OPERA: track reconstruction with electronic detectors

Lazzaro Claudia, ETH Zurich

PhD Seminar ETHZ 2009

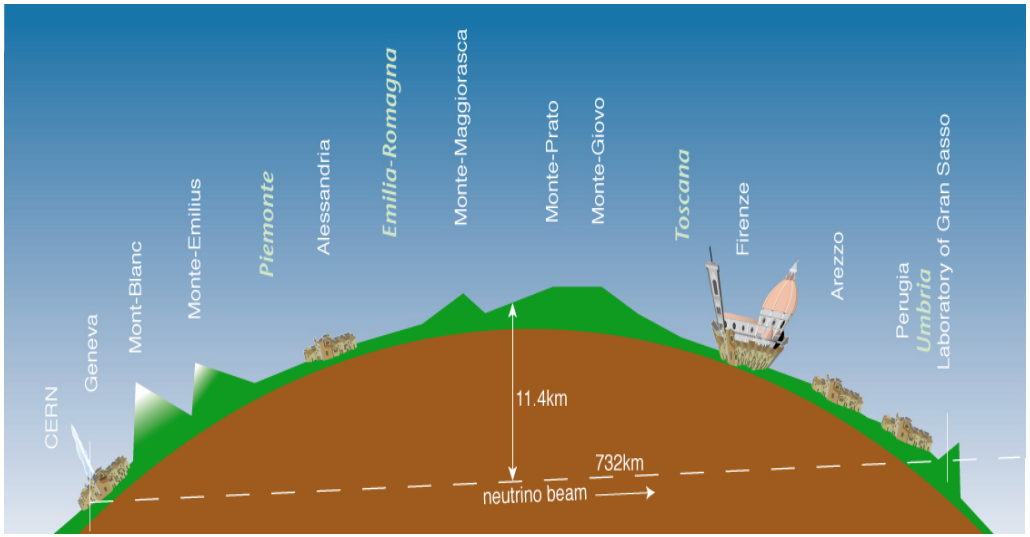
- ✗ *OPERA electronic detectors*
- ✗ *event's reconstruction*
- ✗ *Kalman filter*
- ✗ *conclusions*

OPERA

Unambiguous evidence for ν_τ appearance in a pure ν_μ beam

↓

proof of $\nu_\mu \rightarrow \nu_\tau$ oscillation in the parameter region of atmospheric neutrino



<E_ν> =17GeV

(anti ν_μ)/ν_μ = 2.1%

(anti ν_e + ν_e)/ν_μ = 0.9%

ν_τ negligible

Beam optimized for maximal number of ν_τ CC interactions

*flux 4.5*10^{19} proton on target/year (200 days run)*

↓

2900 ν_μ CC/kton/year

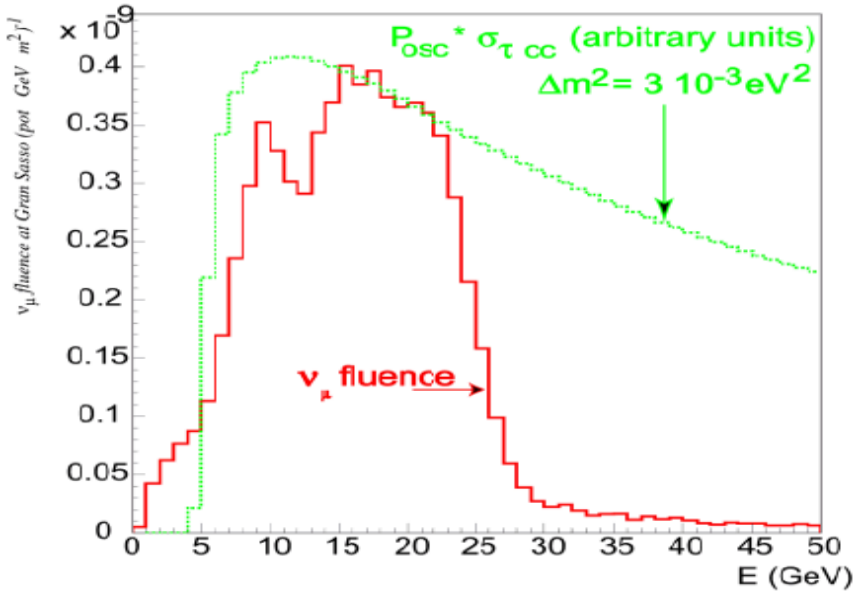
870 ν_μ NC/kton/year

OPERA target ~ 1.28 kton

OPERA spectrometer ~1.35 kton

CC=charge current events

NC= neutral current events



Why measurement of the flux?

Measurement of the ν_μ flux is necessary to obtain an estimation of the number of τ expected...

$$N_\tau = \int \phi_{\nu_\mu}(E) * \sigma_{\nu_\tau}(E) * P(\nu_\mu \rightarrow \nu_\tau)\, dE$$

- ν_μ flux at LNGS
- Cross section of ν_τ
- $P_{\mu\tau} = \sin^2(2\theta_{23}) \sin^2(1.27 \Delta m^2 \frac{L}{E})$

full mixing

$\Delta m^2 = 2.4 * 10^{-3}\, eV^2$ → $P_{\mu\tau} \simeq 1.7 * 10^{-2}$

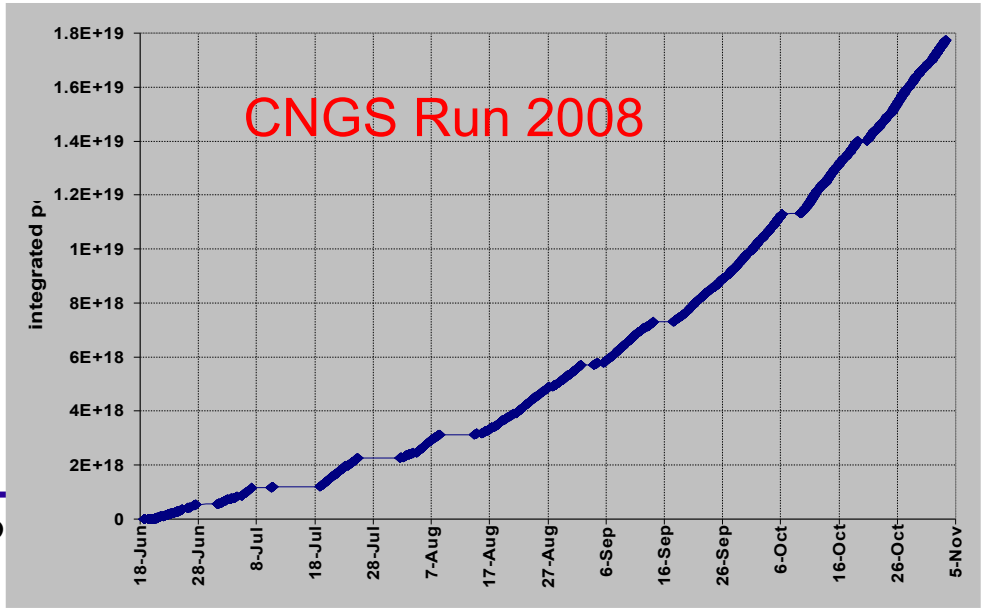
$LNGS: L/E = 43\, Km/GeV$

...and then to obtain an estimation of the oscillation parameters

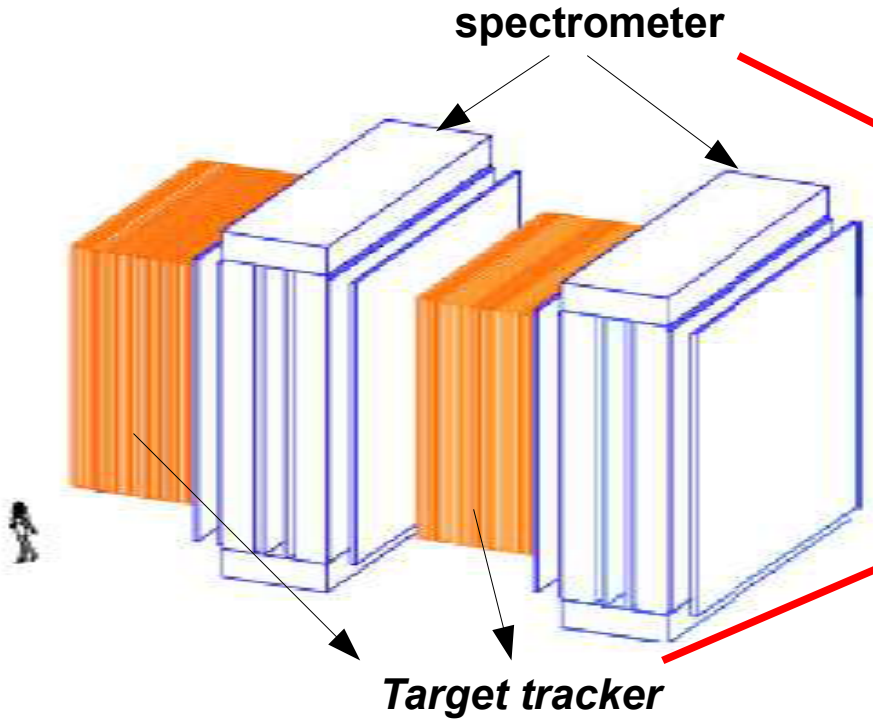
Goal of the thesis: estimation of the ν_μ flux and comparison with the expectated flux given by FLUKA simulation (there isn't a near detector at CERN)

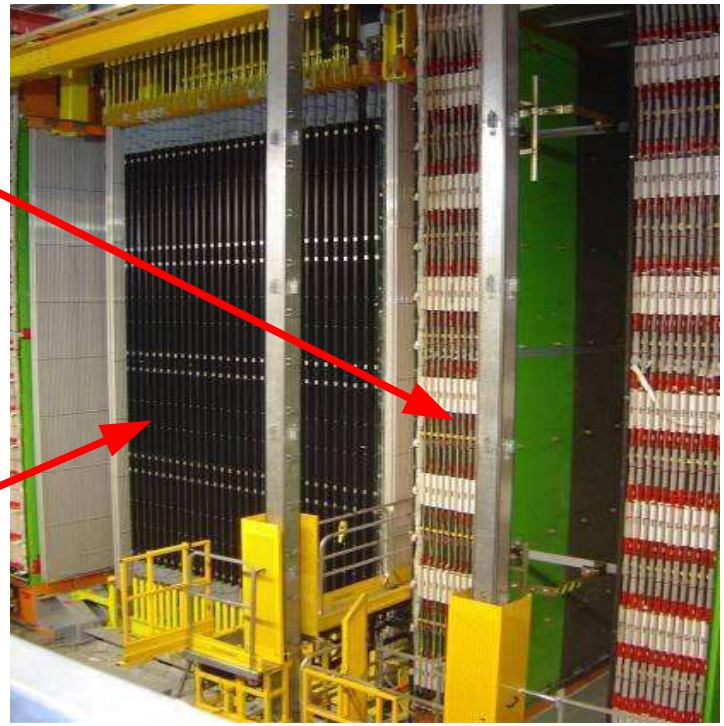
CNGS run 2008 (from 18 june to 3 november):
$1.78 * 10^{19}$ p.o.t. (proton on target)
10100 events on time
probable 1700 interactions in the bricks
0.7 τ expected

Run 2009 forecast:
173 days, $3.6 * 10^{19}$ p.o.t



OPERA: electronic detectors

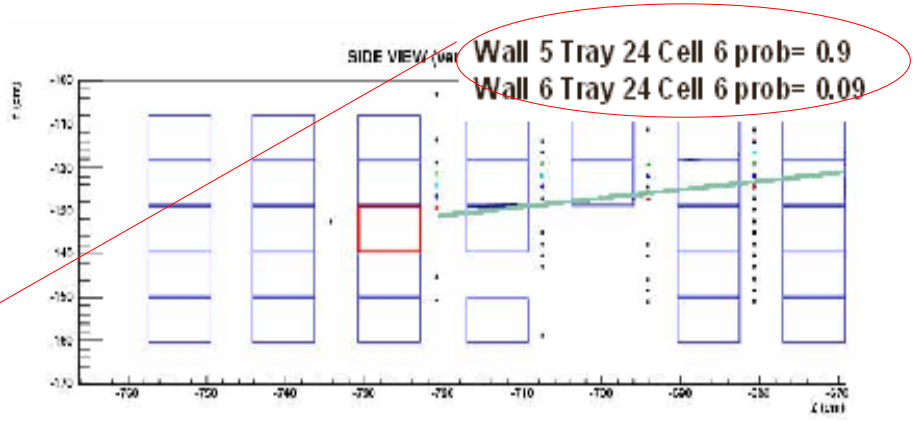




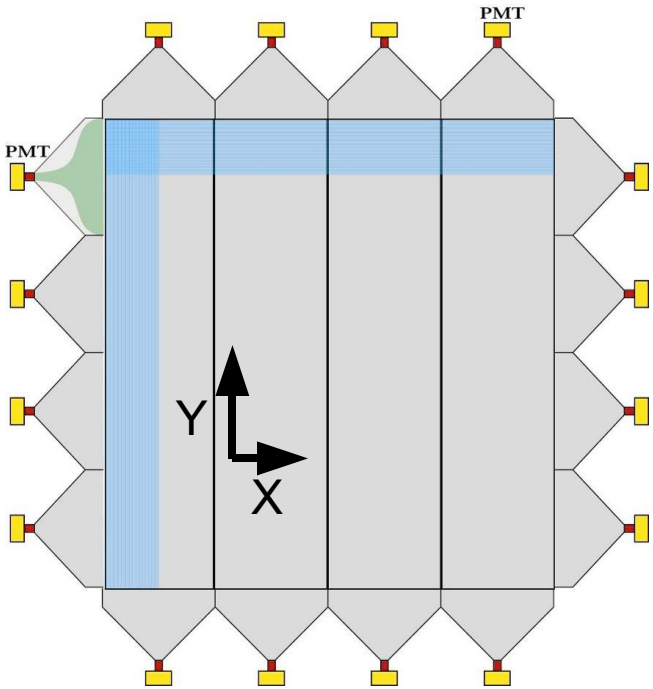
First step: trigger on ν interaction on time with the beam.

Second step: brick selection, reconstruction of event in target trackers and spectrometer in order to identify brick with interaction. Estimation of the charge and momentum of μ track.

It can be necessary to extract more than one brick, brick finding procedure gives the probability for each brick to contain the ν interaction

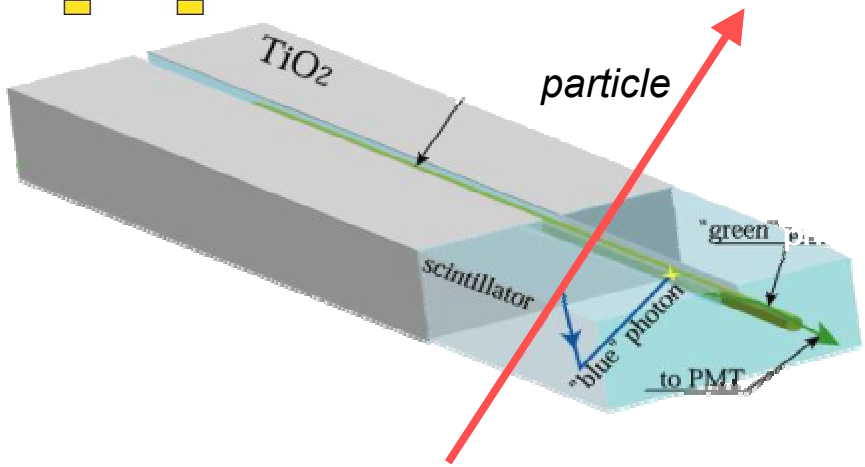


Target Tracker



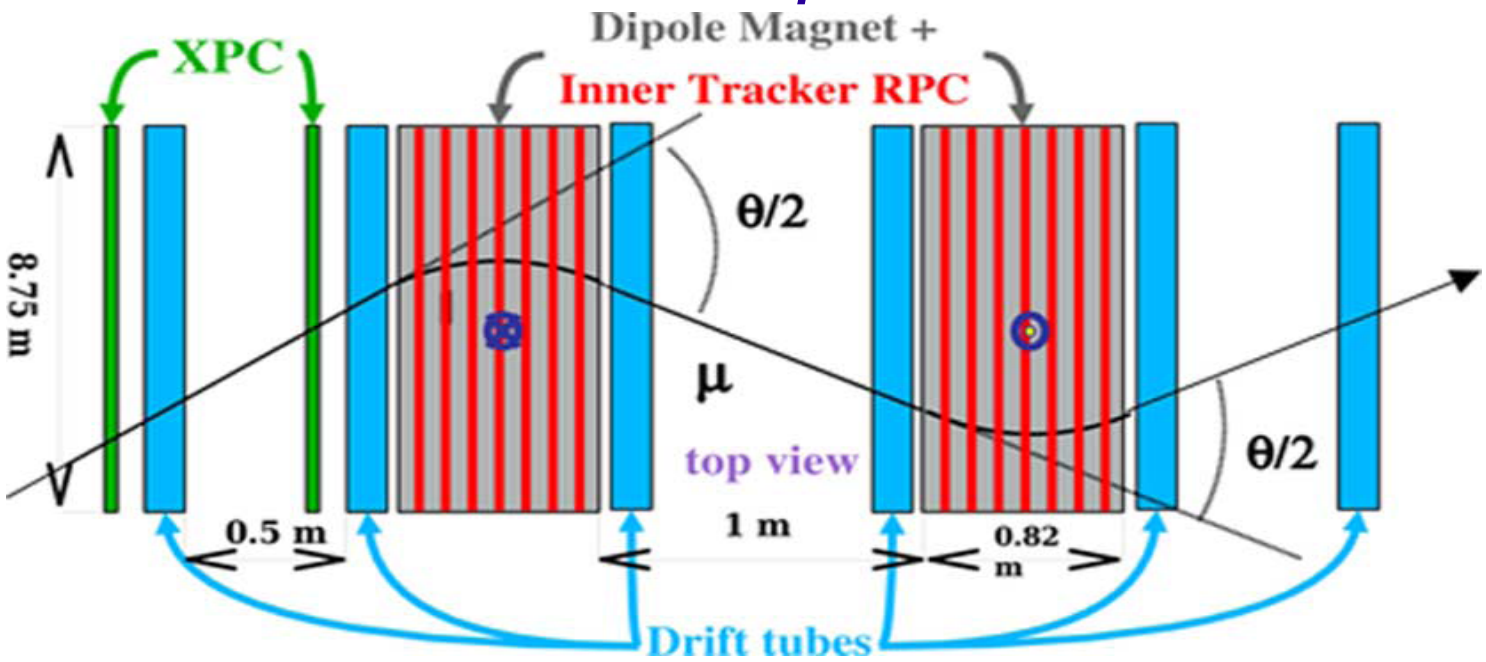
Each Super Module (SM):

- *31 planes 7mx7m*
- *256 plastic scintillator strips in X and Y direction, each with wavelenght shifting fiber*
- *4 groups with 64 fibers each connect to a multianode PMT*



p.e. x m.i.p >5
detection efficiency 99%
brick finding efficiency 80%

Spectrometer



- ✗ *Pattern reconstruction*
- ✗ *μ identification*
- ✗ *Momentum and charge measurement*
- ✗ *Beam monitoring*

Inner Tracker:

2 x 12 Fe planes 8.75 m x 8.2 m 50 mm

magnetic field: 1.55T (track's curvature in the horizontal plane)

2 x 11 RPC planes 20mm thick with:

- *horizontal strips 3.5 cm x 8.7 m (224 per plane)*
- *vertical strips 2.6 cm X 8m (336 per plane)*

Drift tubes

6 walls with 3 planes of drift tubes

spatial resolution $\delta x \approx 0.35$mm

$\Delta p/p \leq 0.25$ $p < 30$ GeV

Reconstruction of the on time events

(1) μ tracking:

✔ *in every detector (TT and RPC) the most probable segments are built*

✔ *the segments are connected to create 2-dim tracks (in the xz and yz planes)*

✔ *merging of the compatible 2-dim tracks to build 3-dim track*

(2) mometnum reconstruction

On 3-dim track the Kalman filter is applied in order to evaluate the position of the vertex and the momentum of the particle.
The charge of the muon is obtained by the measurement of the curvature in the magnetic field
For 2-dim tracks reduced fit is applied

(3) CC and NC events:

In case a 3-dim track is reconstructed in the events, they are analysed in order to identify the particle as muon, and to divide the events in charged (with μ^-) and neutral (without μ^-) current interaactions.

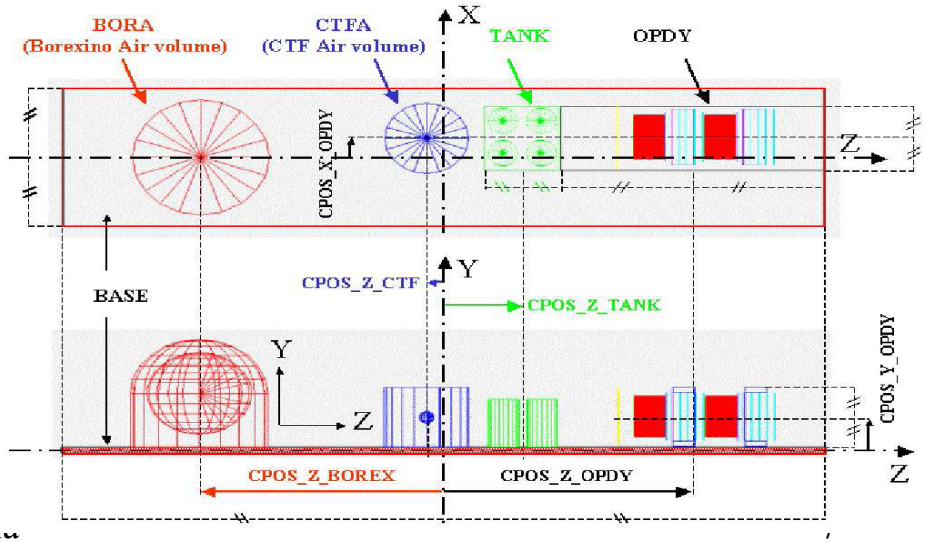
Brick identified
μ track recognized

Classification of the event:

NC or CC if a μ track is or isn't identified in the event

external if the vertex is outisde the detector (in the rock or in the Borexino area), in this case only a μ track is reconstructed in the detector (VETO is useful for select this events)

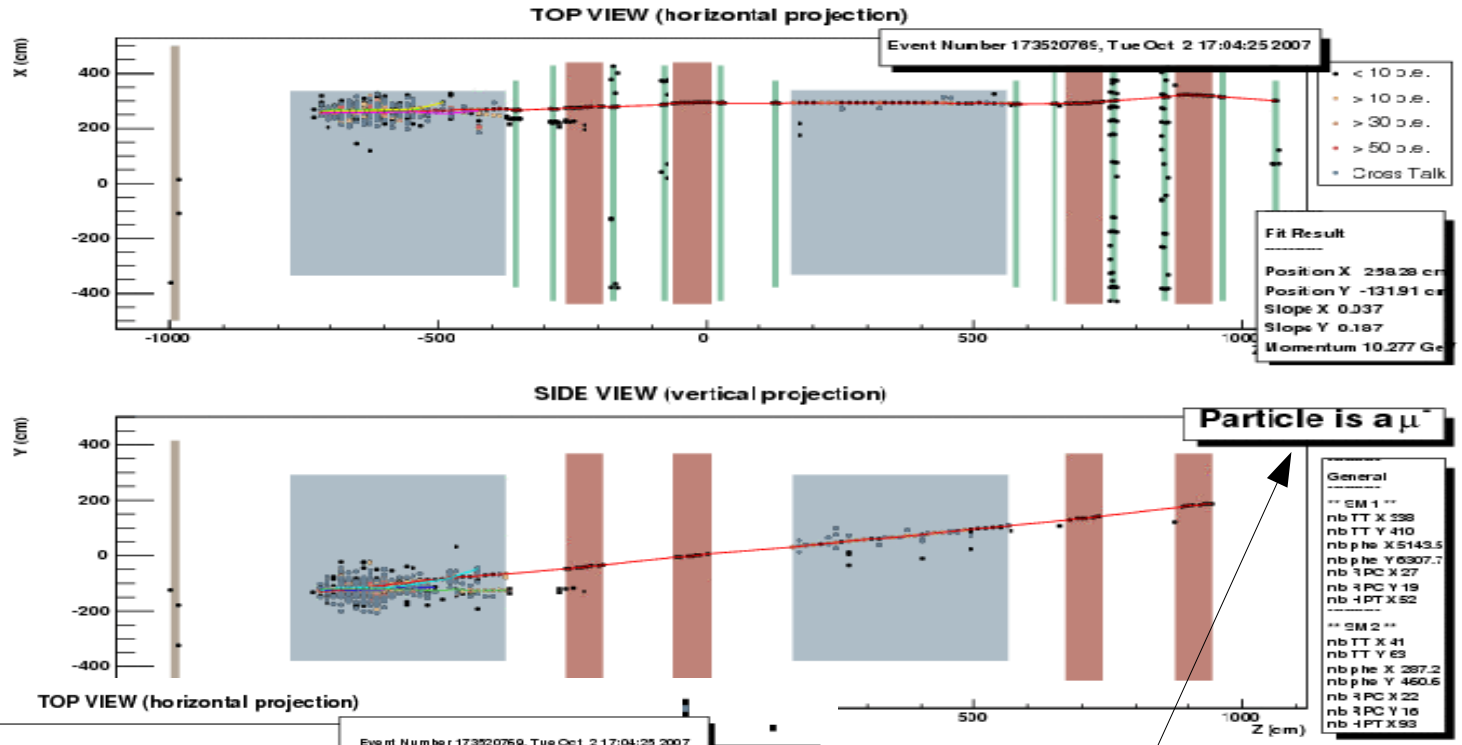
layout in hall C at LNGS



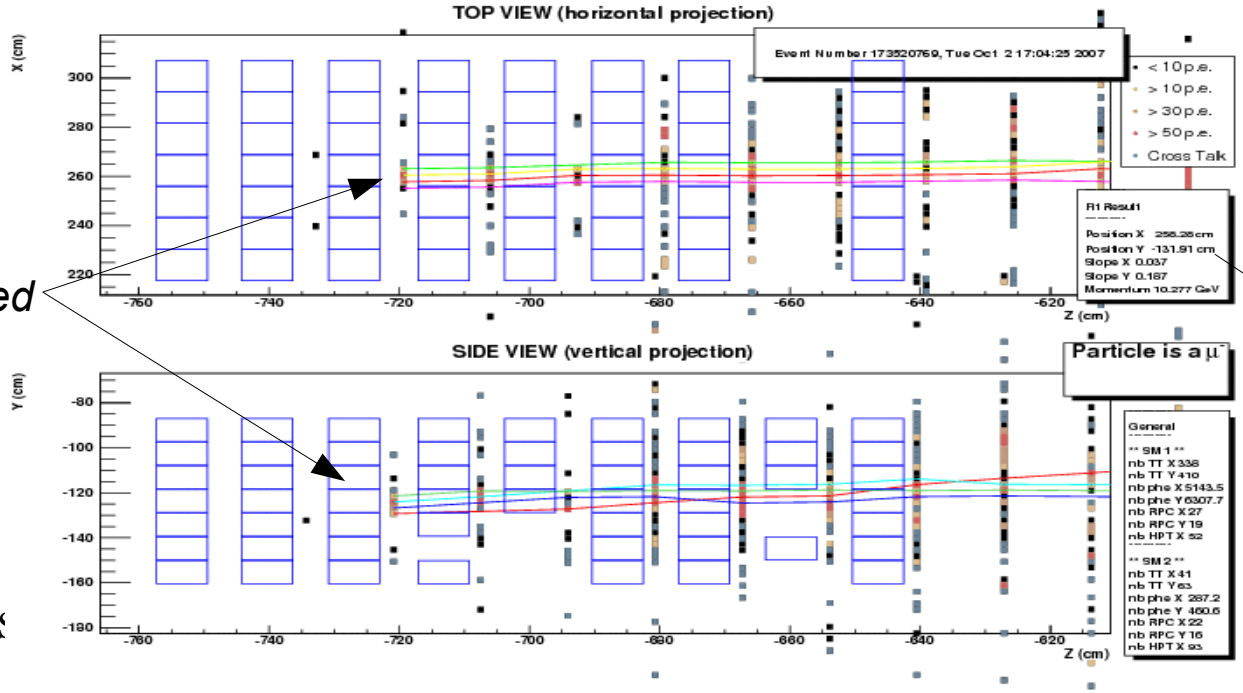
Example: real events

Reconstruction of one event in the 2007 run

CC internal events



Brick identified



Particle is identified as μ

Fit result, prediction of the vertex

Kalman Filter: estimation of μ momentun

The Kalman filter is an iterative procedure to determine the 5 fit parameters (P vector) of a 3-dim track:

$x,\ y,\ p_x/p_z,\ p_y/p_z,\ q/p$

and the error matrix (W)

At the end of the procedure x,y is the position of the track's start, and p_x, p_y, p_z the 3 components of the momentum p, and q the muon charge

The iterative procedure begins at the end of the track with the initialisation step, and is different for stopping and outgoing muons.

In the first step (initialization) the following parameters are calculetd:

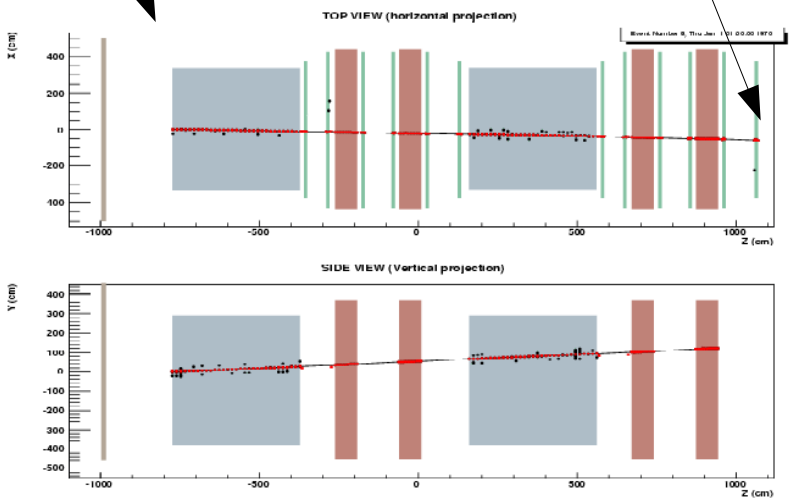
last x , last y, slope x, slope y , q/p

For every step the vector P_i and W_i (the error matrix) are calculated from P and W of the previuos point, in two steps:

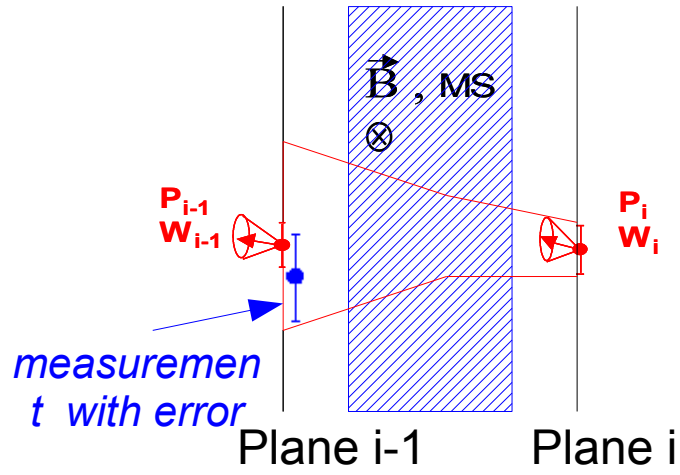
1. *the propagation includes geometrical extrapolation of the new position, lost energy estimation*
2. *the addition of the new measurement point with error*

Beginning of the track end kalman procedure

end track of the beginning kalman procedure

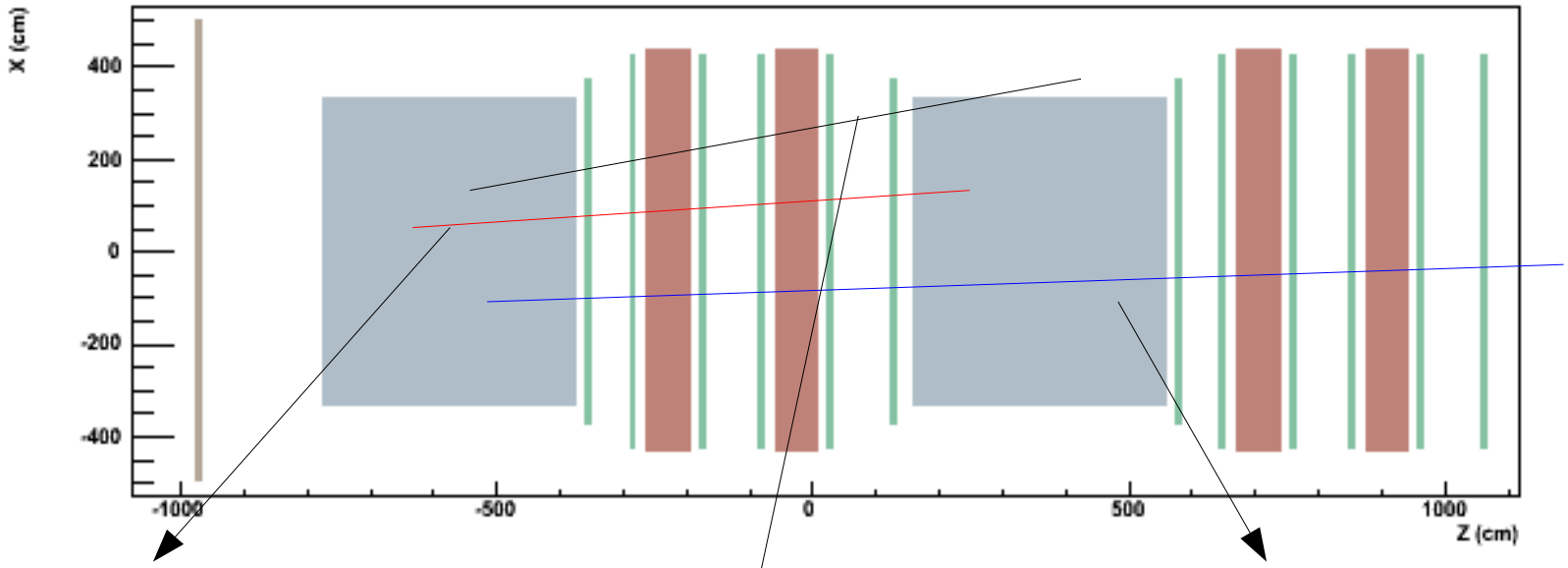


Propagation P_{i-1} P_i



Kalman filter initialization

initialization: estimation of the 5 parameters at the end of the track.
This can be done with different procedures, it depends on the topology of the track



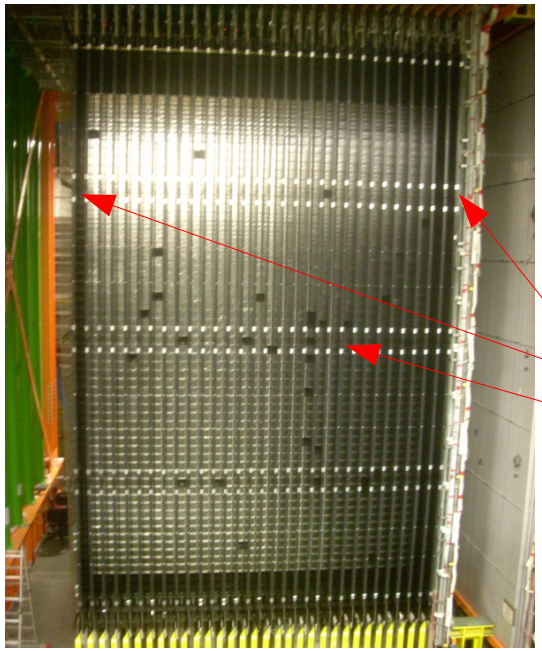
Stopping muons: momentum set to 200MeV

Target initial: momentum estimated by the spectro if possible

Through going muons: momentum estimated using the drift tubes information

The charge is estimated by the drift tubes information (if the track crossing DT in the SM1 or 2), otherwise the procedure attempts a parabolic fit in the RPC; by default,in the other case, it is set to -1

Momentum resolution with Kalman filter

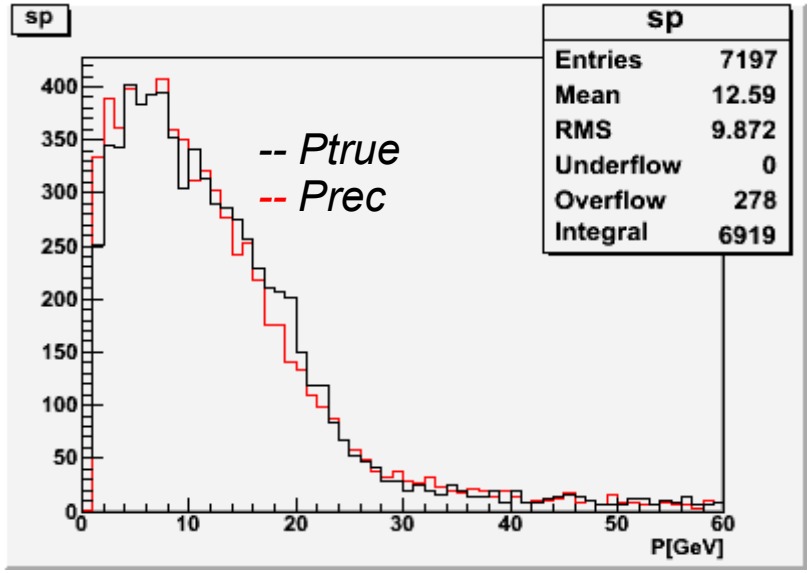


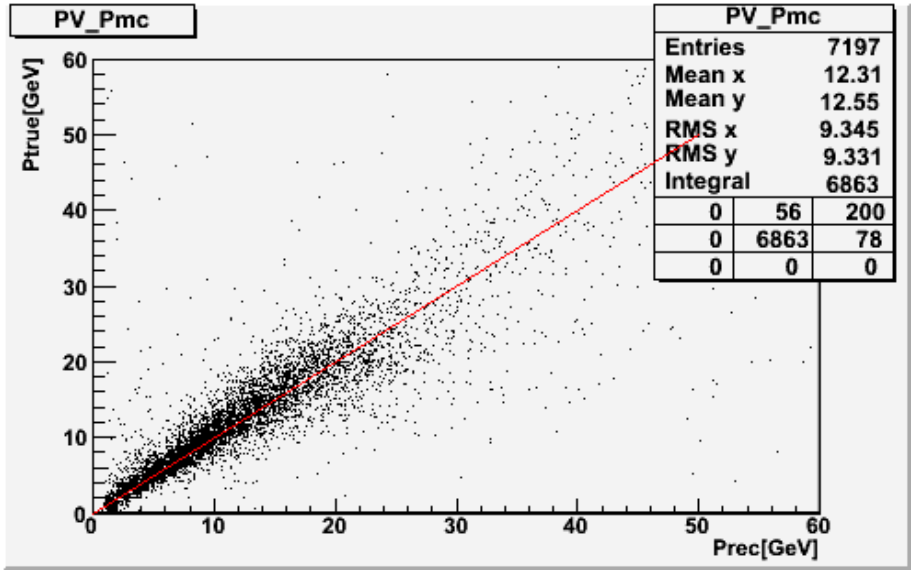
To estimate the ν_μ spectrum interacting in OPERA the reconstruction of the μ momentum in the event is the most important parameter

In the last year the corrected geometry (real brick configuration) was implemented in the Kalman filter, this include:

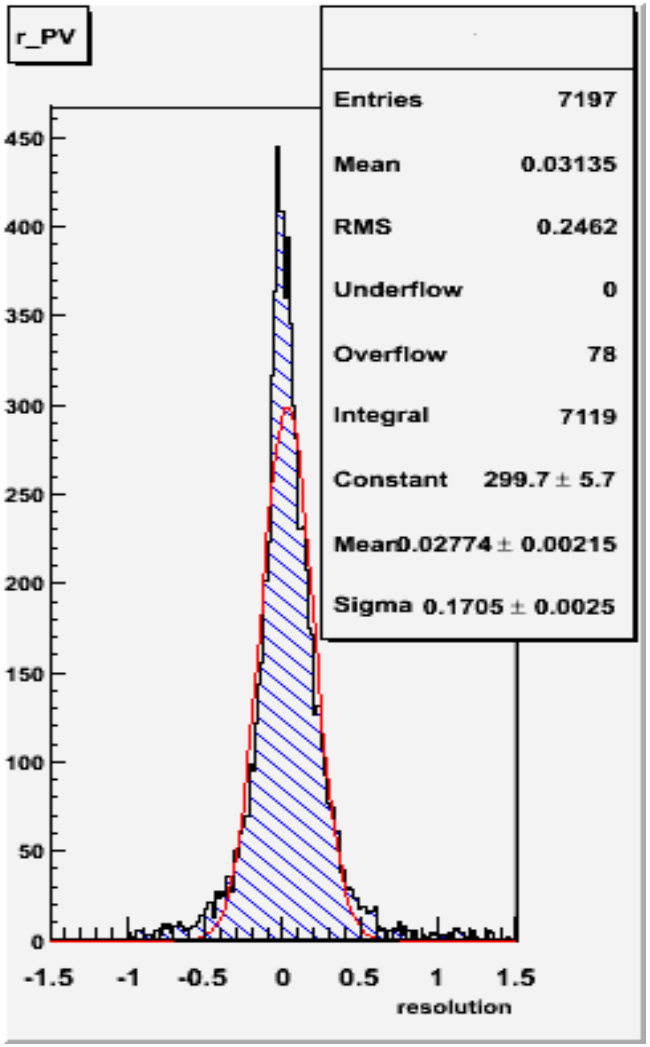
- ✔ *empty planes*
- ✔ *single bricks missing*

MC analysis on 7900 CC (charge current) events simulated; only track identified as muon were selected





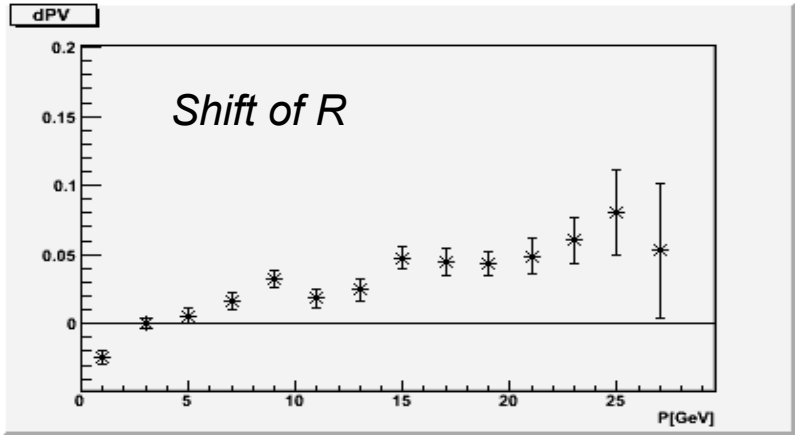
Momentum resolution with Kalman filter (2)

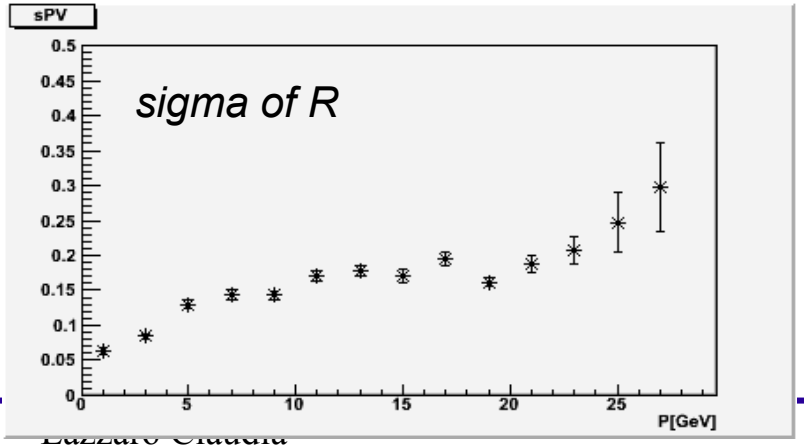


Momentum resolution

$$R: \frac{1/p_{rec} - 1/p_{mc}}{1/p_{mc}}$$

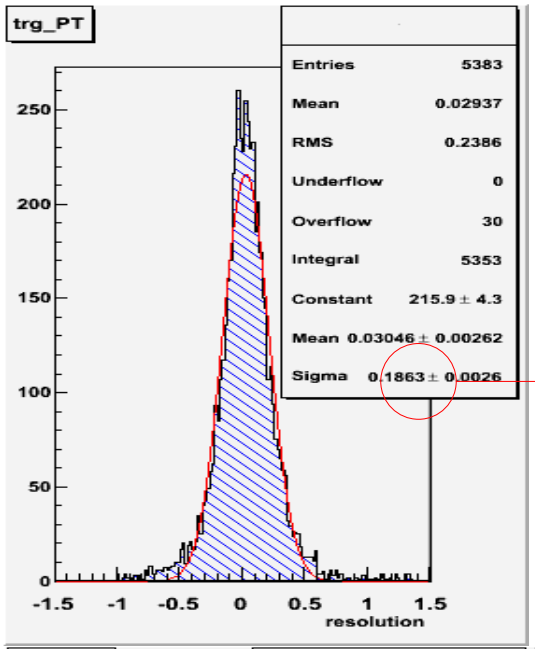
- ✔ *small shift problem on the momentum estimation*
- ✔ *sigma resolution below 20% in interesting region*





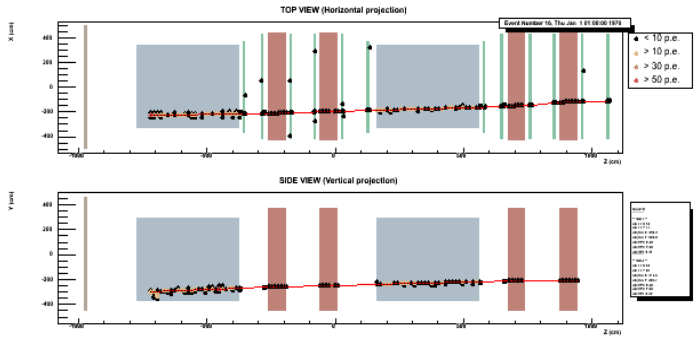
Momentum resolution with Kalman filter (3)

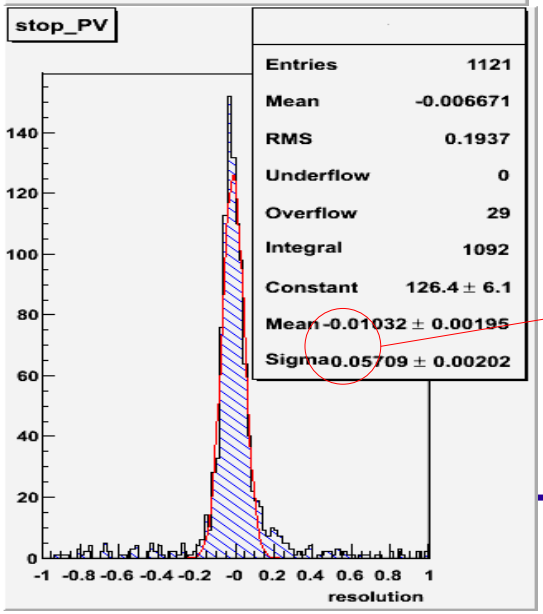
The Kalman filter resolution is strictly dependent on the topology of the track, and on the initialization process



Through going events (tracks exit from detector): momentum and charge are estimated with Drift tube data or RPC data

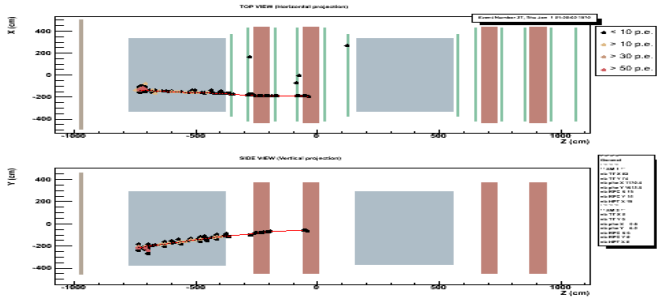
$\sigma_p \cong 19\%$





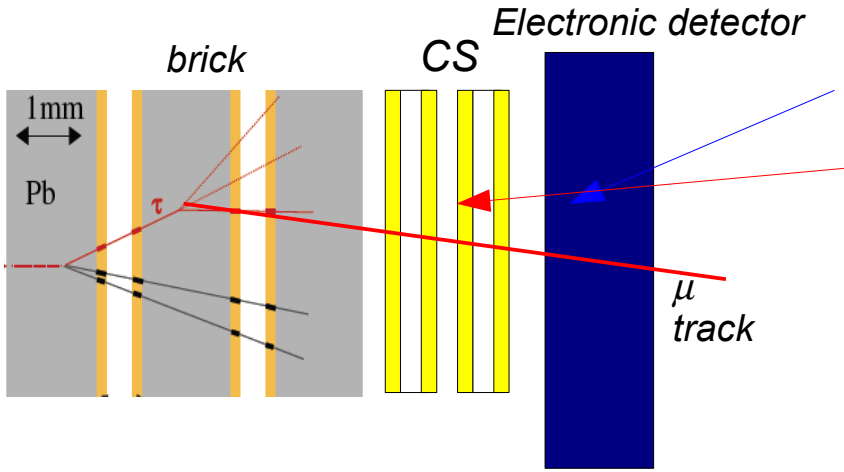
Stopping events: momentum initialization sets to 200MeV, charge from curvature in the spectrometer if it is possible, otherwise put by default as negative

$\sigma_p \cong 6\%$



Position estimated by Kalman and CS

The brick finding procedure use the track position estimated by the Kalman in the first plane to select the brick in wich the neutrino interaction occurred



Position predicted by the Kalman

⇓

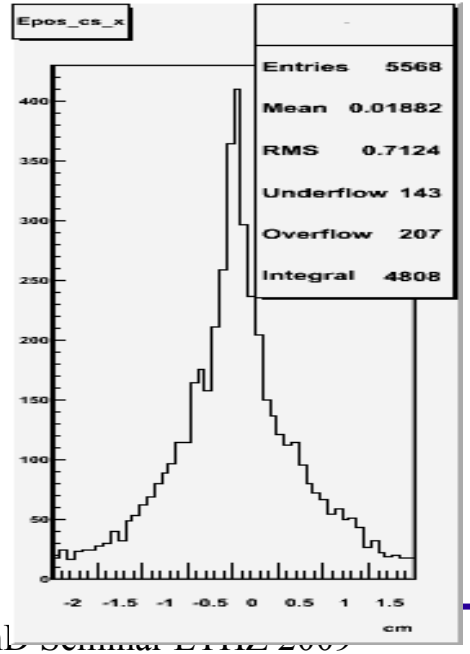
position extrapolated on the CS

⇓

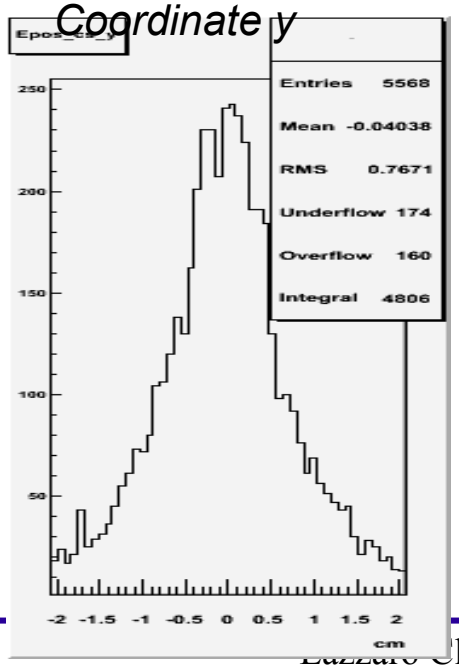
before unpacking the brick, the CS are scanned to confirm the track

Residual beetwen true position and position extrapolated with Kalman estiamtion on the CS

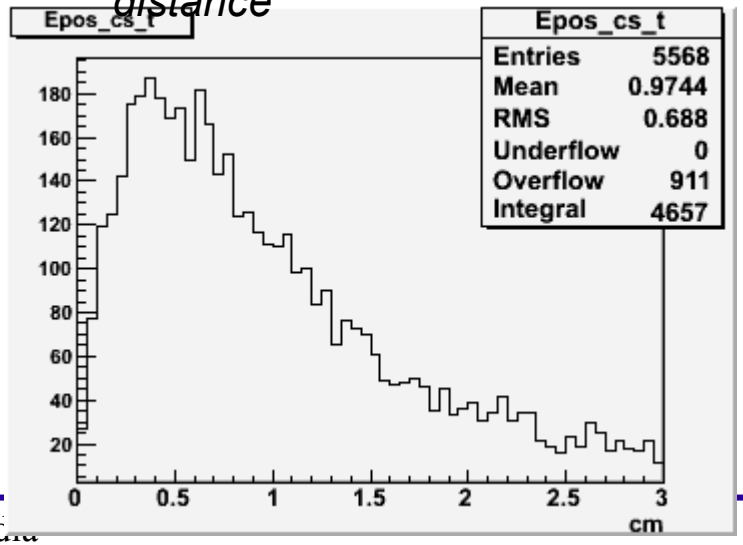
Coordinate x



Coordinate y



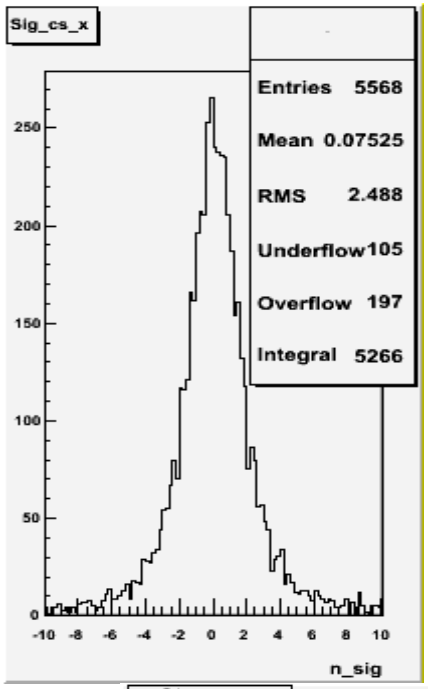
distance



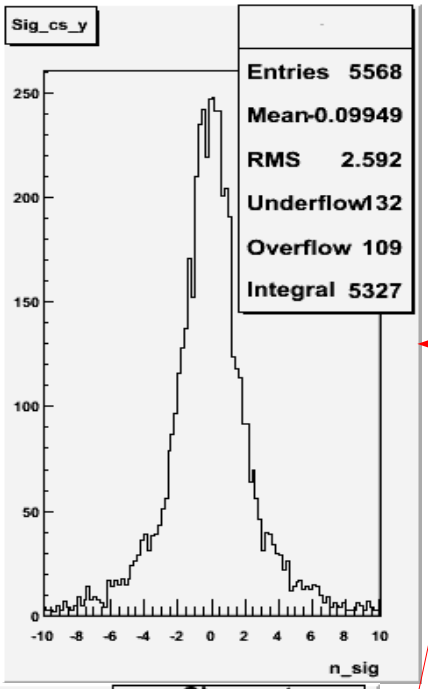
Work in progress

Some analysis on the errors of the position estimated on CS

Coordinate x

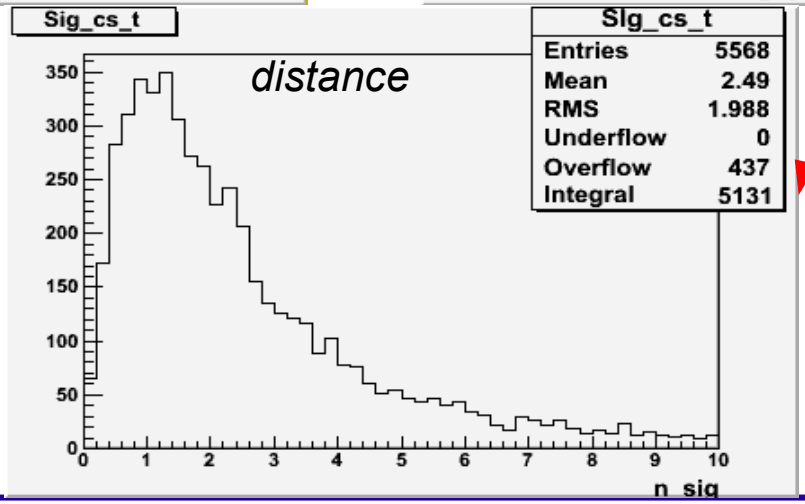


Coordinate y



These are used to calculate the probability to identify the correct brick, and if necessary the possibility to extract more than one brick for events.

Distributions of the ratio between residual and residual's error for coordinates and distance show evidence for an underestimation of the errors



Preliminary studies point out that for quasi elastic events the errors are correct estimated, these events are generally more simple to reconstruct, so the point is the correct tracking of the μ

More analyses are necessary

Conclusion

- ✗ *measurement of the flux is needed in OPERA to estimate the number of expexted τ, and the neutrino oscillation parameters*
- ✗ *muon momentum is the most important information to estimate the neutrino spectrum, some corrections on the Kalman filter made in last months, and now the results are acceptable.*
- ✗ *Analysis on the errors of the vertex position estimation given by the Kalman are still in progress*
- ✗ *about 3500 new events should be collect with the new run (2009).*