OPERA: A First ν_τ Appearance Candidate

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Overview

The OPERA Experiment

ν_τ Candidate

Background & Sensitivity

Outlook & Conclusions

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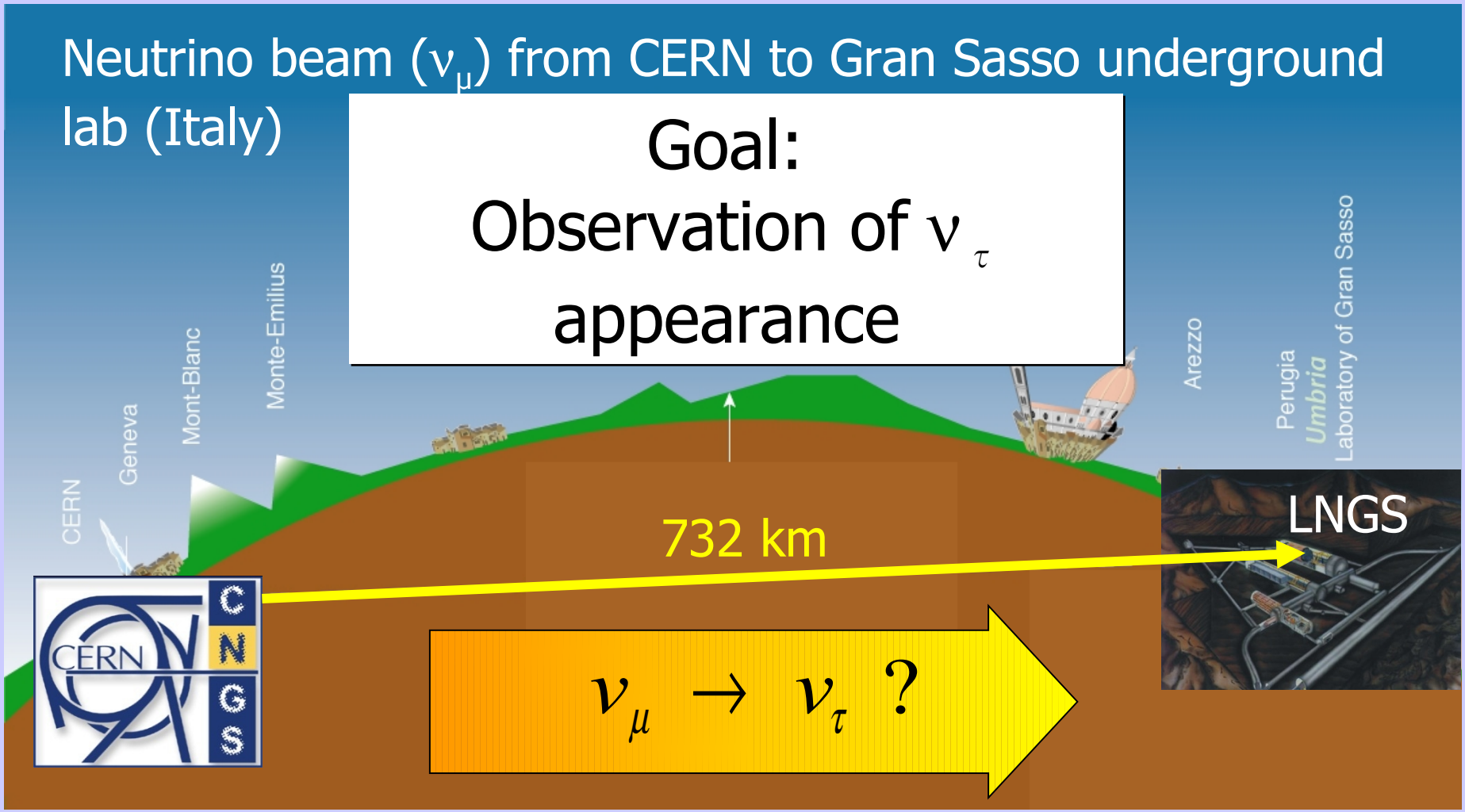
OPERA:
Oscillation Project with Emulsion tRacking Apparatus

Neutrino beam (ν_μ) from CERN to Gran Sasso underground lab (Italy)

Goal:
Observation of ν_τ appearance



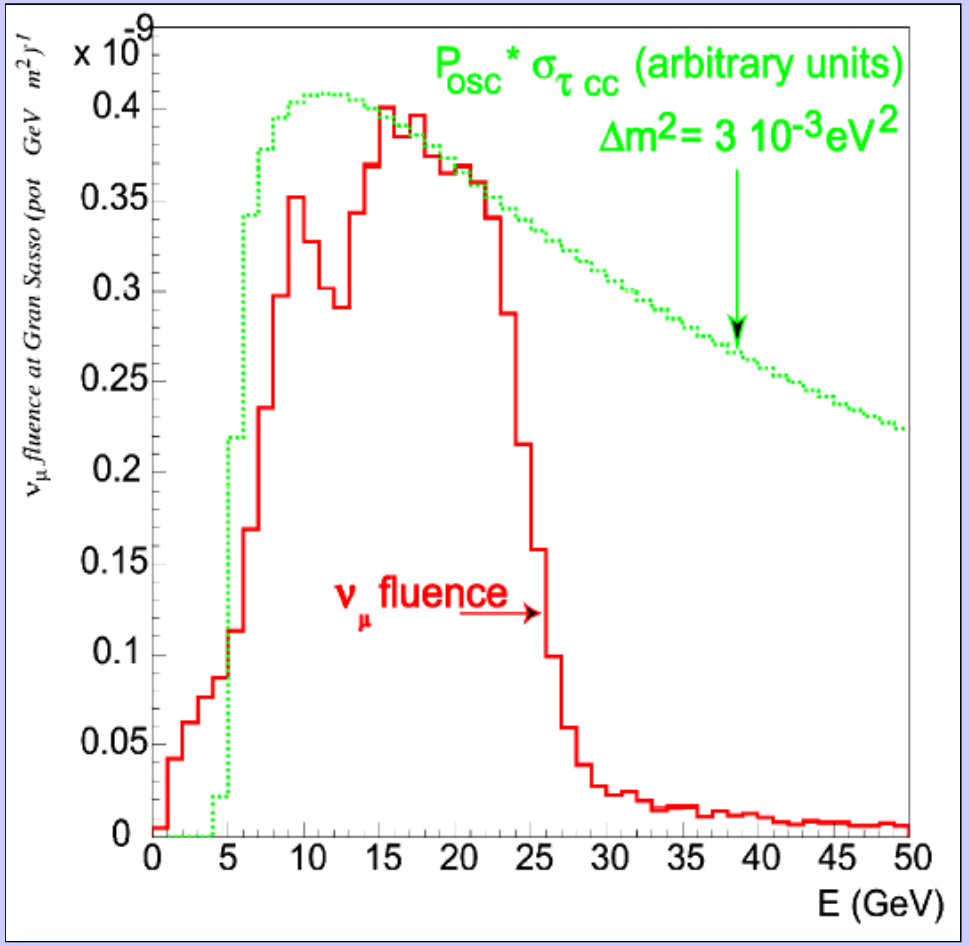
Physics runs: 2008, 2009 and 2010 completed.

CERN Neutrinos to Gran Sasso Beam

Beam Characteristics:

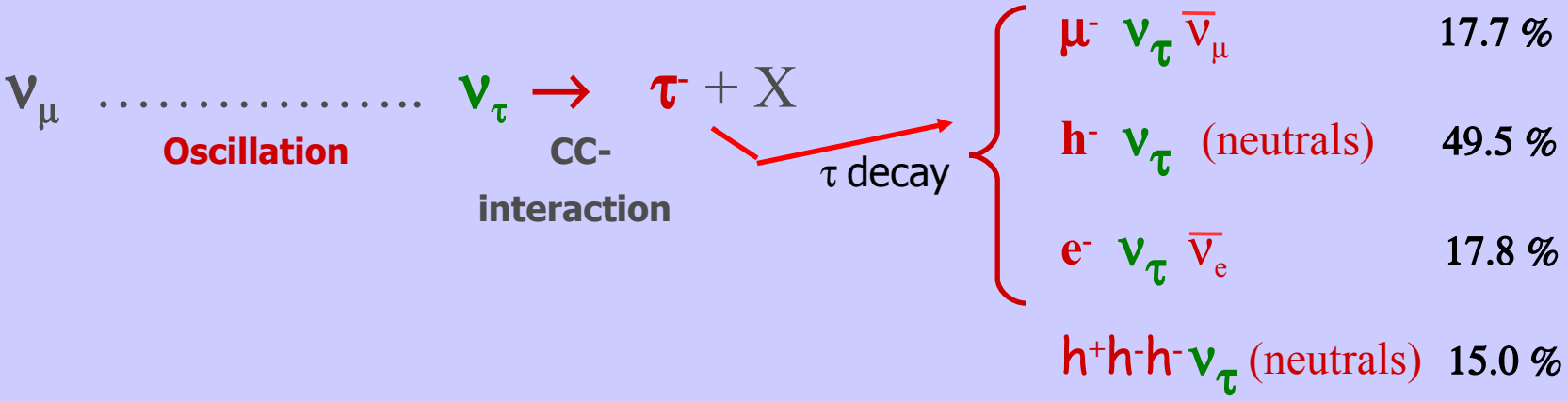
p.o.t./year	$4.5\ 10^{19}$
$<E_\nu>$	17 GeV
L	732 km
$(\nu_e+\bar{\nu}_e)/\nu_\mu$	0.87%
$\bar{\nu}_\mu/\nu_\mu$	2.1%
ν_τ/ν_μ	negligible ($\sim 10^{-7}$)

Total exposure expected:
$22.5 \cdot 10^{19}$ p.o.t.

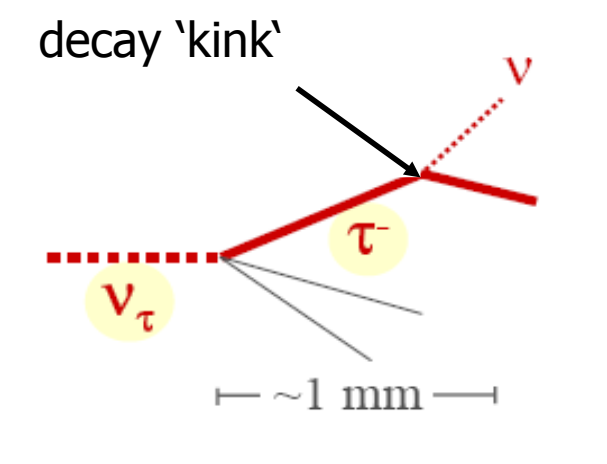


Detector Concept

- Goal: Direct observation of ν_τ in ν_μ beam



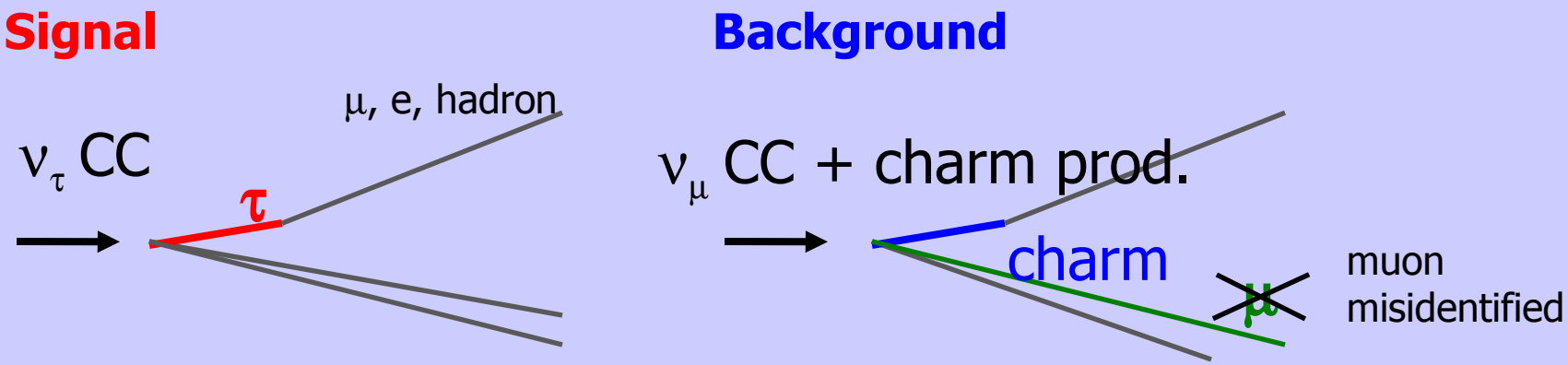
- OPERA has to look for this special topology



Background Processes

Most important background processes:

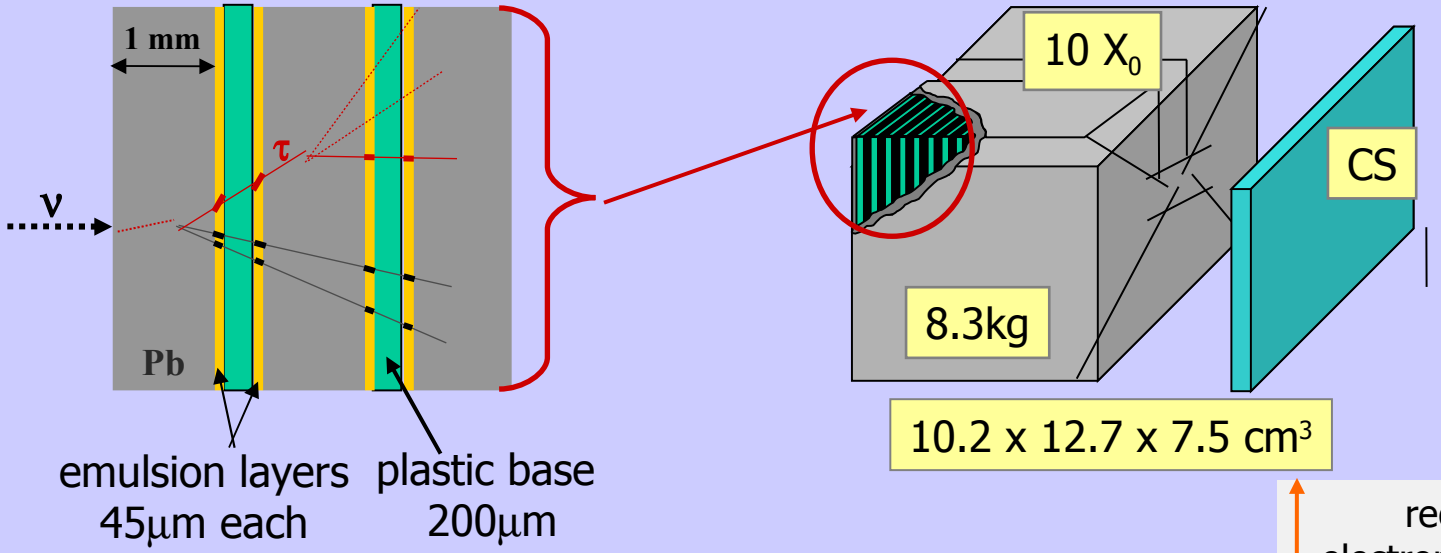
- Charm production and decay
- Hadron re-interactions in lead
- Large-angle muon scattering in lead

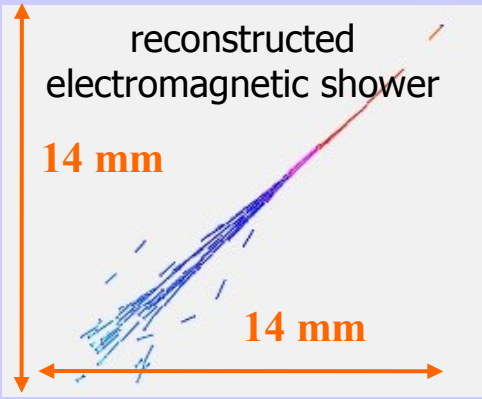


Use Emulsion Cloud Chambers (ECC) to achieve a high enough spatial resolution and density.

The OPERA Brick

- Sandwich of 56 Pb sheets 1mm + emulsions
- High spatial resolution (track: $\sigma_x \approx 0.05\mu m$, $\sigma_\theta \approx 2mrad$, vertex: $\sigma_x \approx 1\mu m$)
- Changeable Sheets (CS) with emulsion doublet for first checks

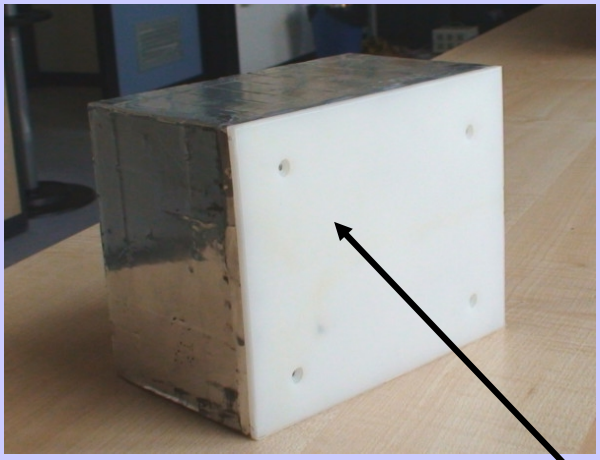


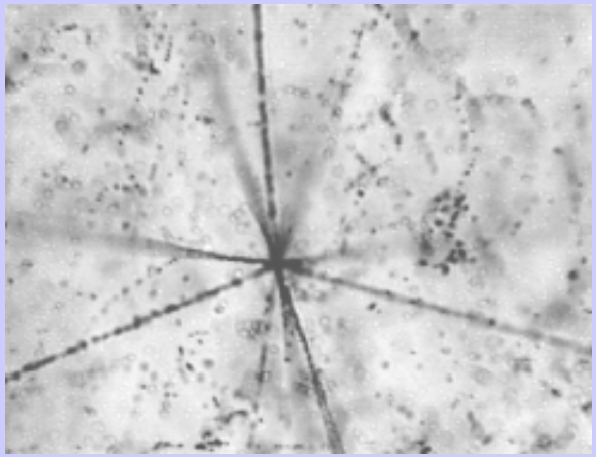


ECC = Stand-alone Detector:

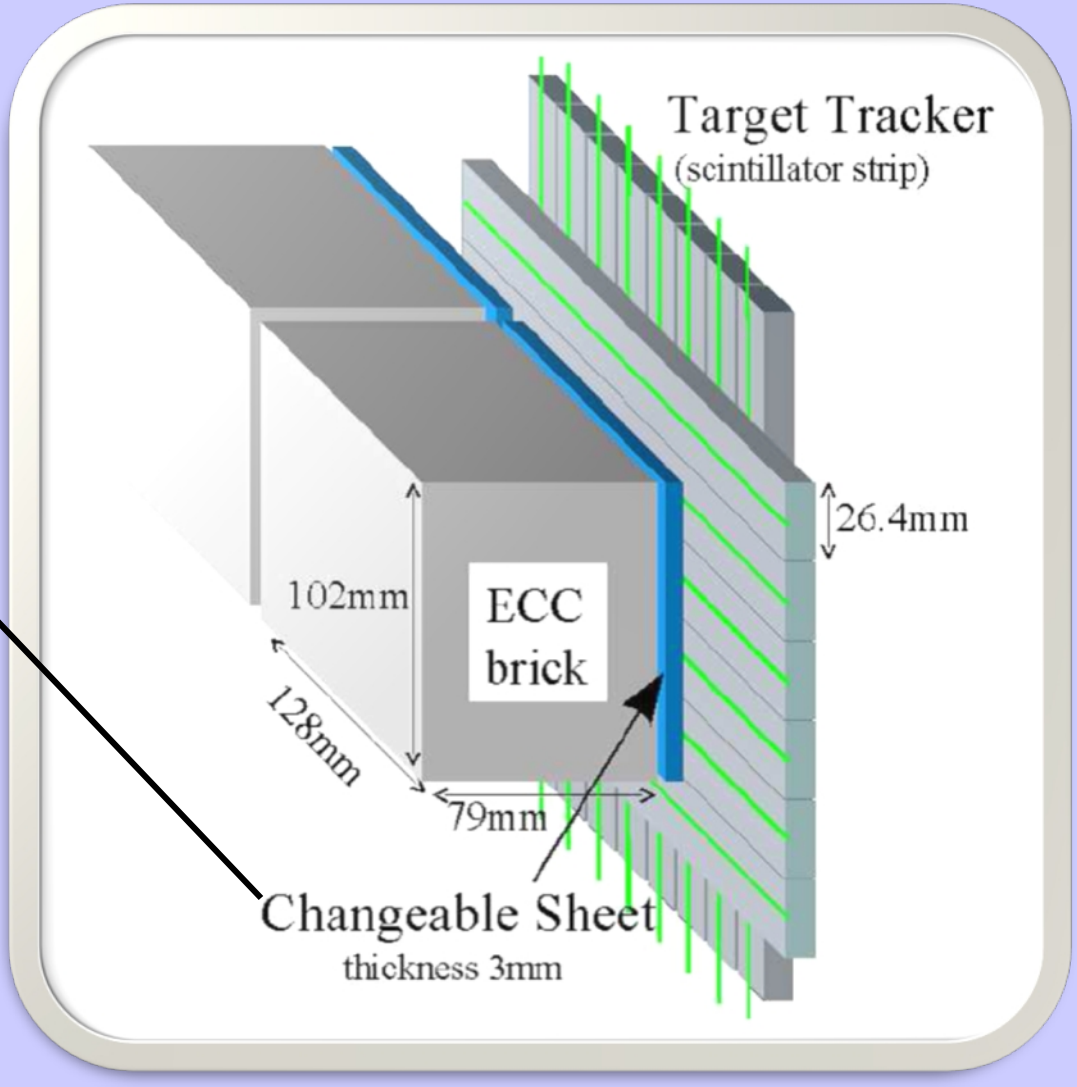
- Momentum measurements for hadrons (multiple scattering)
- Pion/Muon separation at low energy (dE/dx)
- Electron identification and energy measurements for e,γ

Hybrid Detector

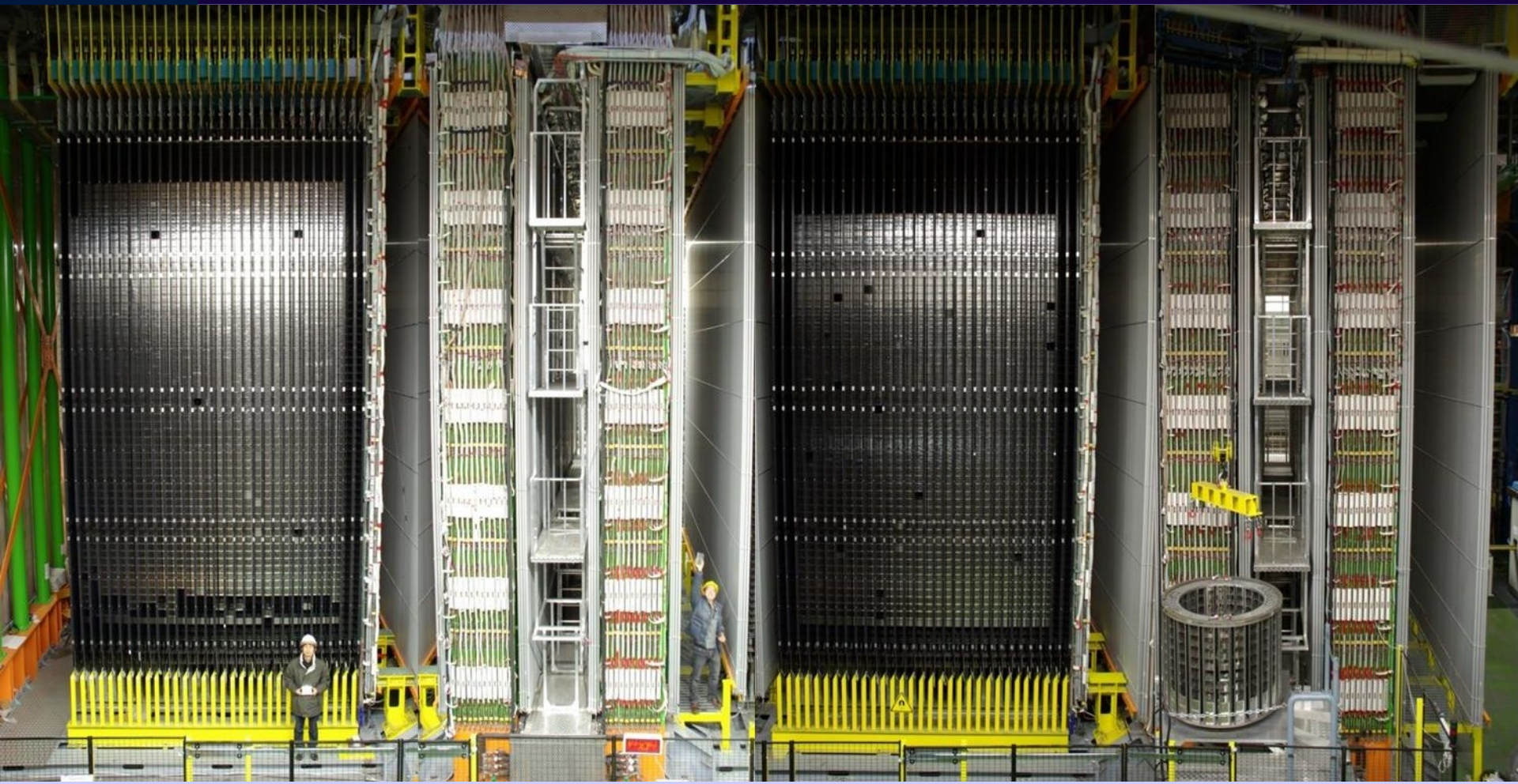




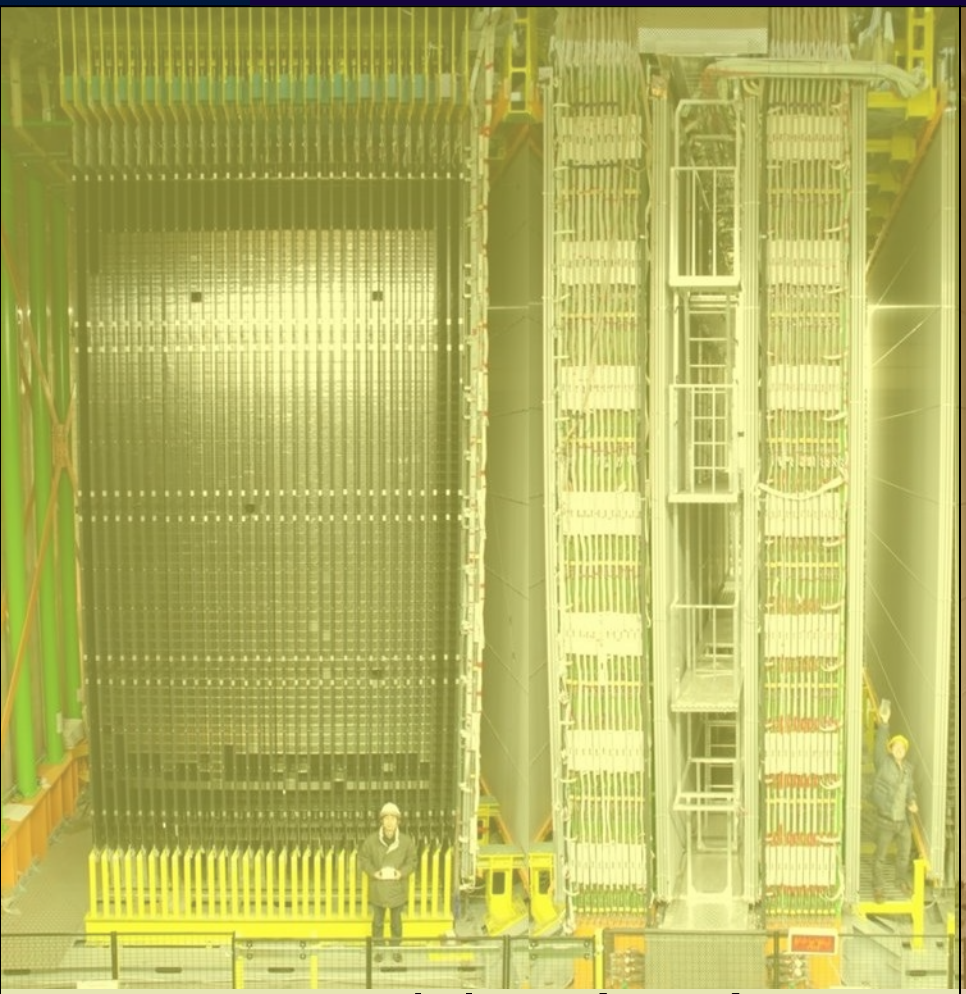
Emulsion Cloud Chambers



The OPERA Detector



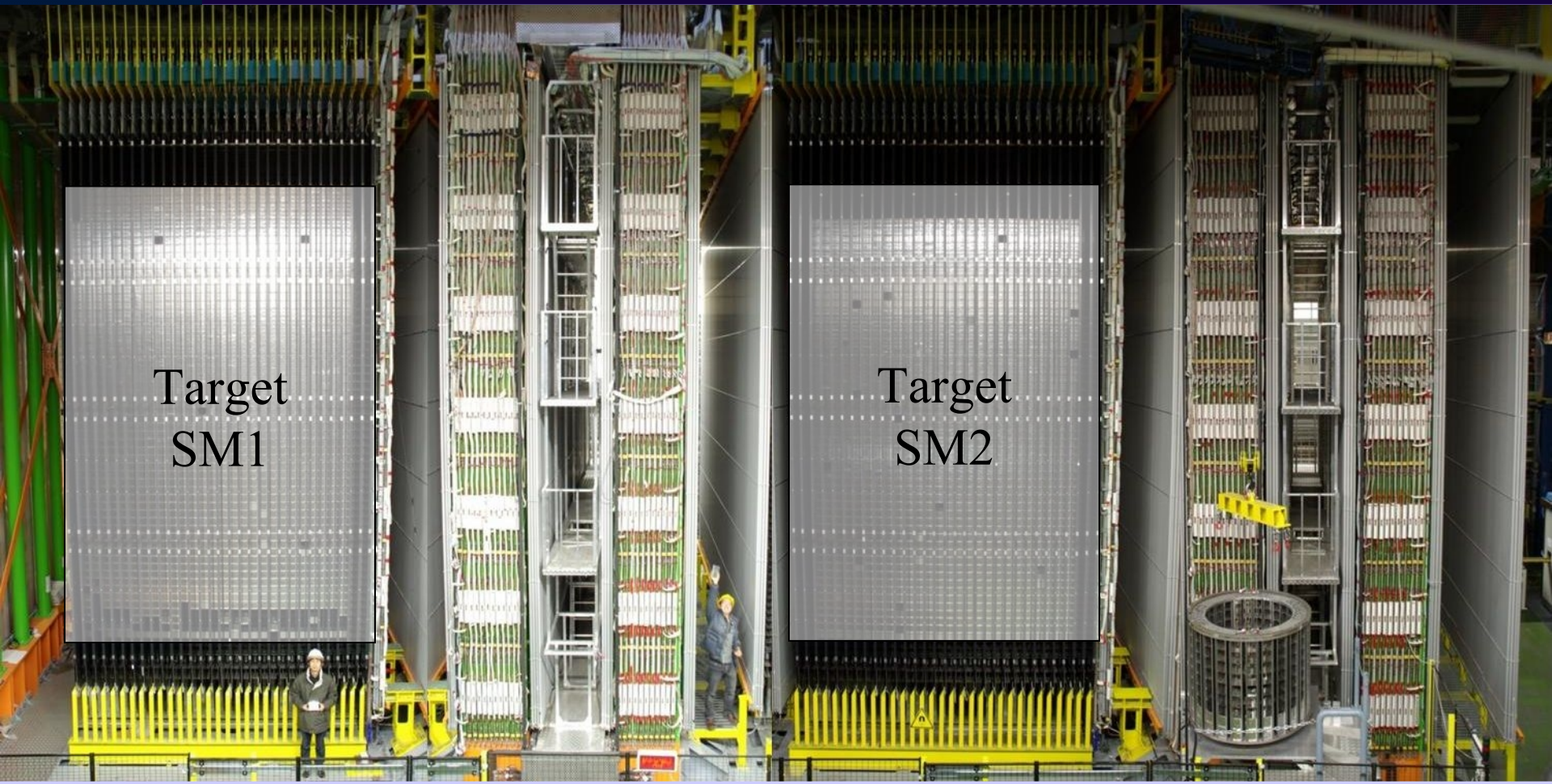
The OPERA Detector



Super Module 1 (SM1)

Super Module 2 (SM2)

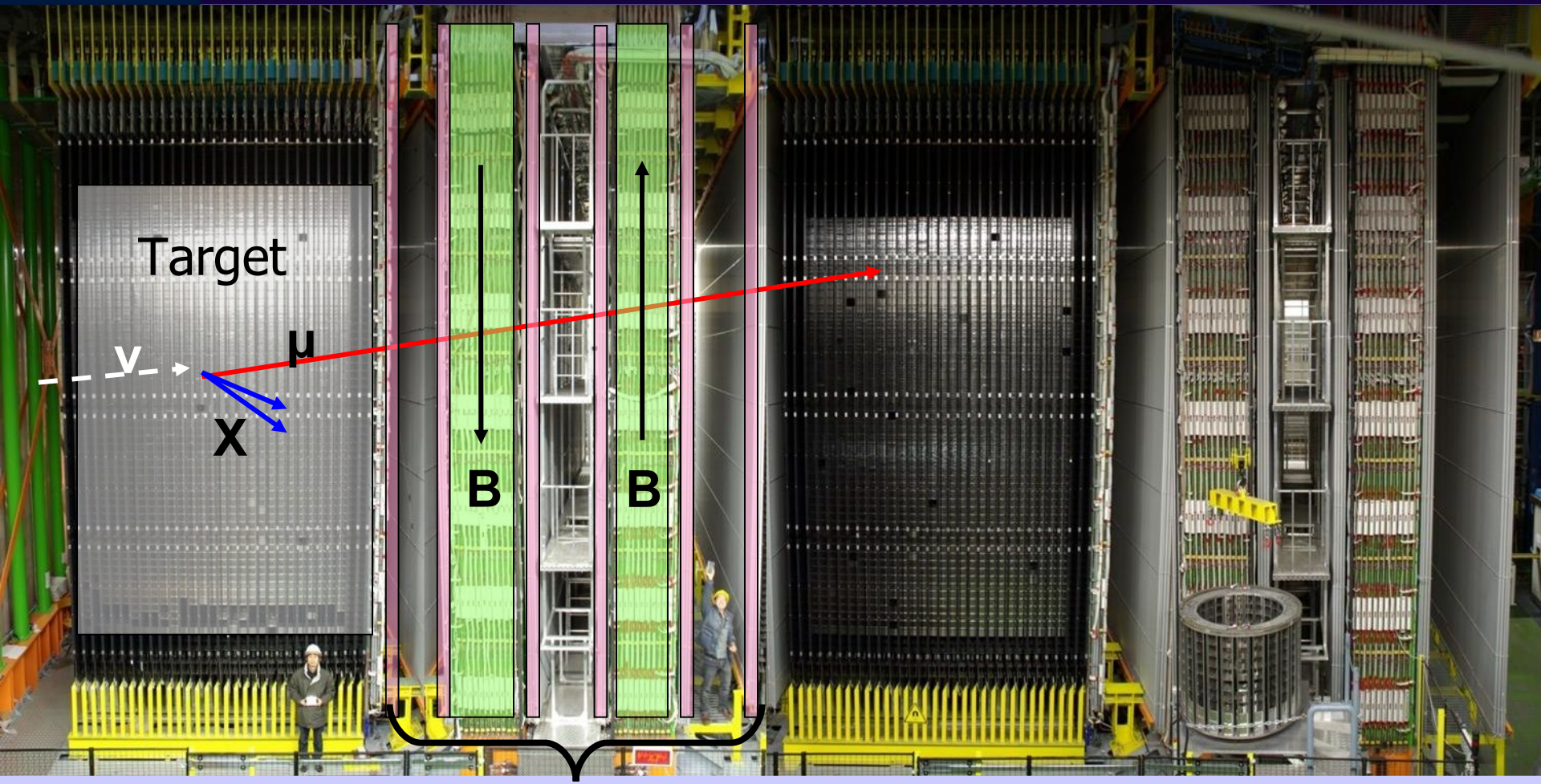
The OPERA Detector



Target Region:
- Target Tracker (Scintillator)
- Lead/Emulsion Bricks (75.000 per SM)

→ Target mass: ~1.25 kton

The OPERA Detector



Magnetic Spectrometer:

Magnet Region: Iron & RPCs

Precision Tracker: 6 planes of drift tubes

Expected Performance (Proposal)

Assumptions: Maximal mixing, 22.5×10^{19} p.o.t. (5years @ 4.5×10^{19} p.o.t./year)

τ Decay Channel	B.R. (%)	Signal	Background
$\tau \rightarrow \mu$	17.7	2.9	0.17
$\tau \rightarrow e$	17.8	3.5	0.17
$\tau \rightarrow h$	49.5	3.1	0.24
$\tau \rightarrow 3h$	15.0	0.9	0.17
Total		**10.4**	**0.75**

Expected Events:

~ 23600 ν_μ CC+NC interactions

~ 520 $\bar{\nu}_\mu$ interactions

~ 205 $\nu_e + \bar{\nu}_e$ interactions

~ 115 ν_τ CC interactions

For full mixing and $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 (scales with $(\Delta m^2)^2$).

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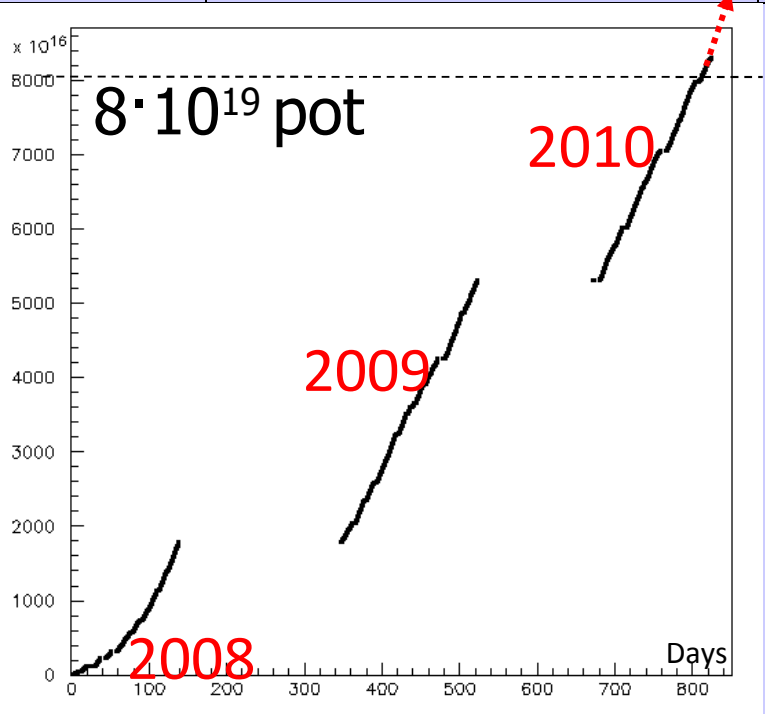
CNGS Beam Performance & Statistics

2006	0.076x10^{19} p.o.t.	no bricks	Commissioning
2007	0.082x10^{19} p.o.t.	38 events	Commissioning
2008	**1.78x10^{19} p.o.t.**	**1698 events (scan input)**	**First physics run**
2009	**3.52x10^{19} p.o.t.**	**3693 events (scan input)**	**Physics run**
2010	**4.04x10^{19} p.o.t. (23.Nov.)**	**4246 events (scan input)**	**Physics run**

9637 events (scan input) collected until 23/11/2010



Event Statistics (June 2010)

Analysis of first data:

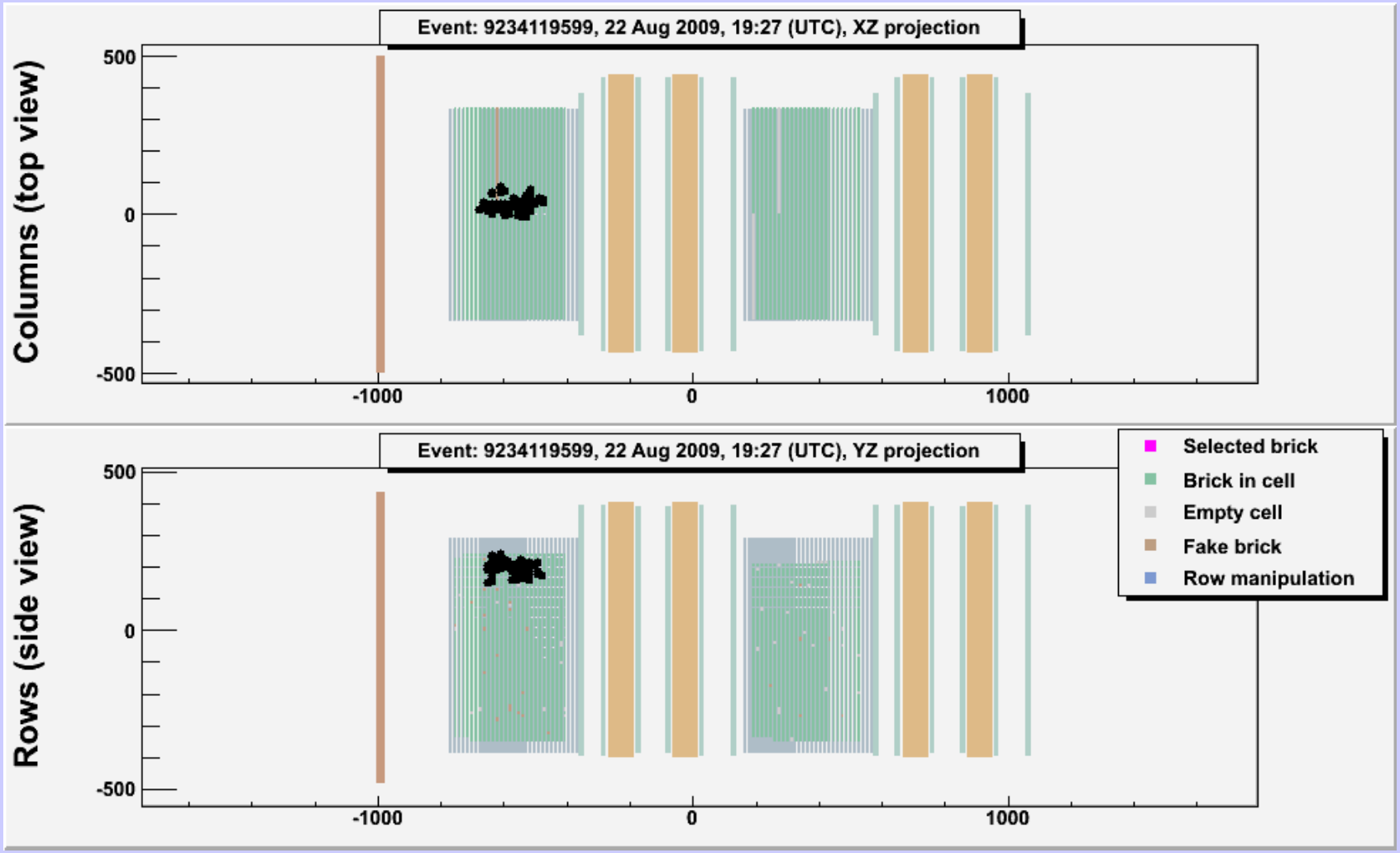
- 5391 events collected by 2008-2009 run
- Brick tagging efficiency times vertex location efficiency: ~60%
- 1617 neutrino vertices located (50% of 2008-2009 statistics)
- 1088 events with decay search completed
  (187 NC and 901 CC events)
- Corresponds to 1.89×10^{19} p.o.t.
- 35% of 2008-2009 events

Expected Signal: 0.5 ν_τ events

(for full mixing and $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2)

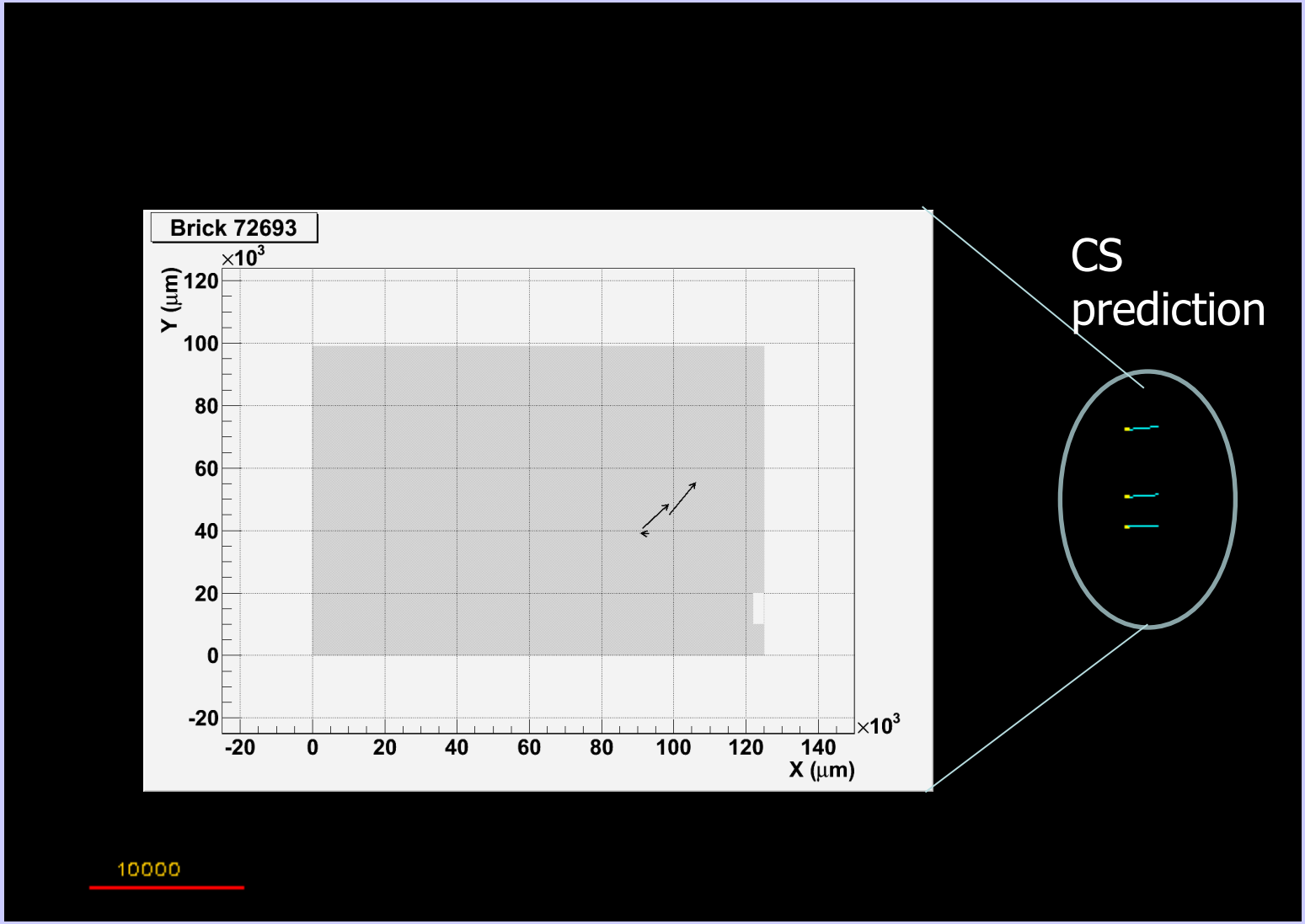
Muonless Event 9234119599

Electronic Detector View:



(Date: 22 August 2009, 19:27 (UTC))

From CS to Vertex Localisation



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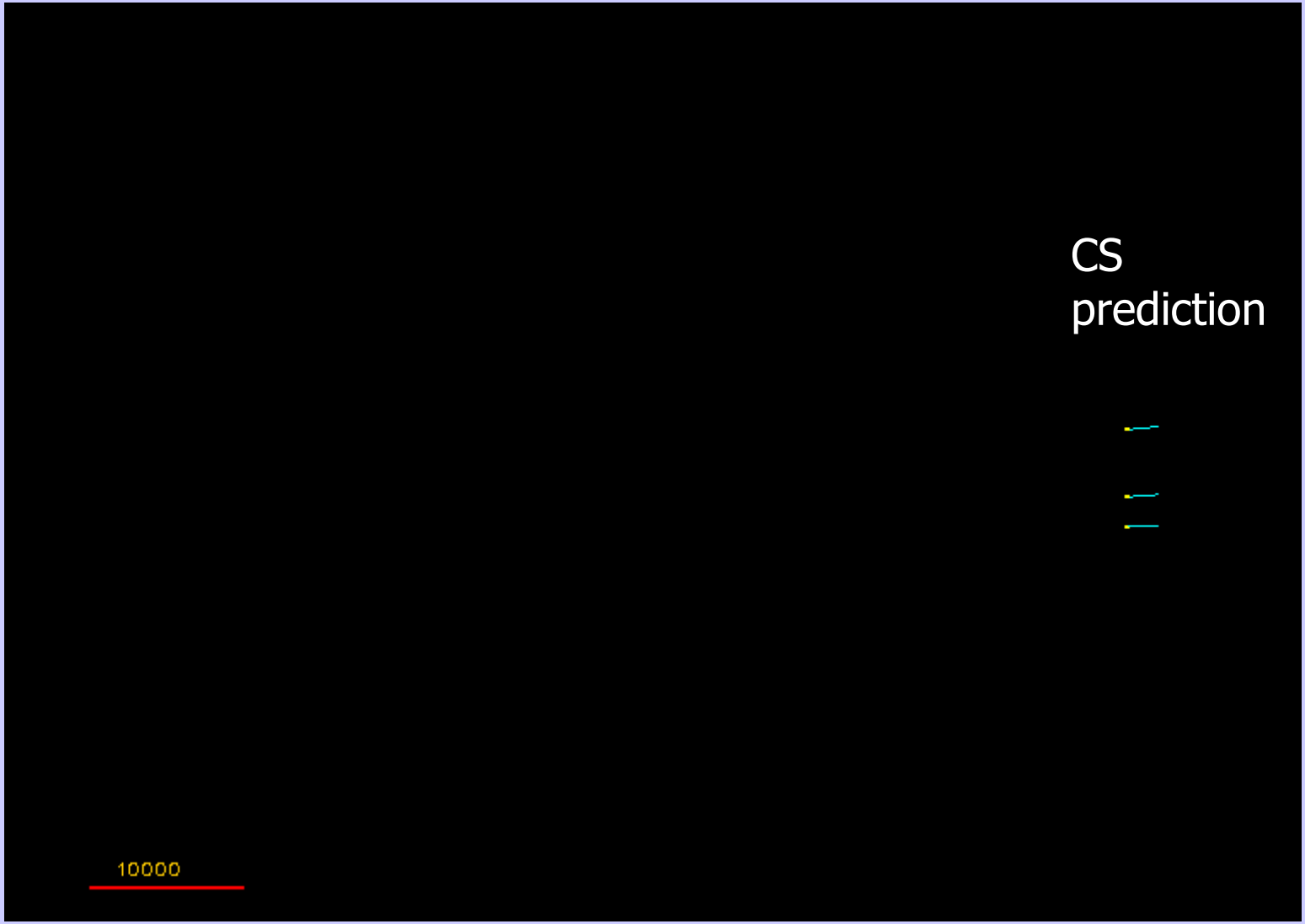

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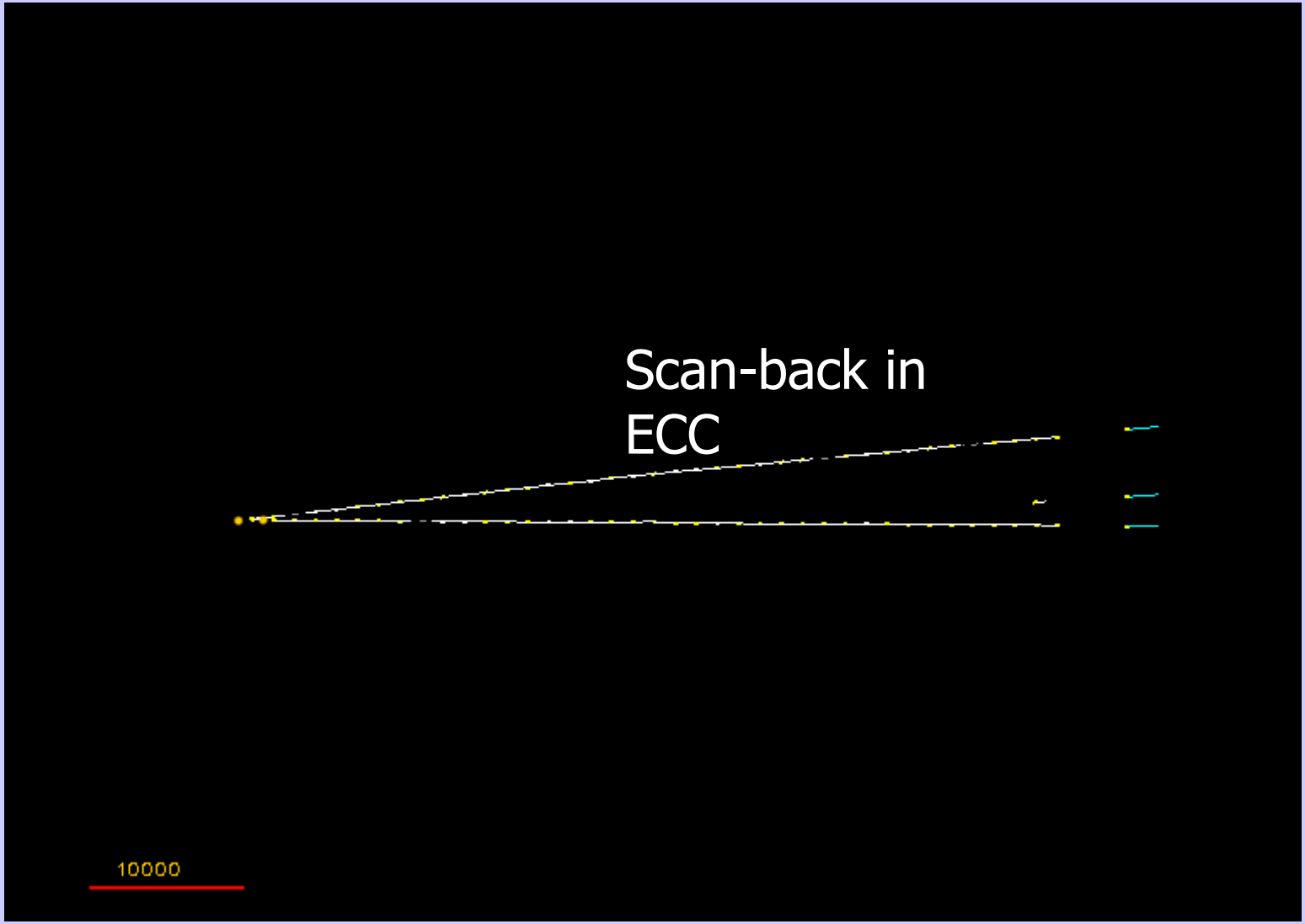

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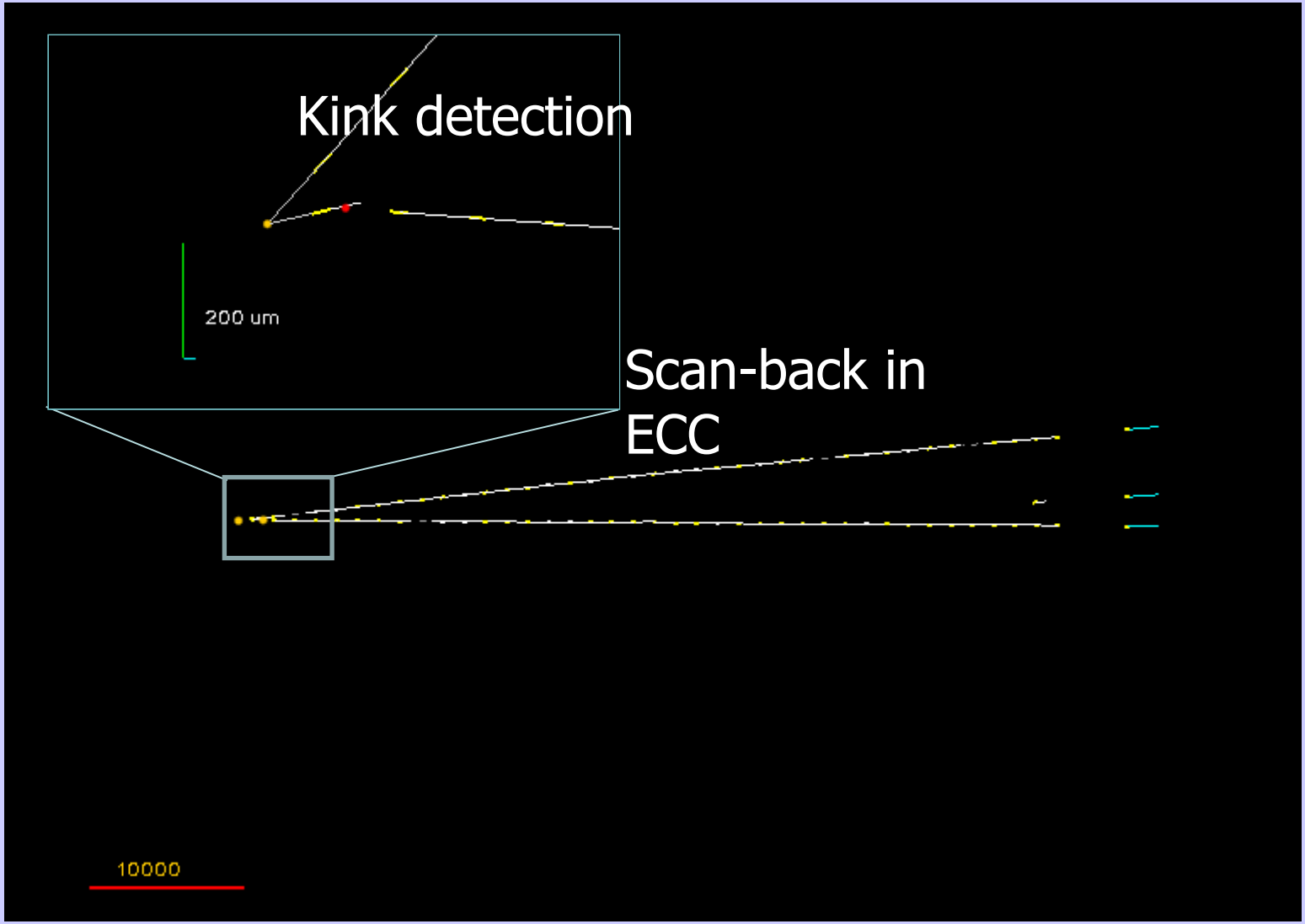
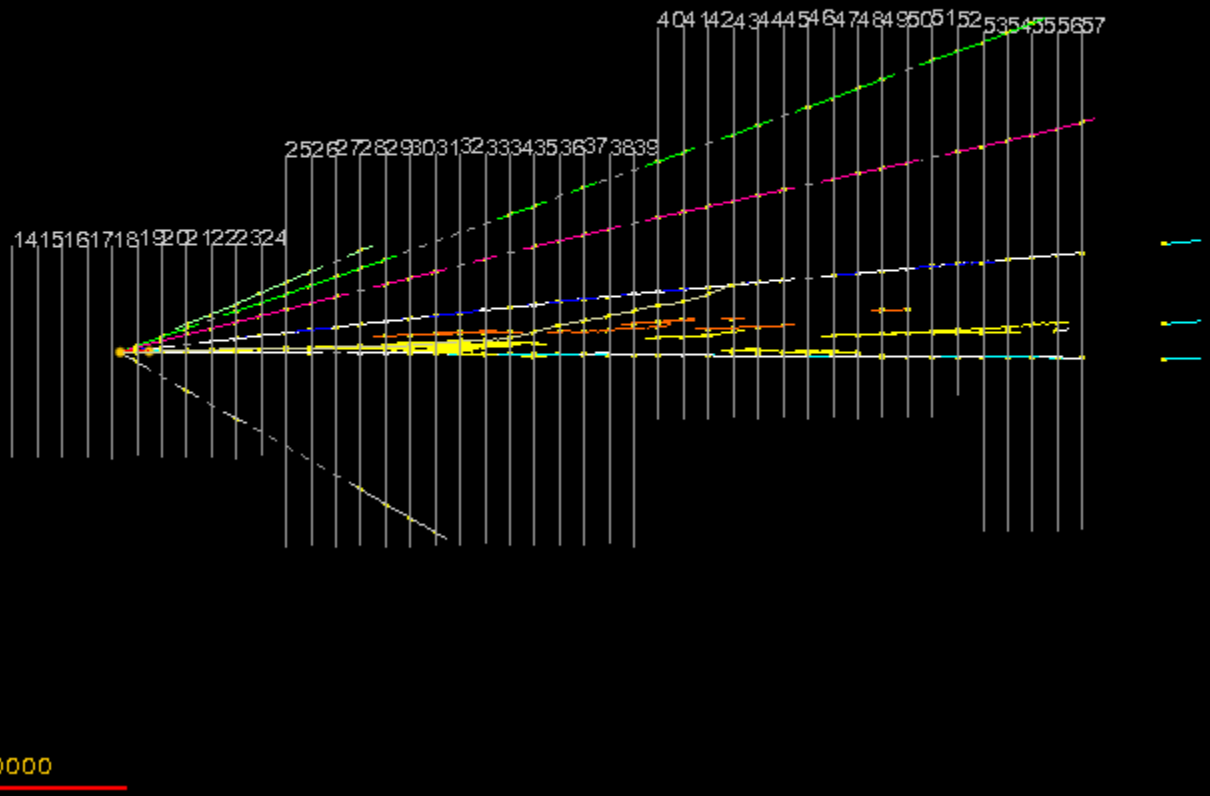
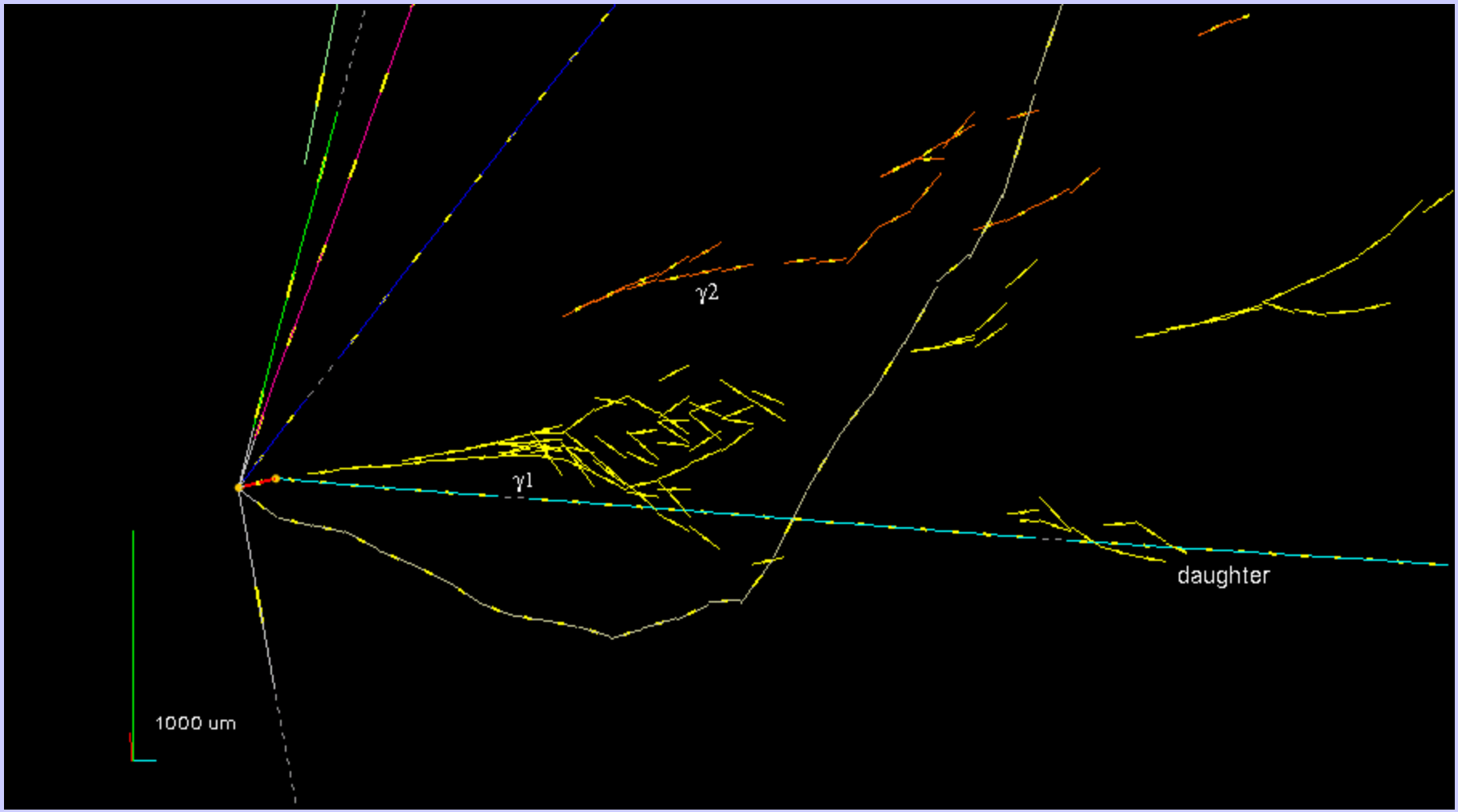


From CS to Vertex Localisation

Large-area scan,
full reconstruction of vertices and γ



Reconstructed ν_τ Candidate



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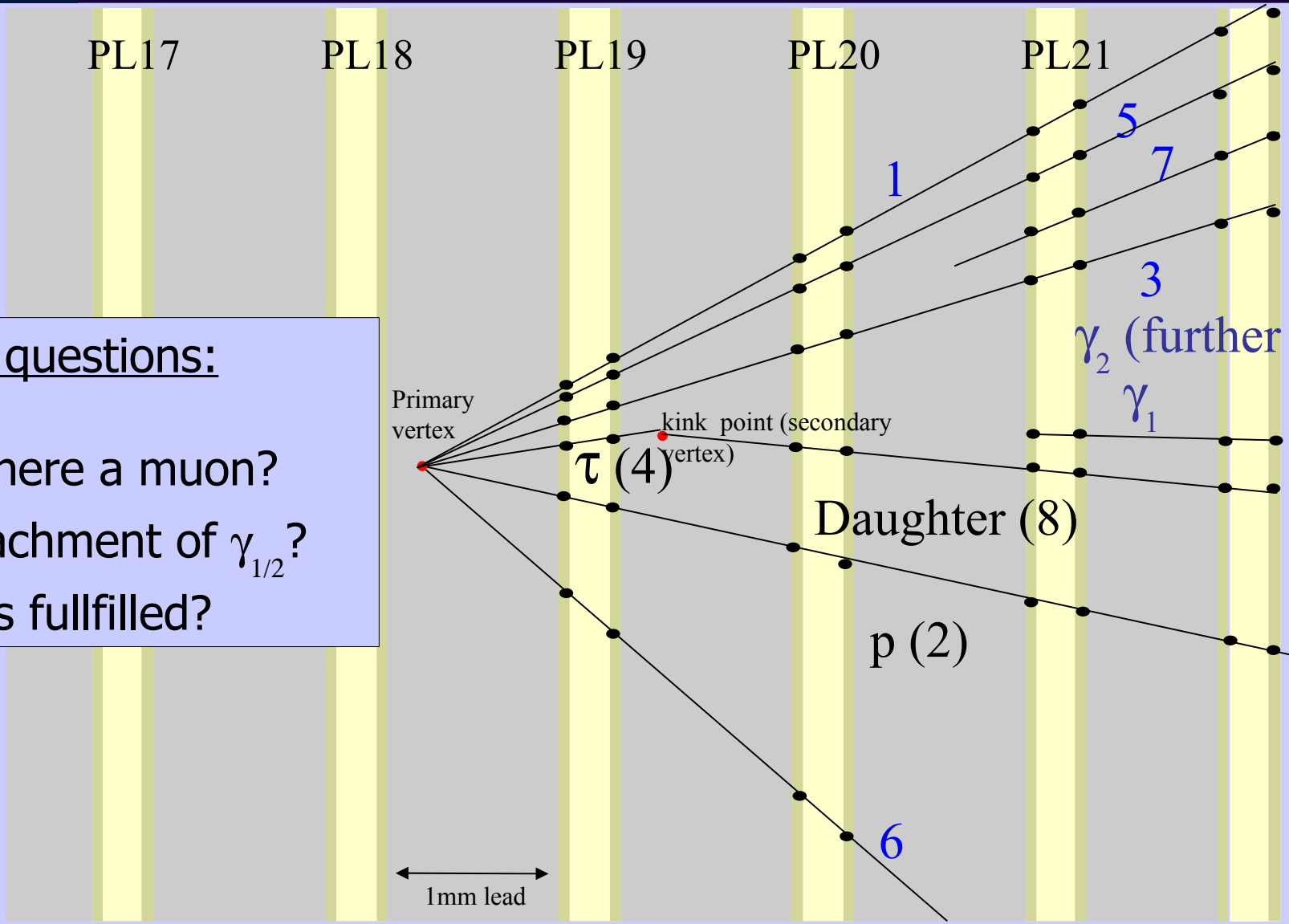
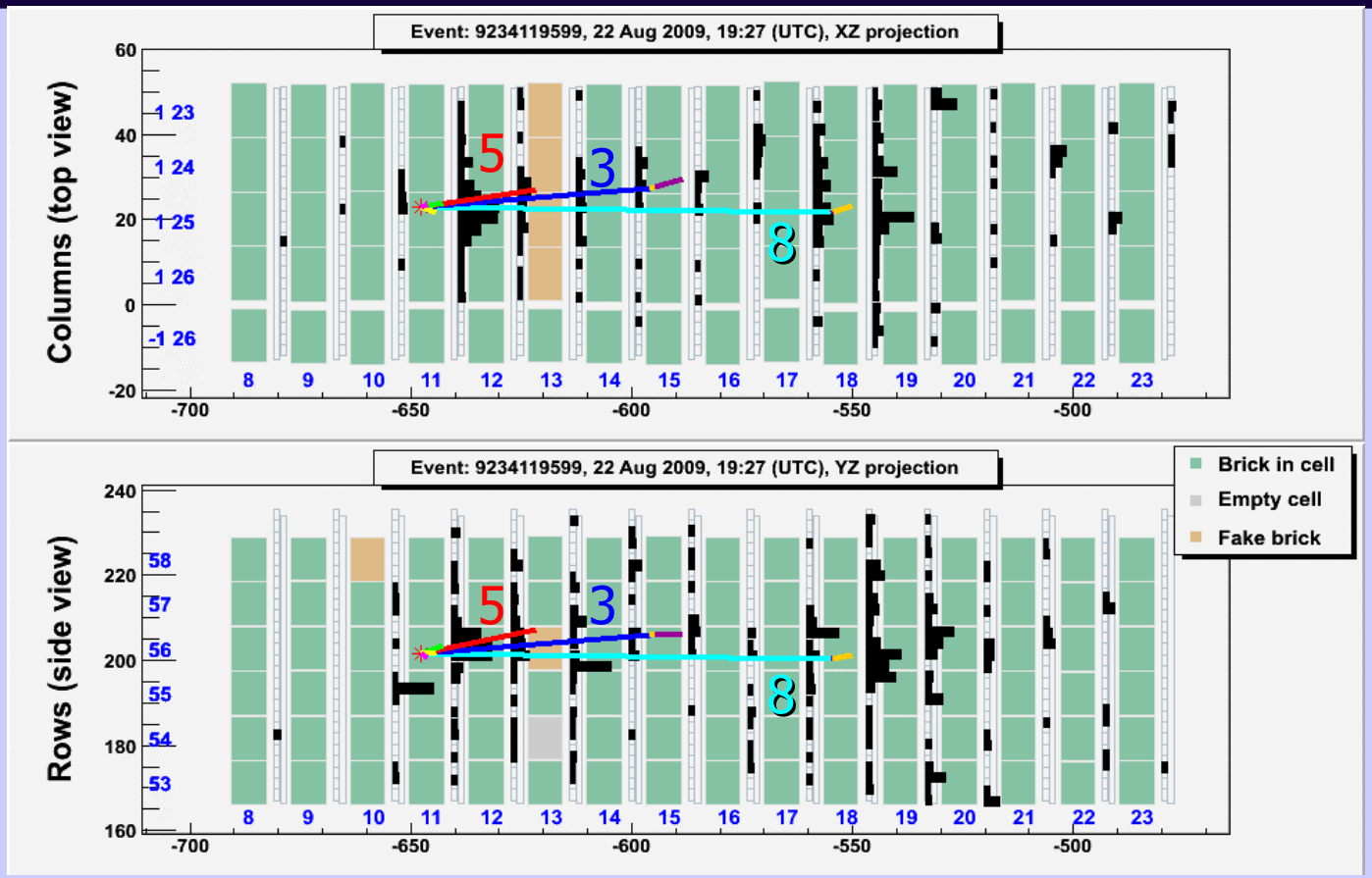


Main questions:

- Is there a muon?
- Attachment of $\gamma_{1/2}$?
- Cuts fullfilled?

Track Analysis



- 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 Track Features

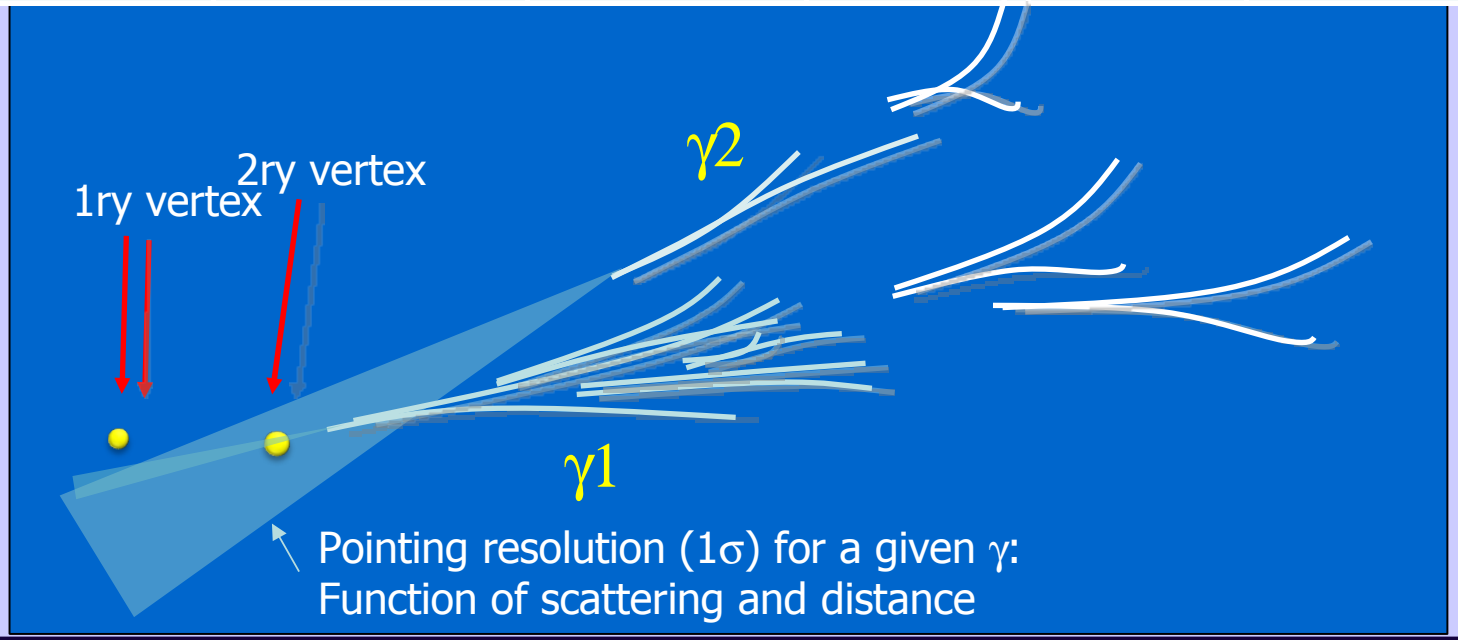
TRACK NUMBER	PID	Probability	MEASUREMENT 1			MEASUREMENT 2		
			tan Θ_X	tan Θ_Y	P (GeV/c)	tan Θ_X	tan Θ_Y	P (GeV/c)
1	HADRON range in Pb/em=4.1/1.2cm	Prob(μ)≈10^{-3}	0.177	0.368	0.77 [0.66,0.93]	0.175	0.357	0,80 [0.65,1.05]
2	PROTON	range, scattering and dE/dx	-0.646	-0.001	0.60 [0.55,0.65]	-0.653	0.001	
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/em=9.5/2.8cm	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-Attachment to 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 Varianbles of Candidate

Satisfying all selection criteria for hadronic kink → first ν_τ candidate !

- $\gamma 1$ and $\gamma 2$ are both assumed as attached to 2_{ry} vertex
- The uncertainty on P_t due to the alternative $\gamma 2$ attachment is < 50 MeV

VARIABLE	AVERAGE	Selection criteria
kink (mrad)	41 ± 2	>20
decay length (μm)	1335 ± 35	within 2 lead plates
P daughter (GeV/c)	12^{+6}_{-3}	>2
Pt (MeV/c)	470^{+230}_{-120}	>300 (γ attached)
missing Pt (MeV/c)	570^{+320}_{-170}	<1000
ϕ (deg)	173 ± 2	>90

10 years old criteria (@Proposal) ⟶ Blind analysis

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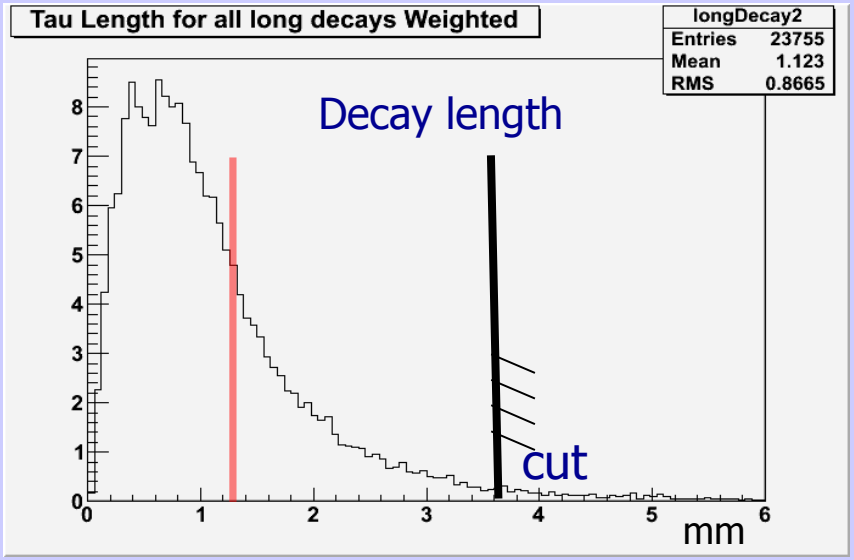
ϕ (deg)	173 ± 2	>90

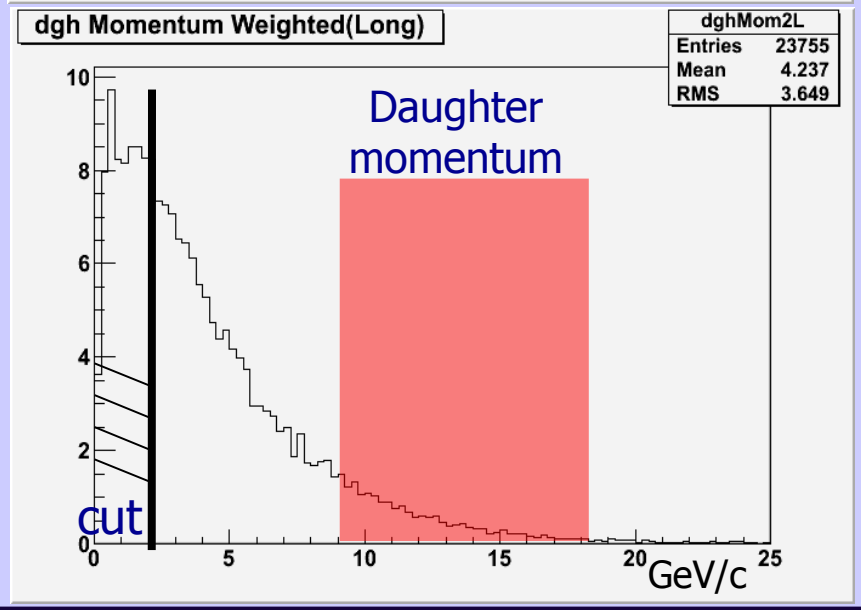
→ >600 if no γ

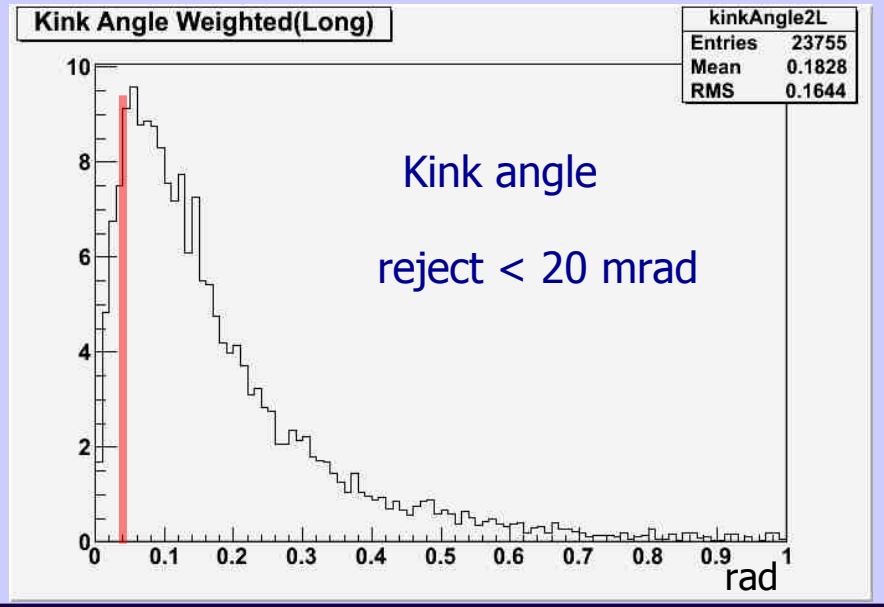
10 years old criteria (@Proposal) → Blind analysis

Characteristics of Decay Topology



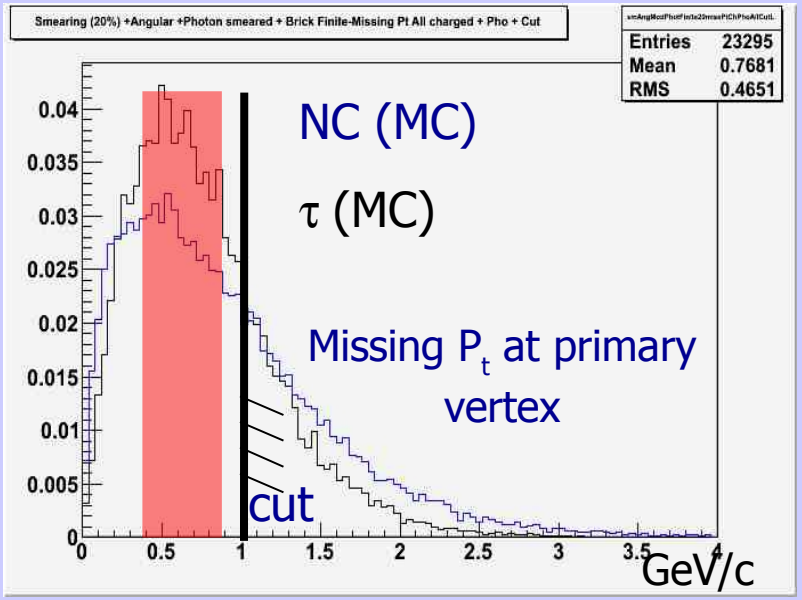
Red regions:
Measured values for ν_τ candidate



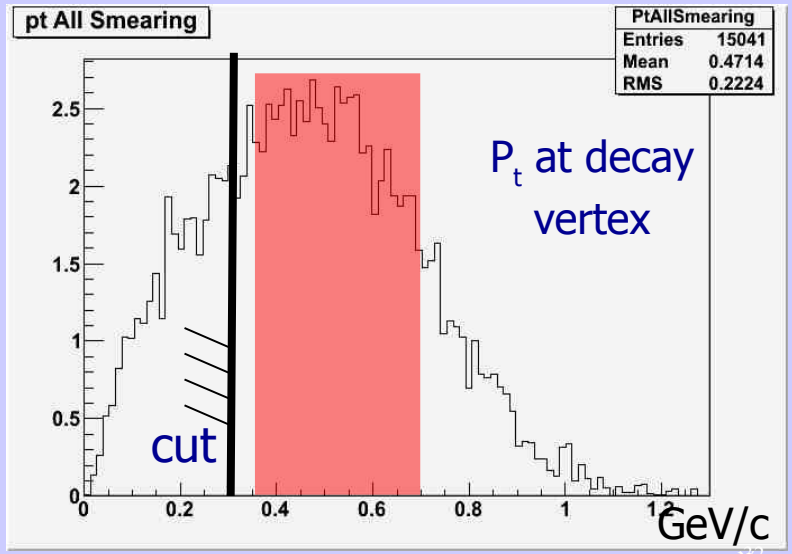


Kinematical Cuts to be Passed

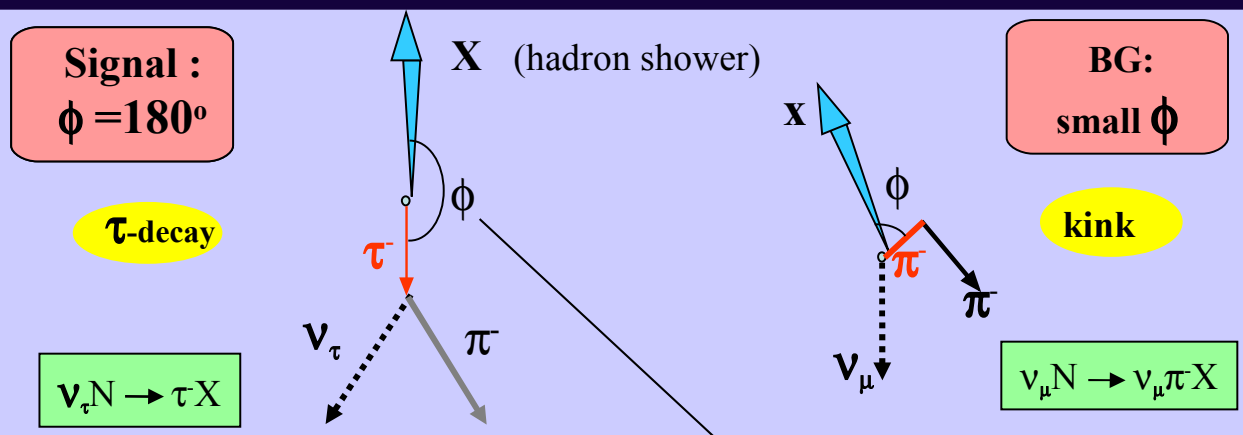
Reject NC events with larger missing P_t (neutrino)

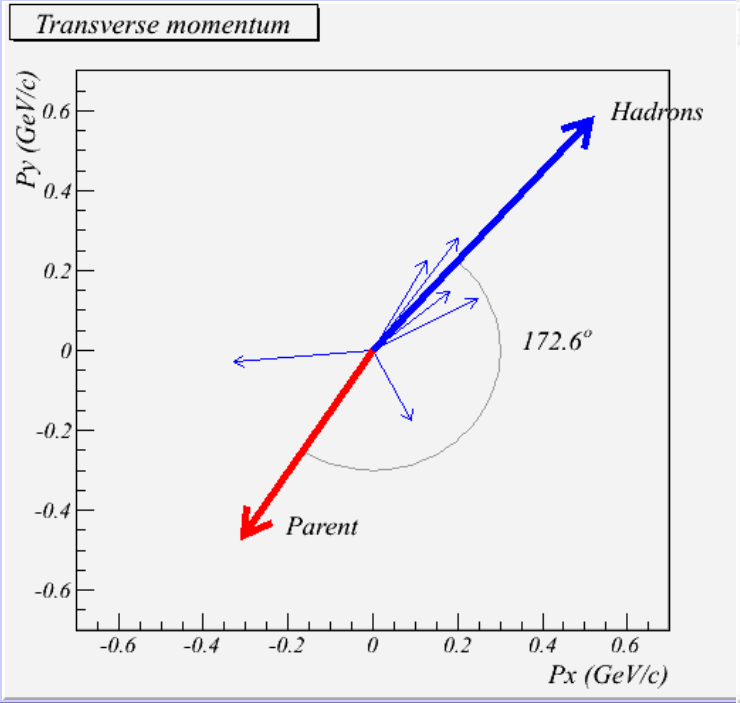


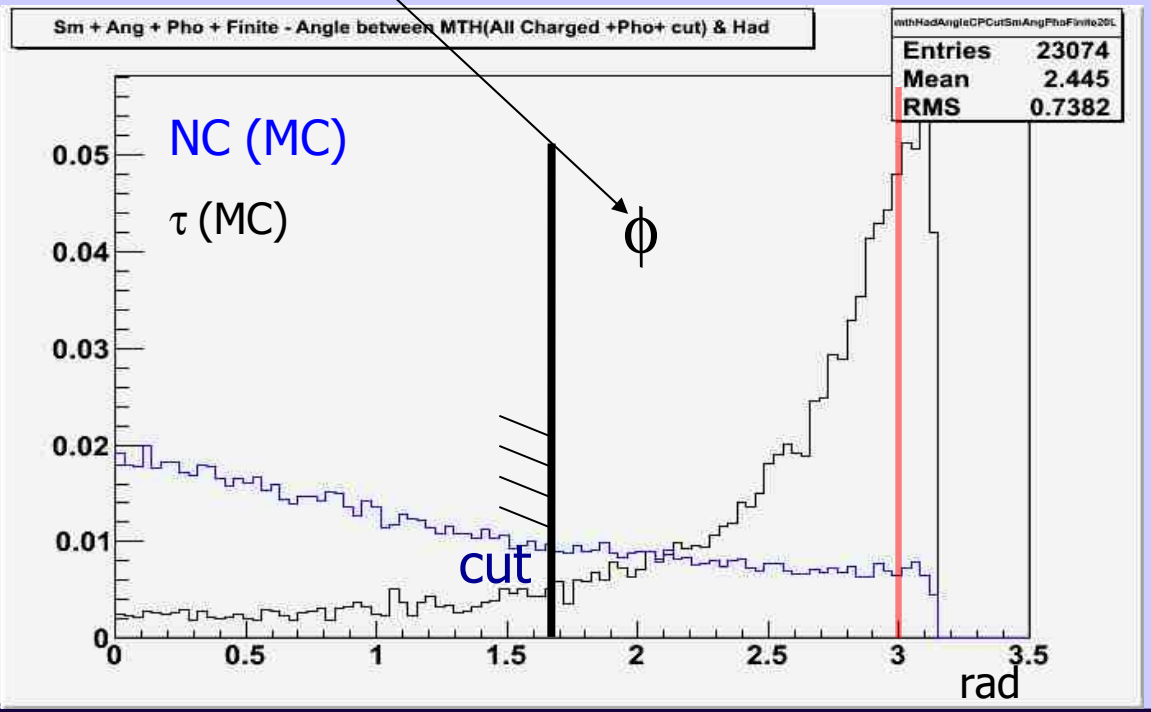
Reject hadron re-interactions



P_t Characteristics







Interpretation of the Event

- Invariant mass of $\gamma\gamma$-system: Compatible with π^0 mass value
- Invariant mass of the $\pi\gamma\gamma$-system: Compatible with ρ (770)

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

- ρ is created in about 25% of the τ decays:

$$\tau \rightarrow \rho\ (\pi\ \pi^0)\ \nu_\tau$$

OPERA collaboration:
"Observation of a first ν_τ candidate event in the OPERA experiment…",
Phys. Lett. B 691 (2010) 138

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Expected Background

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

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

Significance of ν_τ Observation

We observe 1 event in the 1-prong hadronic τ decay channel

- Background expectation for 1-prong hadron decay:
  0.018 ± 0.007 (syst) events

  Probability that the observed event is due to background: 1.8 %
  Significance of ν_τ observation in OPERA: 2.36 σ

- Total background from all decay modes:
  0.045 ± 0.020 (syst) events

  Probability that the observed event is due to background: 4.5 %
  Significance of ν_τ observation in OPERA: 2.01 σ

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Conclusions

- OPERA searches for $\nu_\mu \rightarrow \nu_\tau$ appearance.
- A complete analysis of a subsample has been done.
- One muonless event with a $\tau \rightarrow$ 1-prong hadron decay topology has been detected.

Conclusions

- The event passes all kinematical cuts.

→ It is our first candidate event for $\nu_\mu \rightarrow \nu_\tau$ appearance.

→ Δm^2_{23} values > 7.5 x 10^{-3} eV^2 can be excluded at 90% CL

The probability for the event to be background induced is 1.8%.
→ 2.36 σ significance

(If all decay modes are included: 4.5% → 2.01 σ significance)

Outlook

- 2010: Getting close to nominal 4.5×10^{19} p.o.t.
- 2011: Partial compensation expected for the 2012 break
- 2012: LHC stop ? $\rightarrow$ no SPS, no p.o.t.
- We need enough p.o.t. (22.5×10^{19}) to obtain a significant (4σ) result with high probability
  $\rightarrow$ we need a run 2013, if SPS is stopped 2012
- All events of 2008 and 2009 scanned by end of 2010.

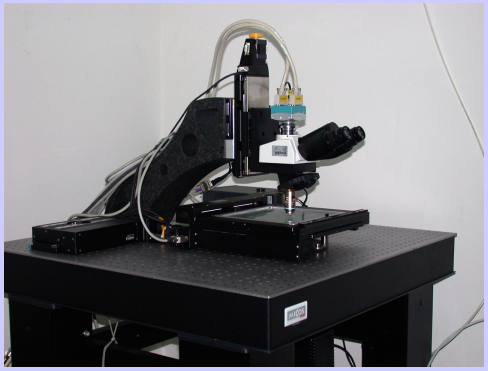
Waiting for more ν_τ candidates…

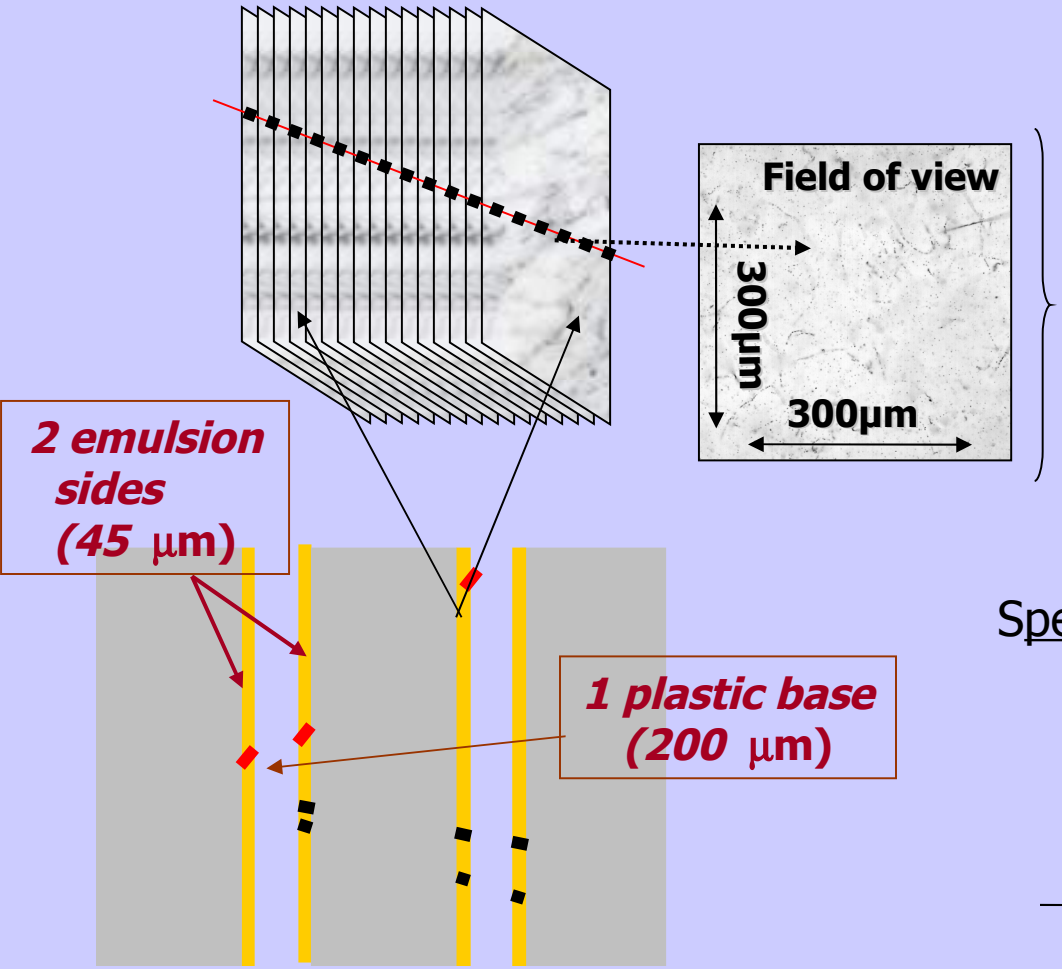
Thank you for your attention!

Backup Slides:

Emulsion Scanning

- 12 scanning laboratories in Europe and Japan





Speed : 20cm²/hour/emulsion side

(in Japan >60cm²/hour)

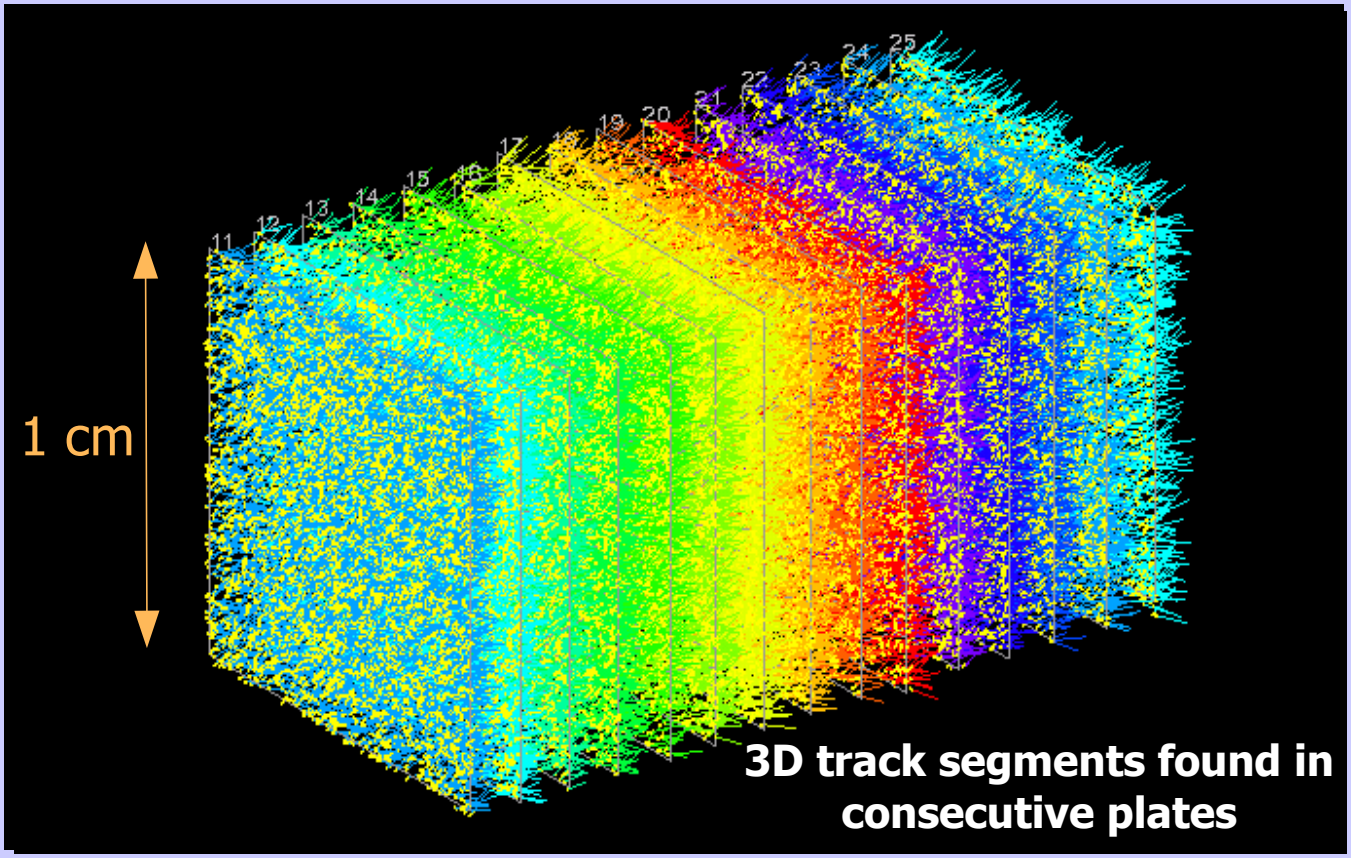
1 emulsion sheet (2 sides)

⟶ 12h scanning ~5GB

Emulsion Scanning

The frames correspond to the scanning area:

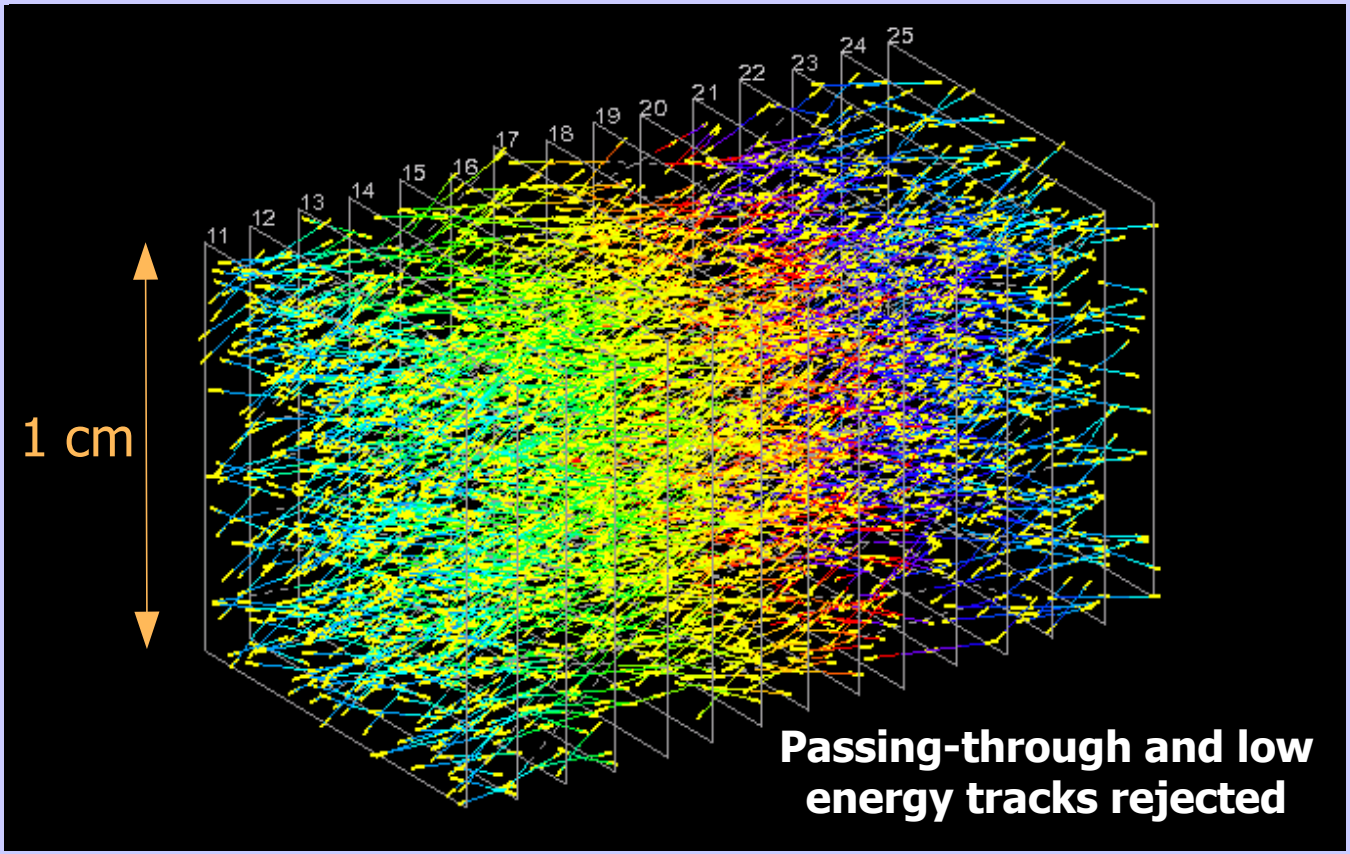
- Yellow short lines: Measured tracks
- Other colored lines: Interpolation or extrapolation



Emulsion Scanning

The frames correspond to the scanning area:

- Yellow short lines: Measured tracks
- Other colored lines: Interpolation or extrapolation



Emulsion Scanning

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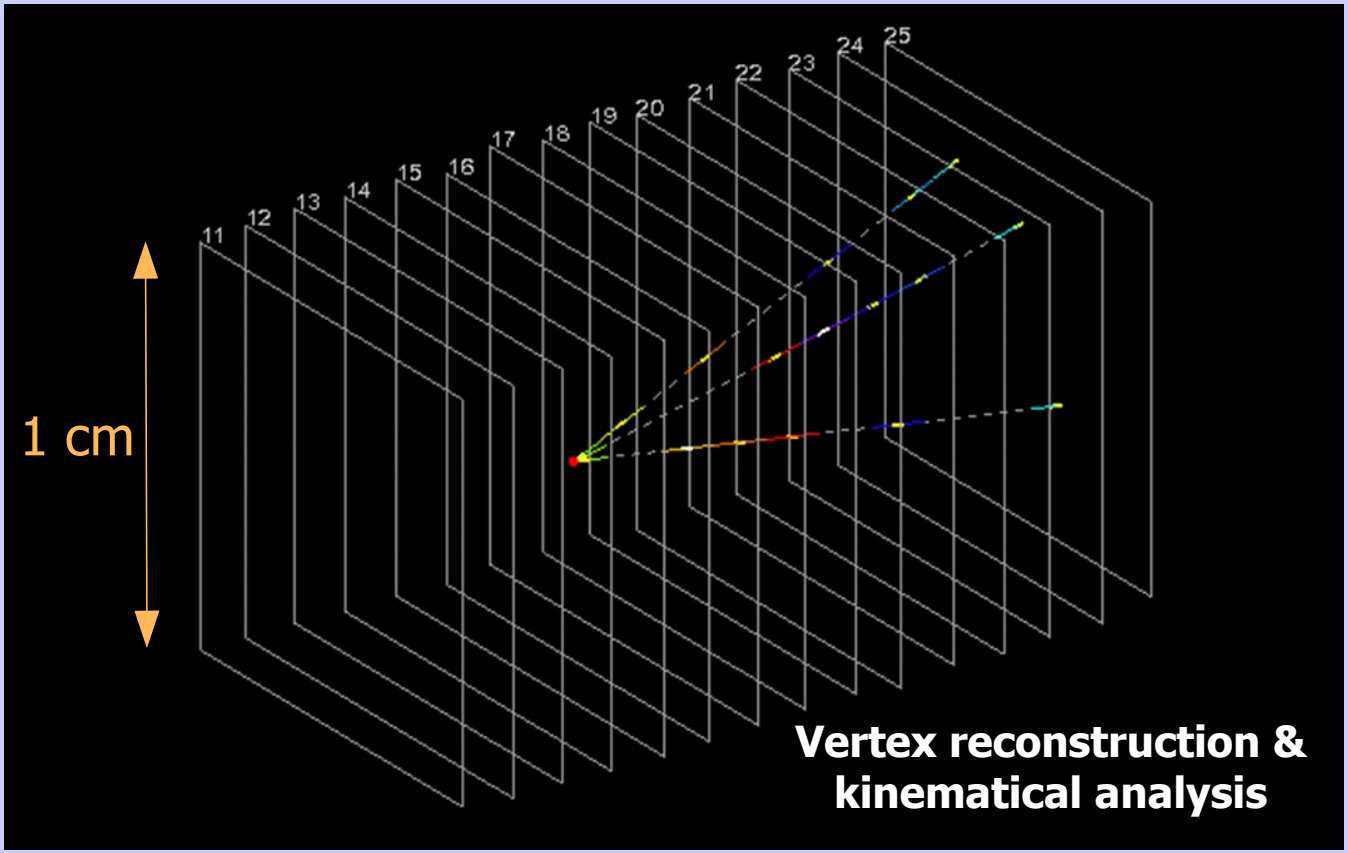

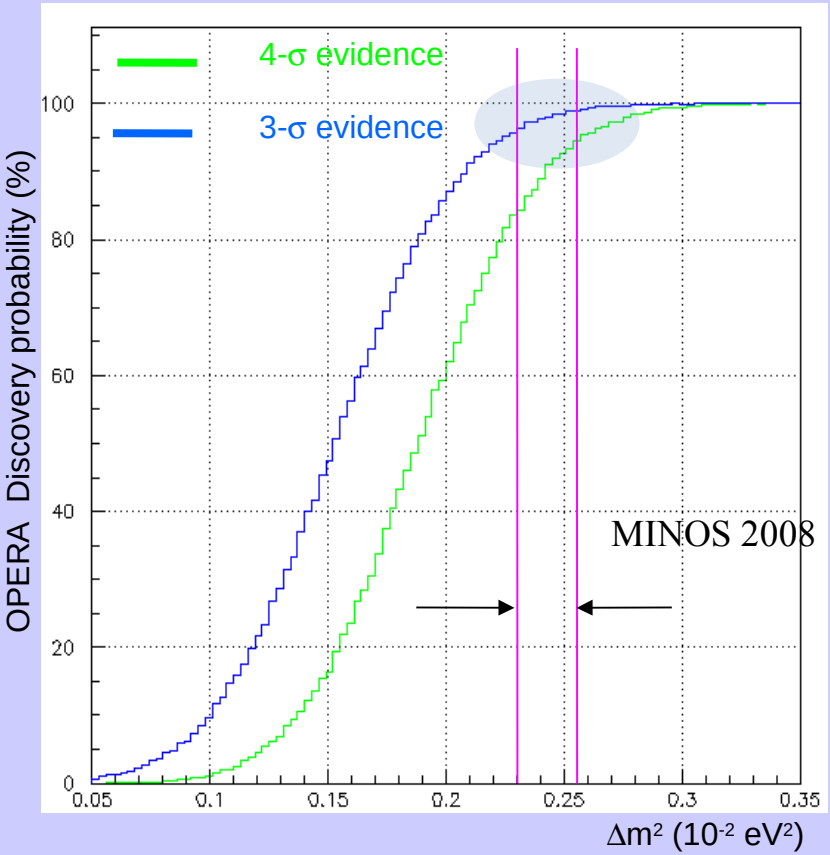
4-σ evidence
3-σ evidence
MINOS 2008
OPERA Discovery probability (%)
0
20
40
60
80
100
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Δm² (10⁻² eV²)