OPERA

- physics programme,
- experimental concept,
- first results with beam and cosmic,
- short term prospects.

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EPS 2007
Manchester

The OPERA Collaboration: 150 physicists, 36 institutions in 13 countries

Belgium
IIHE Brussels

Bulgaria
Sofia

Croatia
IRB Zagreb

France
LAPP Annecy
IPNL Lyon
IReS Strasbourg

Germany
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-South
Jinju

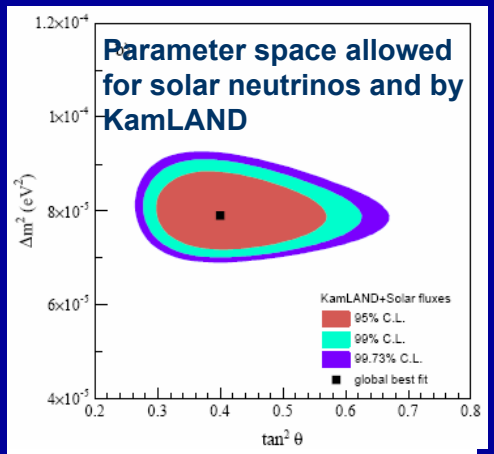
Russia
INR Moscow
NPI Moscow
ITEP Moscow
SINP MSU Moscow
JINR Dubna
Obninsk

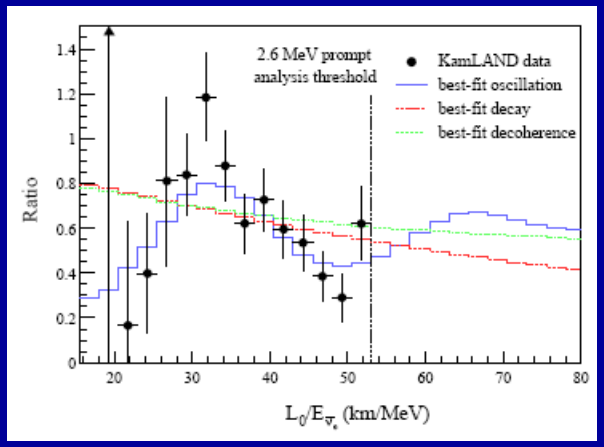
Switzerland
Bern
Neuchâtel
ETH Zurich

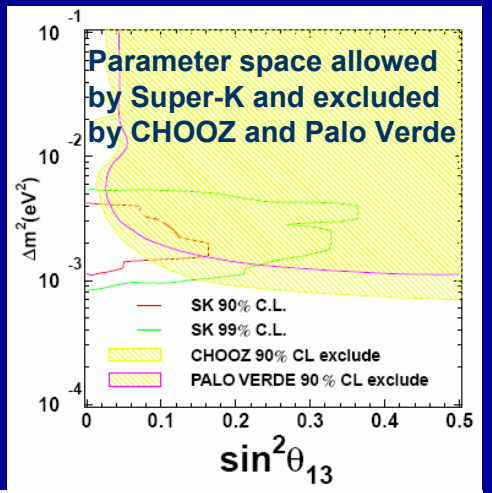
Tunisia
Tunis

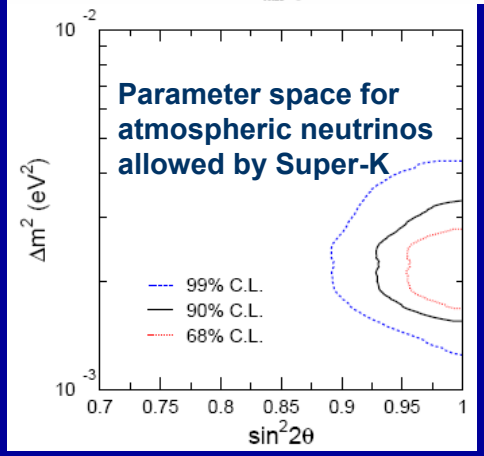
Turkey
METU Ankara

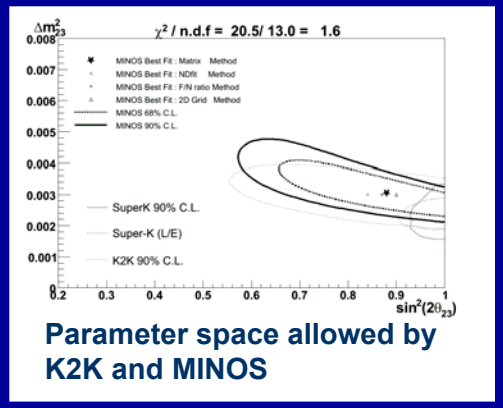
Physics Programme: compelling evidences of neutrinos oscillation at all available sources: Sun, atmosphere, LBL reactors & accelerators

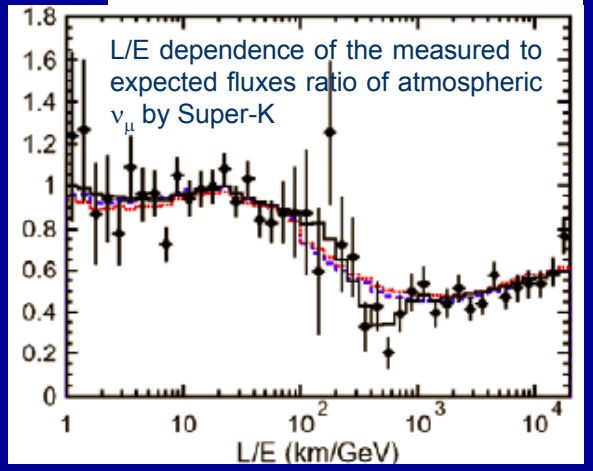












No evidence yet of flavour APPEARANCE tagged by identification of ℓ^- emitted in CC interaction

OPERA Main Physics Programme: tag the ν_τ appearance in a ν_μ beam by τ^- identification

Admitted dominant interpretation of ν_μ disappearance in the atmospheric sector (neglecting matter effects):

$$P\left(\nu_\mu \rightarrow \nu_\tau\right) \approx \cos\theta_{13}^4 \sin^2 2\theta_{23} \sin^2\left(1.27 \frac{\Delta m_{23}^2 \left[eV^2\right] L\left[km\right]}{E\left[GeV\right]}\right)$$

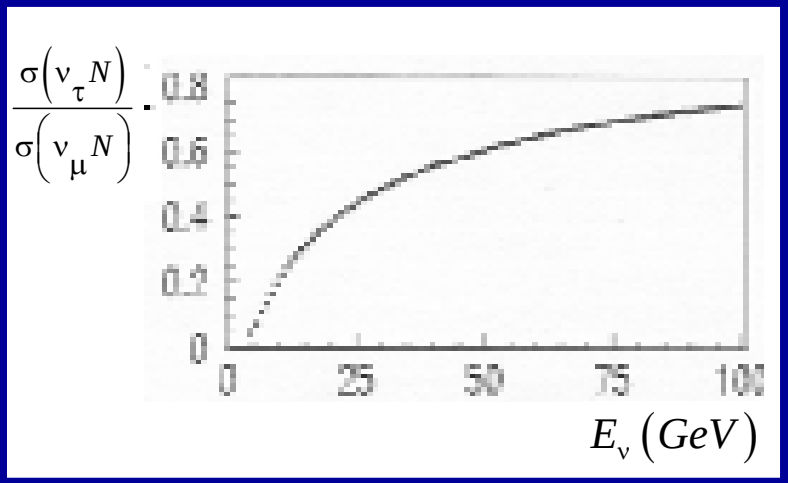
$$\cos\theta_{13}^4 \sin^2 2\theta_{23} \approx 1.$$

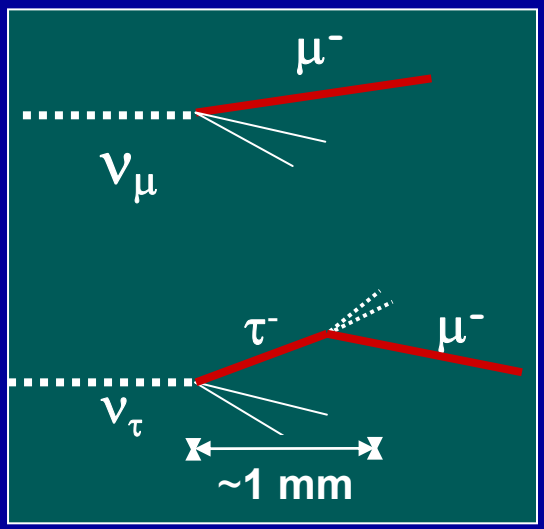
$$\Delta m_{23}^2 = 2.5^{+0.05}_{-0.06} \cdot 10^{-3} eV^2$$

Compatible with full $\nu_\mu - \nu_\tau$ mixing and no ν_e admixture in ν_3

Design an experiment – CNGS and OPERA - able to tag the ν_τ appearance in a ν_μ beam by τ^- identification

- $\langle E_\nu \rangle$ well above ν_τ CC threshold (6.3 *GeV*) for decent cross-section
- $\langle E_\nu \rangle / L$ not much different than Δm^2 for decent P_{osc}
- Massive target to collect enough events
- High spatial resolution to resolve the τ^- path length ≈ 1 *mm*
- Very low background not to dilute the expected low signal





OPERA Hybrid concept : Target cells

Target is an assemblage of elementary autonomous cells or "bricks"

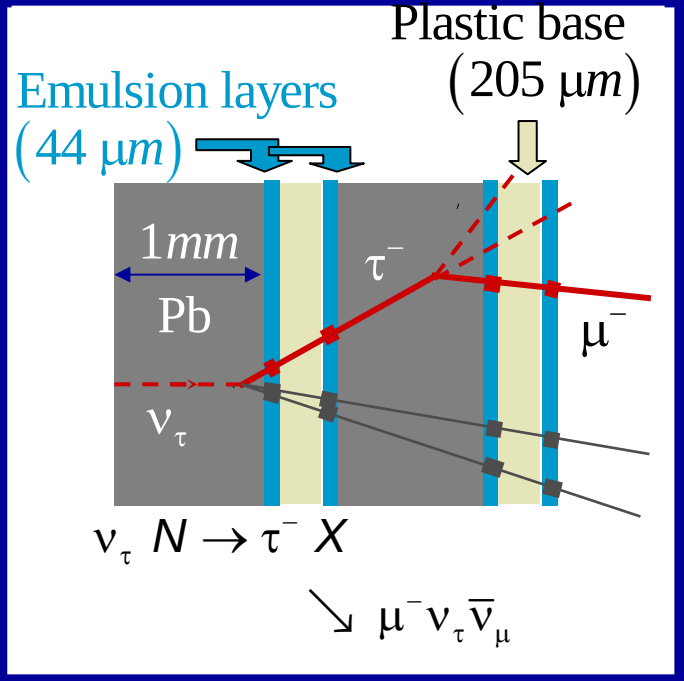
• based on "Emulsion Cloud Chamber" technique used by DONUT to observe directly the ν_τ

• provides large mass and micron and mrad precisions

• quasi on-line analysis : bricks in which events have occurred are removed and analysed on daily base - typically 25.

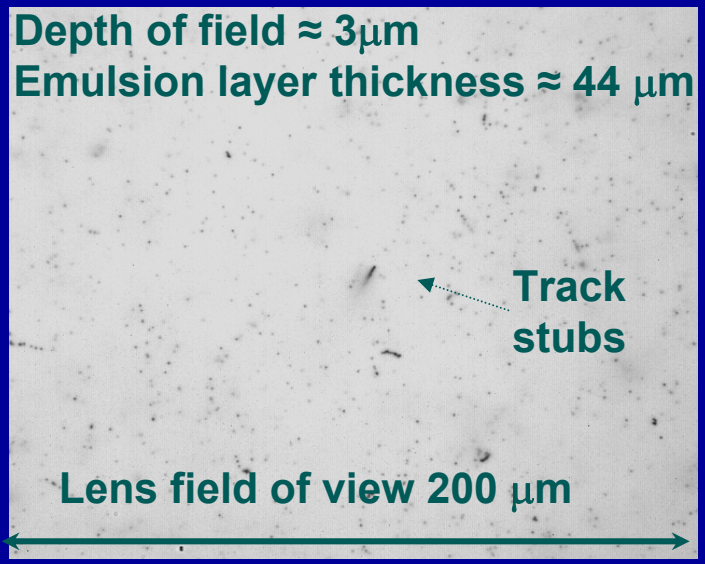
Brick

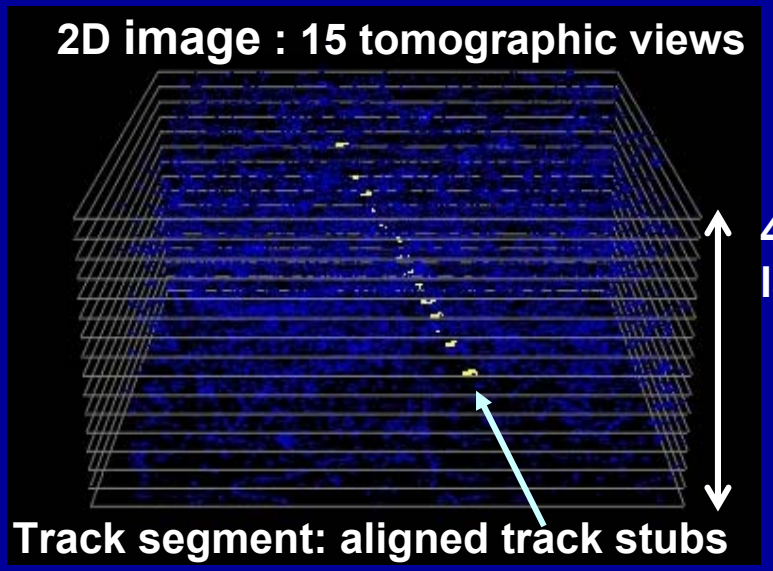
- **56 lead plates interleaved with 57 sheets of nuclear emulsion**
- ***4″×5″×7.5 cm*, 8.3 *kg*.**
- **10 X_0**

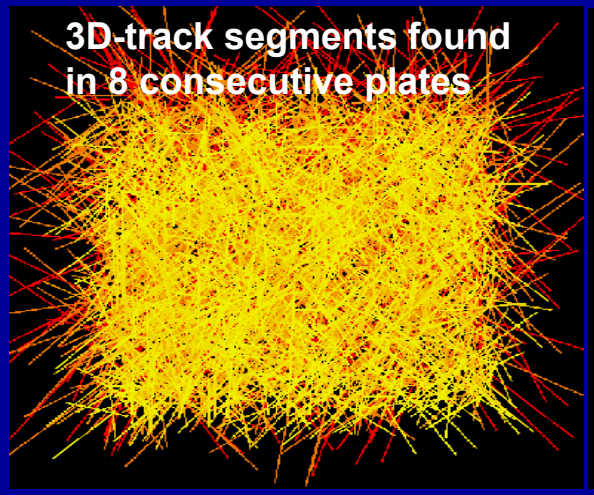


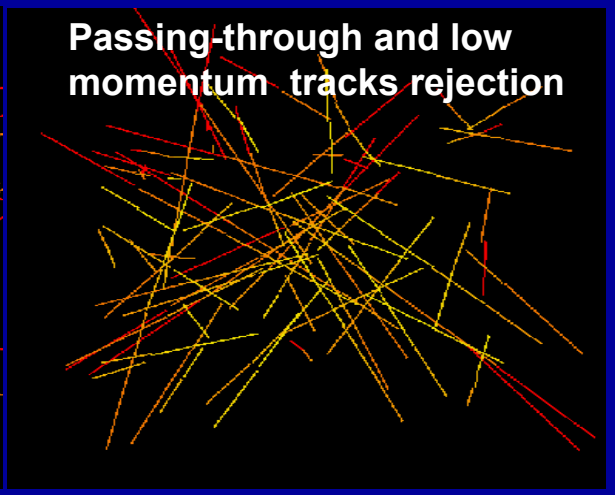
Tracks : series of aligned segments in emulsion layers

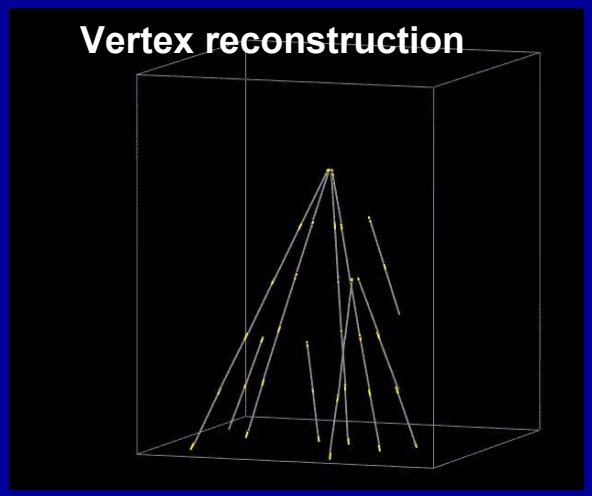
OPERA target : How to scan for tracks in an ECC



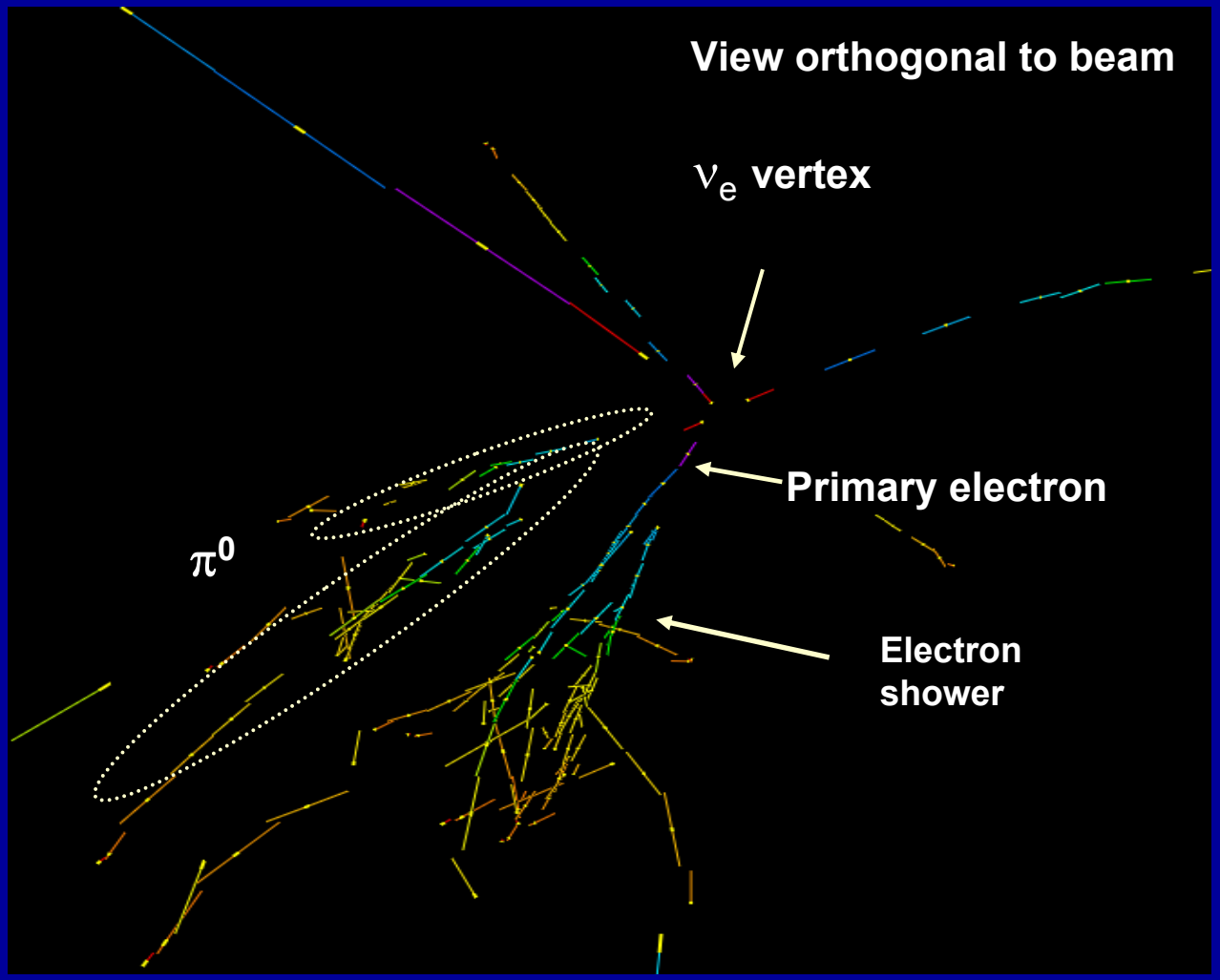








OPERA target : What you can see and reconstruct in an ECC



PEANUT rehearsal : bricks exposed to NuMI in front of MINOS near detector

Particle ID and kinematics in ECC : d*E*/d*x* (grain counting) and Coulomb multiple scattering

Particle ID

- $e^{\pm}$ / π^0 separation : electron tracks counting at vertex
- $e^{\pm}$ / $(\mu^{\pm}, \pi^{\pm})$ separation (CMS)

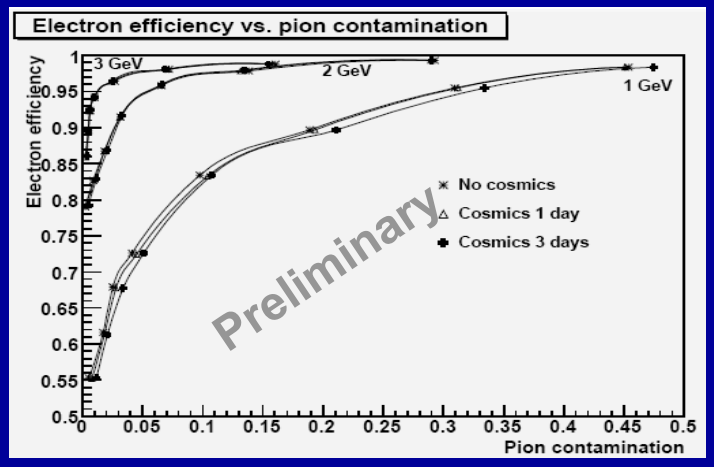
dE/dx : efficiency > 90 %, purity > 99 % above 2 GeV/c

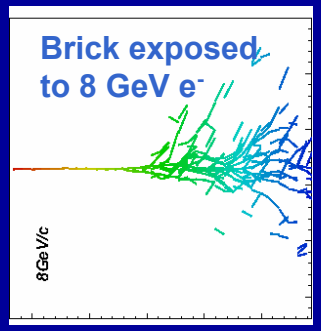
- $\mu^{\pm}$ / $\pi^{\pm}$ separation in brick where track stops (dE/dx and CMS)

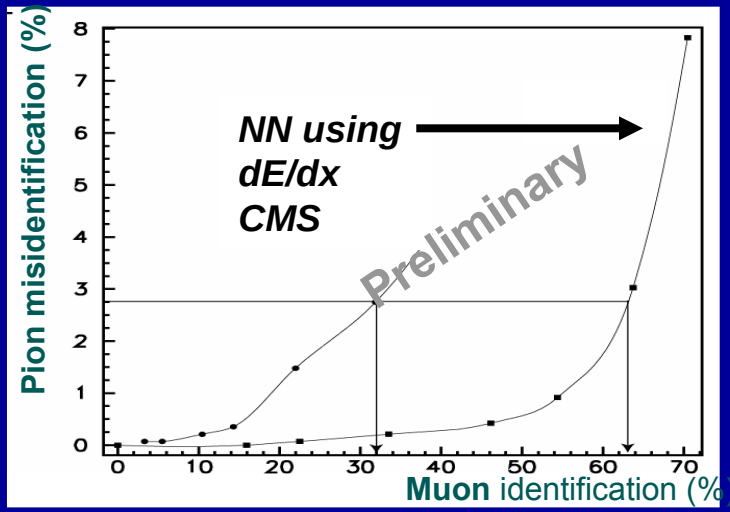
e.g. 65% μ efficiency, 3 % π misidentification

Kinematics

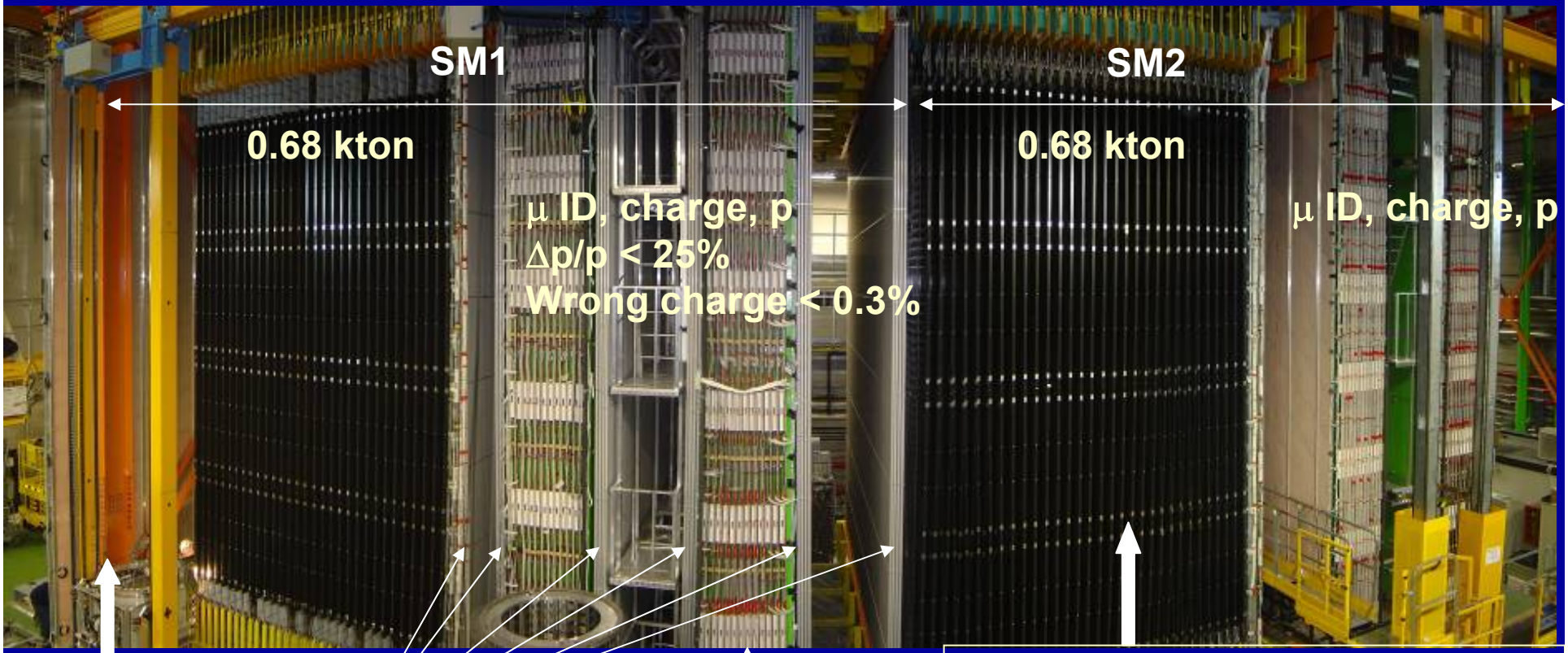
- $e^{\pm}$ energy from shower parametrization : $\Delta E/\sqrt{E} \approx 0.25$
- $\mu^{\pm}, h^{\pm}$ momentum (CMS) e.g. $0.25 < \Delta p/p < 0.30$ below 8 GeV/c







OPERA detector : Veto plane + 2 identical super-modules



Veto plane (RPC)

High precision tracker
- 6 4-fold layers of drift tubes

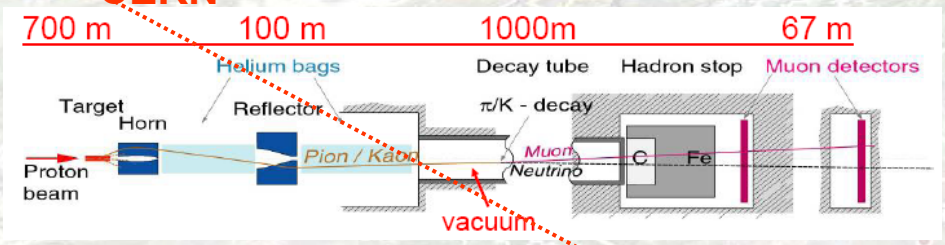
Instrumented dipole magnet
- 1.53 *T*
- 22 XY planes of RPC in both arms

Muon spectrometer (8×10 m^2)

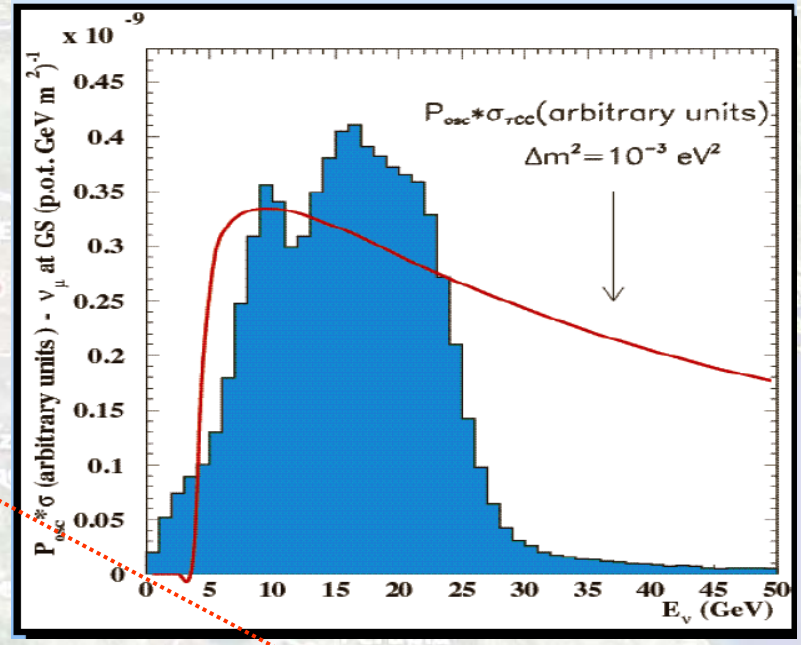
Target and Target Tracker (6.7m)^2

- Target : 77500 bricks, 29 walls
- Target tracker : 31 XY doublets of 256 scintillator strips + WLS fibres + multi-anodes PMT for
  - Brick selection
  - Calorimetry

CERN Neutrino beam to Gran Sasso *L*=730*km*



730 km



Energy spectrum maximizes

$$P_{osc}\left(\nu_\mu \to \nu_\tau\right) \times \sigma^{CC}_{\nu_\tau} \times \varepsilon_{\tau^-}$$

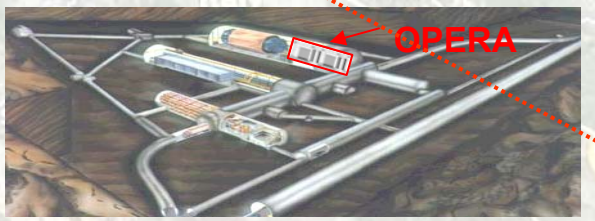
at $sin^2 2\theta_{23} = 1$; $\Delta m^2_{23} \approx 2.5 \cdot 10^{-3} eV^2$

given $L = 730km$

$$\frac{\langle E \rangle}{L} \approx \frac{17GeV}{730\,km} \approx 10\,\Delta m^2_{23}\left[10^{-3} eV^2\right]$$

Beam contamination

$\bar{\nu}_\mu$	4.1%
$\frac{\nu_e + \bar{\nu}_e}{\nu_\mu}$	0.9%
prompt ν_τ	negligible



LNGS

Overburden : 3800 m.w.e.

Cosmic muons flux : 1 m^{-2} $hour^{-1}$

Signal and background events
$\nu_\mu - \nu_\tau$ oscillation channel

τ^- decay channels	Signal ÷ $(\Delta m^2)^2$ – Full mixing		Background: Charm Hadron interaction Muon scattering
	$\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	$\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	
$\tau^- \rightarrow \mu^-$	2.9	4.2	0.17
$\tau^- \rightarrow e^-$	3.5	5.0	0.17
$\tau^- \rightarrow h^-$	3.1	4.4	0.24
$\tau^- \rightarrow 3h$	0.9	1.3	0.17
ALL	10.4	15.0	0.76

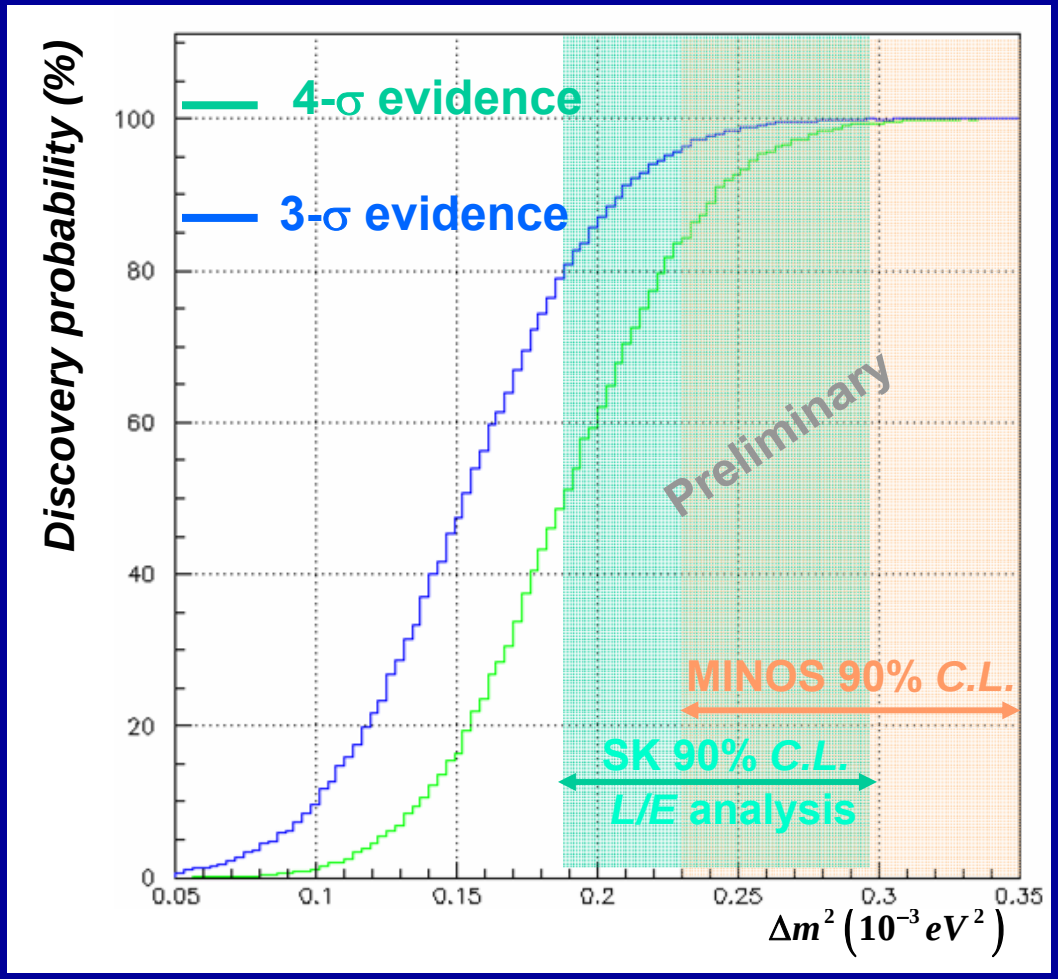
Preliminary

5 years of data taking

Nominal beam intensity $4.5 \cdot 10^{19}$ p.o.t. / year

1.35 *kton* target mass (25% reduction w.r.t. proposal)

OPERA Discovery probability vs. Δm^2



- 5 years of data taking
- Nominal beam intensity:

  $4.5 \cdot 10^{19}$ p.o.t. / year
- 1.35 *kton* target mass

OPERA Subsidiary Physics Programme : Improve CHOOZ upper limit on $\sin^2 2\theta_{13}<0.14$

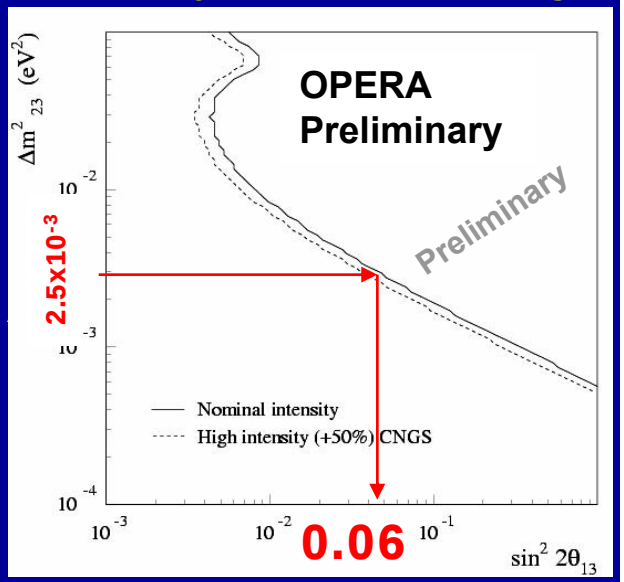
Possible subdominant interpretation of ν_μ disappearance in the atmospheric sector (neglecting matter effects):

$$P\left(\nu_\mu \rightarrow \nu_e\right) = \sin^2 2\theta_{13}\, \sin^2 \theta_{23}\, \sin^2\left(1.27\,\frac{\Delta m^2_{23}\left[eV^2\right] L\left[km\right]}{E\left[GeV\right]}\right)$$

$$\left.\begin{array}{l} \sin^2 \theta_{23} \approx 0.5 \\ \sin^2 2\theta_{13} < 0.14 \end{array}\right\} \text{Compatible with full } \nu_\mu - \nu_\tau \text{ mixing and small } \nu_e \text{ admixture in } \nu_3$$

$$\Delta m^2_{23} = 2.5^{+0.05}_{-0.06} \cdot 10^{-3}\, eV^2$$

Inherent limitation :
Intrinsic 0.9 % ν_e background in ν_μ beam



2006 CNGS run with empty target: time structure

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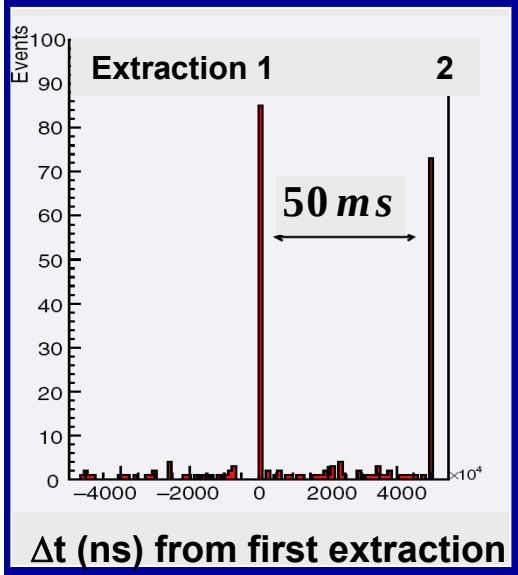
- August : $7.6 \cdot 10^{17}$ pot during 13 days = 5 days nominal intensity
- November : $0.6 \cdot 10^{17}$ pot during 25 hours interrupted by major water leak in beam reflector



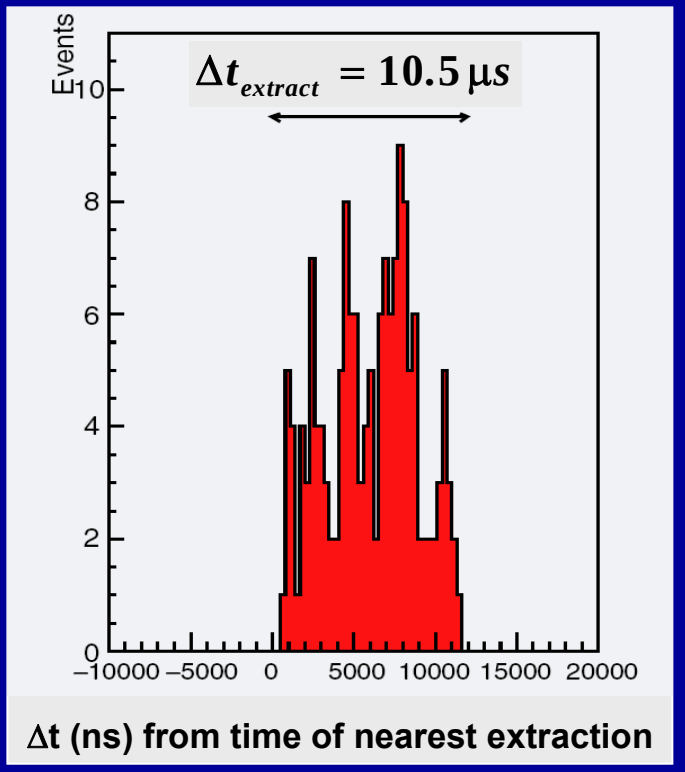
On-time event :

$$t_{LNGS} - \left(t_{SPS} + TOF\right) < \Delta t_{extract}$$

$$TOF = 2.44\,ms$$

$$\Delta t_{extract} = 10.5\,\mu s$$

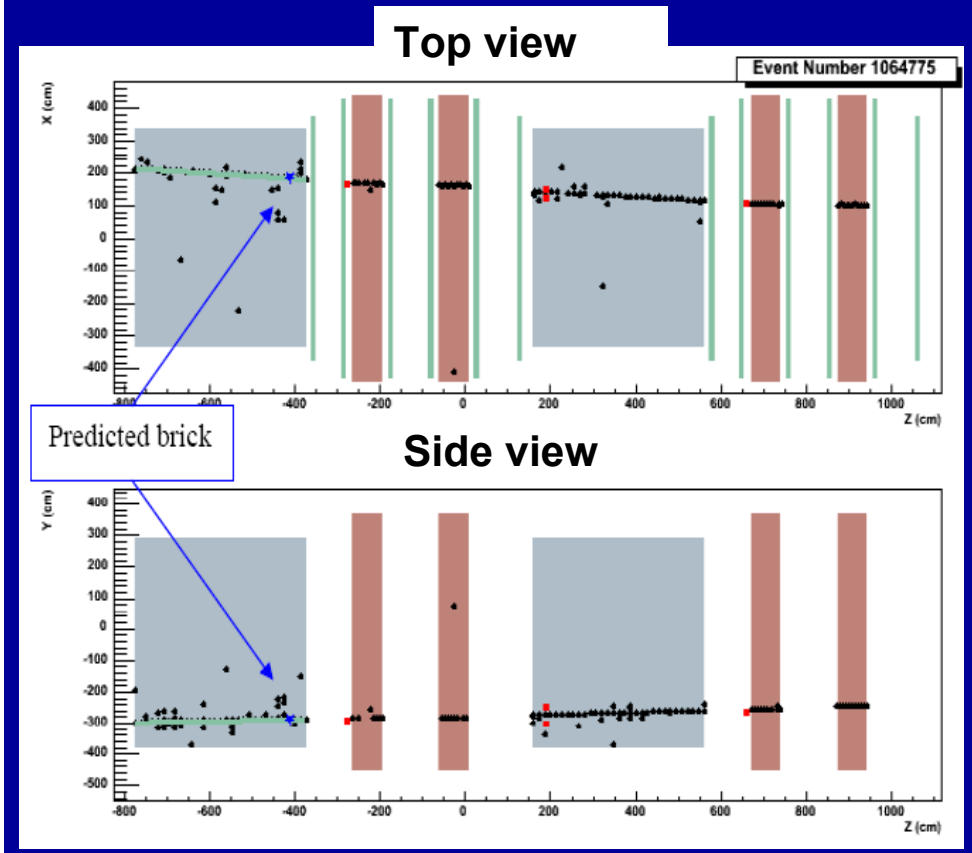
Clocks synchronized by GPS



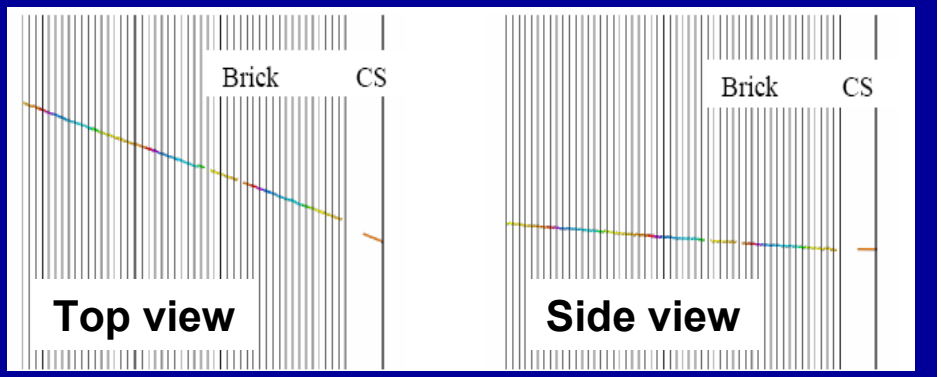
319 beam events observed
300 expected from beam intensity
Cosmic background in extraction gate : 10^{-4}

2006 CNGS run: details of a muon track from a CC event in the rock in front of OPERA

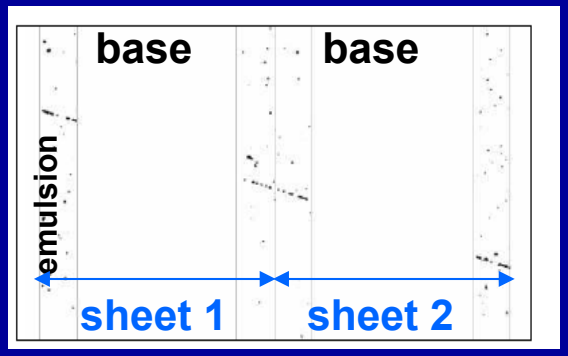
In the electronic detectors



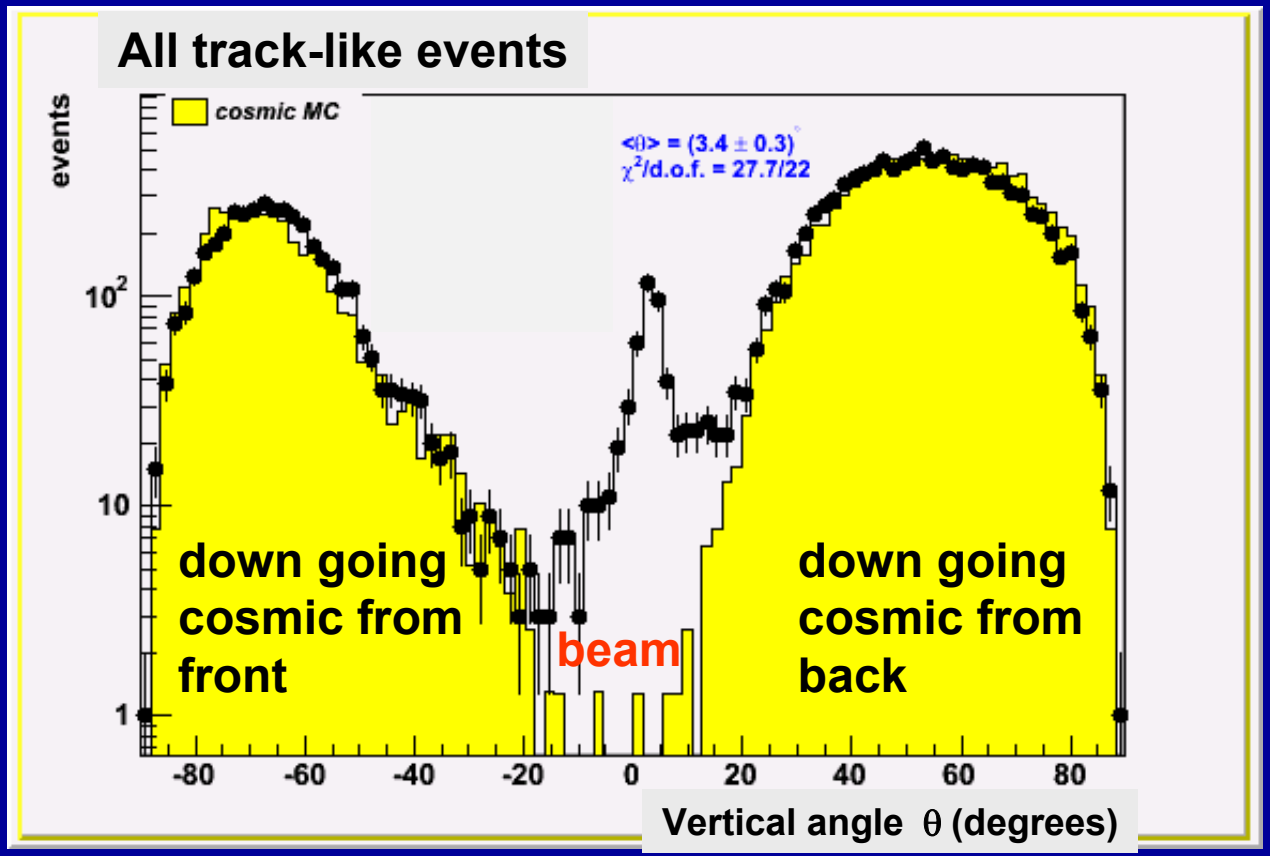
In the brick



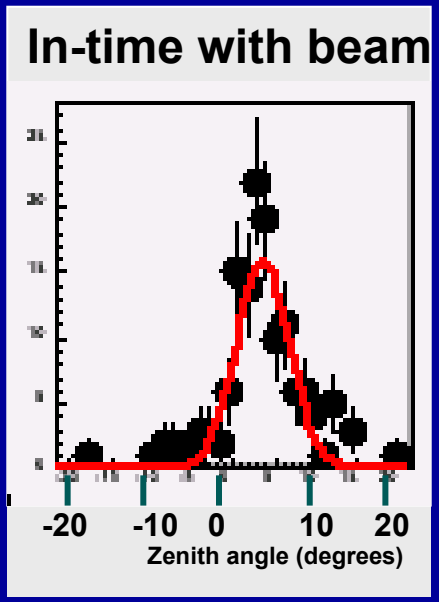
Inside emulsion sheets doublet attached to the back of the brick



2006 CNGS run: angle w.r.t. horizontal



- data : cosmic + beam
- absolute cosmic MC



θ expected from beam geometry: 3.3°

$\langle\theta\rangle = 3.4° \pm 0.3°$

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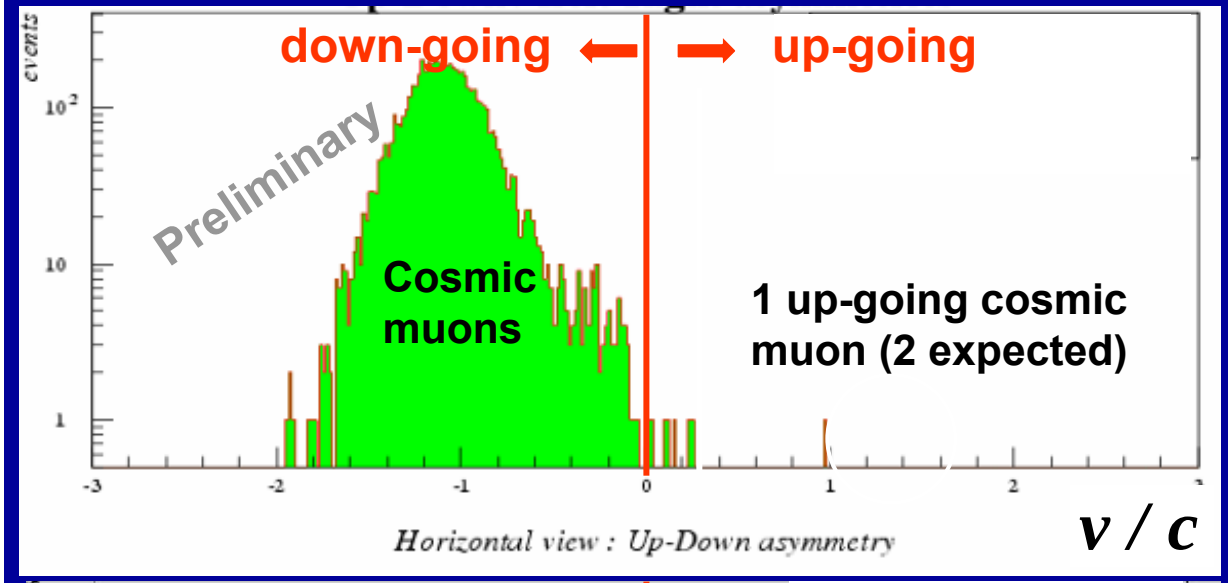
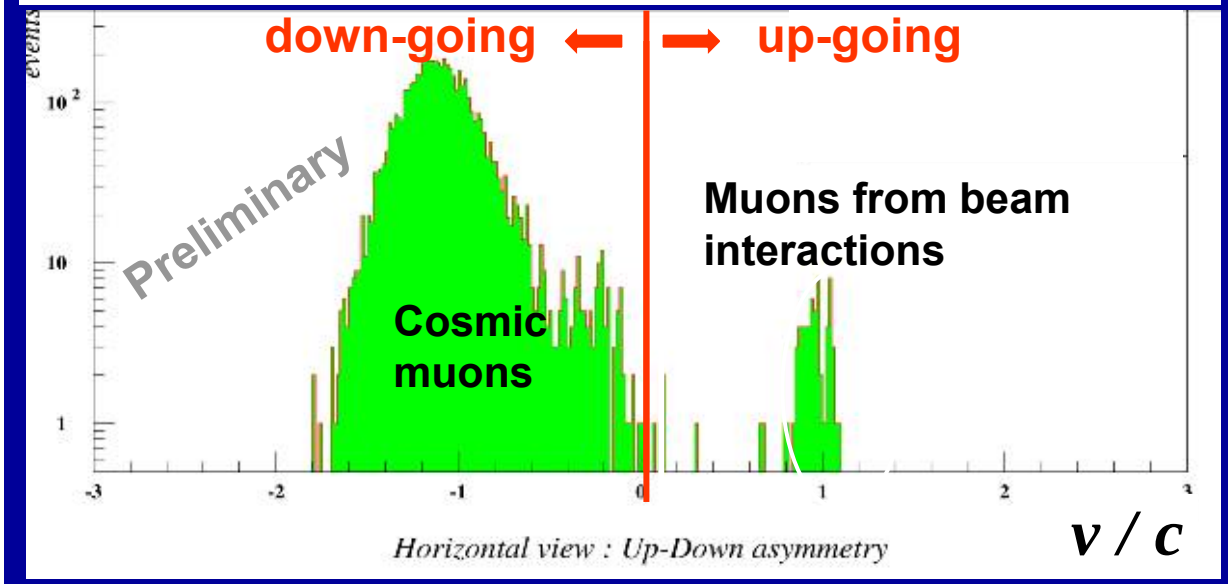
2006 CNGS run: using muon hits time information



Resolution = 10 *ns*

Cosmic run

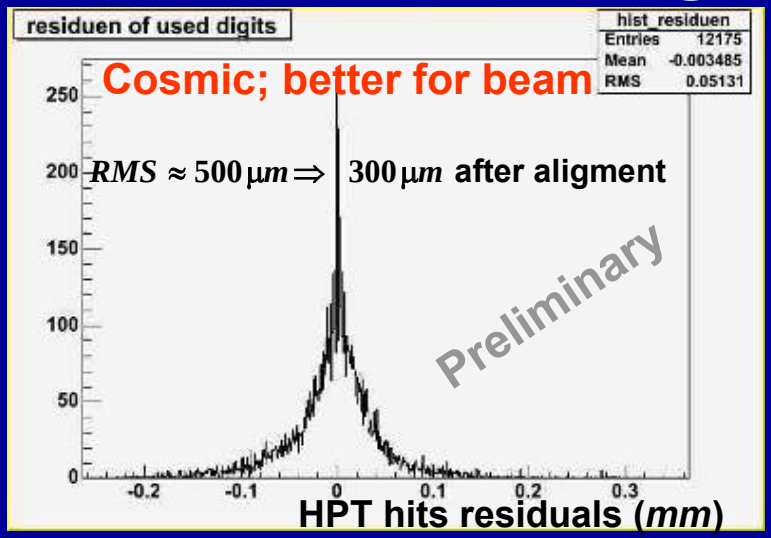


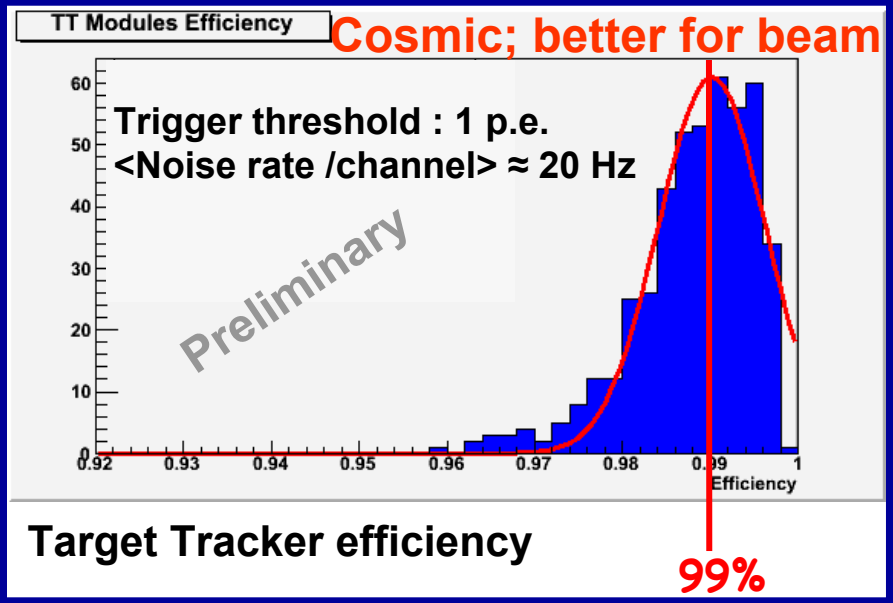
During August beam run:
Beam + Cosmic

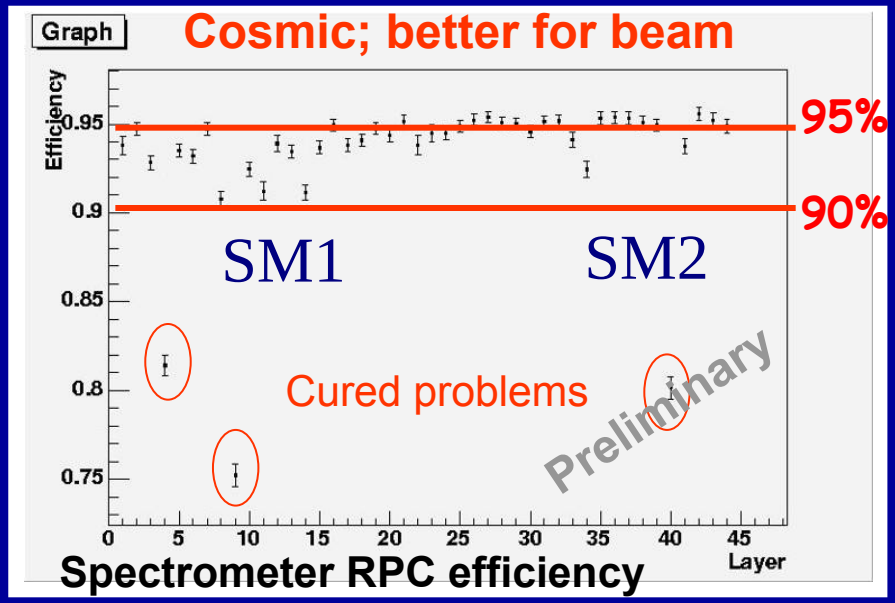
Electronic detectors status and commissioning

All electronic detectors commissioned but
- **2 HP drift tubes layers to be commissioned in Summer 2007.**
- **RPC veto plane to be commissioned in Summer 2007.**

DAQ and slow control operational and being fine tuned.

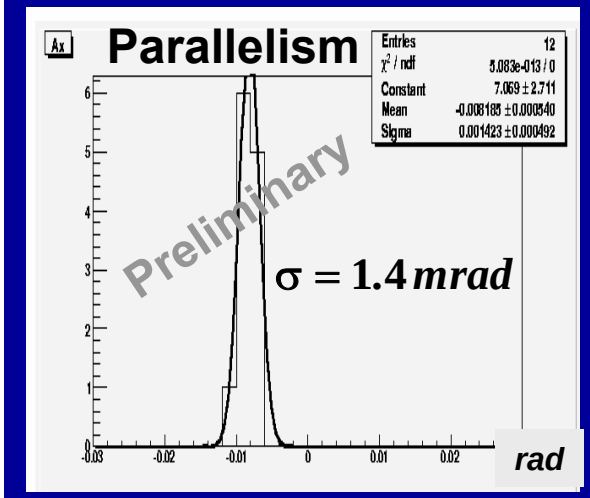


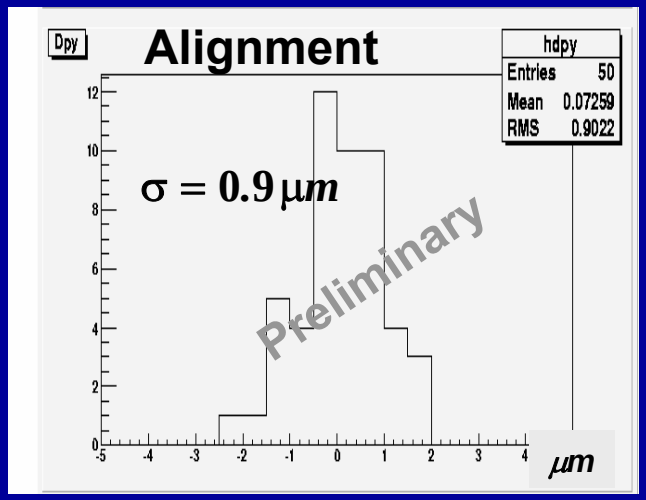




Commissioning: Brick geometrical quality and tracker to brick connection using cosmic rays

Emulsion sheet to sheet

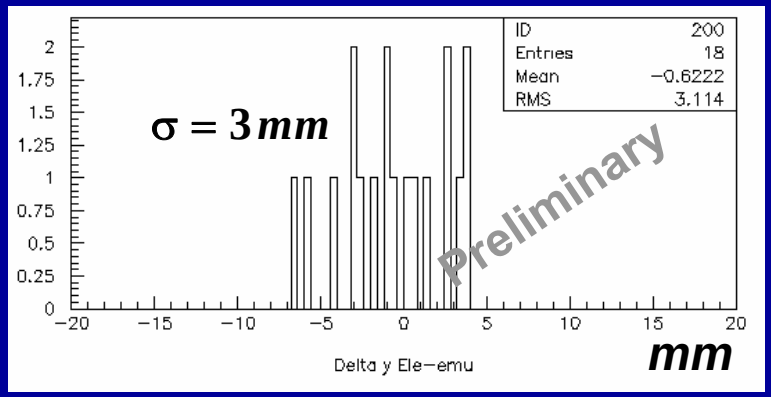




Precision required to
- **measure *p* by CMS**
- **detect small angle 1-prong τ^- decays**

Vertical track position difference between prediction by target tracker and measurement in emulsion.

Prediction quality :
- **efficient brick selection**
- **fast track finding in emulsion**

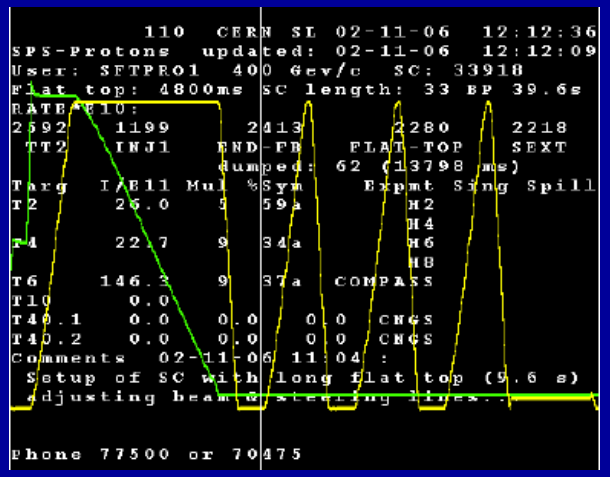


Autumn 2007
CNGS Commissioning and Physics RUN

3 weeks of CNGS commissioning run + 3 weeks of physics run following June CERN SPSC recommendation

- **If intensity as in August 2006 : 1.7 10^{13} pot/extraction (70% nominal)**
- **If extraction scheme as in November 2006: 3 double fast extraction per 36 s SPS cycle**
- **If typical 70 % efficiency of the machines complex**
- **If target filling programme as scheduled**

Target mass	**505(37%) → 615(46%) *tons***
Beam intensity	**0.43 · 10^{19} pot** **≈ 10% nominal year** **≈ 10 × flux in 2006**
Events in bricks	**180**
Charm events	**10**



Summary as Conclusions

- **Electronic detectors commissioning completed during summer 2007 and performances according to specs.**

- **Target tracker to brick connection and brick intrinsic geometrical quality according to specs.**

- **Brick production rate reaching cruse speed and completion of target filling expected in phase with CNGS beam availability in 2008.**

- **2006 run very useful rehearsal despite major early beam fault during November run.**

- **6 weeks of beam run in autumn 2007 including 3 weeks of physics run: 180 events in bricks expected including 10 charm; full size test of the detector and the analysis chain.**

- **More will be learned on the EEC technique after wide variety of test runs during summer 2007.**