Status of the OPERA experiment

On behalf of the OPERA Collaboration
Andrea Russo
INFN - Napoli

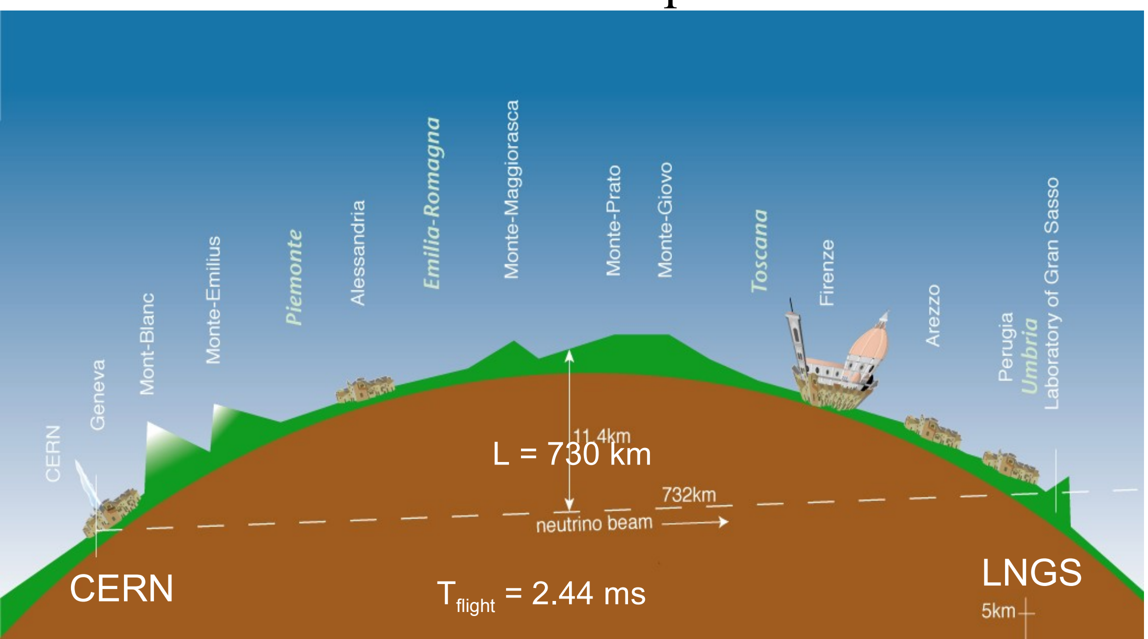
QFTHEP 2010

OPERA: first direct detection of neutrino oscillations in appearance mode in the $\nu_\mu \rightarrow \nu_\tau$ channel

following the Super- Kamiokande discovery of oscillations with atmospheric neutrinos and the confirmation obtained with accelerator beams.

OPERA main features:

1) long baseline, 2) high neutrino energy, 3) ≅ Kton detector mass, 5) **detect short lived taus** produced in tau neutrino interactions

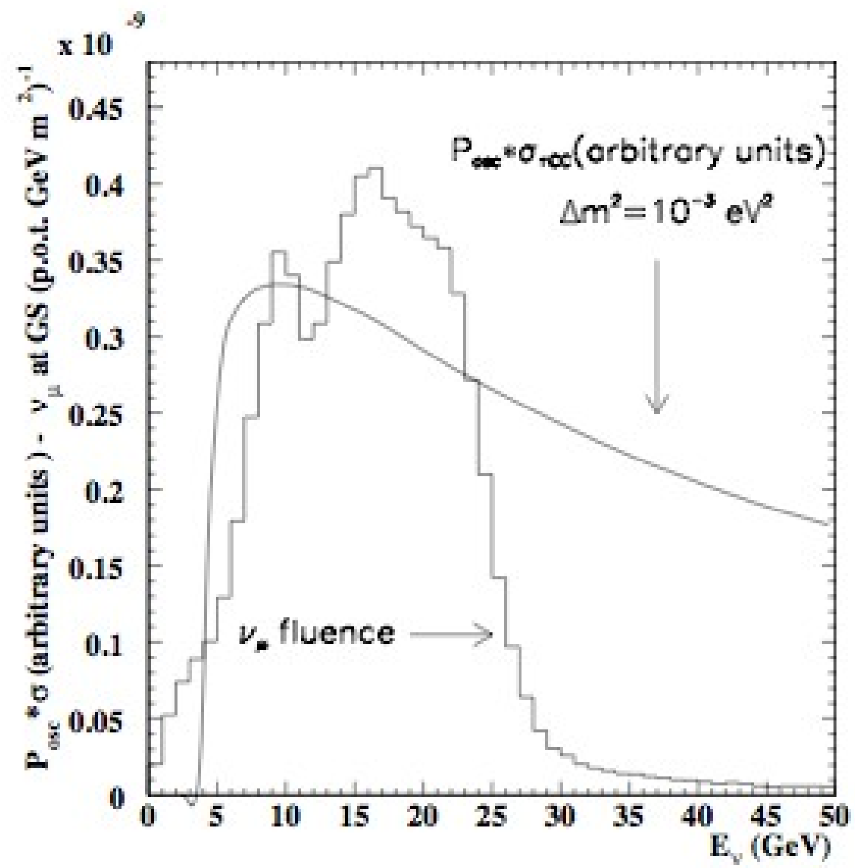


Expected neutrino interactions for 22.5x10[19] pot:

~ 23600 ν_μ CC + NC

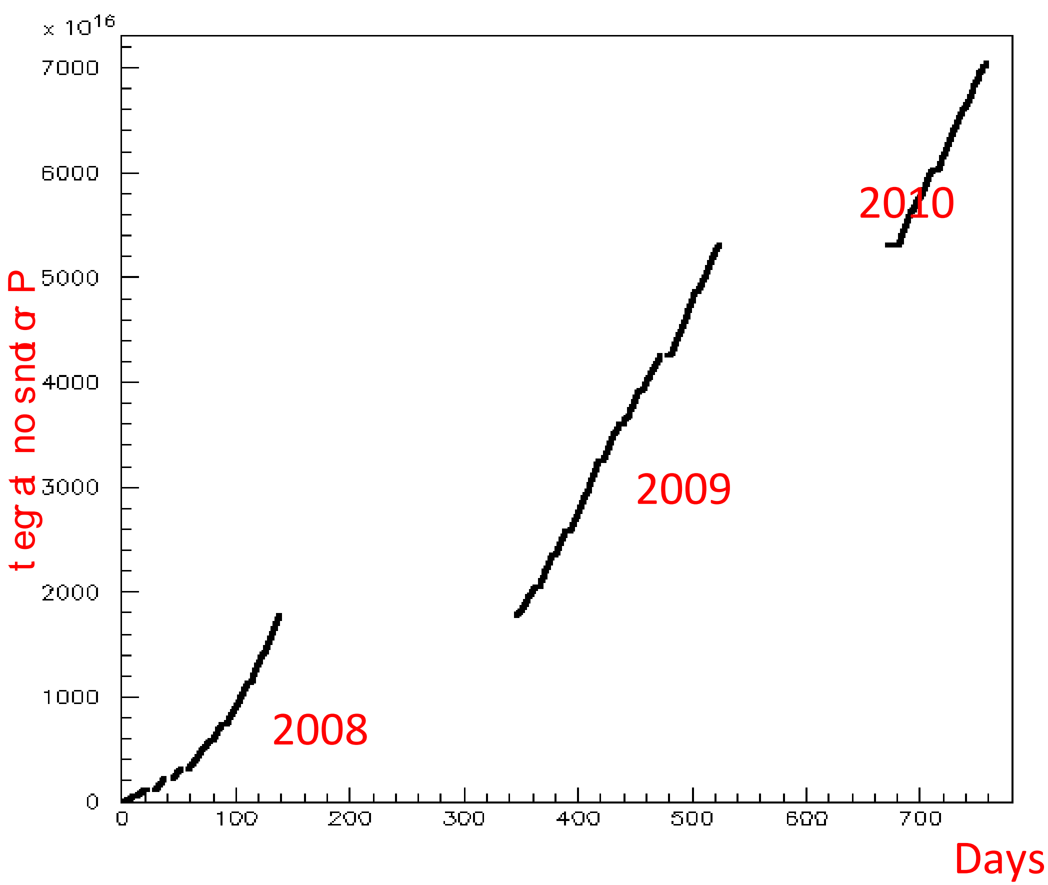
~ 160 $\nu_e + \nu_e$ CC

~ 115 ν_τ CC ($\Delta m^2 = 2.5 \times 10^{-3}$ eV^2)



CNGS neutrino beam performances

2006	0.076×10^{19} pot	Commissioning
2007	0.082×10^{19} pot	Commissioning
2008	**1.78×10^{19} pot**	**First physics run**
2009	**3.52×10^{19} pot**	**Physics run**
2010	**1.74×10^{19} pot (19 July)**	**Physics run**

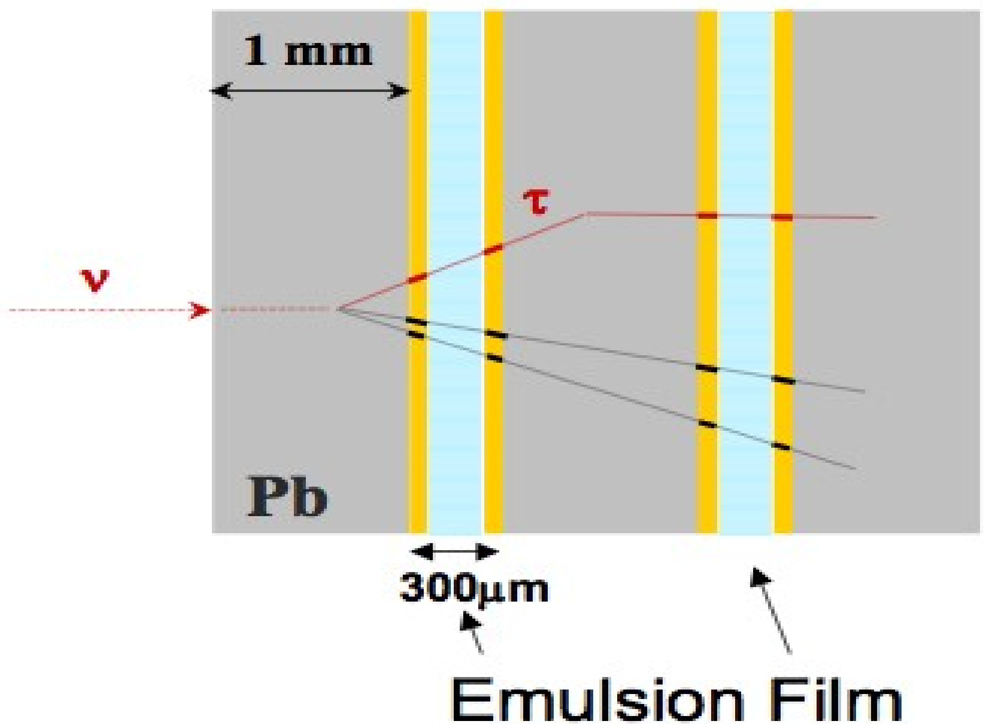


Improving features in 2010: beam close to nominal intensity;

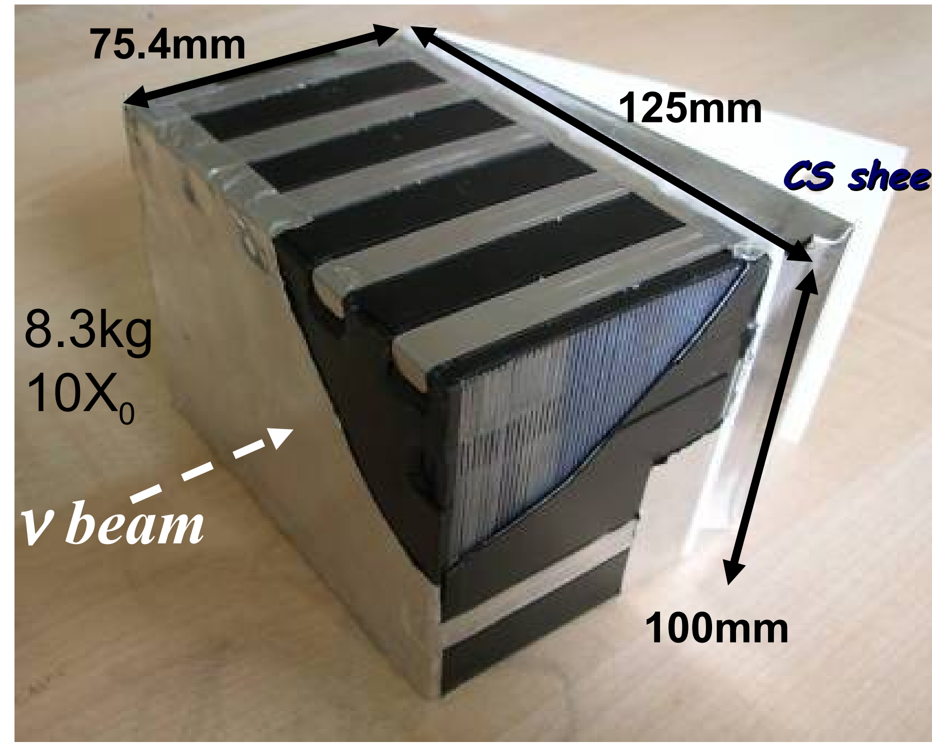
Aiming at higher intensity run in 2011

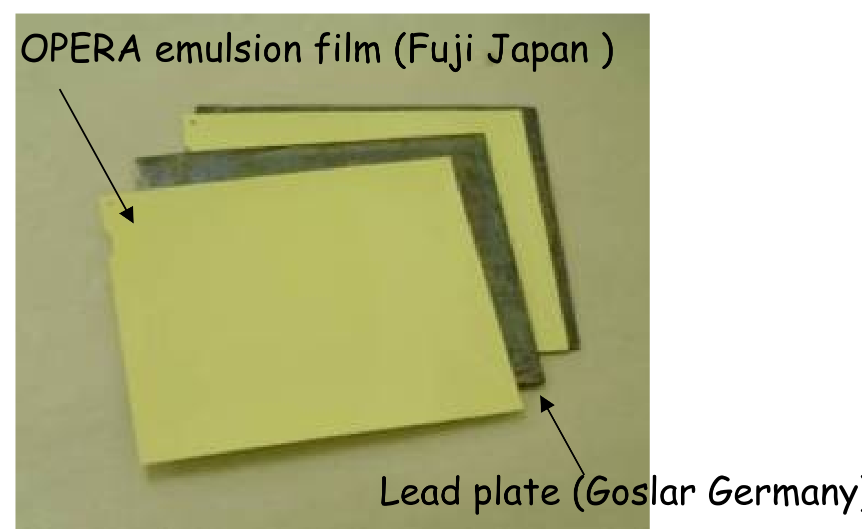
Detecting τ leptons with ECC detectors

The heart of the experiment:
THE ECC TARGET BRICKS



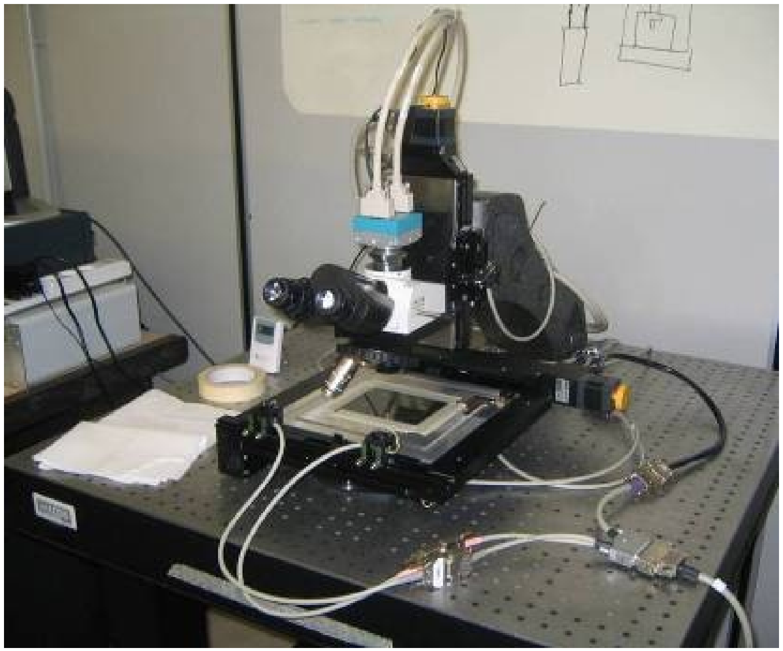
Stack of
57 OPERA films,
56 lead plates (10 X_0)





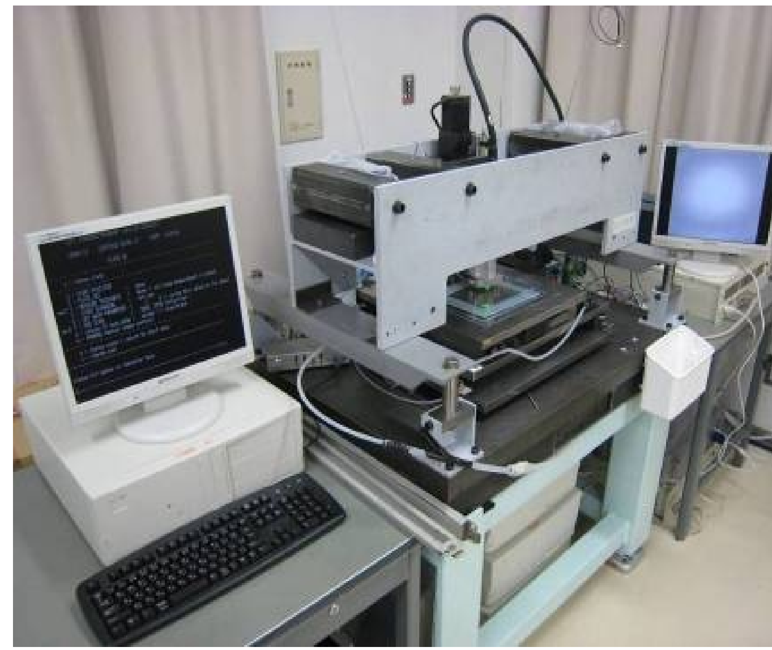
Emulsion film scanning

EU: ESS (European Scanning System)



- Scanning speed/system: 20cm²/h
- Customized commercial optics and mechanics
- Asynchronous DAQ software

Japan: SUTS (Super Ultra Track Selector)



- Scanning speed/system: 75cm²/h
- High speed CCD camera (3 kHz), Piezo-controlled objective lens
- FPGA Hard-coded algorithms

<u>Similar performances</u>

- ~ 0.3 micron spatial resolution
- ~ 2 mrad angular resolution

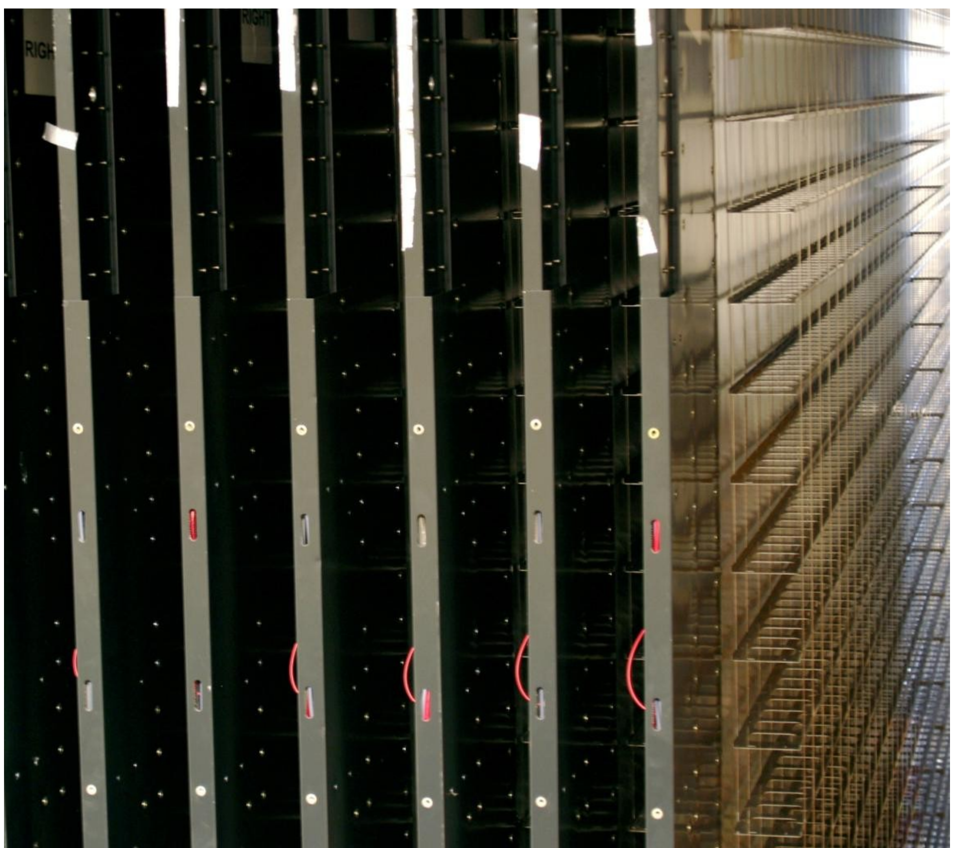
The target region of the OPERA detector

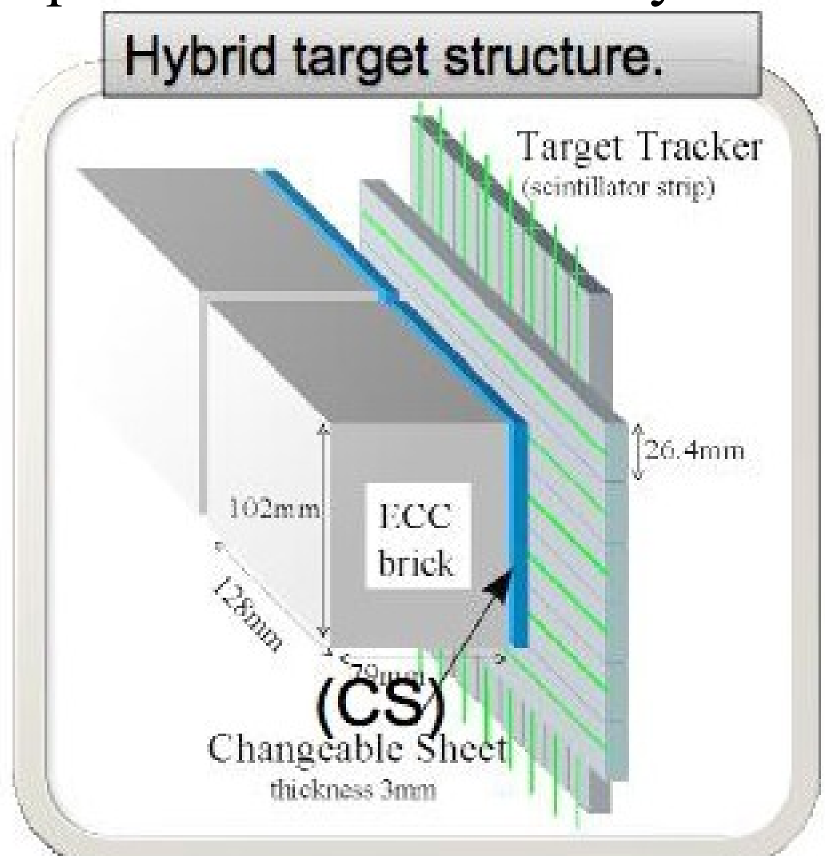
The OPERA detector is hybrid: *bricks* are organized in *walls* interleaved with scintillating strips

Electronic detectors:

•Provide timing information on neutrino events

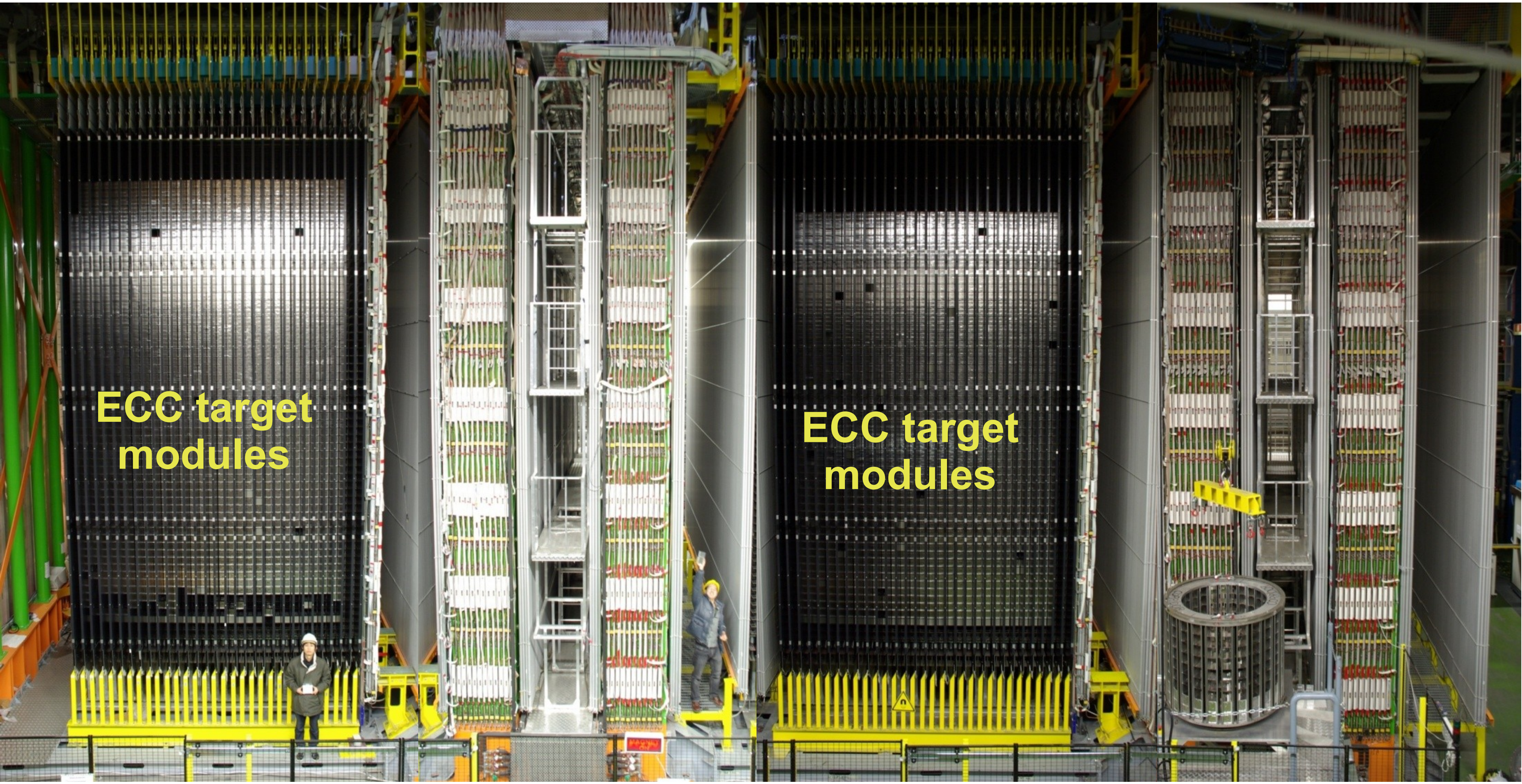
•Preselect the neutrino interaction point with ≅cm accuracy





The OPERA detector

SM1 SM2

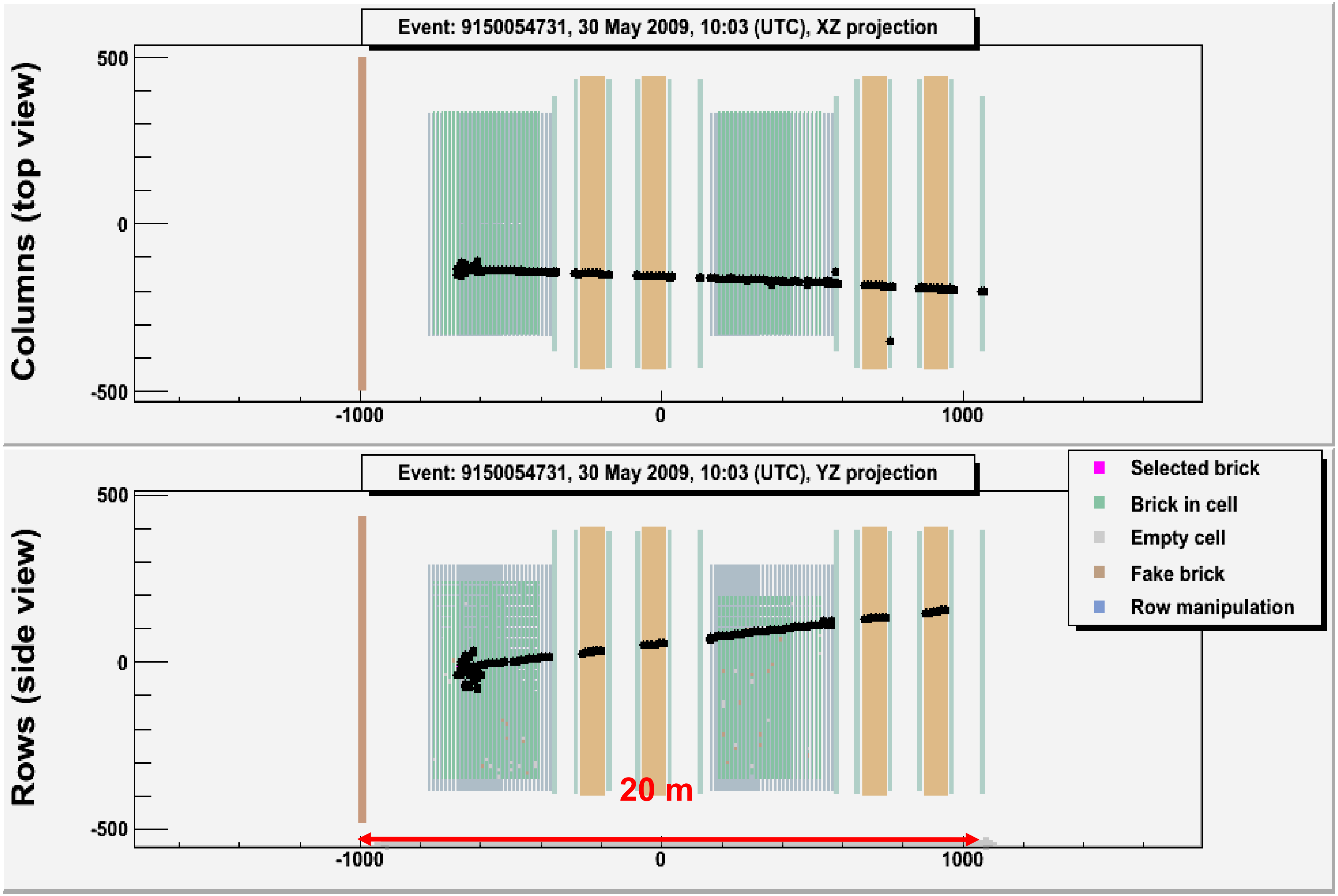


Target area Muon spectrometer Target area Muon spectrometer

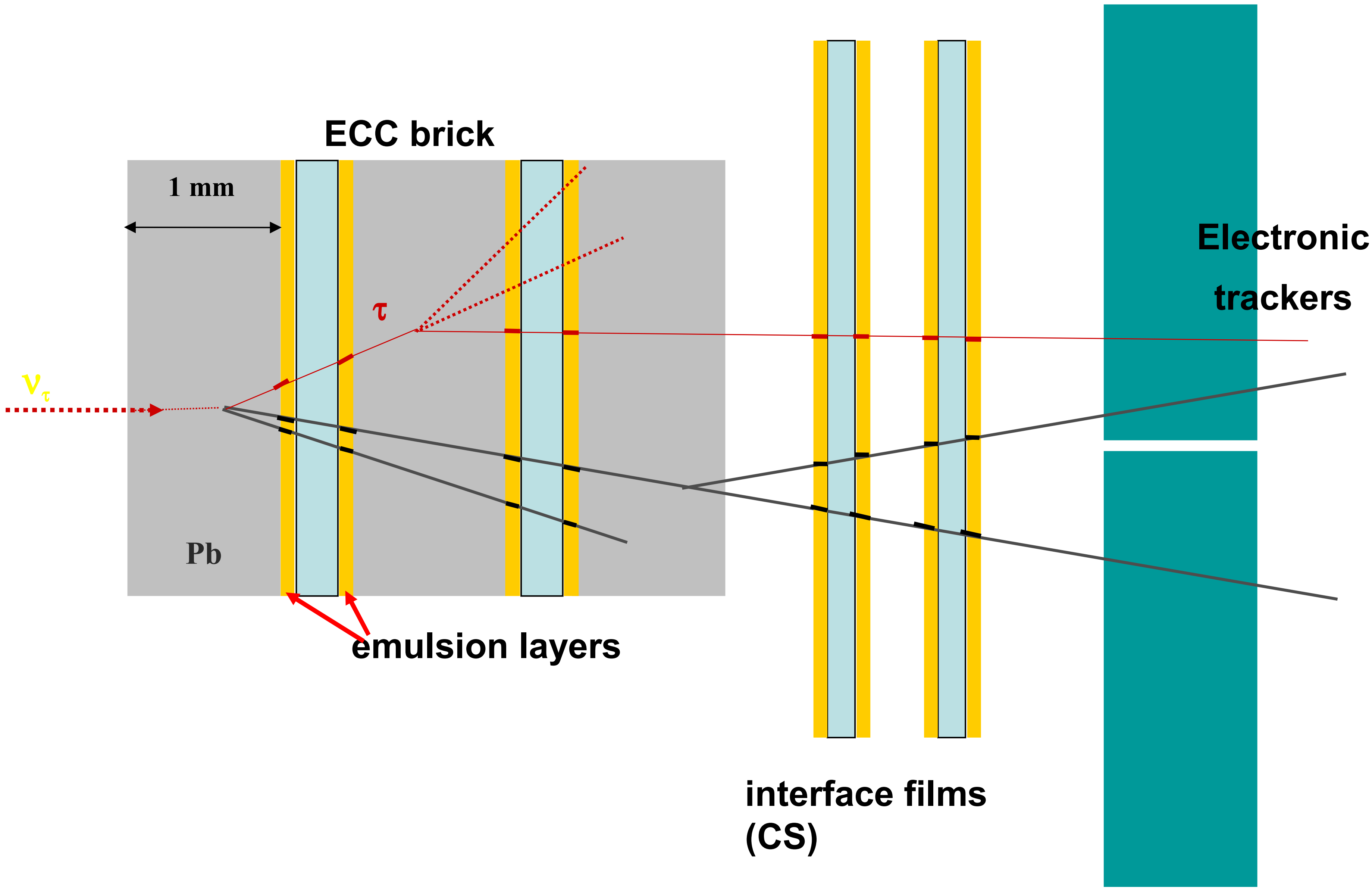
ν event reconstruction

Neutrino event reconstruction in tho phases:

1)Electronic detector reconstruction



2) emulsion analysis



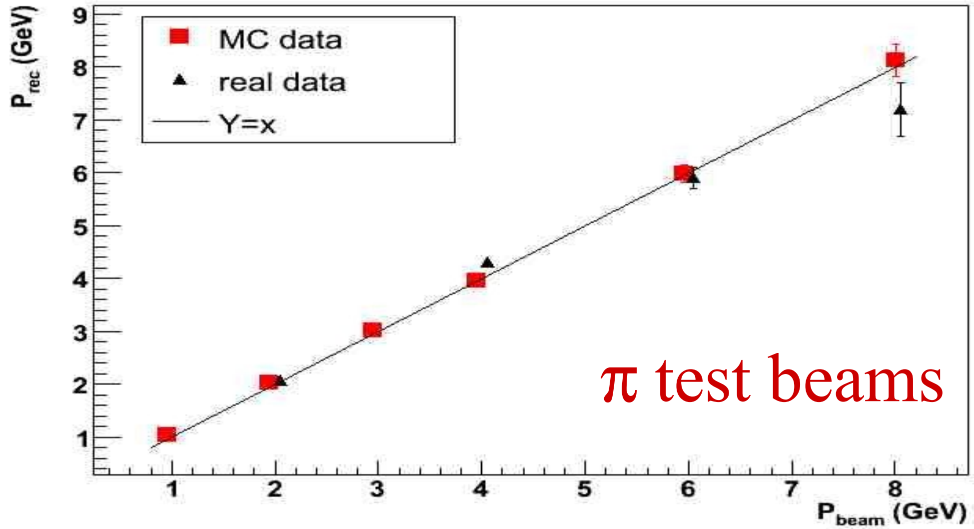
Kinematical measurements in ν event analysis

Important to achieve large signal/background ratio

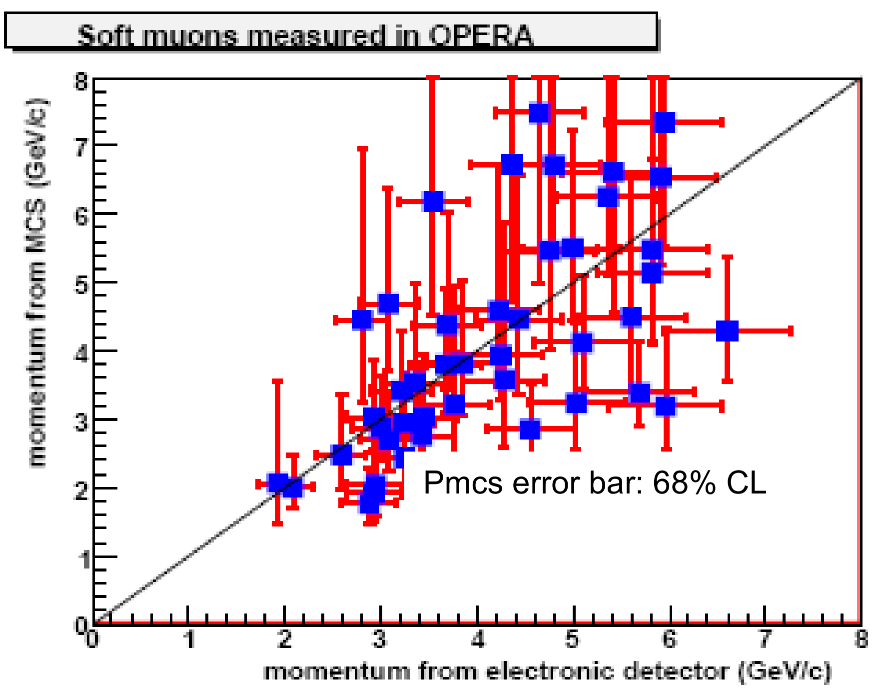
The use of a succession of lead plates as ν target allows:

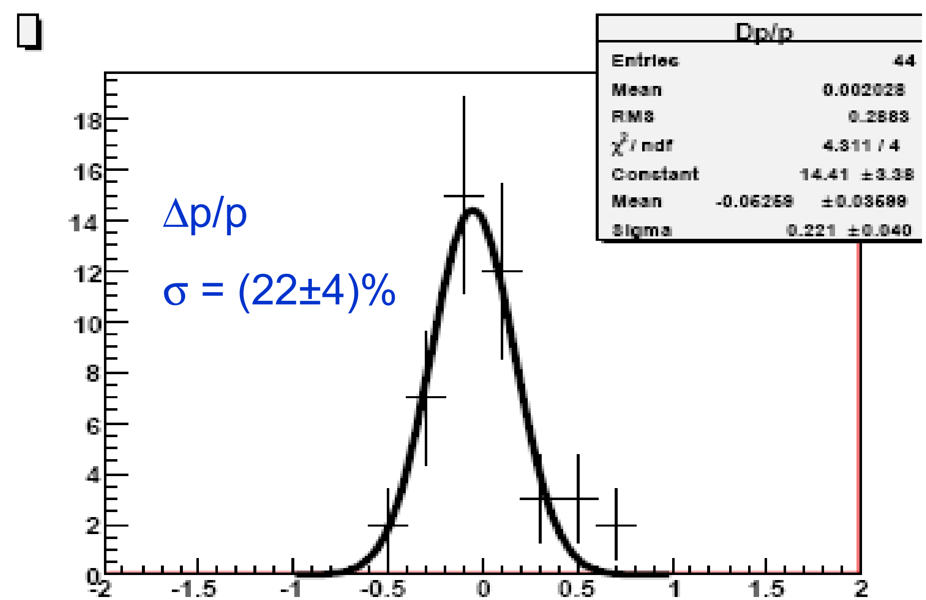
- e/γ identification and e/m shower calorimetry
- momemtum measurement for charged particles

Momentum measurement by Multiple Coulomb Scattering

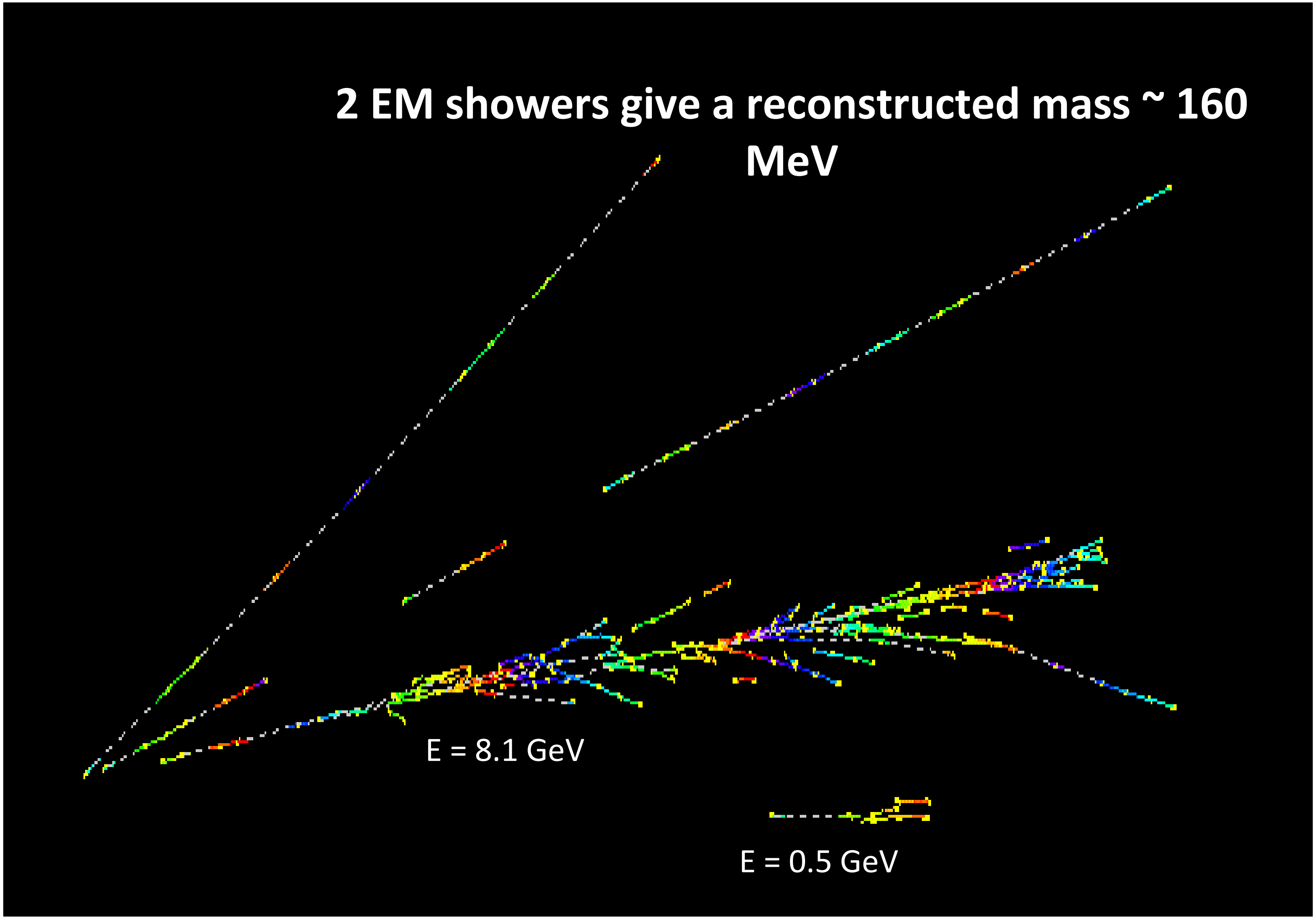


Comparison with muon spectrometer measurements



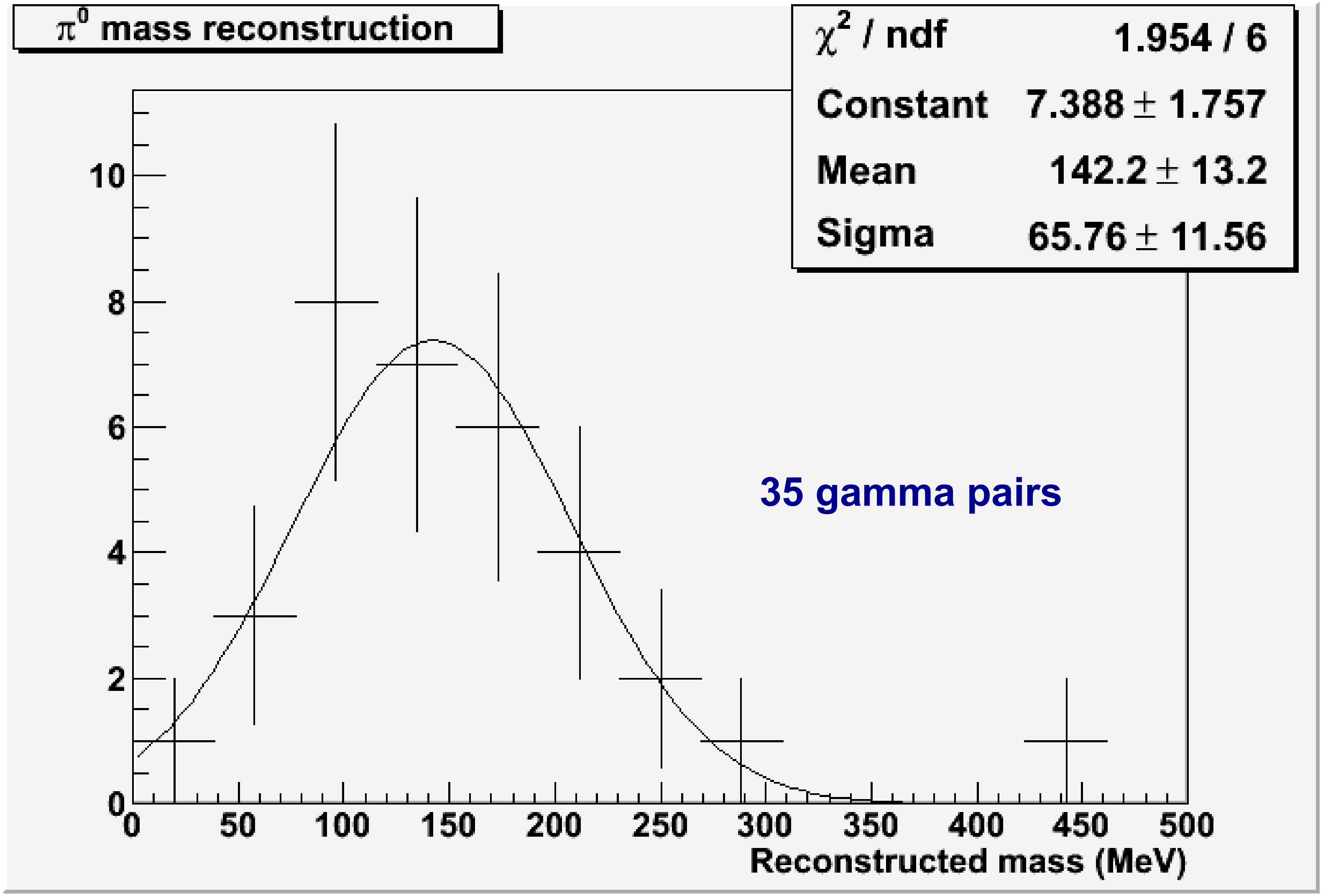


γ detection and π^0 mass reconstruction



EM shower energy measured by shower shape analysis and Multiple Coulomb Scattering method

π^0 mass resolution (data)

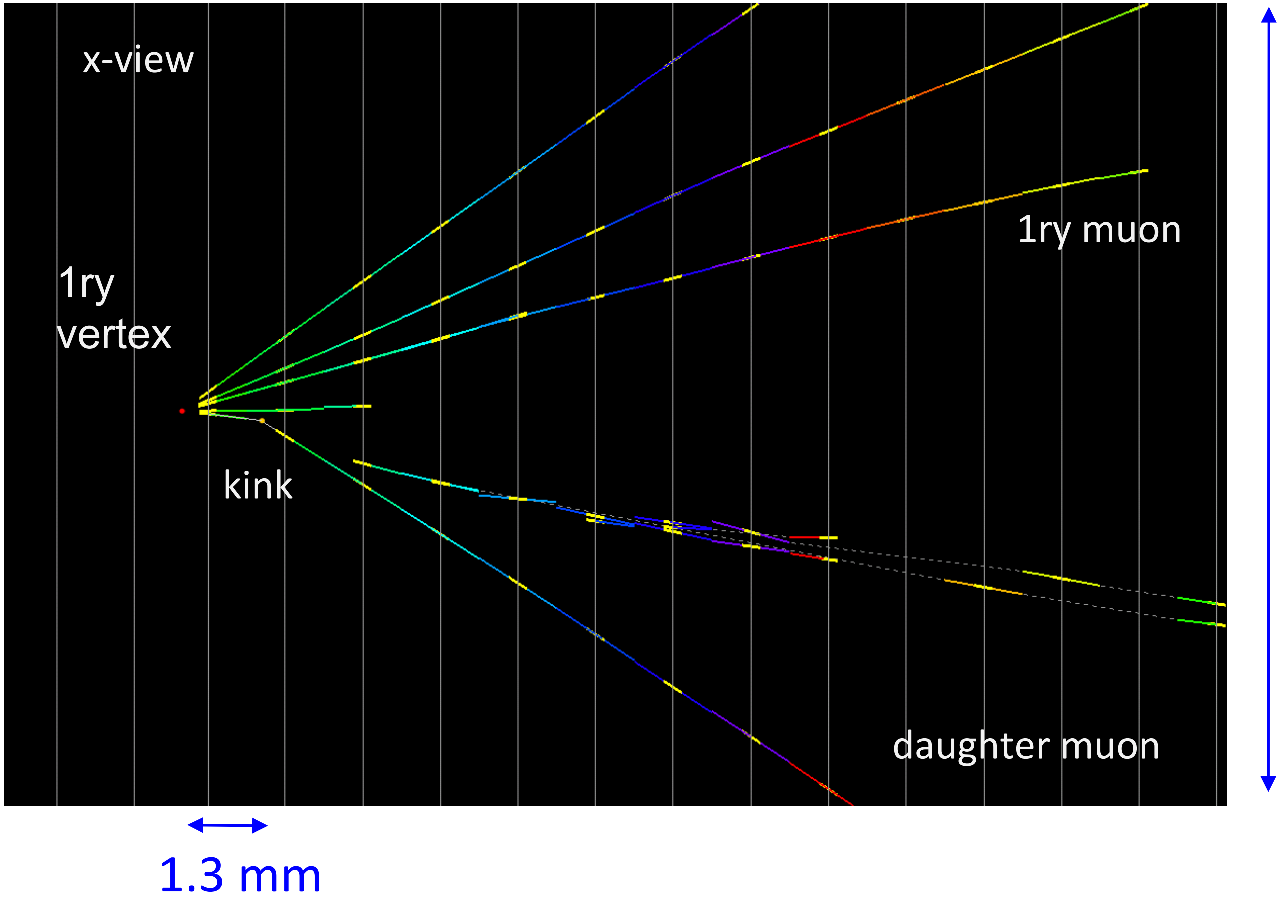


1 σ mass resolution: ~ 45%

Detection of charmed particle produced in ν_μ CC interactions

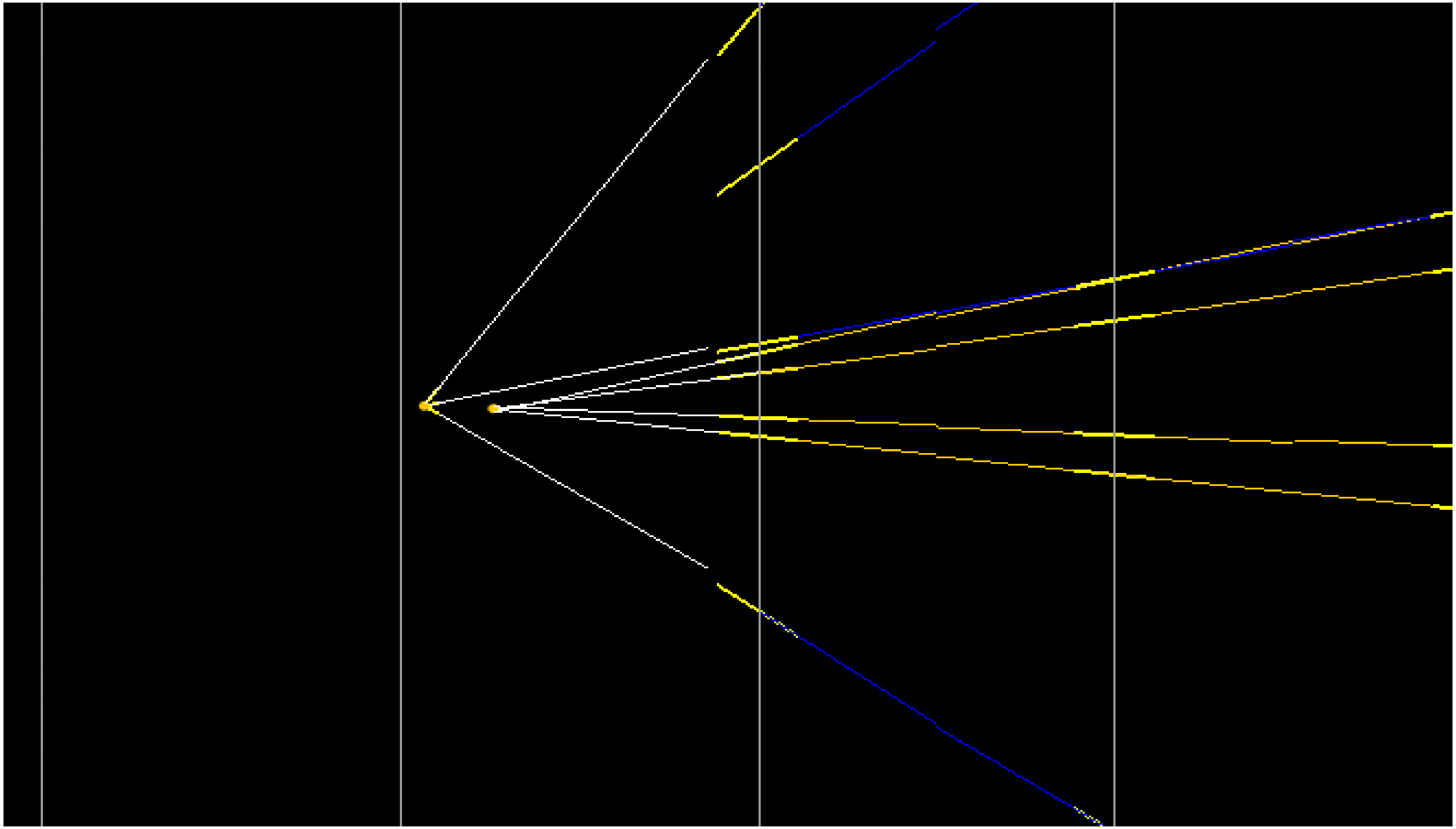
The study of charmed particles production in neutrino events in OPERA is important because of their short lifetime (similar to the τ) and because they represent a background source to all tau decay channels

Charm candidate event (dimuon)



flight length: 1330 microns
kink angle: 209 mrad
IP of daughter: 262 microns
daughter muon: 2.2 GeV/c
decay Pt: 0.46 GeV/c

Charm candidate event (4-prong)



Flight lenght: 313.1 microns

ϕ : 173.2^0

minimum invariant mass: 1.7 GeV

Event statistics

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Observation of a first ν_τ candidate event in the OPERA experiment in the CNGS beam

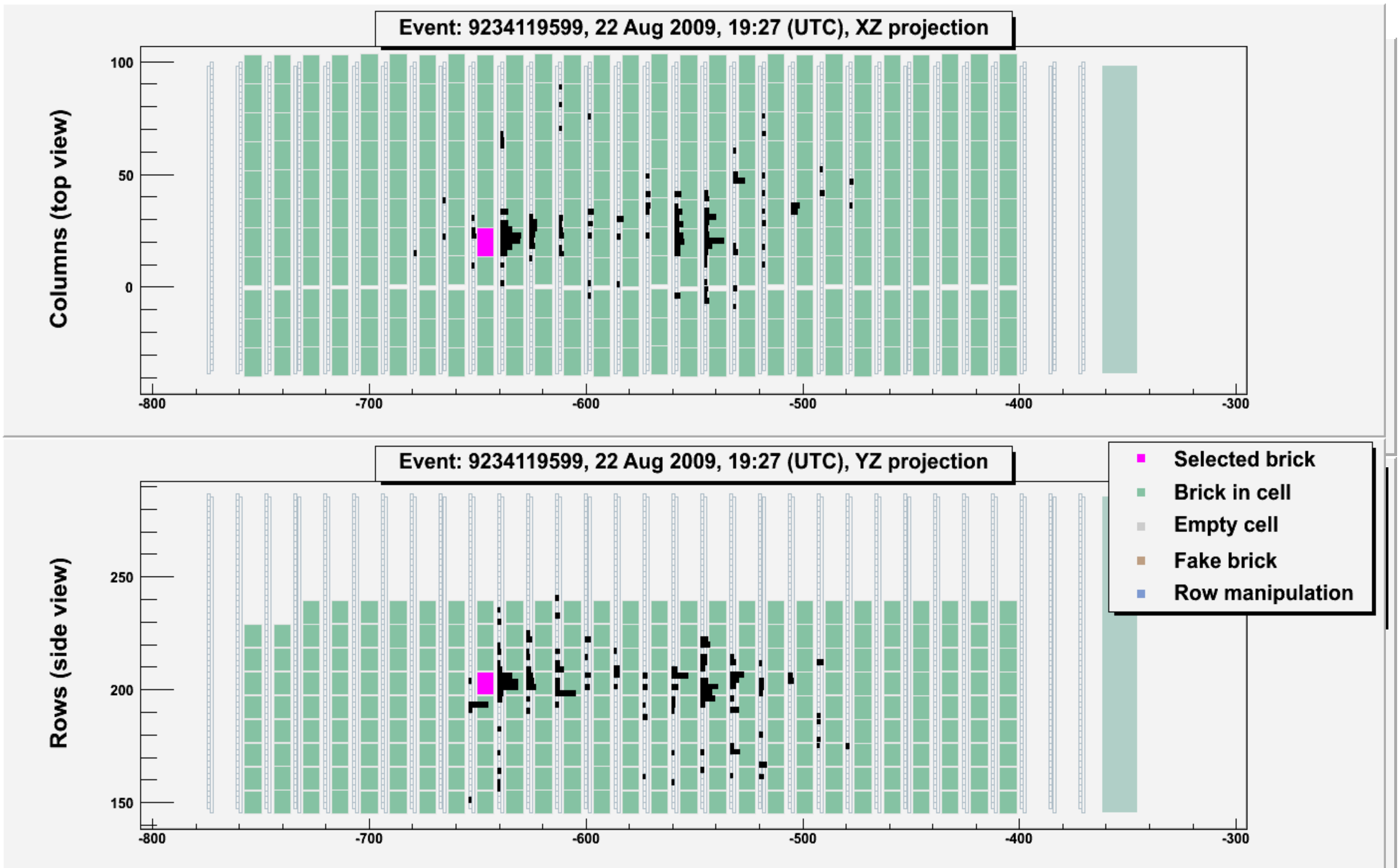
Total found neutrino vertices: 1617
Events with search of decay topologies completed: 1088
(current number is ≅1700)

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

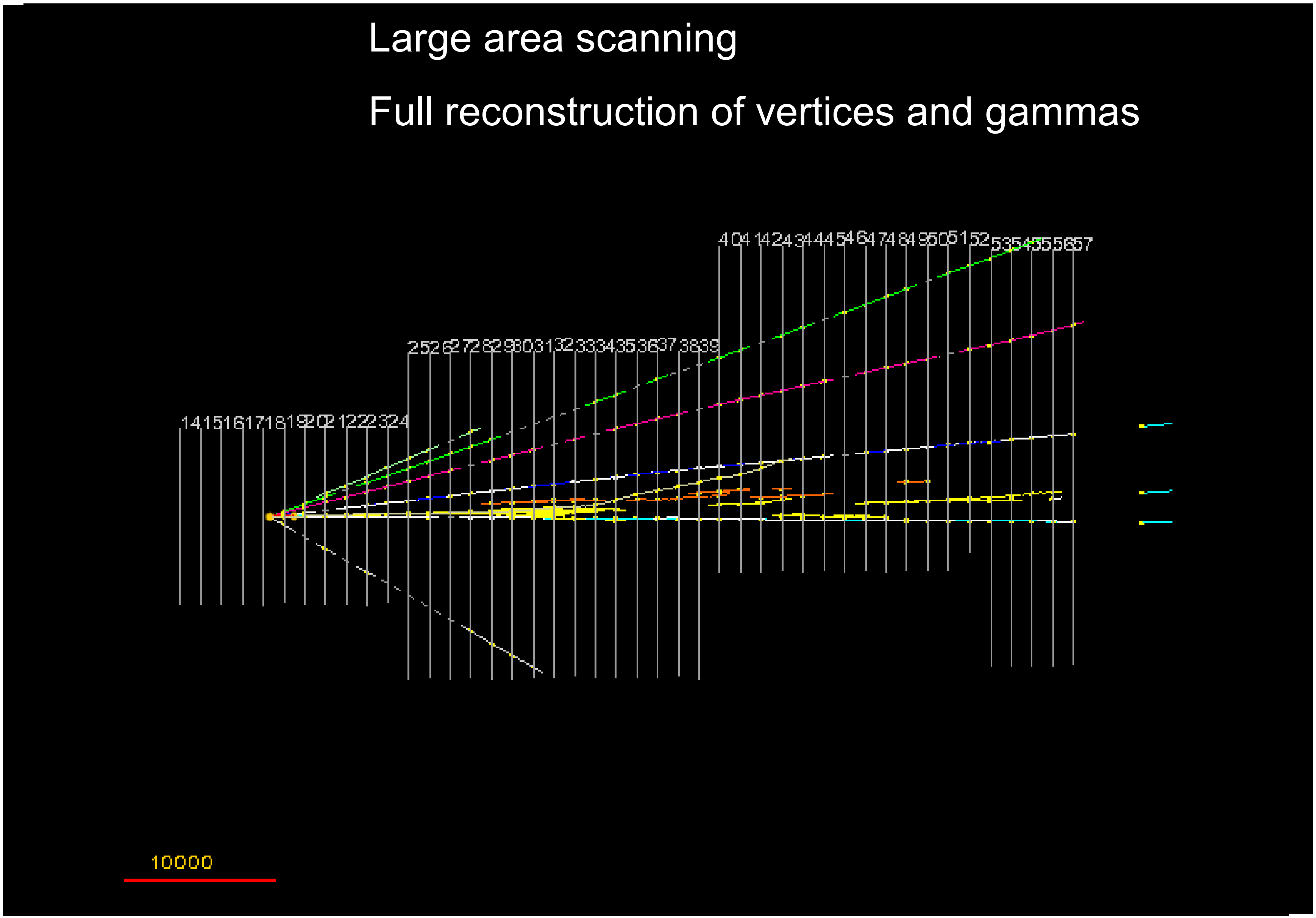
With the above statistics, and for $\Delta m^2_{23} = 2.5 \times 10^{-3}\ eV^2$ and full mixing,
OPERA expects: ~ 0.5 ν_τ events

A very interesting event

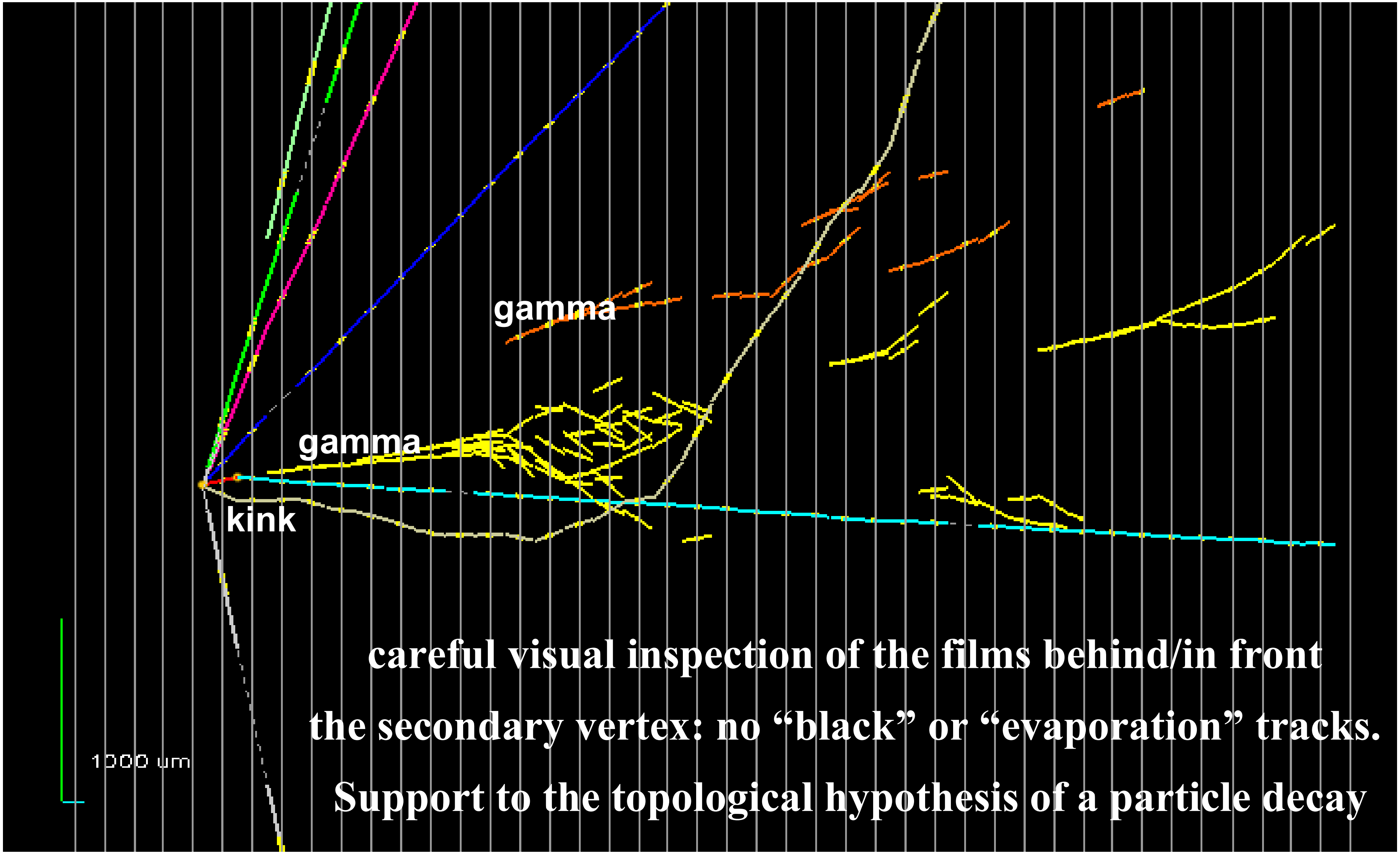
Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC) (as seen by the electronic detectors)



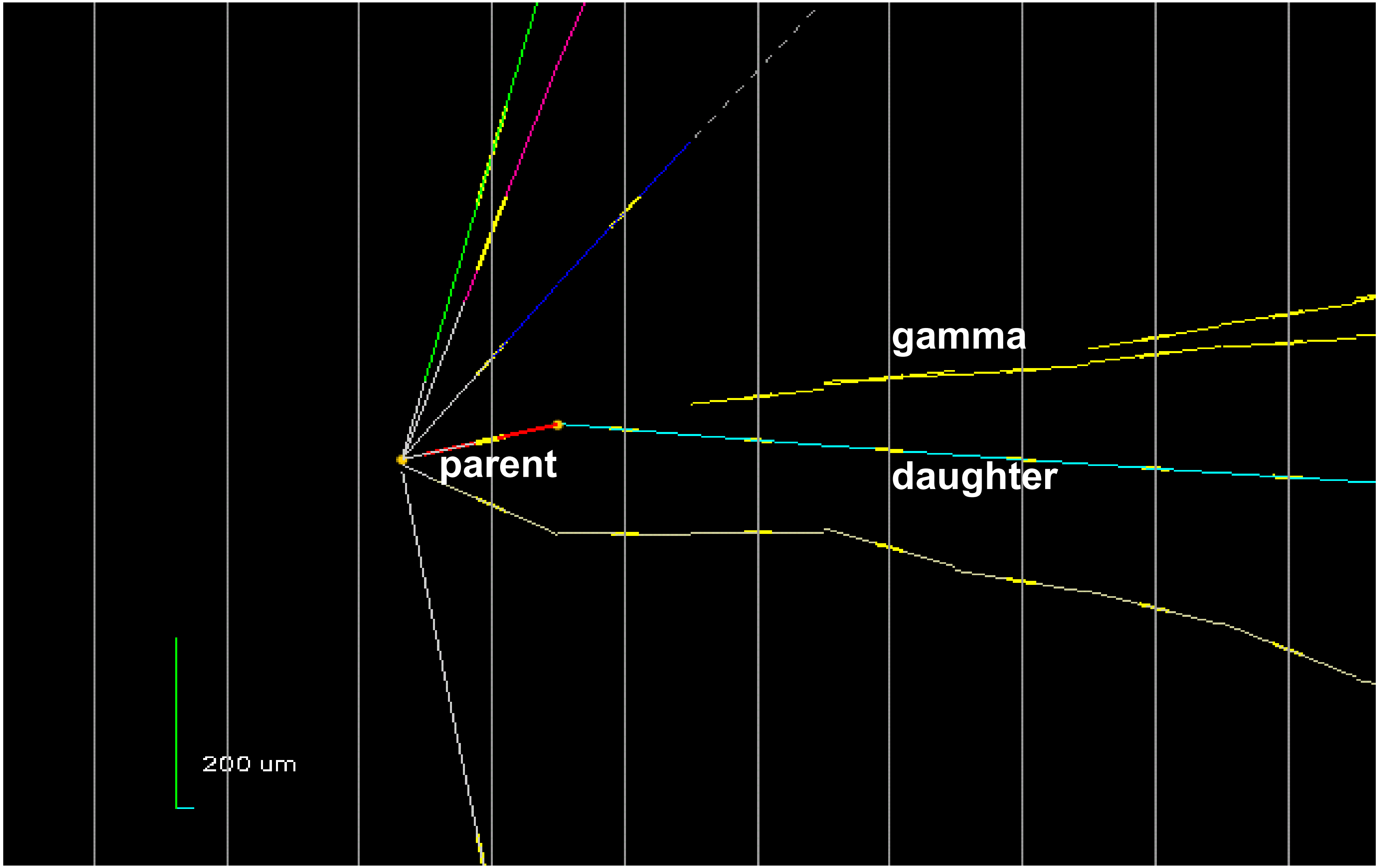
From CS to vertex location



Event reconstruction (I)



Event reconstruction (II)

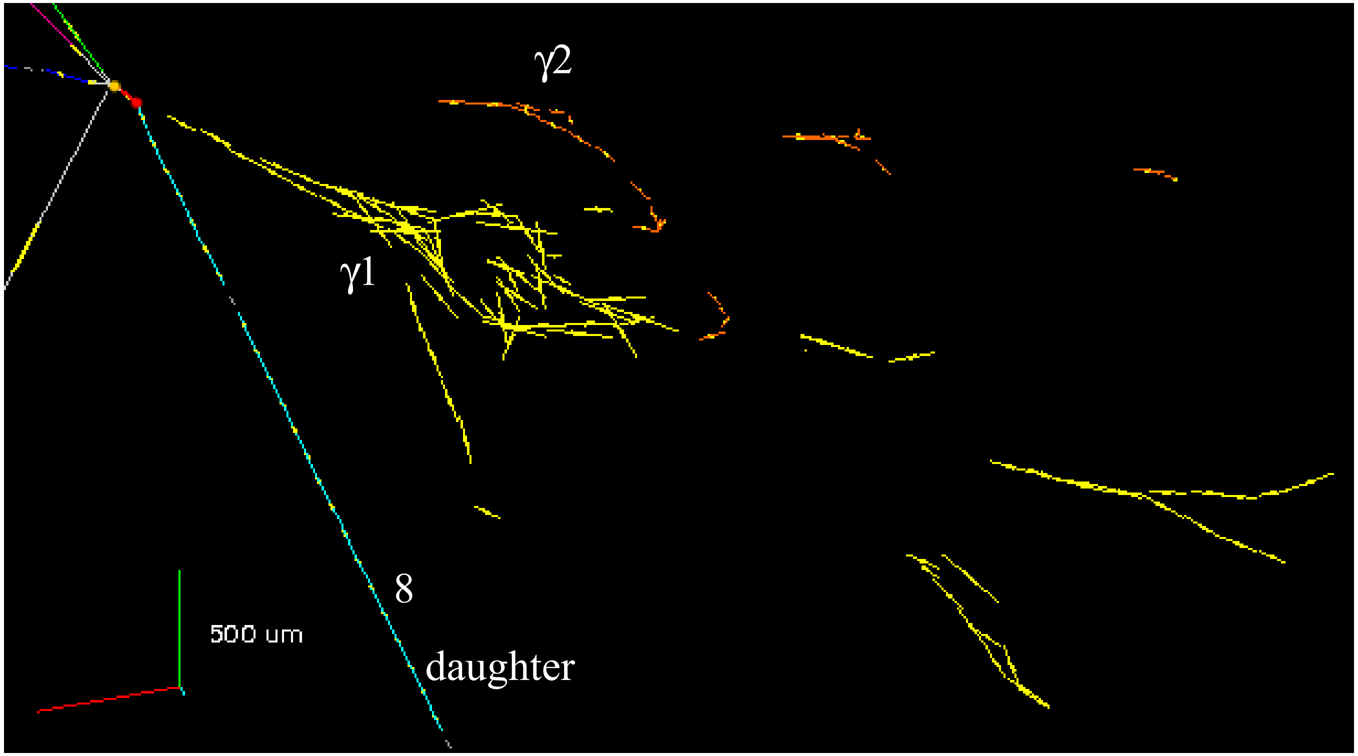


Features of event tracks

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	

Residual probability to be a ν_μCC event (due to a possibly undetected large angle muon) ~1%.

γ detection



- length available for γ detection downstream of the vertices: 6.5 X_0

- 2 gammas detected, both assumed to come from secondary vertex after impact parameter analysis

	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

Kinematical variables

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

VARIABLE	AVERAGE
kink (mrad)	**41 ± 2**
decay length (μm)	**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
Uncertainty on Pt due to the gamma attachment choice is smaller than 50 MeV

Topological and kinematical analysis

OPERA analysis flow (as defined in the experiment proposal) applied to this candidate event:

- 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 ≥ 1 gamma pointing to the decay vertex
- missing Pt at primary vertex lower than 1 GeV/c
- azimuth angle between the resulting hadron momentum direction and the parent track direction larger than $\pi/2$ rad

Event interpretation and invariant mass analysis

- This event passes all cuts, with the presence of at least 1 gamma pointing to the secondary vertex
- This event is a ν_τ candidate with 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 below).
- The invariant mass of the (daughter+γ+γ) system is compatible with that of the ρ (770). The ρ appears in about 25% of the τ decays: $\tau \rightarrow \rho\ (\pi^- \pi^0)\ \nu_\tau$.

(γ+γ) mass	(γ+γ+daughter) mass
120 ± 20 ± 35 MeV	$640\ ^{+125}_{-80}\ ^{+100}_{-90}$ MeV

Background sources

- Prompt ν_τ ~ 10^{-7}/CC
- Decay of charmed particles produced in ν_e interactions ~ 10^{-6}/CC
- Double charm production ~ 10^{-6}/CC

- Decay of charmed particles produced in ν_μ interactions ~ 10^{-5}/CC
- Hadronic reinteractions ~ 10^{-5}/CC

Statistical significance

1 ν_τ candidate in the 1 prong decay channel observed.

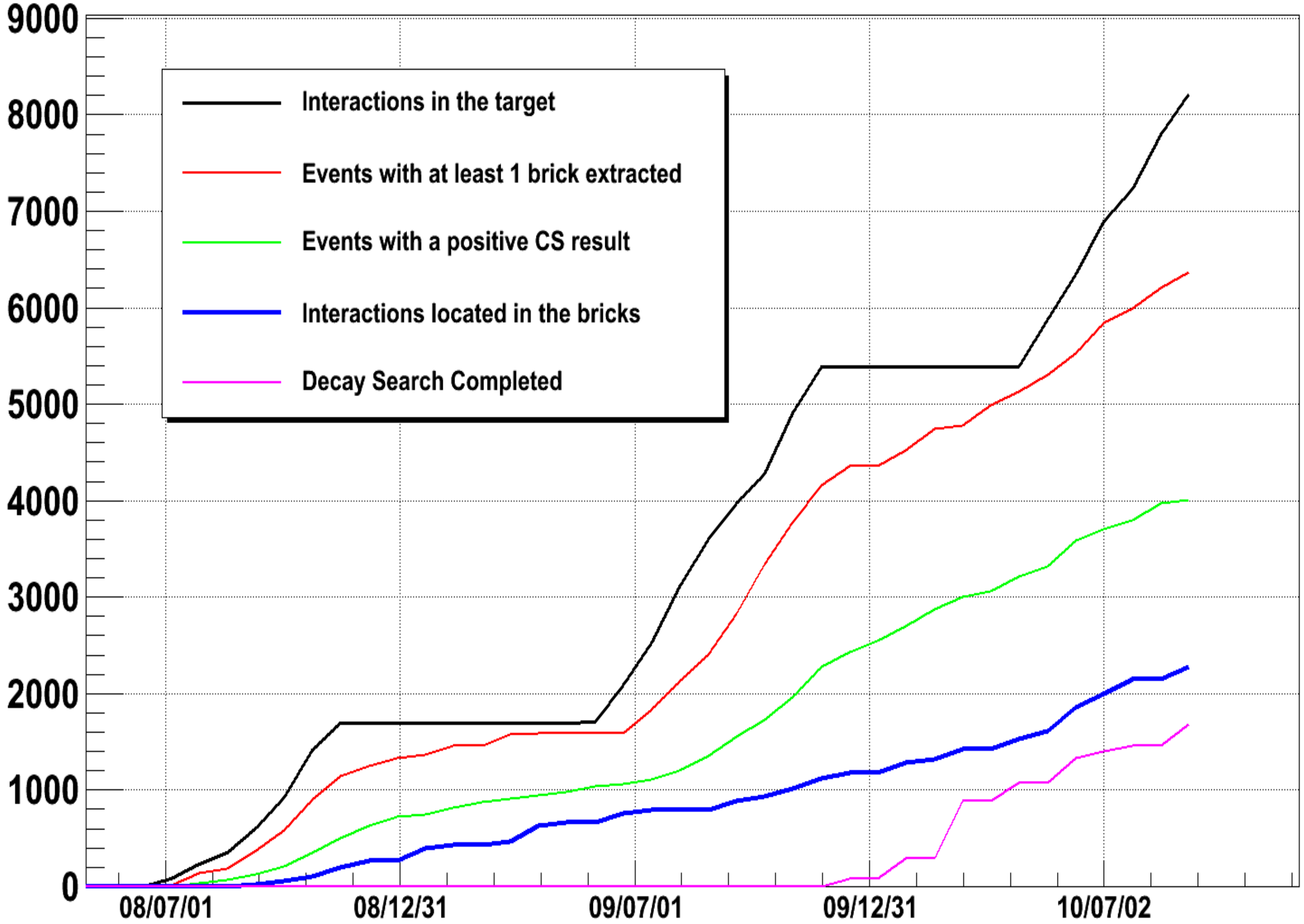
Given the statistics mentioned before, the background expectation is:

Considering all decay channels: 0.045 ± 0.020 (syst) BG events
Considering only $\tau \rightarrow 1$prong channel: 0.018 ± 0.007 (syst) BG events

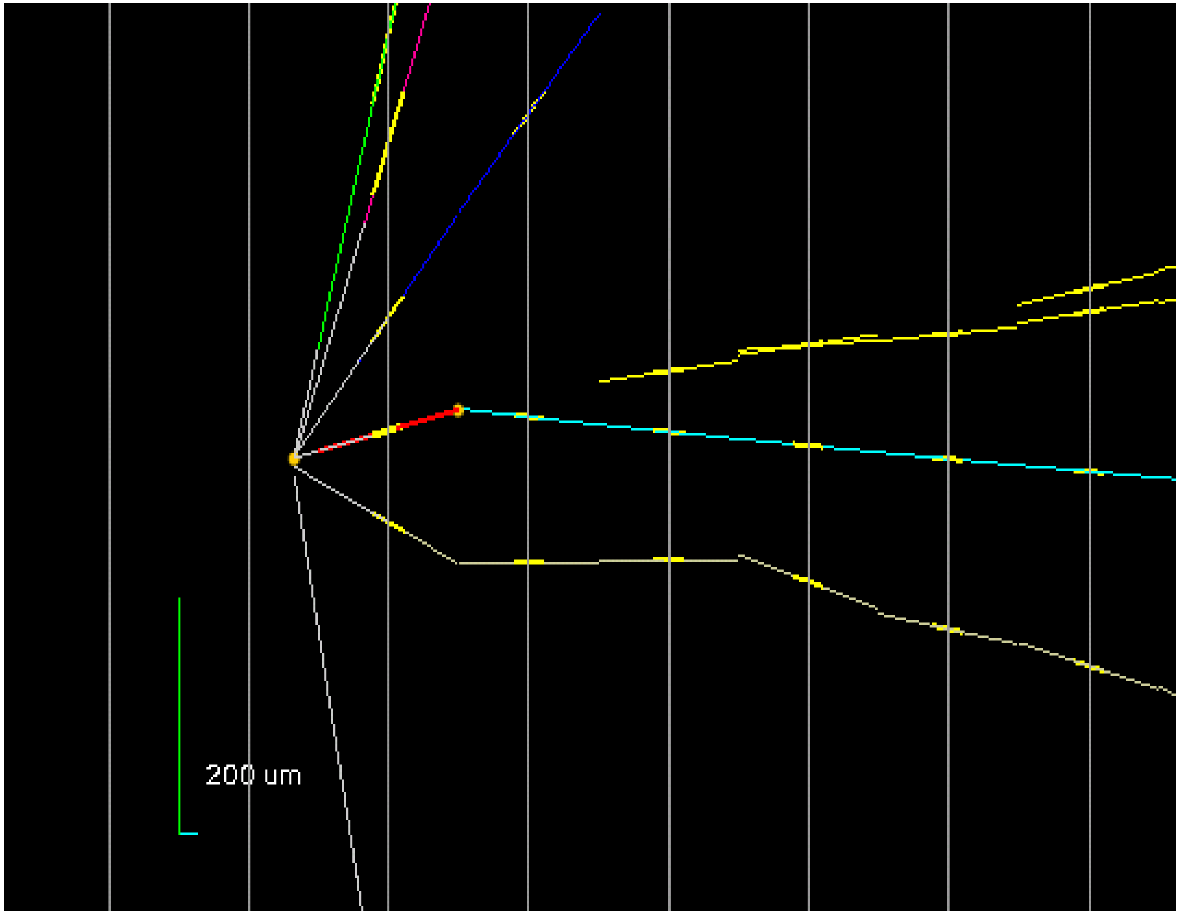
The probability to observe at least 1 BG event is (all decay channels) 4.5%.
The probability to observe at least 1 BG event is (only t $\rightarrow$ 1prong) 1.8%.

The observation of 1 ν_τ canditate event corresponds to a significance of 2.01 σ if we consider all dacay channels, 2.36 σ for the 1prong decay channel.

Outlook



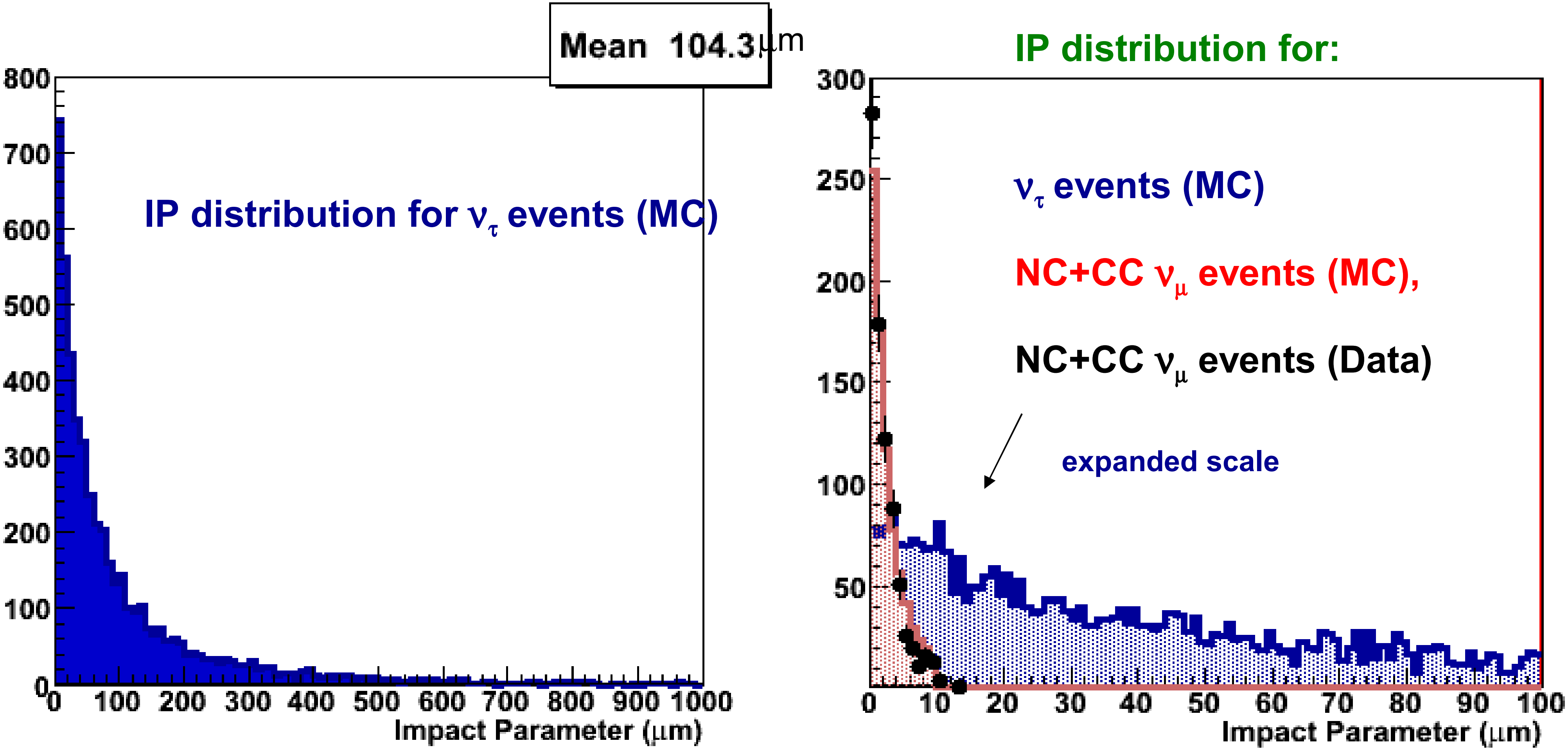
At the present scanning speed we expect to complete the analysis of 2008+2009 runs by the end of 2010 (NB we expect about 2 taus in this sample)



Thank you for your attention!

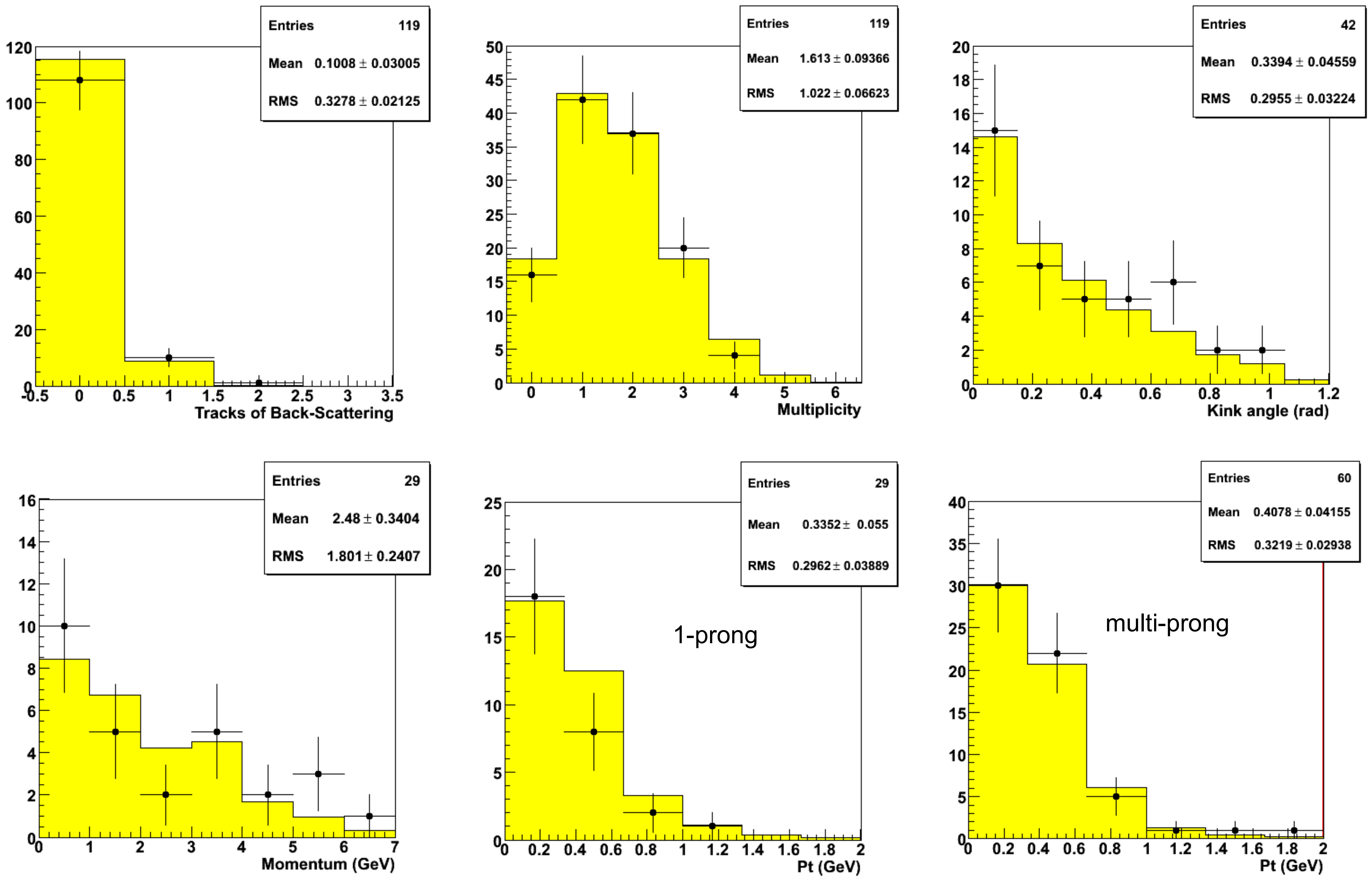
SPARES

Impact parameter measurement



DATA/MC comparison: good agreement in normalization and shape

(pion test-beam exposure)

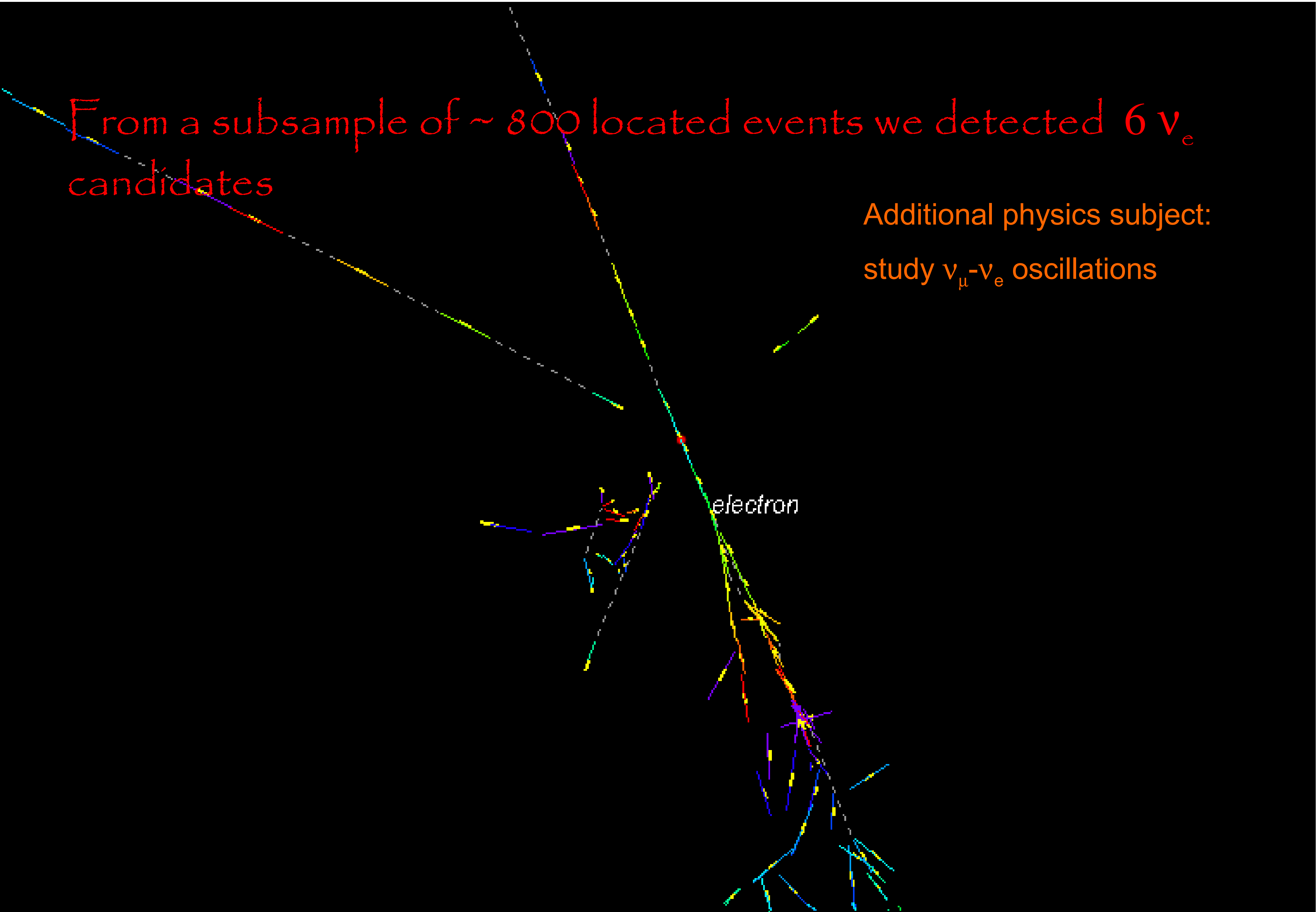


ν_e candidate event

From a subsample of ~ 800 located events we detected **6 ν_e** candidates

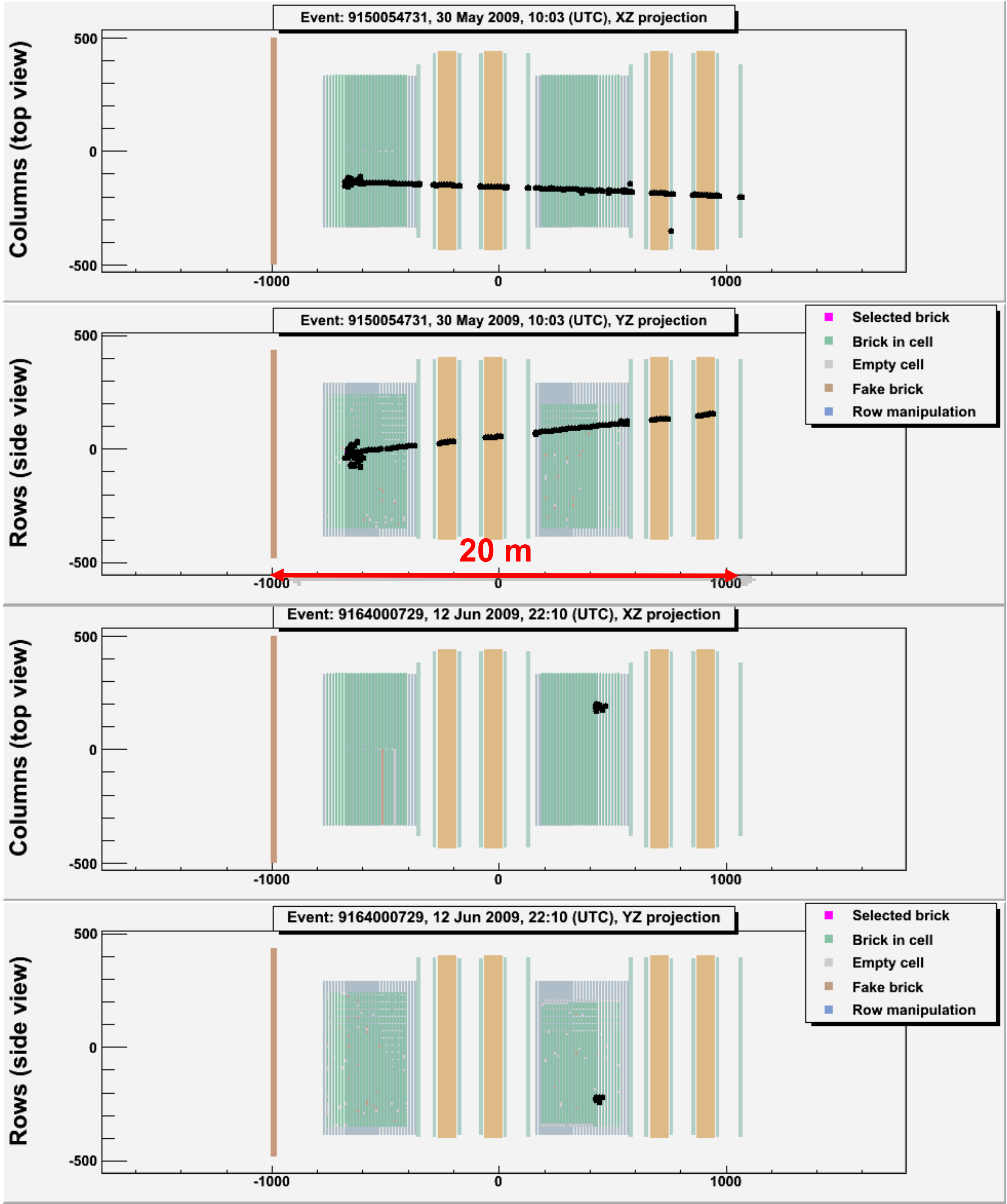
Additional physics subject:

study ν_μ-ν_e oscillations



Typical ν_μCC- and NC-like events

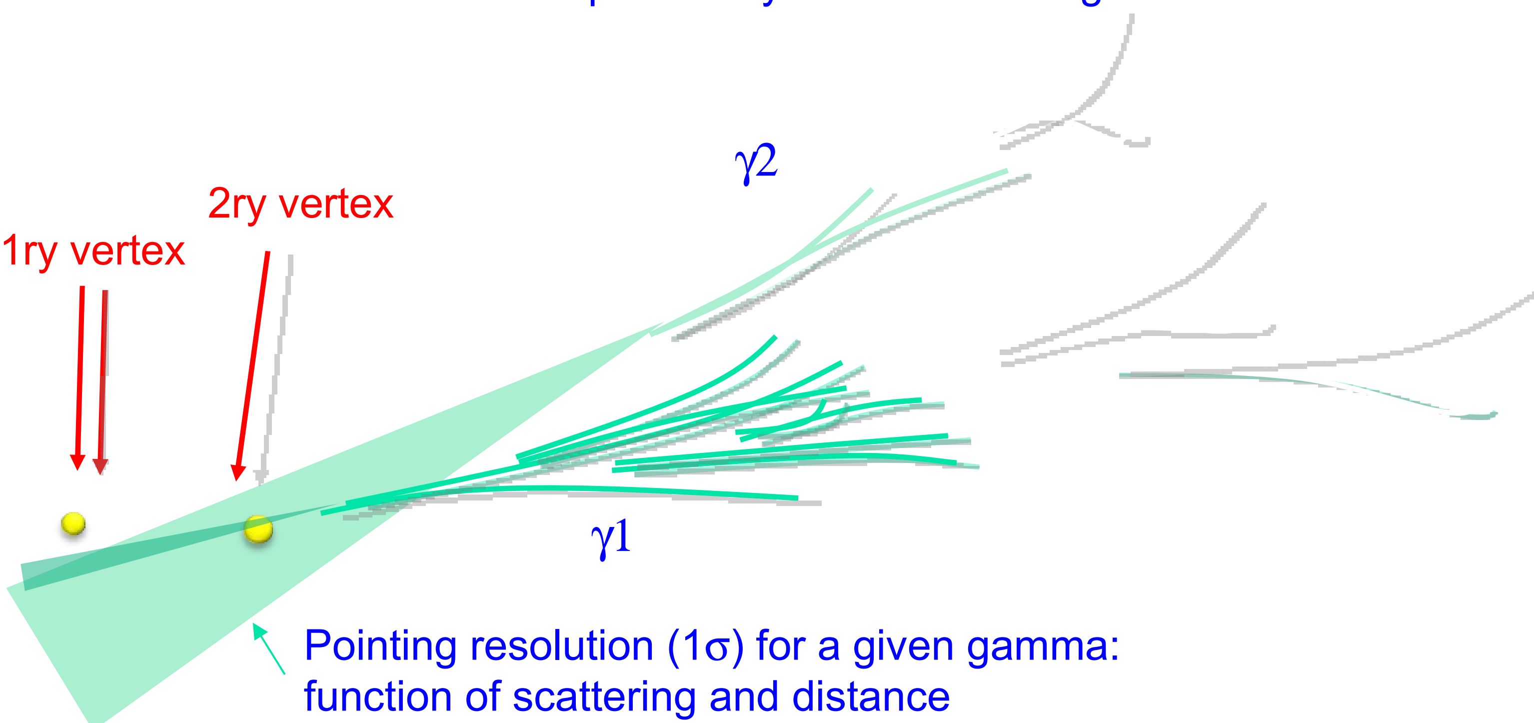
The measured ratio of NC-like/CC-like events after muon ID and event location is ~20%, as expected from simulations



γ attachment to the vertices

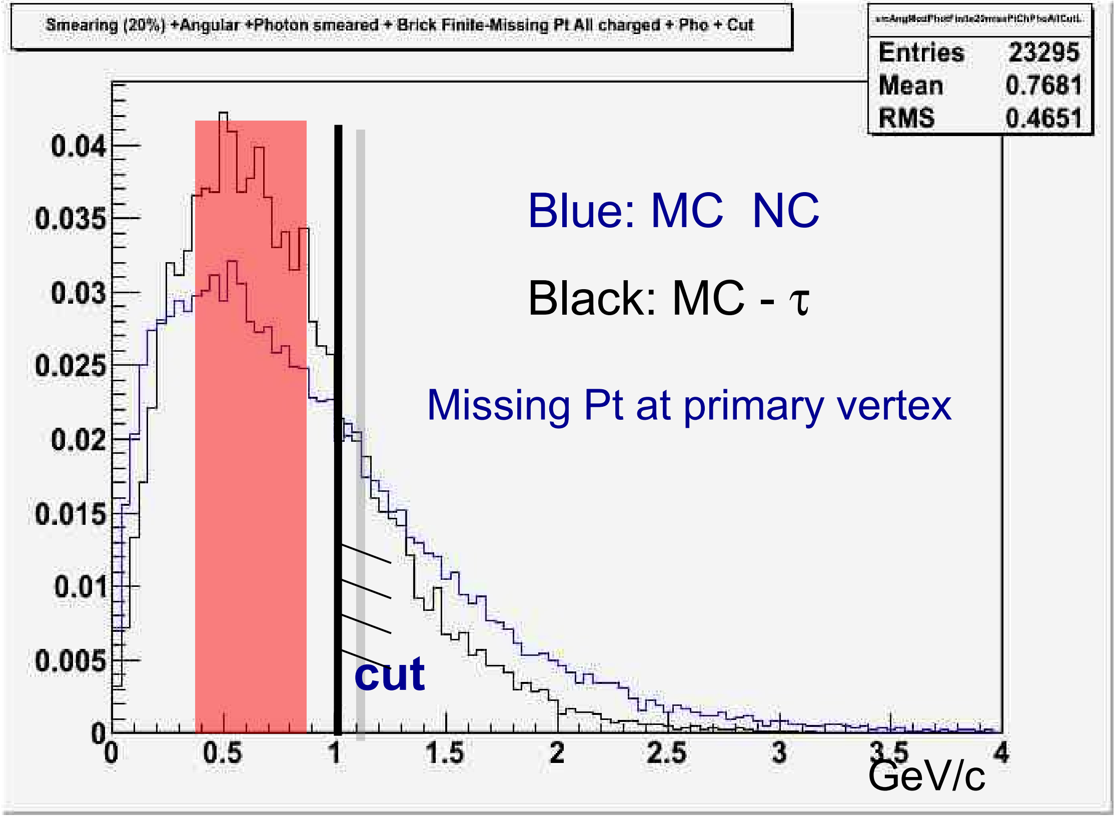
	Distance from 2ry vertex (mm)	IP to 1ry vertex (μm) <resolution>	IP to 2ry vertex (μm) <resolution>	Prob. of attach. to 1ry vtx*	Prob. of attach. to 2ry vtx*	Attachment hypothesis
1st γ	2.2	45.0 <11>	**7.5** <7>	$<10^{-3}$	**0.32**	**2ry vertex**
2nd γ	12.6	85.6 <56>	**22** <50>	0.10	**0.82**	**2ry vertex**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

* probability to find an IP larger than the observed one

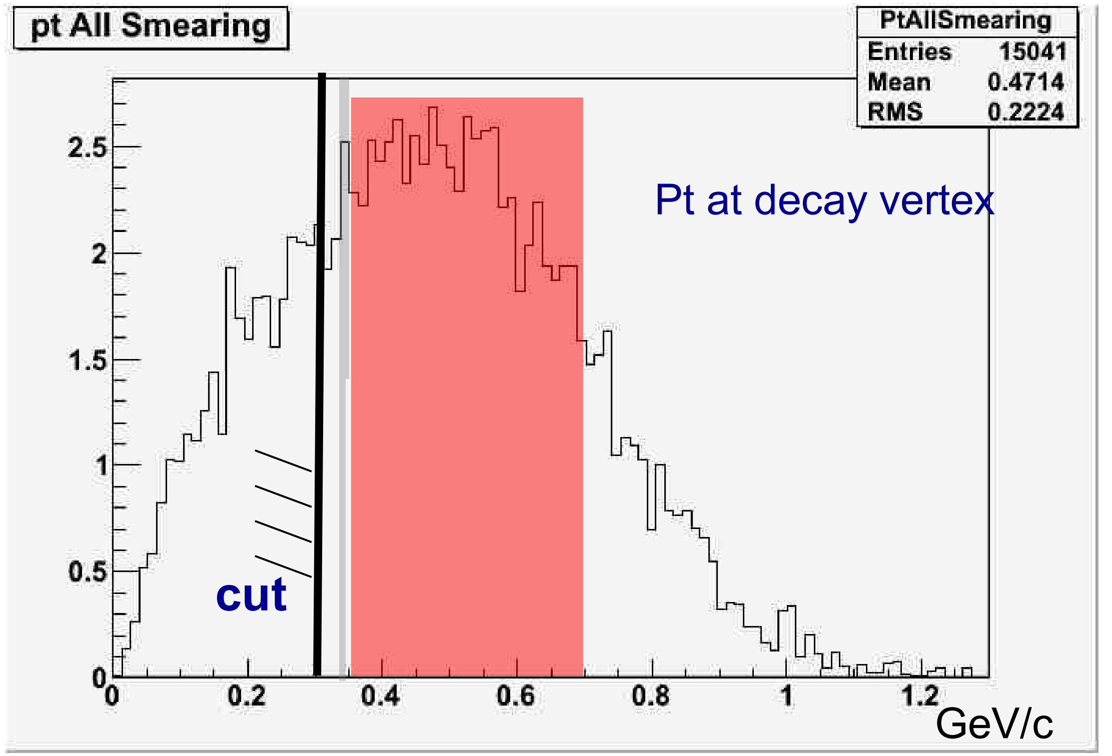


Kinematical cuts to be passed

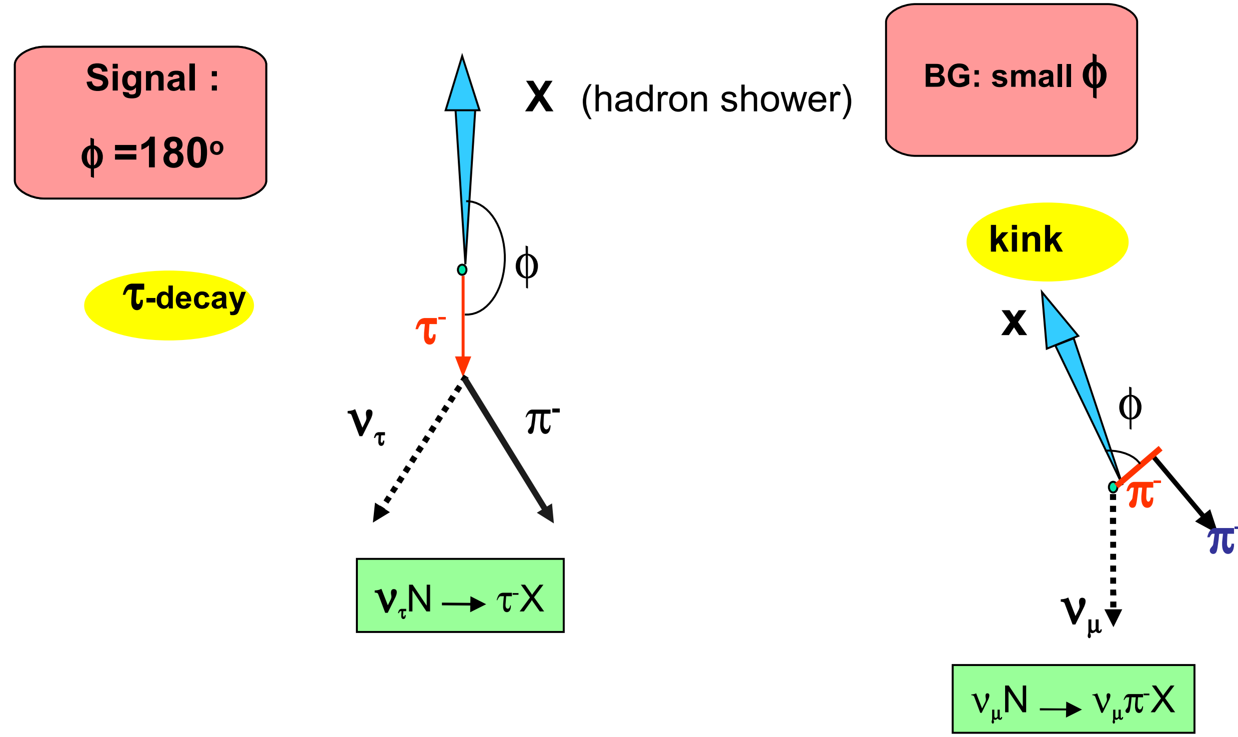
Reject NC events with larger missing Pt (neutrino)

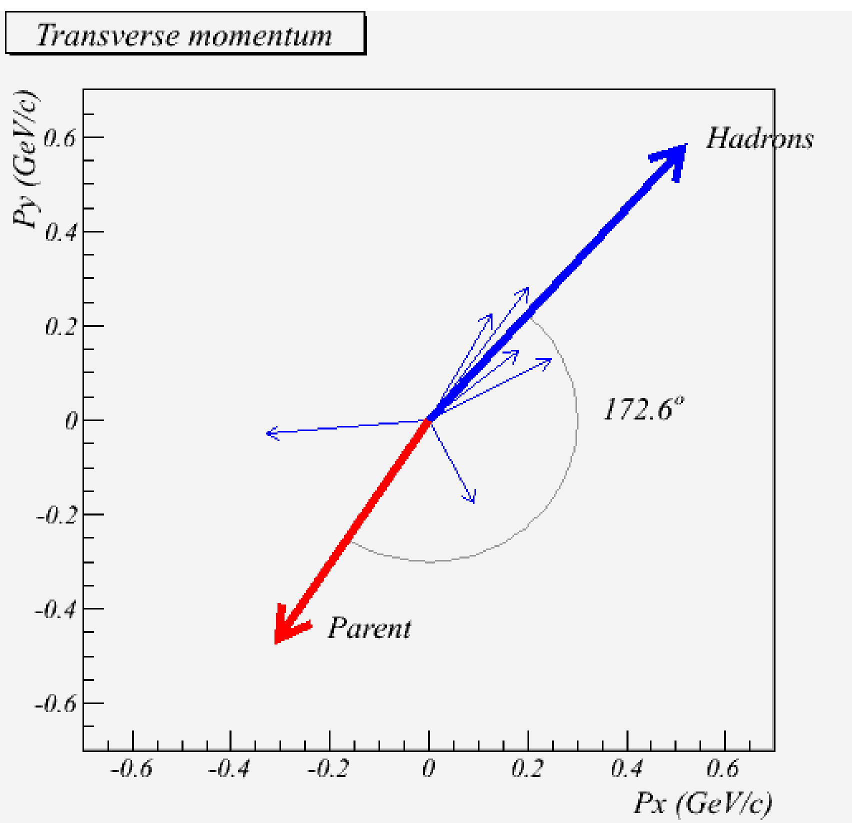


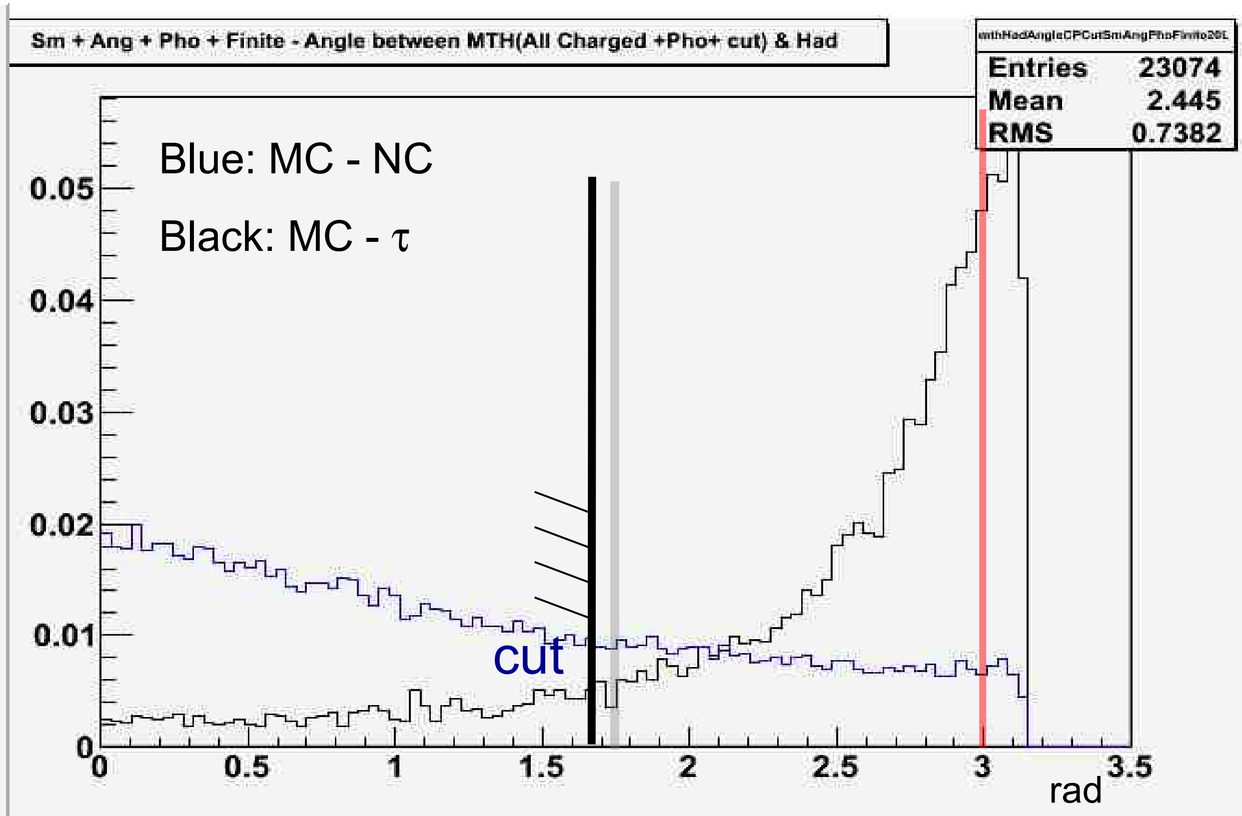
Reject hadron interactions



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



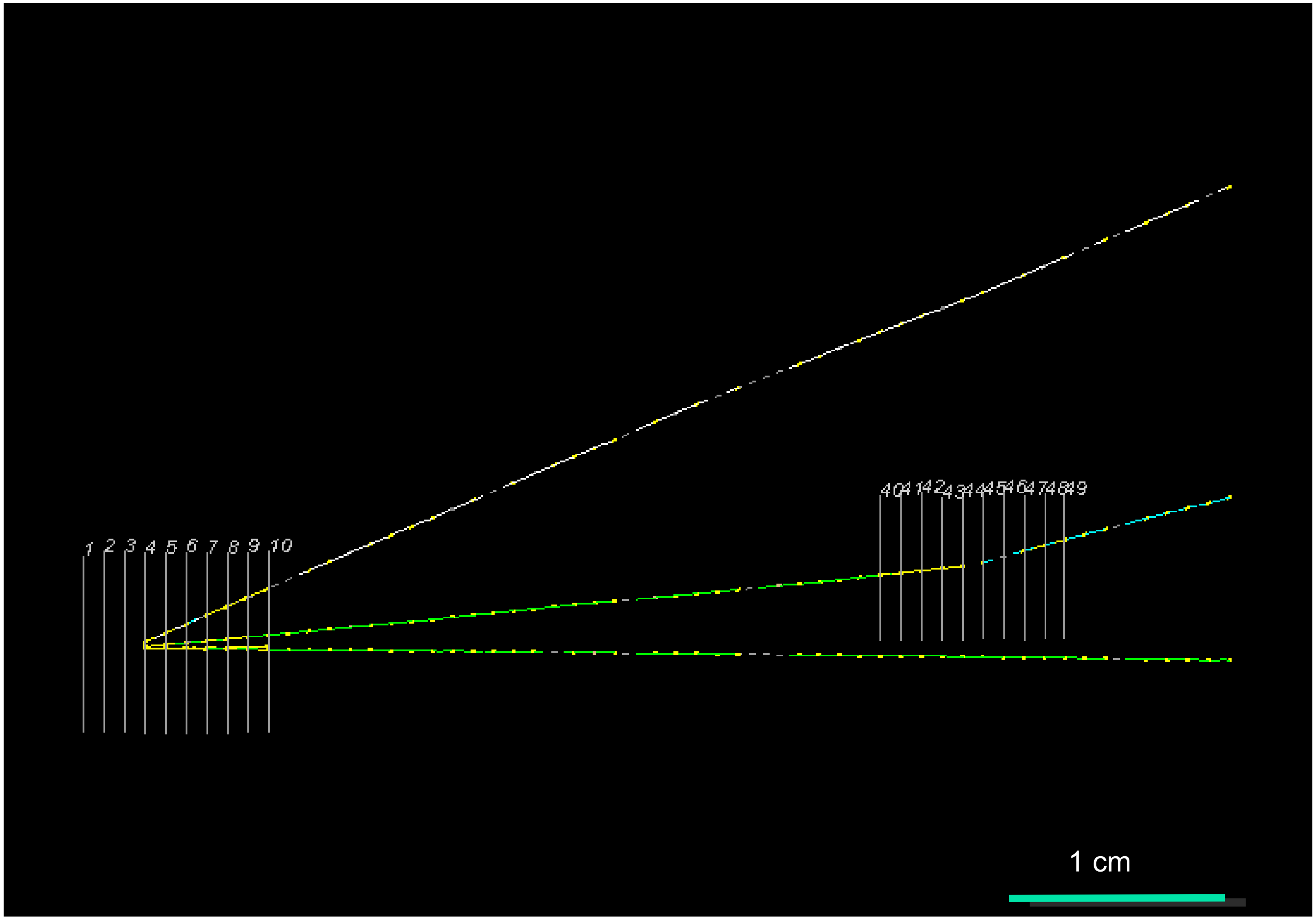




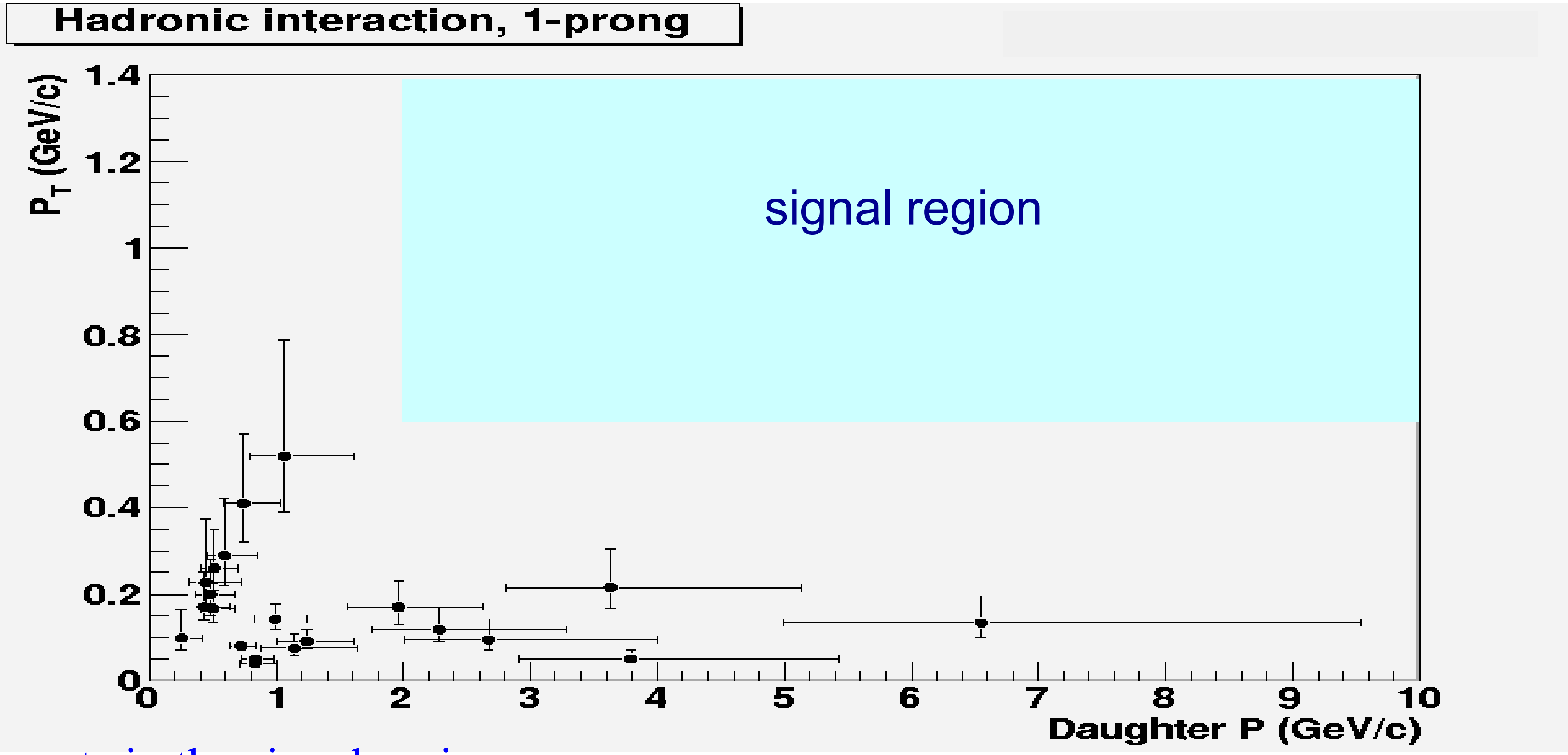
Hadronic re-interaction studies for background evaluation

- Search for hadronic interactions along a total of 9 m of hadron track measured for scanned events. This is about a factor 8 larger than the so far scanned track length for NC events (number of NC x hadron multiplicity x 2 mm decay length).

- Goal: ~100 m as needed to fully validate (eventually replace) the MC background prediction



Hadronic re-interaction studies, present status

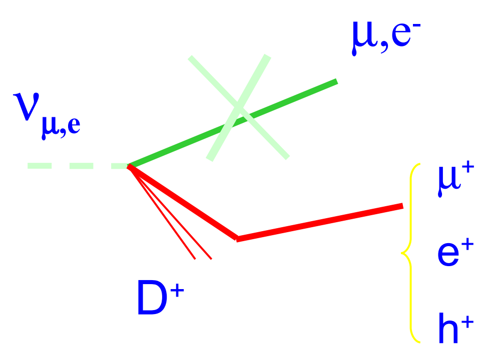


- no events in the signal region
- 90% CL upper limit of 1.54 x 10^{-3} kinks/NC event
- the number of events outside the signal region is confirmed by MC

Charm background

Charmed particles have similar

decay topologies to the $\boldsymbol{\tau}$



- charm production in CC events represents a background source to all tau decay channels
- for the 1-prong hadronic channel 0.007±0.004 (syst) background events are expected for the analyzed statistics
- further charm BG reduction is under evaluation by implementing the systematic follow-down of low energy tracks in the bricks and the inspection of their end-range, as done for the "interesting" event. For the latter we have 98-99% muon ID efficiency.
- this background is suppressed by identifying the primary lepton with ~ 95% muon ID

Charm search: 20 candidate events selected by the kinematical cuts,

Expected: (16.0 ± 2.9) + ~2 BG events