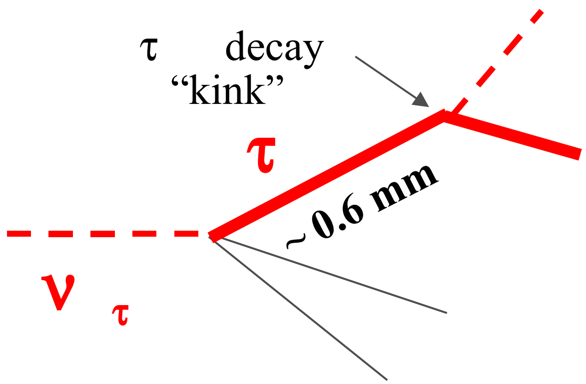
The OPERA experiment at Gran Sasso

Consiglio di Laboratorio

7 luglio 2010

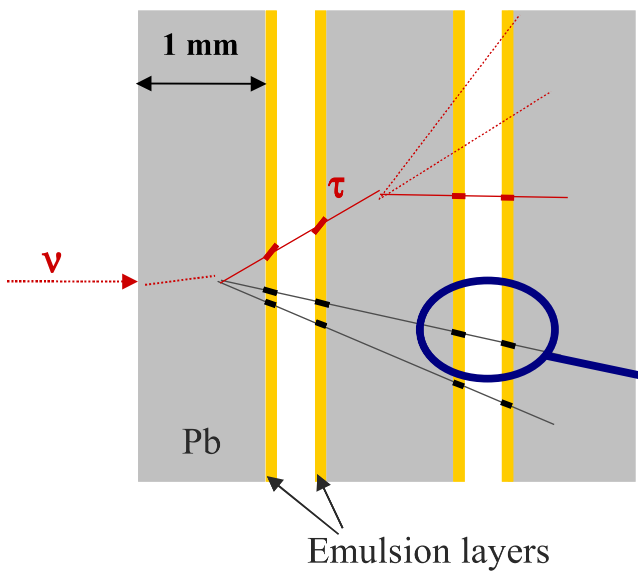
Primary goal for OPERA: ν_τ appearance detection



Two conflicting requirements:

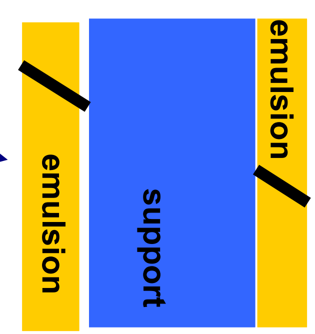
- **τ topology-based selection (kink observation) : μm resolution needed**
- **Low neutrino cross section: large sensitive target mass needed**

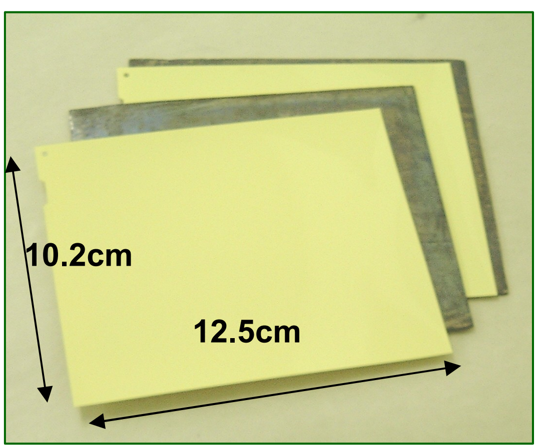
OPERA adopts the ECC concept (Emulsion Cloud Chamber):



1 mm thick Pb layers interleaved with emulsions

Emulsion: 2 layers (44 μm thick) poured on a 205 μm plastic base

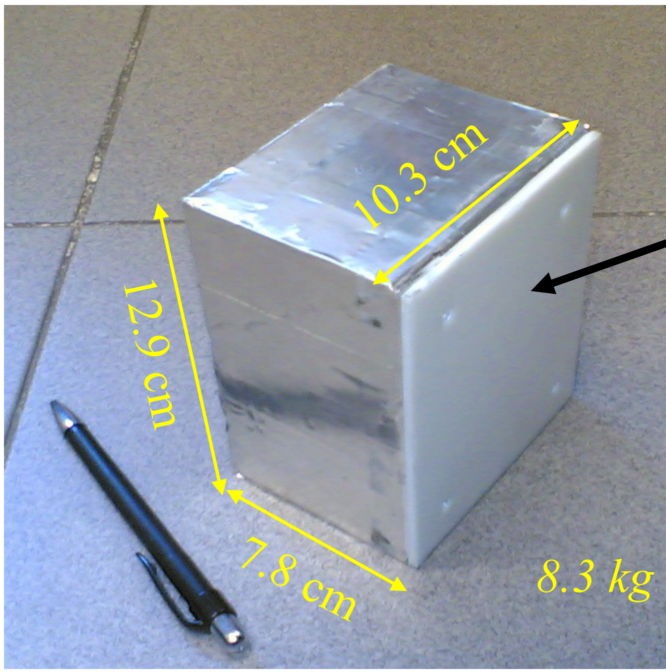




Emulsion spatial accuracy
($\Delta x \approx 1\ \mu m$ $\Delta \theta \approx 1$ mrad)

The OPERA bricks

56 Pb sheets (1 mm thick) / 57 Emulsion layers (300 μ m thick) = 10 X_0
2 additional Emulsion layers (CS, Changeable Sheets) added downstream to confirm brick predictions from electronic detectors

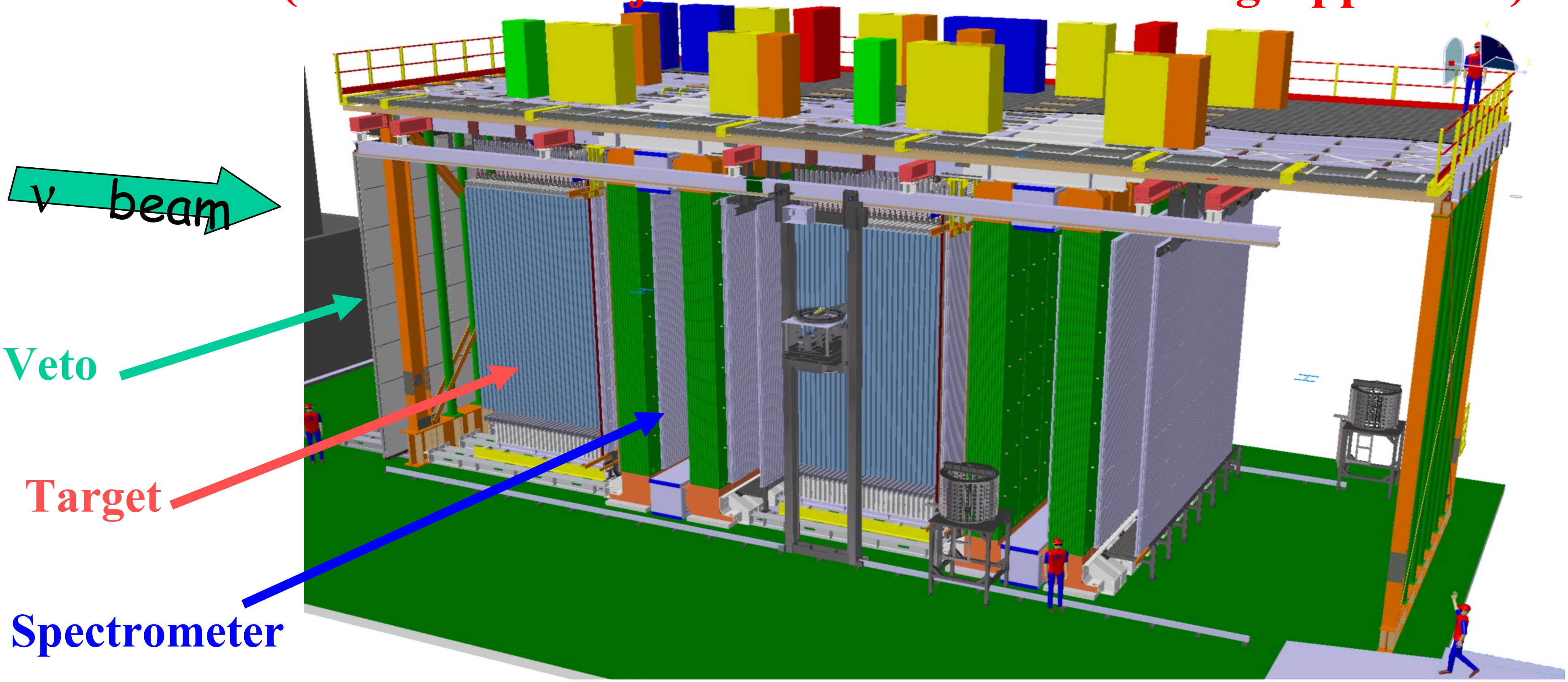


Changeable sheets box

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

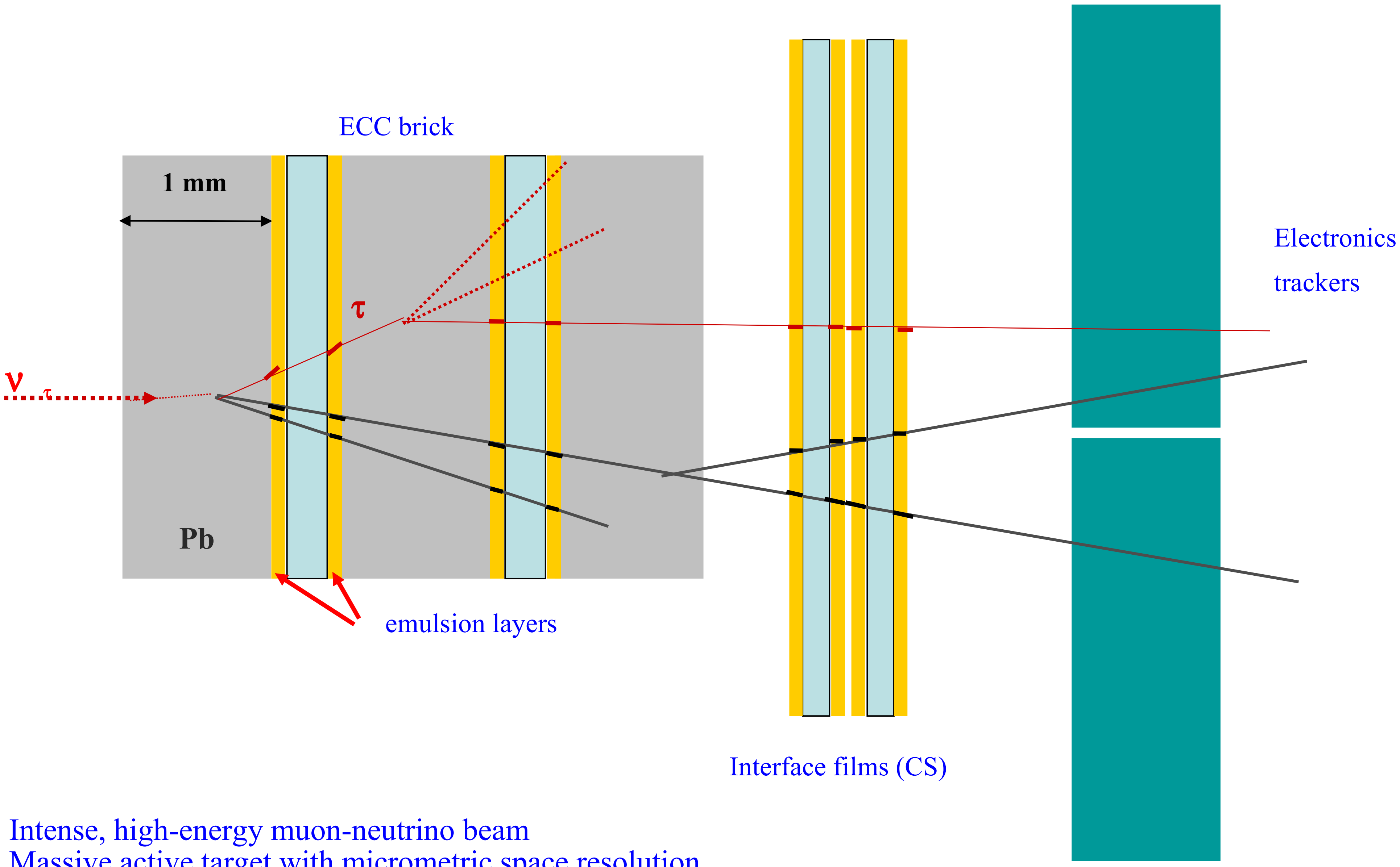
- **Neutrino interaction vertex and decay topology reconstruction**
- **Measurement of charged particles momenta by Multiple Coulomb Scattering (20-30% resolution)**
- **dE/dx for π /μ separation at the end of their range**
- **Electron identification and energy measurement**

OPERA (Oscillation Project with Emulsion tRacking Apparatus)



- 2 Supermodules (1 Supermodule = 1 target section + 1 spectrometer)
- 2 Target sections with 150000 bricks arranged into walls
- 1 Brick= 56 lead sheets (target) alternated to 57 nuclear emulsions (vertex reconstruction)
- Target sect.=31 Target Walls/Target Tracker (xy scintillator strips)
- Total target mass (1250 tons of lead)
- Spectrometer: 1 kton dipolar magnet equipped with drift tubes and RPCs
- Veto system to tag external neutrino interactions (glass RPCs)

THE PRINCIPLE OF THE EXPERIMENT: ECC + ELECTRONIC DETECTORS



- Intense, high-energy muon-neutrino beam
- Massive active target with micrometric space resolution
- Detect tau-lepton production and decay
- Use electronic detectors to provide "time resolution" to the emulsions and preselect the interaction region

LNF group contribution

LNF group played a key role in the OPERA construction/installation (general mechanical structure, Brick-support walls, Brick Assembly Machine) with contributions by SPAS, SSCR, SEA and the support by Accelerator Division.

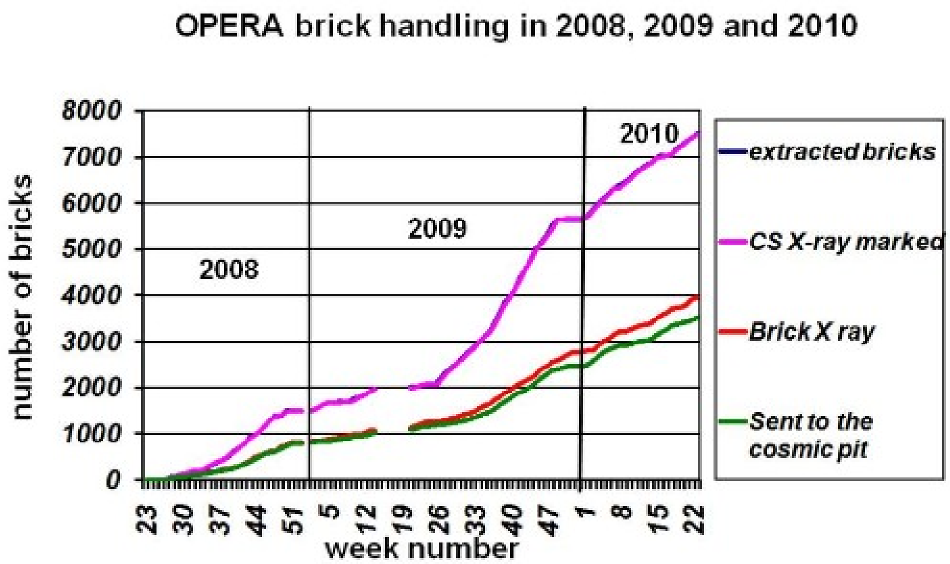
Presently we are heavily involved in data-taking with coordination duties in the OPERA management:

- **Deputy spokesman (F. Terranova)**
- **Technical coordinator (M. spinetti)**
- **Electronics Detectors coordinator (A. Paoloni)**

In addition M. Ventura is the Magnets project leader and A. Mengucci is on charge for the operation of the RPC gas system.

Brick handling

Brick handling procedures: CS + Brick X-ray exposure, Brick X-ray and cosmic rays exposure for emulsions precision alignment.

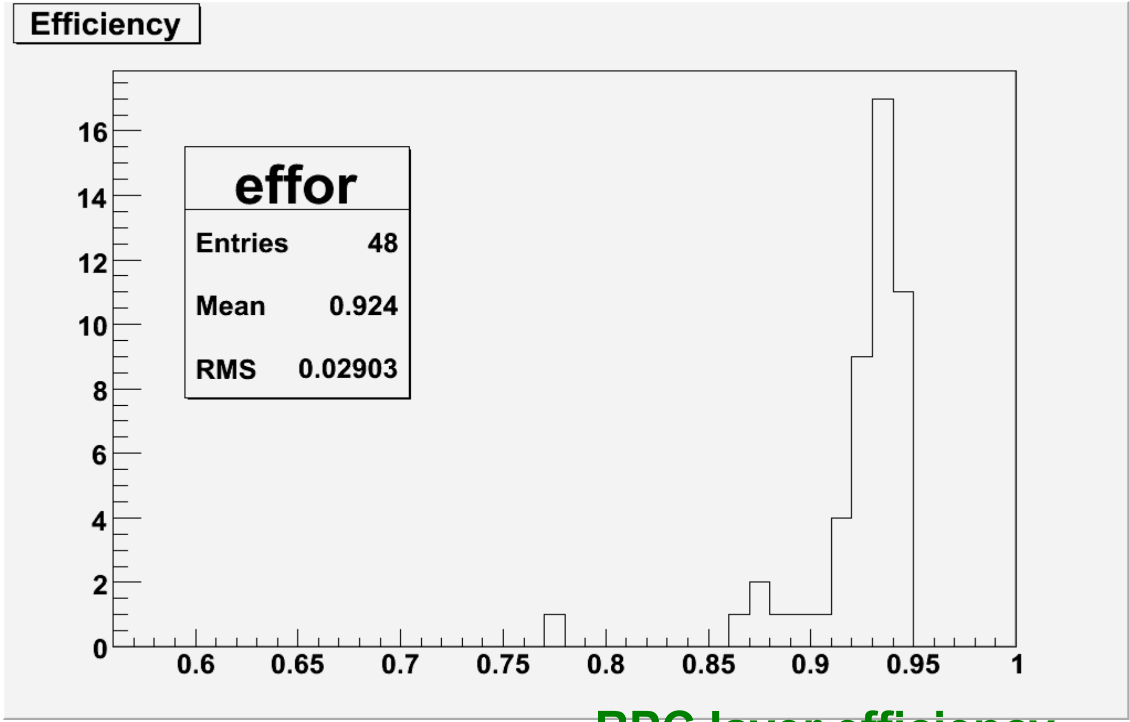


Our group contributed to the realization and the maintenance of the X-ray and cosmic rays exposure machines (thanks to the SPAS service, A. Cecchetti, D. Orecchini and S. Cerioni, N. Intaglietta and M. Ventura).

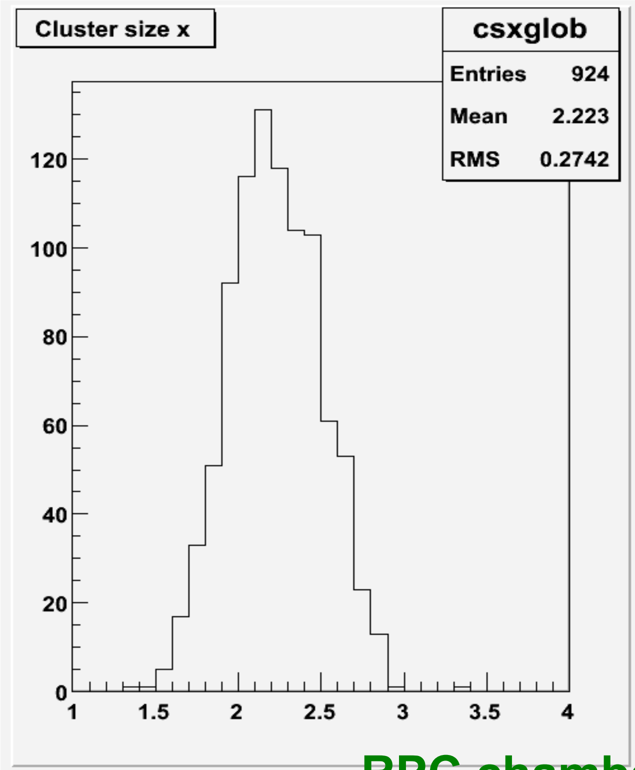
Blocked rows recovery done by A. Mengucci (70% recovered out of 80 blocked rows).

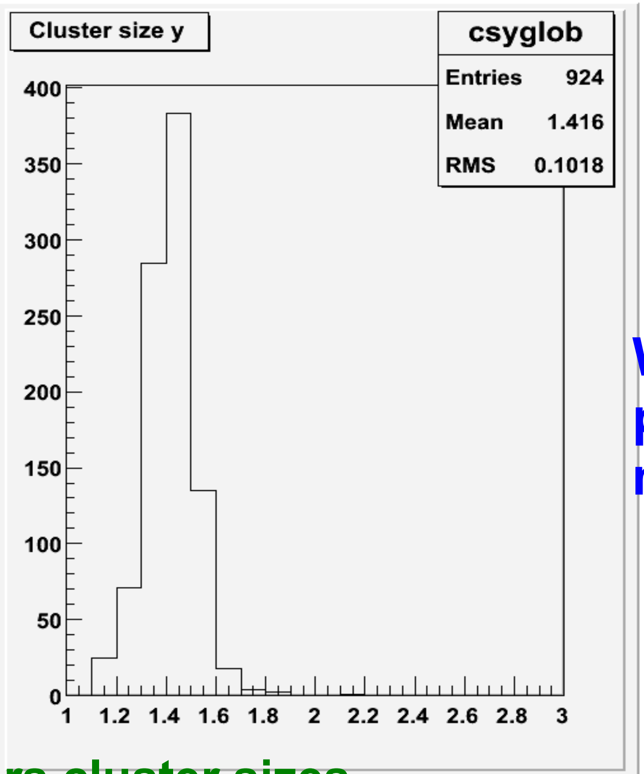
RPC system

LNF group contributed to the design/installation/commissioning of the RPC system.
We realized also the drift tubes trigger electronics.



RPC layer efficiency



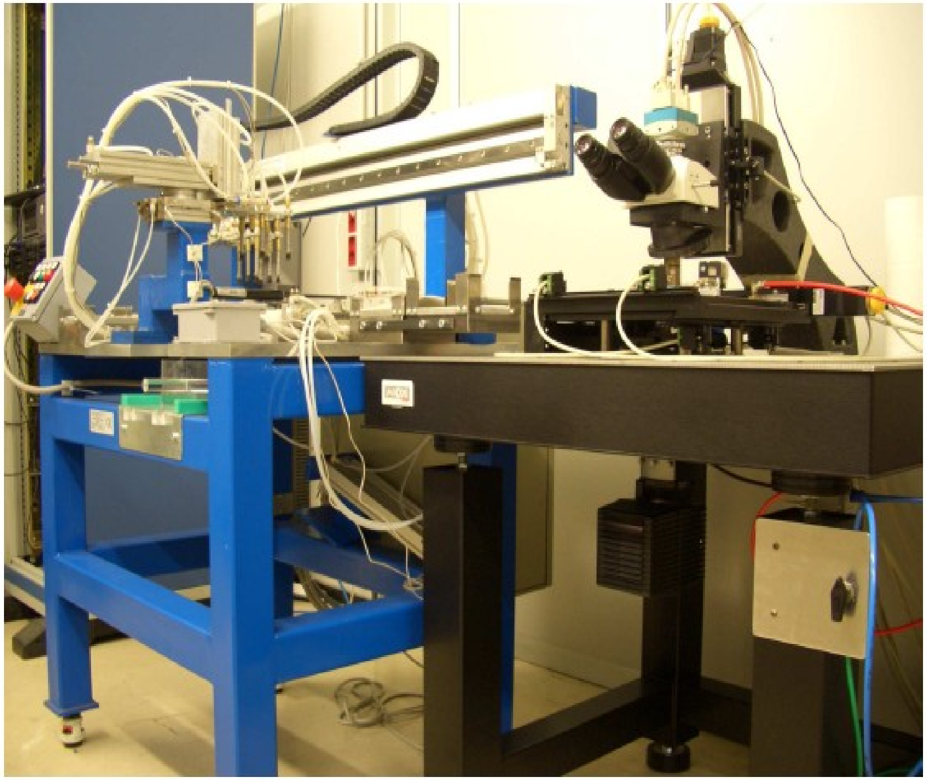


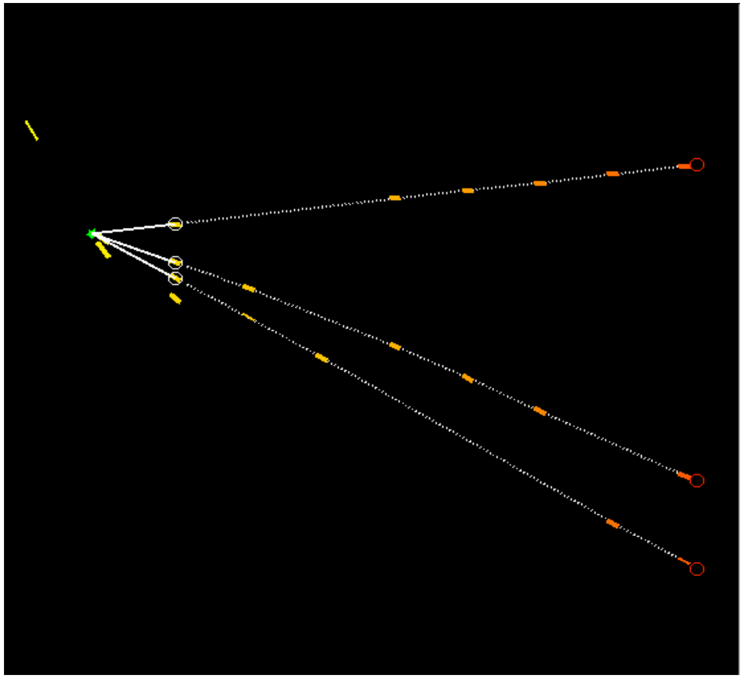
RPC chambers cluster sizes

We are involved in the system performance monitoring and maintenance.

LNF scanning laboratory

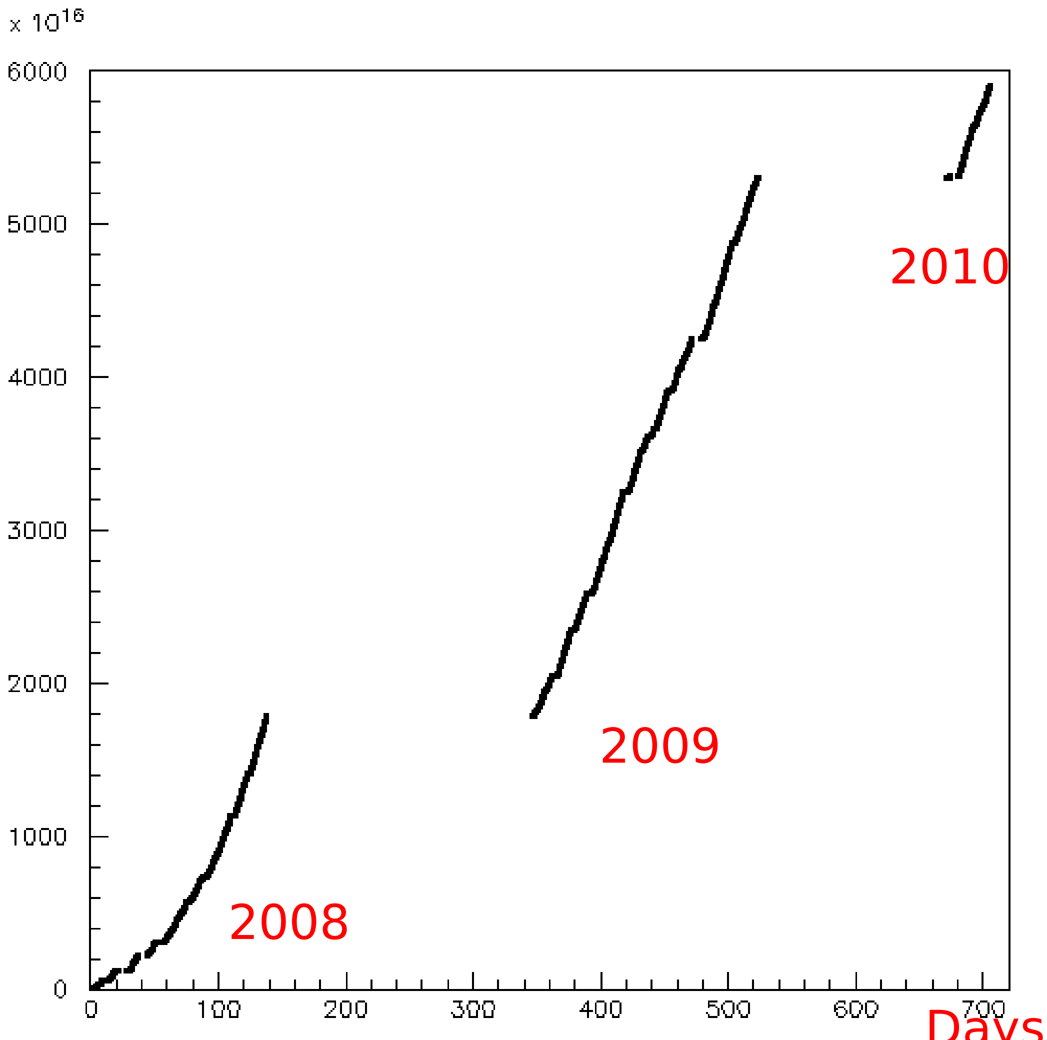
Thanks to the effort of U. Denni, V. Chiarella and especially M. Paniccia, we have an operative scanning laboratory (9 vertex located on 15 bricks received for 2008-2009 runs).
M. Paniccia moved to LAPP (Annecy) and is going to be replaced by a new Post-Doc from August.





CNGS performance

2006	0.076×10^{19} pot	no bricks	Commissioning
2007	0.082×10^{19} pot	38 ev.	Commissioning
2008	**1.78×10^{19} pot**	**1698 ev.**	**First physics run**
2009	**3.52×10^{19} pot**	**3693 ev.**	**Physics run**
2010	**1.33×10^{19} pot (28 June)**	**1430 ev.**	**Physics run**



6821 events collected until 28 June 2010 (within 1σ in agreement with expectations)

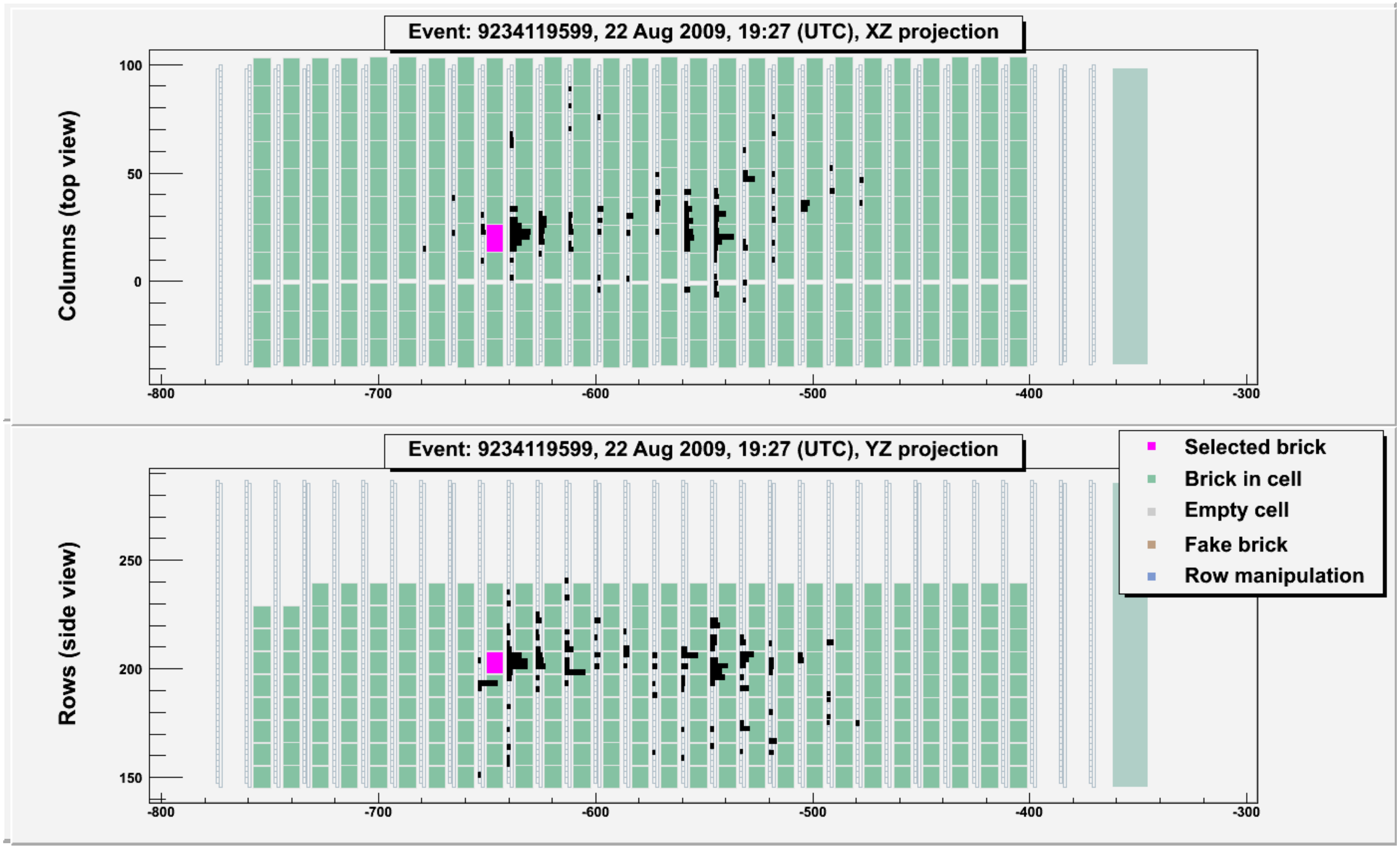
CNGS accelerator chain efficiency = 73%
CNGS efficiency = 97%

2010 run (29 April – 22 November): ~ 4×10^{19} pot expected (close to 4.5×10^{19}, nominal value)

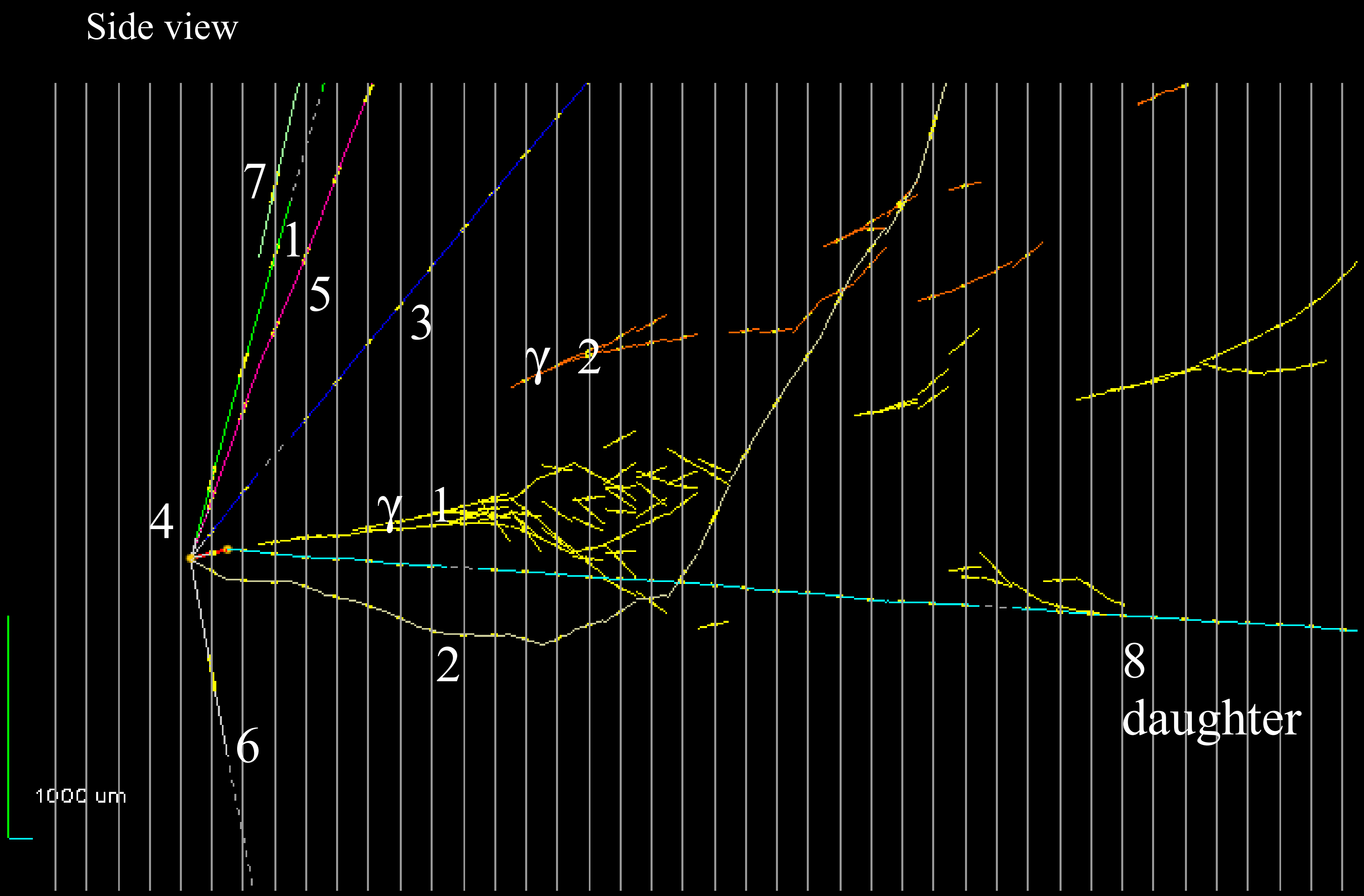
Multi Turn Extraction, needed to overcome the present limitations (2×10^{13} pot/extraction) under debugging

The electronics detectors of the experiment are running smoothly.

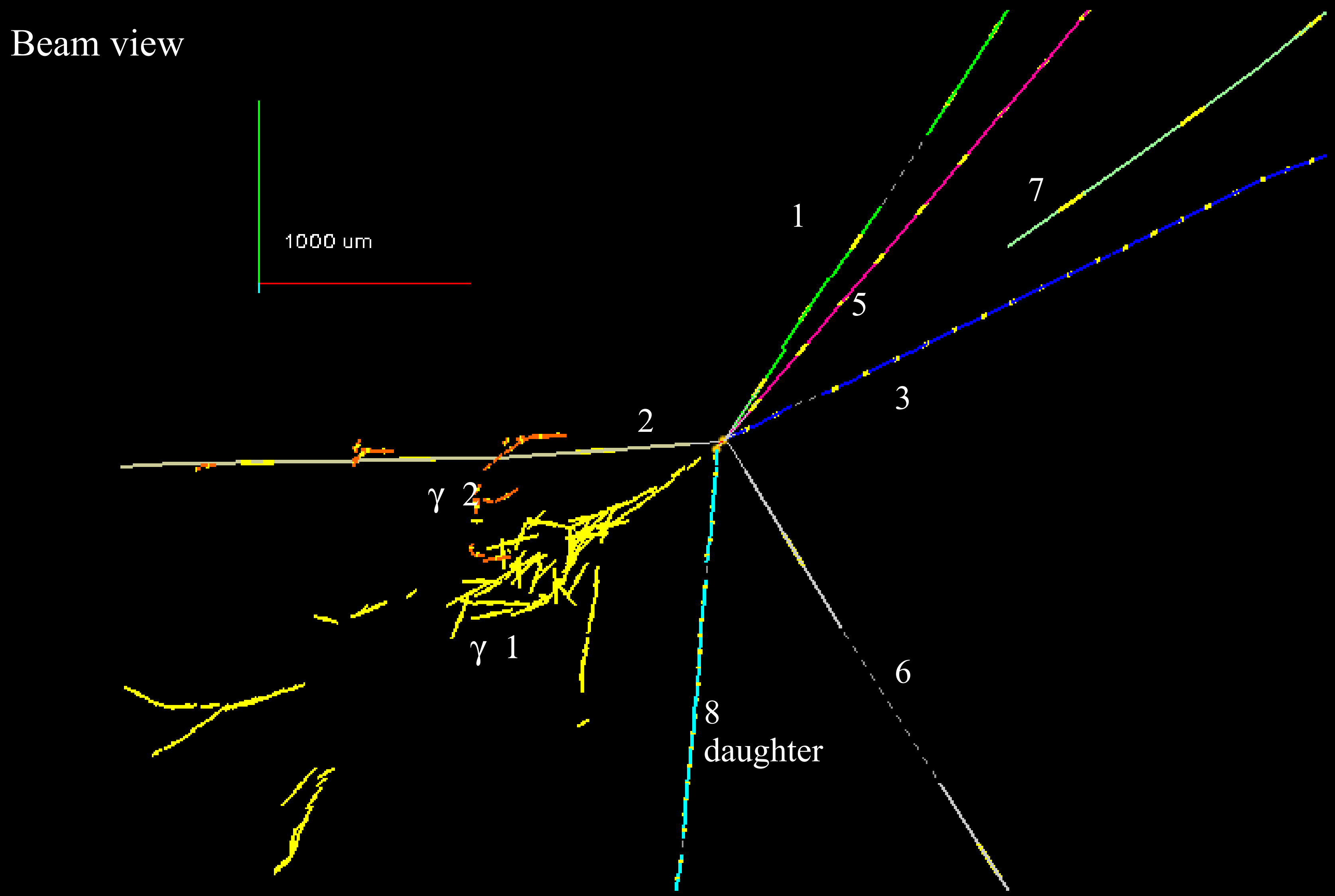
Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC)
(as seen by the electronic detectors)

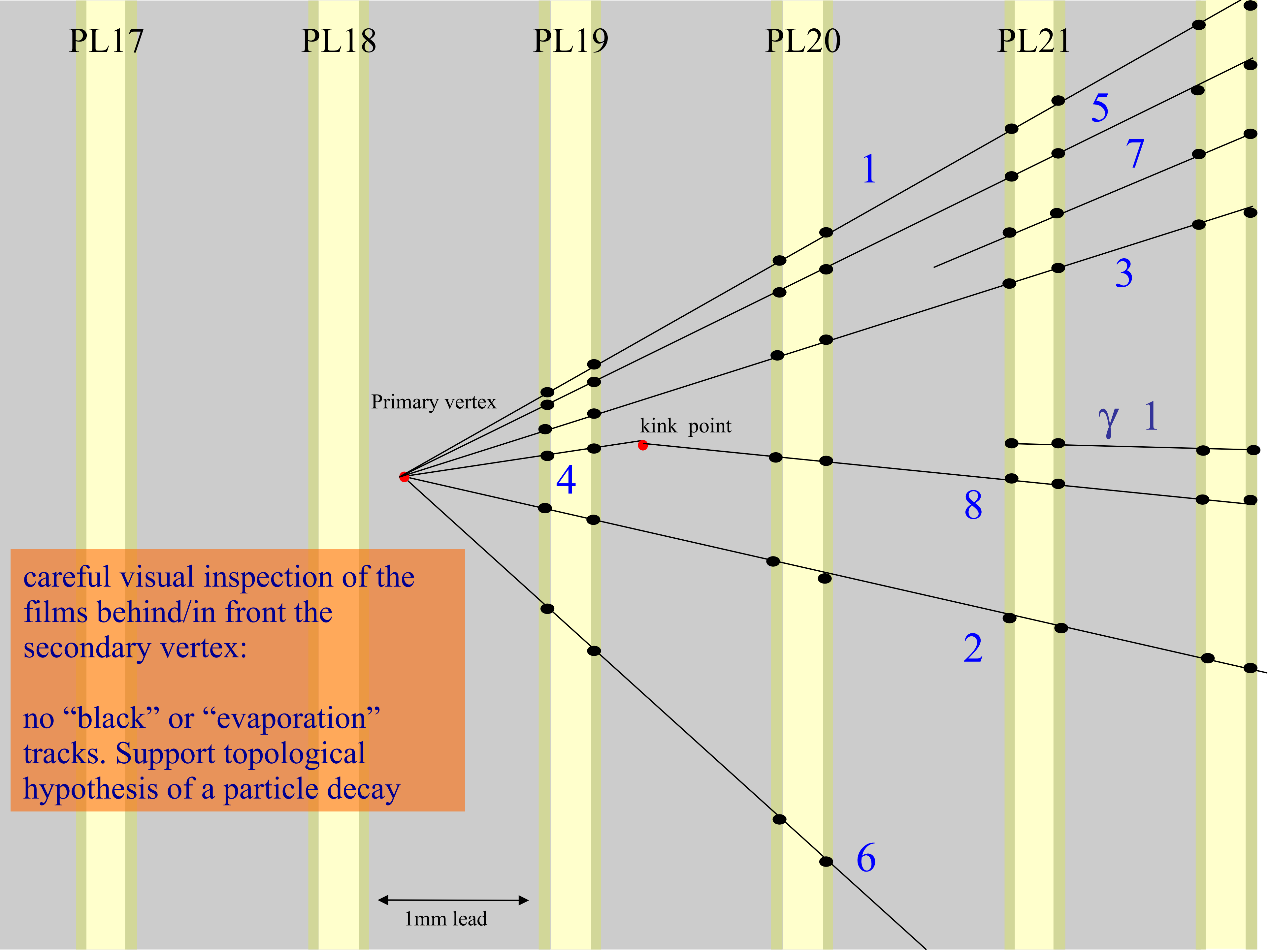


Event topological features (2)



Event topological features (1)

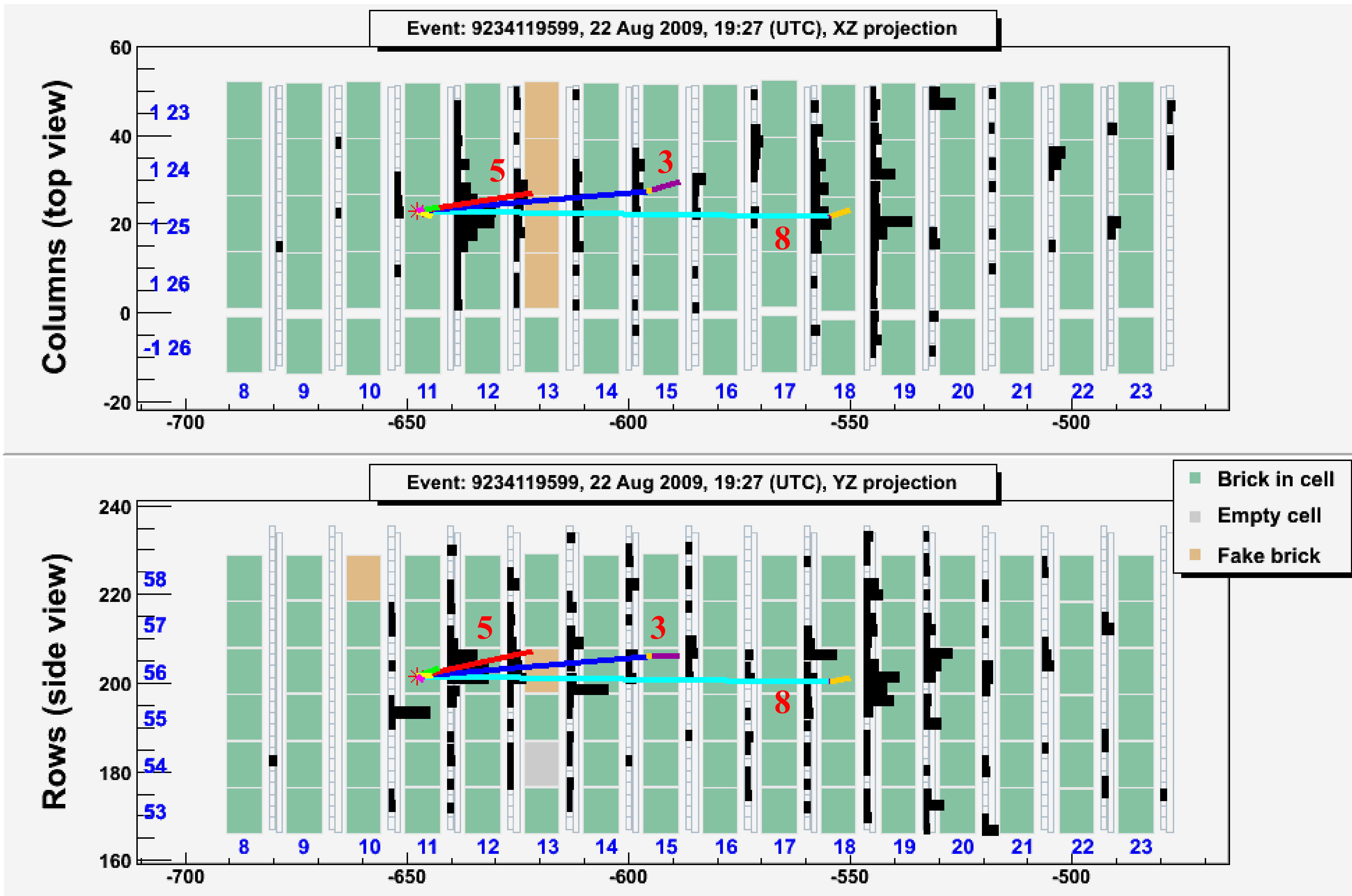




careful visual inspection of the films behind/in front the secondary vertex:

no “black” or “evaporation” tracks. Support topological hypothesis of a particle decay

Vertex tracks followed down (through several bricks) to assess the muonless nature of the event. Residual probability of ν_μ CC event (due to a possibly undetected large angle muon) ~1%. **"Nominal" value of 5% assumed**



Event tracks' features

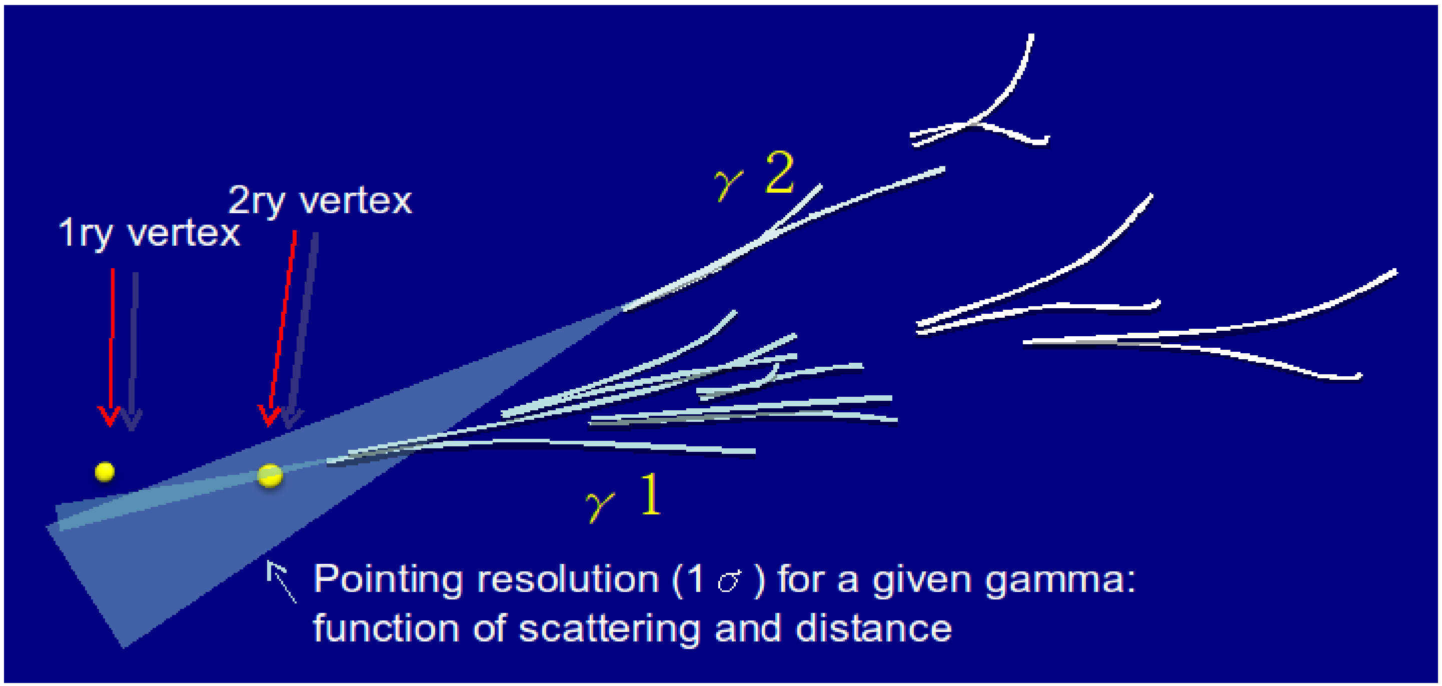
TRACK NUMBER	PID	Probability	MEASUREMENT 1			MEASUREMENT 2		
			tan Θ_X	tan Θ_Y	P (GeV/c)	tan Θ_X	tan Θ_Y	P (GeV/c)
1	HADRON range in Pb/emul=4.1/1.2 cm	Prob(μ)≈10^{-3}	0.177	0.368	0.77 [0.66,0.93]	0.175	0.357	0.80 [0.65,1.05]
2	PROTON	range, scattering and dE/dx	-0.646	-0.001	0.60 [0.55,0.65]	-0.653	0.001	
3	HADRON	interaction seen	0.105	0.113	2.16 [1.80,2.69]	0.110	0.113	1.71 [1.42,2.15]
4 (PARENT)			-0.023	0.026		-0.030	0.018	
5	HADRON: range in Pb/emul=9.5/2.8 cm	Prob(μ)≈10^{-3}	0.165	0.275	1.33 [1.13,1.61]	0.149	0.259	1.23 [0.98,1.64]
6	HADRON: range in Pb/emul=1.6/0.5 cm	Prob(μ)≈10^{-3}				0.334	-0.584	0.36 [0.27,0.54]
7	From a prompt neutral particle		0.430	0.419	0.34 [0.22,0.69]	0.445	0.419	0.58 [0.39,1.16]
8 (DAUGHTER)	HADRON	interaction seen	-0.004	-0.008	12 [9,18]	-0.009	-0.020	

muonless event (favored hypothesis)

γ detection

Total radiation length downstream the vertices: 6.5 X_0

	Distance from 2ry vertex (mm)	Energy (GeV)
1^{st} γ	2.2	5.6 ± 1.0 ± 1.7
2^{nd} γ	12.6	1.2 ± 0.4 ± 0.4



	Distance from 2ry vertex (mm)	IP to 1ry vertex (μ m) <resolution>	IP to 2ry vertex (μ m) <resolution>	Prob. of attach. to 1ry vtx*	Prob. of attach. to 2ry vtx*	Attachment hypothesis
1^{st} γ	2.2	45.0 <11>	**7.5** <7>	$<10^{-3}$	**0.32**	**2ry vertex**
2^{nd} γ	12.6	85.6 <56>	**22** <50>	0.10	**0.82**	**2ry vertex** (favored)

* probability to find an IP larger than the observed one

Kinematical variables

The kinematical variables are computed by averaging the two sets of track parameter measurements

We assume that:
γ 1 and γ 2 are both attached to 2^{ry} vertex

VARIABLE	AVERAGE
kink (mrad)	**41 ± 2**
decay length (μ m)	**1335 ± 35**
P daughter (GeV/c)	**12^{+6}_{-3}**
Pt daughter (MeV/c)	**470^{+230}_{-120}**
missing Pt (MeV/c)	**570^{+320}_{-170}**
ϕ (deg)	**173 ± 2**

The average values are used in the following kinematical analysis

The uncertainty on Pt due to the alternative γ 2 attachment is < 50 MeV

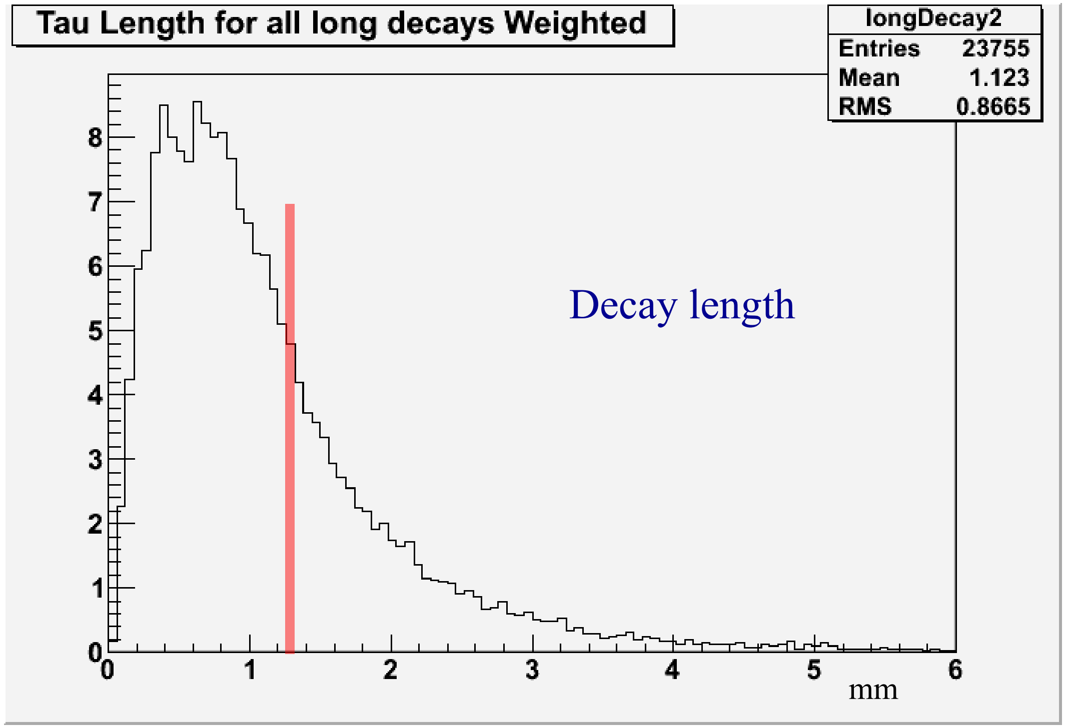
ANALYSIS

OPERA nominal analysis flow applied to the hadronic kink candidates:

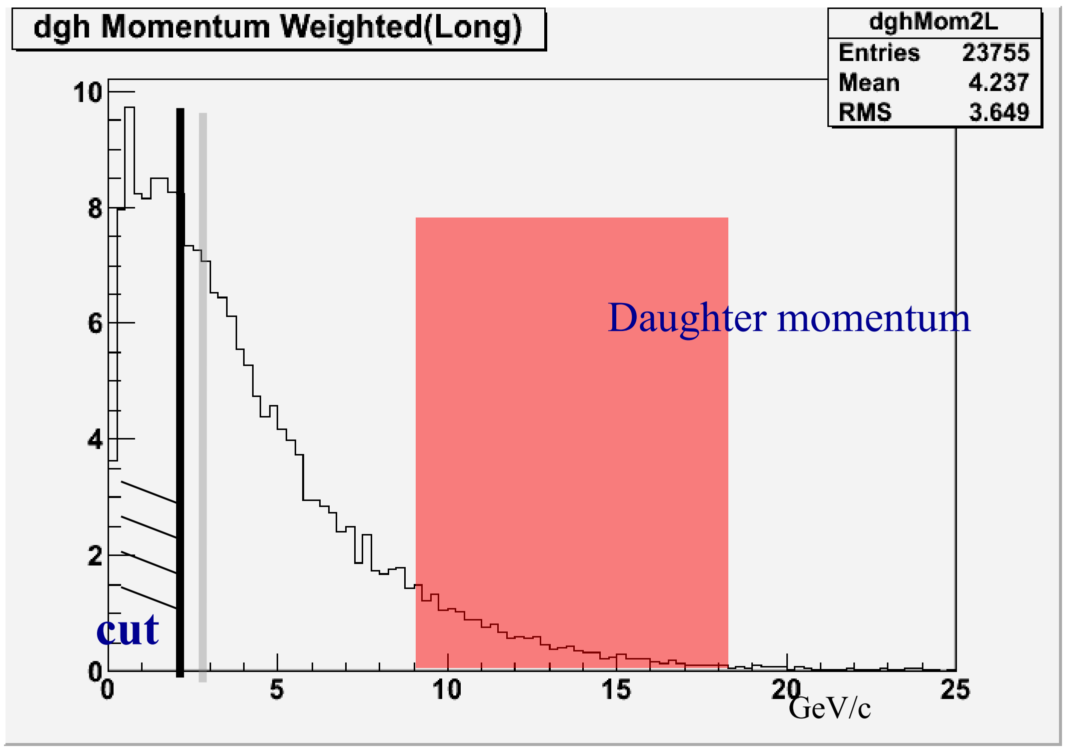
(more refined selection criteria being developed were not considered here not to bias our analysis)

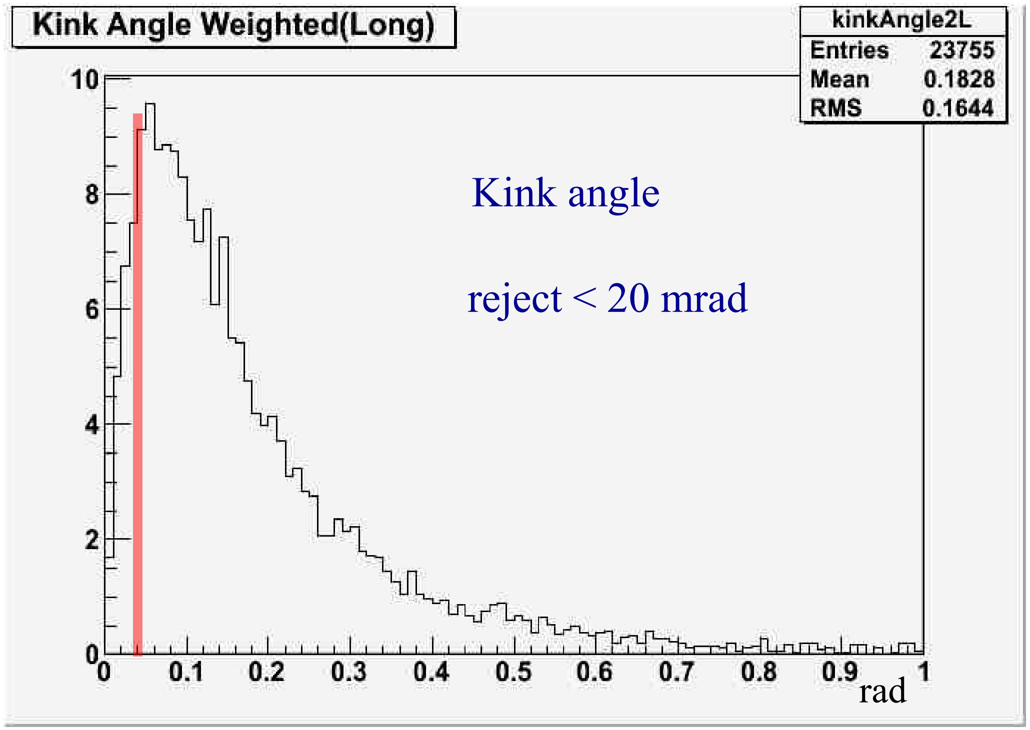
- kink occurring within 2 lead plates downstream of the primary vertex
- kink angle larger than 20 mrad
- daughter momentum higher than 2 GeV/c
- decay Pt higher than 600 MeV/c, 300 MeV/c if $\geq$ 1 gamma pointing to the decay vertex
- missing Pt at primary vertex lower than 1 GeV/c
- azimuthal angle between the resulting hadron momentum direction and the parent track direction larger than π /2 rad

Features of the decay topology



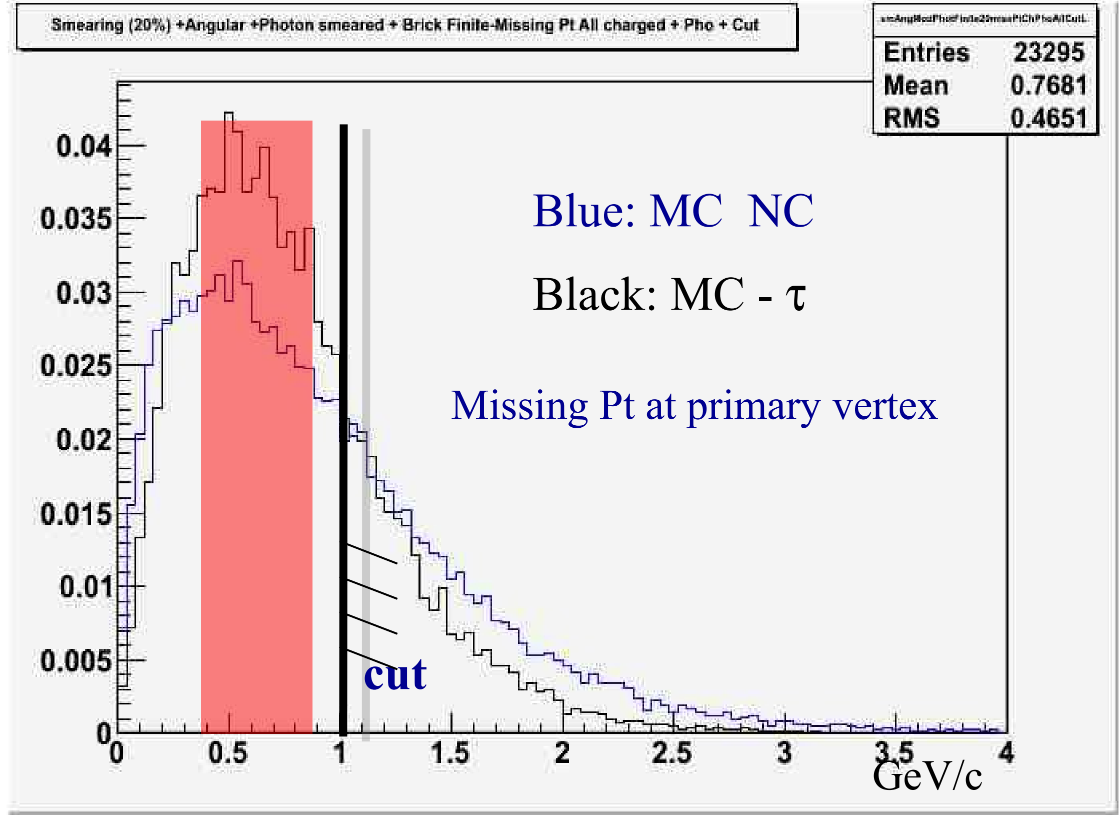
red bands: values for the “interesting” event with uncertainties



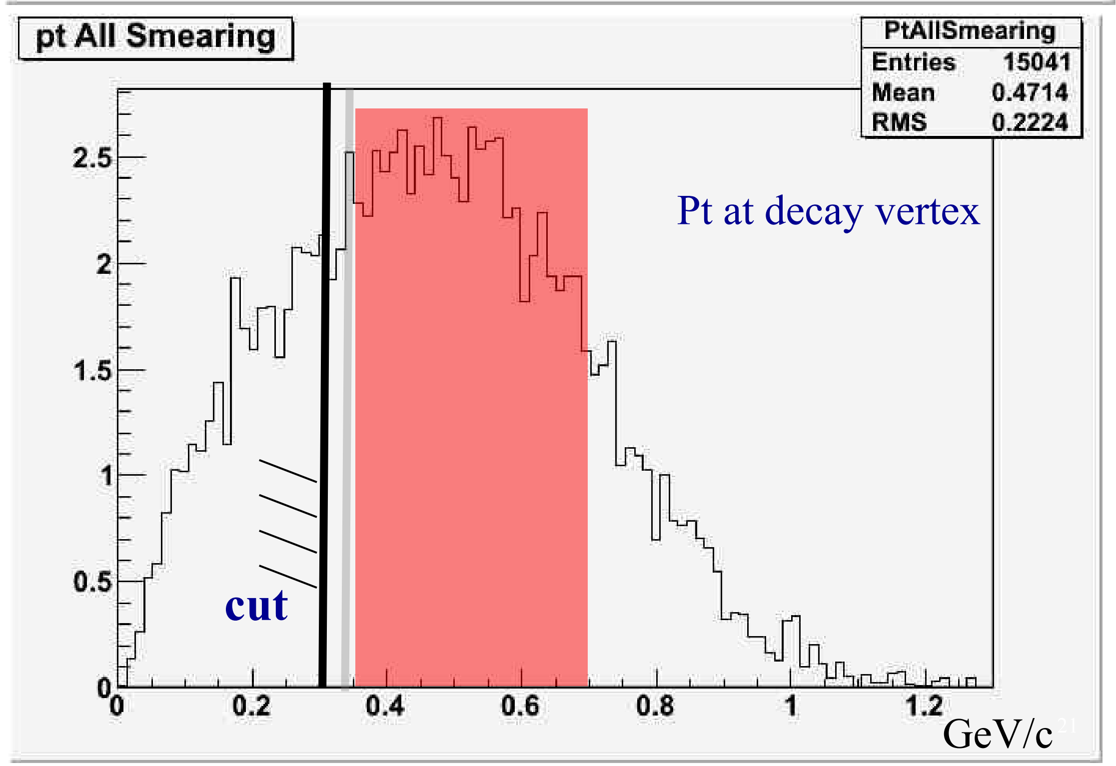


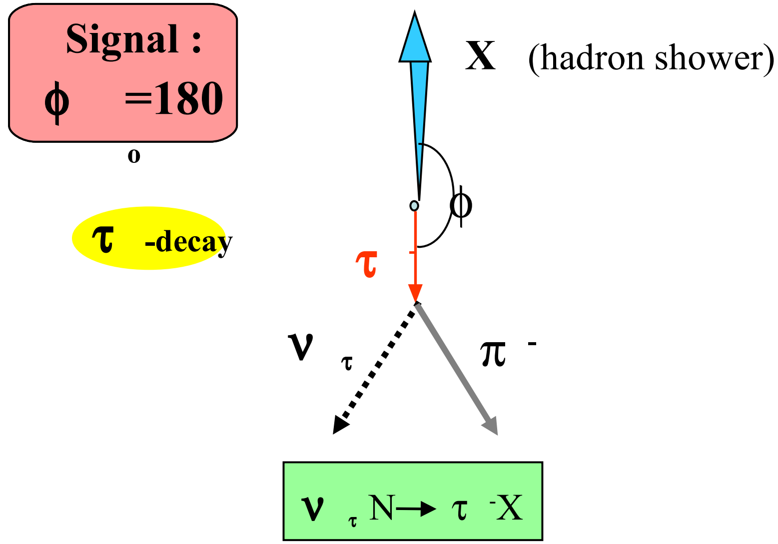
Kinematical cuts to be passed

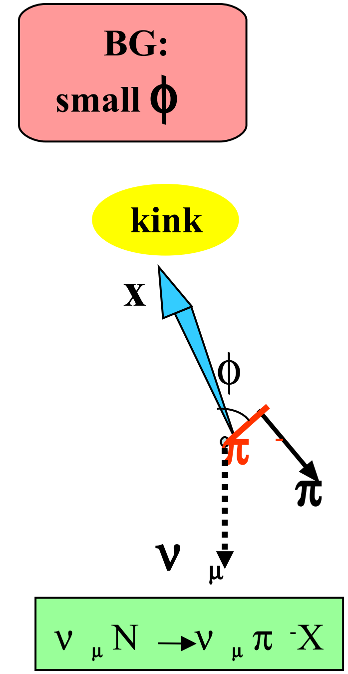
Reject NC events with larger missing Pt (neutrino)



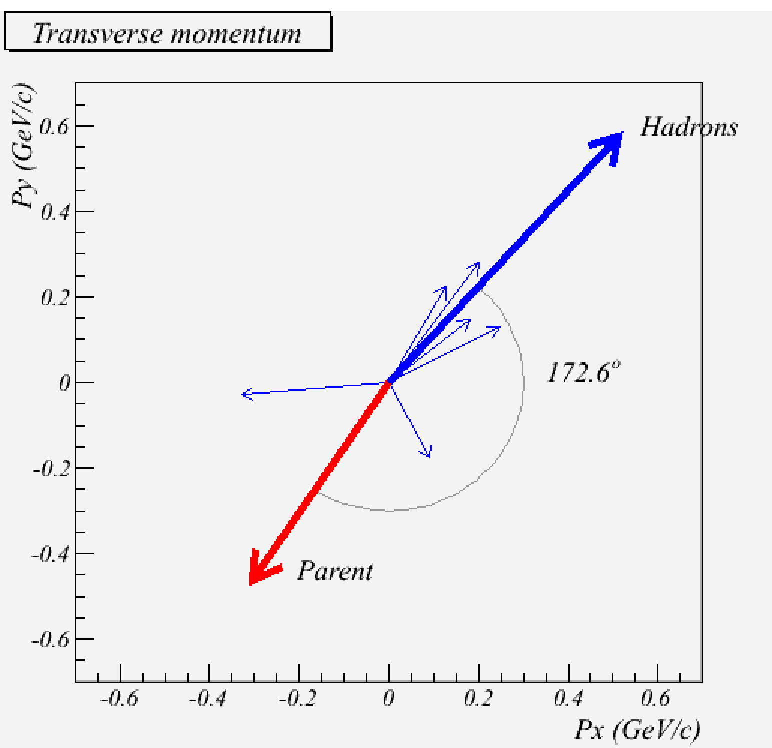
Reject hadron interactions

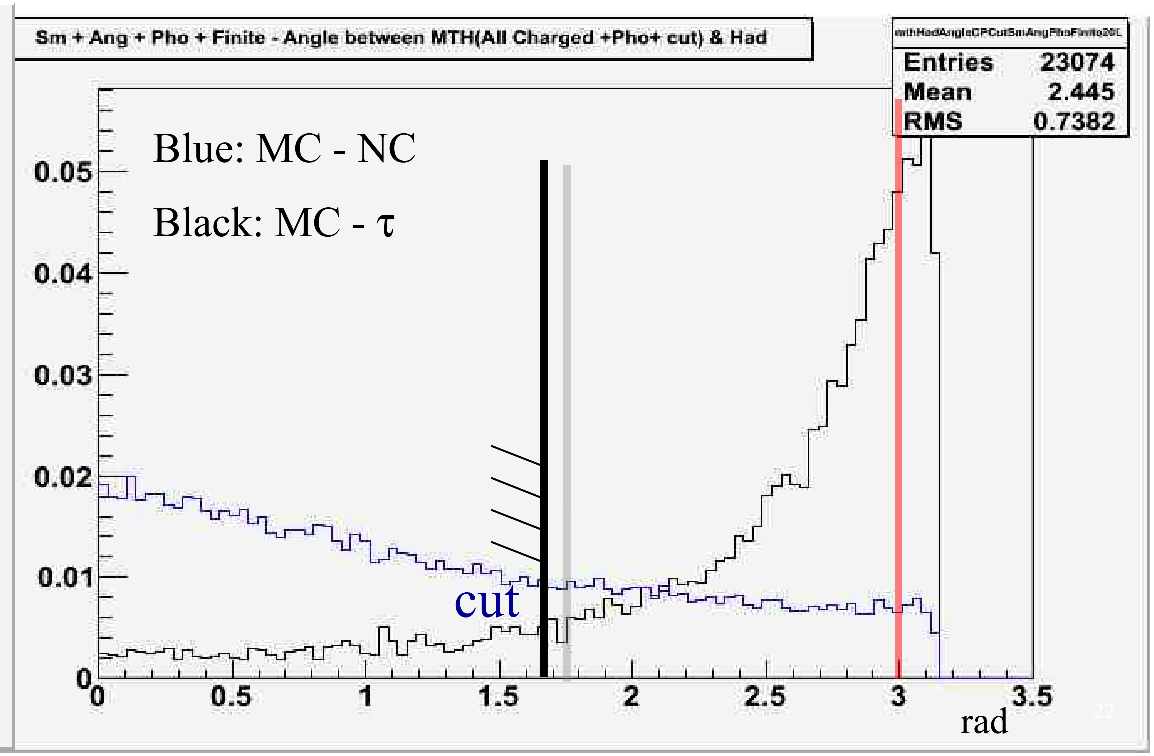






Azimuthal angle between
the resulting hadron momentum
direction and the parent track
direction





Event nature and invariant mass reconstruction

The event passes all cuts, with the presence of at least 1 gamma pointing to the secondary vertex, and is therefore a candidate to the $\tau \rightarrow$ 1-prong hadron decay mode.

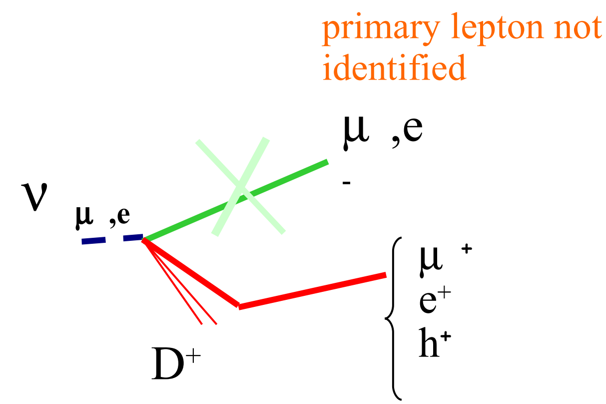
The invariant mass of the two detected gammas is consistent with the π^0 mass value (see table below).

The invariant mass of the $\pi^- \gamma \gamma$ system has a value (see below) compatible with that of the ρ (770). The ρ appears in about 25% of the τ decays:
$\tau \rightarrow \rho \ (\pi^- \pi^0) \ \nu_\tau$.

π^o mass	ρ mass
$120 \pm 20 \pm 35$ MeV	$640^{+125}_{-80}{}^{+100}_{-90}$ MeV

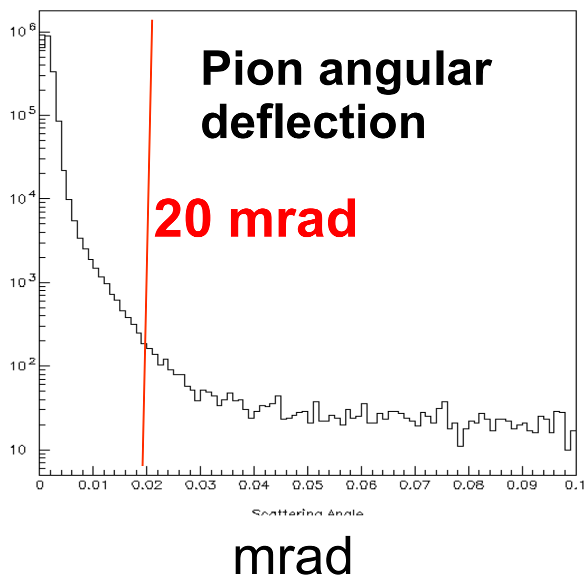
Background estimation

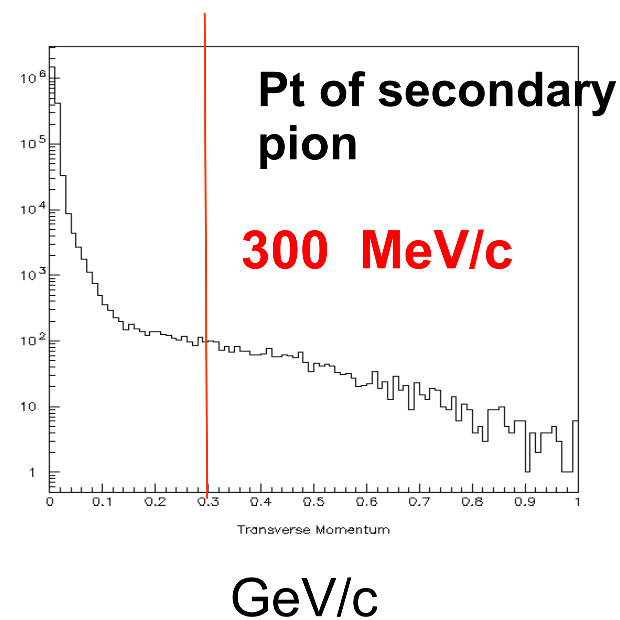
Charmed particles have similar decay topologies to the τ .
This background can be suppressed by identifying the primary lepton → ~ 95% muon ID with the electronics detectors (improvable to 98-99% following low energy tracks in the bricks and inspecting their end-range).



Hadronic reinteractions estimation with FLUKA, validated with test-beam pion events and following hadronic tracks on real data far from the neutrino vertex.

Typical scattering distributions for : 5 GeV π^+ (FLUKA)





Event statistics

Brick tagging efficiency times vertex location efficiency: ~ 60%
Total found neutrino vertices: 1617
Events for which "decay search" was completed: 1088 (187 NC)

This is ~35% of the total 2008-2009 run statistics, corresponding to 1.85×10^{19} pot

With the above statistics, and for $\Delta m^2_{23} = 2.5 \times 10^{-3}$ eV^2 and full mixing, OPERA expects:

0.16 ± 0.04 (syst) ν_τ CC events in the 1-prong hadron τ decay channel

0.54 ± 0.13 (syst) ν_τ CC events in all τ decay channels

With a background expectation of:
0.011 events (hadronic reinteractions) + 0.007 events (charm) = 0.018 ± 0.007 (syst) events
0.045 ± 0.020 (syst) summing over all decay channels

By considering the 1-prong hadron channel only, the probability to observe 1 event due to a background fluctuation is 1.8%, for a statistical significance of 2.36 σ on the measurement of a first ν_τ candidate event in OPERA.

If one considers all τ decay modes which were included in the search, the probability to observe 1 event for a background fluctuation is 4.5%. This corresponds to a significance of 2.01 σ.

Conclusions

The OPERA experiment at LNGS is aimed at the first detection of neutrino oscillations in appearance mode through the study of the $\nu_{\mu} - \nu_{\tau}$ channel.

In the analyzed sub-sample of 2008-2009 data, the first ν_{τ} candidate event has been observed in the 1-prong hadron decay channel and studied in detail.

To improve the statistical significance we need to successfully complete data taking in the CNGS beam and perform the analysis of the full data sample.

The 2010 run started on 29 April and it is supposed to end on 22 November. The data taking is going on smoothly.

The LNF group after having heavily contributed to the installation of the experiment, is contributing to the run and the analysis of the experiment.