The OPERA experiment at LNGS

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Salerno University & INFN

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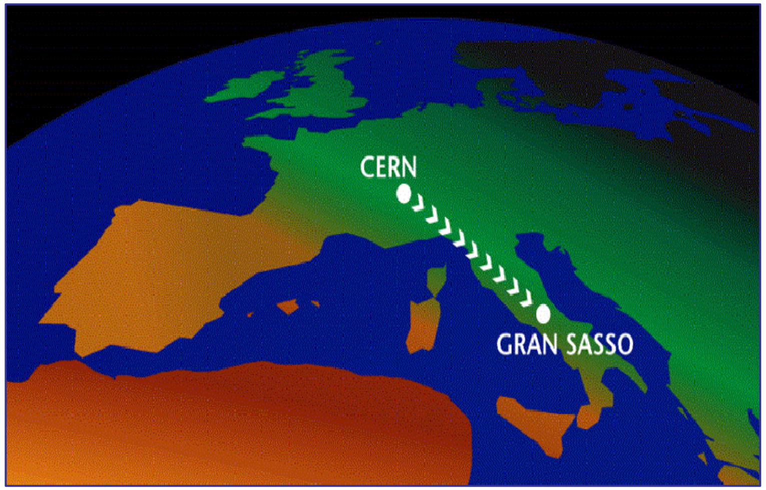
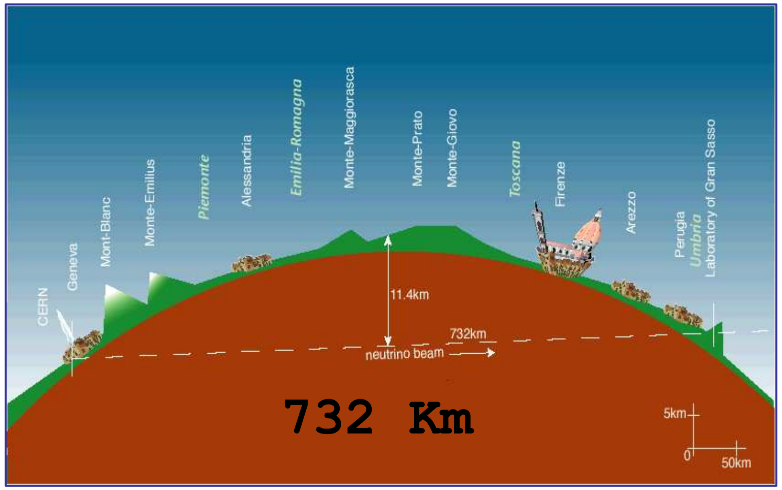
Outline

- ✓ Introduction
- ✓ The OPERA Detector at work
- ✓ Data Analysis
- ✓ OPERA latest news …

Oscillation Project with Emulsion tRacking Apparatus





- Long baseline neutrino physics experiment
- CNGS quasi - pure ν_μ beam, <L> = 732 km, <E> = 17 GeV
- Appearance signal $\nu_\mu \to \nu_\tau$ (by product $\nu_\mu \to \nu_e$)
- Hybrid setup (Nuclear Emulsions + electronics)
- Atmospheric neutrino data allowed region oscillation search

The OPERA Collaboration

180 physicists, 33 institutions in 12 countries

Belgium
IIHE-ULB Brussels

Croatia
IRB Zagreb

France
LAPP Annecy
IPNL Lyon
IPHC 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
Jinju

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

Switzerland
Bern
ETH Zurich

Tunisia
CNSTN Tunis

Turkey
METU Ankara

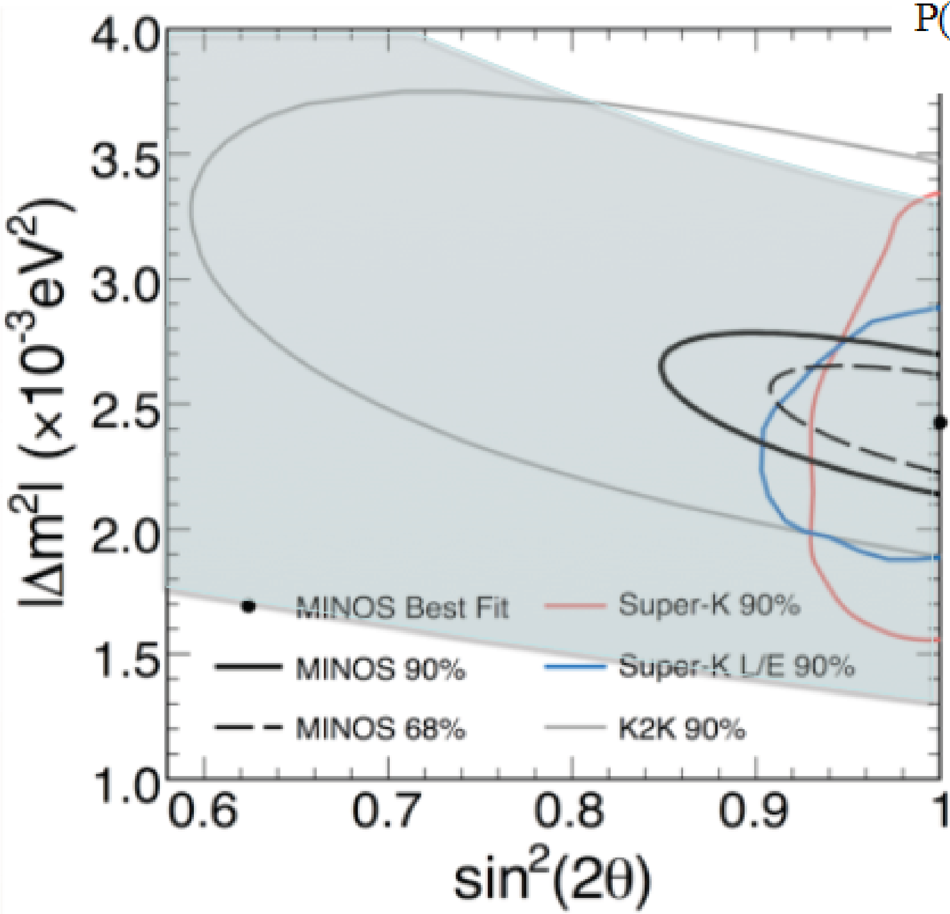
http://operaweb.lngs.infn.it

Physics motivation

- Super-K (1998) : atmospheric neutrino anomaly interpretable as ν_μ->ν_τ oscillation
- CHOOZ (reactor) : ν_μ->ν_e oscillation could not explain the anomaly
- K2K and MINOS (accelerator): confirmation of the Super –K ν_μ disappearance signal

$$P(\nu_\mu \to \nu_\tau) \cong \sin^2(2\theta_{23})\cos^4(\theta_{13})\sin^2\left(\frac{1.27\Delta m^2_{32}L(Km)}{E(GeV)}\right)$$

$$|\Delta m^2| = (2.43 \pm 0.13) \times 10^{-3}\ \mathrm{eV}^2$$

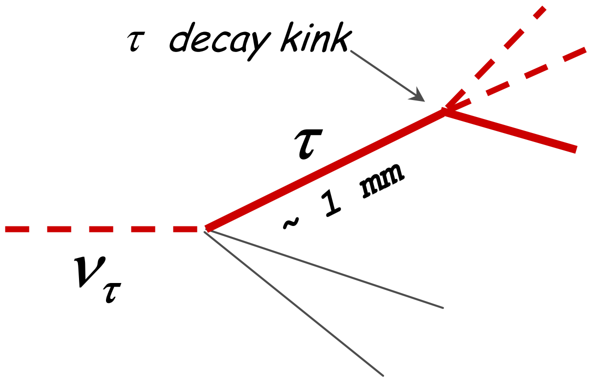


Full mixing and
$\Delta m^2_{23} \sim 2.4 \times 10^{-3}$ eV^2

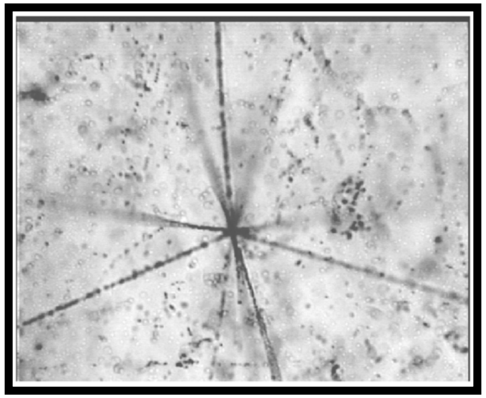
The grey band indicates the OPERA allowed region (90% CL) for the above parameter values for 22.5×10^{19} pot

Challenge

Detection of ν_τ CC interaction in a quasi- pure ν_μ beam and direct observation of the τ lepton decay topologies.



$\tau^- \rightarrow \mu^- \ \nu_\tau \ \nu_\mu$		(17.4%)
$\tau^- \rightarrow e^- \ \nu_\tau \ \nu_e$		(17.8%)
$\tau^- \rightarrow h^- \ \nu_\tau \ n(\pi^0)$		(49.5%)
$\tau^- \rightarrow \pi^+ \pi^- \pi^- \ \nu_\tau \ n(\pi^0)$		(14.5%)

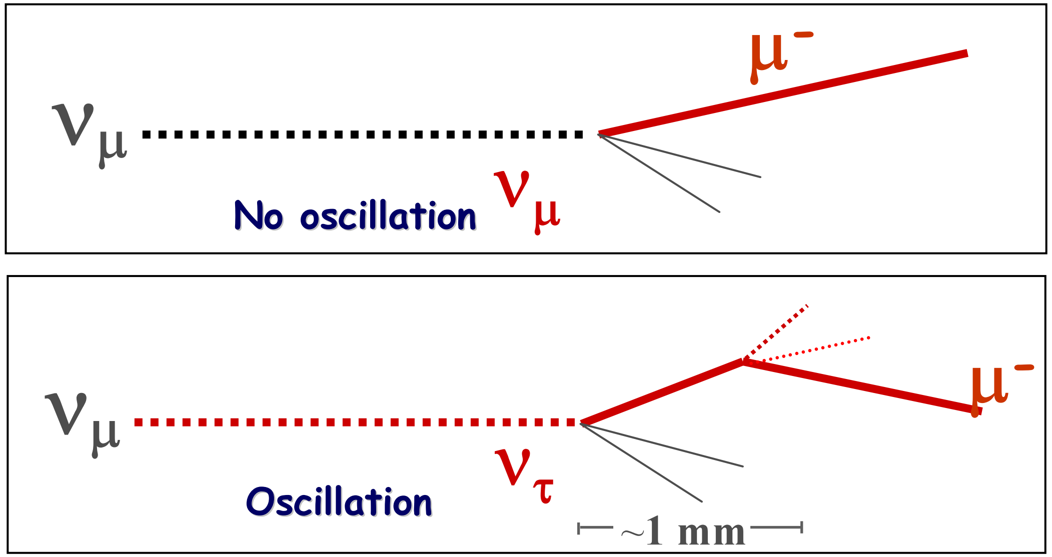


Nuclear emulsions + Lead (ECC) "active target"

- 3D particle reconstruction
- Sub-micron spatial resolution

High background rejection

ν_τ events topological signature



τ decay channel	Signal $\Delta m^2 = 2.5E^{-3}$ eV^2	Background
$\tau \to \mu$	2.9	0.17
$\tau \to e$	3.5	0.17
$\tau \to h$	3.1	0.24
$\tau \to 3h$	0.9	0.17
Total	10.4	0.75

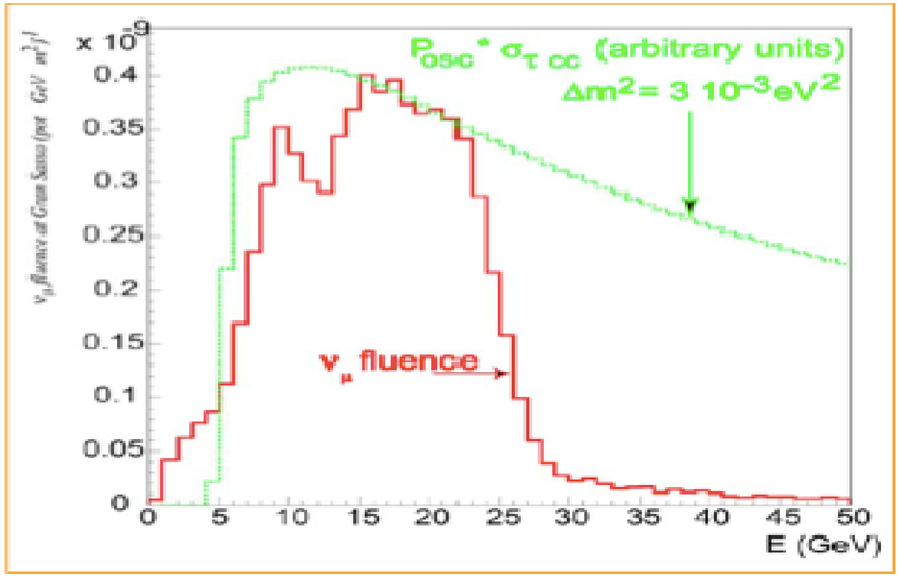
Expected data sample after 5 years

Target: ~ 1250 tons, 22.5E^{19} p.o.t.

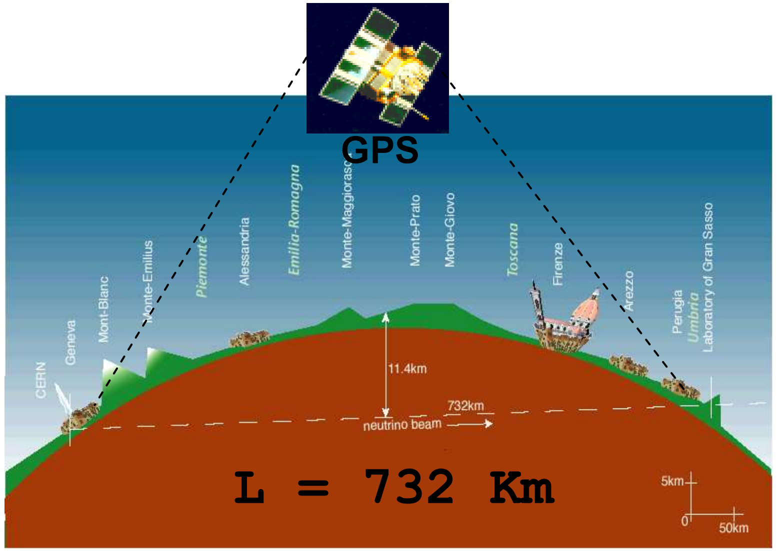
- \> 20000 neutrino interactions
- ~ 100 ν_τ interactions
- ~ 10 ν_τ identified
- < 1 background event

CNGS neutrino beam

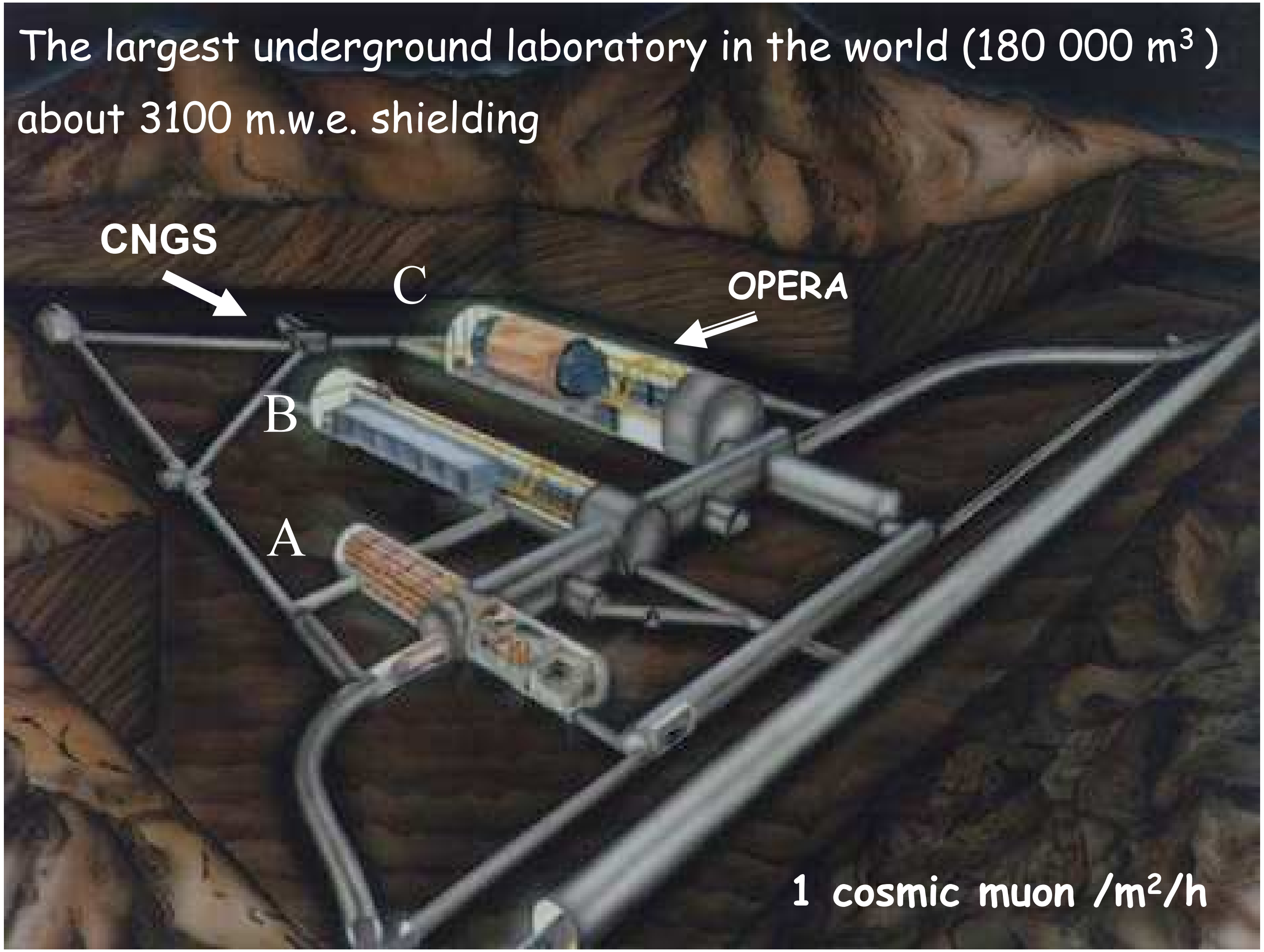
< E >	17 GeV
ν_μ(CC + NC)/year	~4700
ν_τ CC/year	~20
$(\nu_e + \overline{\nu}_e)/\ \nu_\mu$ CC	0.87%
$\nu_\mu\ /\ \overline{\nu}_\mu$ CC	2.1%
ν_τ prompt	negligible



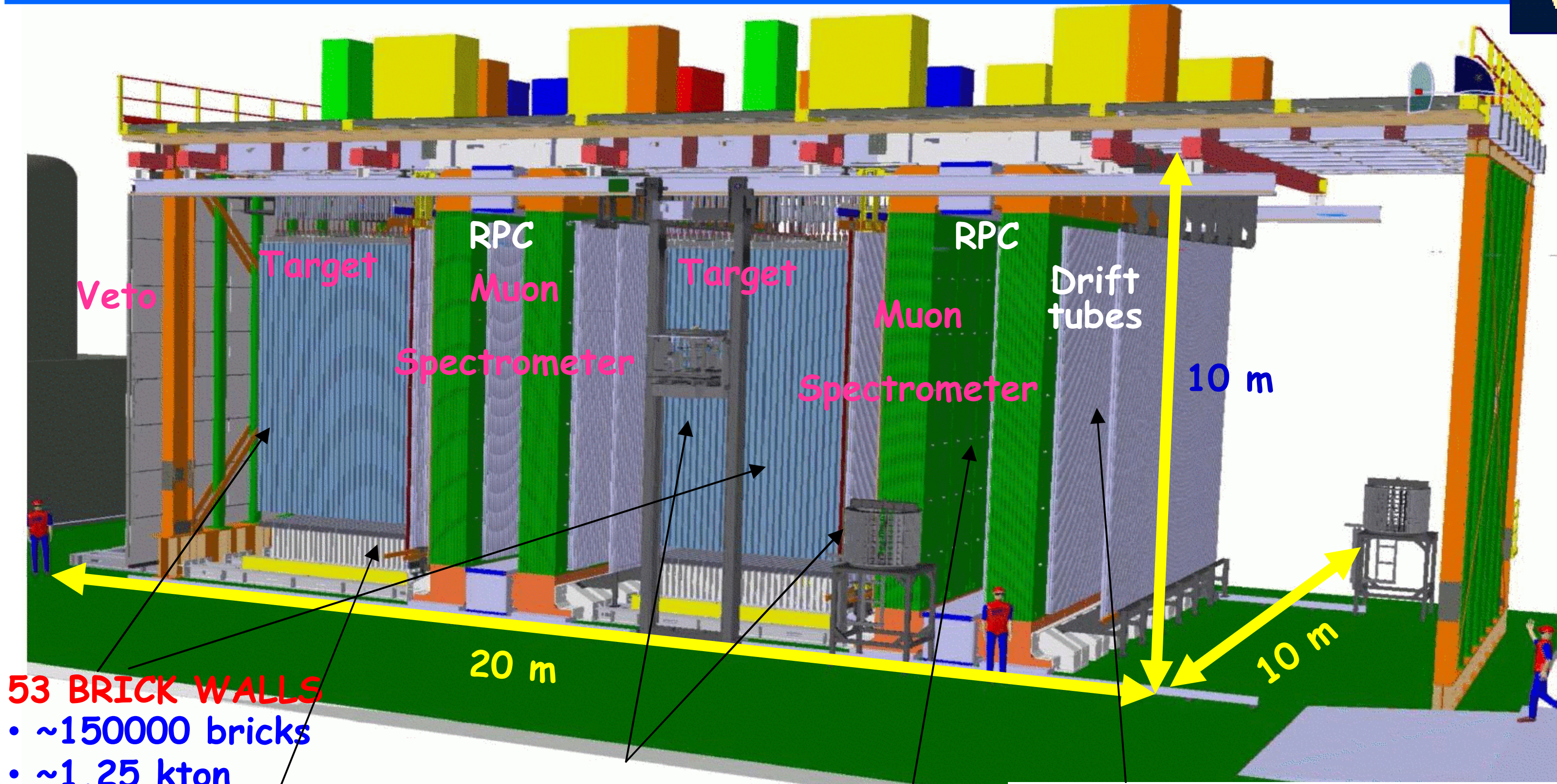
The beam is optimized to maximize the number of ν_τ CC interactions



LNGS - Gran Sasso National Lab



OPERA detector



53 BRICK WALLS
- **~150000 bricks**
- **~1.25 kton**

Brick Manipulator System

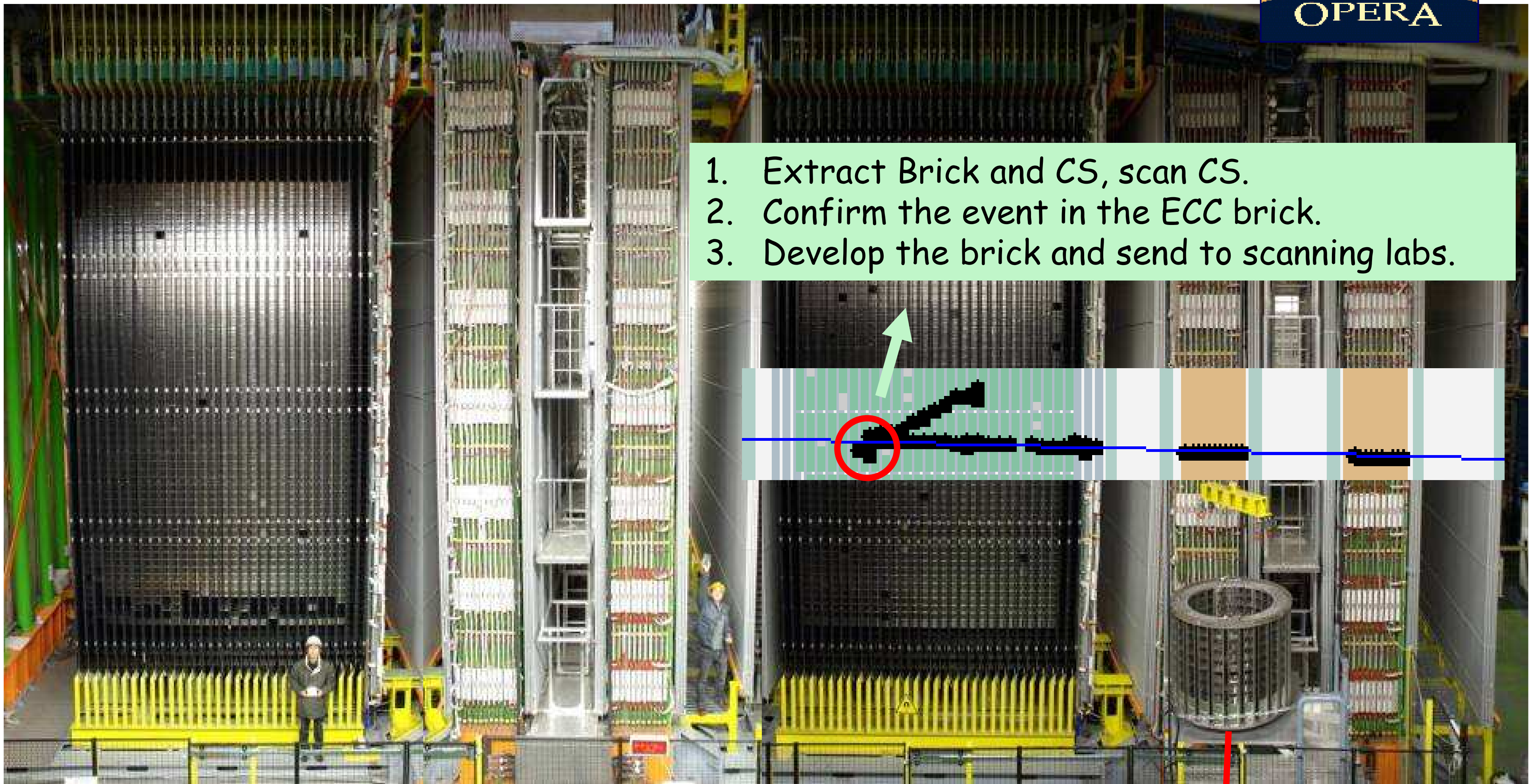
HIGH PRECISION TRACKERS
- spatial resolution < 0.5 mm

TARGET TRACKERS
- Trigger task
- Brick identification
- 2 x 31 scintillating strip walls read with PMT
- 0.8 cm resolution

INNER TRACKERS
- 990-ton dipole magnets (B = 1.55 T)
- RPC resolution ~1.3 cm

(Ref. JINST 4 (2009) P04018)

SM1 SM2

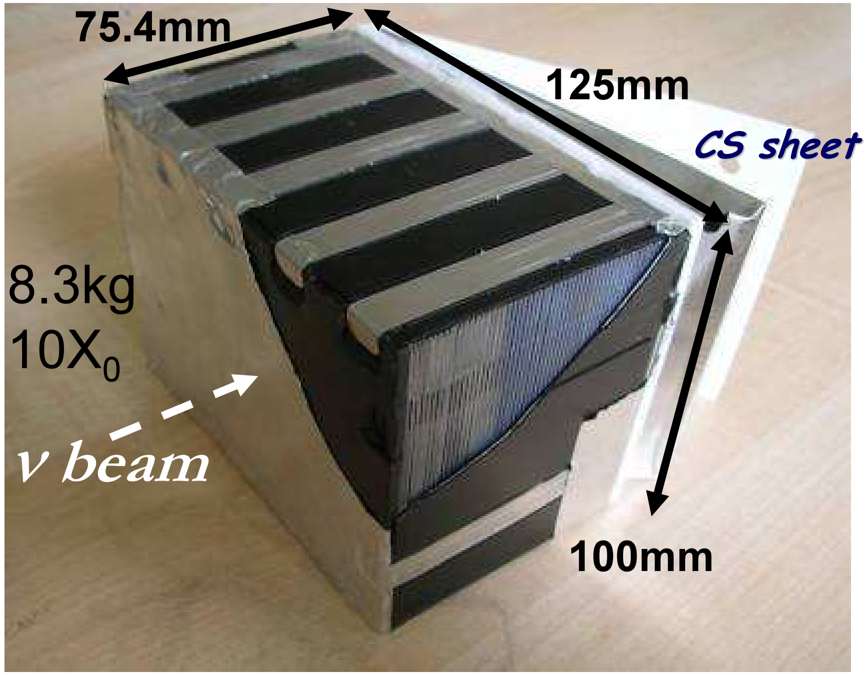


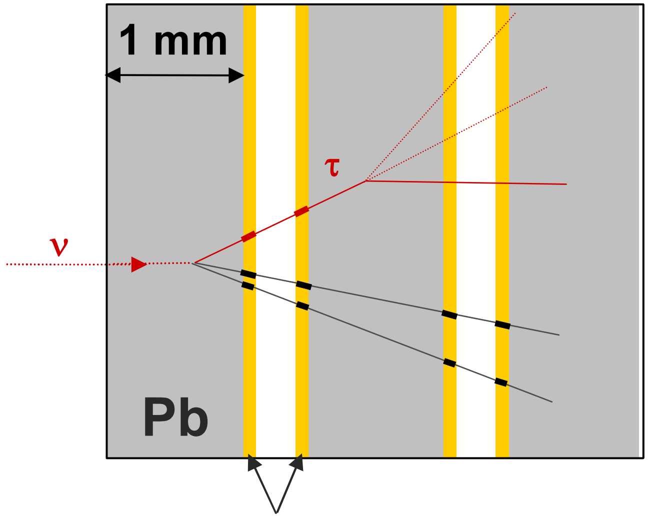
Target area
(ECC + CS + TT)

Muon spectrometer
(Magnet+RPC+PT)

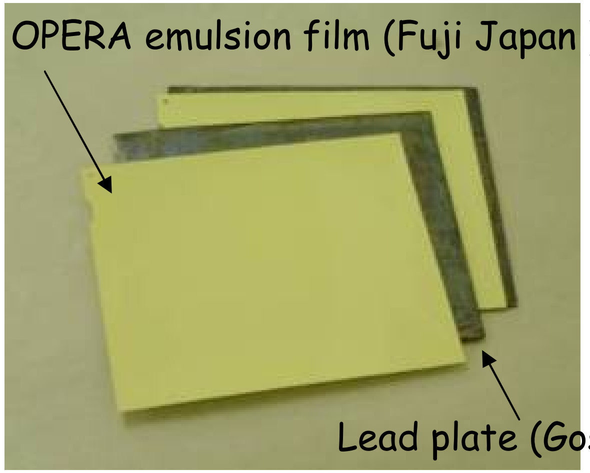
Brick Manipulator System

ECC target brick



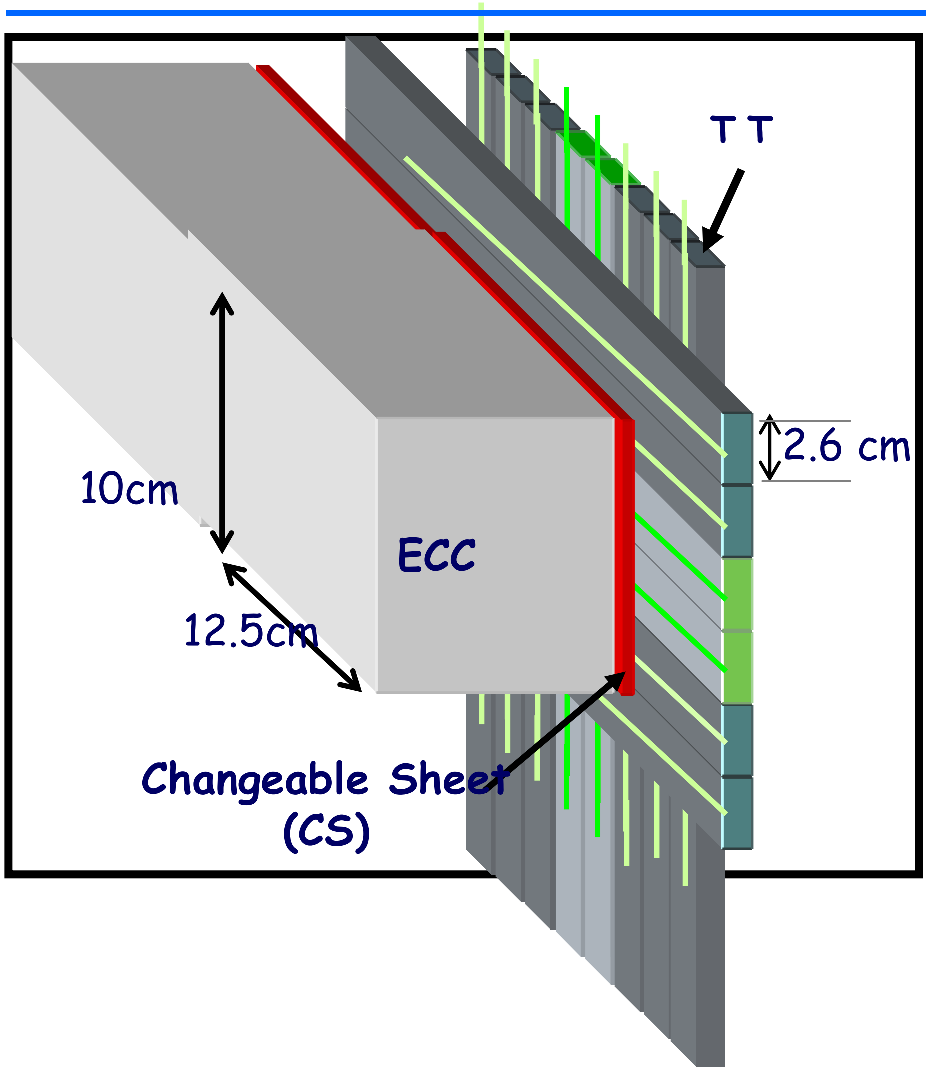


2 emulsion layers (42 μm thick) poured on a 200 μm plastic base

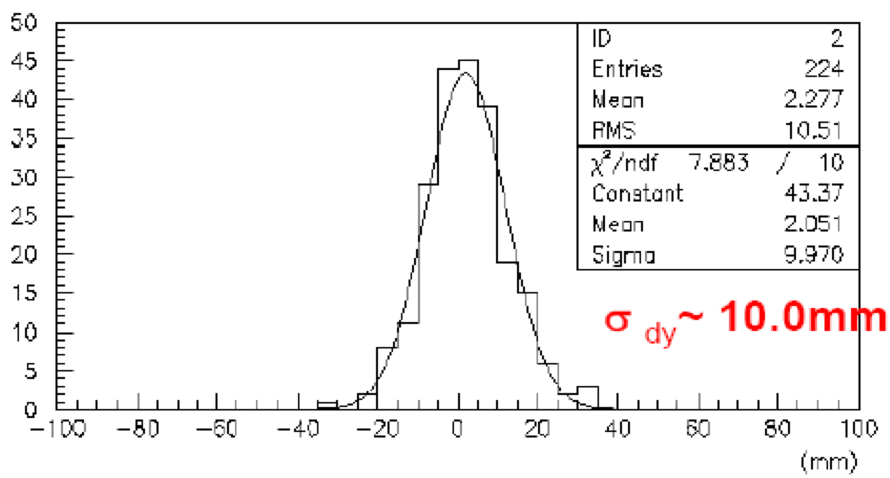


- 57 emulsion films + 2 CS interface sheet
- 56 * 1 mm Pb (lead + 0.04 % Ca) plates

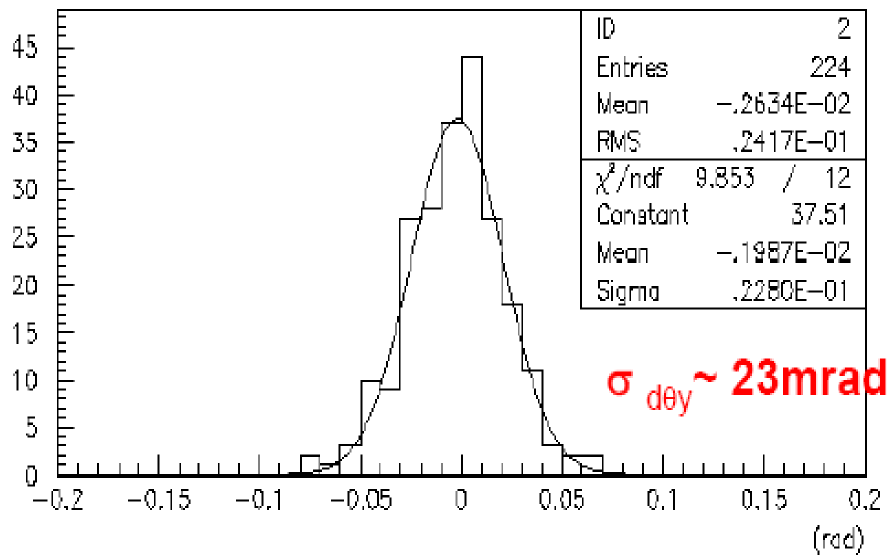
CS interface sheet



Interface emulsion films: high signal/noise ratio for event trigger and scanning time reduction



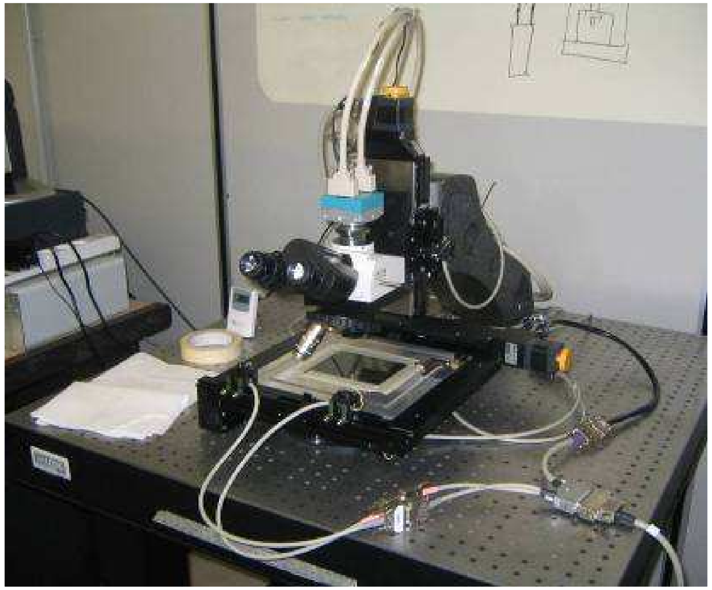
Position accuracy of the electronic predictions



Angular accuracy of the electronic predictions

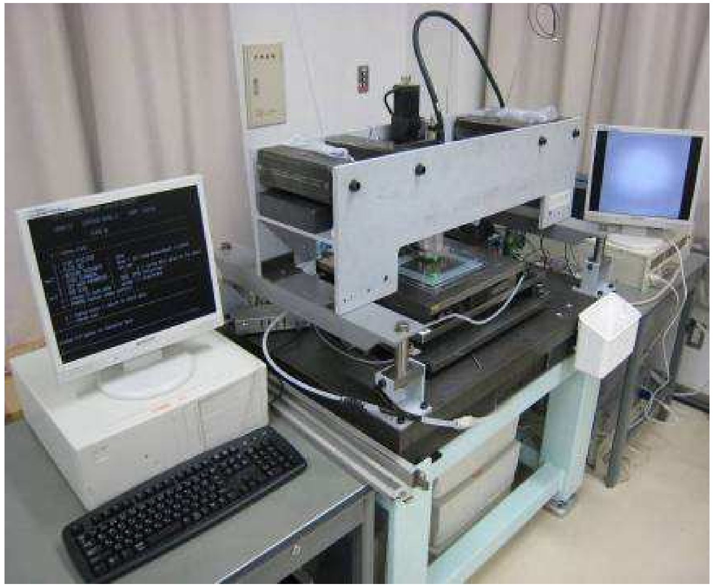
Emulsion films scanning

EU: ESS (European Scanning System)



- Scanning speed/system: $20 cm^2/h$
- Customized commercial optics and mechanics
- Asynchronous DAQ software

Japan: SUTS (Super Ultra Track Selector)



- Scanning speed/system: $75 cm^2/h$
- High speed CCD camera (3 kHz), Piezo-controlled objective lens
- FPGA Hard-coded algorithms

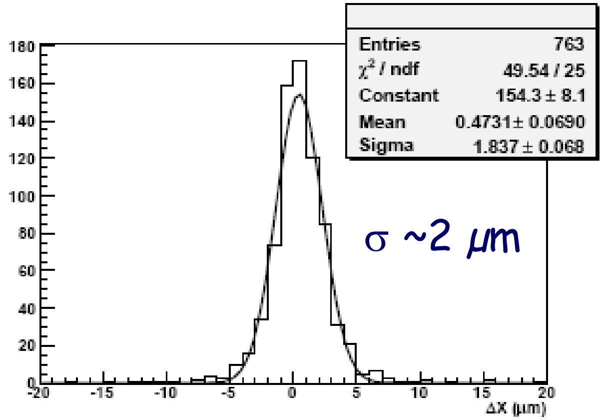
<u>Both systems demonstrate:</u>

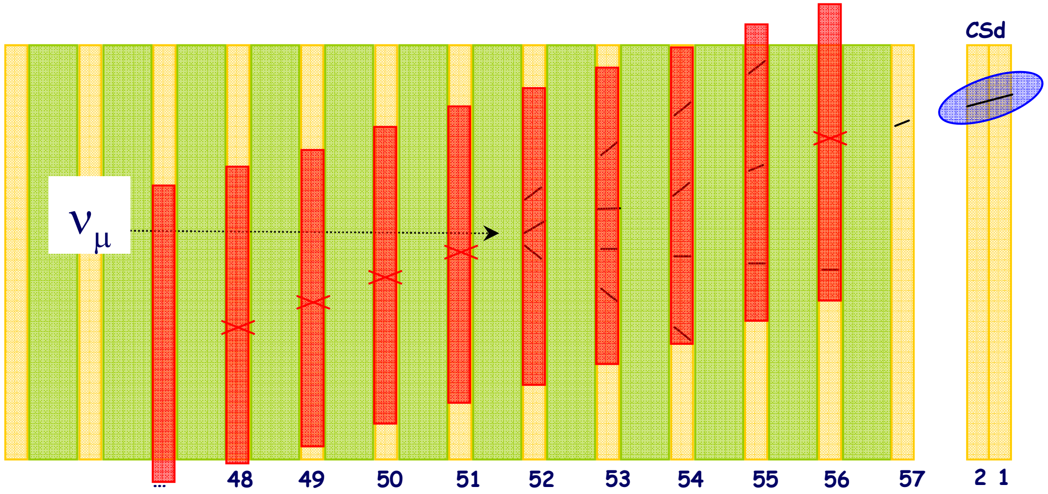
- ~ 0.3 μm spatial resolution
- ~ 2 mrad angular resolution
- ~ 95% base track detection efficiency

Vertex finding

Track follow-up film by film:

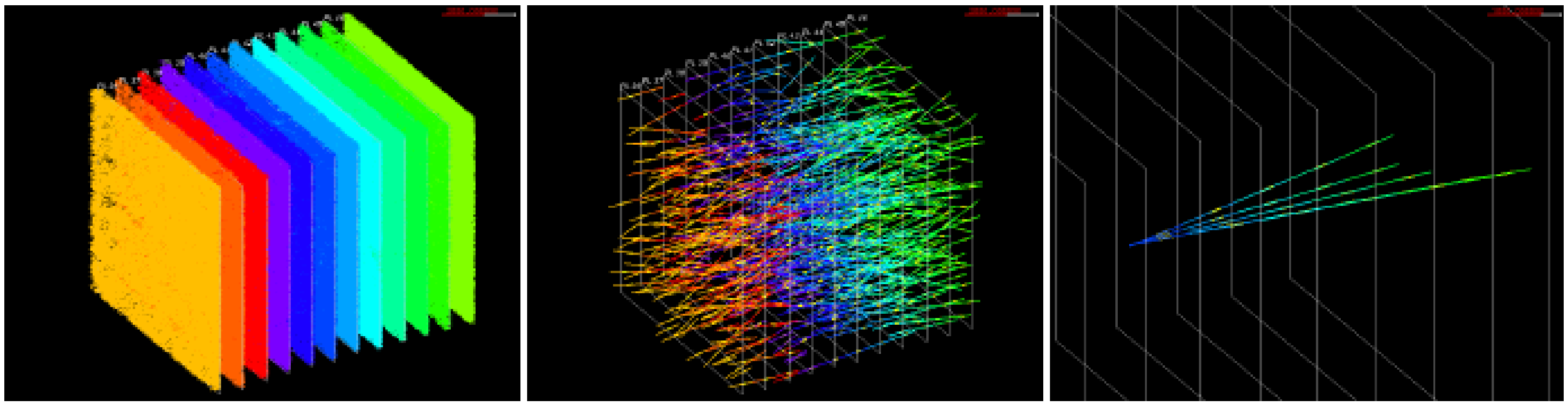
- *alignment using cosmic ray tracks*
- *definition of the stopping point*



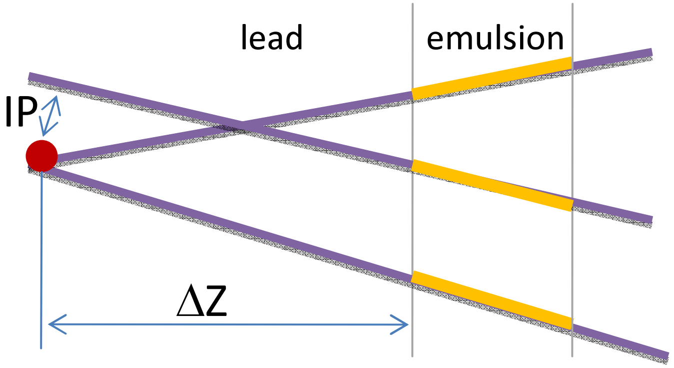


Ref. JINST 4 (2009) P06020

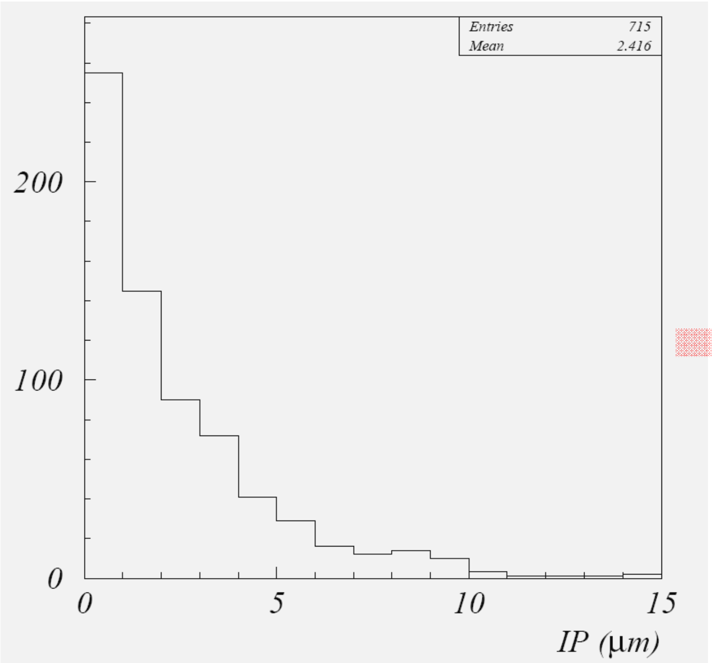
Volume scanning (~2 cm^3) around the stopping point

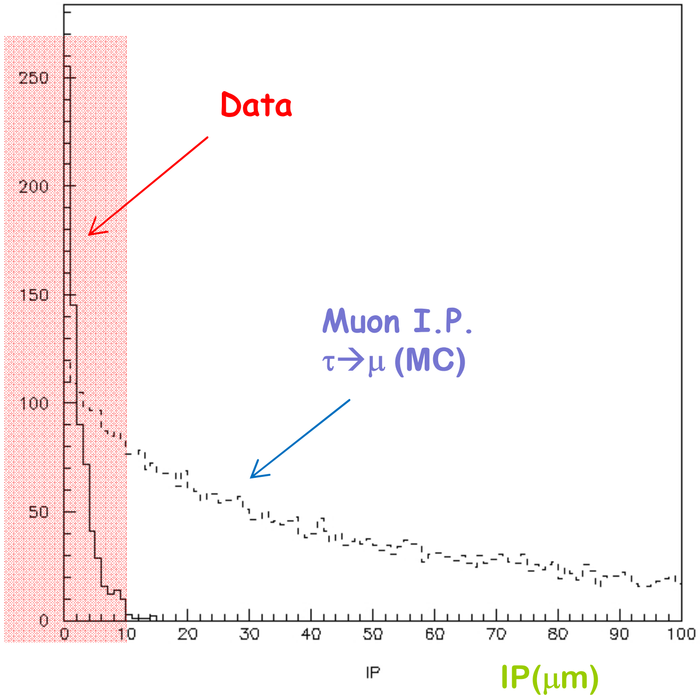


Decay search



The IP evaluation is a crucial point in order to detect decay topologies





IP of the muon tracks attached to the neutrino vertices found

OPERA status

2000: approval of the CNGS project
2003: start of detector construction
2004: end of CNGS beam civil engineering

2006: commissioning run (empty detector's target)
- 7.6E^{17} pot

2007: short pilot run (40% target)
- 8.2E^{17} pot, 38 ν events in the target

2008: 1st physics run
- 1.78E^{19} pot, 1663 ν events in the target, **0.7 ν_τ expected**

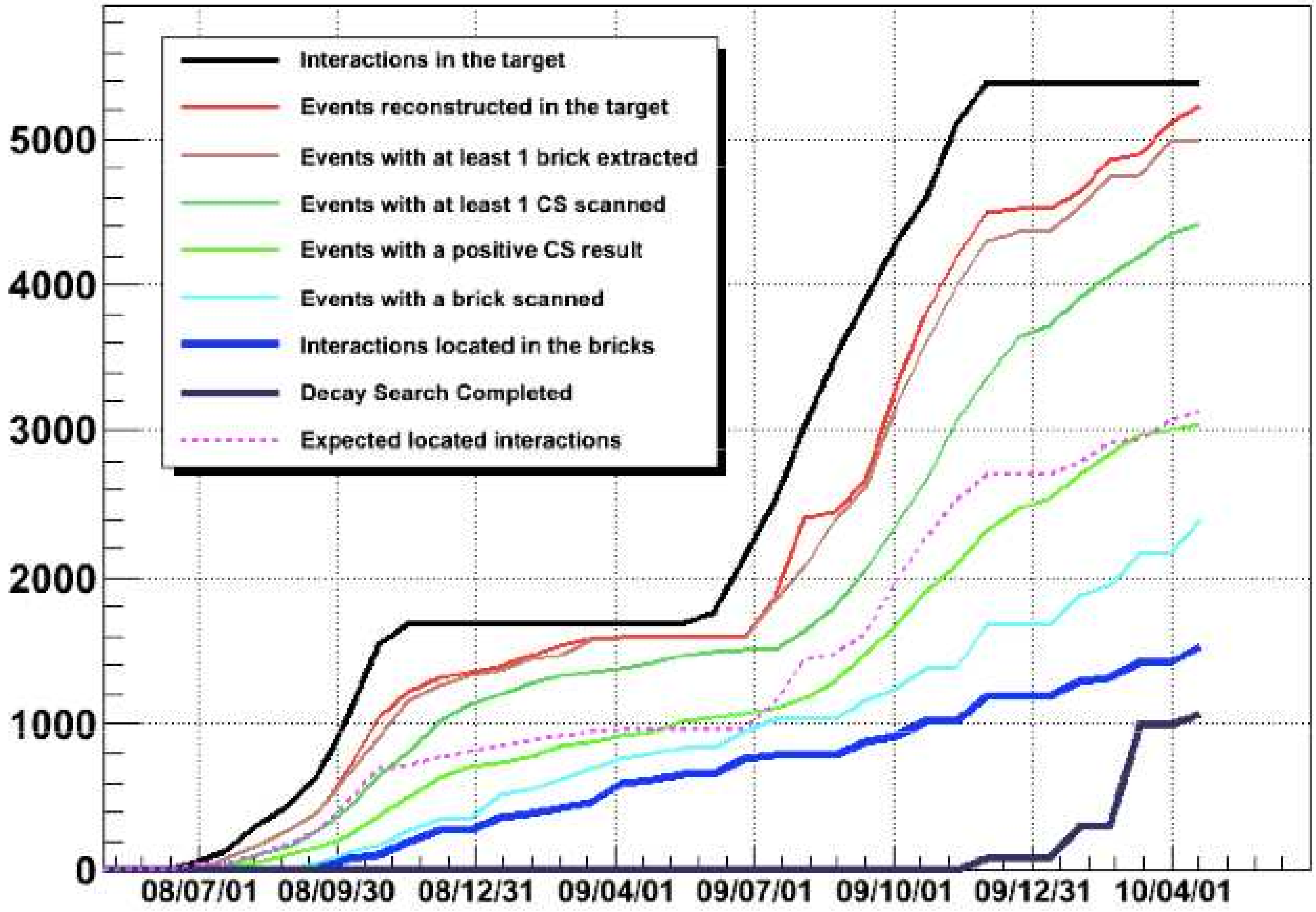
2009: 2nd physics run
- 3.52E^{19} pot, 3693 ν events in the target, **~2 ν_τ expected in total**

2010: 3rd physics run (May – November)
- hope to reach more than 4 E 19 pot

1 year CNGS nominal: 4.5E^{19} pot

Performance Plot

2008+2009 Run



NC/CC events: Data vs MC

NC/CC ratio

To be independent of the tracking efficiency, an event is identified as CC if the number of touched planes is more than 14.

	CC identified	CC misidentified	NC identified	NC misidentified
MC	96.1%	3.9%	69.0%	31.0%

	OpCarac (fiducial volume) efficiency CC	OpCarac (fiducial volume) efficiency NC
MC	96.9%	88.2%

	CC identified	NC identified
Data	(1928) 78.0%	(545) 22.0%

$$\underbrace{\epsilon_{OpCarCC}}_{\text{OpCarac efficiency for CC}} \times \underbrace{eff_{CC}}_{\text{CC identified efficiency}} \times \underbrace{n_{CC}}_{\text{True number of CC}} + \underbrace{\epsilon_{OpCarNC}}_{\text{OpCarac efficiency for NC}} \times \underbrace{ineff_{NC}}_{\text{NC misidentified efficiency}} \times \underbrace{\epsilon_{NC/CC}}_{\text{True ratio NC/CC = 0.29}} \times n_{CC}$$

$$CC_{measured} = \epsilon_{OpCarCC} \times eff_{CC} \times n_{CC} + \epsilon_{OpCarNC} \times ineff_{NC} \times \epsilon_{NC/CC} \times n_{CC}$$

$$NC_{measured} = \epsilon_{OpCarCC} \times ineff_{CC} \times n_{CC} + \epsilon_{OpCarNC} \times eff_{NC} \times \epsilon_{NC/CC} \times n_{CC}$$

MC NC/CC = 21.2%
Data NC/CC = 28.3%

We find more NC events in the data, which are due to interacting neutrons coming from a neutrino interaction in the rock or materials in front of the detector. Characterisation of this «noise» under study! 15

Visible NC/CC takes into account:

✓NC/CC true ratio (0.3)

✓Target interactions selectionefficiency

✓Muon ID efficiencies

✓Events migrations due to misidentification CC - NC

-- **NC excess in data described by MC when including BCK due to external interactions:**

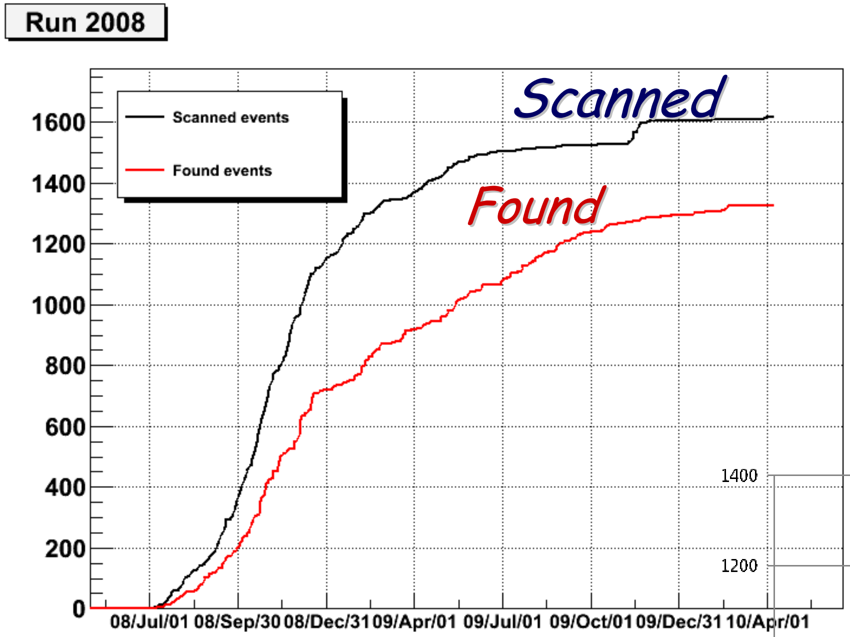
-- **NC/CC ratio by <u>cutting harder</u> on the fiducial volume:**

Data 2008: NC/CC= 0.230 ± 0.014 (stat.)

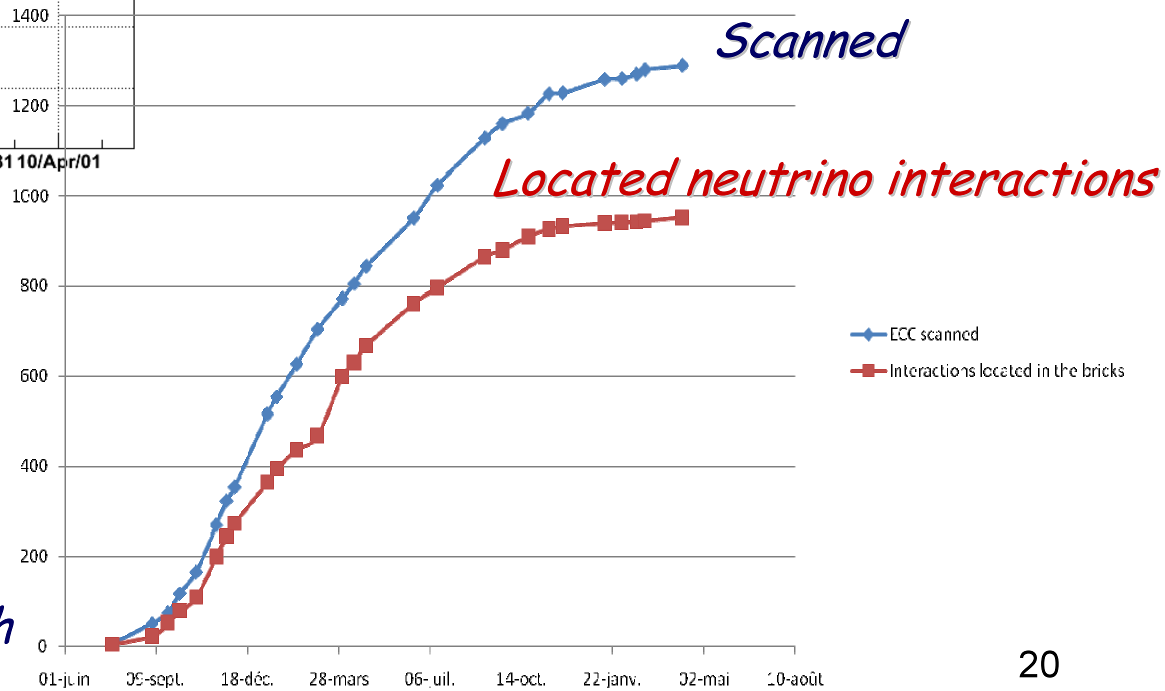
Data 2009: NC/CC= 0.228 ± 0.009 (stat.)

MC:NC/CC= 0.236 ± 0.005 (stat.)

Run 2008 event location (completed)



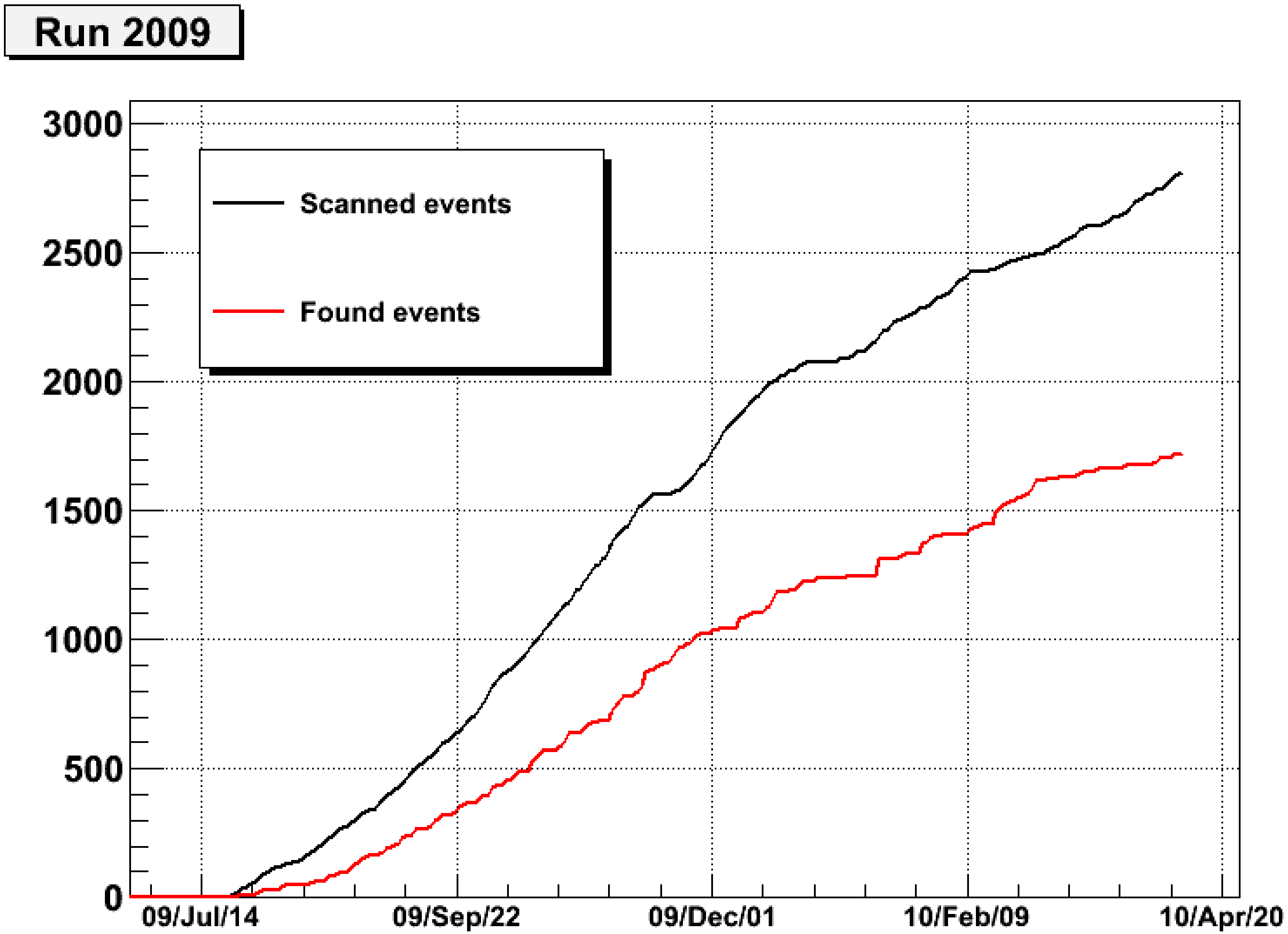
Cs scanning and brick selection



Located interactions in ECC ,

then used for the decay search

Run 2009 event location (in progress)



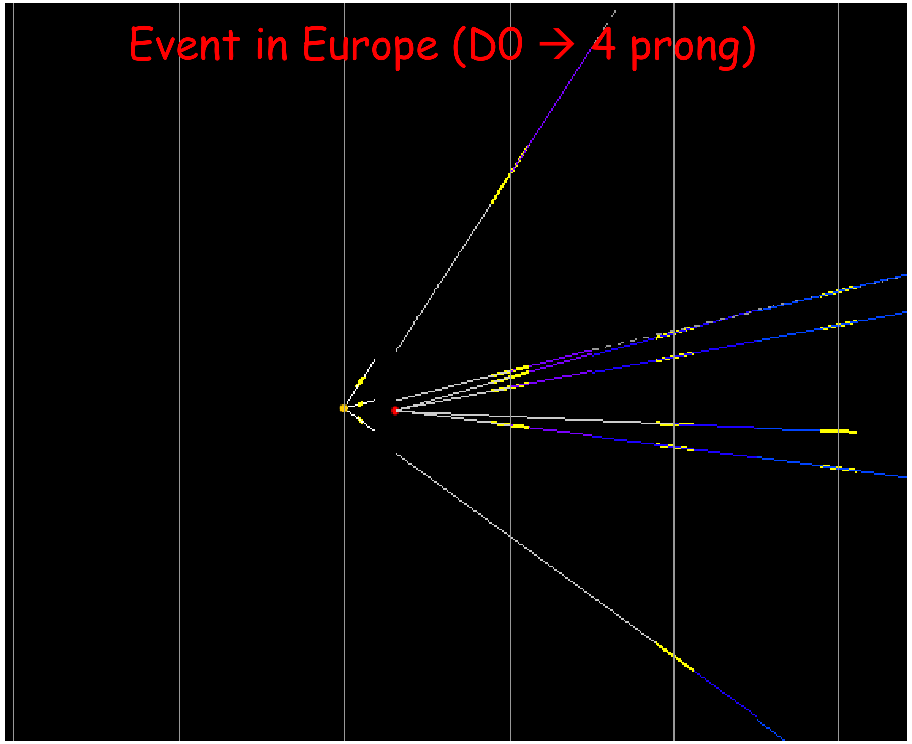
CS scanning results

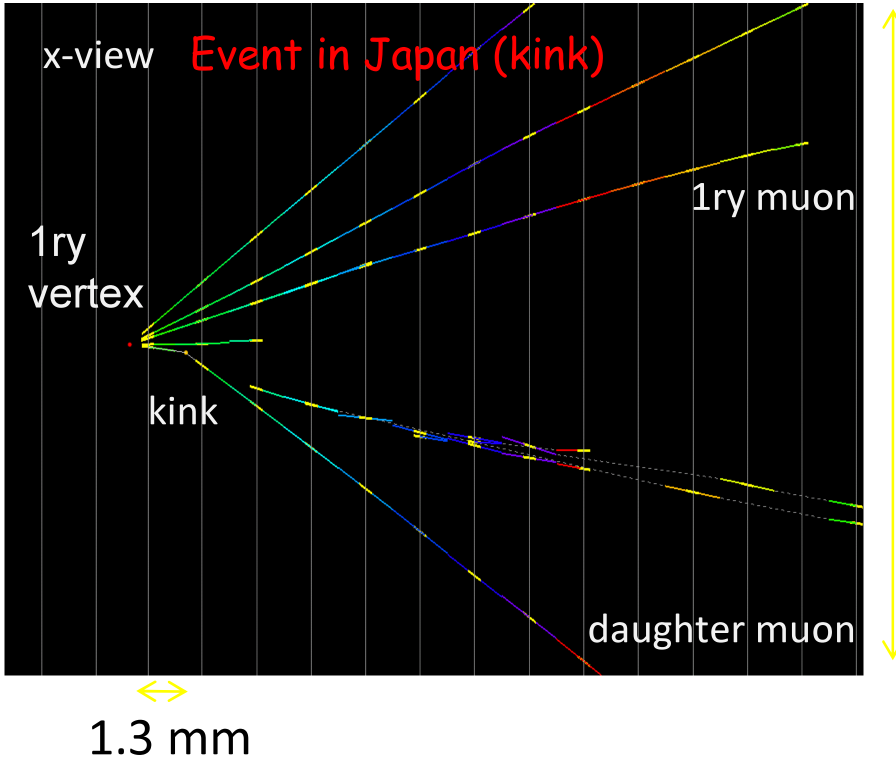
Event location details (Run 2009)

	NC	CC	All
Events predicted by the electronic detector	1097	2460	3557
Events with at least 1 brick extracted	1050	2389	3439
CS scanned	826	2143	2969
Found in CS	447	1418	1865
Neutrino interactions in the bricks	112	550	662
Located in dead material	3	15	18
Interactions in the upstream brick	4	50	54
Decay search completed	53	226	279

Charm events (I)

- Charm topology analogous to τ (similar lifetime): reference sample for the decay finding efficiency
- Systematic decay search completed on 1088 neutrino located interactions
- 20 events found showing a charm decay topology

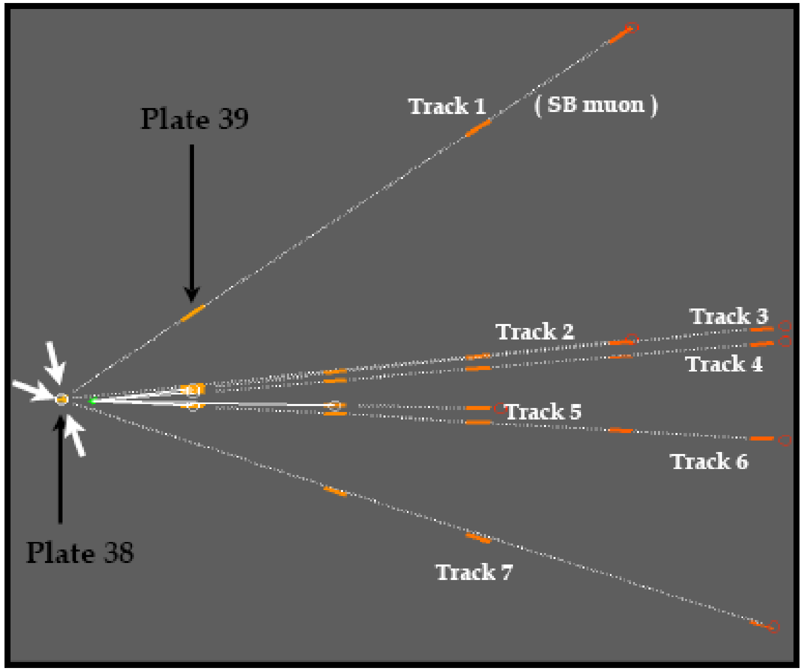




Charm events (II)

Event 234654975

Brick 85405



VERTEX 1

	Impact Parameter
Track 1	1,36
Track 2	0,88
Track 7	0,51

X	66716,60
Y	49892,8
Z	90,9

Primary vertex

VERTEX 2

	Impact Parameter
Track 3	1,13
Track 4	1,81
Track 5	1,99
Track 6	1,39

X	66710,10
Y	49899
Z	403,9

Decay vertex

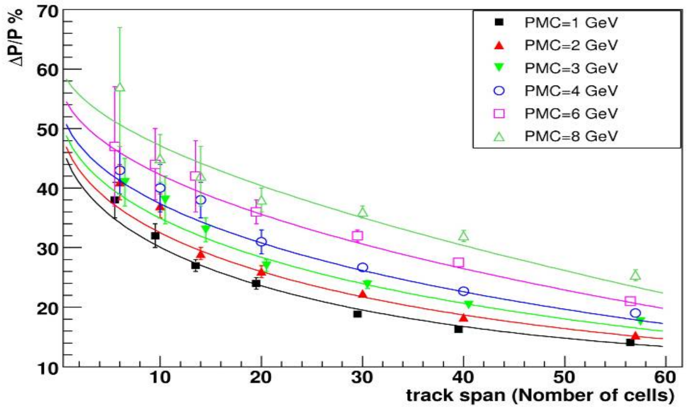
D^0

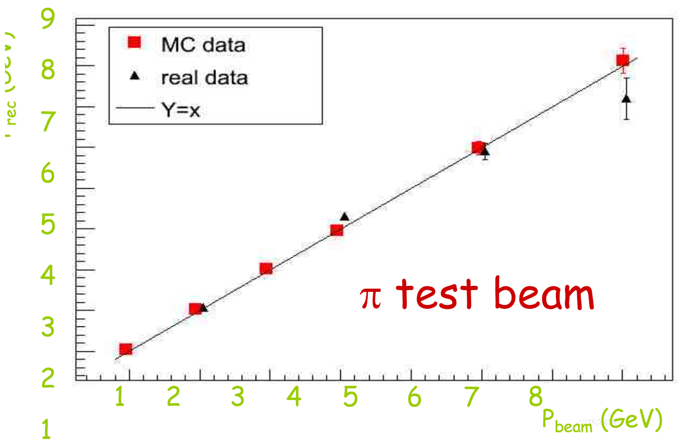
Tx	Ty	Flight Length (μm)	phi	minimum mass (GeV/c^2)
-0,0207	0,0198	313,1	173,2°	1,7

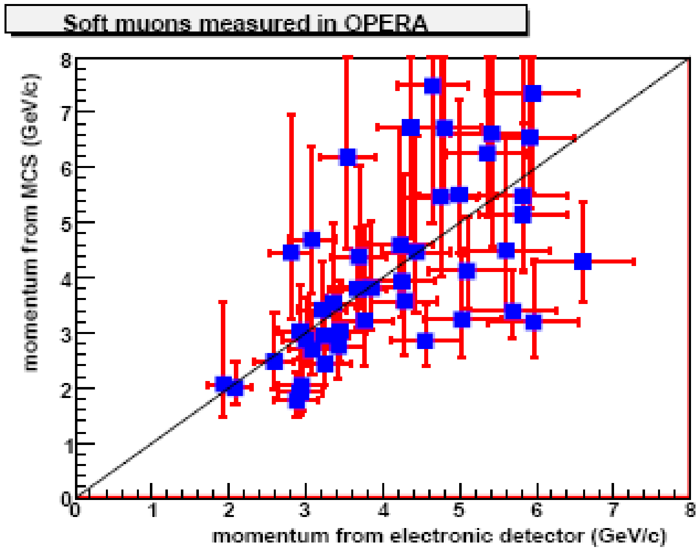
Particles momenta measuremnts by MCS

Test beam data samples of pions and several MC samples were produced and used for the development of the method.

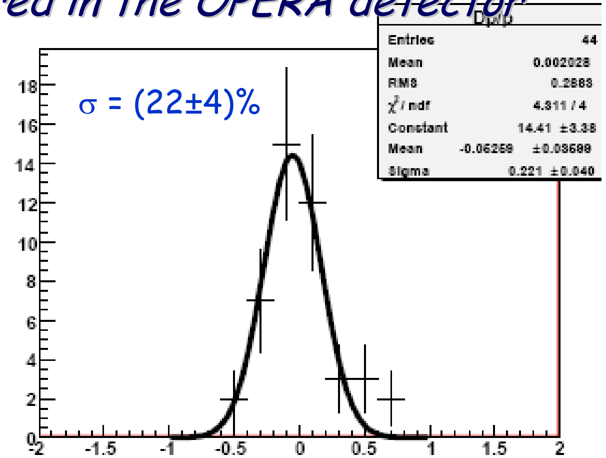
Very detailed results are given and should be considered as reference ones for further MCS investigations.



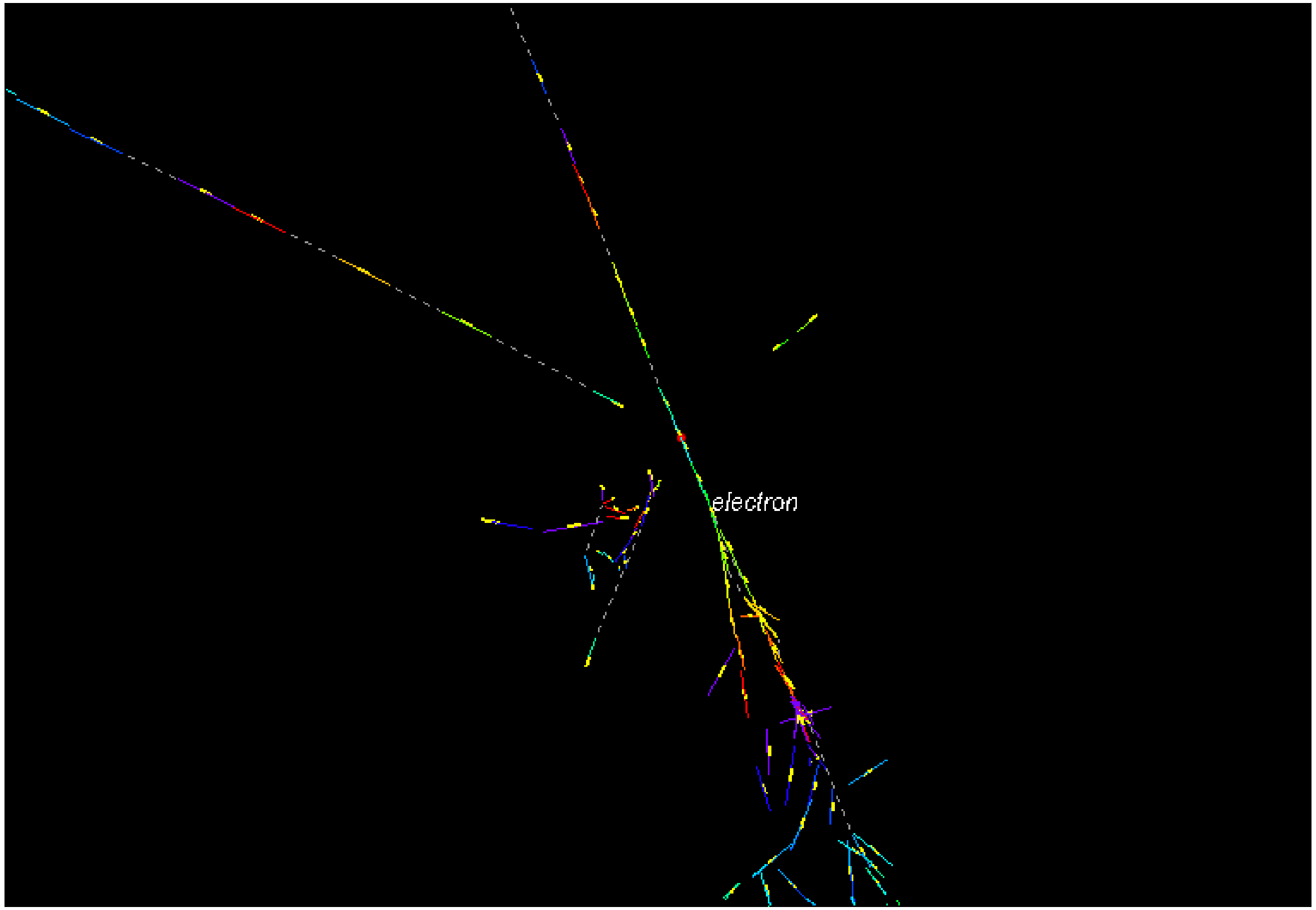




Measurements were performed also on several selected soft muon events registered in the OPERA detector



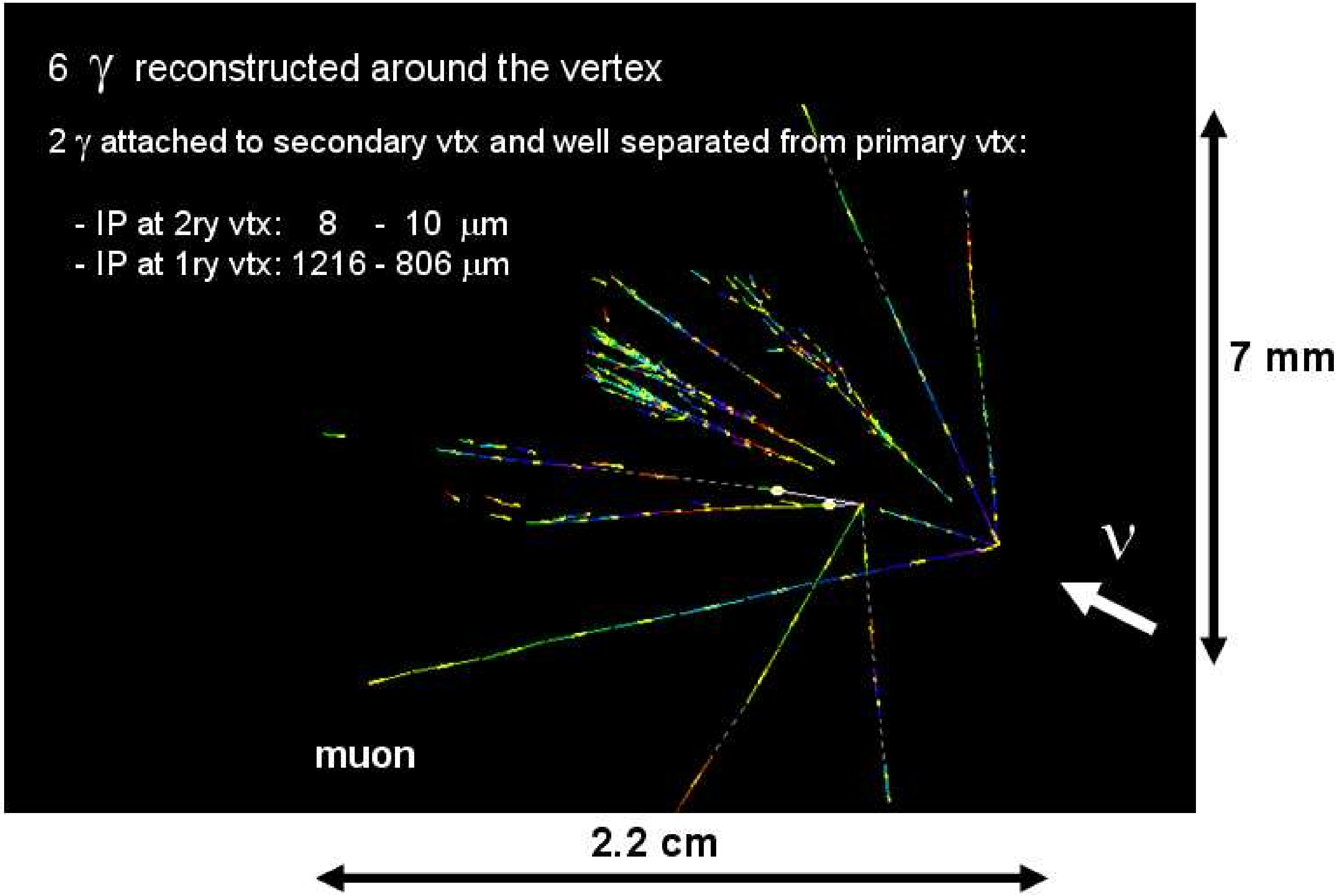
ν_e CC interaction



6 electron neutrino interactions were found in a subsample of 800 CC located interactions.

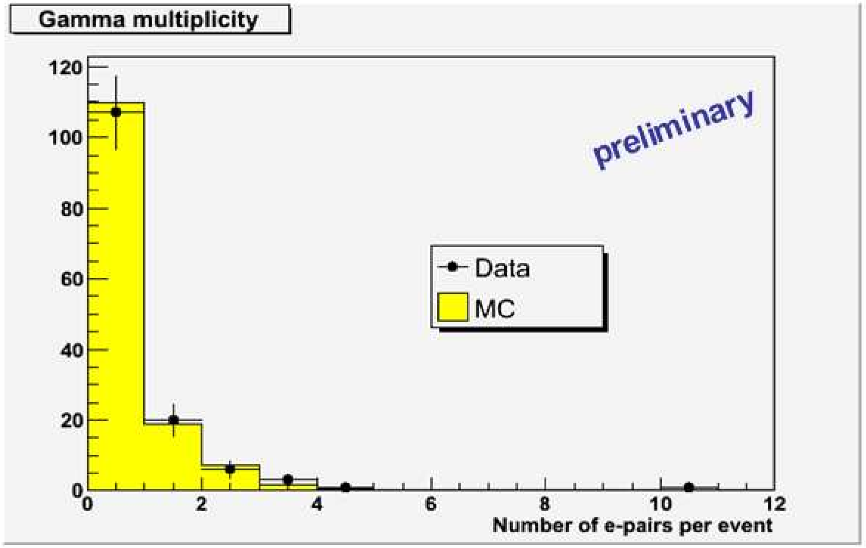
γ reconstruction (I)

Example of reconstructed γ's in real neutrino interactions

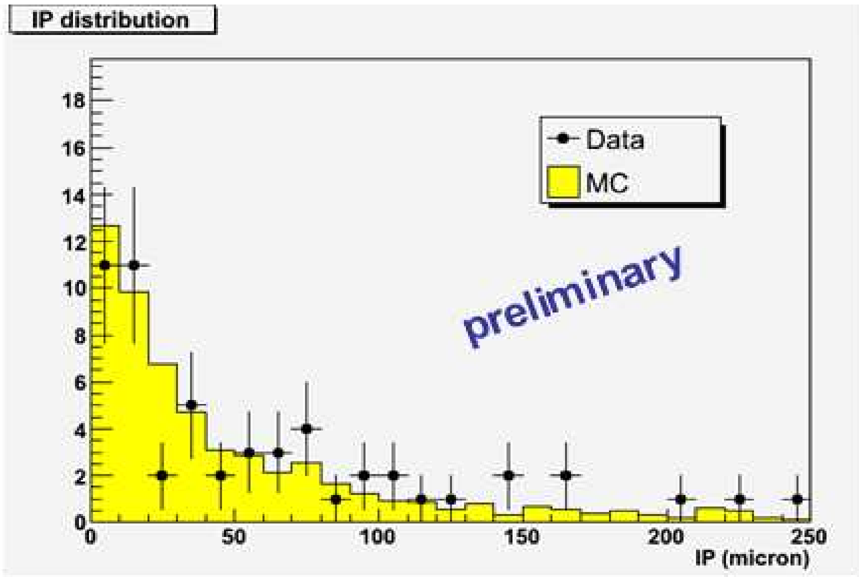


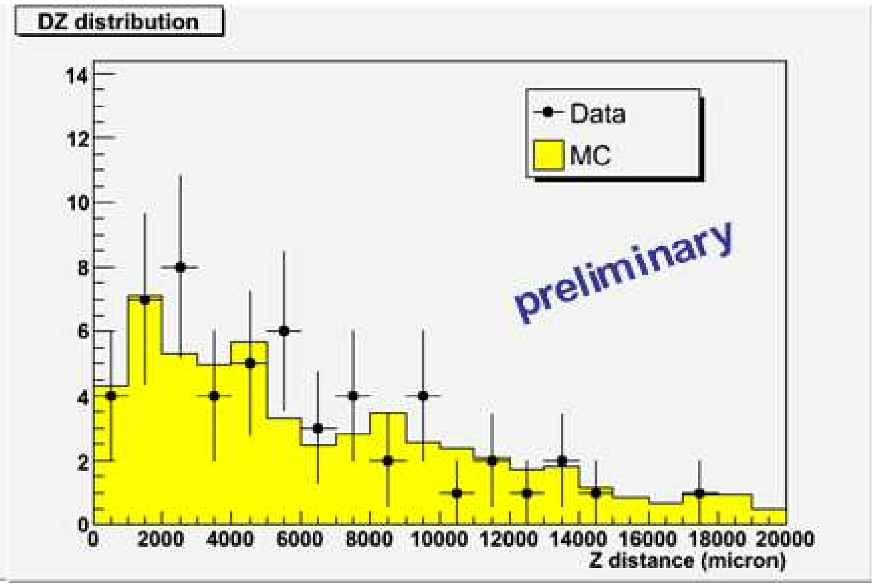
Important for τ hadronic decay channels (signal vs background discrimination)

γ reconstruction (II)



Comparison data/MC for the Gamma multiplicity in ν_μ CC+NC events





Conclusions

• The OPERA experiment at LNGS was designed and successfully constructed to ensure the detection of neutrino oscillations in appearance mode through the study of the $\nu_\mu \to \nu_\tau$ channel.

• The analysis of neutrino data taken in the CERN CNGS beam in the 2008-2009 runs is successfully on going.

• Decay event topologies due to charmed particles have been observed in agreement with expectations, as well as events induced by prompt ν_e present in the CNGS beam.