Data Analysis of the Target Tracker in the OPERA Experiment

"Neutrino Physics at Accelerators" Workshop

S.Dmitrievsky
(DLNP, JINR)

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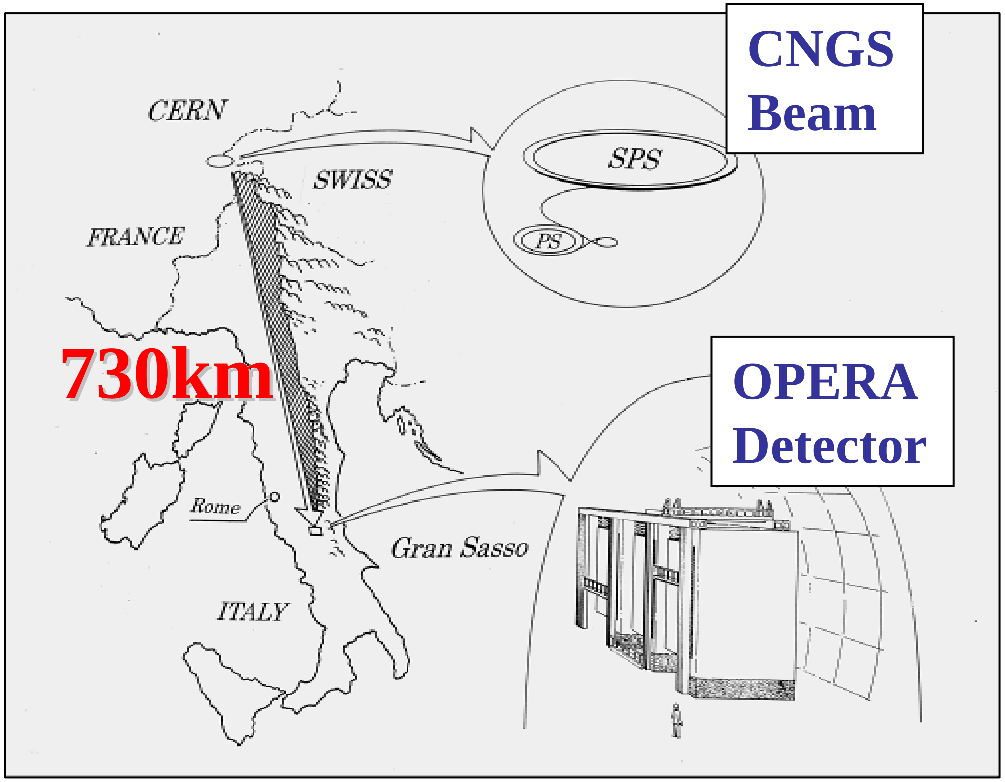
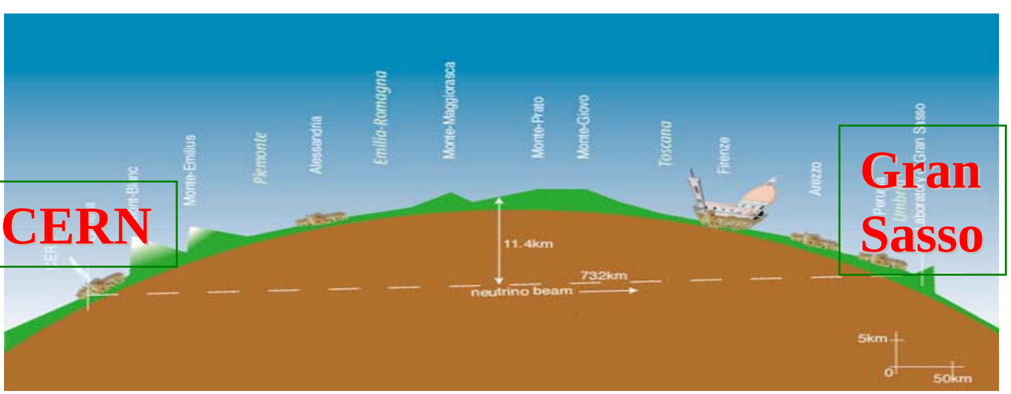
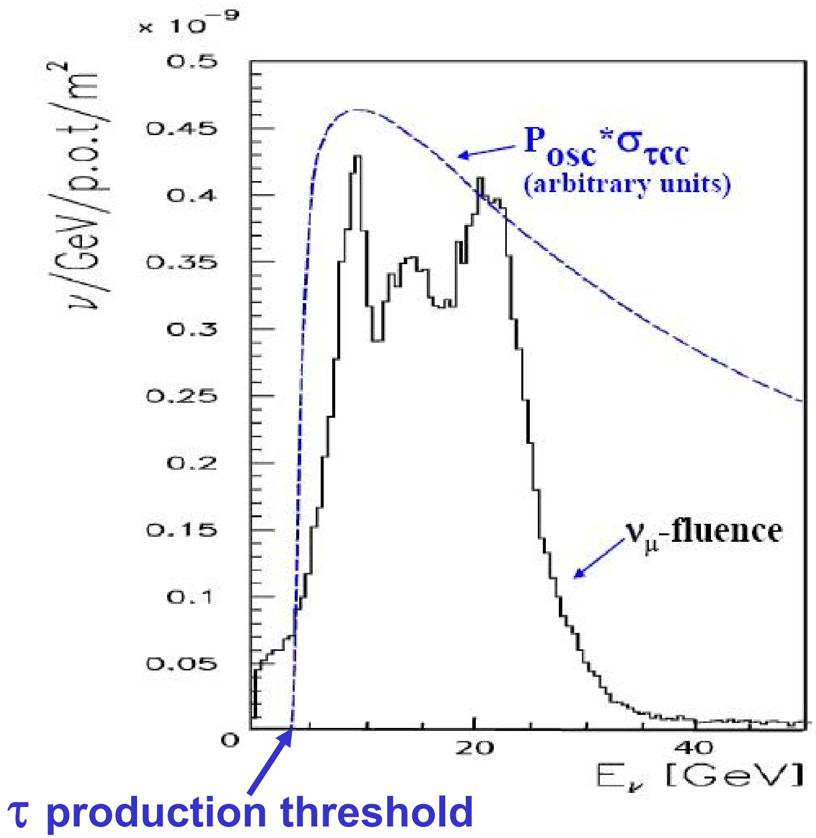
OPERA experiment is designed for direct observation of ν_τ appearance in the CNGS long baseline beam as a result of $\nu_\mu \rightarrow \nu_\tau$ oscillation.



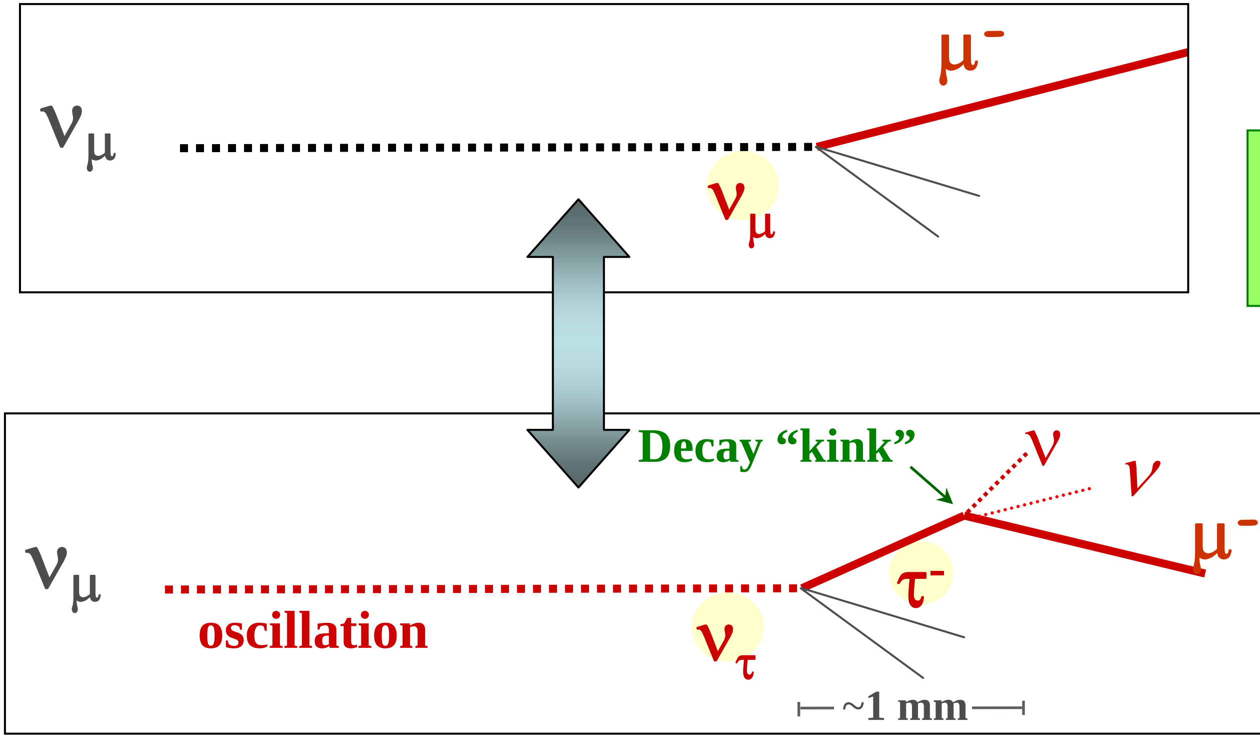


Nominal intensity: 4.5*1019 pot/year



ν_μ flux optimized for the maximal number of ν_τ charged current interactions

Detection of the ν_τ appearance signal



The challenge is to identify ν_τ interactions from ν_μ interactions

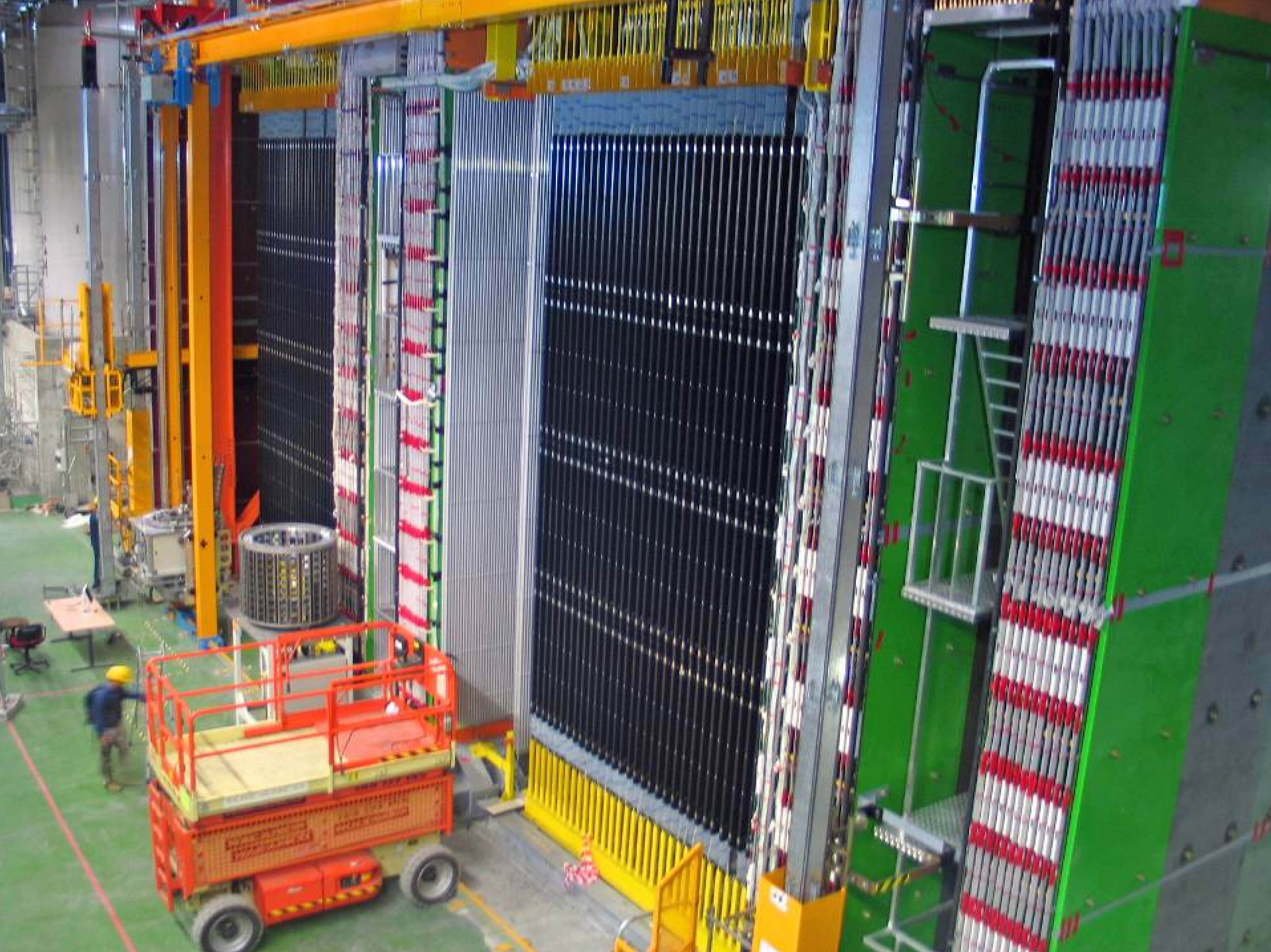
Topology selection:
$\Downarrow$
Kink signature

Two conflicting requirements:

- **Large mass ⟺ low Xsection**
- **High resolution**
  - ➡ signal selection
  - ➡ background rejection

Target: 1300 tons, 5 years running

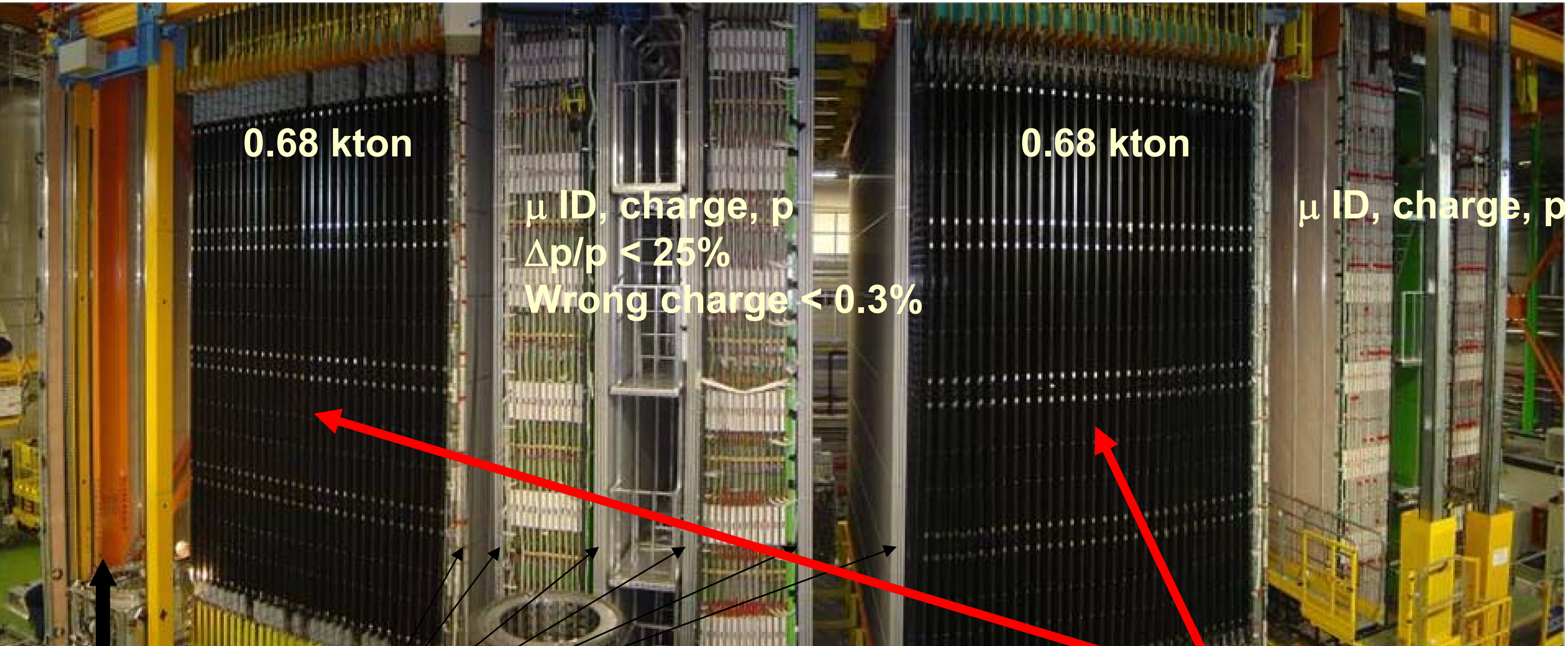
- **22 000 neutrino interactions**
- **~120 ν_τ interactions**
- **~12 ν_τ identified**
- **< 1 event of background**



Outline:

- Target Tracker Description.
- Efficiency of the TT.
- Brick Finding Program.
- Outlook.

OPERA detector: 2 identical super-modules (target, TT, Spectrometer) + veto system



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 ($8\times10\ m^2$)

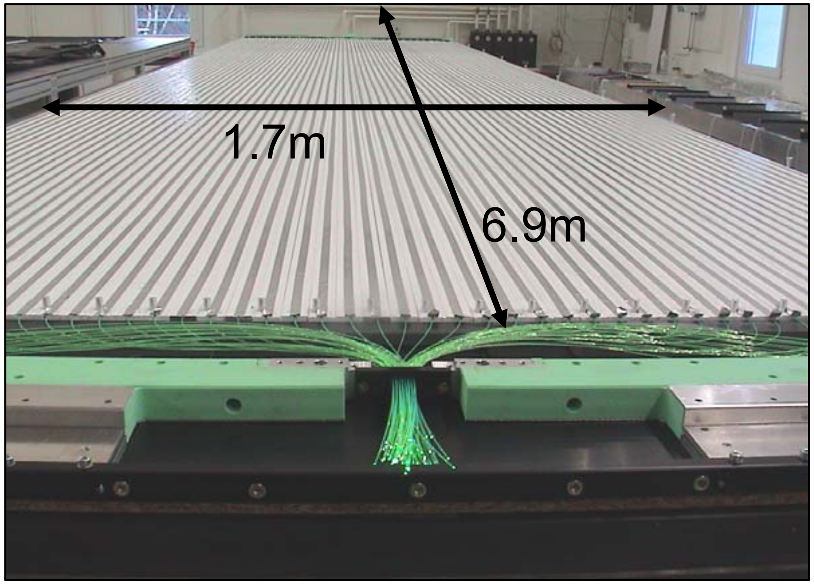
Target and Target Tracker ($6.7m$)^2

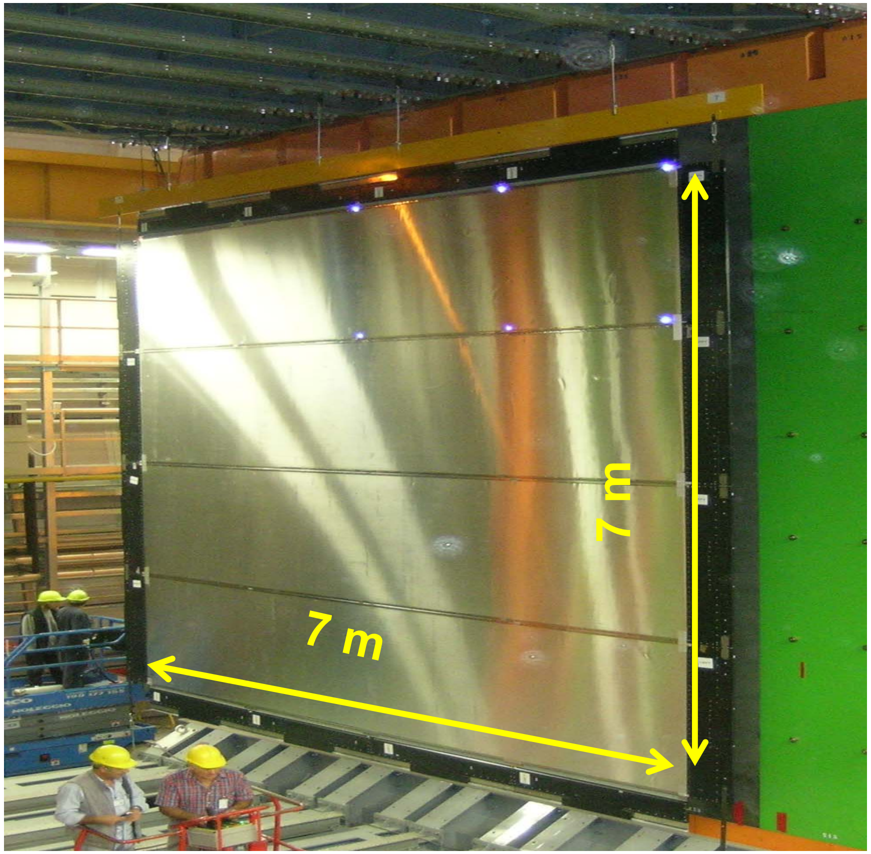
- Target (1SM) : 77500 bricks, 29 walls
- Target tracker : 31 XY doublets of 256 scintillator strips + WLS fibres + multi-anode PMTs

Target Tracker

Target Tracker tasks:

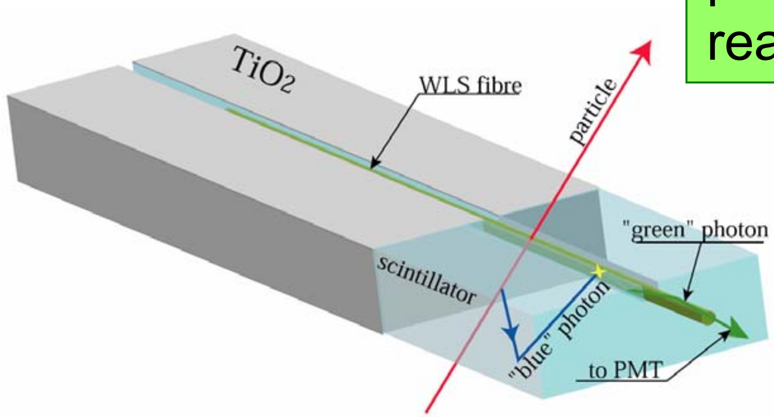
- Trigger
- Brick finding
- Initiate muon tagging
- Calorimetric measurement



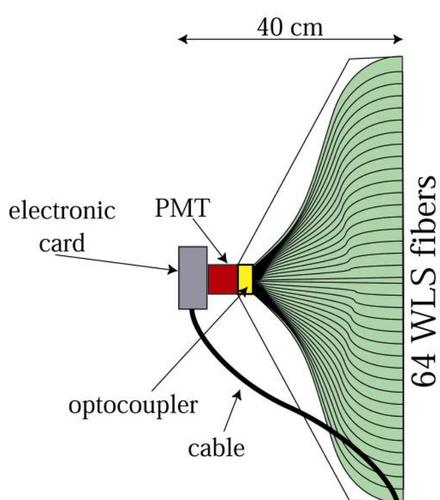


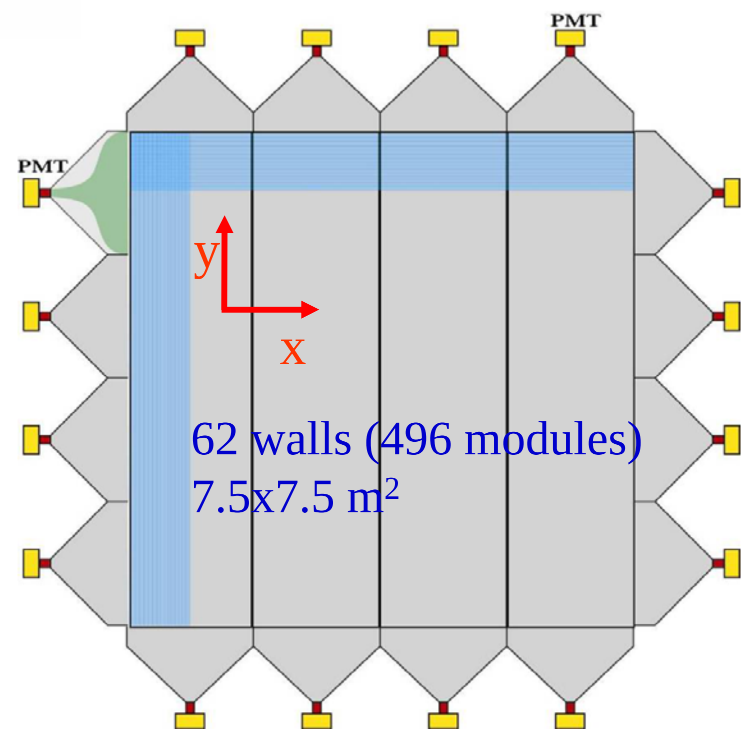
Target Tracker

detection technique:
plastic scintillating strips
readout by Kuraray WLS fibres



Hamamatsu MA-PMT
(64 channels) 3x3 cm^2



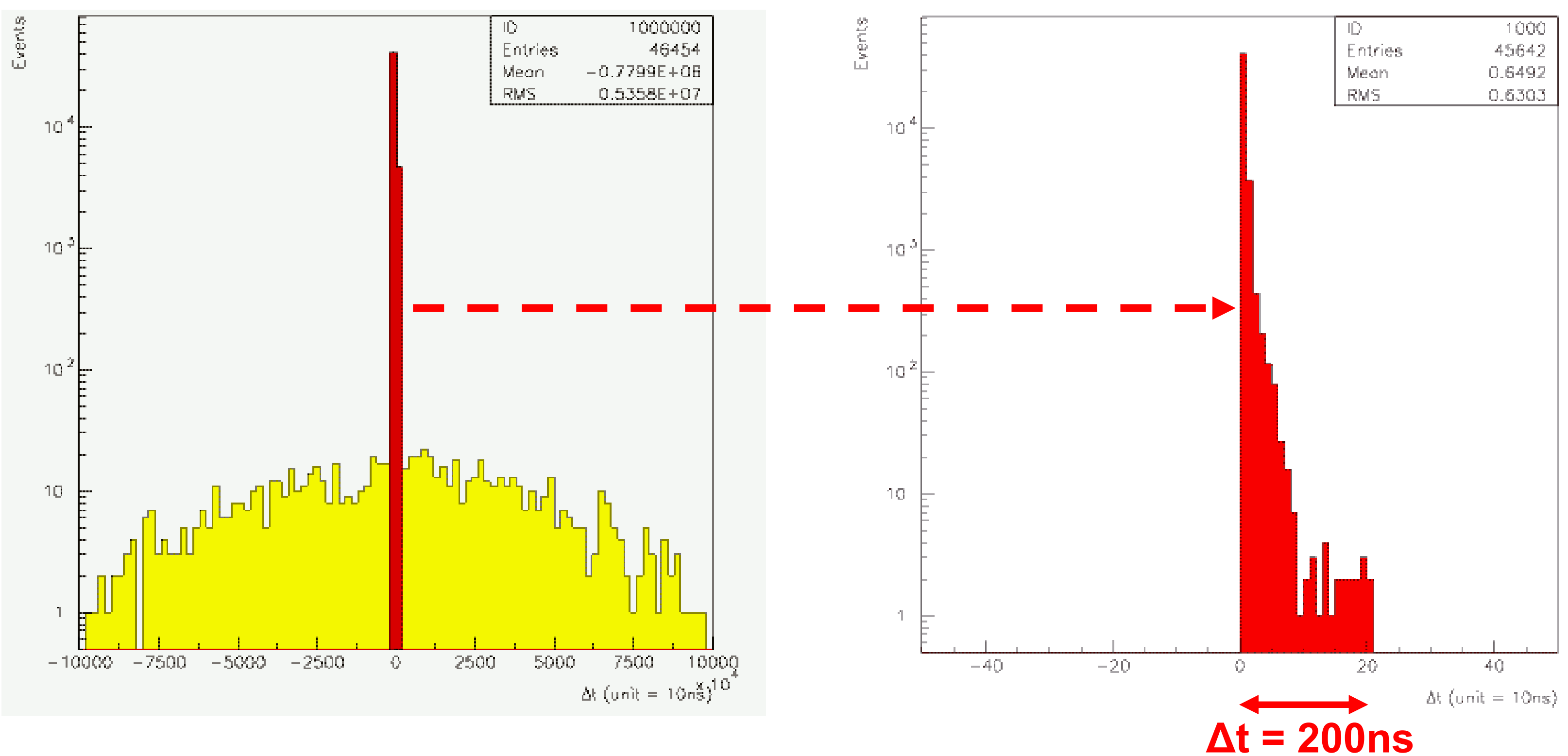


TT DAQ: Event Builder

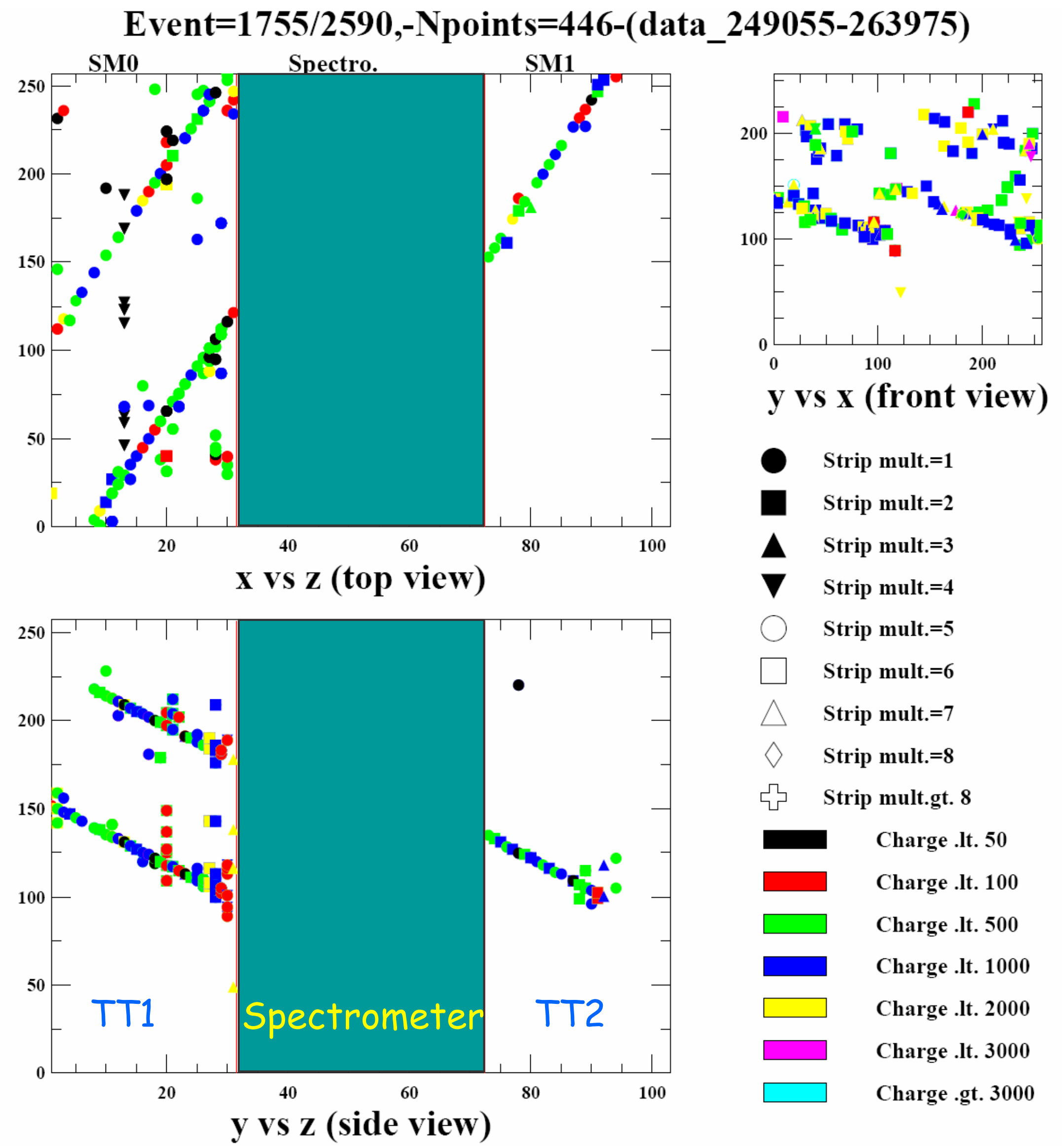
Trigger scheme:

L0: 1 p.e. threshold
L1: 3 planes in XY coincidence within 200ns or >1500ADC in 1 plane
L2: cut at 10 hits, global window $\Delta\tau$ = 6μs

Time difference between consecutive hits



Cosmic Rays in TT

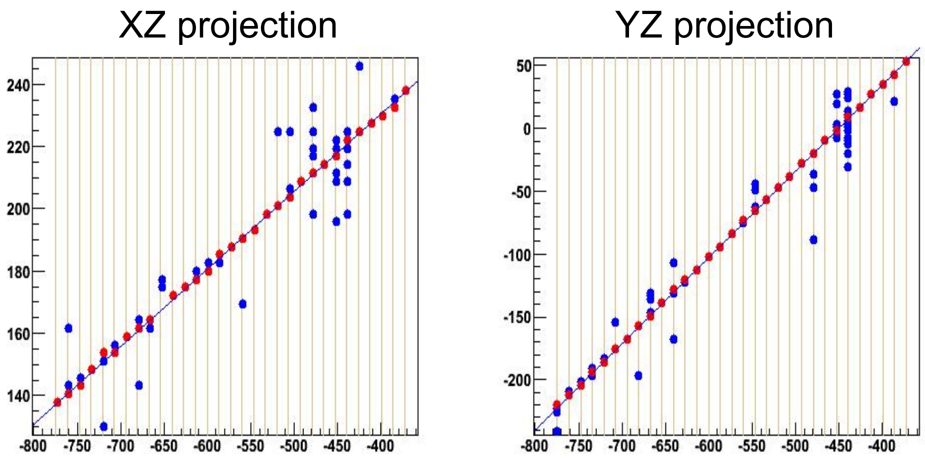


In absence of CNGS beam (and Pb/emulsion bricks), cosmic rays are used to:

- test the TT alignment;
- verify the m.i.p. detection efficiency;
- measure their angular distribution and estimate the induced background on CNGS events.

Estimation of TT Modules Efficiency

5-30 thousand events with straight 3D muon tracks

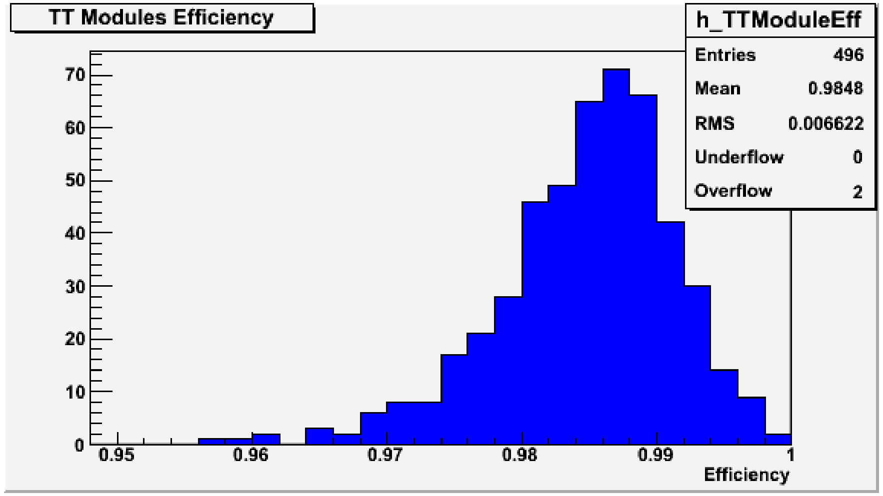


Muonic event

1. Track reconstruction;
2. Selection of track hits with an energy > 1, 2 or 3 p.e.;
3. Calculation of present and missed hits of modules crossed by the track.

Efficiency of each of 496 TT modules is calculated as

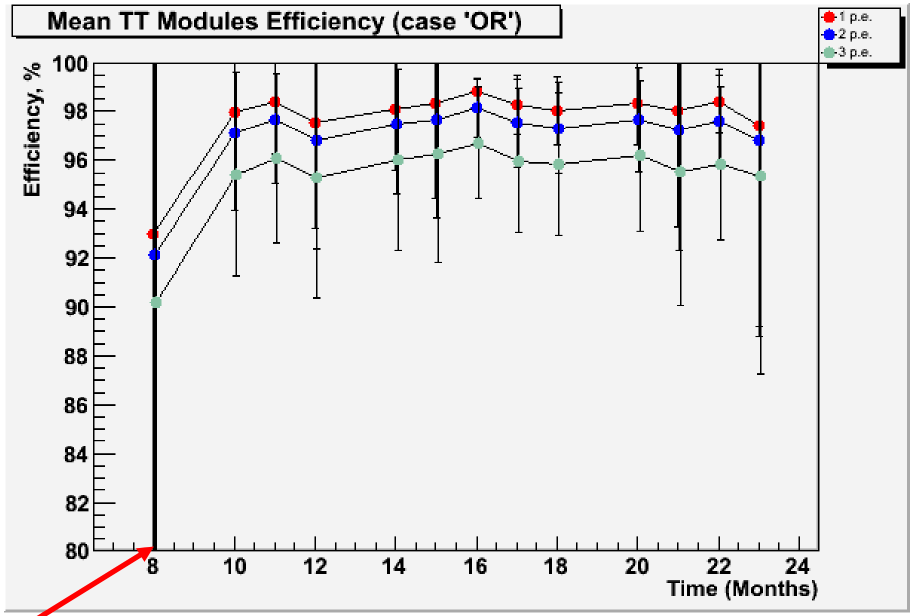
$$E_m = \frac{N_{\text{pres}}}{N_{\text{pred}}}$$



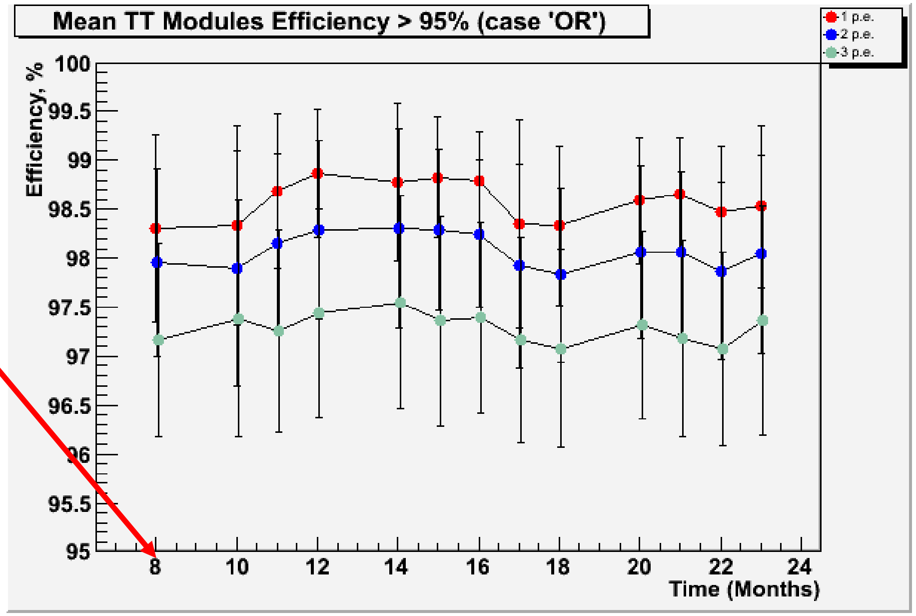
Efficiency of TT Modules

Efficiency calculated in such a way is formed of:

- modules working (live) time;
- m.i.p. detection efficiency;
- DAQ performance.



August 2006

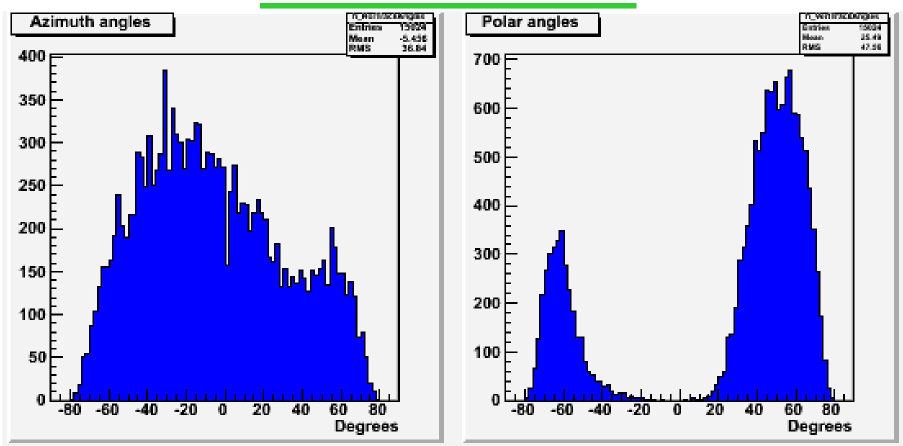


Knowing mean efficiency of the modules we can observe ageing of plastic scintillator and then take it into account.

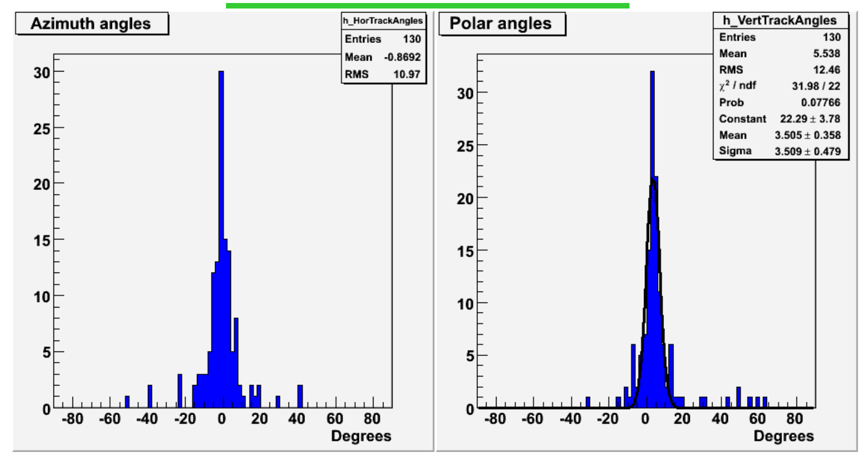
Beam Direction

2006 August CNGS run

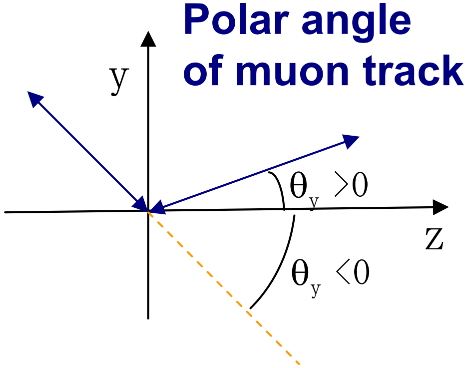
Cosmic events



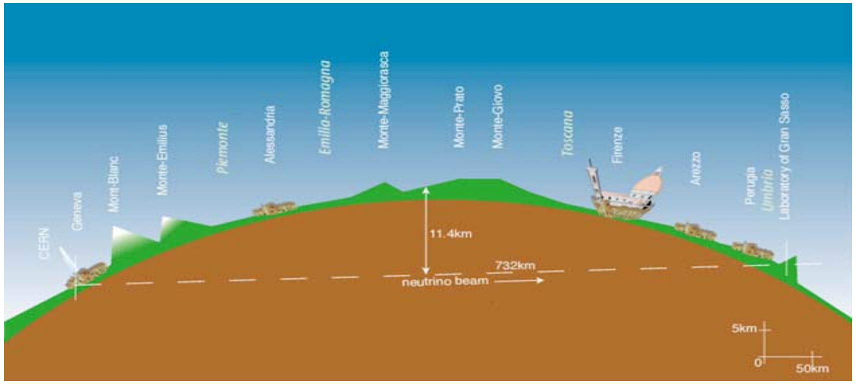
Neutrino events



$<\theta_y>=3.5\pm0.3°$



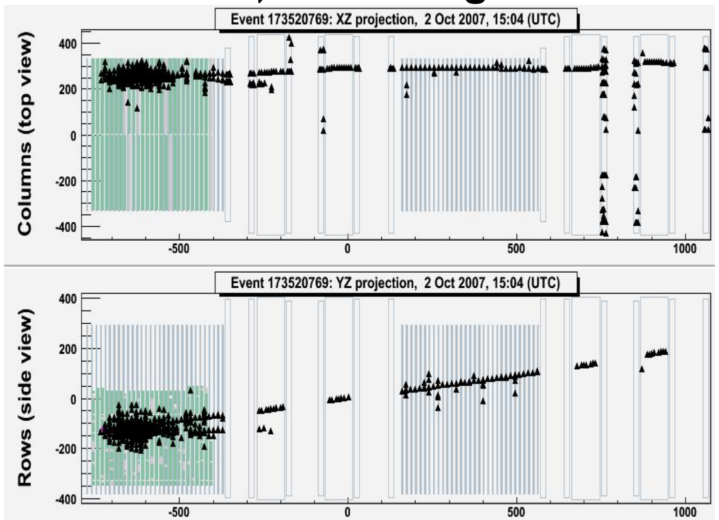
Polar angle of muon track



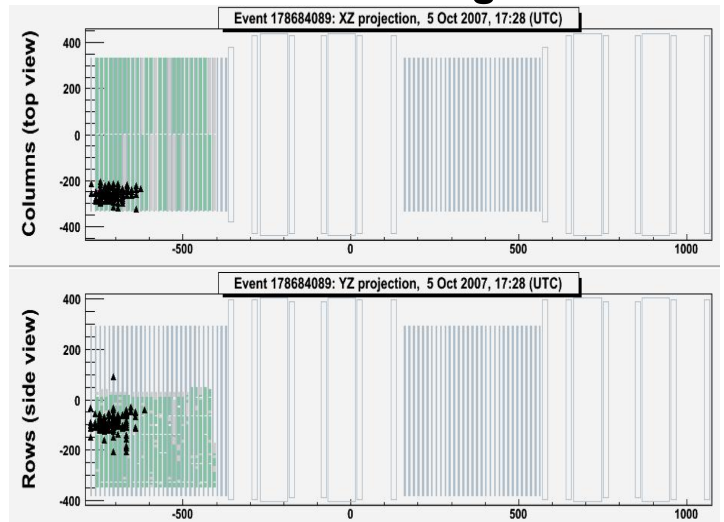
Expected $\theta_y=3.3°$

CNGS vs Cosmic Events

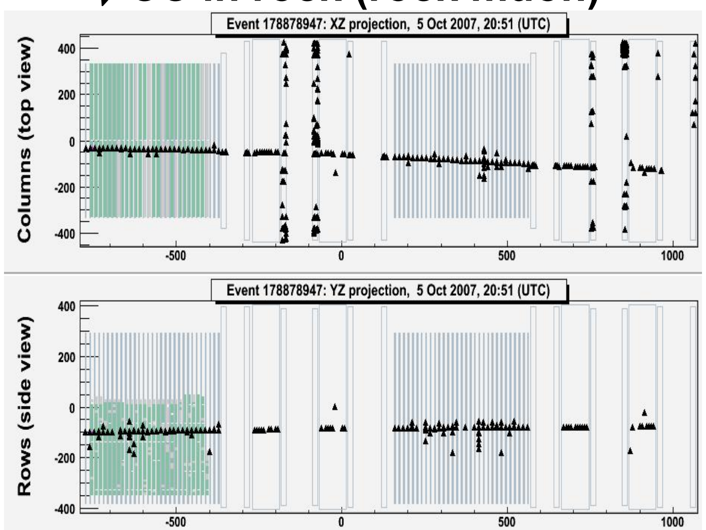
νCC in target



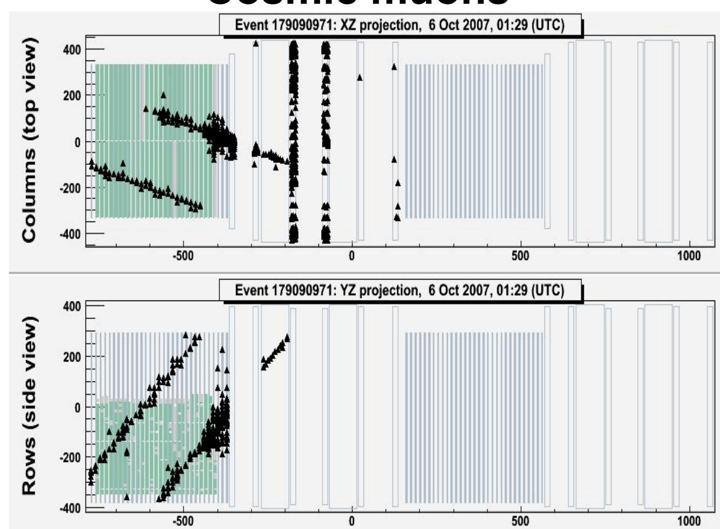
νNC in target



νCC in rock (rock muon)

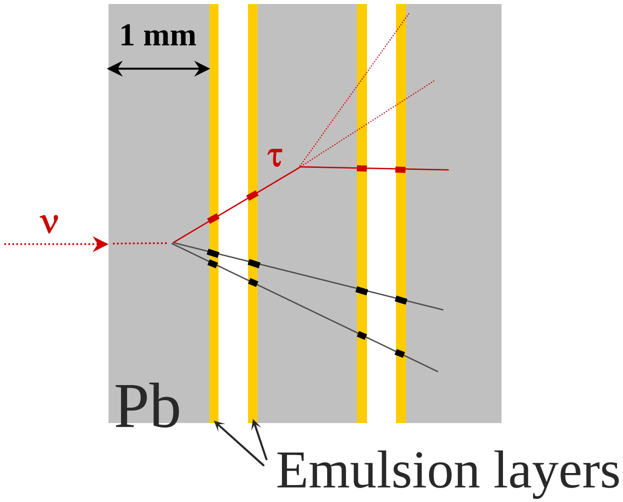


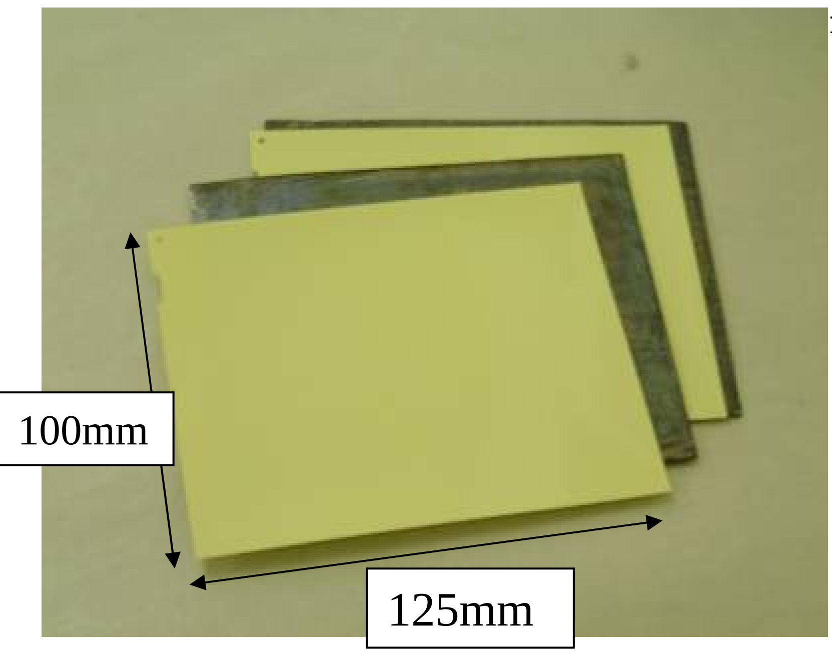
Cosmic muons

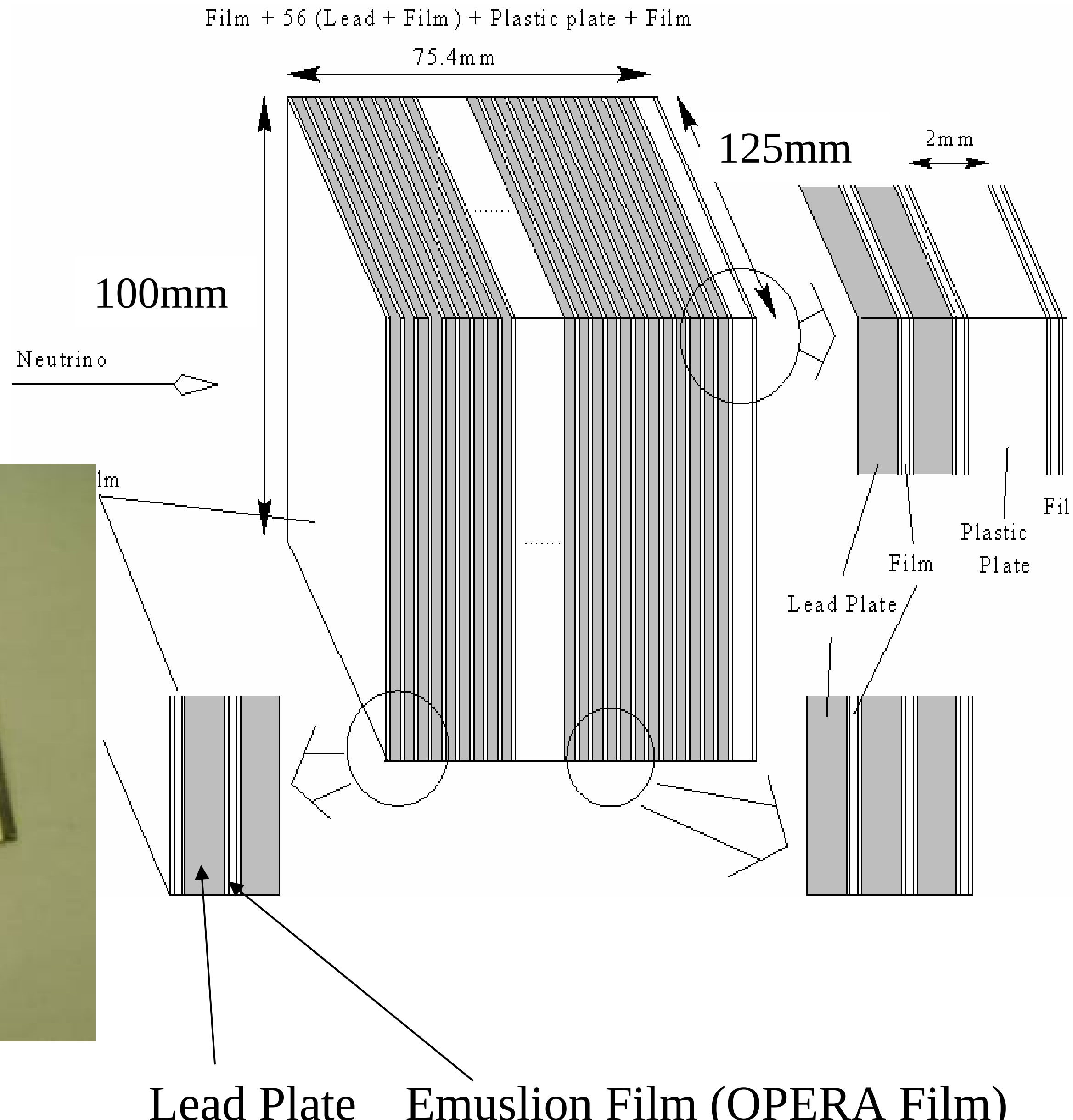


OPERA ECC Brick

Lead plate(1mm) / Emulsion Film (OPERA film) Sandwich







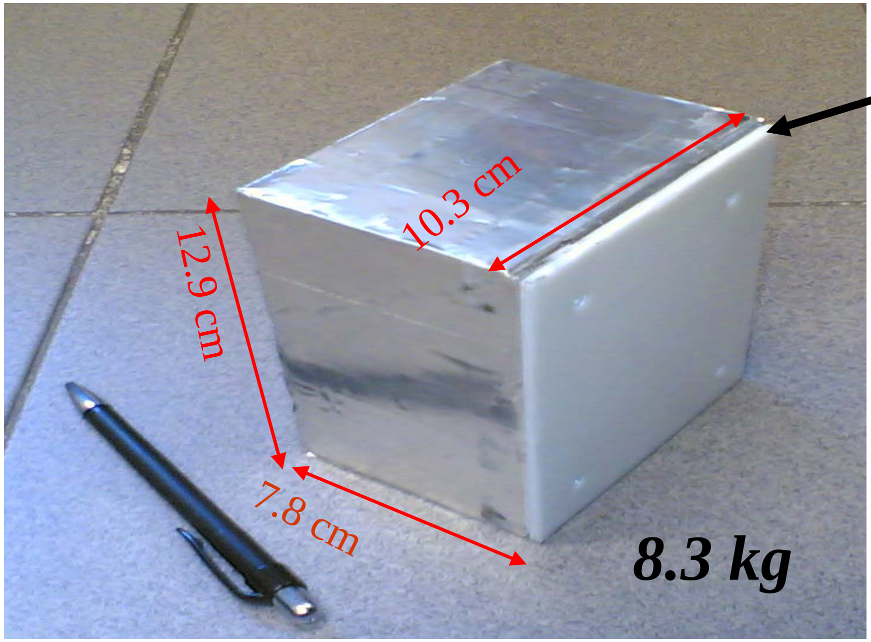
Vertex Brick Finding

5 years of data taking

~155000 target bricks

~25 neutrino events per day
No new bricks will be inserted instead of the extracted ones!

Changeable sheets box



To preserve effective mass of the detector and to decrease the scanning load brick finding efficiency should be as high as possible.

The *OpBrickFinder* Program

Our program developed as a standard OPERA package and integrated in the OpRelease framework.

Visual control of event processing is implemented by the *EventViewer* subpackage.

Description: http://astronu.jinr.ru/wiki/index.php/Brick_Finder

Our brick finding strategy includes:

-- Event cleaning (cellular automaton);

-- Muon track reconstruction (Kalman filter, Hough transform, tracing method);

-- Reconstruction of a hadron shower axis (robust line-fitting method);

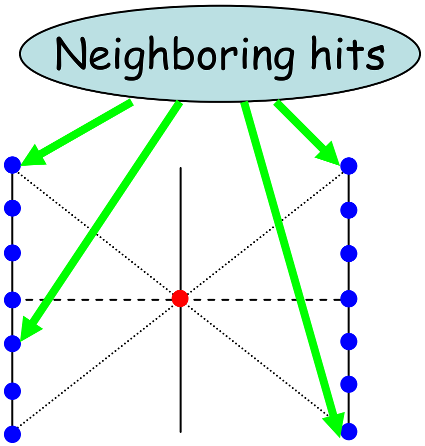
-- Determination of the most probable vertex walls (neural network);

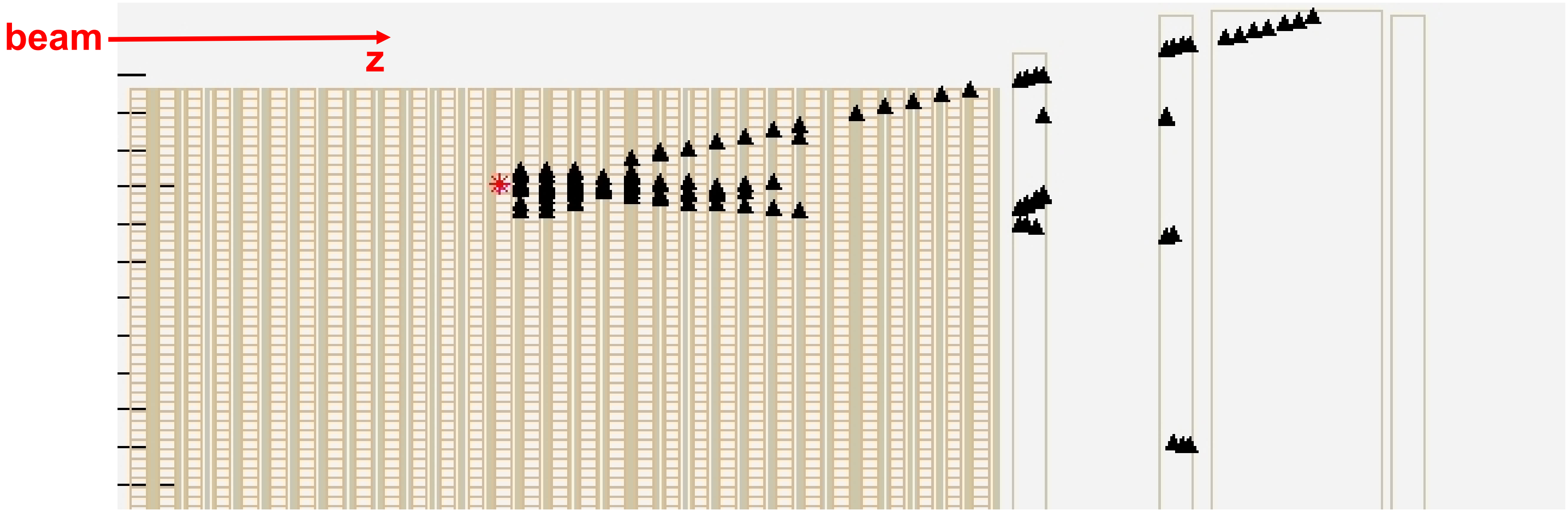
-- Localization of the most probable vertex bricks.

Event Cleaning

Back-scattering particles, neutron or gammas interaction with the detectors, natural radioactivity background, PMT noise, etc. initiate separate hits.

To facilitate the vertex location we filter off isolated hits using a cellular automaton algorithm:
each hit that has no neighbors in two adjacent walls in a given angle range is removed.



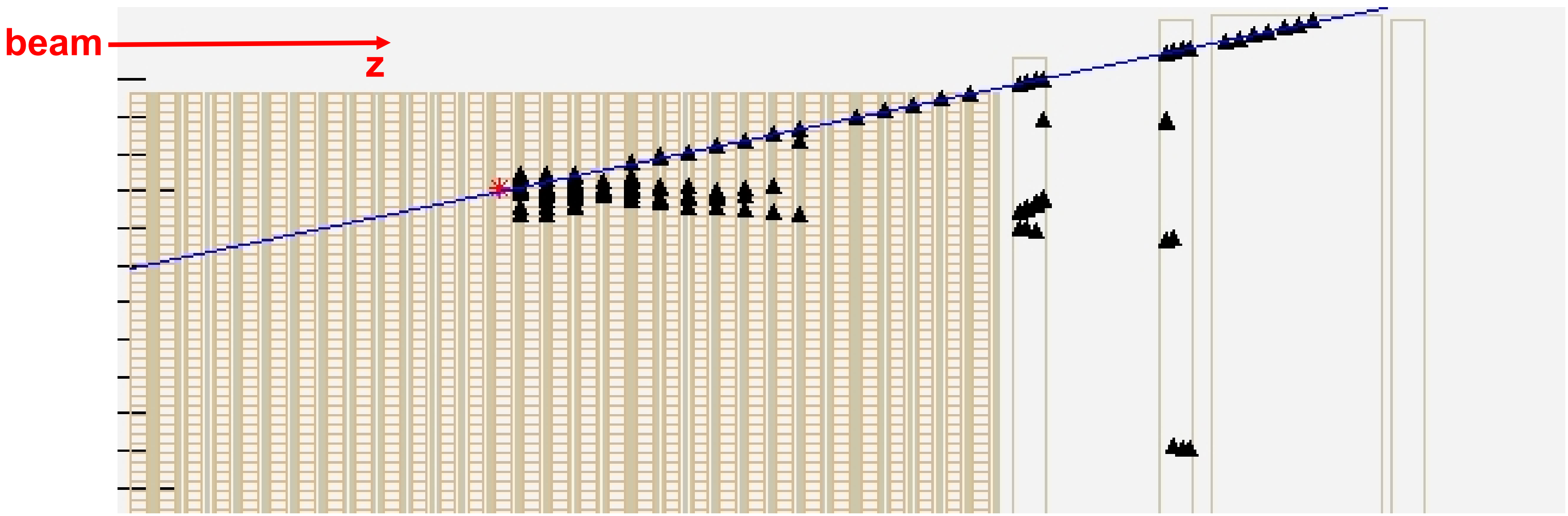


Reconstruction of a Muon Track Direction

In $\nu_\mu CC$ and $\tau \rightarrow \mu$ events a muon is produced which can be recognized in the TT by its long track.
We can try to locate the neutrino interaction using a muon track information.

3 track reconstructing methods:

Hough Transform (only for rectilinear tracks)
Kalman Filter
Tracing Method (if there is no too strong shower)



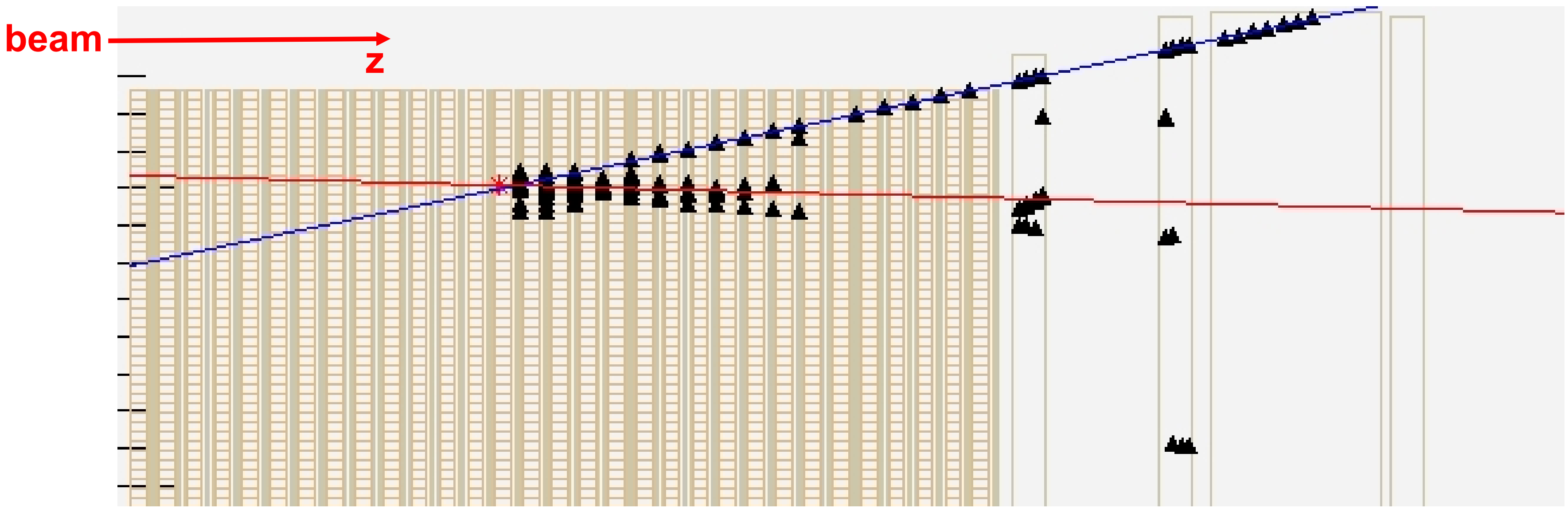
Reconstruction of a Hadron Shower Axis

A pitch of the TT - 26 mm, ➡ distinct tracks near a vertex can't be single out! In order to determine some general direction to the vertex we try to find an axis of the whole hadron shower.

Minimization functional of a robust line-fitting method:

$$L(a,b) = \sum_i w_i(d_i, A_i) d_i^2 \xrightarrow[a,b]{} \min$$

A *robust weight* of each point is calculated taking into account its amplitude, i.e. energy of corresponding hit, and distance from a fitted line.



Vertex Wall Determination

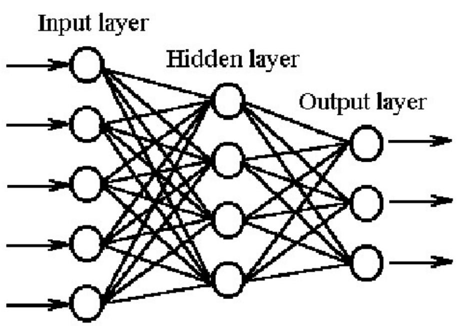
Because of back-scattering process neutrino interaction vertex can be located NOT in the brick wall that is in front of the first touched TT plane!

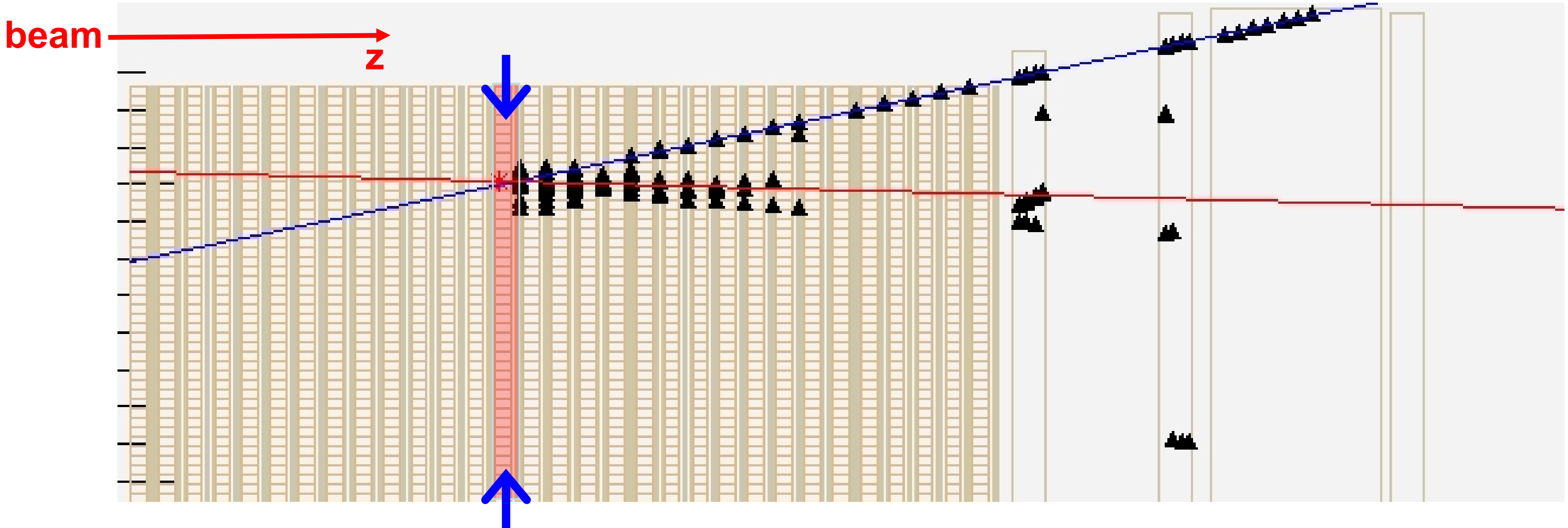
For the vertex wall determination we use a neural network (NN) trained on MC data.

NN input parameters for the first 3 TT walls include:

- number of hits in a wall;
- standard deviation of the hits;
- energy deposited in a wall, and so on.

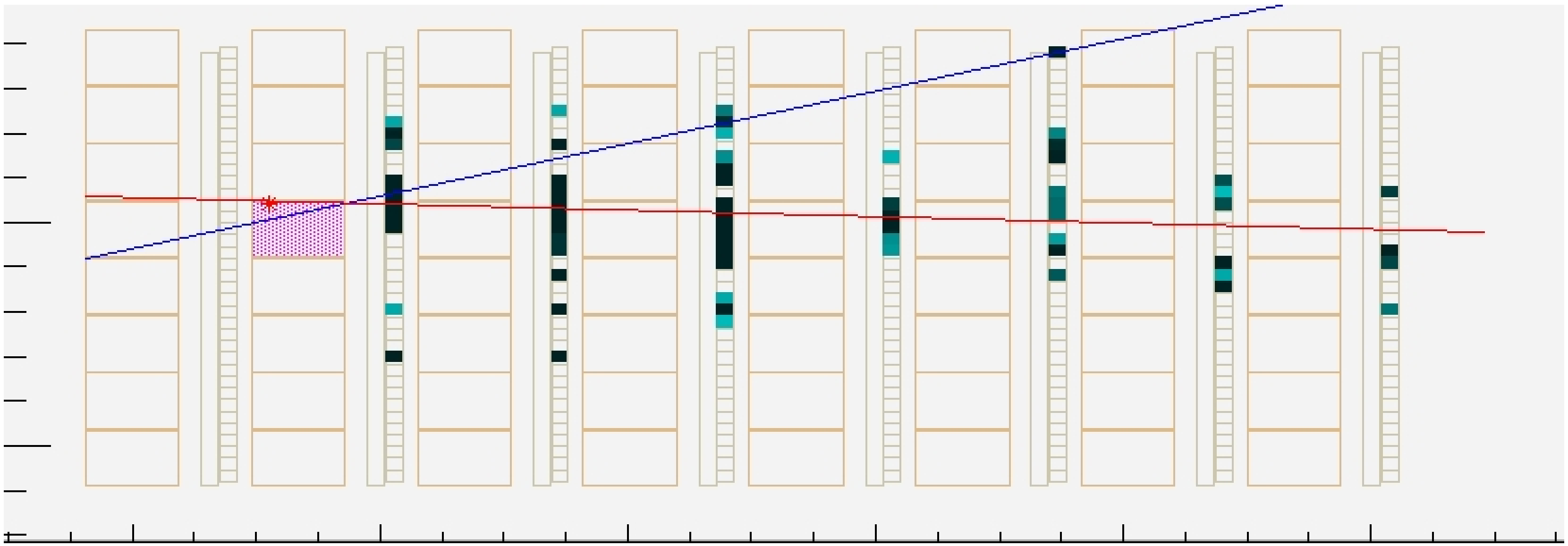
NN shows us the wall most probably containing the vertex.





Determination of the Most Probable Bricks

Taking into account information of the NN, and using muon track and/or shower axis directions our program defines several bricks that most likely contain neutrino interaction vertex and prints out their coordinates and probabilities.



Brick Finding Efficiency

MC data:

Used statistics:

NN training – 15000 events
NN testing - 3500 events

Obtained efficiency:

Wall finding - ~85%

Brick finding:

1 brick extraction - ~70%
2 brick extractions - ~85%
3 brick extractions - ~92%

Real data:

38 neutrino events registered
69 bricks extracted
Scanning is in progress…

Outlook

The electronic detectors of OPERA take data almost continuously (95% live time) and with the expected tracking performances.

The data analysis chain for all electronic detectors has been validated during the CNGS beam periods and with cosmic rays in 2006 & 2007.

Efficiency of the TT modules > 98%.

Brick finding efficiency is about 70%(MC).

38 on-time neutrino events has been registered. First target bricks are being scanned in search of neutrino interaction vertices.

TT detector is ready for data taking during the coming CNGS runs.