OPERA neutrino oscillation experiment: on the way to ν_τ observation

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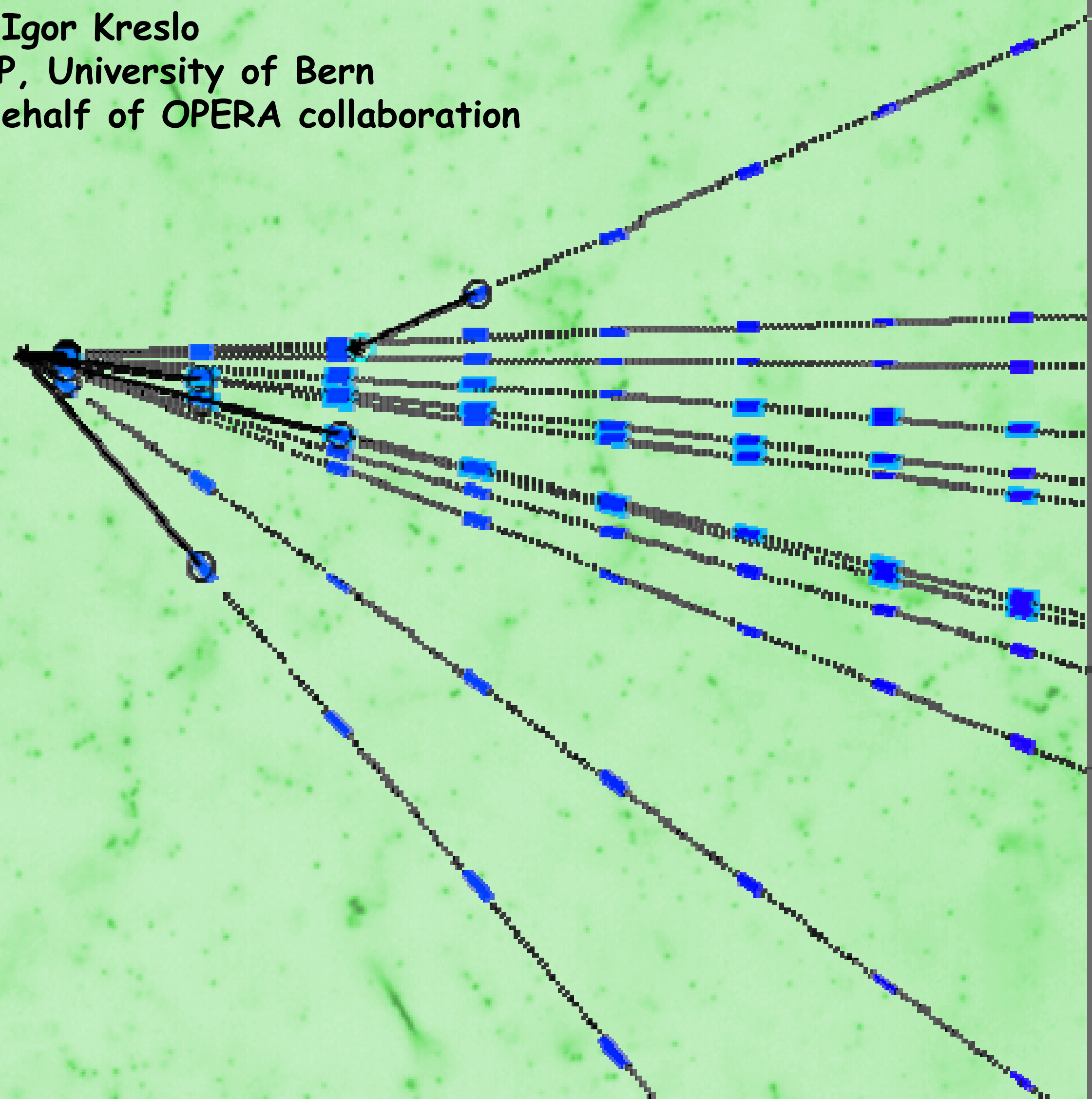
LHEP, University of Bern
on behalf of OPERA collaboration



Motivation:

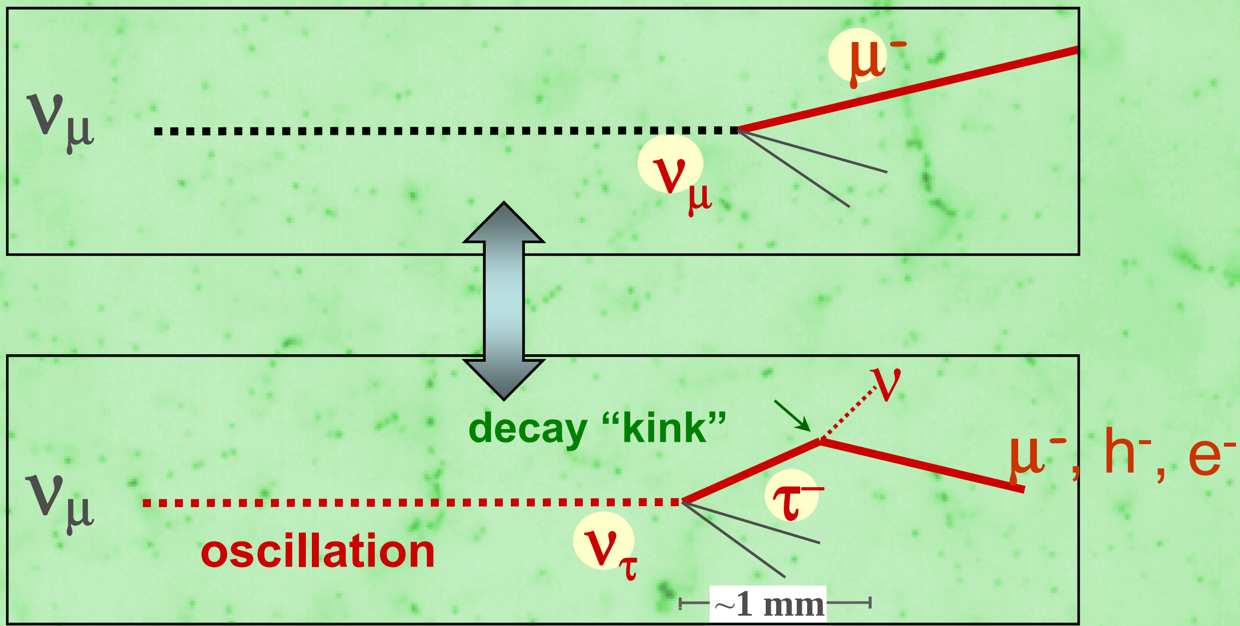
☺ Discovery of atmospheric neutrino oscillations by Super-Kamiokande

☹ One tile of the full picture is still missing - direct detection of neutrino oscillations in appearance mode

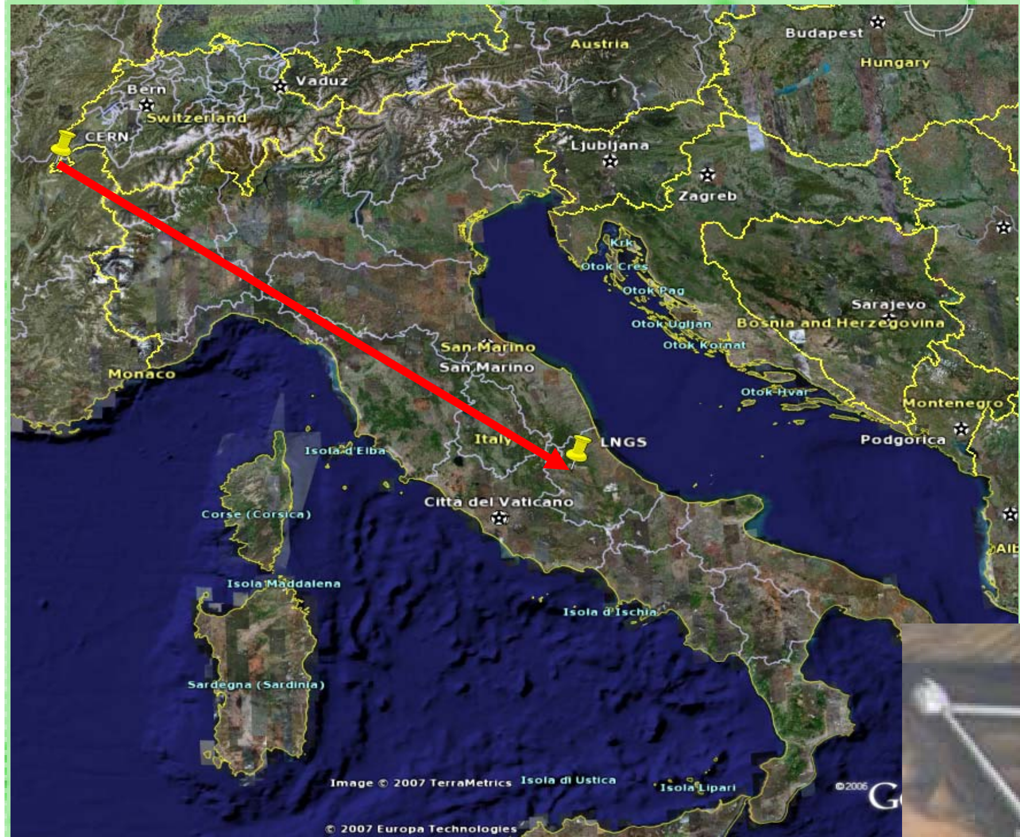
$$P(\nu_\mu \rightarrow \nu_\tau) \sim \sin^2 2\theta_{23} \cos^4\theta_{13} \sin^2(\Delta m^2_{23} L/4E)$$

Requirements:

1) high neutrino energy, 2) long baseline, 3) high beam intensity, 4) detect short lived τ's



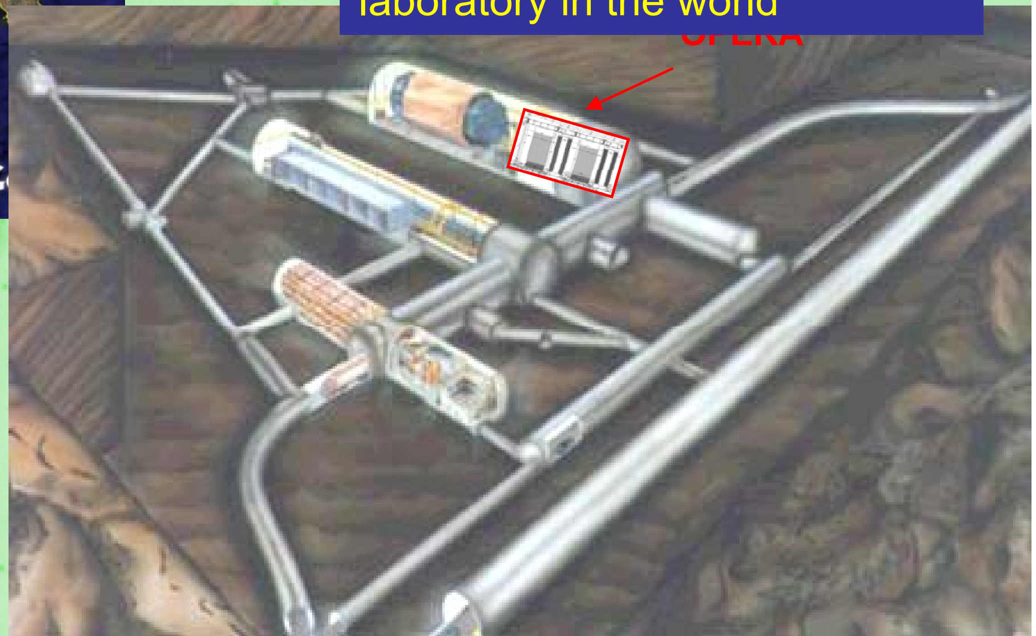
CNGS beam: tuned for τ-appearance at LNGS (730 km away from CERN)



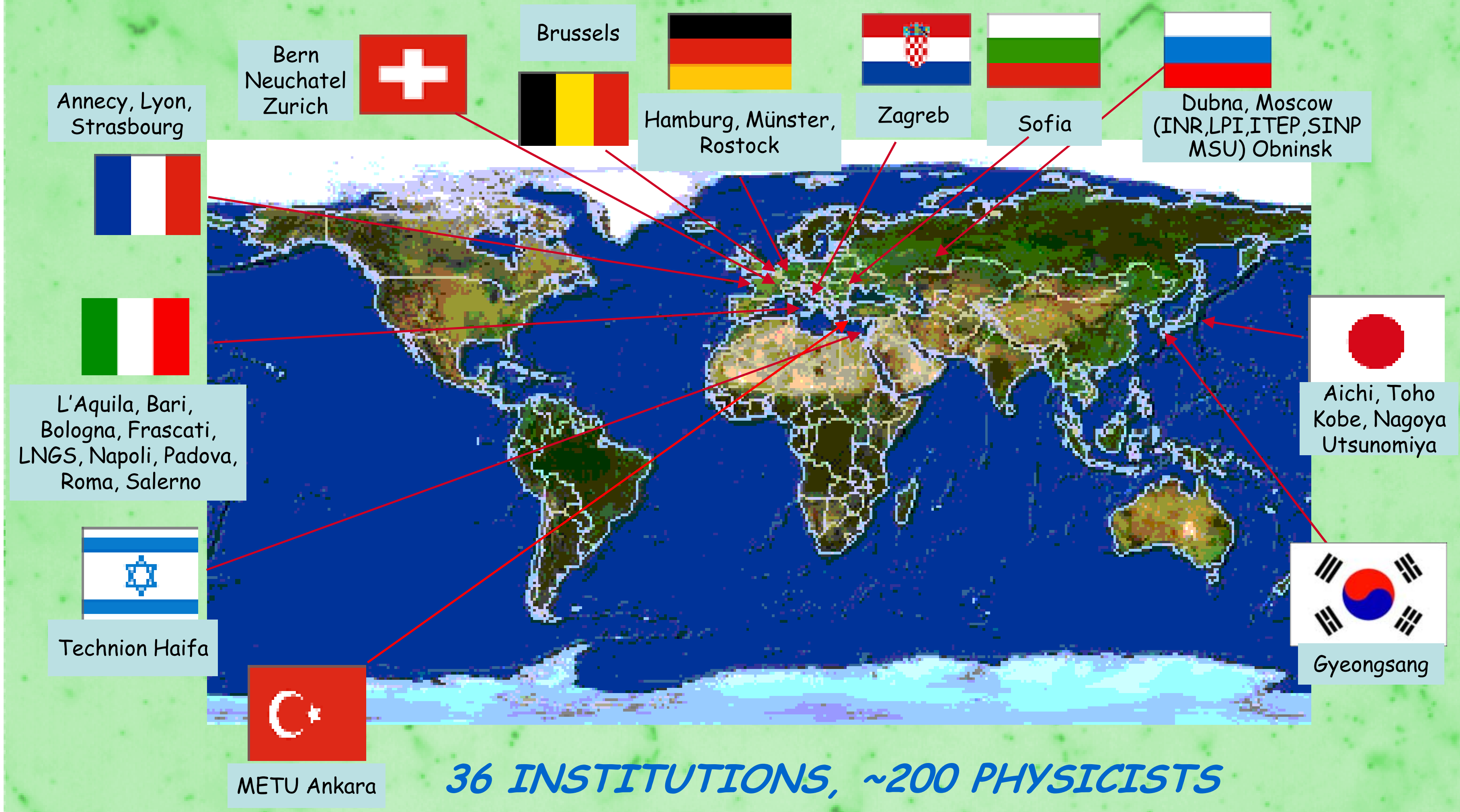
Mean ν_μ energy 17 GeV

Requested to deliver: 22.5 x 10^{19} pot

LNGS: the largest underground laboratory in the world



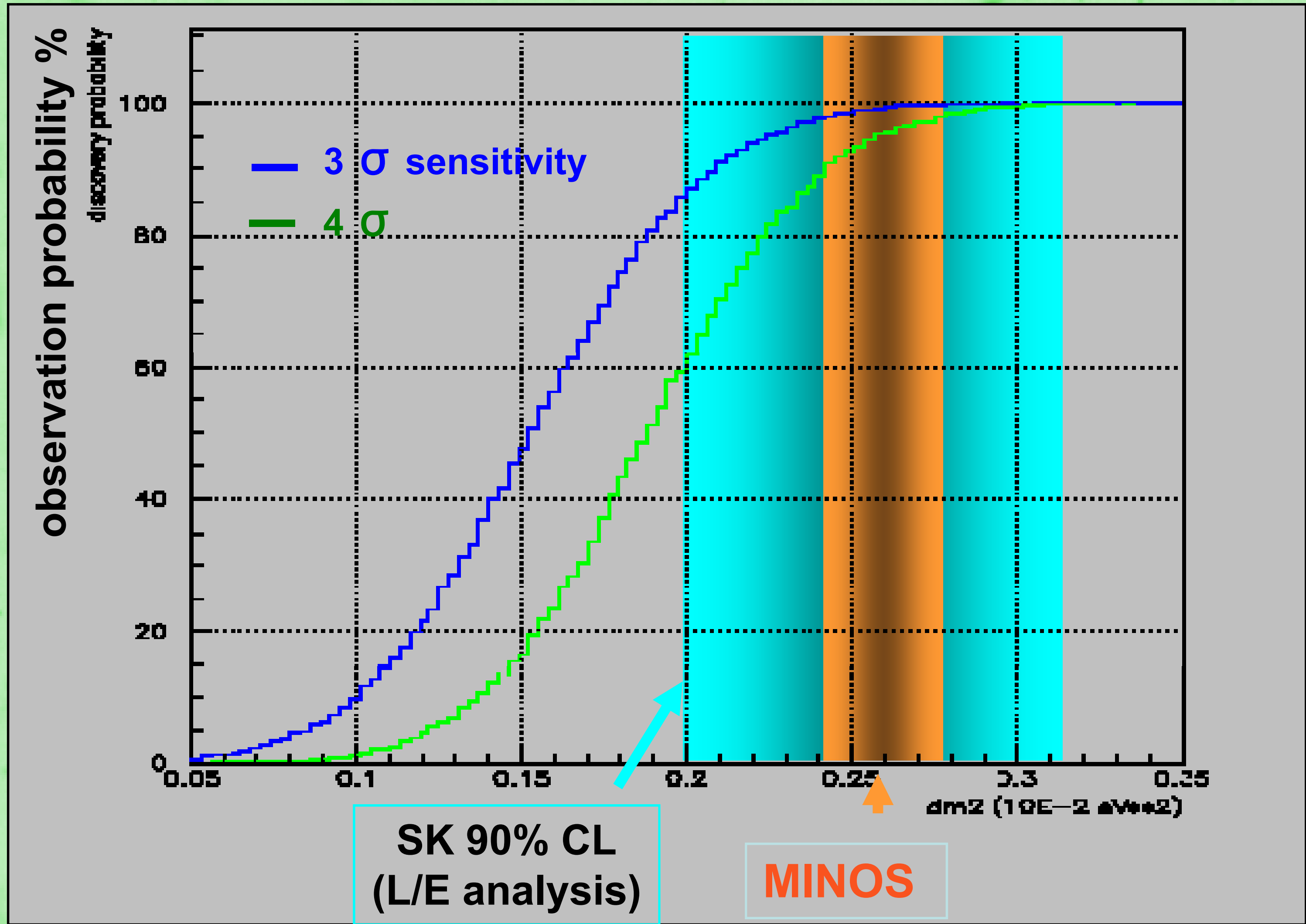
The OPERA collaboration



36 INSTITUTIONS, ~200 PHYSICISTS

OPERA ν_τ appearance observation probability

Assuming 22.5x10^{19} pot, 10-15 signal events, < 1 BG



OPERA detector concept

Conflicting requirements:

Large mass (low cross-section)

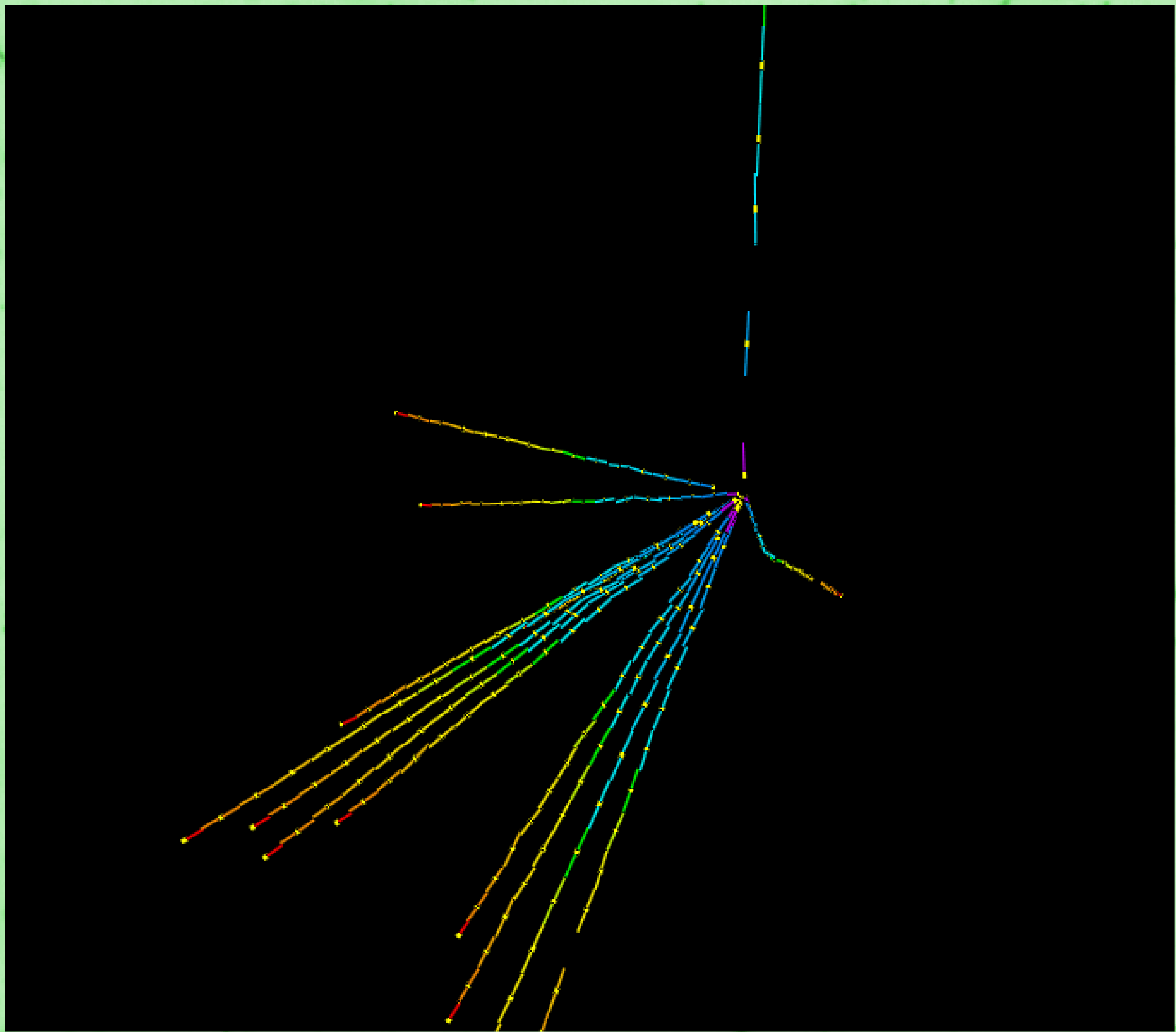
High granularity (signal selection and background rejection)

- Detection method: novel nuclear emulsion film technique (Nagoya/Fuji film) coupled to modern automatic scanning devices (Japan, Europe). Unprecedented large scale
- Very successful for medium scale past experiments: E531, CHORUS, DONUT
- OPERA: sandwich arrangement of emulsion films and lead plates (ECC technique)
- Complement with electronic detectors (hybrid apparatus) to provide ROI location, time correlation to the beam, and contribute to the kinematical event analysis

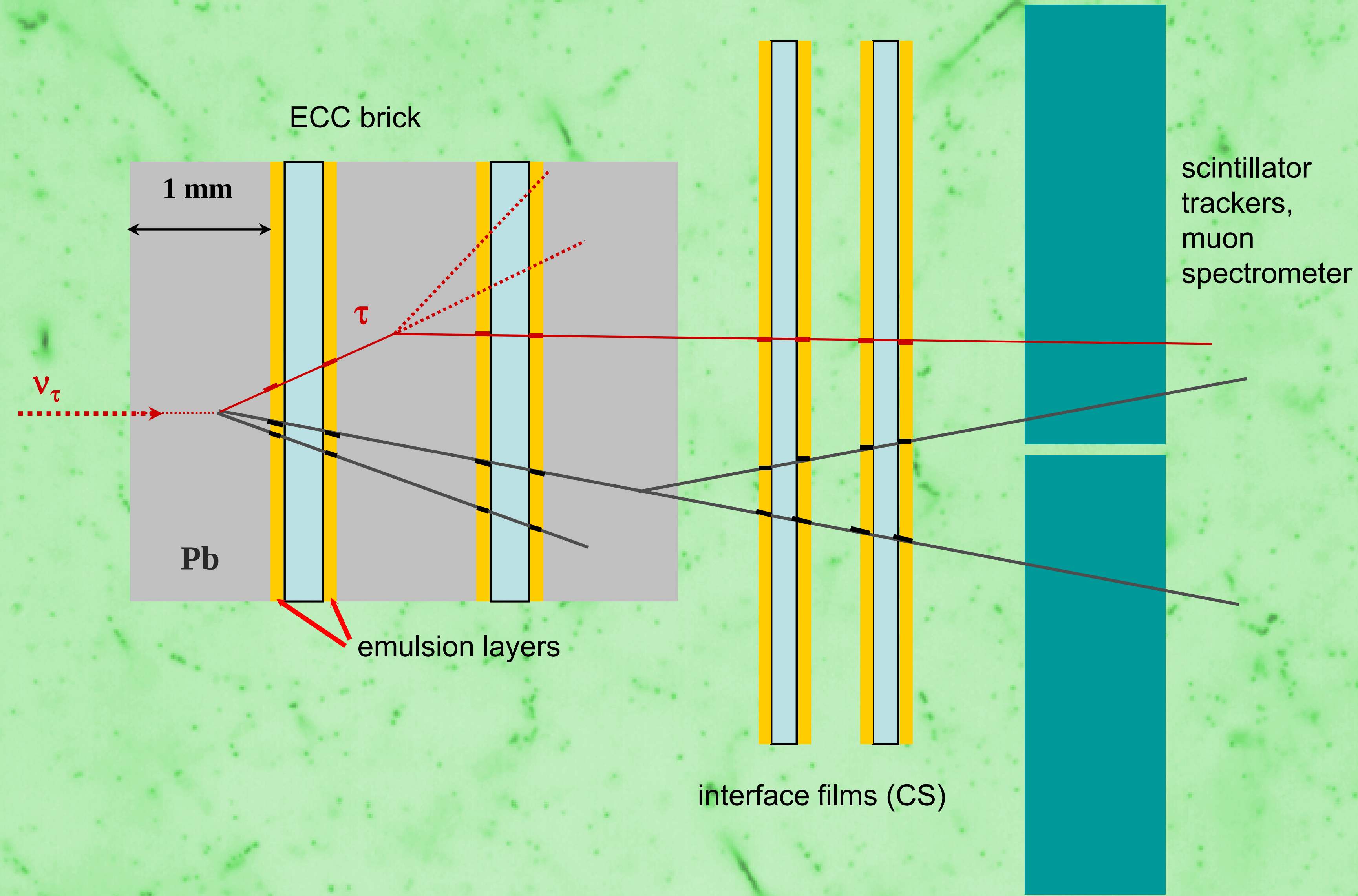
Target: 1300 tons, $\Delta m^2_{23}=2.5\times10^{-3}$ eV^2

~25,000	neutrino interactions
~120	ν_τ interactions
~10	ν_τ identified
~ 0.5	BG events

ECC technique: 2000 discovery of ν_τ's with the DONUT experiment.



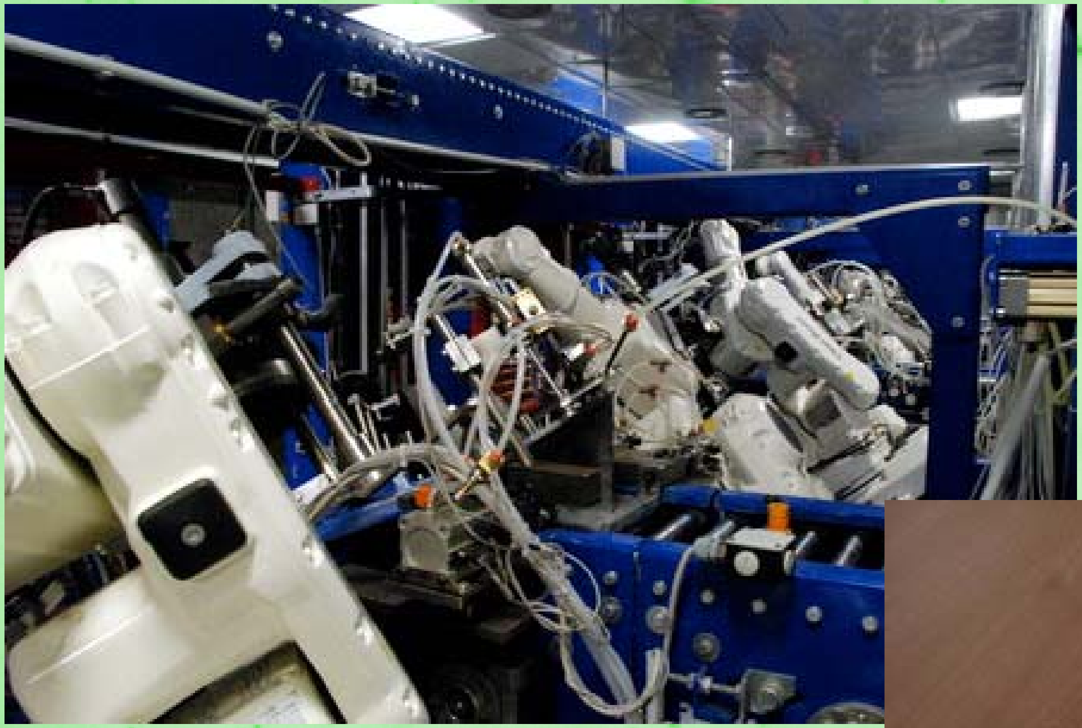
OPERA detector concept scheme



OPERA detector and related facilities

OPERA Detector in Hall C of LNGS, GranSasso, Italy

ECC bricks assembling



Robots of the
brick assembly machine

Assembled brick with interface emulsions

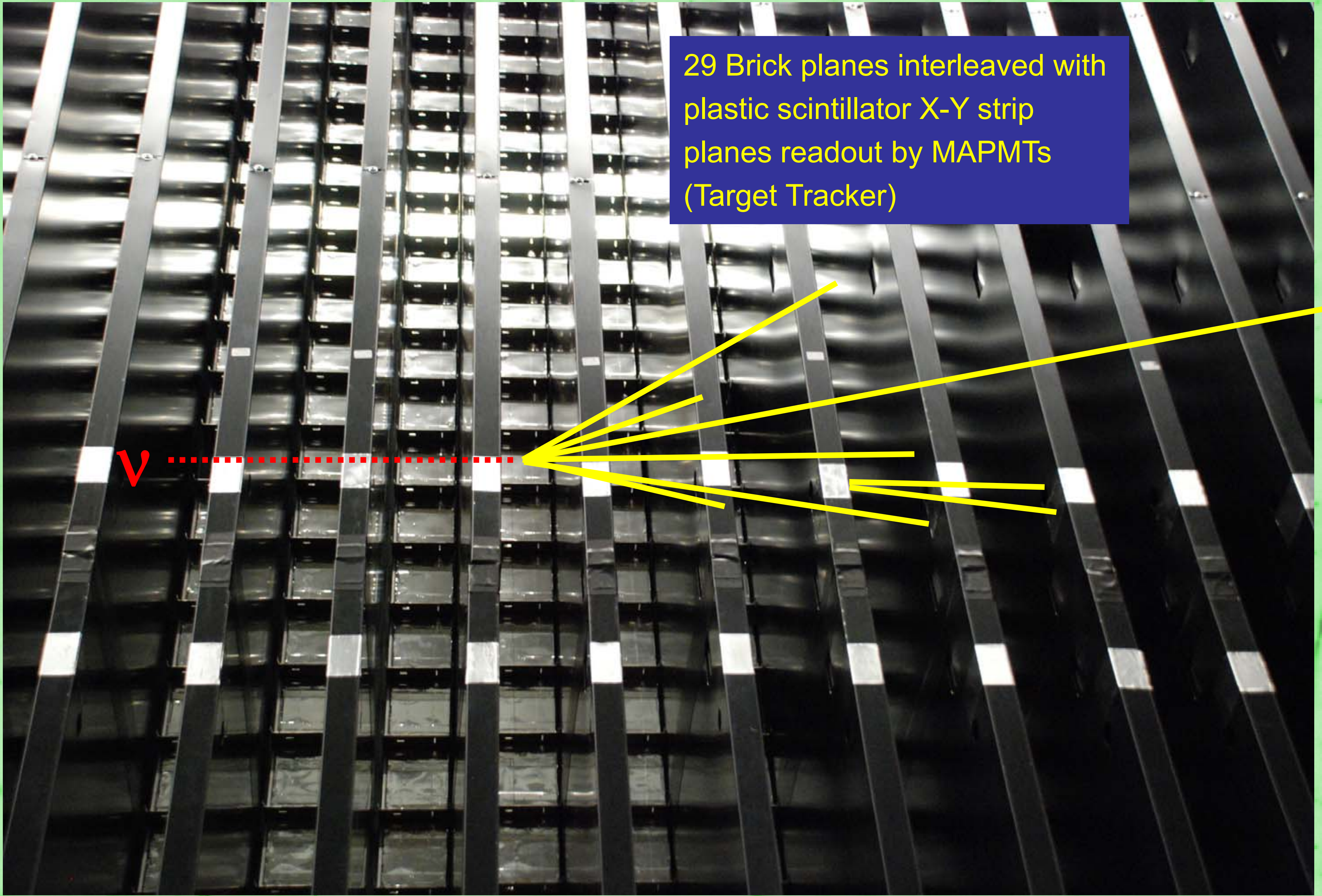
~150,000 bricks produced and installed:

8.3 kg and 10 X_0 each

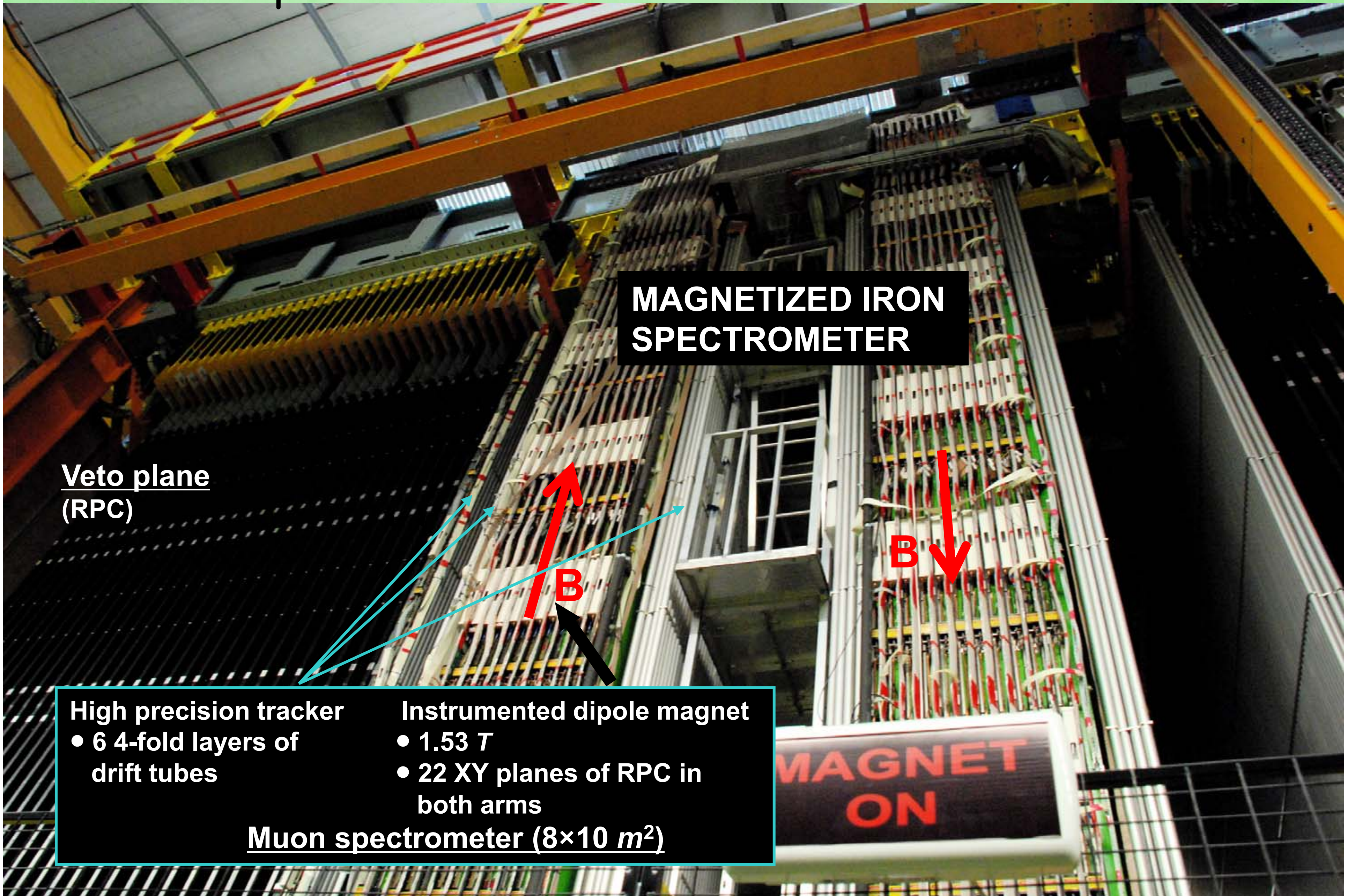
57 +2 emulsion films and 57 1mm lead plates per brick (12.5 cm x 10 cm)

For a total of 105,000 m^2 of lead surface and 111,000 m^2 of film surface (~ 8.9 million films)

Target section of OPERA detector (SM0)



Muon spectrometer section of OPERA detector



Brick insertion and extraction

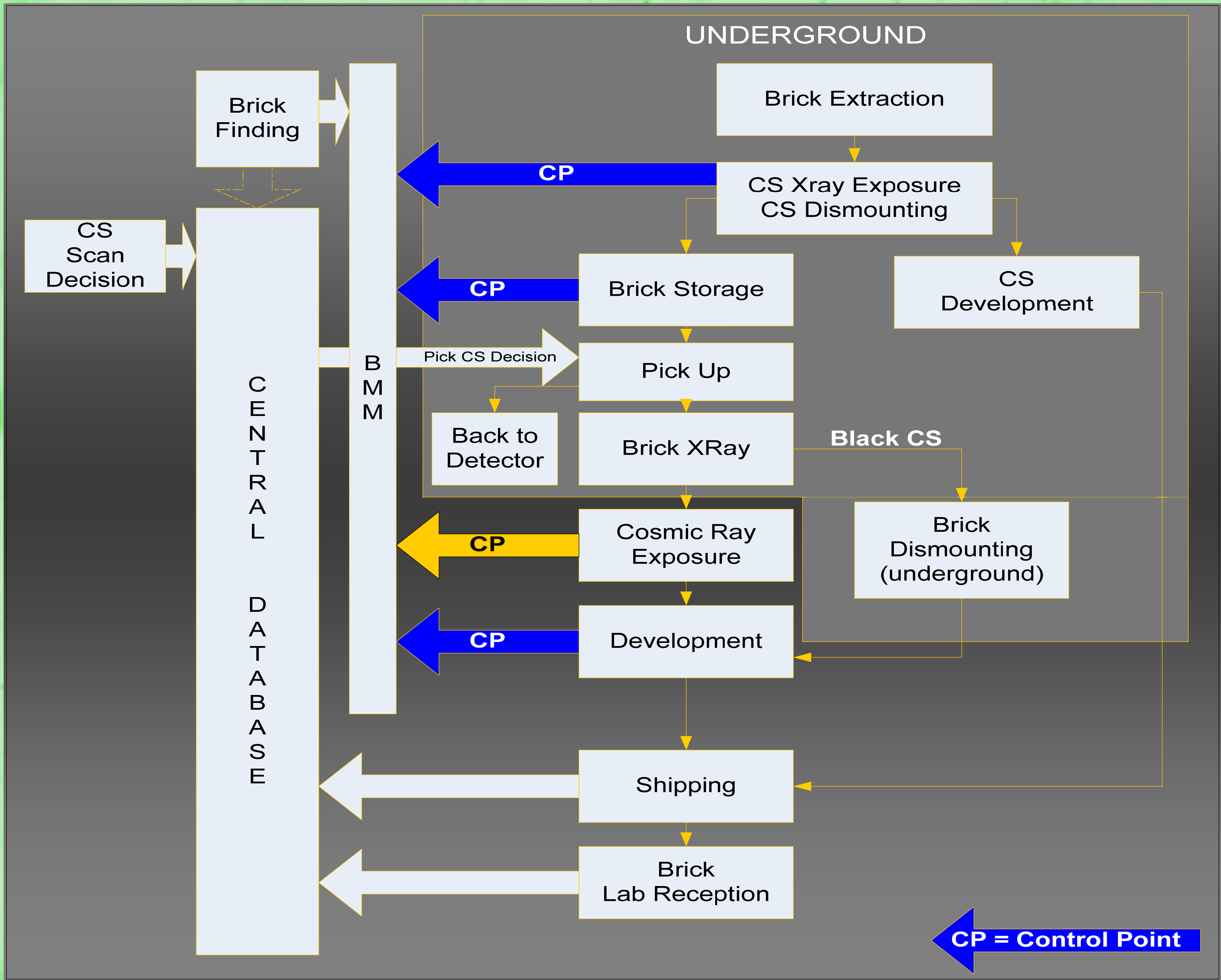
Automatic brick manipulation machine

Post-extraction brick processing

Large facilities for brick handling after extraction:

- X-ray marking
- Cosmic-ray alignment
- Industrial emulsion processing

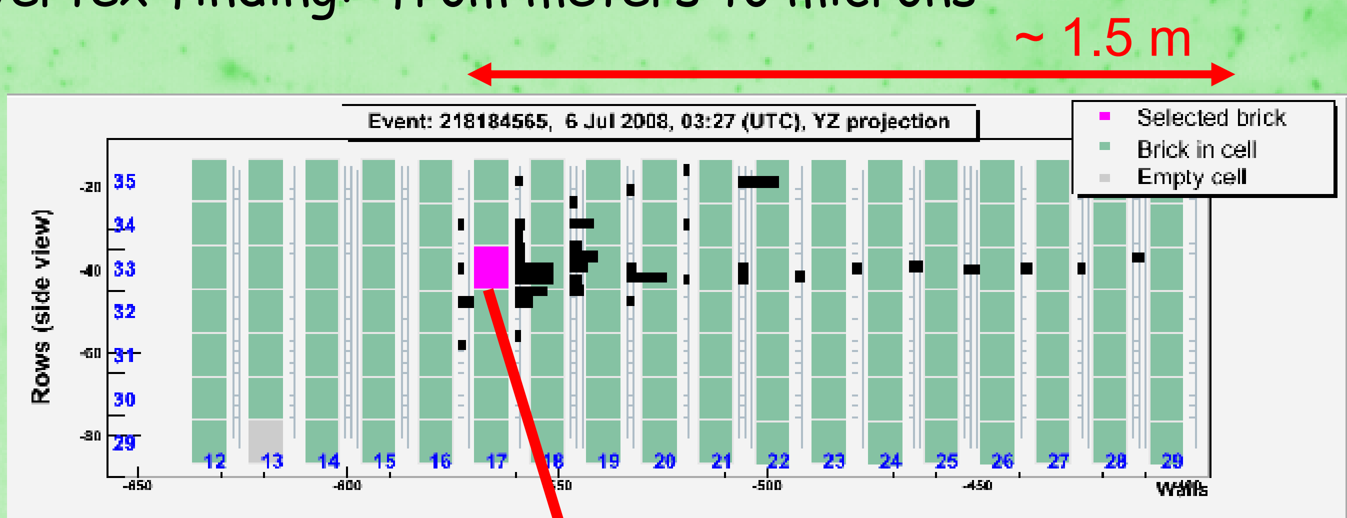
Brick life from the trigger to the scanning laboratory



Automatic high-speed microscopes (~40 in the collaborations)

LHEP Bern: Swiss Scanning Station with 5 microscopes.

From trigger to vertex finding: from meters to microns



Brick finding information: Super module 1

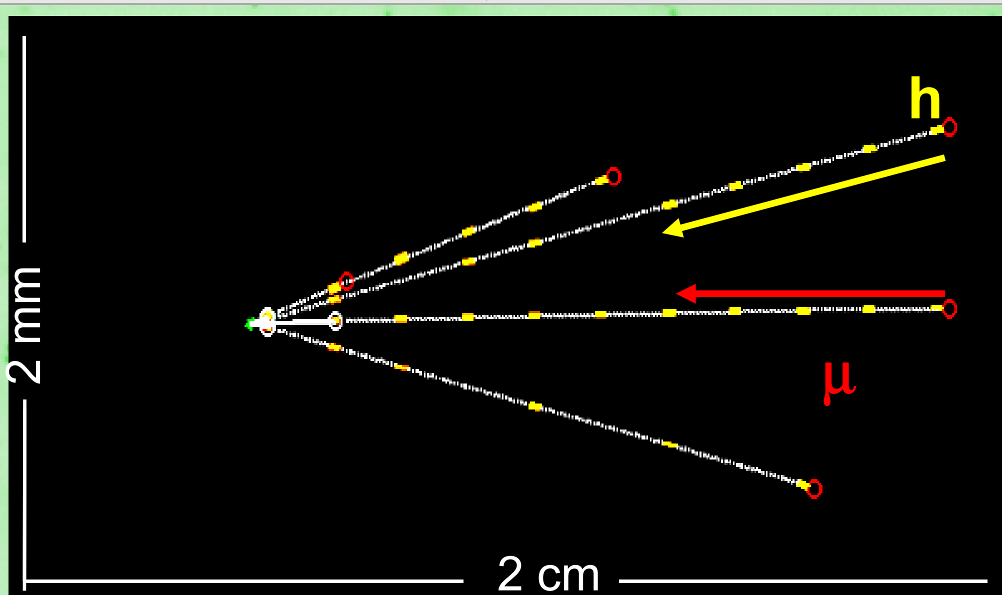
	BrickId	Wall	Side	Column	Row	Prob	CS x	CS y
brick 1:	1036423	17	1	9	33	0.59	[illegible]	15.6
brick 2:	1036448	17	1	9	32	0.37	[illegible]	120.9
brick 3:	1067422	16	1	9	32	0.02	[illegible]	117.9

Muon track parameters: Mu-

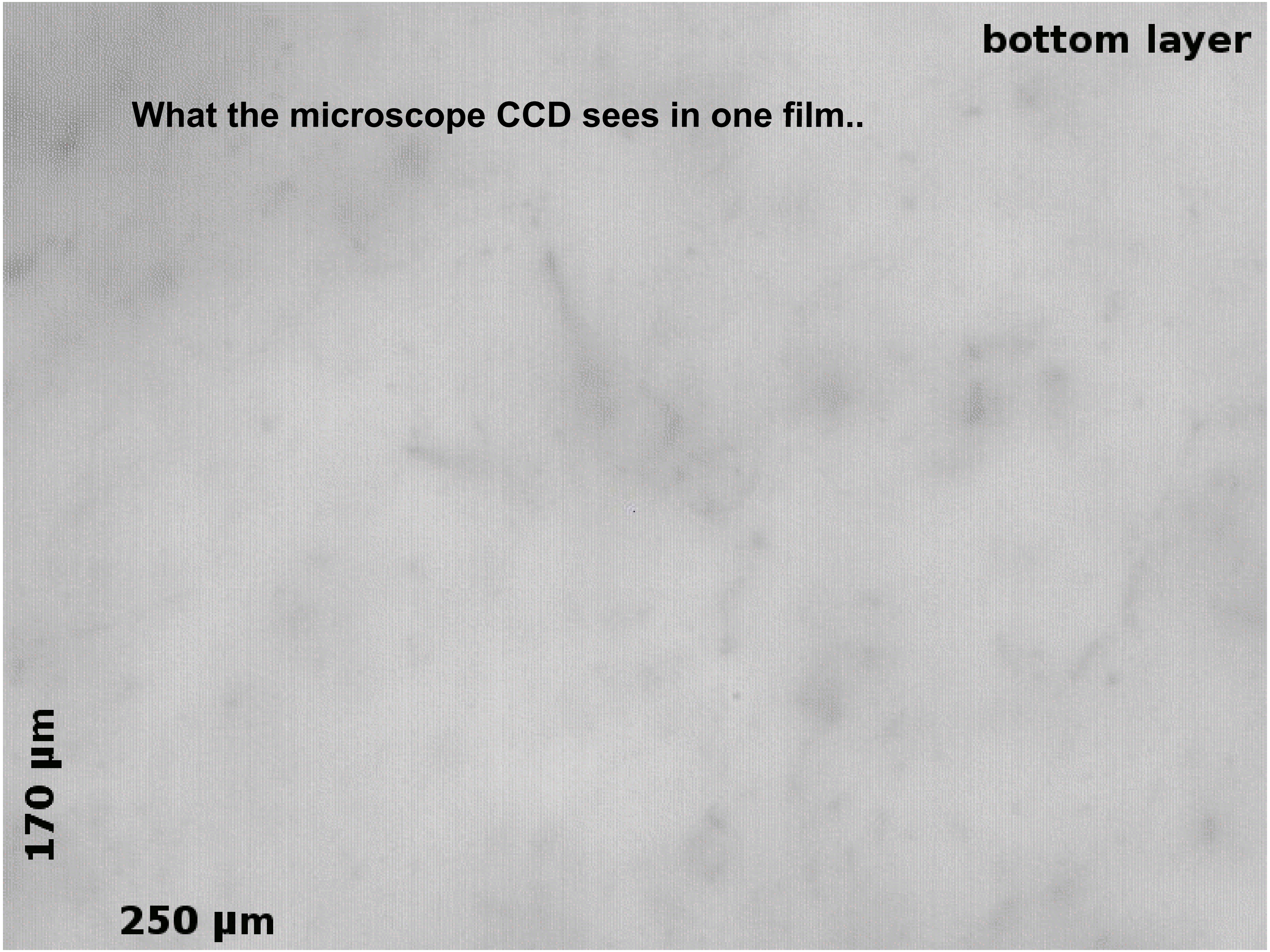
Momentum: 3.394 GeV/c

Angle XZ (rad): 0.134+/-0.009

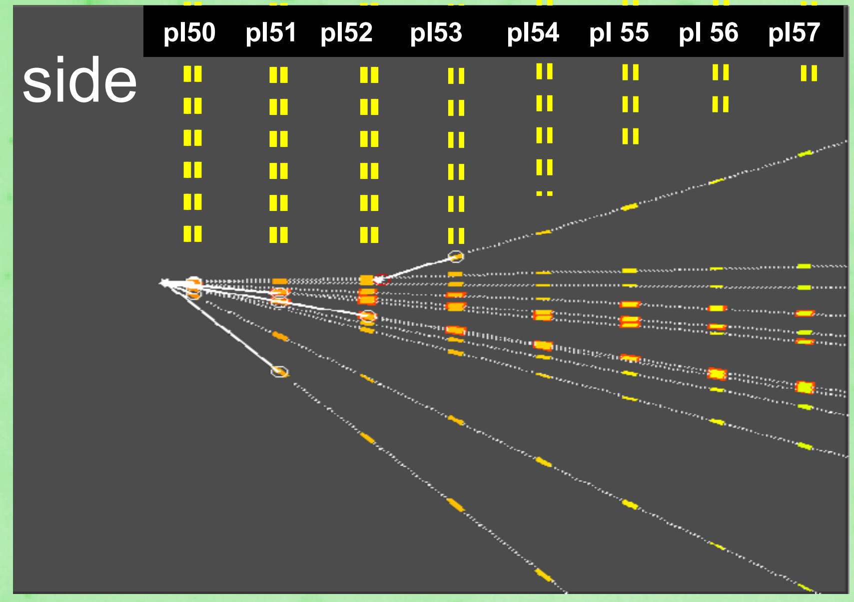
Angle YZ (rad): 0.028+/-0.009

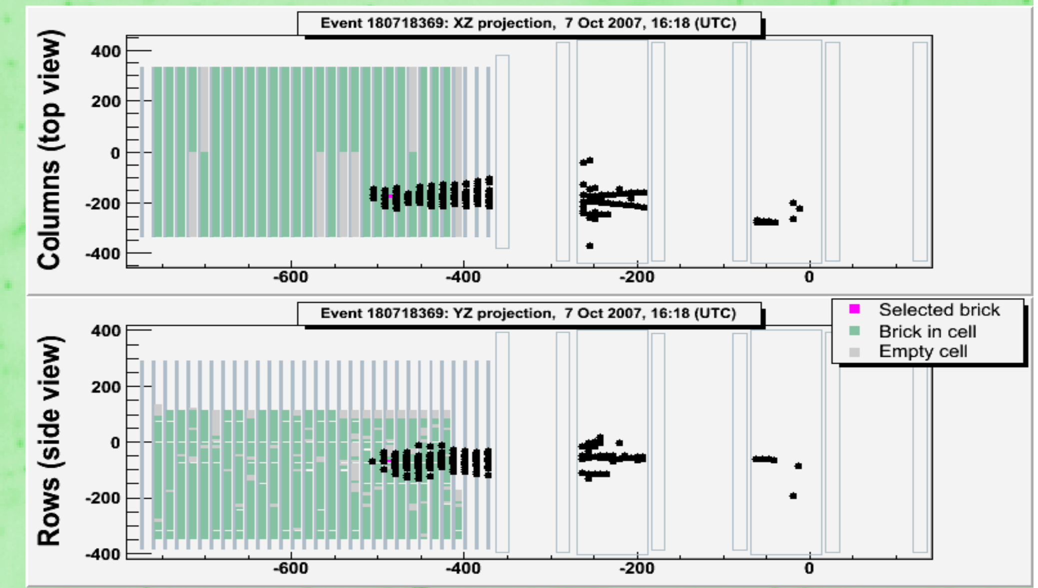


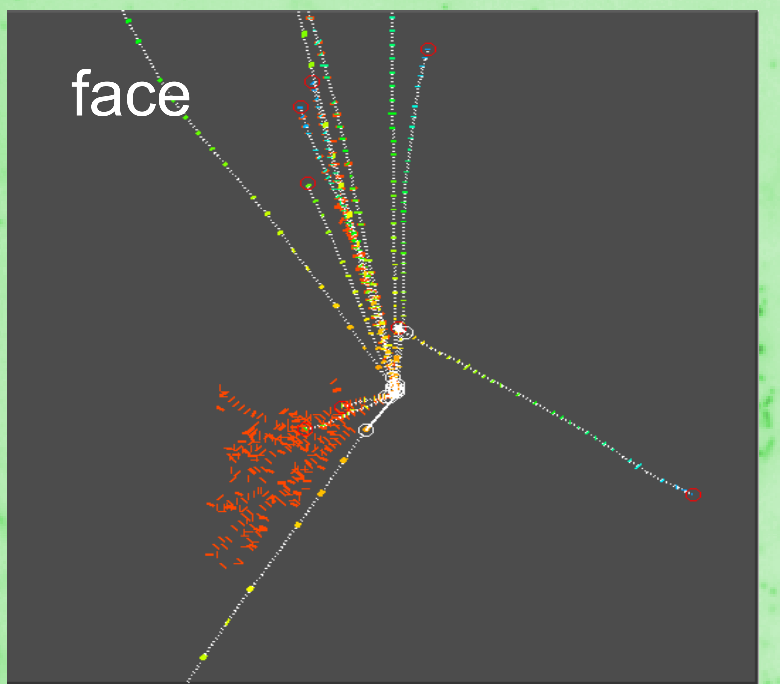
What the microscope CCD sees in one film..



Reconstructed Charmed event example (real data)





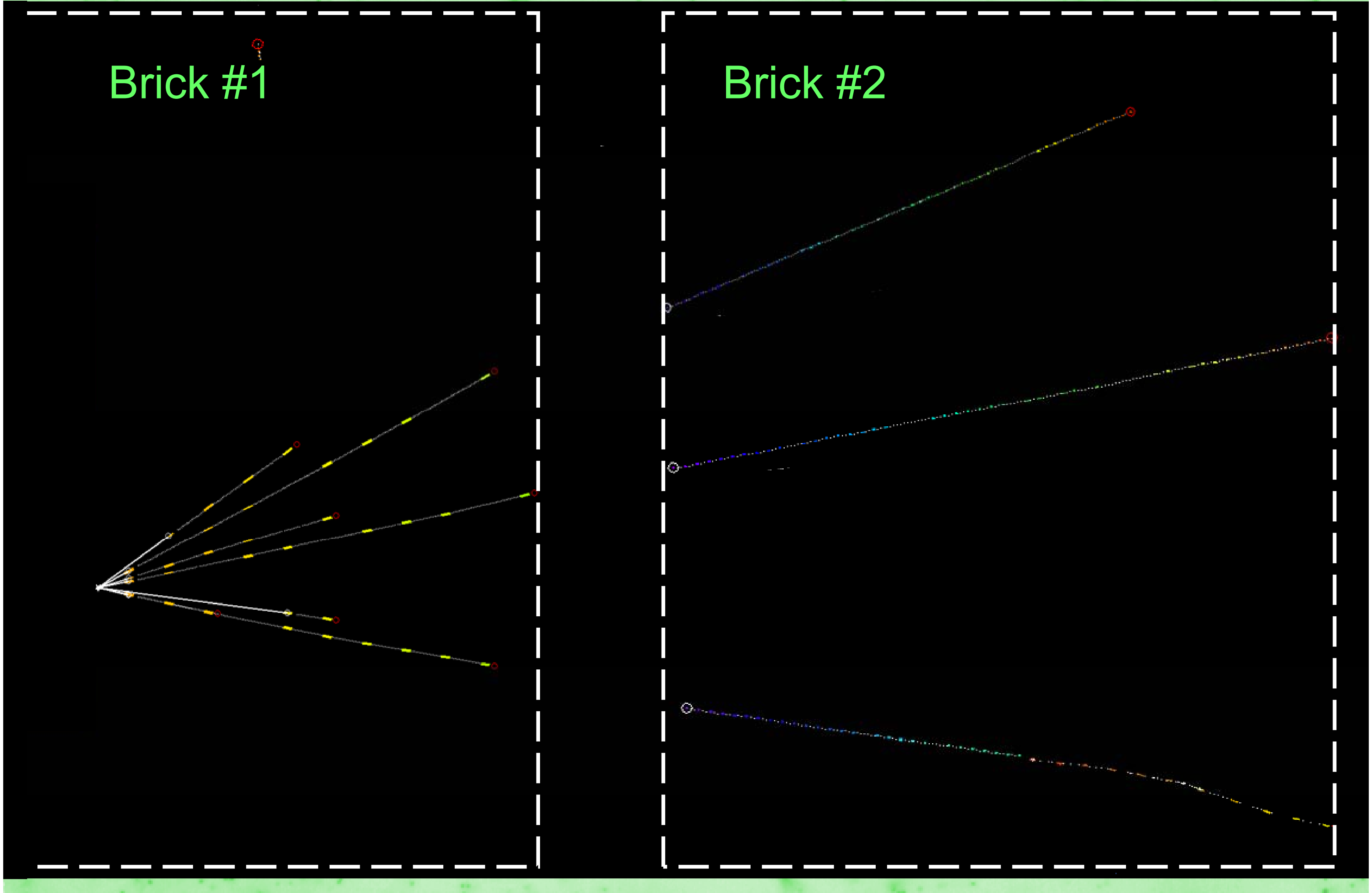


Clear kink topology
Two EM showers pointing to the vertex

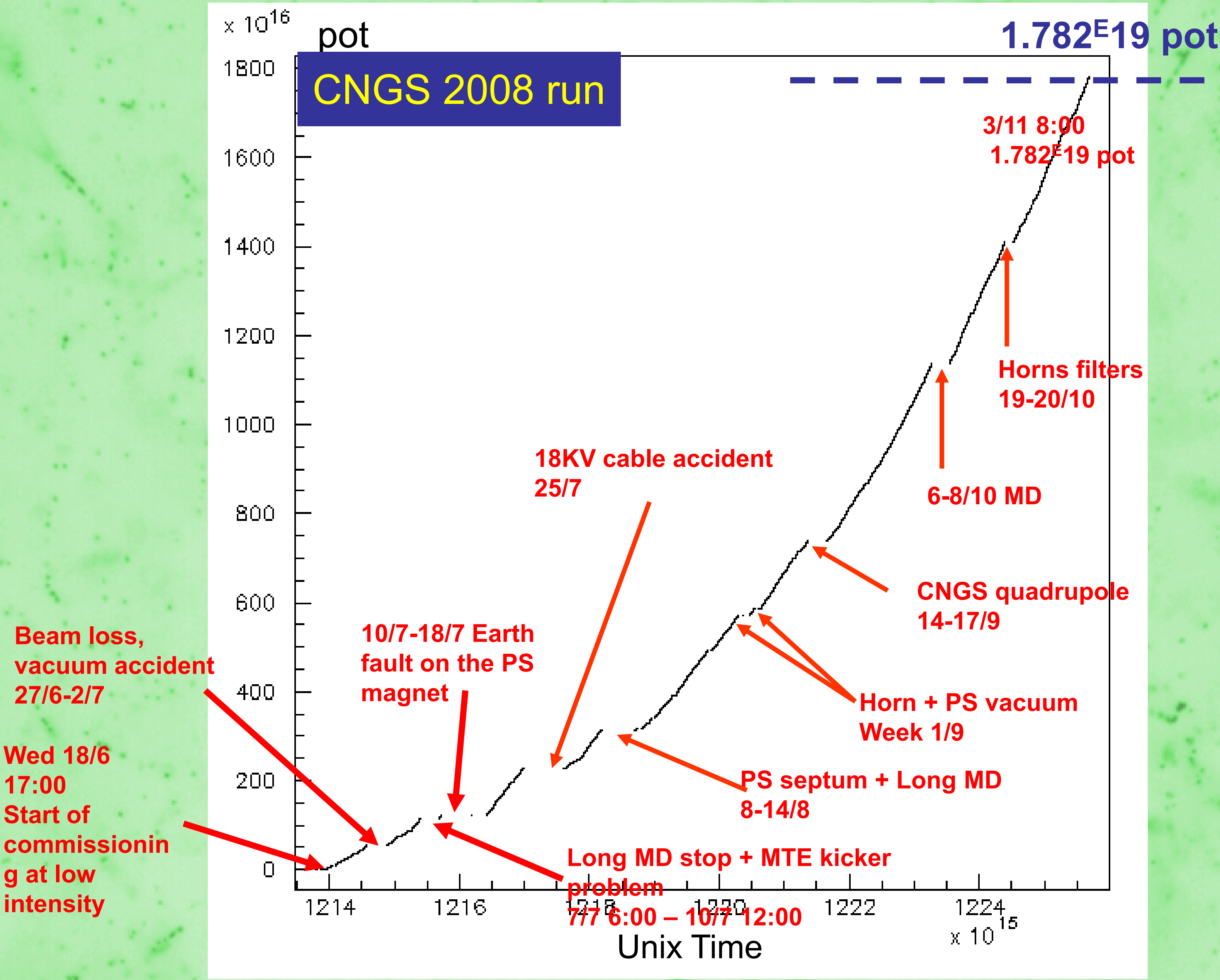
Flight length	3247.2 μm
θ_{kink}	0.204 rad
$P_{daughter}$	3.9 (+1.7 -0.9) GeV
P_T	796 MeV

4×10^{-4} probability for a hadron re-interaction to have a $P_T > 600$ MeV

Reconstructed neutrino vertex and brick-to-brick connection



CNGS beam from start till now…



OPERA from start till now…

May 2006: electronic detector commissioning

Aug 2006: technical run, **0.76×10^{18} pot** collected

319 interactions in the rock, mechanical structure and iron of the spectrometer

Oct 2006: start of brick production

Oct 2007: pilot physics run (~40% target) **0.82×10^{18} pot**

first 38 neutrino events in the lead/emulsion target

Jun 2008: OPERA detector filled and fully commissioned (~150,000 bricks)

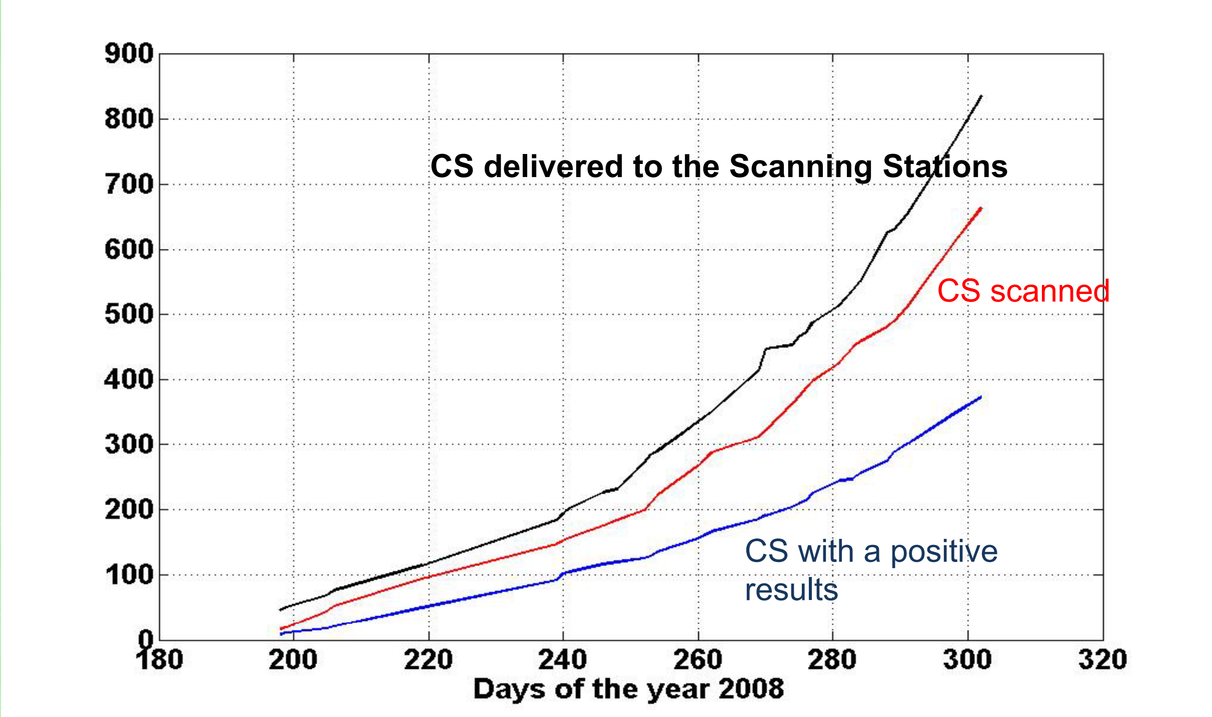
Jun 2008: Start first OPERA production run

Nov 2008: **18×10^{18} pot** and **~1700** neutrino events in the target:

Expected number of **IDENTIFIED** charmed events in detector: **26**

Expected number of **IDENTIFIED** **tau events : 0.6 τ**

Detection efficiency with real data (preliminary low statistics analysis)



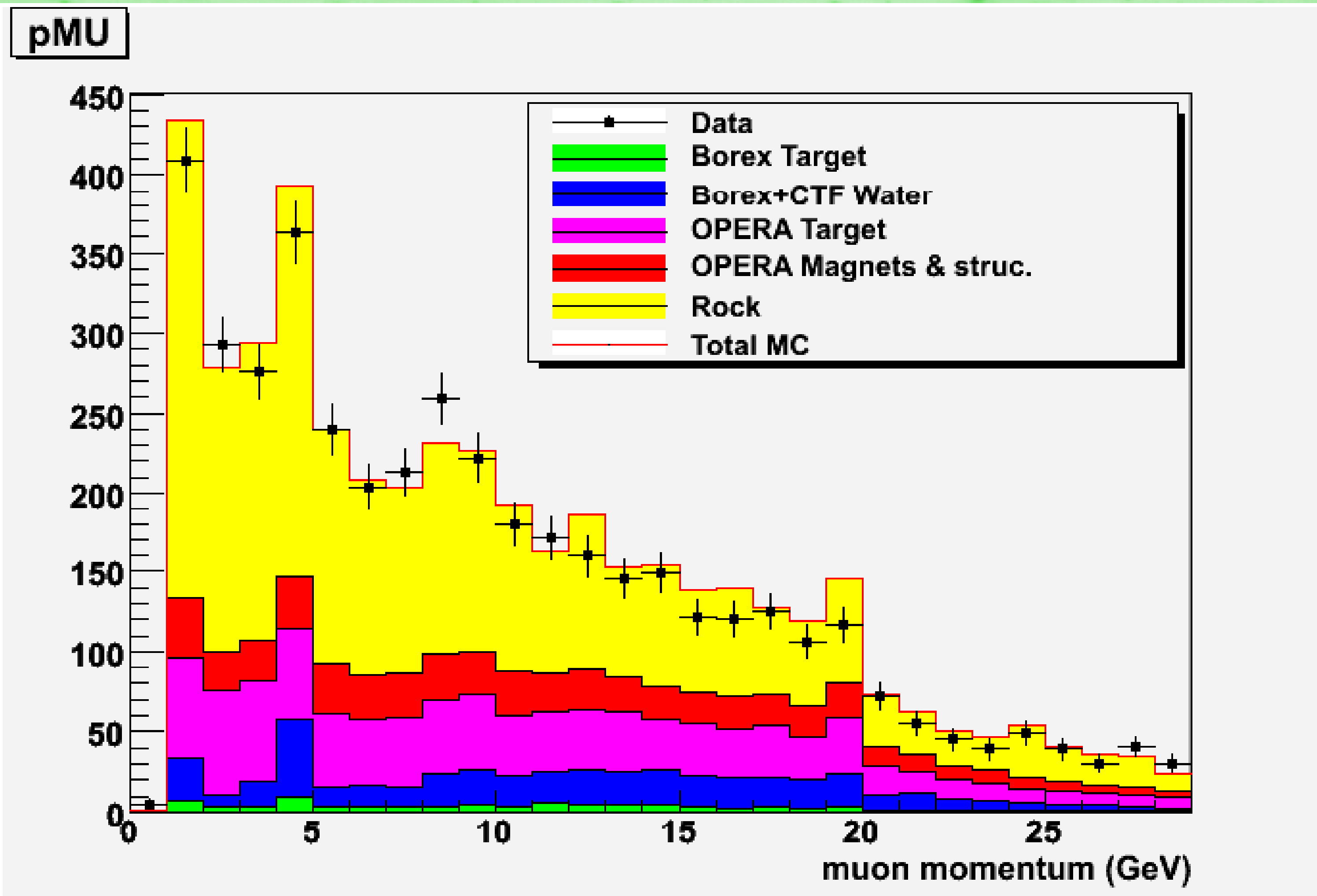
Brick finding efficiency: from CS measurement (only one brick extracted): 67±5 (stat)% (MC predicts 72%). Rise to >80% by extracting a second brick if required

CS finding efficiency: 74 ± 6% (~80% expected by MC) measured with a first set of real data. More precise estimates with increasing statistics. New method being tested: better efficiency ~89±3%

Vertex finding efficiency: for CC ranges from 86 to 96 % (93% from MC)
for NC ranges from 74 to 89 (81% from MC)

Example of analysis and event reconstruction capabilities:

momentum reconstruction for CNGS related muon tracks



The OPERA experiment has started full data taking in the CNGS beam:

- 2008 run: ~1.8×10^{19} pot, ~1700 interactions in the bricks
- ~26 identified charm decays and ~0.6 identified τ events expected
- by today ~20% of bricks are processed ("learning curve")

Detector and ancillary facilities performed extremely well

The event analysis chain successfully proceeds "quasi-on-line"

Detection efficiencies and BGs are being computed with real data

Interesting events have already been analyzed (Charm, Nu-e)

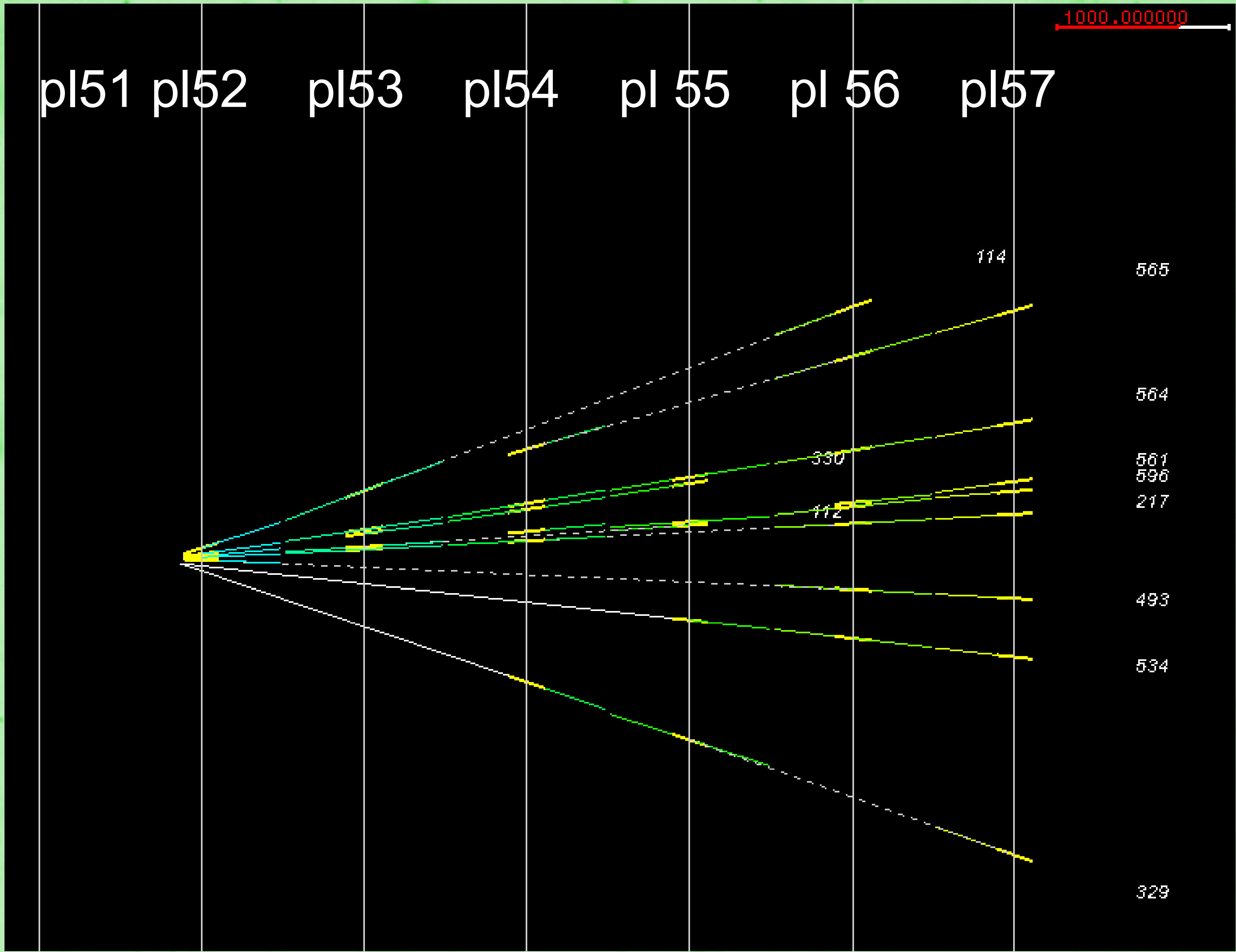
Forecast for 2009:

- 173 days of running: ~3.5×10^{19} pot (requested 4.5×10^{19})
- Sufficient integrated statistics for candidate events (~2 events)
- Precise evaluation of efficiencies, BG and sensitivity

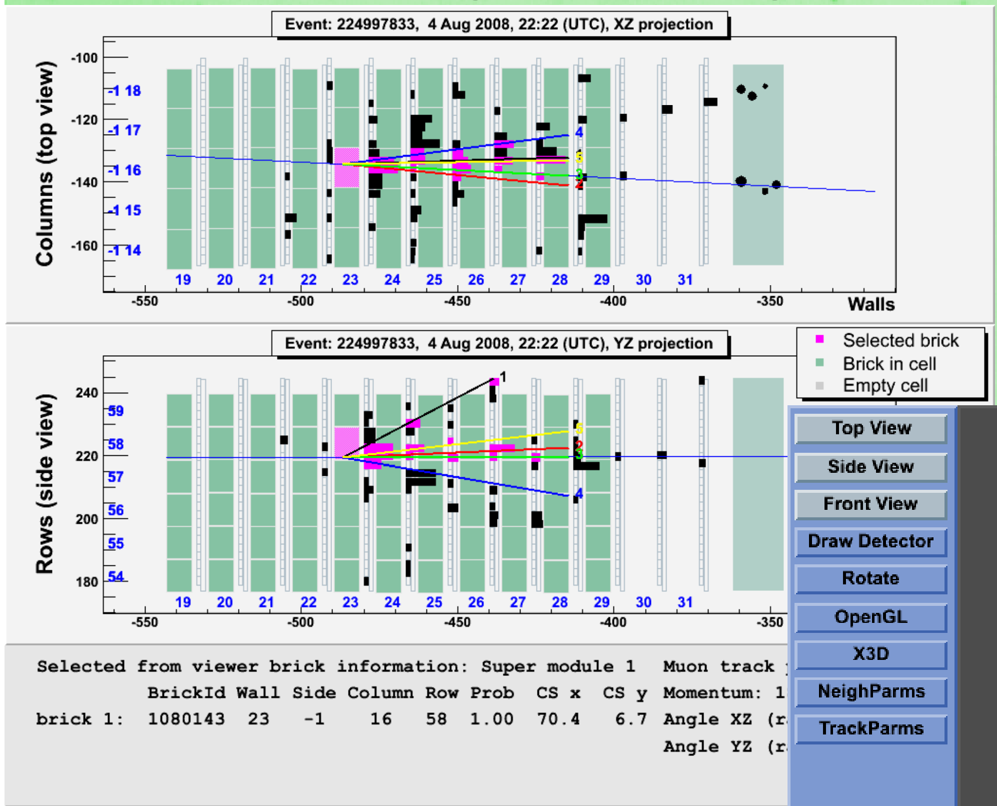
The collaboration and the CERN beam teams are very motivated and committed.

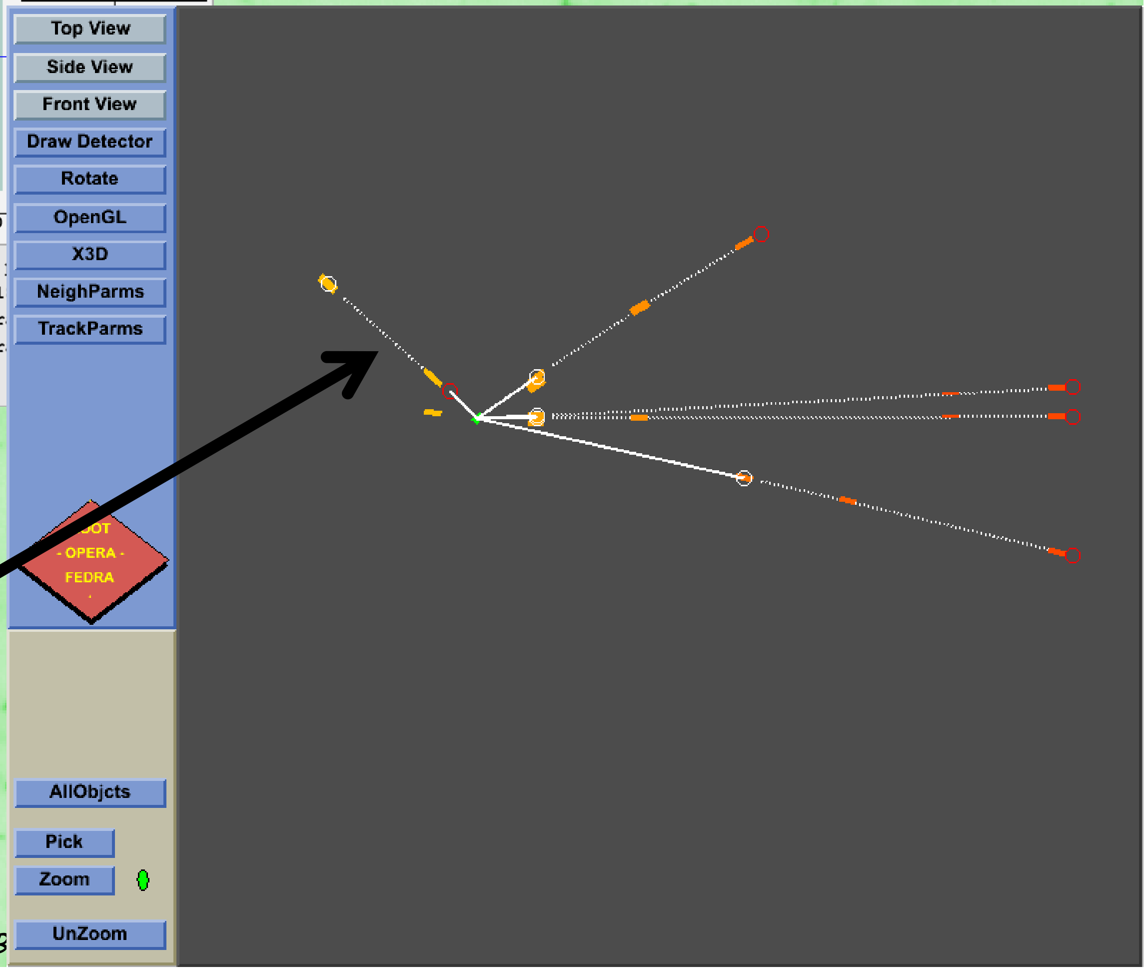
Additional Slides: some event vertices

Reconstructed neutrino vertex in ECC brick



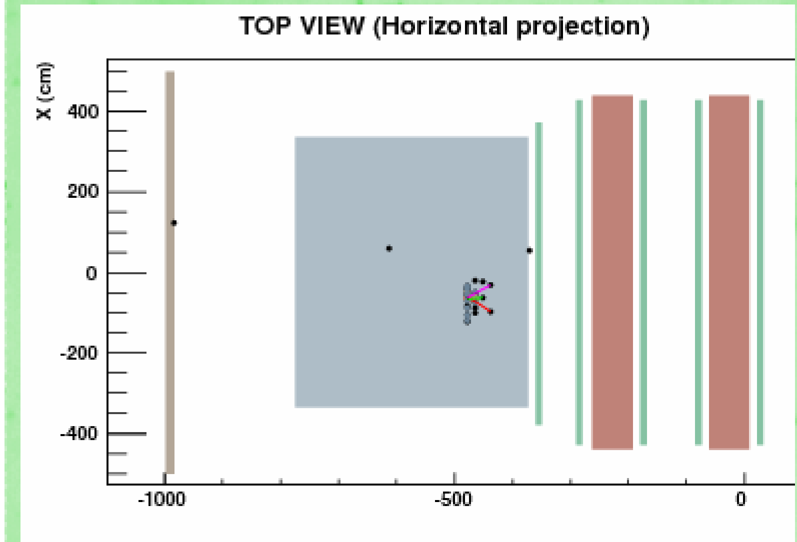
Back scattering – a challenge for brick finding

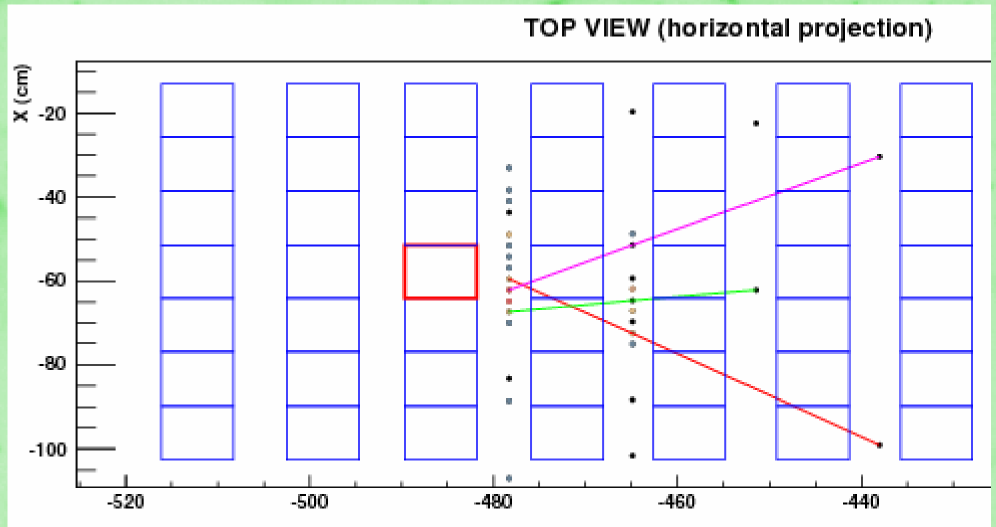




Backward going particle

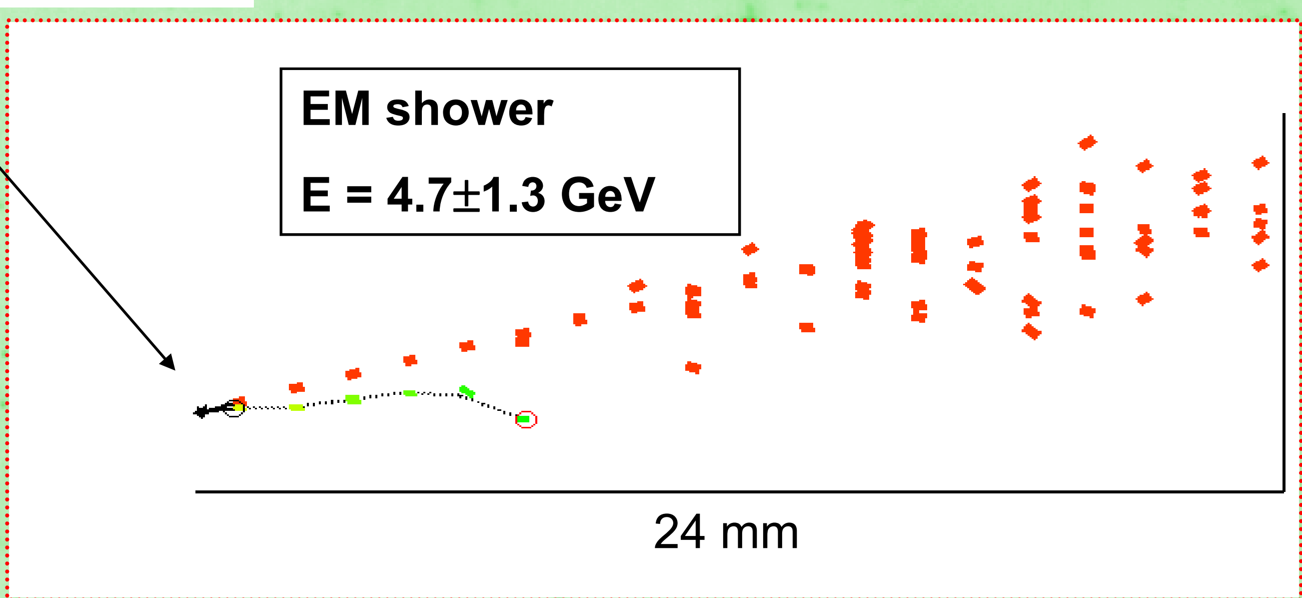
Event 183545620 located in Bern – first ν_e candidate



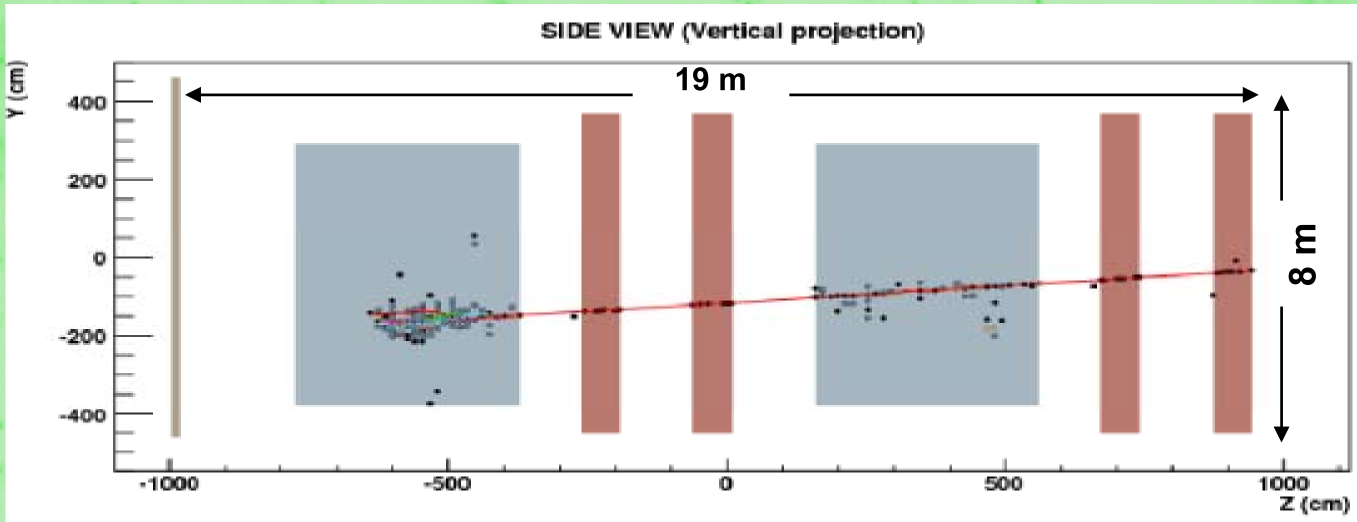


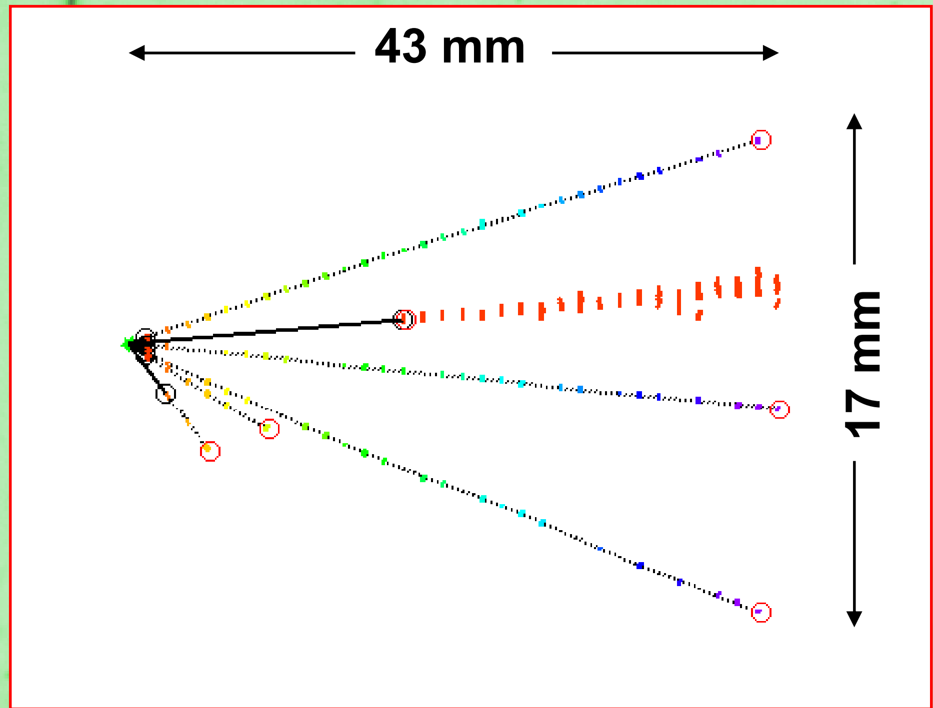
Neutrino vertex

IP = ~3µm



Event 178969961: $\nu_\mu CC$ interaction



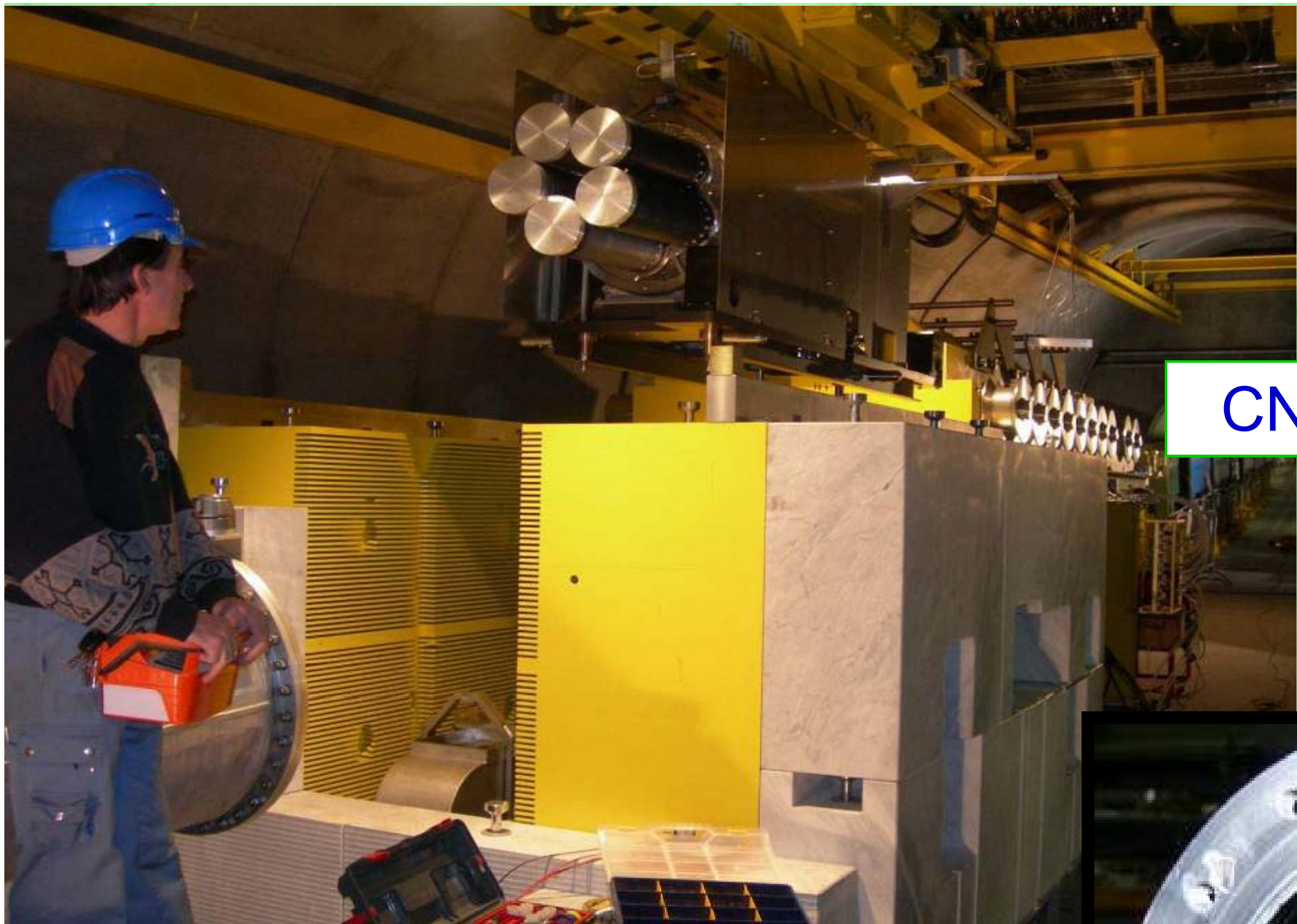


5 prongs

<IP> = 9 μm

EM shower pointing to the vertex (γ conversion)


The HORN
pions, kaons
3,75 t
7,5 t



CNGS target

5 mm diameter rods

CNGS neutrino flux at LNGS

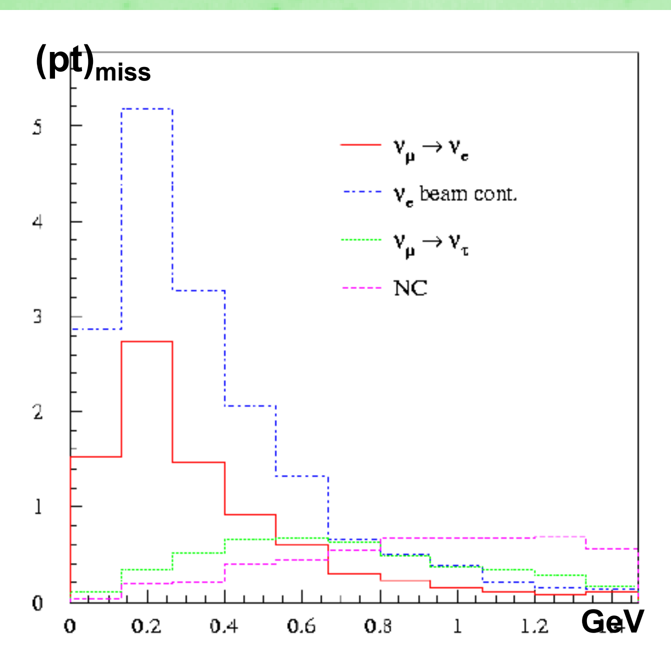
	$E_\nu < 30$ GeV	$E_\nu < 100$ GeV	$E_\nu < 400$ GeV	ν_i/ν_μ - CC (%)
ν_μ	496	580	604	
ν_e	2.26	5.02	5.44	0.89
$\bar{\nu}_\mu$	6.5	14.0	15.1	2.4
$\bar{\nu}_e$	0.13	0.33	0.38	0.06

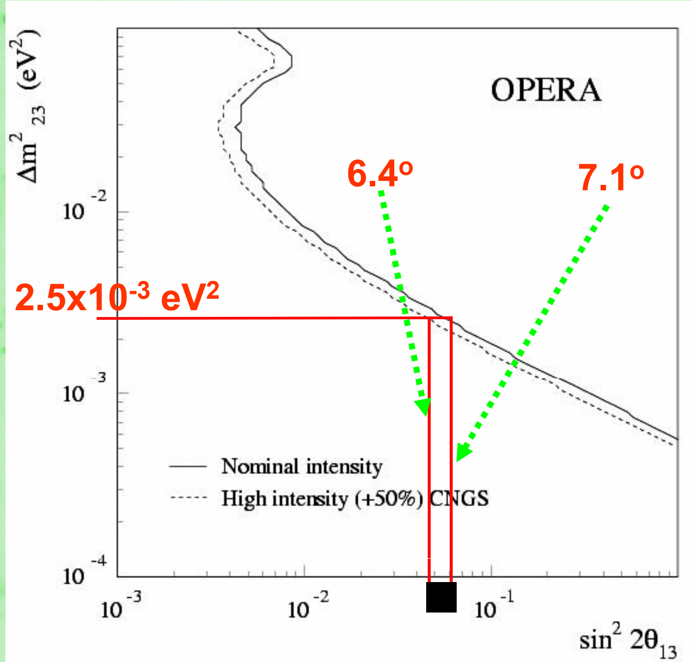
$\nu_\mu \to \nu_e$ oscillation search

Θ_{13}	SIGNAL	ν_e beam	$\tau \to e$	ν_μ NC	ν_μ CC
9°	9.3	18	4.5	5.2	1.0
7°	5.8	18	4.5	5.2	1.0
5°	3.0	18	4.6	5.2	1.0

$\Delta m_{23}^2 = 2.5 \times 10^{-3}\ eV^2$ $\Theta_{23} = 45°$

nominal CNGS beam 5 years



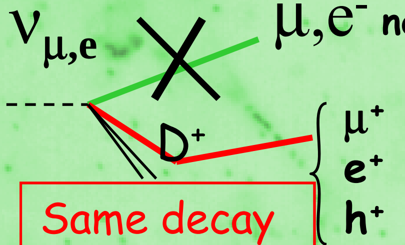


Combined fit of E_e, E_{vis}, $(pt)_{miss}$ to improve S/B ratio

90% C.L. limits on $\sin^2(2\Theta_{13})$ and Θ_{13} :

$\sin^2(2\Theta_{13})<0.05$ $\Theta_{13} < 7.1°$

τ search : Backgrounds

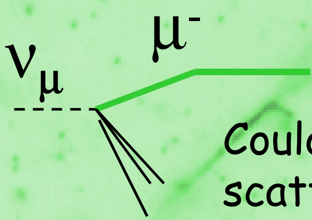


Primary lepton not identified

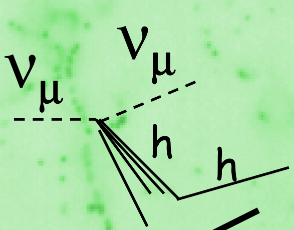
Same decay topology as τ

Charm production in CC, common to the 3 channels

Good muon identification is fundamental



Coulombian large angle scattering of muons in Lead : Bck. to $\tau \rightarrow \mu$



Hadronic interactions in Pb: Bck. to $\tau \rightarrow$ h or to $\tau \rightarrow \mu$ (if hadron mis-identified as muon)

Expected number of background events after 5 years running with nominal beam:

	$\tau \rightarrow e$	$\tau \rightarrow \mu$	$\tau \rightarrow h$	$\tau \rightarrow 3h$	Total
Charm background	.173	.008	.134	.181	.496
Large angle μ scattering		.096			.096
Hadronic background		.077	.095	.	.172
Total per channel	.173	.181	.229	.181	.764