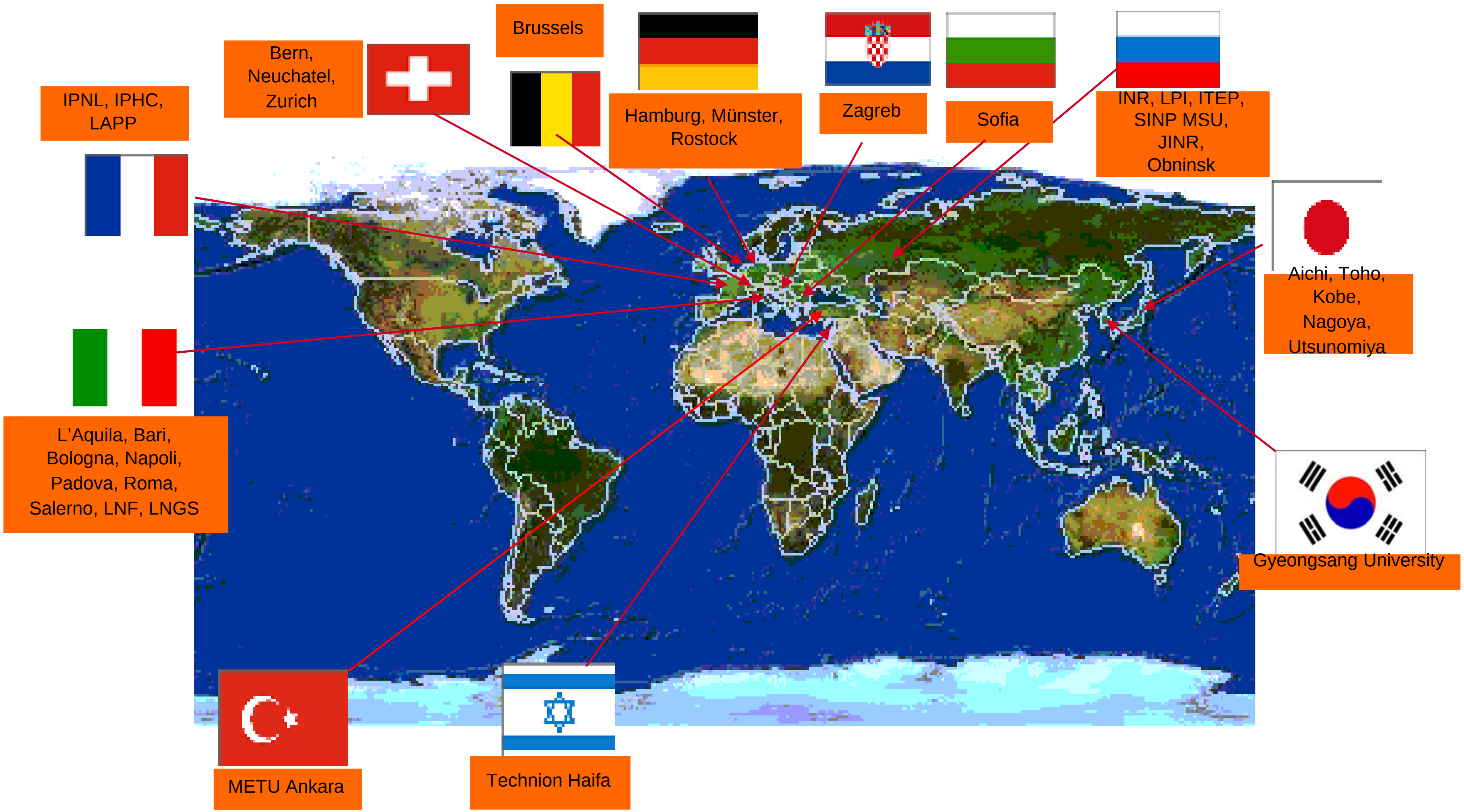
Recent results from the OPERA experiment

Francesco Di Capua
INFN -Napoli

La Thuile 02/03/2009

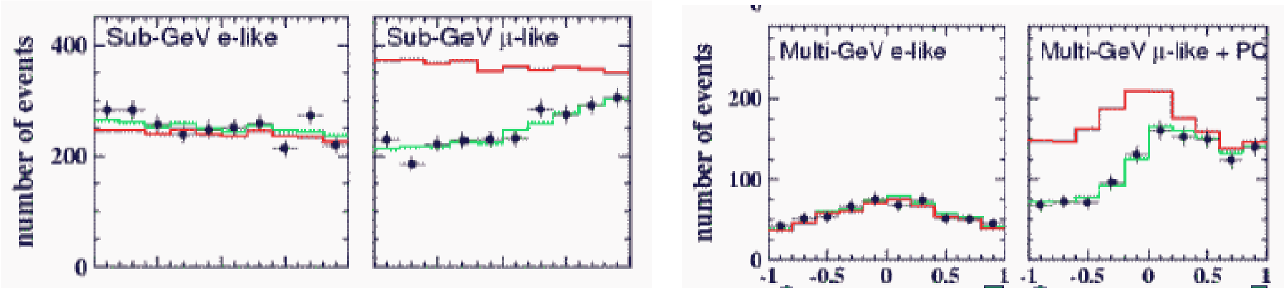
The Opera Collaboration



35 INSTITUTIONS, ~200 PHYSICISTS

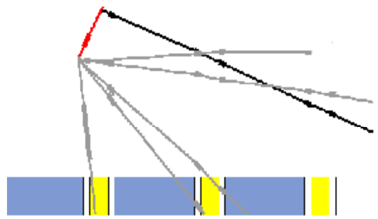
OPERA physics motivation

• Since 1998 SK observed strong atmospheric neutrino anomaly: deficit of ν_μ (and not ν_e) with zenith angle dependence



• The goal of OPERA is to directly measure for the first time neutrino oscillation in appearance mode (1999 CNGS beam design)

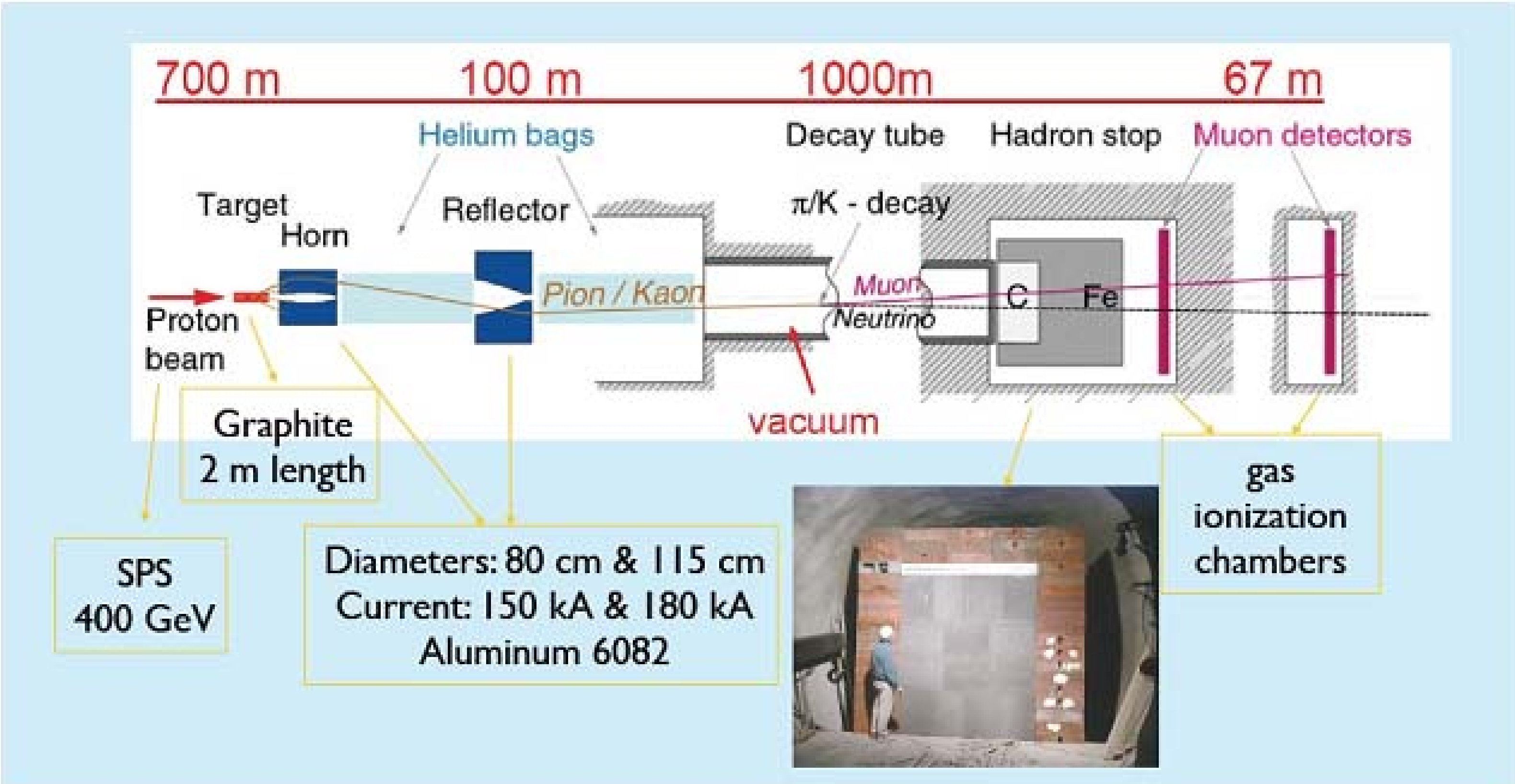
• Using an almost pure ν_μ beam, the $\nu_\mu \rightarrow \nu_\tau$ transition is detected by observing the τ lepton decay, induced after a neutrino-lead CC interaction. τ decay is observed by means of Emulsion Cloud Chambers



2000 DONUT "sees" the ν_τ in the ECC

• The detector is located on the CNGS (CERN to Gran Sasso) beam line at a distance from the neutrino source of 730 Km

The CNGS beam



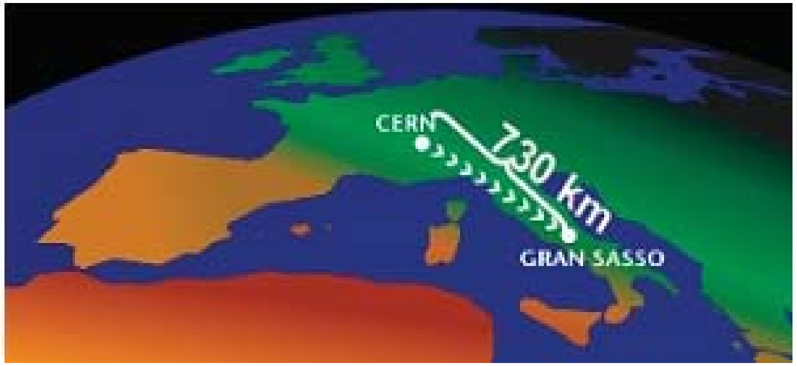
The CNGS is a conventional neutrino beam: 400 GeV/c protons from the CERN SPS hit a graphite target producing pions and kaons which decay in flight and produce neutrinos

The CNGS beam

- The beam is optimized for ν_τ appearance in the atmospheric oscillation region. The present best fit is now from Minos 2008:

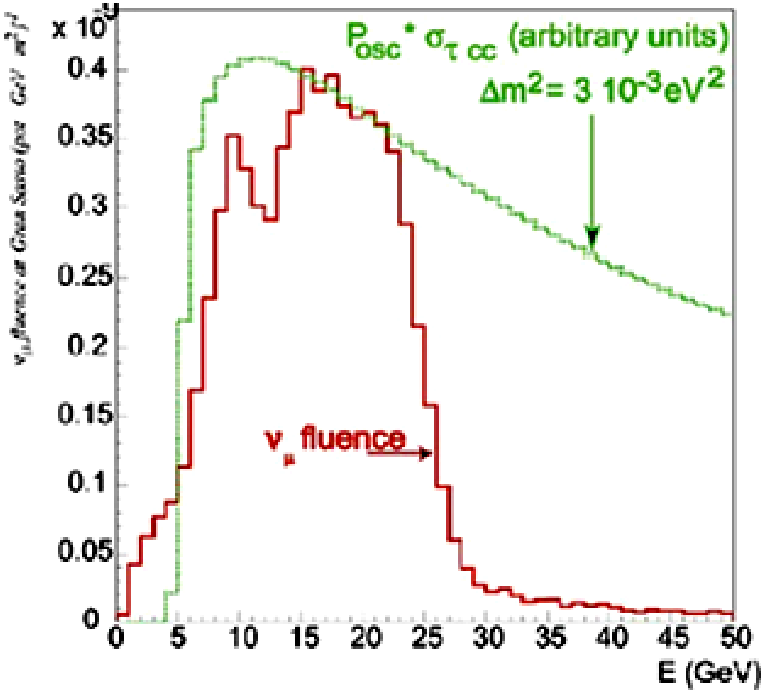
$$\Delta m^2=(2.43\pm0.13)\times10^{-3}eV^2$$

$$\sin^2 2\theta_{23}=1.0$$

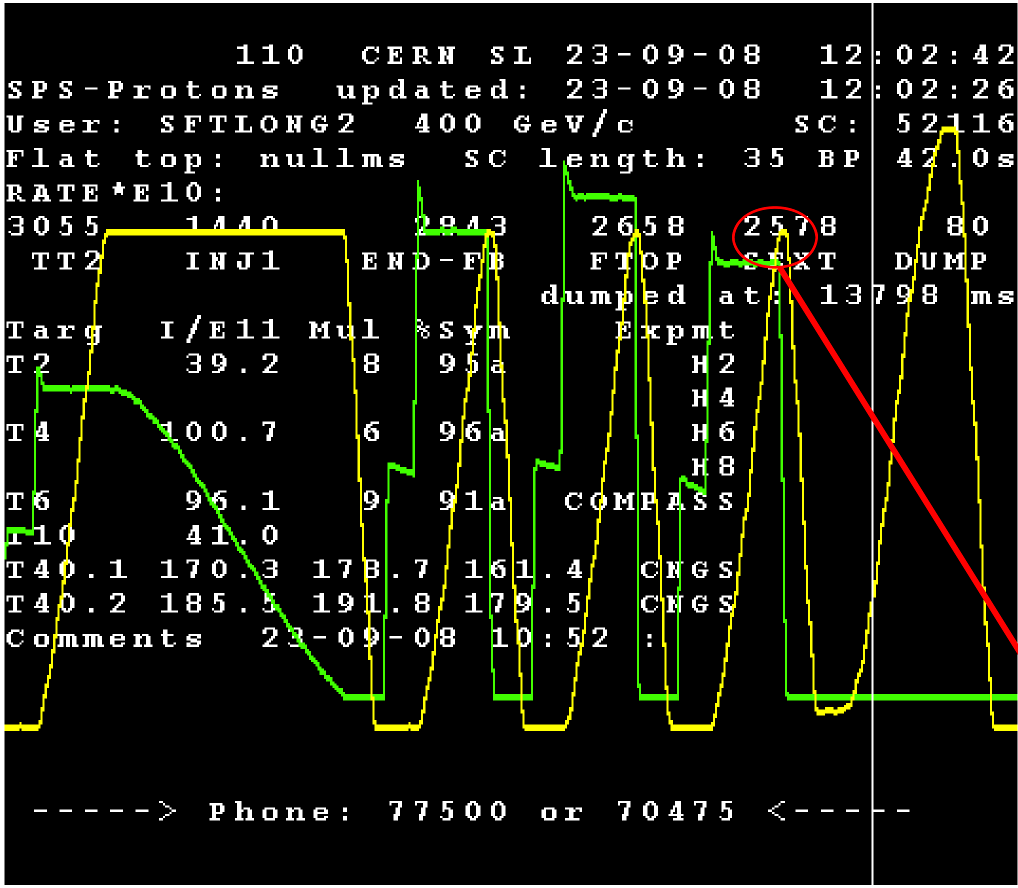


- Although the maximum of oscillation probability at 730 Km is at about 1.5GeV, we need to take into account the ν_τ CC cross-section and the production threshold of 3.5GeV

$<E_{\nu\mu}>$	17 GeV
$(\nu_e+\overline{\nu}_e)/\nu_\mu$	0.87%
$\overline{\nu}_\mu/\nu_\mu$	2.1%
ν_τ prompt	negligible
p.o.t./year	4.5×10^{19}



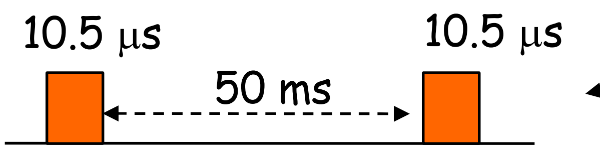
Proton extraction from SPS for CNGS

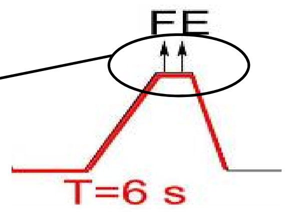


SPS magnetic field
SPS current

CNGS cycle (6 sec):
two extractions/cycle

SPS supercycle in September 2008





OPERA detection principle

oscillation

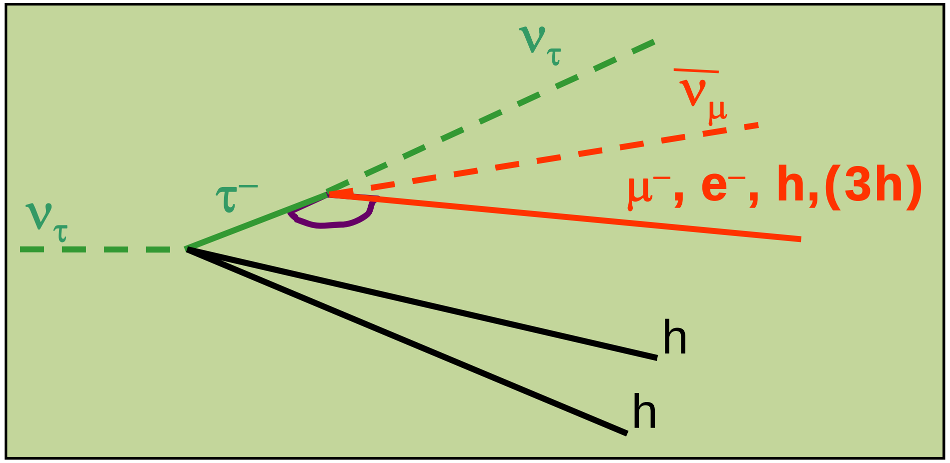
$\nu_\mu \leftrightarrow \nu_\tau$

CC interaction

$\nu_\tau N \rightarrow \tau X$

τ decay

(T~10^{-13} s; $c\tau$~87μm)



$\tau \rightarrow e$ (17.8%)

$\tau \rightarrow \mu$ (17.4%)

$\tau \rightarrow h$ (49.5%)

$\tau \rightarrow 3h$ (15.2%)

- The detection of τ lepton requires an identification of a decay topology
- The detector must fulfill the following requests:
  1. Large mass due to small neutrino cross-section (1.3 Kton)
  2. Micrometric and Milliradian resolution to observe the "Kink" (photographic emulsions)
  3. Select neutrino interactions (electronic detector)
  4. Identify muons and their charge to reduce charm background (electronic detector)

An hybrid detector (emulsion + electronic detector) fulfills these requirements

τ identification

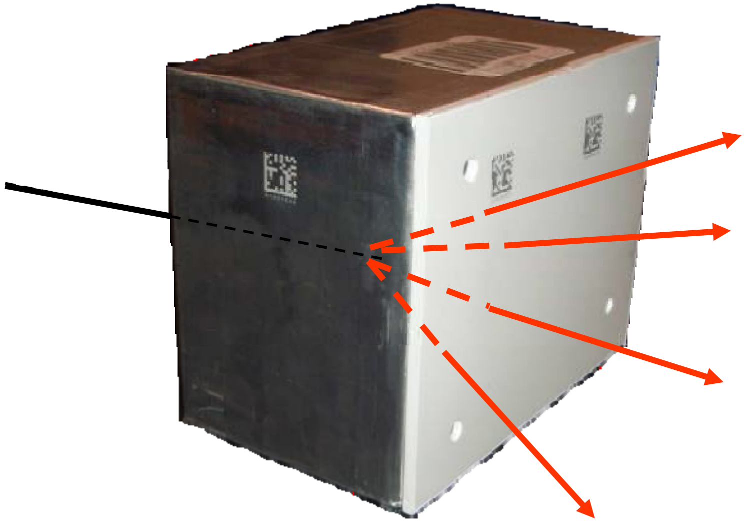
• The target is divided in about 150000 ECC's, so called "bricks", each brick weights 8.6 Kg

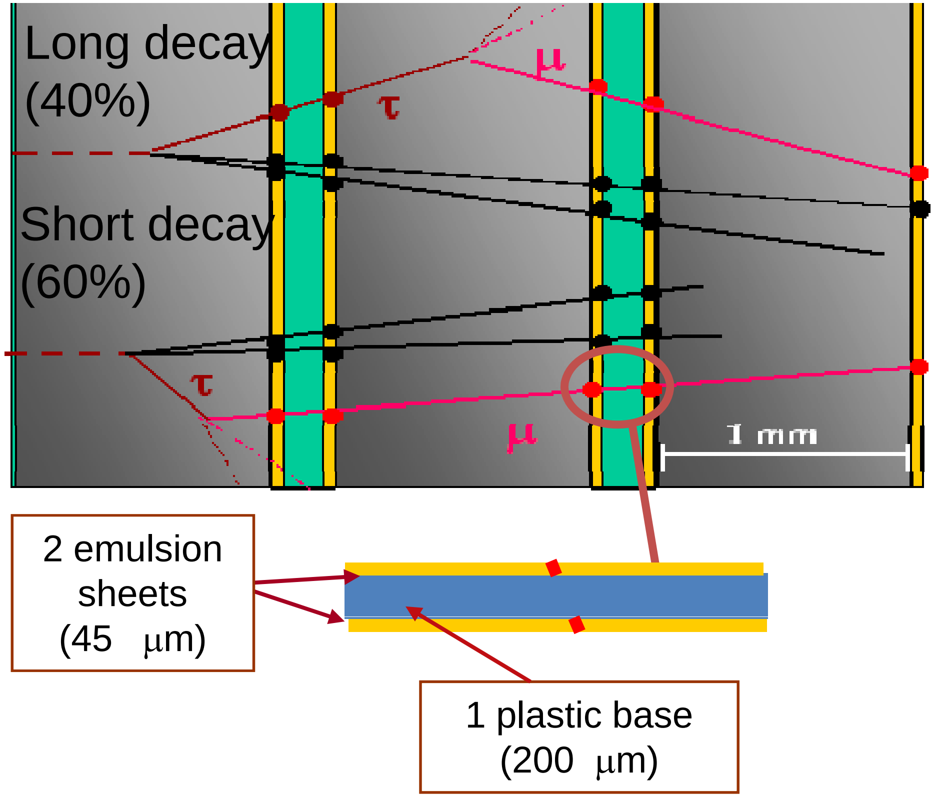
• One brick is made by a sandwich of:

56 Pb sheets (1mm)

57 FUJI emulsion films (300μm)

2 changeable sheets (300μm)





ECC as a complete stand-alone detector.....

• Neutrino interaction vertex and decay topology reconstruction

• Measurement of charged particles momenta by Multiple Coulomb Scattering (20-30% resolution)

• Electron and photon identification and energy measurement

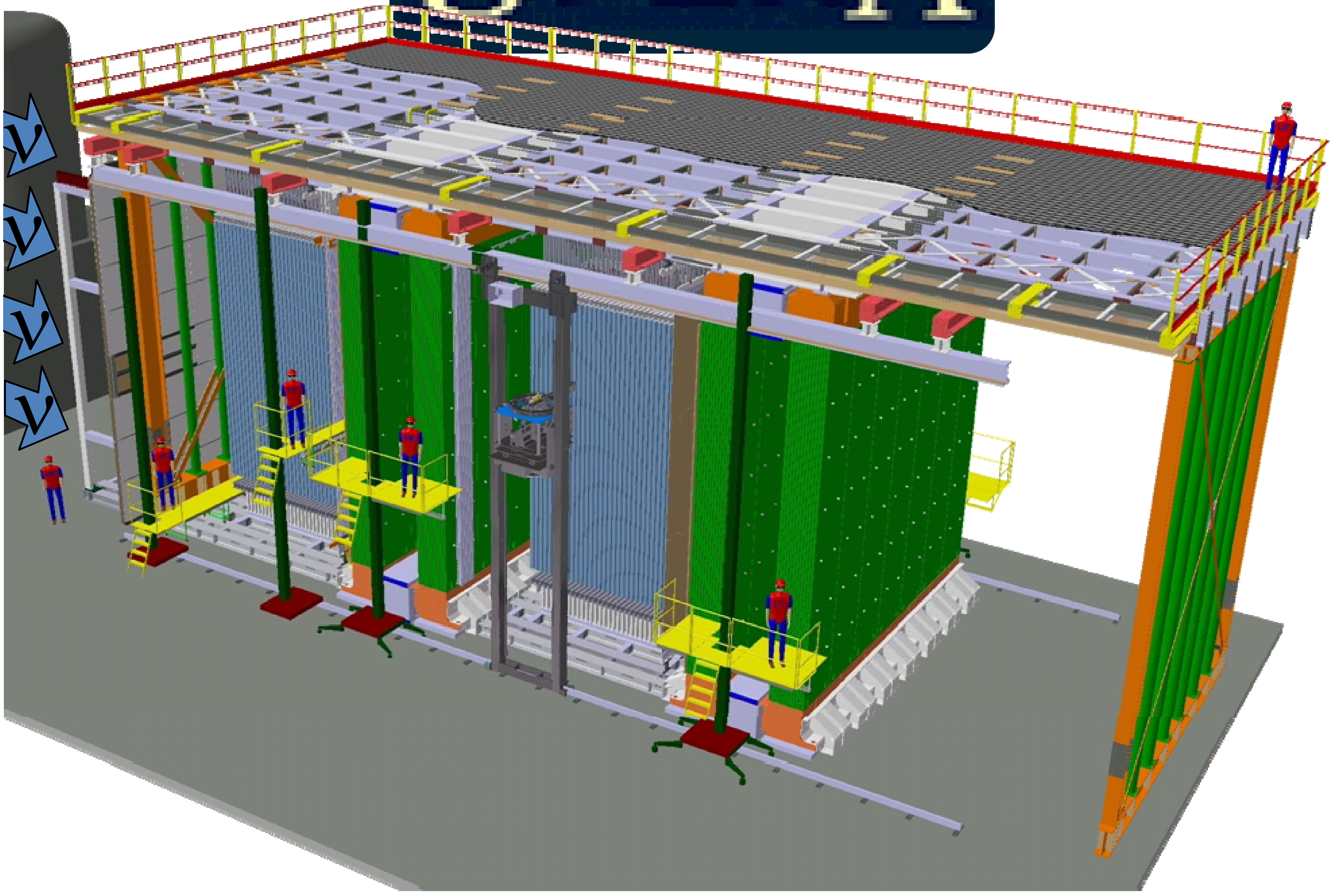
• dE/dx for π/μ separation at the end of their range

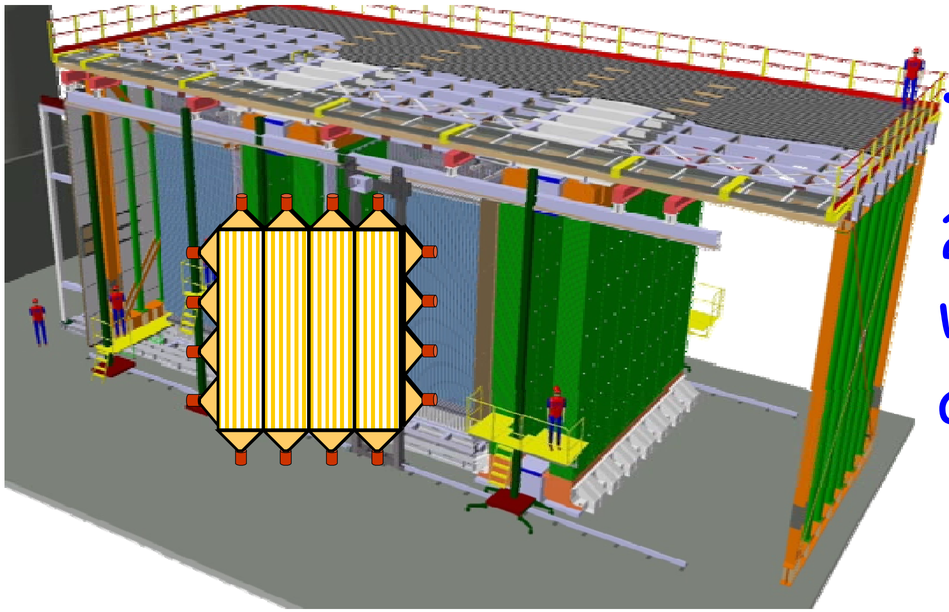
OPERA: expected signal and backgrounds

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

τ decay channels	ε(%)	BR(%)	Signal		Background
			$\Delta m^2 = 2.5 \times 10^{-3}\ eV^2$	$\Delta m^2 = 3.0 \times 10^{-3}\ eV^2$	
$\tau \to \mu$	17.5	17.7	2.9	4.2	0.17
$\tau \to e$	20.8	17.8	3.5	5.0	0.17
$\tau \to h$	5.8	49.5	3.1	4.4	0.24
$\tau \to 3h$	6.3	15	0.9	1.3	0.17
ALL	$\varepsilon \times$BR=10.6%		**10.4**	**14.9**	**0.75**

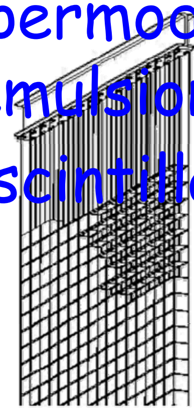
OPERA

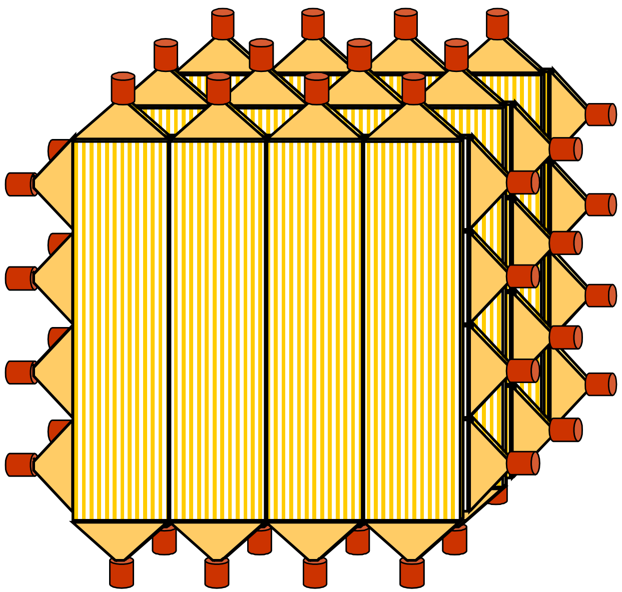




The target:

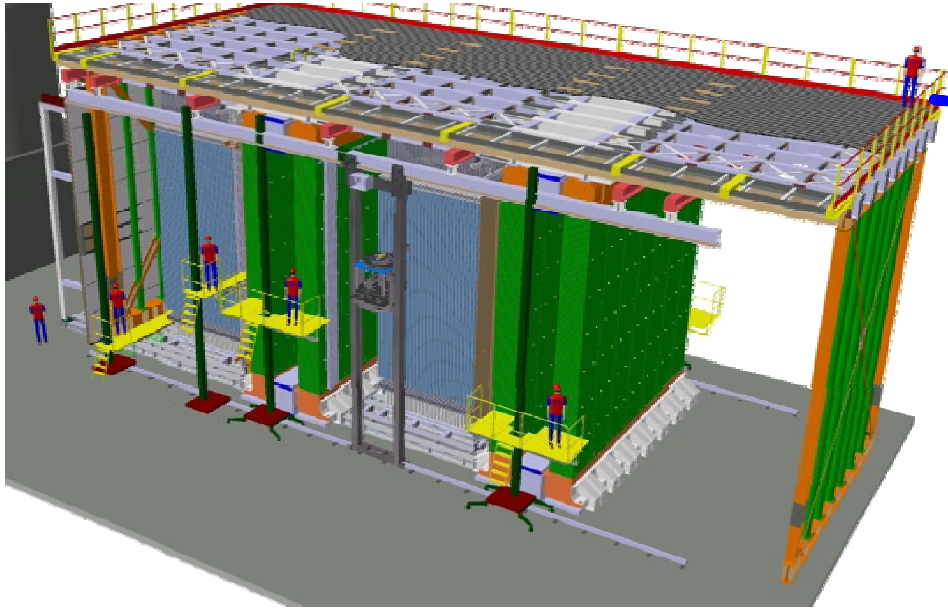
2 identical Supermodules each with 27 lead-emulsion brick walls alternated to scintillator planes

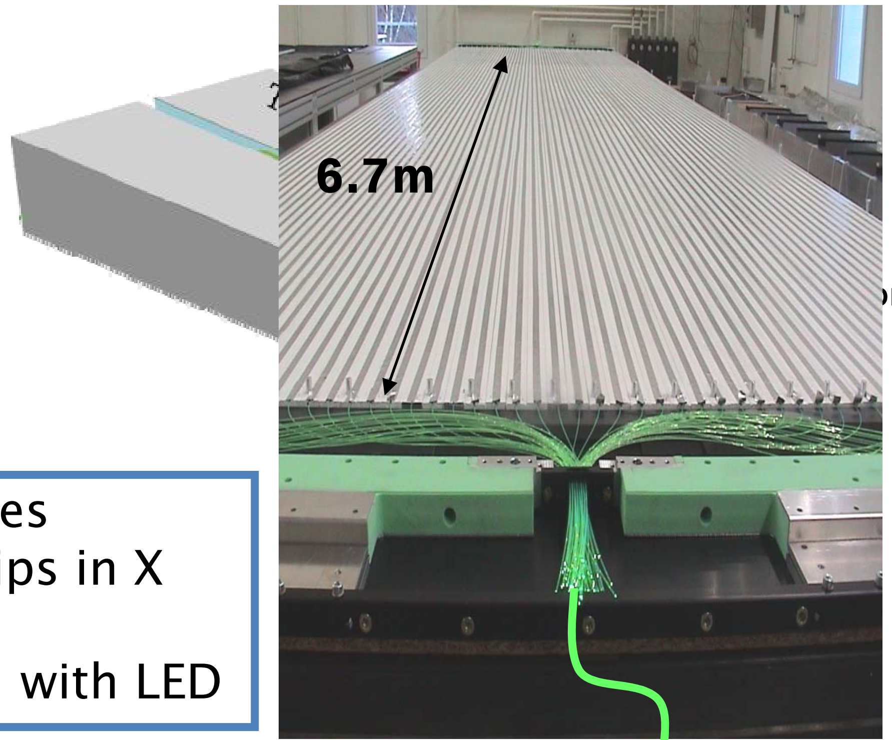


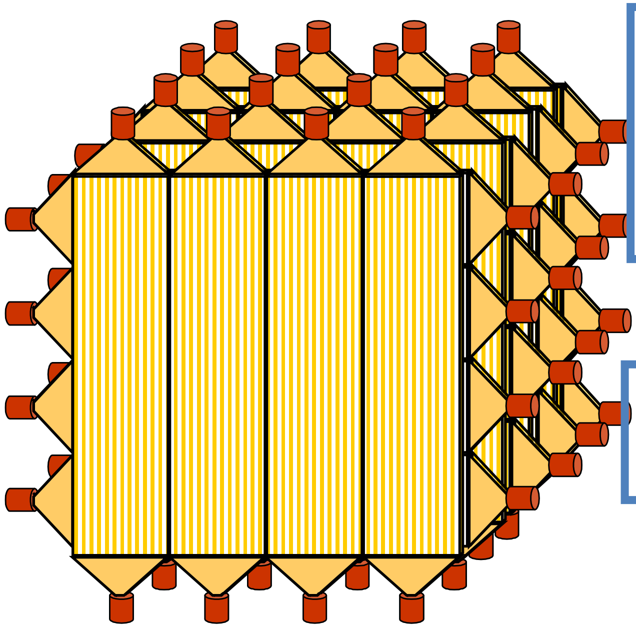


- Target
  - 150036 bricks.
  - 8.85 millions emulsion films/8.55 millions lead plate.
- Target Tracker
  - 2×31 planes
  - Scintillator strips ~ 6.7m long

The target Tracker

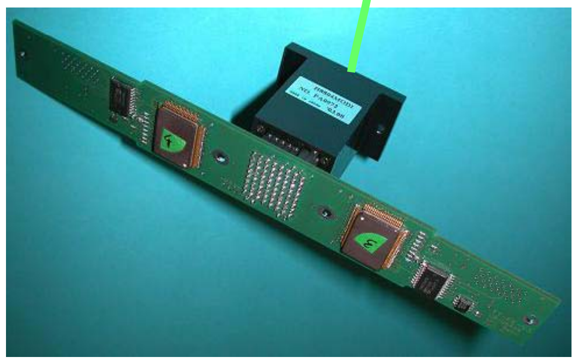






- 2×31 planes
- 4 × 64 strips in X and in Y
- Calibrated with LED

- PM Hamamatsu H7546 64 channels

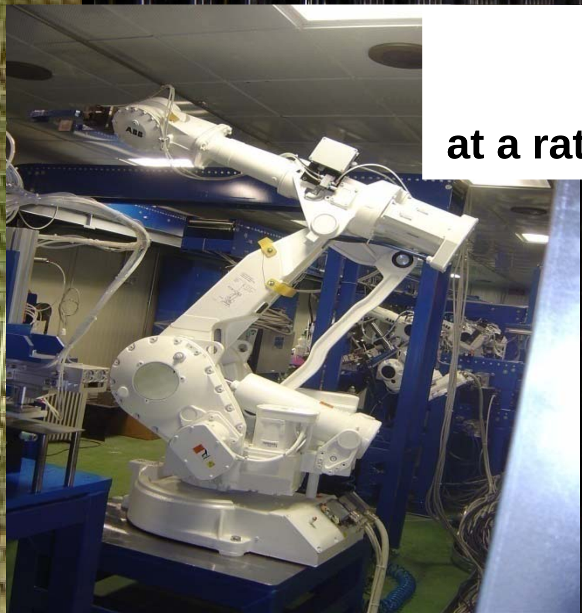


Brick Target

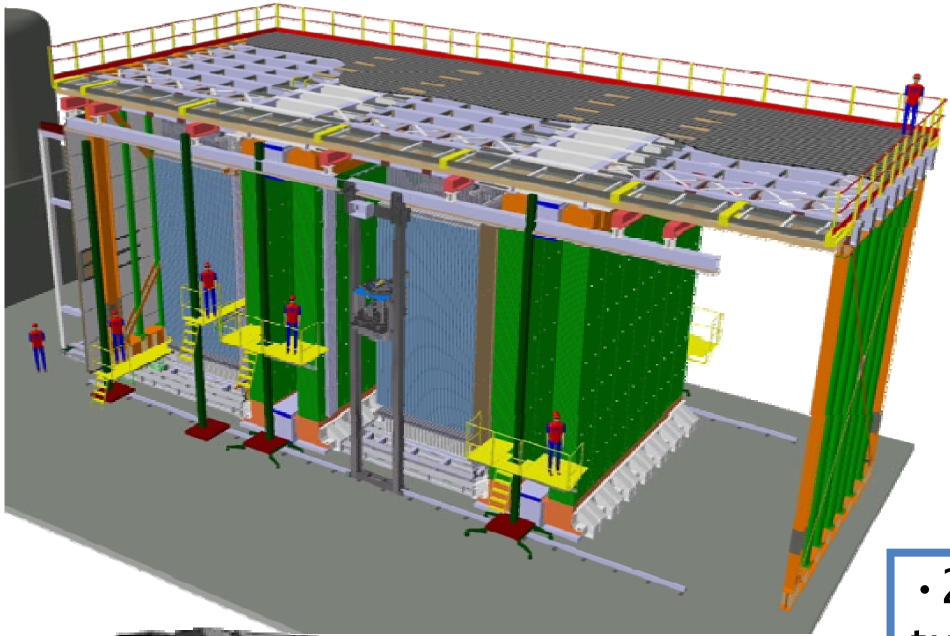
First wall installed

Side view of the first SuperModule (empty)

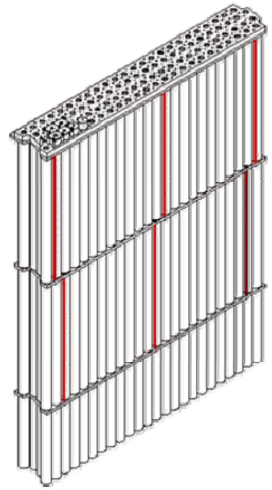
Brick filling of 146621 bricks finished in 2008
3415 additional bricks for a total of 150036 inserted in 2009



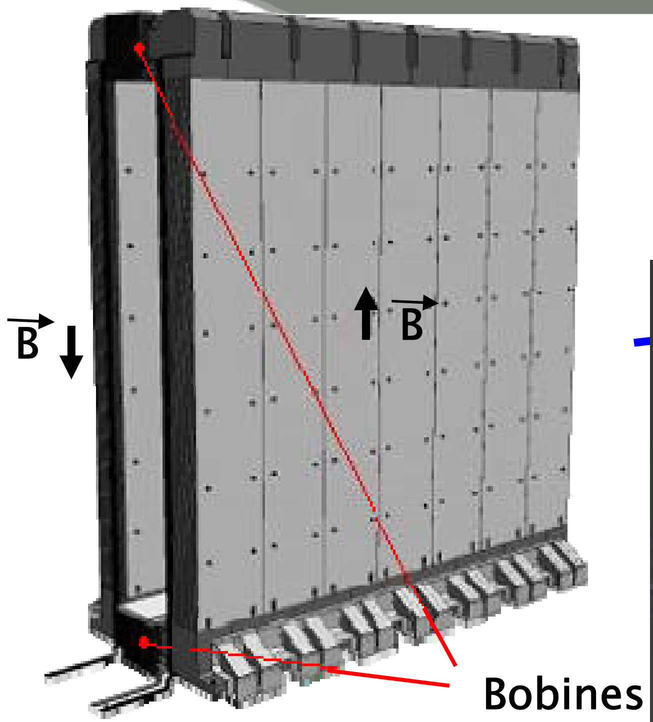
Brick Assembly Machine:
robots piling up bricks
at a rate up to 700 bricks/day in a dark room



The spectrometers



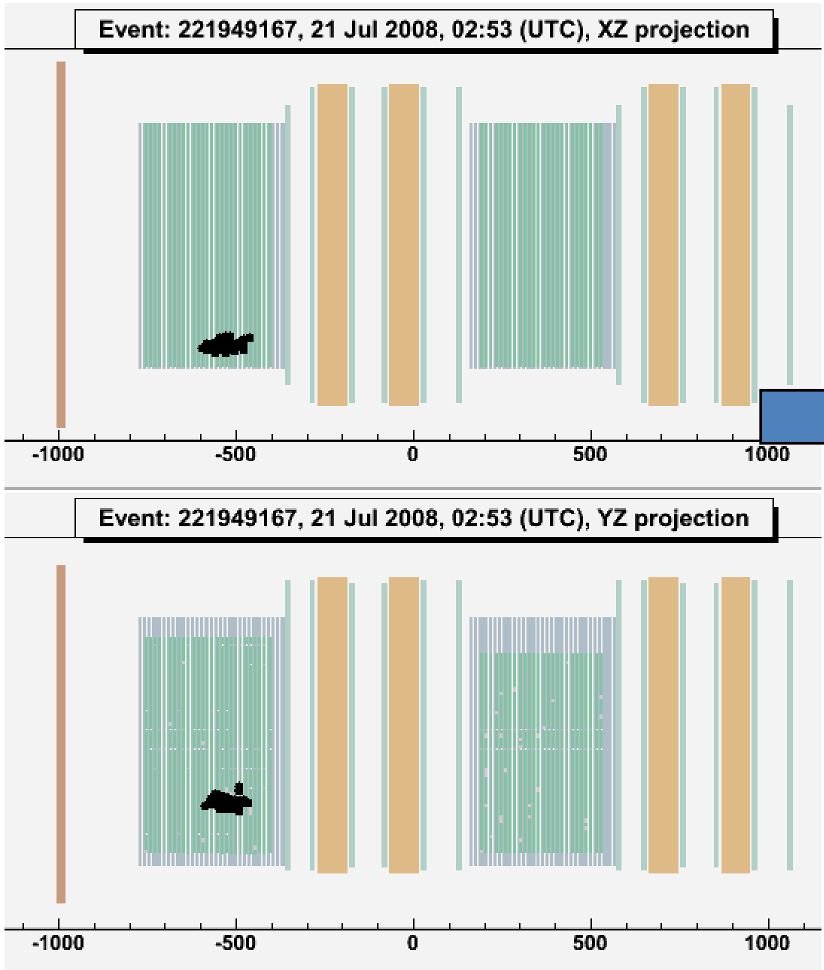
- 2300 vertical drift tubes
- 2 × 6 stations
- 7,9m high
- Resolution: 350μm

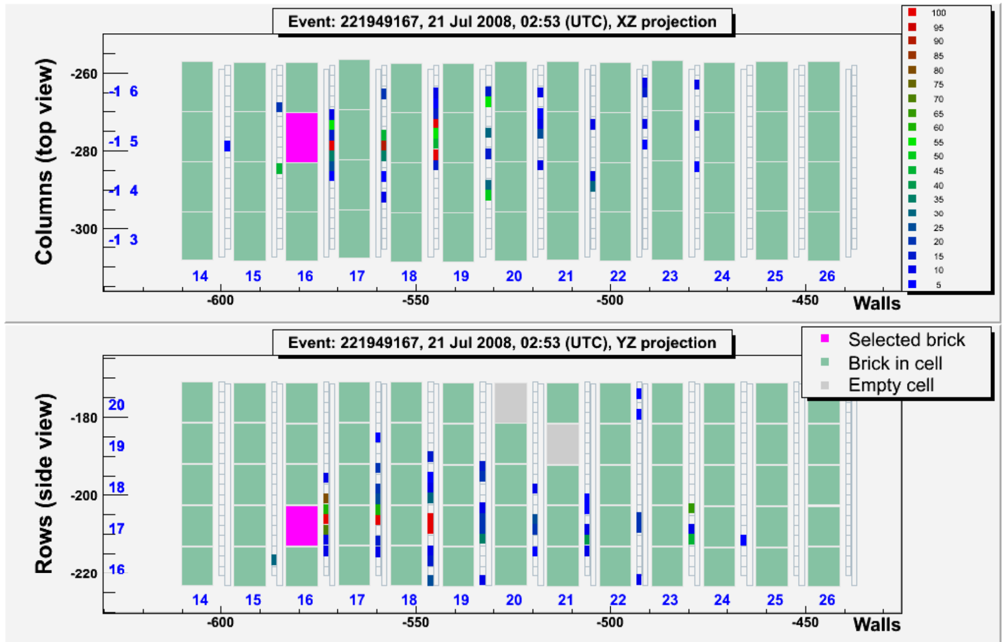


ε miss charge	0.1%-0.3%
Δp/p (<50 GeV/c)	~ 20%
μ ID (with TT)	~ 95%

OPERA working chain (1)

1. Trigger on event "on time" with CNGS and selection of the brick using electronic detectors information (brick finding algorithm)



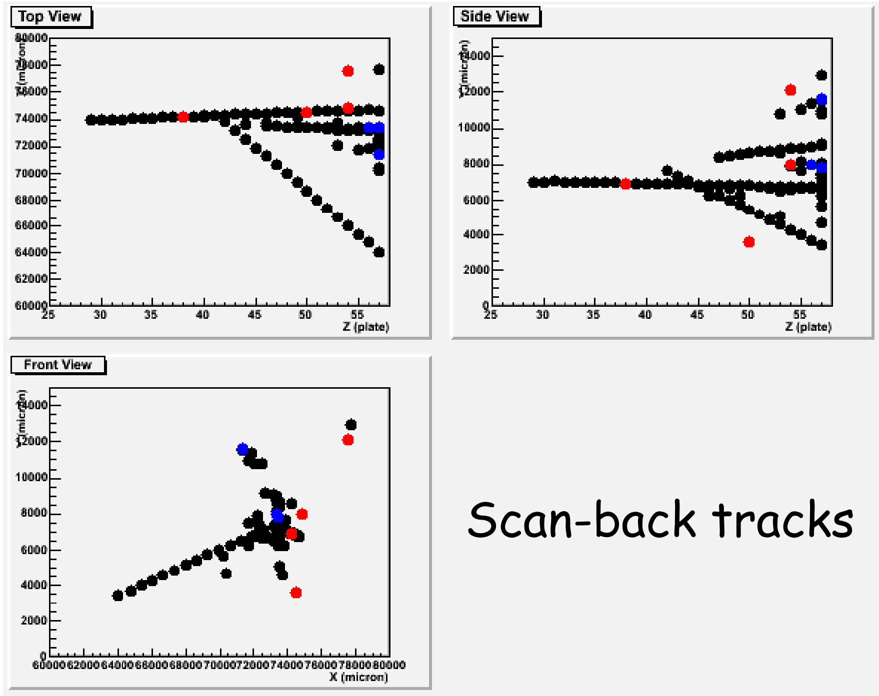


OPERA working chain (2)

2. Brick removed by BMS (brick manipulator system)
3. The emulsion interfaces (CS), separated from the brick, are developed and a connection with respect to the electronic predictions is searched for in one of two Scanning Stations, located in Europe (LNGS) and in Japan (Nagoya)
4. If any track is found in the CS, the brick is exposed to X-rays beam and to cosmic rays for sheets alignment
5. The brick is disassembled and the emulsion films are developed and sent to one of scanning labs

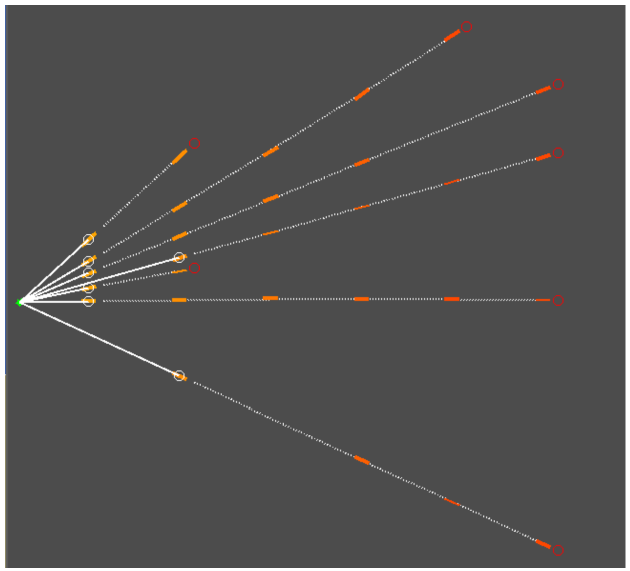
OPERA working chain (3)

6. The selected scanning lab receive the brick: the tracks found in CS are searched for in the most downstream films of the brick and followed until the neutrino interaction is found



7. A volume scan around the neutrino interaction is performed and the neutrino vertex fully reconstructed

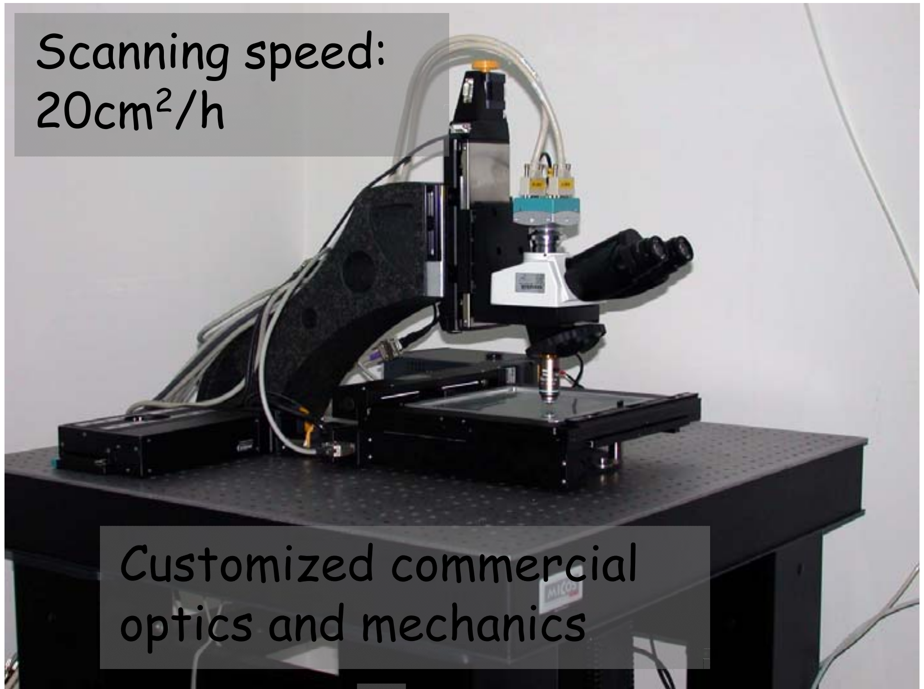
8. The scanning lab stores the information about the brick in a local database. Information are then copied in one of two synchronized central database



OPERA emulsions' data taking:
the automated microscopes

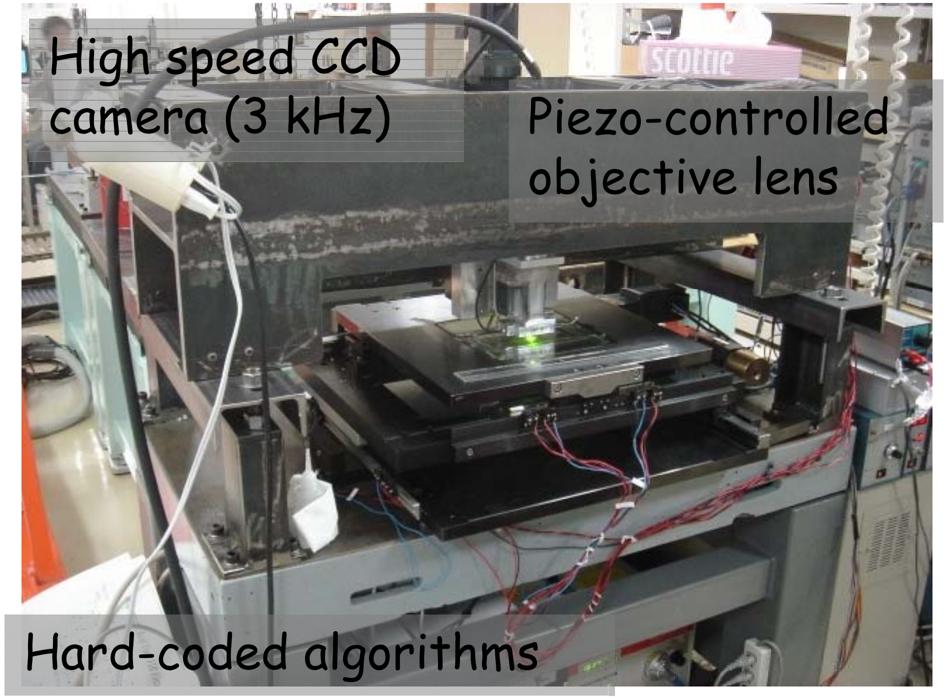
Up to 150 bricks for week can be extracted from the target and analyzed by using high-speed automated systems. Scanning labs are ready with ~40 microscopes available, shared in Japan and Europe

European scanning system

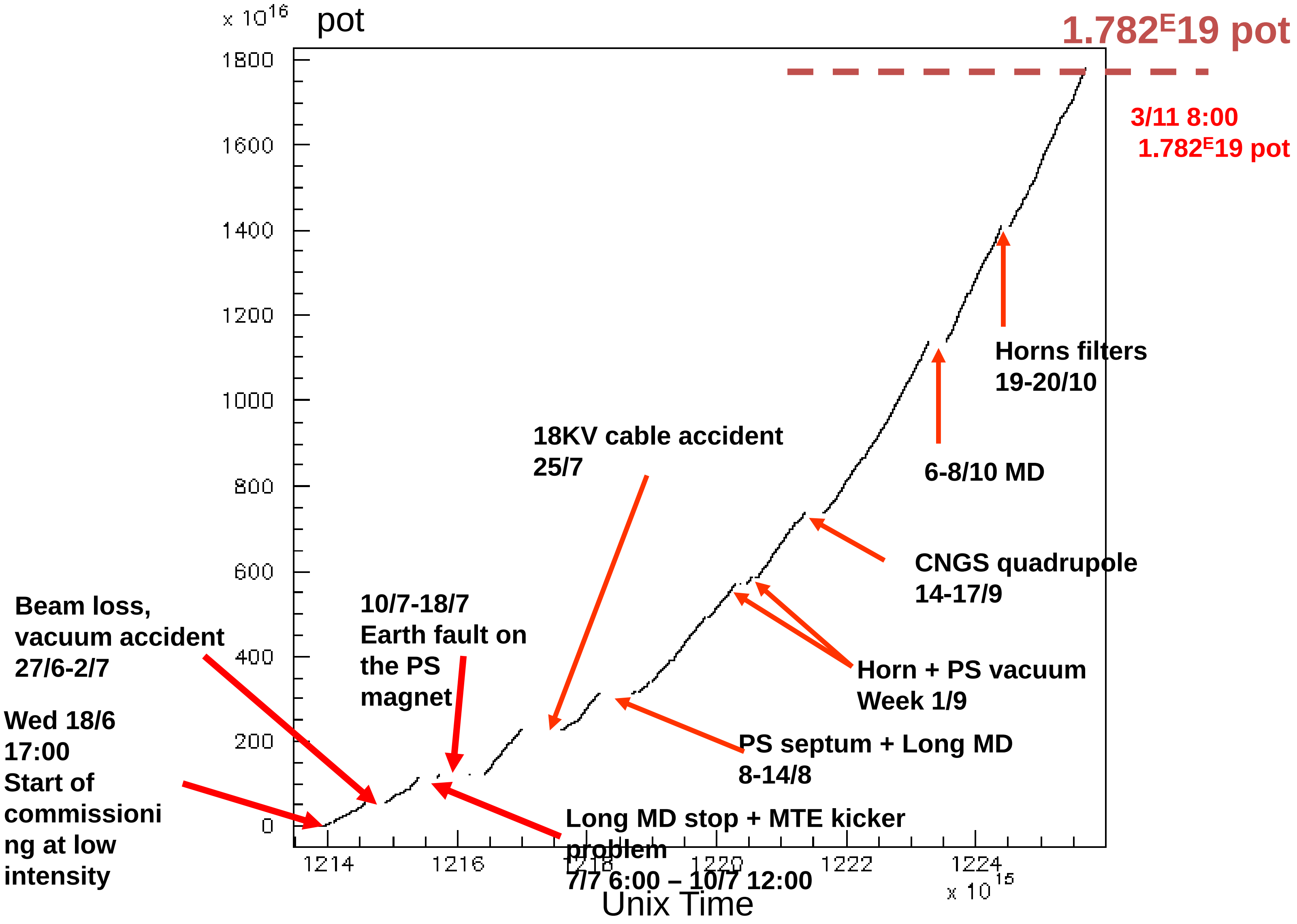


asynchronous DAQ software

S-UTS (Japan)



2008 run: CNGS integrated intensity



2008 run:
Started June 18th, end on November 3rd

Beam performance for the 2008 run:

Efficiency	60% (expected 80%)
Intensity (p.o.t. / extraction)	$2x10^{13}$
Integrated p.o.t.	$1.78x10^{19}$pot (80% of the expectations)

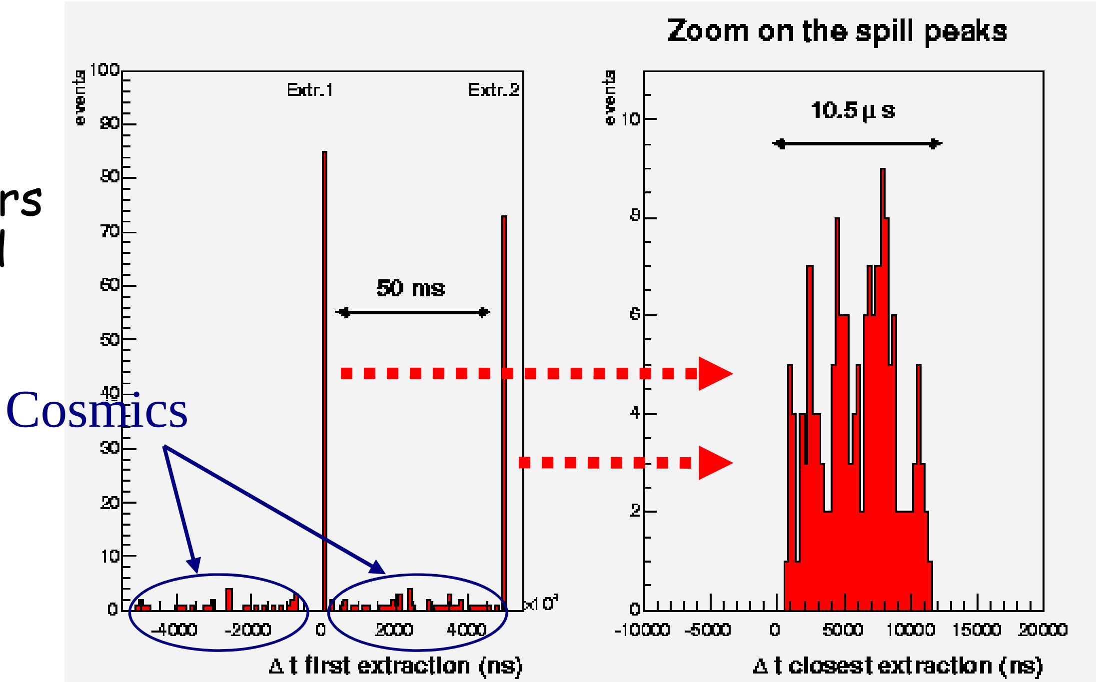
Detected interactions:

Recorded on time event	10058
Candidate ν Interaction (In the target)	1690 (MC expected 1700)

Number of expected tau's ~0.7

CNGS+OPERA run summary

Events in the electronic detectors are time-stamped (10 ns bin) and correlated through GPS with CNGS *beam*

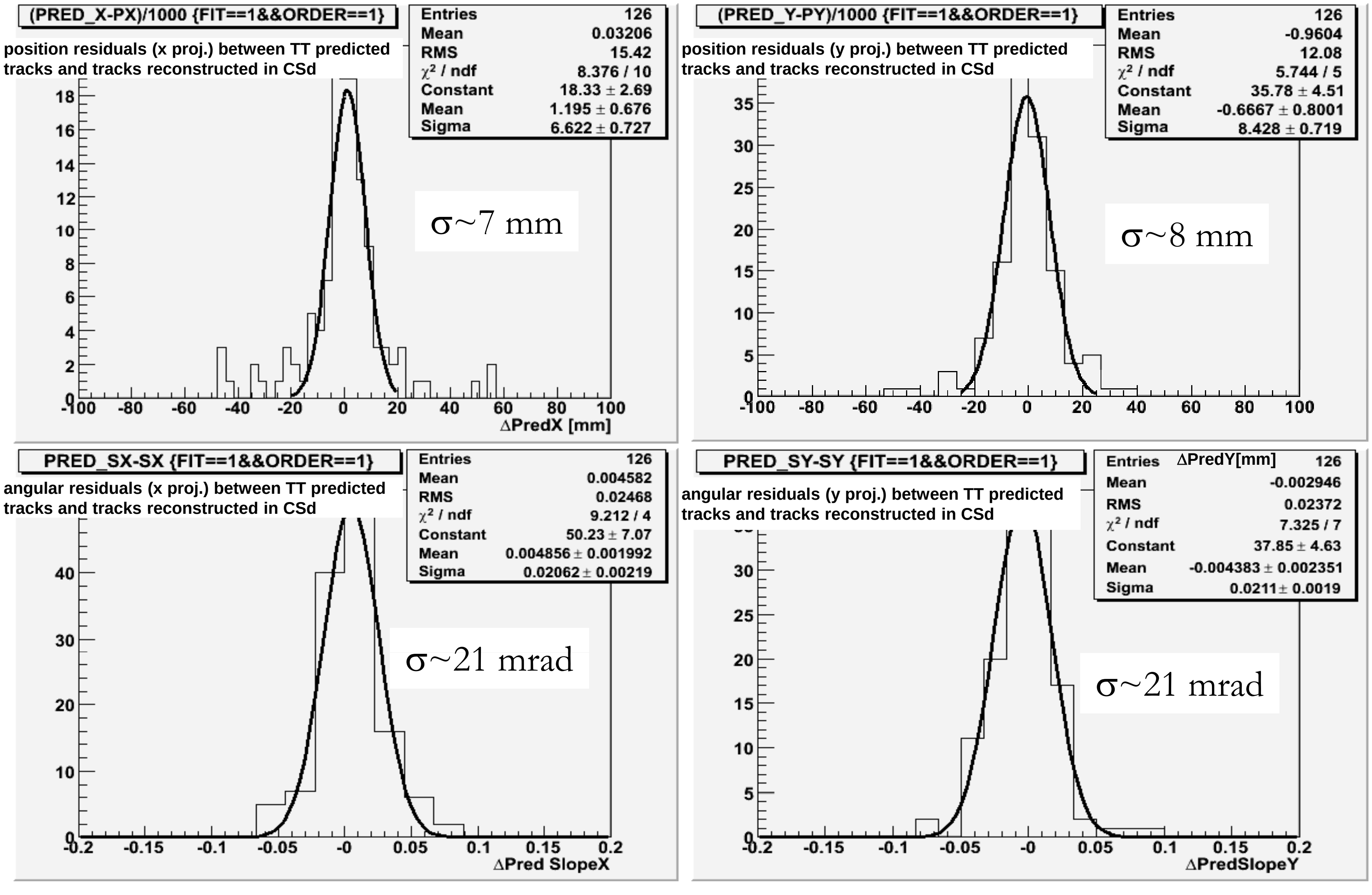


	Delivered pot	Target filling	On-time events	Target events
2006	$8.2*10^{17}$	Empty	347	0
2007	$8.24*10^{17}$	80% of first Target	393	38
2008	$1.78*10^{19}$	Full	10058	1690

Perspectives for 2009 CNGS run: $4.5*10^{19}$ pot requested ($3.5*10^{19}$ scheduled)

Changeable Sheet scanning

TT-CS agreement: CC interactions



Vertex location results (European subsample)

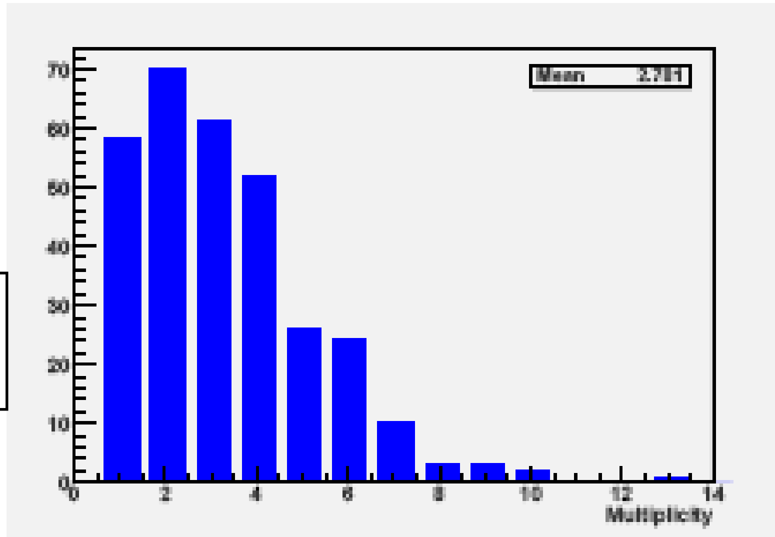
	NC	CC	Total
Bricks received by the labs	76	368	444
Scanning started	71	351	422
CS to Brick connection	64	329	393
Vertices located in the brick	45	270	315
Tracks passing through bricks	7	25	32
Vertices in dead material	1	6	7
Under analysis	11	28	39

Vertex location efficiency:

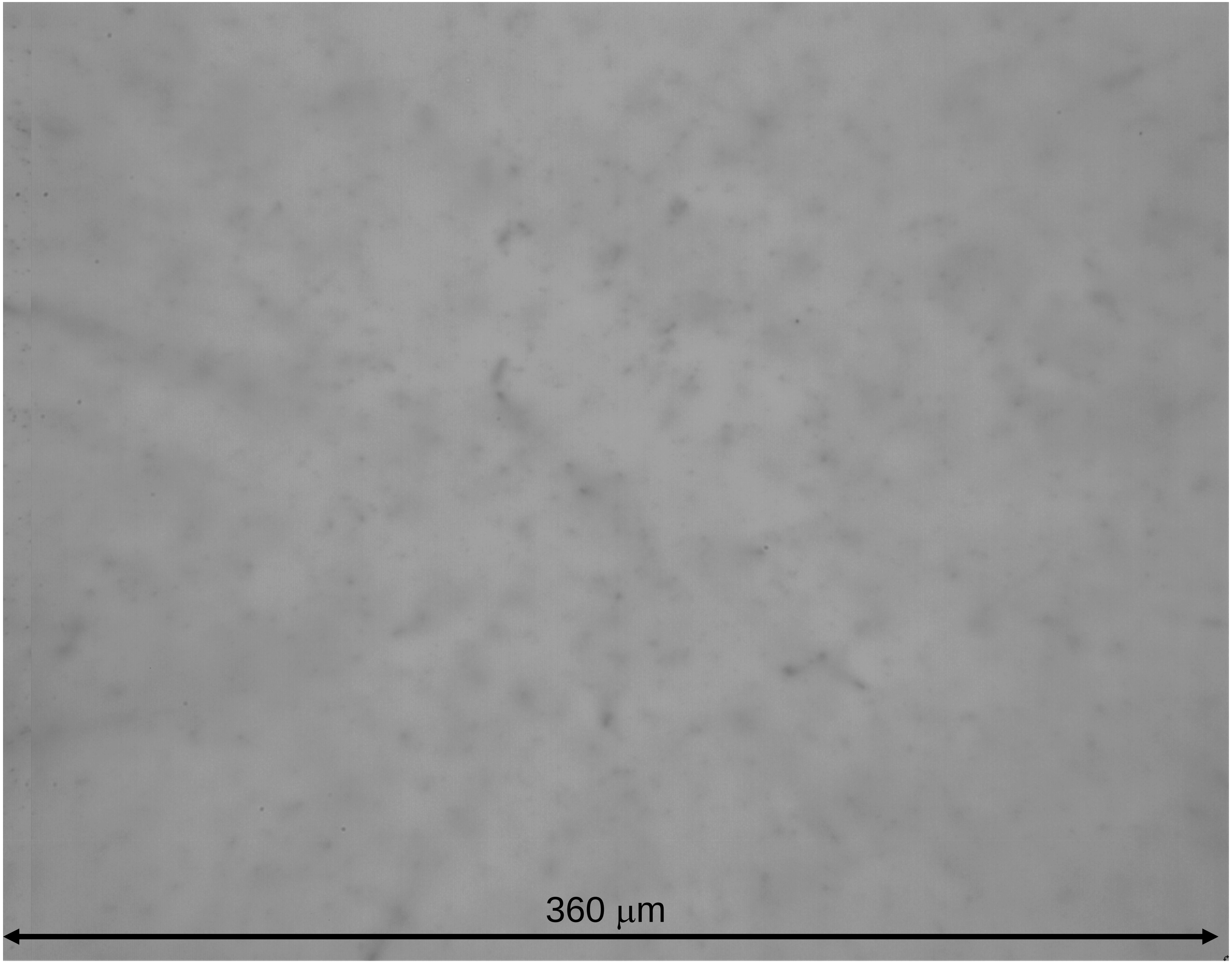
Charged-current:
270/(329-25-6) = 91±2%
Neutral-current:
45/(64-7-1) = 80±5%

Iterative process (CS and brick scan) for not connected and not located events

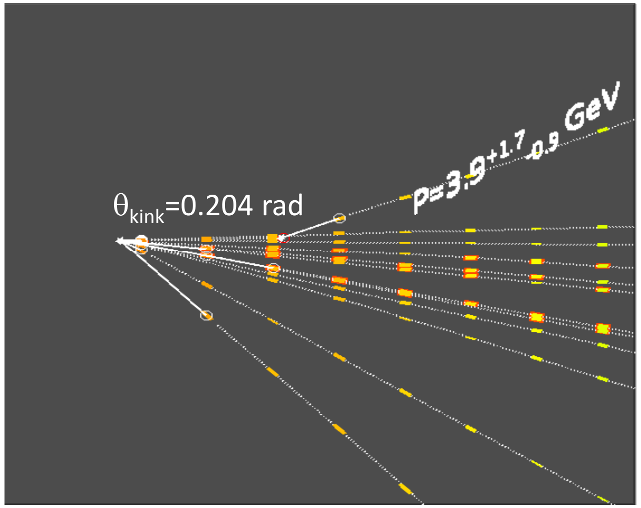
1ry vertex multiplicity distribution

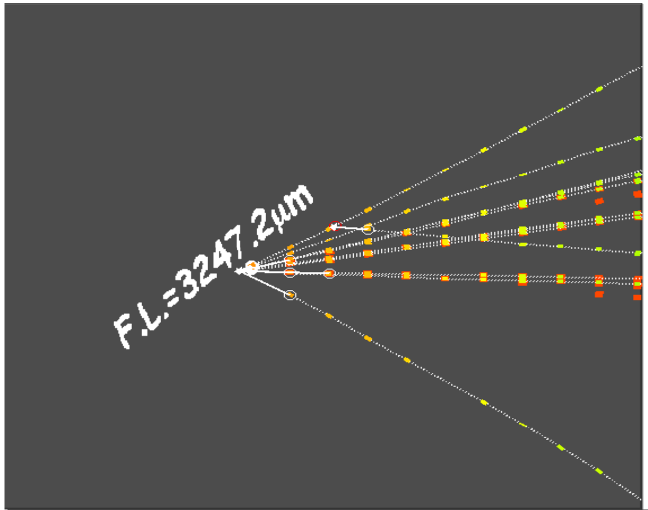


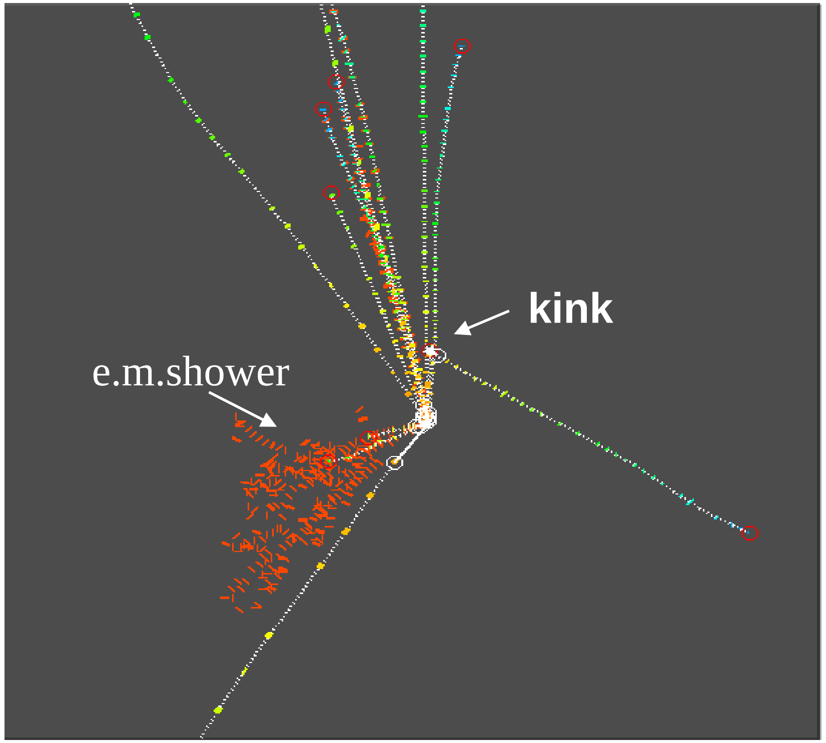
Event gallery


360 μm

Topological and kinematical analysis - first charm-like event







Daughter momentum = 3.9 +1.7-0.9

θkink = 0.204 rad

Flight length = 3247 μm

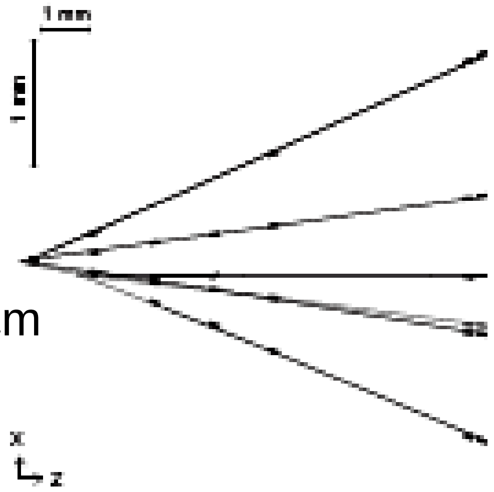
PT = 796 MeV

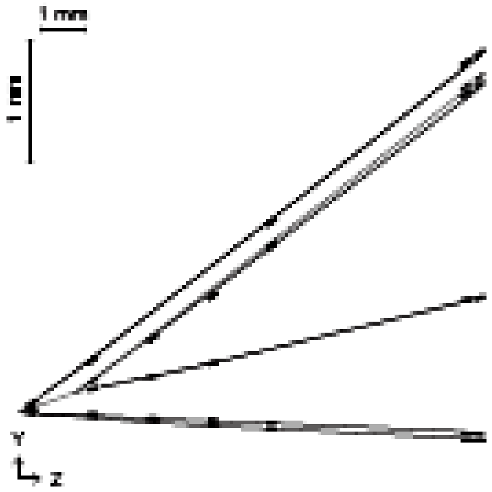
PTMIN = 606 MeV (90% C.L.)

The main background source is the hadron reinteraction

The probability that a hadron reinteraction has a Pt larger than 600 MeV is $4*10^{-4}$

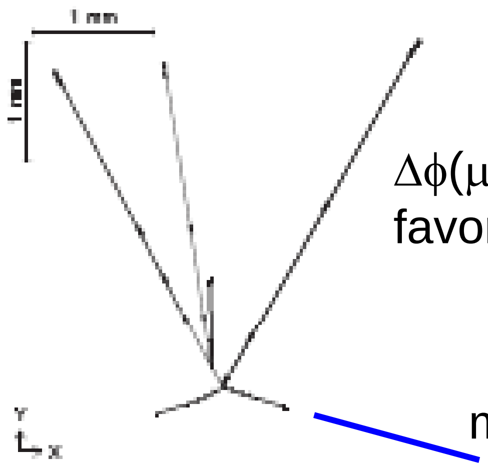
Topological and kinematical analysis - second charm-like event





Flight length = 1050μm

Daughter's momentum (GeV):
P1=2.4+1.3-0.6
P2=1.3+0.4-0.3
P3=1.2+1.7-0.4
PTOT=4.8+2.2-0.8



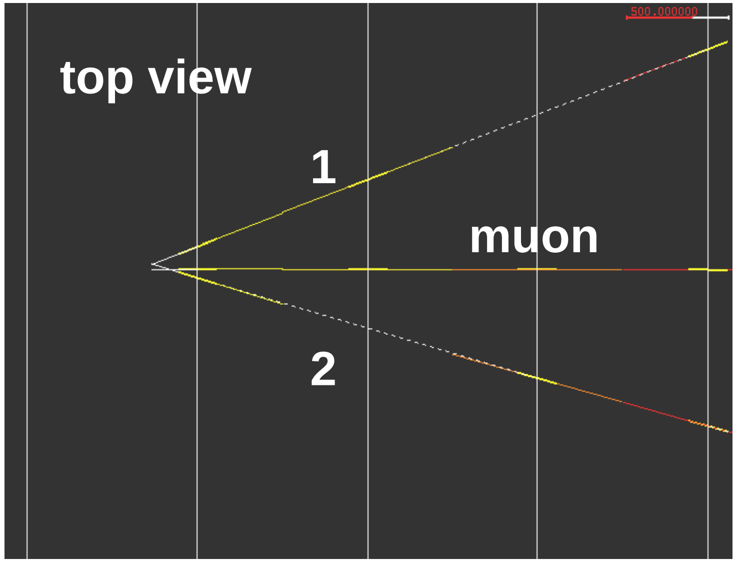
$\Delta\phi$(μ-charm) =150 degree
favors charm interpretation

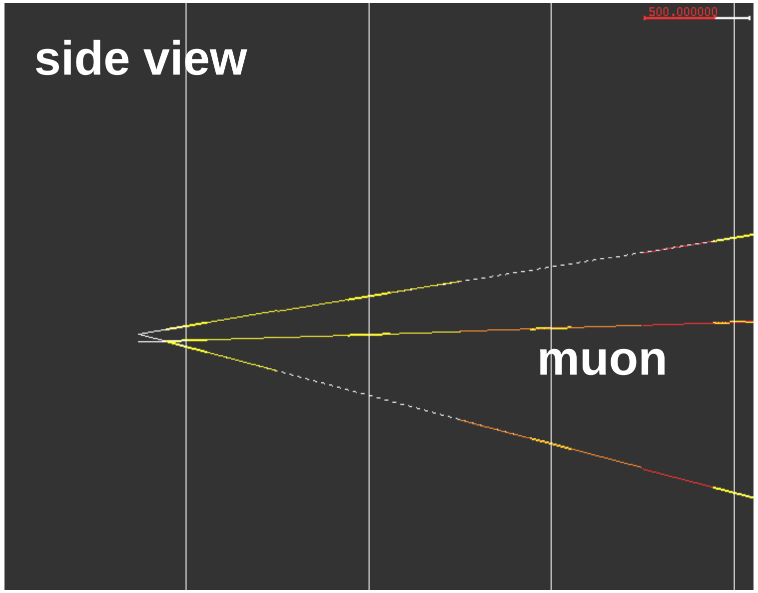
muon

Inv. Mass=1.1+0.2-0.1 GeV
(D+->K$\pi\pi$ hypothesis)

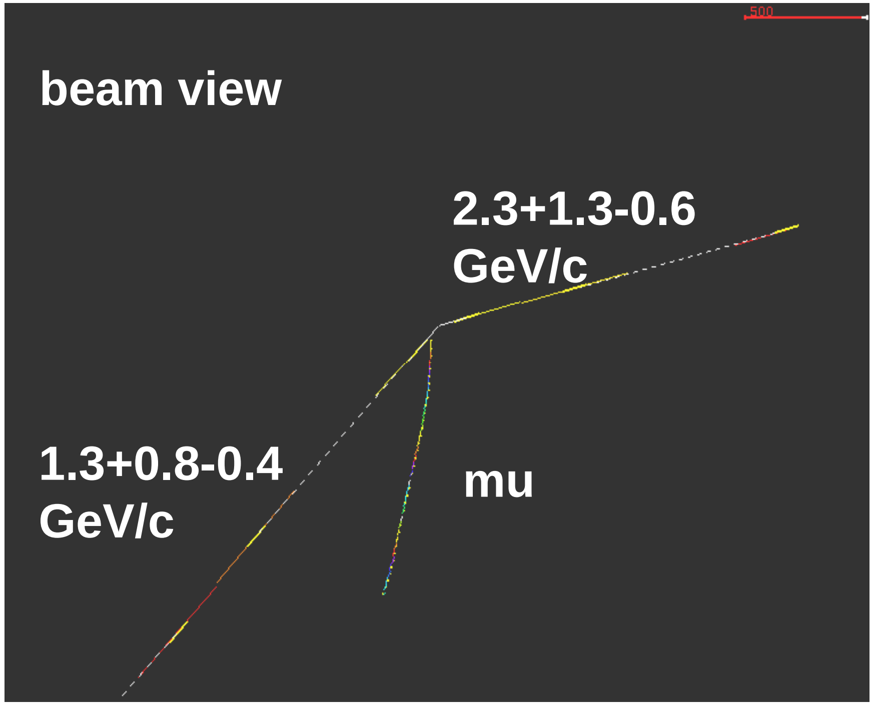
Inv. Mass=1.5+0.4-0.1 GeV
(Ds->KKπ hypothesis)

Topological and kinematical analysis - third charm-like event

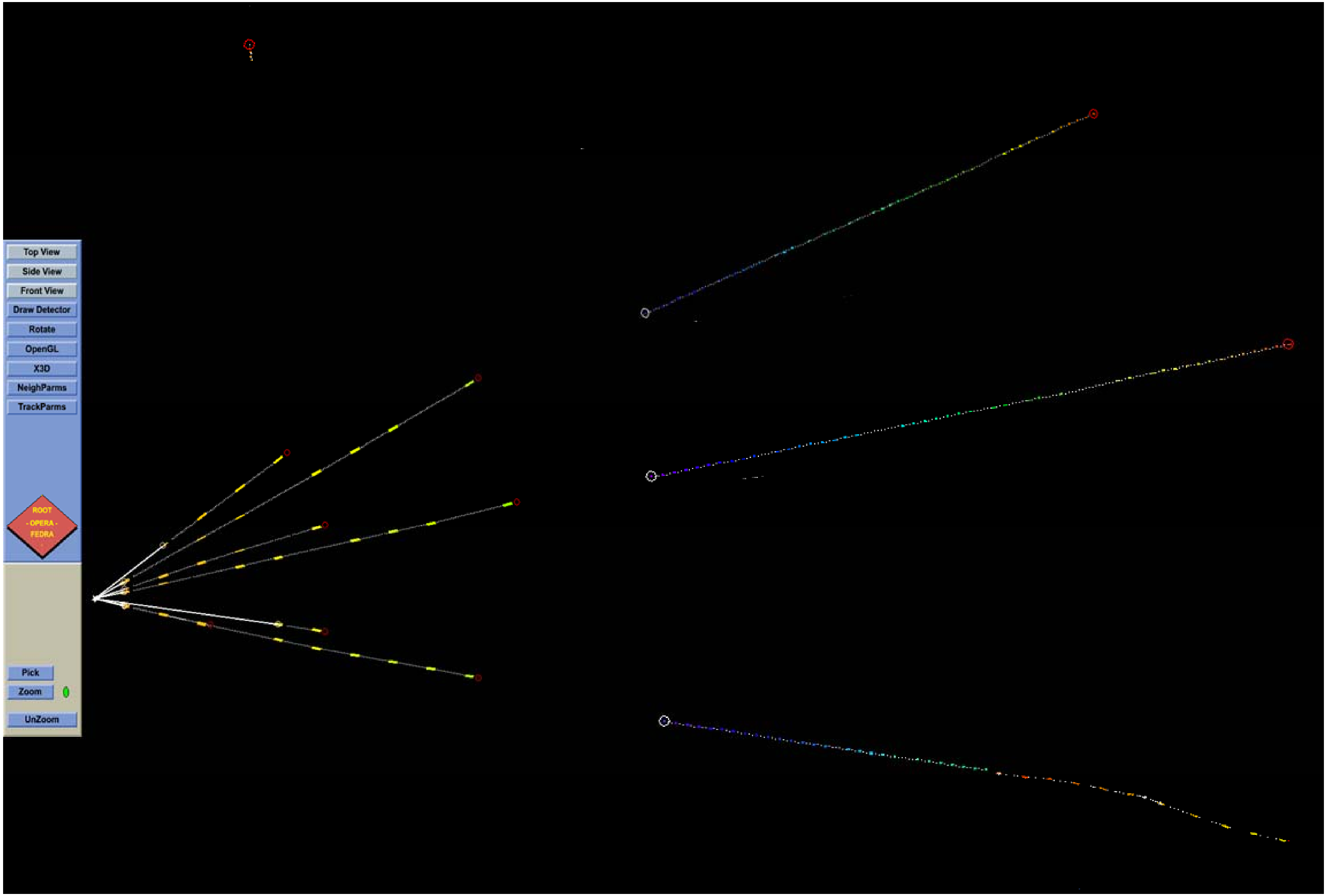


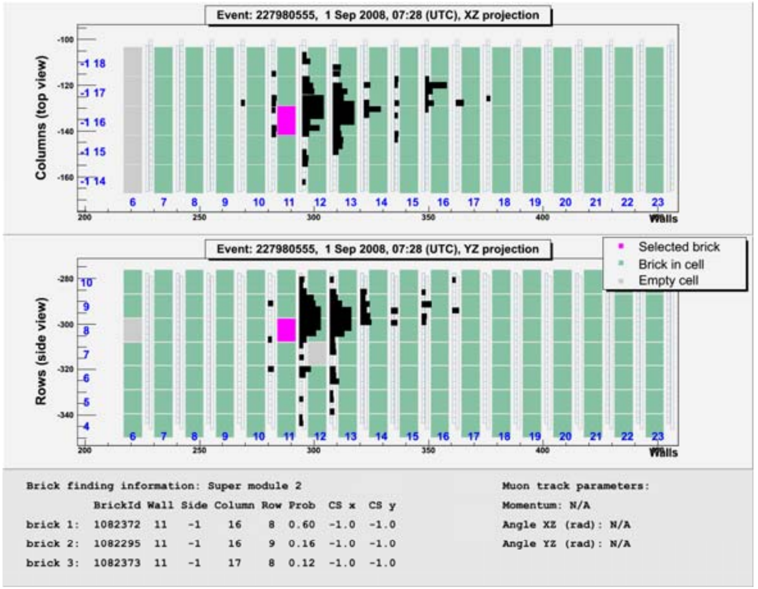


Impact Parameter w.r.t. the vertex
trk 1   0.3563 0.1562   0.5 μm
trk 2 -0.2815 -0.2423   0.4 μm
muon -0.0001 0.0303 62.8 μm

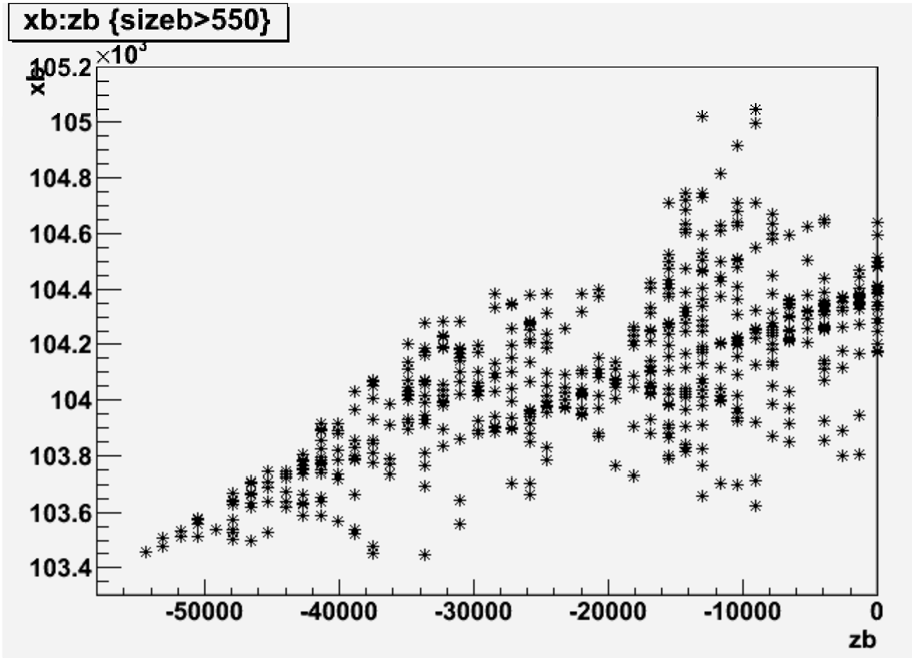


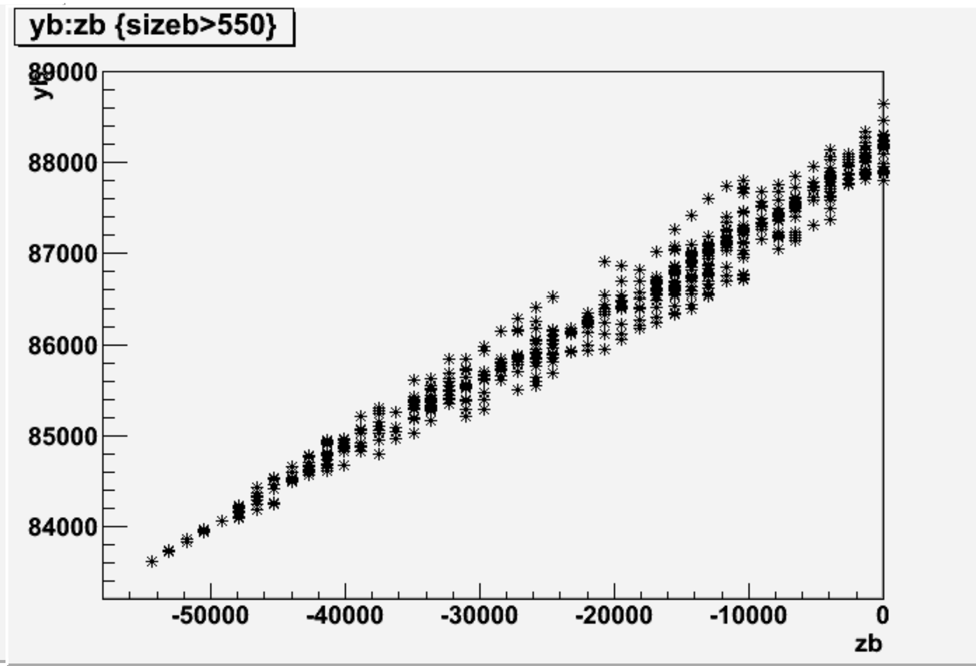
Brick to brick connection





~20 GeV electromagnetic shower reconstructed





Conclusions

- The OPERA detector successfully operated during 2008 CNGS run

- Partial recovery of the beam after a rather problematic start: 1.78x10^19 instead of 2.2x10^19 expected pot

- About 1700 neutrino events inside bricks (<1τ expected): data sample to fine tune OPERA analysis and to estimate efficiencies and background

- Scanning and analysis are on going

- In the next CNGS run the integrated intensity is expected to reach 3.5x10^19 pot : this means for OPERA about 2 τ expected