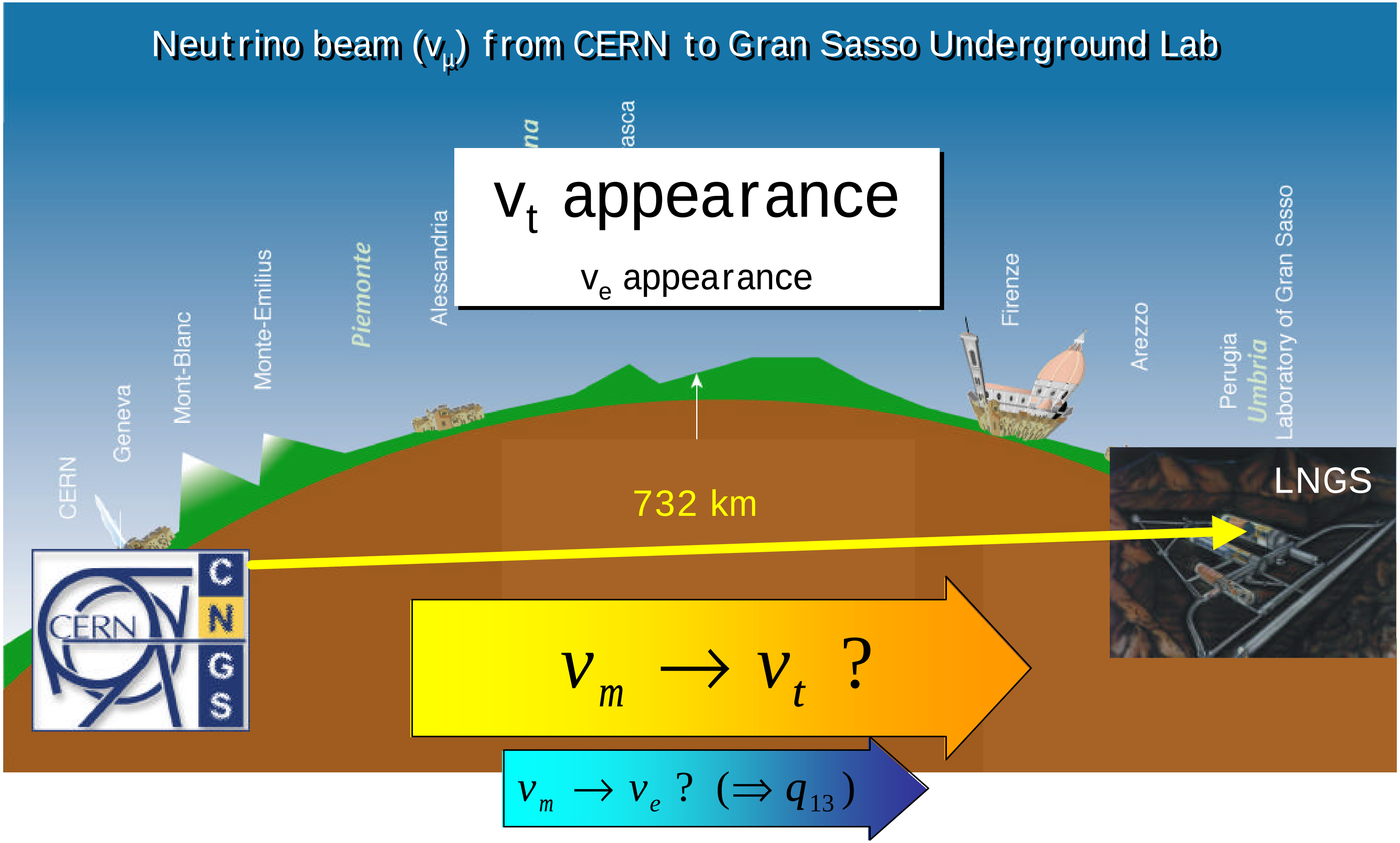
Status of the OPERA experiment

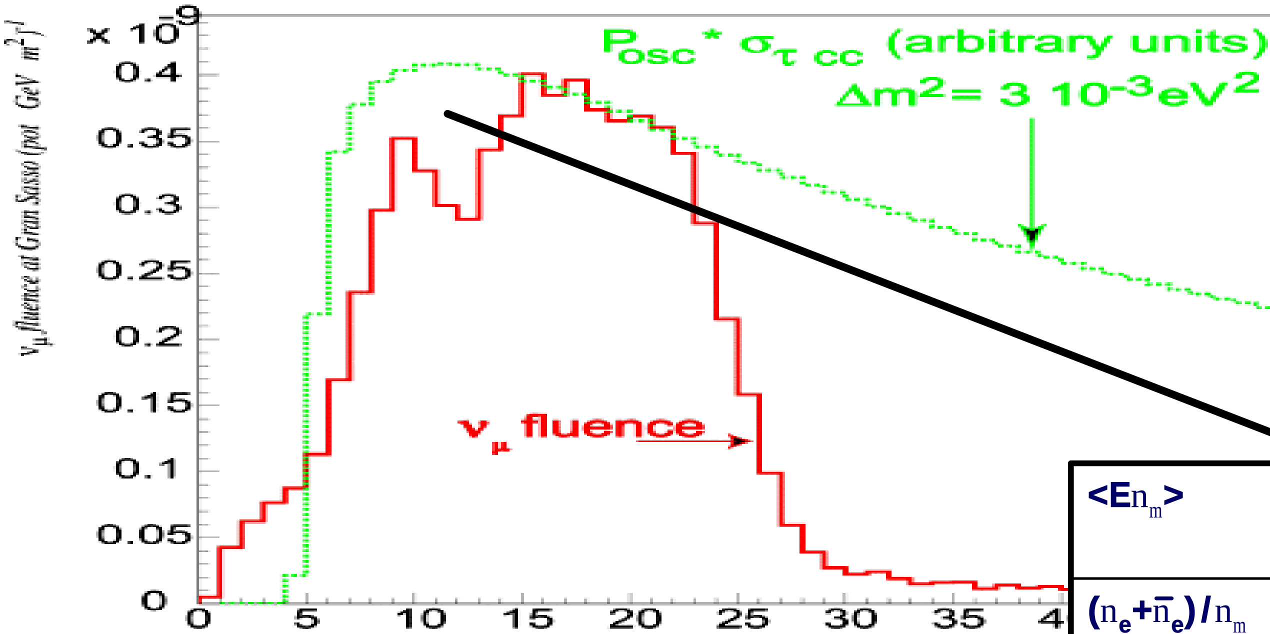
Caren Hagner

Universität Hamburg

OPERA Physics Goal



CNGS neutrino beam



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

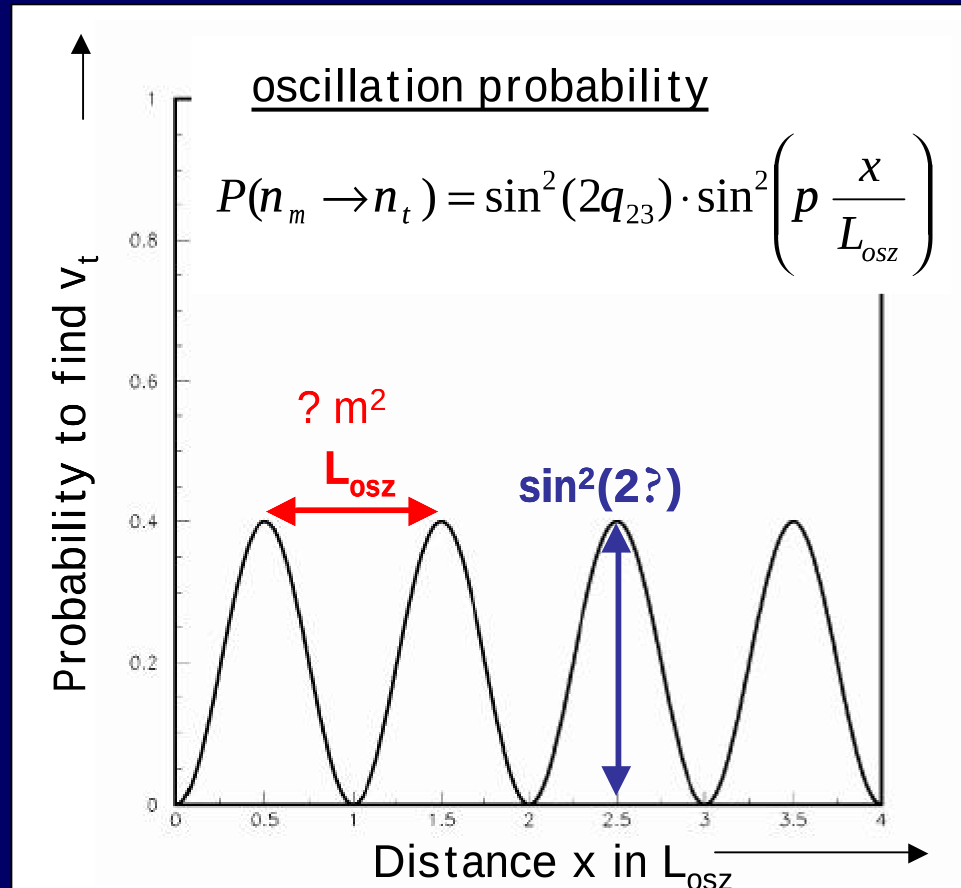
Neutrino Oscillations in Opera

$$L_{osz}(\text{in km}) = \frac{2.48 \cdot E(\text{in GeV})}{\Delta m^2(\text{in eV}^2)}$$

CNGS:
L_{osz} ~ 17000 km
E ~ 17 GeV,
? m^2 ~ $2 \cdot 10^{-3}$ eV^2

<L/E> = 43 Km/GeV :
« off peak »

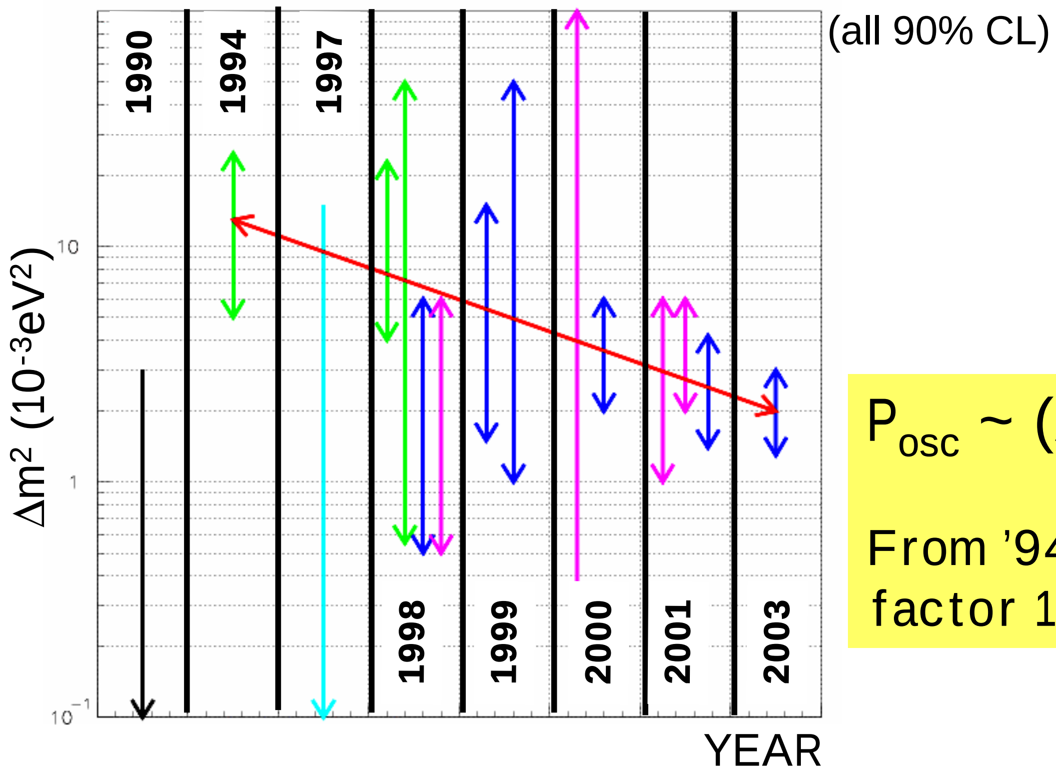
P_{osc} ~ (? m^2)^2



OPERA:
6200 n_m CC+NC /year
19 n_t CC/year (@ $2 \cdot 10^{-3}$ eV^2)

Δm^2 versus YEAR

Frejus
Kamiokande
IMB
Super-K
Macro

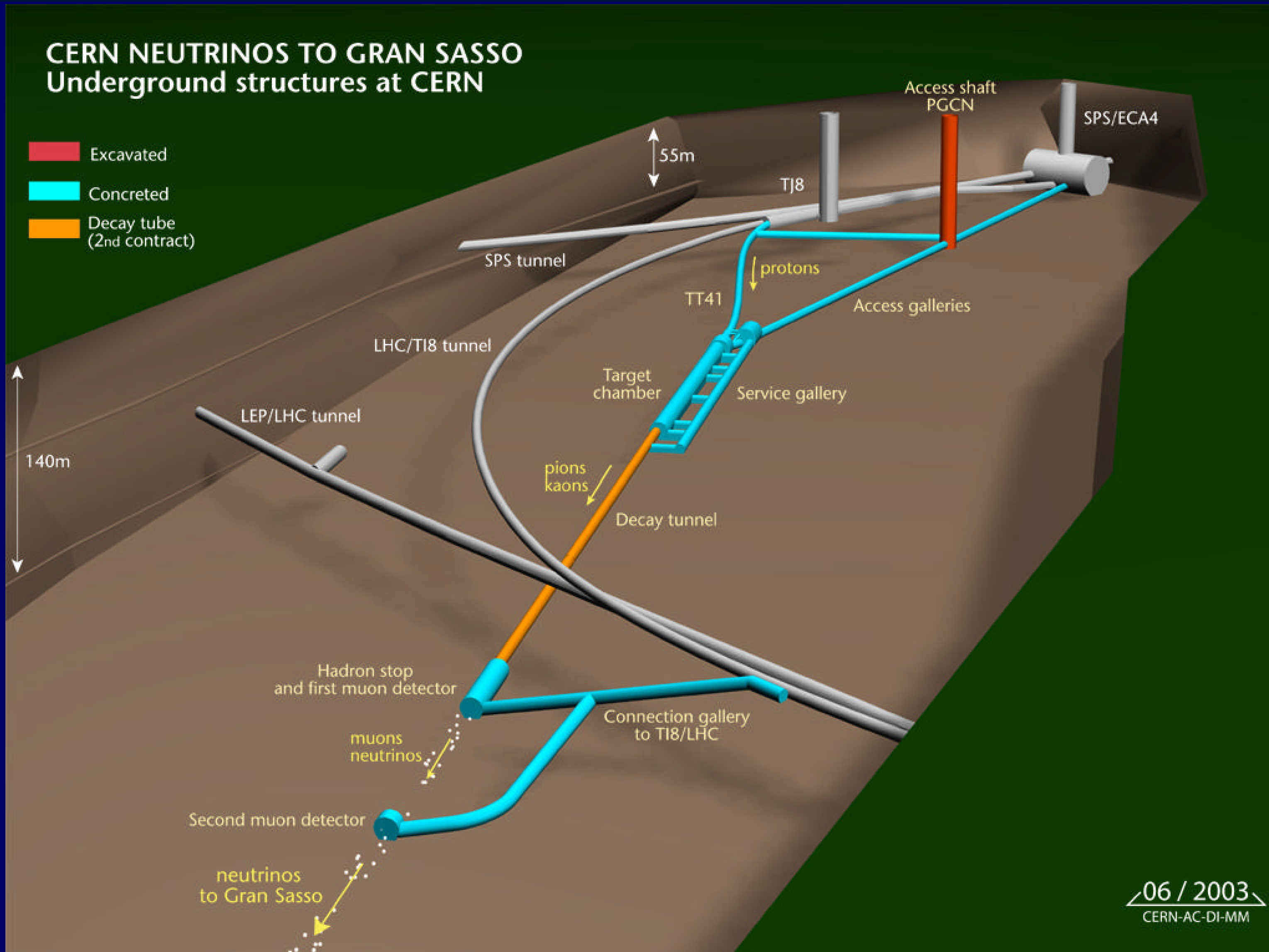


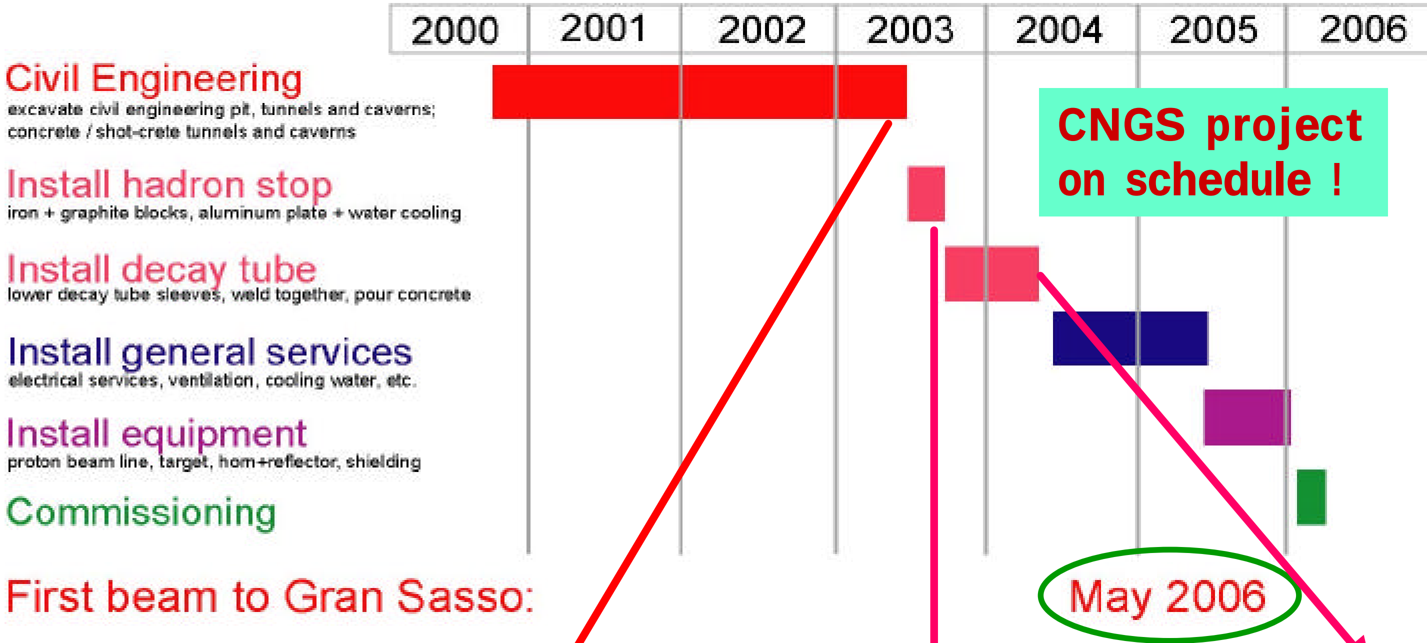
$P_{osc} \sim (\Delta m^2)^2$

From '94 to '03
factor 100 decrease !!

Impact both on $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_e$ oscillation searches

CNGS neutrino beam





First beam in May 2006

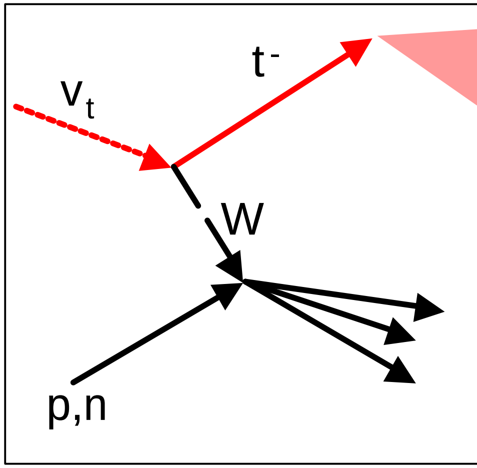
Intensity increase (1.5) under study with dedicated machine tests

Decay tube installed and vacuum tested

Civil engineering completed

Hadron stop installed

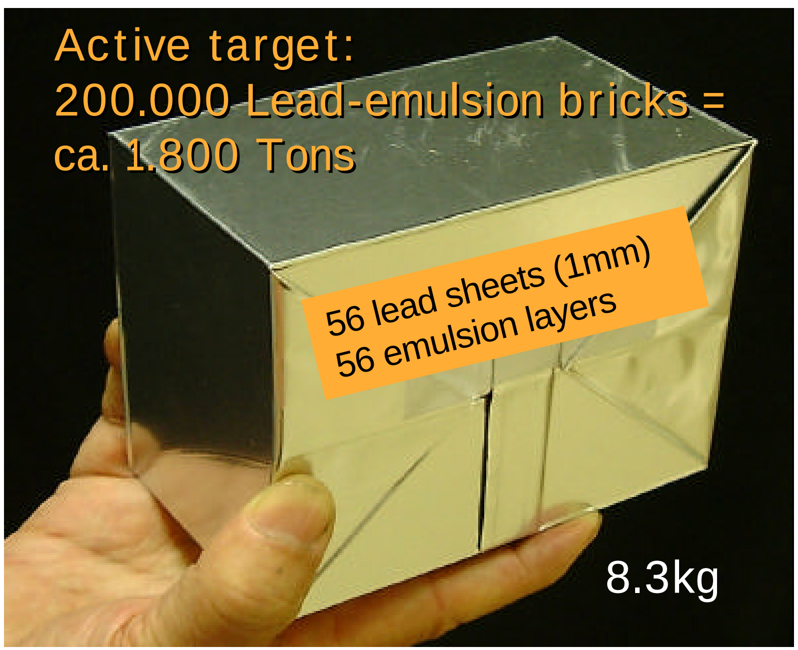
Detection of tau-neutrinos:

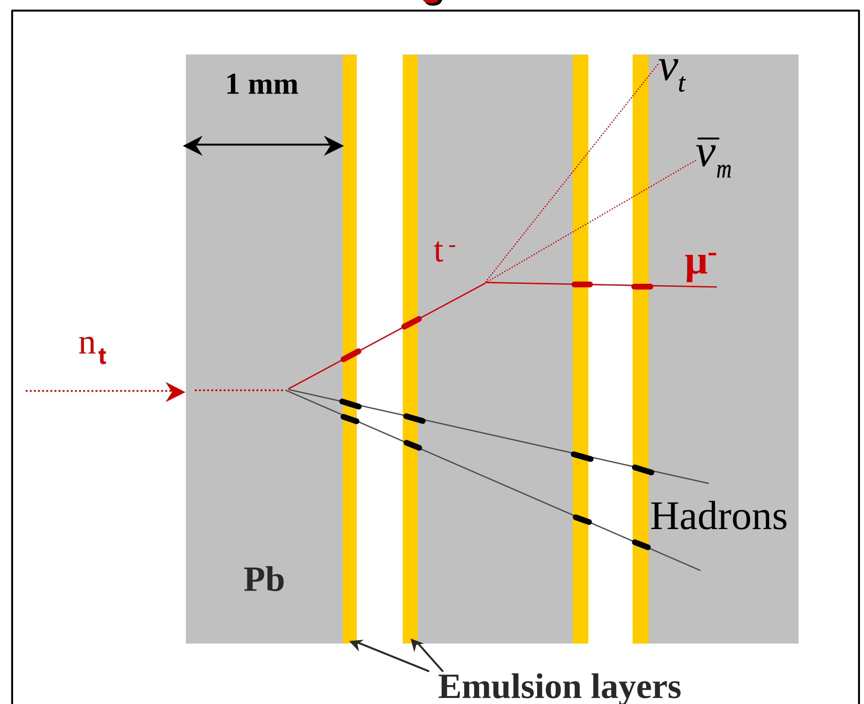


t-decay:

$t^- \rightarrow m^- + \bar{v}_m + v_t$	18%	kink
$t^- \rightarrow e^- + \bar{v}_e + v_t$	18%	kink
$t^- \rightarrow p^-(np^0) + v_t$	48%	kink
$t^- \rightarrow p^- p^- p^+(np^0) + v_t$	15%	multi-prong

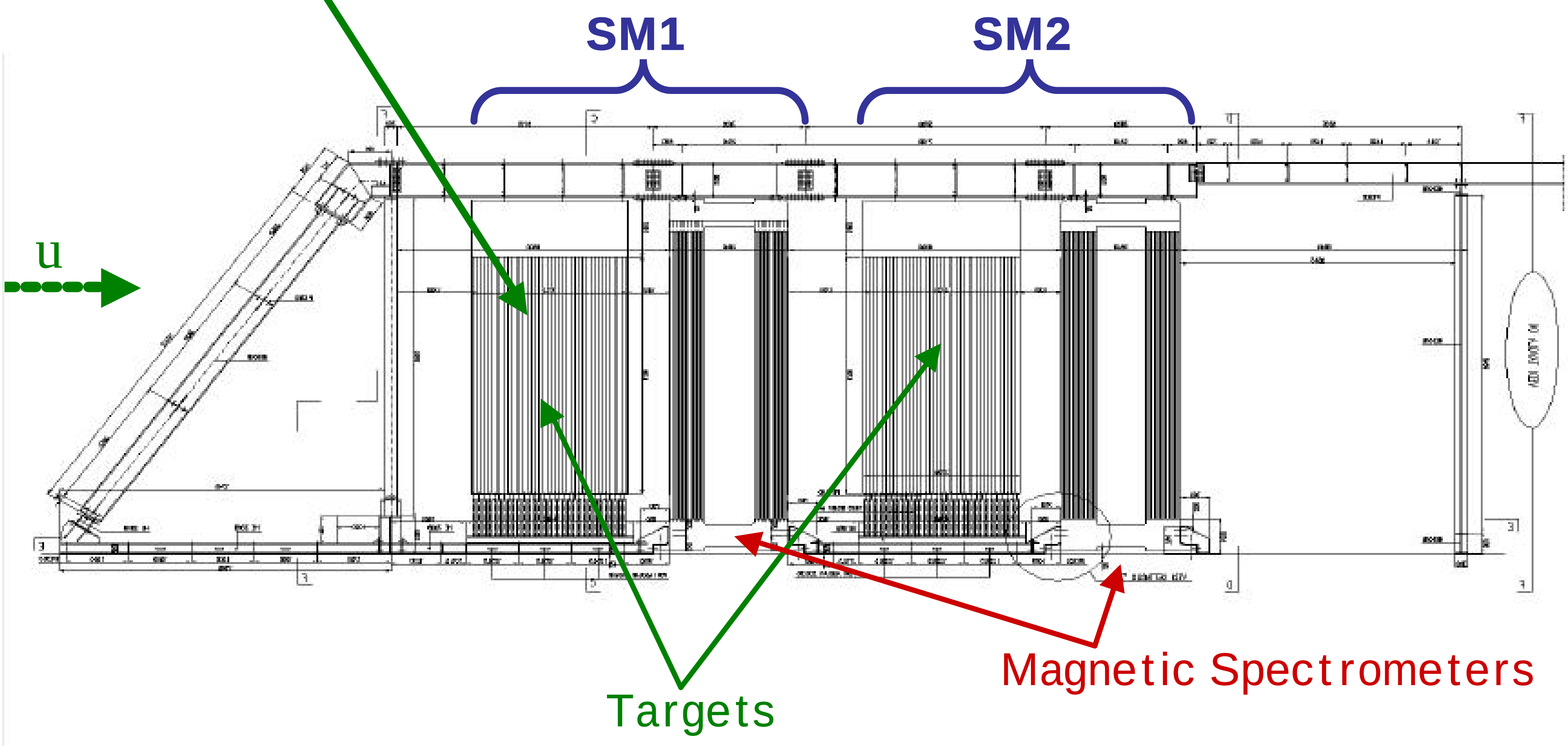
Typical topology of t-decay:
"Kink" in mm-range of vertex





OPERA structure (2 Super-Modules)

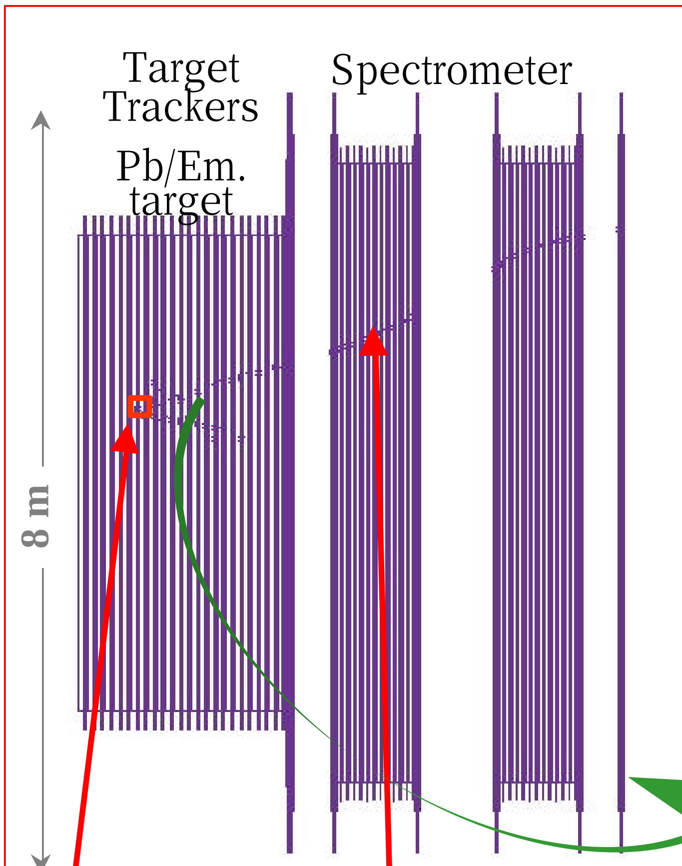
31 target planes / supermodule (in total: 206336 bricks, 1766 tons)

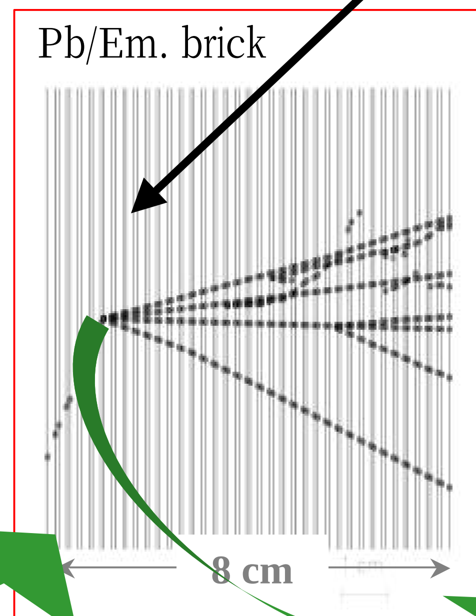


Proposal: July 2000, installation at LNGS started in May 2003

Electronic detectors:

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

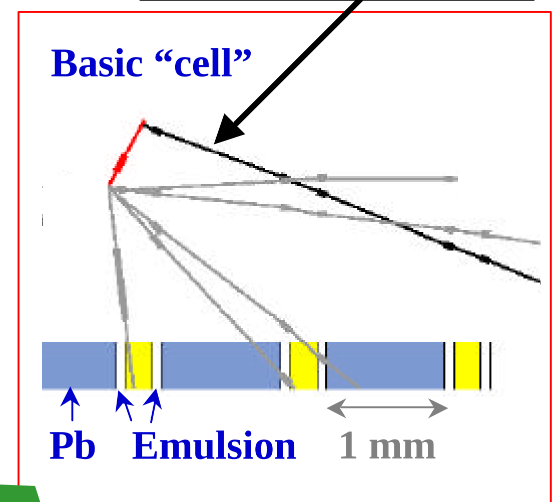




ECC emulsions analysis:

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

Link to mu ID,
Candidate event



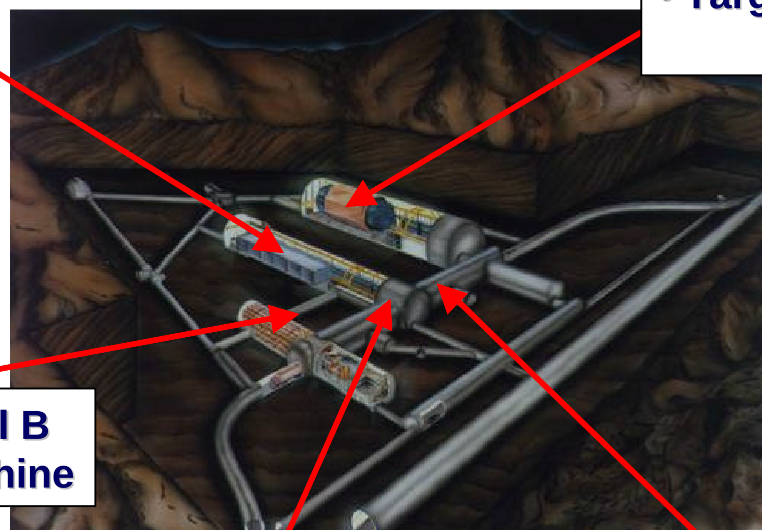
Brick finding, muon ID, charge and p

Installation at Gran Sasso

Hall C – Detector

- Installation started May 2003
- Magnet SM1 completed June 2004
- Magnet SM2 partially assembled
- Mechanical Structure Extended, completed for SM1 August 2004
- Target Section SM1 just started

Hall B
Downloading & Preassembly

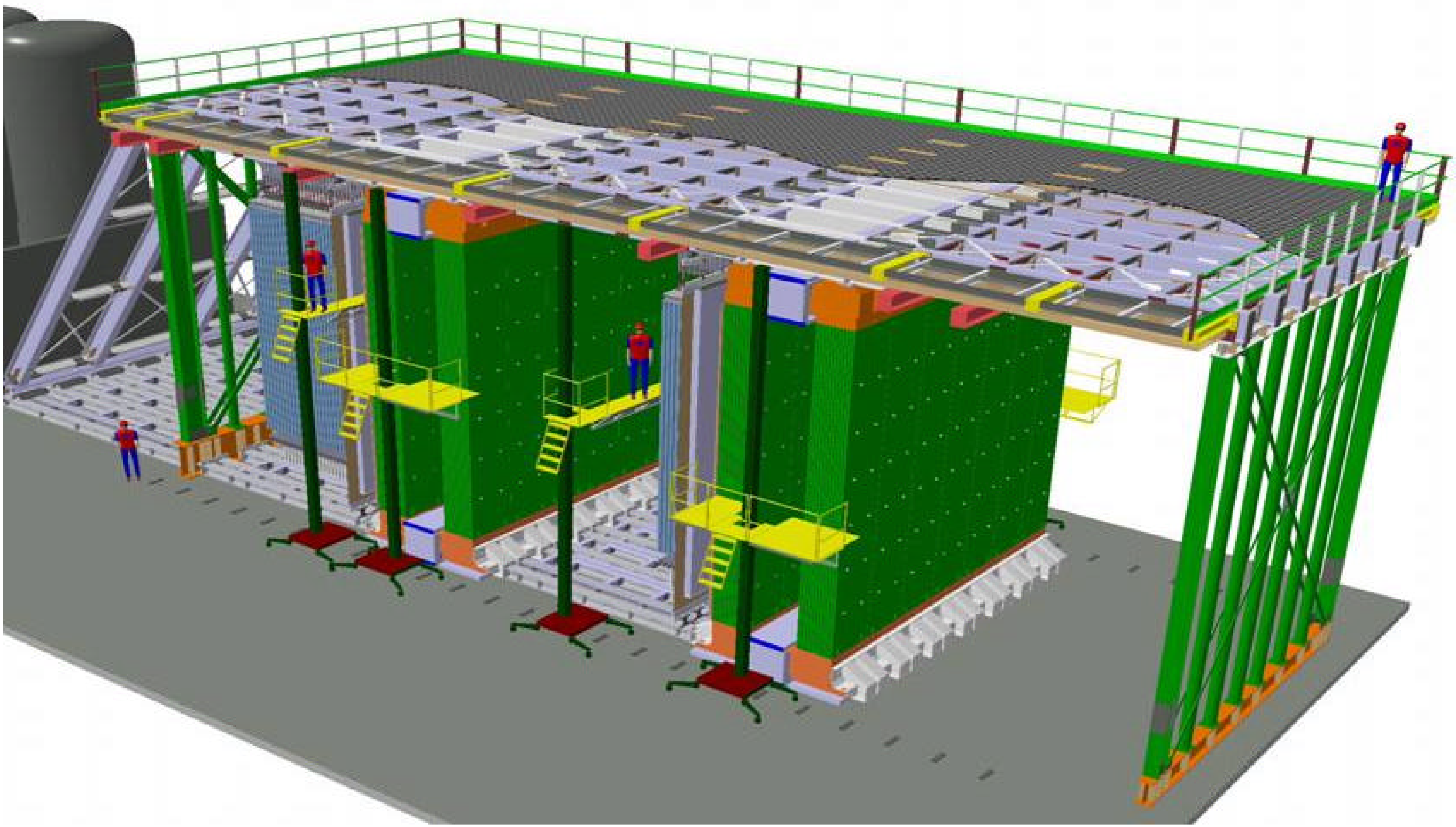


Bypass Hall A – Hall B
Brick Assembly Machine

Hall B - Emulsion storage
Remote Counting Room

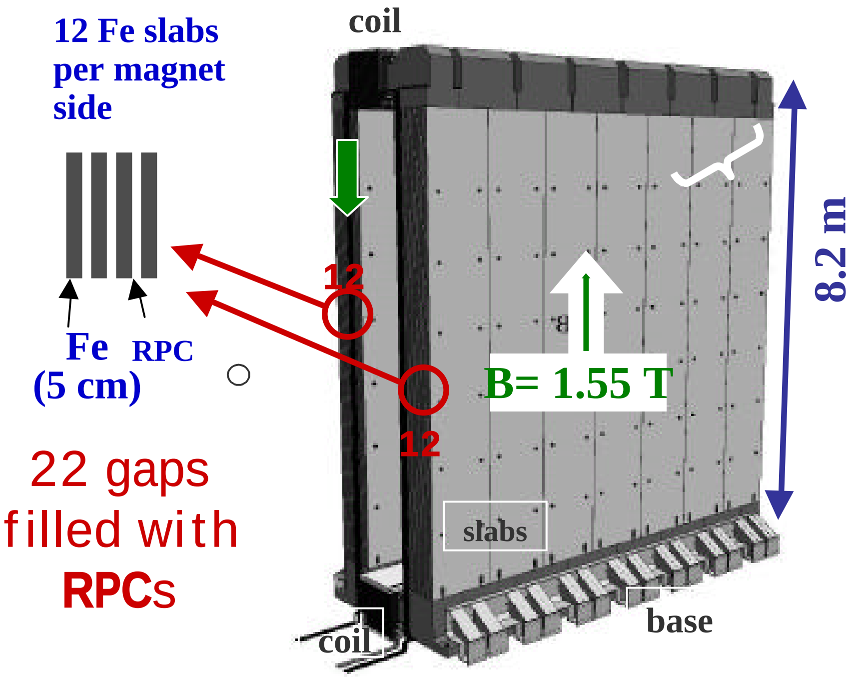
Truck Gallery
Emulsion test underground
CS darkroom

Detector Assembly & Installation



Spectrometer: Magnets

Total Fe weight ~ 1 kton



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

D**p**/**p** = 20-25%

μId > 95% (with Target Tracker)

Spectrometer: RPCs (Bakelite)

- **1160 RPC** + **all needed strips produced** (for the 2 spectrometers)
- **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)

RPCs undergo several quality tests:

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

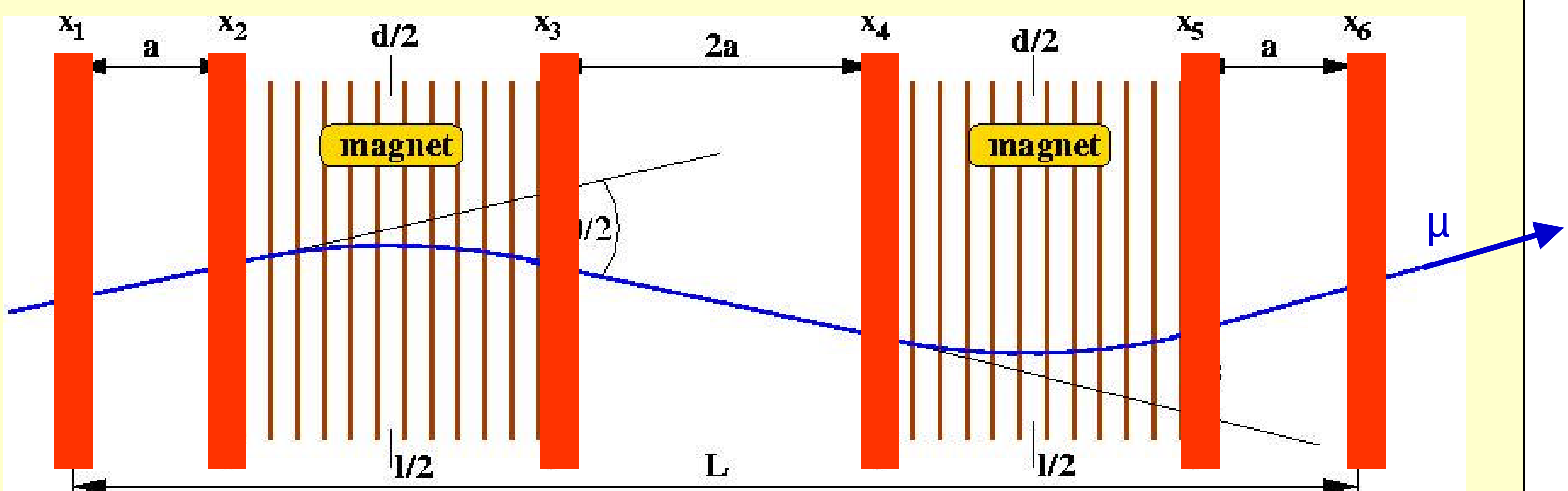
Gas and HV tests repeated in Hall C

Spectrometer: Precision Tracker

Universität Hamburg

Purpose: measure charge and momentum of myons
(position resolution: < 300µm)

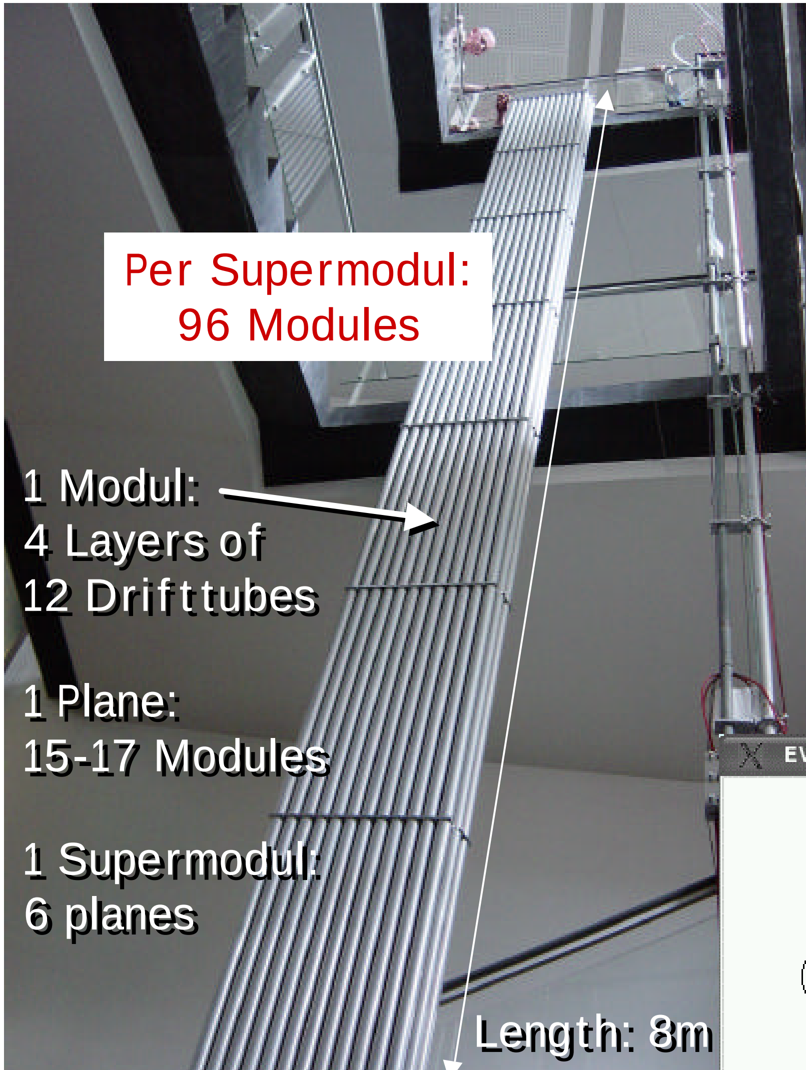
Precision Tracker of one Supermodul (SM)

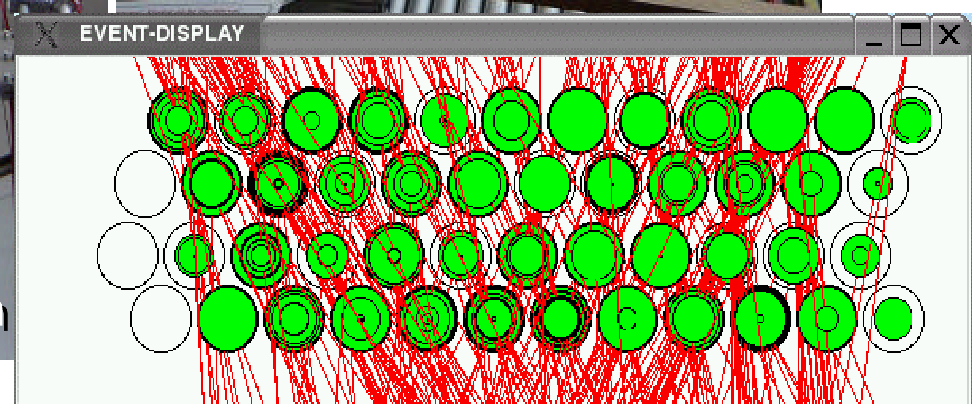


Per plane: 816 Drifttubes
Per SM: 4896 Drifttubes

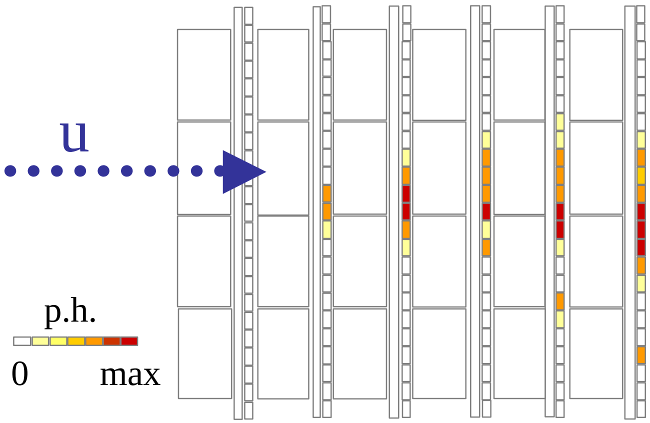
Total (2 SM): ca. 10000 Drifttubes

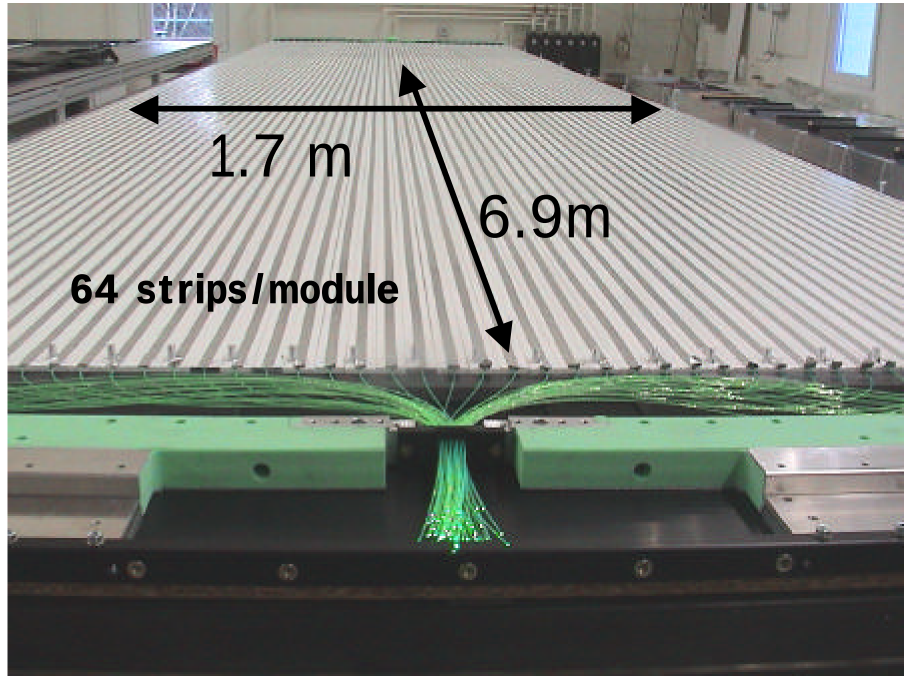
First Precision Tracker Modules





Target Tracker





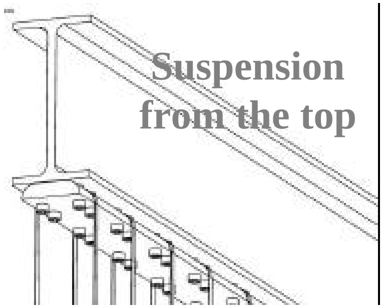
- Neutrino interaction trigger
- Brick localization
- Muon tracking and ID

XY planes, 7000m^2 in total
32256 Scintillator strips **6.86m x 2.6cm x1cm**
AMCRYS-H (Kharkov) + Kuraray WLS
1000 MaPMT Hamamatsu 64channels

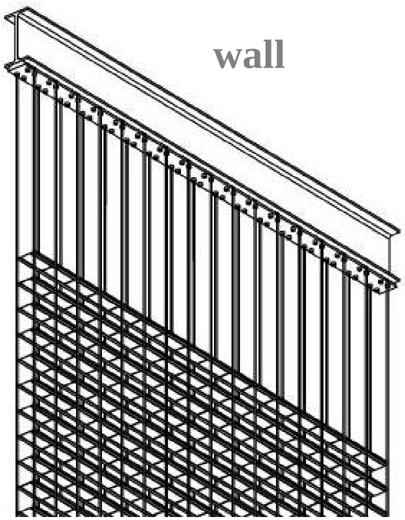
Construction of the modules in progress (8/week)
Installation at LNGS since September 2004

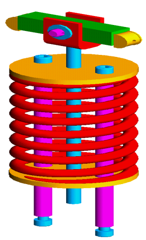
Target Tracker Installation

Support structure for brick walls



Construction in progress
Installation at LNGS :
September 2004-December 2005



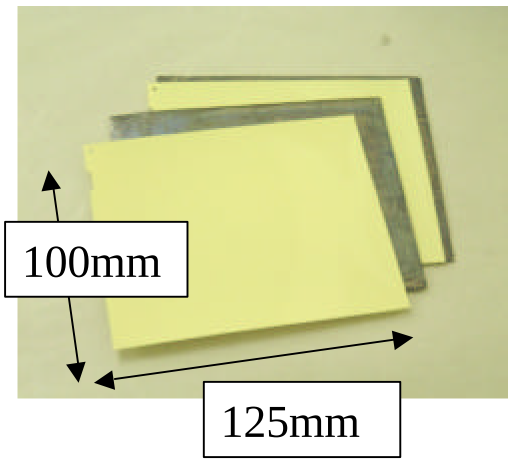


Tensioning
from the
bottom

Full size prototype

Lead Production & Fuji Emulsion

Mass production started April 2003 (~150 000 m²)
20% produced
Refreshing performed in the Tono Mine in Japan (700 bricks/day)



Refreshing condition

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

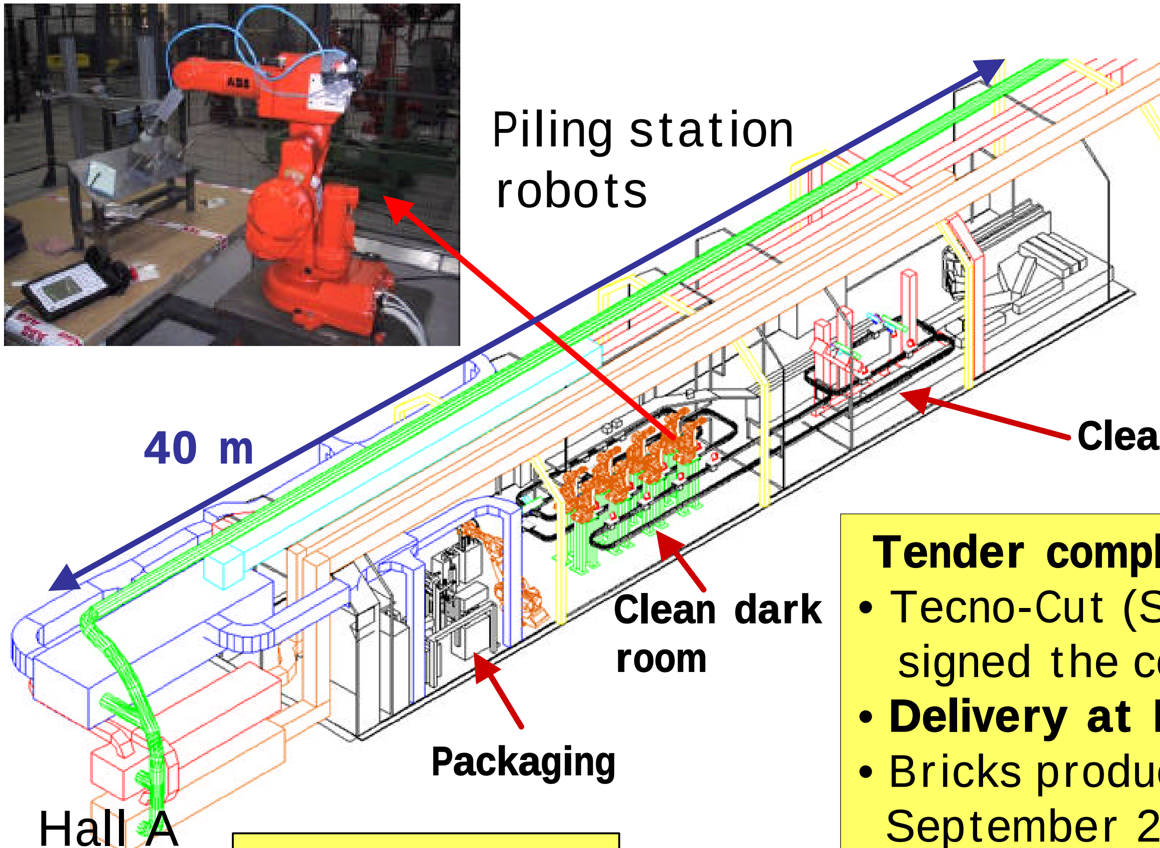
Pb ready for prototype mass production (Germany)

~10^7 sheets needed

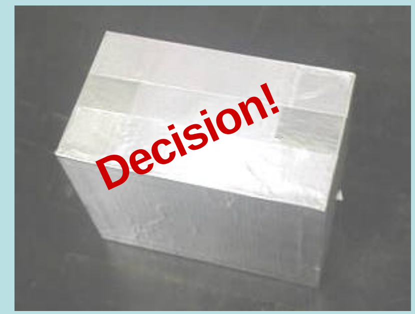

Emulsion storage barrack
(5 cm Fe shielding at LNGS)

Brick Assembly Machine (BAM)

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



Mechanical packaging

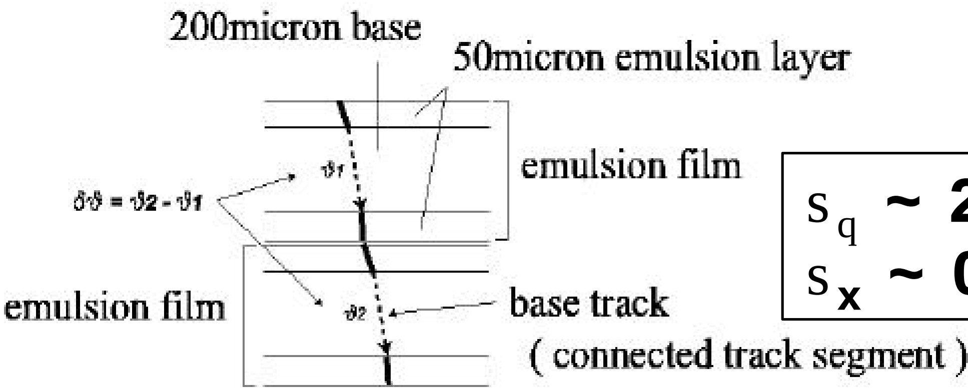


BAM at LNGS

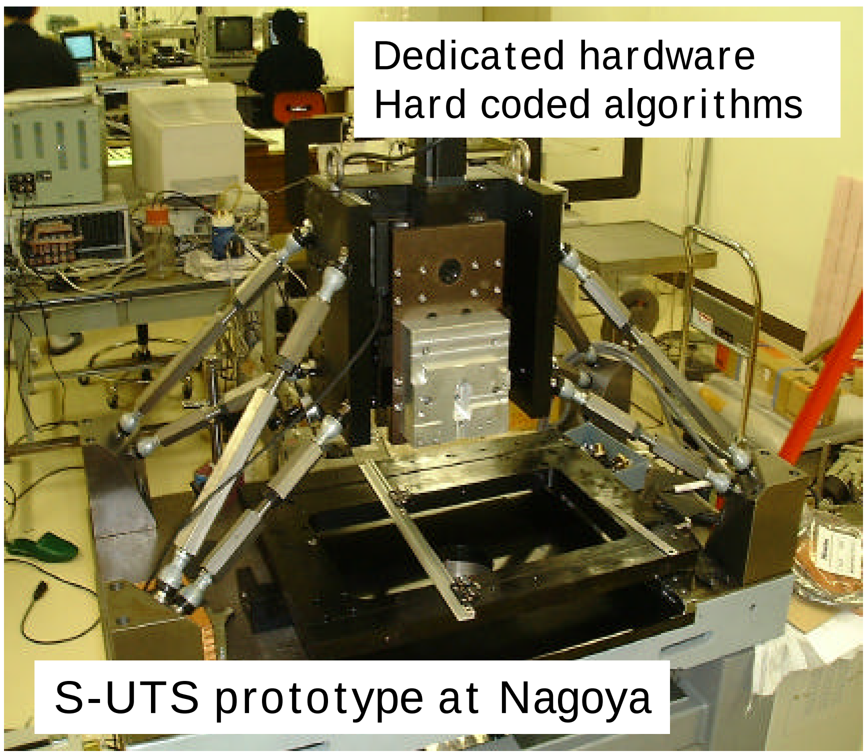
Tender completed in November 2003
- Tecno-Cut (Swiss-Italian) consortium signed the contract in January 2004
- **Delivery at LNGS: April 2005**
- Bricks production:
  September 2005 – September 2006
  End of filling SM1: 24 March 2006
  SM2: 29 September 2006

Automatic Scanning: Nagoya and Europe R&D efforts

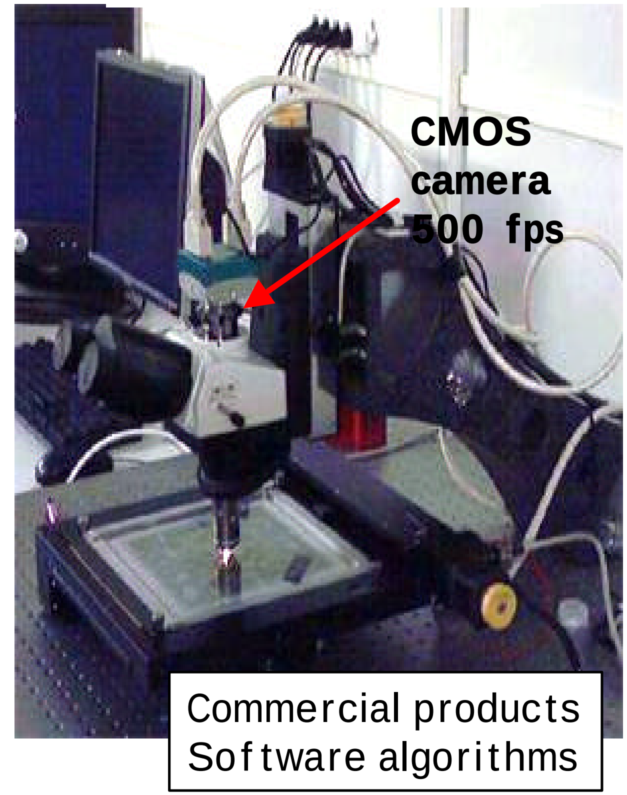
Bari, Bern, Bologna, Lyon, Münster, Napoli, Roma, Salerno



σ_θ ~ 2mrad
σ_x ~ 0.5μm



European station



Final version of the european system
ready and working at 20 cm^2/hour
(15 stations under installation)

Installation Summary

- OPERA installation is sticking to schedule

- Work in Hall C will slow down for 3 weeks because of safety work
  -> this time will be used for completing the commissioning of the target installation withour changing the overall schedule

- Interference with BOREXINO still a big worry
  - PC loading station operating in Hall C
  - Opera isolation of PC leakage from BOREXINO
  - Independent fire extinguishing system

  Under study by LNGS management

Milestones

Achieved :
- Refreshing facility installed
- First magnet completed
- Brick packaging decision
- BAM ordering
- Scanning speed 20cm^2/h

→ **SPSC, July 04**

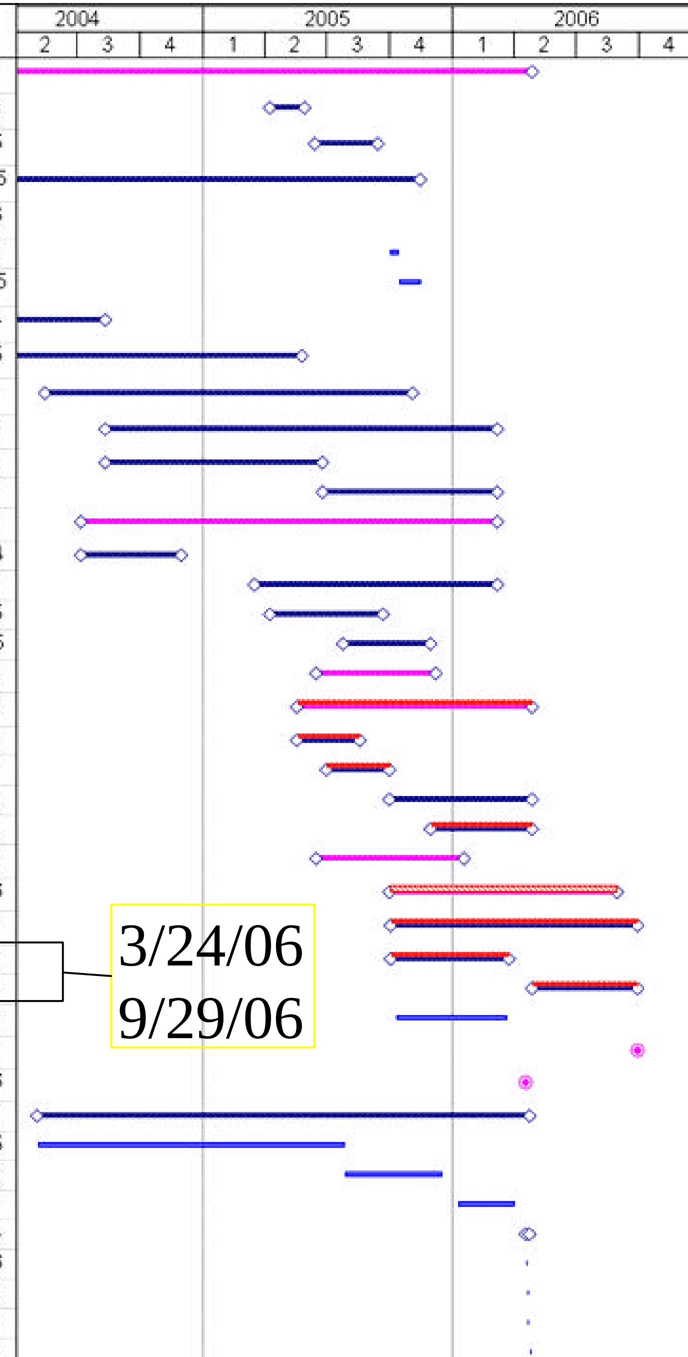
Next Milestones
1. Target installation commissioning: sep 04
2. Emulsion delivery @ LNGS : oct 04
3. BMS automation validation : dec 04
4. BAM commissioning @ factory : feb 05
5. Start brick filling : sep 05

→ **In progress**

→ **On schedule** First shipment will leave Japan in october

General Planning

ID	Task Name	Duration	Start	Finish
226	INSTALLATION IN GS EXPERIMENT HALL C	153.83 w	Mon 2/10/03	Thu 4/27/06
227	**C R & ELECTRONIC ROOM**	7 w	Fri 4/8/05	Mon 5/30/05
233	**BAM**	13 w	Mon 6/13/05	Wed 9/14/05
237	**SPECTROMETERS (2 MAGNETS & RPC's)**	134.03 w	Mon 2/10/03	Mon 11/14/05
238	**Preliminary working**	15 w	Mon 2/10/03	Wed 5/28/03
239	Veto plane mechanics	2 w	Fri 9/30/05	Fri 10/14/05
240	**Veto plane detector**	4 w	Fri 10/14/05	Mon 11/14/05
241	**Magnet 1**	58.35 w	Fri 5/30/03	Wed 8/11/04
274	**Magnet 2**	95.15 w	Fri 5/30/03	Wed 5/25/05
311	**TARGET TRACKERS MOUNTING**	72 w	Fri 5/14/04	Fri 11/4/05
330	**TARGET WALLS**	73.94 w	Wed 8/11/04	Tue 3/7/06
331	**SM1**	41.18 w	Wed 8/11/04	Fri 6/24/05
410	**SM2**	32.76 w	Fri 6/24/05	Tue 3/7/06
489	**XPC's & PRECISION TRACKERS**	79.34 w	Mon 7/5/04	Tue 3/7/06
490	**XPC 1**	20.88 w	Mon 7/5/04	Tue 11/30/04
496	**Precision tracker 1**	46.24 w	Wed 3/16/05	Tue 3/7/06
529	**XPC 2**	23.05 w	Fri 4/8/05	Wed 9/21/05
535	**Precision tracker 2**	18 w	Mon 7/25/05	Tue 11/29/05
568	**CABLING (detector to control room)**	24.35 w	Wed 6/15/05	Tue 12/6/05
571	**MANIPULATORS**	44.8 w	Wed 5/18/05	Thu 4/27/06
572	**SM1 cavern side**	13 w	Wed 5/18/05	Fri 8/19/05
578	**SM1 corridor side**	13 w	Thu 6/30/05	Fri 9/30/05
585	**SM2 cavern side**	25.8 w	Fri 9/30/05	Thu 4/27/06
589	**SM2 corridor side**	17.43 w	Wed 11/30/05	Thu 4/27/06
594	COMMISSIONNING WITHOUT BRICKS	27.35 w	Wed 6/15/05	Tue 1/17/06
597	ECC BRICK MANUFACTURING WITH BAM	43 w	Fri 9/30/05	Wed 8/30/06
599	WALL BRICK FILLING (2b/min 8h/day)=960 bricks)	47.2 w	Mon 10/3/05	Fri 9/29/06
600	SM1 brick filling	21.6 w	Mon 10/3/05	Fri 3/24/06
602	SM2 brick filling	21.6 w	Thu 4/27/06	Fri 9/29/06
604	COSMIC DATA TAKING WITH BRICKS	20 w	Mon 10/10/05	Tue 3/21/06
605	FULL DETECTOR COMPLETED	0 d	Fri 9/29/06	Fri 9/29/06
606	**CNGS Beam delivery**	0 d	Wed 4/19/06	Wed 4/19/06
607	OPERA RUNNING	94.6 w	Mon 5/3/04	Mon 4/24/06
608	OPERA LNGS external building	60 w	Mon 5/3/04	Wed 7/27/05
609	Emulsion processing laboratory	20 w	Thu 7/28/05	Fri 12/16/05
610	Processing tests	12 w	Mon 1/9/06	Fri 3/31/06
611	**OPERA brick processing cycle**	**0.8 w**	**Wed 4/19/06**	**Mon 4/24/06**
612	First brick extraction	1 d	Wed 4/19/06	Wed 4/19/06
613	Brick cosmic rays exposure	1 d	Thu 4/20/06	Thu 4/20/06
614	Emulsion development	1 d	Fri 4/21/06	Fri 4/21/06
615	Emulsion shipping to scanning labs	1 d	Mon 4/24/06	Mon 4/24/06



Tau detection efficiency

Channels considered at the time of the CNGS approval in 1999 :

$\tau \rightarrow e$	(DIS+QE, long)	3.0%
$\tau \rightarrow \mu$	(DIS+QE, long)	2.6%
Overall efficiency		ε = 5.6%

Eff * BR	*DIS long*	*QE long*	*DIS short*	*Overall**
t ® *e*	**2.7**	**2.3**	**1.3**	**3.4**
t ® *m*	**2.4**	**2.5**	**0.7**	**2.8**
t ® ***h***	**2.8**	**3.5**	**-**	**2.9**
Total	**8.0**	**8.3**	**1.3**	**9.1 %**

*** weighted sum on DIS and QE events**

Improvements under study:

use changeable sheet on the back side of the brick

Brick finding strategy : +10% (signal/background ratio unchanged)

channel t→3 prongs (1.0% eff, including BR 15%) : +10%

Number of Background Events

5 years running @ nominal intensity

(in red : possible improvements)	t→e		t→μ		t→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 background:
  - New CHORUS data: cross section increased by 40%
  - Could be reduced with p/μ id by dE/dx by 40% (tests at KEK and PSI)
- Large angle μ scattering:
  - Upper limit from past measurement used so far
  - Calculations including nuclear form factors -> factor 5 less (tests 2004 in X5 beam with Si detectors)
- Hadronic background:
  - Estimates based on FLUKA standalone: 50% uncertainty
  - Comparison FLUKA with CHORUS data and GEANT4: reduce uncert. to ~15%

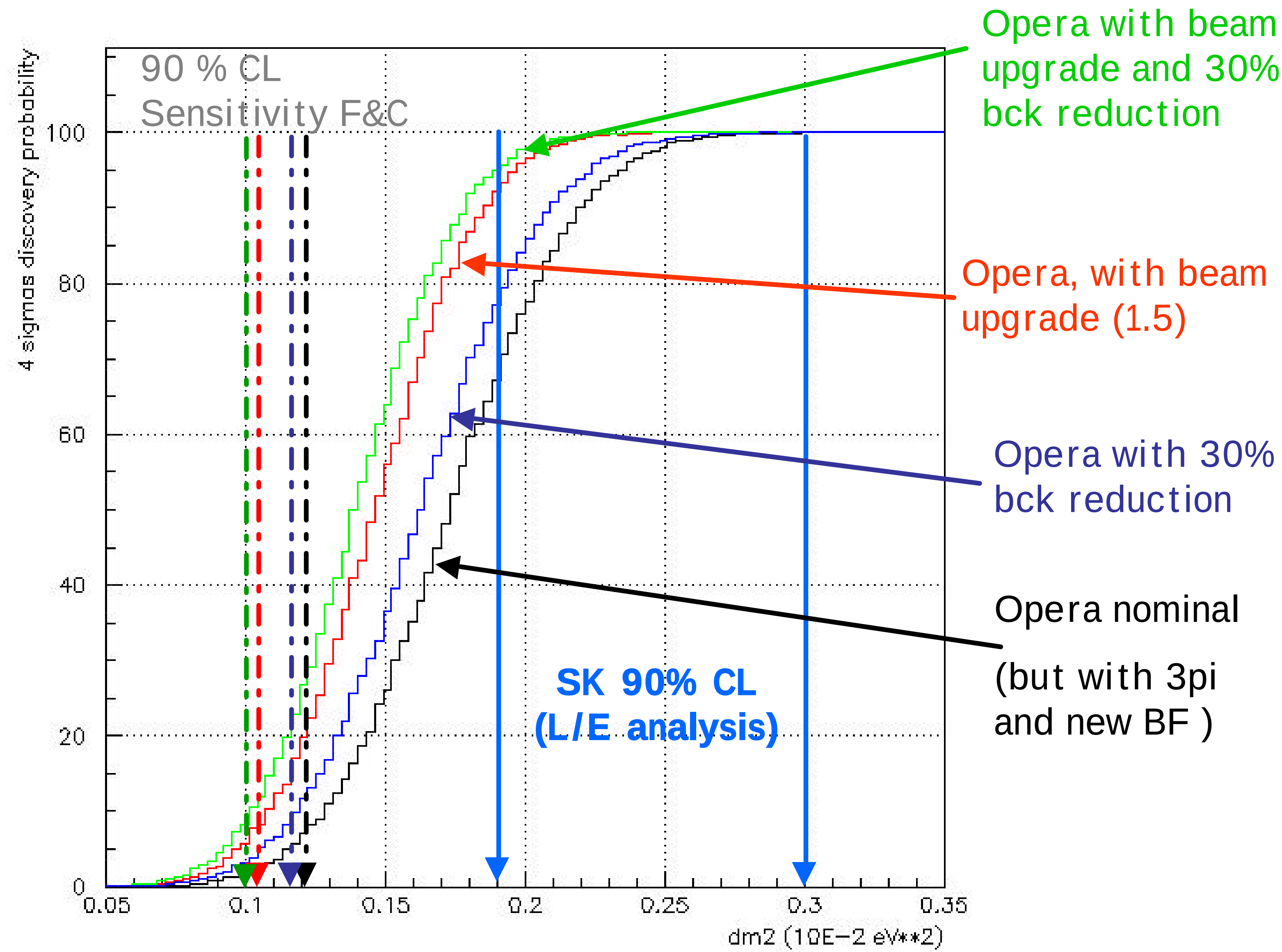
ν_τ? ν_μ sensitivity

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

	signal (Δm^2 = 1.9 x 10^{-3} eV^2)	signal (Δm^2 = 2.4 x 10^{-3} eV^2)	signal (Δm^2 = 3.0x 10^{-3} eV^2)	BKGD
OPERA 1.8 kton fid.	6.6(10)	10.5(15.8)	16.4(24.6)	0.7(1.1)
+ 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 (4s)



ν_e –appearance and ?$_{13}$

Beam Systematics

- Assumed 5% error on the ν_e flux
  (see A. Guglielmi talk at NOW04 for details on the CNGS systematics)

- With OPERA detector it is possible to (thanks to the spectrometer):
  - Measure the μ^- energy spectrum (at high-energy ν_μ from K^+ decays dominate)
  - Measure the μ^+ energy spectrum (anti- ν_μ from K^- decays dominate)

- Good samples (O(1Kevts)) to cross-check the beam simulation

- Given the small number of expected events in OPERA (see later) the sensitivity to θ_{13} is dominated by the statistical fluctuations of the background

  ® **more pots are needed!!!**

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

		signal	t ® e	n_mCC	n_mNC	n_eCC beam
Location eff.	x	0.53	0.053	0.52	0.48	0.53
Total eff.	e	0.31	0.032	0.34×10^{-4}	7.0×10^{-4}	0.082

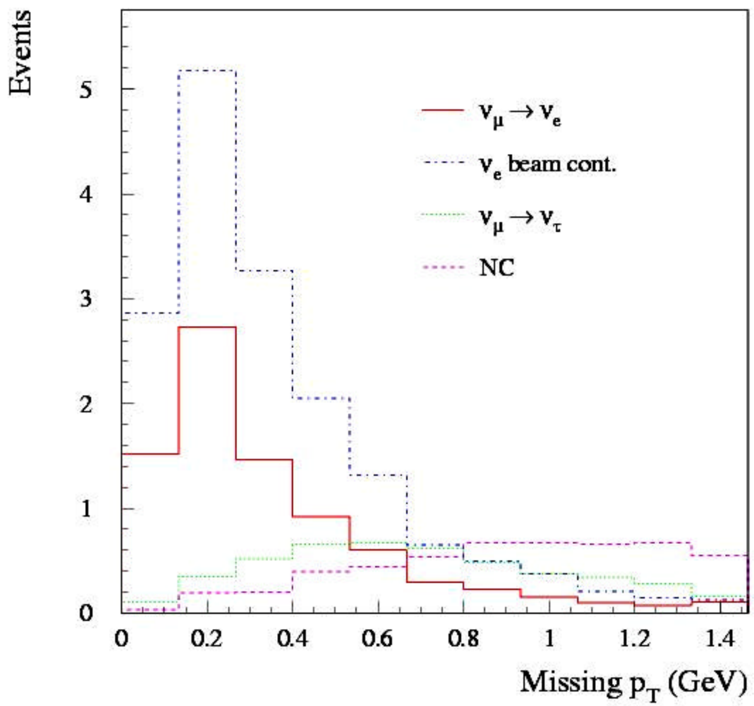
Expected signal and background assuming 5 years data taking with the nominal CNGS beam and $Dm^2_{23}=2.5 \times 10^{-3}$ eV^2, $\sin^2 2q_{23}=1$

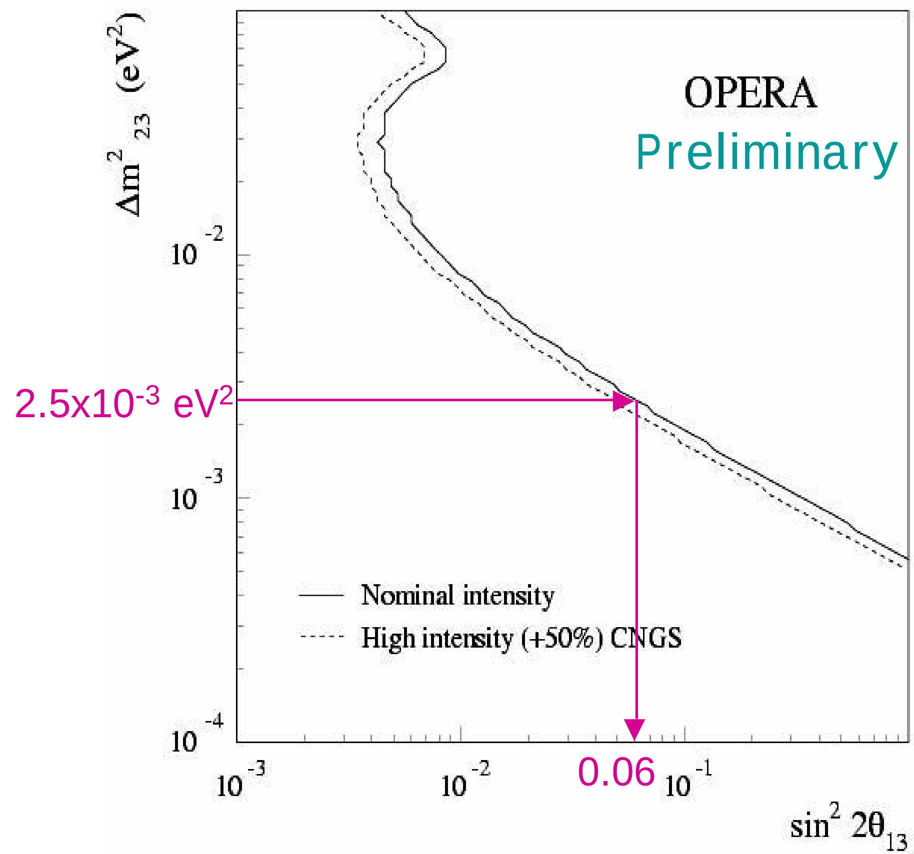
q_{13}	signal	t ® e	n_mCC	n_mNC	n_eCC beam
9°	9.3	4.5	1.0	5.2	18
8°	7.4	4.5	1.0	5.2	18
7°	5.8	4.6	1.0	5.2	18
5°	3.0	4.6	1.0	5.2	18
3°	1.2	4.7	1.0	5.2	18

OPERA sensitivity to θ_{13}

Simultaneous fit of
- E_e,
- missing p_T
- E_{vis} distributions

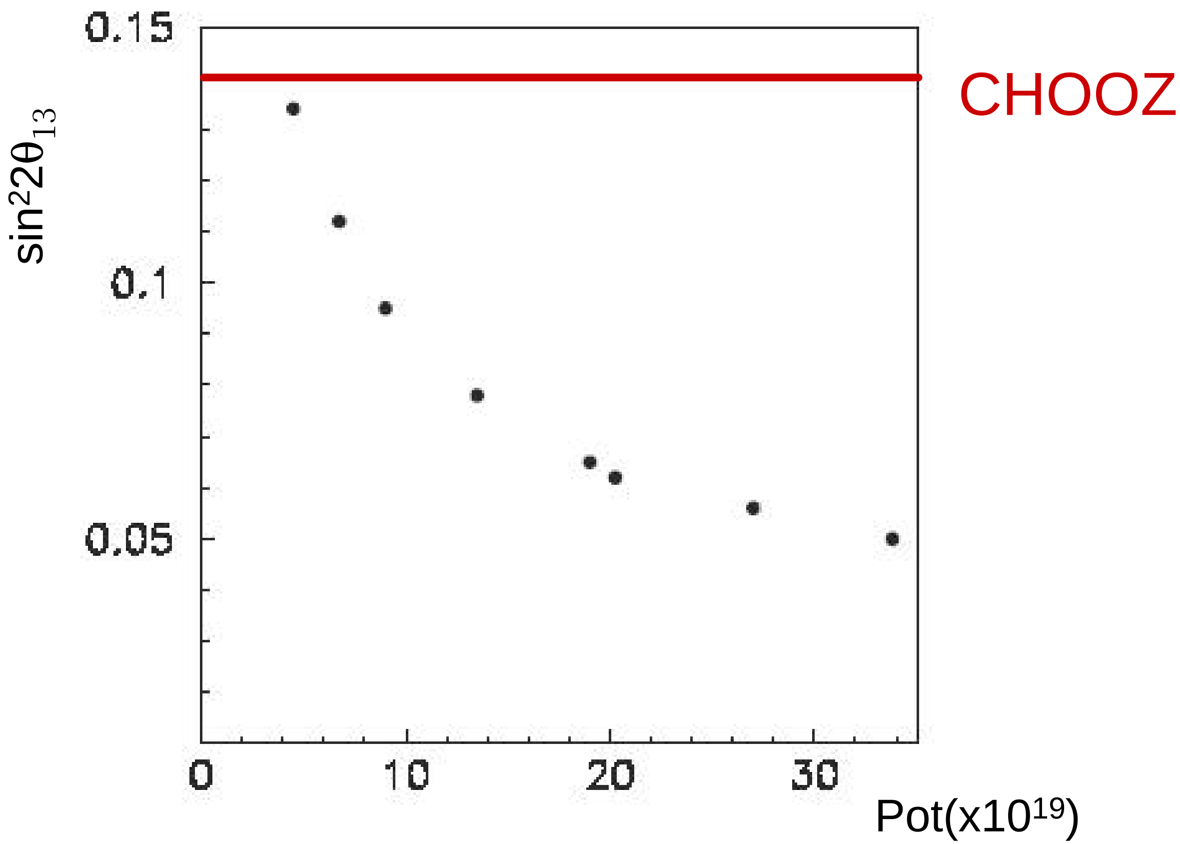
-> gives sensitivity at 90%





Pots are an important issue

OPERA $\sin^2 2\theta_{13}$ as a function of the pots



On Peak / Off Peak

Migliozzi et al , Phys. Lett. B563(2003)73

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

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

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

$$+ \alpha^2 \cos^2\theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(\hat{A}\Delta)}{\hat{A}^2}$$

O_1 leading term

O_2: 1 at osc. max

O_3: 0 at osc. max

O_4: suppressed by α^2

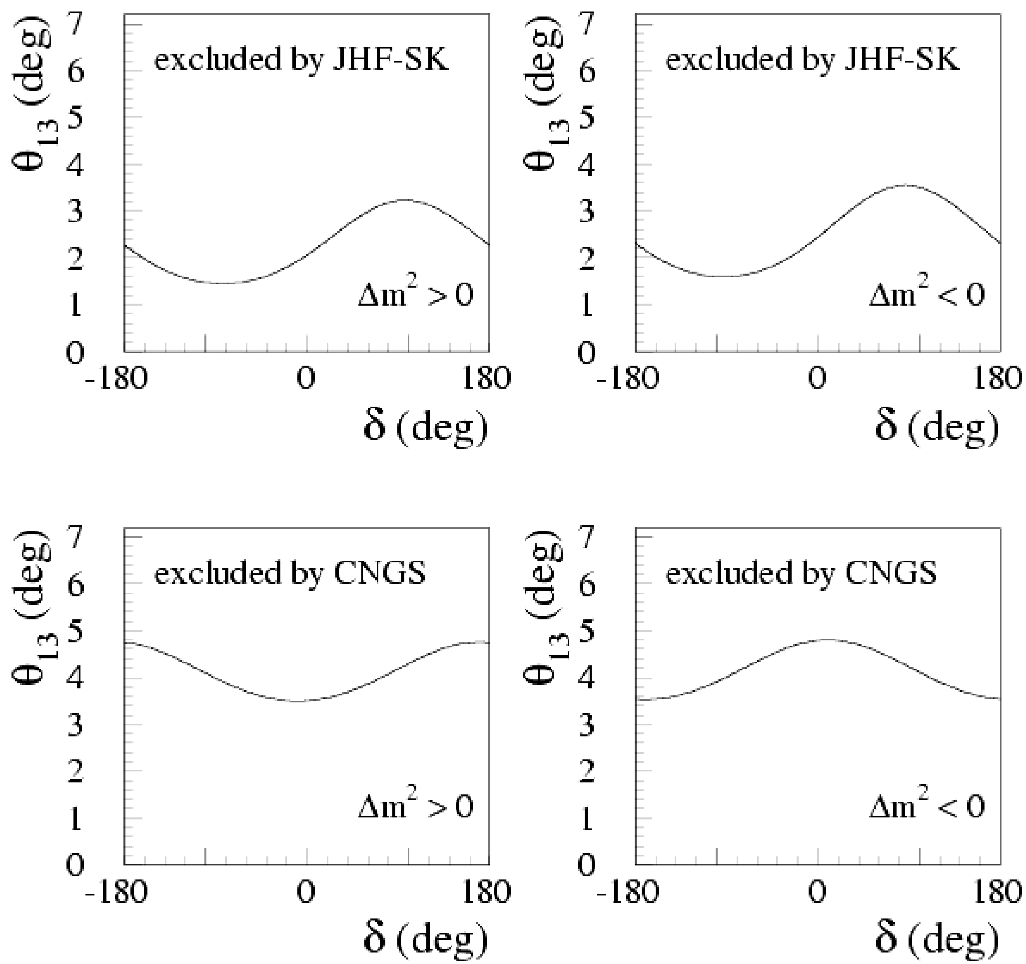
$$\alpha \equiv \frac{\Delta m^2_{21}}{|\Delta m^2_{13}|} \qquad \xi \equiv \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \approx O(1)$$

$$\hat{A} \equiv 2\sqrt{2} G_F n_e \frac{E}{\Delta m^2_{13}} \qquad \Delta \equiv \frac{\Delta m^2_{13} L}{4E}$$

The hierarchy among the different O terms depends on the “on peak”-”off peak” choice

On Peak / Off Peak effect on CPV

$Dm^2 > 0$ $Dm^2 < 0$



There are δ_{CP} values for which the sensitivity on θ_{13} is even better than the one computed in the 2-flavor approximation (δ_{CP}=0).

Notice the different behaviour on Δm^2 of the CNGS sensitivity
$\Rightarrow$ Possible measurement of the sign of ? m^2_{31} if T_{13} is large !

Caren Hagner

Conclusions

- Despite difficulties at LNGS
  installation of OPERA experiment following schedule

- Completion of Supermodule 1 foreseen Sept 05
  Completion of SM2 Feb 06, SM2 filled in Sept 06
  OPERA needs physics run in 2006 to start physics program

- Efficiency and background based on robust numbers from previous experiments: improvements under study

- In order to cover the SuperK allowed range of ? m^2:
  - At least nominal beam conditions (4.5 10^9 pot/year) needed!
  - Even more protons on CNGS target are needed
    - either by increasing number of CNGS cycles
    - or (and) increasing proton intensity in the SPS
    - ? multi-turn ejection from PS to SPS is urgently needed

END

Check of Decay Detection Efficiency

Charm is a reference sample

CHORUS

- About 2000 neutrino induced events with an identified charmed particle in the final state have been detected in the emulsions of the CHORUS experiment
- The total charm cross-section and, separately the neutral and the charged ones, may be predicted to the OPERA case with an accuracy equal or better than 10%
- The error on the total charm production cross-section is expected to be dominated by systematics which at present are 10%

OPERA

- We assume 5000 DIS events per year
  (shared mode, standard operation, no pot increase considered)
- 5% total charm cross-section
  - 250 charm events expected
  - About 100 ÷ 150 would be detected (assuming 50% eff.)

Efficiency Check II

**All decay topologies (kink, multi-prong)
can be analysed separately**

- Already after 1 year data taking
  (i.e. precision measurements for about 100-150 charm candidates)
  the efficiency can be estimated with an accuracy better than 20%

- After 3 years of such a dedicated study
  the precision will be limited to ~10%
  by the error on the predicted number of charm events
  (i.e. systematic error on the CHORUS cross-section)

How to check the reliability of the kinematical cuts? (I)

IN OPERA THE CRUCIAL TAG FOR A TAU CANDIDATE IS THE DETECTION OF A DECAY TOPOLOGY

- A minimum bias sample has to be carefully scanned in order to check the reliability of the Monte Carlo used to define the kinematical cuts in the hadronic channel
- NB The kinematical analysis in OPERA is not a crucial item, unlike in the NOMAD experiment (see Table)

	OPERA n_m NC	NOMAD n_m NC	OPERA t ® h	NOMAD t ® h
e_{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

Rejection **efficiency**

How to check the reliability of the kinematical cuts? (II)

- The Monte Carlo used in OPERA has been carefully validated with data by the NOMAD Collaboration:
  Kinematics and dynamics of neutrino interactions well modeled

- NOMAD had C target (light material) while in OPERA has Pb (heavy material), but the used model does not depend on the nucleus

- We plan to precisely scan a minimum bias sample of about 1000 located neutrino interactions :

  (~750 CC (~4% stat $\Delta\varepsilon$), ~250 NC (~6% stat $\Delta\varepsilon$))

  to fine tune the intranuclear interaction model in describing the interactions on lead

Brick Wall Installation

Tendering	(start)	MAY 2003
Tendering	(end)	OCT 2003
Production contracts signed		JAN 2004
First wall prototype built		JUL 2004
First wall delivered at LNGS		OCT 2004
Last wall delivered at LNGS		JUN → DEC 2005

Reference marks positioning (for alignment)		✓	JUNE 2004
Rails installation/alignement	1^{st} SM	✓	AUGUST 2004
Walls installation/alignement	1^{st} SM		OCT 04 → JUN 05
Rails installation/alignement	2^{nd} SM		JUN/JUL 2005
Walls installation/alignement	2^{nd} SM		JUL 05 → FEB 06