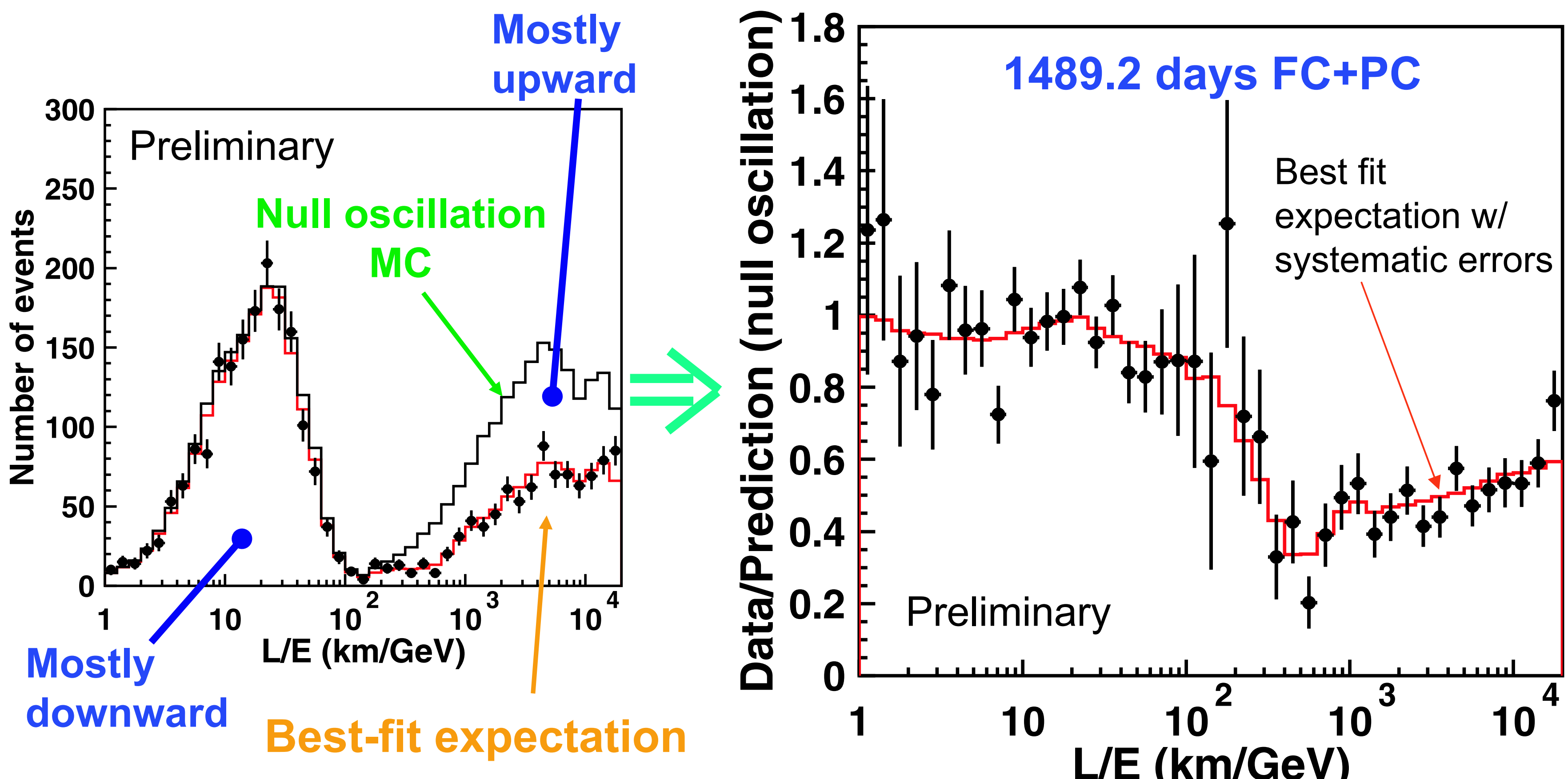
$$\Delta m^2 = 2.5 \cdot 10^{-3} eV^2$$

$$\Delta m^2 = 2.0 \cdot 10^{-3} eV^2$$



Atmospheric Neutrino: L/E signature of Oscillation ?

Preliminary analysis selecting events having better reconstructed L/E
Ishitsuka@noon2004



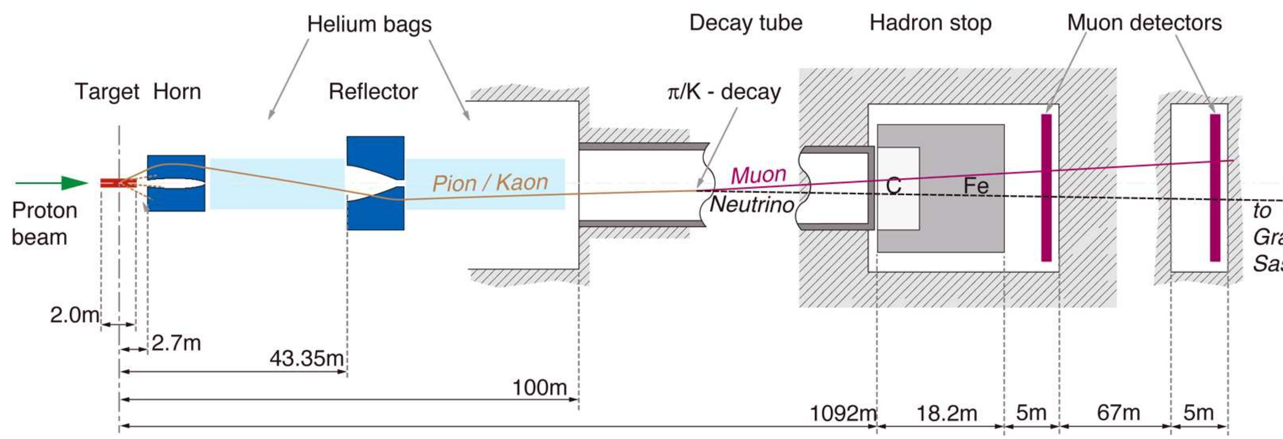
$m^2=2.4\text{x}10^{-3}$,$\sin^2 2$ =1.00
$^2_{min}$=37.8/40 d.o.f

First dip is observed as expected from neutrino oscillation

CNGS project

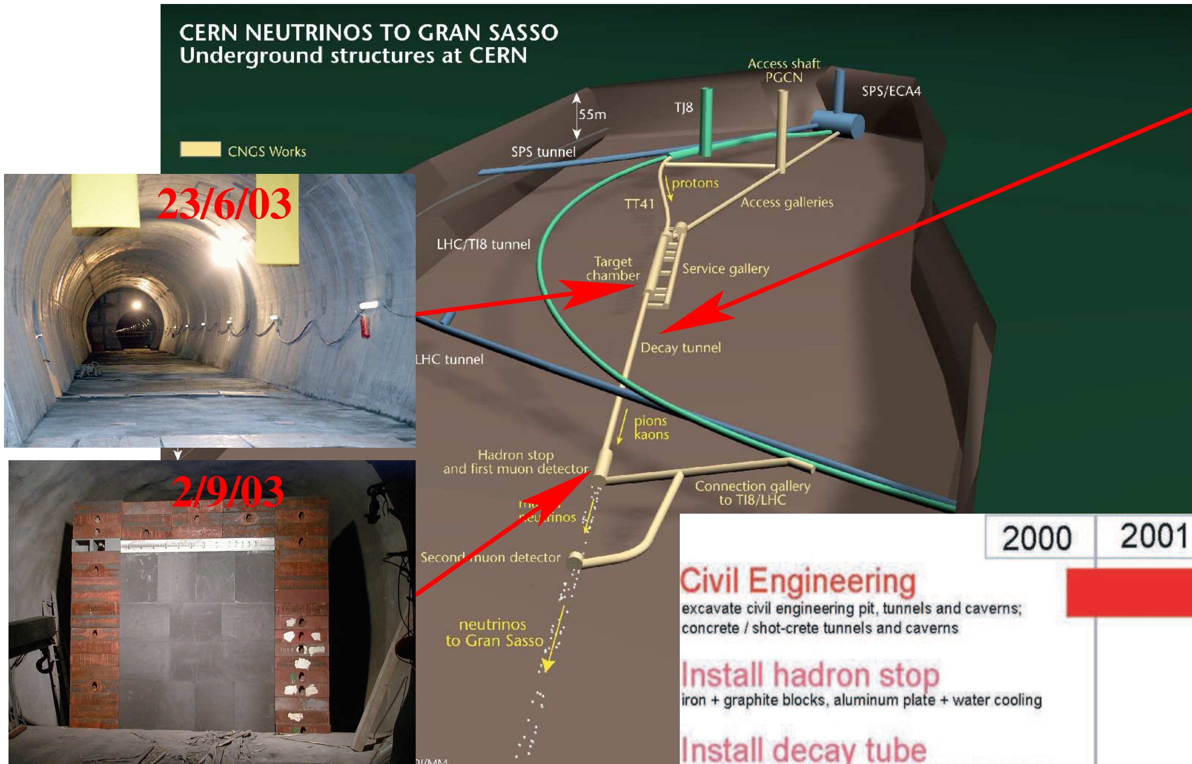
Conventional High energy Neutrino Beam from CERN to LNGS

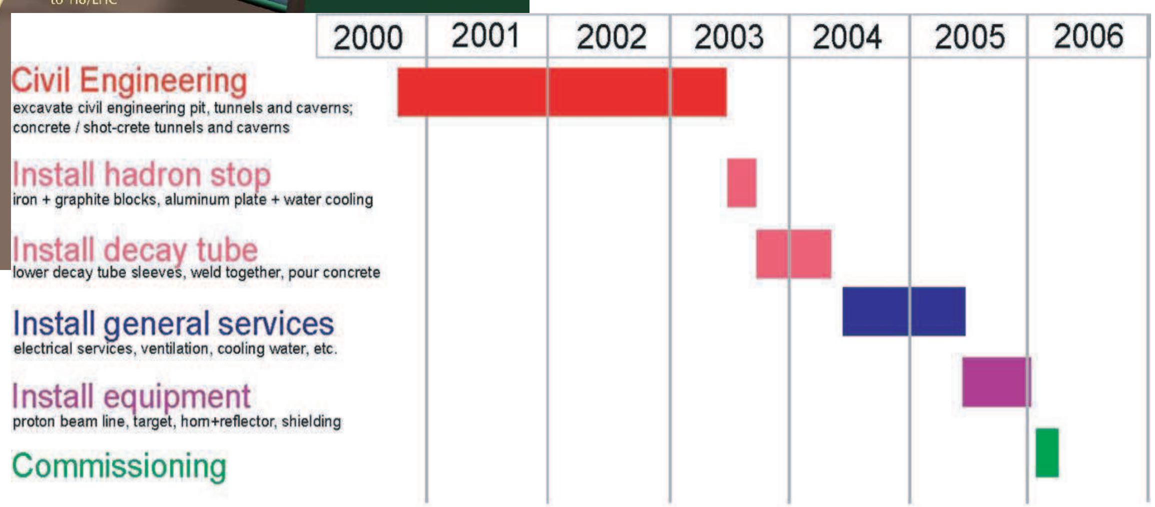
Proton Energy	400 Gev
L	732 km
$< E_{\nu_\mu} >$	17.4 GeV
$4.5 \cdot 10^{19}$pot/year	



Careful design of optics to reduce material (reinteractions!) along the beam line

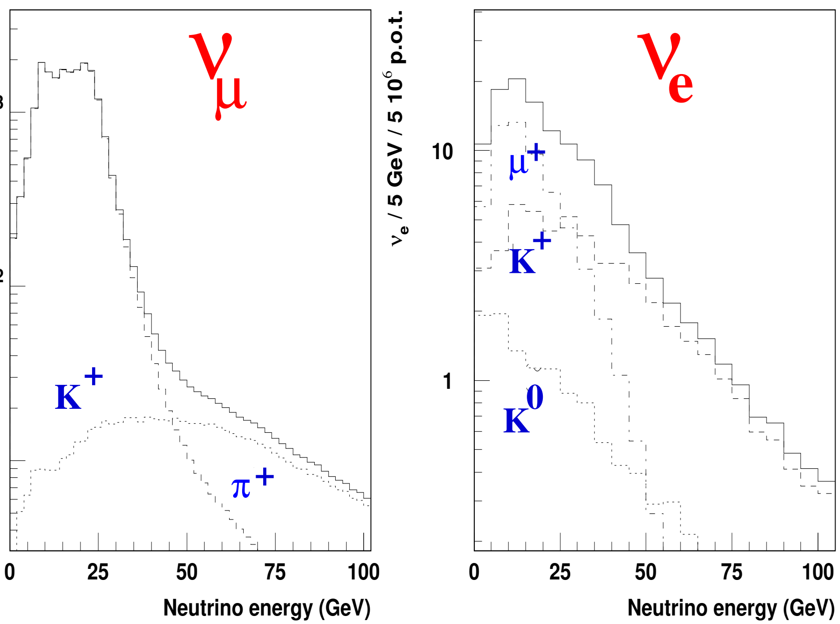
Status of the project





First beam to Gran Sasso: May 2006

The CNGS Neutrino Beam



Designed on the base of the WANF experience

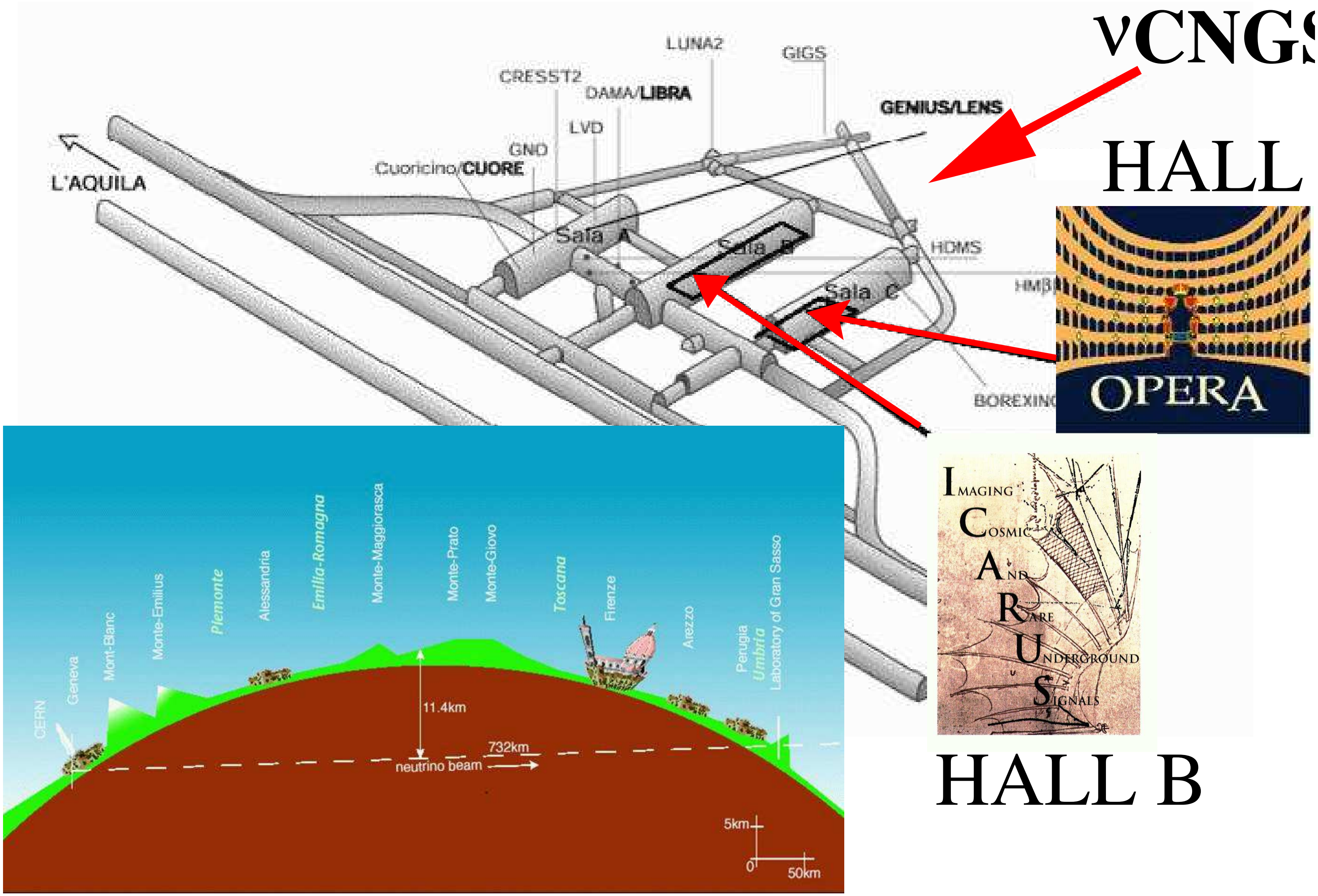
Almost pure ν_μ beam (WANF ν_μCC/pot known to $\sim 8\%$)

the ratio $\nu_e/\nu_\mu \sim 0.8\%$ with a global systematic error $\sim 3\%$

The ν energy is chosen well above the ν_τCC threshold, to allow the detection of ν_τ appearance in the beam

Neutrino Facility	Proton energy (GeV)	L (km)	$E_\nu(GeV)$	pot/year (10^{19})
KEK PS	12	250	1.5	0.005
FNAL NUMI	120	732	3 - 8 - 17	36
CERN CNGS	400	732	17.4	4.5
CERN L.E.x1.5	400	732	1.8	6.7
CERN WANF	450	0.8	24.2	1.5

The Gran Sasso Laboratory



νCNGS

HALL

HALL B

ν_τ appearance detection

$$\nu_\tau + N \rightarrow \tau^- + X$$

ν_τ CC

τ^-	$\rightarrow$	$\mu^- \, \overline{\nu}_\mu \, \nu_\tau$	18%
	$\rightarrow$	$e^- \, \overline{\nu}_e \, \nu_\tau$	18%
	$\rightarrow$	$h^- \, \nu_\tau \, n\pi$	50%
	$\rightarrow$	$\pi^- \, \pi^+ \, \pi^- \, \nu_\tau \, n\pi$	14%

Required High mass and high granularity

OPERA: observation of τ decay kink (a la Chorus)

requires high space resolution

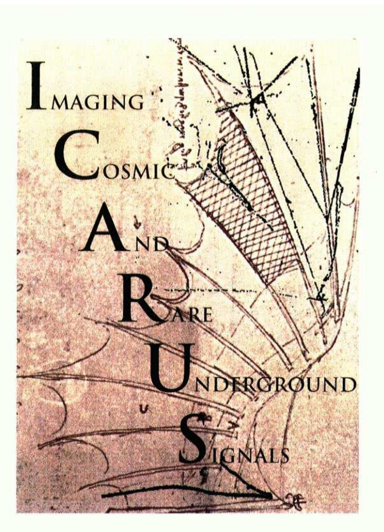
Photographic Emulsions combined with Pb Target (ECC, Emulsion Cloud Chamber)

ICARUS: event kinematics (a la NOMAD) escaping neutrinos

requires good reconstruction of kinematics

fine grained ($\sim mm$) LAR calorimetry over large volumes

The ICARUS collaboration (25 institutes, ≈146 physicists)

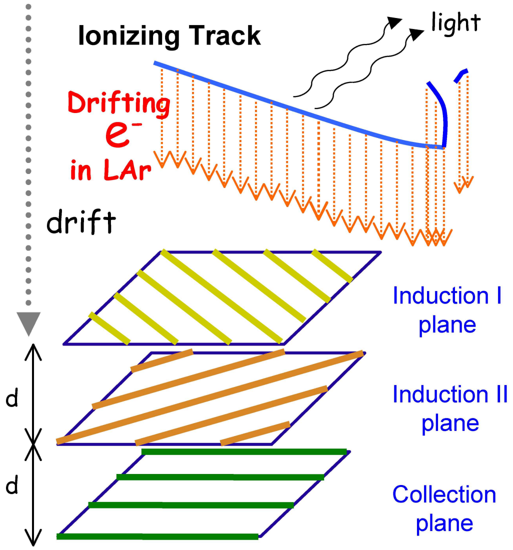


M. Aguilar-Benitez, S. Amoruso, Yu. Andreew, P. Aprili, F. Arneodo, B. Babussinov, B. Badelek, A. Badertscher, M. Baldo-Ceolin, G. Battistoni, B. Bekman, P. Benetti, E. Bernardini, A. Borio di Tigliole, M. Bischofberger, R. Brunetti, R. Bruzzese, A. Bueno, C. Burgos, E. Calligarich, D. Cavalli, F. Cavanna, F. Carbonara, P. Cennini, S. Centro, M. Cerrada, A. Cesana, C. Chen, D. B. Chen, Y. Chen, R. Cid, D. Cline, P. Crivelli, A.G. Cocco, A. Dabrowska, Z. Dai, M. Daniel, M. Daszkiewicz, C. De Vecchi, A. Di Cicco, R. Dolfini, A. Ereditato, M. Felcini, A. Ferrari, F. Ferri, G. Fiorillo, M.C. Fouz, S. Galli, D. Garcia, Y. Ge, D. Gibin, A. Gigli Berzolari, I. Gil-Botella, S.N. Gninenko, N. Goloubev, A. Guglielmi, K. Graczyk, L. Grandi, K. He, J. Holeczek, X. Huang, C. Juszczak, D. Kielczewska, M. Kirsanov, J. Kisiel, L. Knecht, T. Kozlowski, H. Kuna-Ciskal, N. Krasnikov, P. Ladron de Guevara, M. Laffranchi, J. Lagoda, Z. Li, B. Lisowski, F. Lu, J. Ma, N. Makrouchina, G. Mangano, G. Mannocchi, M. Markiewicz, A. Martinez de la Osa, V. Matveev, C. Matthey, F. Mauri, D. Mazza, A. Melgarejo, G. Meng, A. Meregaglia, M. Messina, C. Montanari, S. Muraro, G. Natterer, S. Navas-Concha, M. Nicoletto, G. Nurzia, C. Osuna, S. Otwinowski, Q. Ouyang, O. Palamara, D. Pascoli, L. Periale, G. Piano Mortari, A. Piazzoli, P. Picchi, F. Pietropaolo, W. Polchlopek, T. Rancati, A. Rappoldi, G.L. Raselli, J. Rico, L. Romero, E. Rondio, M. Rossella, A. Rubbia, C. Rubbia, P. Sala, N. Santorelli, D. Scannicchio, E. Segreto, Y. Seo, F. Sergiampietri, J. Sobczyk, N. Spinelli, J. Stepaniak, M. Stodulski, M. Szarska, M. Szeptycka, M. Szeleper, M. Terrani, R. Velotta, S. Ventura, C. Vignoli, H. Wang, X. Wang, C. Willmott, M. Wojcik, J. Woo, G. Xu, Z. Xu, X. Yang, A. Zalewska, J. Zalipska, C. Zhang, Q. Zhang, S. Zhen, W. Zipper.

ITALY: L'Aquila, LNF, LNGS, Milano, Napoli, Padova, Pavia, Pisa, CNR Torino, Torino Univ., Politec. Milano.
SWITZERLAND: ETH/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, CIEMAT
RUSSIA: INR (Moscow)

ICARUS: A new detection tecnique

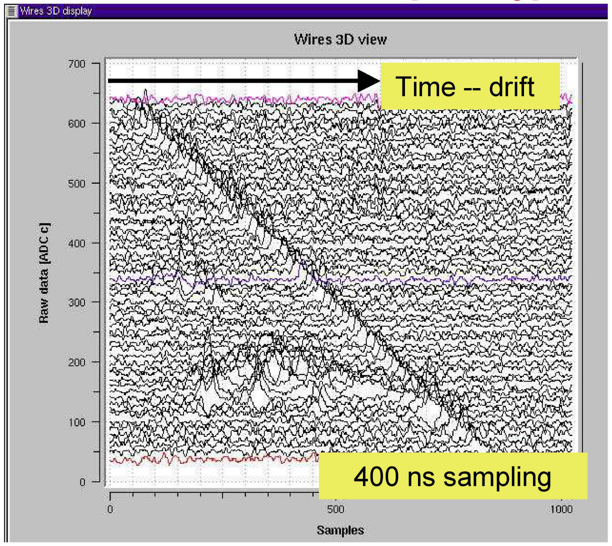
1 mip produces ≈ 20000 electrons per 3mm



Non-Destructive read-out

$\longrightarrow$ 3D IMAGING

Raw Data from a 10 m³ prototype



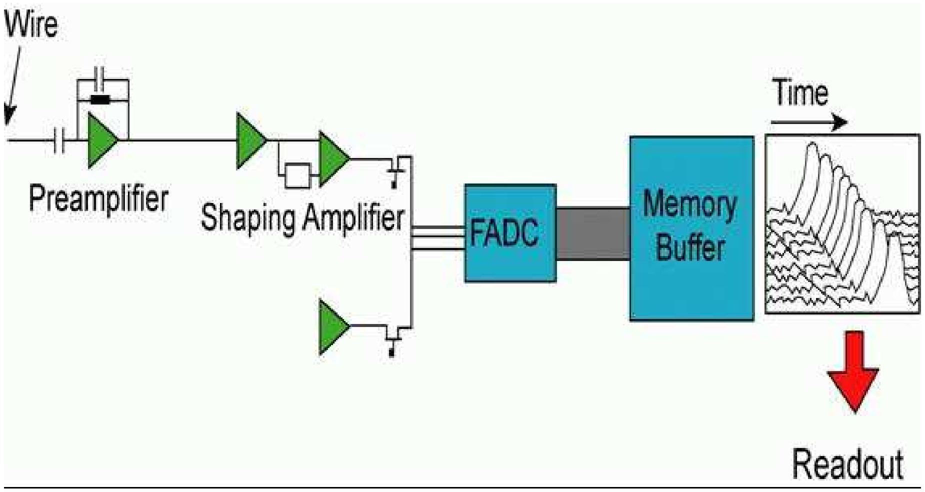
Density 1.4 g/cm^3

Radiation Length 14 cm

Interaction Length 80 cm

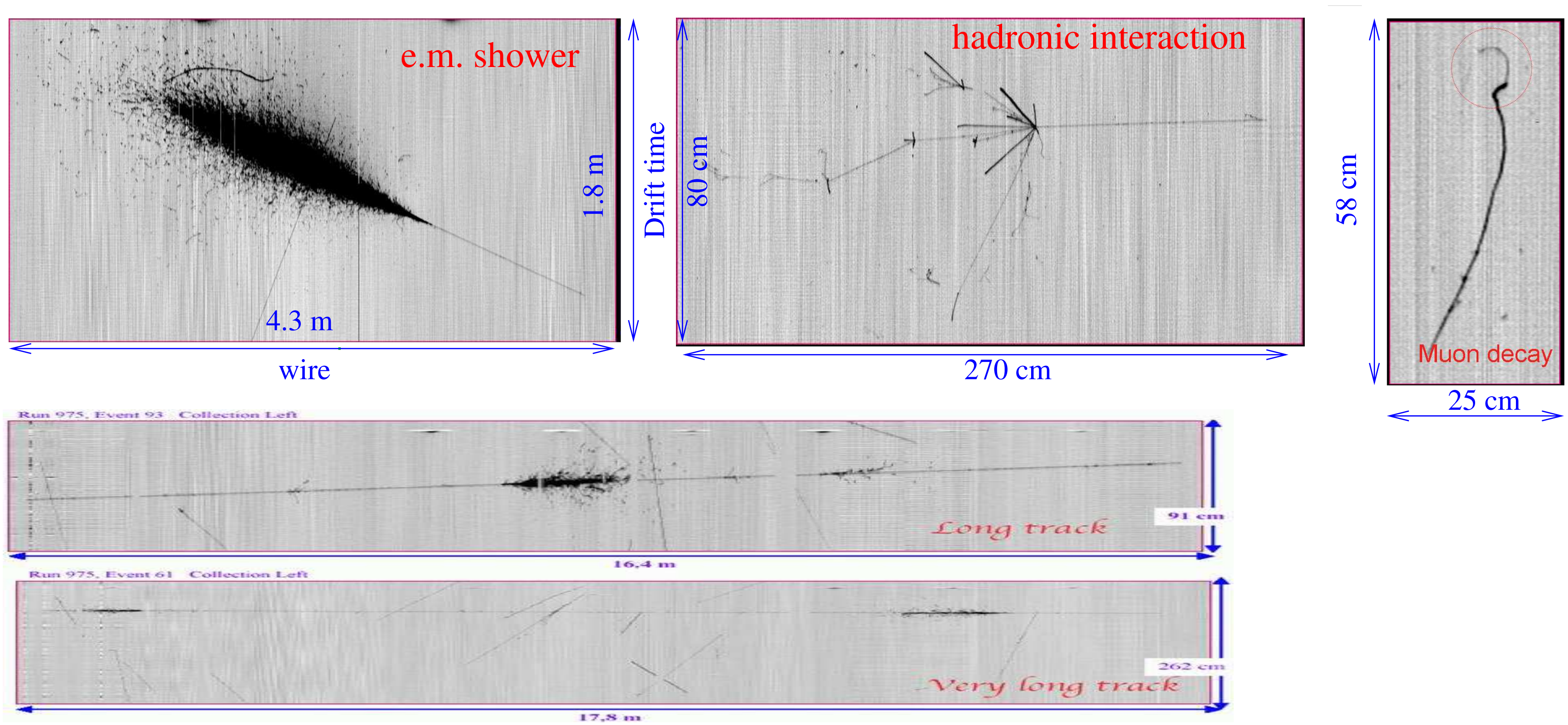
dE/dx$_{mip}$=2.1 MeV/cm

T=88 K @ 1 bar

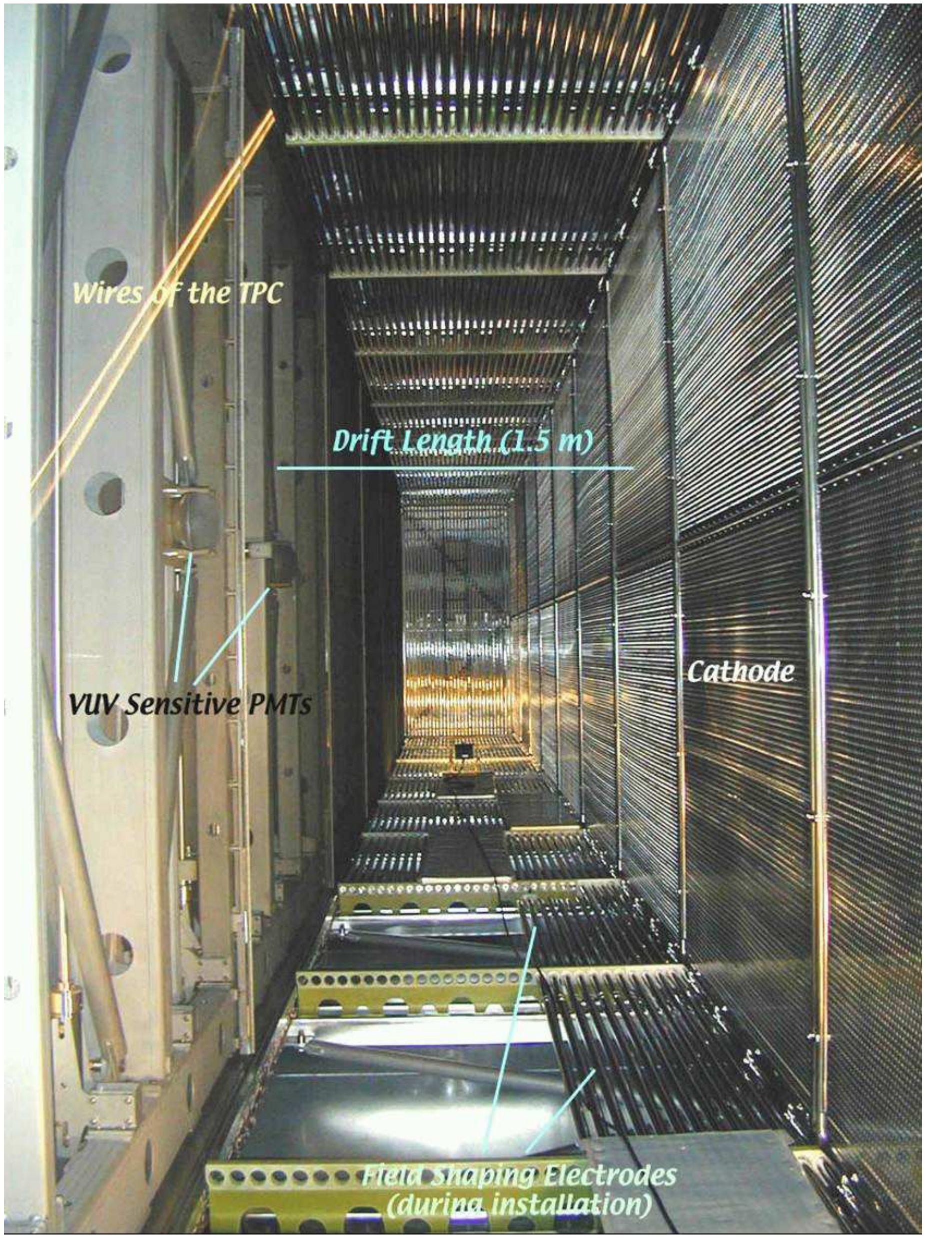


ICARUS Data Quality: Electronic Bubble Chamber

T600 test run: 27000 triggers with cosmic ray



The T600 Detector



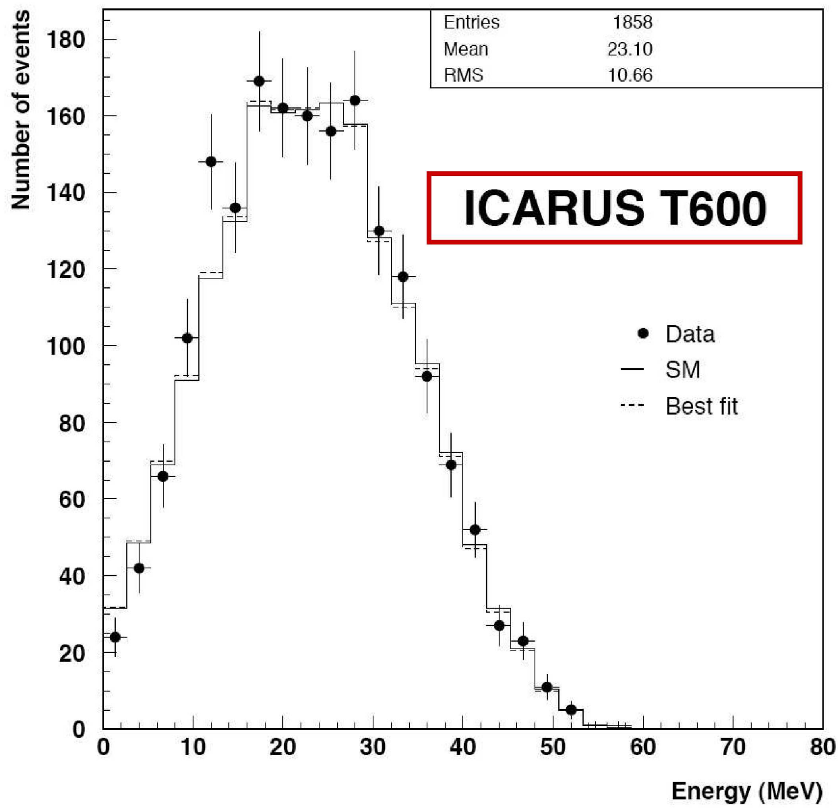
- Approved and funded in 1996
- Built between years 1997 and 2001
- Completely assembled in the INFN assembly hall in Pavia
- Full scale Demonstration test run in surface conditions of one half-module in summer 2001
  - $\rightarrow$ Three months duration
  - $\rightarrow$ Completely successful
  - $\rightarrow$ Data Taking with cosmic rays
  - $\rightarrow$ Detector performance
  - $\rightarrow$ Full scale analyses
- Full unit assembly terminated in 2002
- Waiting to be installed at LNGS

Measurement of the muon decay spectrum and the ρ parameter

Michel electron data are compared to MC generated for different ρ and η values

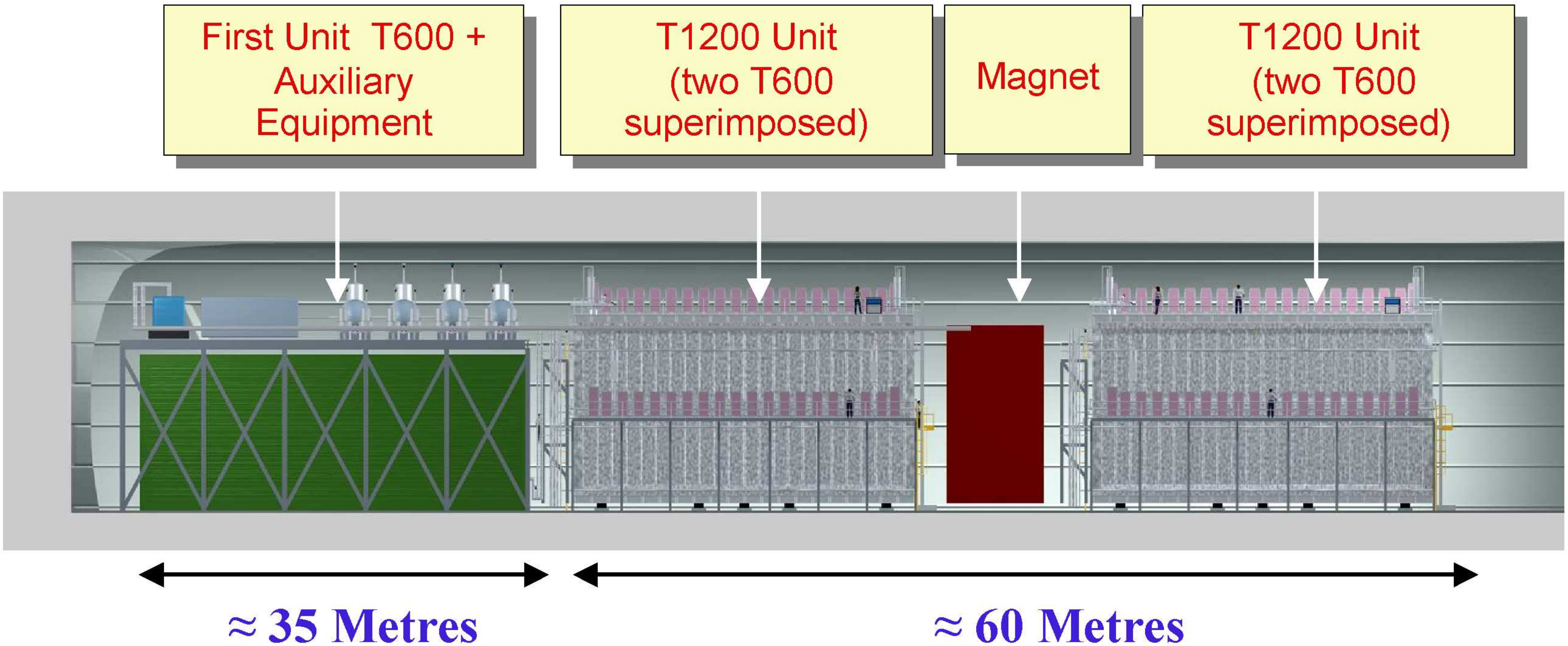
Given the **high level of correlation** between the two parameters we **measure** only ρ by **restricting** η to the physically allowed region |η| < 1

Author	Value	Assumption
Peoples	0.750 ± 0.003	$\eta \equiv 0$
Sherwood	0.760 ± 0.009	$\eta \equiv 0$
Fryberger	0.762 ± 0.008	$\eta \equiv 0$
Derenzo	0.752 ± 0.003	$-0.13 < \eta < 0.07$
SLD	$0.72 \pm 0.09 \pm 0.03$	lepton univers.
CLEO	$0.747 \pm 0.010 \pm 0.006$	lepton univers.
ARGUS	0.731 ± 0.031	lepton univers.
L3	$0.72 \pm 0.04 \pm 0.02$	lepton univers.
OPAL	$0.78 \pm 0.03 \pm 0.02$	lepton univers.
DELPHI	$0.78 \pm 0.02 \pm 0.02$	lepton univers.
ALEPH	0.742 ± 0.016	lepton univers.
This analysis	$0.72 \pm 0.06 \pm 0.08$	$-0.020 < \eta < 0.006$

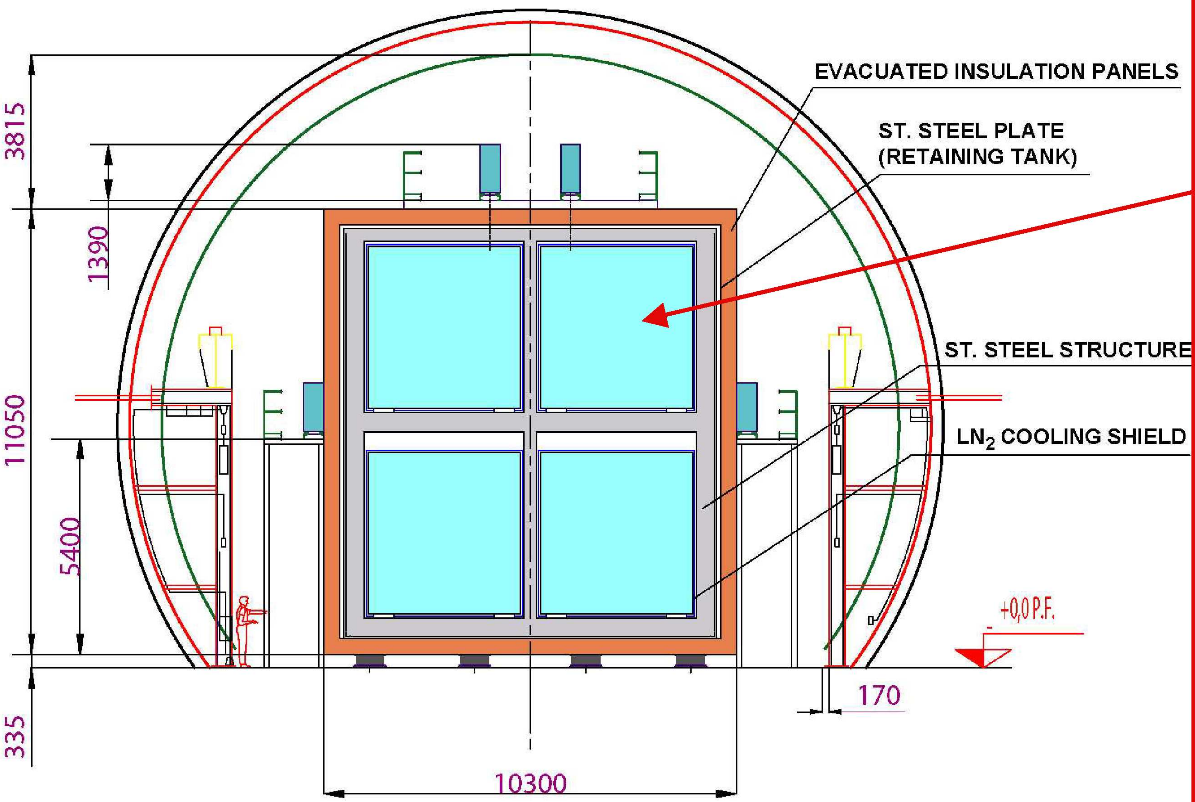


$$\frac{\sigma_E}{E} = (11 \pm 1)\% / \sqrt{E(MeV)} \oplus (1.97 \pm 0.05)\%$$

ICARUS detector configuration in LNGS Hall B (T3000)



The T1200 "unit"

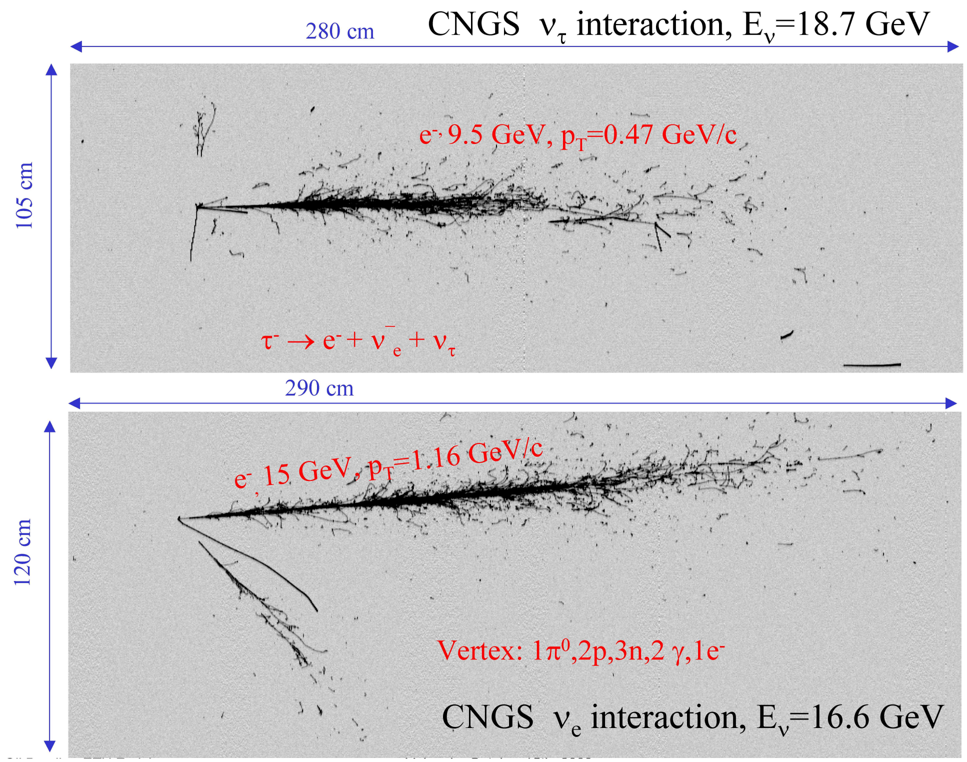


- Based on cloning the present T600 containers
  - A cost-effective solution given tunnel access conditions
- Preassembled modules outside tunnel are arranged in supermodules of about 1200 ton each (4 containers)
  - Time effective solution (parallelizable)
- Drift doubled 1.5 m ➔ 3 m
  - sensible solution given past experience
- Built with large industrial support (AirLiquide, Breme-Tecnica, Galli-Morelli, CAEN, …)
  - "order as many as you need" solution

Detailed engineering project was produced by Air Liquide (June 2003) T1200 cryostat ready for tendering

ICARUS and CNGS neutrino beam

- The excellent granularity and energy resolution of the liquid argon TPC allows to naturally study all kinds of events from CNGS neutrinos
  - ν_μ CC to study online beam profile, beam steering, provide normalization
  - ν_e CC to search for $\nu_\mu \to \nu_e$ oscillations with the best sensitivity until the JHF-SK program turns on
  - ν_τ CC to search for $\nu_\mu \to \nu_\tau$ oscillations, with a sensitivity at least similar to that of the OPERA experiment
  - NC events to search for $\nu_\mu \to \nu_s$ oscillations or exotic models



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

- T3000 detector (2.35 kton active, 1.5 kton fiducial)
- Integrated pots: $5 \times 4.5 \times 10^{19}$ **Conservative** $= 2.25 \times 10^{20}$ pots

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

- Several decay channels are exploited (electron is the golden one)
- (Low) backgrounds measured in situ (control sample)
- High sensitivity to signal and oscillation parameters determination

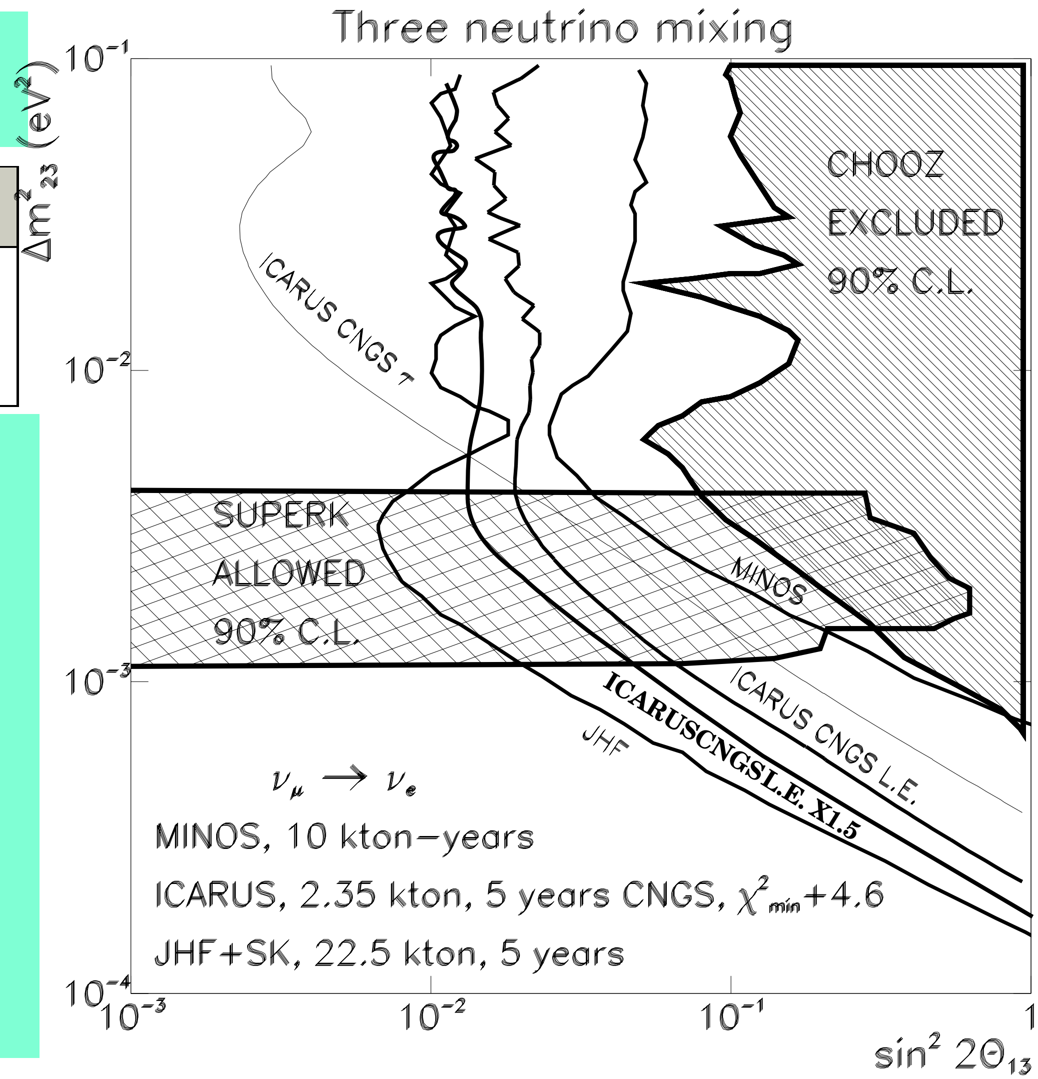
$\nu_\mu \rightarrow \nu_e$ appearance search summary

For $\Delta m^2_{23} = 2.5 \times 10^{-3}$

$(sin^2\ 2\theta_{13})_{CNGS\tau} < 0.04$	or	$\theta_{13} < 6^0$
$(sin^2\ 2\theta_{13})_{CHOOZ} < 0.14$	or	$\theta_{13} < 11^0$
$(sin^2\ 2\theta_{13})_{MINOS} < 0.06$	or	$\theta_{13} < 7^0$

Limited by statistics for CNGS!

ICARUS offers the best sensitivity until JHF starts



OPERA

COLLABORATION

36+1 groups
~ 165 physicists

→ Korean group joined

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

Korea
Gyeongsang

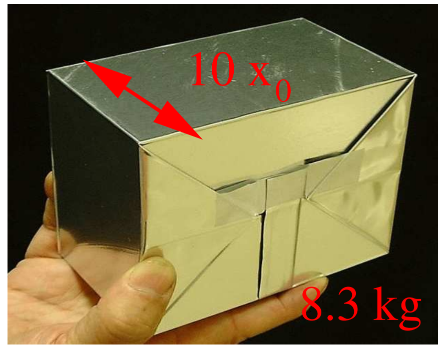
Russia
INR Moscow, ITEP Moscow, JINR Dubna, Obninsk

Switzerland
Bern, Neuchâtel

Turkey
METU Ankara

OPERA: an hybrid detector

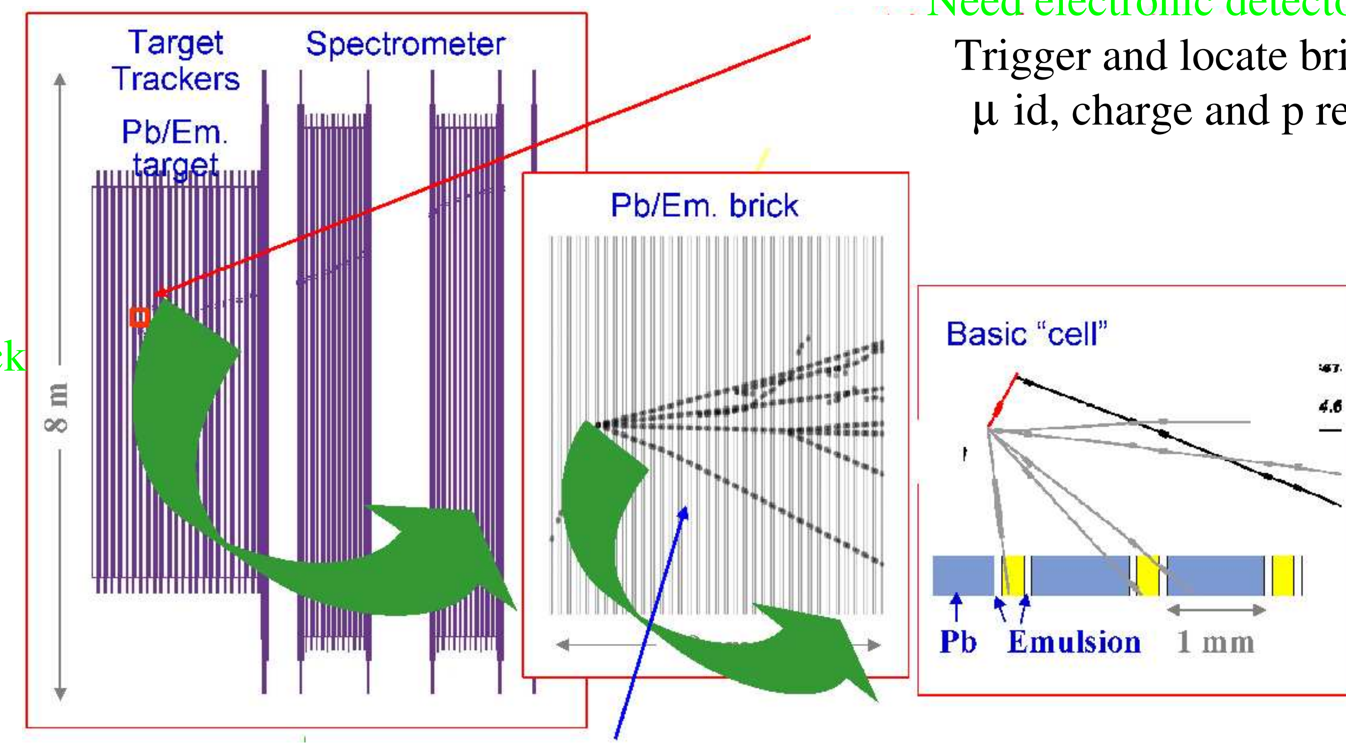
It' a complete standalone detector
neutrino interaction vertex
kink topology reconstruction
measure momenta of hadrons by
multiple scattering
dE/dx $\pi\mu$ separation at low energy
electron identification and
measurement of energy of electron
and gammas



Based on the concept of the
Emulsion cloud chamber (ECC)
(validated by DONUT observ. of ν_τ)

Need electronic detector
Trigger and locate brick
μ id, charge and p rec

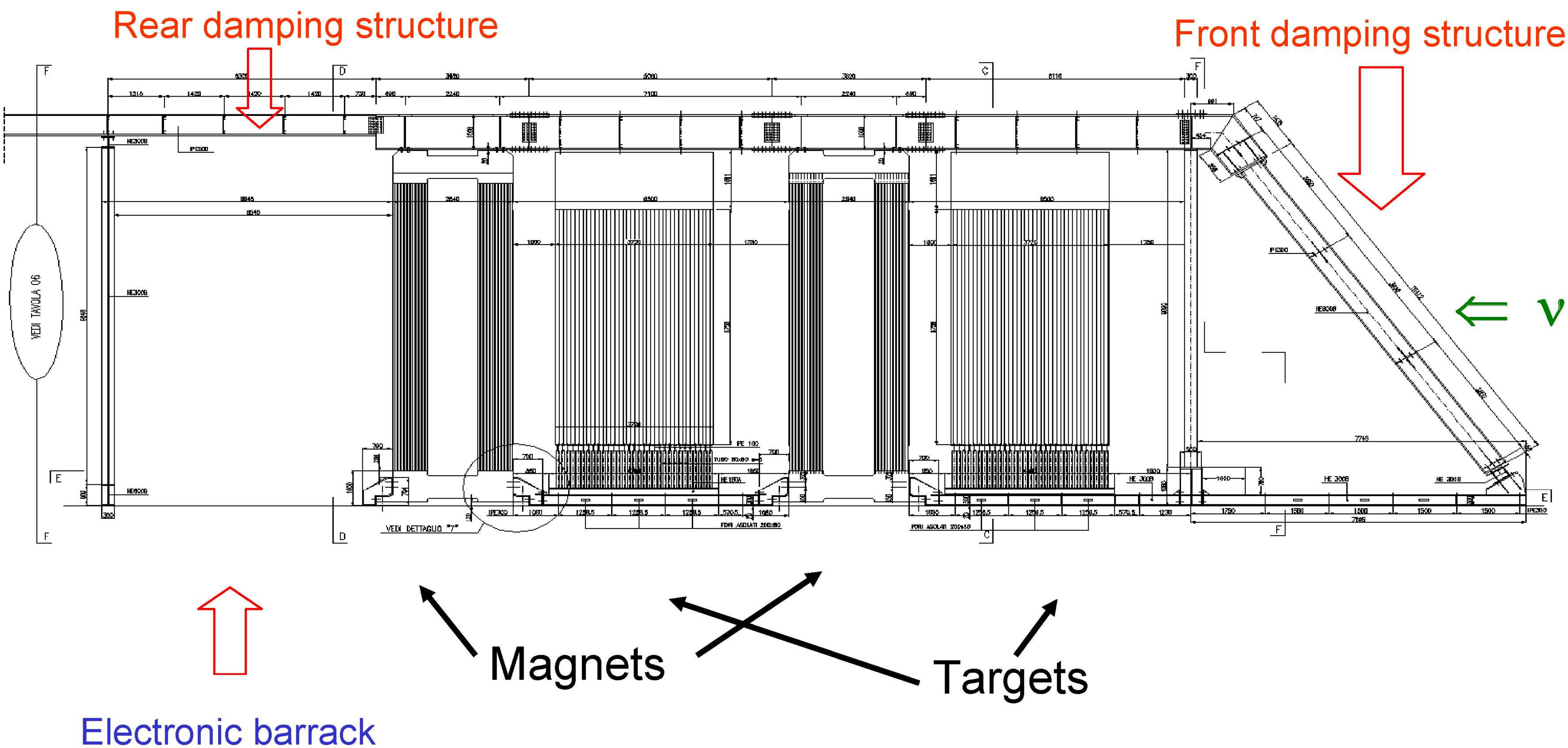
Extract selected Brick



Opera: the final design with 2 Supermodules

2 Muon Spectrometers;

31 target planes / spectrometer (206k bricks, 1.8 ktons)



Target

Emulsion mass production started April 2003 ($\sim$ 150000 M^2)

Refreshing done in Tono Mine in Japan: 2 years required

One batch sent to LNGS every 2 monthw starting summer 2004

$\rightarrow$ emulsion storage ready @ LNGS june 2003

Pb + 0.7% Ca (1 mm thick @ 10 μm) ready for a prototype mass production in Goslar (Germany)

Brick assembly machine ($\sim$206000 bricks assembled at a rate of $\sim$ 2 bricks/min

- SPECS document completed end 2002
- 10 companies have been working for a preselection run in May 2003
- 4 companies have been selected and invited to the tender
- tender completed in Nov 2003
- Tecno-cut (Swiss-Italian) consortium got the BAM contract in Jan 2004
- Vacuum Vs. Mechanical option still open

$\rightarrow$ emulsion storage ready LNGS june 2003

Emulsion refresh developed ad Nagoya University with Fuji

Initial Sensitivity

Production $\longrightarrow$ Beam exp $\longrightarrow$ Develop

Grain density $\sim 35/100\mu m$

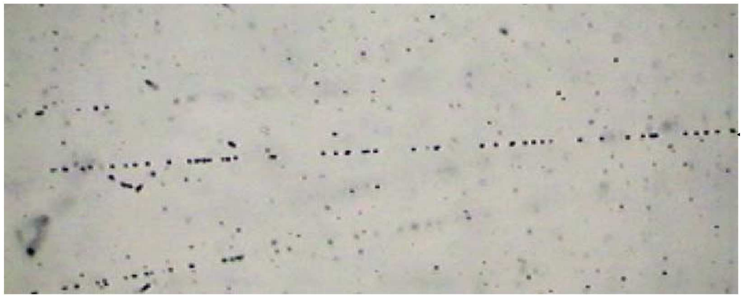
Refresh (T=30^0, R.H. 98%, 3 days)

Production $\longrightarrow$ Beam exp $\longrightarrow$ Refresh $\longrightarrow$ Develop

Grain density $\sim 8/100\mu m$

Sensitivity after Refresh

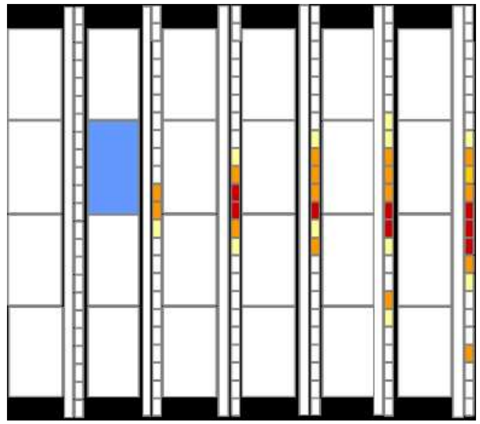
Production $\longrightarrow$ Refresh $\longrightarrow$ Beam exp $\longrightarrow$ Develop



Grain density $\sim 35/100\mu m$

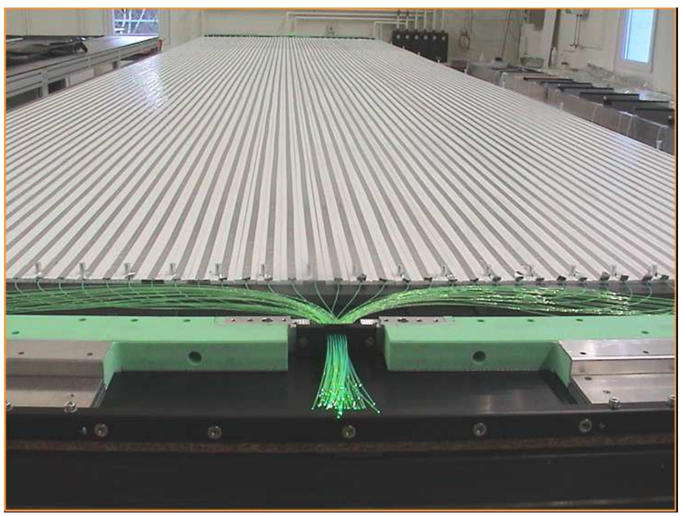
NO Sensitivity degradation after refresh

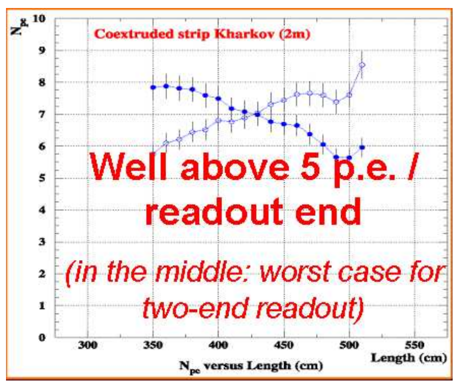
Target Tracker



32256 Target Tracker scintillator strips
$(2.6\ cm \times 1.0cm\ \times 7\ m)$

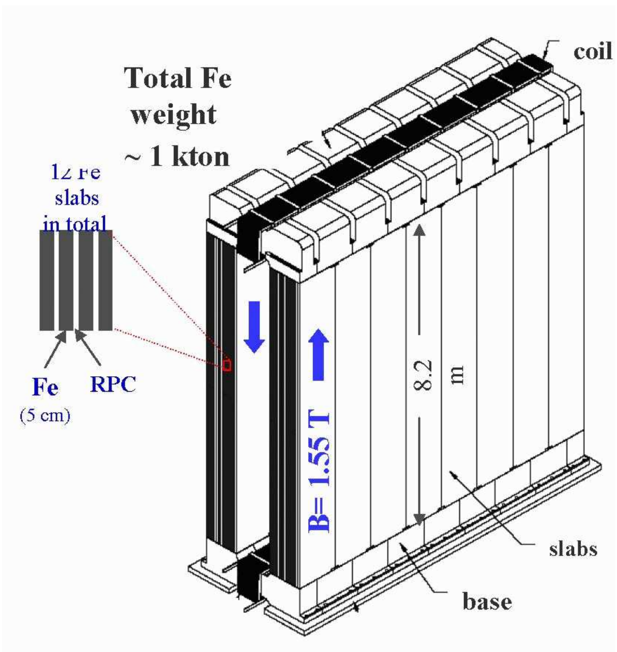
- Neutrino interaction vertex
- Brick localization
- Muon tracking and ID

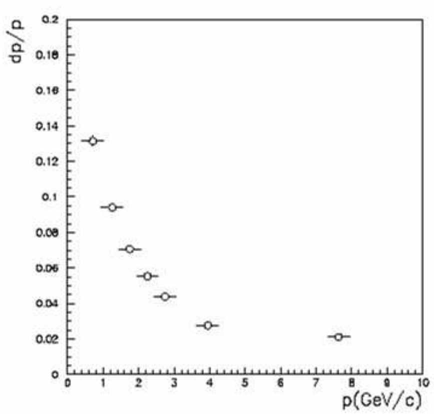




- XY planes ∼7000 m^2
- 1000 MaPMT Hamamatsu 64 channels

The muon spectrometers





Magnet instrumented with:

- RPC inside iron gap (μ-id, shower energy)
- Drift Tubes (μ-momentum measurement)

$\mu - Id > 95\%$ (with target tracker)

Expected numbers of events for $\nu_\mu \rightarrow \nu_\tau$ appearance search

full mixing 5 years run @ 4.5$\times 10^{19} pot/year$

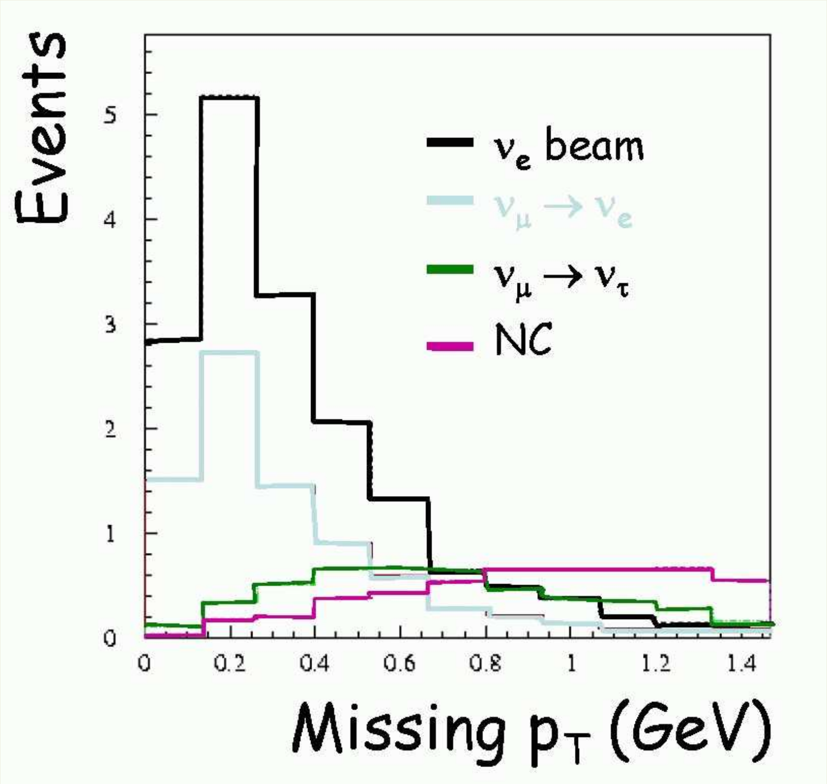
	Signal $\Delta m^2\ (eV^2)$ 1.3×10^{-3}	Signal $\Delta m^2\ (eV^2)$ 2.0×10^{-3}	Signal $\Delta m^2\ (eV^2)$ 3.0×10^{-3}	BCKD
OPERA (1.8 kTon Fid.)	3.1 (4.7)	7.3 (11)	16.4 (24.6)	0.7 (1.06)
ICARUS (1.5 kTon Fid.)	3.2 (4.8)	7.6 (11.4)	17.2 (25.8)	0.7 (1.06)

(...) with extra beam factor 1.5

OPERA sensitivity to θ_{13}

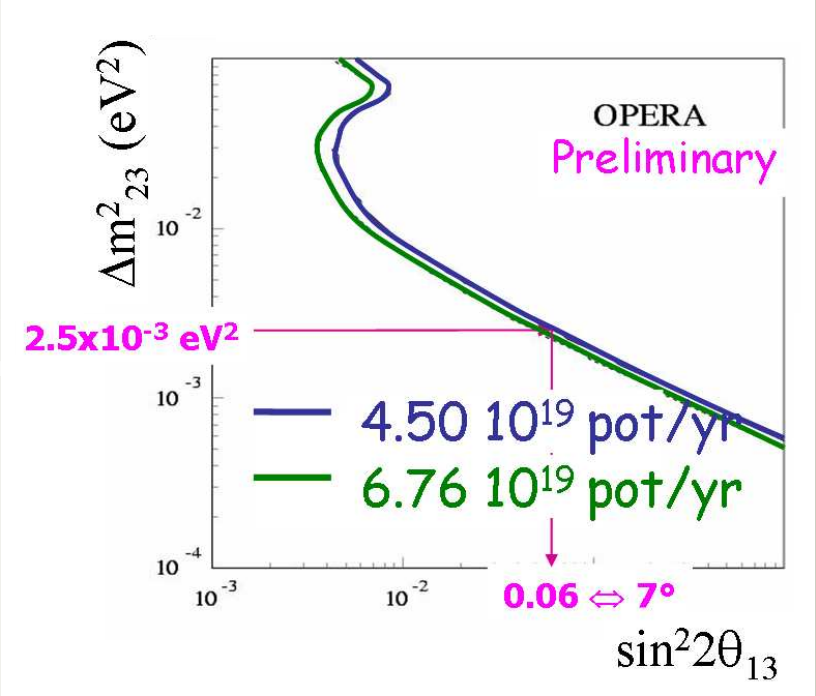
Simultaneous

fit of the E_e, p_T and E_{vis} distributions



Only 15% increase scanning because the event

location is already performed for ν_τ search



CONCLUSIONS

- The CNGS program is on schedule and beam operation will start in 2006
- OPERA is installing the detector and is proceeding on schedule
- ICARUS is ready to install his first T600 module and preparing to realize two T1200 modules and the magnetic spectrometer
- Both experiments are working to be ready for first neutrinos which will be delivered in 2006
- High sensitivity to the ν_τ appearance search
- Possibility to study the $\nu_\mu \rightarrow \nu_e$ oscillations with improved sensitivity for θ_{13}