The Status of OPERA: Long Baseline Neutrino Oscillation Experiment

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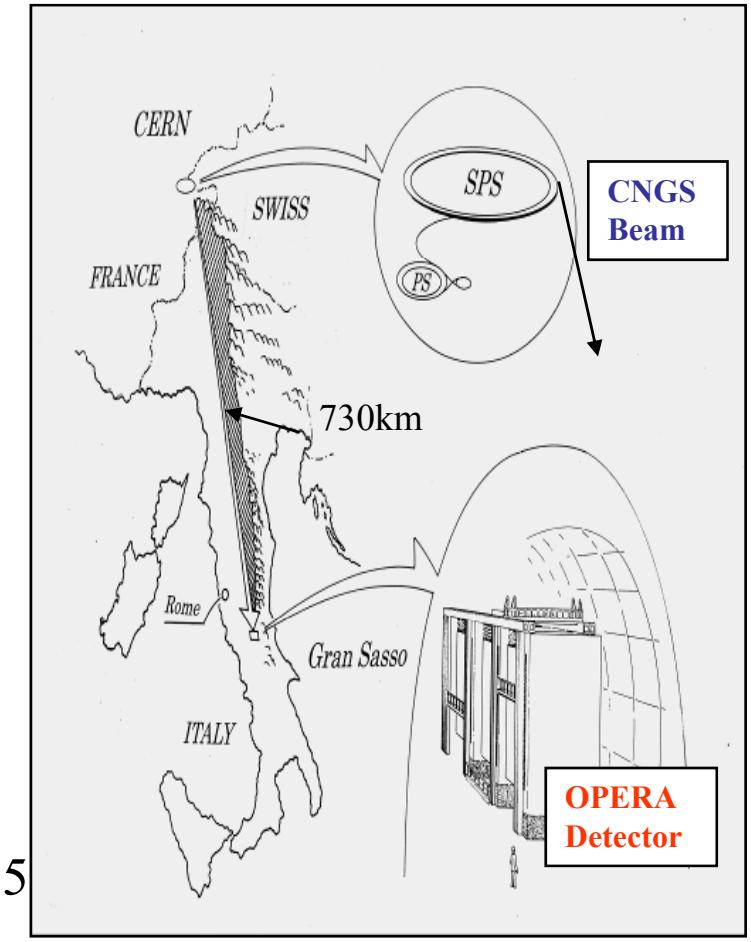
OPERA Collaboration

OPERA Experiment

- Search for ν_τ appearance at the Gran Sasso laboratory (732 km from CERN)

- Answer unambiguously on the origin of the ν oscillations observed at the atmospheric Δm^2 scale



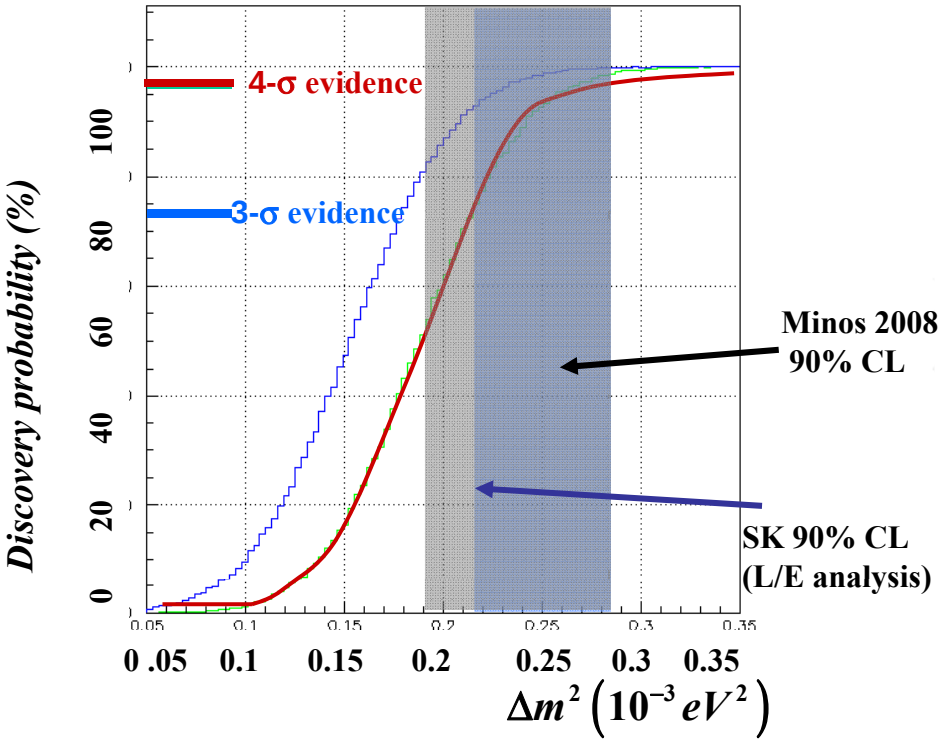
- Search for $\nu_\mu \rightarrow \nu_e$ and put new constraints on θ_{13}
- Global 3ν oscillation analysis: (2008) :

Best fit: $\Delta m_{23}^2 = 2.39 \times 10^{-3}$ eV^2 and $\sin^2 2\theta_{23} = 0.995$

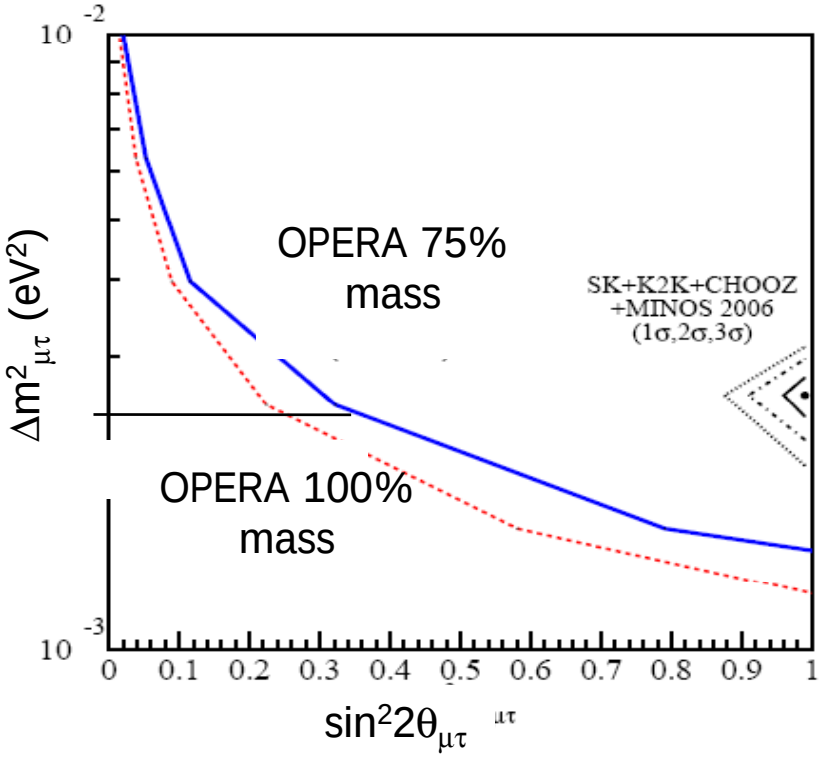
$2.06 < \Delta m_{23}^2 < 2.81 \times 10^{-3}$ eV^2 3σ range

Expected Performance

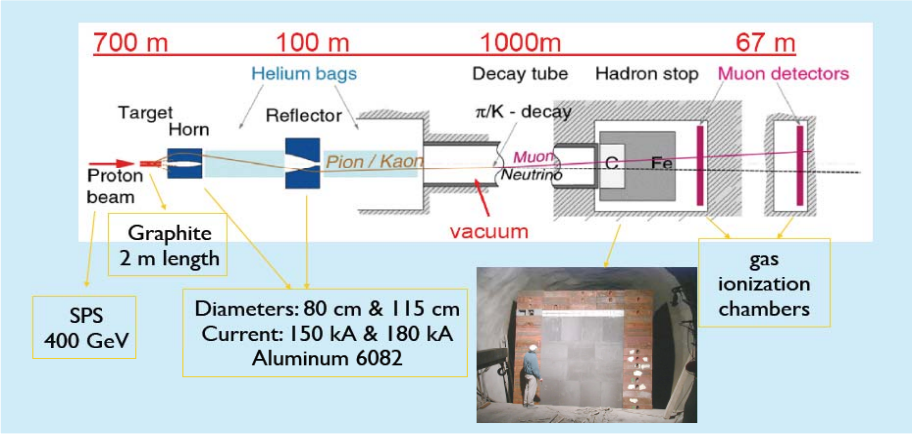
OPERA discovery probability vs. $\Delta m^2_{\mu\tau}$

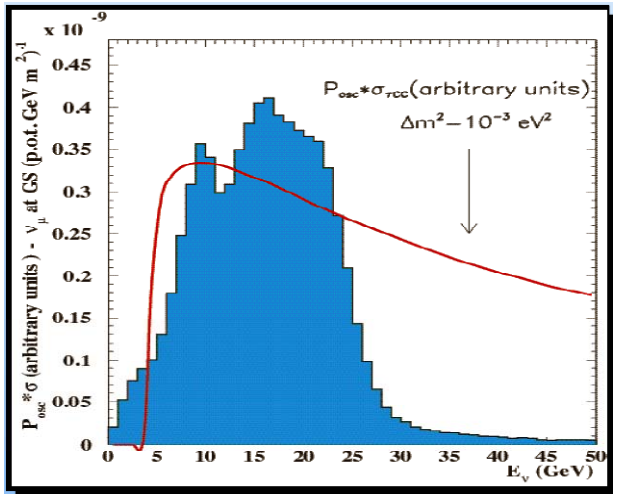


Exclusion plot at 90% C.L.



Cern Neutrino to Gran Sasso





➢ 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

➢ Although the maximum of oscillation probability at 730 km is at about 1.5 GeV, we need to take into account the ν_τ CC cross section and the production threshold of 3.6 GeV.

$<E_{\nu\mu}>$	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}
ν_μ CC/kton/year	~2900
ν_τ CC/kton/year	~16

➢ Operation since 2007
➢ Major accidents
  ➢ Time freeze in SPS supercycle, hole in SPS magnet
  ➢ Replacement of PS magnet with short circuit
  ➢ Electrical problem of 18KV "Electricitè de France" power cable

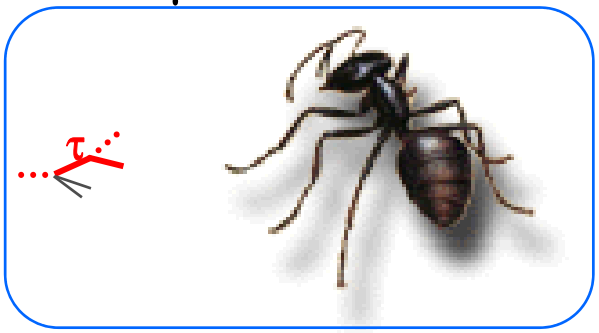
Principle of ν_τ detection

- Goal: direct observation of ν_τ in ν_μ beam

$$P(\nu_\mu \rightarrow \nu_\tau) \approx \cos^4(\theta_{13}) \sin^2(2\theta_{23}) \sin^2\left(1.27 \frac{\Delta m^2_{23} L}{E}\right)$$

ν_μ ..... ν_τ → τ^- + X

Oscillation — CC- interaction



τ-Decay

- Detector concept

$\mu^- \nu_\tau \bar{\nu}_\mu$	17.7 %
$h^- \nu_\tau$ neutrals	48.6 %
$e^- \nu_\tau \bar{\nu}_e$	17.8 %
$h^+h^-h^- \nu_\tau$ neutrals	15.2 %

- **Micrometric spatial resolution → Emulsion**
- **Large Mass → Lead Target**

} **ECC**

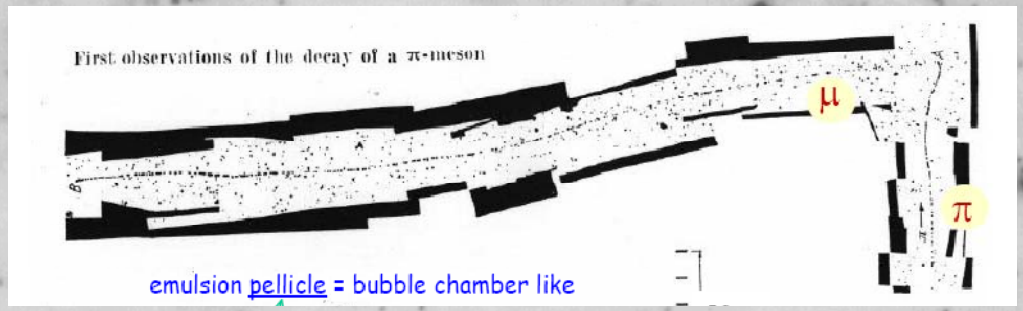
- **Trigger Neutrino Interaction → Target Tracker**
- **Identify muons and charge → Spectrometer**

} **Electronic Detector**

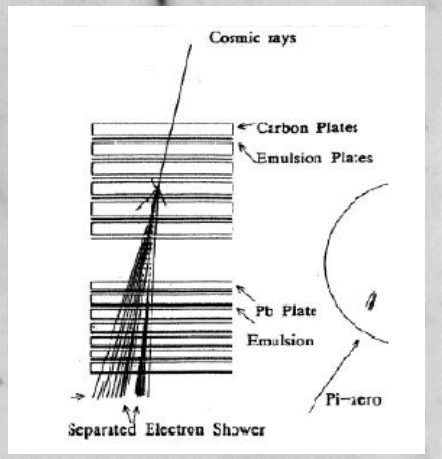
} **Hybrid-detector**

Brief emulsion history

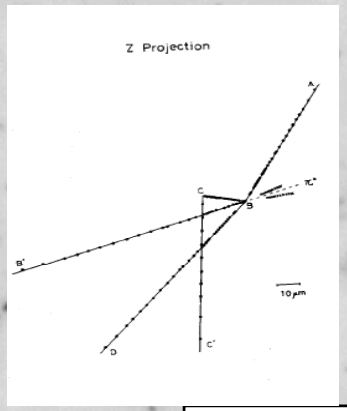
➢1947: Discovery of $\pi \rightarrow \mu\, \nu_\mu$



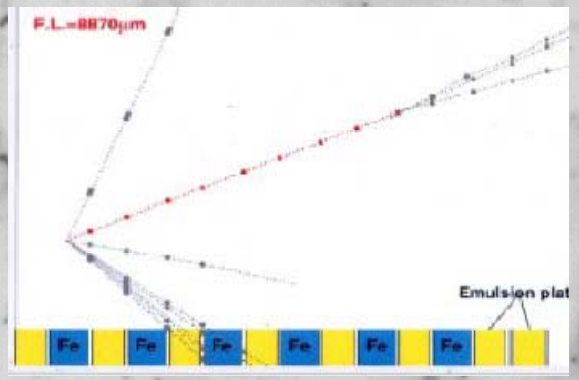
➢1950's: Cosmic ray experiments



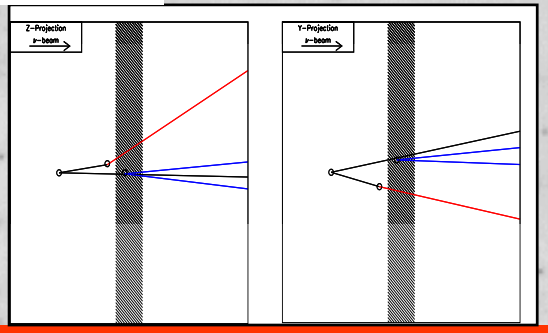
➢1971: Discovery of "X- particle"



➢2000: (DONUT) ν_τ detection

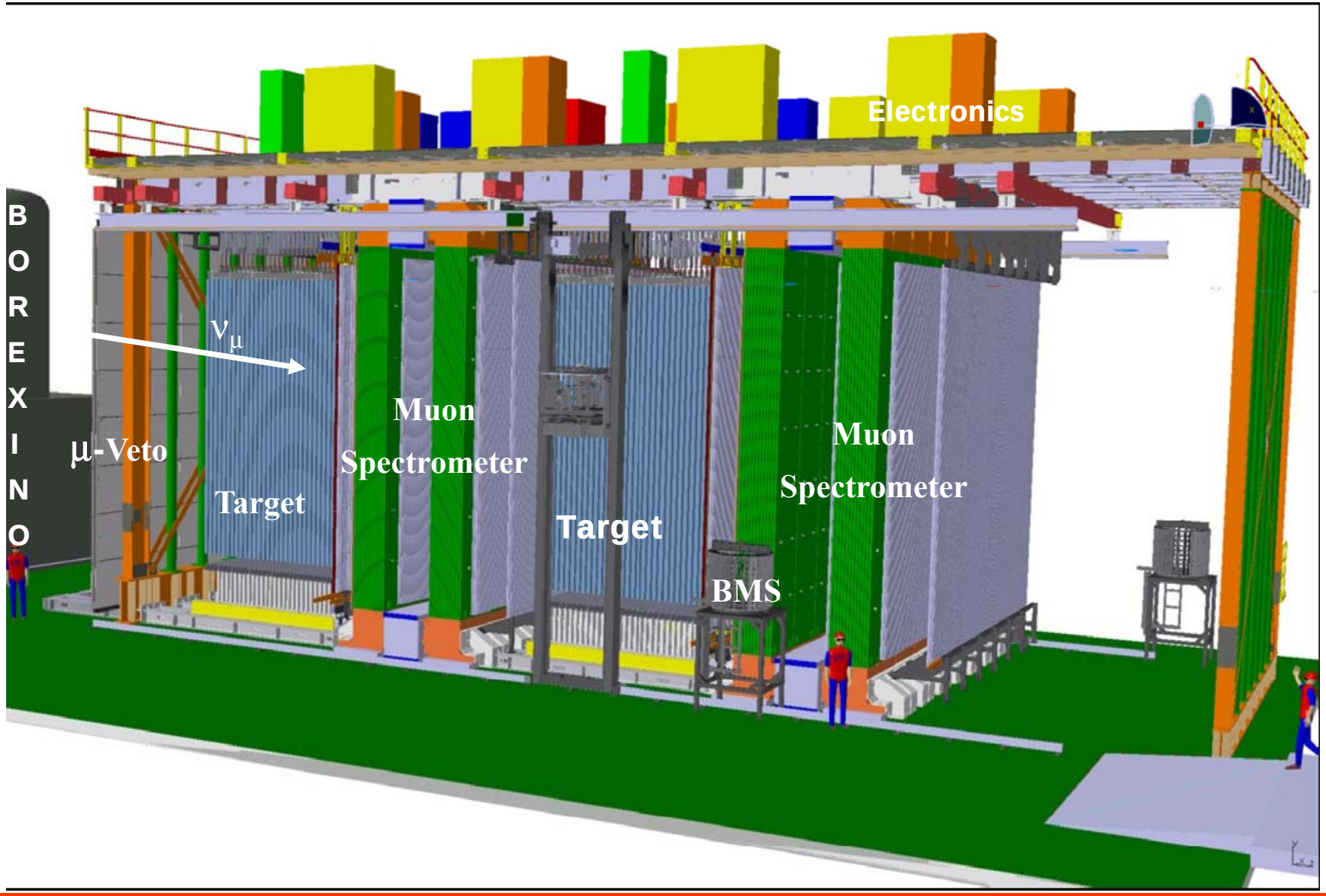


➢2007: (CHORUS) Associated charm production

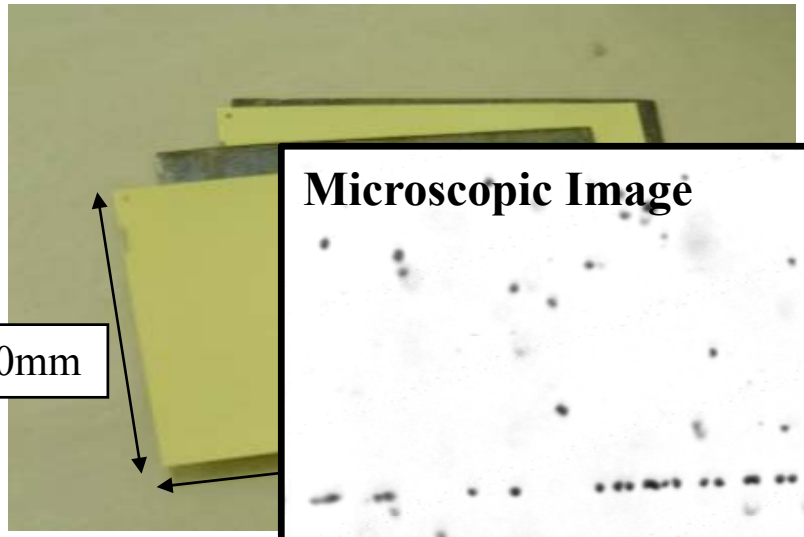


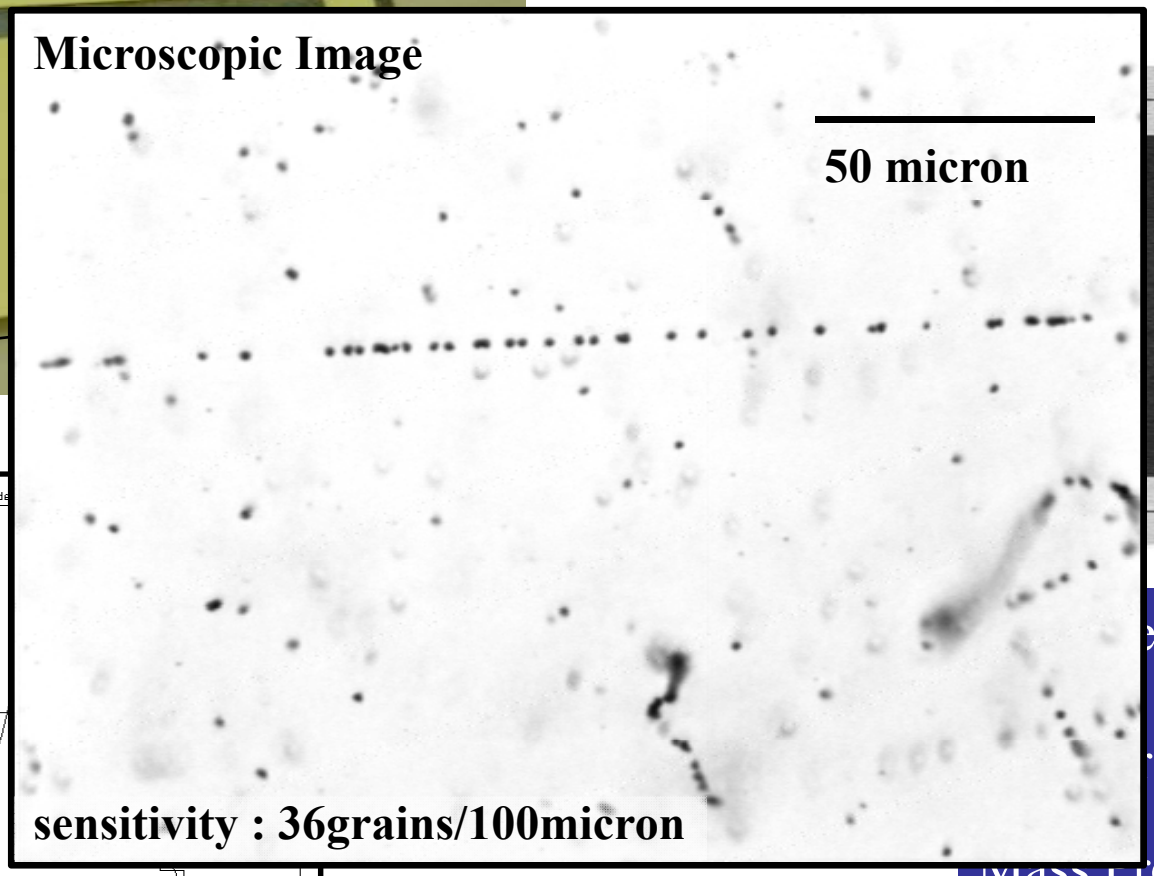
➢OPERA: $\nu_\mu \rightarrow \nu_\tau$ oscillations

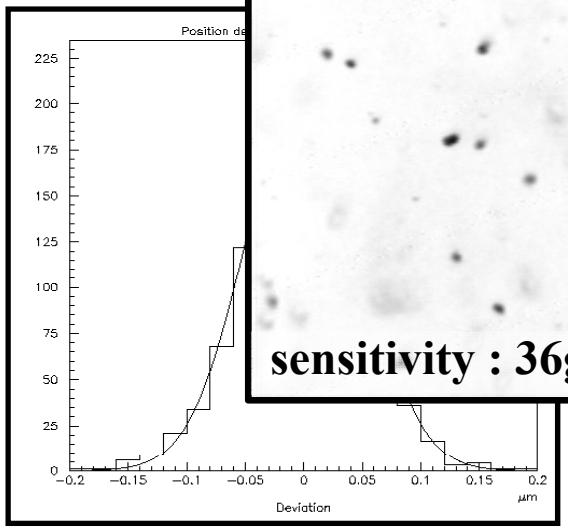
The Detector

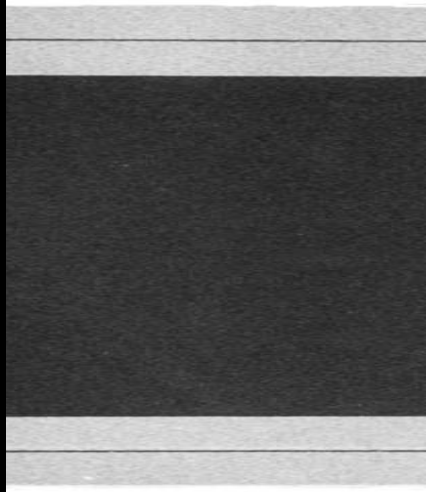


OPERA Emulsion









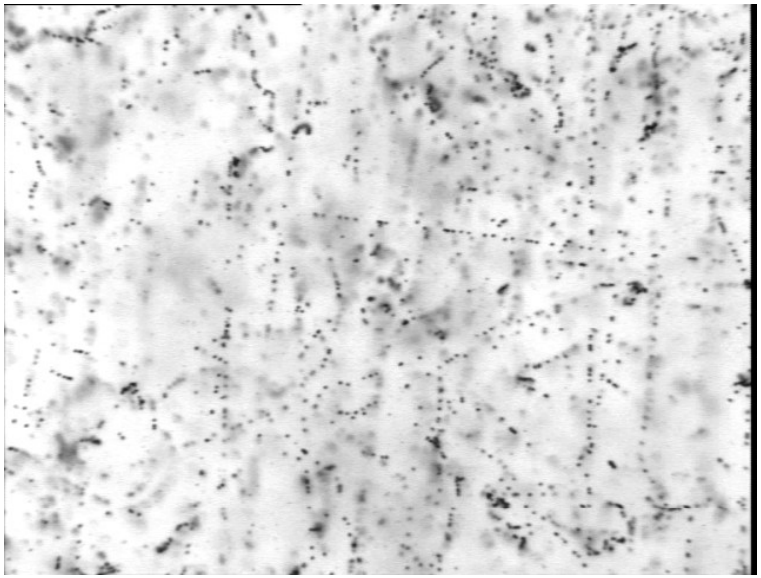
ea ~ 150, 000

of films ~ 10^7

Mass Production using

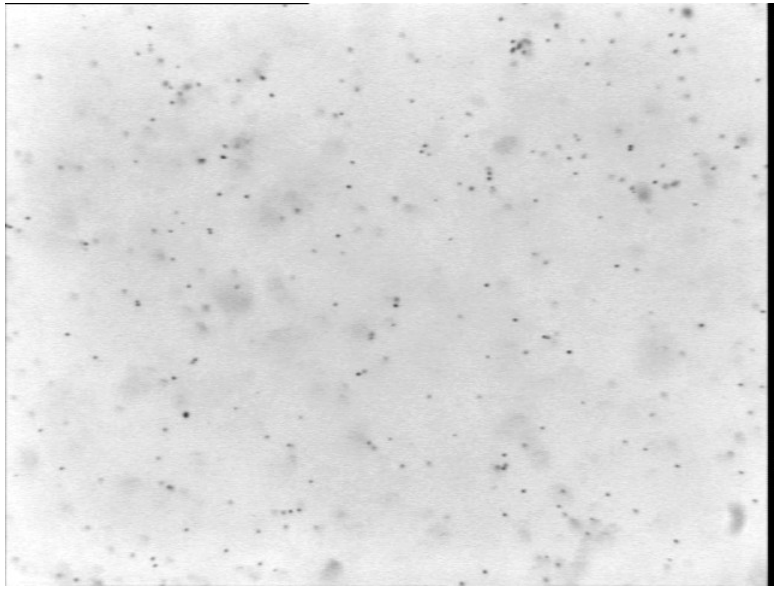
Refreshing

➢ **T= 30℃, RH > 95% for 3 days**



Before Refresh

B.G. > 30 tracks / mm^2



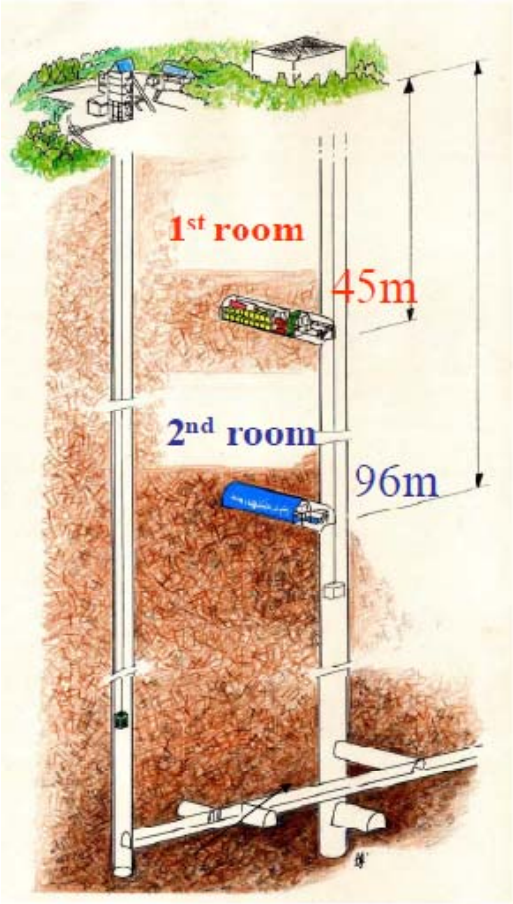
After Refresh

B.G. < 1 track / mm^2

➢ ~98% of the recorded tracks can be erased

Refreshing

In Tono Mine



In Gran Sasso

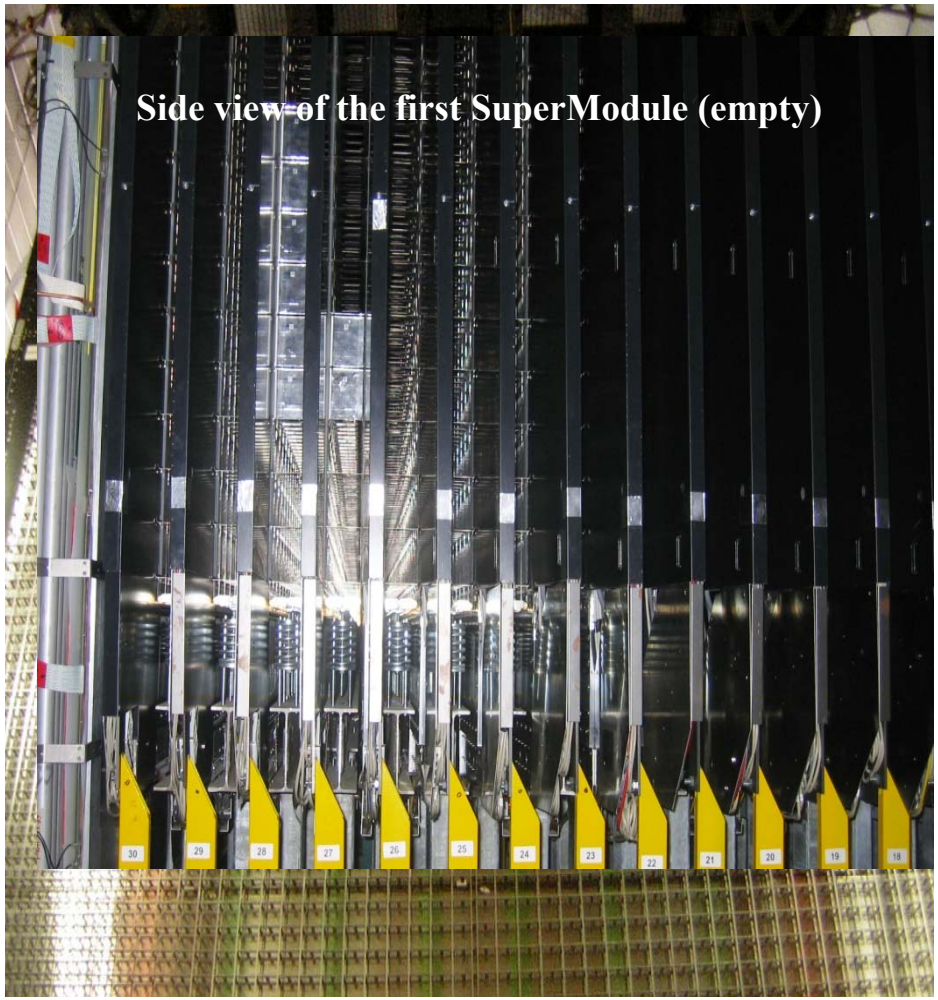
Japan, Russia, Turkey

9.3 M refreshed and shipped to GS

~300,000 films refreshed

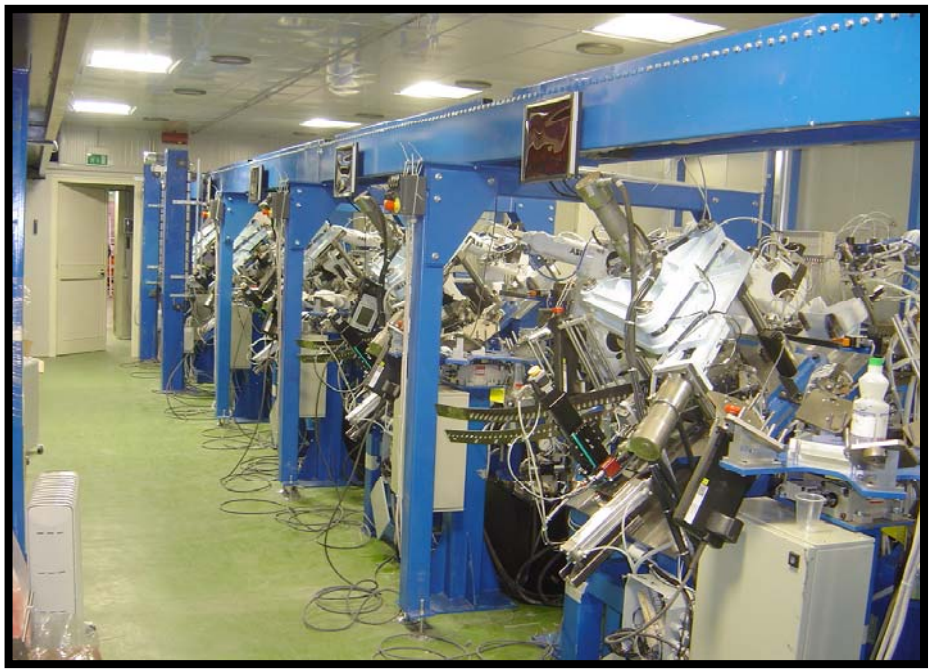
OPERA Brick

➢The basic unit: The BRICK



➢Total number of bricks: 152000 (1350 tons)

Brick Production

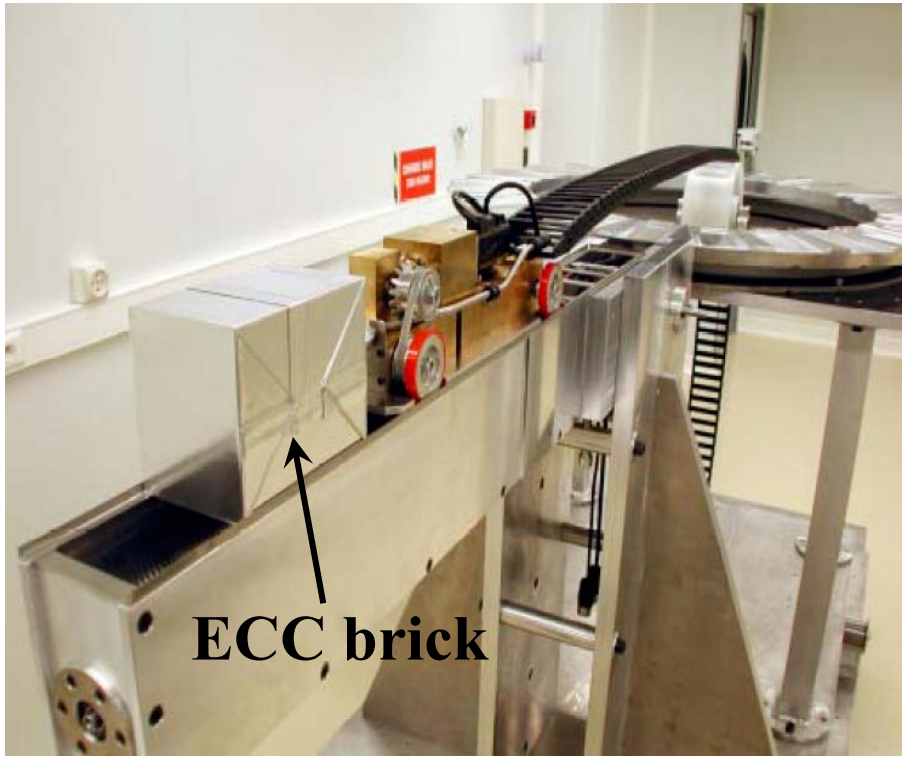


- 8 multidirectional arms for pilling
- 1 multidirectional arms for wrapping.

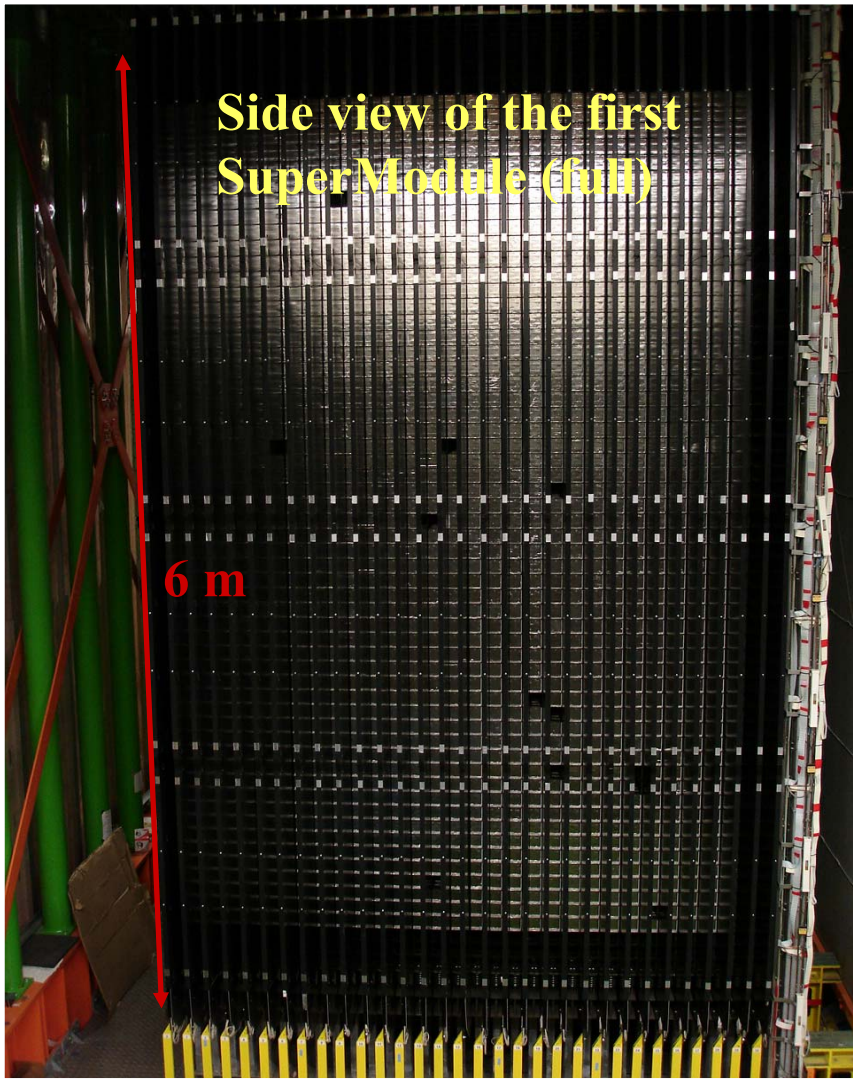
- Bricks have to be produced automatically
- Very tight tolerances
- Working in a dark room.
- Speed ~700 bricks/day

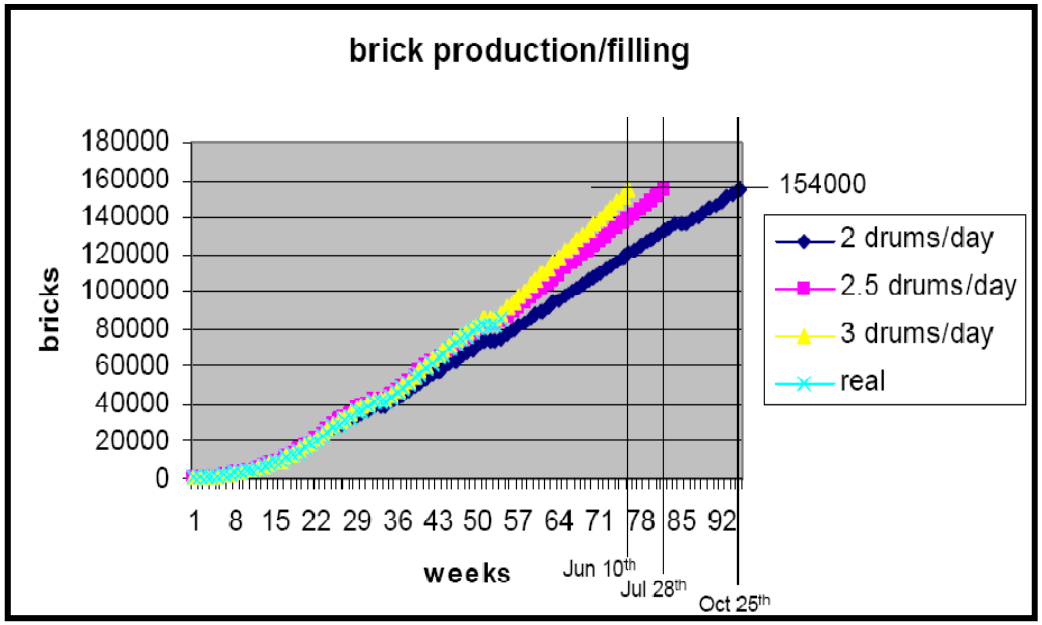
Brick Manipulation System

➢High precision robot-manipulator for Brick handling: to fill the detector, to extract the bricks daily



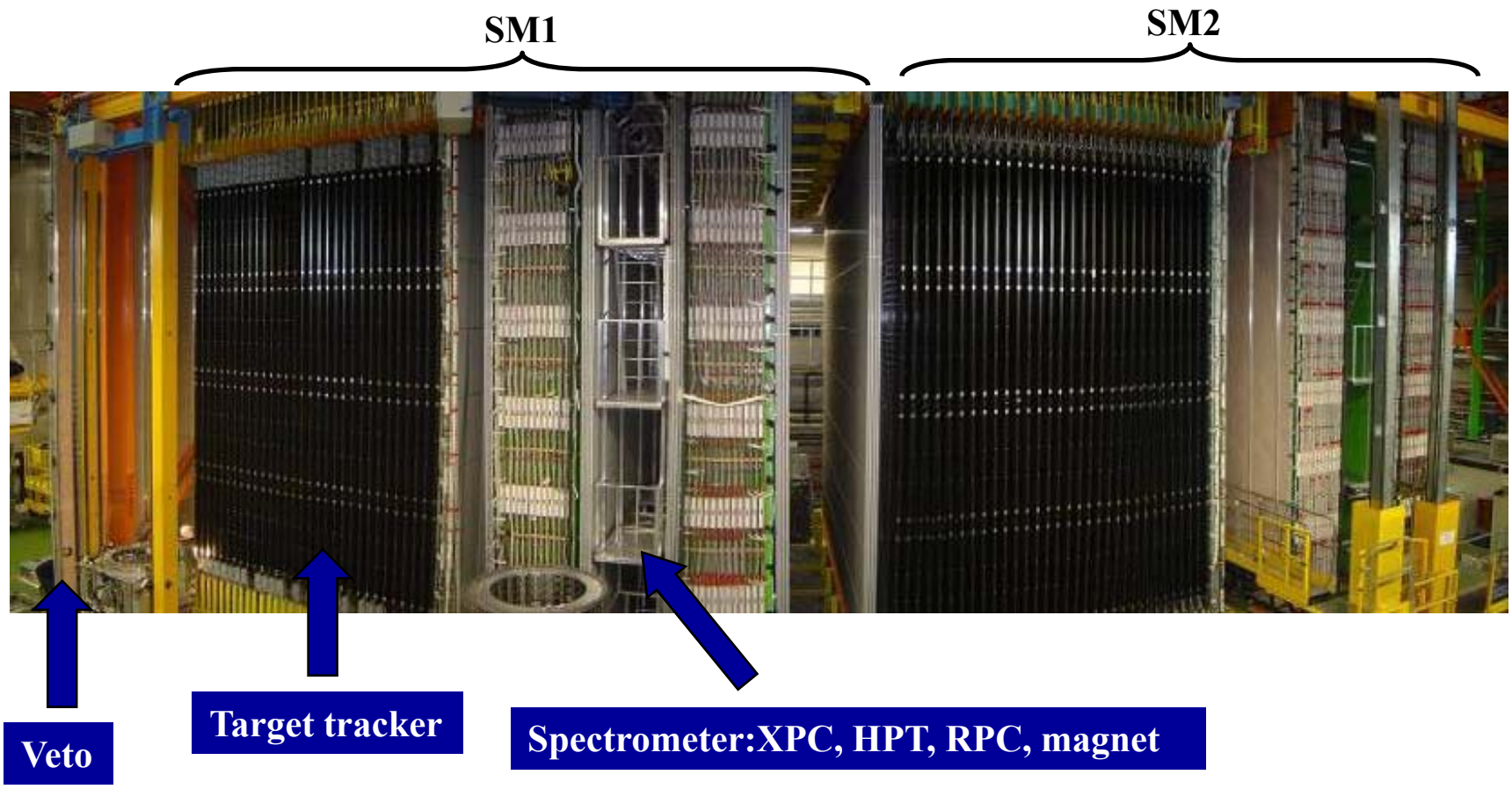
Brick production and filling



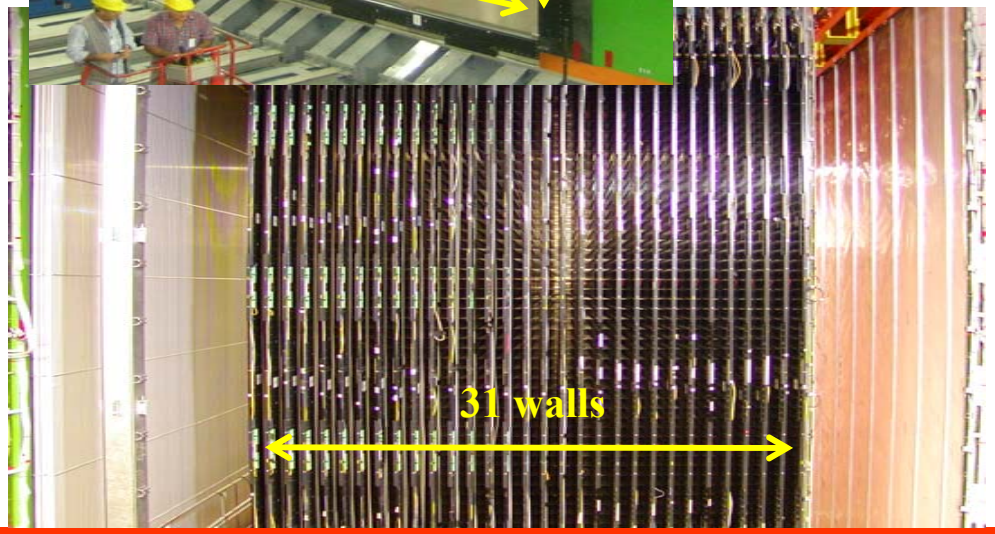


~1.5 years for OPERA.
This is long process !

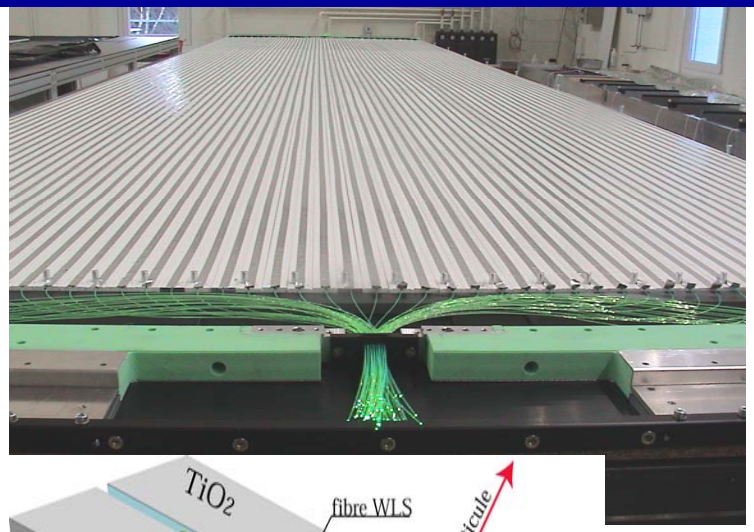
Electronic Detectors

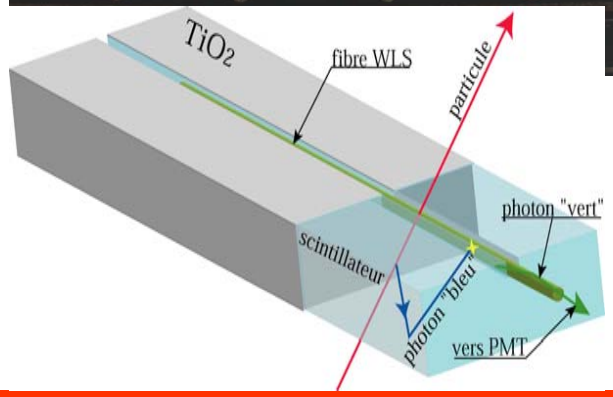


Target Tracker



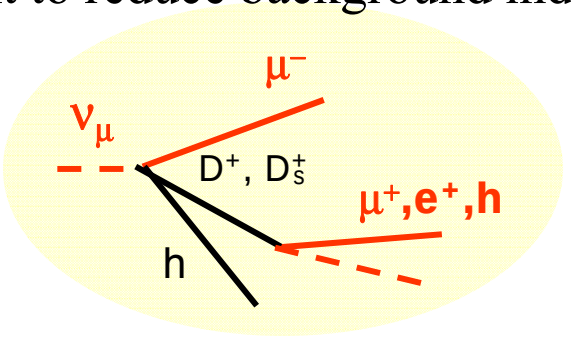
- The main goals of the target tracker are the trigger on the neutrino events and the identification of the brick to be extracted and then analysed
- It is made of plastic scintillator strips, each with a wavelength shifting fibre
- The fibres are connected in groups of 64 to multi-anode Hamamatsu PMTs at both ends



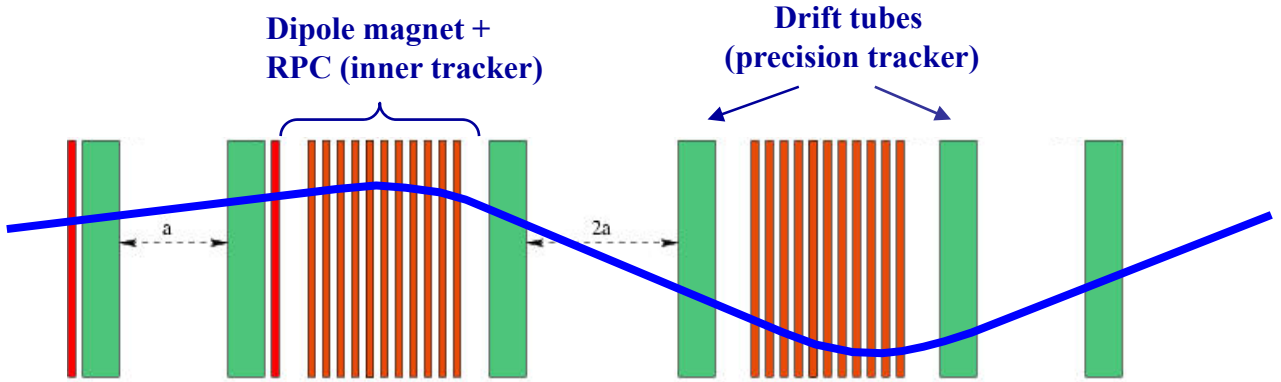


Muon Spectrometer

- μ tagging (improvement of τ→μ efficiency and tag of ν_μCC events)
- μ charge measurement to reduce background induced by charm decay:

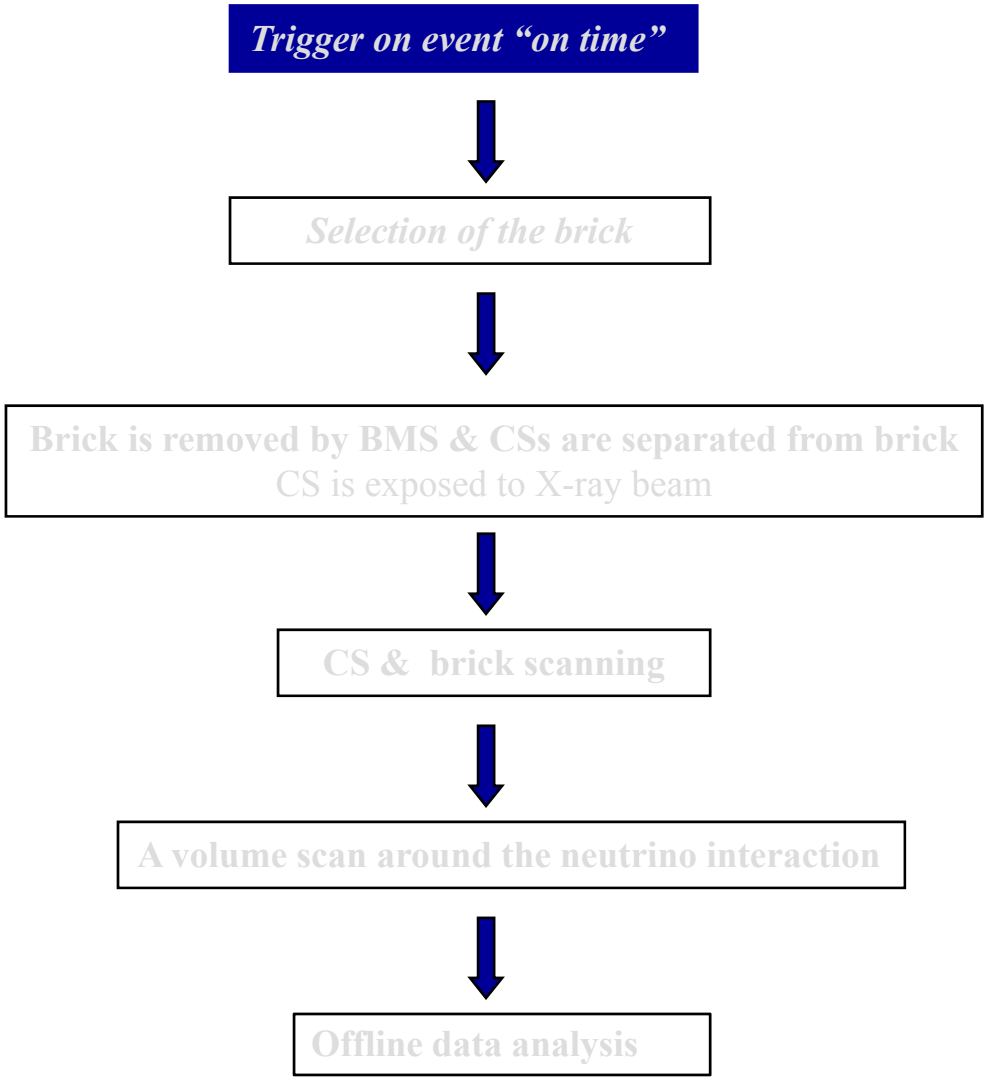


⇒ Inner tracker (RPC in magnet) and precision tracker (drift tube, 8 m length)



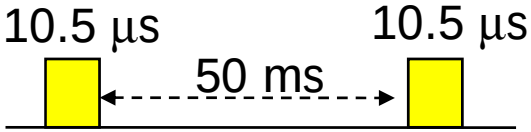
- $\varepsilon_{\text{miss charge}}$ ~ (0.1 - 0.3)%
- Δp/p < 20% for p < 50 GeV
- μ_{id} > 95% (with target tracker)

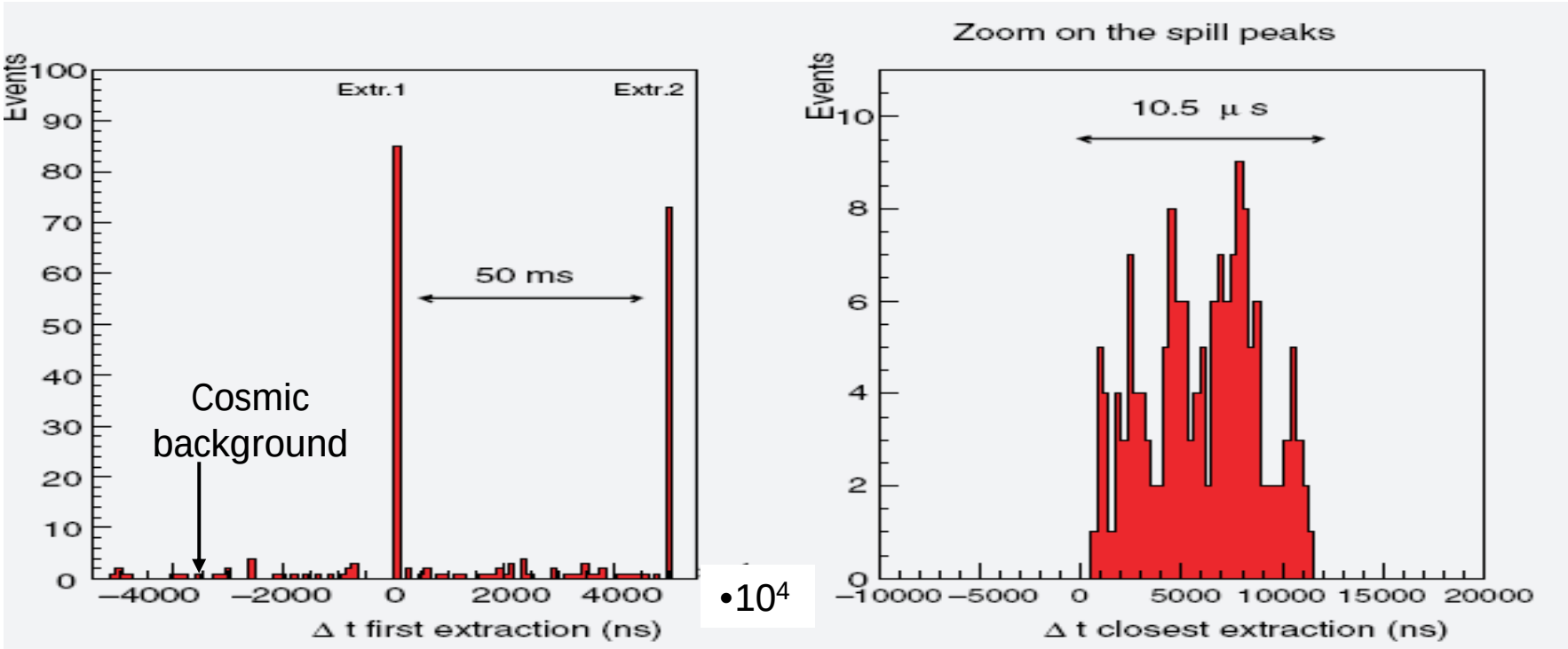
OPERA analysis chain



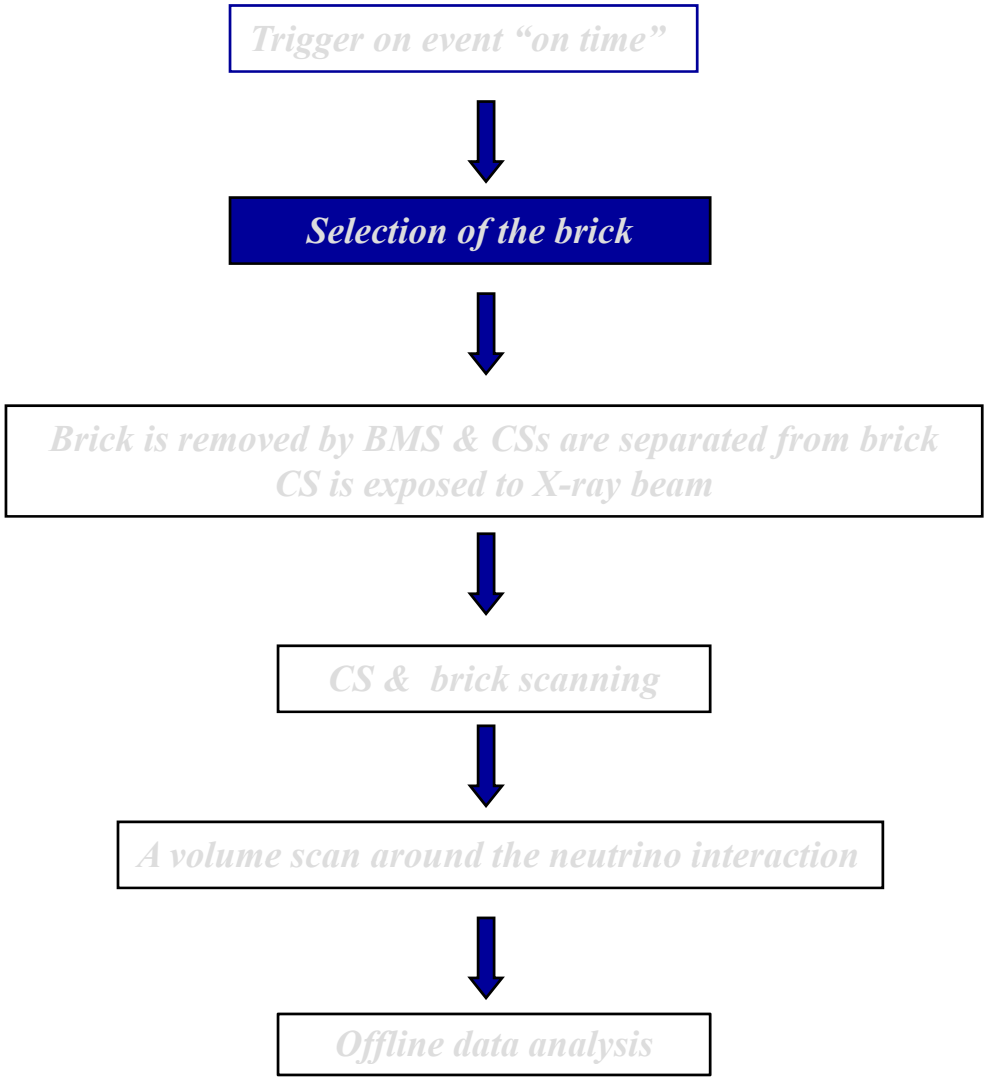
Time Synchronisation

- event selection by using GPS timing information
- narrow peak of the order of the spill width (10.5 μs)
- practically no background O(10^{-4})



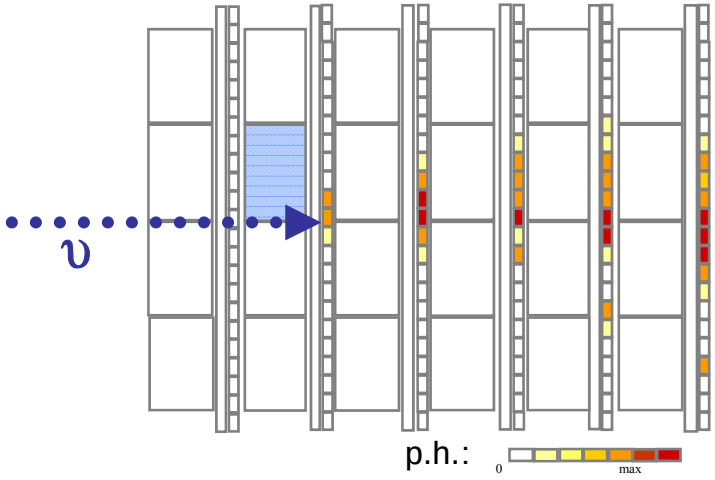


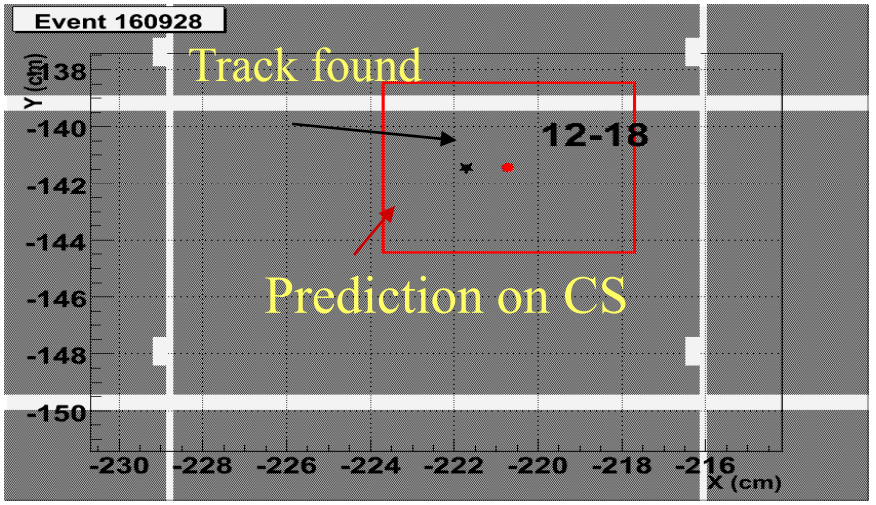
OPERA analysis chain



Brick finding

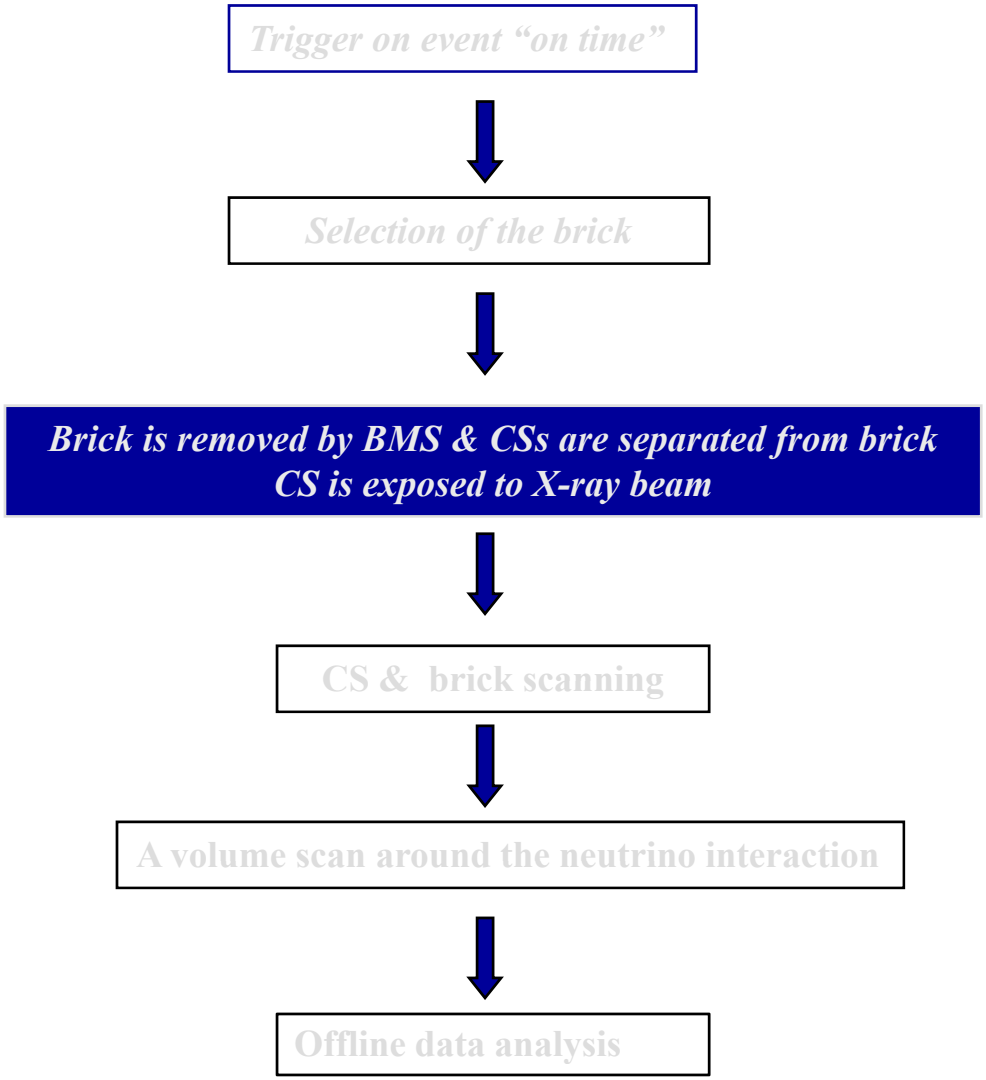
- track reconstruction in electronic detectors
- prediction for location of primary vertex
- TT give approximate angle and position of tracks for scanback (3cm x 5cm)
- one or more bricks are extracted and stored





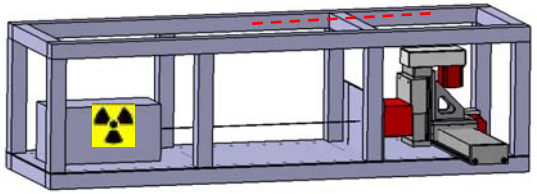
Brick finding with the target tracker (TT)

OPERA analysis chain

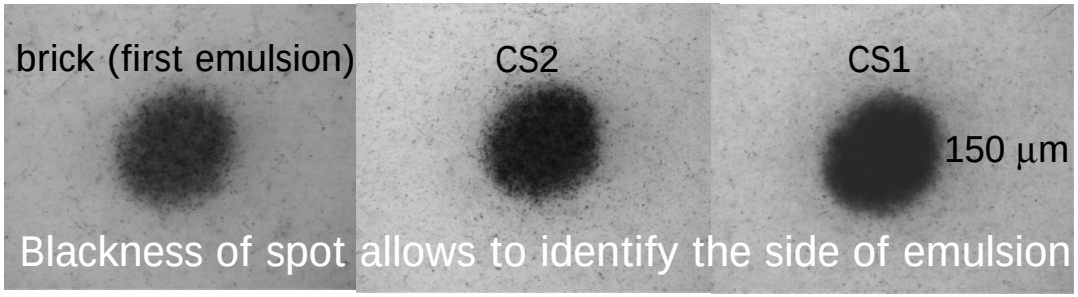


Processing CS & Brick

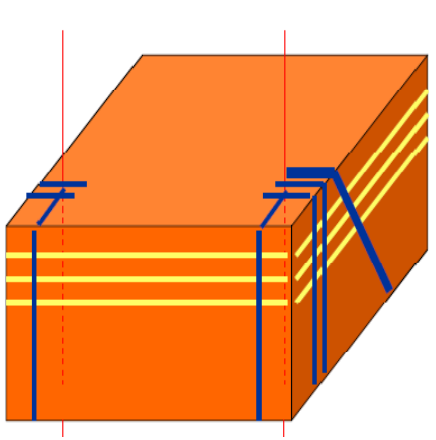
- **Processing of CS**
  - x-ray markings for alignment → ~ 10 μm
  - connection of CS-doublets and brick
  - search area is scanned for track with matching angle

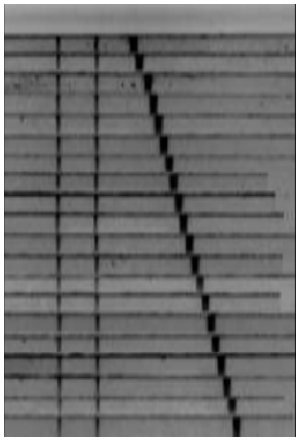


x-ray machine



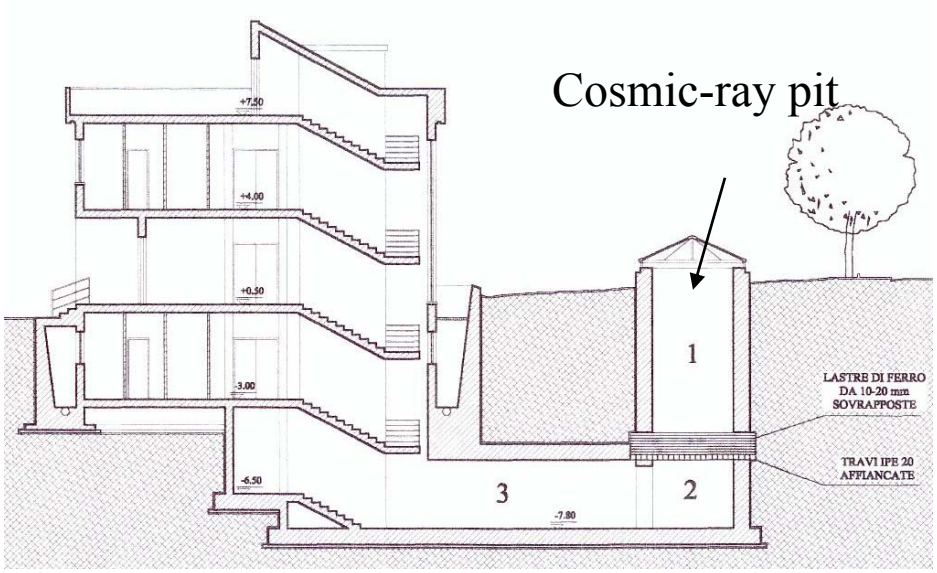
- **Processing of Brick**
  - x-ray markings → ~ 40 μm
  - first film to film connection
  - film number identifier



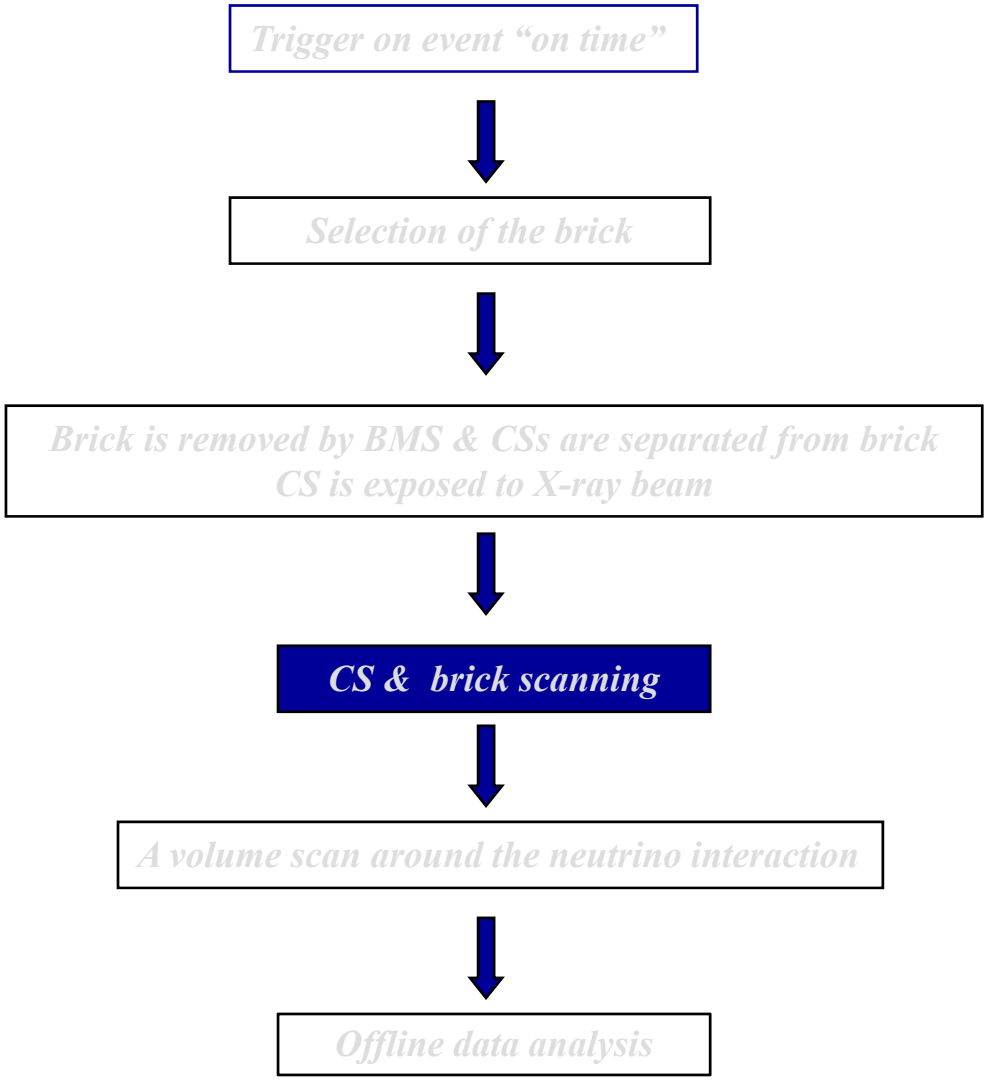


Development at the GS

- bricks are put into cosmic ray pit
- cosmic rays used for local alignment
- 5 automatic development chains ready
- 50 bricks/day (16h)



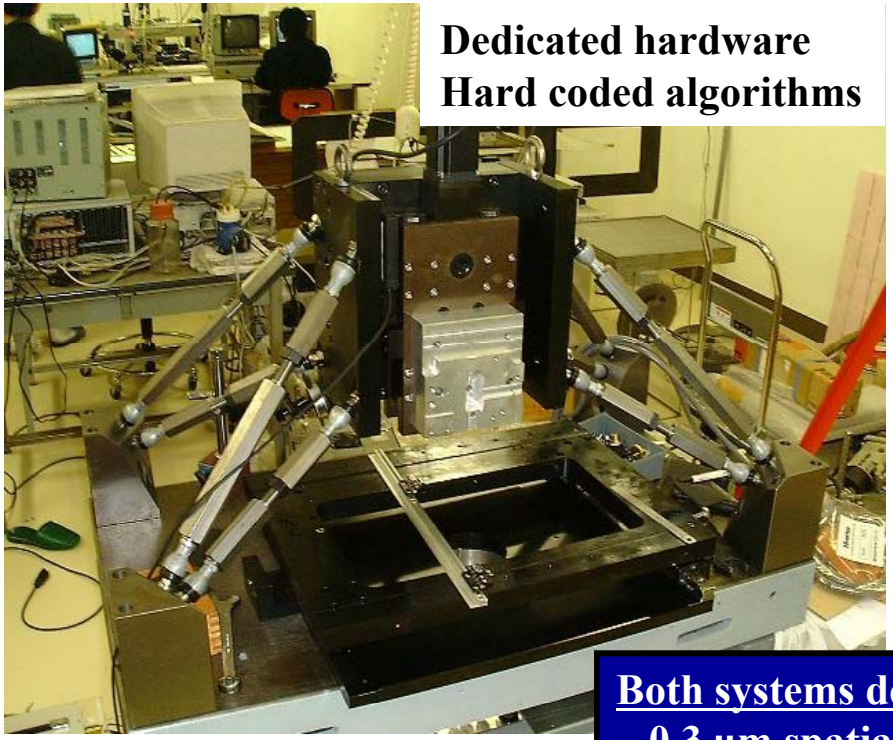
OPERA analysis chain



Automatic Scanning System

S-UTS(Japan)

- Scanning speed of 72 cm2/h



Dedicated hardware
Hard coded algorithms

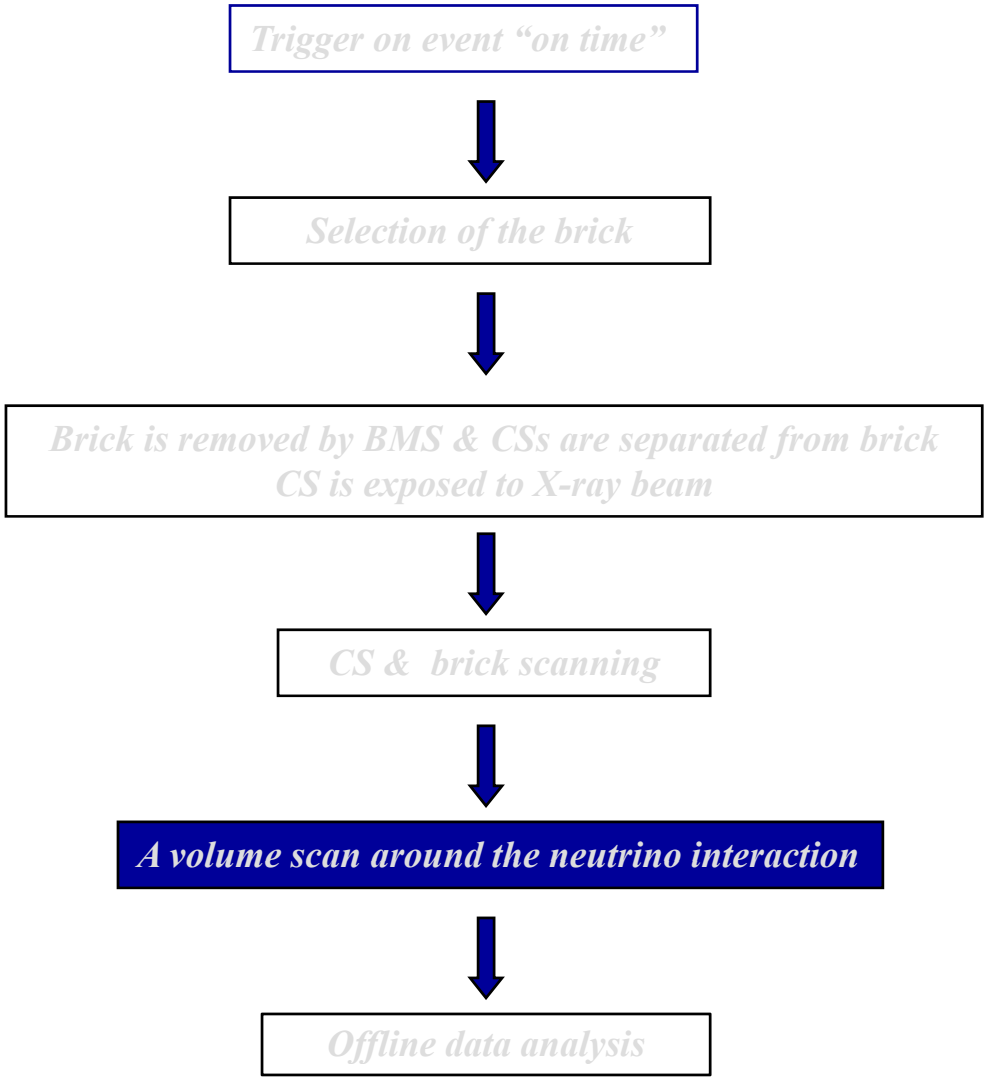
European scanning system

- European system: recent version working at 20cm^2/hr/side

Commercial hardware
Software algorithms

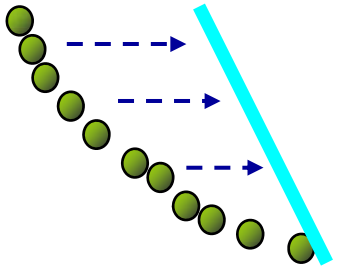
Both systems demostrate:
- ~0.3 µm spatial resolution
- ~ 2 mrad angular resolution
- ~ 95% base track detection efficiency

OPERA analysis chain

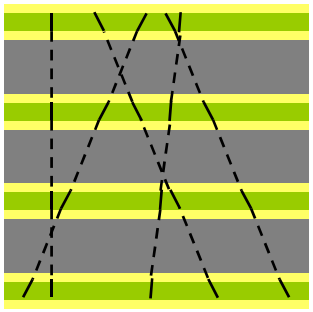


Basic Ideas of Volume Scanning

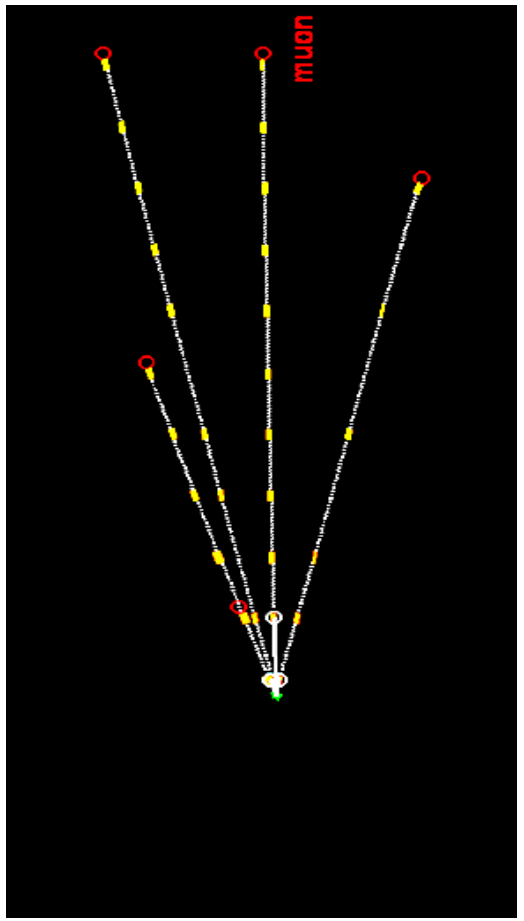
Track processing takes further steps to reach physics goals

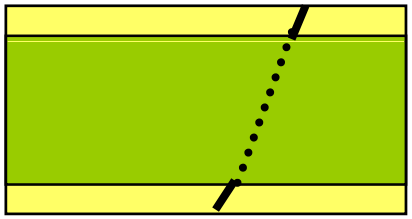


3D reconstruction of microtracks

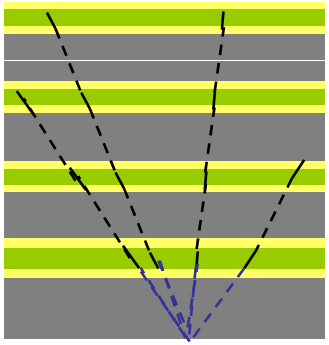


Track linking through different emulsion sheets



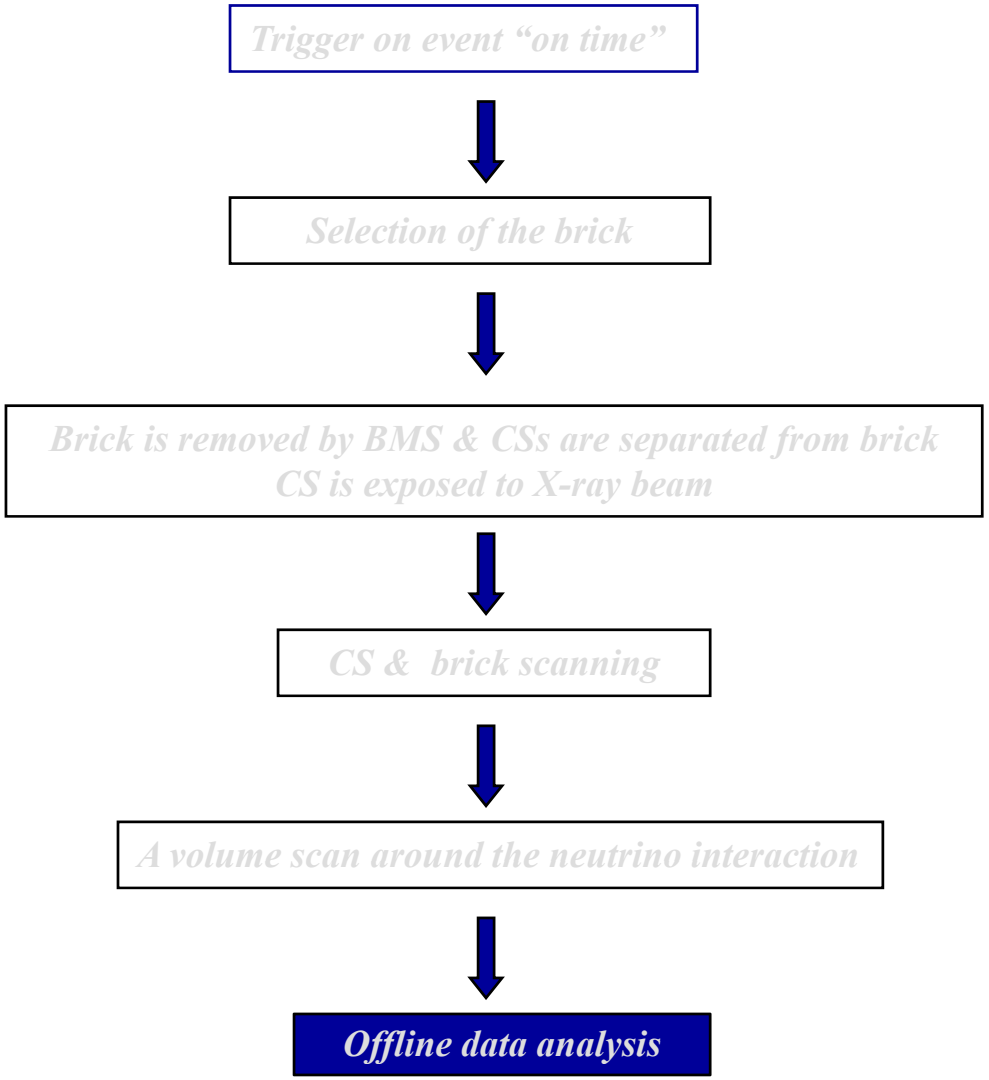


Track linking through emulsion base



Vertex/Decay Reconstruction

OPERA analysis chain

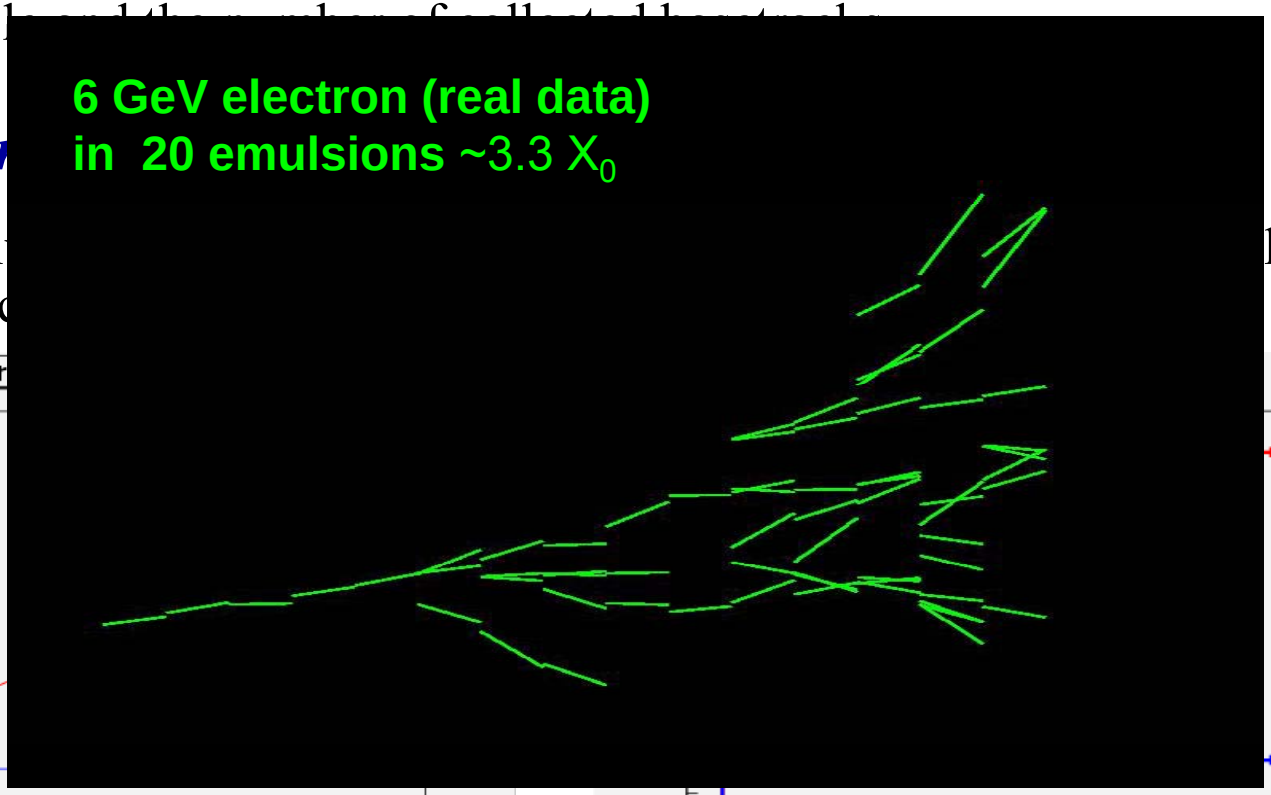


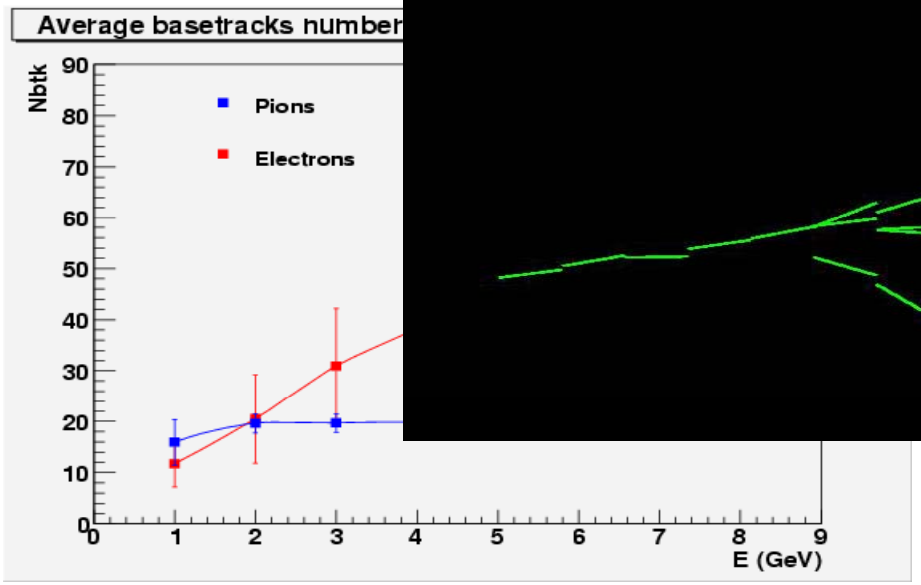
Electron reconstruction and identification

e/π separation: Method use a neural network based on the reconstructed shower longitudinal profi

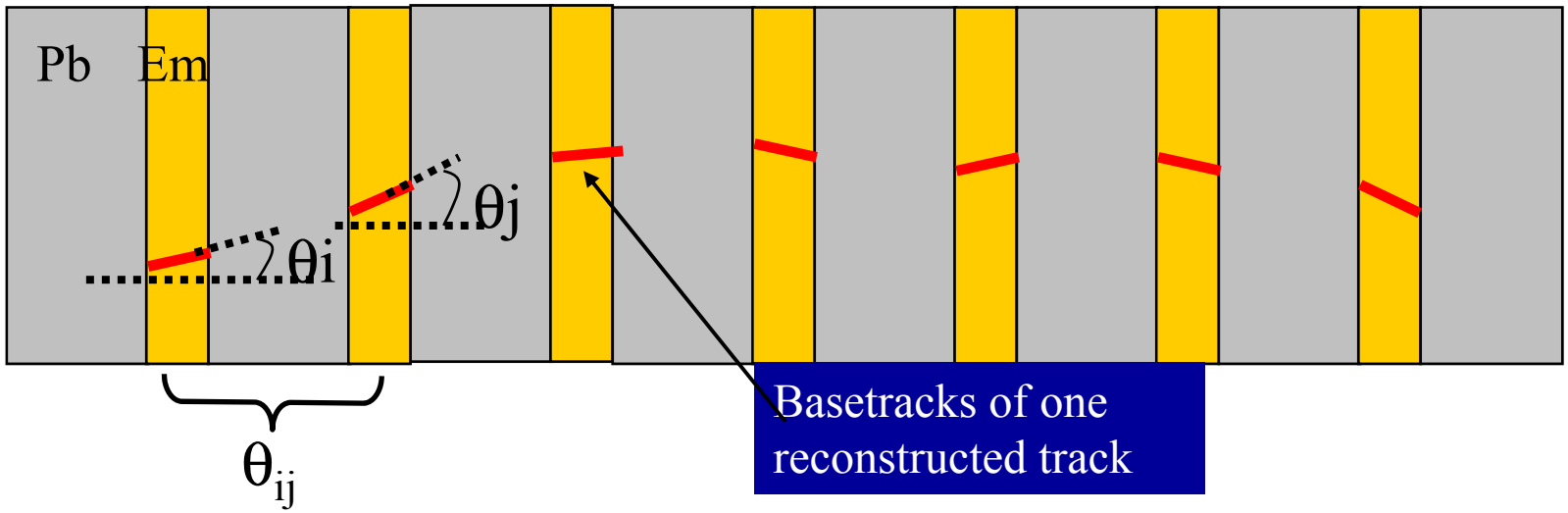
Reconstructio

Starting from a gi ks in a cone using connec



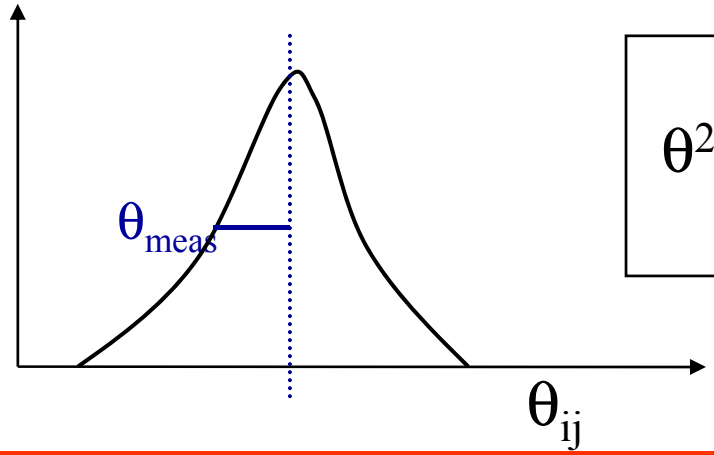


Momentum measurement for charged hadron



Principle : to use the angular differences θ_{ij} of particle tracks measured in emulsion, due to multiple coulomb scattering in lead.

For a given track, the rms of the slope diff. θ_{ij} is linked to the particle momentum

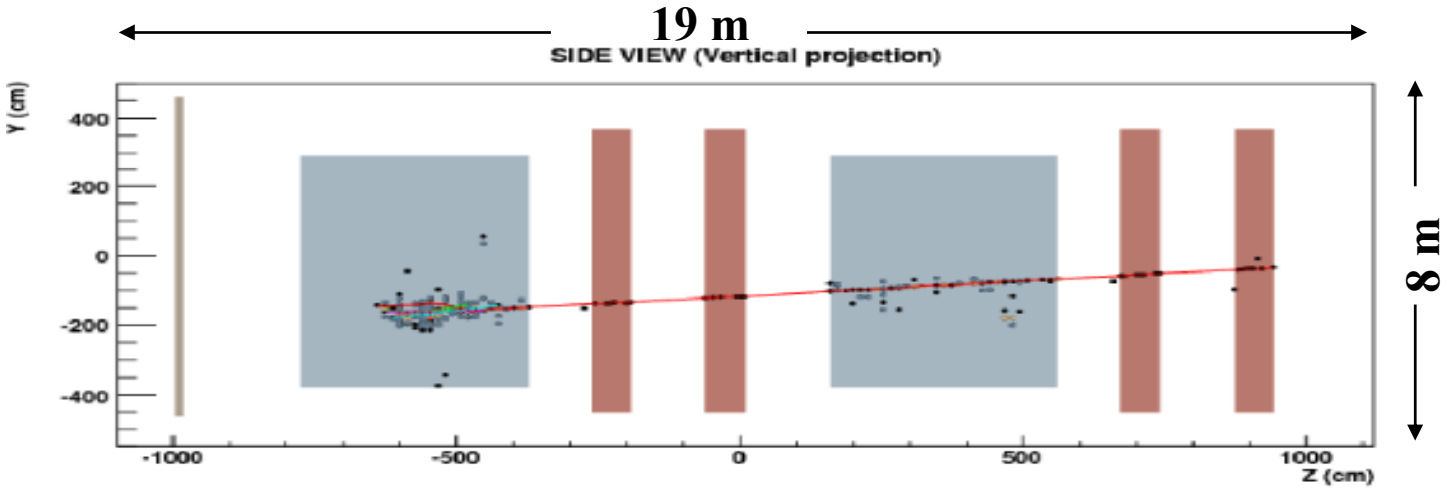


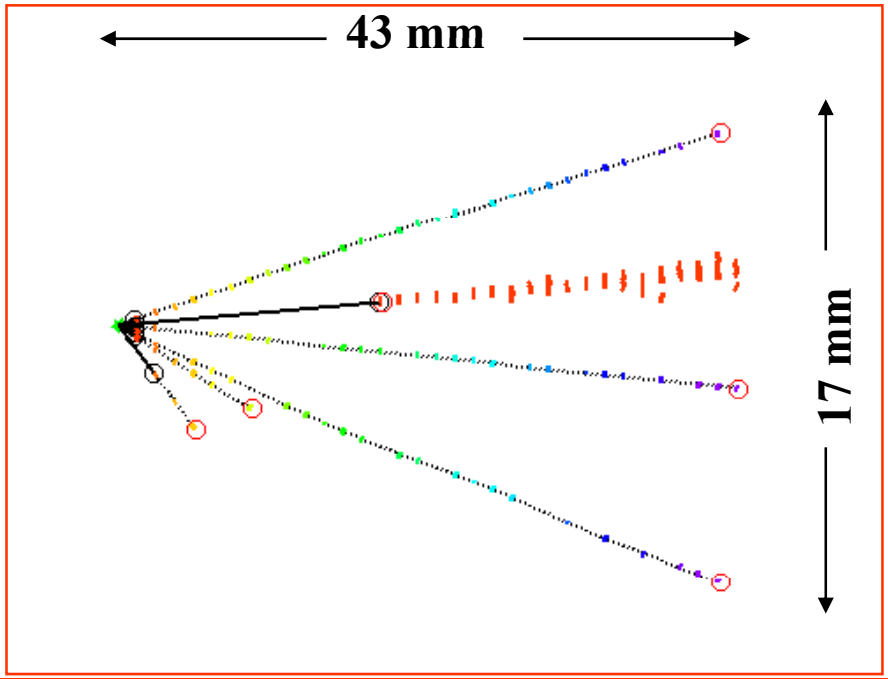
$$\theta^2_{meas} = \frac{13.6^2 * X}{X_0 * p^2} + \delta\theta^2$$

RMS θ_{ij}

Resolution on Basetracks

Neutrino events in OPERA



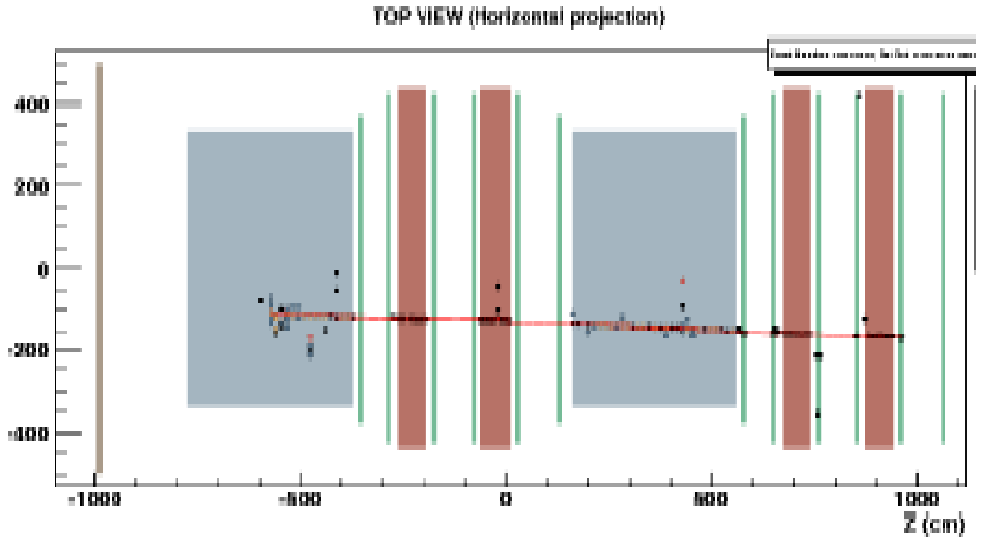


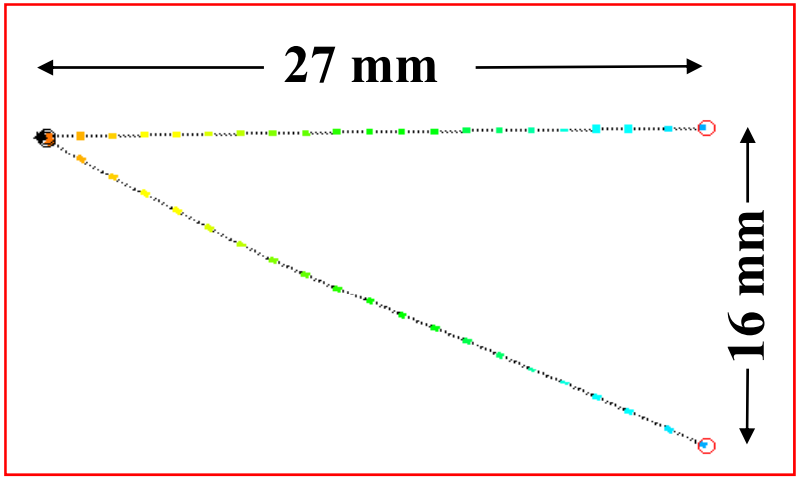
5 prongs associated to the neutrino interaction

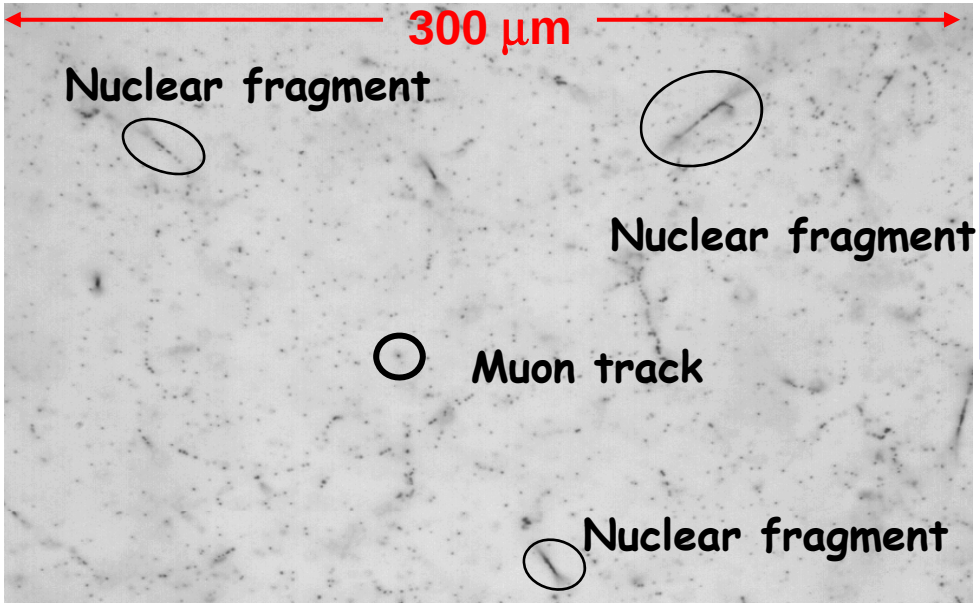
<IP> = 9 μm

Electromagnetic shower pointing to the vertex (γ conversion)

Neutrino events in OPERA

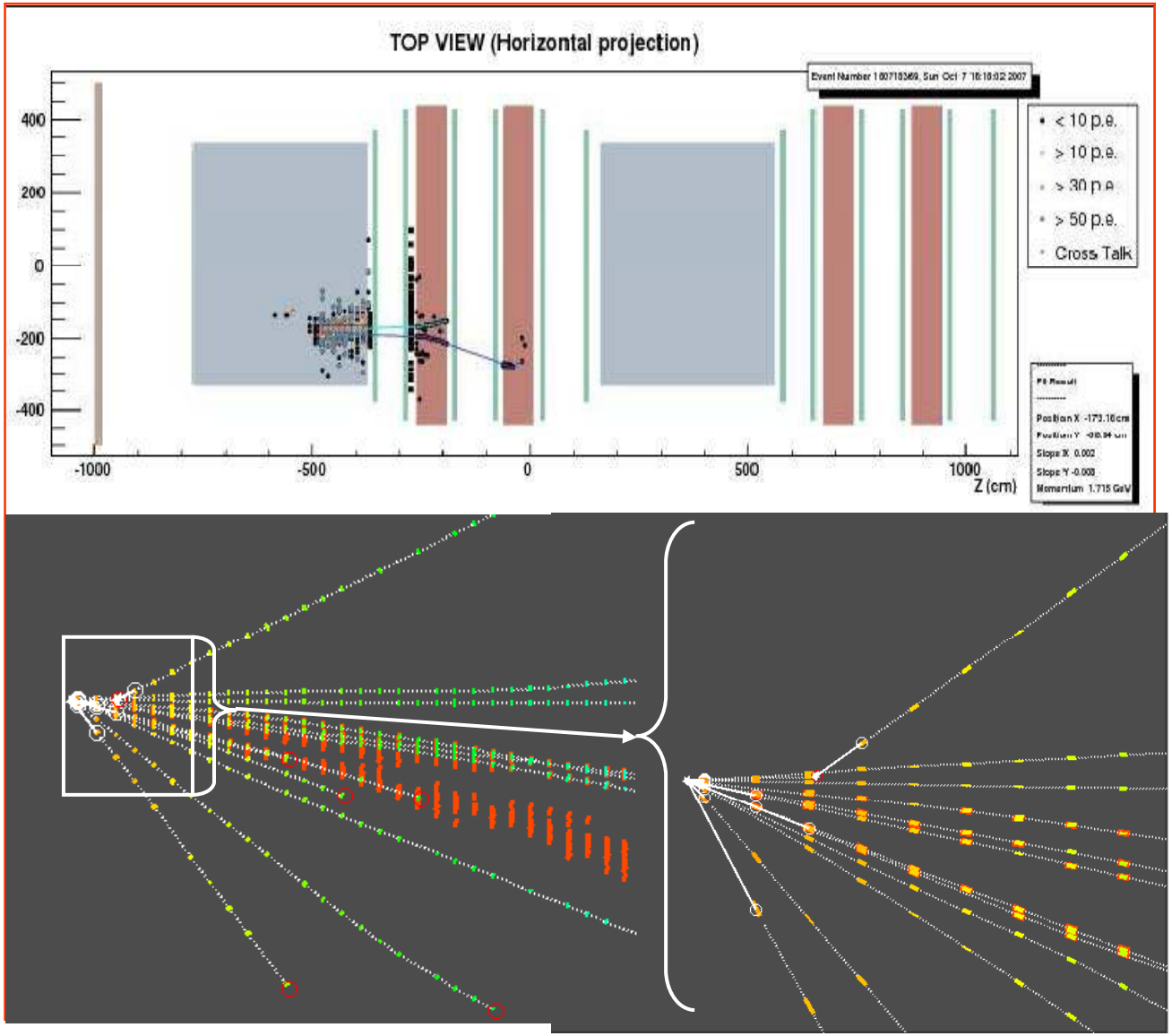






The visual inspection allow the observation of nuclear fragments and the classification of the event as DIS

Charm-Candidate

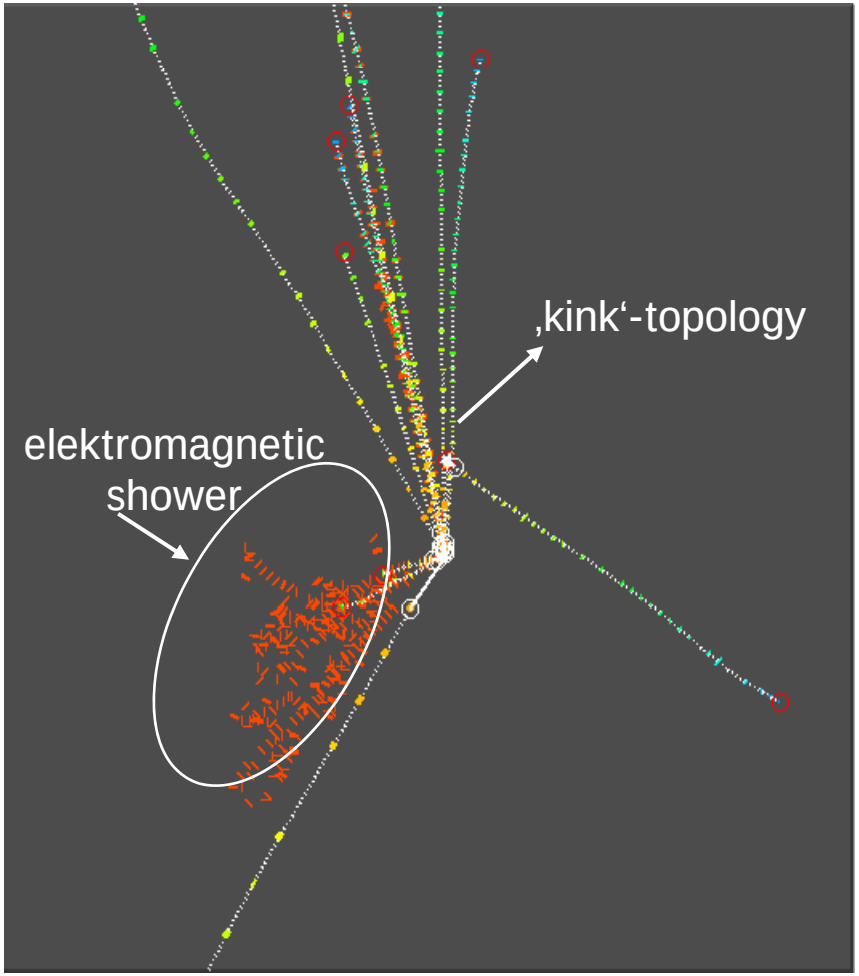


Charm-Candidate

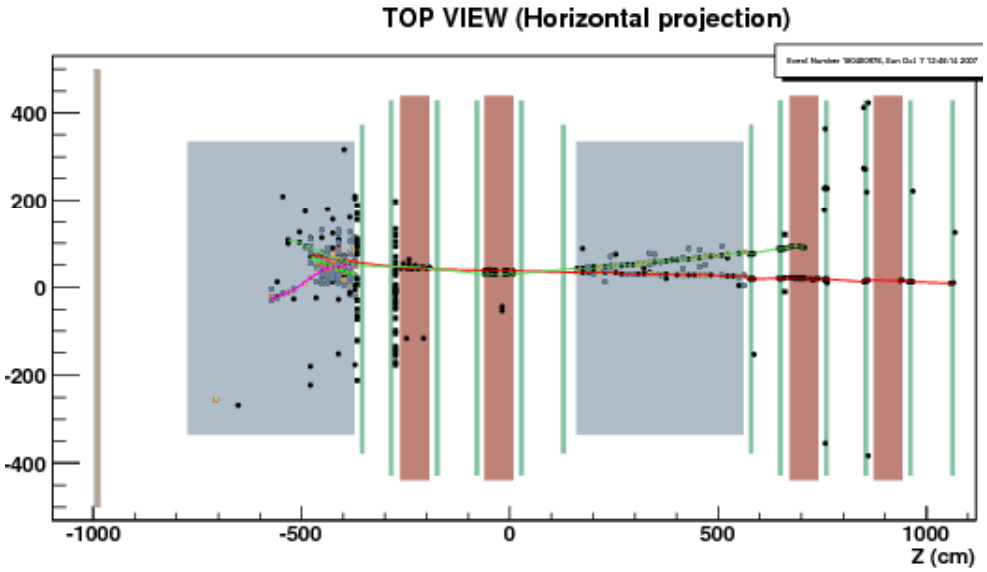
Secondary Vertex:

- daughter momentum = $3.9\ ^{+1.7}_{-0.9}$ GeV
- kink angle = 0.204 rad
- flight length = 3247 µm
- P_T = 796 MeV
- PT_{MIN} = 606 MeV (90% C.L.)

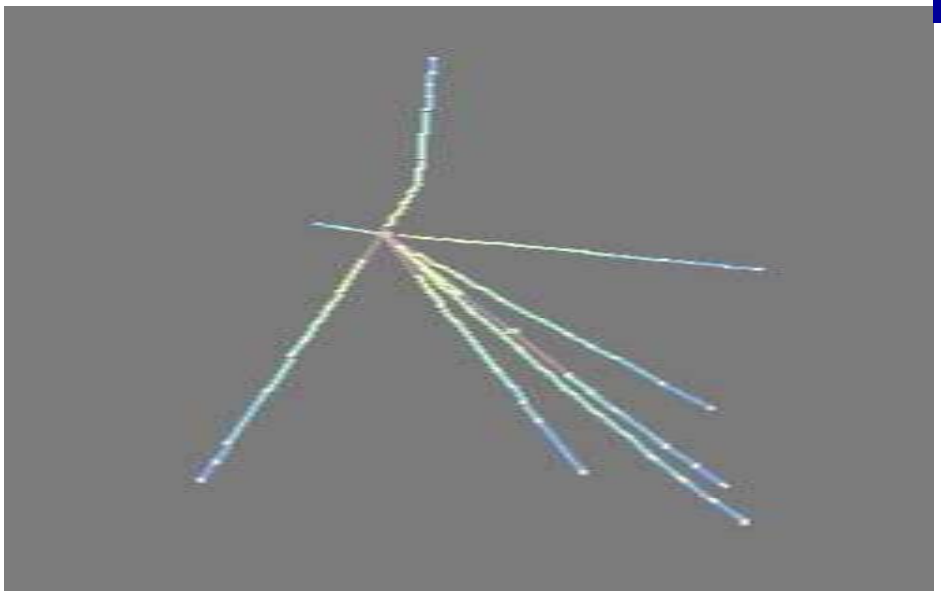
Preliminary!

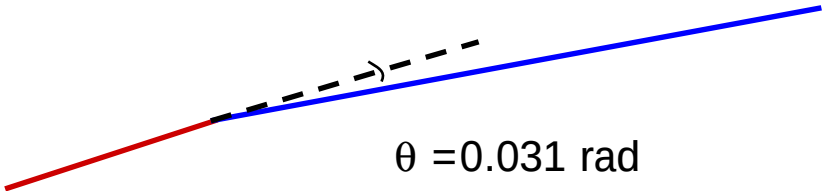


Neutrino events in OPERA



- flight length of parent ~ 5mm
  - too long for t
- momentum of daughter: P = 3.1 ± 0.7GeV
  - measured by multi-scattering
- PT=96±20MeV (Cut for Charm >=250MeV)
- Hadronic re-interaction





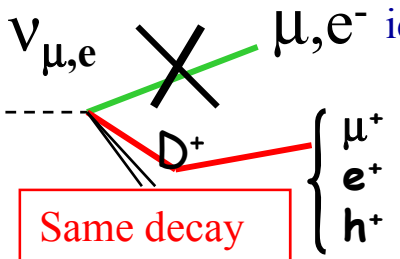
2007 Run

- We expect 32±6 interaction events in bricks, divided in 75% CC and 25% NC @8.24×10^{17} p.o.t
- We found 38 events, divided in 29 CC (76%) and 9 NC (24%)
- The 38 events were shared in Europe (19) and Japan (19)

2008 Run

- 2008 run started on June 18th and will finish on November 3rd.
- ~ 2×10^{19} p.o.t.
- ~1700 events in Brick

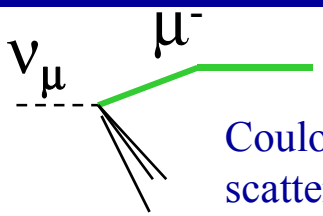
Background



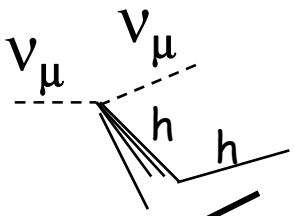
Primary lepton not identified

Same decay topology as τ

Charm production in CC, common to the 3 channels
Good muon identification is fundamental



Coulombian large angle scattering of muons in Lead : Bck. to $\tau \rightarrow \mu$



Hadronic interactions in Pb: Bck. to $\tau \rightarrow$ h or to $\tau \rightarrow \mu$ (if hadron mis-identified as muon)

Expected number of background events after 5 years running with nominal beam:

	$\tau \rightarrow e$	$\tau \rightarrow \mu$	$\tau \rightarrow h$	$\tau \rightarrow 3h$	Total
Charm background	**.173**	**.008**	**.134**	**.181**	**.496**
Large angle μ scattering		**.096**			**.096**
Hadronic background		**.077**	**.095**	**.**	**.172**
Total per channel	**.173**	**.181**	**.229**	**.181**	**.764**

Expected Performance

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

τ^- decay Channels	Signal ÷ Δm^2 (Full mixing)		Background
	2.5×10^{-3} (eV^2)	3.0×10^{-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

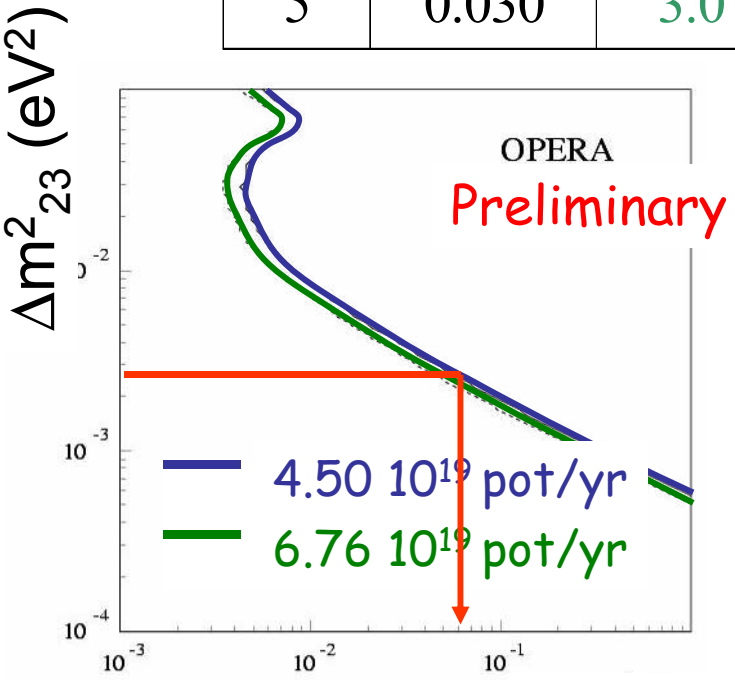
Conclusions

- The OPERA is an emulsion detector at kiloton scale (1.3kton)
- OPERA is now taking data.
- In 2007: first CNGS neutrino run:
  - Test and tuning of electronic detectors, brick finding algorithms and scanning strategy
  - Validation of reconstruction software and analysis tools
  - 38 neutrino events collected
  - The concept of the OPERA detector has been successfully validated!
- 2008 run started on June 18th and will finish on November 3rd.

awaiting the first ν_τ-candidate

$\nu_\mu \rightarrow \nu_e$ expected signal and background

θ_{13} (deg)	$\sin^2 2\theta_{13}$	Signal $\nu_\mu \rightarrow \nu_e$	$\nu_\mu \rightarrow \nu\tau$, $\tau \rightarrow e\nu_\tau\nu_e$	ν_μ CC	ν_μ NC	ν_e CC
9	0.095	9.3	4.5	1.0	5.2	18
7	0.058	5.8	4.6	1.0	5.2	18
5	0.030	3.0	4.6	1.0	5.2	18



	$\sin^2 2\theta_{13}$	θ_{13}
CHOOZ	**<0.14**	**11^0**
OPERA	**<0.06**	**7.1^0**

Ref: Komatsu et al. J. Phys. G29 (2003) 443.