OPERA
first events from
the CNGS neutrino beam

J.MARTEAU, IPNL-IN2P3,
on behalf of the OPERA collaboration

XLII Rencontres de Moriond
Electroweak session, La Thuile, March 10-17, 2007

1. The OPERA experiment

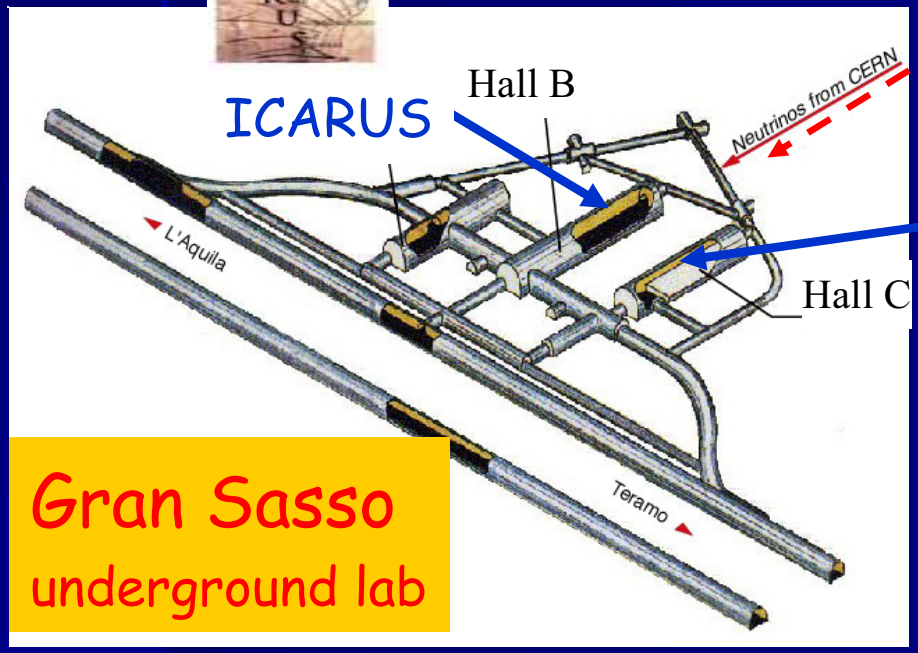
The CNGS project

- Search for ν_τ appearance in the CNGS ν_μ beam
- Validation of the $\nu_\mu \rightarrow \nu_\tau$ hypothesis
- in the "atmospheric" sector
- Secondary oscillations $\nu_\mu \rightarrow \nu_e$ search

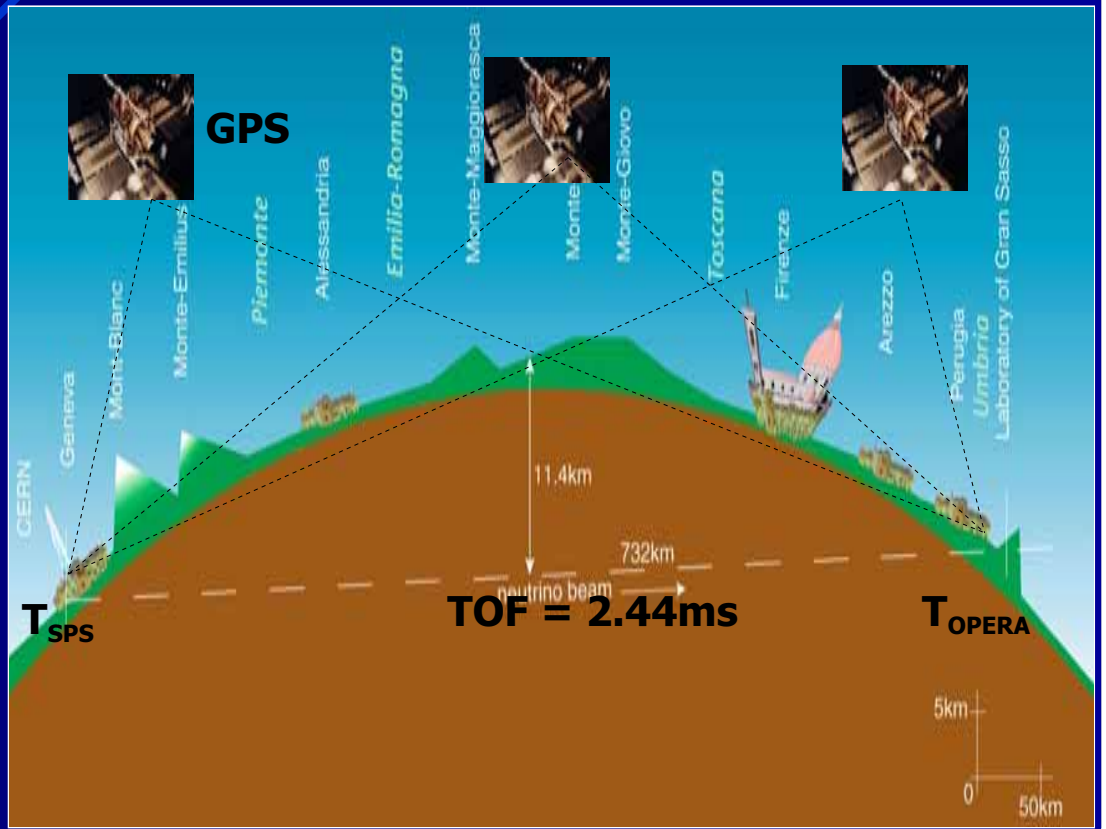
CERN (730 km) (1999)

ν

(2002)



OPERA (CNGS1) (2000)



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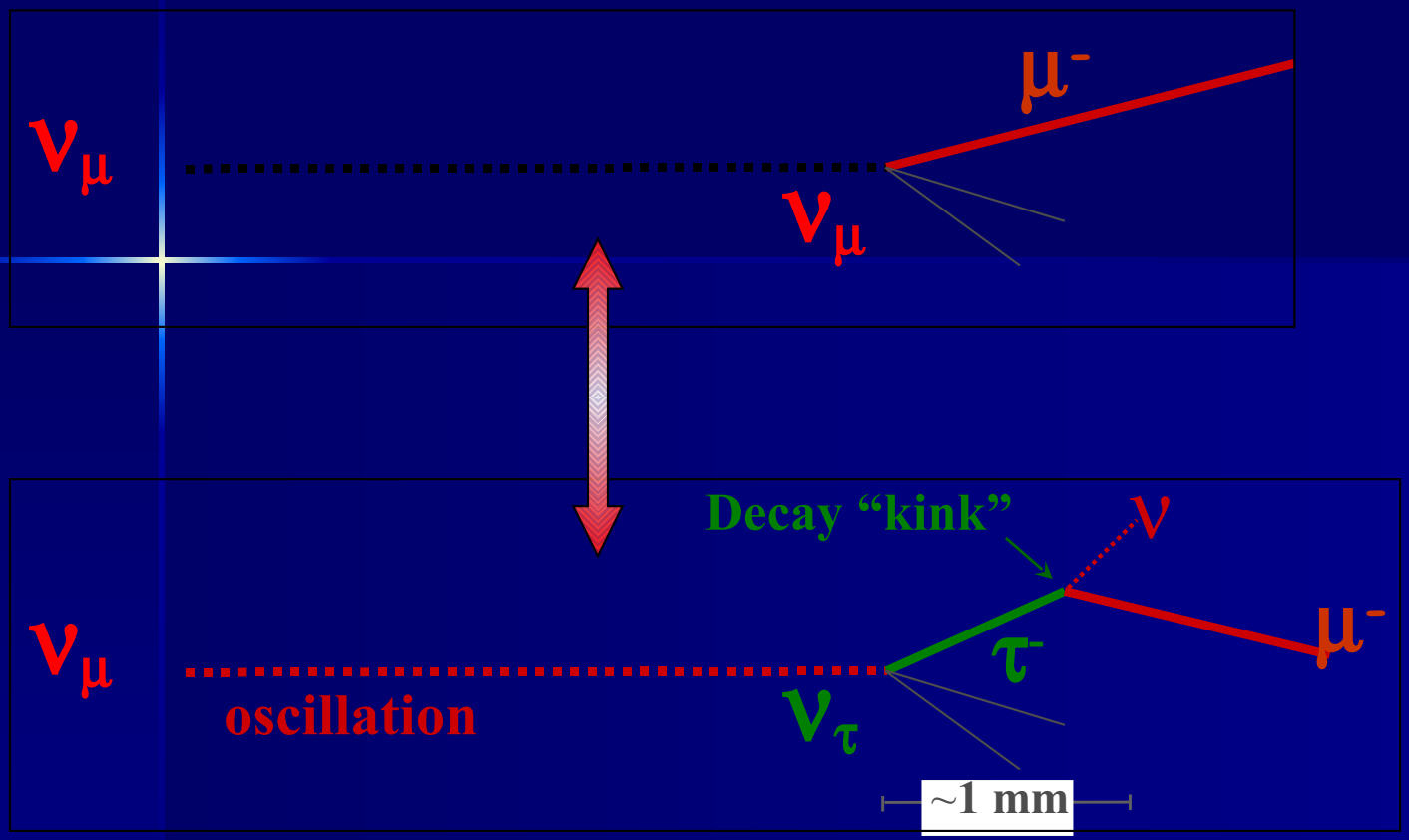
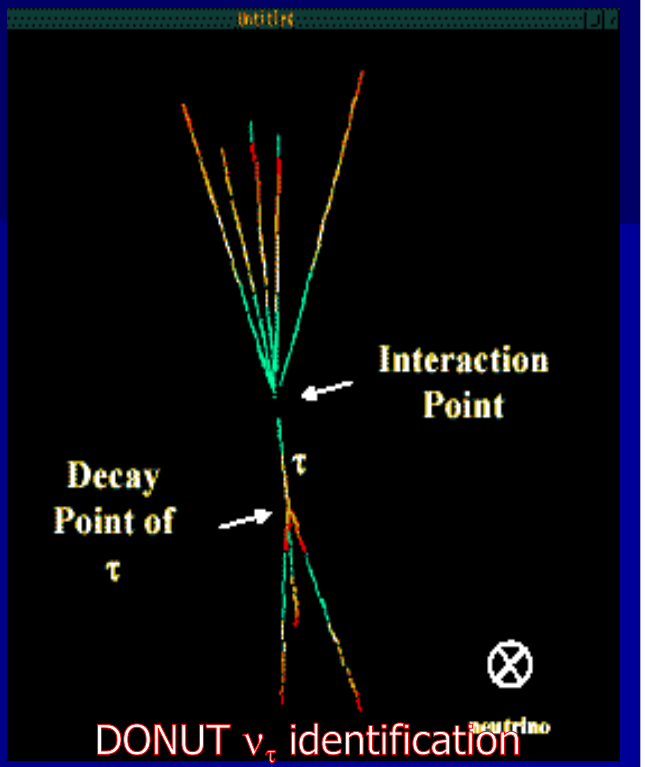
Events topological signature





DONUT ν_τ identification

2 contradictory requirements:

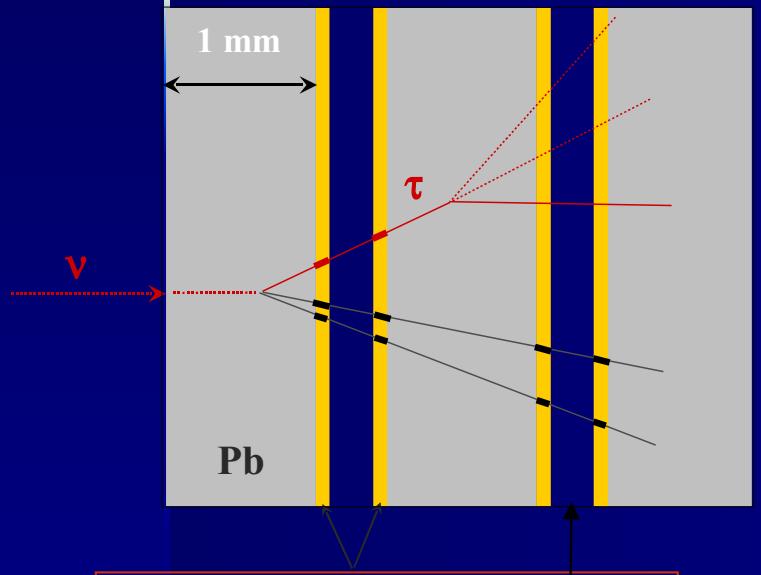
- Low X-section ⇒ high mass
- High granularity
  - signal identification
  - background rejection

Target :1800 tons, 5 years running

- **30 000 neutrino interactions**
- **~150 ν_τ interactions**
- **~15 identified ν_τ**
- **< 1 background event**

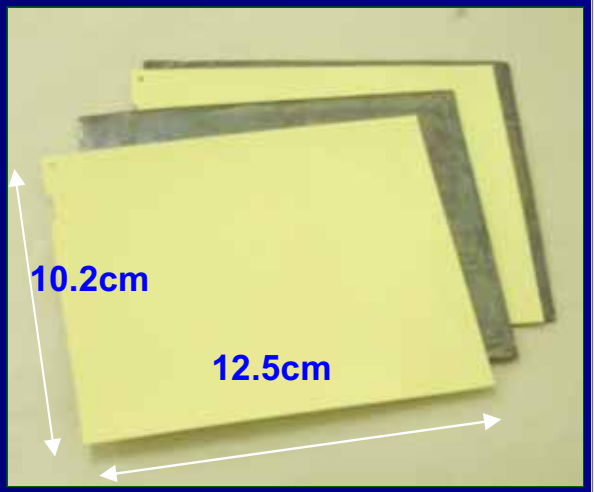
Nuclear emulsions technology

- "Emulsion Cloud Chamber" (DONUT)
- 56 Pb + 57 emulsions sheets
- Emulsions : spatial resolution
- Compact and modular structure
- CS doublet for event prediction

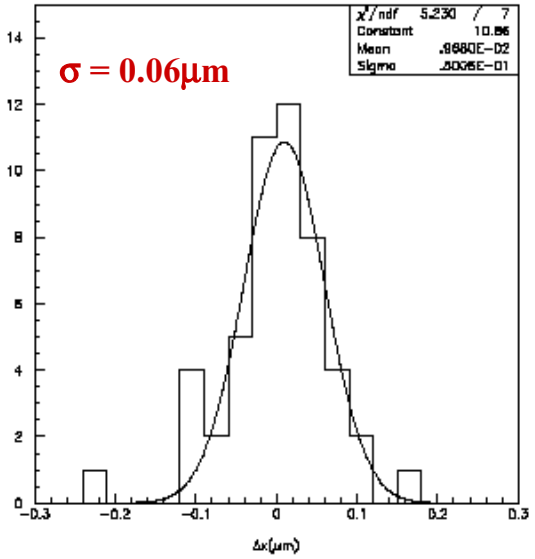


2 emulsion layers
(44 μm thick)
poured on a
200 μm plastic base

υ Interaction
From NUMI exposure



intrinsic tracking accuracy



- ν interaction vertex search
- kink topology reconstruction
- MCS momenta measurement
- dE/dx e/π separation at low E
- e id. and e/γ E measurement

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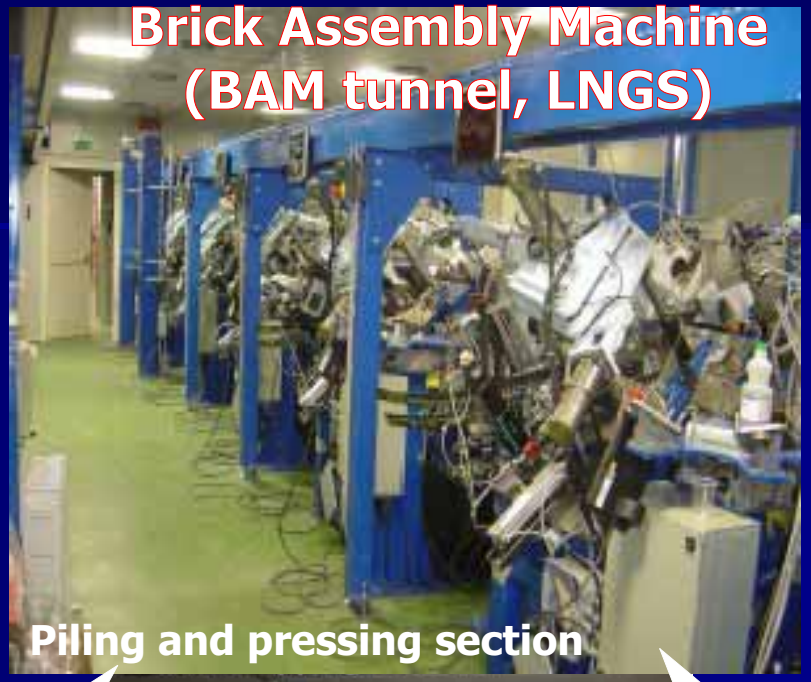
Bricks elements & production

Lead production (JL Goslar, Germany)

Lead storage (LNGS)

Brick Assembly Machine (BAM tunnel, LNGS)



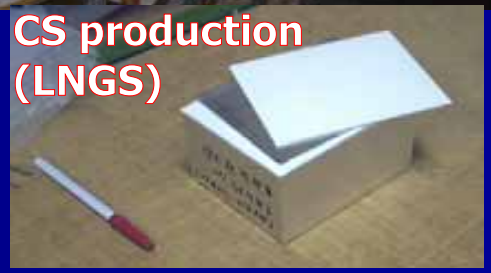
Piling and pressing section

Wrapping section

Emulsion refreshing (Tono mine, Japan)

Emulsion storage (LNGS)

CS production (LNGS)



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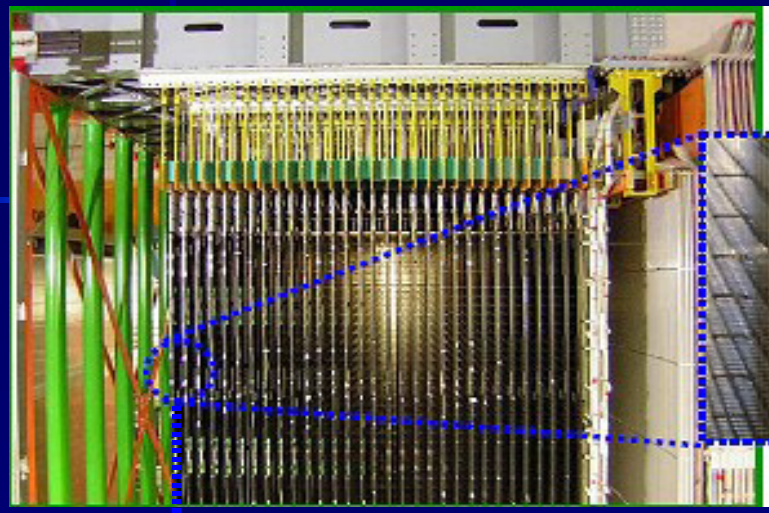
Bricks finding & manipulation

- With bricks one builds walls…



The target structure contains the bricks.
31target layers per supermodule

1 target layer is made of:

1 brick wall (52x64 bricks)

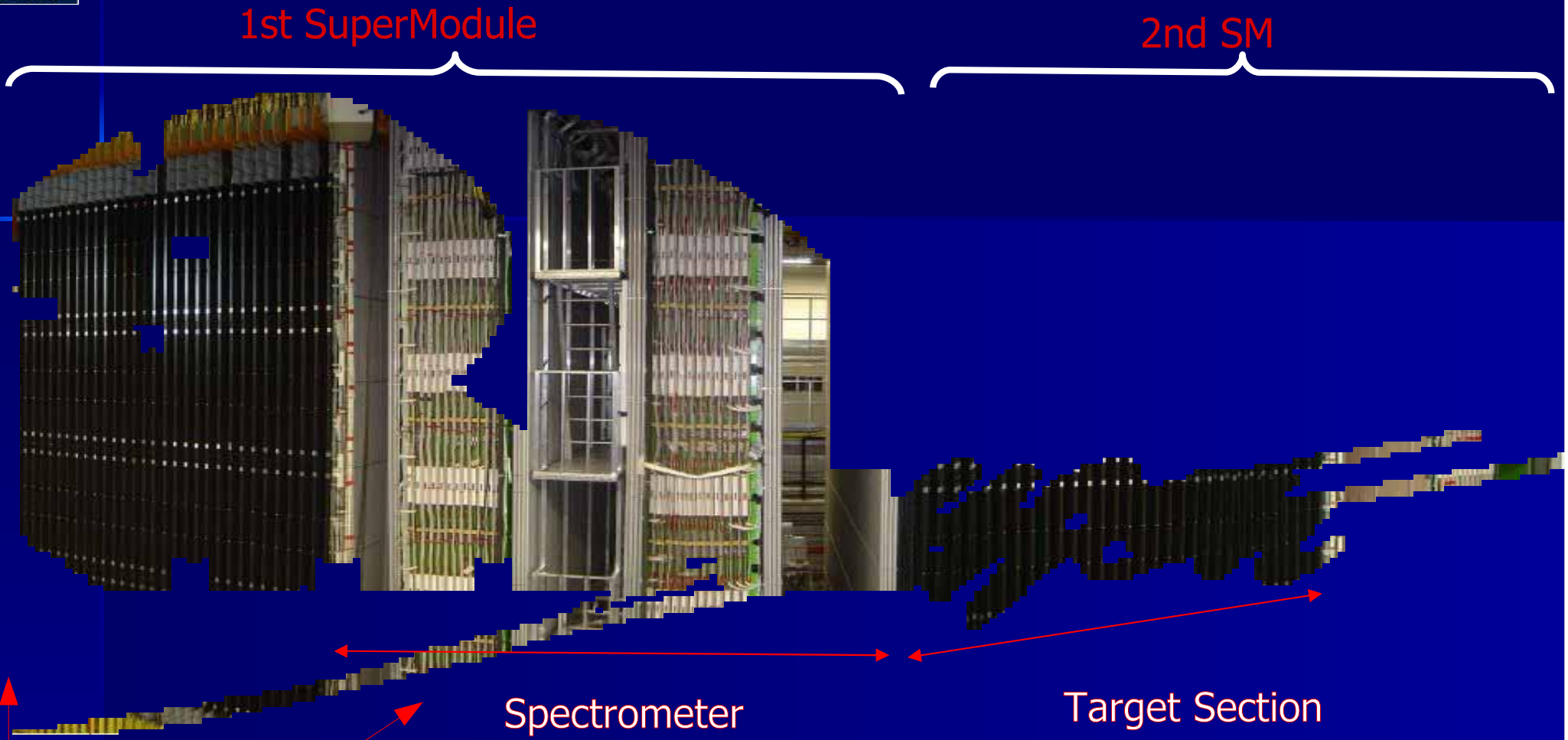
1 scintillator detector plane (target tracker)

1st brick wall under filling

Vacuum sucker vehicle

Brick Manipulating System (BMS)

The OPERA detector



- T.T. : trigger, neutrino interactions localization (brick finding), kinematics
- Spectrometer : μ id., charge and momentum measurement
- Bricks : ν vertex id., decay kink search, kinematics, e/π sep., e/γ E meas.

The OPERA detector construction

September '03

September '04

November '05

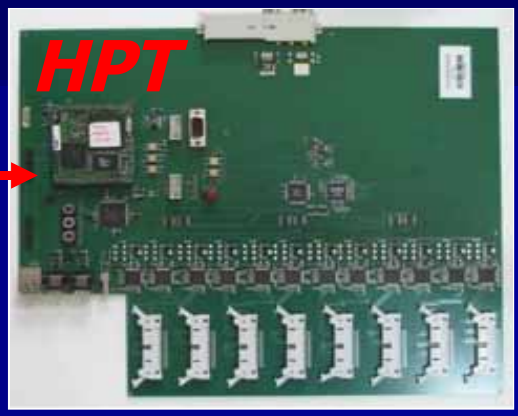
- Today : all electronic detectors commissioned and running since '06 except Veto (march '07) and HPT 2nd SM (1st half '07)
- General DAQ and GPS clock distribution running
- On-line software and DB schemes commissioned

2. Data taking and analysis

DAQ general features

➢ The distributed DAQ is based on Ethernet. Each sensor (1200) is seen as a node in a Gigabit standard network. The basic "element" of the system is a daughter board ("mezzanine") embedding FPGA, FIFO, μ–processor (AXIS)

R/O: RPC tracker



R/O: drift tubes

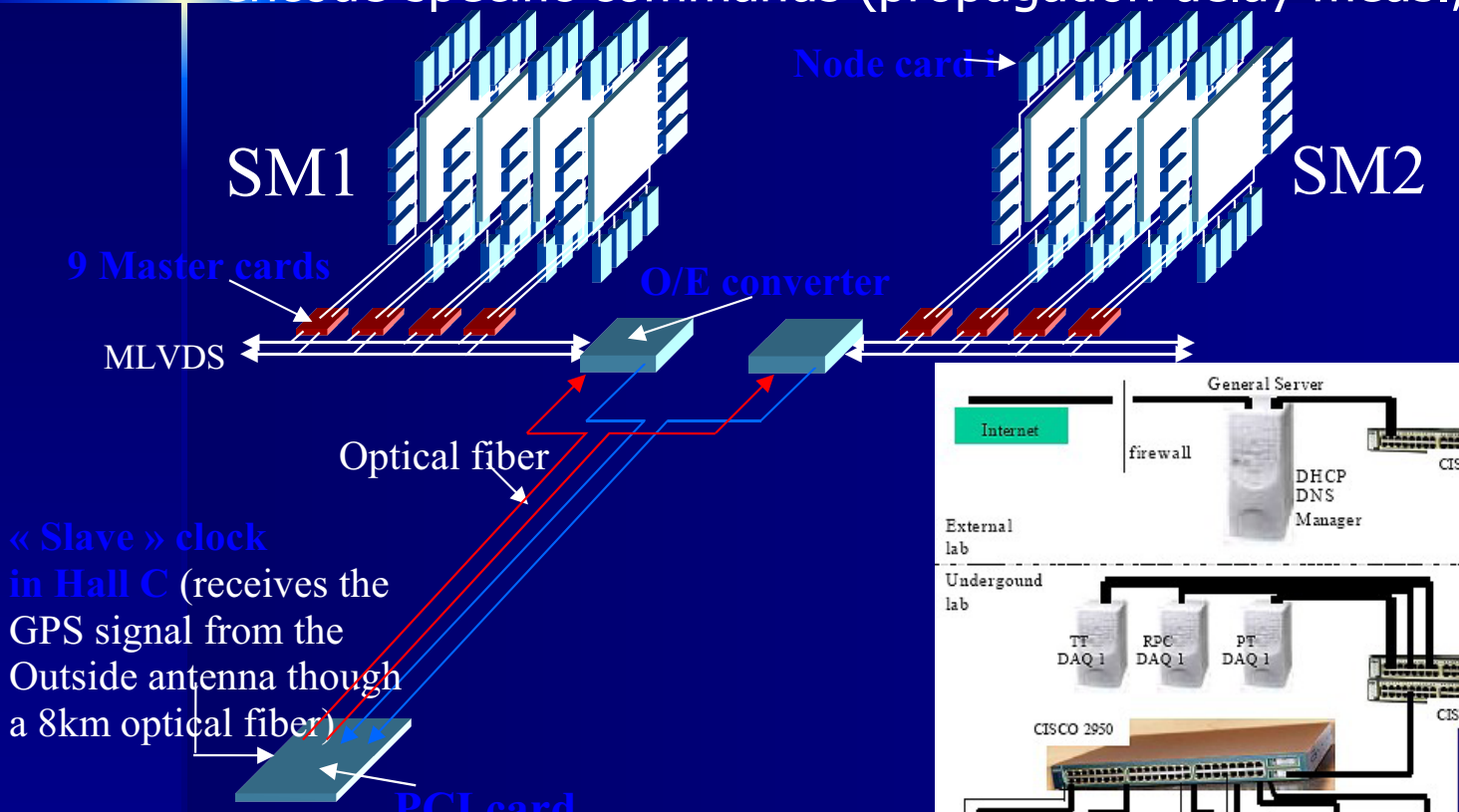
R/O: scintillator + WLS fibres + MaPMT

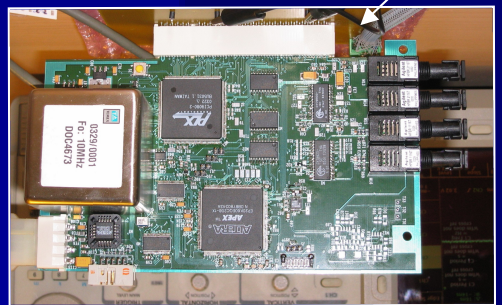
➢ The client/server protocol used relies on the CORBA standard implemented in C++ with interfaces into postgreSQL and Oracle database.

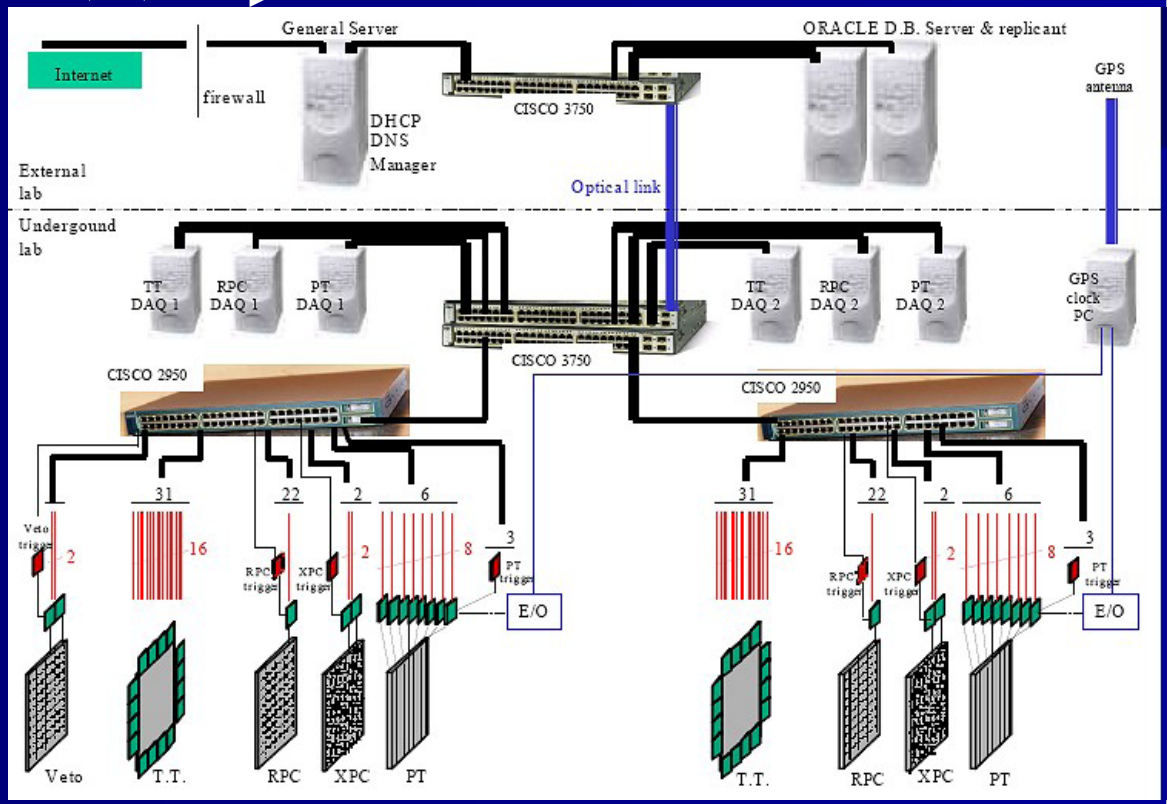
This software is completely object oriented and uses the Interface Description Language (IDL) to describe the distributed objects independantly of the programming language. InterORB protocols guarantee interoperability.

Clock distribution & network architecture

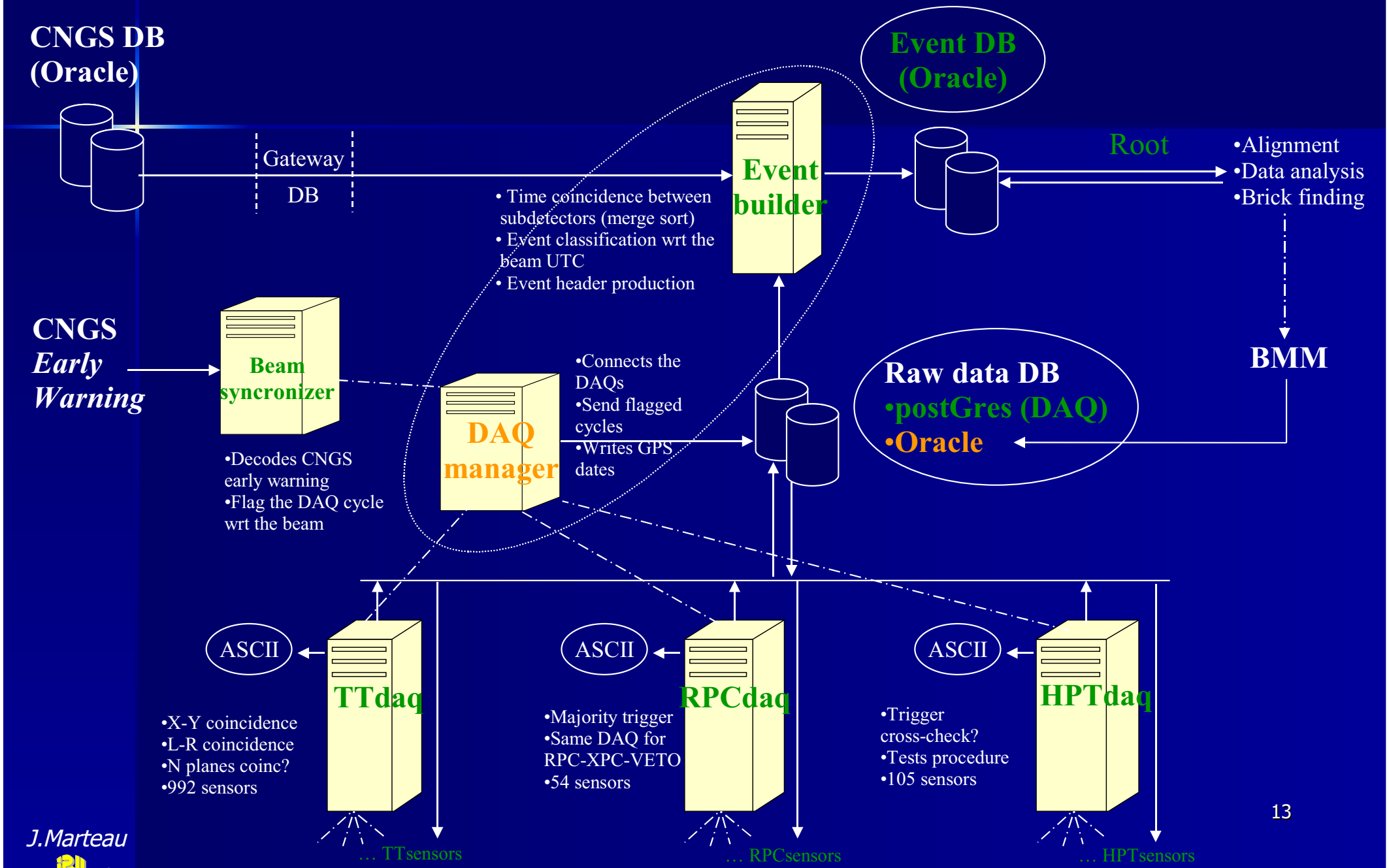
➢ Each individual node runs a local 100MHz clock generated via a common 20MHz clock send from a precise and stable oscillator. The oscillator is plugged onto a dedicated PCI board which locks the clock signal on the GPS and encode specific commands (propagation delay meas., reset, reboot etc).





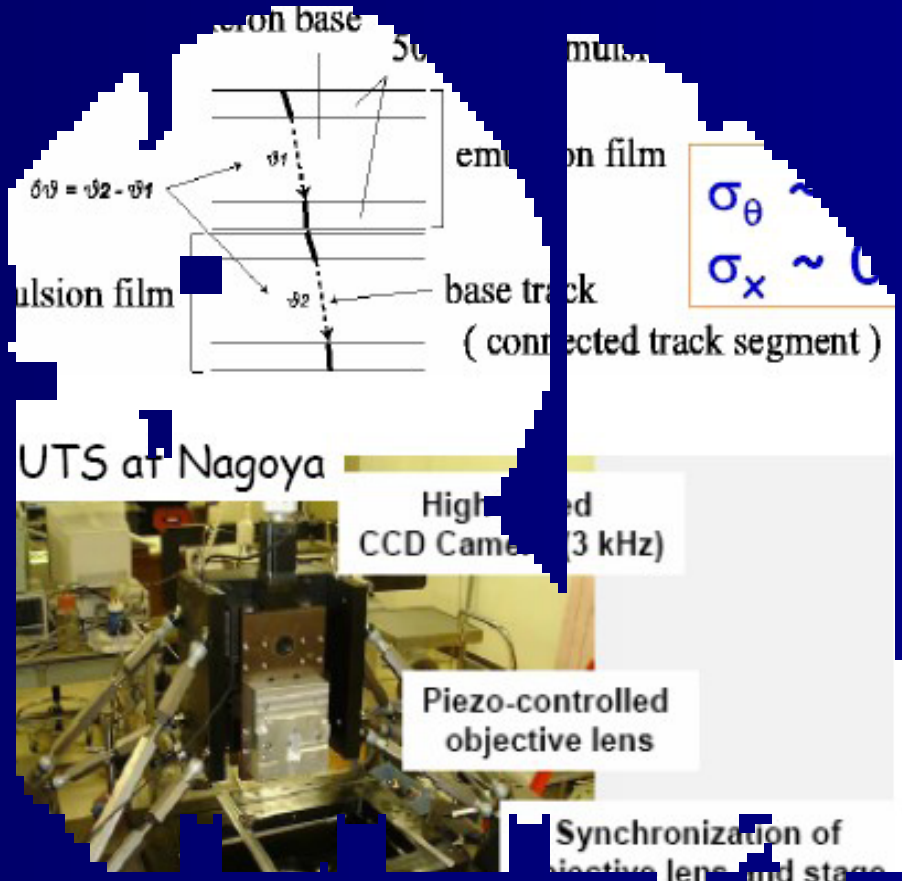


On-line software



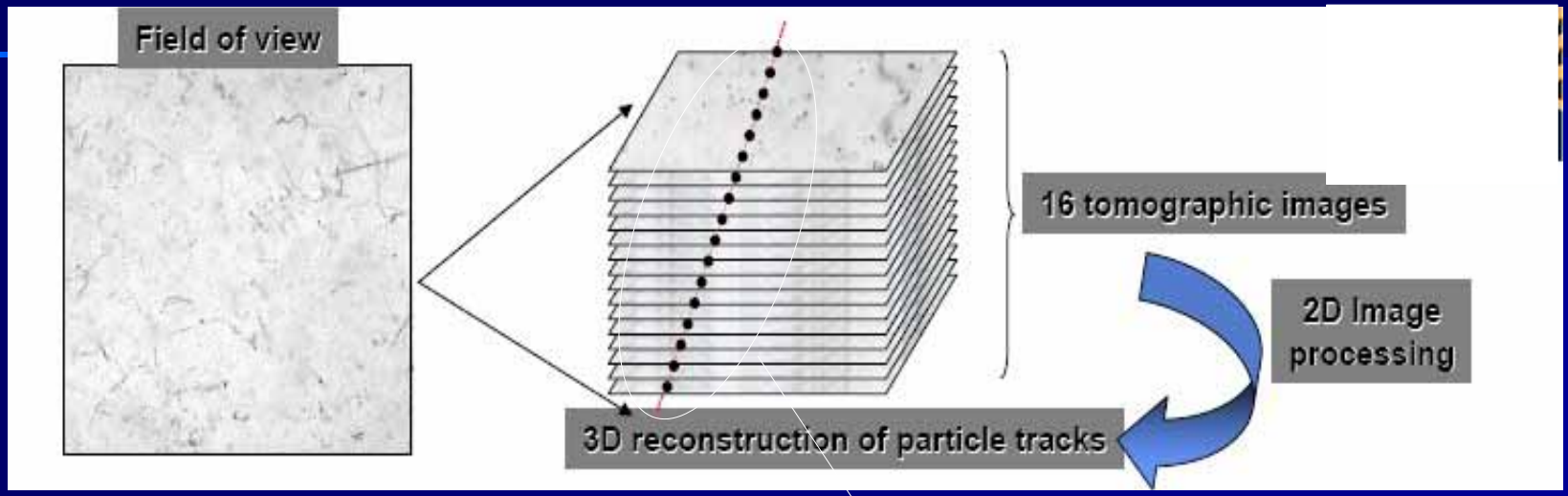
Off-line emulsion scanning

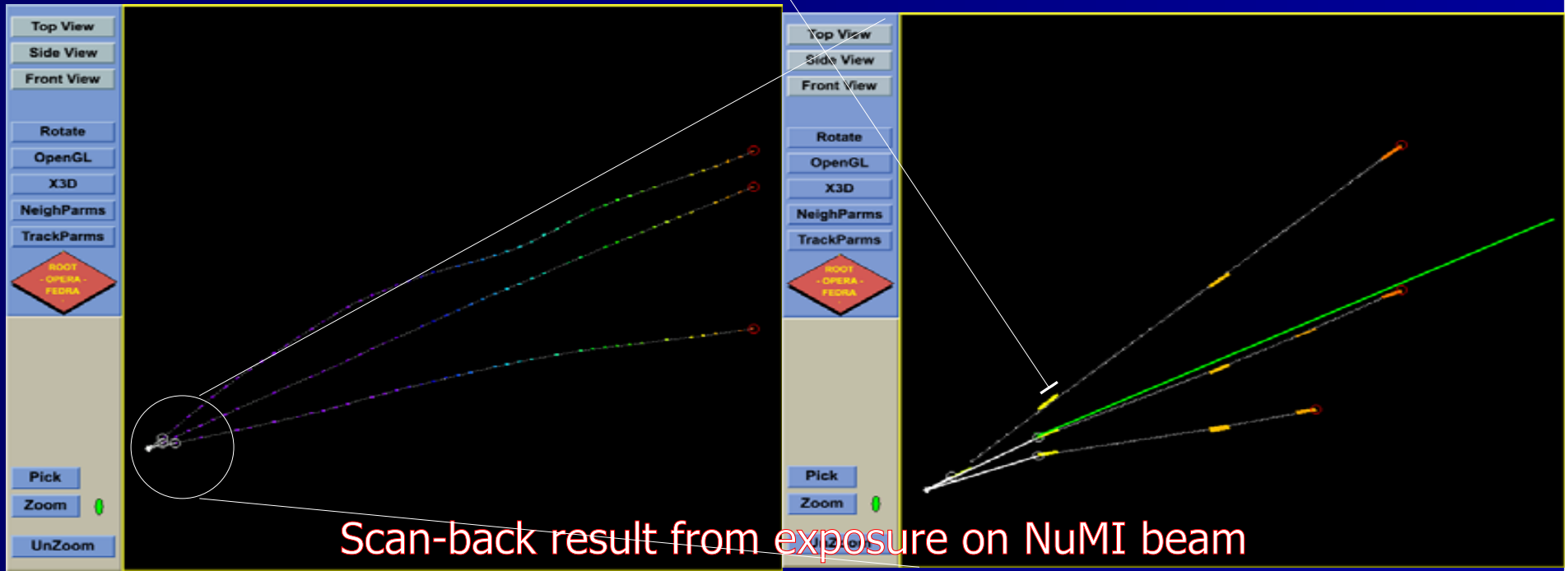
Two different systems (both operational) are running for scanning systems : "hard"-coded oriented (Japan) or "soft"-coded oriented (Europe).
Both systems are ready and working at more than 20cm^2/hour (10 required).



Off-line emulsion scanning

- Tracks reconstruction by analysis of ~16 "slices" per emulsion
- Identification of "base"-tracks (both emulsion sheets)
- Scan back of tracks in successive emulsions of a brick



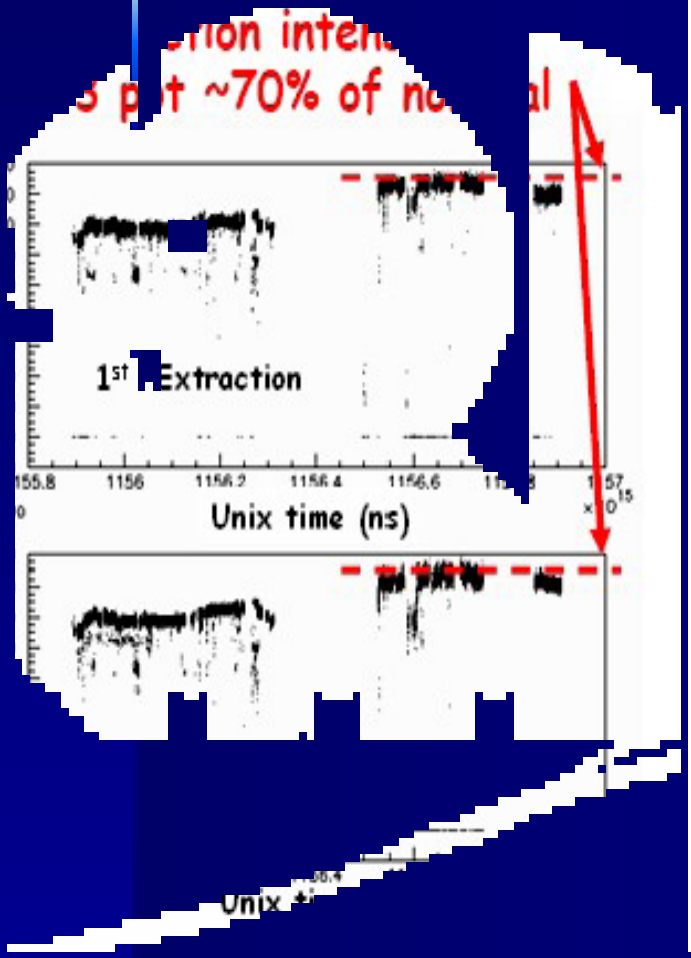


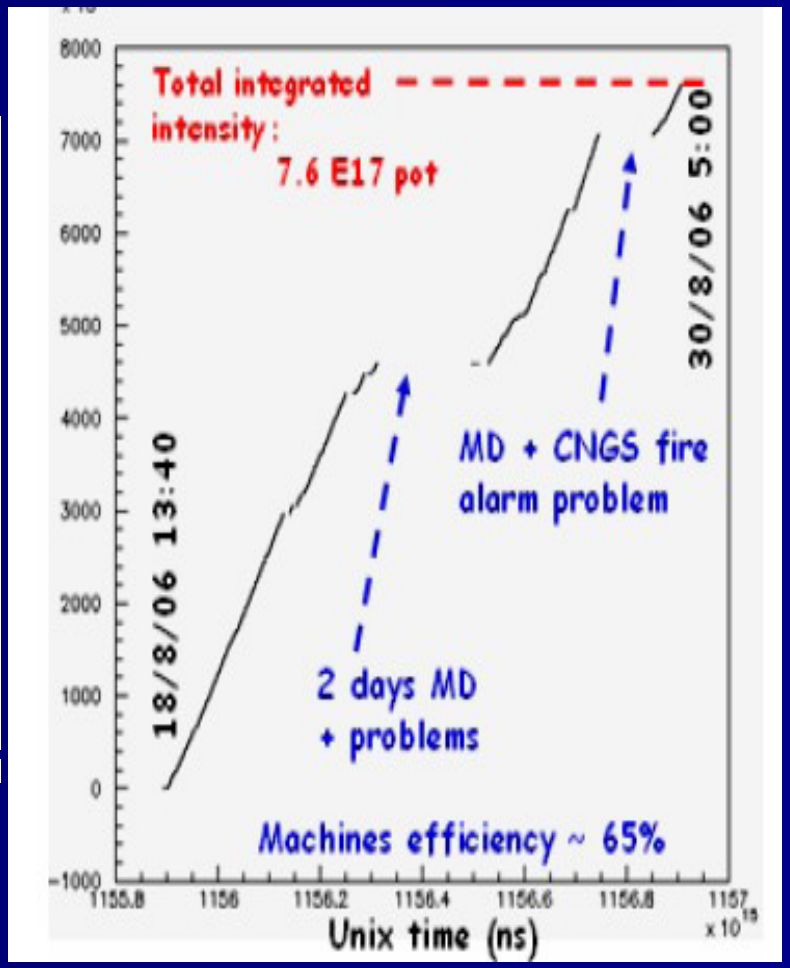
Scan-back result from exposure on NuMI beam

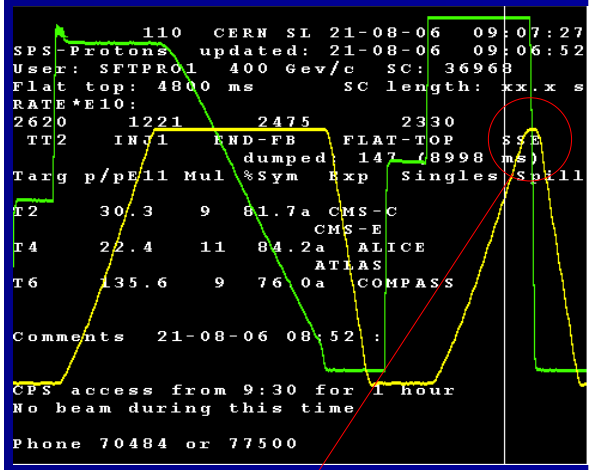
3. First neutrino events

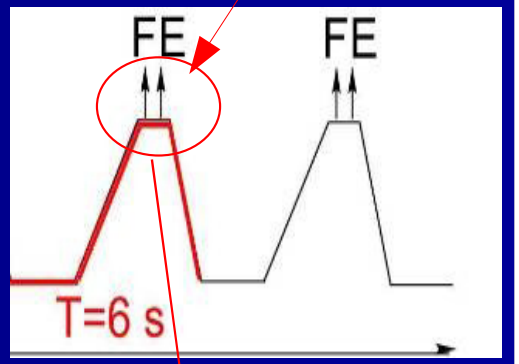
August '06 run

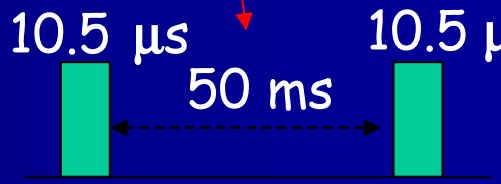
- 8.5 days of real beam operation (121 hours within 2 weeks of operation)
- Used for electronic detectors, DAQ, GPS commissioning and tests of CNGS-OPERA information exchange (gateway DB, early warning signal...)
- Beam side informations :











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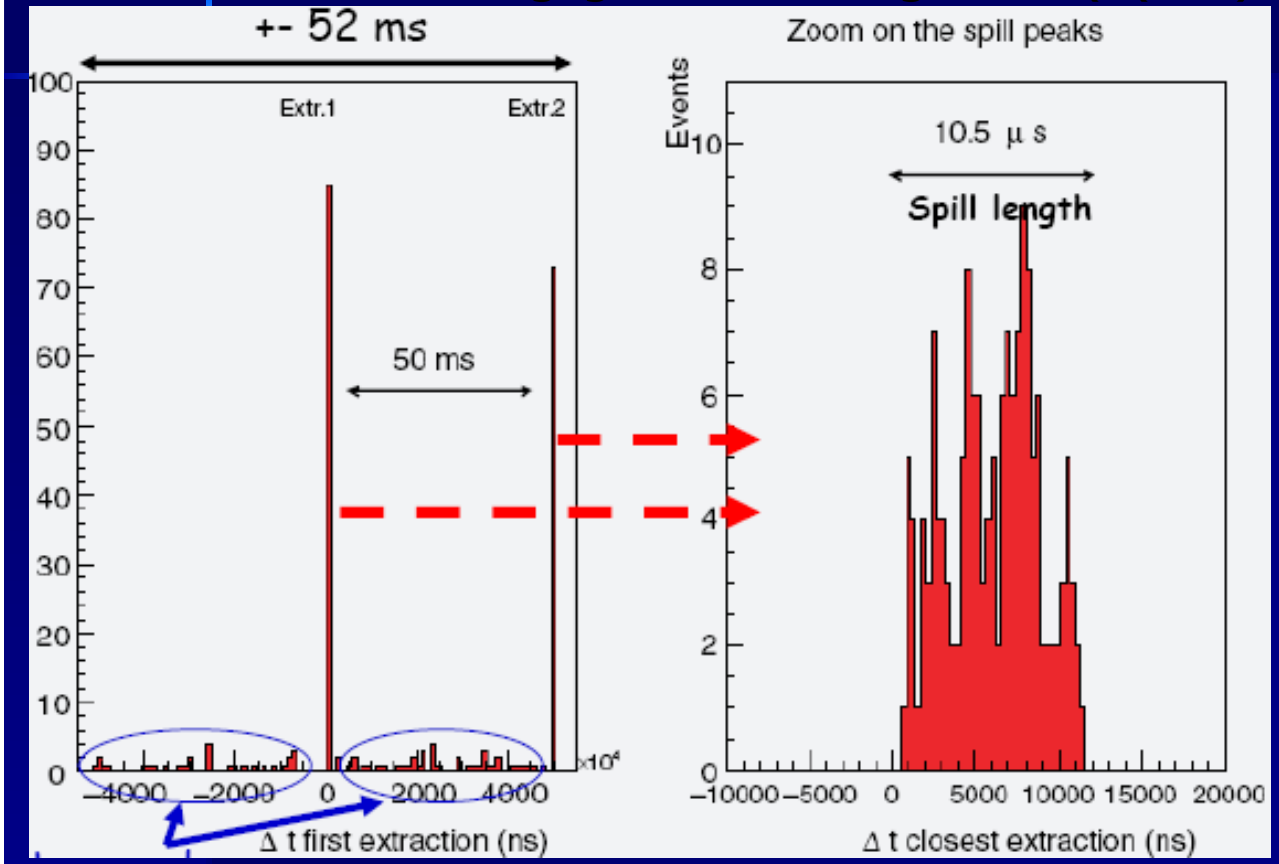
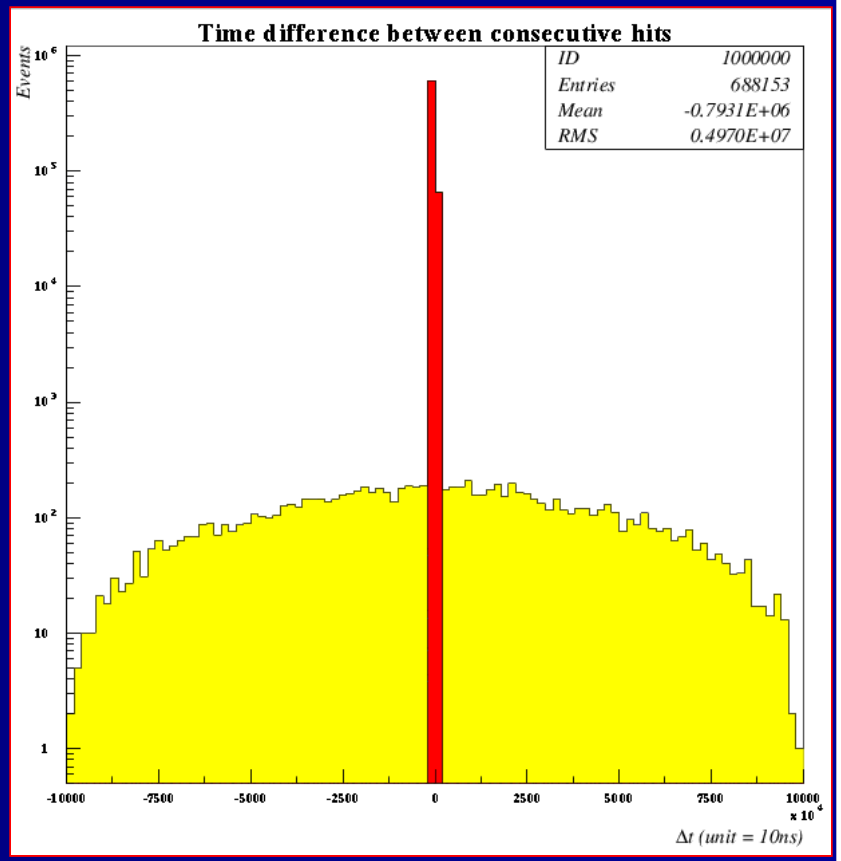
Timing issues

- Events selection from GPS time information : $T_{OPERA} - (T_{SPS} + TOF) < T_{GATE}$
- The events time distribution is peaked around the 2 extraction peaks times within negligible CR background (o(10^{-4}) in ~ms windows)



Cosmic rays bckd

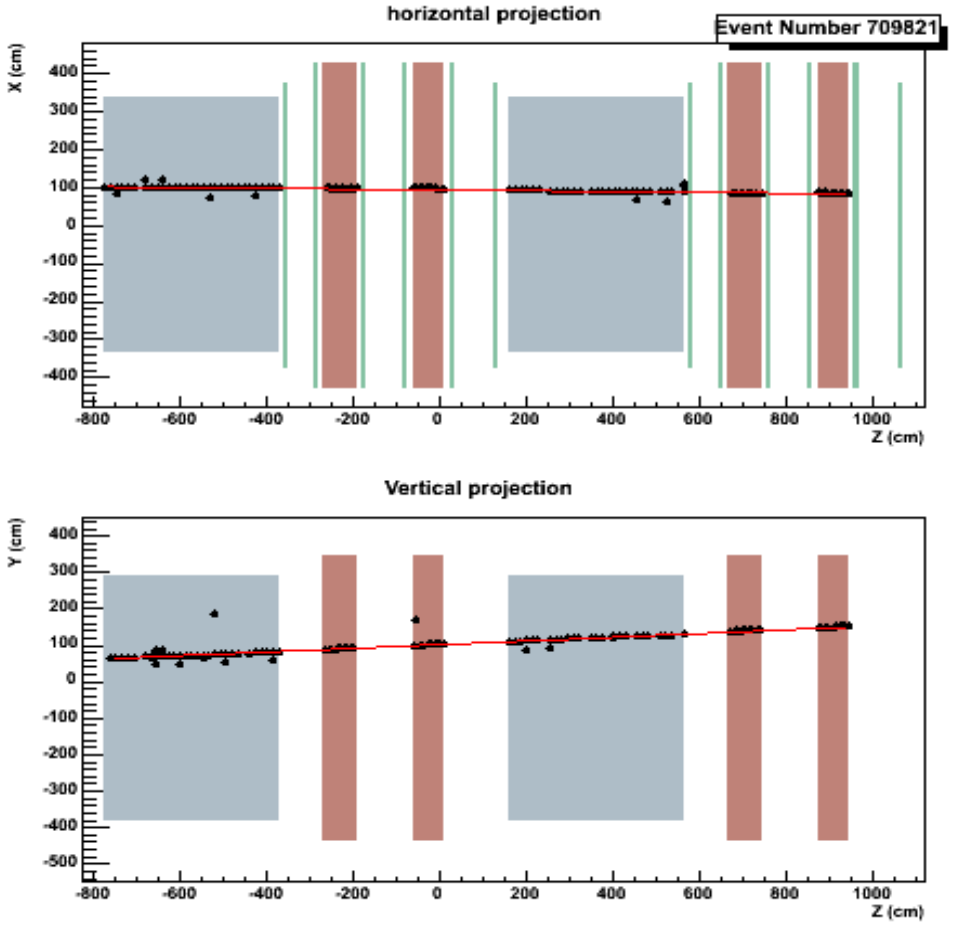


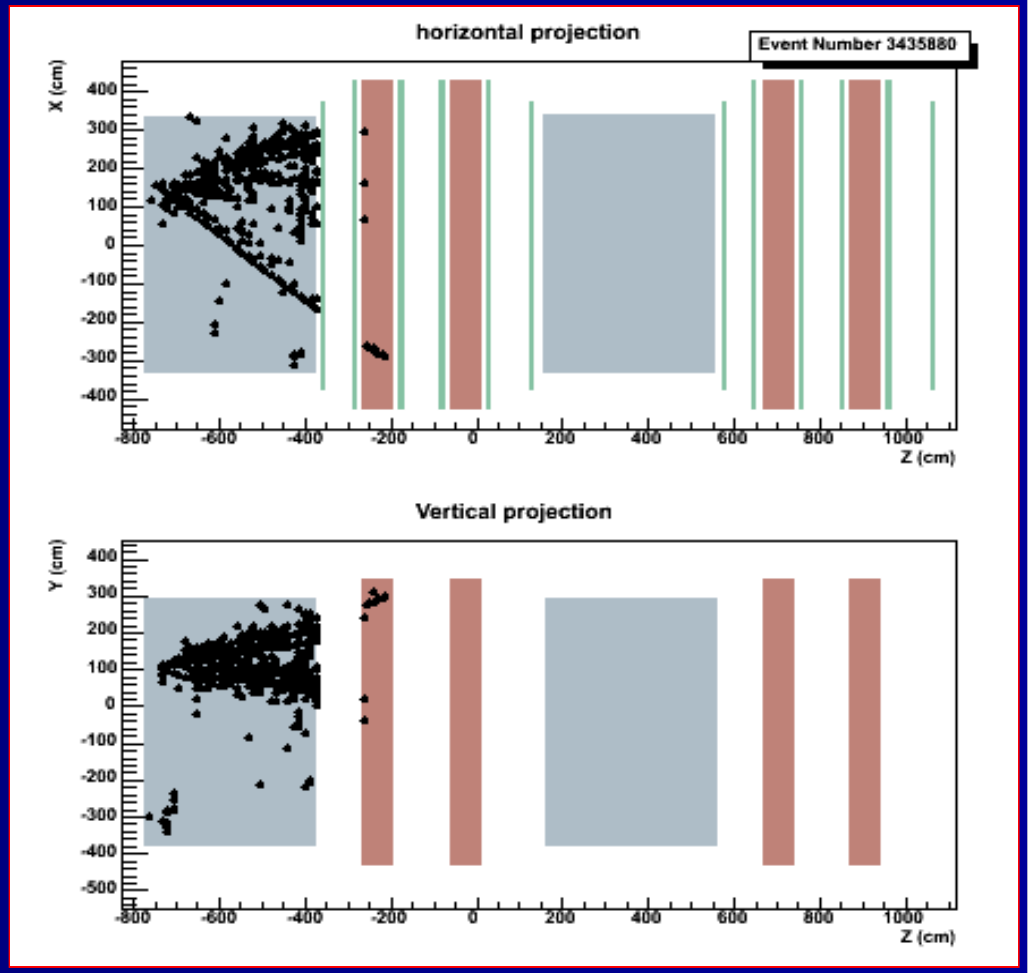
- All hits : the consecutive times difference distribution shows a peak of width ~$T_{COINCIDENCE}$ (typ. 200ns)

August '06 run

- Neutrino induced interactions : 319 detected altogether (in agreement with the predictions)
- ¾ muons coming from the rock, ¼ neutrino interactions in the detector

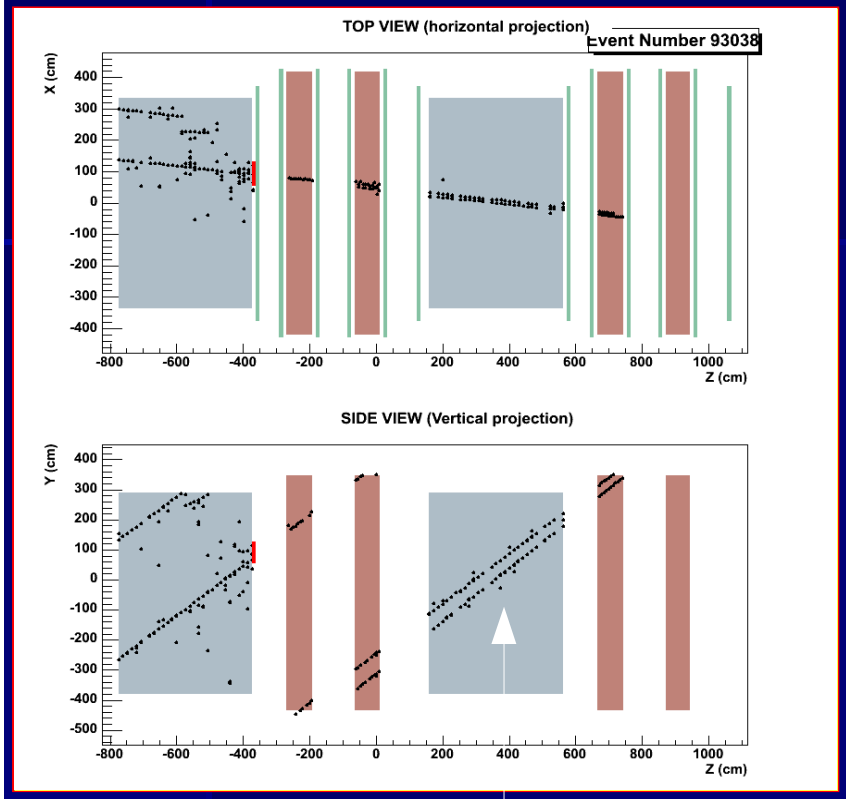
CC event originated from material in front of the detector





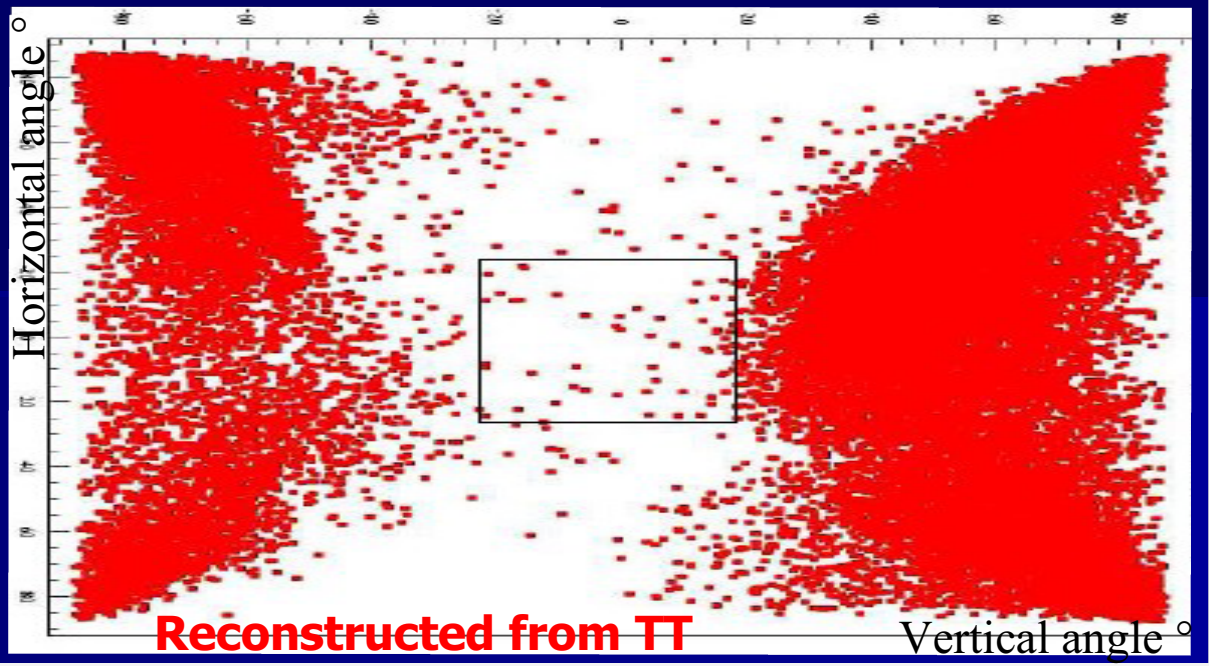
CC event originated in the detector's target material

CNGS vs cosmics events



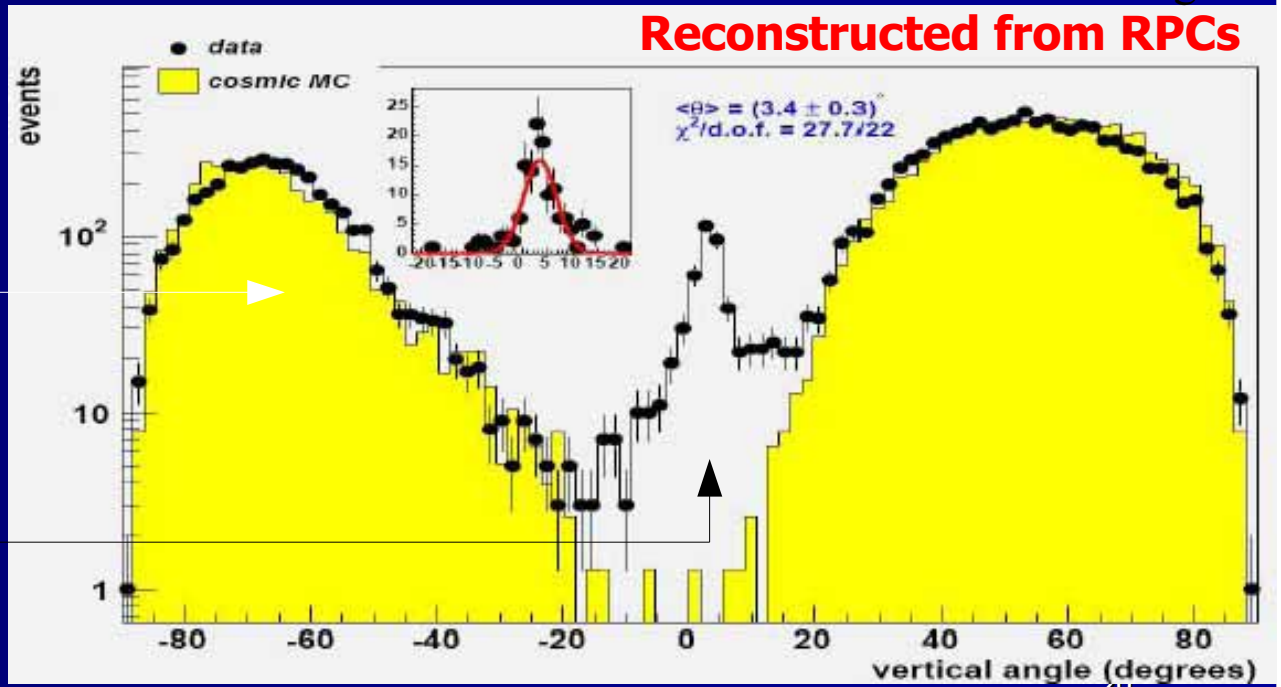
Cosmic rays induced events with a typical down-going topology

Beam events: ~horizontal tracks

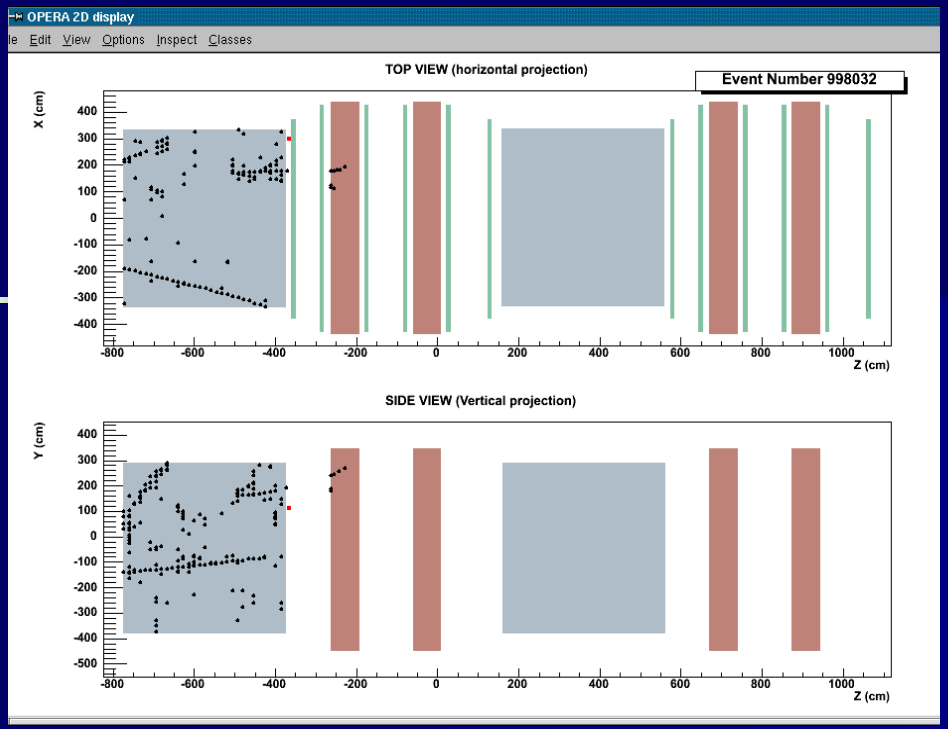


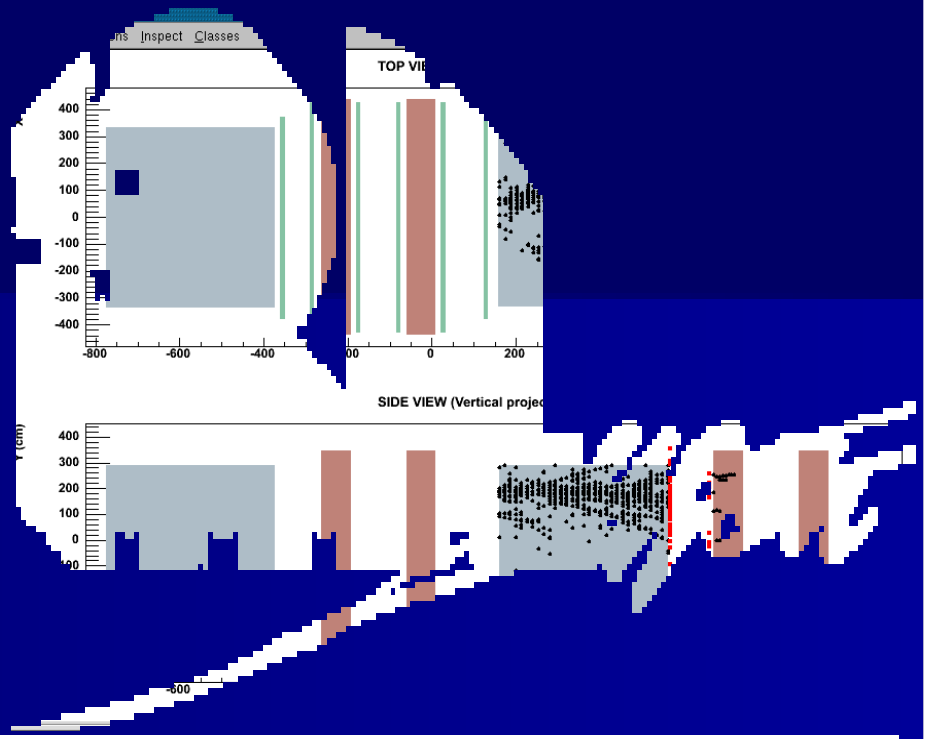
Reconstructed from TT

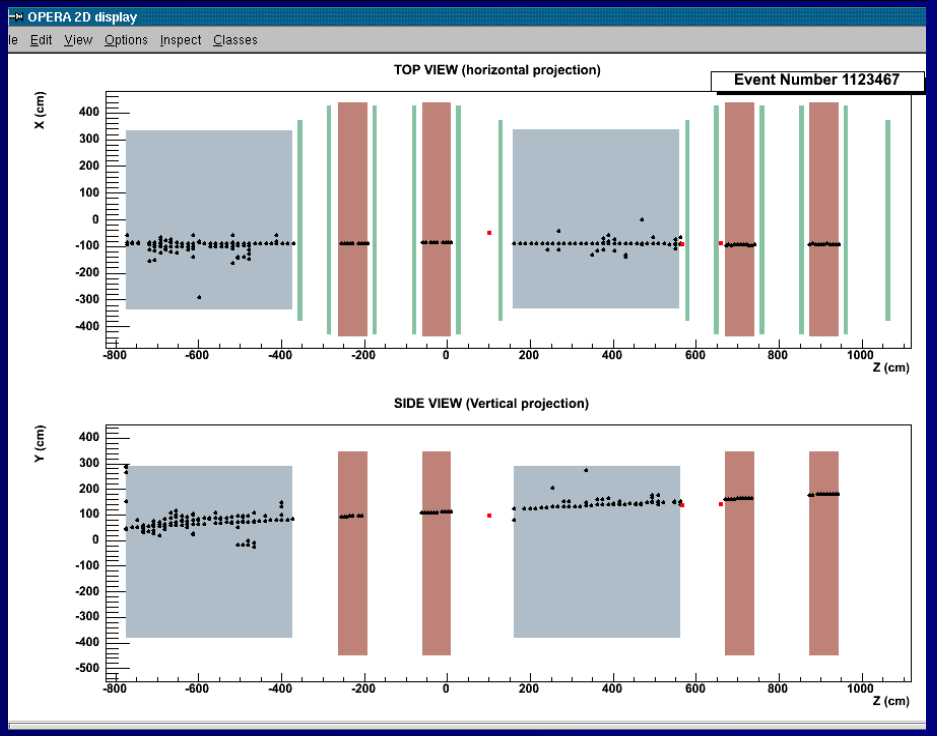
Reconstructed from RPCs

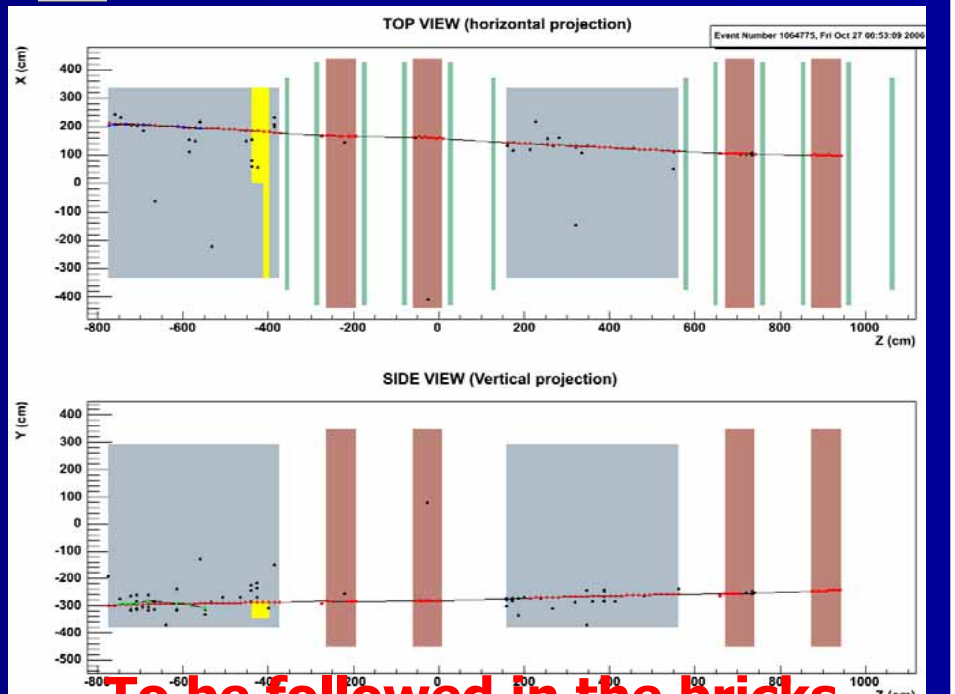


October '06 run









To be followed in the bricks...

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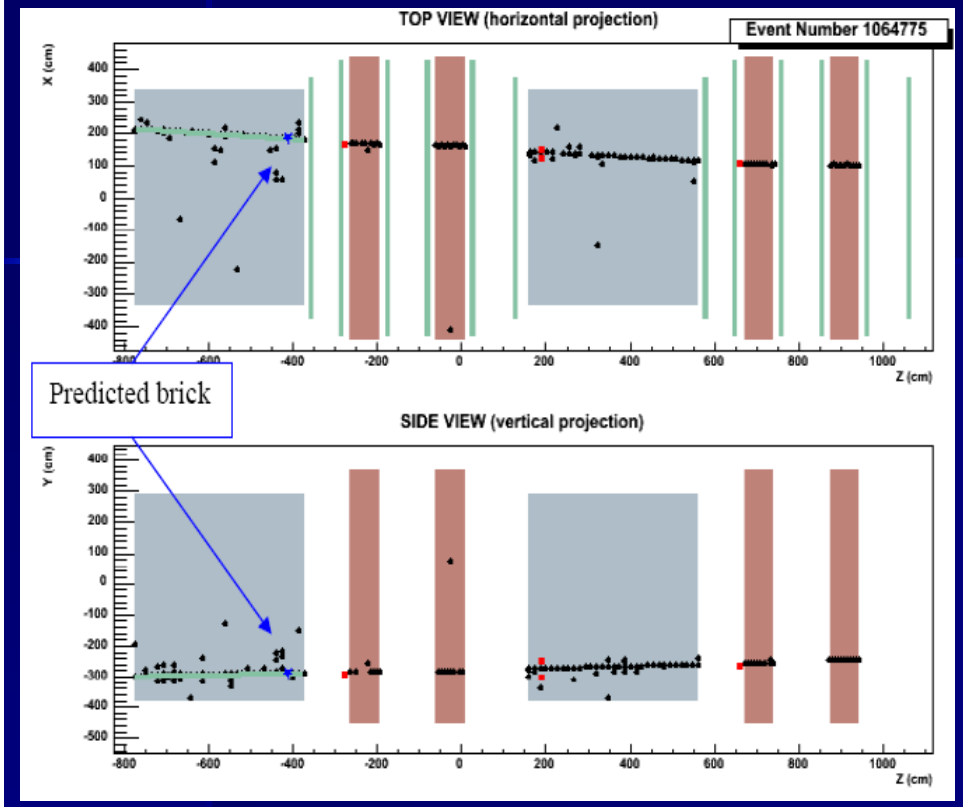
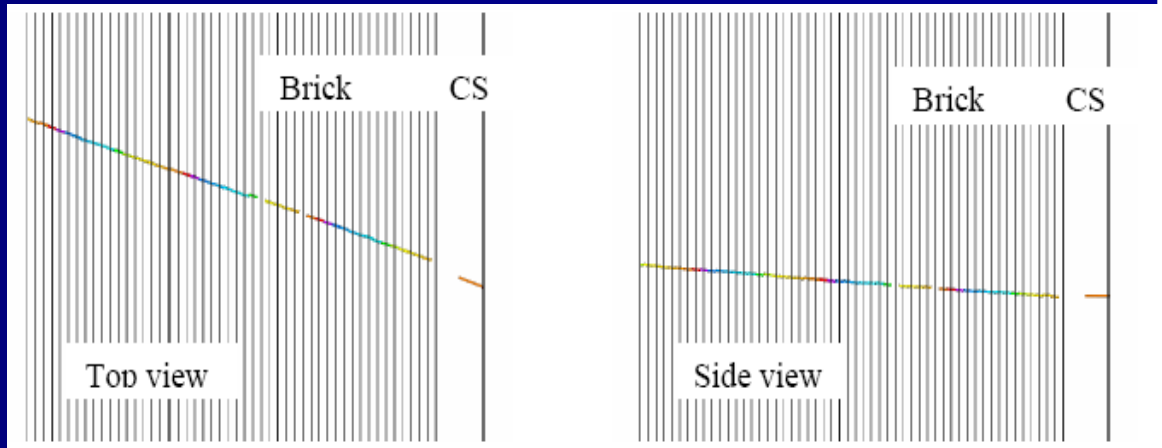
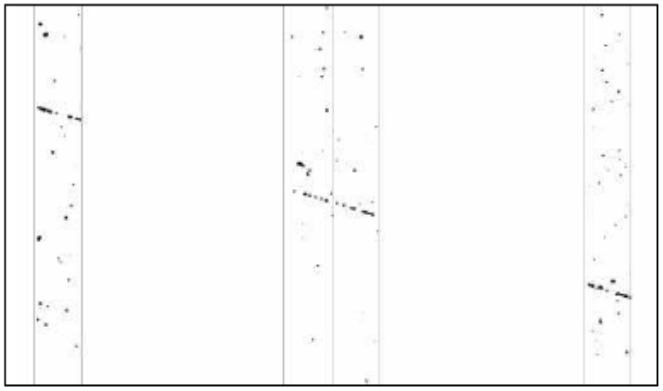
October '06 run



- Short run due to CNGS leak problem.
- 25 neutrino events collected.
- 1kbricks in the target (BAM pilot run)
- 1 brick crossing muon identified.
- Brick extracted from the wall.





Details of the CS scanning showing the reconstructed grains.

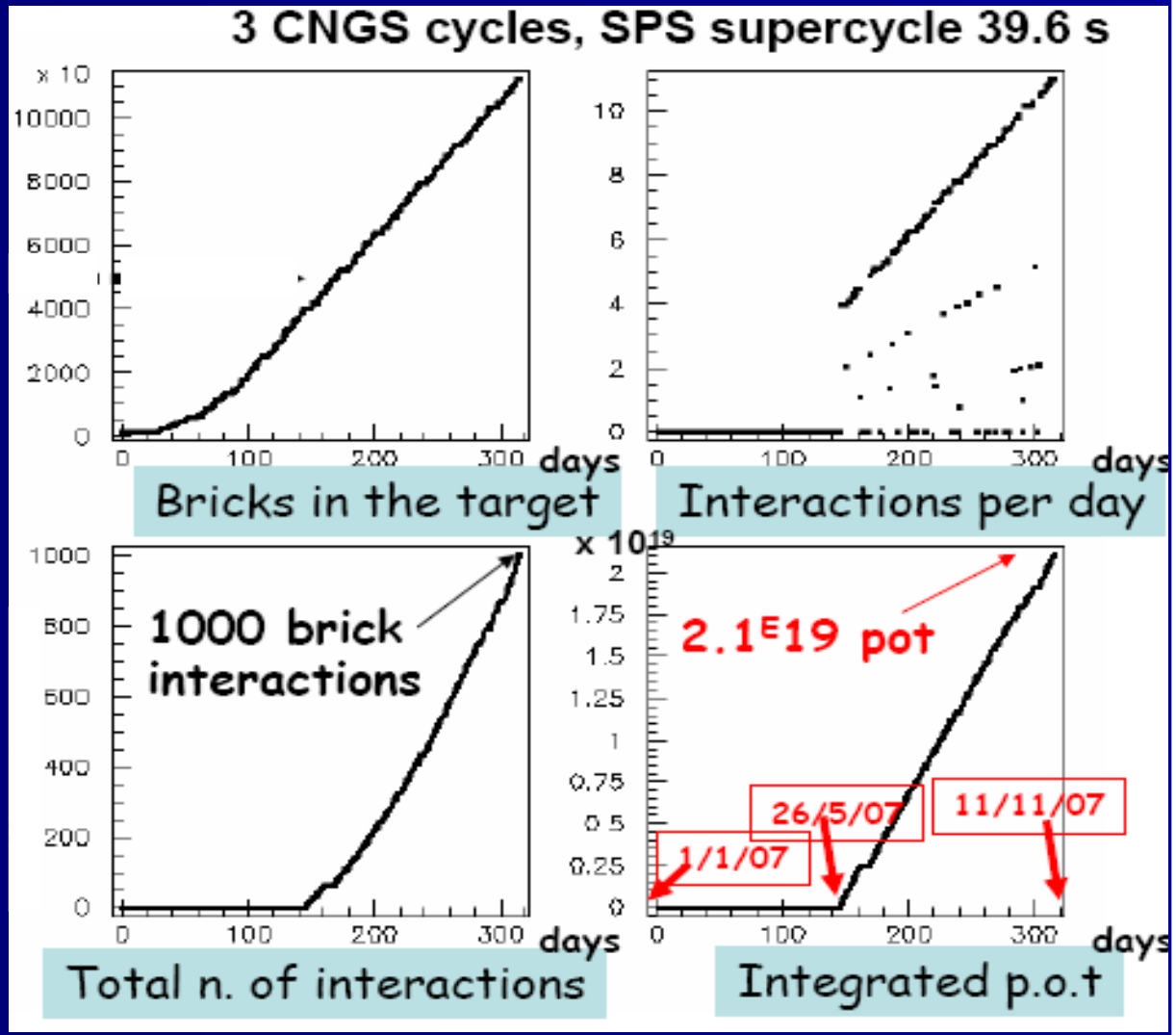
- Extrapolation from ED predictions to bricks validated for beam events.
- Under evaluation for cosmics.
- Requires additional run to tune at least the brick finding procedure

Conclusions and perspectives

Physics commissioning run in 2007

- '06 runs allow to commission the ED, DAQ & GPS systems, interconnection with CNGS, ED-bricks extrapolation, brick processing
- Meanwhile BAM & BMS ramp-up to expected production rates. 112Kbricks should be inserted into the target by Nov.11th (end of SPS program).
- The target will be filled by April '08.

Running in '07 is mandatory to :
• Complete the commissioning of the 2 spectrometers
• Finally align the ED (~1000 tracks are needed)
• Tune the BF algorithms and measure their efficiency
• Valid the CS and brick scanning strategy
• Tune and evaluate the vertex finding methods (around 1kevts in the bricks expected, ~20 charm events).
2007 schedule not yet finalized : start-up around September?

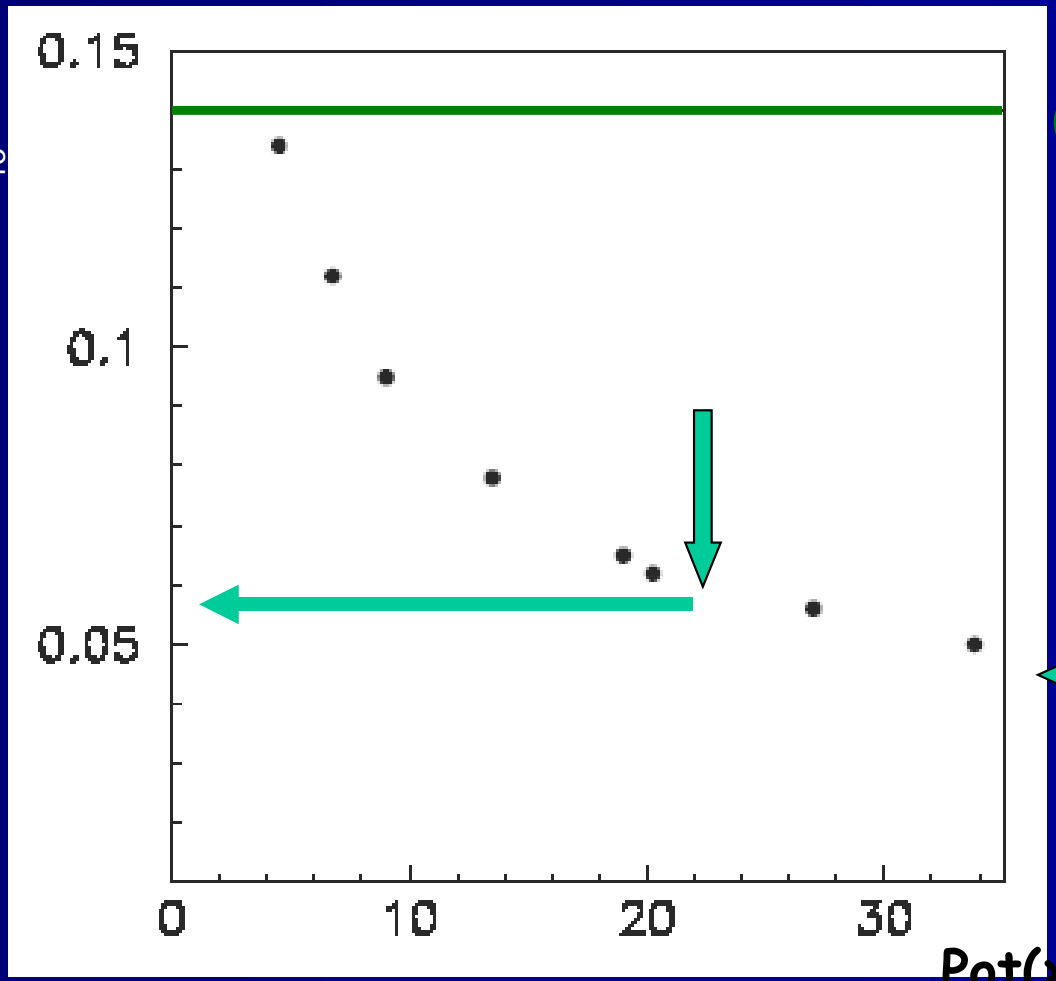


Sensitivity to $\sin^2 2\theta 13$

- 5 years run @ 4.5 10^{19} pot/year
- Assuming full mixing and $\Delta m^2 23 = 2.5\ 10^{-3}\ eV^2$

Nb of events
(5 years running)

Signal @ CHOOZ limit	13.0
$\tau \rightarrow e$	4.5
ν_μCC	1.0
ν_μNC	5.2
ν_eCC beam	18.0



Conclusions

The OPERA experiment has completed almost entirely the construction of all electronic detectors and faces the last (large) effort of brick production and insertion.

The data collection from electronic detectors and from the scanning systems have been validated during the 2 beam runs in '06.

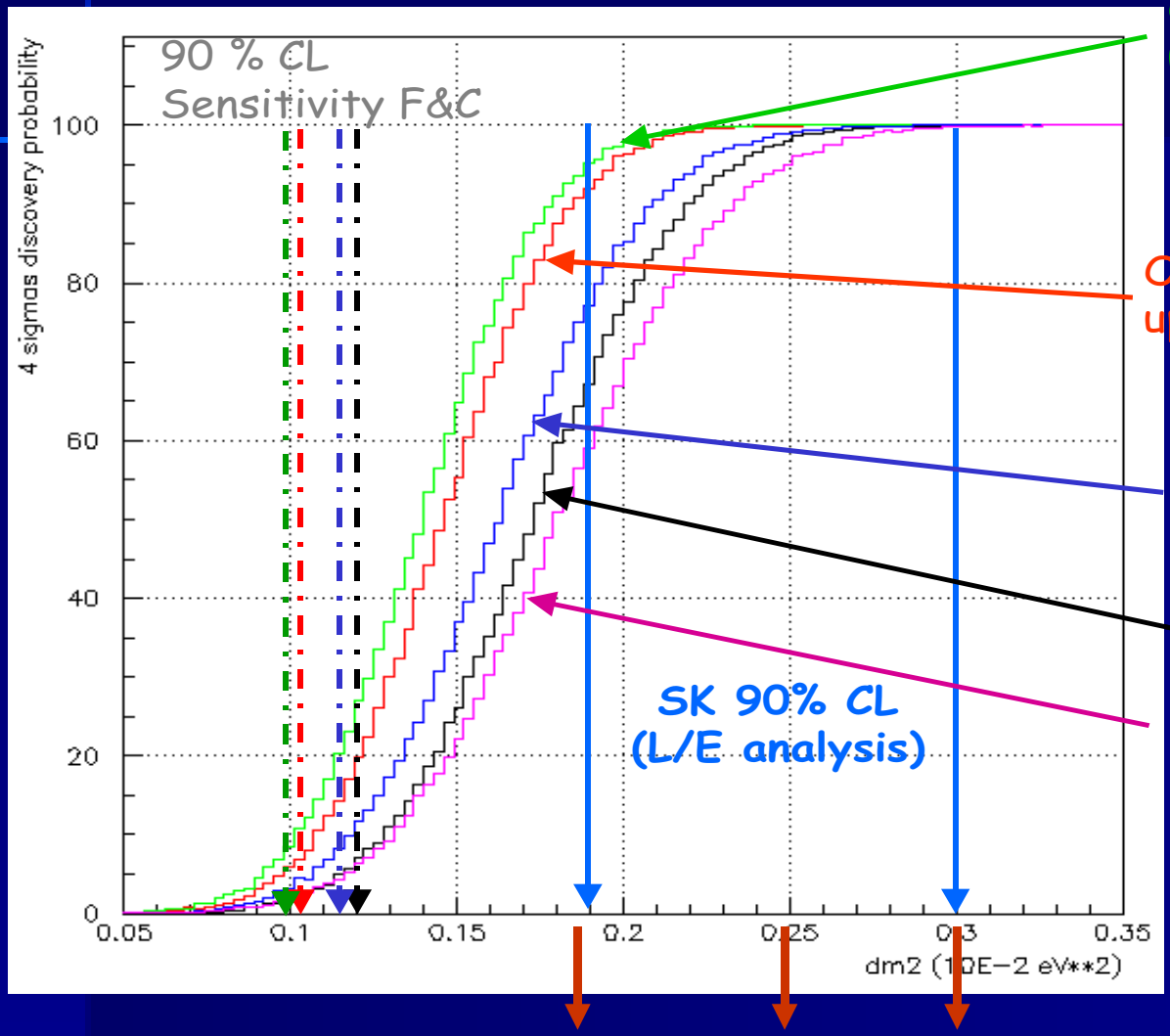
After the CNGS repair campaign a physics commissioning run is required for final tunings while completing the filling of the detector

Ready for the full oscillation physics in '08.

The end

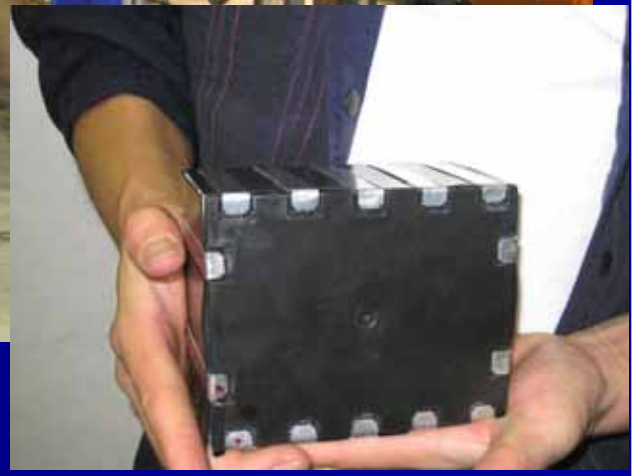
OPERA nominal discovery potential

- 5 years run @ 4.5 10^{19} pot/year, assuming full mixing

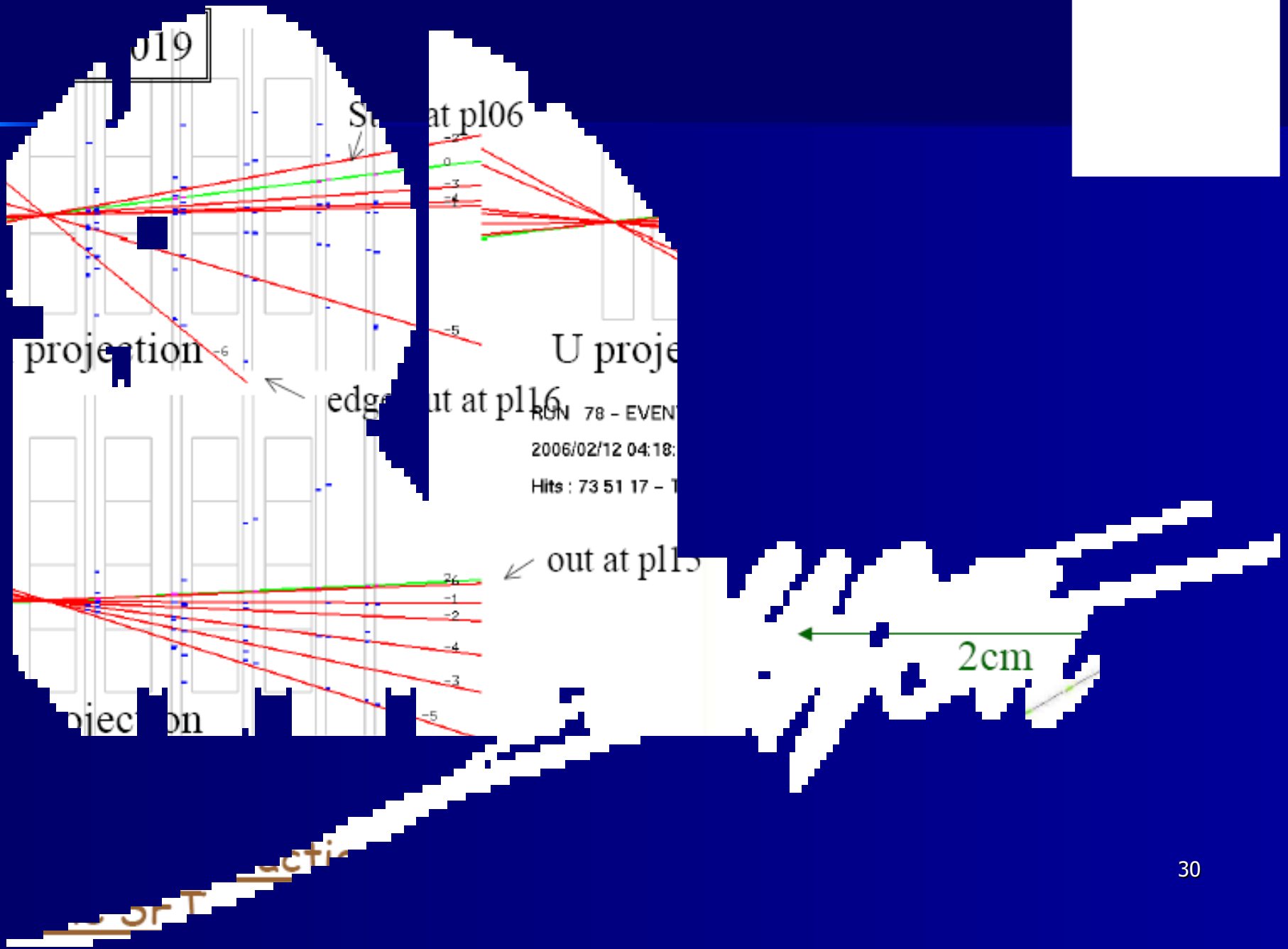


Number of τ events 8.0 12.8 19.9 background : 1.0 -> 0.8 events

Scanning rehearsal with bricks in NuMI beam : PEANUT

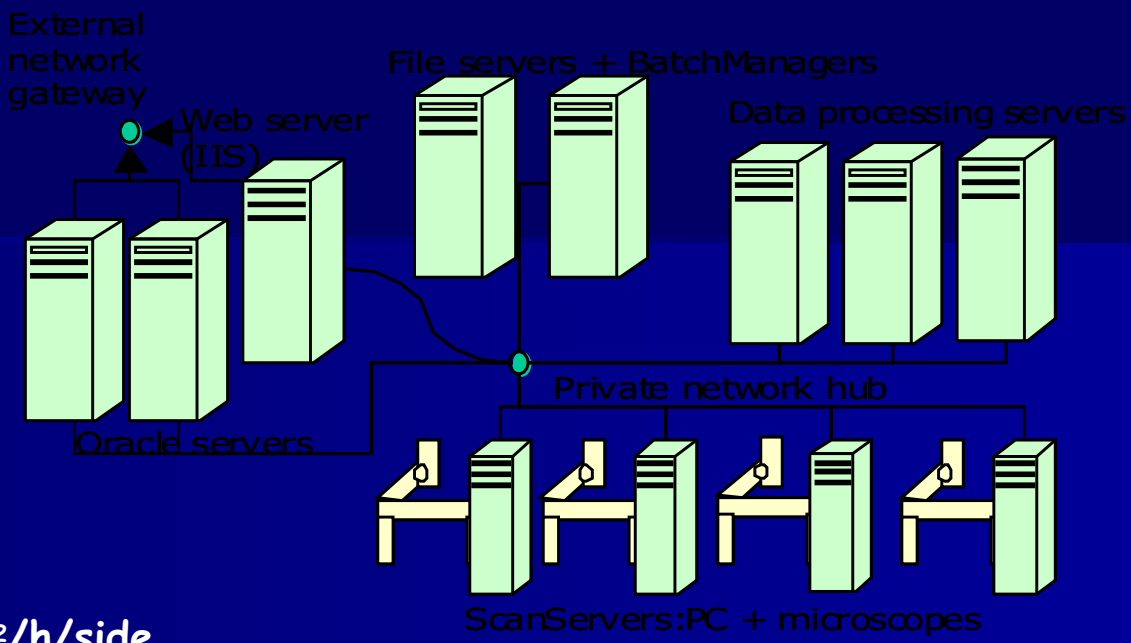


Scanning rehearsal with bricks in NuMI beam : PEANUT



Scanning in Europe

- 25 microscopes already working
- 11 labs (Bari, Bern, Bologna, Lyon, LNF, LNGS, Napoli, Neuchatel, Padova, Roma, Salerno)



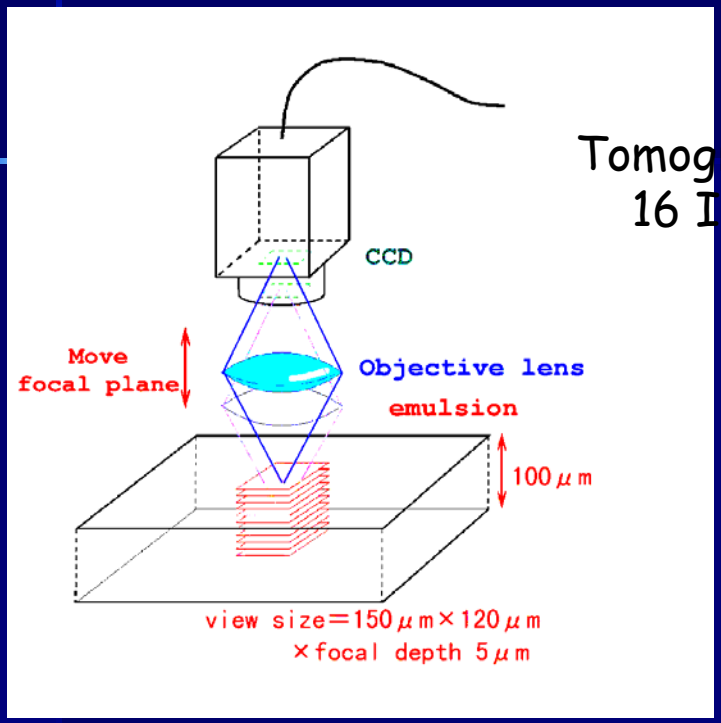
Performances:

- Scanning speed in area scan mode: 20 cm²/h/side
- Base-track transverse precision):
  0.3 μm (tanθ=0), 0.3 μm (tanθ=0.7)
- Base-track longitudinal precision :
  0.3 μm (tanθ=0), 0.7 μm (tanθ=0.7)
- Microtrack finding efficiency (depends on track slope):
  > 95% (average value)
- Fake base tracks (tanθ<0.4): < 1 fake track/cm2
- *Scanning speed in point scan mode*

(excluding plate change / intercalibration / recalibration): 1.2 s/prediction
(15 min/brick for 15 predictions, 1h35min/brick for 100 predictions)

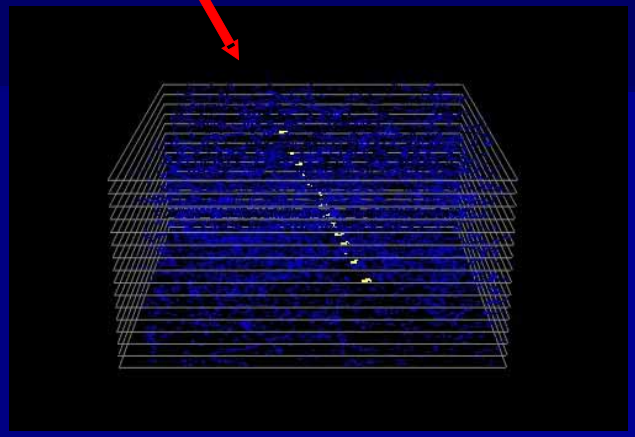
Scanning in Japan

Track Recognition by Track Selector

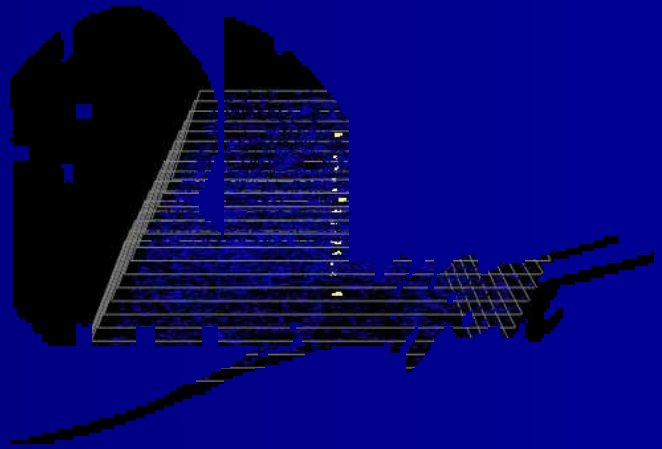


Tomographic
16 Images

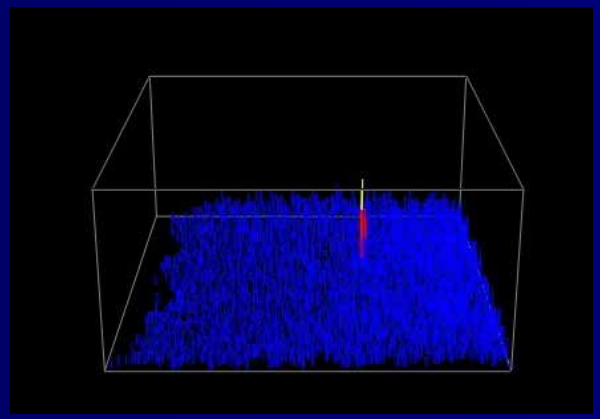
Penetrating Track



Give counter shift



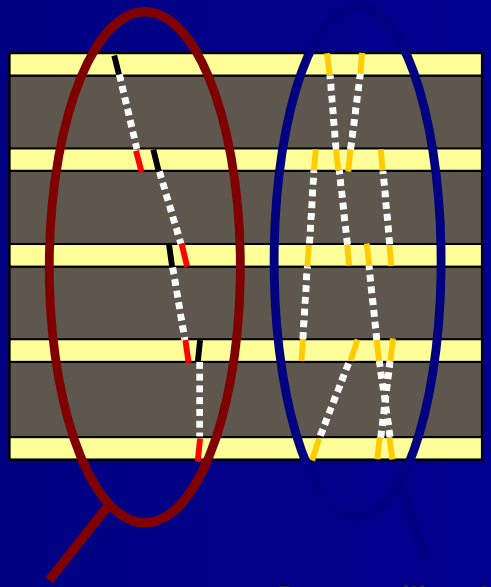
Sum and
Discriminate



Vertex finding

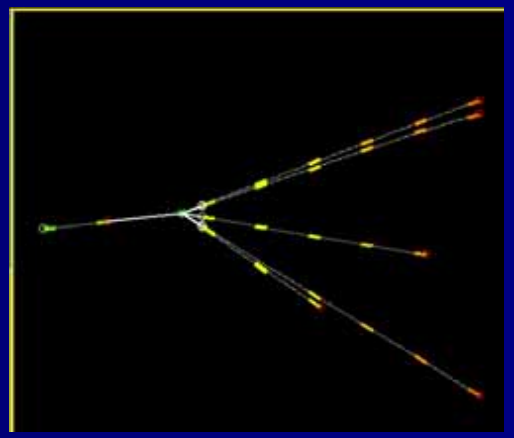
Scan-back strategy tested on 8 GeV/c pions to produce interactions

- *Scanback: measure tracks on downstream plate and follow back to interaction point (realistic test of performance in OPERA)*
- *TotalScan around track disappearance points to confirm the interaction*

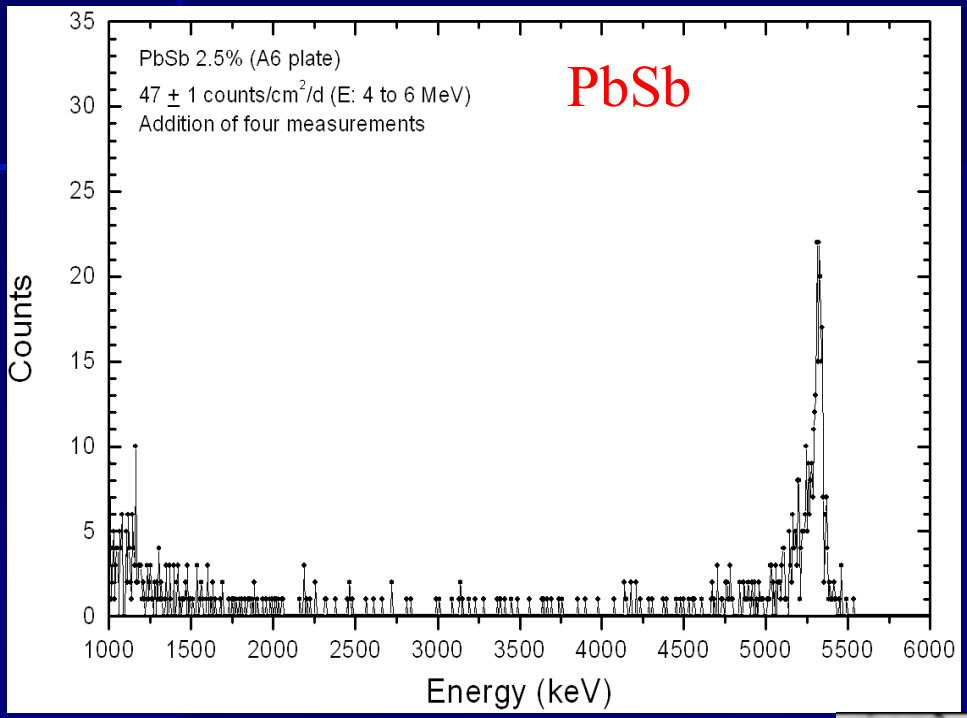


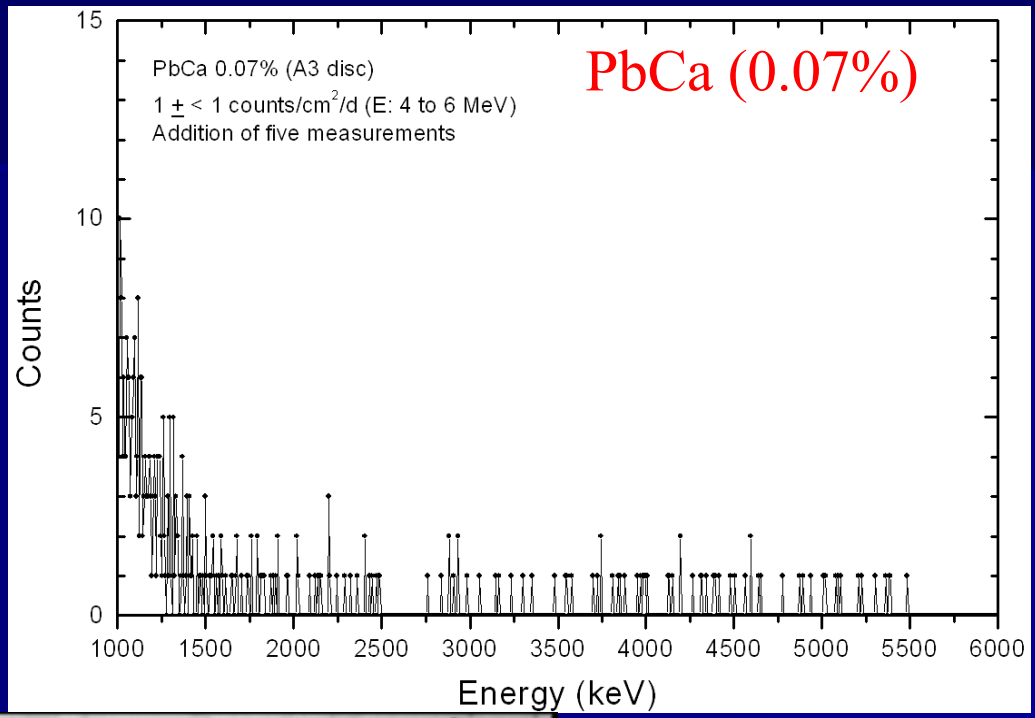
Scan-back tracks

Inter-calibration tracks (cosmic rays, plate to plate alignment)

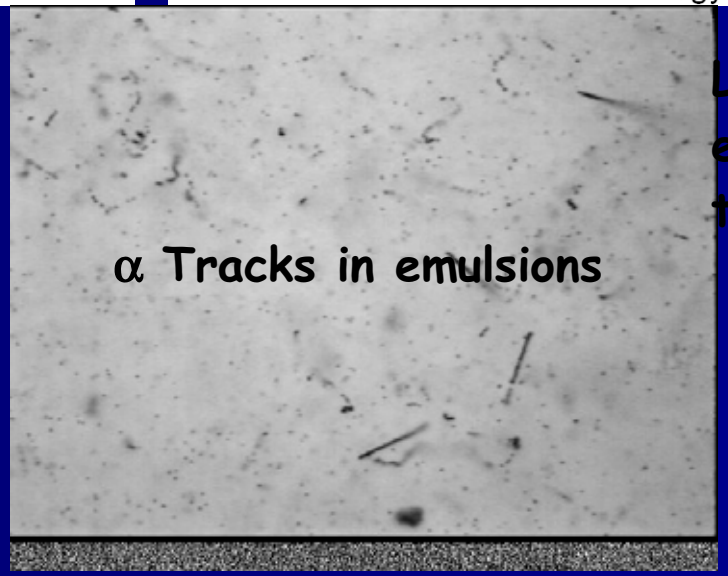


Summary of alpha measurements



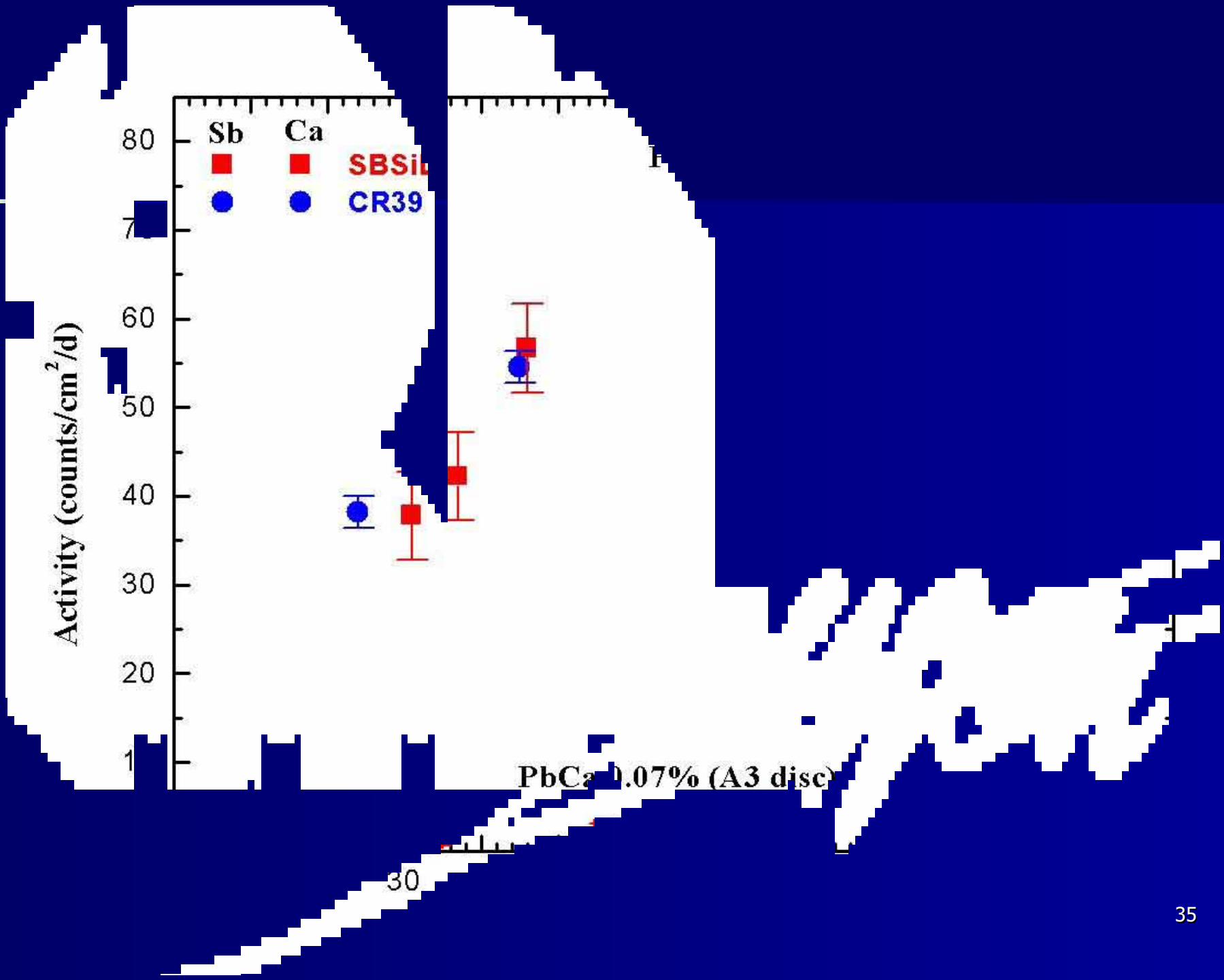


The full energy peak indicates ^{210}Po surface contamination



Low rate due to ^{210}Po evaporation during the PbCa melting

Summary of alpha measurements

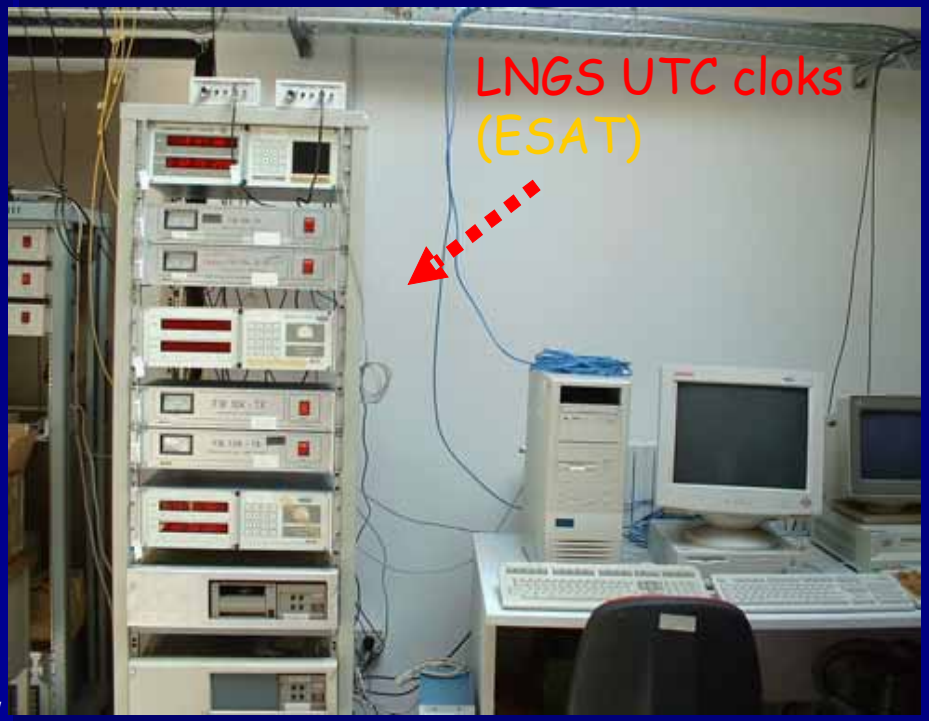


CERN-LNGS UTC clocks intercalibration

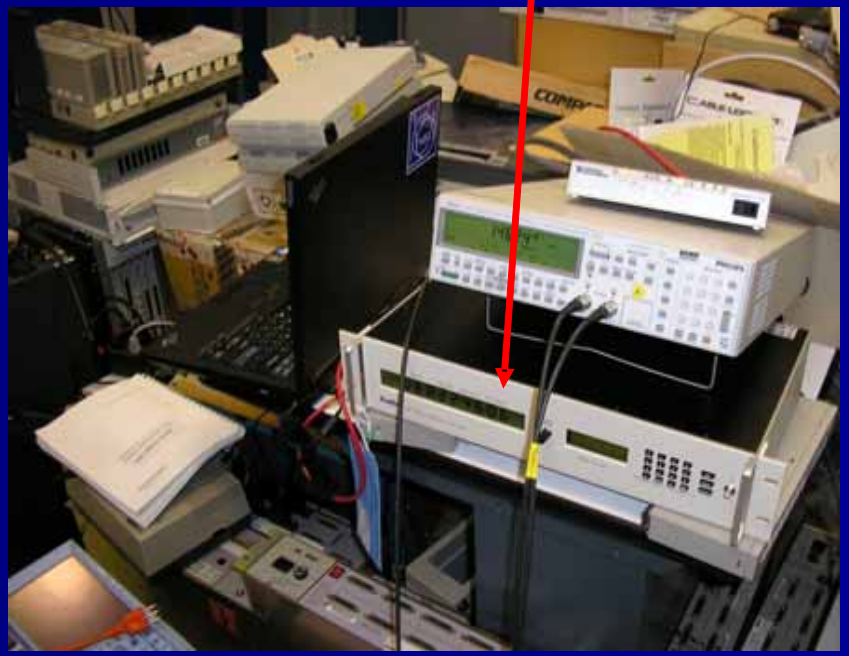
For the neutrino spill syncronization both CERN and LNGS have a double unit (including a spare) UTC clock system, but from different manifacturers.
The CERN system was calibrated by the Swiss metrology institute METAS.

CERN and LNGS systems have comparable performance (<100 ns) and their single units are in both cases based on a GPS system + Rb clock.

One of the CERN UTC units was installed and running for one month in Gran Sasso in order to check for relative offsets and time stability of the two systems. Action was taken also to measure all the delays in the LNGS time distribution chain

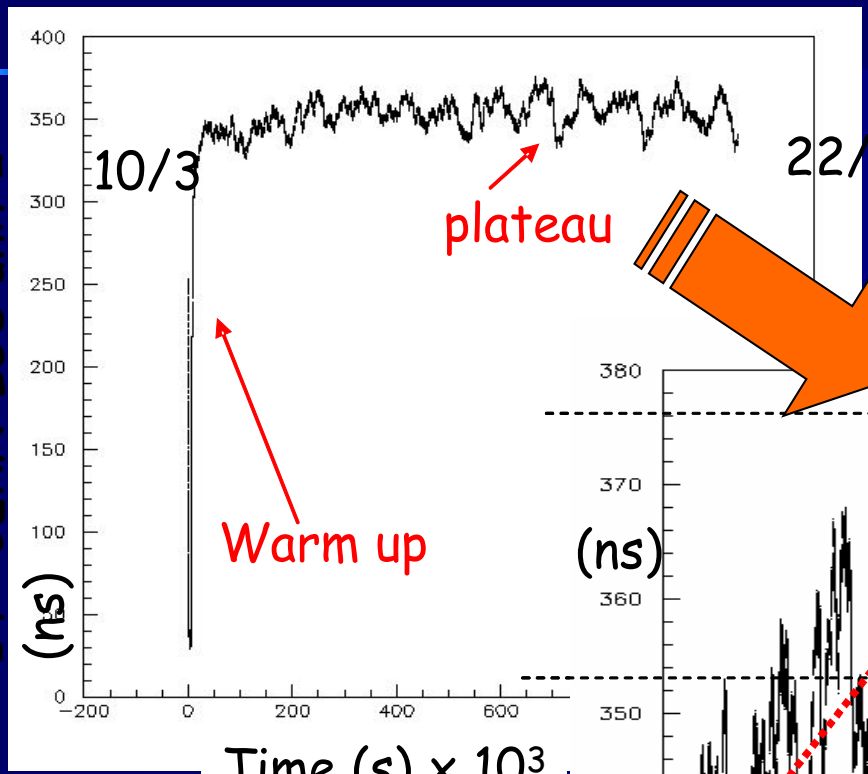


CERN Symmetricom XL-DC unit installed at LNGS

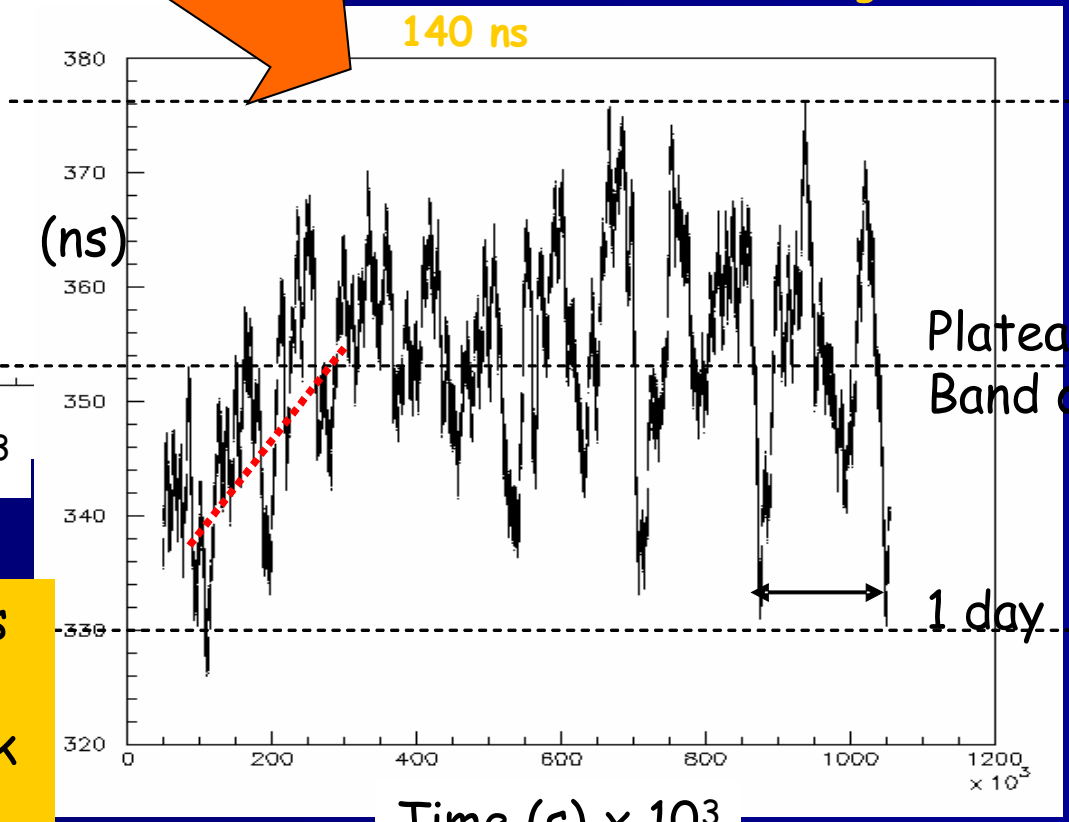


CERN-LNGS UTC clocks intercalibration

Time difference measured during 12 days with a time interval counter (300 ps accuracy)



It was measured an offset of about 350 ns due to the antenna cable delays of the LNGS units and mismatch in the geodesic reference system.
In addition it was measured that the two LNGS units differ among themselves by 140 ns



Correcting for the offsets the CERN and LNGS UTC systems were able to track each other within 20 ns