

The Status of the OPERA experiment

O.Sato(Nagoya Univ.)

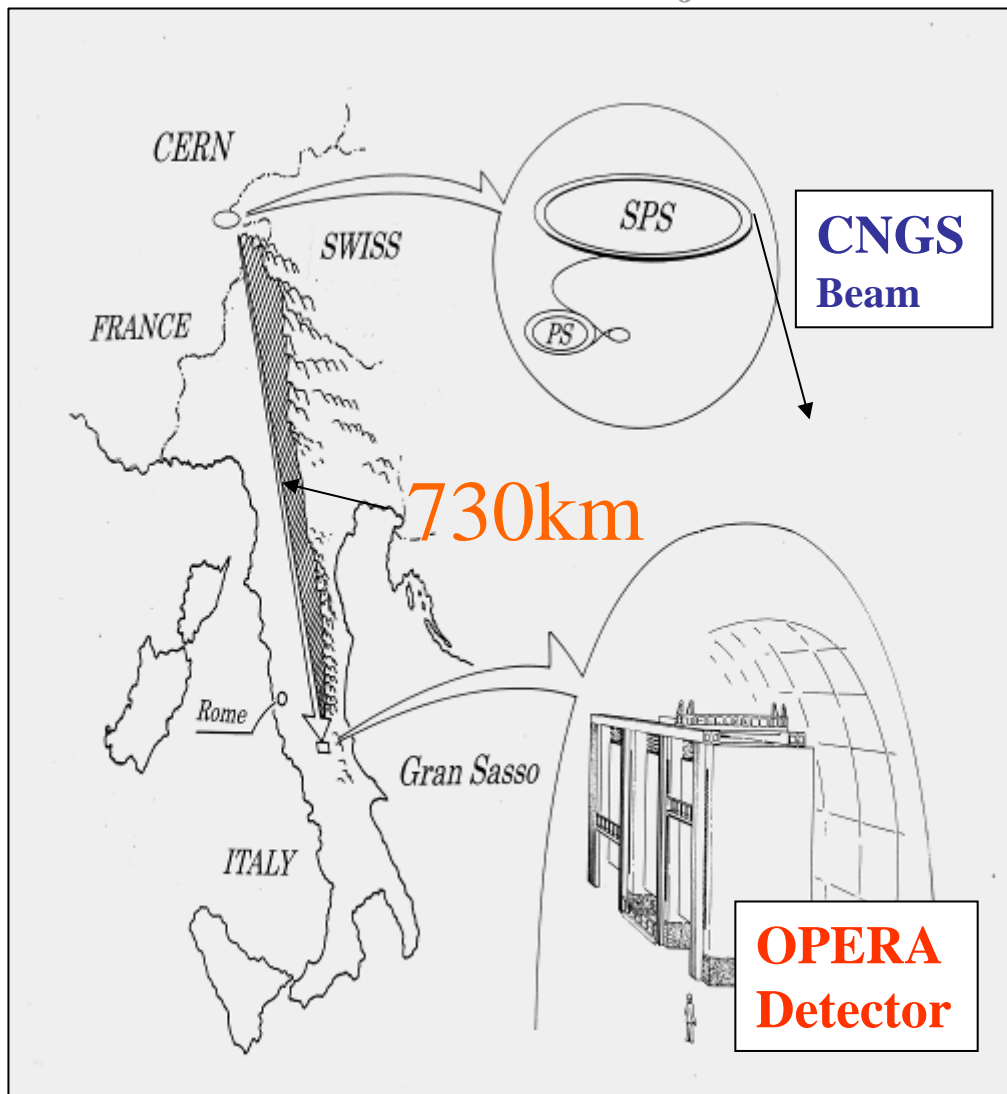
On behalf of OPERA collaboration

2007.Jun.13 DBD07



OPERA

Oscillation Project with Emulsion-tRacking Apparatus



**An Emulsion-Counter
Hybrid experiment for
Tau neutrino
Appearance
Detection.**

Collaboration :

13countries 37 Institutes

**First Neutrino
to Gran Sasso
at 2006 August**

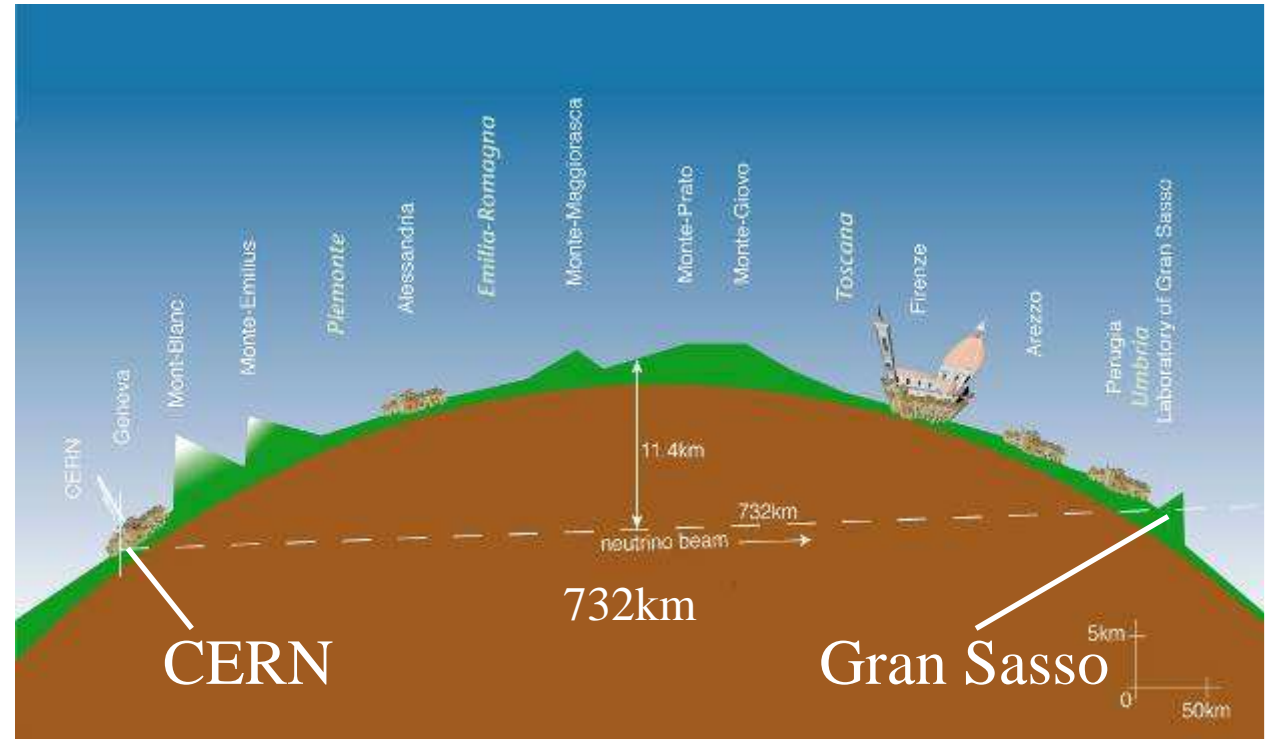
CNGS beam

Optimized to study $\nu\tau$ appearance

Nominal ν beam

ν_μ (m ⁻² / pot)	7.45×10^{-9}
ν_μ CC / pot / kton	5.44×10^{-17}
$\langle E \rangle_\nu$ (GeV)	17
$(\nu_e + \bar{\nu}_e) / \nu_\mu$	0.85 %
$\bar{\nu}_\mu / \nu_\mu$	2.0 %
ν_τ prompt	negligible

400GeV protons from SPS



⇒ Interactions at Gran Sasso

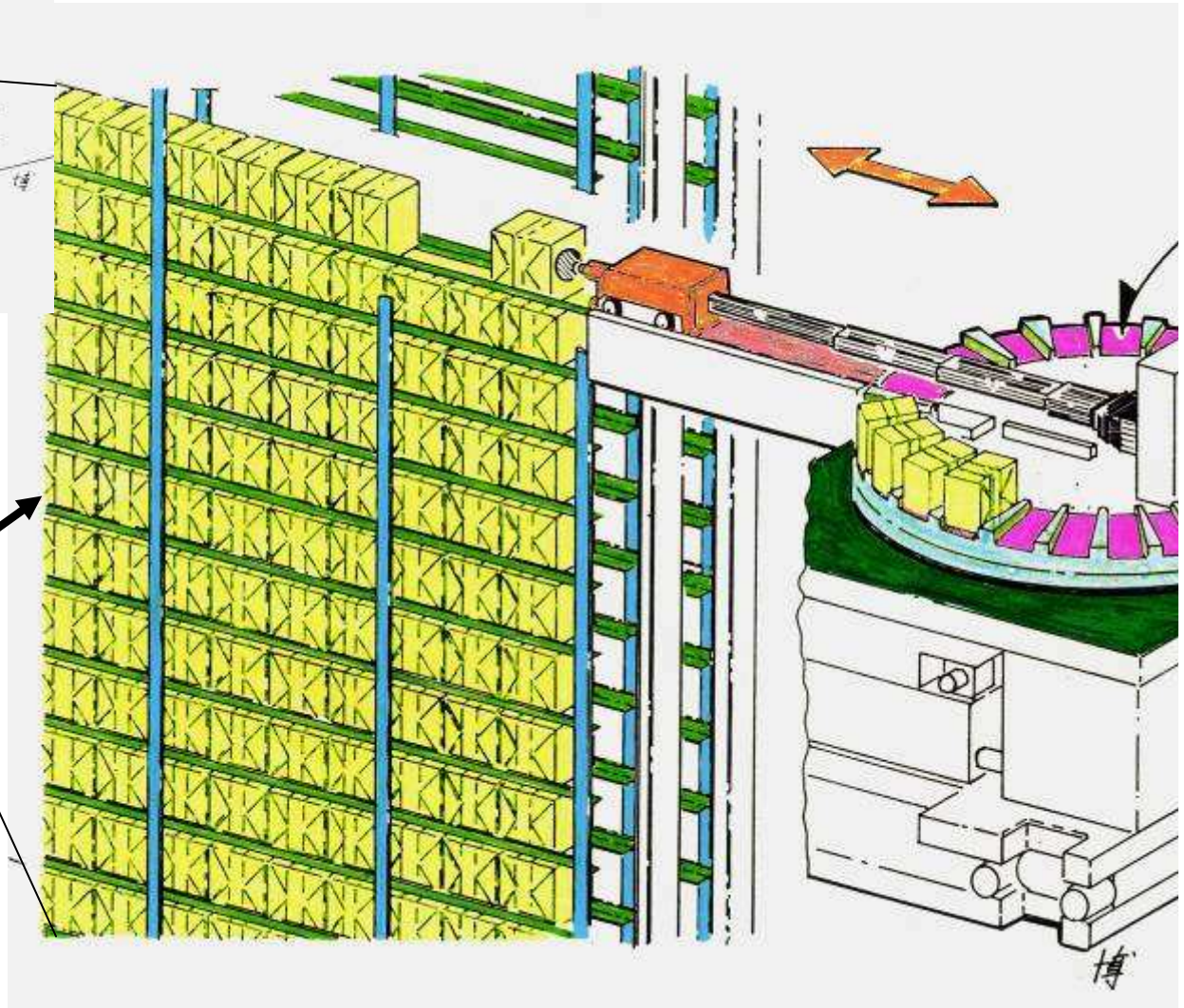
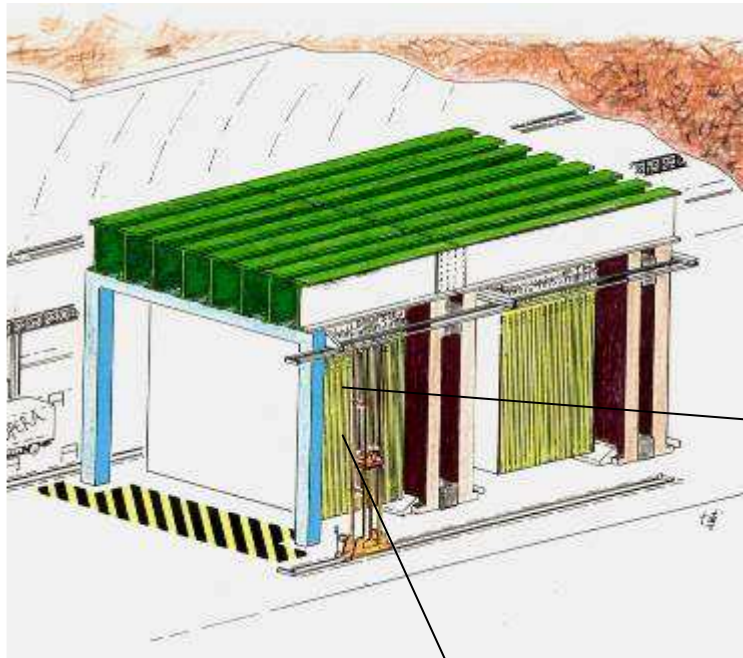
~ 3600 ν NC+CC /kton/year
 ~ 16 ν_τ CC /kton/year

for $\sin^2 2\theta = 1$, $\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$

Shared SPS operation
 200 days/year
 4.5×10^{19} pot / year

~200k ECC bricks

ECC Weight ~1700ton

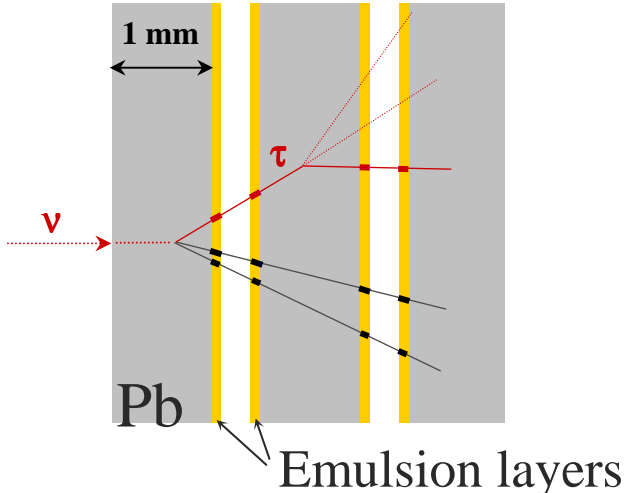


64 × 52ECC/Wall

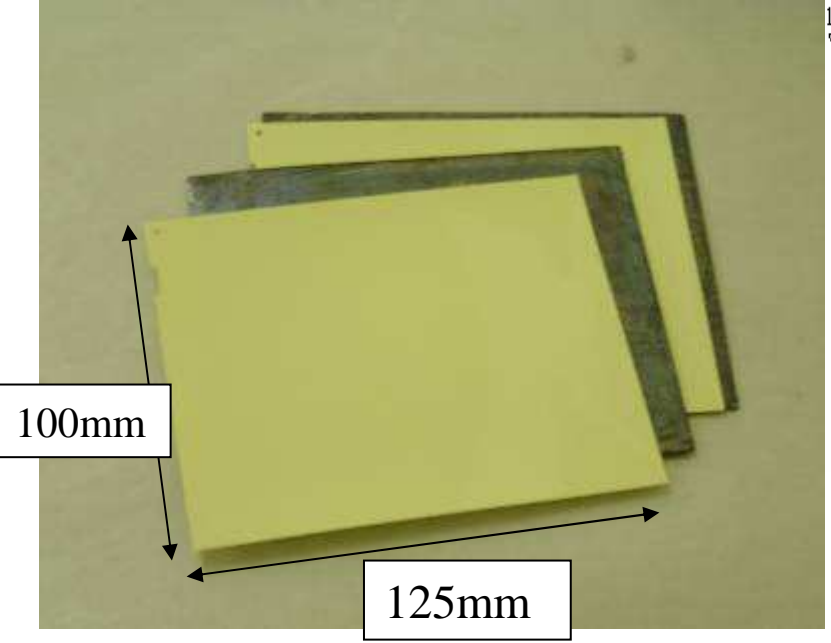
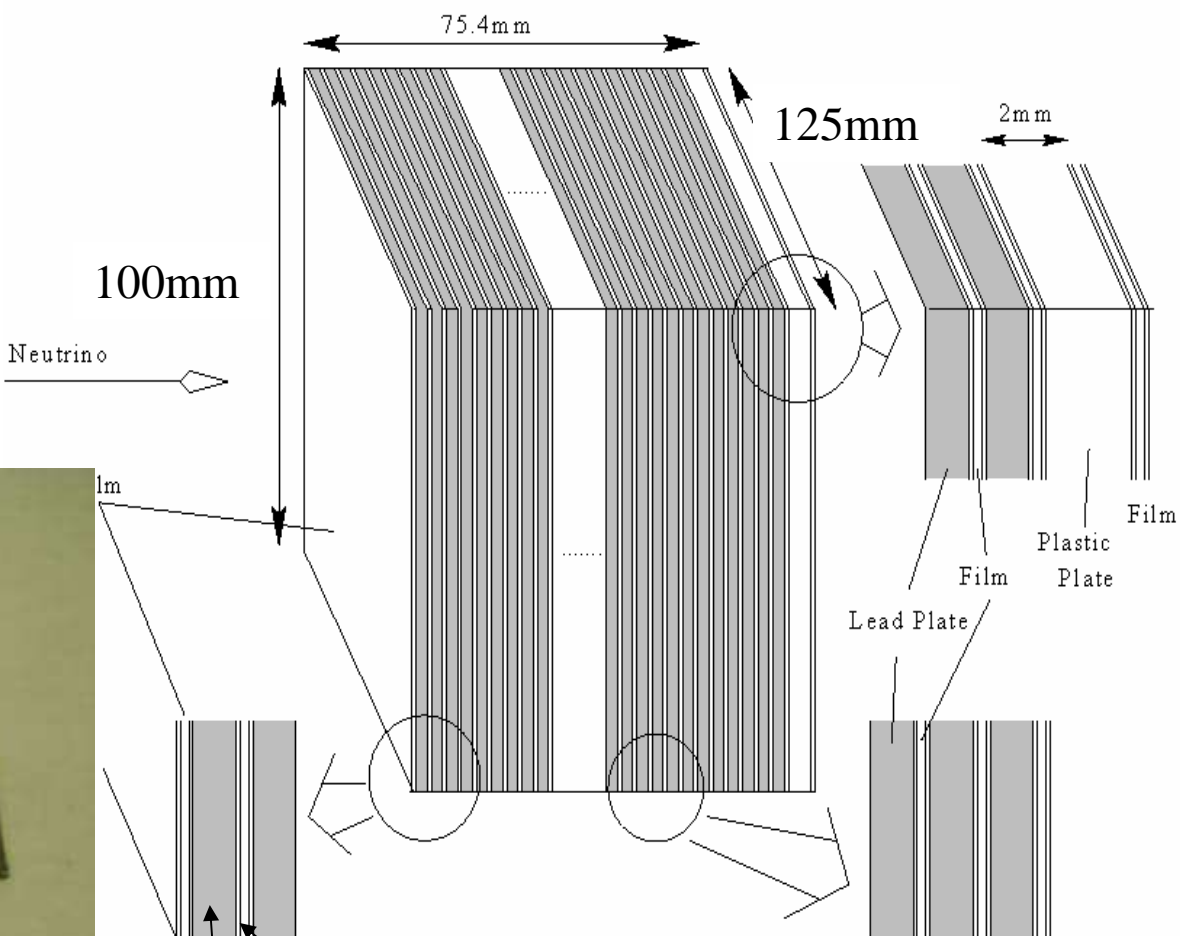
Total 62 Walls

OPERA ECC Brick

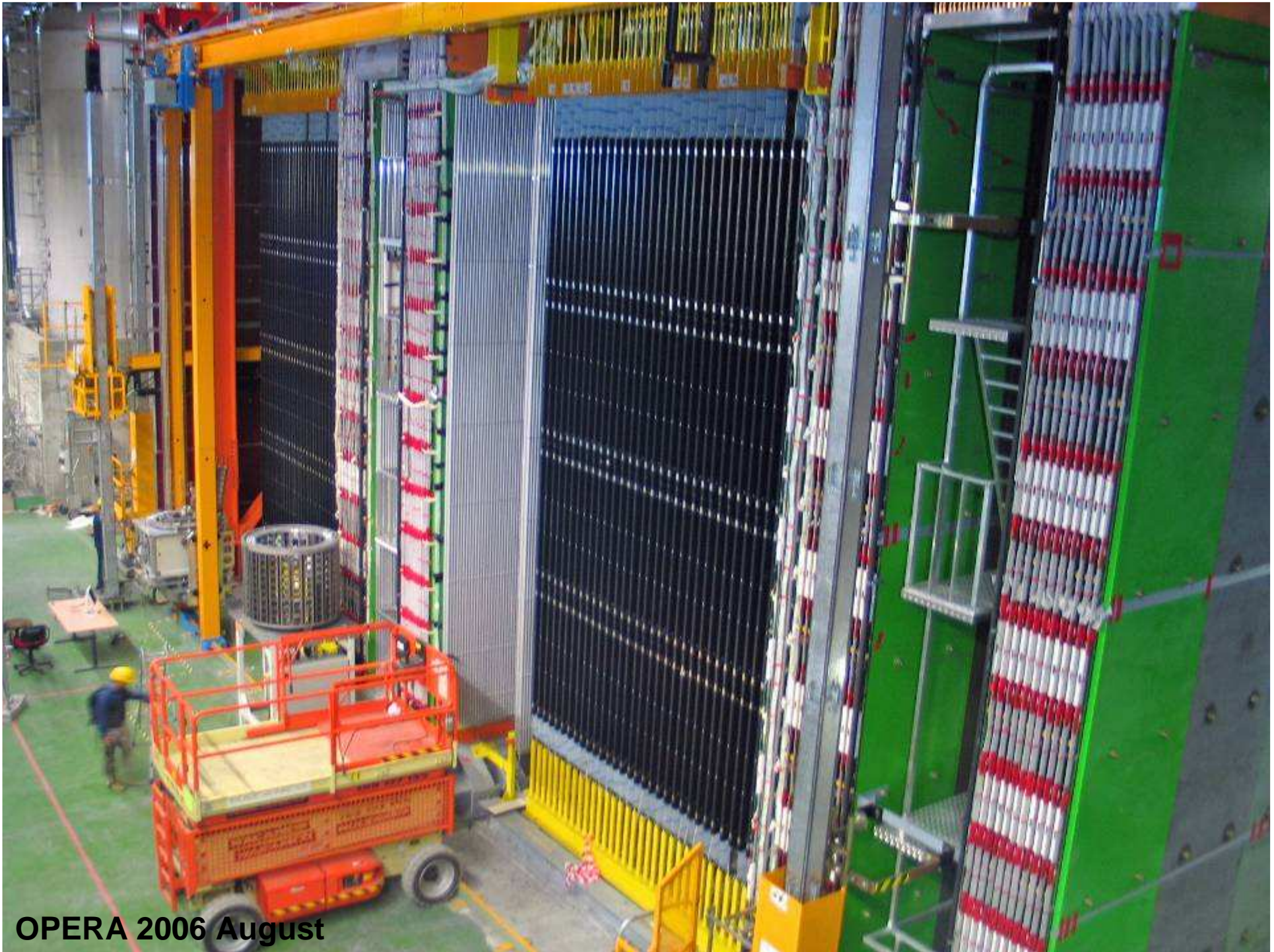
Lead plate(1mm) / Emulsion Film (OPERA film) Sandwich



Film + 56 (Lead + Film) + Plastic plate + Film



Lead Plate Emulsion Film (OPERA Film)

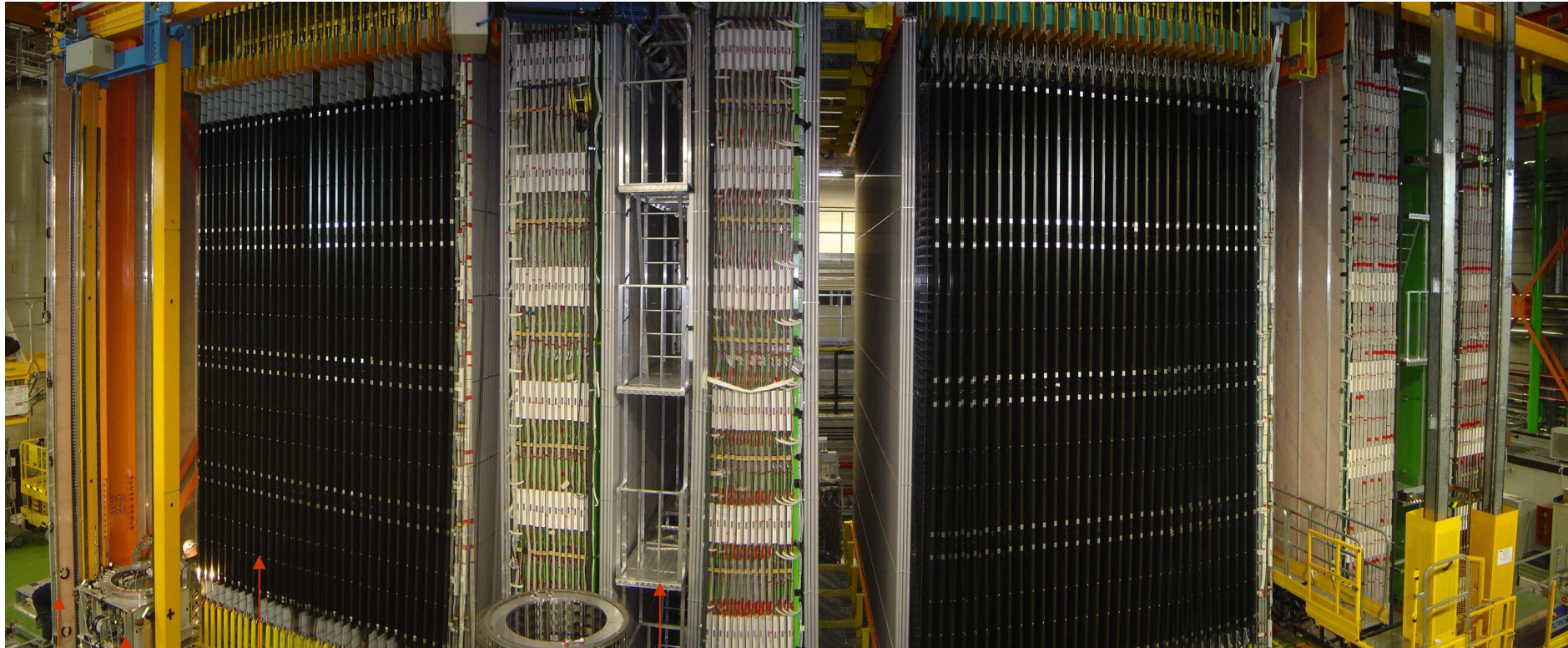


OPERA 2006 August

Electronic detectors installation finished

SM1

SM2



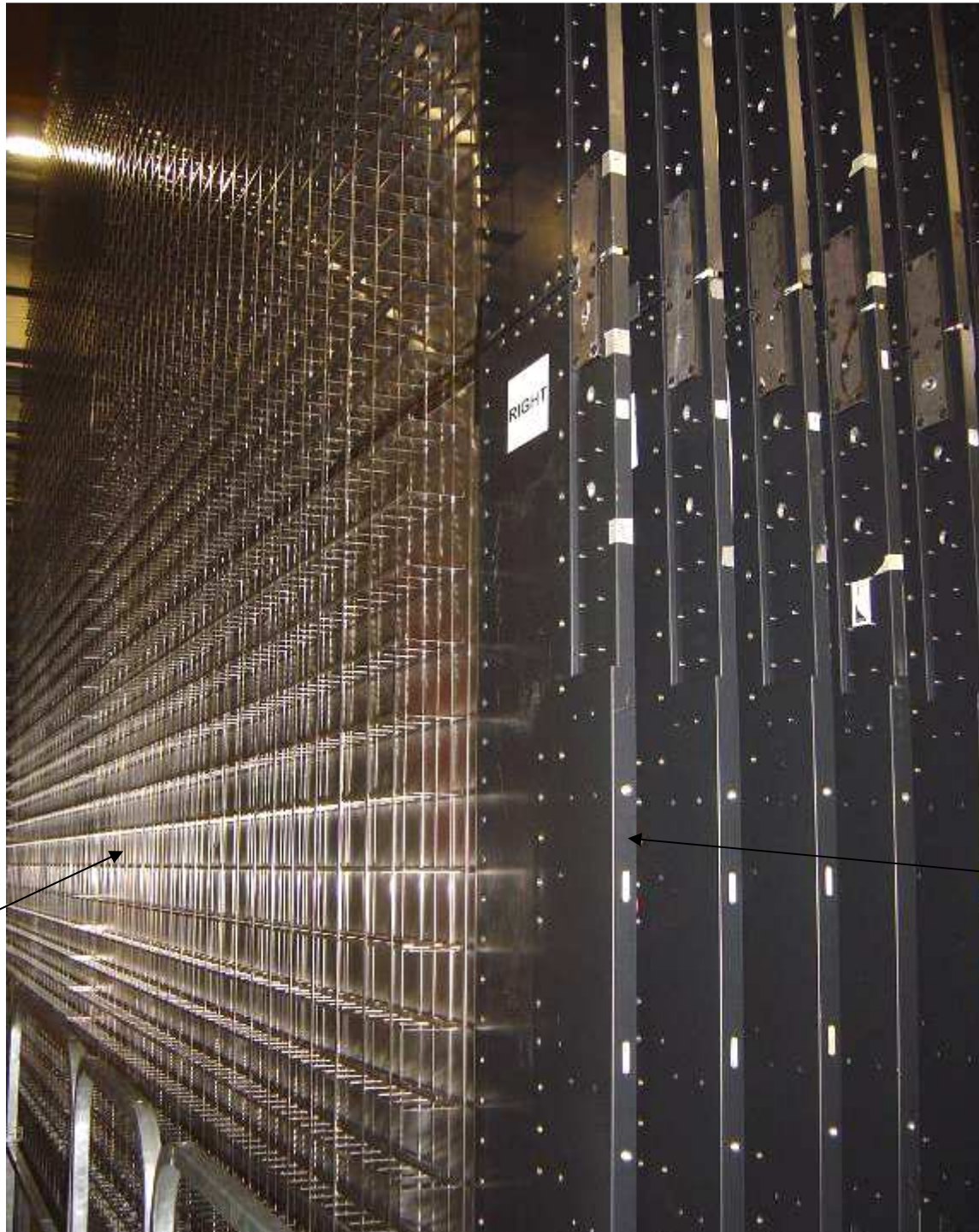
Veto

Target tracker

BMS

Spectrometer:
XPC, HPT, RPC, magnet

All installed and running



**Wall
for
ECC
bricks**

**Target
Tracker**

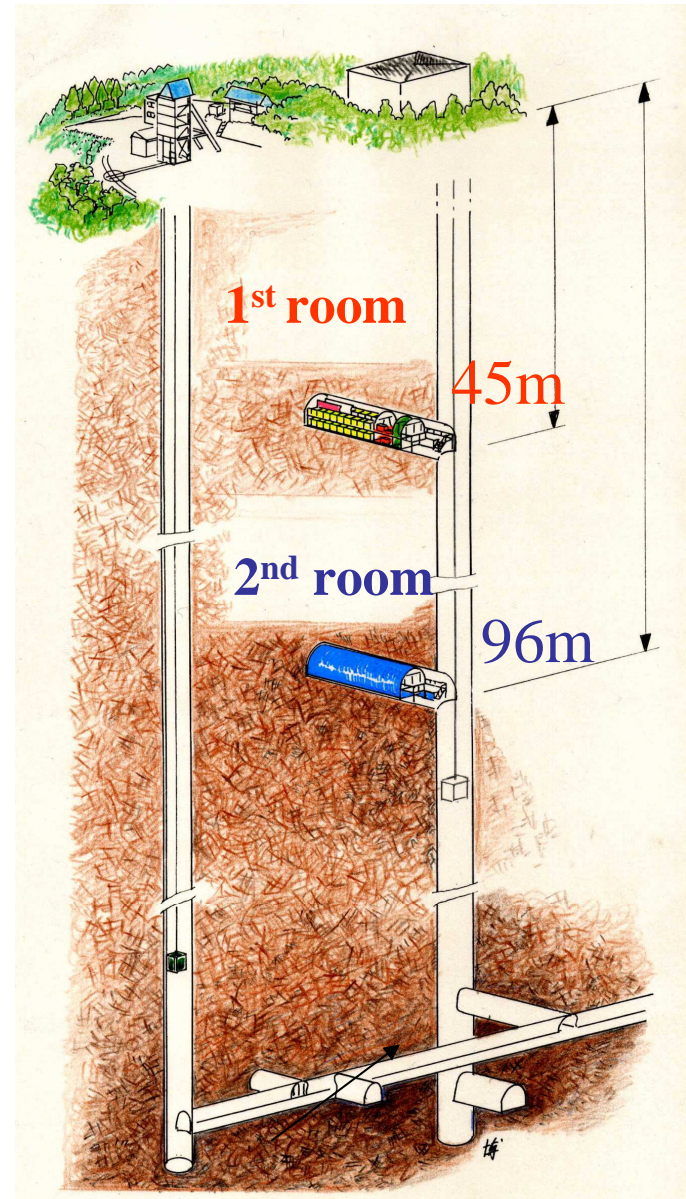
Emulsion storage room in LNGS

~Films for 140,000 Bricks at LNGS underground Iron Shield



Refresh Facility

TONO Mine underground



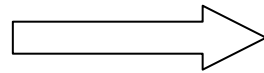
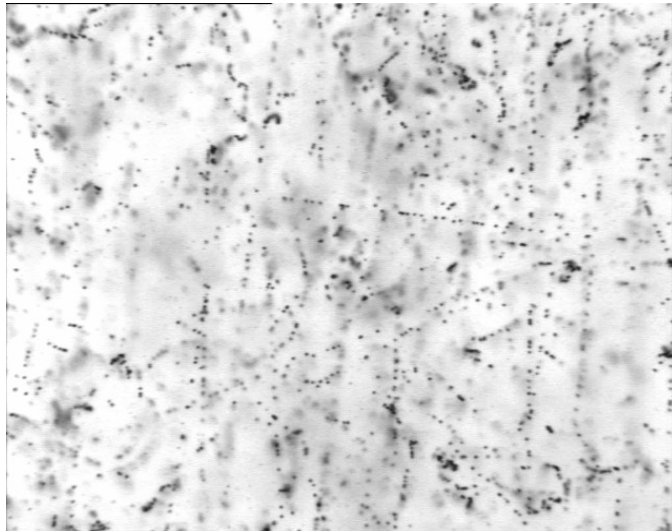
Cosmic ray flux

1st room 1/50(115m.w.e.)

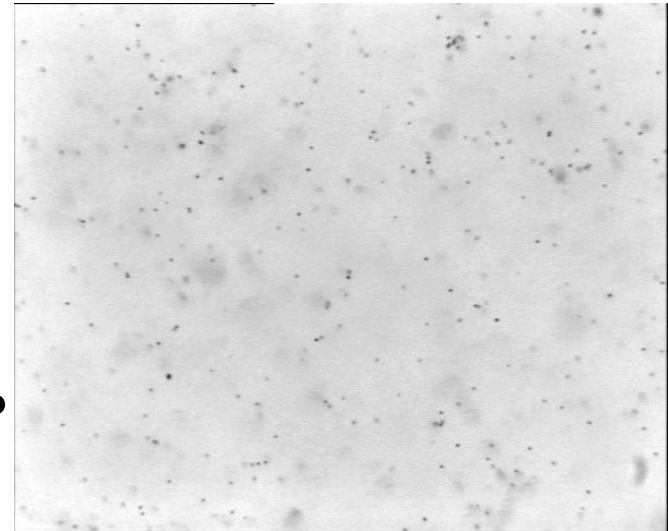
2nd room 1/400(220m.w.e.)

8M films have been refreshed and shipped to Gran Sasso.

Refreshing



Refresh
• $T = 30^{\circ}\text{C}$
• $\text{RH} > 95\%$
3 days



Before Refresh
B.G. > 30tracks / mm²

After Refresh
B.G. < 1tracks / mm²

We can erase unwanted BG tracks.
~98% of the recorded tracks can be erased

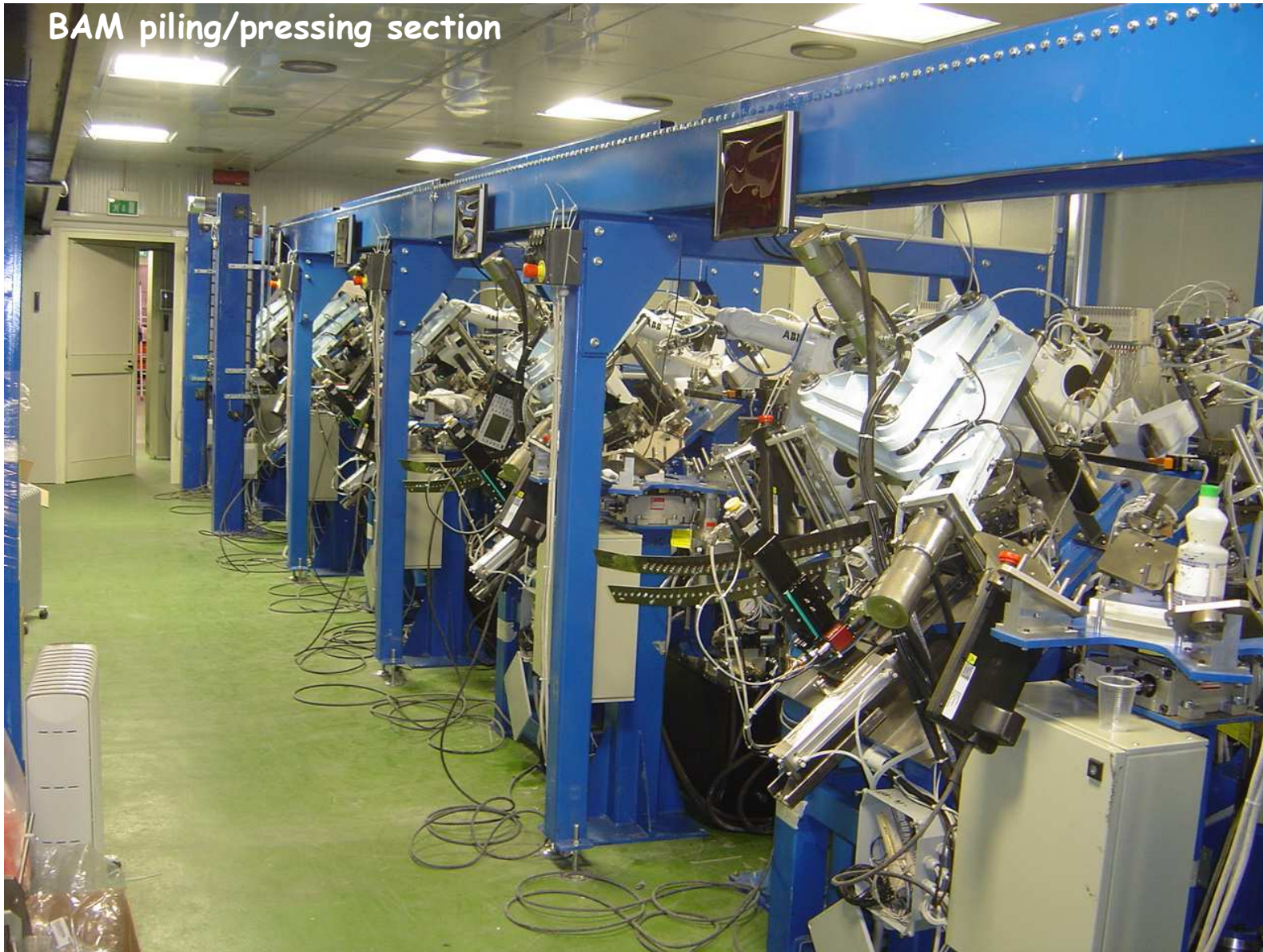


Refreshing Facility @ TONO mine

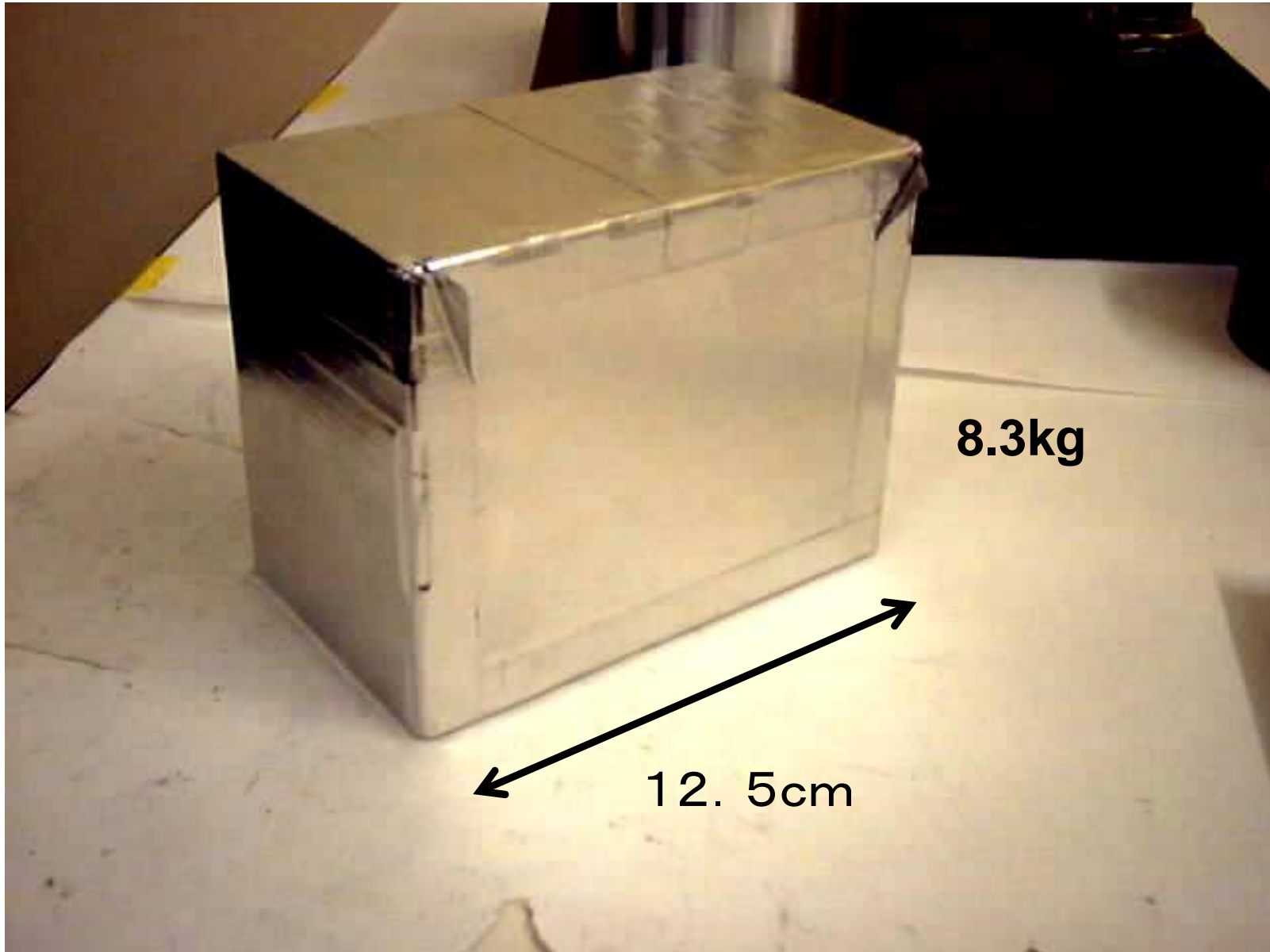


The Brick Assembly Machine (BAM) (INFN,Italy)

BAM piling/pressing section



ECC Brick

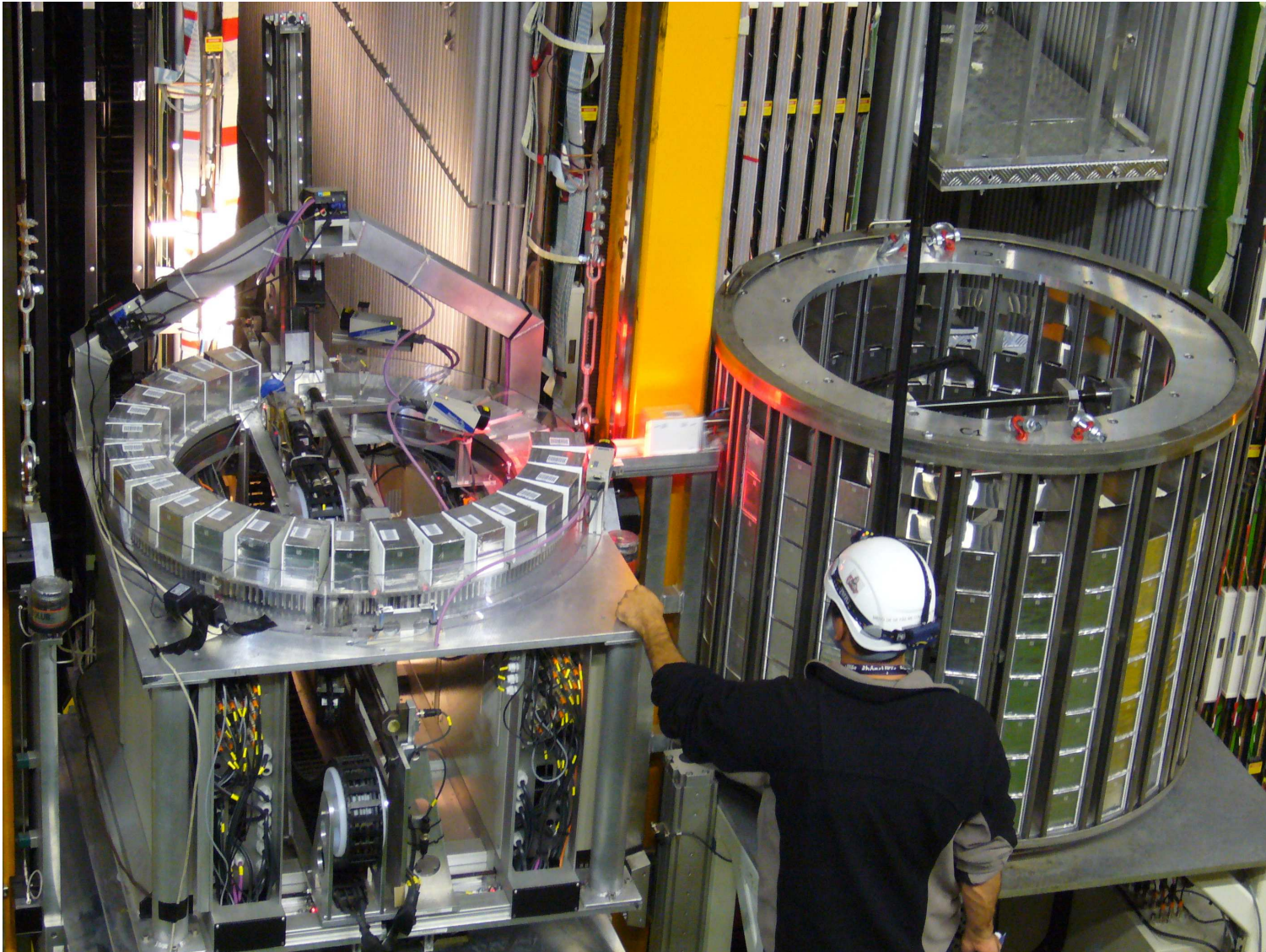


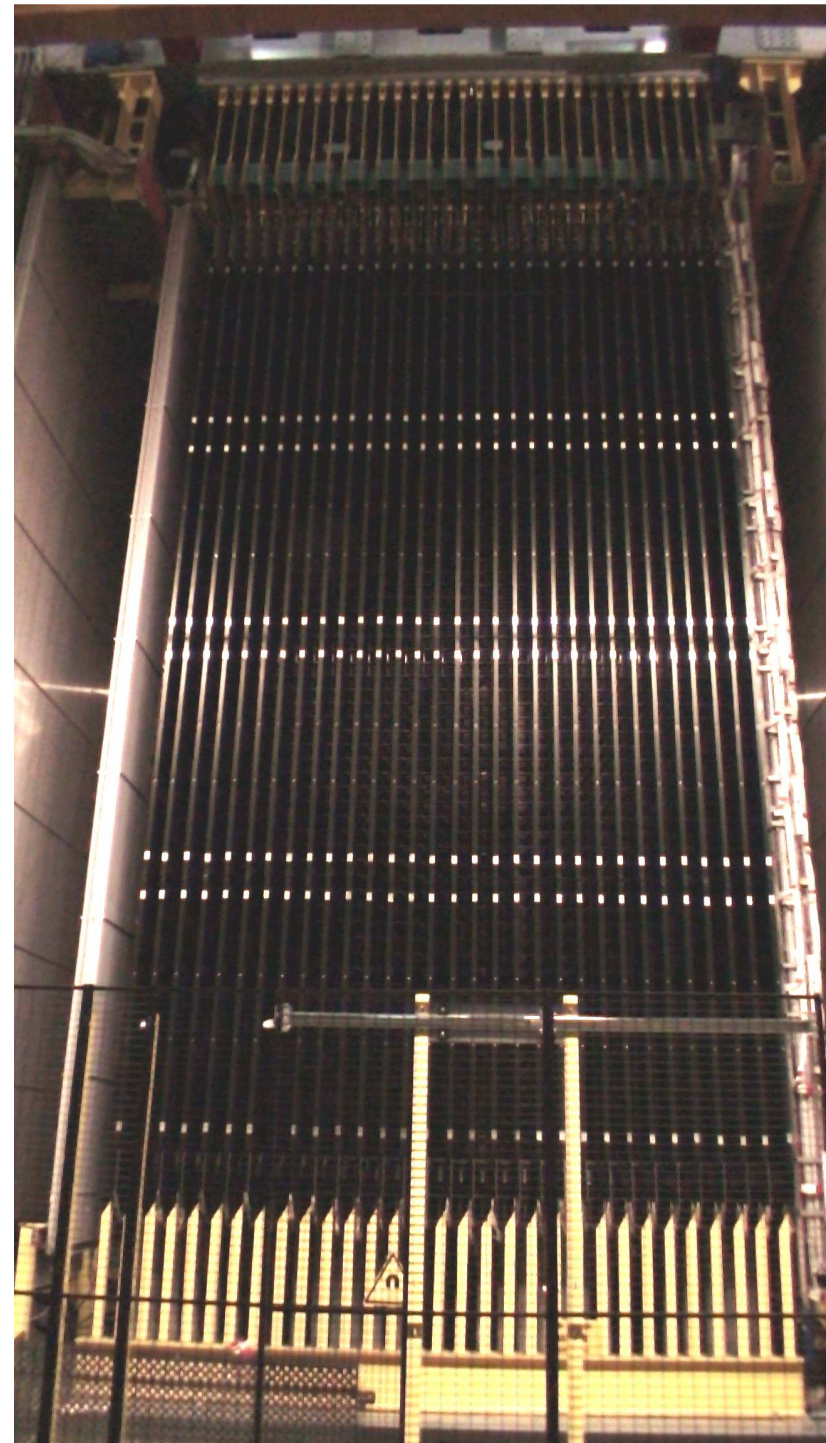
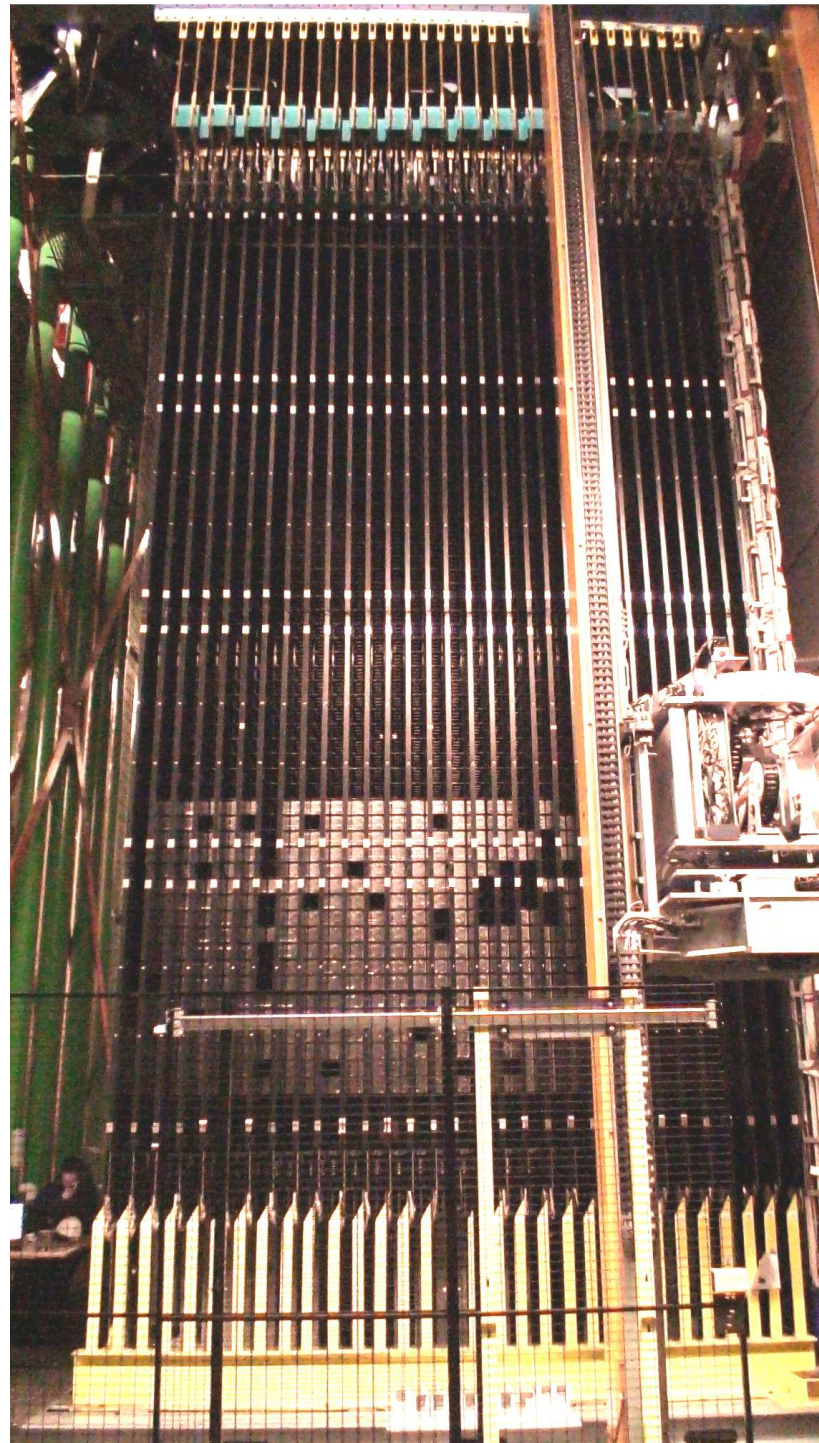
1st ECC in Detector hall, Oct 23rd



~ 1000 ECC were installed before Oct-run.

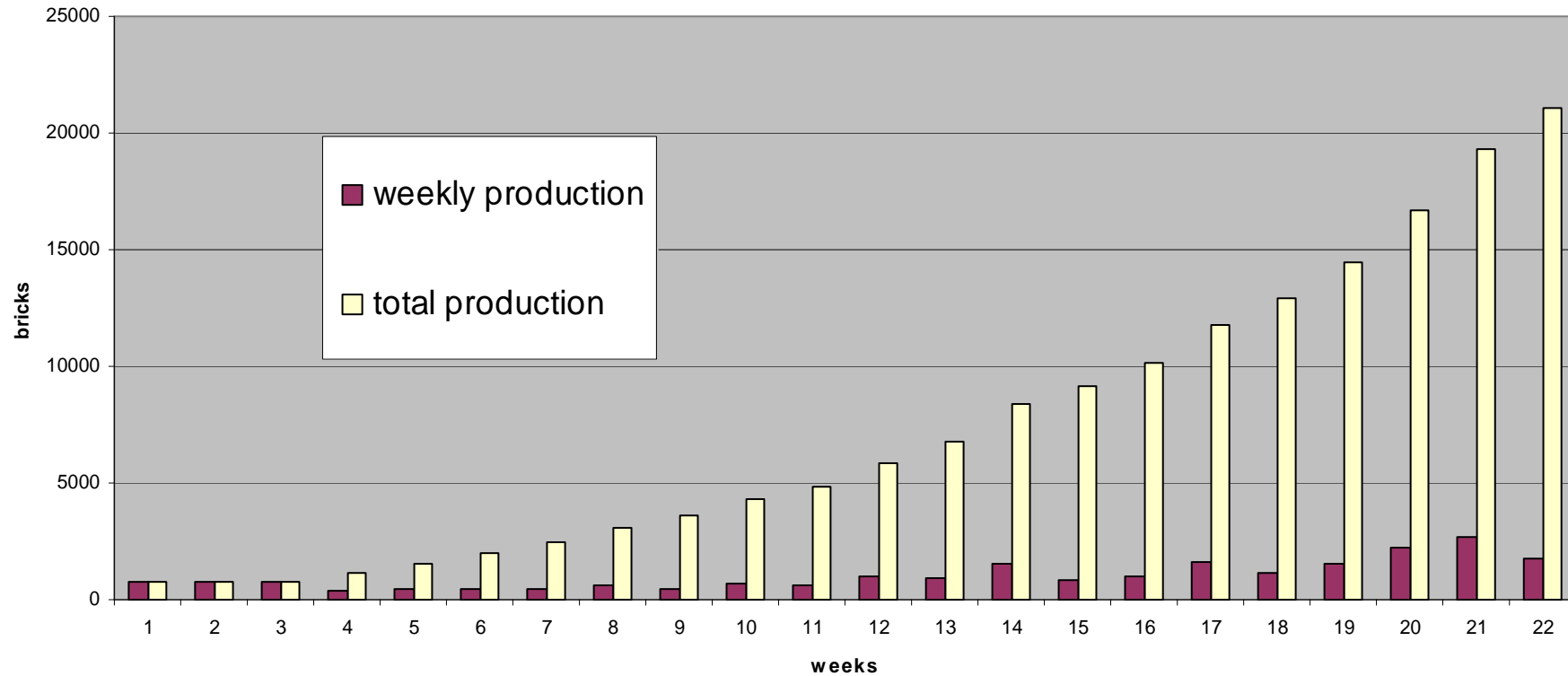
Brick Manipulator System (BMS, LAPP France)





OPERA brick production

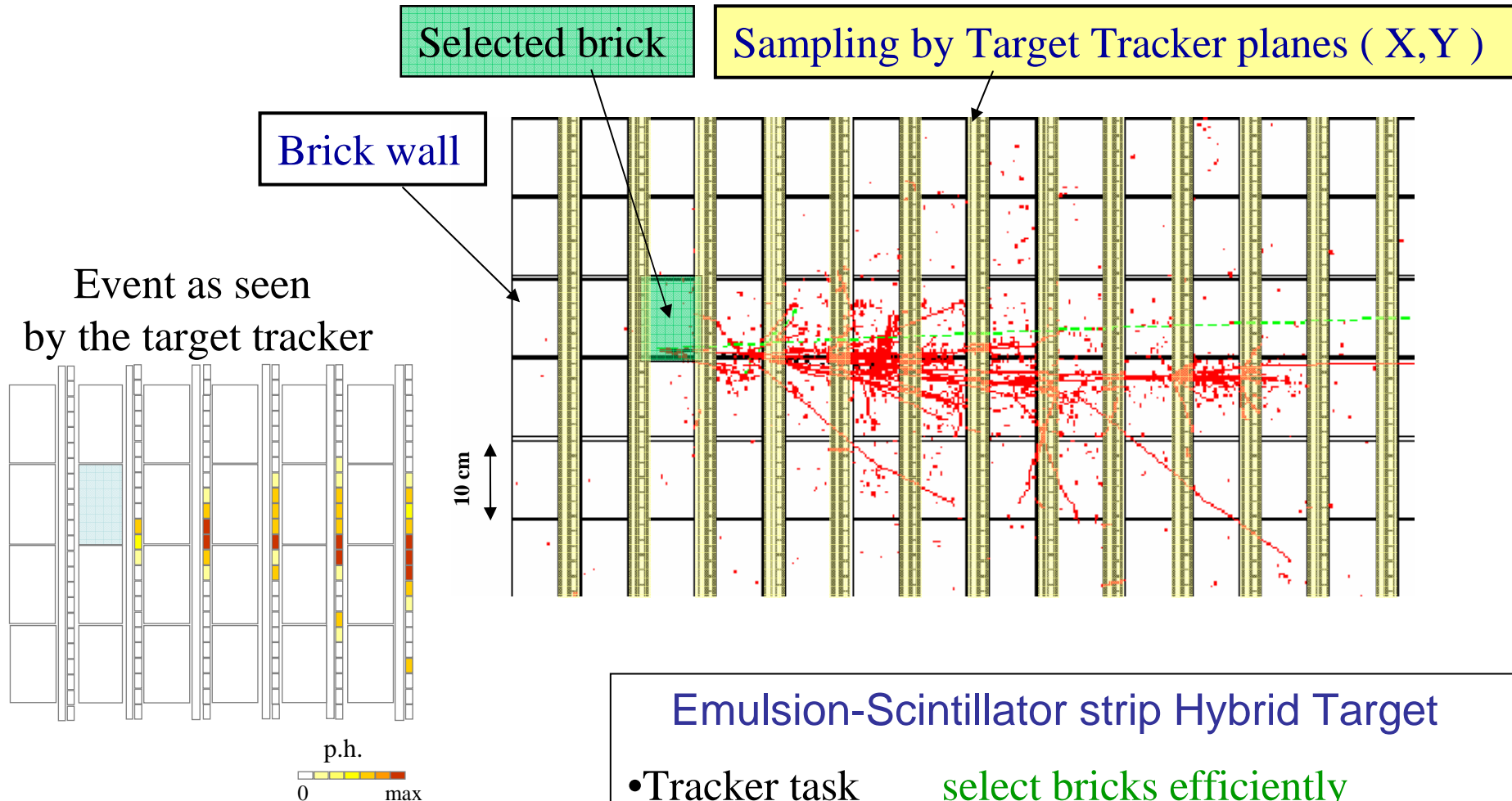
Rate in last 22 weeks



Till last Friday **21062** real bricks delivered in hallC

= 90 drums

Brick tagging by TT



Selected bricks extracted daily using dedicated robot

Emulsion-Scintillator strip Hybrid Target

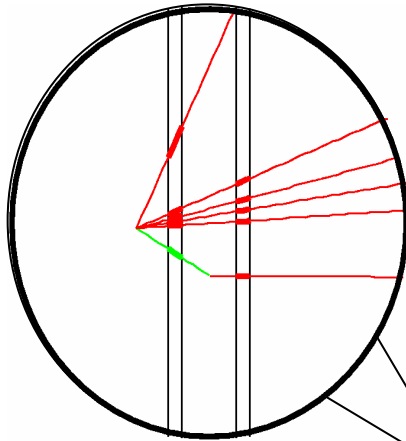
- Tracker task **select bricks efficiently**
- High scanning power + low background **allow coarse tracking**



Vertex location in OPERA ECC Bricks

(Lead Plate (1mm) + Emulsion Film) × 56

ν τ int & τ decay



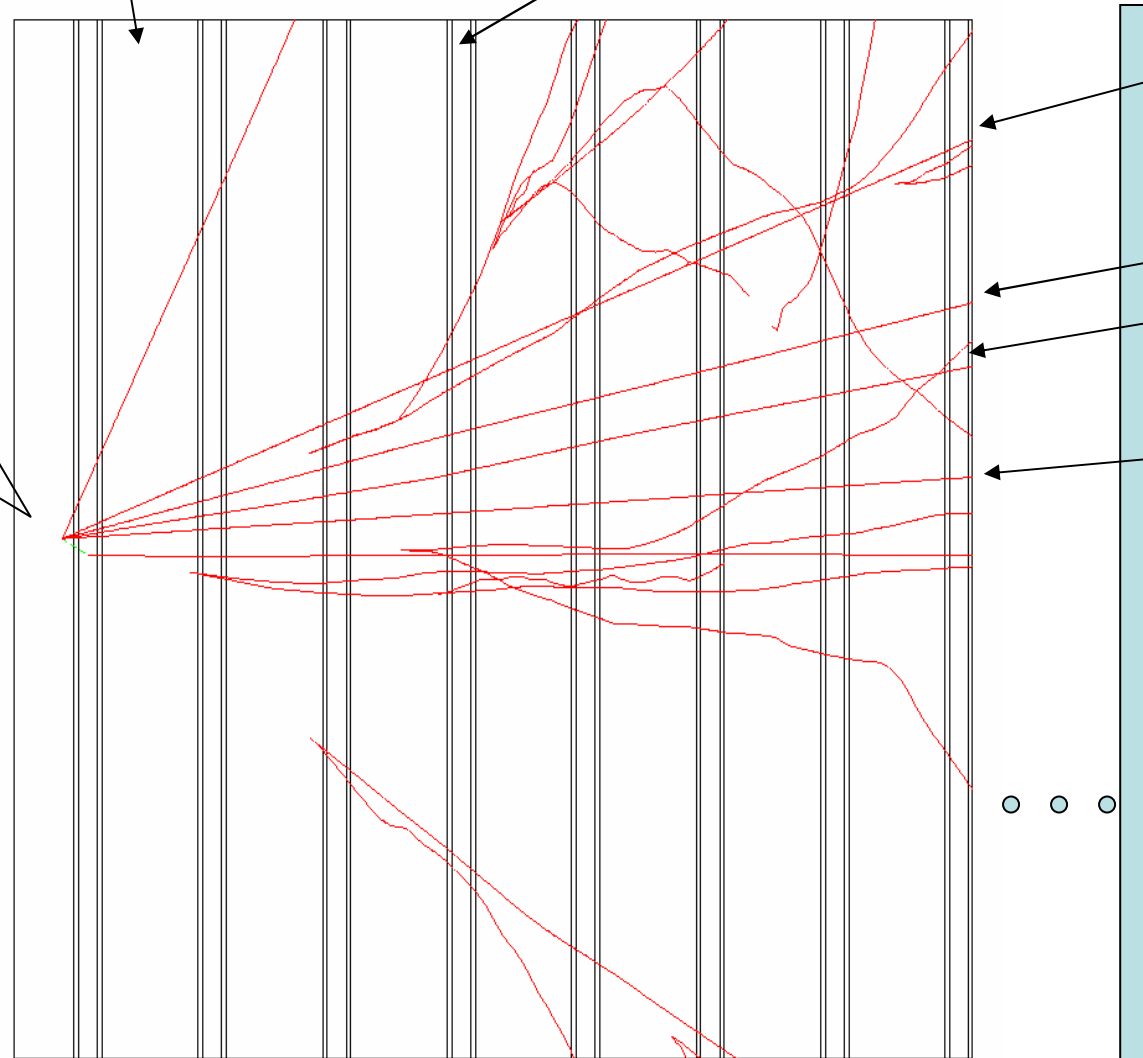
.....→

ν μ → ν τ



Lead:Target

Film:Tracking



Same sequence as E531, DONUT, CHORUS

CS

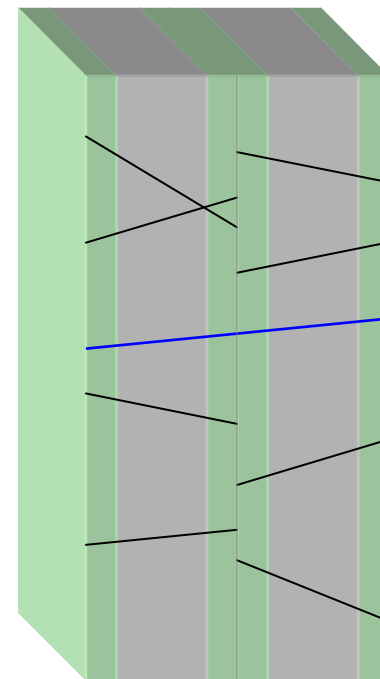
CS Design

- Required Background Level for CS For Brick Tagging

BG tracks \ll 1track/CS (10cmx12cm)

- In order to satisfy this requirement
 - Refresh in GranSasso for CS
 - Doublet Film : coincidence

CS doublet



CS type	Background after refresh (tracks/100cm ²)
Singlet	5000~10000 1 ~ 2% of Accumulated CR
Doublet	< 0.1

OPERA CS facility in GS Hall B



ICARUS T300x2

CS Mass production from September 2006 to June 2007

Neutrino beam exposure 2006

August run (two weeks of beam time)

POT 7.6×10^{17}

TT to CS track linking test

Real CS Stick on Dummy brick(sponge)

Track sample ::

Muons from neutrino interactions by Rock or Iron.

October run (two weeks of beam time → 24 hours) POT 0.6×10^{17}

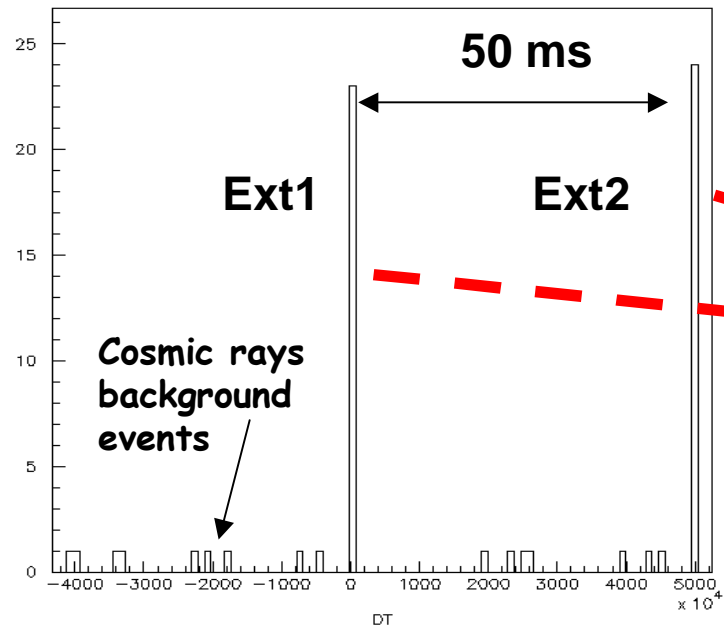
Full chain check for location

Real CS & Brick

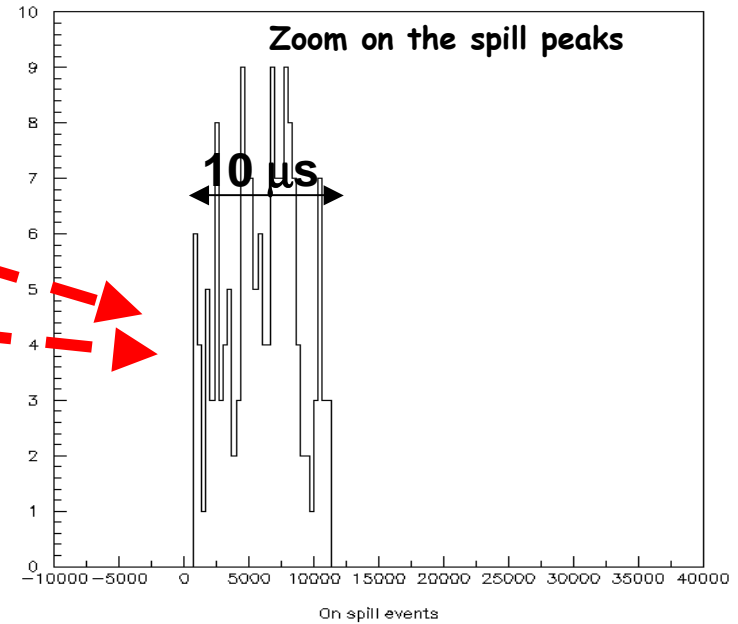
Track sample ::

Muons from neutrino interactions by Rock or Iron

Timing : Event vs Extraction @Aug '06 RUN



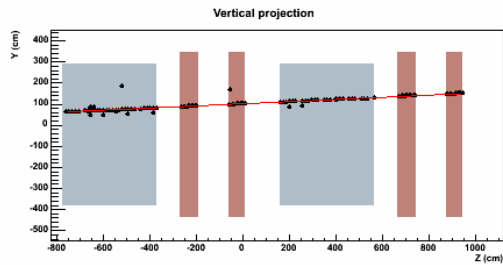
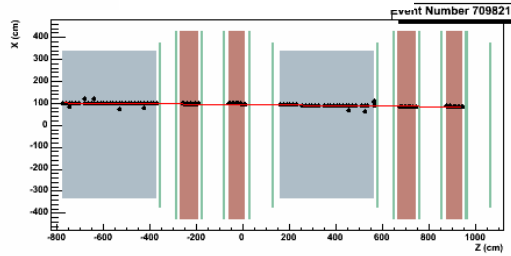
Δt first extraction (ns)



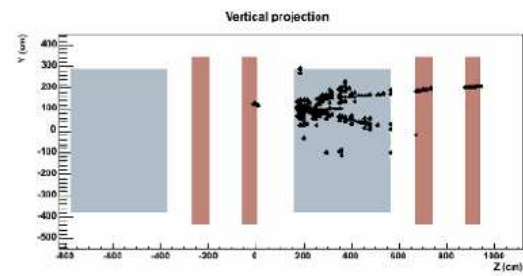
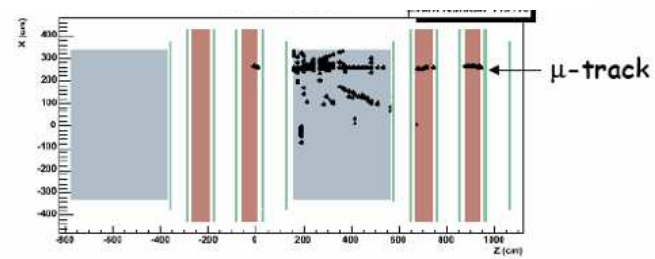
Δt closest extraction (ns)

Event Display of real data

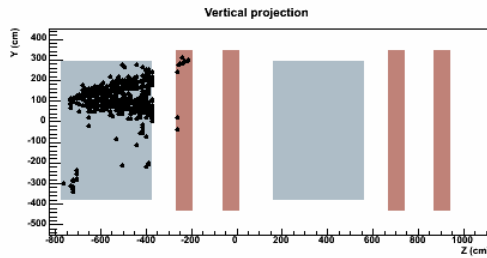
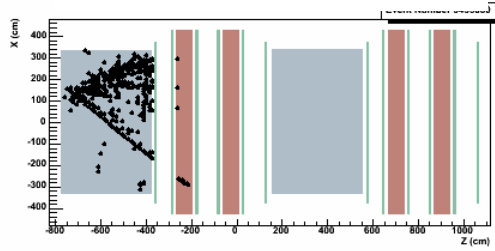
Rock muon



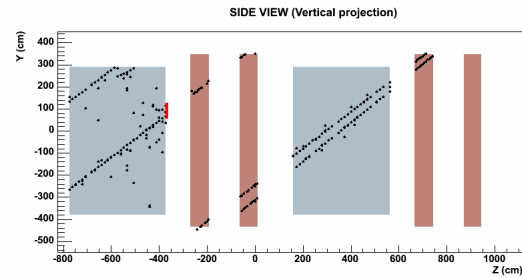
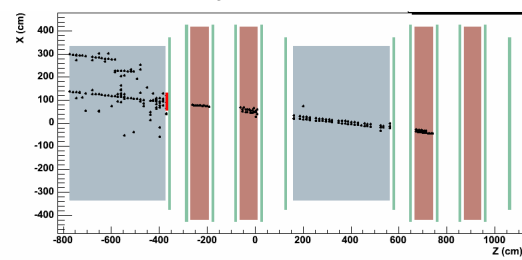
Neutrino int. at Magnet Iron



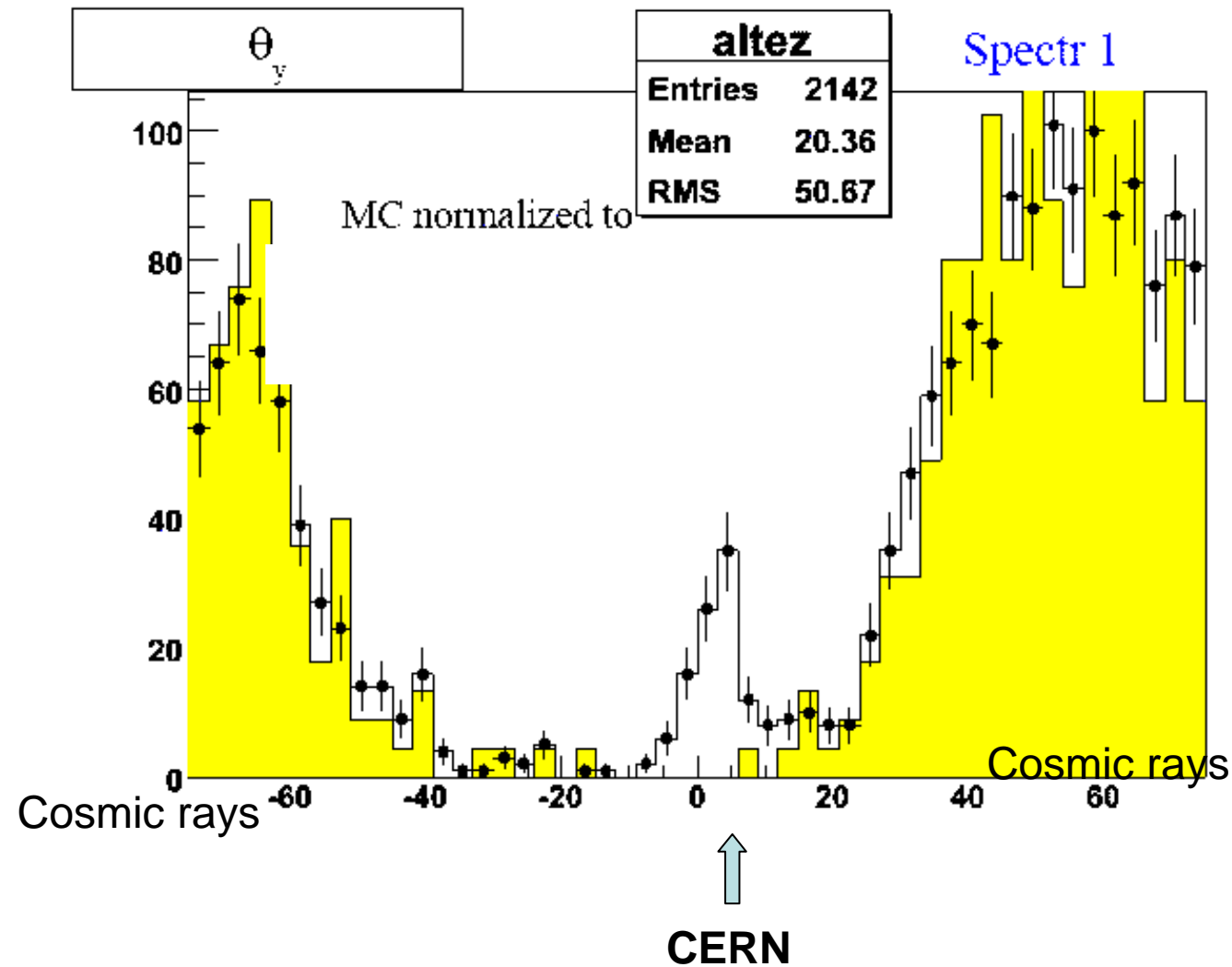
Neutrino int. in TT



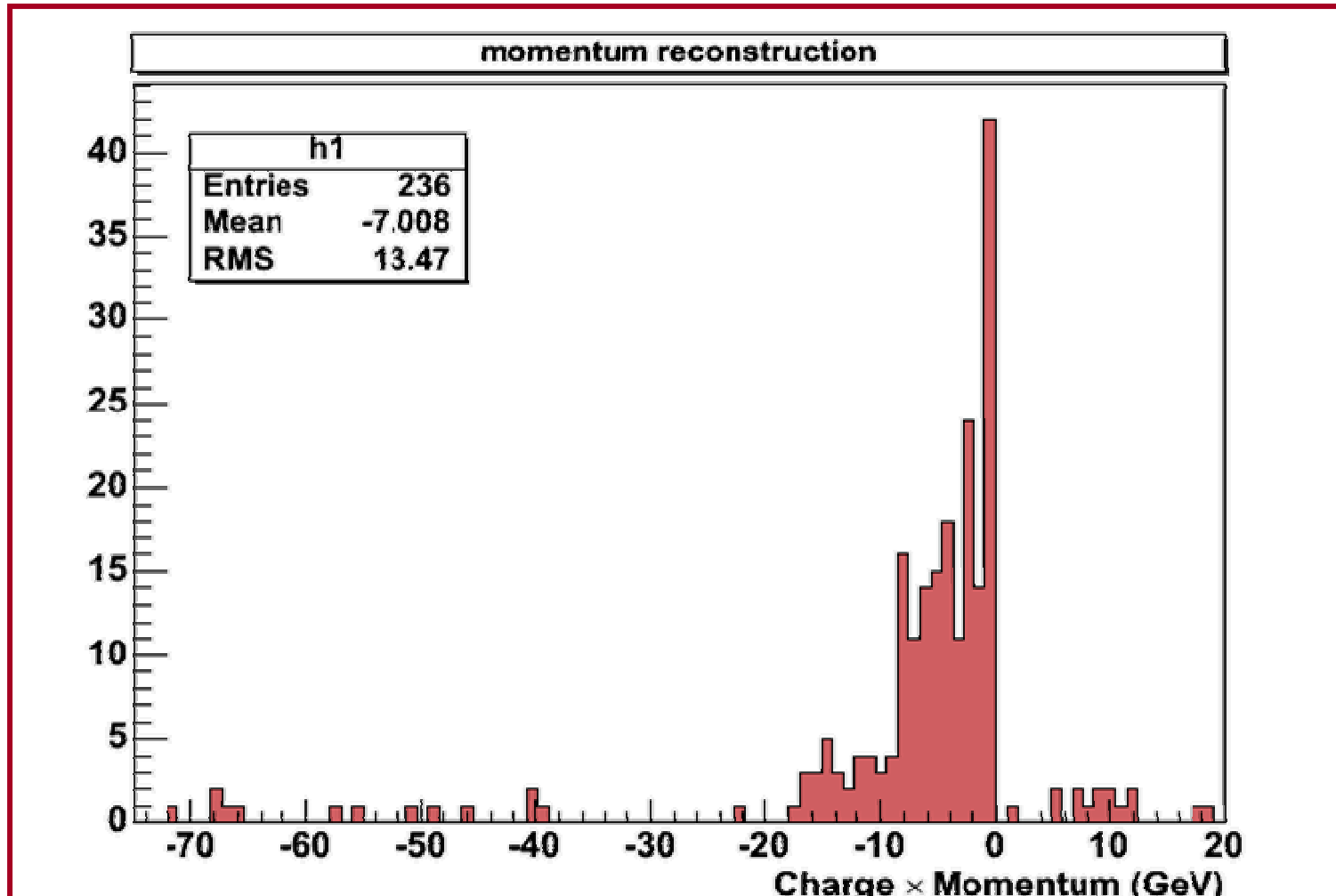
Cosmic ray event (off-timing)



CERN direction observed by muons

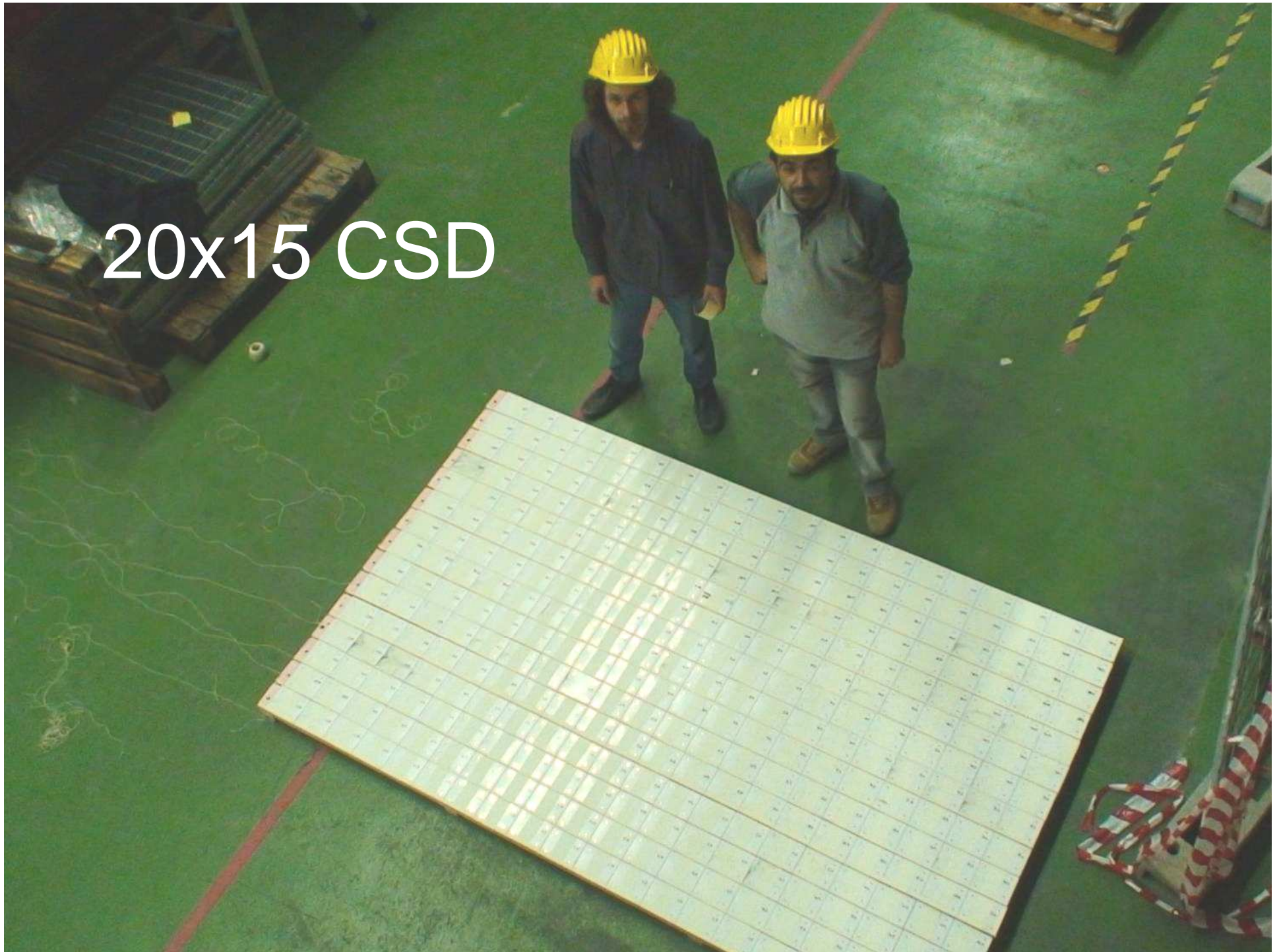


Momentum distribution for neutrino related mu by spectrometer.



Charge well reconstructed.

20x15 CSD



Installation

end 18:00 Aug17th

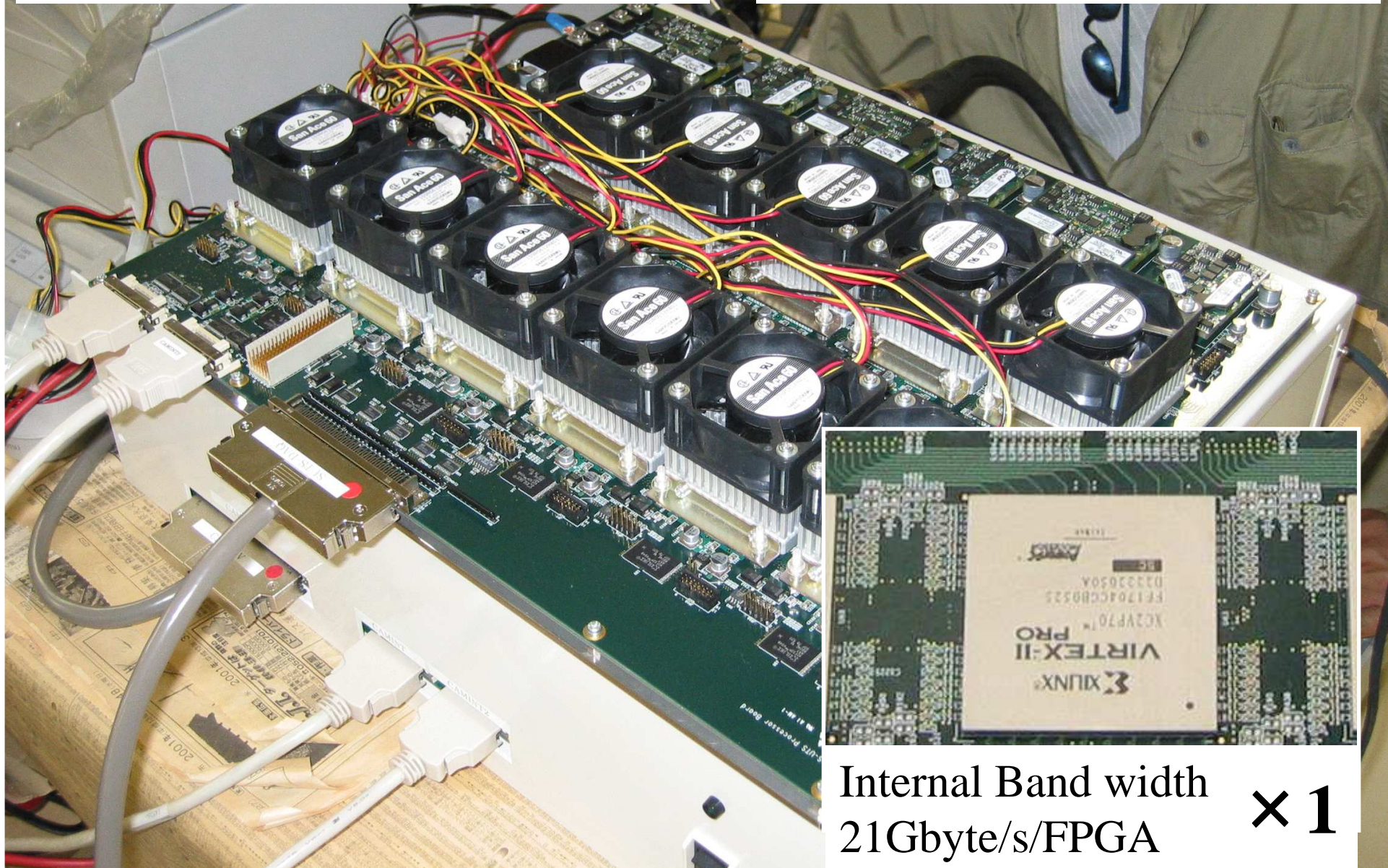


Scanning speed :
 $20\text{cm}^2/\text{h}$



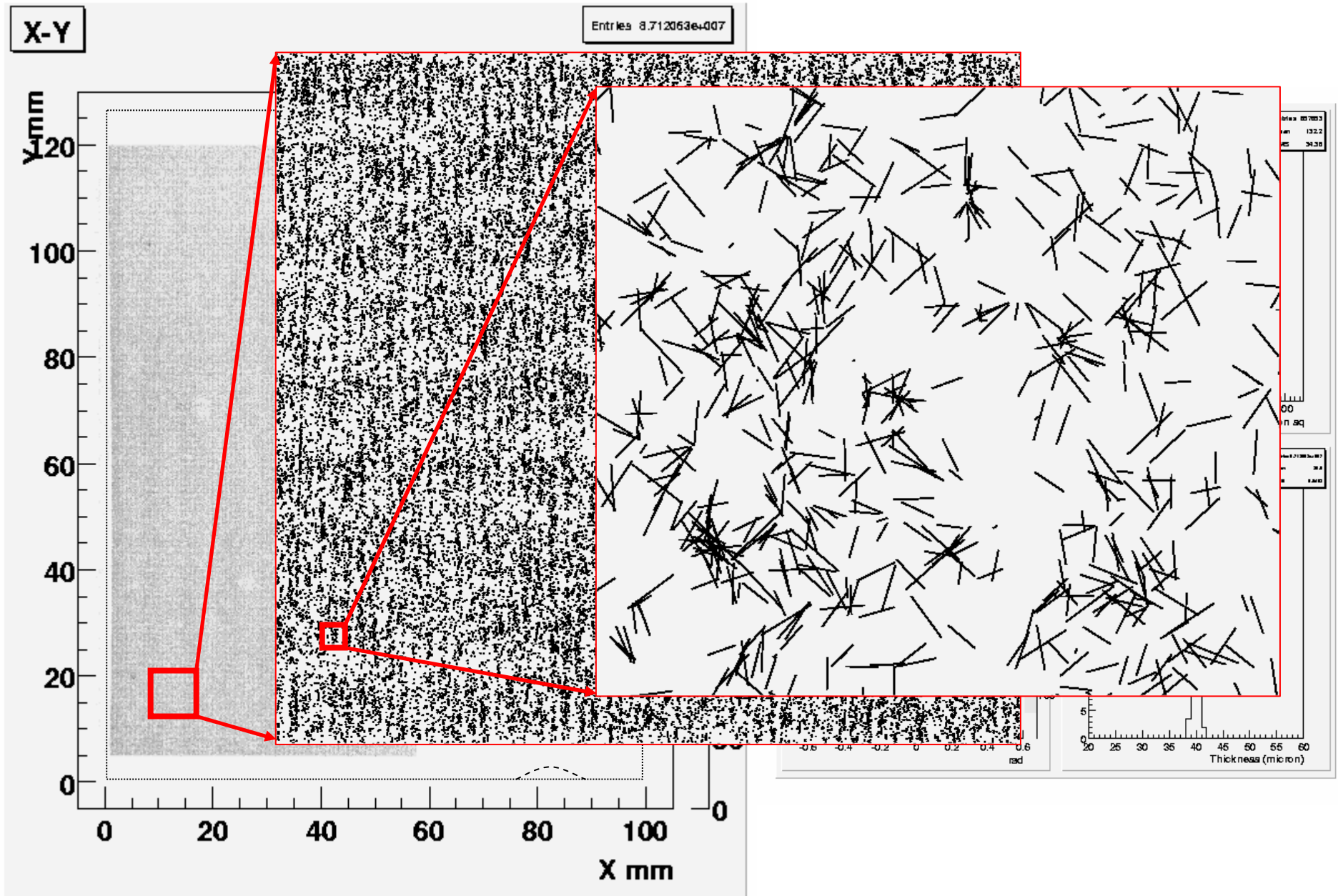
SUTS Track recognition board

Processing speed :
Up to 40cm²/h/board



Internal Band width
21Gbyte/s/FPGA × 1

174969 2-20-1-1 87,120,627 Micro Track



2006 August run

- POT 7.6×10^{17} , Target :: 300 CS no Bricks
- About 300 on time events recorded by electric detector.
- 12 rock muon events are predicted into CS area.
- 1st Events have been located in EMULSION @Sep 2006

Several events have been found both Nagoya and LNGS.

Nagoya 9 ev trial 7 found . LNGS 11 ev trial 9 found .

- 8 cosmic ray events are predicted into CS area.

Nagoya 6 ev trial 6 found . LNGS 6 ev trial 4 found.

TT prediction accuracy is about a few mm .

➔ No difficulty to locate on CC-like events in emulsion.

Back ground track density in CS is confirmed well less than 1.

➔ Location for NC-like events also expected no difficulty.

2006 October run

- POT 0.6×10^{17} , Target :: 1000 Bricks with CS.
- Two weeks of beam exposure planned,
But stopped due to water leak at CNGS reflector.
Running time was about 24 hours and 30 events stored.

One Rock muon predicted event by TT to Brick .

Full chain of procedure have been examined.

- TT prediction (Brick tagging)
- Extraction of corresponding Brick
- Develop CS & Brick
- CS Scanning
- Track scanning into Brick

Brick & CS



CS are stuck on
Real Brick

And install into wall

Event number: 1064775

CSD ID: 3000370

Brick location: W29/RW9/COL12, rock side

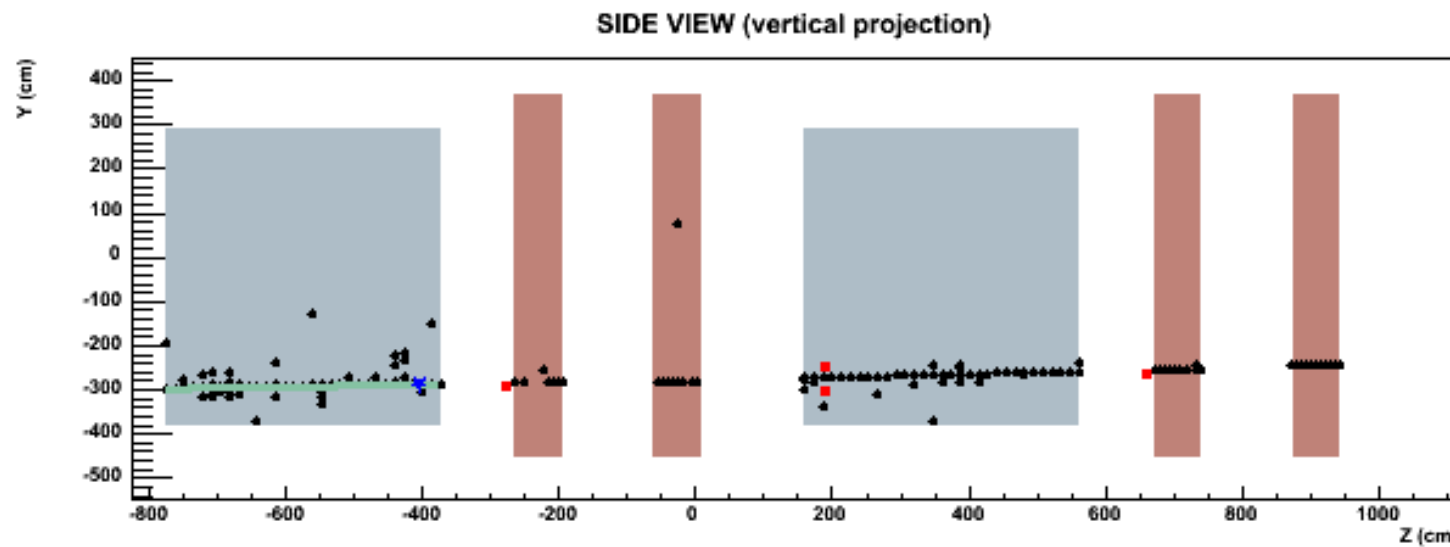
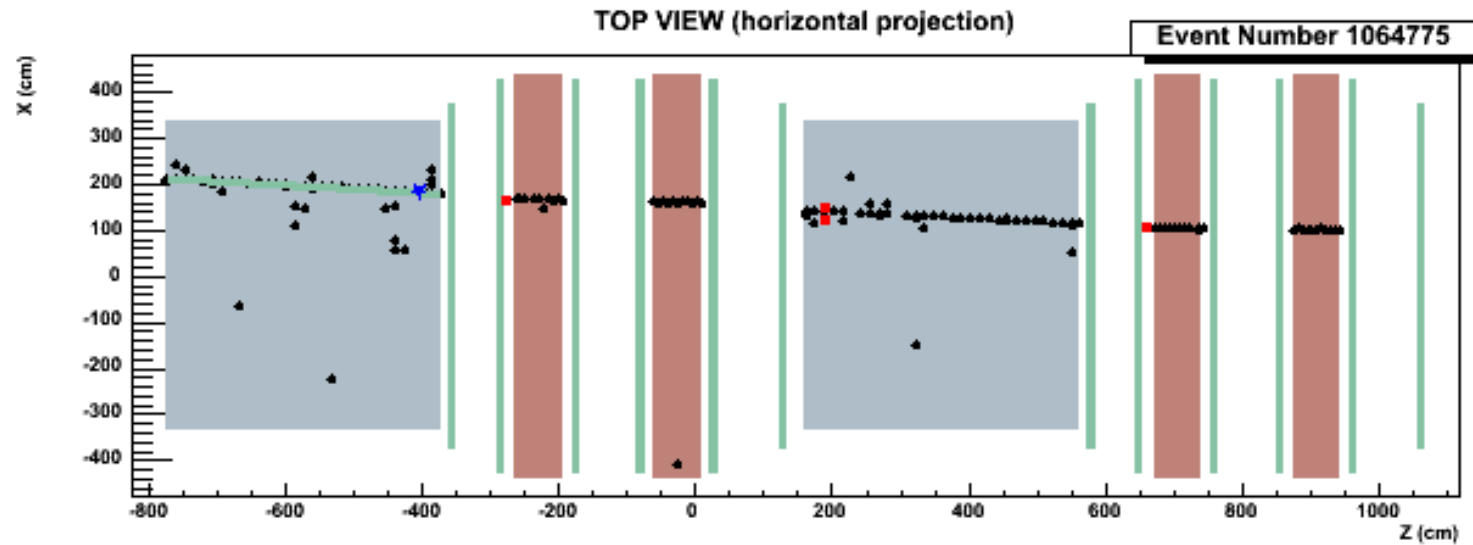
$SX = -0.0839 \pm 0.0013$

$SY = 0.0259 \pm 0.0012$

$PX = 181.54 \pm 0.27 \text{ cm}$

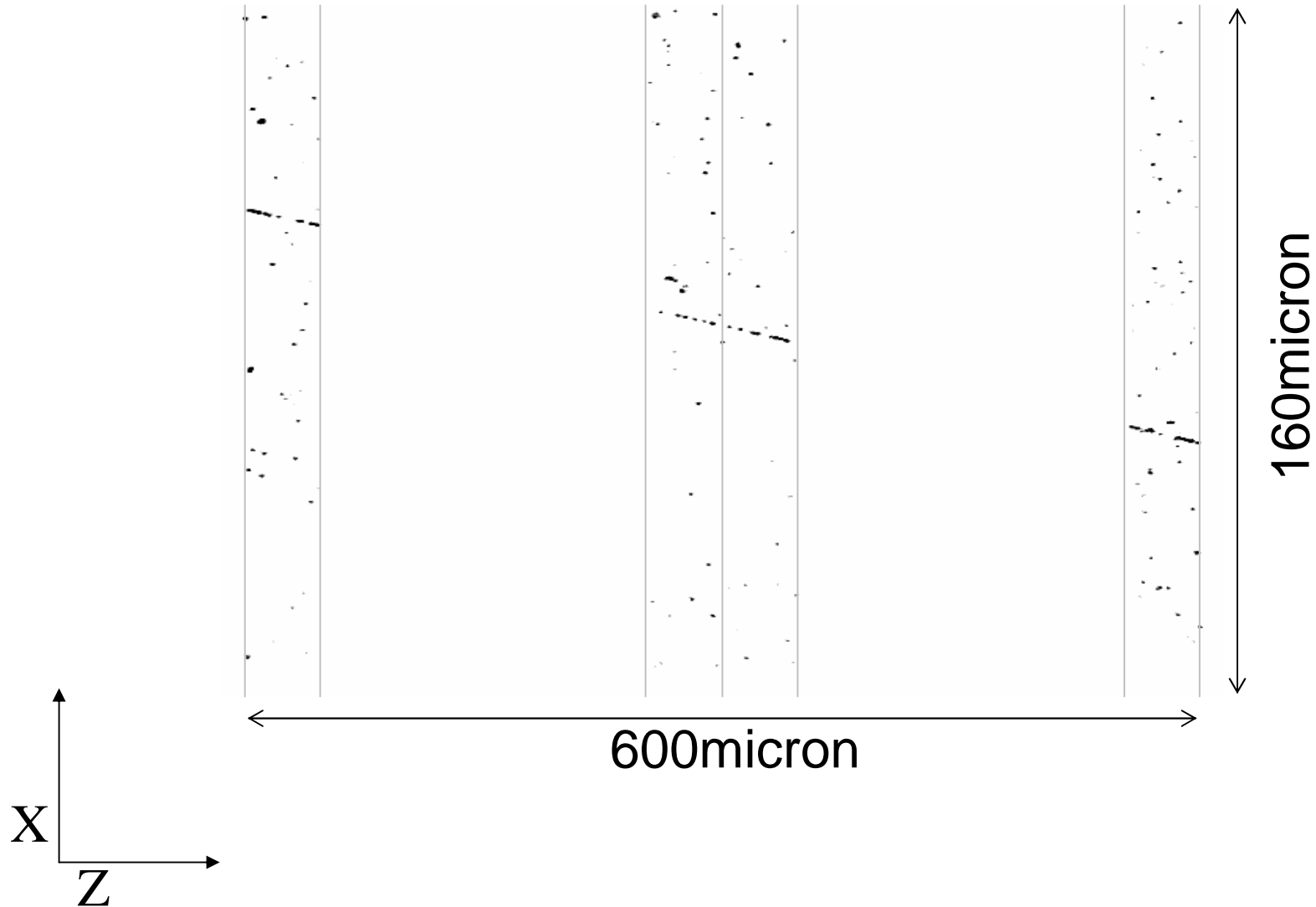
$PY = -288.03 \pm 0.25 \text{ cm}$

$PZ = -401.82 \text{ cm}$

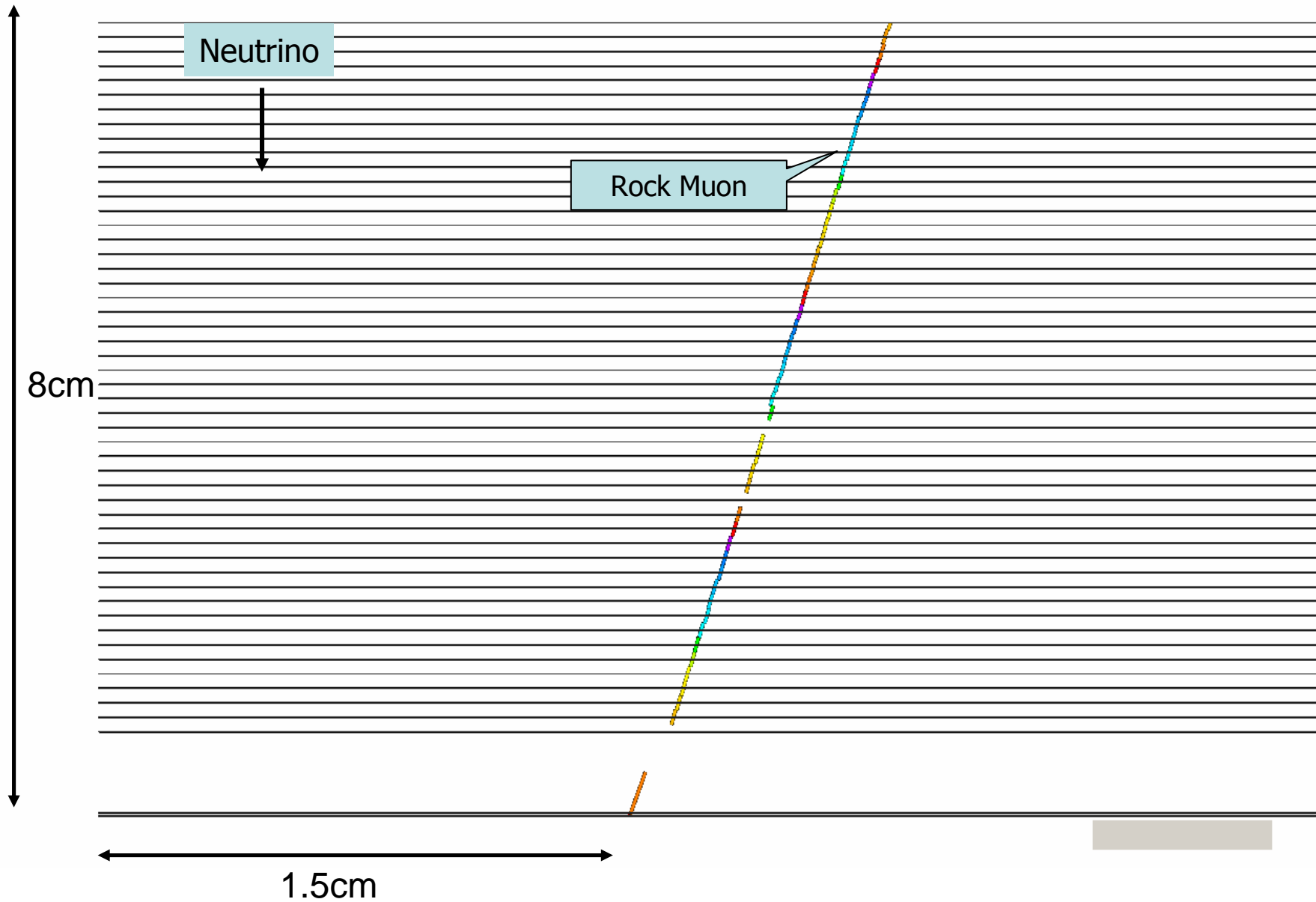


with Dario and Antoine

Found track in CSD



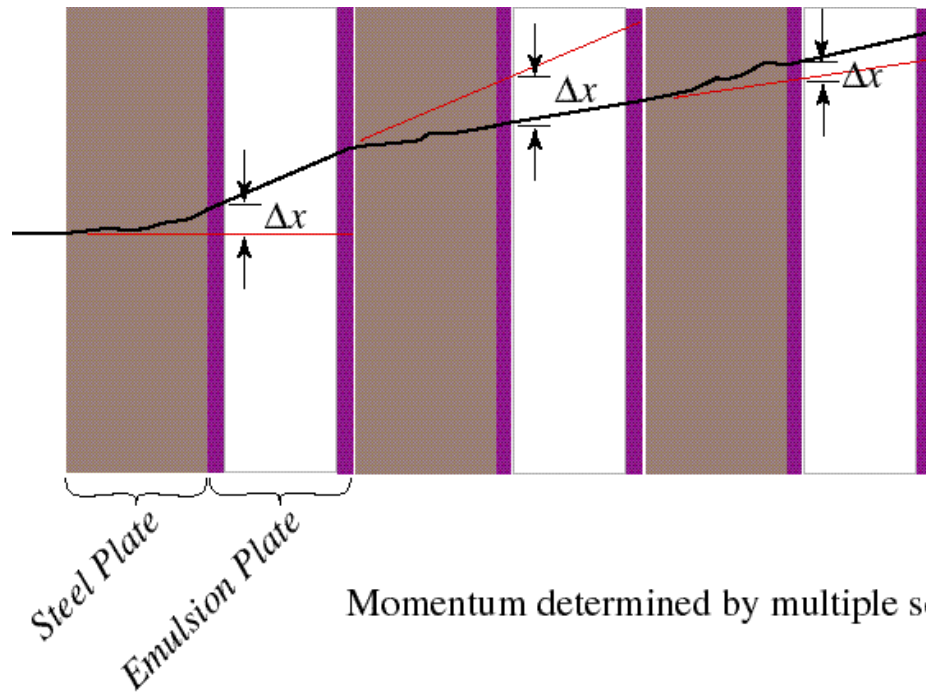
Connection from CSD to Brcik



Momentum measurement

M.Komatsu(Nagoya Univ.)
Developed in DONUT Analysis.

$P\beta$ measurement using Multiple Scattering in ECC Bricks



57 plates are scanned.
 $P = 6.4 +1.2 -0.9 \text{ GeV/c}$

Muon Spectrometer Value
 $P = 7.05 \pm 0.4 \text{ GeV/c}$
Sign :: negative.

Momentum determined by multiple scattering:

$$\frac{\Delta\vartheta^{rms}}{\vartheta^{rms}} \propto \frac{1}{\sqrt{n}} \quad n : \text{number of measurements}$$

For example: 10 GeV/c has *rms* deflection of 0.3 μm

2007 May cosmic ray test

- Target :: 15000 Bricks with CS.
- Couple of weeks of cosmic ray data taking and full chain of procedure test .

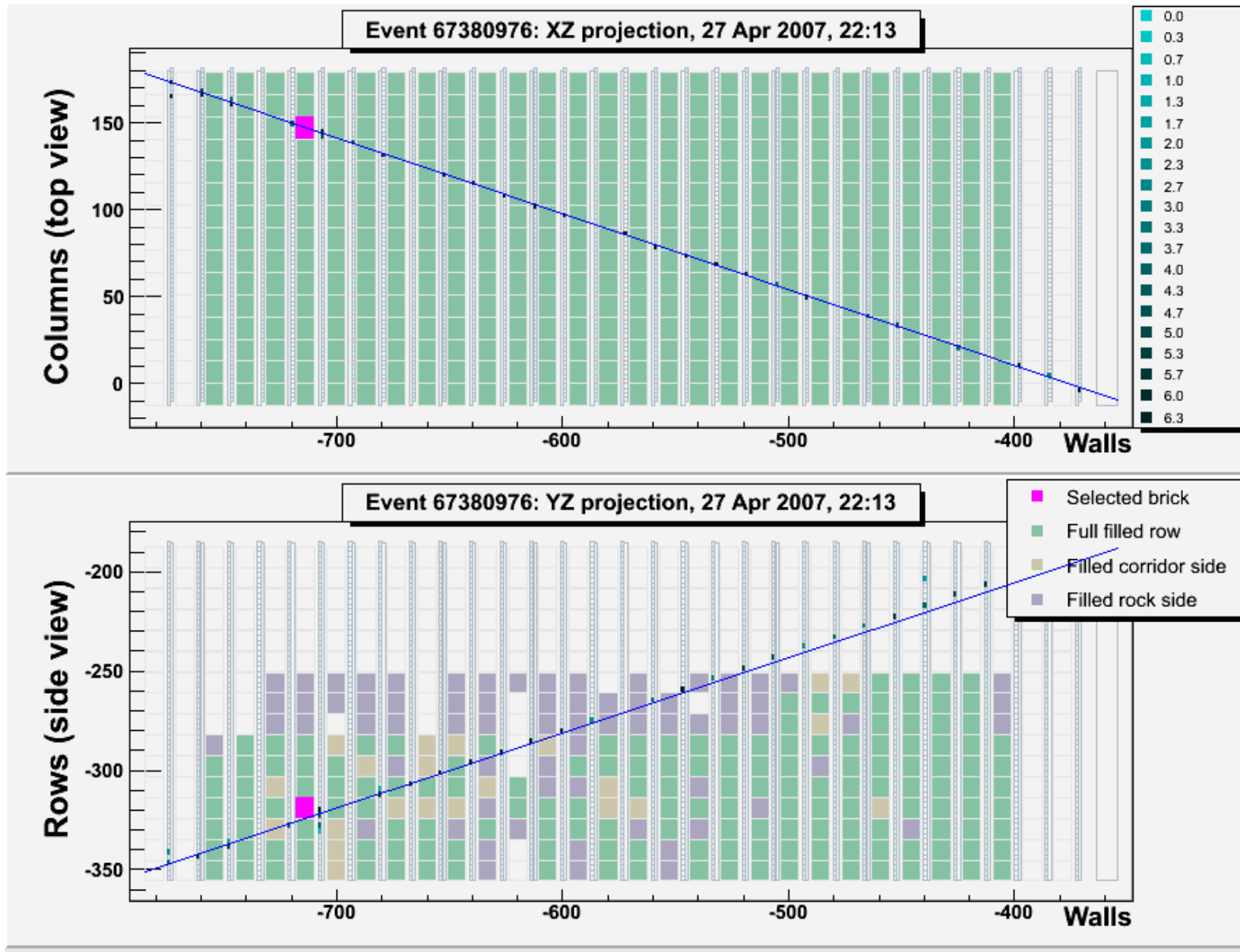
17 cosmic ray events have been selected for location.
Analysis going on now.

Just scanning stage of CS: 7 found/8 trial ev Nagoya.
CS quality is same as August/October run.

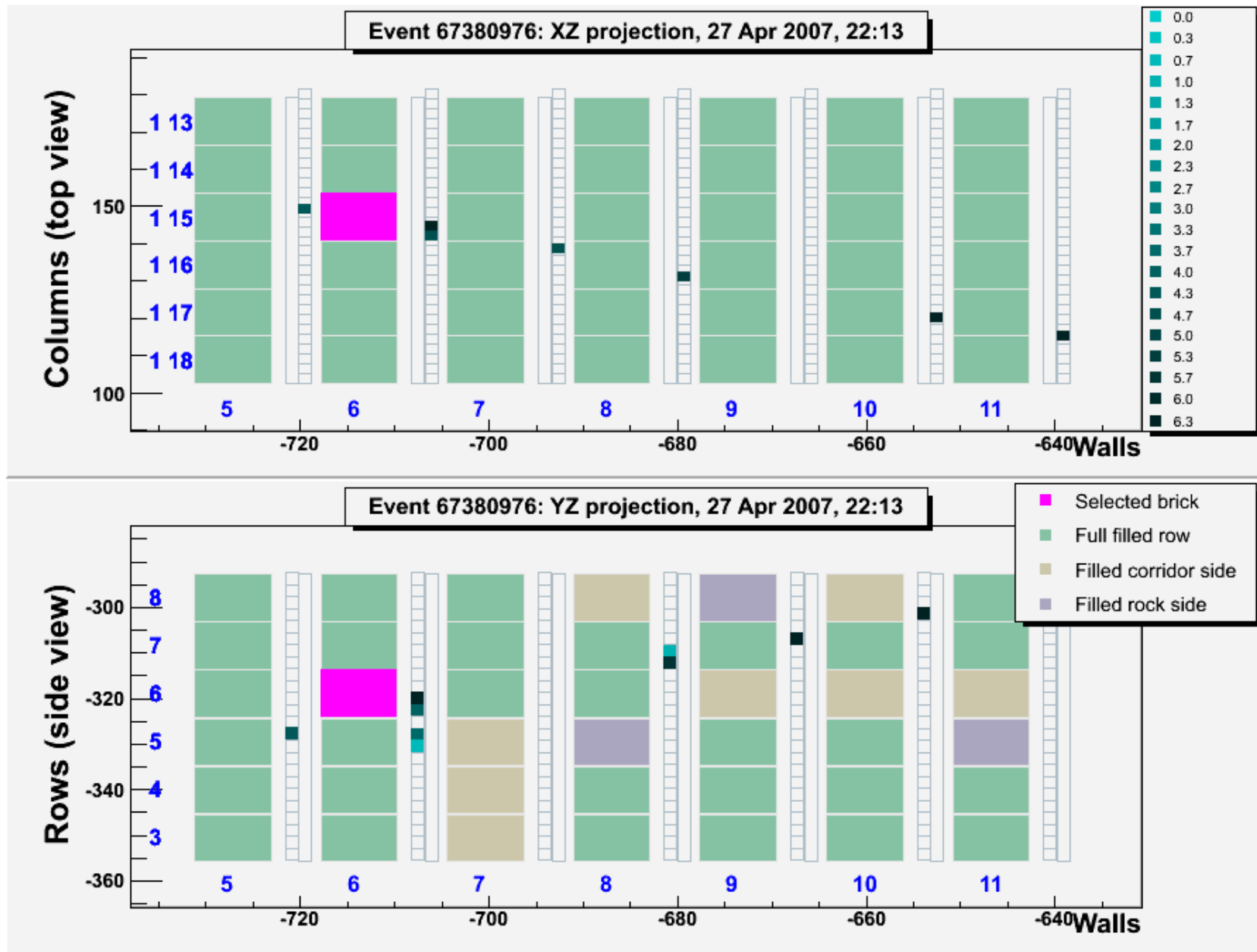
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- Track scanning into Brick

2007 May cosmic ray test



2007 May cosmic ray test



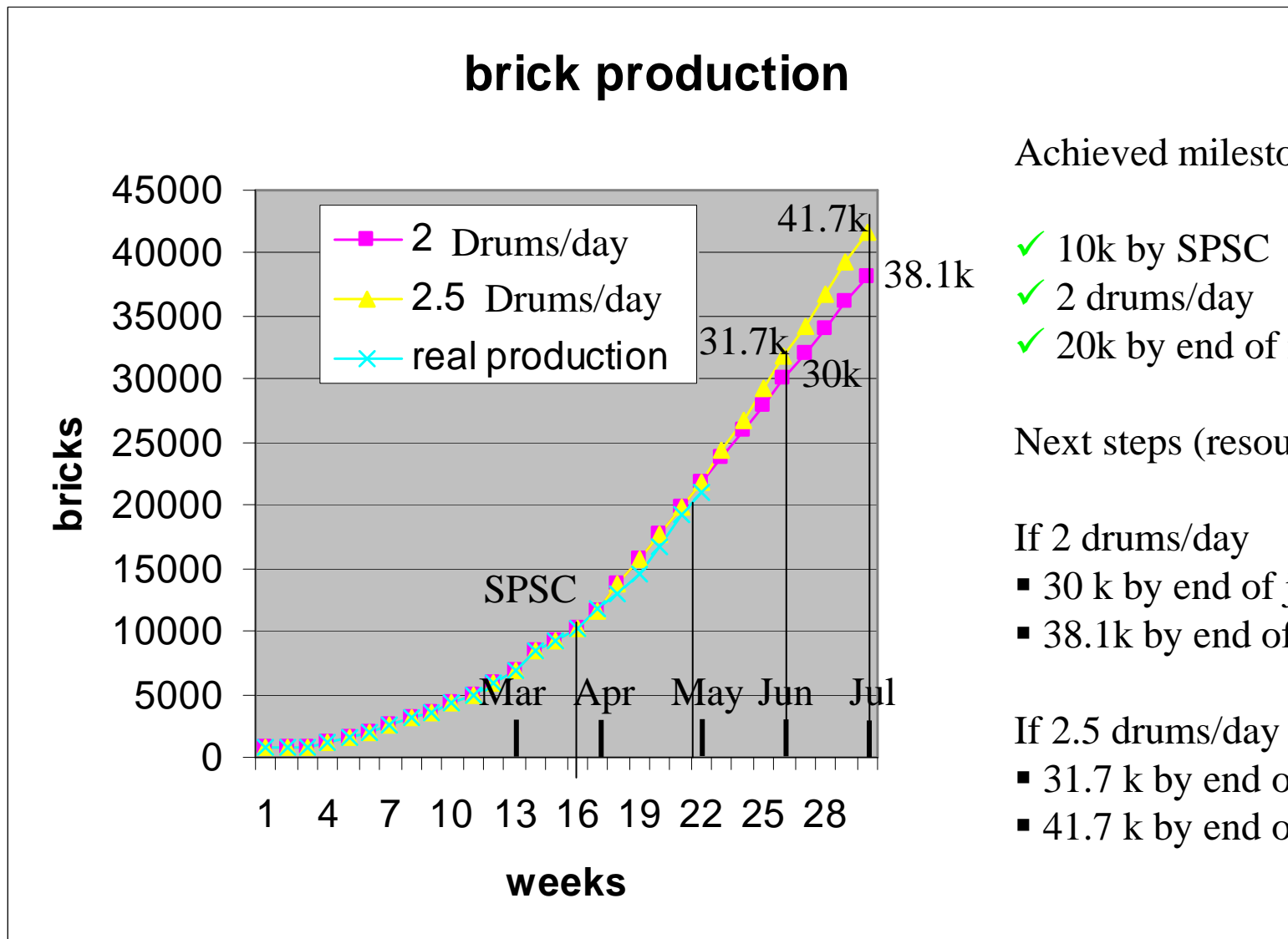
Schedule 2007

- neutrino beam exposure in September 2 – 3weeks
Today target amount is 20000 brick ,
Storing target continuously and
at that time target amount will be 50000 –60000 brick.

Several 100 neutrino interaction will be stored
in our targets brick.

➔ Real neutrino location will be start this autumn.

OPERA brick production



Achieved milestones:

- ✓ 10k by SPSC
- ✓ 2 drums/day
- ✓ 20k by end of may

Next steps (resource dependent !):

If 2 drums/day

- 30 k by end of june
- 38.1k by end of july

If 2.5 drums/day

- 31.7 k by end of june
- 41.7 k by end of july

Summary

- Event location by CNGS neutrino induced muons in 2006 runs
 - [1] Data taking (TT) performance well
 - [2] OPERA found tracks in REAL CS in August run.
 - [3] A full chain of REAL procedure for location was done using a rock muon event in October run.
- Brick installing started from End of Sep/2006.
About 20000 Bricks stored now.
- 2007 May cosmic ray test under filling 15000 brick condition.
REAL Chain ::
Prediction/ Brick extraction / development/ Scanning
Working well under large level of 15000 brick stored condition.
- 2007 Sep CNGS neutrino beam will expose to target 50000-60000 brick.
- Full (170,000 Bricks) installation planned till 2008 Mar.



Expected Event Yield

Target Mass :1700 ton

Full mixing, 5 years run @ 4.5×10^{19} pot / year

$\nu_\mu \nu_e$ Interaction

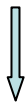
Clear ν_τ CC events

ν_μ CC	23500					
ν_μ NC	7075	Δm^2	1.9×10^{-3} eV ²	2.4×10^{-3} eV ²	3.0×10^{-3} eV ²	B.G.
$\bar{\nu}_\mu$ CC	494					
ν_e CC	188	Final Design	8.0	12.8	19.9	0.8
$\bar{\nu}_e$ CC	17					

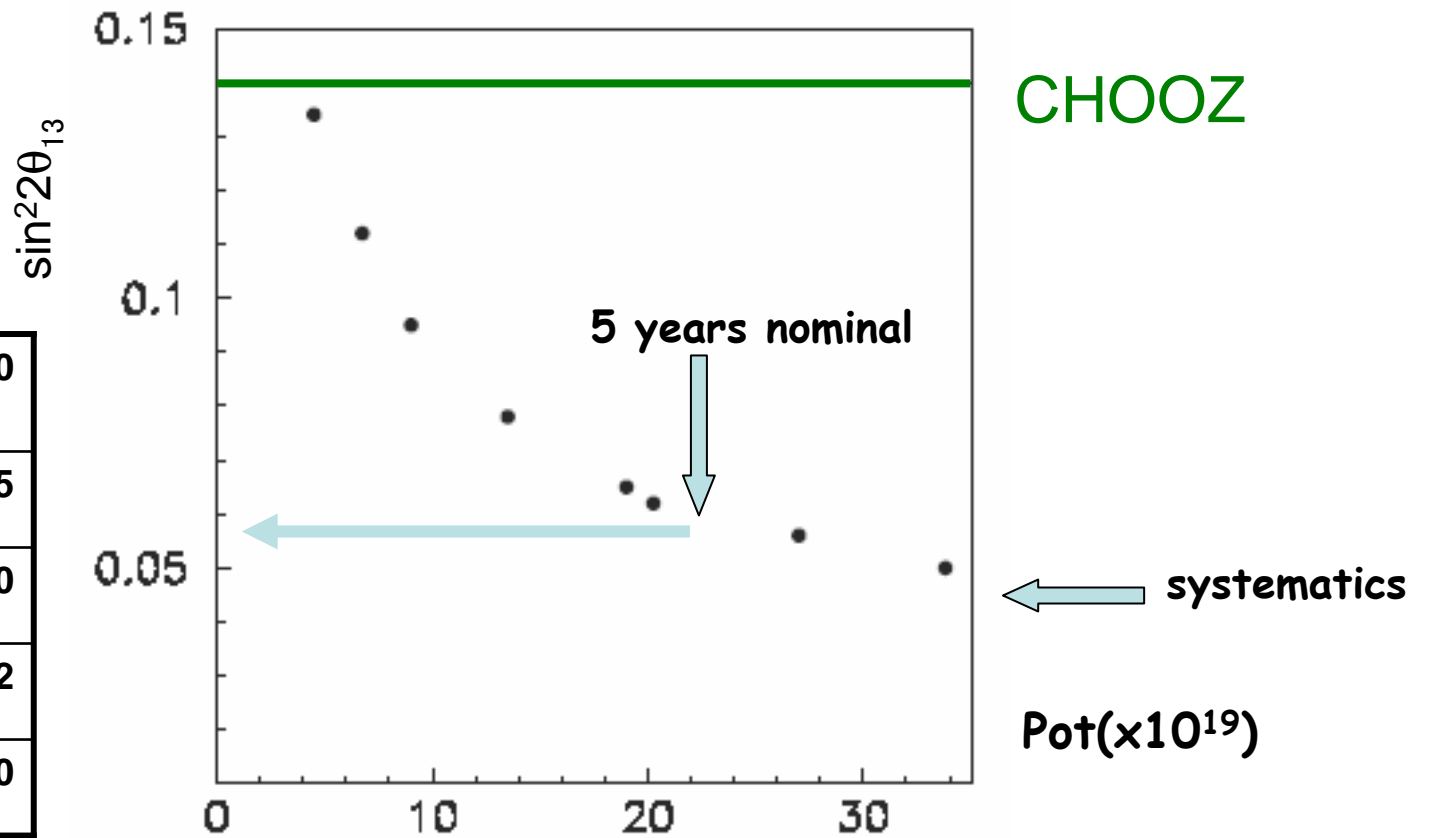
$\sin^2 2\theta_{13}$ sensitivity

Assuming : $\theta_{23}=\pi/4$, $\Delta m^2_{23} = 2.5 \times 10^{-3} \text{ eV}^2$

Nb of events
(5 years running)



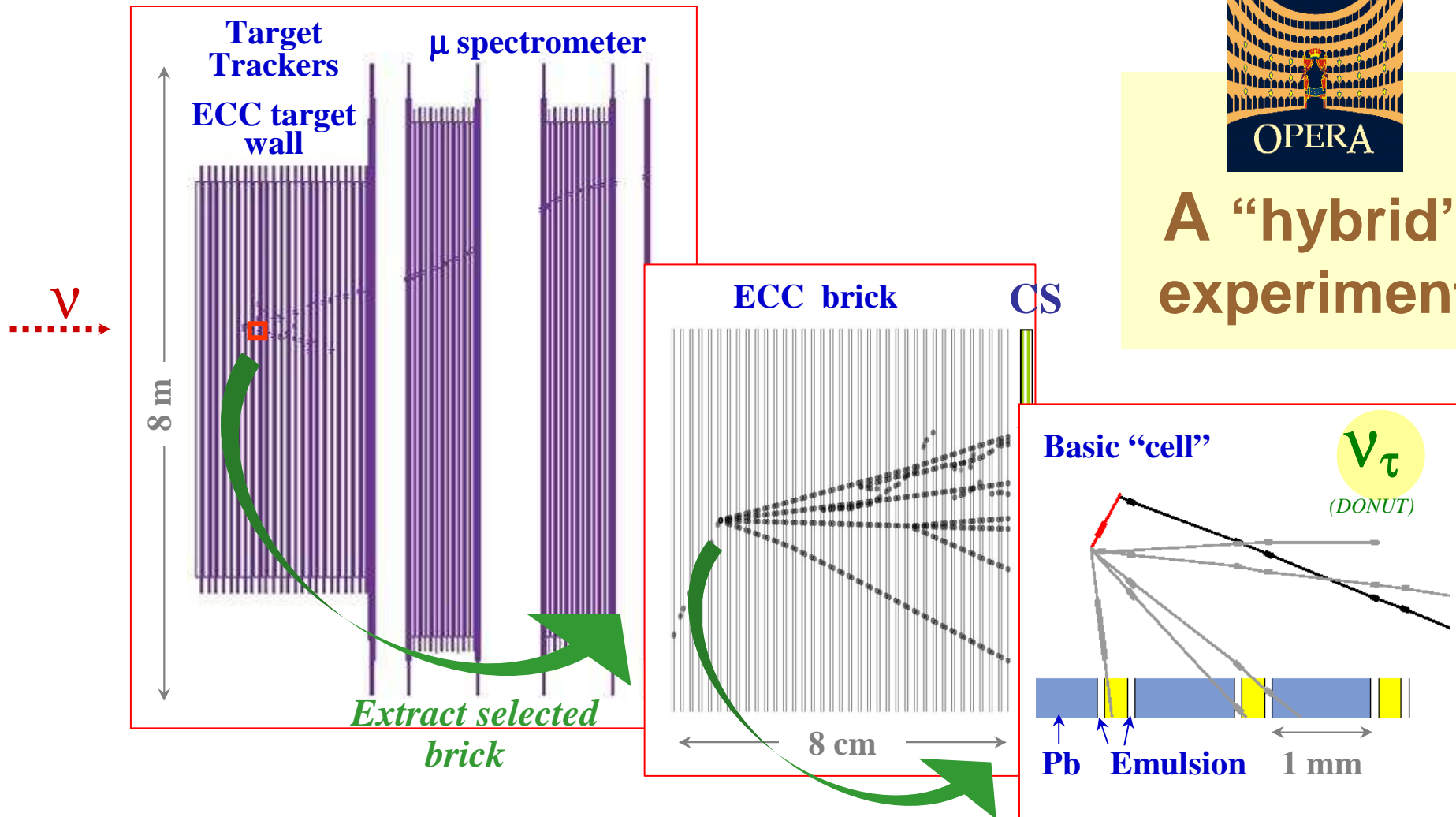
Signal @ CHOOZ limit	13.0
$\tau \rightarrow e$	4.5
ν_{μ} CC	1.0
ν_{μ} NC	5.2
ν_e CC beam	18.0



The end



A "hybrid" experiment



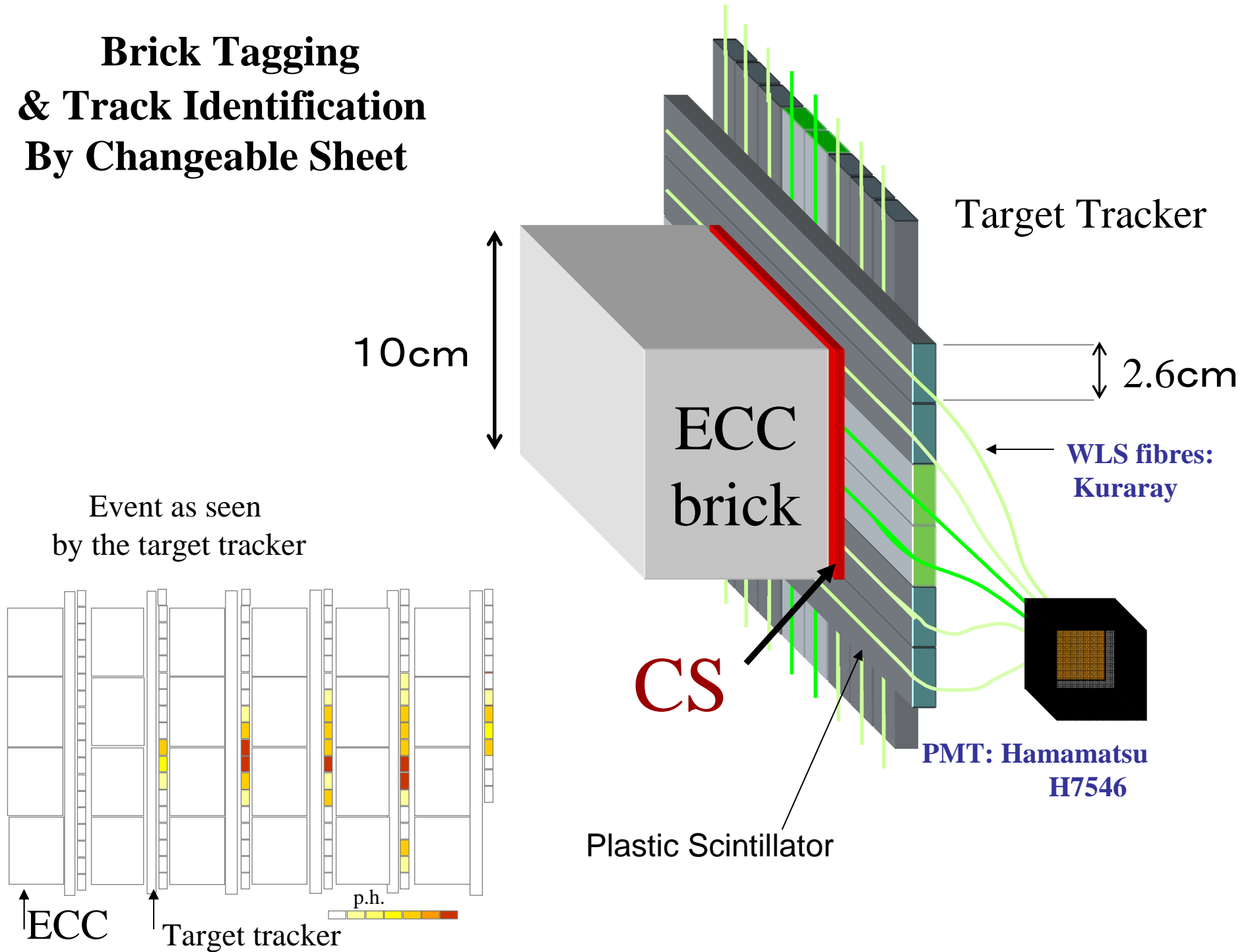
Electronic detectors

- select ν interaction brick
- μ ID, charge and p

Emulsion scanning

- vertex search
- decay search
- e/γ ID, kinematics

Brick Tagging & Track Identification By Changeable Sheet





Muon identification and the measurement of its charge and momentum

- Reject charm background
- Tag and analyze $\tau \rightarrow \mu$ candidates

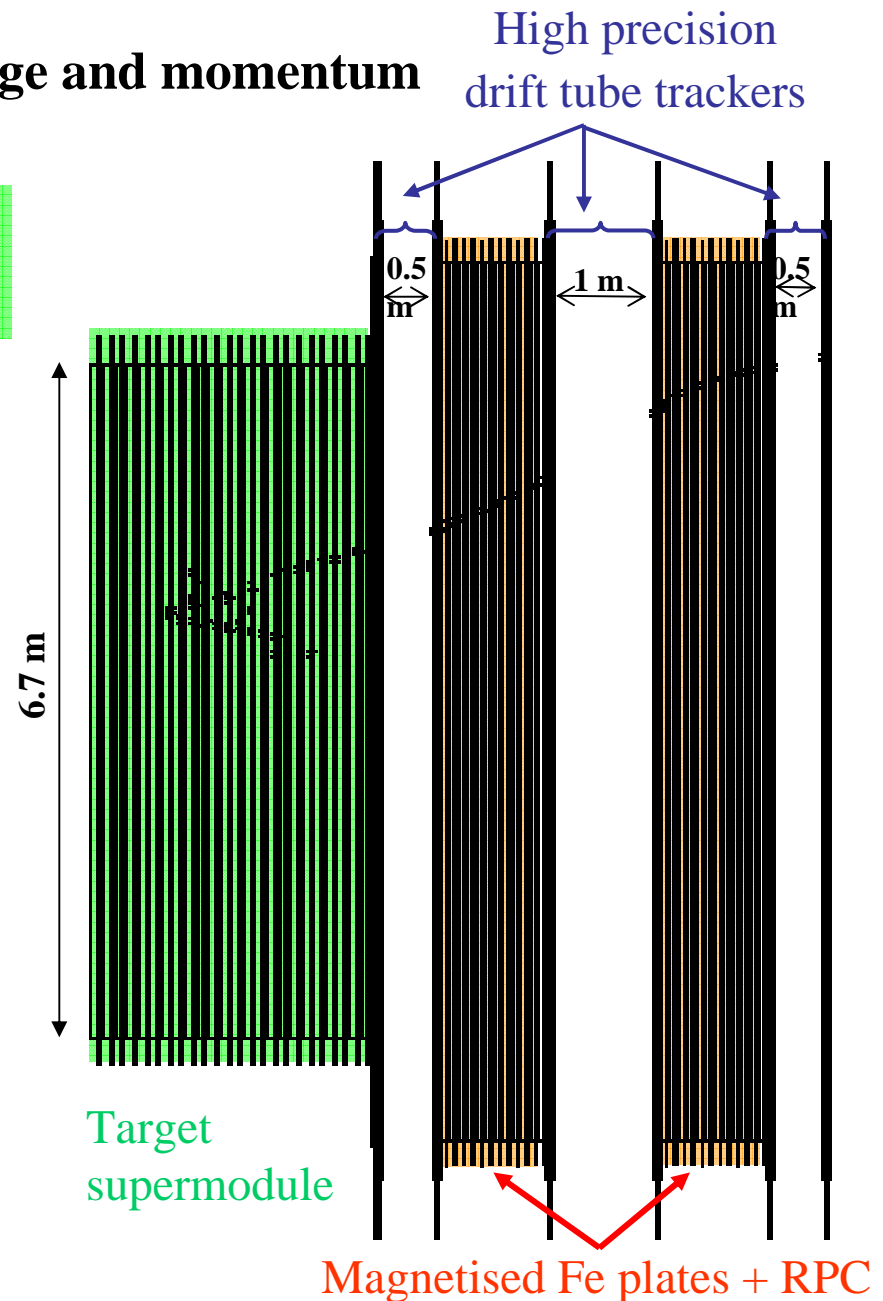
with target + spectro as calorimeter:
measure E_ν spectrum

- Fe Walls: $7.1\lambda_{\text{int}}$ instrumented with RPC
identify muons
shower energy measurement

- Spectrometer: 3 external high resolution
drift tubes

$$\frac{\sigma_p}{p} < 25\% \quad \text{for } p < 25\text{GeV}/c$$

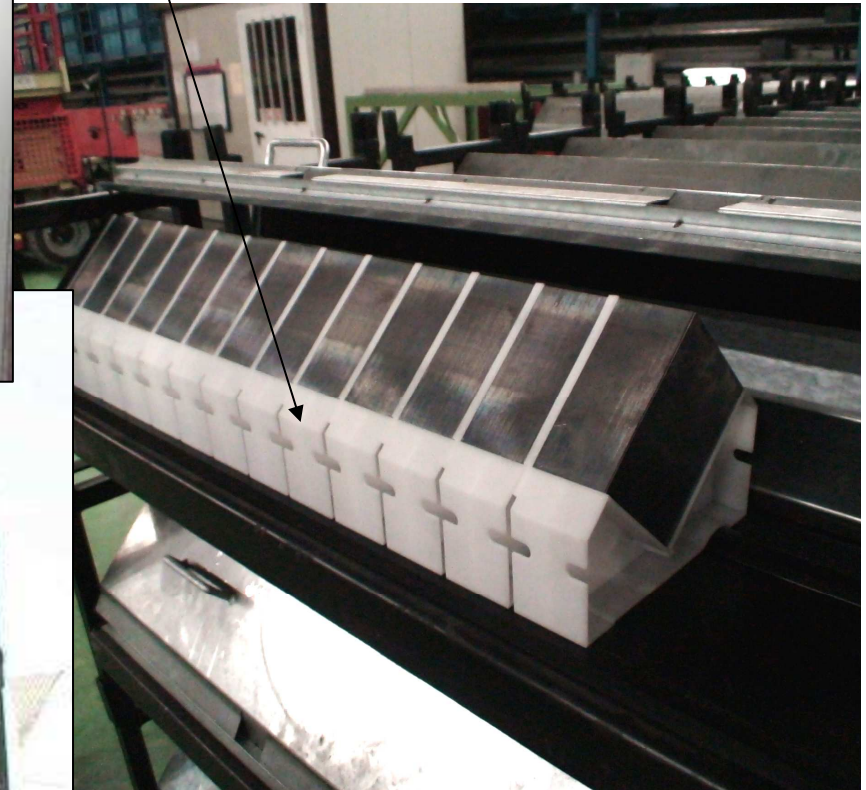
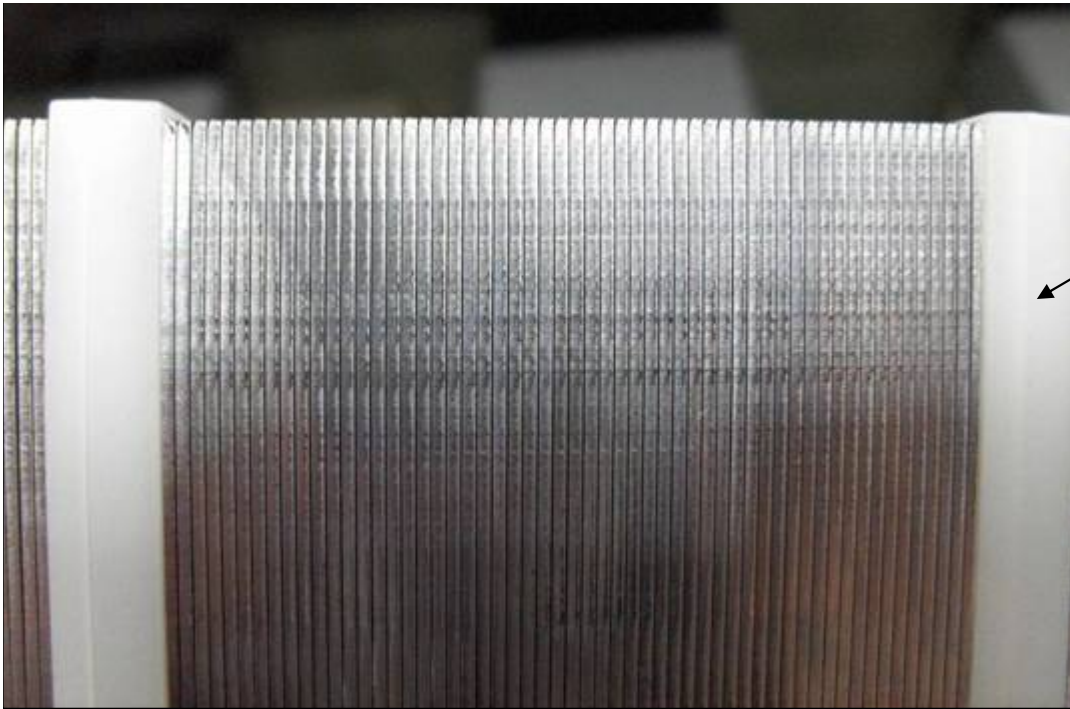
Wrong charge < 0.5 %



Lead production

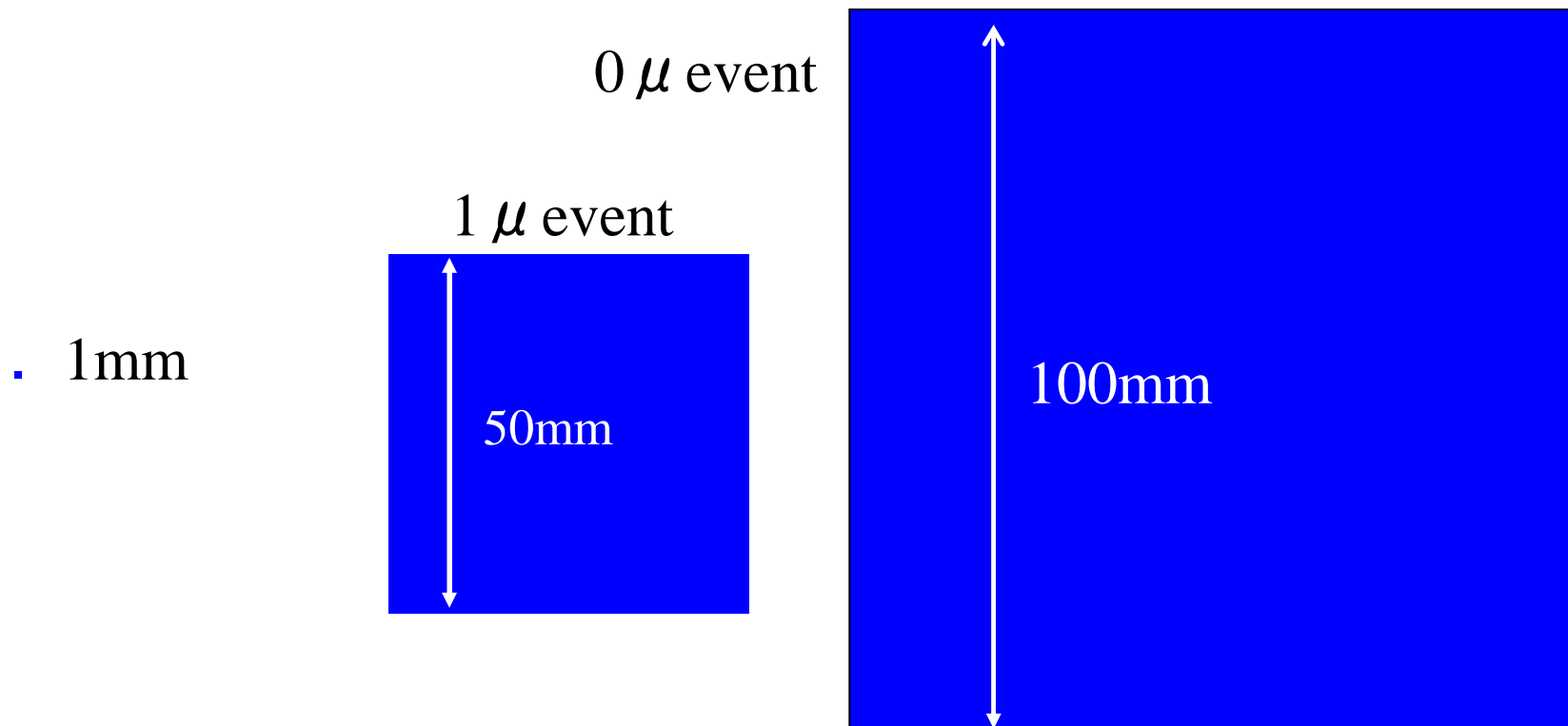
PbCa type

56 lead plates on 1 palette.



Required Scanning Power for CS

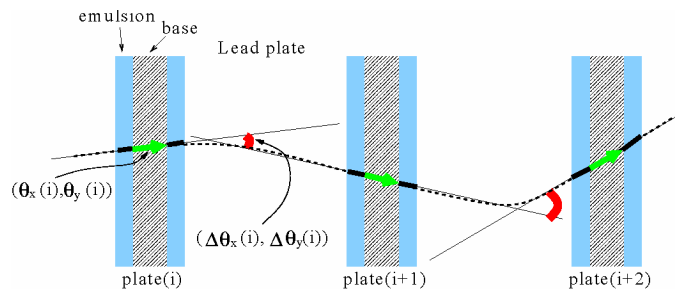
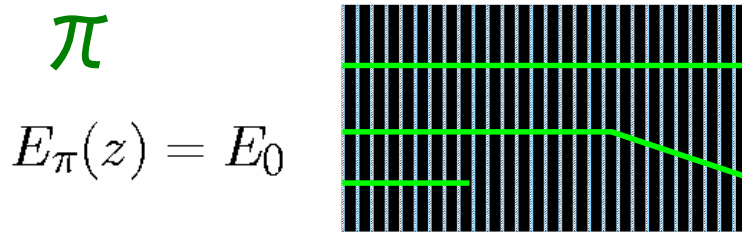
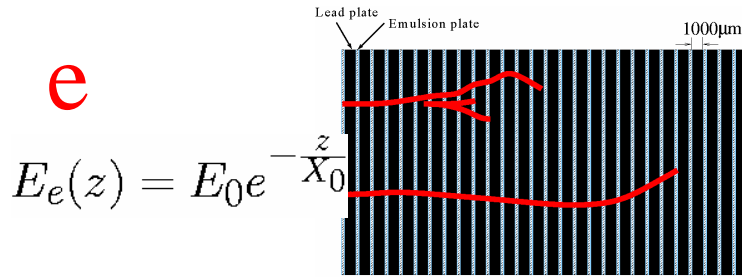
	Area to be scanned	Events /day	Scanning area cm ² /day	
CHORUS	1mmx1mm	1000	10	
OPERA 1 μ	5cmx5cm	23	575	計 1275
OPERA 0 μ	10cmx10cm	7	700	



Electron identification

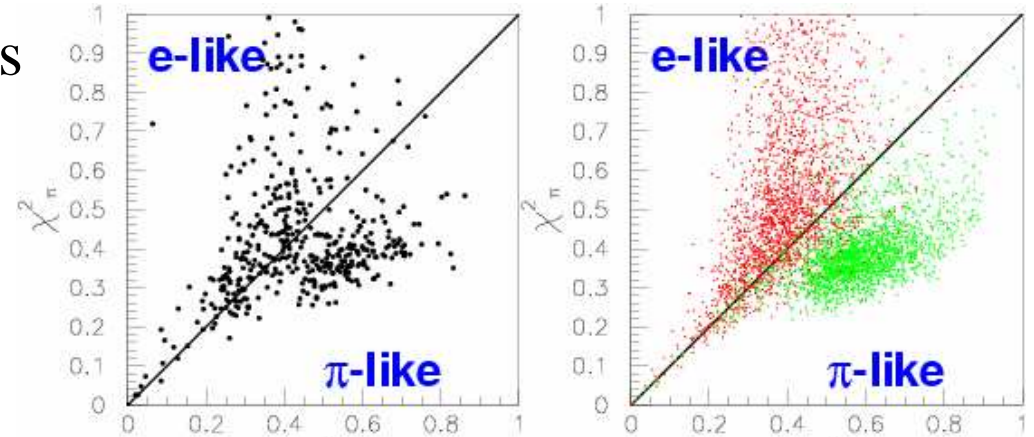
Shower detection & χ^2 analysis

2GeV

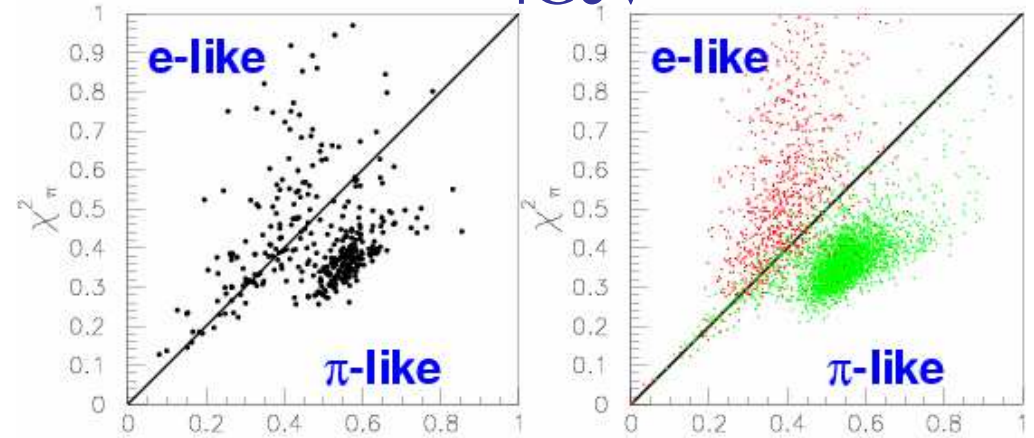


$$\Delta\theta_{e,\pi}(i) \equiv \sqrt{\left(\frac{13.6(MeV/c)}{p_{e,\pi}(z)} \sqrt{d/X_0}\right)^2 + (\sqrt{2}\delta\theta)^2}$$

$$\chi_{e,\pi}^2 \equiv \sum_{i=1}^{N-1} \frac{\{(\Delta\theta_x(i) - \Delta\theta_{e,\pi}(i))/\Delta\theta_{e,\pi}(i)\}^2 + \{(\Delta\theta_y(i) - \Delta\theta_{e,\pi}(i))/\Delta\theta_{e,\pi}(i)\}^2}{2(N-1)}$$



Data χ_e^2 4GeV MC χ_e^2



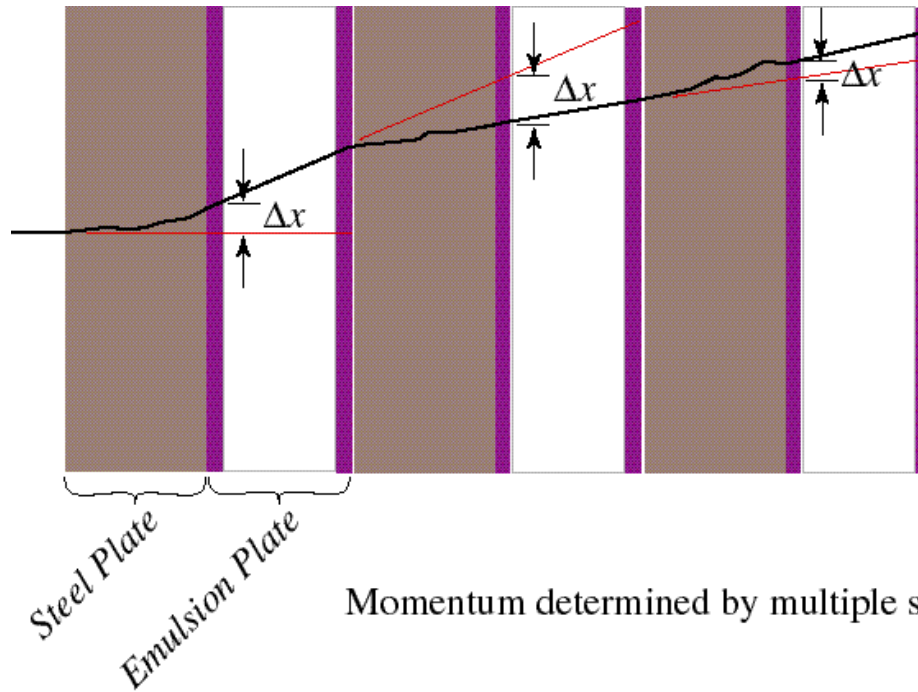
Data χ_e^2 MC χ_e^2

eff~90%,
 mis-id prob~5%

Momentum measurement

M.Komatsu(Nagoya Univ.)
Developed in DONUT Analysis.

$P\beta$ measurement using Multiple Scattering in ECC Bricks



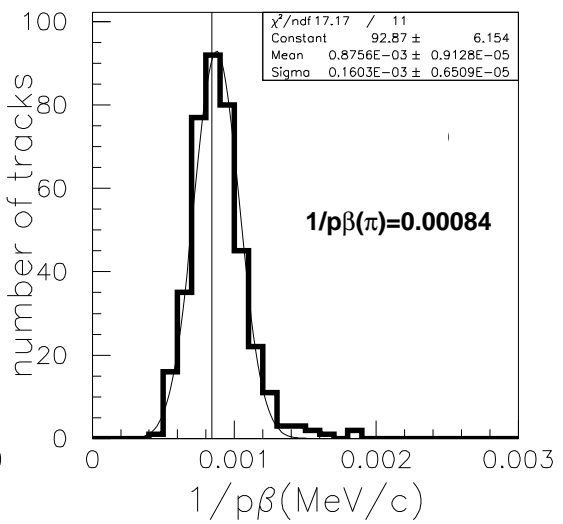
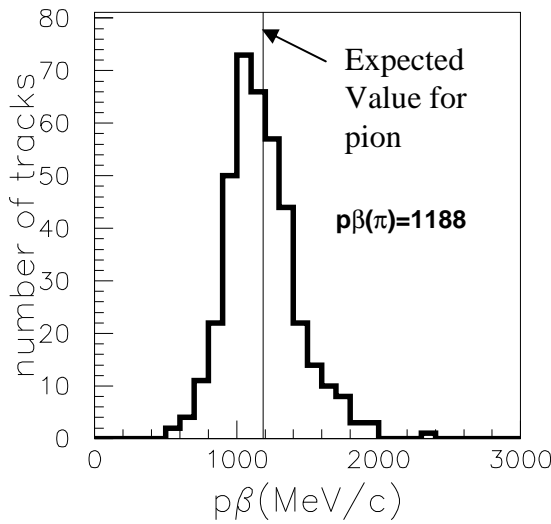
$$\frac{\Delta\vartheta^{rms}}{\vartheta^{rms}} \propto \frac{1}{\sqrt{n}} \quad n : \text{number of measurements}$$

For example: 10 GeV/c has *rms* deflection of 0.3 μ m

Momentum measurement

$p\beta$ measurement using Multiple Scattering

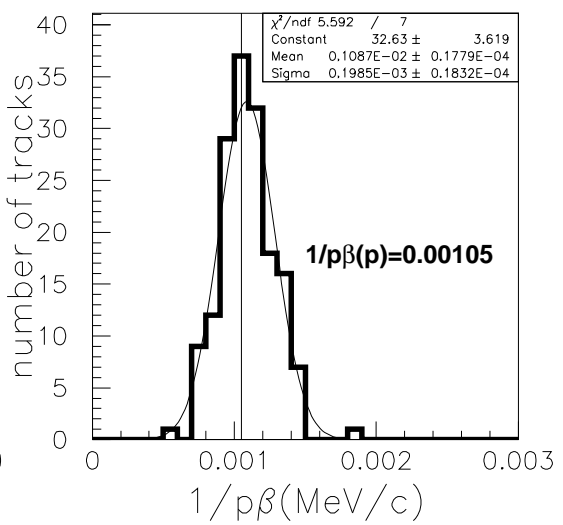
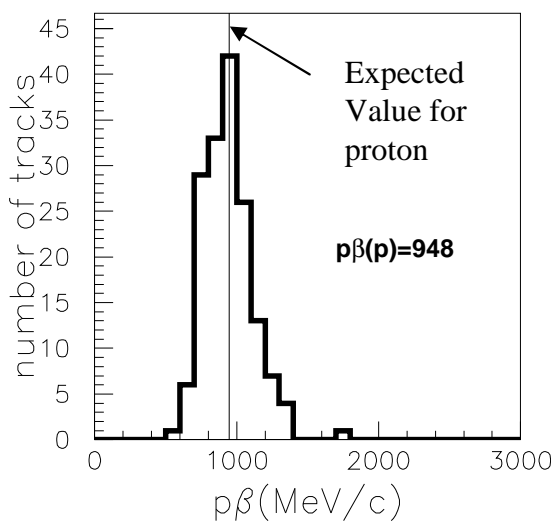
Low
 dE/dX



Consistent
with Pion

Resolution
 $\sigma_{p\beta} \sim 16\%$

Higher
 dE/dX



Consistent
with Proton

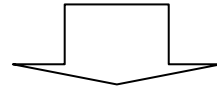
Emulsion Film

Taku Nakamura(Nagoya Univ.)
R&D @ Nagoya & Fujifilm

OPERA

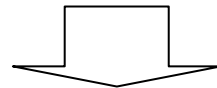
Film area required **150,000 m²**

Number of Films **1.2 × 10⁷**
(100mm × 125mm)



Mass production using commercial film
production line

R&D Fujifilm & Nagoya ('98—'02)



Mass production start April 2003

8,000 m²/month ~ 2 years

Emulsion Film Refreshing

Taku Nakamura(Nagoya Univ.)
R&D @ Nagoya & Fujifilm

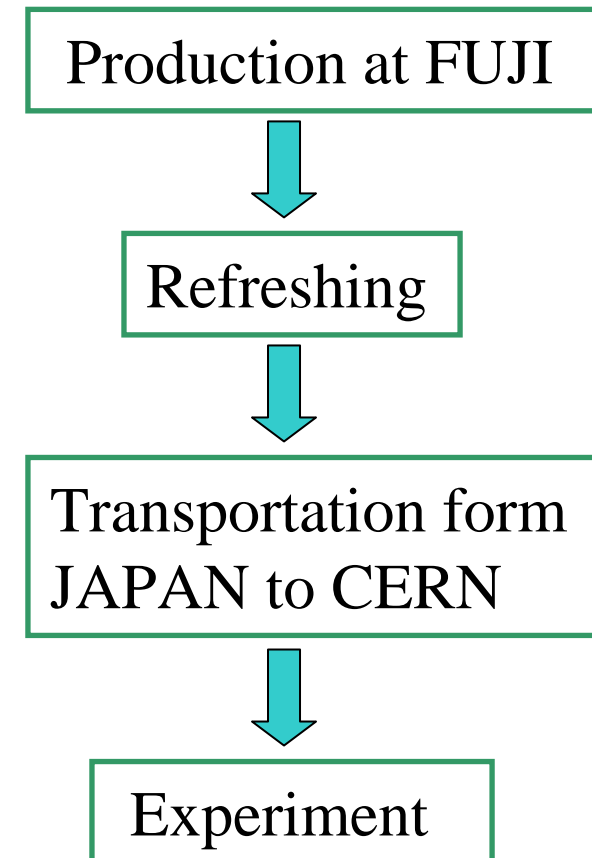
Erasing unwanted cosmic ray tracks recorded randomly during the film production process, before installation

Refreshing condition

- Humidity : **>95%R.H**
- Temperature : **30°C**
- Time : **~3days**

Confirmed erasing rate :

98% of the recorded tracks were erased

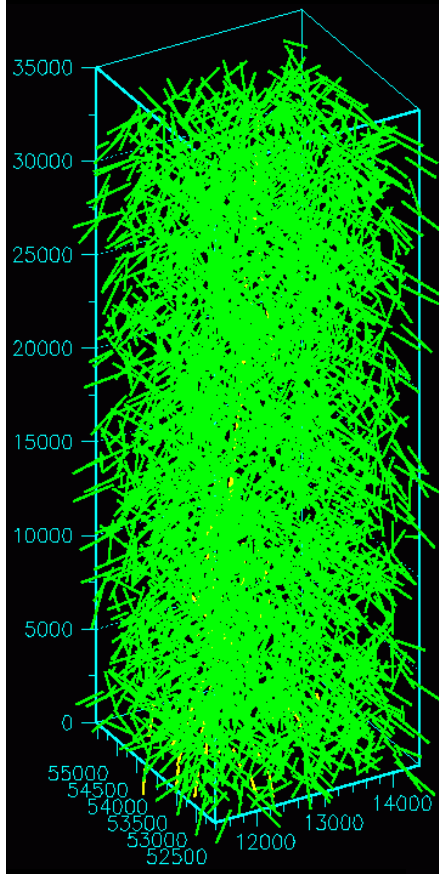


B.G. density & e Shower

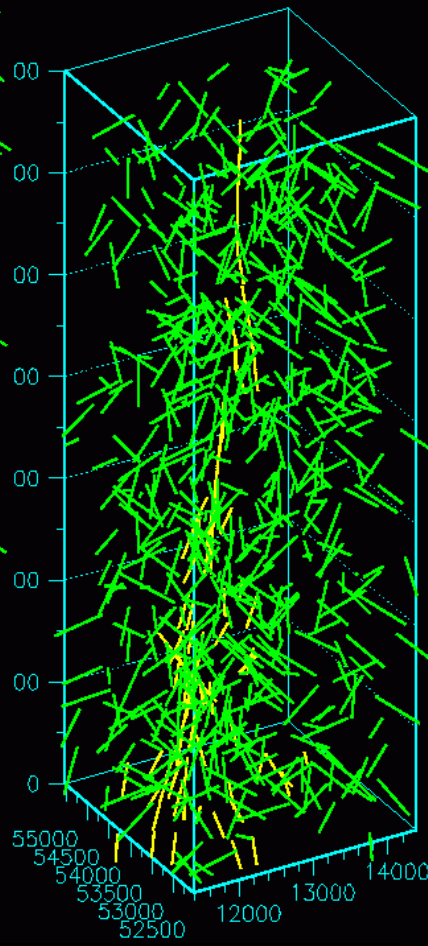
2GeV/c e Shower data

B.G. 30 / mm²

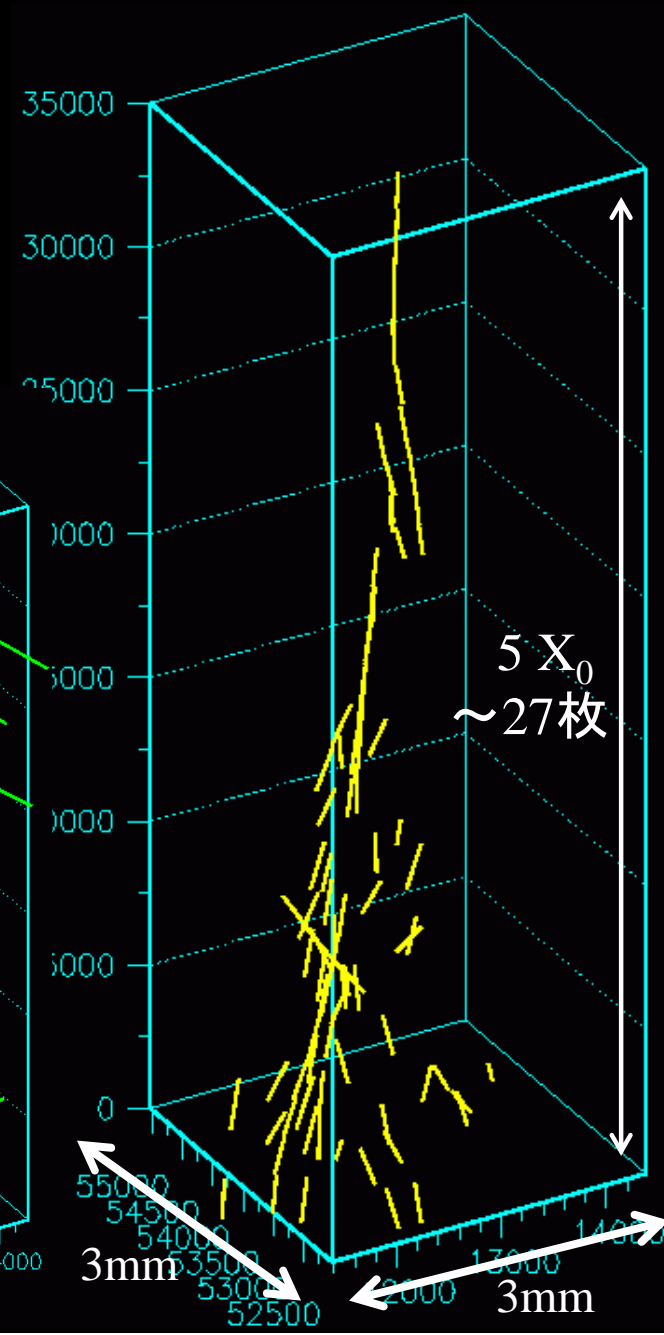
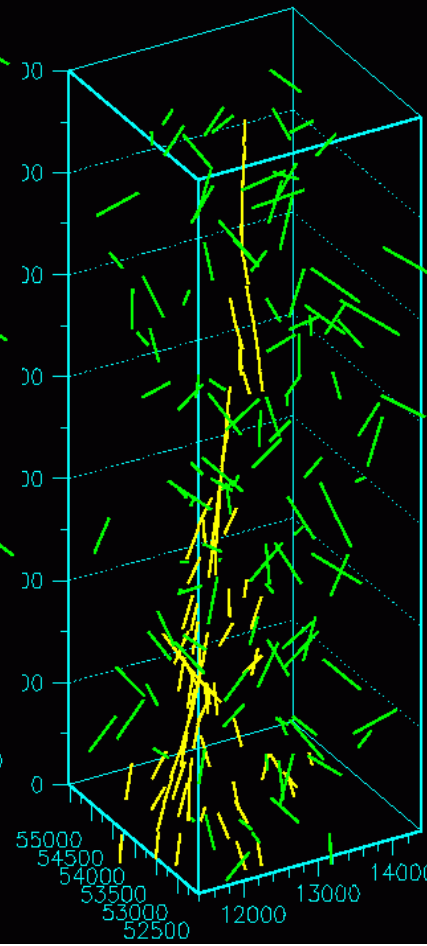
data ———
MC ———



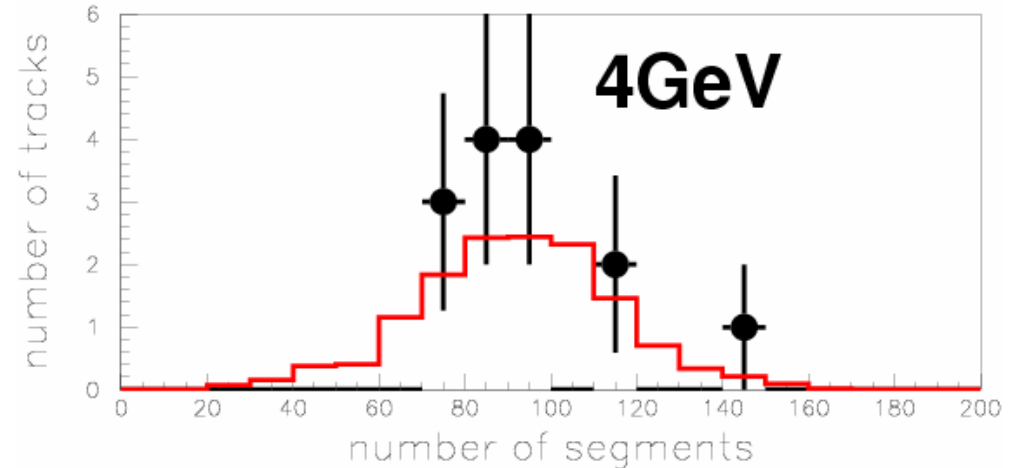
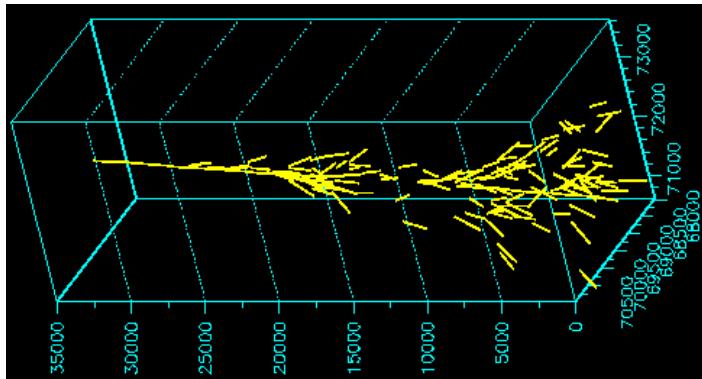
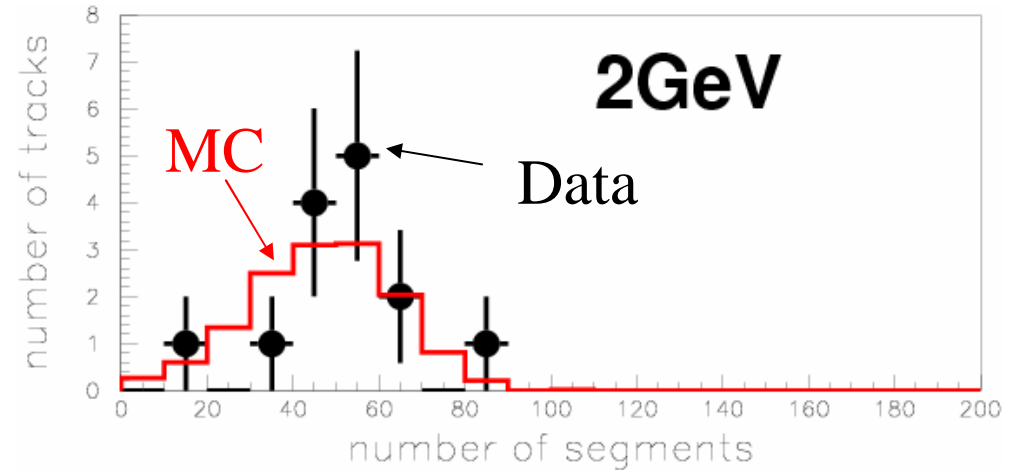
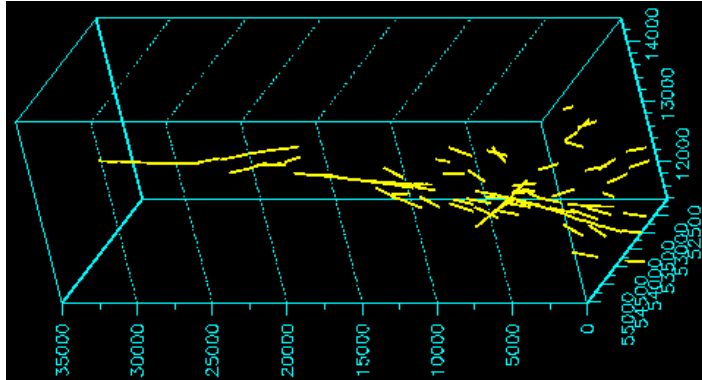
B.G. 5 / mm²



B.G. 1 / mm²



Electromagnetic shower



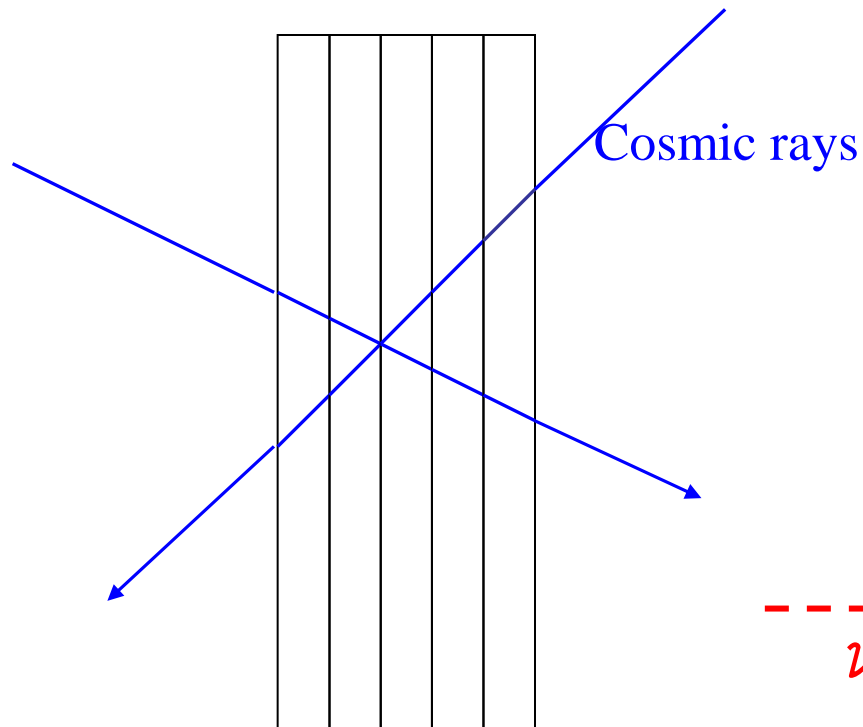
Energy determination
by calorimetric method
(in study)

$$\frac{\Delta E}{E} \sim \frac{0.4}{\sqrt{E(\text{GeV})}} \quad @ \text{ a few GeV}$$

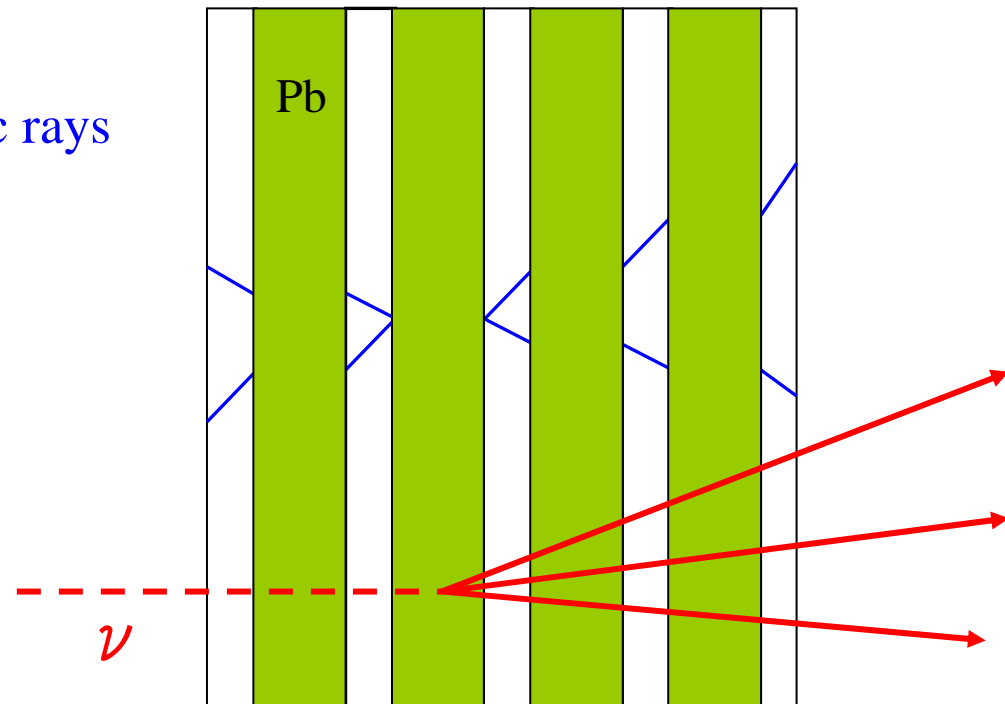
Virtual Refresh

Distinguish the Cosmic ray tracks accumulated after Refresh by Alignment

During transportation



RUN



Different Alignment