F Ronga INFN Frascati

Neutrino LBL Experiments in Europe

Motivations for neutrino LBL experiments

The CERN-Gran Sasso beam

The Gran Sasso Laboratory and past experiments

Status of OPERA

Status of ICARUS

New projects

Conclusions

Important note! : European collaborators in USA/JAPAN and JAPAN/USA collaborators in Europe.

Status of neutrino mass and oscillations

3 x 3 mixing matrix U with parameters:

(same parameters as in the CKM quark matrix)

θ_{12}, θ_{23} **measured**

θ_{13} δ **(phase) unknown**

If both different from 0 ==>CP violation

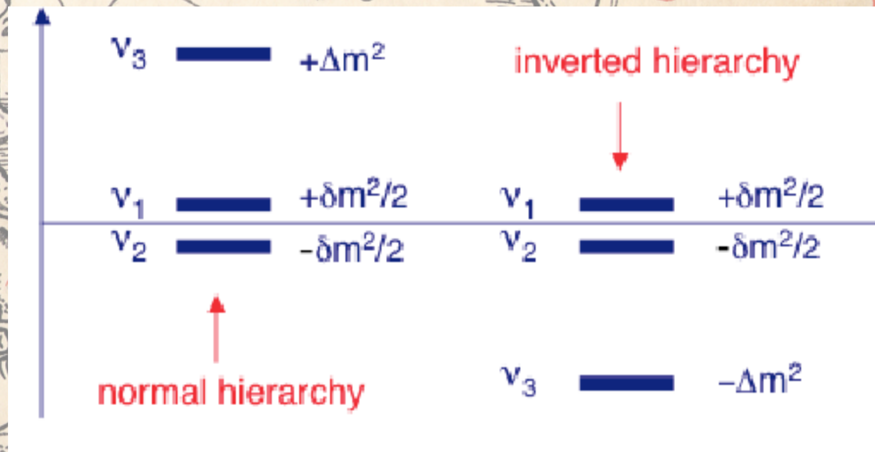
Δm^2_{12} δm^2_{23} **measured**

M_0 **unknown**

M_0 direct mass measurement β decay

2 β decay if Majorana neutrino

astrophysical measurement (Wmap..)



Neutrino Oscillations : after the discovery we are in the precision measurement era

standard scenario No LSND

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric $\sin^2(2\theta_{23})\sim 1$

$\nu_\mu \rightarrow \nu_e$ terrestrial exp. $\sin^2(2\theta_{13})<0.1$

Solar/reactor $\sin^2(2\theta_{12})\sim 0.8$

The PMNS (Pontecorvo Maki-Nakagawa-Sakata) matrix U (90% intervals)

0.79 - 0.86	**0.50 - 0.61**	**0.0 - 0.16**
0.24 - 0.52	**0.44 - 0.69**	**0.63 - 0.79**
0.26 - 0.52	**0.47 - 0.71**	**0.60 - 0.77**

Big success of particle physics without accelerators

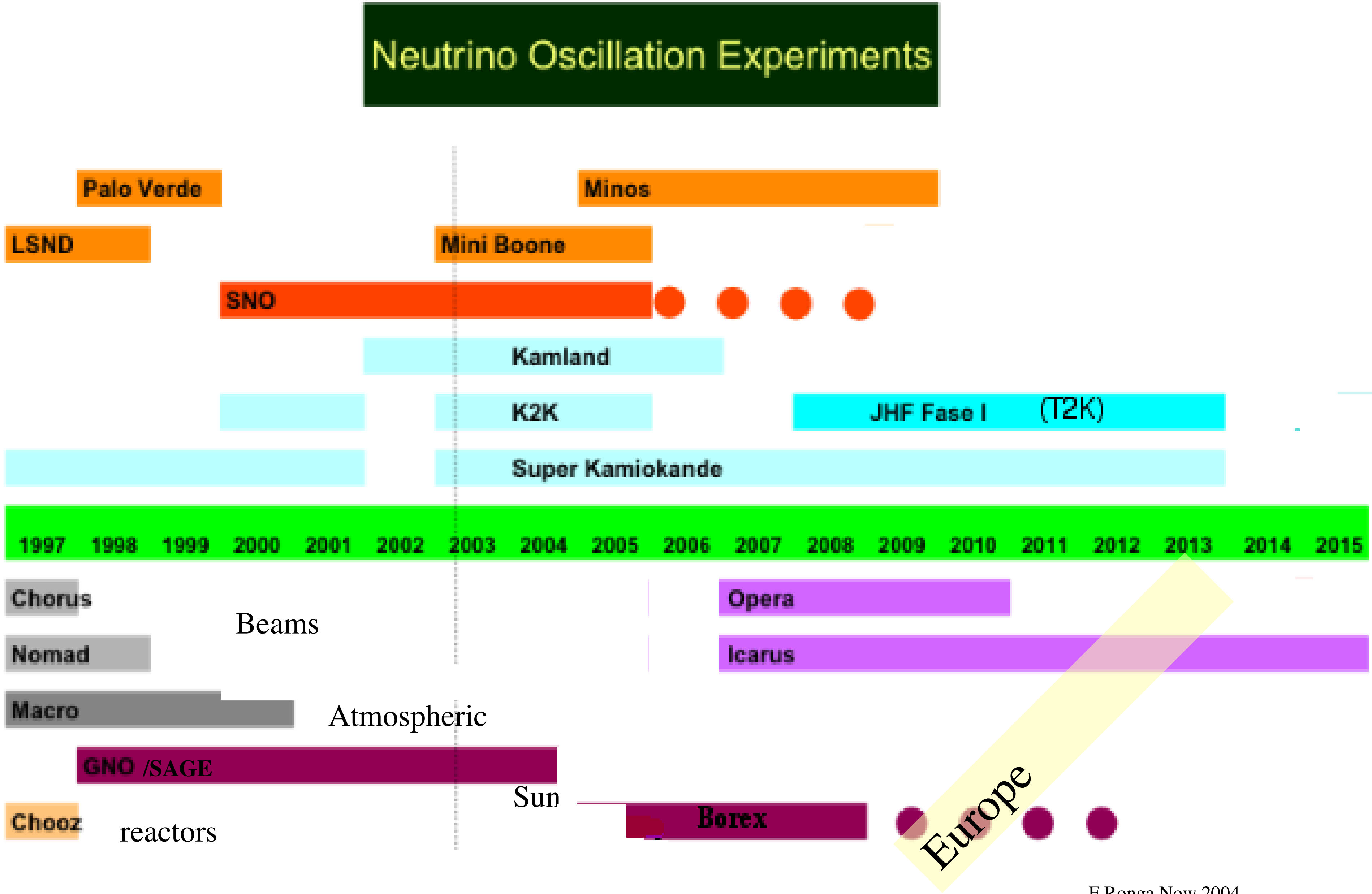
Europe : CHOOZ (reactor),GALLEX, SAGE(solar ν), and MACRO (atmospheric ν)

Open questions for terrestrial neutrino beam experiments:

1) How different from 1 is **$\sin^2(2\theta_{23})$ atmospheric?** **==>Improve the precision in θ_{23} (and Δm^2_{23})**
2) How different from zero is θ_{13} ? **==>Improve the limits in θ_{13}**. Only if $\theta_{13} \neq 0$ (and $\delta \neq 0$) you can have CP violation
3) If θ_{13} >~0.001 is possible to measure δ
4) Precision check of the oscillation mechanism : tau appearance, unitariety of the mixing matrix ecc
5) Measurement of the sign of Δm^2_{23}

In the next few years Europe should contribute to #2 and #4

Neutrino Physics and EUROPE



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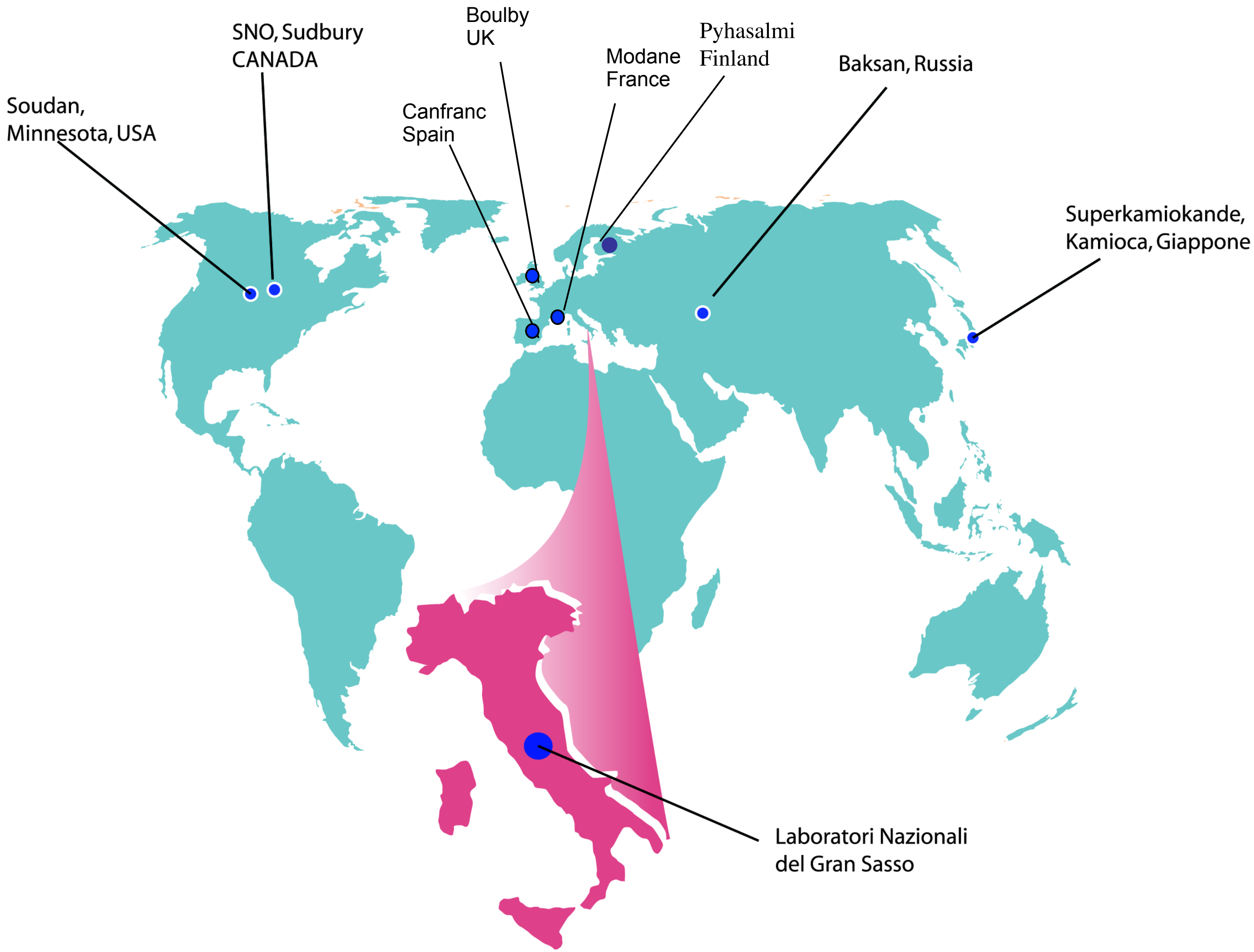
Underground Laboratories



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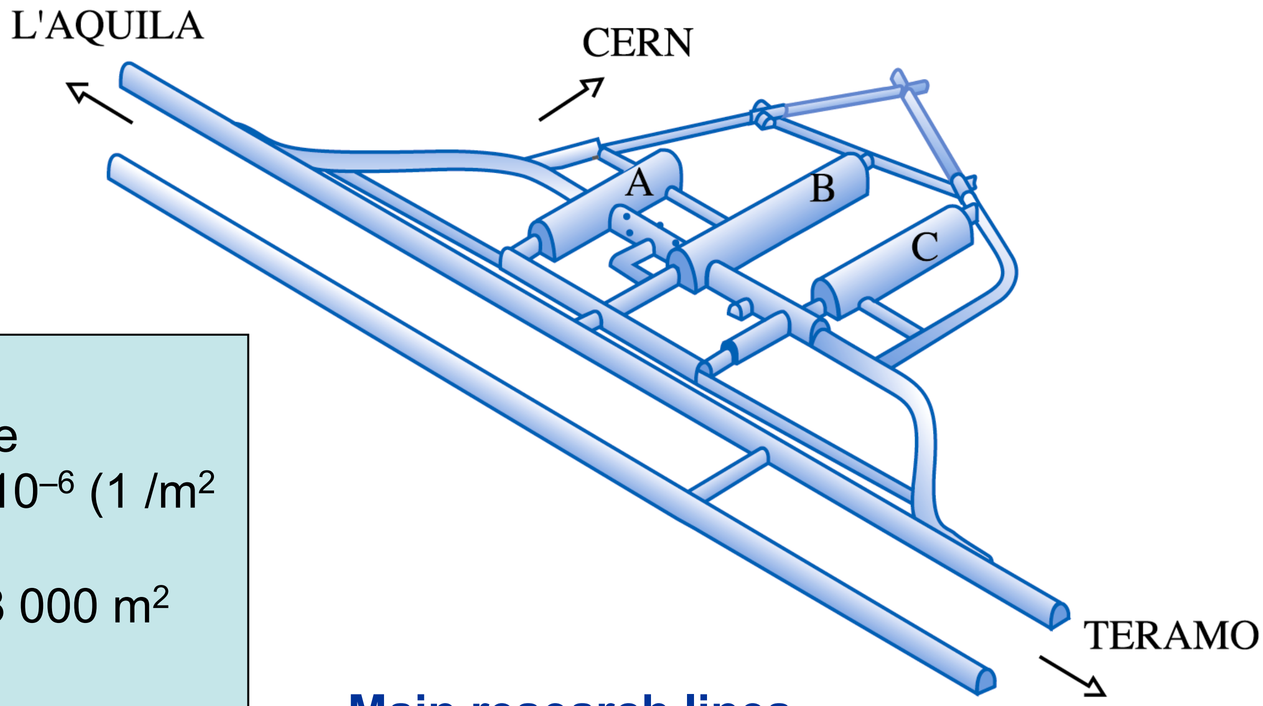
LABORATORI NAZIONALI DEL GRAN SASSO - INFN

Largest underground laboratory for astroparticle physics

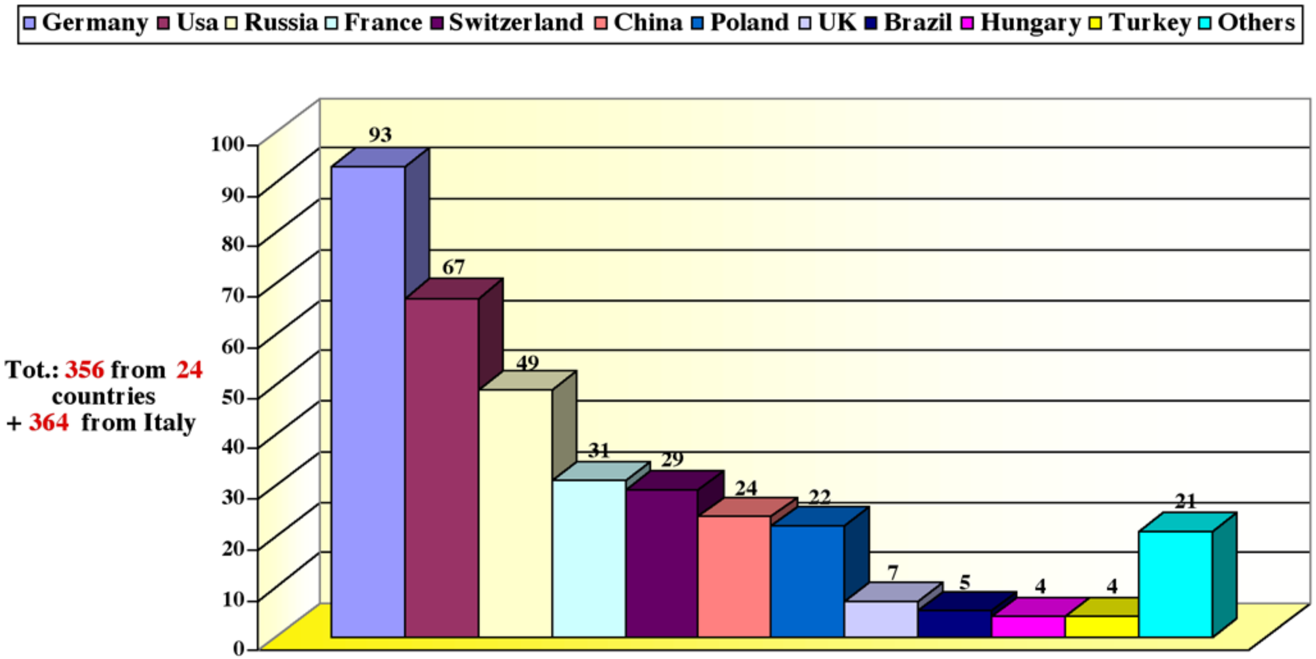


1400 m rock coverage
cosmic μ reduction= 10^{-6} (1 /m^2 h)
underground area: 18 000 m^2
external facilities
easy access
756 scientists from 25 countries
Permanent staff = 66 positions

Main research lines

- **Neutrino physics**
  (mass, oscillations, stellar physics)
- **Dark matter**
- **Nuclear reactions of astrophysics interest**
- **Geophysics**
- **Biology**

LNGS Users



Foreigners: 356 from 24 countries

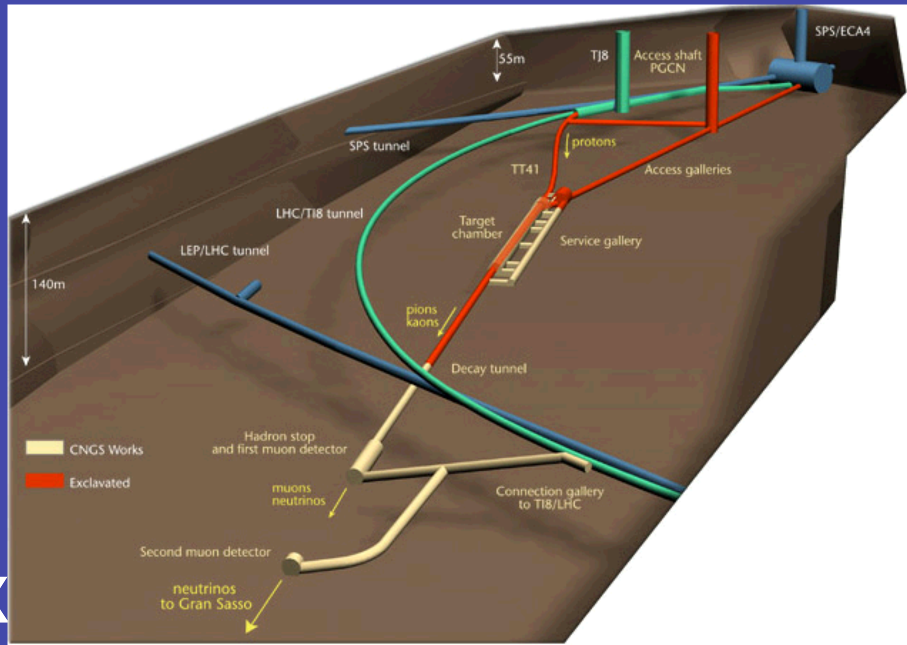
Italians: 364

Permanent Staff: 64 people

ν beam from CERN:

ICARUS

OPERA



EX

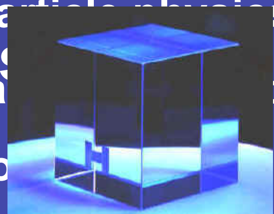
10 astropa s esperiments:

7 in opera paration

4 exp. geo

1 exp. biology

6 proposals for future exps.

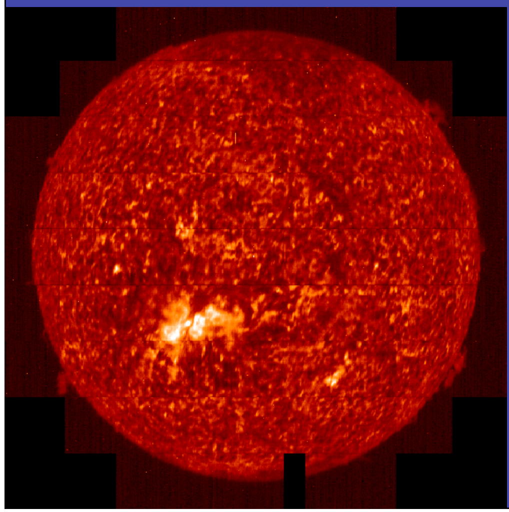


ββ decay and rare events

Cuoricino; GENIUS-TF

Dark Matter

DAMA/LIBRA; CRESST; HDMS



Solar ν

GNO

Luna

Borexino

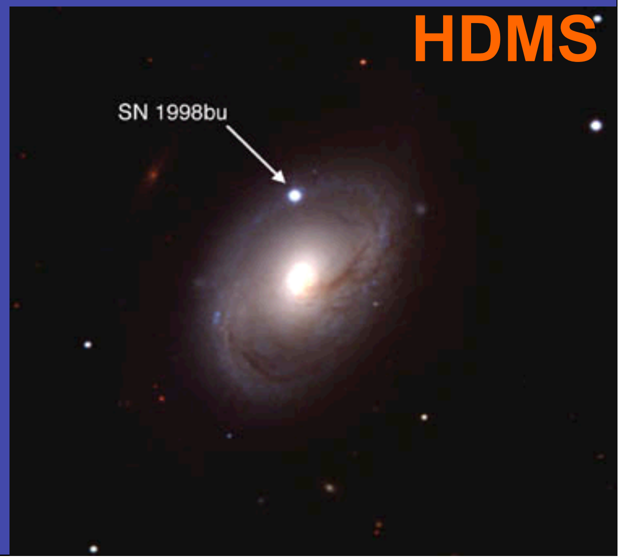
ICARUS

ν from Supernovae

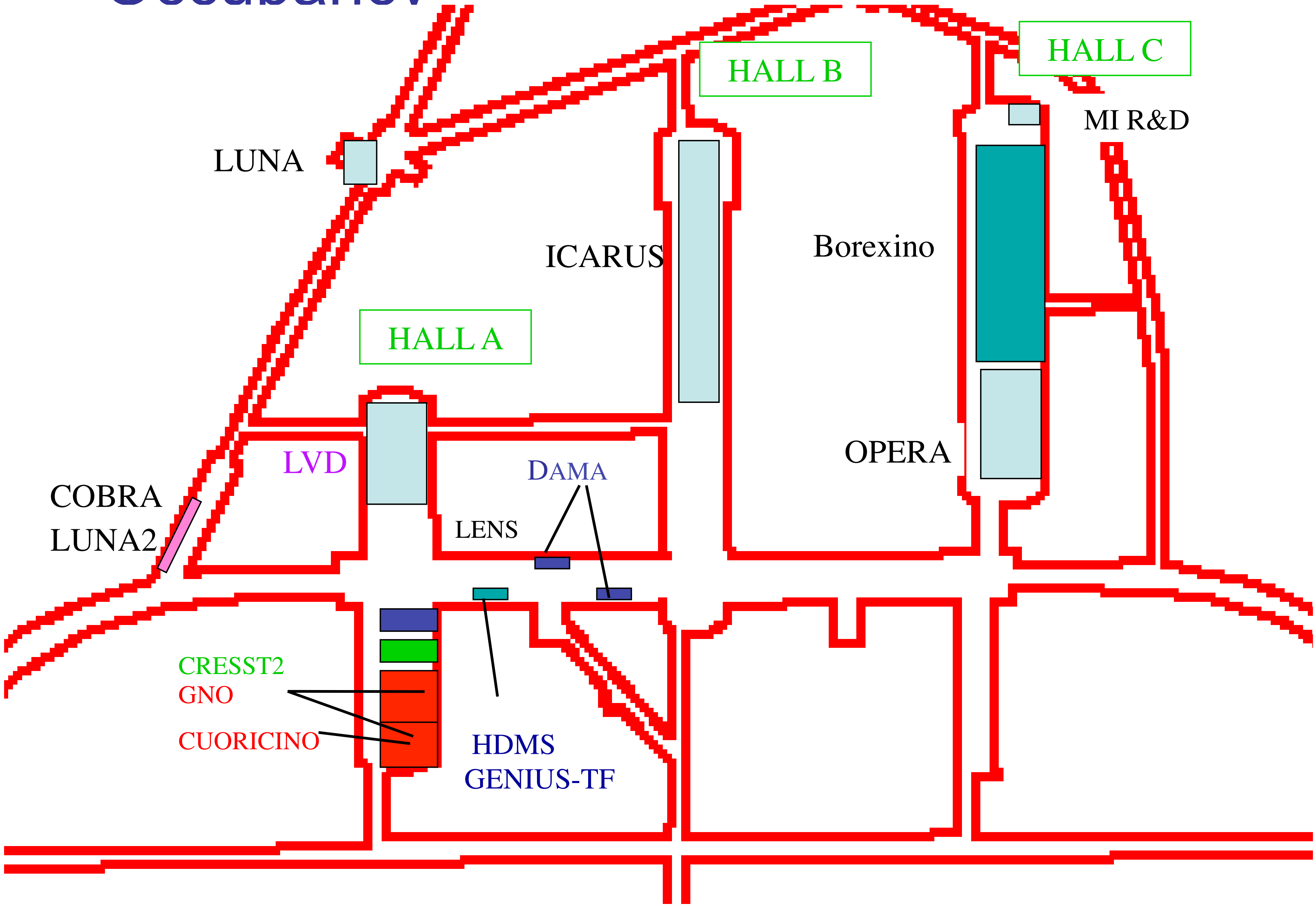
LVD

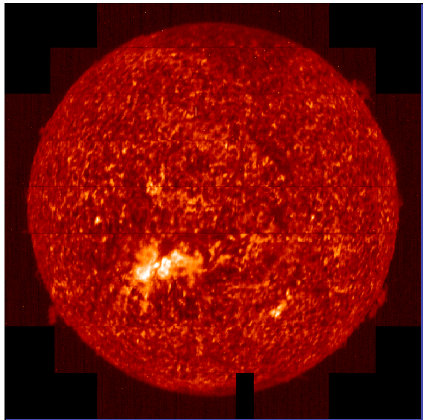
Borexino

ICARUS



Occupancy

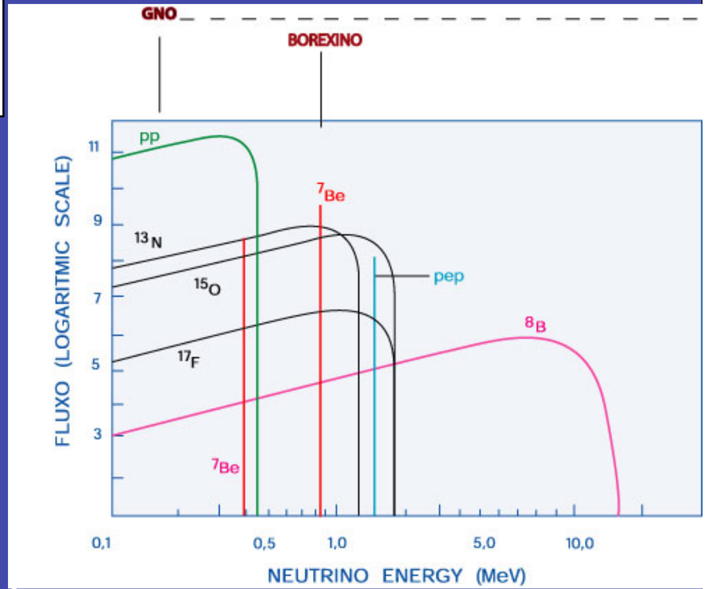

HALL B
HALL C
MI R&D
LUNA
ICARUS
Borexino
HALL A
LVD
DAMA
OPERA
COBRA
LUNA2
LENS
CRESST2
GNO
CUORICINO
HDMS
GENIUS-TF



GNO

Collab.:
Italy, France, Germany

Goals: measurement of the interaction rate with an accuracy of 4-5% and monitoring the neutrino flux over a complete solar cycle.

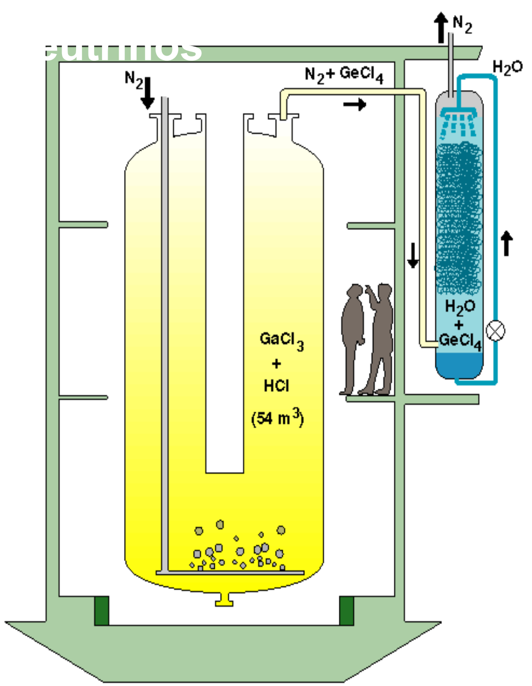


101 tons Gallium Cloride solution

^{71}Ge(ν_e,e)^{71}Ge

Energy threshold > 233 keV

SSM → 115 -135 SNU

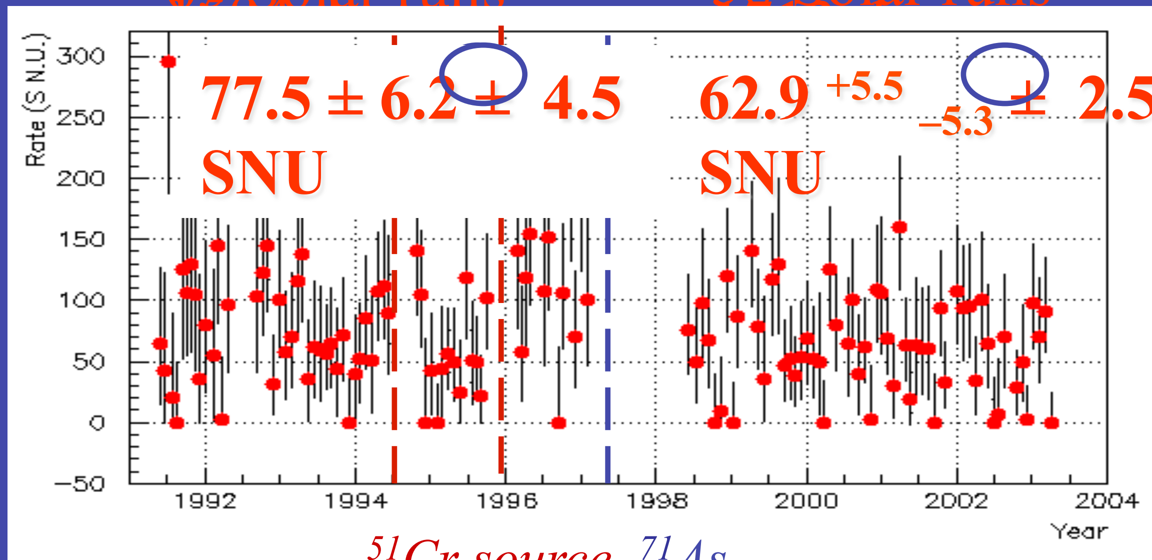


GALLEX

65 Solar runs =

GNO

58 Solar runs =



77.5 ± 6.2 ± 4.5 SNU

$62.9^{+5.5}_{-5.3} \pm 2.5$ SNU

^{51}Cr source, ^{71}As experiments

INFN

MACRO and the Gran Sasso Hall B

1989

(a)

(b)

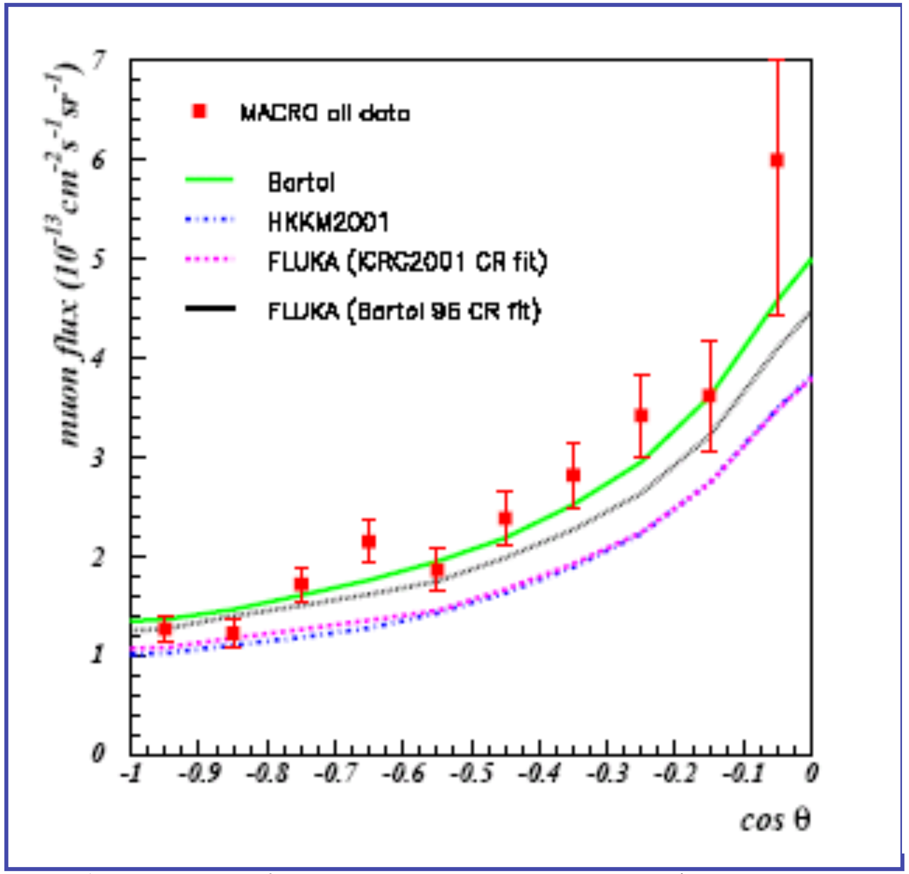
1990

1995-2000

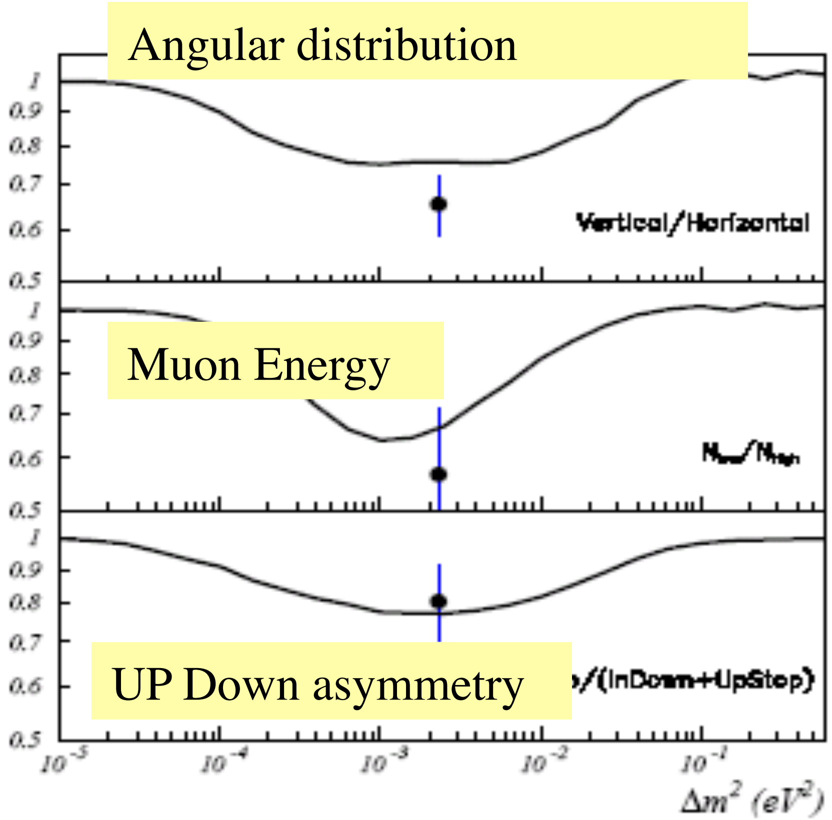
2001

Macro atmospheric neutrinos

final paper Eur. Phys.J. C 36 (2004) 357-373 see Giacomelli's talk

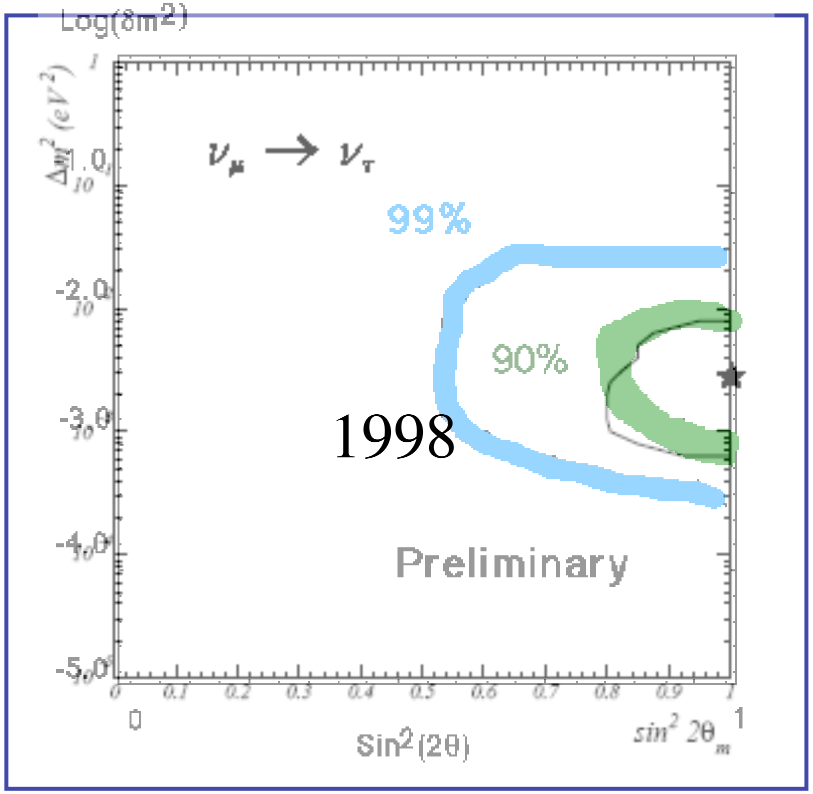


Througoing muons angular distribution: flux normalization problem: new fluxes too lower



Ratios independent from flux normalization

MACRO atmospheric neutrinos



2004 Macro final C.L. regions:

1) No use of absolute fluxes

2) Combination of 3 quantities (Througoing muons angular distribution, Energy information, Up Down asymmetry)

3) Full statistics

1998 Througoing muons angular distribution and use of the Bartol 1996 theoretical flux normalization

Why 2004 and 1998 CL plot very similar?: chance or systematic errors in the neutrino flux too large and the old Bartol flux better than the new one?

Summer 2002- Borexino liquid scintillator spill-out

August 16th, 2002
The Borexino Group in the Hall C of LNGS by a series of unfortunate mistakes leaked 50 liters of pseudocumene in the external environment.
The accident happened in the atmosphere of the hot local debate about the safety tunnel project.

October 2002
Borexino detector sequestrated by the prosecuting magistrate of Teramo.

May 29th, 2003
Information which threw strong doubts upon the water-tightness of the draining system of the Highway and the Gran Sasso laboratory.
Infn decided as a precaution to suspend the activities implying manipulation of any kind of liquid and ask for an immediate intervention of the competent government authorities.

The same day the entire Hall C was placed under judicial attachment by the magistrate.

Gran Sasso "emergency"

.

June 27th, 2003
The Council of Ministers declared the State of Emergency for the Gran Sasso facility (road tunnels, Labs., water system).
This allows radical and urgent technical intervention of a government authority (Commissioner), without bureaucratic delays.

December 2003
Approval of the "first phase" designes by local authorities and Prosecutor.
This enabled the normalization of the activities of the Laboratories.
All the activities back to normal but Borexino and GNO. GNO ended.

August 11 2004
End of the judicial attack, removal of the remaining constraints on Hall C.

Gran Sasso safety works

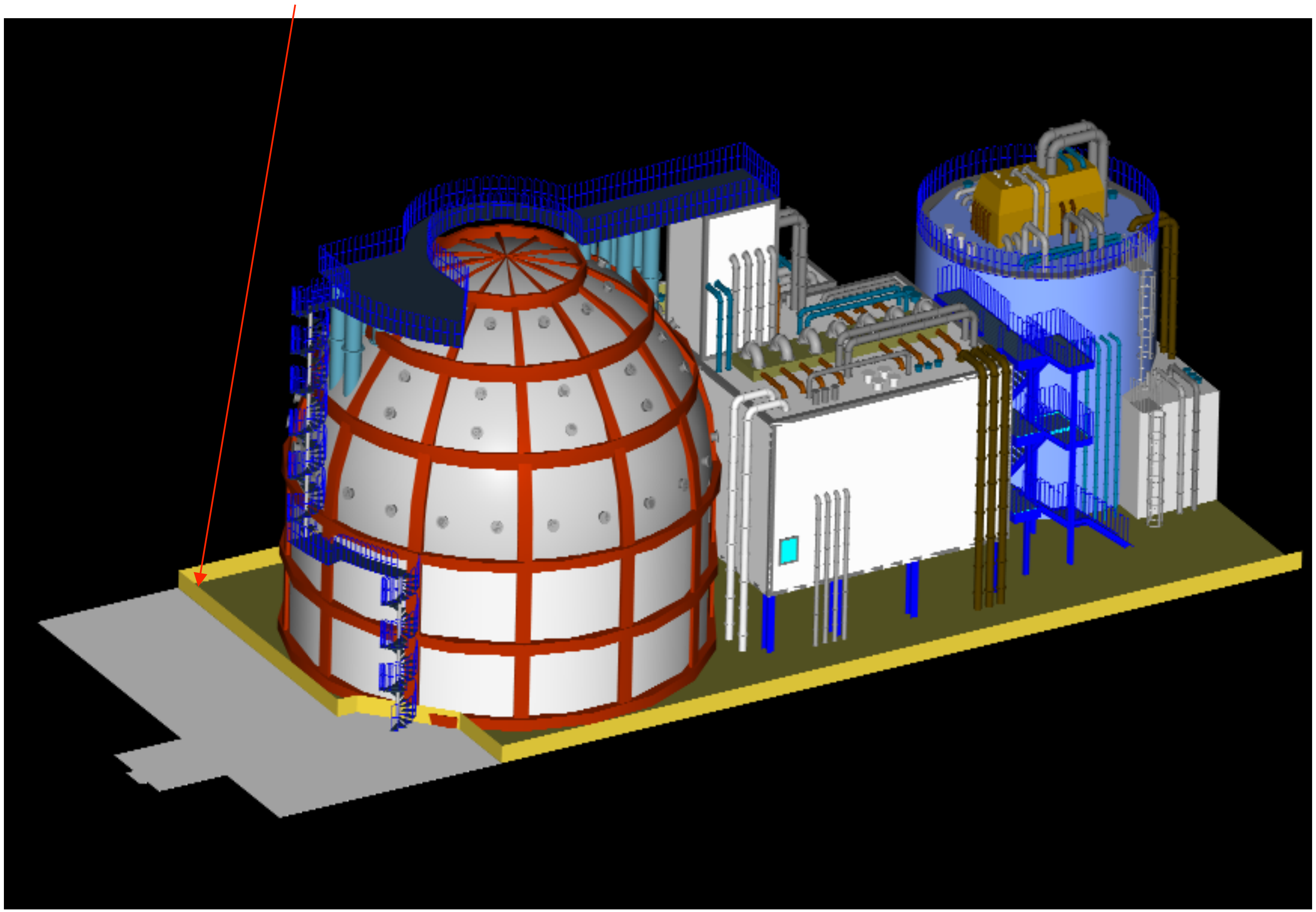
First phase

- Floor waterproofing
- Realization of containment basins
- Safety measure for the drinkable water

Second phase

- Up grade of the ventilation system
- Up grade of the cooling capability
- Up grade of the electrical power

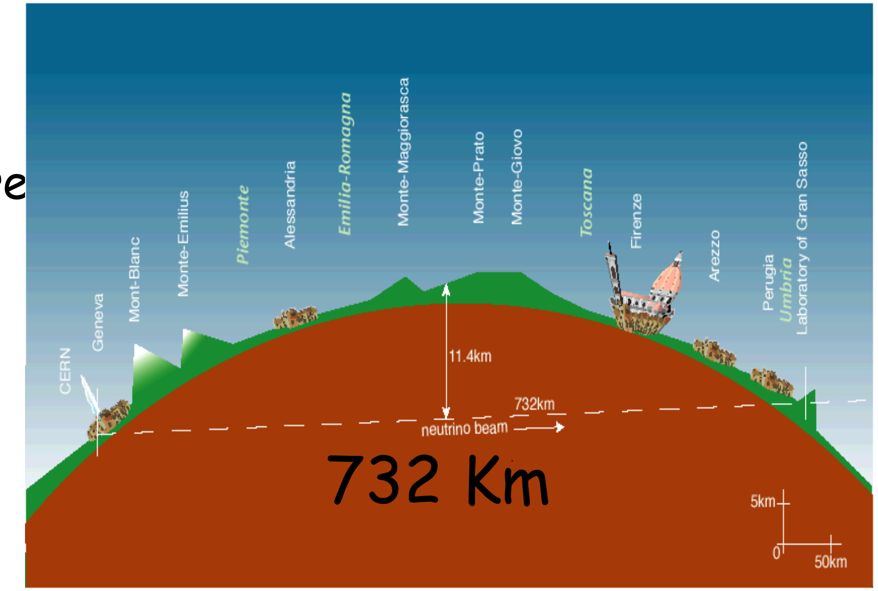
Containment basin



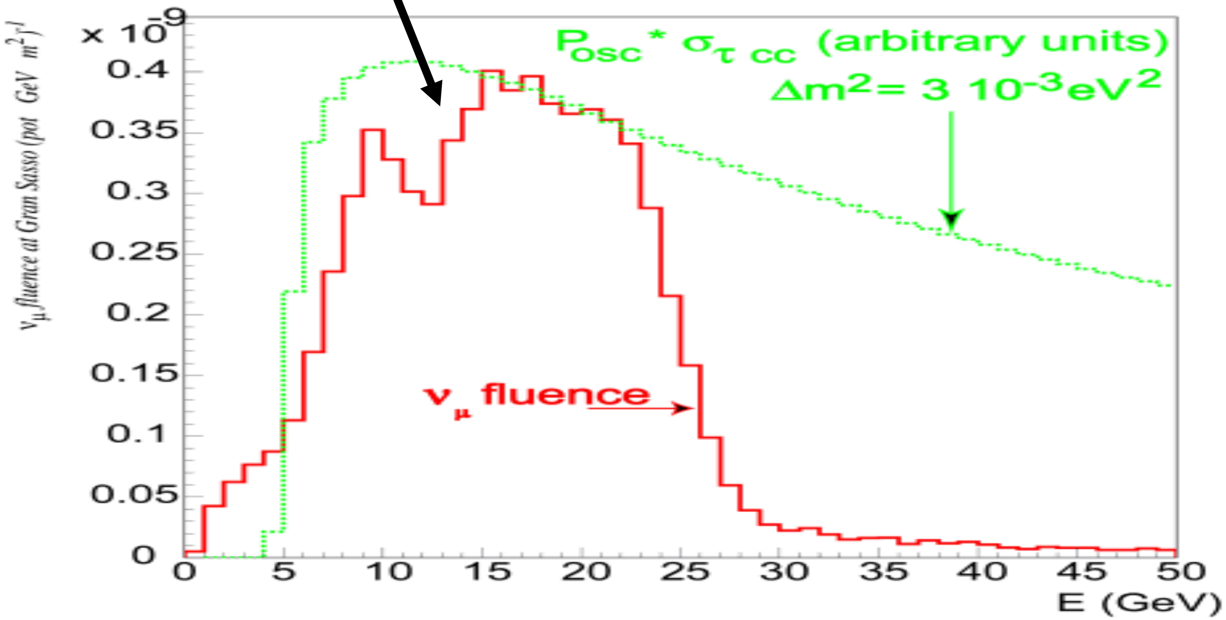
CNGS PROGRAM:

See Guglielmi's talk)

- Provide an unambiguous evidence for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the region of atmospheric neutrinos by looking for ν_τ appearance in a pure ν_μ beam
- Search for the subleading $\nu_\mu \rightarrow \nu_e$ oscillations (measurement of Θ_{13})



Given the distance (732 Km): ν_μ flux **optimized** for the maximal number of ν_τ charged current interactions



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

$<L/E>$ = 43 Km/GeV : « off peak »

OPERA: 6200 ν_μ CC+NC /year

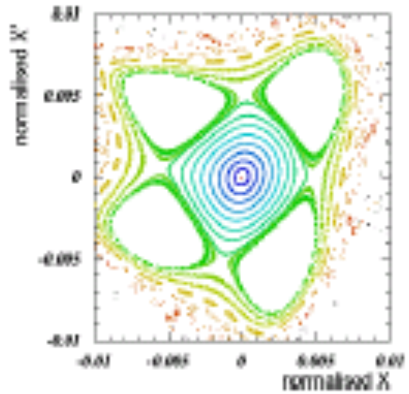
19 ν_τ CC/year (@ 2 10^{-3} eV^2)

CNGS Upgrade

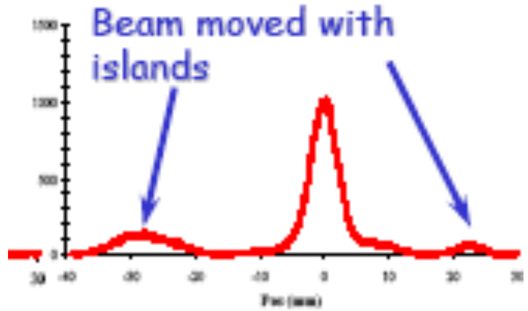
Continuation of machine studies (started in 2003) during 2004 in the framework of the High Intensity Protons Working Group.
Increase of The CNGS intensity possible via increase per extracted beam pulse

- Reduce beam losses at the extraction from the PS (creating radiation problems). New extraction scheme with adiabatic capture of the beam in distinct islands and 5 turns extraction. New hardware (kicker magnet) needed, final design at the end of the tests (end of 2004)

- Double batch injection from PS booster to PS to increase PS pulse intensity from 3 10^{13} to 5 10^{13}



The beam is split in five beamlets to be extracted as a five PS-turn long ribbon



Expected proton intensity increase : 1.5

	2000	2001	2002	2003	2004	2005	2006

Civil Engineering
excavate civil engineering pit, tunnels and caverns; concrete / shot-crete tunnels and caverns

Install hadron stop
iron + graphite blocks, aluminum plate + water cooling

Install decay tube
lower decay tube sleeves, weld together, pour concrete

Install general services
electrical services, ventilation, cooling water, etc.

Install equipment
proton beam line, target, horn+reflector, shielding

Commissioning

First beam to Gran Sasso: May 2006

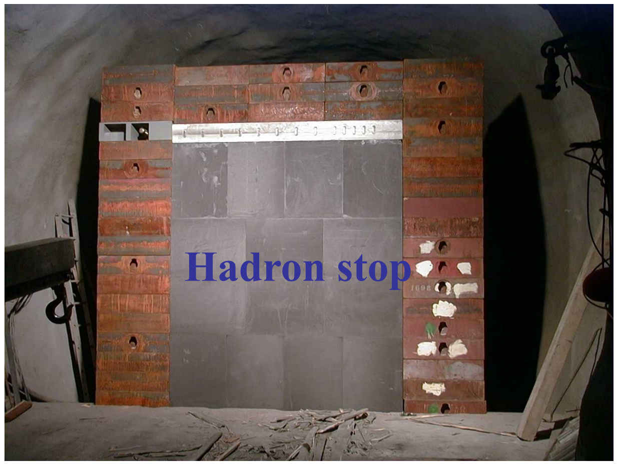
CNGS project on schedule !

First beam in May 2006

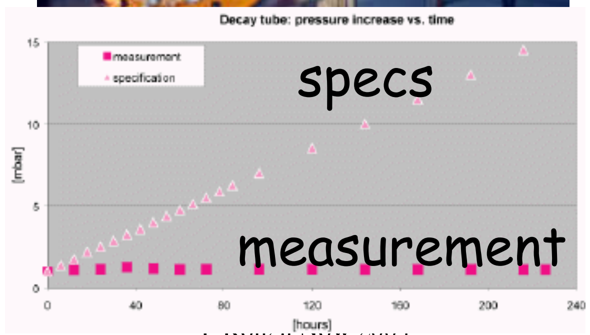
Intensity increase (1.5) under study with dedicated machine tests

Decay tube installed and vacuum tested

Civil engineering completed



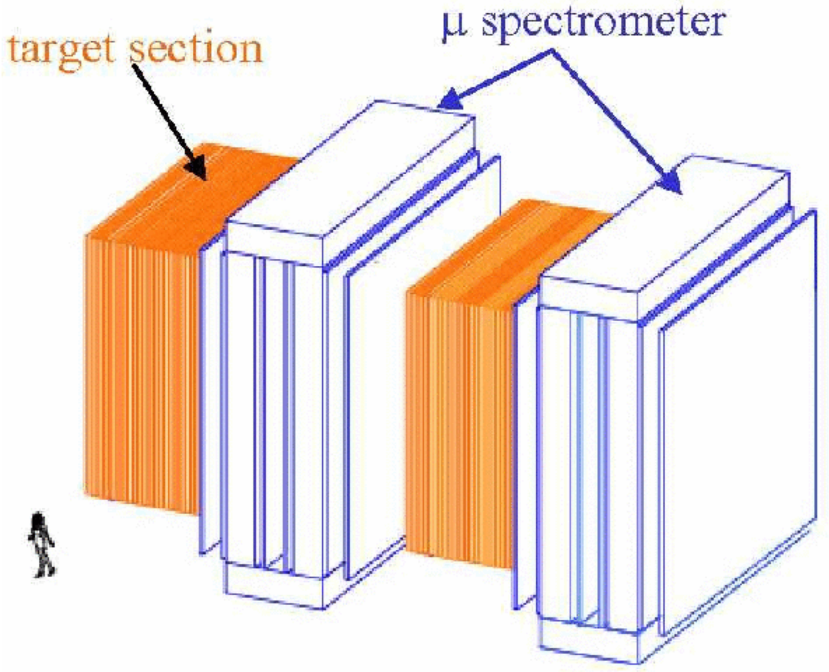
Hadron stop installed



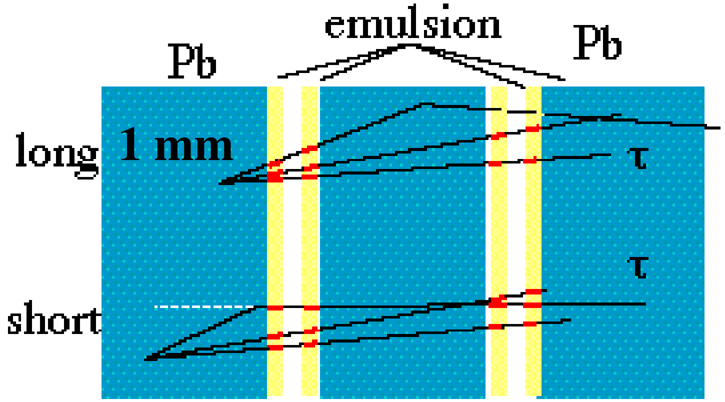
OPERA (see Rosa's talk)

Oscillation Project with Emulsion-tRacking Apparatus

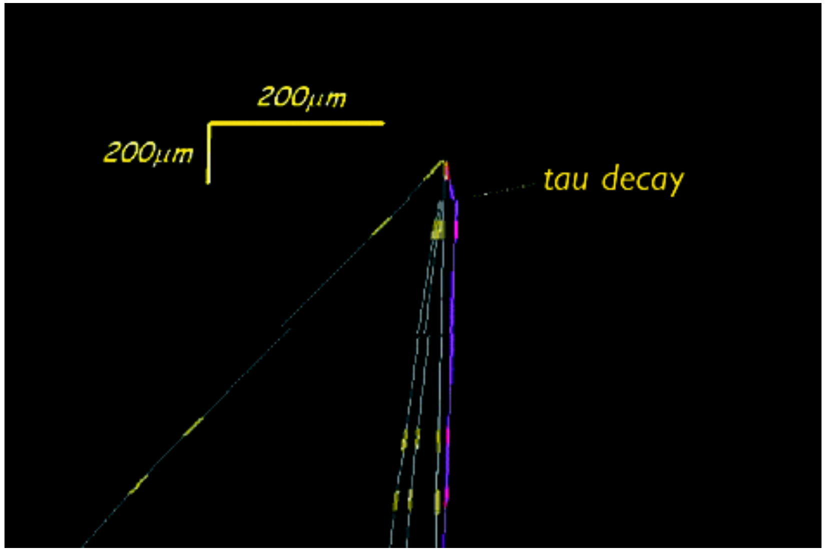
Collab.:
Italy, France, China, Germany, Belgium, Turkey, Switzerland, Russia, Japan, Israel, Croatia



Layers of emulsions and Lead



2 super-modules
1800 t sensitive mass
To detect τ is necessary a μm resolution because the τ decays in a really short time



Use of the electronic detectors:

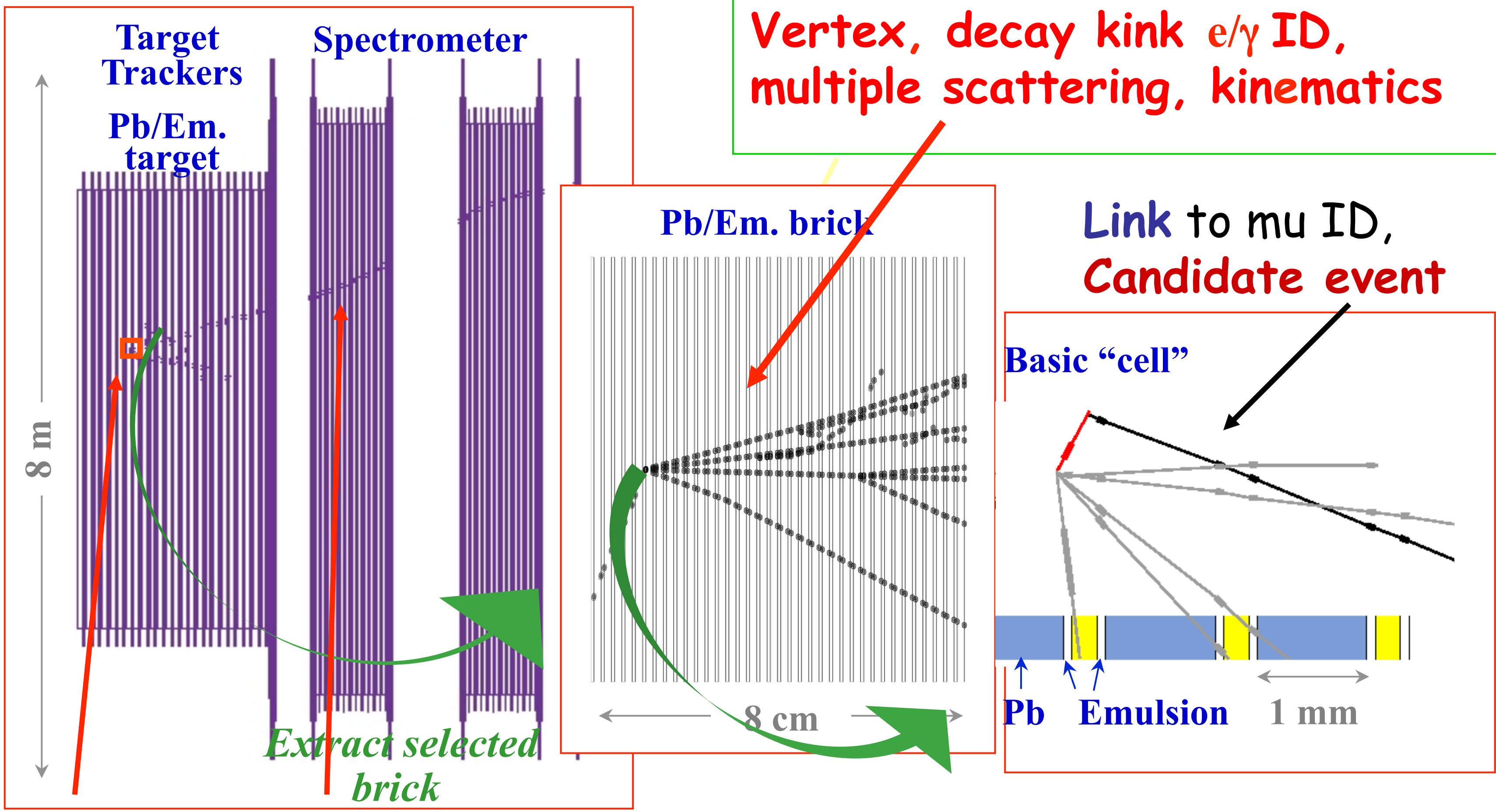
- **trigger** and **localization** of neutrino interactions
- **muon** identification and momentum/charge measurement

→ need for a **hybrid** detector

Electronic detectors:

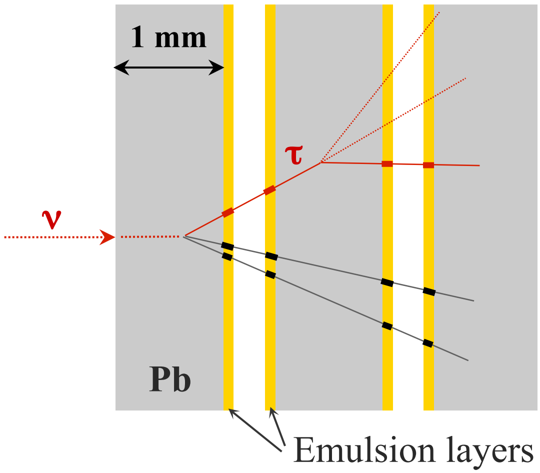
ECC emulsions analysis:

Vertex, decay kink e/γ ID, multiple scattering, kinematics

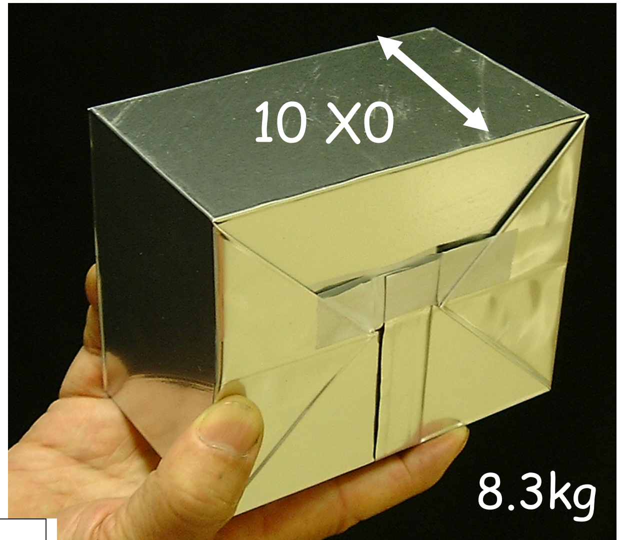


Brick finding, muon ID, charge and p

The basic unit: the « Brick »



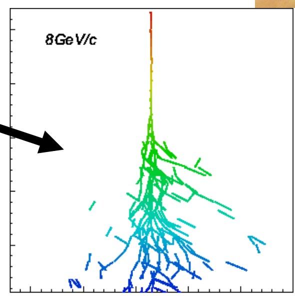
- Based on the concept of the Emulsion Cloud Chamber (**ECC**)
- **56 Pb sheets 1mm + 56 emulsion layers**
- Solves the problem of compatibility of large mass for neutrino interactions + high space resolution in a completely **modular** scheme



10.2 x 12.7 x 7.5 cm

ECC are completely stand-alone detectors:

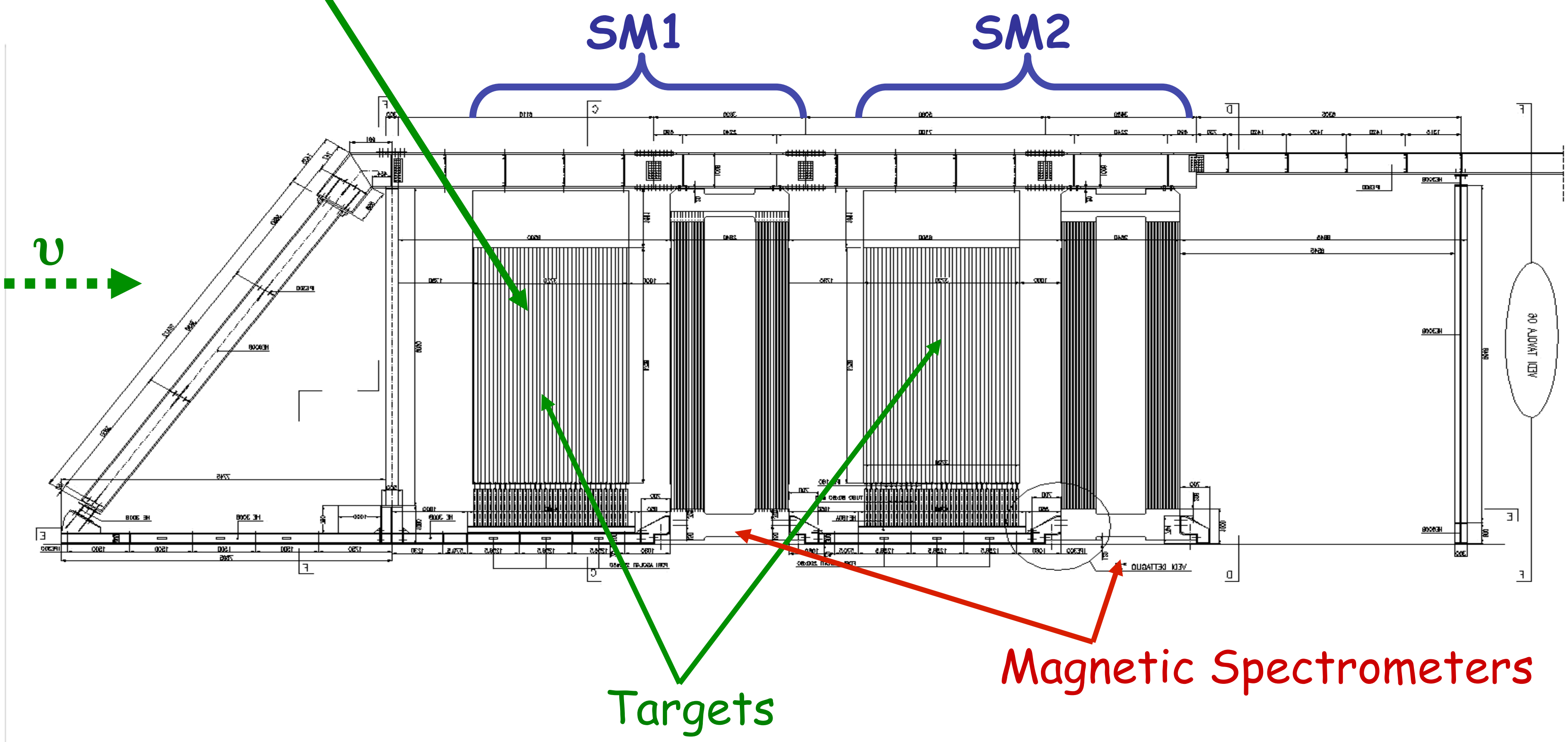
- Neutrino interaction vertex and kink **topology** reconstruction
- Measurement of the **momenta** of hadrons by multiple scattering
- **dE/dx** pion/muon separation at low energy
- **Electron identification** and measurement of the energy of the electrons and photons



ECC Tecnique validated by the direct observation of ν_τ: **DONUT** 2000

OPERA structure with two Super-Modules

31 target planes / supermodule (in total: 206336 bricks, 1766 tons)



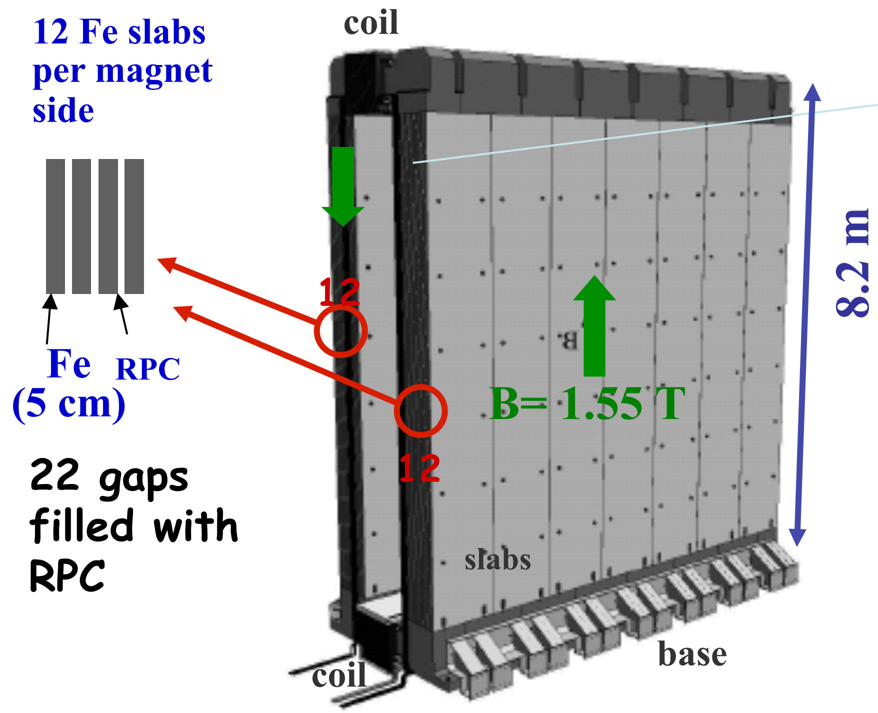
Proposal: July 2000, installation at LNGS started in May 2003

Dipolar magnet

RPCs inside gaps: __muon identification__, shower energy

Drift Tubes: muon momentum

Total Fe weight
~ 1 kton



22 gaps filled with RPC

Magnet of SM1 during installation in Hall C at LNGS

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

$\Delta p/p$ = 20−25%

μId > 95% (with Target Tracker)

Installation started in May 2003
Magnet SM1 completed June 2004
Magnet SM2 completed Apr. 2005
Commissioning: May 2005

F Ronga Now 2004


Assembly frame for vertical slabs
PC
D1
coil
Antiseismic structure
Base magnet 2
Magnet Assembly in Hall C September 2003

Bakelite RPC production and installation

- 1160 RPC + all needed strips **produced** (for the 2 spectrometers)
- FE electronics tendering started
- **19/11/03**: 1rst wall of RPC installed
- **19/5/04**: RPC in SM 1 fully installed

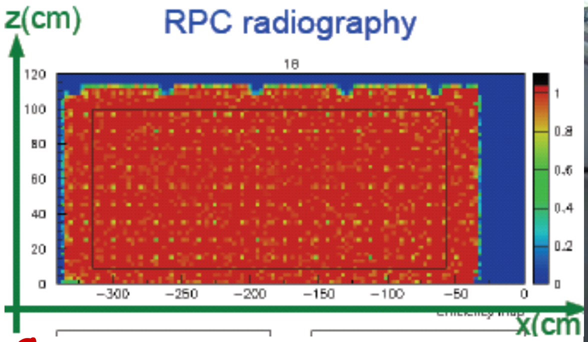
21 chambers x 22 gaps (1540 m^2)

RPC undergo several quality tests:

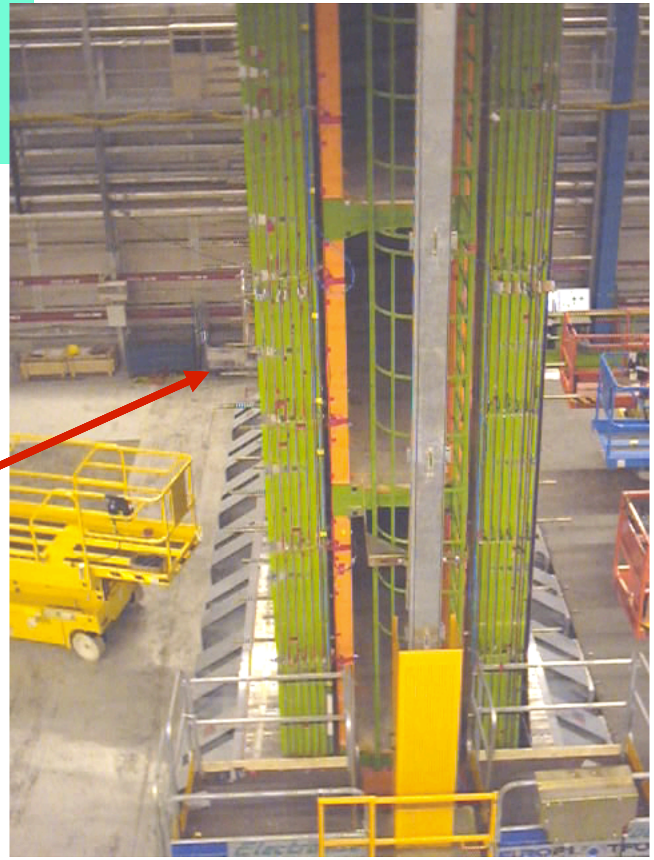
- Mechanical
- Gas tightness
- HV, electrical tests in Ar
- Conditioning with N_2
- Noise, Efficiency with cosmics

Gas and HV tests repeated in Hall C

RPC cosmic ray test (36 RPC)



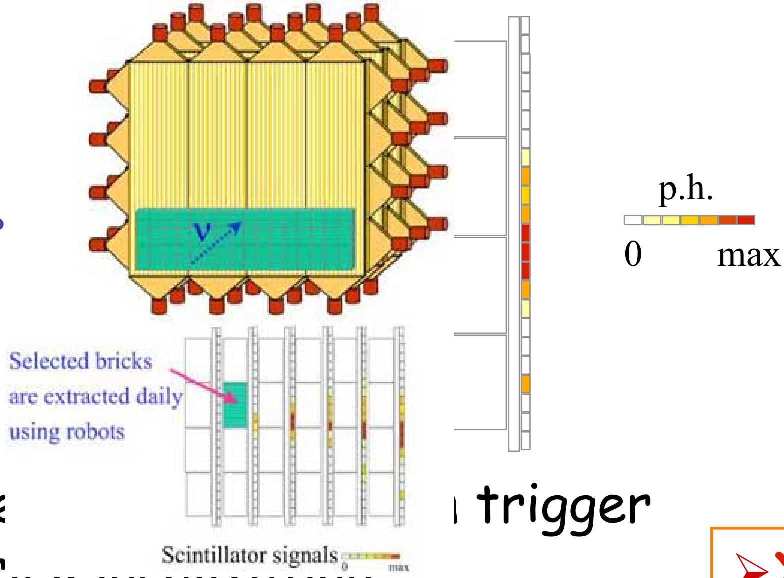
Construction status in March 2004

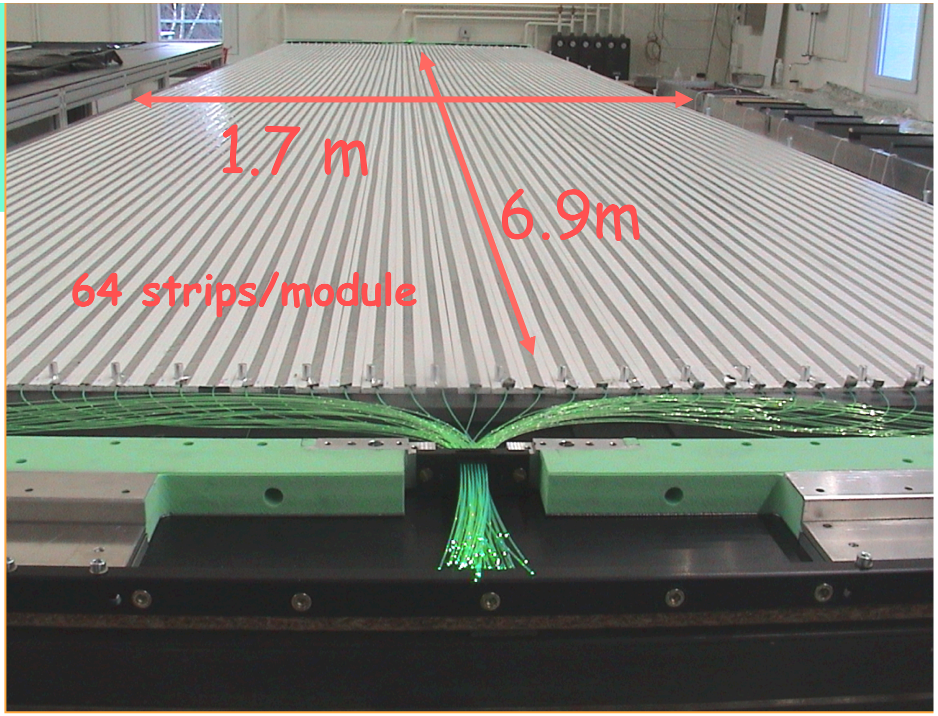


14 of 22 RPC planes installed

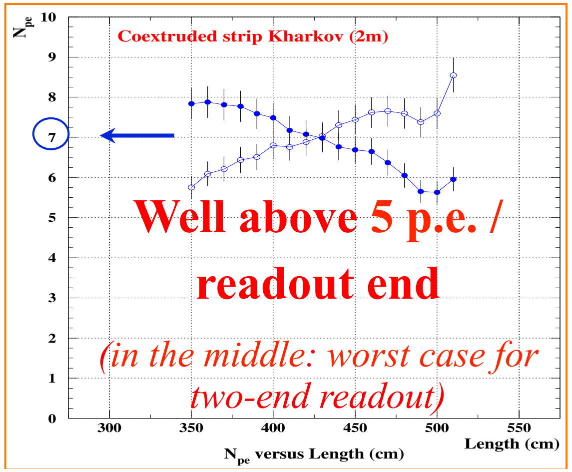
Target Tracker

..ν..





- Ne… trigger
- Br…
- Muon tracking and ID



- **XY planes**, 7000m^2 in total
  - 32256 Scintillator strips 6.86m x 2.6cm x1cm
  - AMCRYS-H (Kharkov) + Kuraray WLS
- **1000 MaPMT Hamamatsu 64channels**
  - Dedicated Front End electronics for gain correction
  - Autotriggerable and threshold @ 1/5 p.e
  - Ethernet DAQ cards

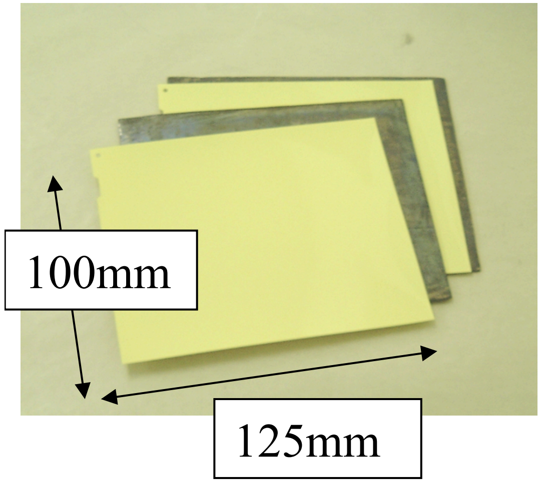
Construction of the modules in progress (8/week)
Installation at LNGS since September 2004

Fuji Emulsion & Lead Production

Mass production started April 2003 (~150 000 m^2)

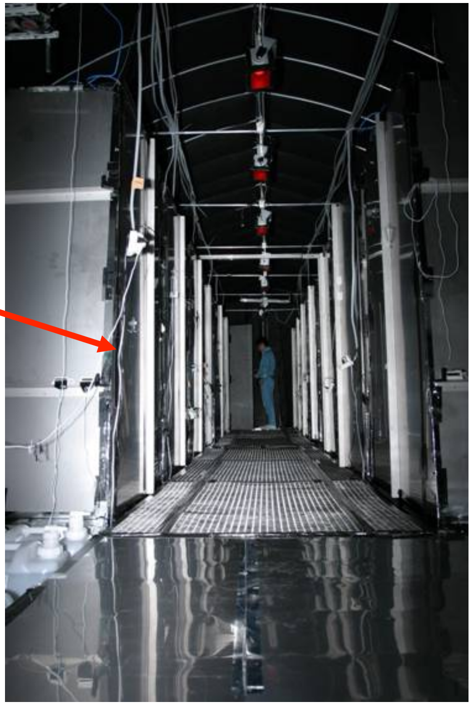
20% produced

Refreshing (erasure of CR tracks) performed in the Tono Mine in Japan (700 bricks/day)



Refreshing condition

- Humidity : > 95%
- Temperature : 30 ºC
- Time : ~ 3 days



Pb (1mm thick @ 10µm) ready for prototype mass production in Germany

(~10^7 plates to be produced at the end)

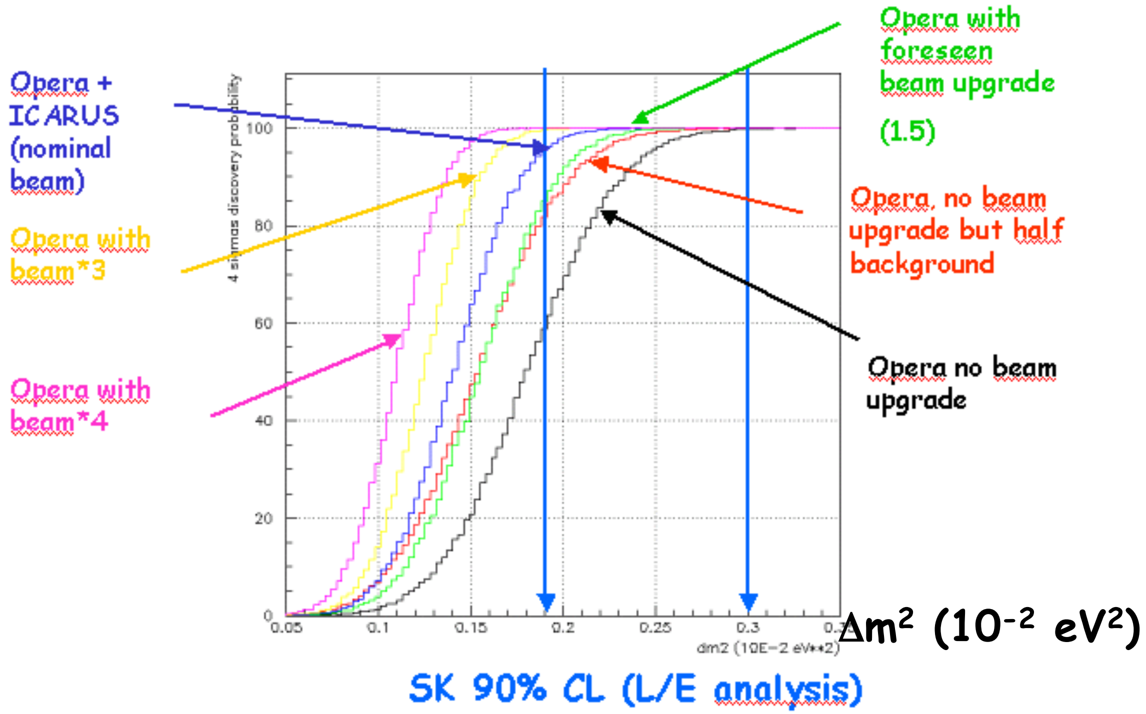
Emulsion storage barrack (5 cm Fe shielding at LNGS)

$\nu_\mu \rightarrow \nu_\tau$ sensitivity

full mixing, 5 years run @ 4.5 x10^{19} pot / year

	signal ($\Delta m^2 = 1.9 \times 10^{-3}\ eV^2$)	signal ($\Delta m^2 = 2.4 \times 10^{-3}\ eV^2$)	signal ($\Delta m^2 = 3.0 \times 10^{-3}\ eV^2$)	BKGD
OPERA 1.8 kton fiducial	6.6(10)	10.5(15.8)	16.4(24.6)	0.7(1.06)

(…) with CNGS beam upgrade (X 1.5)



Probability of observing in 5 years a number of candidates greater than a 4σ background fluctuation

$\nu_\mu \rightarrow \nu_e$: sensitivity

Backgrounds:

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

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

θ_{13}	signal	$\tau \rightarrow e$	ν_μCC	ν_μNC	ν_eCC 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
Efficiency	0.31	0.032	0.34×10^{-4}	7.0×10^{-4}	0.082

S/B enhanced with simultaneous fit of $E_{visible}$, $E_{electron}$ and missing P_t

$\sin^2 2\theta_{13}$	Θ_{13}
<0.06	<7.1°
<0.05 (beam *1.5)	<6.4°

Due to the off-peak baseline CNGS has a sensistivity on θ_{13} with a dependence on δ_{CP} complementary to T2K

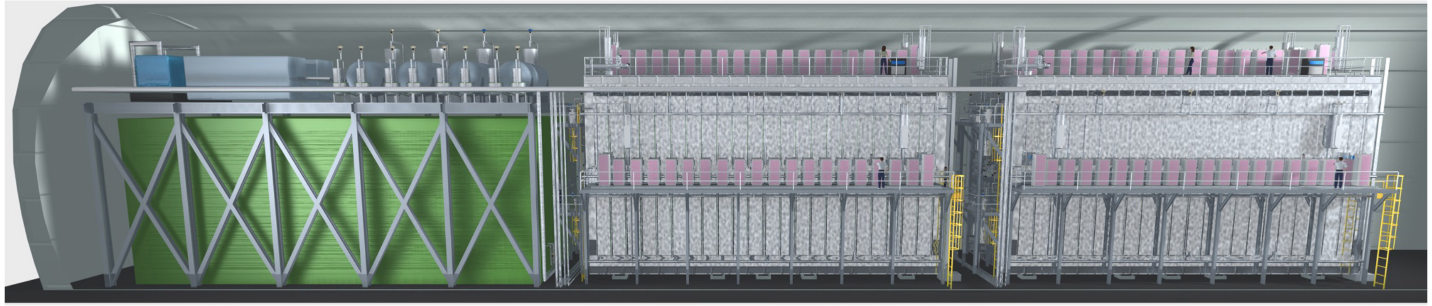
The ICARUS Collaboration

- Research project jointly approved by INFN and CERN
  - **CERN/SPSC 2002-027 (SPSC-P-323) LNGS-EXP 13/89**

  – CNGS Physics Program: ICARUS is an official CERN experiment known as CNGS2 (April 2003)

ICARUS Imaging Cosmic and Rare Underground Signals

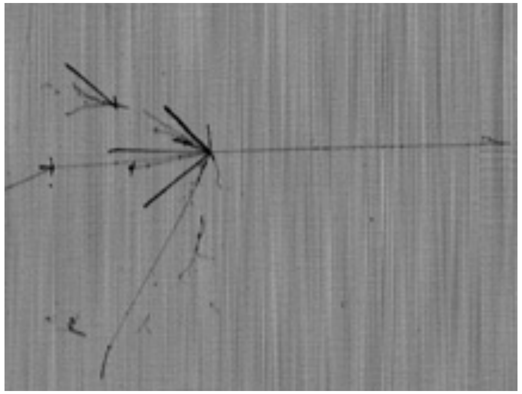
First Unit T600 | T1200 | T1200



Liquid Argon (-176 °C)

Collaboration:
Italy, Poland, China
Spain, Switzerland, USA

First half of T600 module successfully operated in Pavia
Expect to install T600 in 2004
T3000 detector proposed as a series of five T600 modules

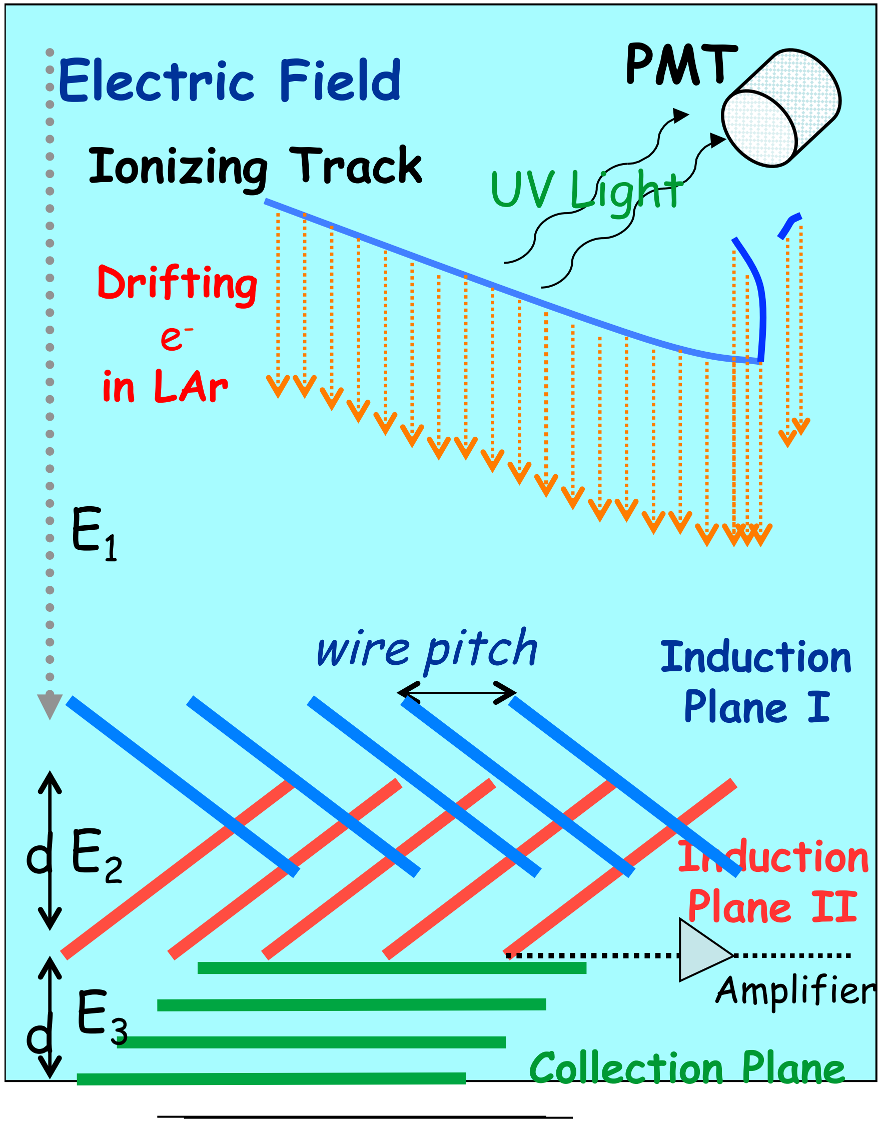


17 m

- Wide physics program
  - ν_τ and ν_e appearance on CNGS
  - atmospheric neutrinos
  - supernova neutrinos
  - solar neutrinos

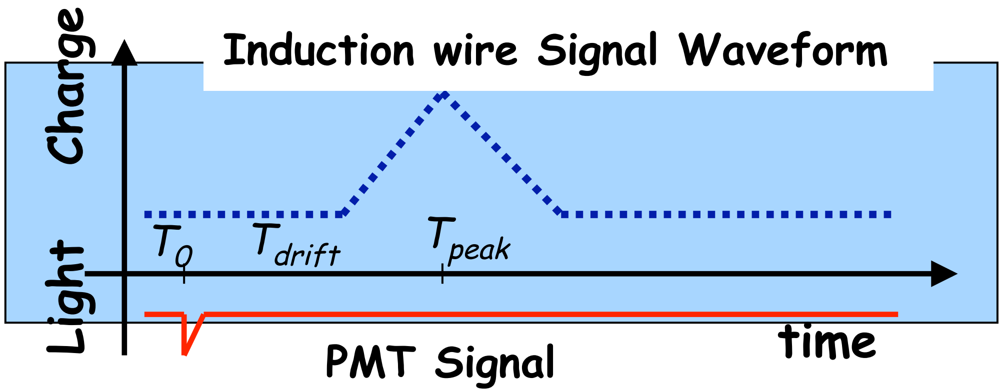
ICARUS: technique

Uniform Imaging in large volume liquid Argon



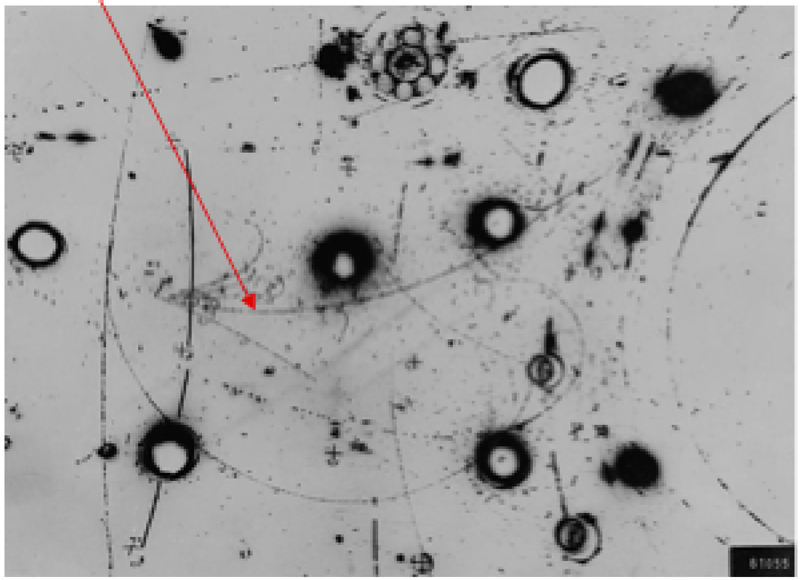
Readout of the ionization electrons using wire planes with different orientation

- 3D reconstruction
  - pixel ≈ 3 x 3 x 3 mm^3
  - High resolution calorimetry
    - imaging + ionization
  - Readout of the Argon scintillation light
  - Event start time
- Very high purity argon i (< 0.1 ppb O_2 equiv.)
  - drift > 5 m - Large dimension uniform detector



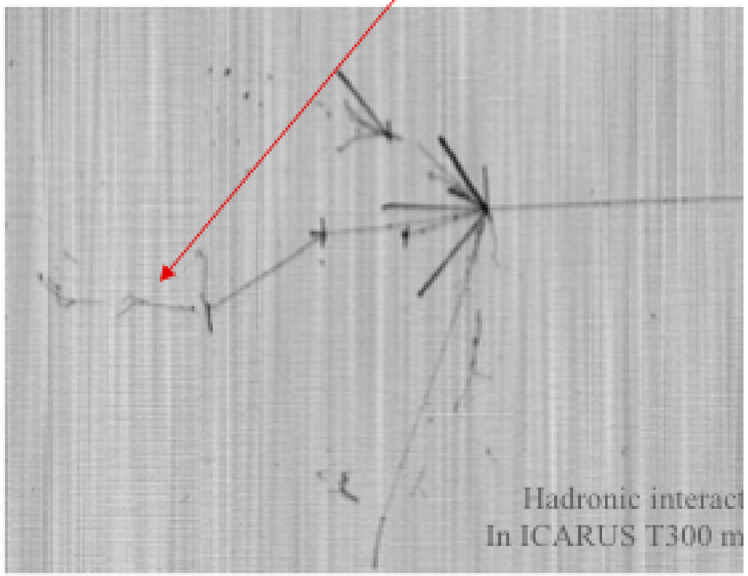
…an "electronic bubble chamber"
with broad physics potential and energy range

Bubble diameter ≈ 3 mm (diffraction limited)



Gargamelle

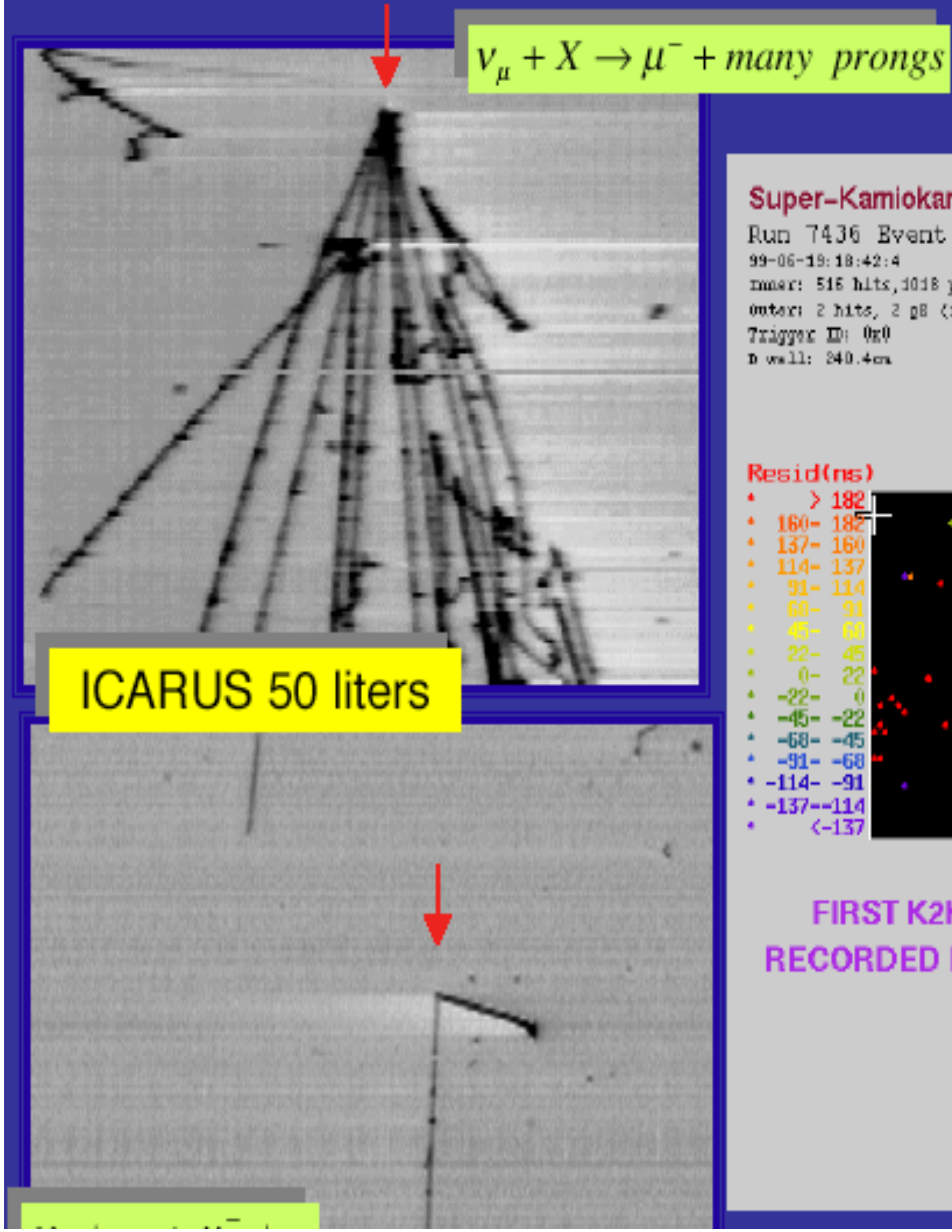
Bubble size ≈ 3 x 3 x 0.4 mm

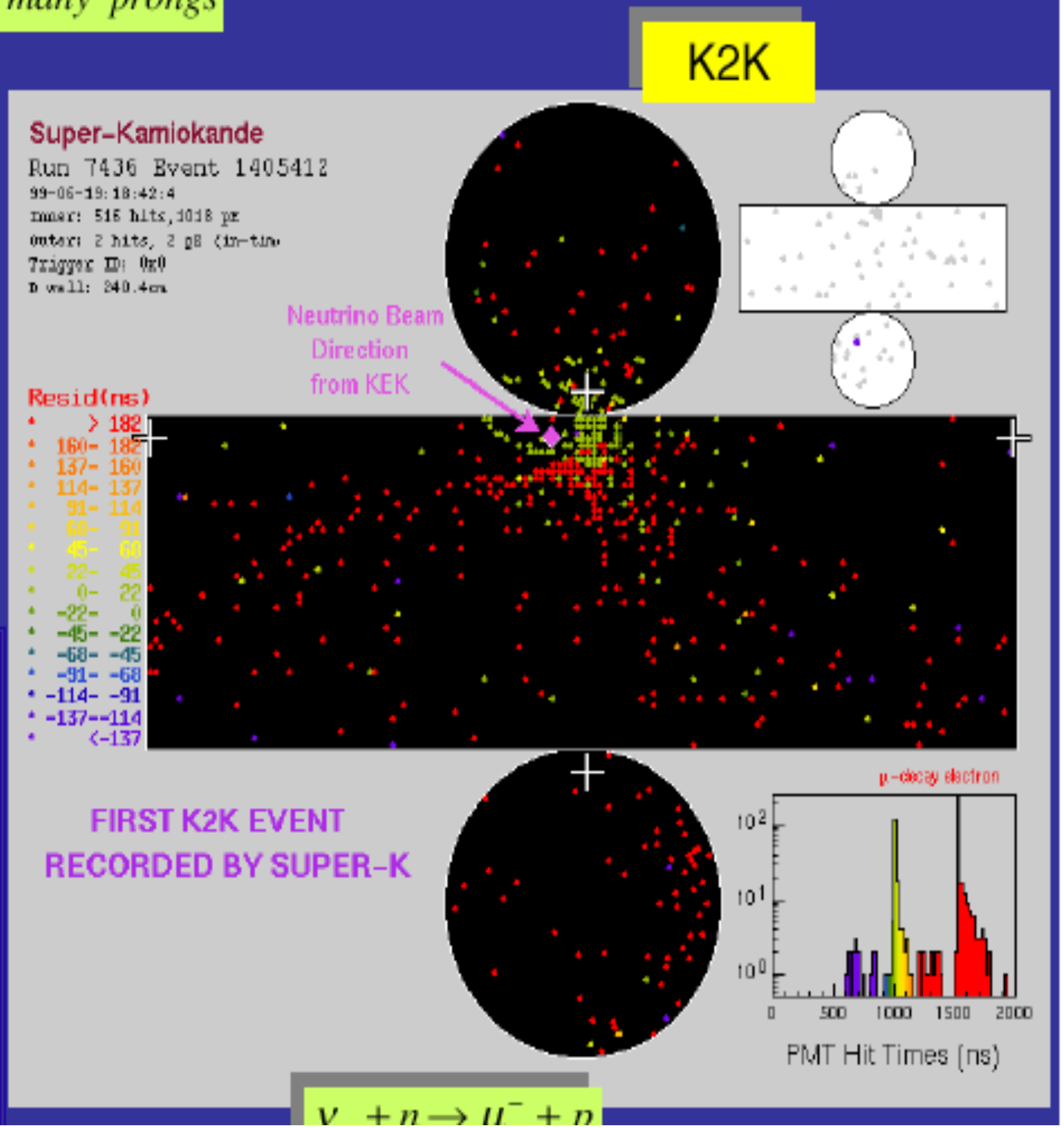


Liquid Ar TPC

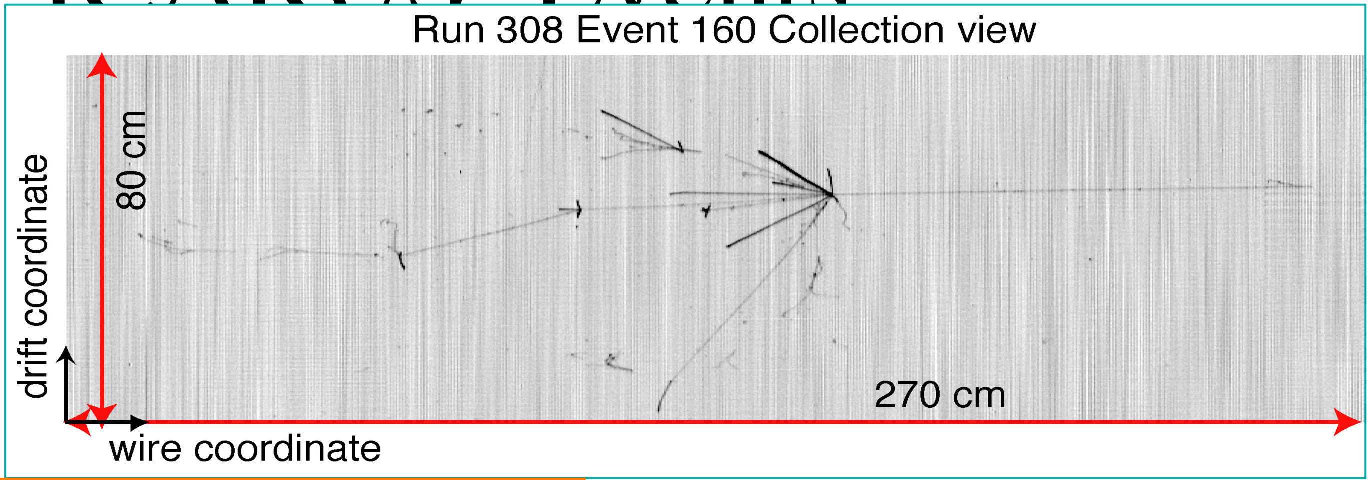
Medium	Heavy Freon	Liquid Argon
Sensitive mass	**3 ton**	**300 ton - …. kton**
Density (g/cm^3)	1.5	1.4
Radiation length (cm)	11.0	14.0
Collision length (cm)	49.5	54.8
dE/dx (MeV/cm)	2.3	2.1

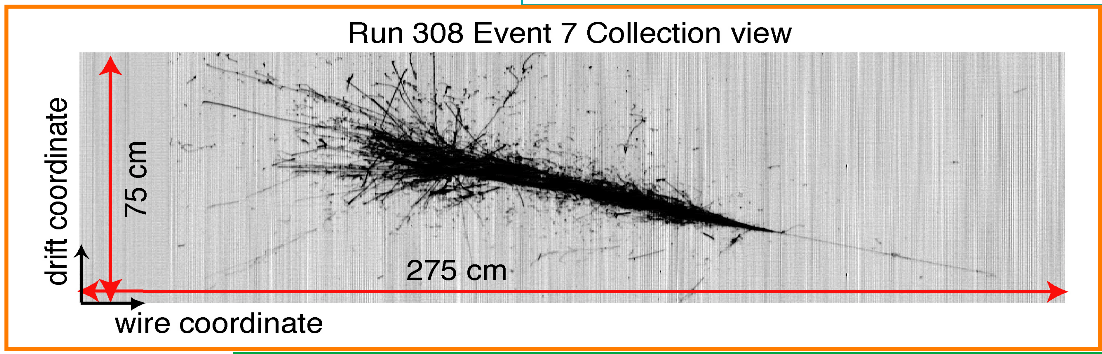
Real neutrino events observed by LAr TPC and water Cerenkov

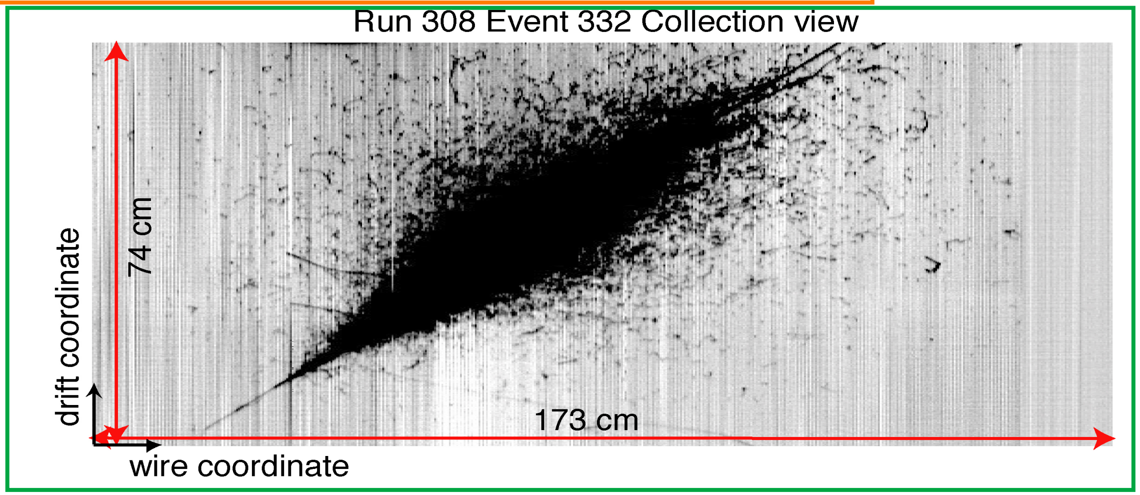


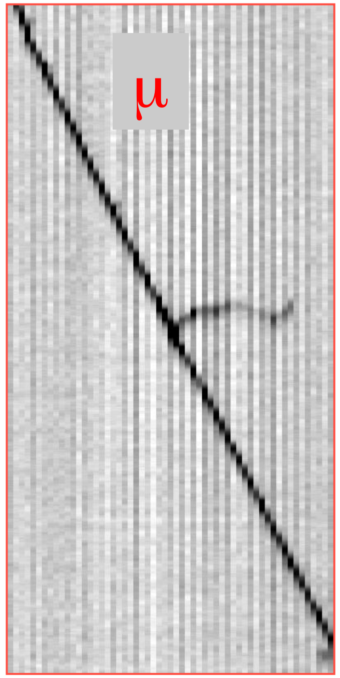


ICARUS: Events



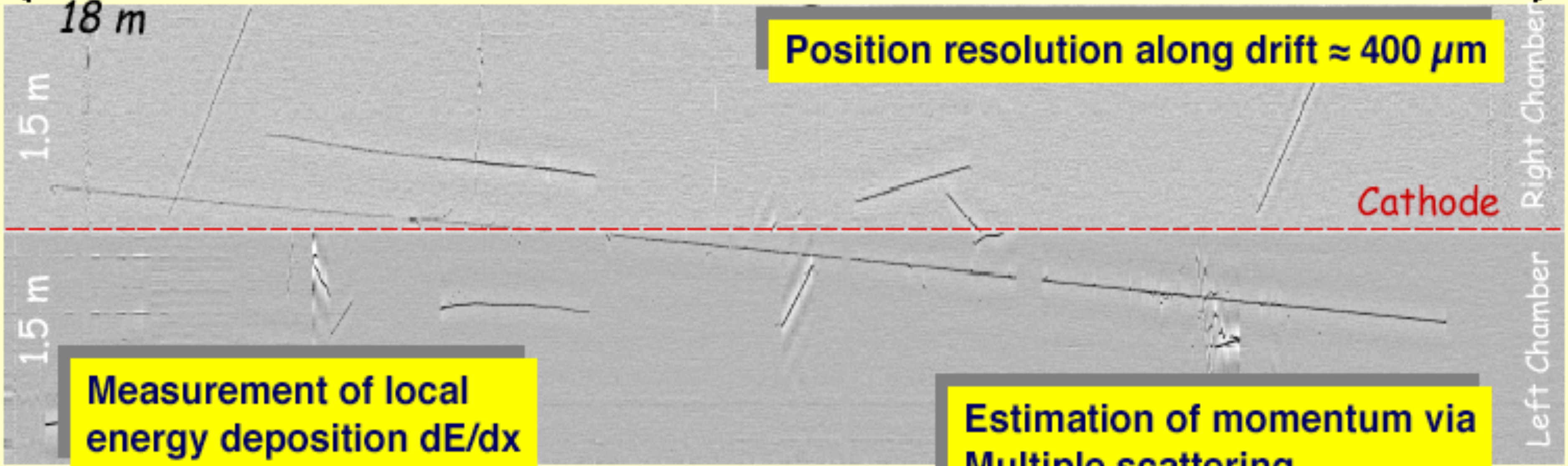






F Ronga Now 2004

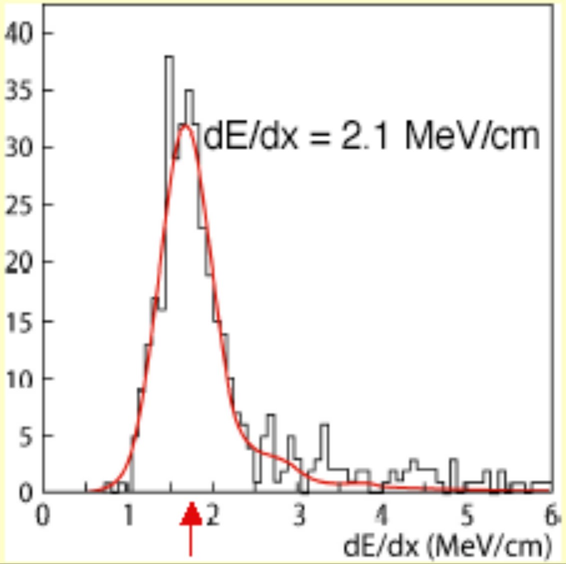
Momentum measurement via multiple scattering in T600



Position resolution along drift ≈ 400 μm

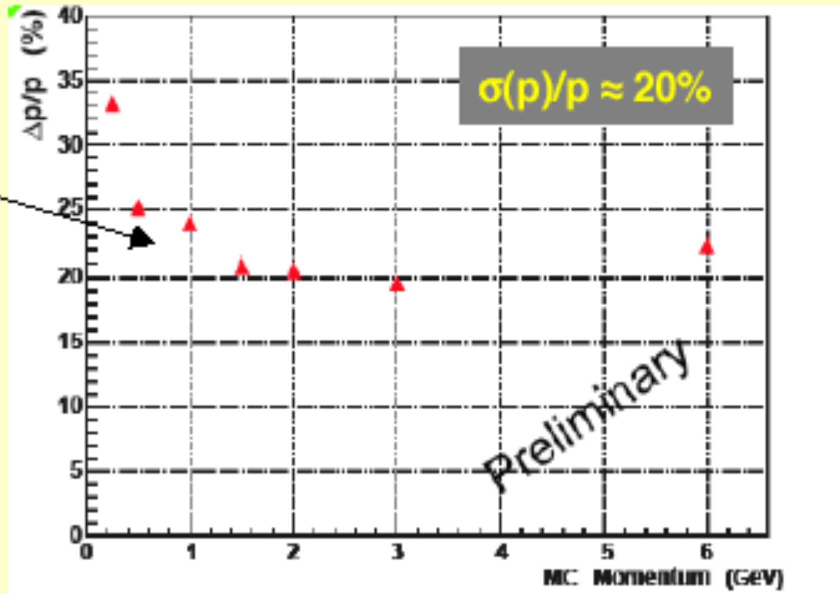
Measurement of local energy deposition dE/dx

Estimation of momentum via Multiple scattering



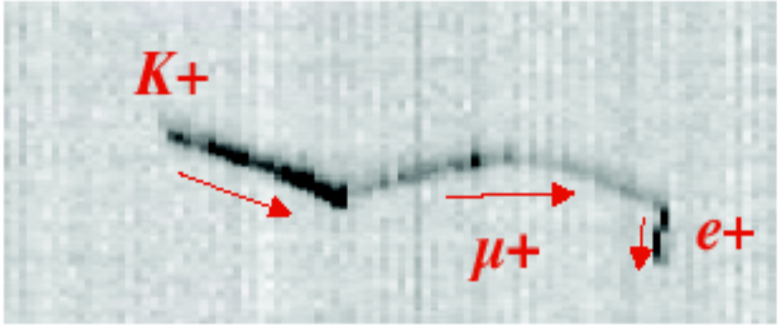
dE/dx distribution along the track

Momentum resolution:

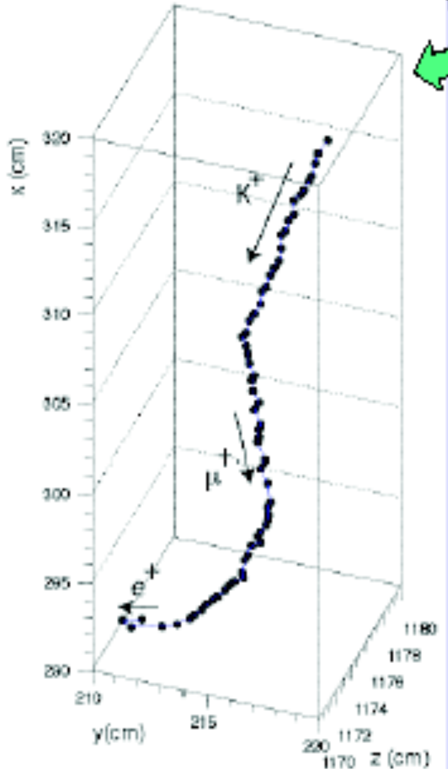


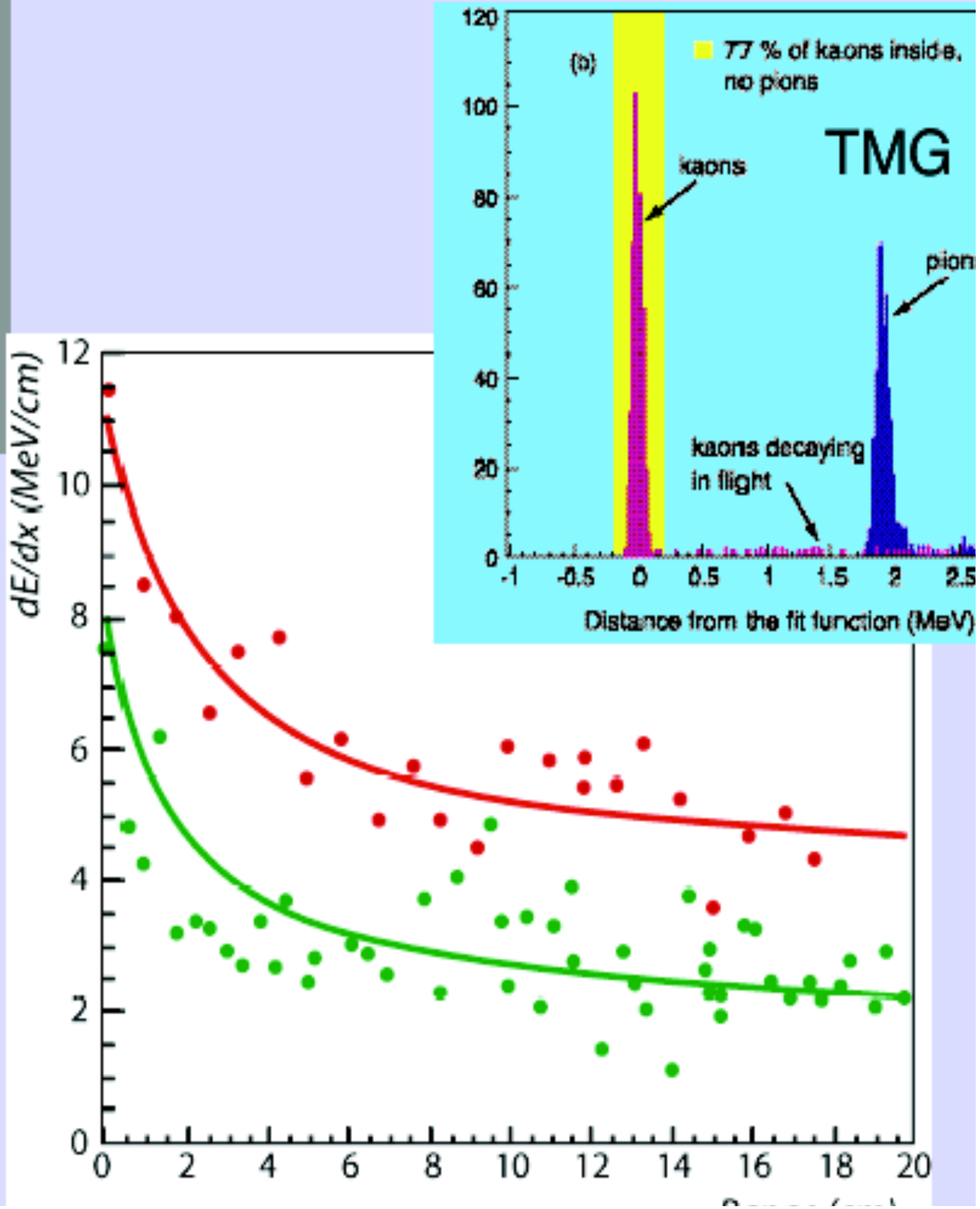
Particle ID example: kaon

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



Run 939 Event 46





CNGS: $\nu_\mu \rightarrow \nu_\tau$ Oscillations

- Main reaction $\nu_\tau + Ar \rightarrow \tau + jet;$ $\tau \rightarrow \begin{cases} e\nu\nu & 18\% \\ \mu\nu\nu & 18\% \\ h^- n h^0 \nu & 50\% \\ h^- h^+ h^- n h^0 \nu & 14\% \end{cases}$
  - Search based on kinematical criteria
  - Natural ν_τ contamination below 10^{-7} w.r.t. ν_μ component
  - Several decay modes investigated (electron decay is the "golden" channel)

Super-Kamiokande: $1.6 < \Delta m^2 < 3.0$ at 90% C.L.

τ decay mode	Signal $\Delta m^2 = 1.6 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 4.0 \times 10^{-3}$ 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

  - 5 years of CNGS operation (4.5×10^{19} p.o.t.)
  - T3000 detector (2.35 kton active LAr, 1.5 kton fiducial)

CNGS: $\nu_\mu \rightarrow \nu_e$ Oscillations

- Main reaction

  $\nu_e + Ar \rightarrow e^- + jet;$

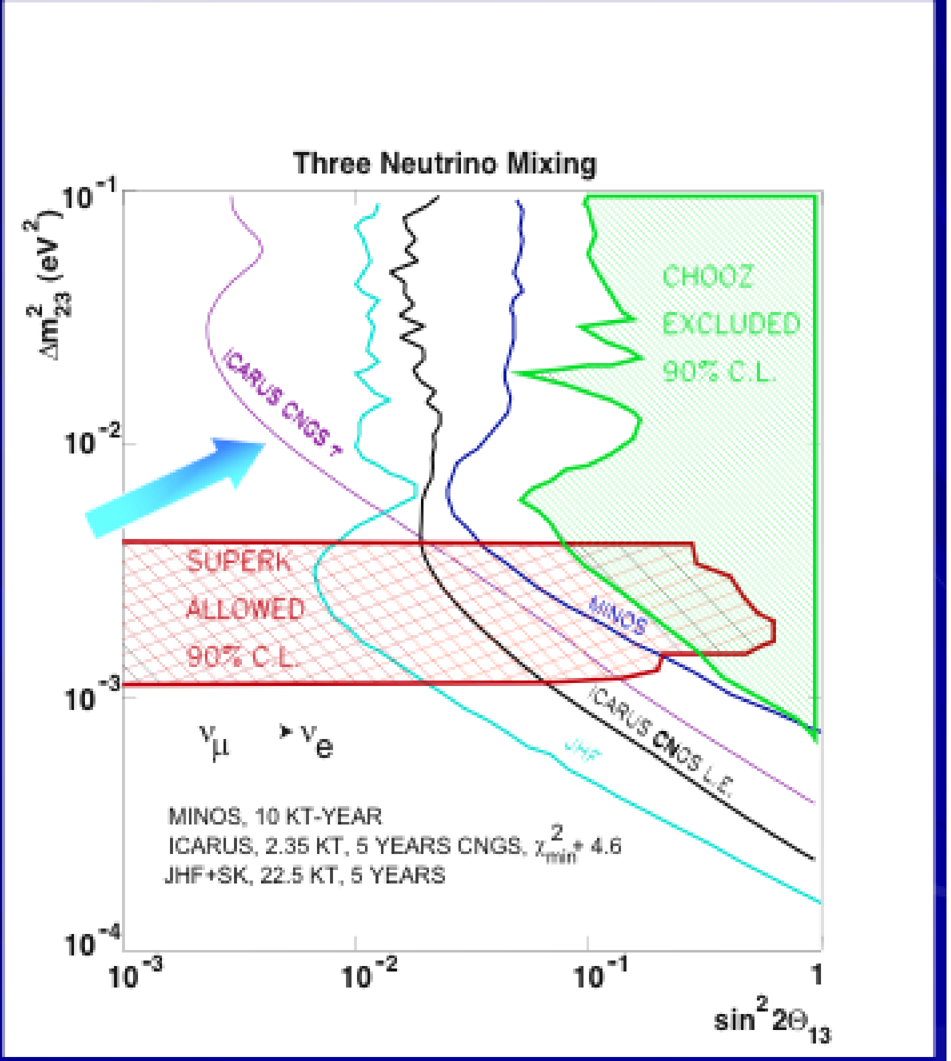
- Natural ν_e contamination 1%
- Limited by CNGS statistics

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

$(\sin^2 2\theta_{13})_{CNGS,\tau} < 0.04 \quad or \quad \theta_{13} < 6^o$

$(\sin^2 2\theta_{13})_{CHOOZ} < 0.14 \quad or \quad \theta_{13} < 11^o$

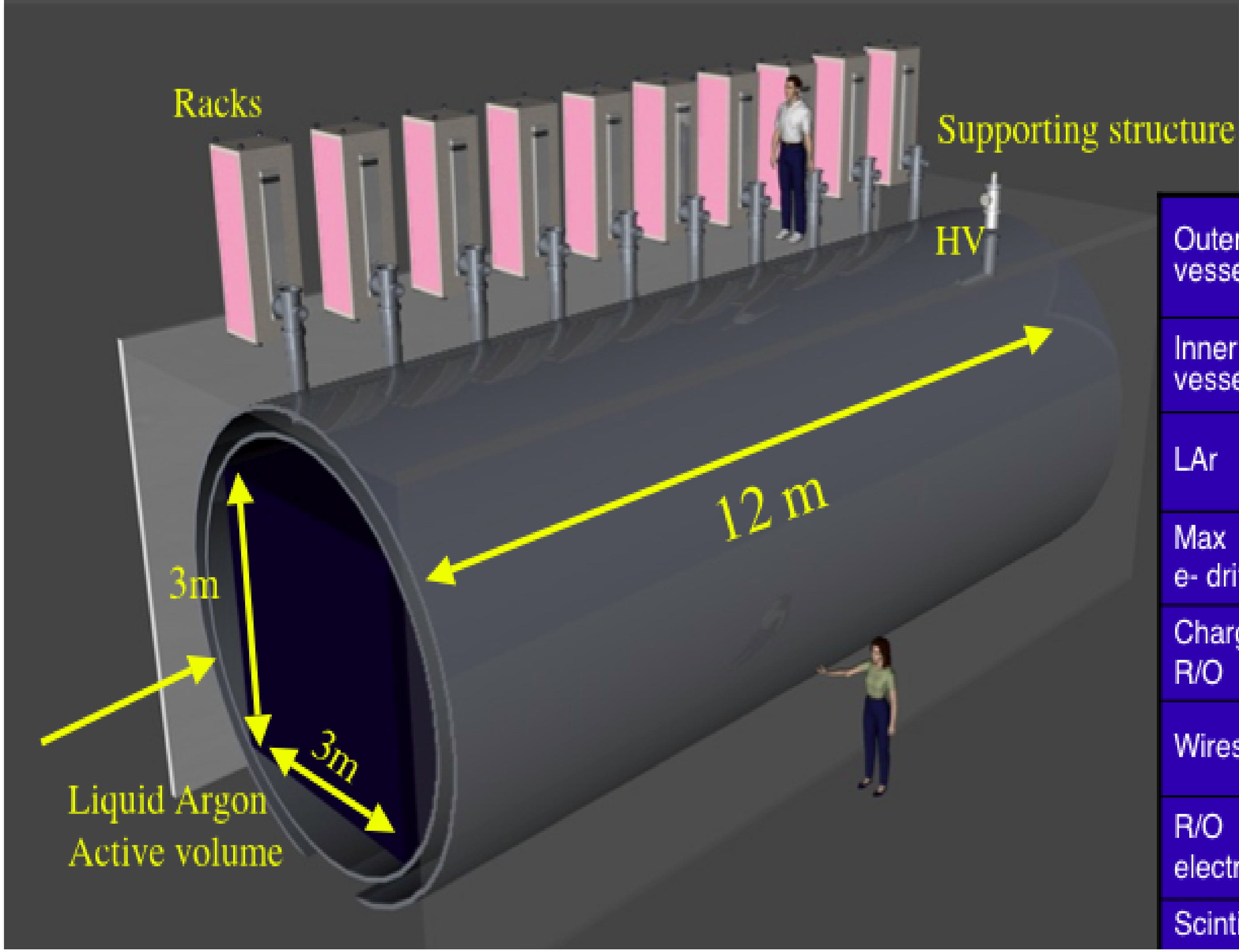
$(\sin^2 2\theta_{13})_{MINOS} < 0.06 \quad or \quad \theta_{13} < 7^o$



Evolution of the ICARUS technique :small detector

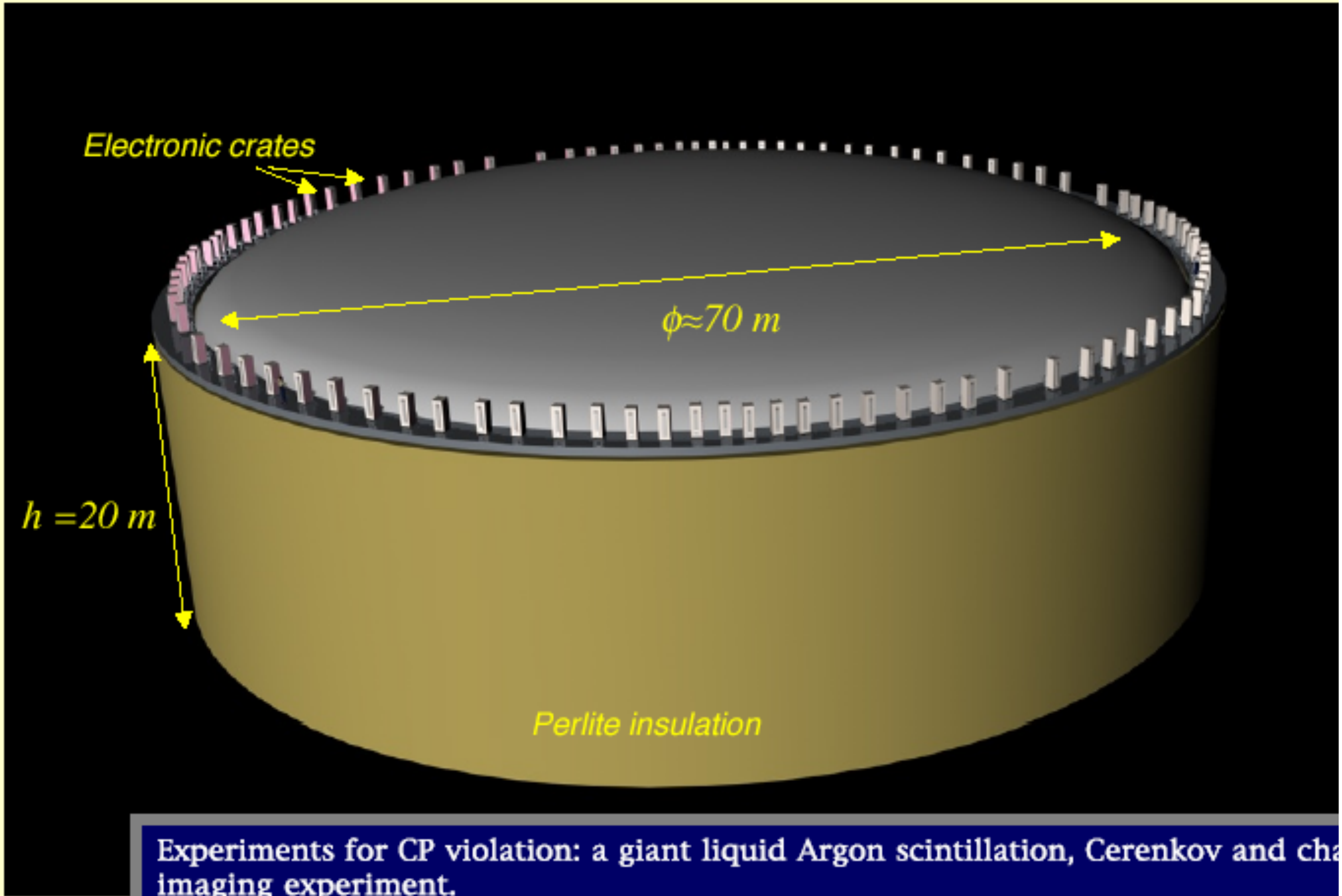
Conceptual design of a ~100 ton LAr TPC for a near station in a LBL facility:

a possibility being further explored



Outer vessel	ϕ ≈ 5m, L≈13m, 15mm thick, weight ≈ 22 t
Inner vessel	ϕ ≈ 4,2 m, L ≈ 12 m, 8 mm thick, ≈ 10 t
LAr	Total ≈ 240 t Fiducial ≈ 100 t
Max e- drift	3 m @ HV=150 kV E = 500 V/cm
Charge R/O	2 views, ± 45° 2 (3) mm pitch
Wires	≈10000 (7000) ϕ = 150 μm
R/O electr.	on top of the dewar
Scintill.	Also for triggering

100 kton liquid Argon TPC detector



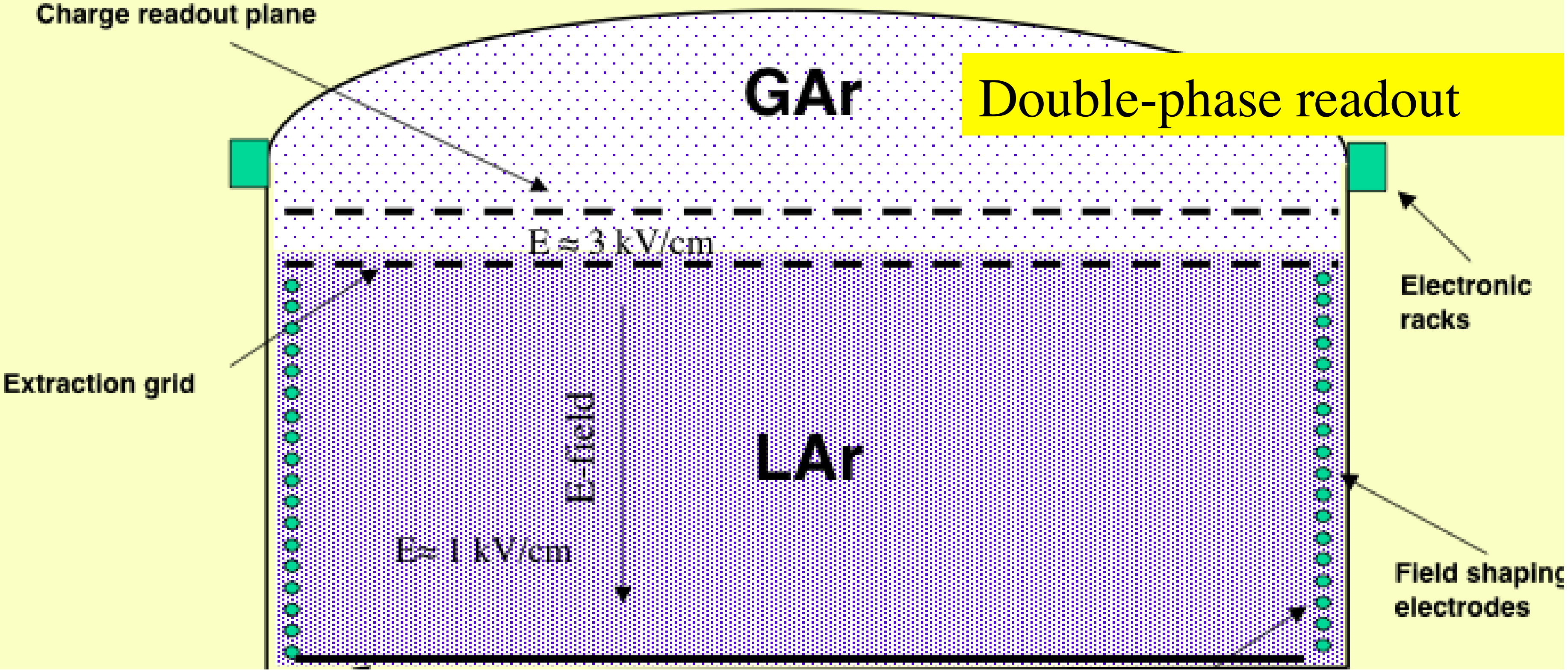
Experiments for CP violation: a giant liquid Argon scintillation, Cerenkov and cha
imaging experiment.

A.Rubbia, Proc. II Int. Workshop on Neutrinos in Venice, 2003, hep-ph/0402110

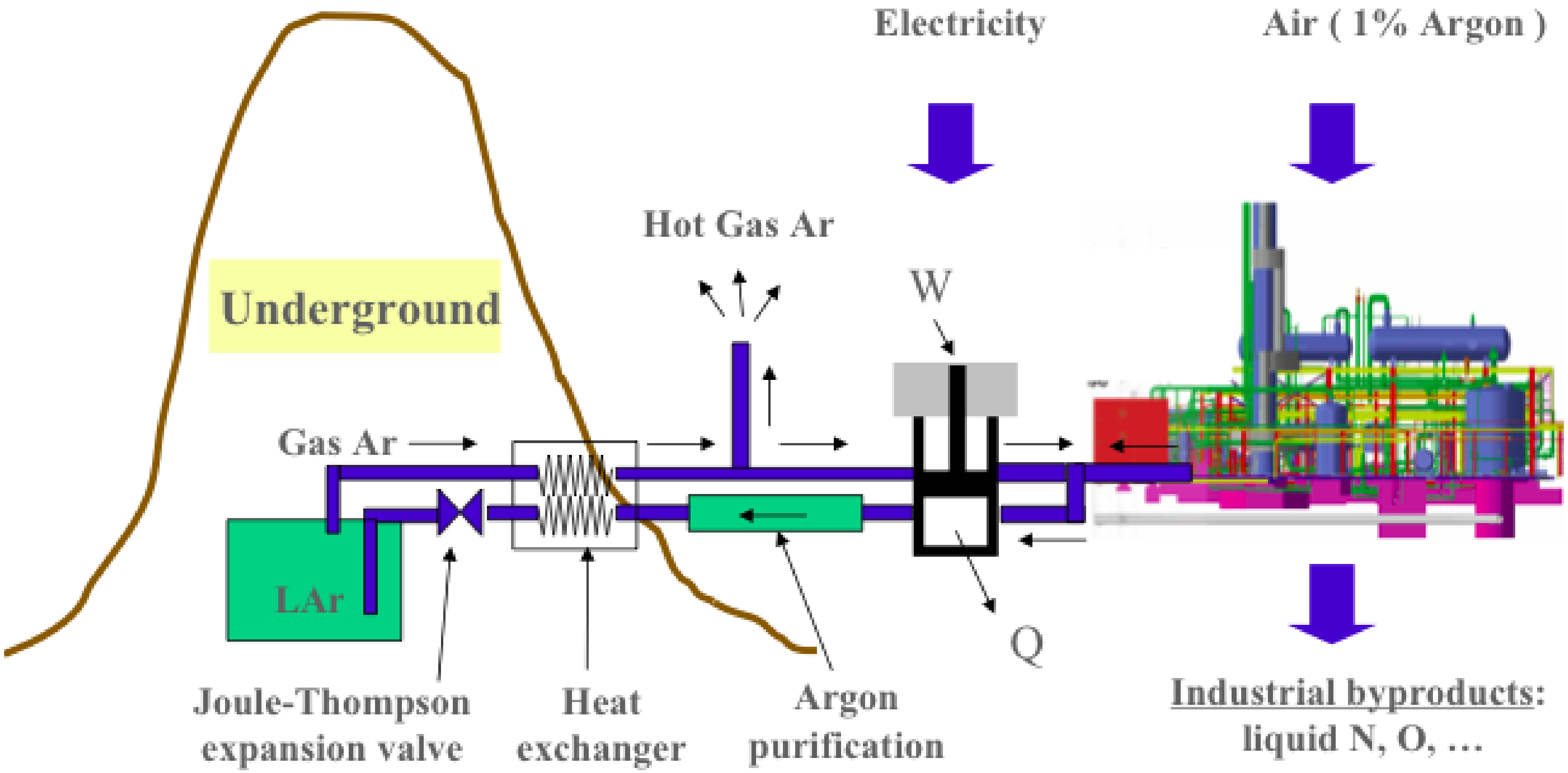
A tentative detector layout

Single detector: charge imaging, scintillation, Cerenkov light

Dewar	ϕ ≈ 70 m, height ≈ 20 m, perlite insulated, heat i
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m³, ratio area/volume ≈ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc ϕ ≈70 m located in gas phase above liquid
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PM
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs single γ counting capability



But a very large cryogenic plant is needed!



- Initial filling: transport LAr or in situ cryogenic plant
  Filling speed 150 ton/day → 2 years to fill
- 5 W/m^2 heat input: 30 ton/day refilling needed
- Continuous re-circulation (purity)

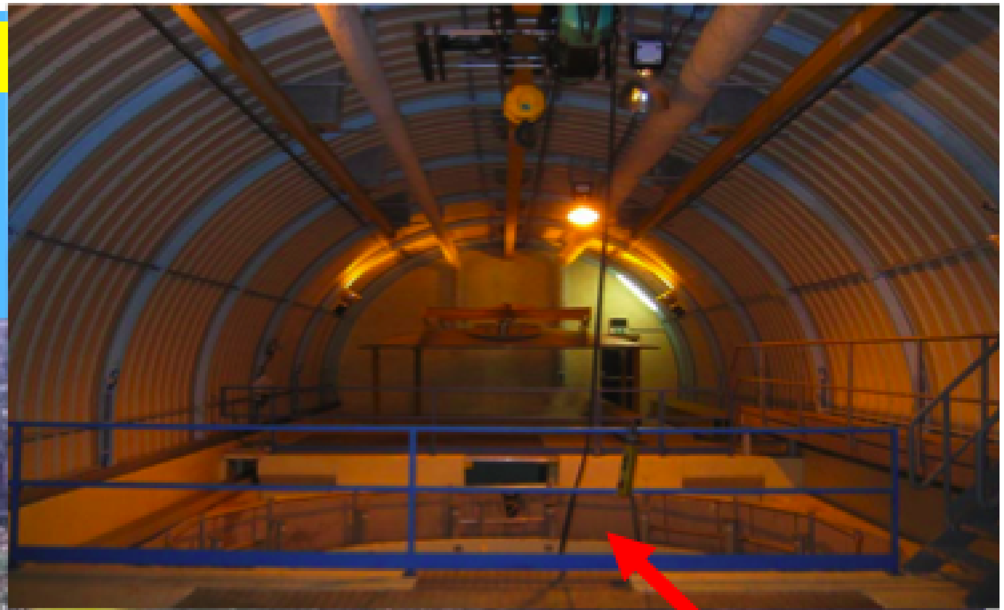
Double-Chooz : site

2 identical detectors ⇒goal : $\sigma_{relative} \cong 0.6\%$

Far detector : using existing infrastructure from the previous experiment @ 1050 m

- **LOI : hep-ex/0405032**
- **detector cost 7.5 Meuros**
- **civil engineering ~5 Meuros (not studied)**
- **LOI accepted**
- **need for a proposal within 6 months**

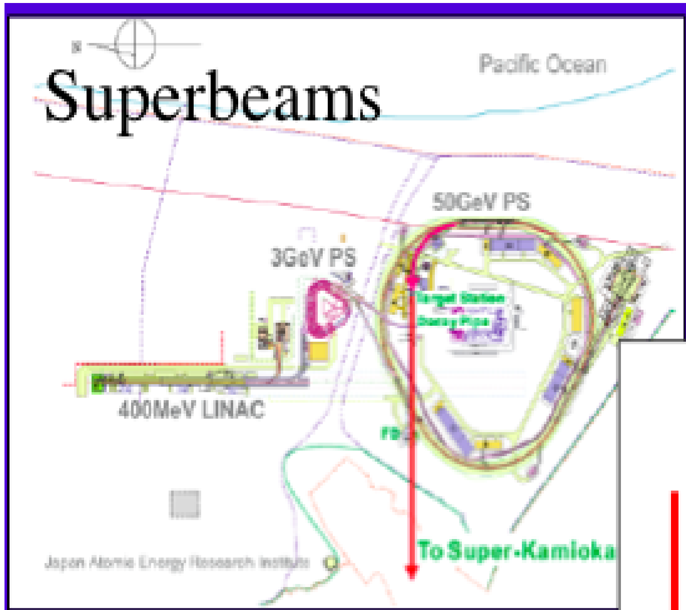
$\sin^2(2\theta_{13}) <\sim 0.02$



Near detector @100-200 m from the nuclear cores in discussion with EDF

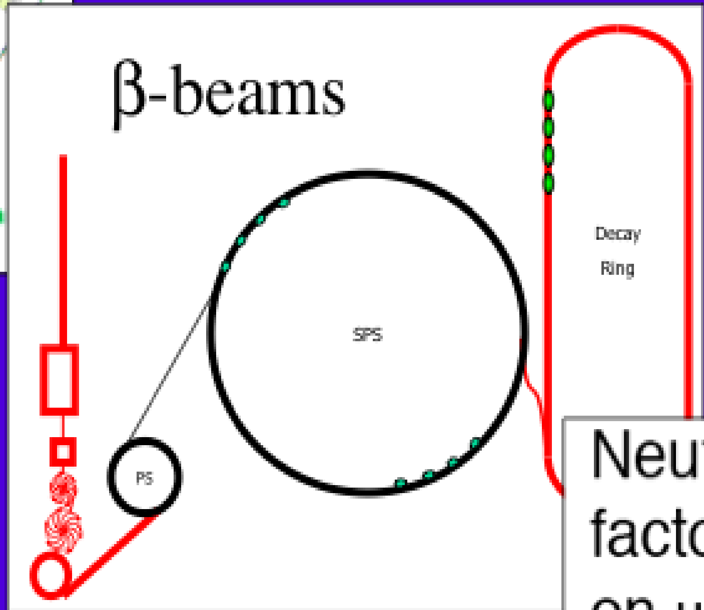
See G Mention's talk

Future Neutrino Beams



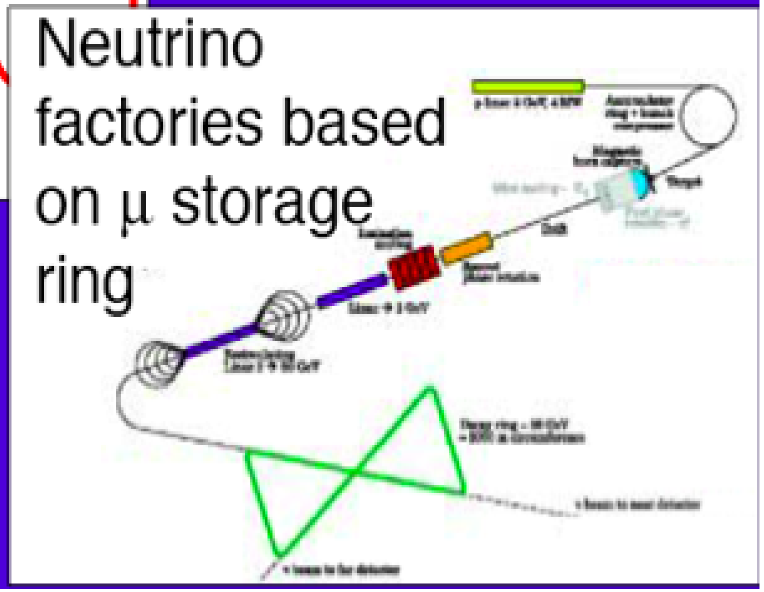
$$\pi^{\pm} \rightarrow \mu^{\pm} \overset{(-)}{\nu}_{\mu}$$

Select focusing sign



$$^{Z}A \rightarrow {}^{Z\mp 1}A \;\beta^{\pm}\; \overset{(-)}{\nu}_{e}$$

Select ion



$$\left.\begin{array}{l} \mu^{-} \rightarrow e^{-}\bar{\nu}_{e}\nu_{\mu} \\ \mu^{+} \rightarrow e^{+}\nu_{e}\bar{\nu}_{\mu} \end{array}\right\}$$

Select ring sign

BETA BEAMS (see Mezzetto's talk)

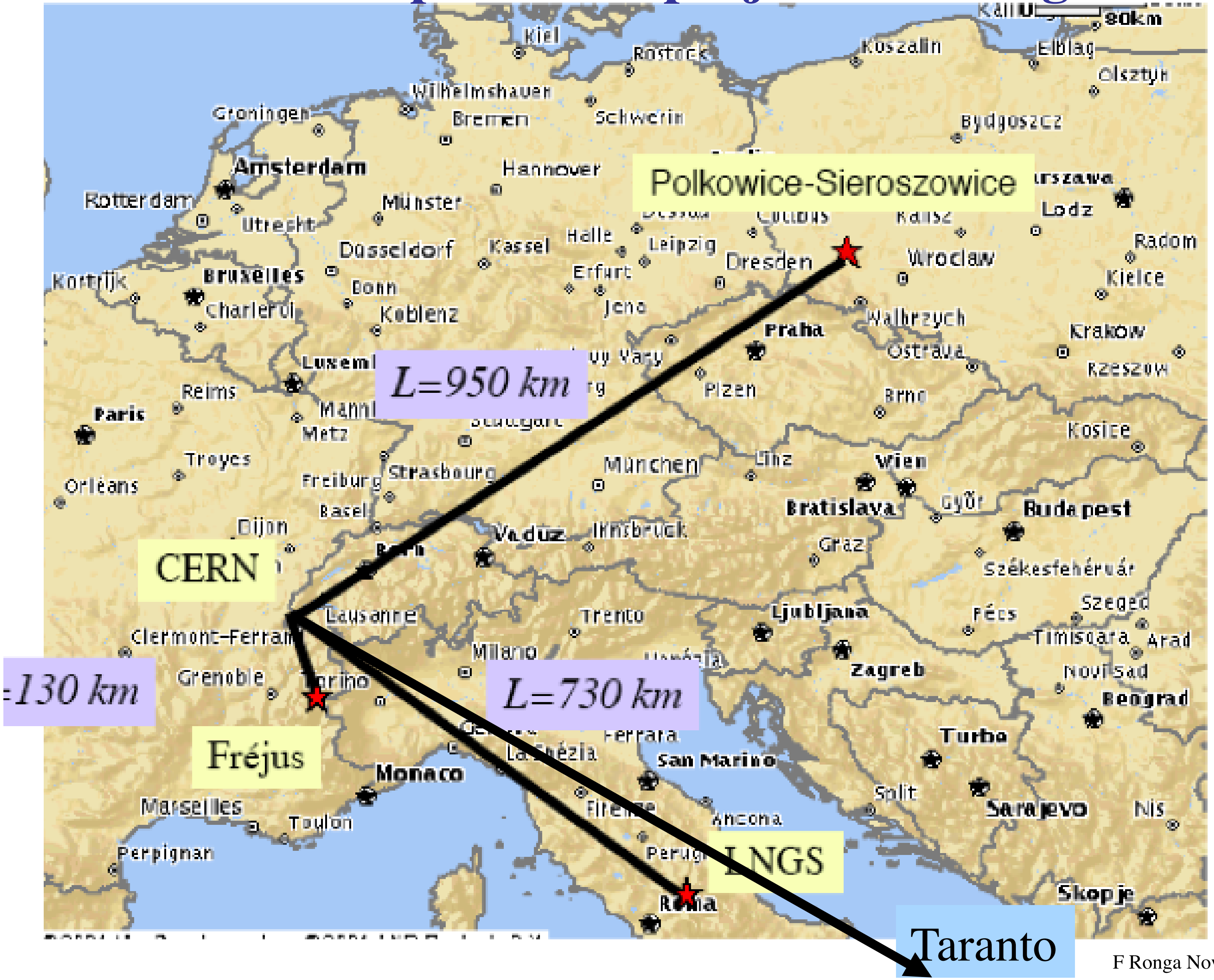
P Zucchelli Phys Lett B532:166 2002

- Just one flavour in the beam
- Energy shape defined by just two parameters: the endpoint energy of the beta decay and the γ of the parent ion.
- Flux normalization given by the number of ions circulating in the decay ring.
- Beam divergence given by γ.

The full ^{6}He flux MonteCarlo code

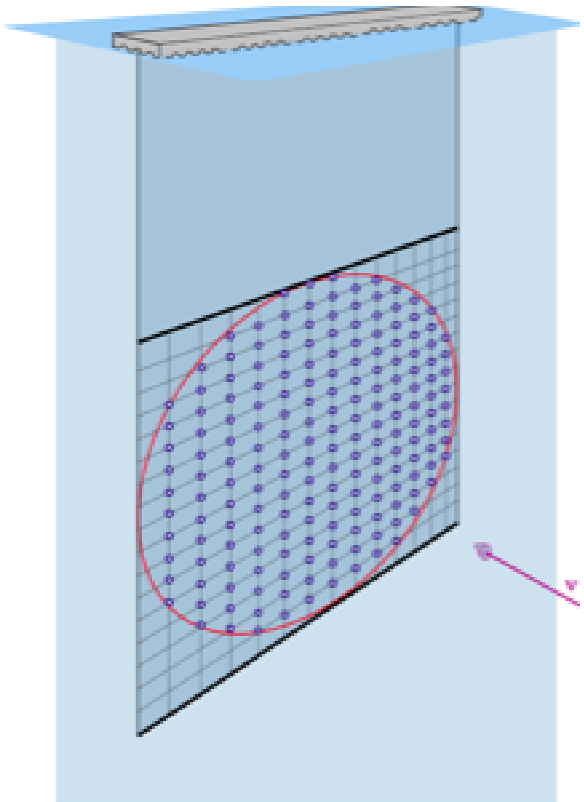
```
Function Flux(E)
Data Endp/3.5078/
Data Decays /2.9E18/
ye=me/EndP
c ...For ge(ye) see hep-ph0312068
ge=0.0300615
2gE0=2*gamma*EndP
c ...  Kinematical Limits
If(E.gt.(1-ye)*2gE0)THEN
   Flux=0.
   Return
Endif
c ...Here is the Flux
Flux=Decays*gamma**2/(pi*L**2*ge)*(E**2*(2gE0-E))/
+ 2gE0**4*Sqrt((1-E/2gE0)**2-ye**2)
Return
```

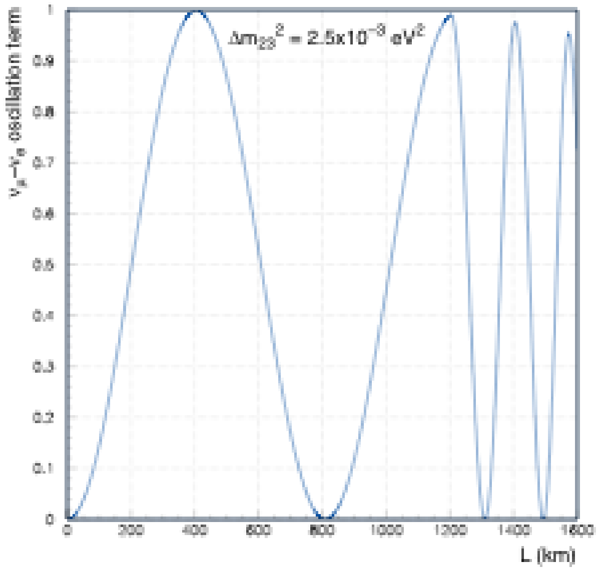
Future European LBL projects: Underground sites

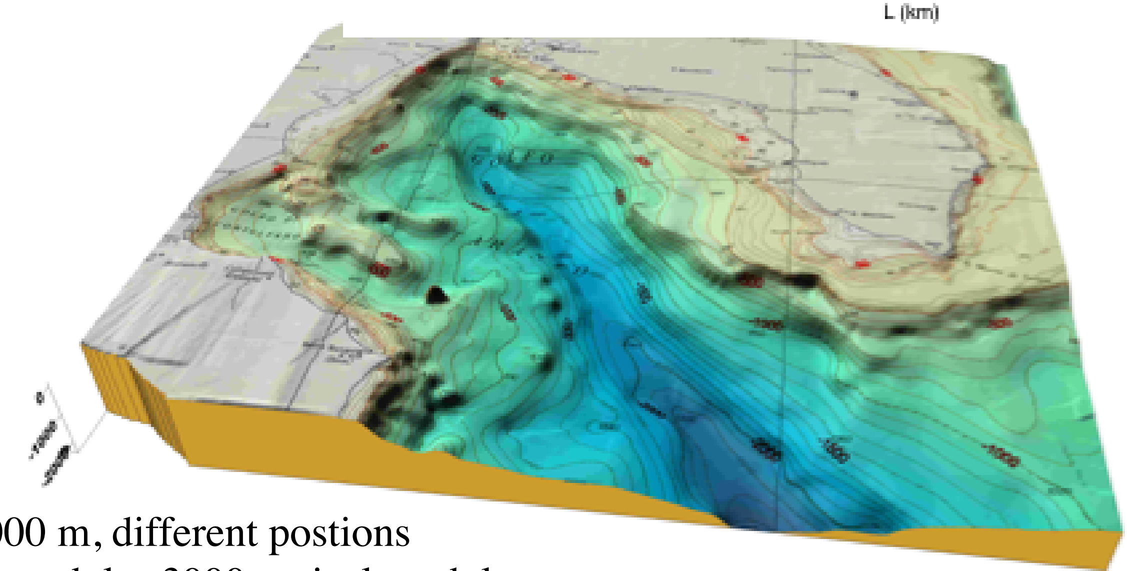


CERN TARANTO (CNGT)

Off axis Modified CNGS beam
Eν~0.8 GeV (second maximum),
$\sin^2(2\theta_{13})<0.002$

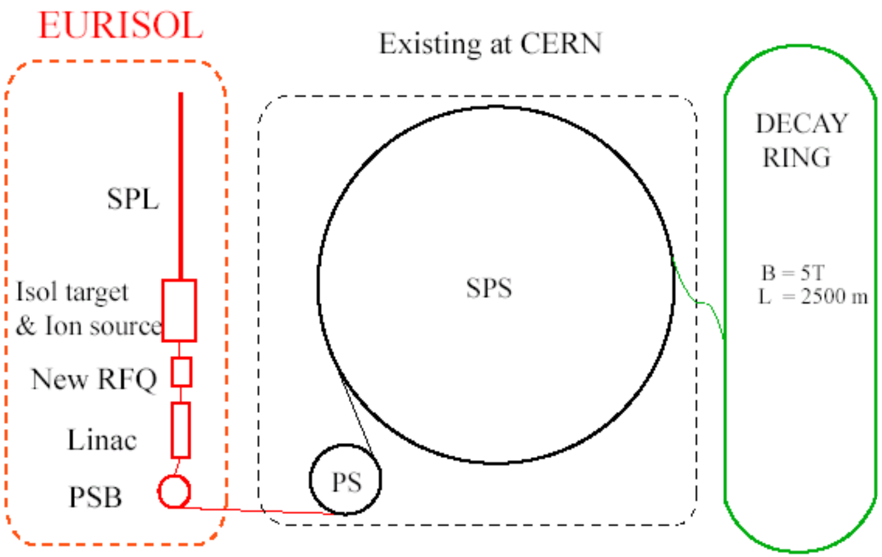






Fiducial mass 2 Mtons, depth~1000 m, different postions
300x 300m^2 plane with 100 supermodules 3000 optical modules

Future Neutrino Physics in EUROPE

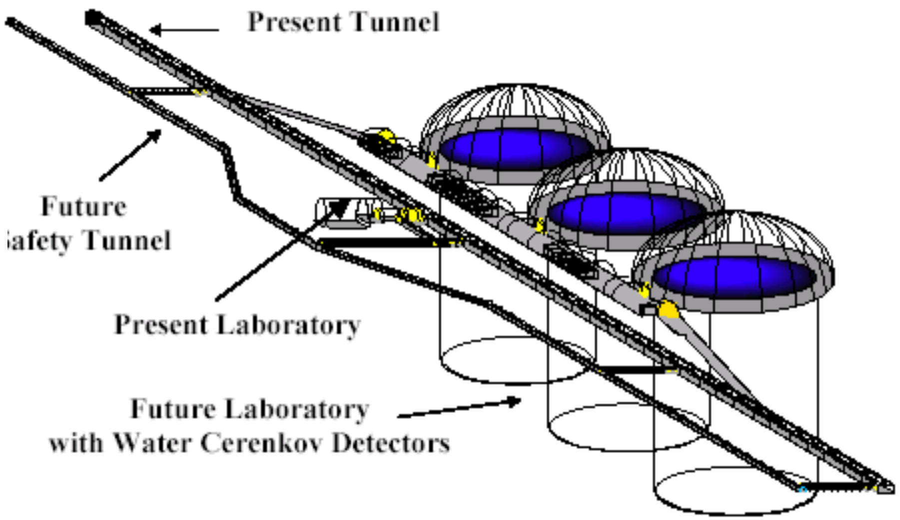


Beams (SPL or BETA) from CERN to FREJUS?

BETA Beam to Gran Sasso?

Or ??

Educated guess on possible costs	USD/CHF	1.60
UNO	960	MCHF
SUPERBEAM LINE	100	MCHF
SPL	300	MCHF
PS UPGR.	100	MCHF
SOURCE (EURISOL), STORAGE RING	100	MCHF
SPS	5	MCHF
DECAY RING CIVIL ENG.	400	MCHF
DECAY RING OPTICS	100	MCHF
TOTAL (MCHF)	2065	MCHF
TOTAL (MUSD)	1291	MUSD

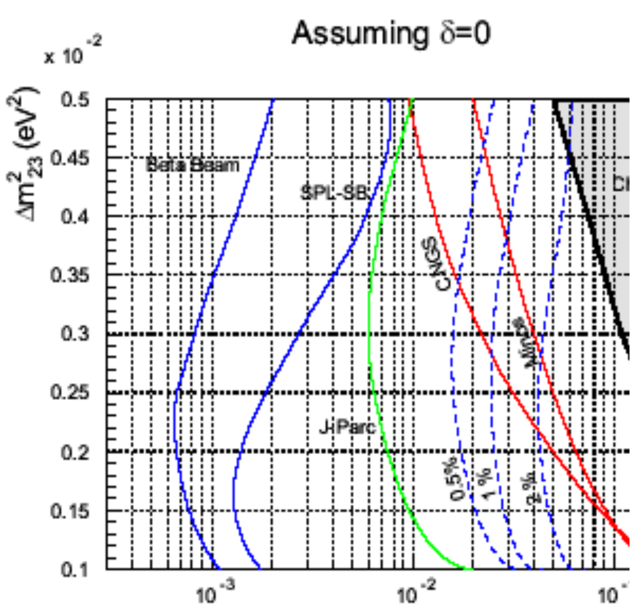


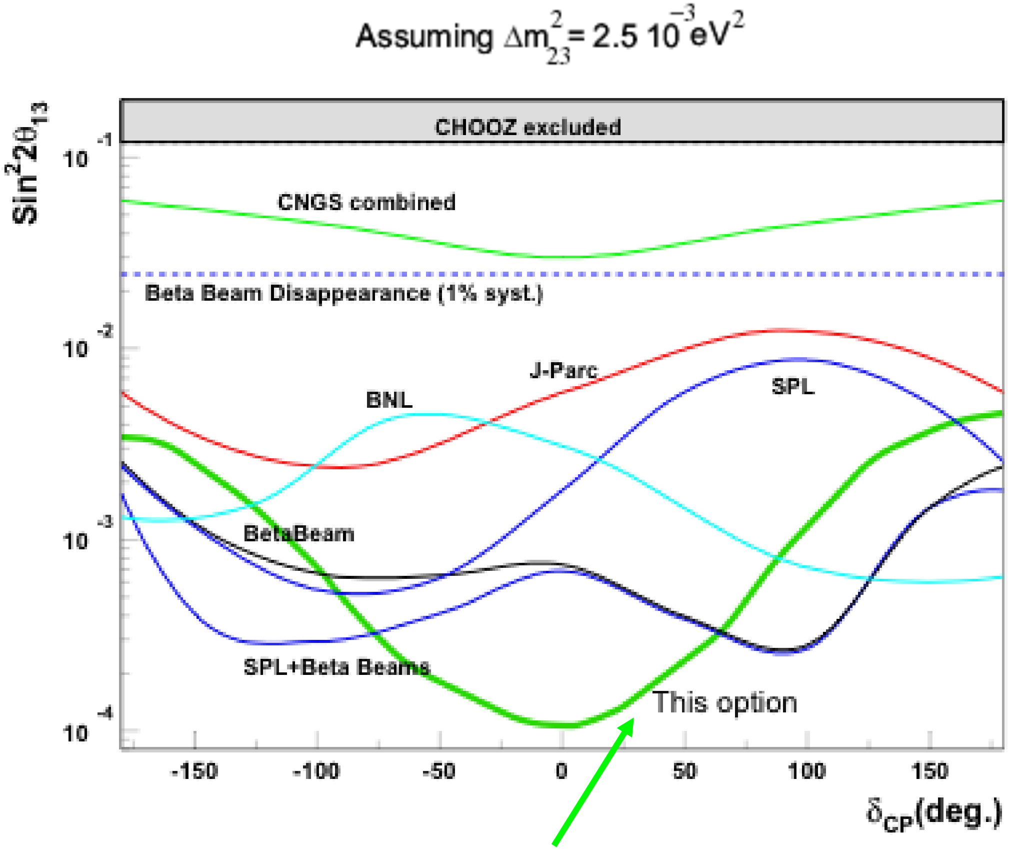
Frejus / Frejus 2

The SuperBeam - BetaBeam synergy: θ_{13} sensitivity

Computed for 5 years running, no signal in the experiment.

- No way to disentangle θ_{13} from δ in a high sensitivity experiment.
- The full information of experiment sensitivity is given by a bidimensional θ_{13} vs δ plot.
- **Beta Beam can measure θ_{13} both in appearance and in disappearance mode. All the ambiguities can be removed for $\theta_{13} \geq 3.4^{\circ}$**





M. Mezzetto, Laboratori del Gran Sasso, 22 marzo 2004..

High γ beta beam (see Migliozzi's talk)

F Ronga Now 2004

Summary of ("super-beam") LBL experiments

(from Kobayashi neutrino 2004 and Mezzetto)

	E_p (GeV)	Power (MW)	Beam	$\langle E_\nu \rangle$ (GeV)	L (km)	M_{det} (kt)	ν_μCC (/yr)	ν_e @peak	$\sin^2(2\theta_{13})$	
K2K	12	0.005	WB	1.3	250	22.5	~50	~1%		I
MINOS(LE)	120	0.4	WB	3.5	730	5.4	~2,500	1.2%	0.06	I
CNGS EU	400	0.3	WB	18	732	~2*2	~10,000	0.8%	0.03	I
T2K-I	50	0.75	OA	0.7	295	22.5	~3,000	0.2%	0.01	II
CNGS+ EU	400	0.3	WB	18	732	~2*2	15000	0.8%	0.025	II
NOνA	120	0.4	OA	~2	810?	50	~4,600	0.3%	~0.006	II
C2GT EU	400	0.3	OA	0.8	~1200	1,000?	~5,000	0.2%	0.002?	II
T2K-II	50	4	OA	0.7	295	~500	~360,000	0.2%	0.0006	
PS++(Cern) EU	20	4	WB	1.6	732	2?	1000?	1.2%	0.006?	III
NOνA+PD	120	2	OA	~2	810?	50?	~23,000	0.3%		III
BNL-Hs	28	1	WB/OA	~1	2540	~500	~13,000			III
SPL-Frejus Beta beam EU	2.2	4	WB	0.32	130	~500	~18,000	0.4%	0.002 0.0007	III
FeHo	8/120	"4"	WB/OA	1~3	1290	~500	~50,000			III

[grey box] Running, constructing or approved experiments

Conclusions: European road map?

In Europe no clear plan for the long term future (up to now).

Weak interactions ==>> long time to do experiment. (30 years to confirm solar neutrino oscillations!.)

Currently Europe involved in:

- Direct mass measurements (KATRIN , cryogenic experiments)
- Double beta experiments (NEMO3, IGEX,CUORE, Germanium DBge76..)
- Solar neutrino experiments (BOREX, SAGE, SAGE+GNO?)
- CNGS ICARUS / OPERA experiments
- New reactor experiments (Double -Chooz)?
- R/D for future detectors and beams
- Astrophysical neutrino experiments (Stellar collapse: LVD, neutrino astronomy: ANTARES, NEMO,NESTOR, Km^3)

This program will take >=one decade

*if no **surprises**!*

Conclusions

Constraints for a long term plan:

1) CERN fully committed in LHC. LHC upgrades?

2) No theoretical guide on neutrino physics, particularly on θ_{13}

In principle two possibilities see Peach nufact 04:

1) The expensive fast train approach : build a neutrino

I hope this workshop could help to clarify a “road map”

2) The slow train approach (normal beams, superbeams, beta beams, MEGATON). At the end could be more expensive of the fast approach, but more research topics (neutrino astrophysics etc)