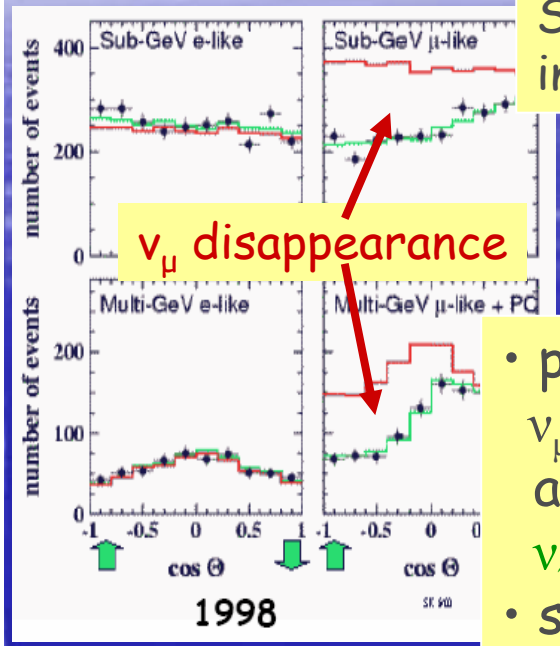
OPERA

- physics motivation - CNGS
- OPERA detector
- ν_τ appearance
- physics program 2006

physics motivation

SK: atmospheric neutrino anomaly interpretable as $\nu_\mu \rightarrow \nu_\tau$ oscillation

CHOOZ: no $\nu_\mu \rightarrow \nu_e$ oscillation



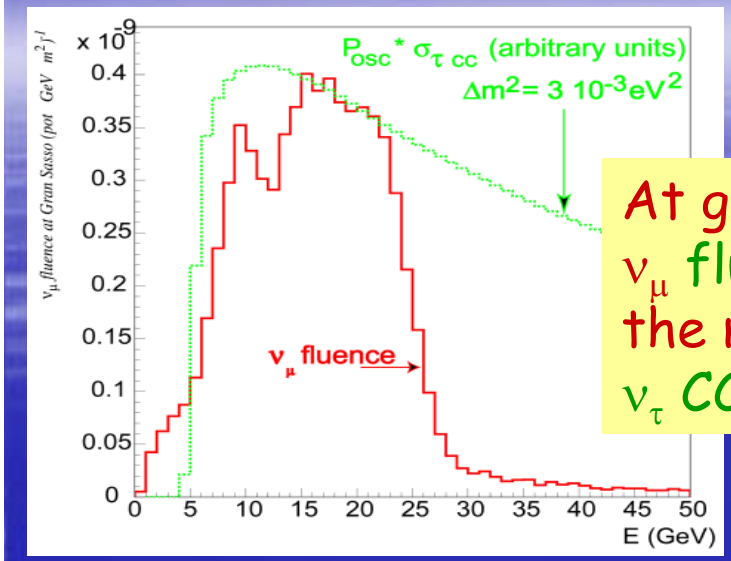
ν_μ disappearance

- provide an unambiguous evidence for $\nu_\mu \rightarrow \nu_\tau$ oscillation in the region of atmospheric neutrinos by looking for ν_τ appearance in a pure ν_μ beam
- search for subleading $\nu_\mu \rightarrow \nu_e$ osc.

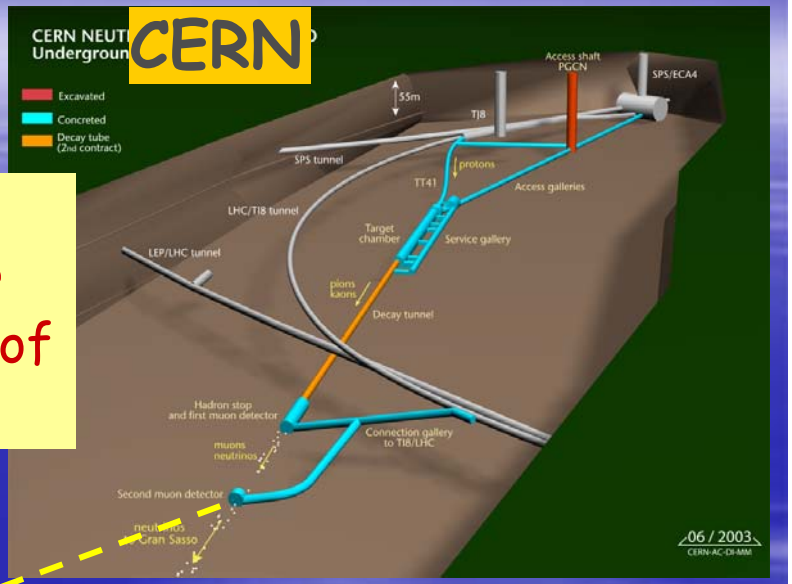
beam CNGS (1999)

CNGS1 (2000)

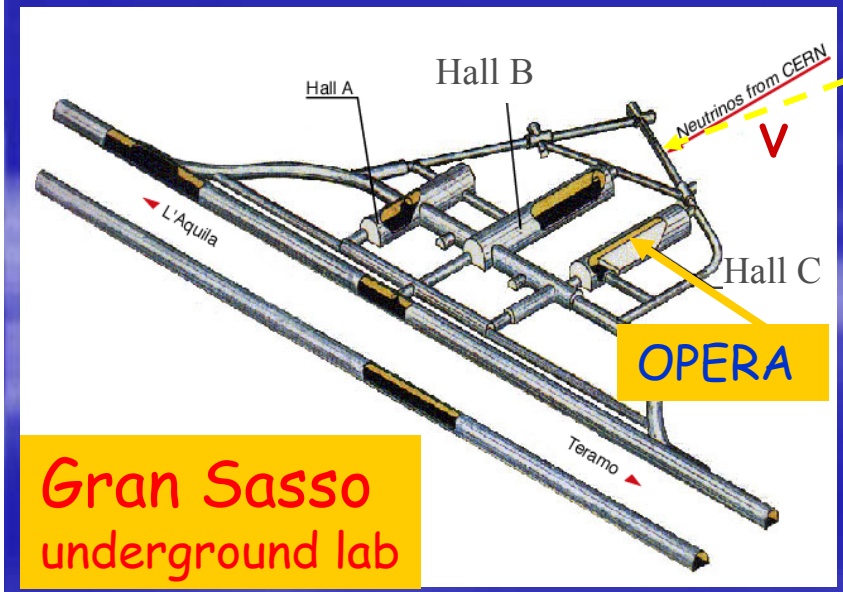
CNGS beam



At given distance:
ν_μ flux optimized for the maximal number of ν_τ CC interactions

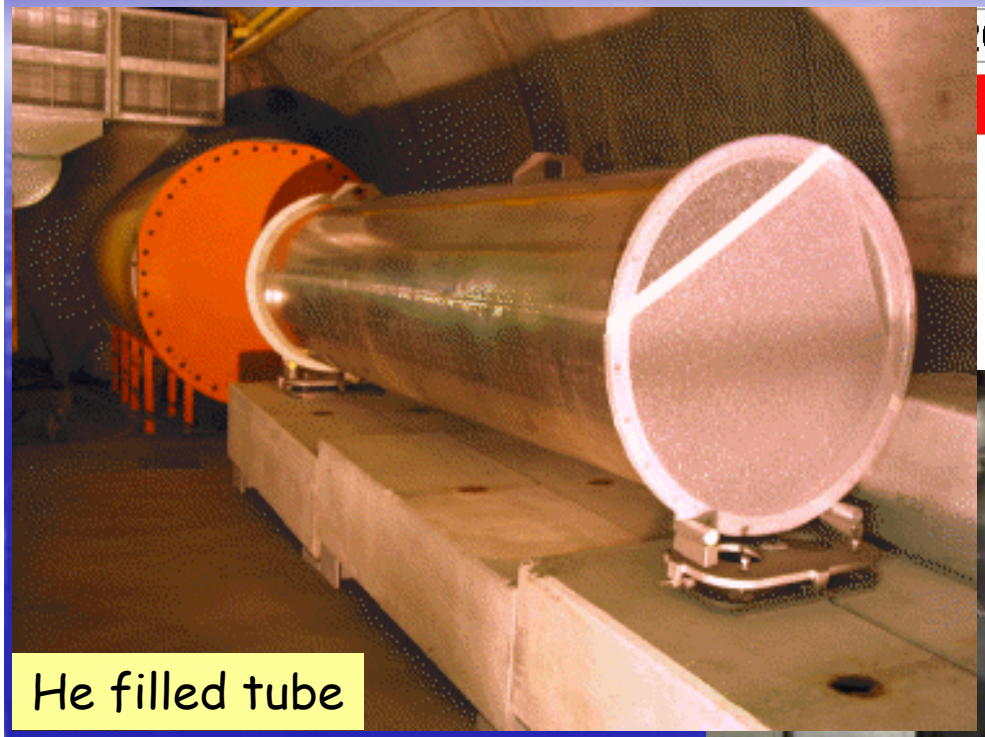


732 km

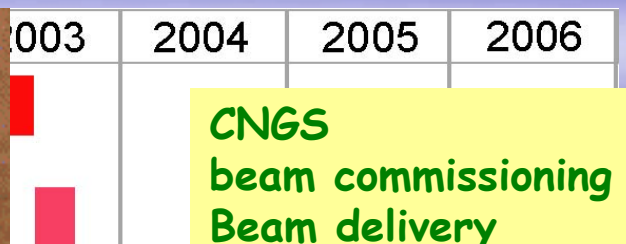


Gran Sasso underground lab

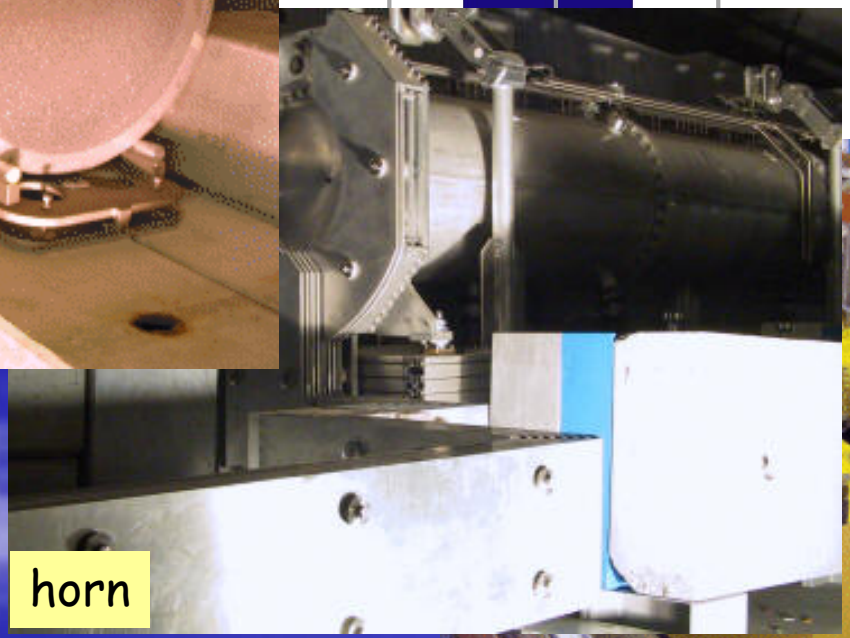
$\langle E\nu_\mu \rangle$	17 GeV
$(\nu_e+\overline{\nu}_e)/\nu_\mu$	0.87%
$\overline{\nu}_\mu$ / ν_μ	2.1%
ν_τ prompt	neglegible



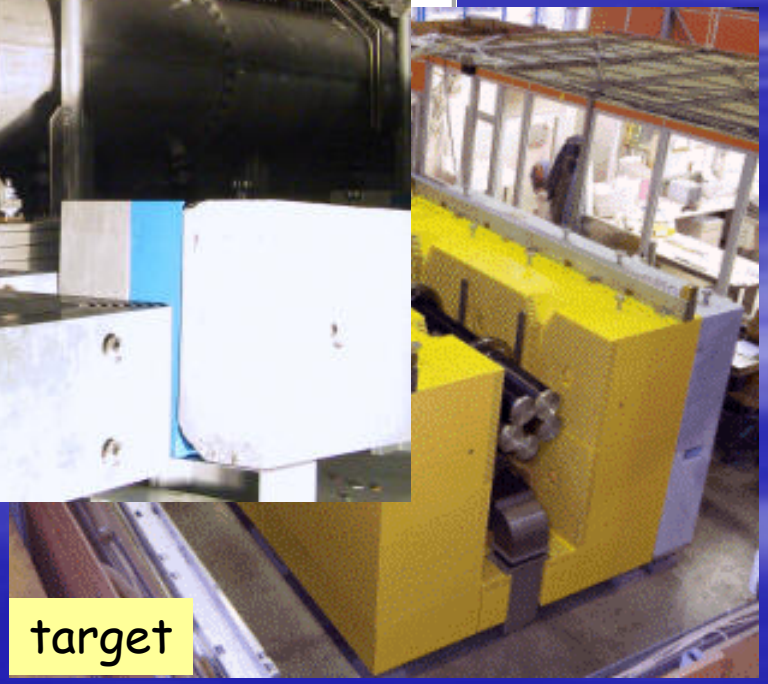
He filled tube



CNGS
beam commissioning : may/june 06
Beam delivery : mid july 06

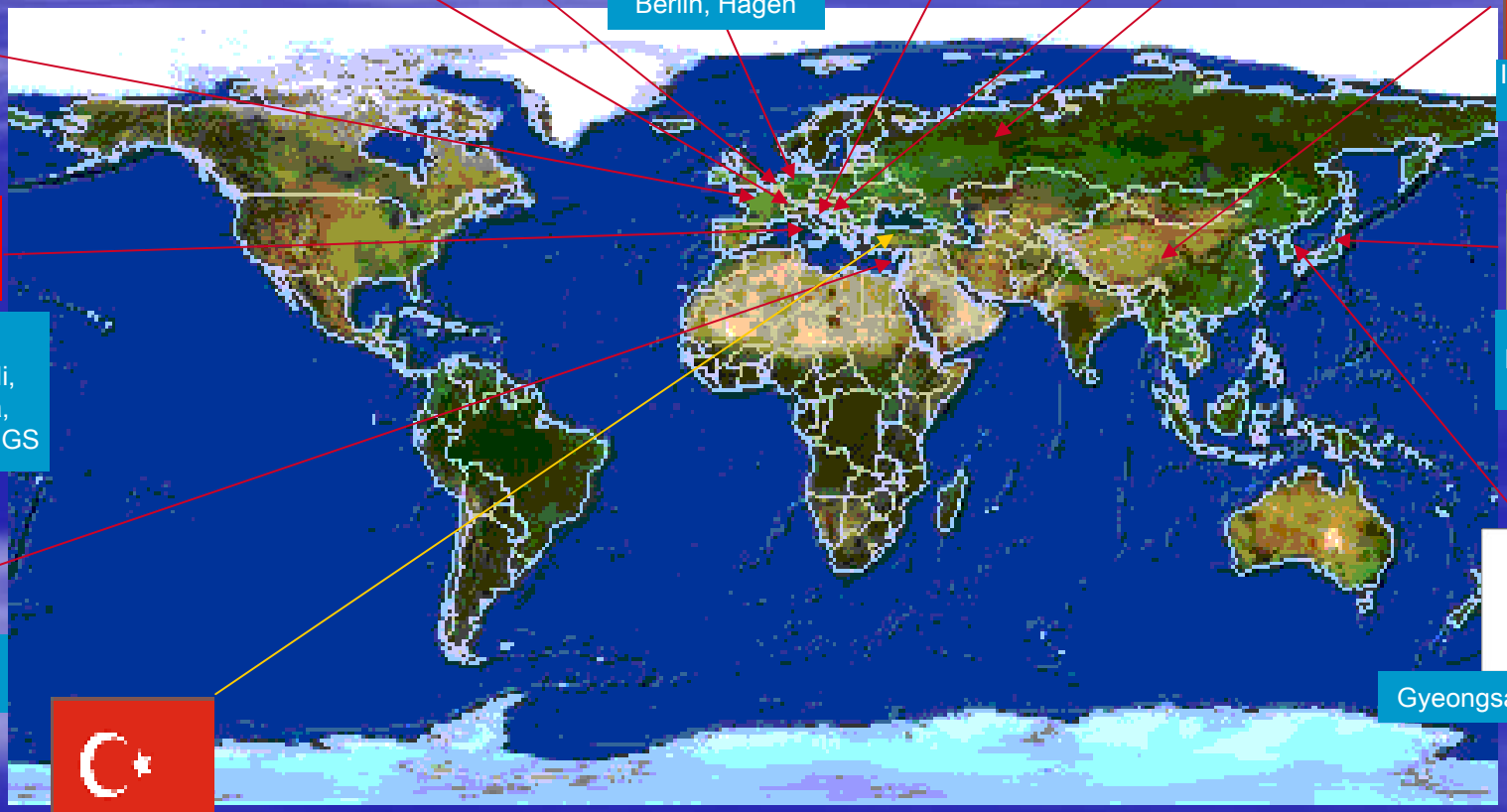


horn



target

The OPERA collaboration



Bern
Neuchatel

Brussels

Hamburg, Rostock,
Münster,
Berlin, Hagen

Zagreb

Sofia

INR ITEP
JINR, Obninsk

LAPP, LAL,
IPNL, IRES

IHEP Beijing
Shandong

L'Aquila, Bari,
Bologna, Napoli,
Padova, Roma,
Salerno, LNF, LNGS

Aichi, Toho
Kobe, Nagoya
Utsunomiya

Technion Haifa

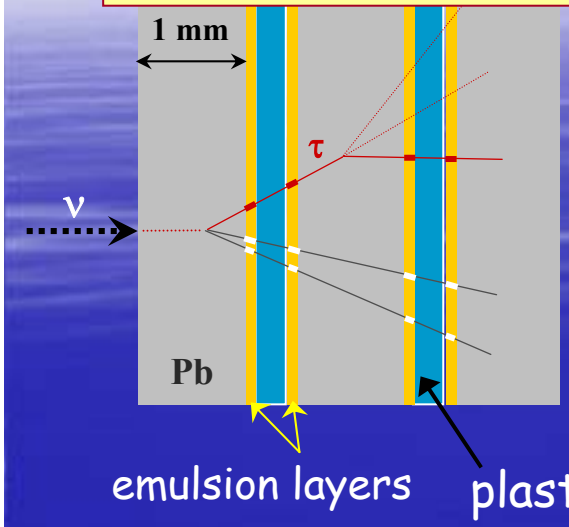
Gyeongsang University

METU Ankara

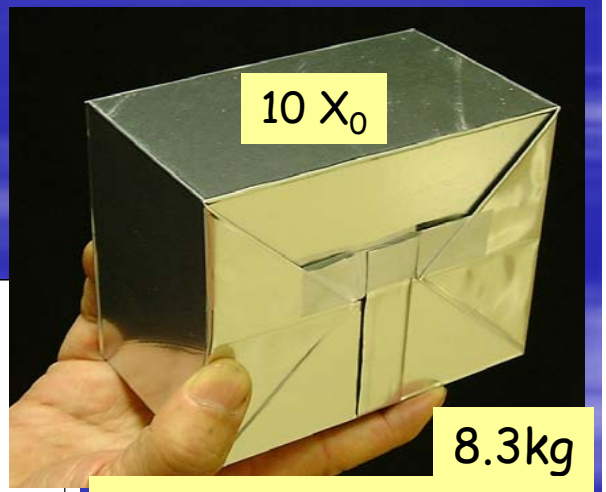
37 INSTITUTIONS, ~160 PHYSICISTS

The detector

basic unit: brick



- Based on the concept of the Emulsion Cloud Chamber (ECC)
- Sandwich of 56 Pb sheets 1mm + emulsion layers
- large mass for neutrino interactions
- high spatial resolution ($\delta x \approx 1\mu m$, $\delta\theta \approx 1mrad$)

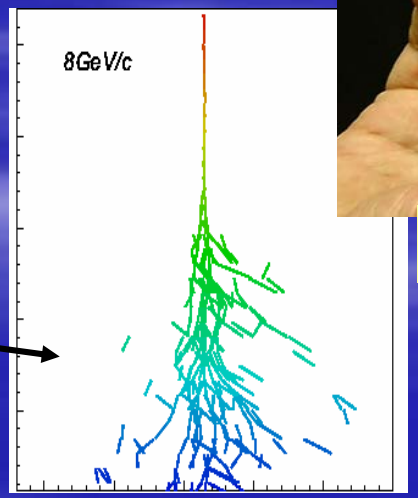


8.3kg

10.2 x 12.7 x 7.5 cm^3

ECC = stand-alone detector:

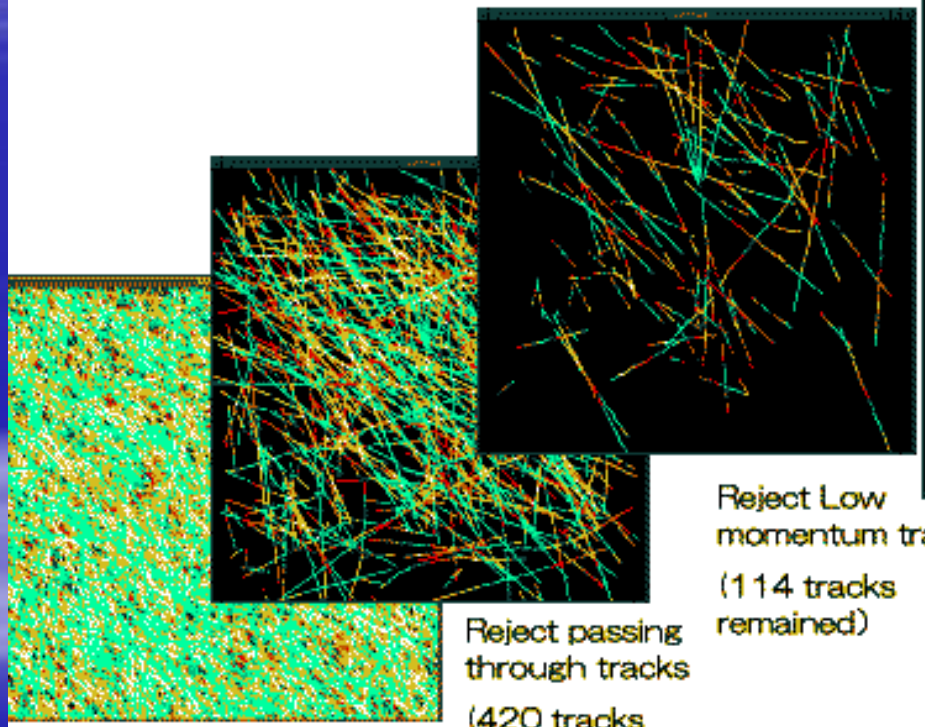
- neutrino interaction vertex
- kink topology reconstruction
- momentum measurements for hadrons (multiple scattering)
- π/μ separation at low energy (dE/dx)
- energy measurements for e,γ



Event Reconstruction

improved techniques developed

R&D @ Nagoya for DONUT Analysis.



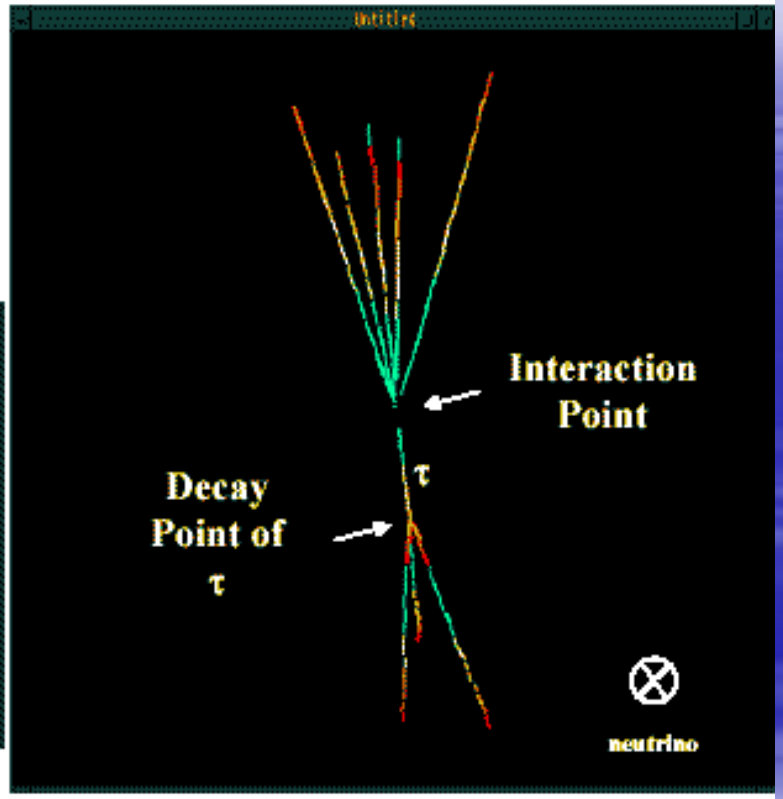
All tracks in the Scanning region (4179 tracks)

Reject passing through tracks

(420 tracks remained)

Reject Low momentum tracks

(114 tracks remained)



Vertex detection :

Neutrino interaction and decay of short lived particles

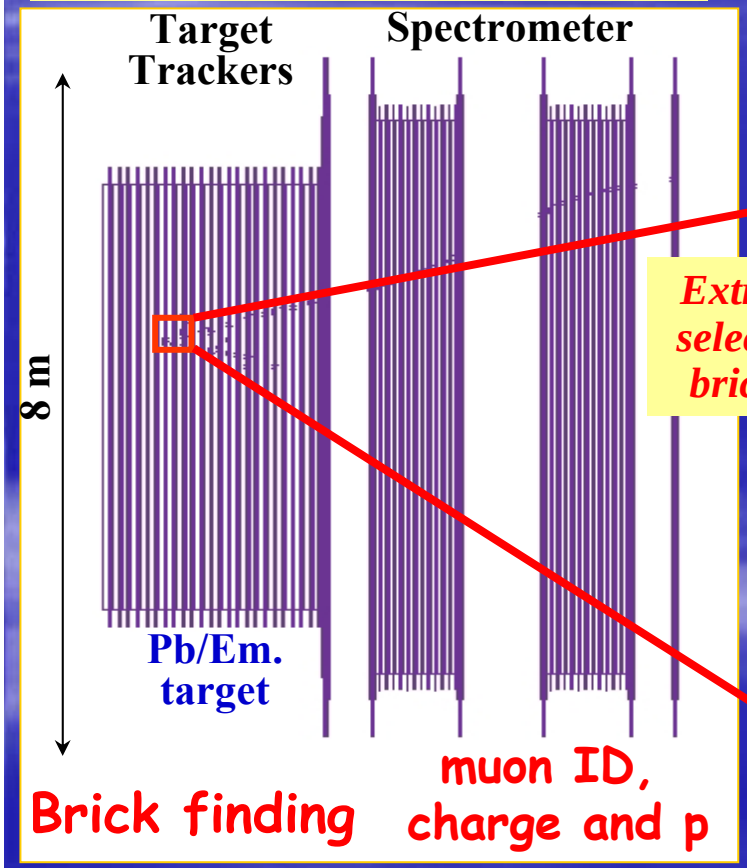
Detection of ν_τ CC in DONUT

brick cannot do:

- trigger for neutrino interaction
- μ identification and momentum + charge measurement

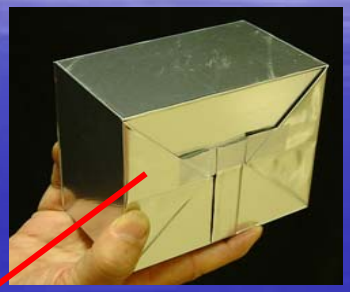
→ Hybrid detector

Electronic detectors:

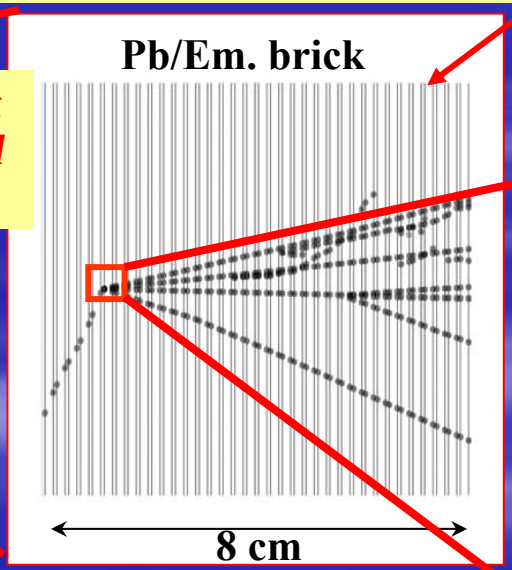


Emulsion analysis:

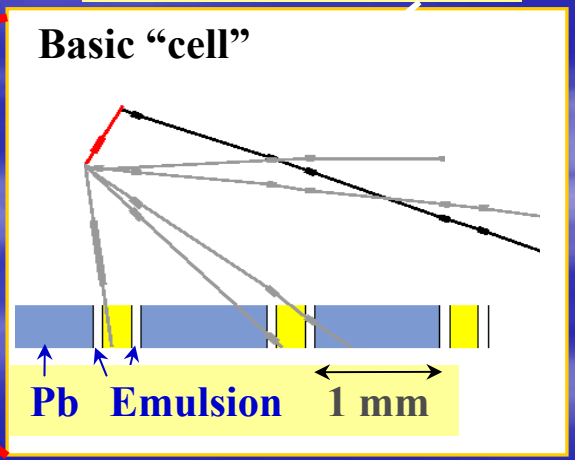
Vertex, decay kink e/γ ID, mult. scat., kinematics



Extract selected brick

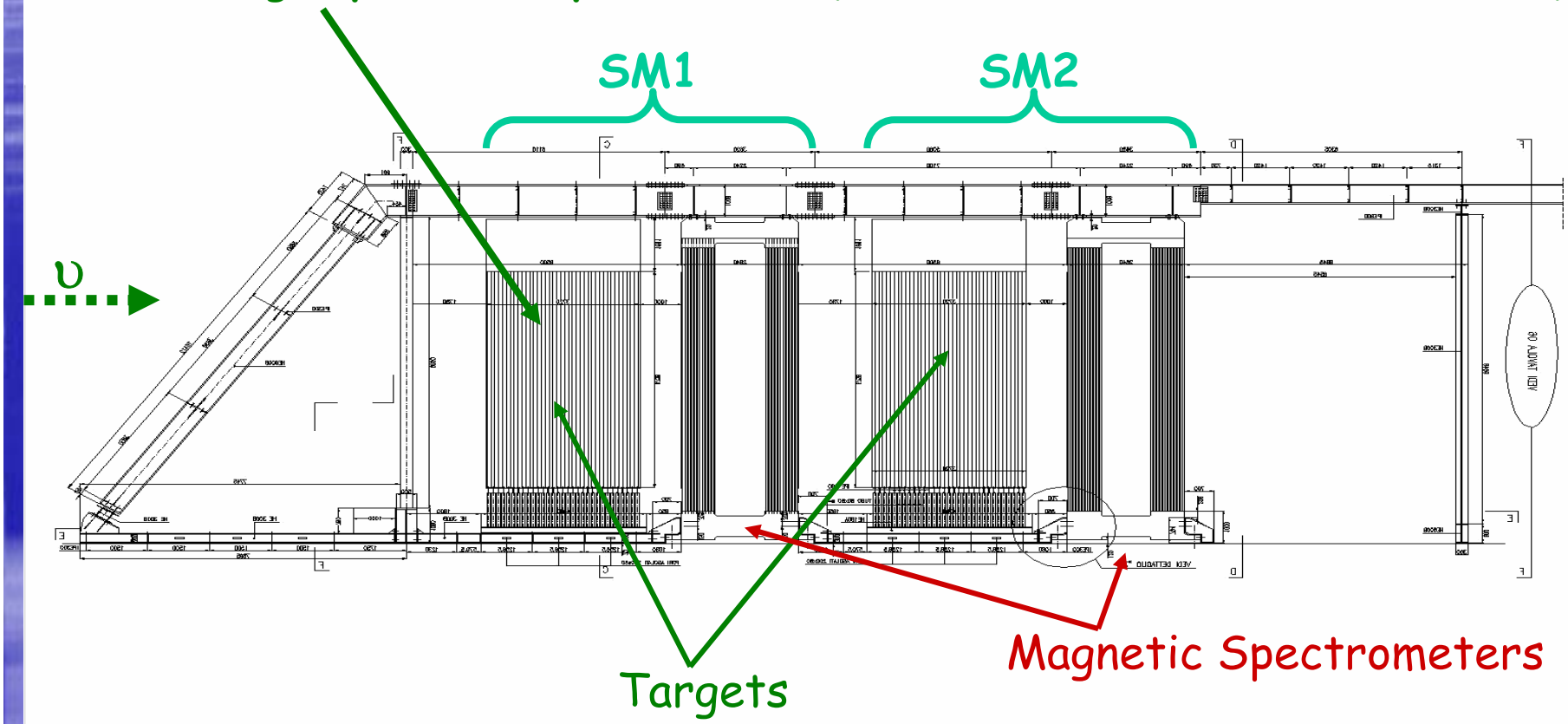


Link to mu ID, Candidate event



Detector structure

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



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

Event rates / integrated rates:

	OPERA* 1.597 ktons
ν_μCC	23300
ν_μNC	7000
$\bar{\nu}_\mu$CC	490
ν_eCC	186
$\bar{\nu}_e$CC	16
	31000

Event rates in 5 years
for 4.5×10^{19} pot /year
in shared mode

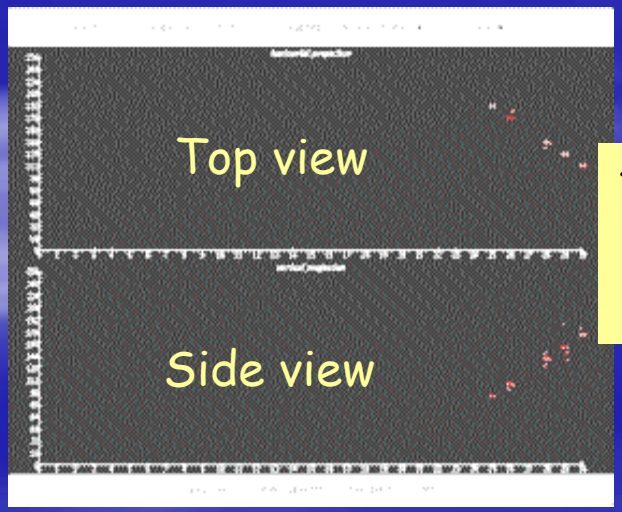
ν_τCC interactions

Δm^2	OPERA
1×10^{-3} eV^2	24
2×10^{-3} eV^2	95
3×10^{-3} eV^2	214

* Average target mass (additional 10K events in the OPERA magnets)

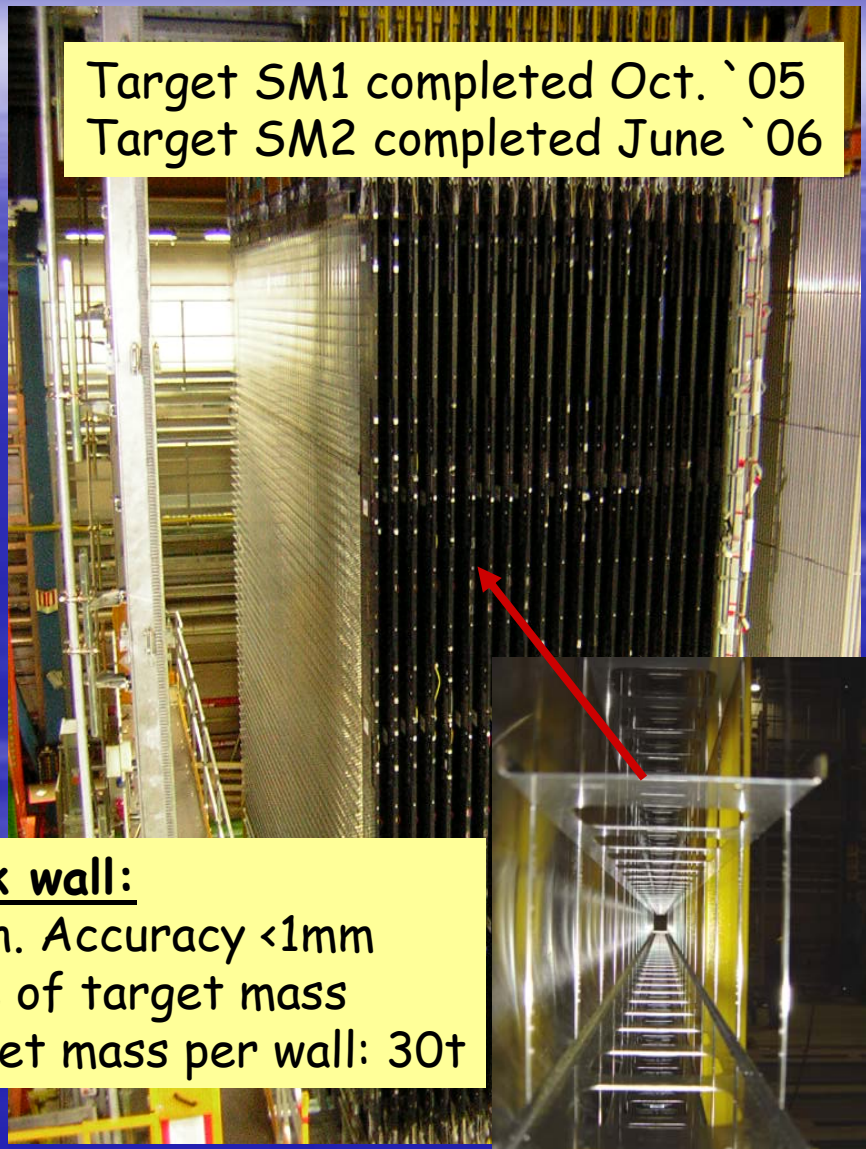
Target tracker

7000m² in total (X,Y)
32256 sc. Strips 7m x 2.5cm x 1cm
496 modules (4X+4Y per plane)
1000 MaPMT (Hamamatsu 64ch.)



magnet

Target SM1 completed Oct. `05
Target SM2 completed June `06



Brick wall:
Mech. Accuracy <1mm
0.6% of target mass
Target mass per wall: 30t

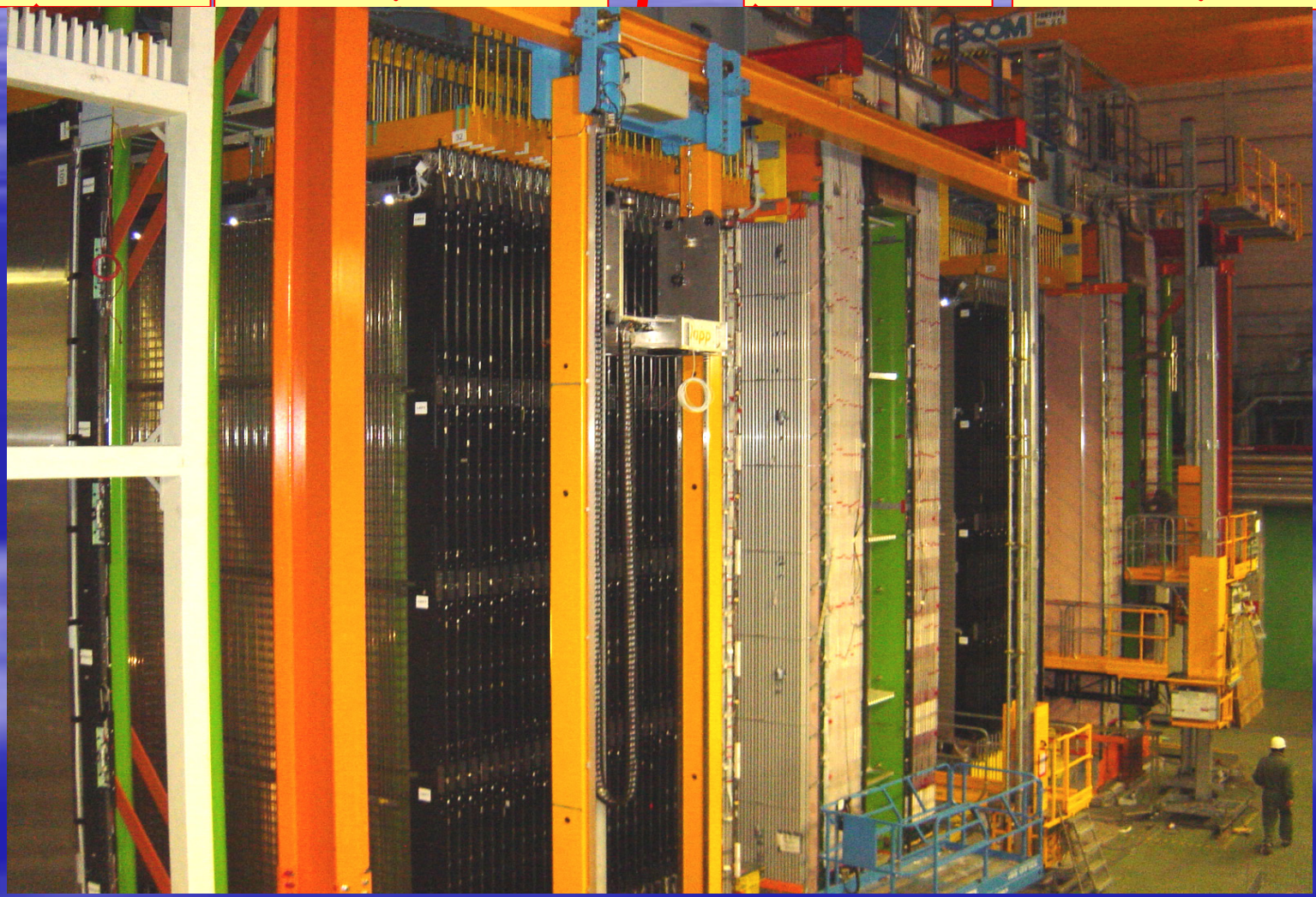
BMS 1 completed
BMS 2 in install.

all TT & Brick walls
Installed

XPC 1&2 , HPT 1&2
Completed

Magnet 1&2
+ RPC
Completed

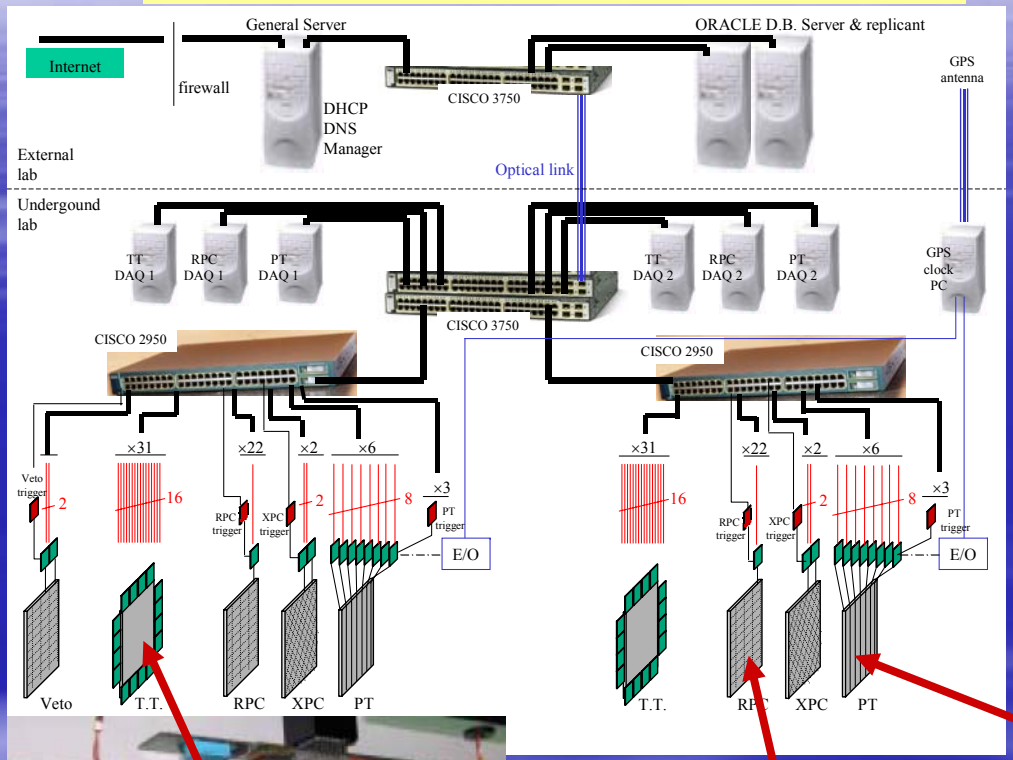
Mechanical structure
Completed



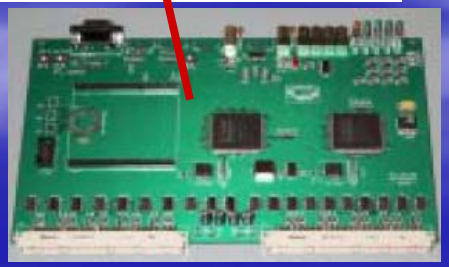
DAQ

Gigabit ethernetwork (1200 nodes)
All parts available

event time stamp using GPS clock
→ Ready for installation



Heart of DAQ:
Mezzanine (CPU, Memory, FPGA, clock Receiver, ethernet)
Final version in test

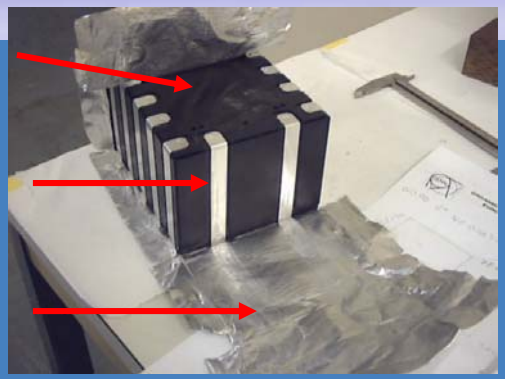


TT: 992 boards produced
(ADC, DAC, HV, test pulse)
TT DAQ running

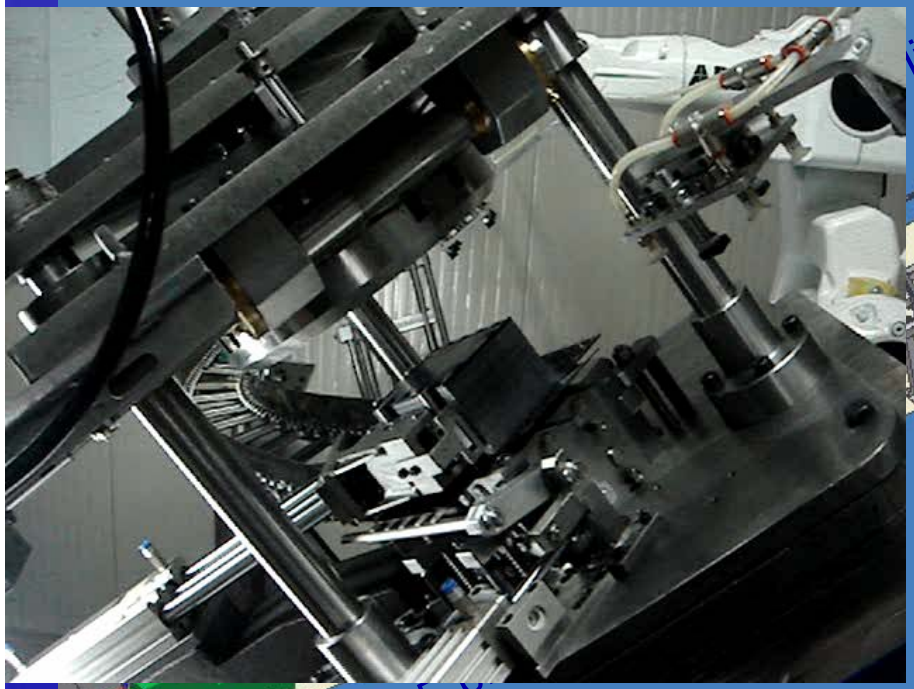
RPC: 54 needed (prod.)

HPT: 96 TDC boards needed
all produced

Brick Assembling Machine

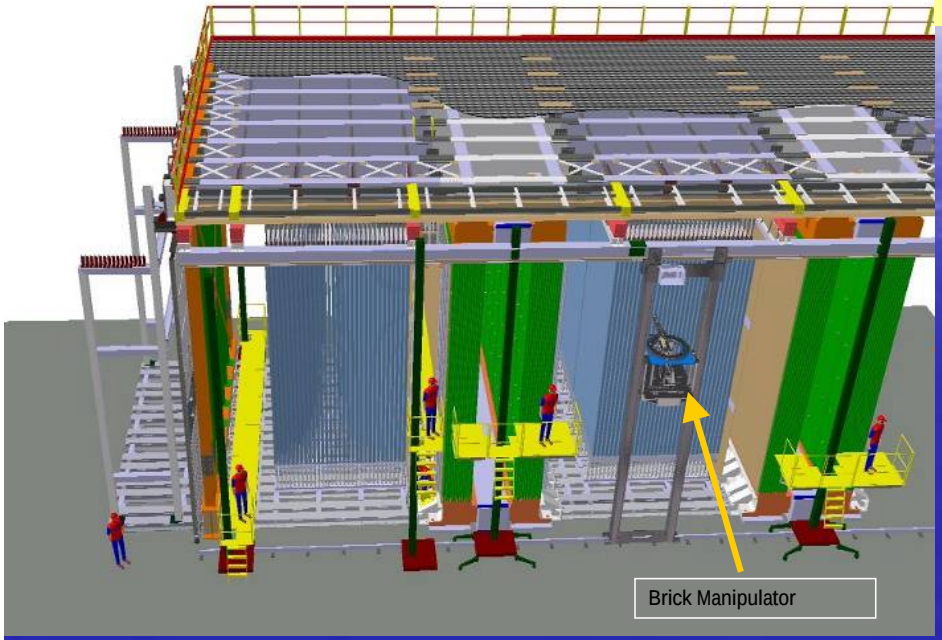


BAM site underground :
completed november 05



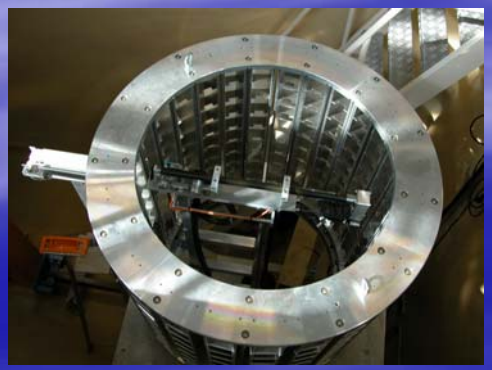
~ 23 million lead plates + emulsion sheets
~ 206,000 bricks at a rate of ~ 2 bricks/minute

Brick Manipulator System

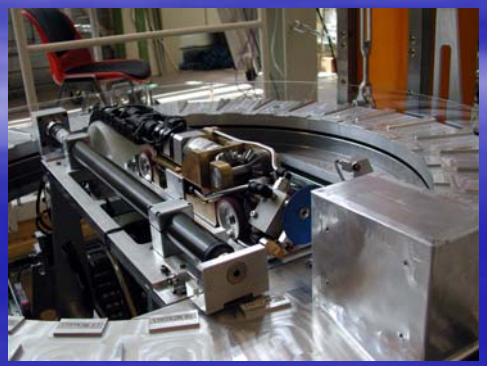


BMS1 rock side installed, being commissioned

Drum for brick transfer



Storage Carrousel



Scanning

Japan + Europe

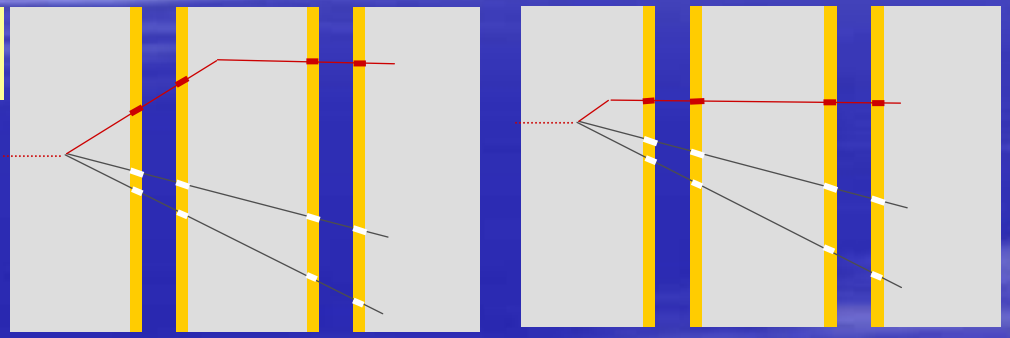
European system:

- 0.3 μm spatial resolution
- 2 mrad angular resolution
- 20 cm^2/h scanning speed achieved
- With 25 systems (9labs)
  → 15 bricks/day (1 shift)

physics potential

τ detection efficiencies *(in % and including BR)*

θ_{kink} > 20mrad



impact parameter
I.P. > 5 to 20 μm

	DIS long	*QE long*	*DIS short*	*Overall* (weighted)
$\tau \rightarrow e$	2.7	2.3	1.3	3.4
$\tau \rightarrow \mu$	2.4	2.5	1.7	2.8
$\tau \rightarrow h$	2.8	3.5	-	2.9
Total	8.0	8.3	1.3	9.1 %

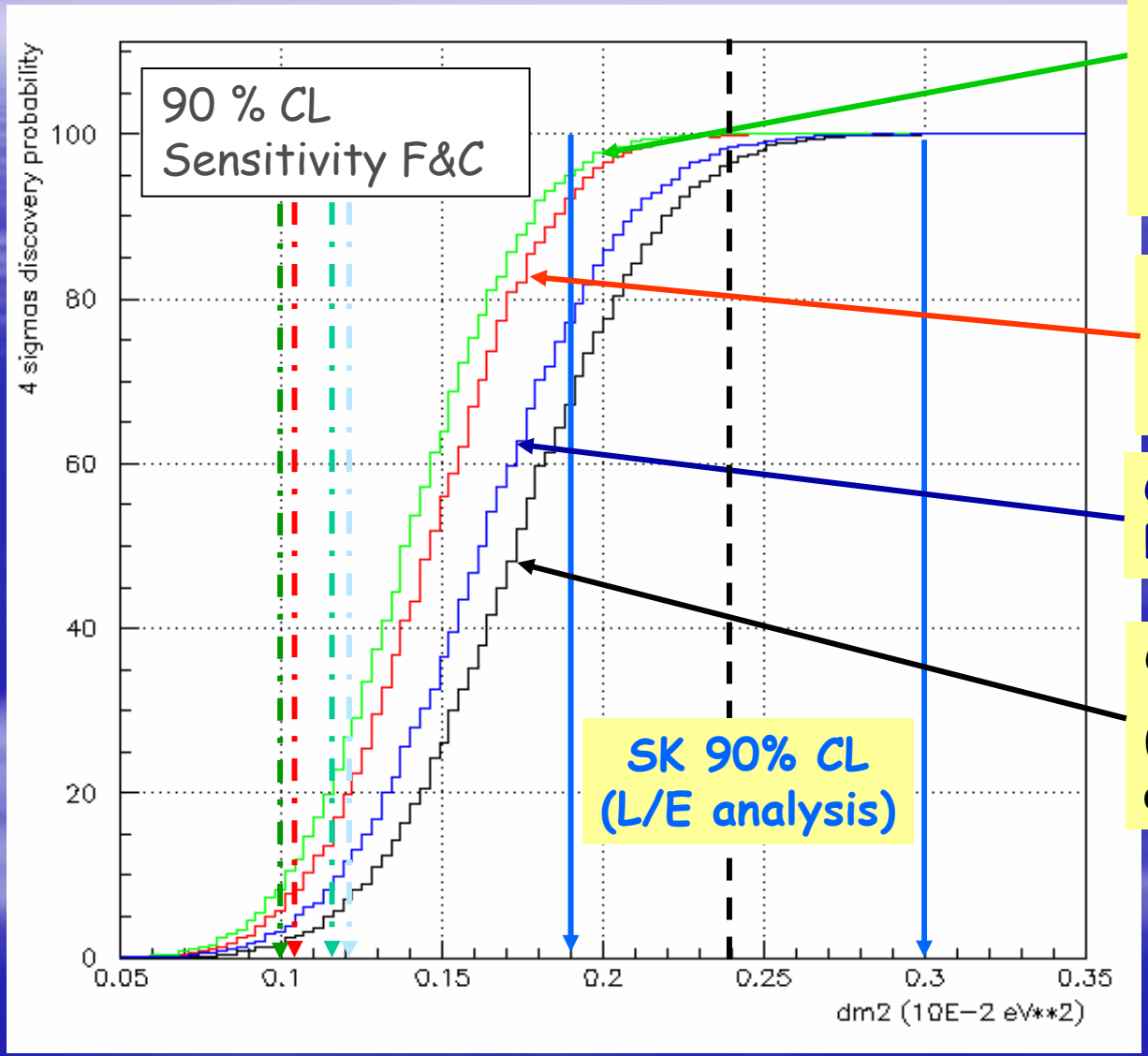
Expected number of τ events

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

Δm^2	1.9 x 10^{-3} eV^2	2.4 x 10^{-3} eV^2	3.0x 10^{-3} eV^2	BKGD
1.8 kton fiducial	6.6(10)	10.5(15.8)	16.4(24.6)	0.7(1.1)
+ improved brick finding + 3 prong decay	8.0(12.1)	12.8(19.2)	19.9(29.9)	1.0(1.5)
Background reduction	8.0(12.1)	12.8(19.2)	19.9(29.9)	0.8(1.2)

(…) with CNGS beam upgrade (X 1.5)

Discovery potential (4σ) vs beam intensity



Opera with beam upgrade and 30% bck reduction

Opera, with beam upgrade (1.5)

Opera with 30% bck reduction

Opera nominal

(but with 3π events and new BF)

physics program 2006

OPERA foresees the completion of the filling with bricks of SM1 beginning of august 2006

→ physics run after completion and commissioning of CNGS beam:

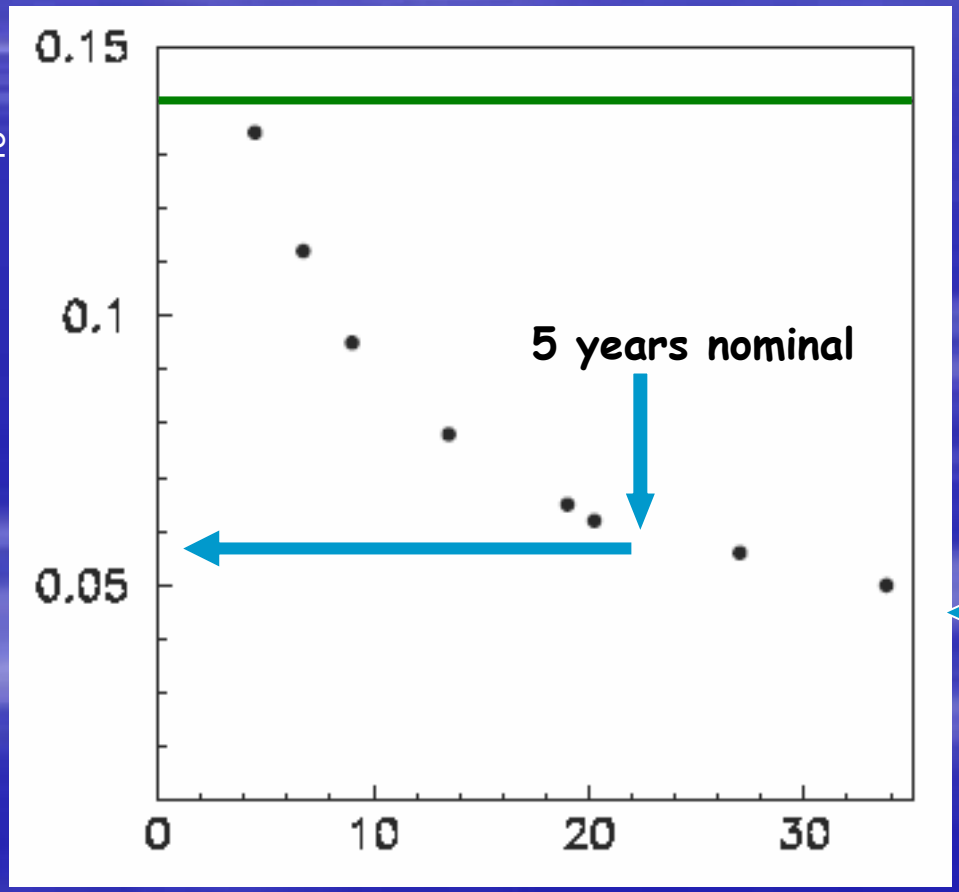
1. low intensity run integrating 0.3 x 10^{19} pot (intensity limited to 2 x 10^{17} pot/d → 15 interactions/d) after beam complete commissioned record ~220 ν interactions + ~500 μ from ν interact. in surrounding material
2. normal high intensity run (~4 x 10^{13} pot/cycle) integrating 10^{19} pot after SM1 complete filled

- validation and monitoring of the CNGS ν beam, check of interaction rates, energy distribution, analysis of μ charge → check $\nu/\bar{\nu}$ content
- understanding the efficiency of the OPERA detector
- check of decay analysis chain
- measurement of the background sources
- tuning of the kinematical analysis
- oscillation searches

end

$Sin^2 2\theta_{13}$ sensitivity

Assuming : $\theta_{23}=\pi/4$, $\Delta m^2_{23} = 2.5 \times 10^{-3}\ eV^2$



CHOOZ

systematics

Pot(x10^{19})

CNGS ↔ T2K complementary

effets de matière : $2\sqrt{2}G_F n_e \frac{E}{\Delta m^2_{13}}$

$\frac{\Delta m^2_{13} L}{4E}$

υ_e appearance with matter effect

$$P_{\nu_\mu \to \nu_e} \cong \sin^2 2\theta_{13} \sin^2 \theta_{23} \frac{\sin^2[(1-A)\Delta]}{(1-A)^2}$$

ν ou $\bar{\nu}$ ←

$$\left[\begin{matrix} + \\ - \end{matrix} \right. \alpha \sin\theta_{13} \xi \sin\delta_{CP} \sin\Delta \frac{\sin(A\Delta)}{A} \frac{\sin[(1-A)\Delta]}{(1-A)}$$

« on peak »
Dominant @T2K

$$+\alpha \sin\theta_{13} \xi \cos\delta_{CP} \cos\Delta \frac{\sin(A\Delta)}{A} \frac{\sin[(1-A)\Delta]}{(1-A)}$$

« off peak »
Dominant @CNGS

$$+O(\alpha^2)$$

$\frac{\Delta m^2_{21}}{|\Delta m^2_{13}|} \sim 2\ 10^{-2}$

$\cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \approx O(1)$

Expected number of BG events (5 years)

(in red : possible improvements)	$\tau \rightarrow e$	$\tau \rightarrow \mu$	$\tau \rightarrow h$	total
Charm background	.210 .117	.010 .007	.162 .160	.382 .284
Large angle μ scattering		.116 .023		.116 .023
Hadronic background		.093 .093	.116 .116	.209 .209
Total per channel	.210 .117	.219 .123	.278 .276	.707 .516

Charm BG

$\pi\mu$ id by dE/dx reduces BG by 40%

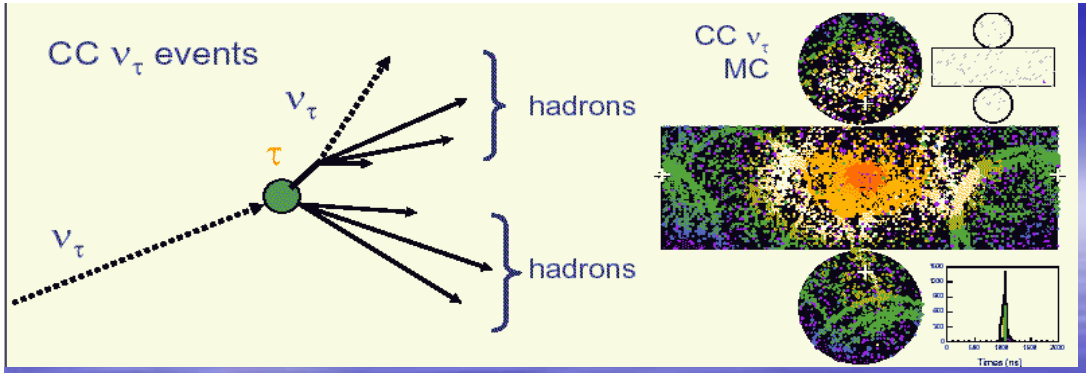
Large angle μ scattering

Incl. nuclear form factors give factor 5 less

Hadronic BG

Comparision of FLUKA with CHORUS data and GEANT 4

→ Reduction of uncertainty by 15%

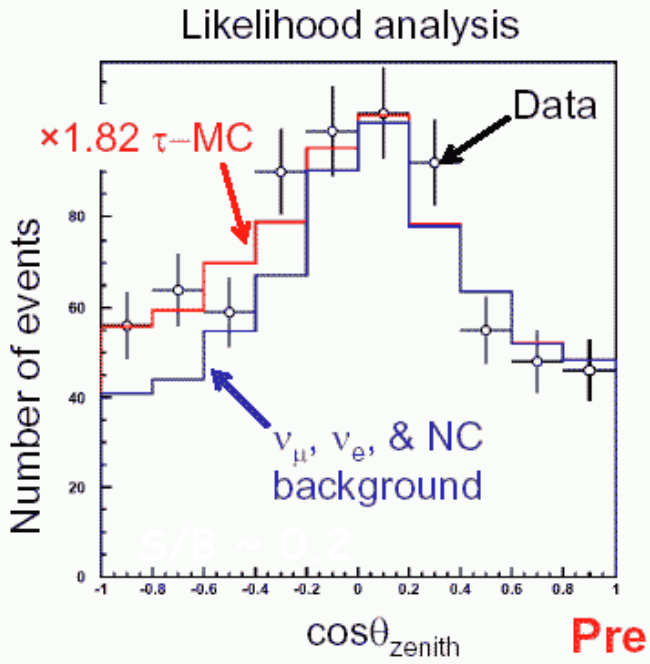


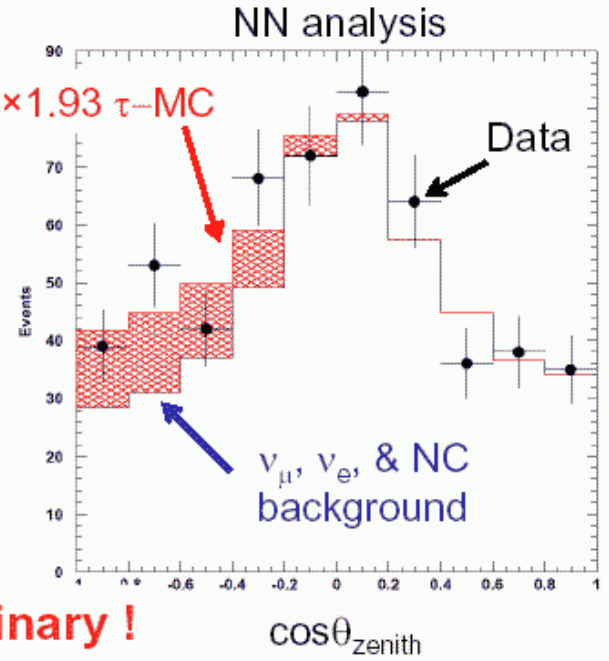
Tau search in SuperK

Large uncertainties on the background expectation : The asymetric shape implies a CC dominated background which is sensitive to oscillation parameters

appearance and disappearance results are not coherent

1.17 sigma effect





Preliminary !

Fitted # of τ events	145±48(stat)	152±47(stat)
	+9 / -36 (osc. para. uncertainty)	+12 / -27 (osc. para. uncertainty)
Expected # of τ events	79±31(stat)	79±31 (stat)