OPERA: ready to run!

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on behalf of the OPERA Collaboration

The detector is ready for the next phase

…waiting for the first neutrino interaction in emulsion…..

Summary

- **Aim and strategy of the experiment**
- **OPERA detector**
- **CNGS 2007 run**
- ν_μ **interactions in a lead-emulsion target**
- **CNGS 2008 run**
- **Conclusions**

The Oscillation Project with Emulsion tRacking Apparatus

OPERA

Long baseline experiment searching for the ν_τ *appearance* in a pure ν_μ beam produced at CERN

CNGS (CERN to Gran Sasso beam)

<E> = 17 GeV, L = 732 km

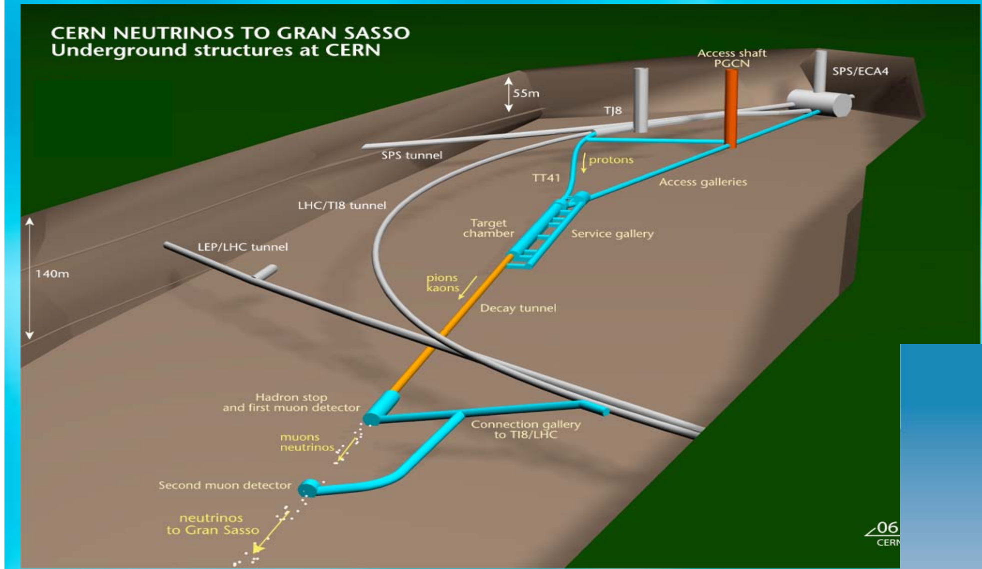
Hybrid set-up (nuclear emulsions + electronic detectors)

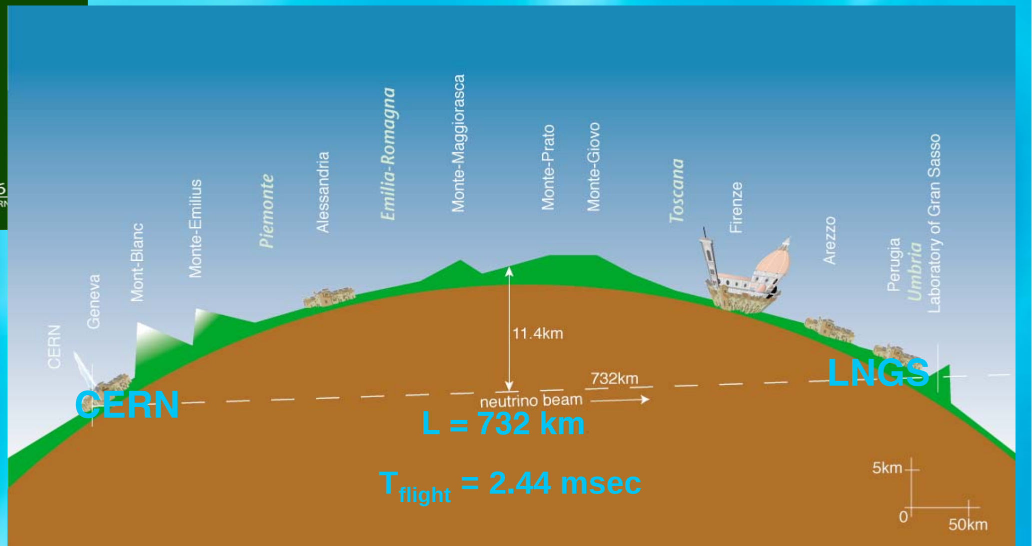
The CERN Neutrino to Gran Sasso beam
CNGS

400 GeV/c protons (CERN SPS) on graphite target
ν beam produced in the decay in flight of secondary π, K's
in 1km-long decay tunnel towards LNGS

optimized for appearance

$\langle E\nu_\mu \rangle$	17 GeV
$(\nu_e + \bar{\nu}_e)/\nu_\mu$	0.87%
$\bar{\nu}_\mu$ / ν_μ	2.1%
ν_τ prompt	negligible





4.5x10^{19} p.o.t./year, 200days/year
ε = 55% shared mode

Aim of the experiment

All the experiments indicate $\nu_\mu \to \nu_\tau$
as the dominant oscillation mode

but still missing:

direct observation of

oscillated ν_τ

Detection of ν_τ CC interactions and *direct* observation of τ decays

⇓

Provide an unambiguous evidence for $\nu_\mu \to \nu_\tau$ oscillations in the parameter region indicated by the atmospheric neutrino data

Experimental signature of the ν_τ appearance

CC interaction

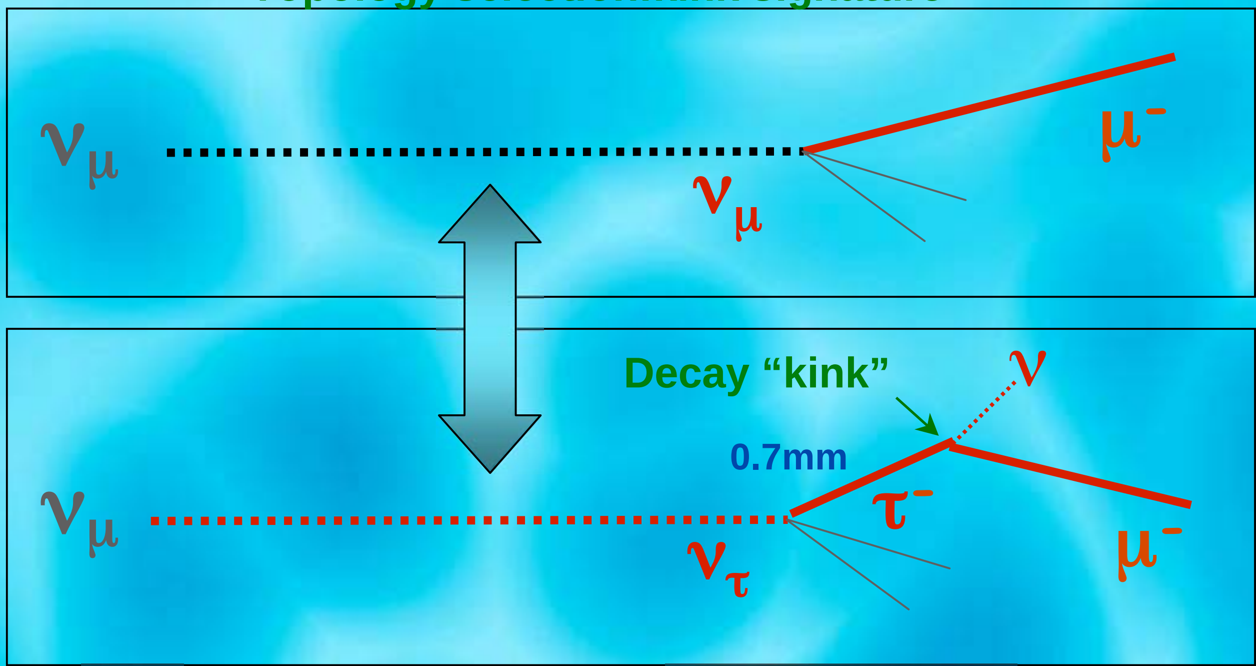
$\nu_\mu \sim \nu_\tau \rightarrow \tau^- + X$

oscillation

	$\mu^- \; \nu_\tau \; \bar{\nu}_\mu$	B. R. ~ 17%
	$h^- \; \nu_\tau \; n(\pi^o)$	B. R. ~ 50%
	$e^- \; \nu_\tau \; \bar{\nu}_e$	B. R. ~ 18%
	$\pi^+ \pi^- \pi^- \nu_\tau \; n(\pi^o)$	B. R. ~ 14%

Detection of the τ decay:
the challenge is to distinguish ν_τ interactions from ν_μ interactions

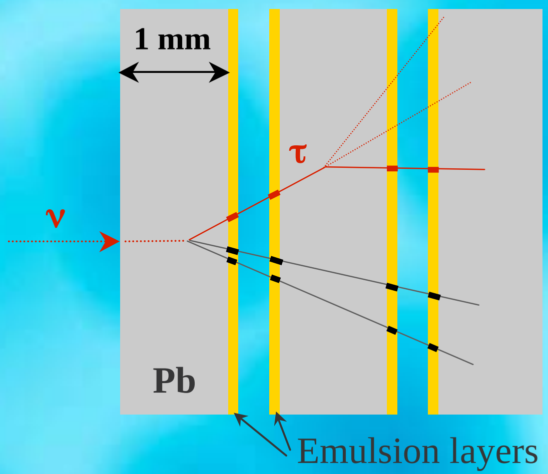
Topology selection:kink signature



Detecting ν_τ

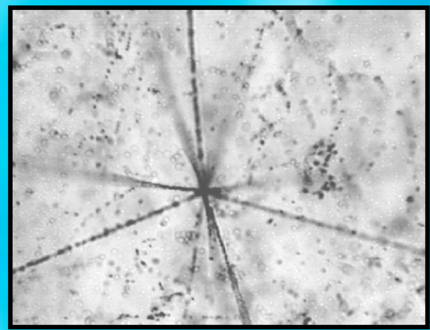
Two conflicting requirements:
- large mass (low cross-section)
- high granularity (signal selection / background rejection)

lead–nuclear emulsion target segmented into basic units called *bricks*



This technology allows a sub-micron spatial resolution, and a 3D reconstruction of particle tracks, necessary for τ detection

Nuclear emulsions (high granularity ~300*hits*/mm)

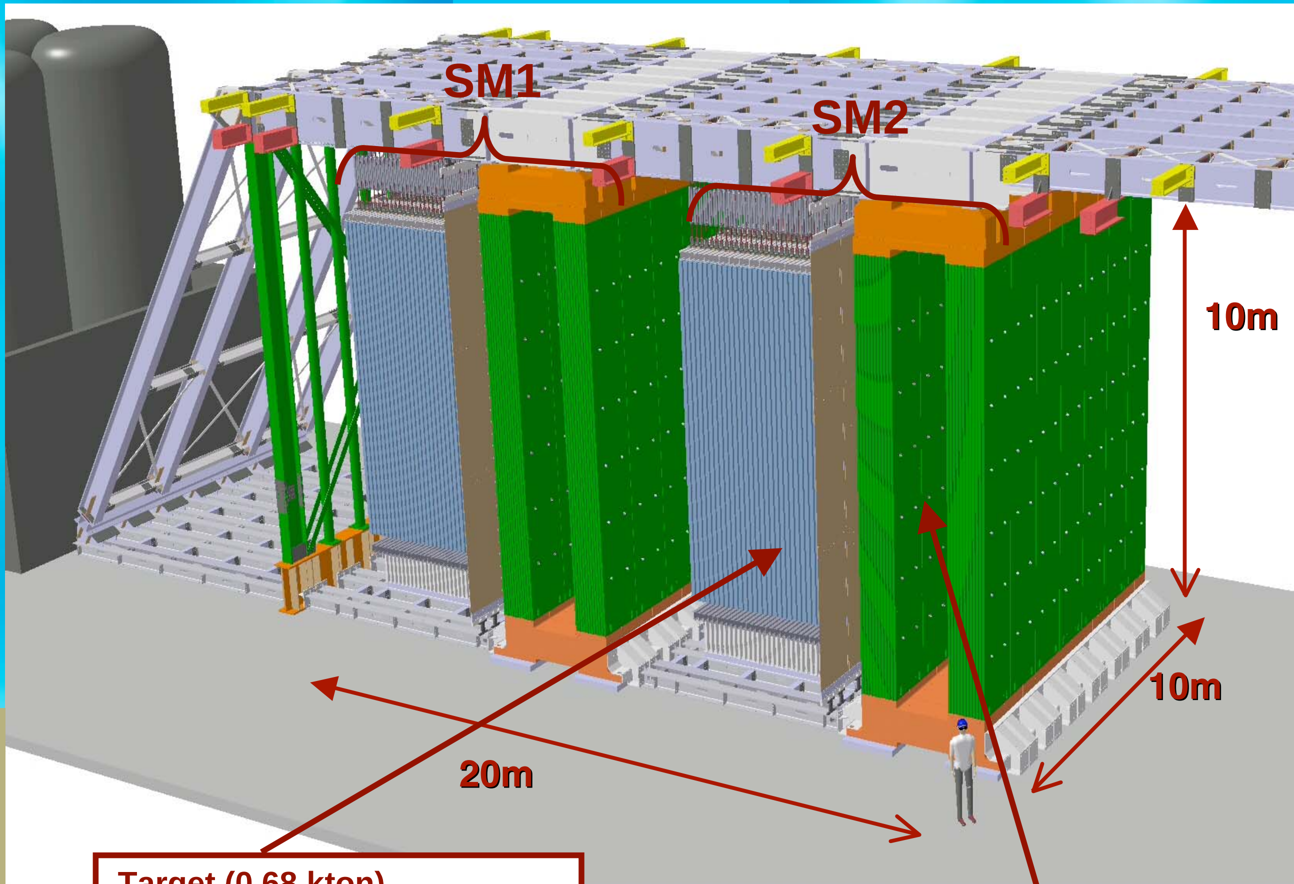


What the brick cannot do:
- signal a neutrino interaction
- identify muons

OPERA Detector Design

LNGS Hall C

Installation started in
May 2003
First observation of the CNGS neutrinos on
August 18th, 2006
First observation of the CNGS neutrinos in emulsion on
October 2nd, 2007



Target:1350 tons

5 year running @ 4.5 10 [19]

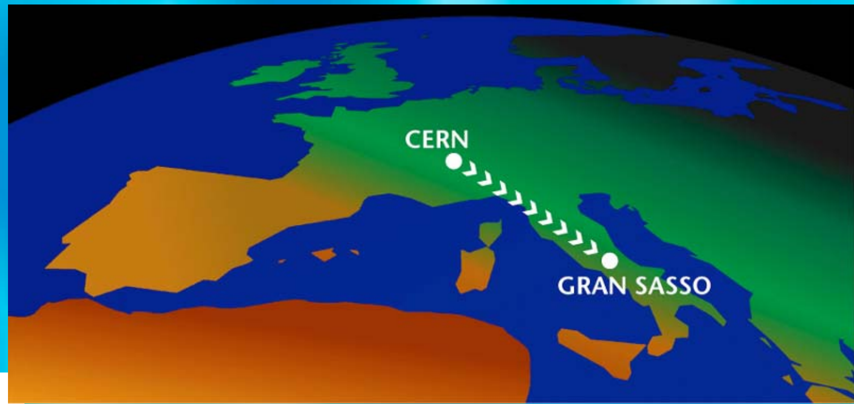
- 22,000 neutrino interactions
- ~110 ν_τ interactions
- ~11 ν_τ identified
- <1 event of background

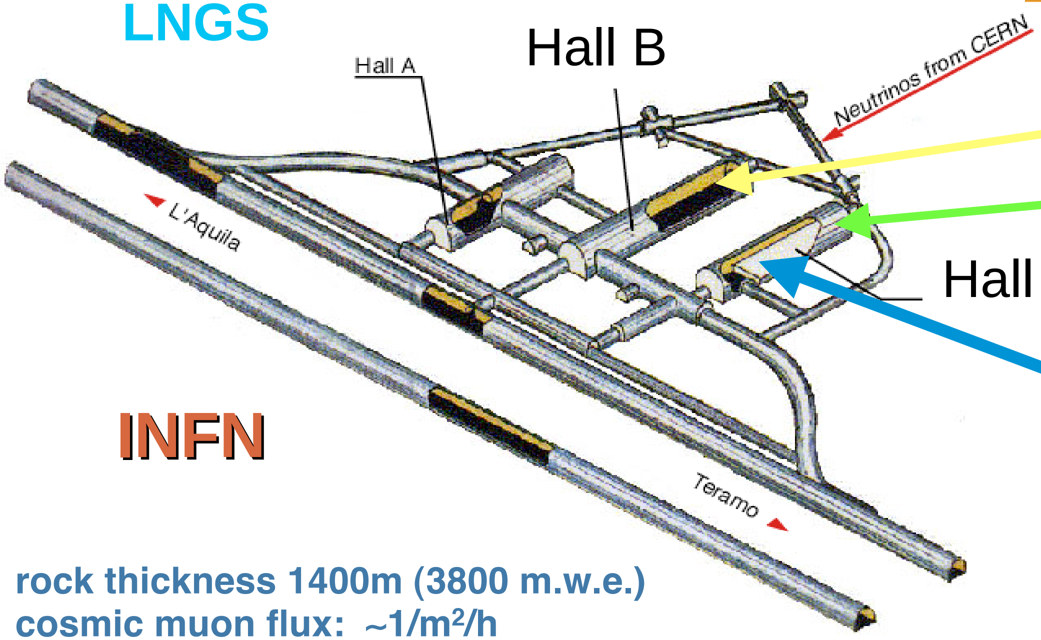
Target (0.68 kton)
29 lead/emulsion brick walls, alternated to scintillator planes, (T T) to select the brick containing neutrino interaction

Muon Spectrometer
Magnet equipped with 22 RPC planes:
ID muons , charge and momentum measurement

OPERA at LNGS

Largest underground laboratory for astro-particle physics





rock thickness 1400m (3800 m.w.e.)
cosmic muon flux: ~1/m^2/h

underground area: 18 000 m^2
external facilities
easy access

$\nu_\mu \rightarrow \nu_\tau$ Oscillation Search

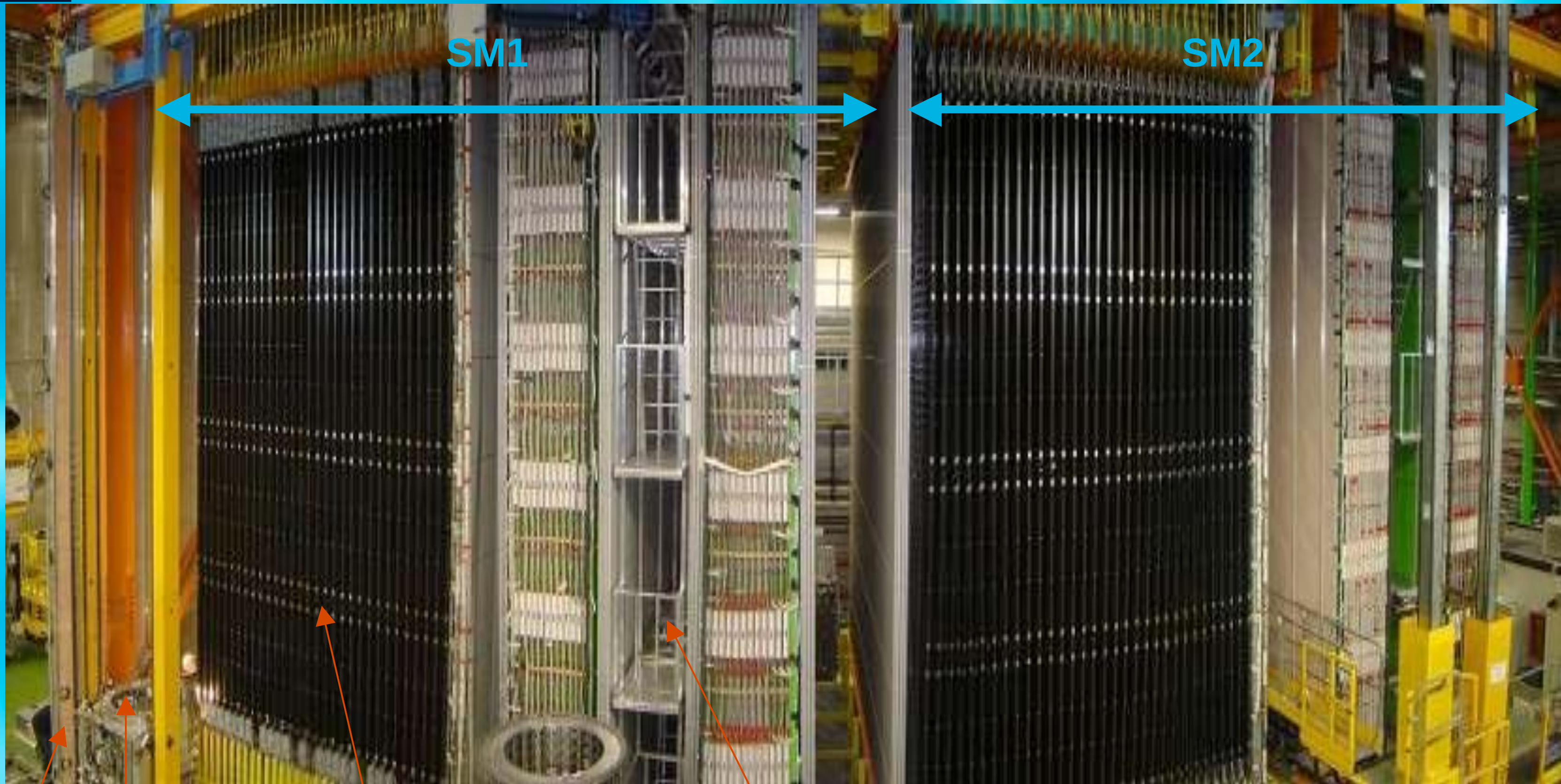
Number of expected signal and background events

τ decay channel	Signal		Background
	$\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	$\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	
$\tau \rightarrow \mu$	2.9	4.2	0.17
$\tau \rightarrow e$	3.5	5.0	0.17
$\tau \rightarrow h$	3.1	4.4	0.24
$\tau \rightarrow 3h$	0.9	1.3	0.17
ALL	10.4	14.9	0.75

Main background sources:
- charm production and decays
- hadron re-interactions in lead
- large-angle muon scattering in lead

full mixing, 5 year run @ 4.5×10^{19} pot/year
25% target mass reduction = 1.35 kton
~150000 bricks

OPERA Detector Today



Veto

BMS

Target (29 walls) + Target Tracker (6.7*m*)^2

Spectrometer: XPC, HPT, RPC, magnet

Detector today: electronics fully instrumented and tested

Brick filling is in progress, > 110000 bricks have already been inserted

75% target: SM1 full, SM2 at 50%

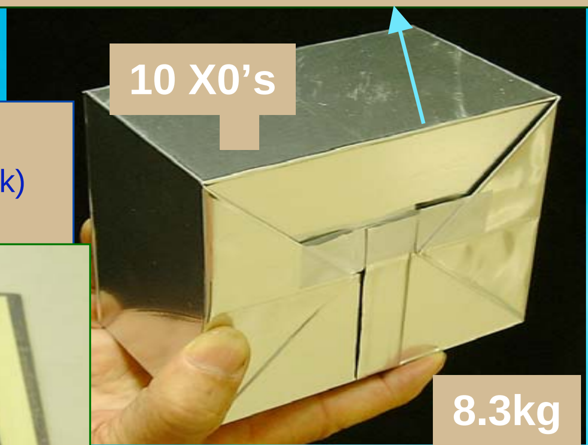
OPERA

Brick Target

- **Micro-metric space resolution (emulsion) + target mass (lead)**
- **Compact and modular structure**

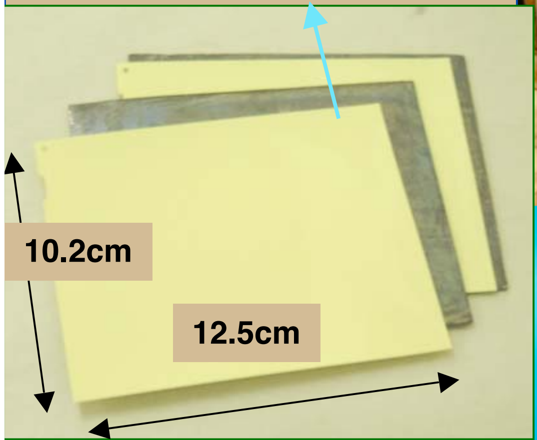
Brick (basic unit)

56 Pb (1mm) plates + 57 emulsion films



Emulsion film

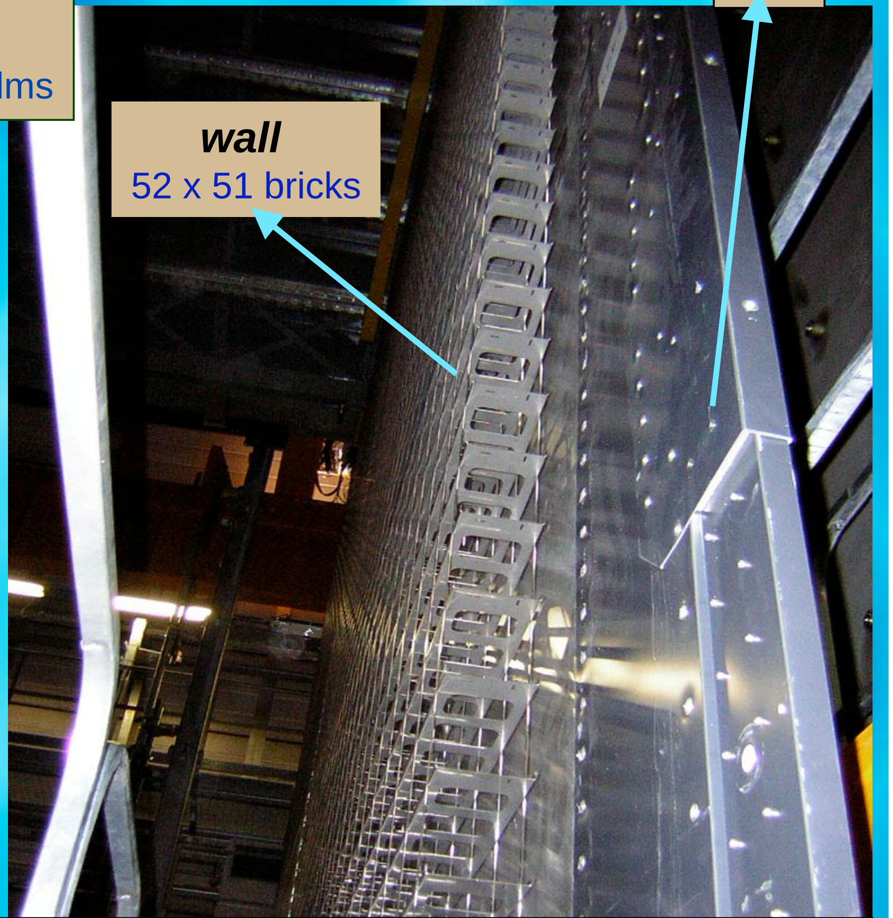
2 emulsion layers (44 μm thick) poured onto a 200 μm plastic



TT

wall

52 x 51 bricks



CS doublet (connection T T- brick)

two double refreshed emulsion films,vacuum packed and glued onto the bottom of each brick

Total target mass : ~ 1350 t

(~150000 bricks, 9M emulsion plates)

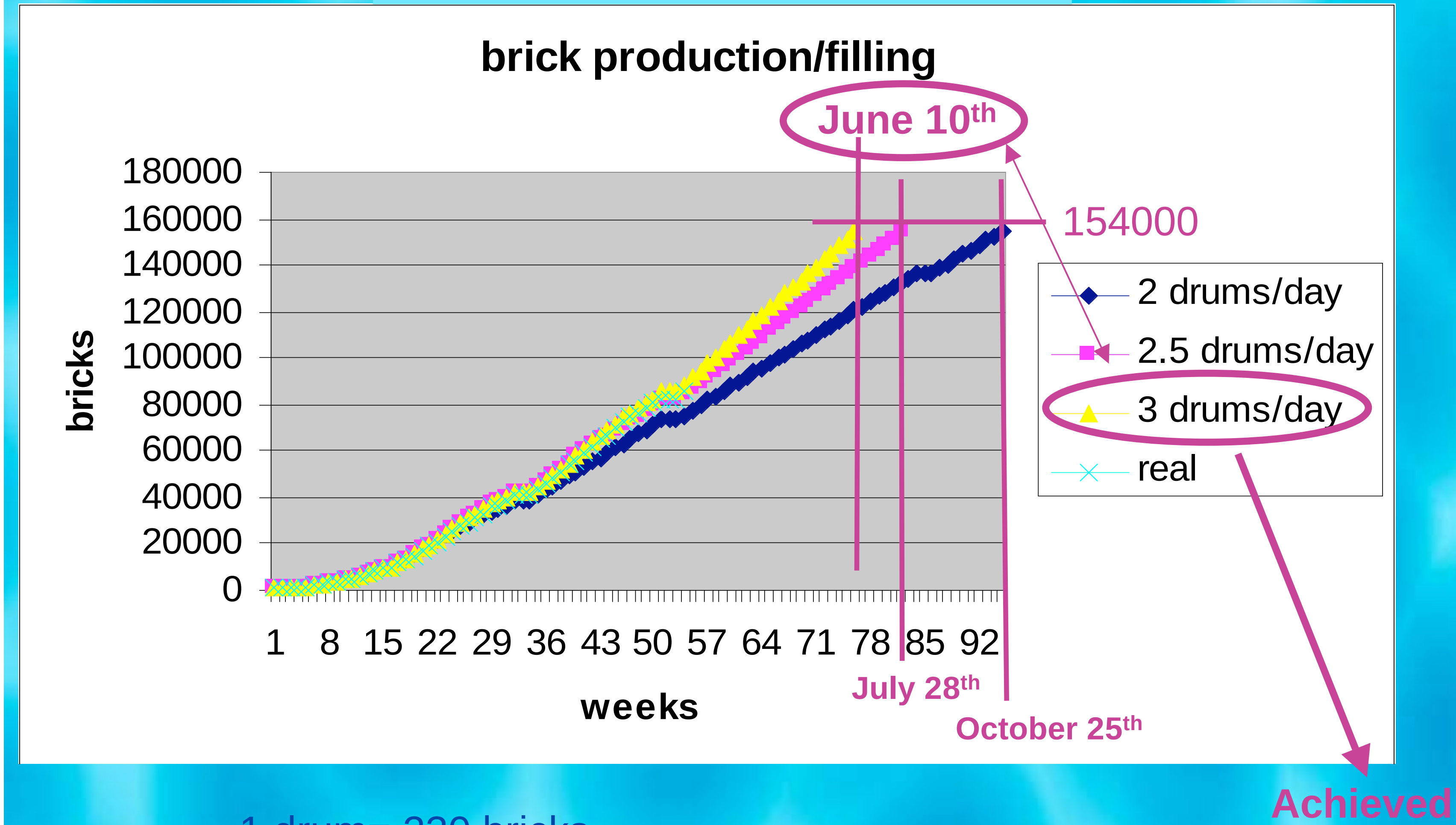
Brick Assembly Machine

Automatic lead/emulsion piling in a dark room

Robots piling up bricks
at a rate of ~ 700 bricks/day

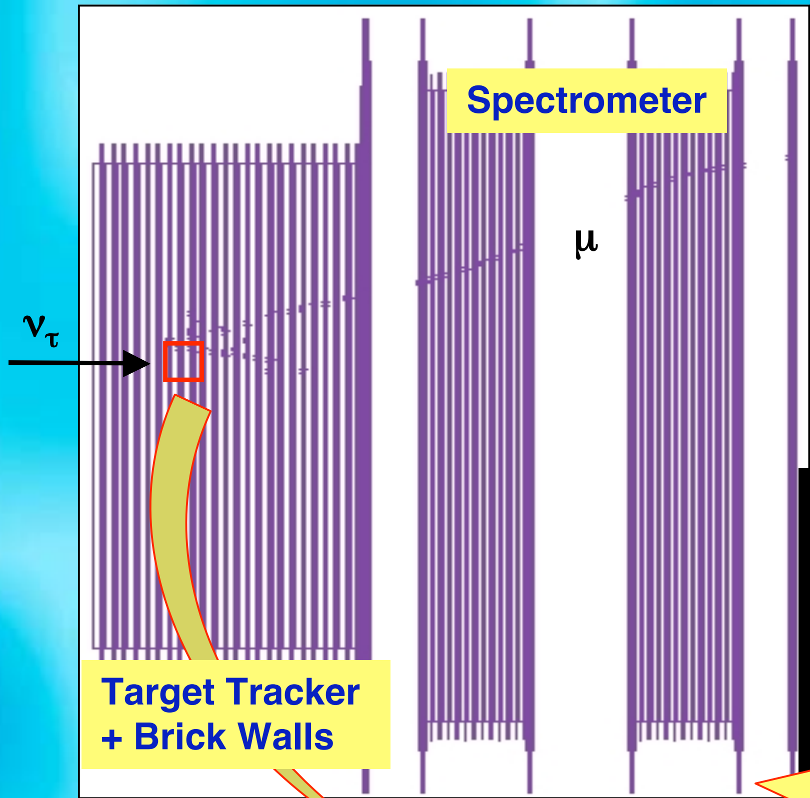
Detector filling

Including 15% contingency (~3 weeks)



1 drum= 230 bricks

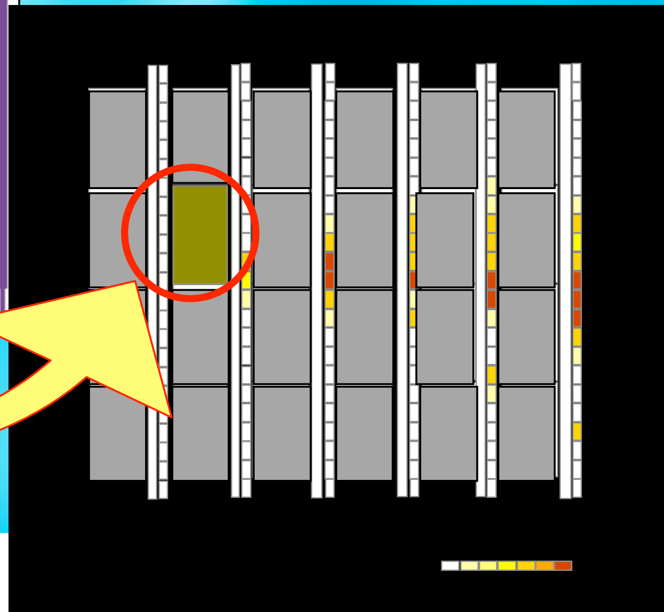
OPERA running



On-line analysis of electronic data

Brick finding algorithm

selection of the interaction brick provided by time correlation of electronic detectors



The selected brick is removed from the target. If an interaction is detected in the CS, the brick is exposed to cosmic rays (alignment) and the emulsions are developed and sent to scanning stations/labs

- Event location
- Decay search
- Particle ID and kinematics
- Event classification

LNGS: Development Facility

Line for the automated emulsion development

5 development chains ready

Maximum rate:
~ 50 bricks/day
(16 hours)

Automated microscopes for nuclear emulsions

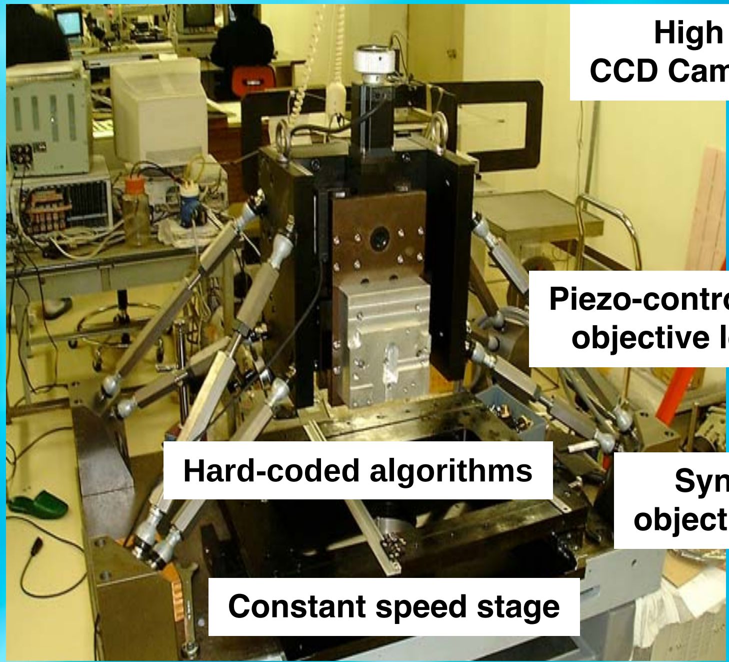
20 ~ 30 bricks will be daily extracted from the target and analyzed using high-speed automated systems

European Scanning System

S-UTS (Japan)

scanning speed ~ 20 cm^2/h

Customized commercial optics and mechanics + asynchronous DAQ software



High speed CCD Camera (3 kHz)

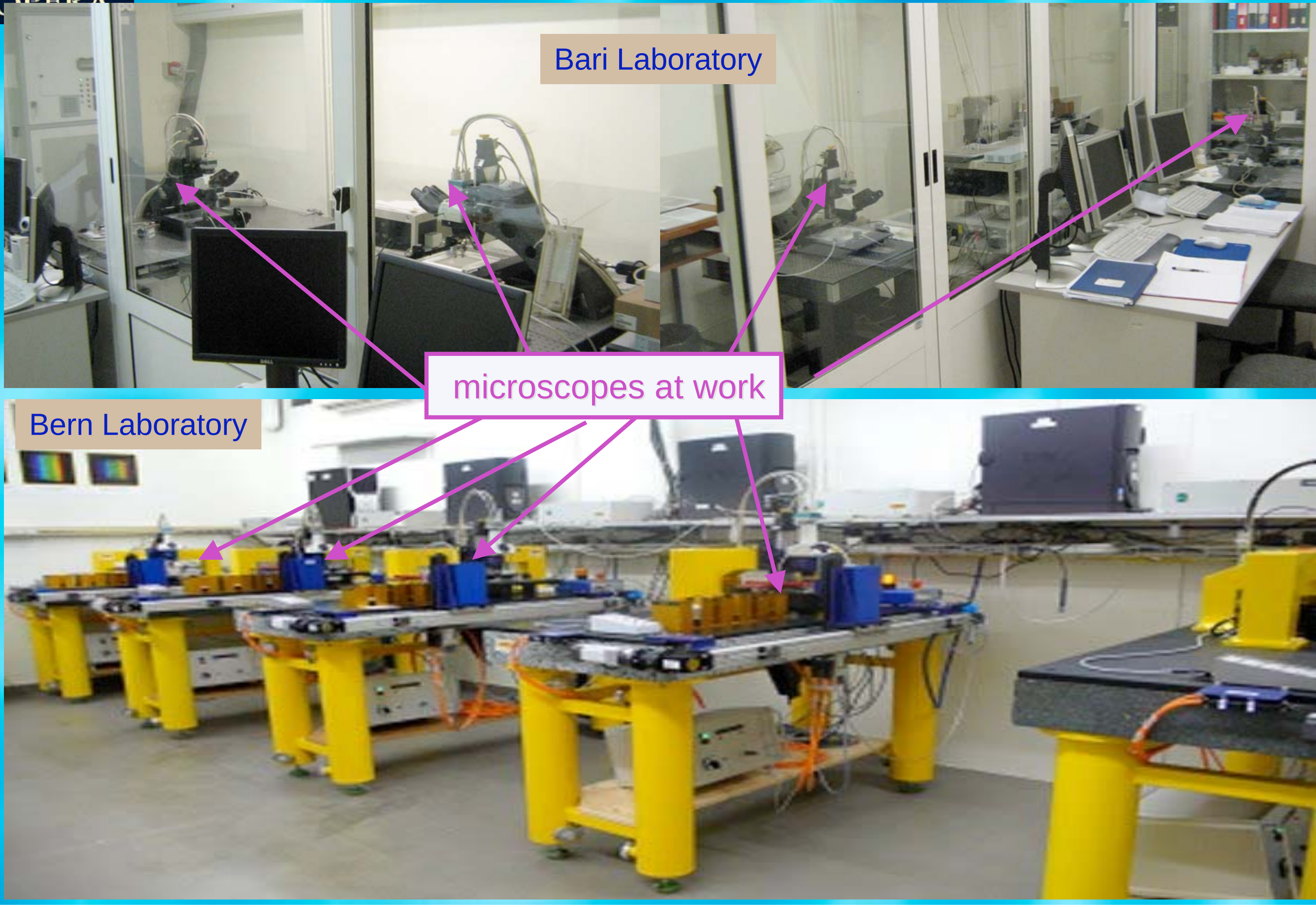
Piezo-controlled objective lens

Hard-coded algorithms

Synchronization of objective lens and stage

Constant speed stage

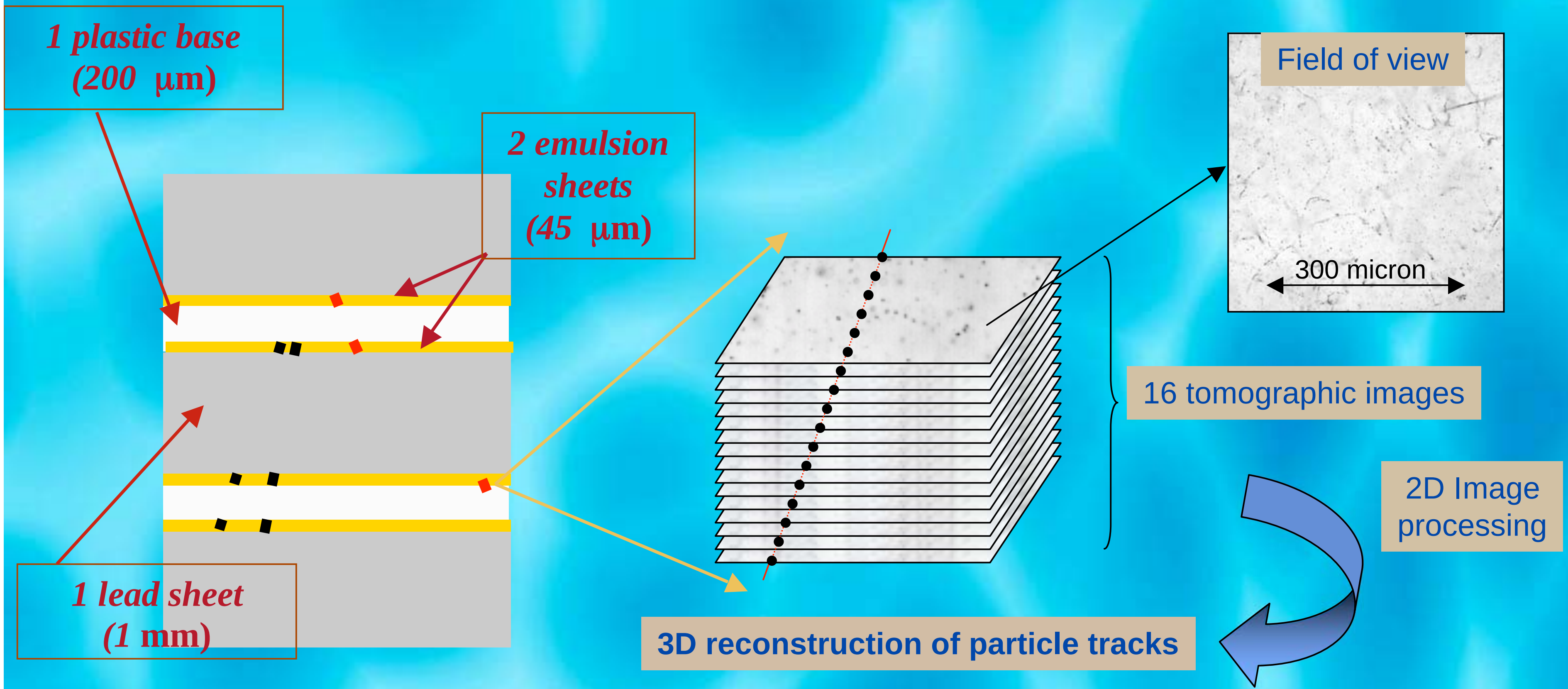
Scanning Laboratories

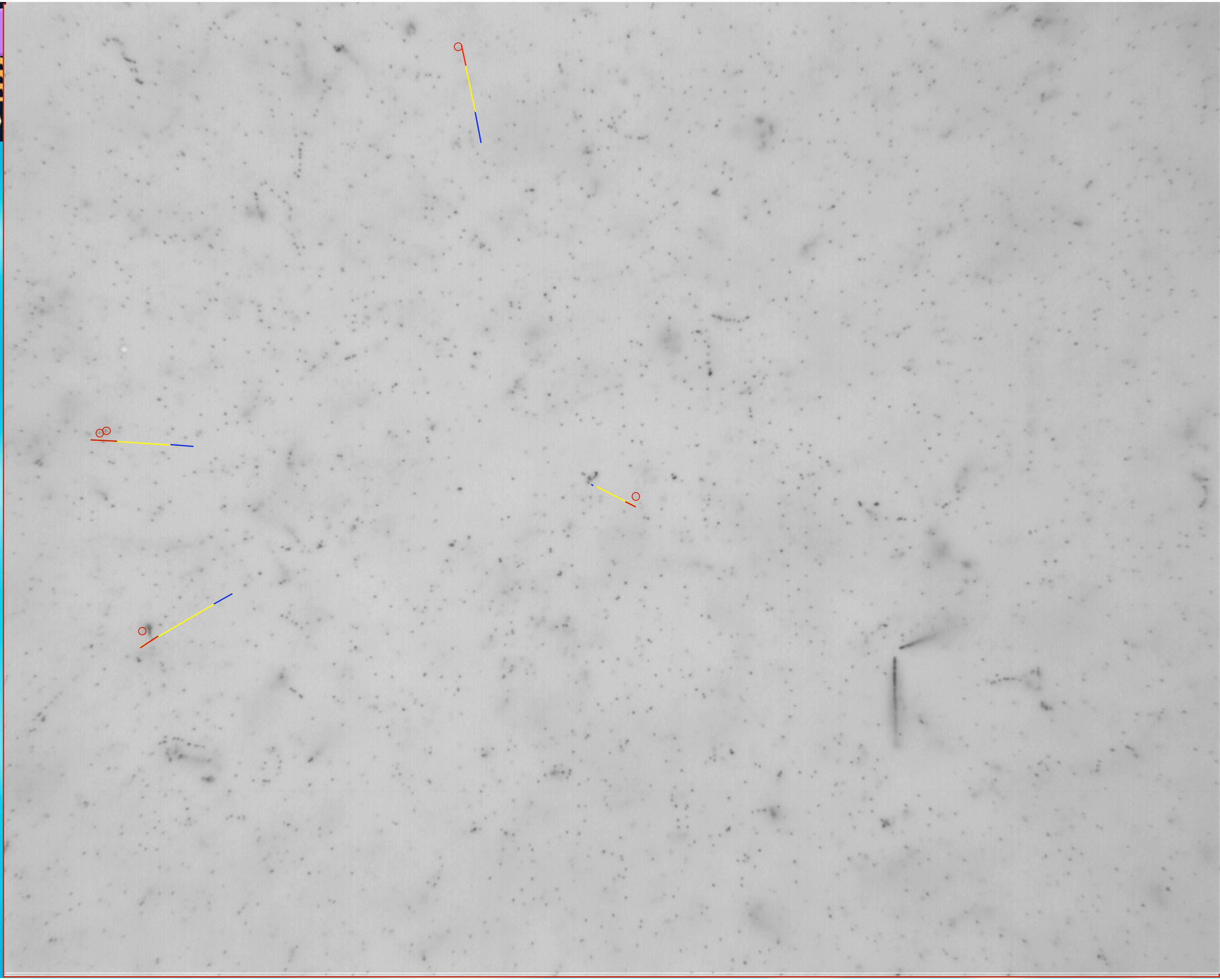


Scanning

Fully automated scanning at high speed (> 20 cm²/h)

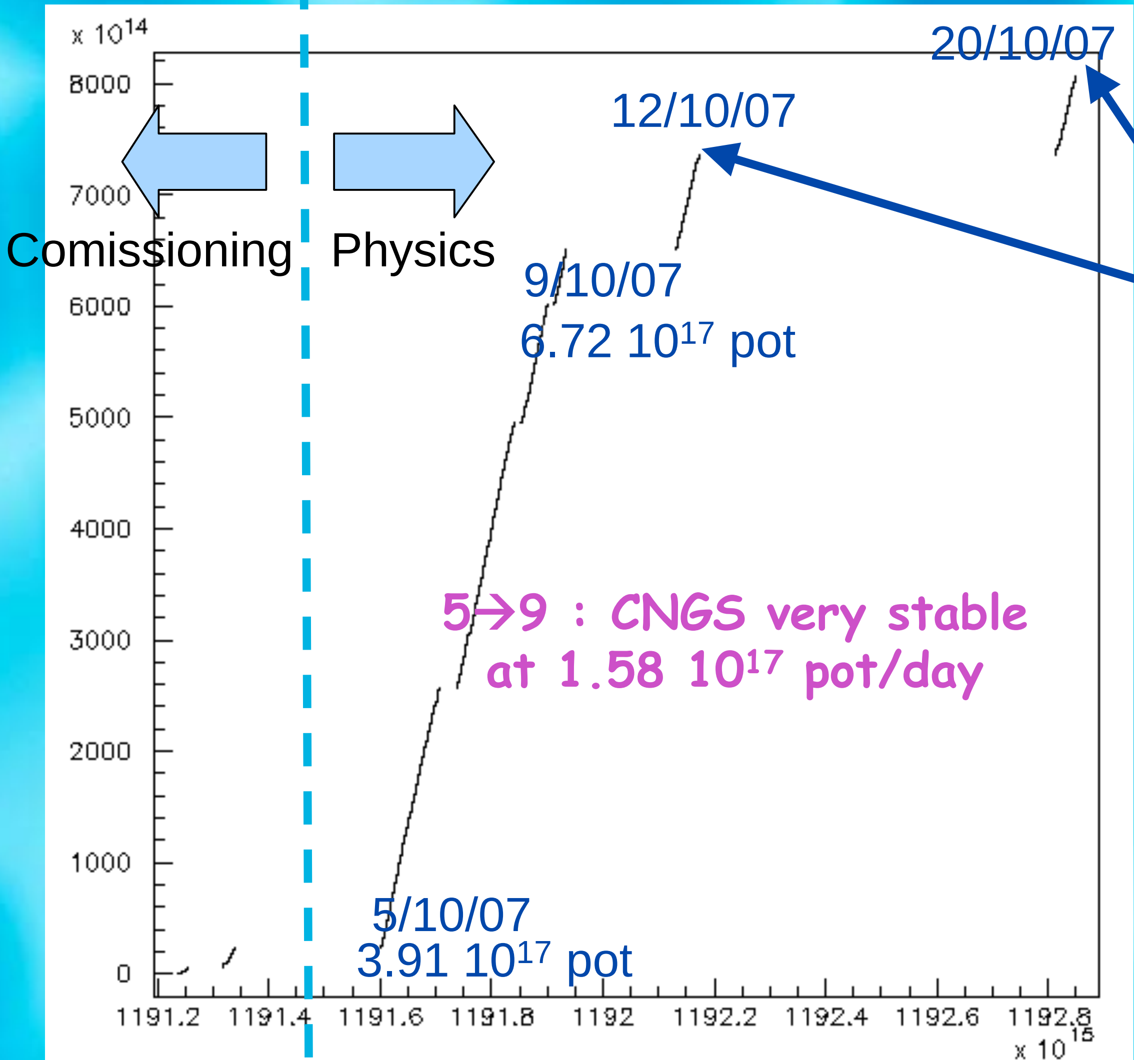
Spatial resolution < 1 μm
Angular resolution < 2 mrad





CNGS 2007 RUN

CNGS integrated intensity from Sept. 24th to Oct 20th 2007: **8.24 10^{17}**



Problems in ventilation control units of the proton target

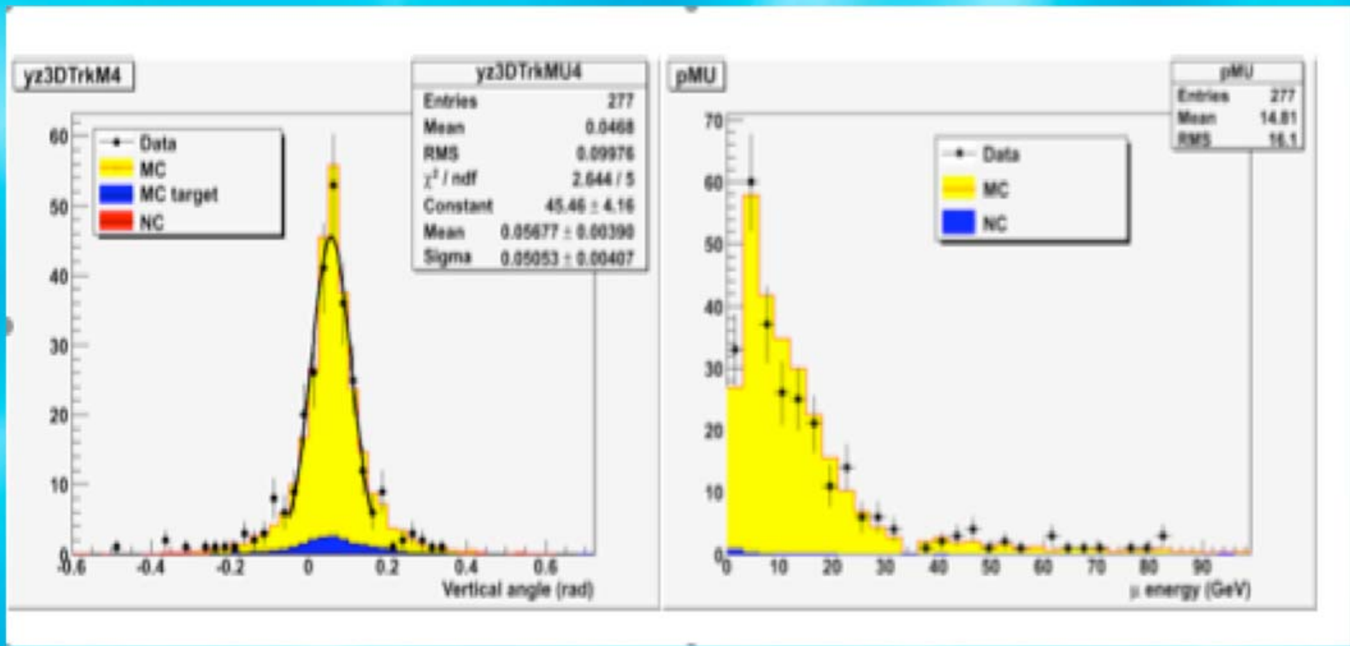
Nominal intensity :
4.5 10^{19} pot /yr (1yr=200 days)

2007 run: Interactions outside the Target

331 events passed the analysis cut
303 had been expected:
ratio similar to the one observed in 2006

→

CNGS operated
in the same conditions as in
2006 run



Muon vertical angle

Energy of the muon (RPC)

2007 run : ν Interactions in the Target

8.24 10^{17} p.o.t.

32±6 expected events in bricks

38 events registered during the 2007 CNGS run :

29 CC 9 NC

Brick handling, Film Processing, Scanning : first test on real neutrino interactions

Summary of the CS measurements

LNGS- European Scanning Station	All 19	CC 15	NC 4
No candidate on CS	1	1*	0
Good candidate on CS	18	14	4

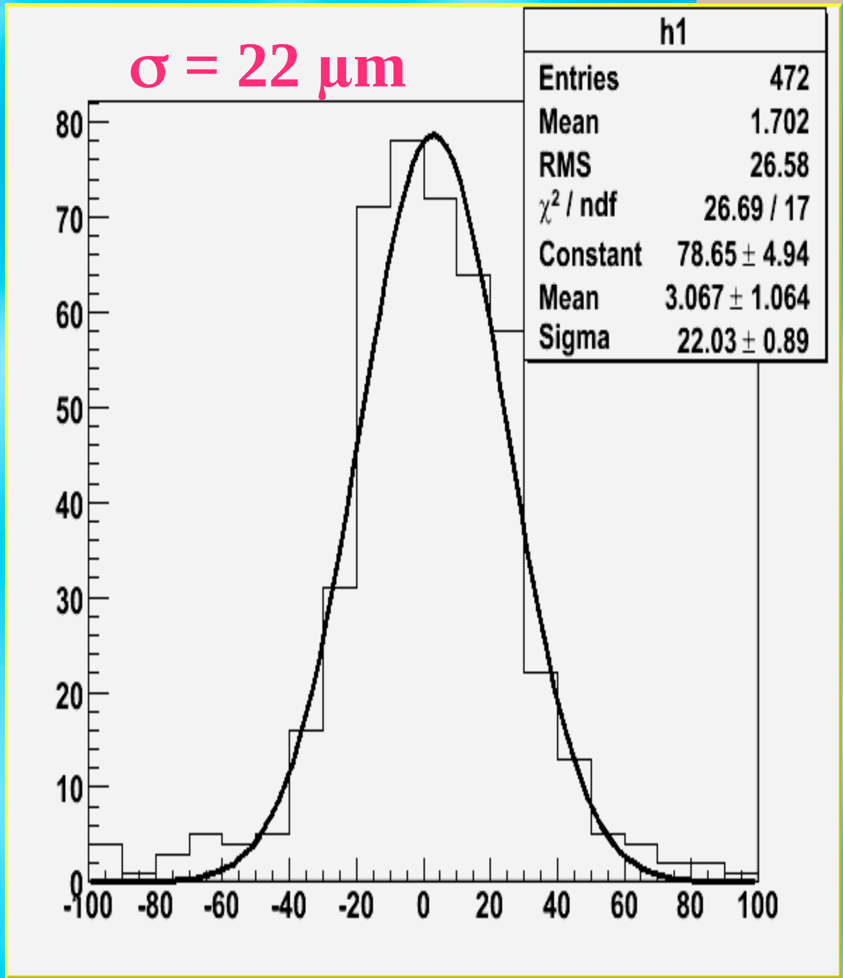
*fiducial volume acceptance

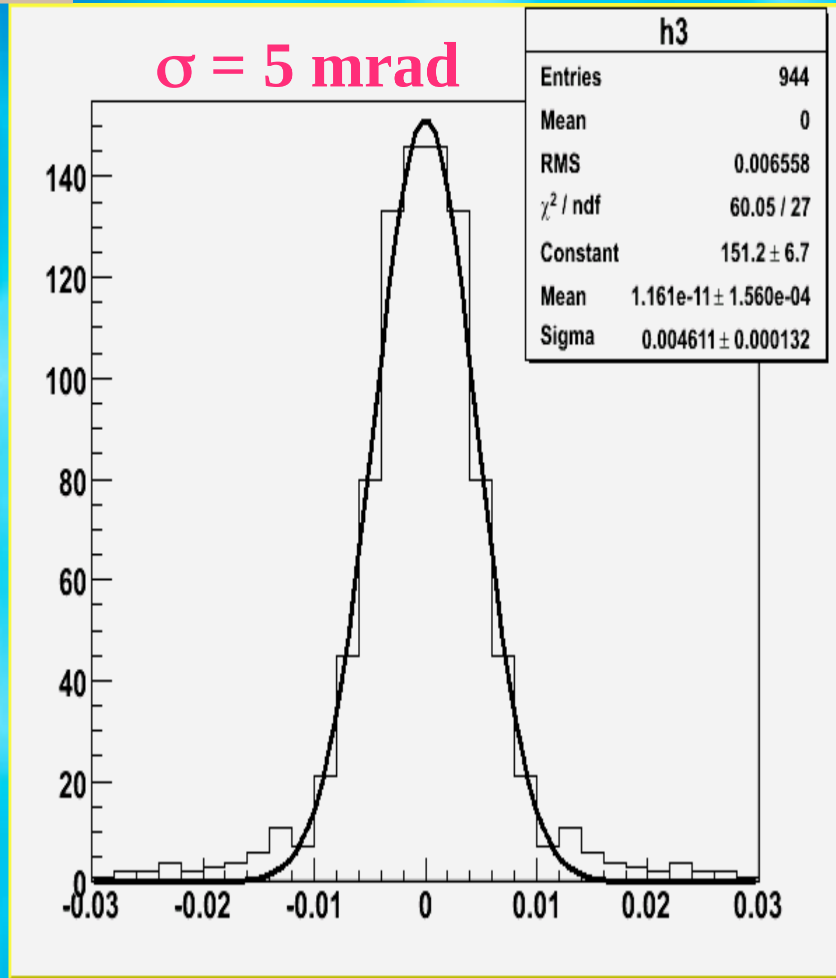
Japan - Nagoya Laboratory	All 19	CC 14	NC 5
No candidate on CS	1	0	1
Good candidate on CS	18	14	4

36 out of the 38 events have a good CS tagging
most of the predictions were found in ~ 2-3 centimeters

CS to brick: design accuracy in position and angle

Test-beam

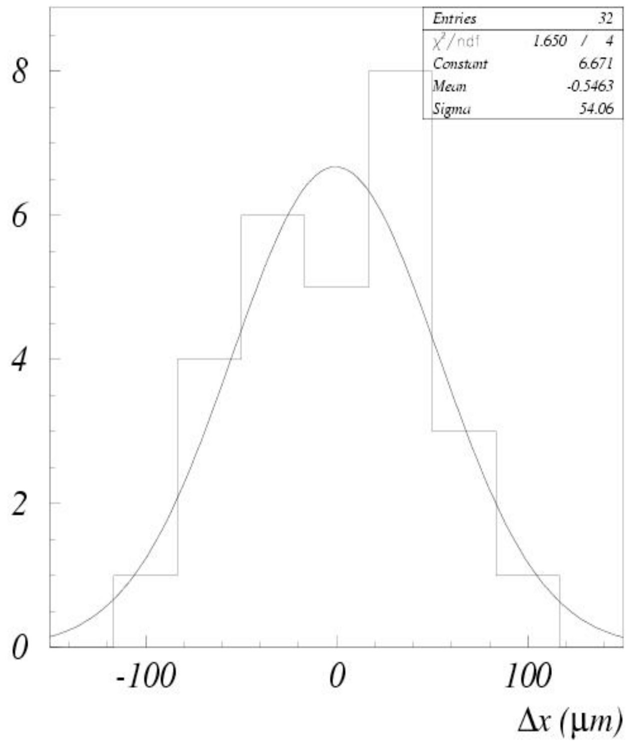




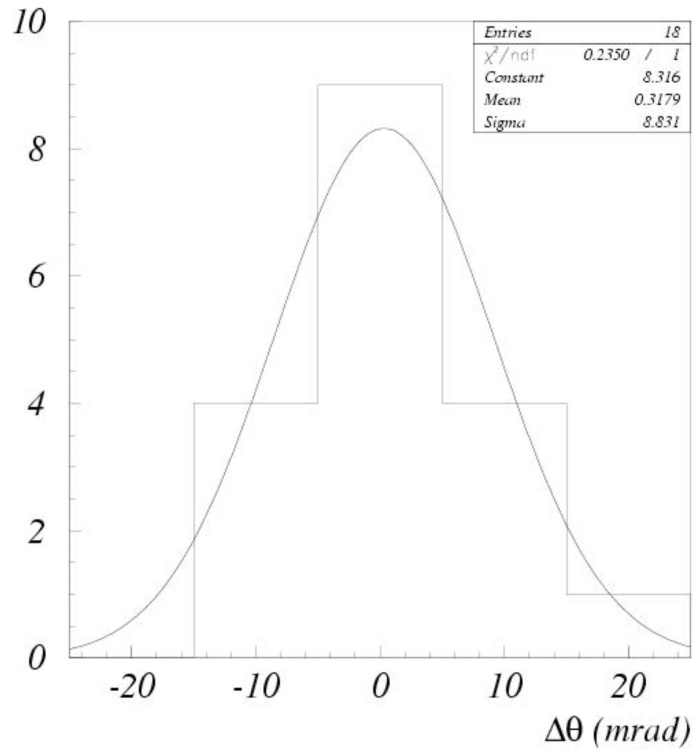
CS to brick connection for neutrino interactions

Data quality looks fine

σ = 54 μm



σ = 9 mrad



Systematical uncertainties (gap, marks, …) dominate

Event Location & Data analysis

	Europe	Japan
All events	19 (15 CC, 4 NC)	19 (14 CC, 5 NC)
Events confirmed in the CSd	18	18
Events located in the bricks	14	10
Interactions in dead material	1	1
CS-Brick mismatch	1	1
Analysis in progress	2	6

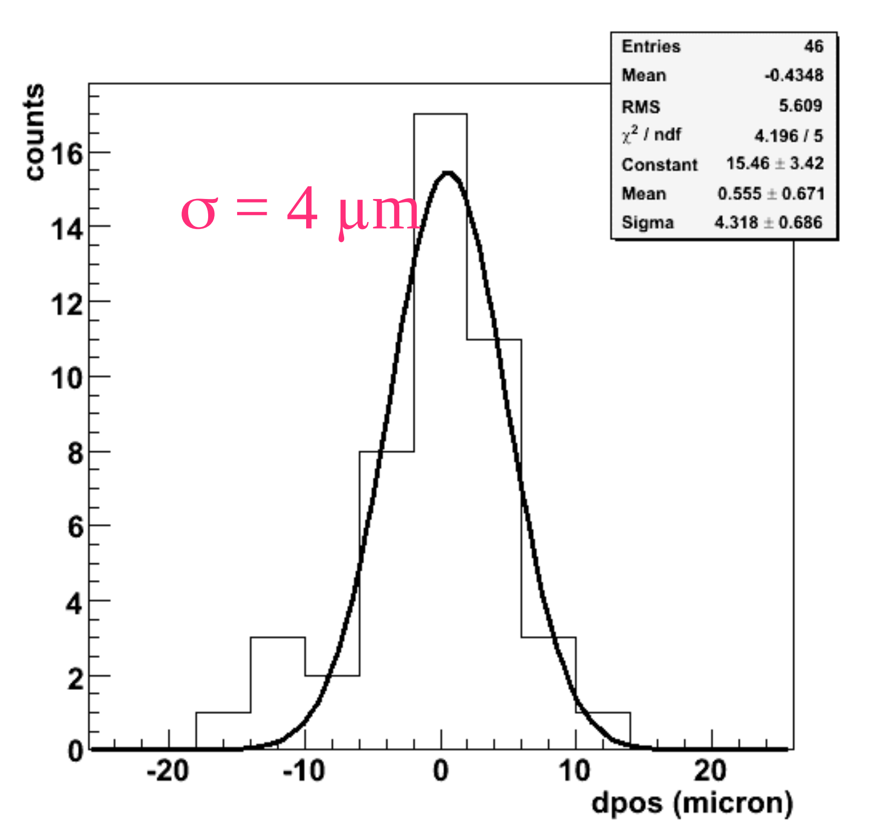
For **28** events out of 36,
analysis is almost completed
On this small sample

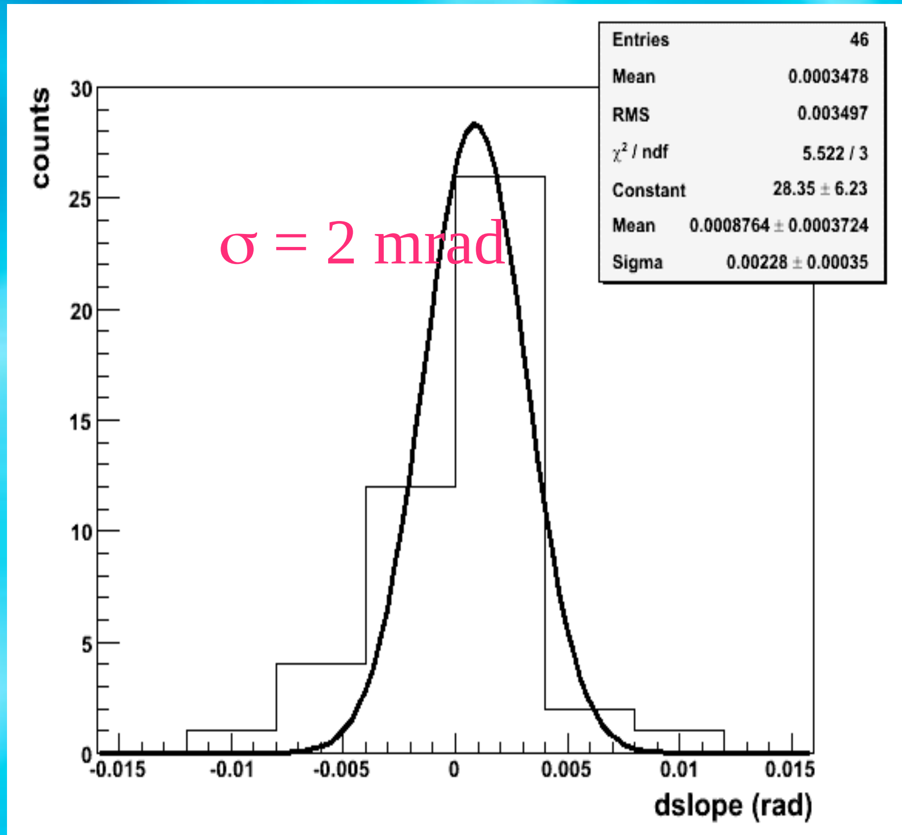
→

Wall Finding : > 95%
Brick Finding : 80% +- 7%

more data needed for a complete tuning

Scan-back accuracy



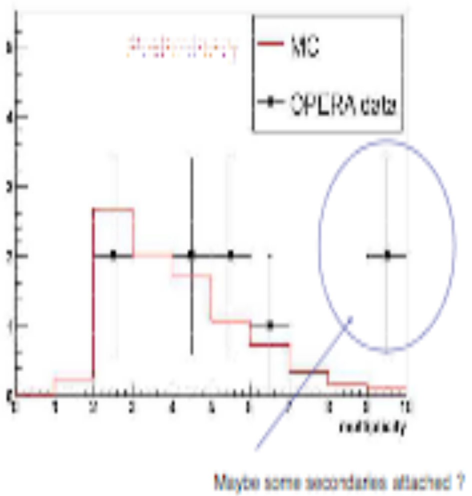


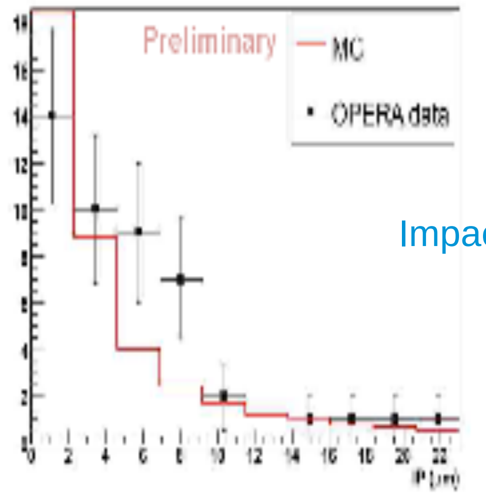
Vertex analysis

PRELIMINARY

Kinematical reconstructed variables

Multiplicity

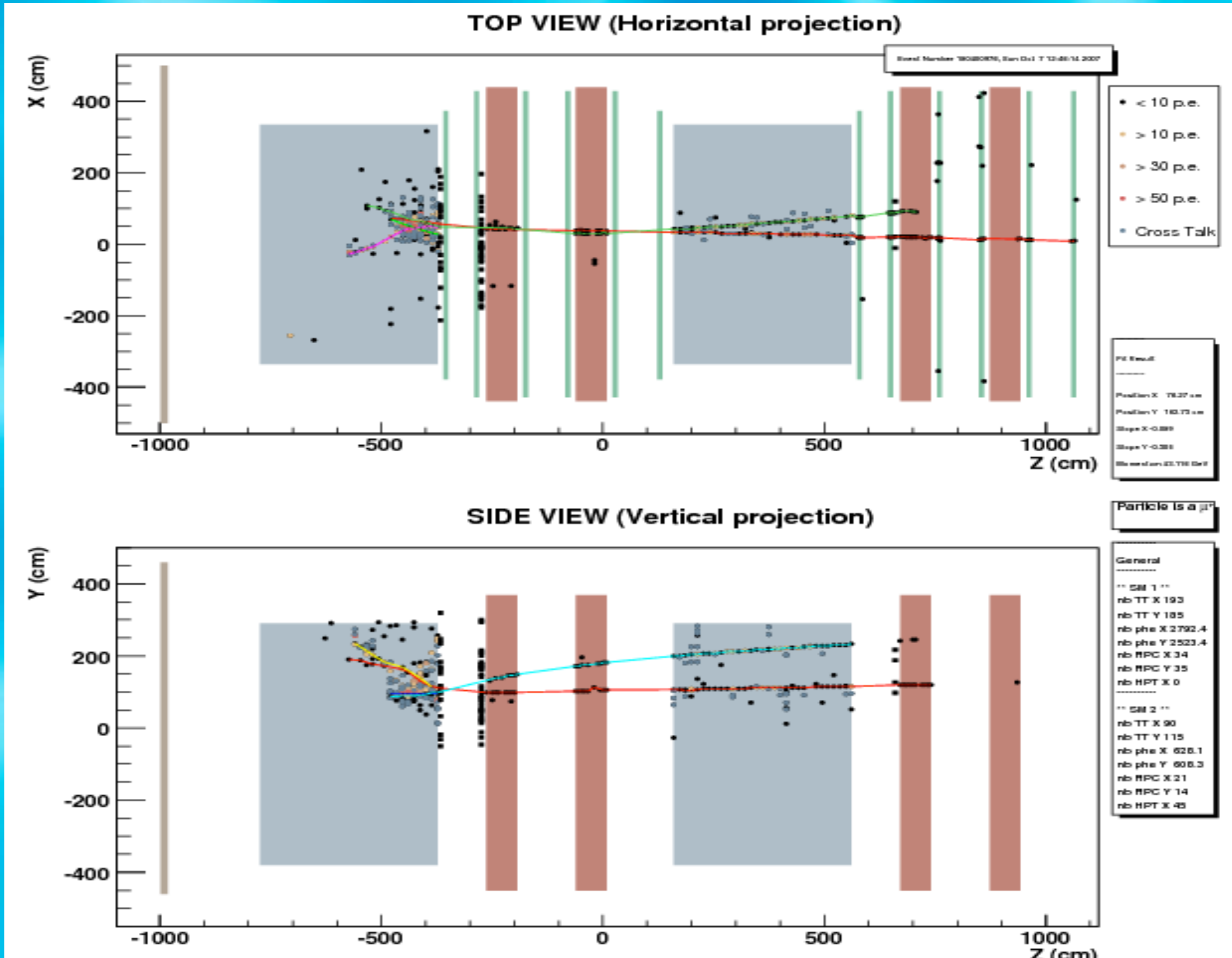




Impact parameter

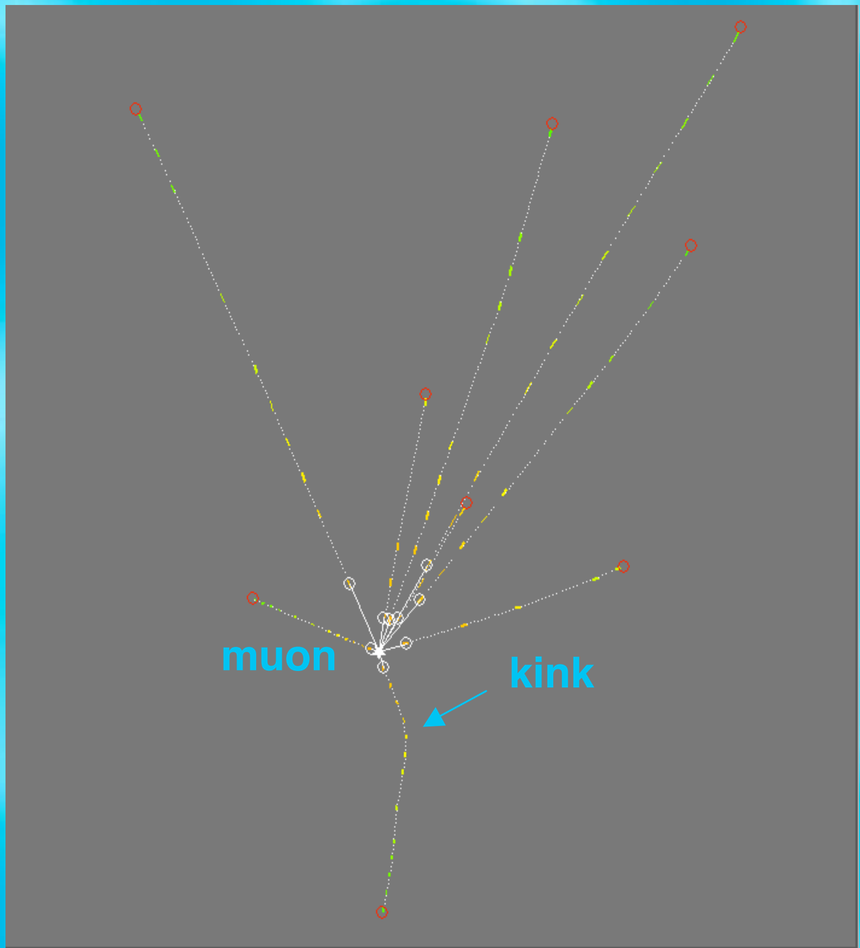
Event 180400976

CC interaction / 9 prongs



Event 180400976

PRELIMINARY



Tracks	TX	TY	P GeV	IP (μm)	
1	0.026	-0.097	-	5.7	kink
2	-0.024	0.019	>20	1.2	mu
3	0.045	0.197	$2.3_{-0.9}^{+3.2}$	1.7	
4	0.024	0.203	$4.5_{-2.1}^{+22.8}$	2.6	
5	0.100	0.051	$4.5_{-2.1}^{+22.8}$	7.9	
6	-0.047	0.199	$2.5_{-1.1}^{+7.0}$	2.9	
7	0.073	0.152	$3.0_{-1.2}^{+7.9}$	8.8	
8	0.085	0.254	$1.6_{-0.7}^{+4.3}$	10.3	
9	0.074	0.201	$1.8_{-0.8}^{+6.0}$	4.6	
10	0.114	0.010		9.0	e-pair
11	0.132	-0.001		18.1	e-pair

Secondary Vertex

Daughter momentum = $1.9^{+0.7}_{-0.4}$

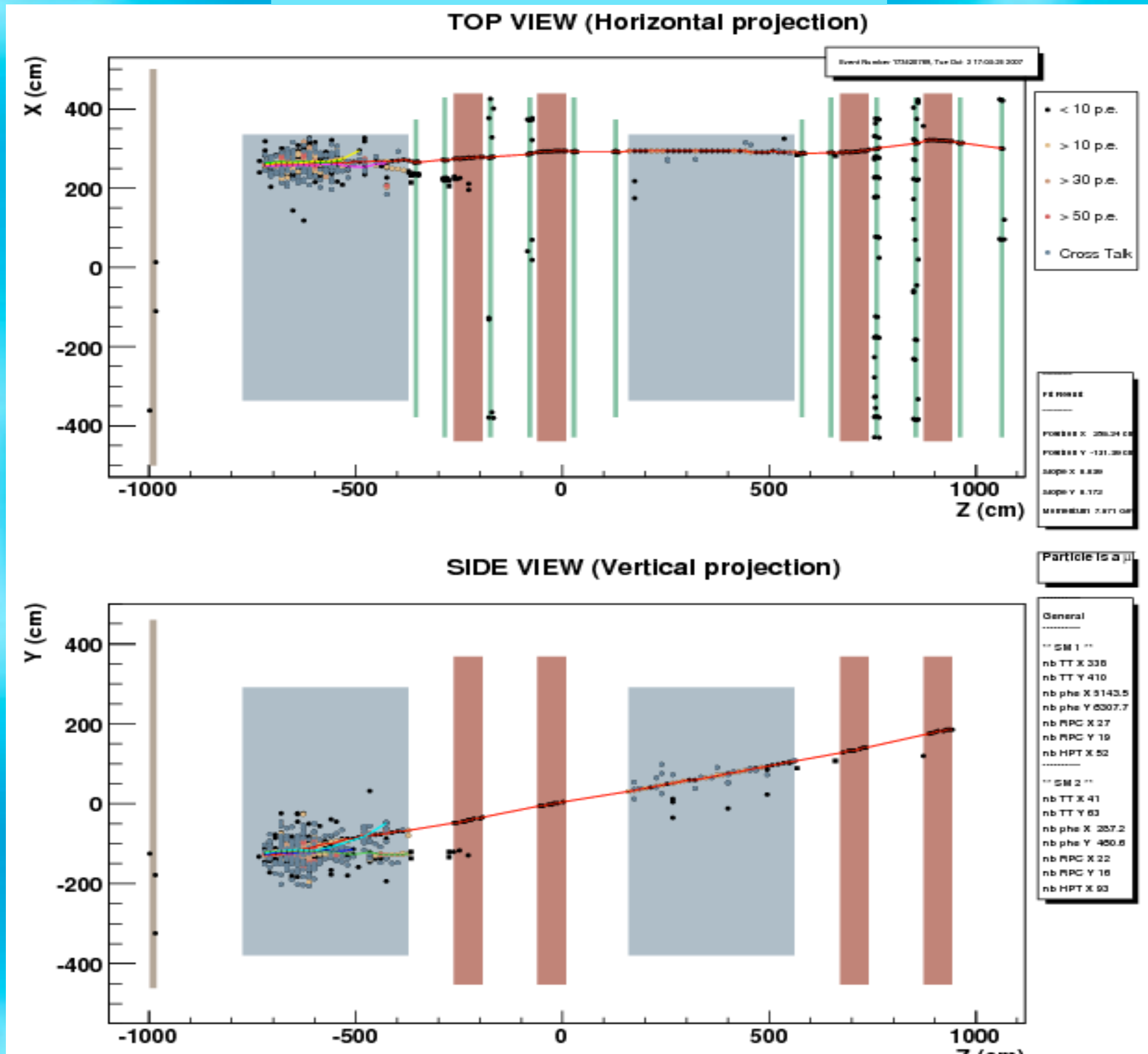
θ_{kink} = 0.031 rad

Flight length = 5901 μm

P_T = 59 MeV

Event 173520769

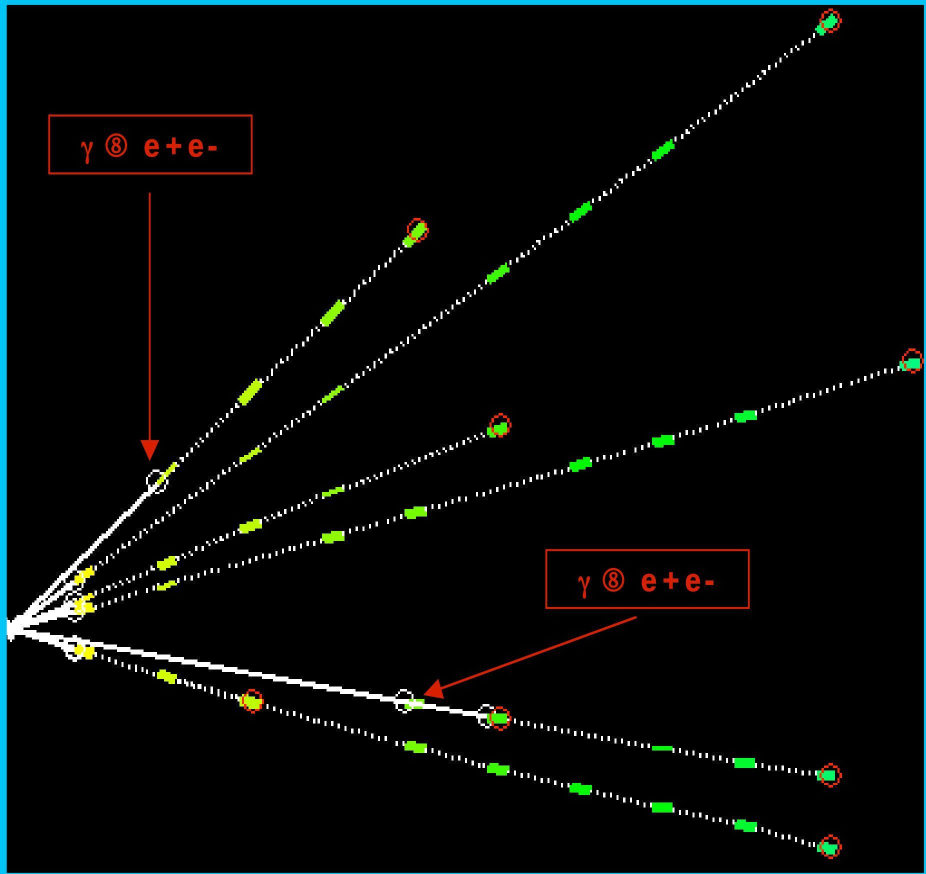
CC interaction / 4 prongs



Event 173520769

PRELIMINARY

Tracks	TX	TY	IP (μm)
1	0.012	0.160	1.9
2	-0.739	0.095	4.7
3	-0.033	-0.060	6.3
4	-0.015	0.065	4.1



$E\gamma_1$: ~ 510 MeV

$E\gamma_2$: ~ 260 MeV

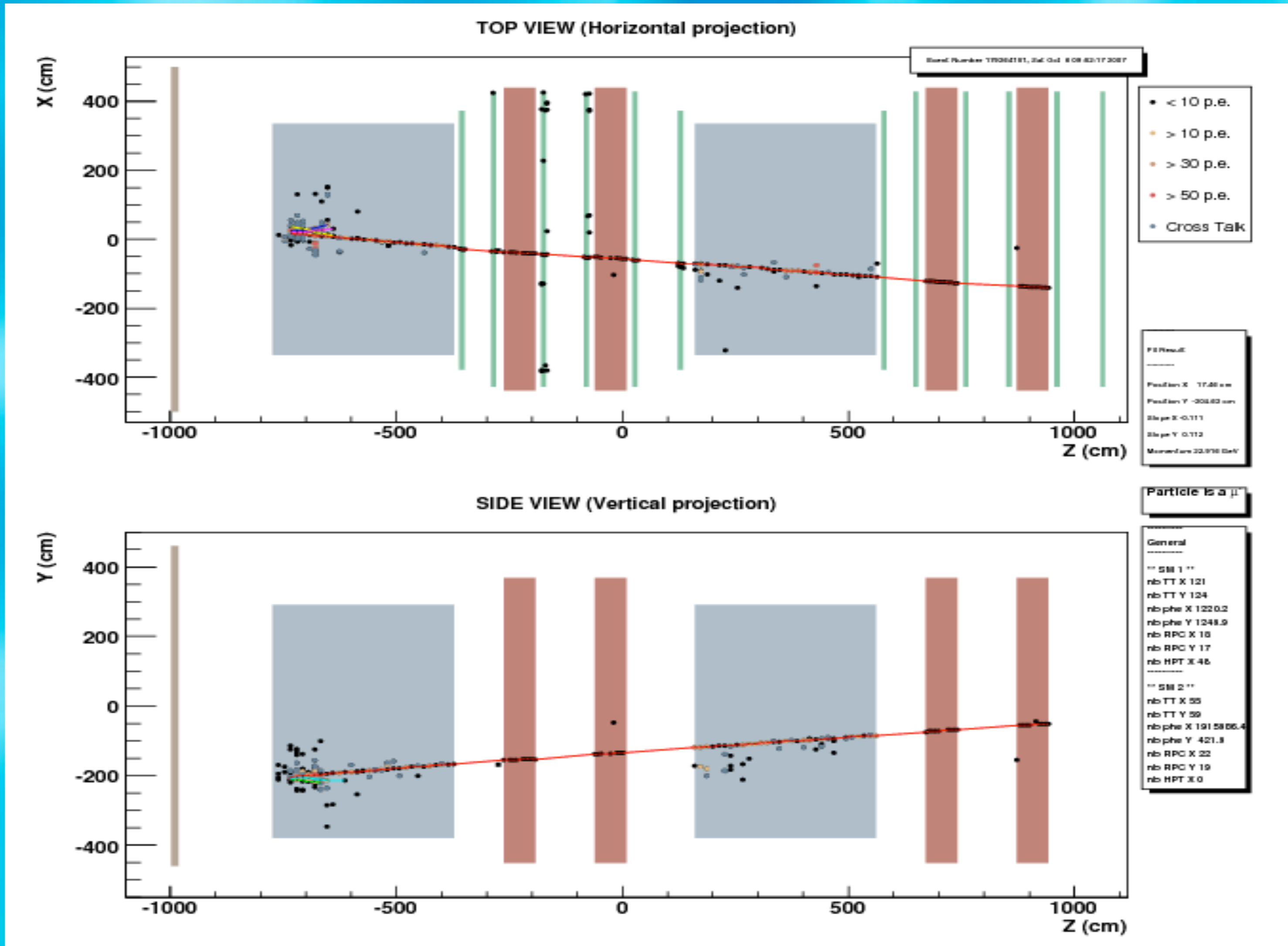
$\theta_{\gamma\gamma}$: 300 ± 20 mrad

compatible with $\pi^0 \rightarrow 2\gamma$:

estimated π^0 mass: 110 ± 30 MeV

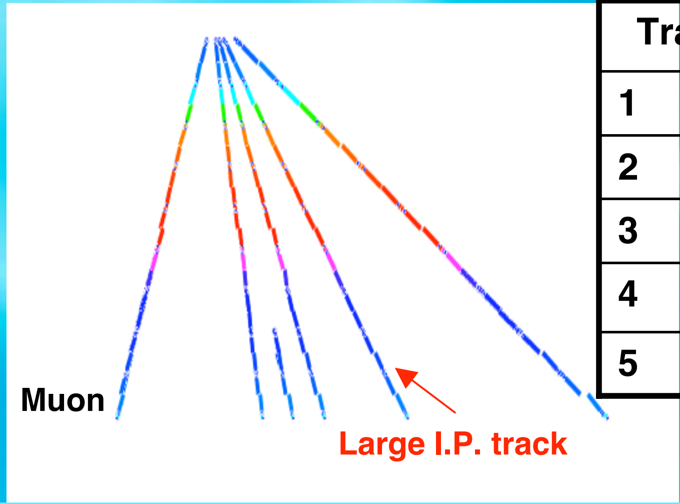
Event 179264151

CC interaction / 5 prongs



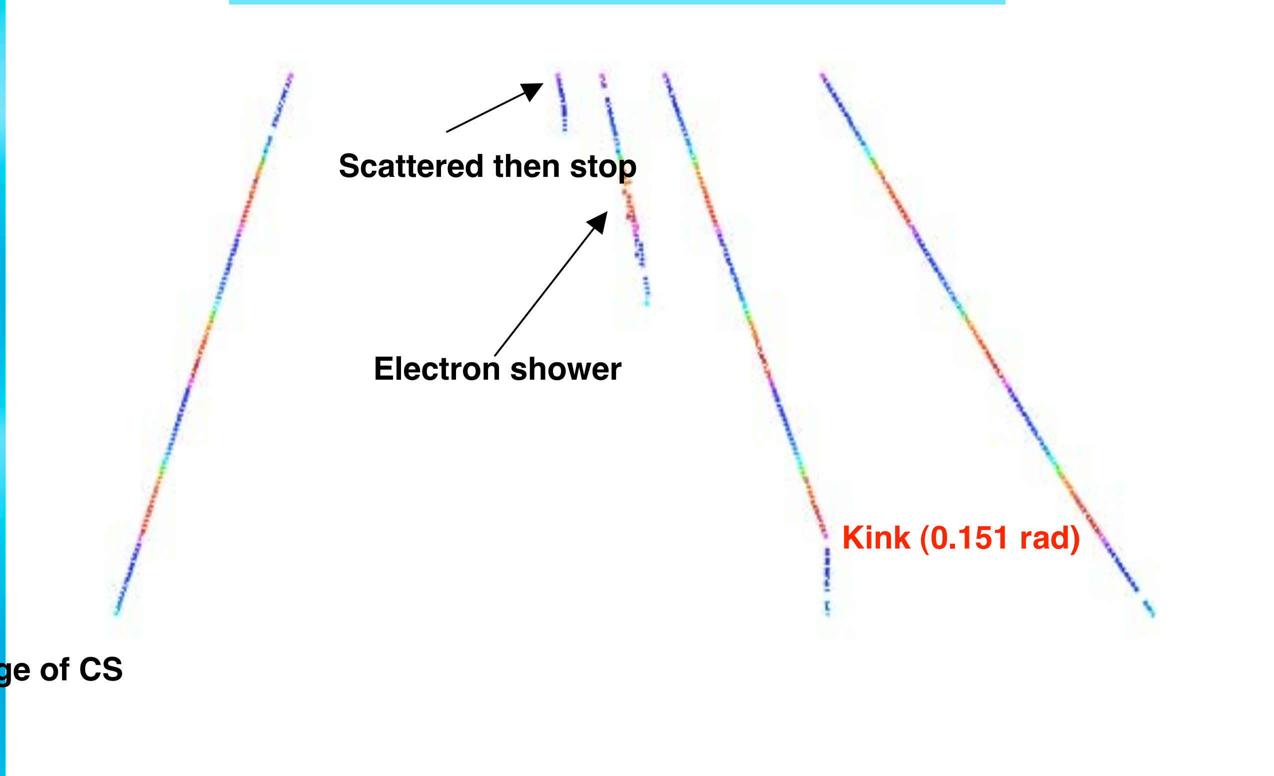
OPERA

PRELIMINARY



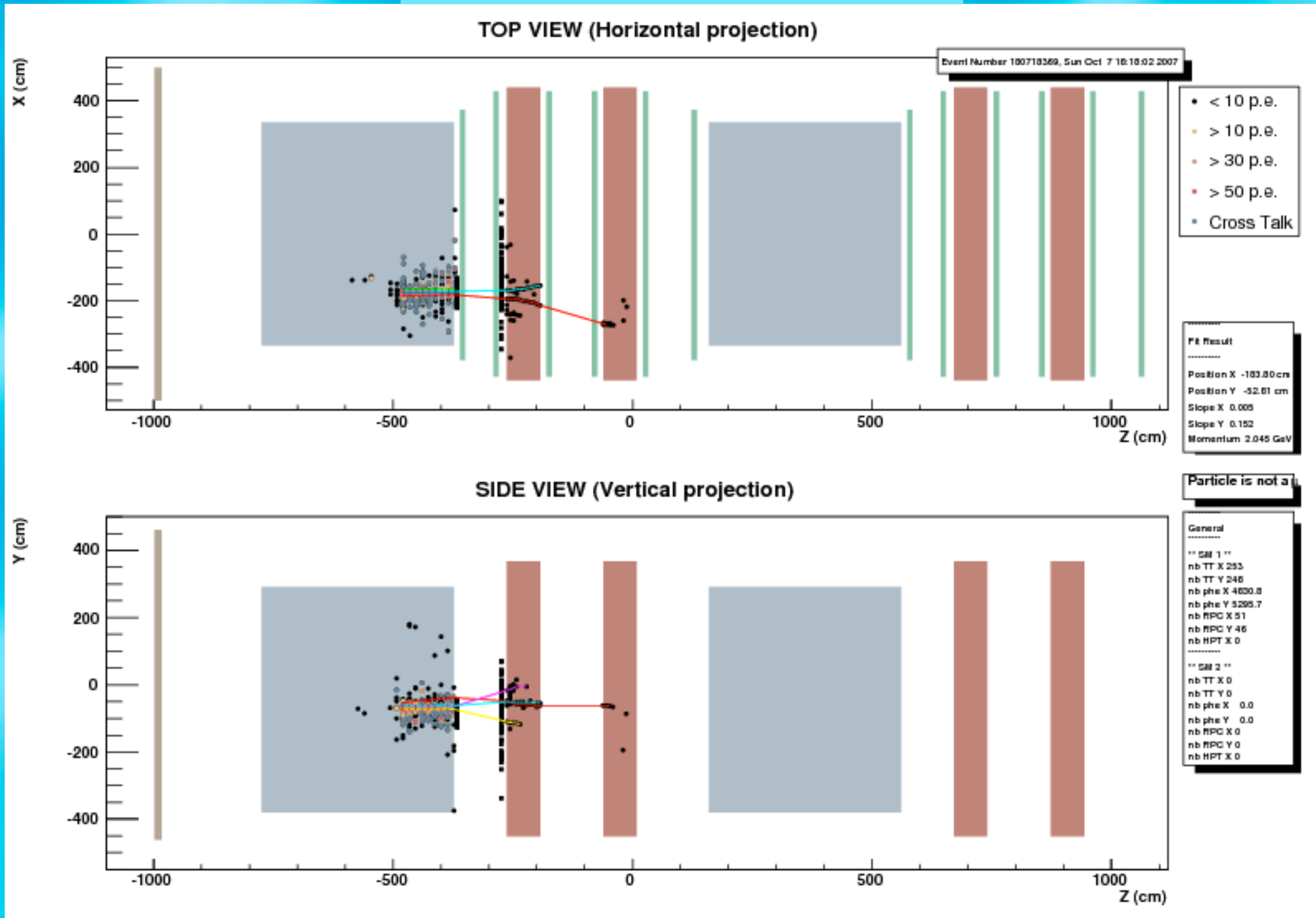
Track	TX	TY	I.P. (micron)
1	0.218	0.110	0.6
2	0.049	0.002	7.0
3	-0.109	0.114	muon
4	0.443	-0.005	0.2
5	0.119	-0.059	22.6

Brick to brick connection: distance 55500micron



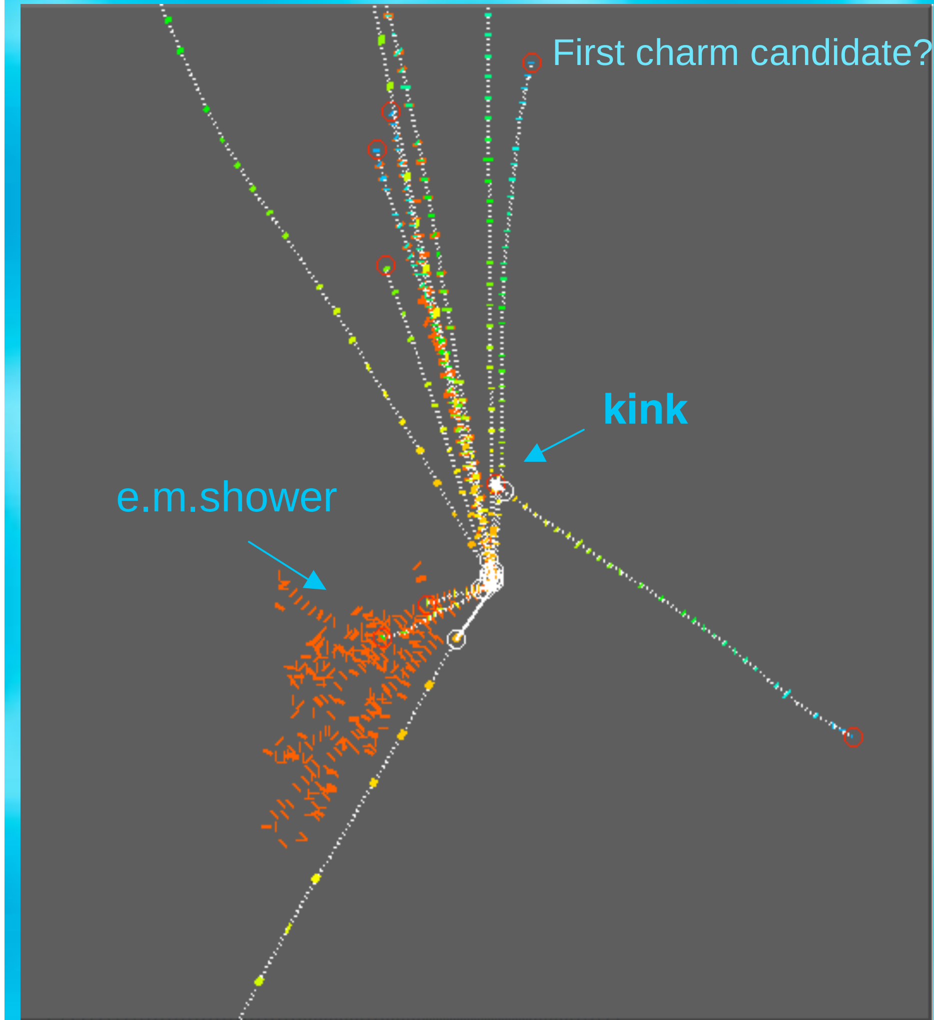
Event 180718369

CC interaction / 10 prongs



Event 180718369

PRELIMINARY



Tracks	TX	TY	IP (μm)	Momentum (GeV)	
1	0.005	0.036	3.3	$1.7^{+0.5}_{-0.3}$	
2	0.005	0.139	1.0	parent	
3	0.002	0.064	6.6	>20.0	
4	-0.021	0.064	7.1	$2.1^{+0.7}_{-0.4}$	
5	-0.029	0.046	2.8	>8.4	
6	-0.031	0.064	7.3	$2.4^{+0.8}_{-0.5}$	
7	-0.076	0.068	4.2	$1.8^{+1.6}_{-0.6}$	
8	-0.089	0.141	6.9	$2.5^{+1.4}_{-0.7}$	
9	-0.183	0.106	5.4	$0.7^{+0.2}_{-0.1}$	
10	-0.297	-0.143	19.2	$0.7^{+0.3}_{-0.1}$	
11	-0.067	0.008	7.3	$3.5^{+3.6}_{-1.2}$	e.pair
12	-0.069	0.005	16.8	$2.0^{+3.1}_{-0.8}$	e.pair

Secondary Vertex

Daughter momentum = $3.9^{+1.7}_{-0.9}$

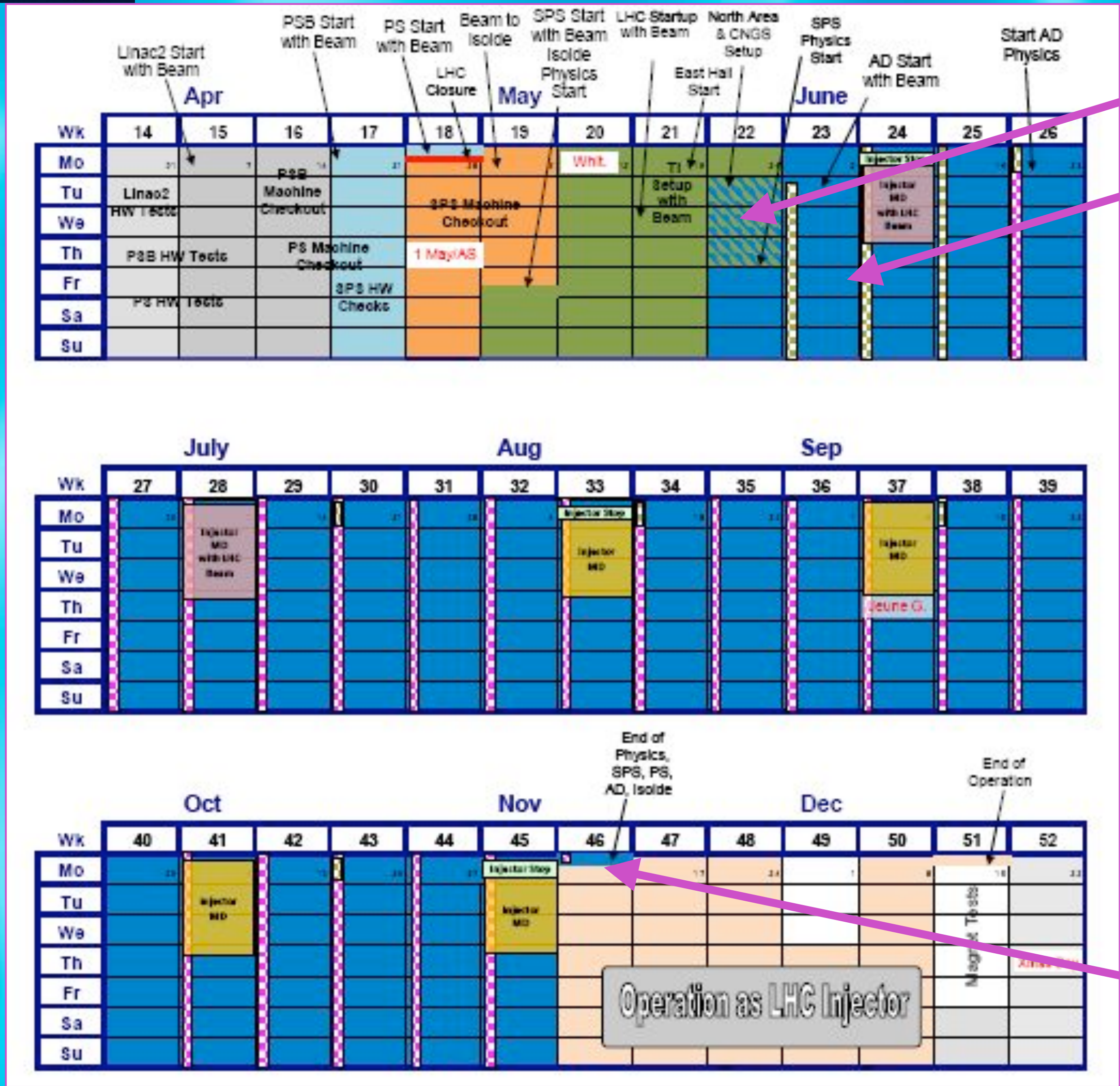
θ_{kink} = 0.204 rad

Flight length = 3247 μm

P_T = 796 MeV

P_T^{MIN} = 606 MeV (90% C.L.)

2008 run : SPS schedule



May 29th

CNGS:~June 20th
Completed repairs

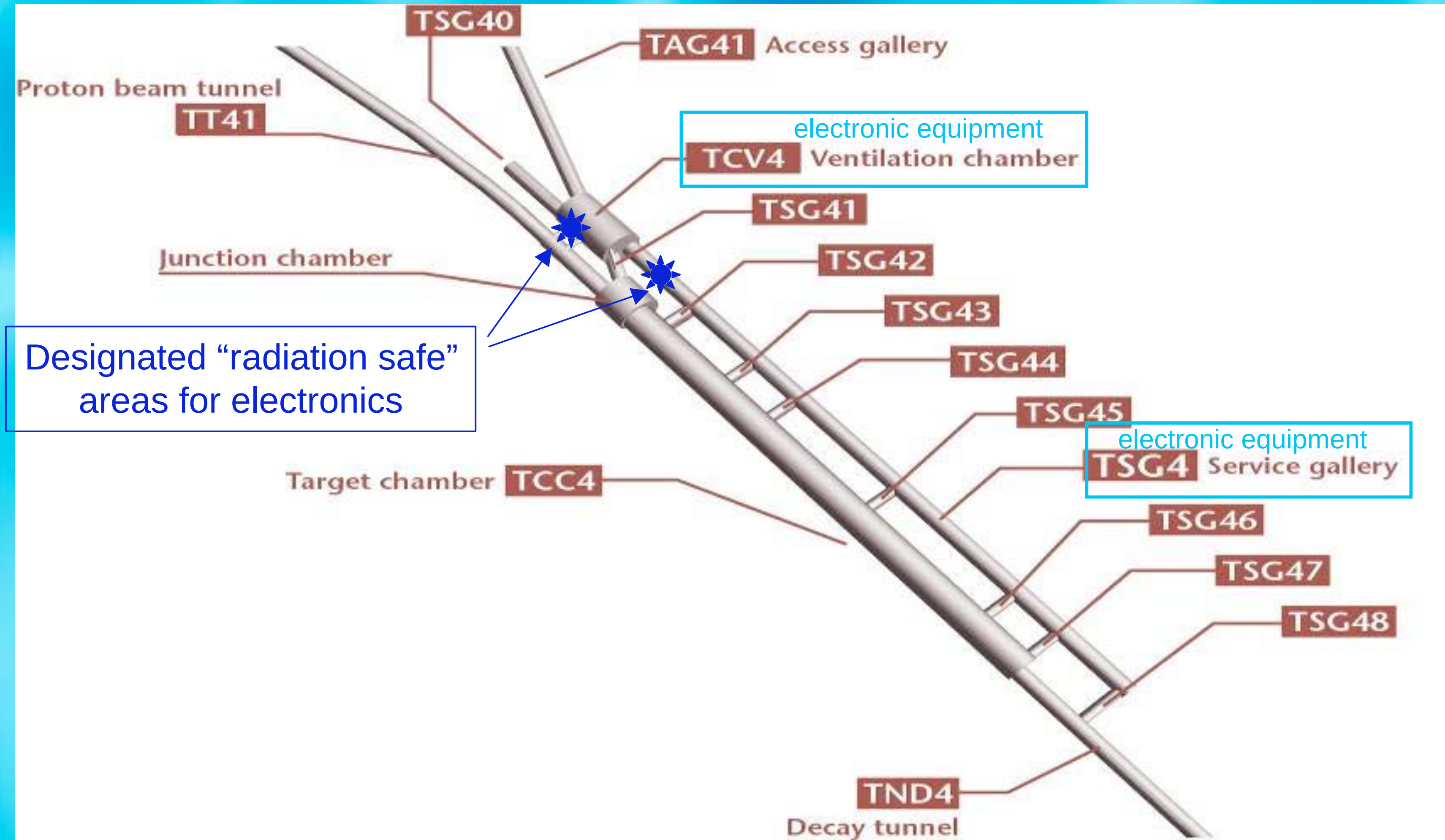
130 days max for the CNGS
Spread over 20 weeks

Nominal CNGS year : 200days

November 10th

CNGS Electronics - underground

Layout of the ventilation control



Radiation effects on electronics

The failed ventilation electronics were installed along the TSG4 (service gallery), next to the ventilation ducts, and in the TCV4 (ventilation chamber).

In both areas the radiation levels, as predicted by the FLUKA simulations and confirmed by the radiation protection measurements, are far too high for COTS components → the electronics should have failed and they did

↓

During the 2007/2008 shutdown, work is organized to remedy the problem and assure nominal running of the facility for 2008 and beyond.

Actions for 2008 shutdown

General guideline:

Replace damaged electronics

Move the electronics out of the CNGS tunnels as possible

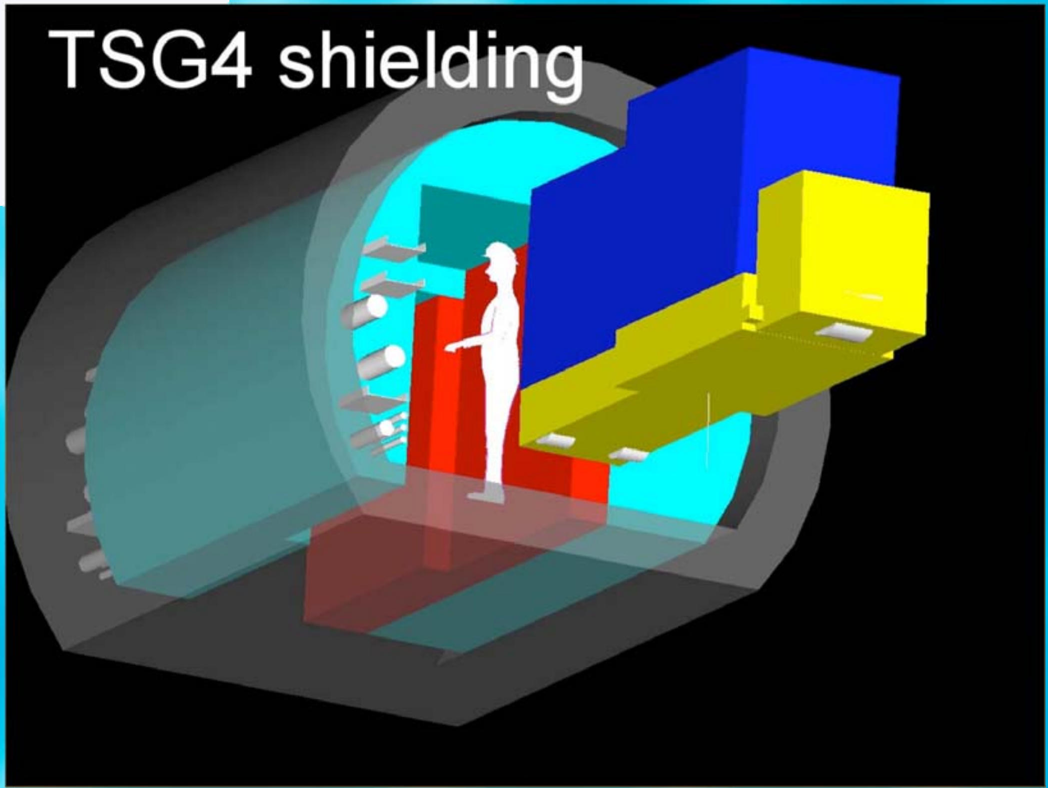
For the equipment which must stay in the area:

1) Create a “radiation-safe” area by adding adequate shielding and move all the electronics into this area
2) Address the sensitivity to radiation of the installed electronics and investigate upgrade possibilities
3) Install a radiation monitoring system for electronics as in LHC

CNGS repair state

Radiation damages repair and protection:

- the work is fully funded
- electronics repair and reshuffling has started
- shielding plugs defined, civil engineering starting
- completion of the work expected by the end of week 23 (June 6th)
- stable beam during week 25 (~June 20th)



2008 run : expected statistics

	Expected 2008 run	Nominal CNGS
Number of days	130	200
Super Cycle (sec.)	48	27.6
Circulating proton	$2x2\ 10^{13}$	$4.8\ 10^{13}$
efficiency	80%	55%
Integrated pot	$2.1\ 10^{19}$	$4.5\ 10^{19}$

Minimal granted by CERN
If no delay in the CNGS repair

Total number of interactions	~ 2000
Tau candidate (@$2.5\ 10^{-3}\ eV^2$)	~ 1

~110 evts/week

no MTE running (only commissioning) in 2008

Conclusions

Neutrino events have been observed in the OPERA bricks during the short CNGS run of 2007:

With the collected small sample, several issues were faced and solved

Brick candidate extraction, brick handling, CS scanning , vertex location: tested the full chain

Analysis and kinematical reconstruction of the neutrino interactions in emulsion are in progress

Next CNGS run with full target expected by june 2008 : First OPERA year !

The detector is ready for the next phase

…waiting for the first

ν_τ interaction

in emulsion…..