

# Status of the OPERA experiment

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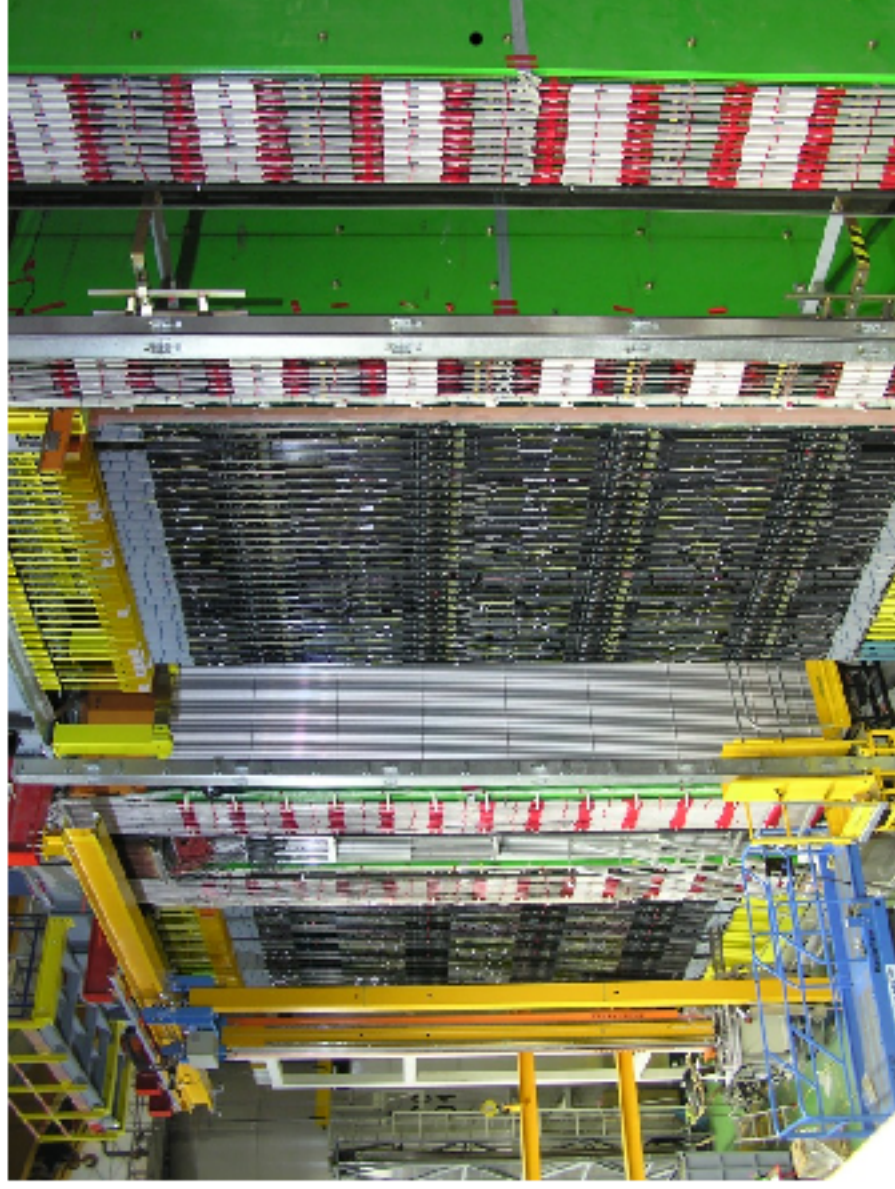
The workshop "Neutrino physics at accelerators"

## Outline

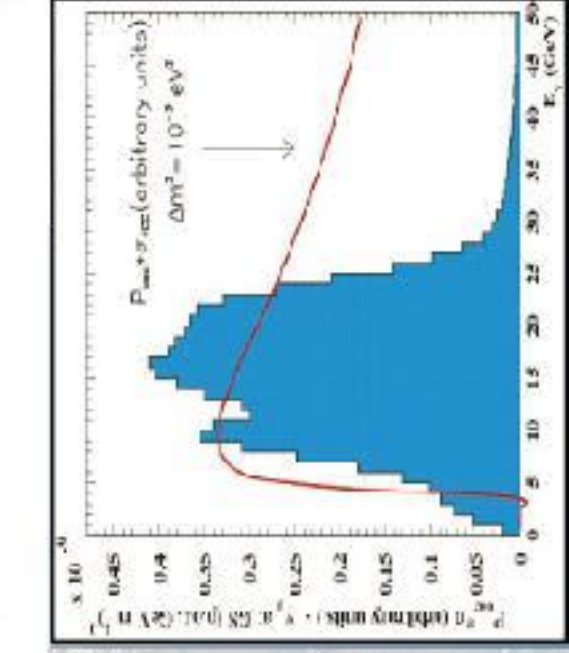
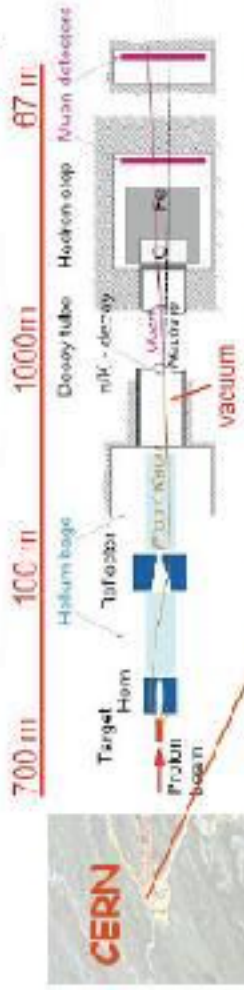
- ◆ OPERA experiment
- ◆ Detector filling
- ◆ October 2007 run
- ◆ Data analysis
- ◆ OPERA request
- ◆ Conclusions

### OPERA: Oscillation Project with Emulsion tRacking Apparatus

- Direct search for  $\nu_\mu \rightarrow \nu_\tau$  oscillations by looking at the appearance of  $\nu_\tau$  in a pure  $\nu_\mu$  beam to explain atmospheric neutrinos anomaly and results of K2K and MINOS.
- Search for the sub-dominant  $\nu_\mu \rightarrow \nu_e$  oscillations for  $\theta_{13}$  measurement.



mbox



Energy spectrum maximizes:

$$P_{osc}(\nu_{\mu} \rightarrow \nu_{\tau}) \propto \alpha_{\nu_e}^{CC} \times E_{\nu}^2$$

$$\text{at } \sin^2 2\theta_{23} \approx 1; \Delta m_{23}^2 \approx 2.5 \cdot 10^{-3} \text{ eV}^2$$

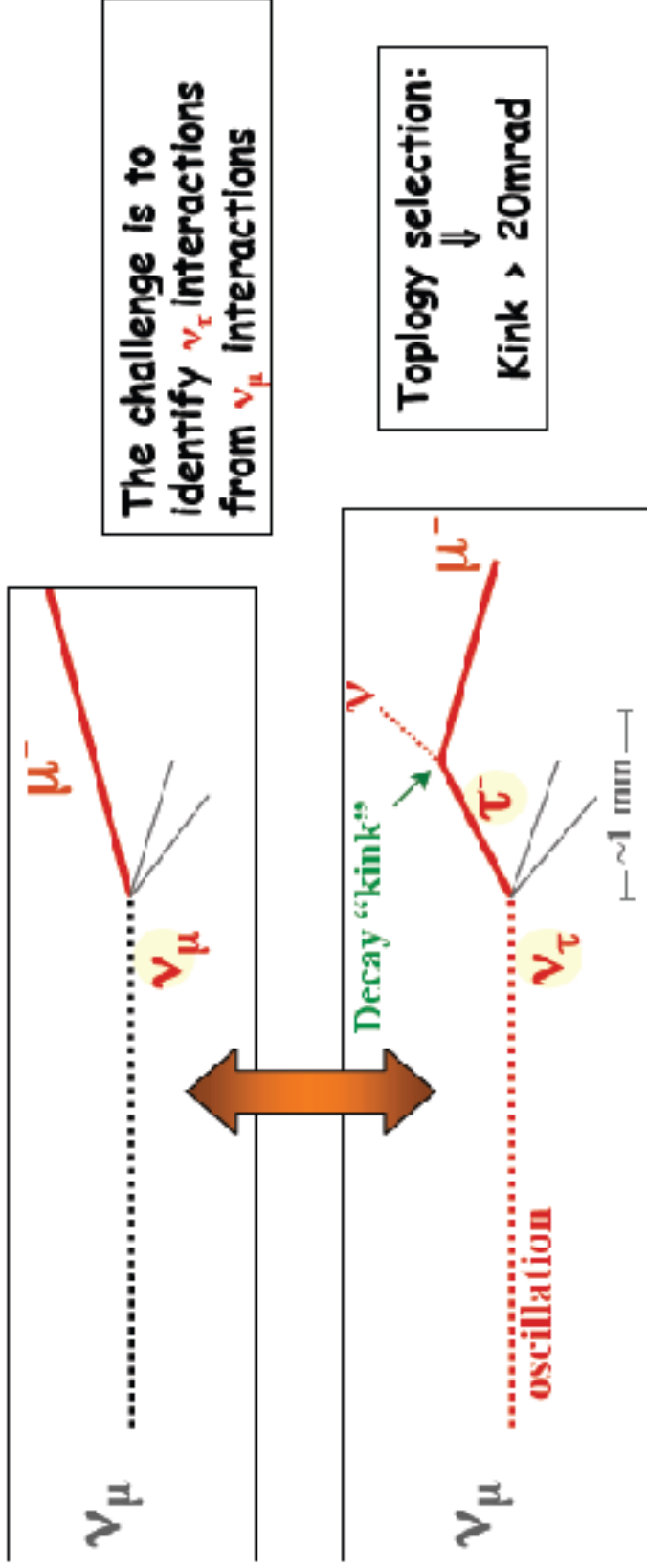
$$\text{given } L = 730 \text{ km} \Rightarrow \frac{L}{4000} \approx 0.1825$$

$$\frac{\langle E \rangle}{L} \approx \frac{17 \text{ GeV}}{730 \text{ km}} \approx 10 \Delta m_{23}^2 [10^{-3} \text{ eV}^2]$$



$\bar{\nu}_{\mu}$	$\nu_{\mu}$	$\nu_{\tau}$
$\frac{\nu_e + \bar{\nu}_e}{\nu_{\mu}}$	4.1%	0.9%
prompt $\nu_{\tau}$	negligible	

# Detection of the $\nu_\tau$ appearance signal



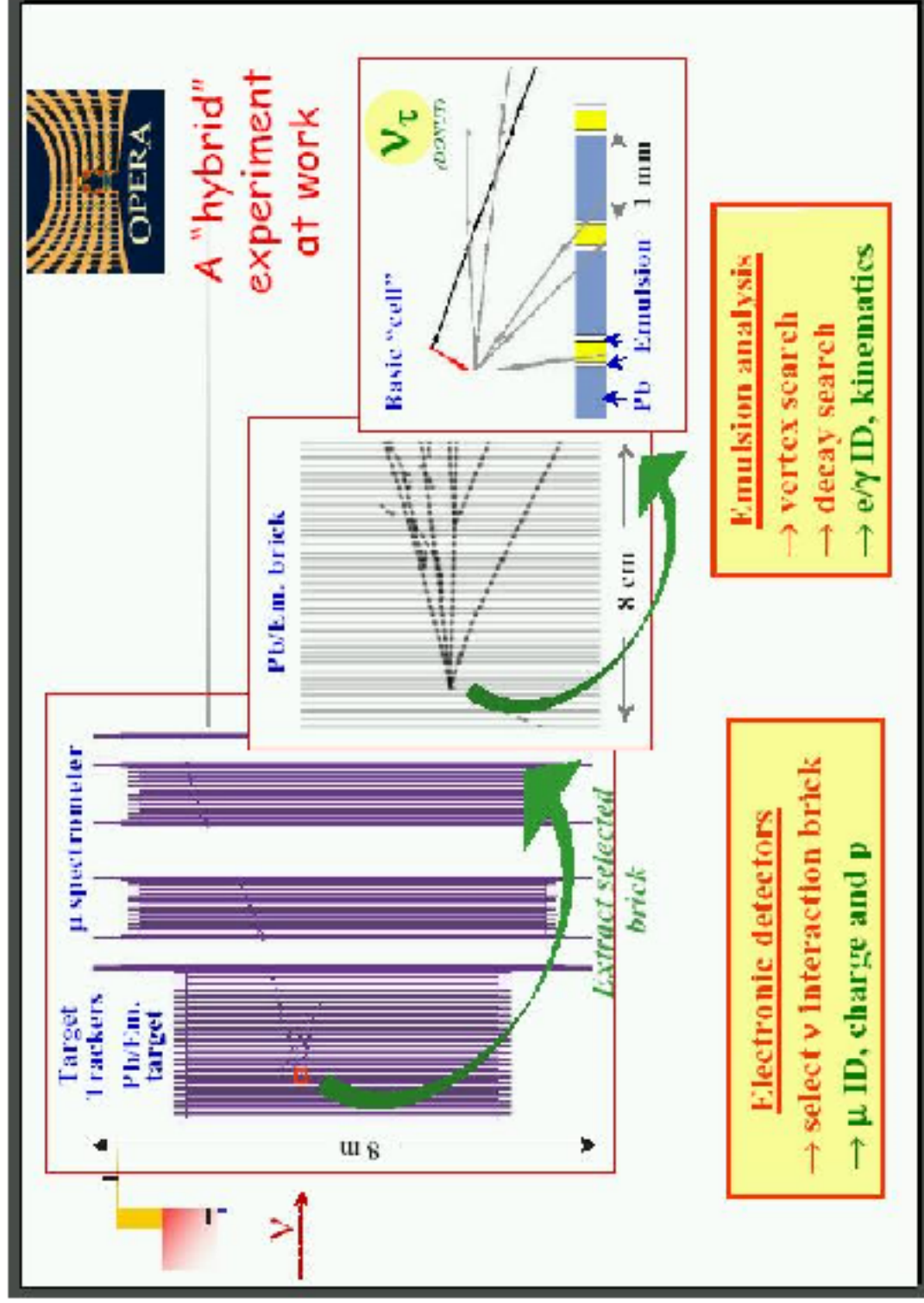
The challenge is to identify  $\nu_\tau$  interactions from  $\nu_\mu$  interactions

Topology selection:  
Kink  $>$  20mrad

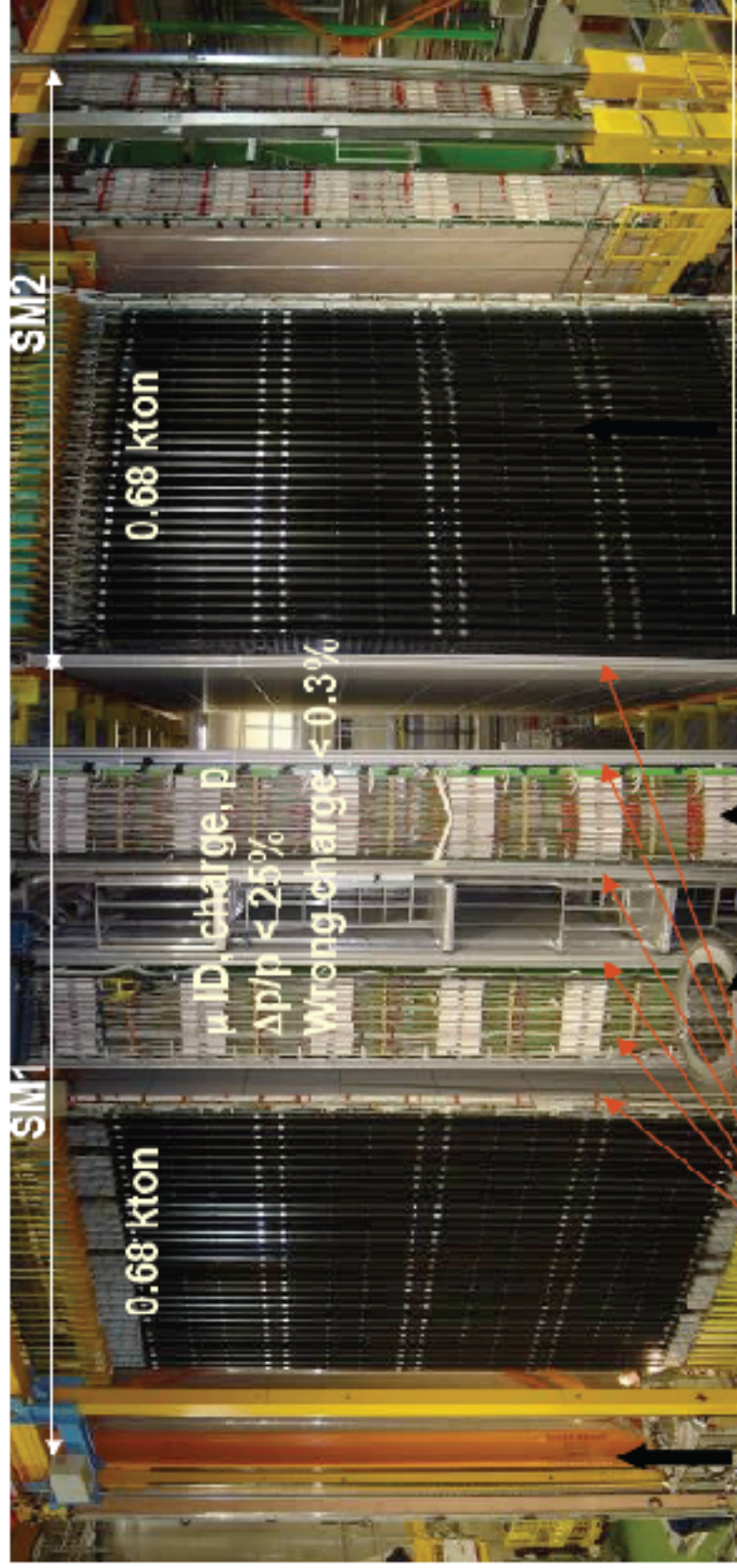
Two conflicting requirements:  
 ➤ Large mass  $\rightarrow$  low Xsection  
 ➤ High resolution  $\rightarrow$   $\tau$  short track (1mm)  
 Hybrid detector

Target: 1300 tons, 5 years running  
 • 22.000 neutrino interactions  
 •  $\sim 120$   $\nu_\tau$  interactions  
 •  $\sim 12$   $\nu_\tau$  identified  
 •  $<$  1 event of background

# Detection of the $\nu_\tau$ appearance signal



# OPERA detector



**Target and Tracker (6.7 m<sup>2</sup>)**

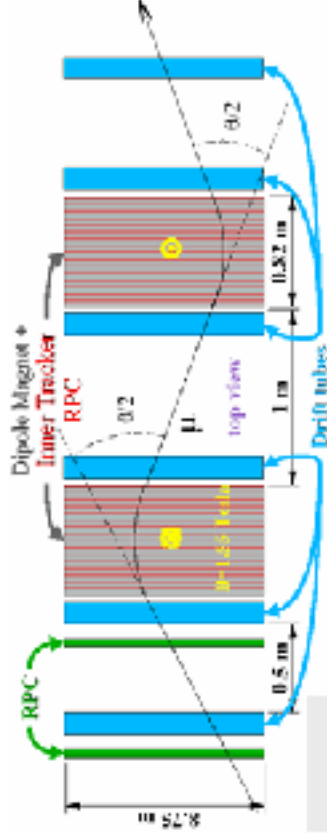
- Target : 77500 bricks, 29 walls
- Target tracker : 31 XY doublets of 256 scintillator strips + WLS fibres + multi-anodes PMT for
  - Brick selection
  - Calorimetry

**High Precision Tracker      Instrumented Dipole Magnet**

- 6 4-fold layers of drift tubes
- 1.6 T
- 22 XY planes of RPC in both arms

**Muon spectrometer (8x10 m<sup>2</sup>)**

# Muon spectrometer



$\mu$  identification:  $\epsilon > 95\%$  (TT)  
 $\delta p/p < 20\%$ ,  $p < 50$  GeV/c  
 misidentified  $\mu$  charge prob.  $< 0.3\%$

## Inner Tracker

11+11 planes of RPC's

21 bakelite RPC's ( $2.9 \times 1.1 \text{ m}^2$ )/plane

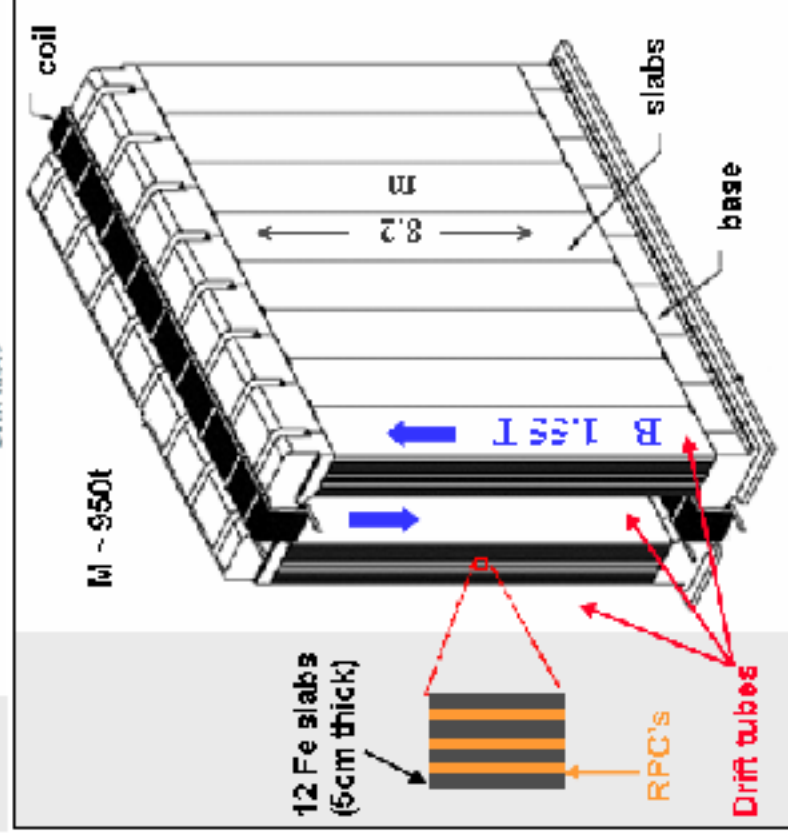
- muon identification (TT)
- range measurement

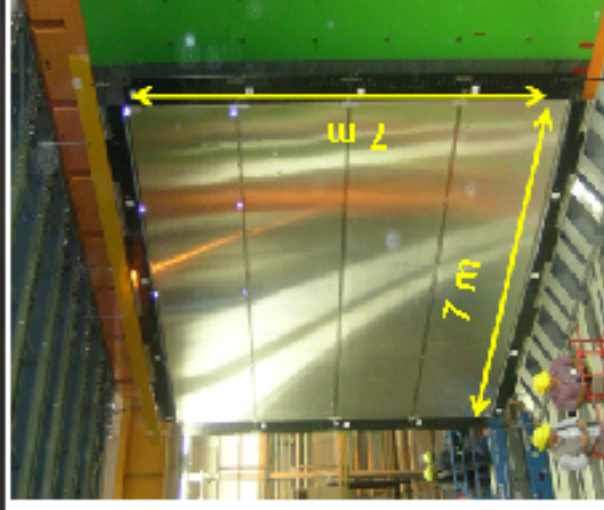
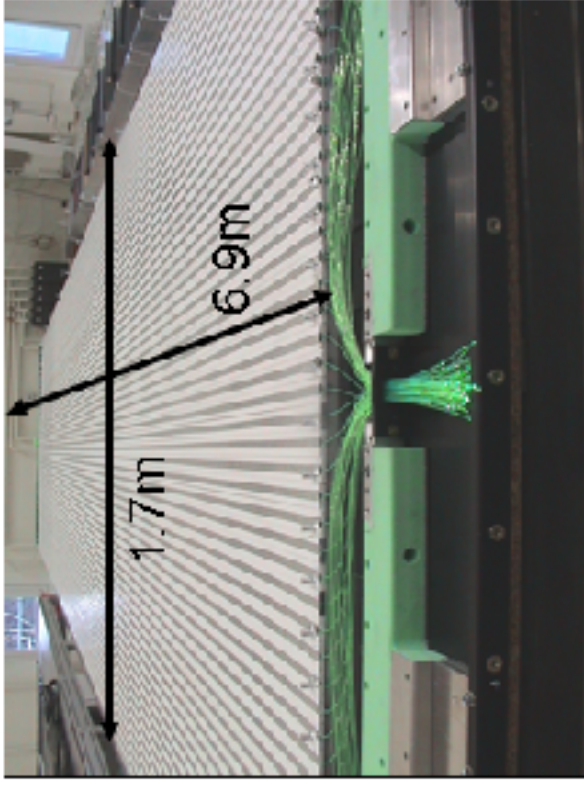
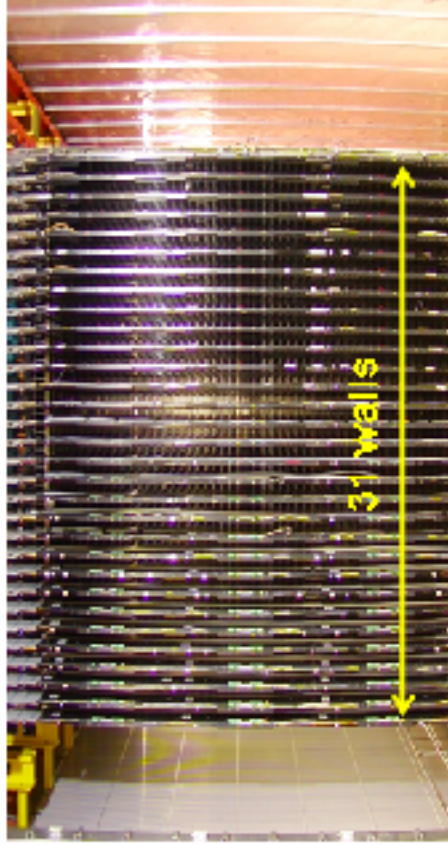
## Precision Tracker

6 planes of Drift tubes space

resolution:  $\sim 300 \mu\text{m}$

- momentum measurement





**Plastic scintillator strips (AMCRYS-H, 6.7m x 2.6cm x 1cm) readout by Kuraray WLS fibres + Hamamatsu PMT/s (64 channels) Target Tracker tasks:**

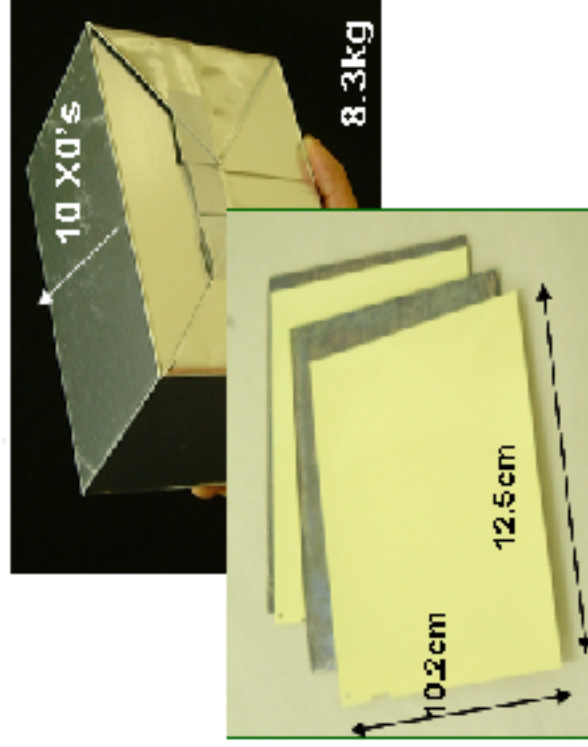
- Trigger:  $\epsilon > 99\%$
- Brick finding :  $\epsilon \approx 70 : 80\%$
- Initiate muon tagging

**Electronic detectors were successfully commissioned in the 2006. After that filling of detector with bricks become the main task.**

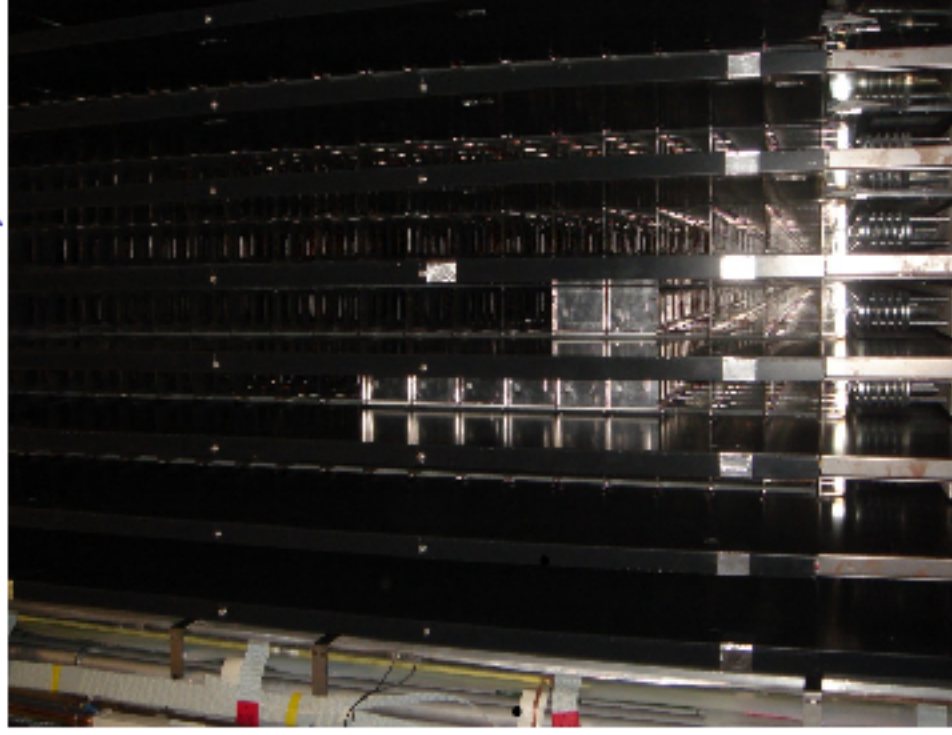


## Lead-Emulsion Target

Brick (target unit) 56 Pb plates + 57 emulsions



Total target mass : 1360 t (about 155000 bricks)



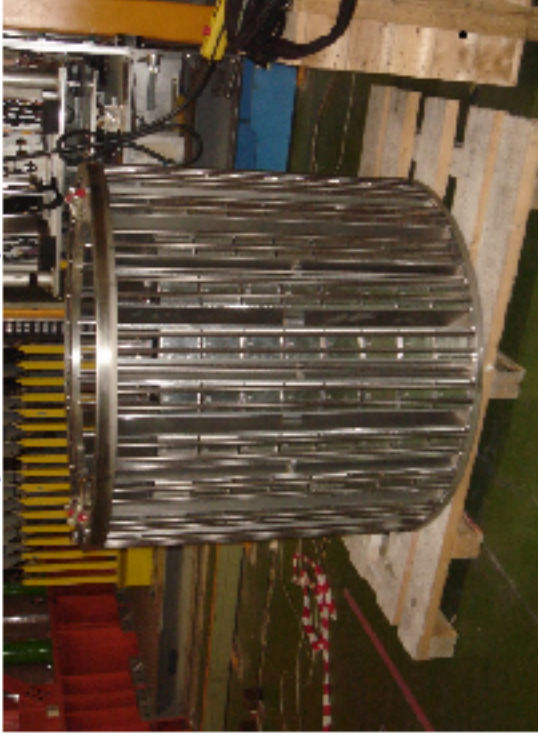
2 emulsion layers ( $44\mu$  thick) poured on a  $200\mu$  plastic base

- Micro-metric space resolution (Emulsion) + target mass (Lead)
- Compact and modular structure

## Brick Manipulation System



## Robot for brick insertion (target filling) and removal (during run)

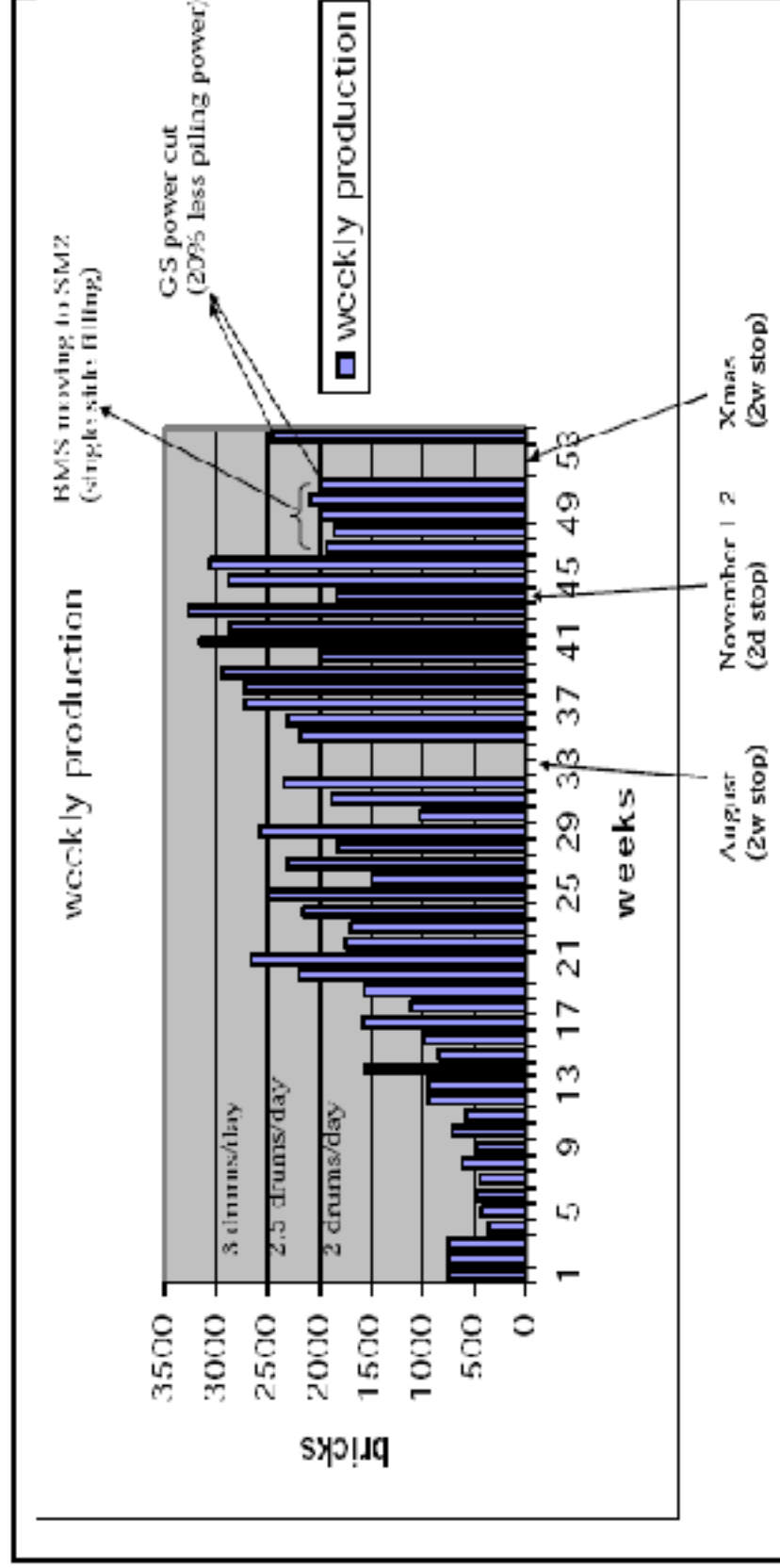


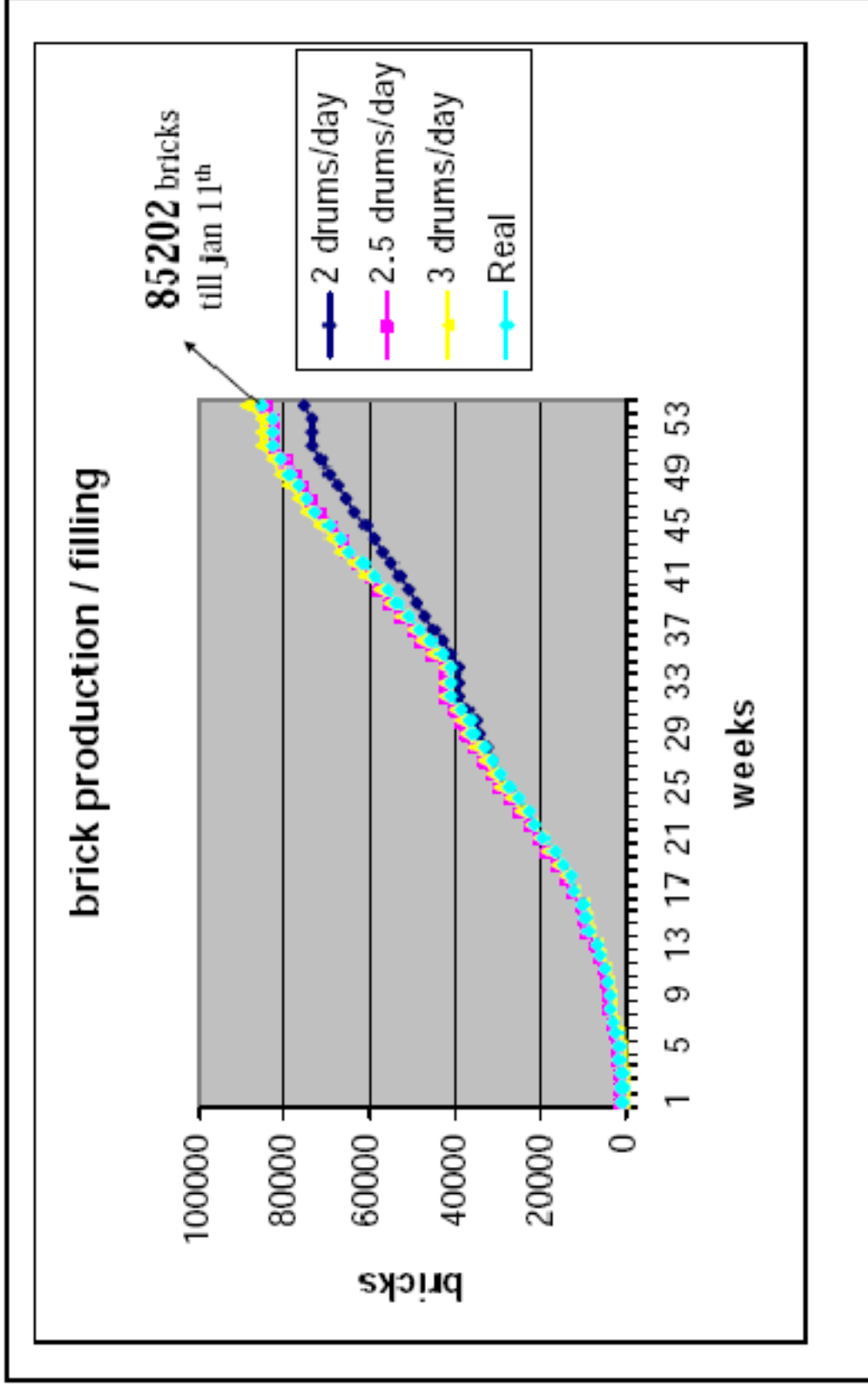
Carousel mechanism



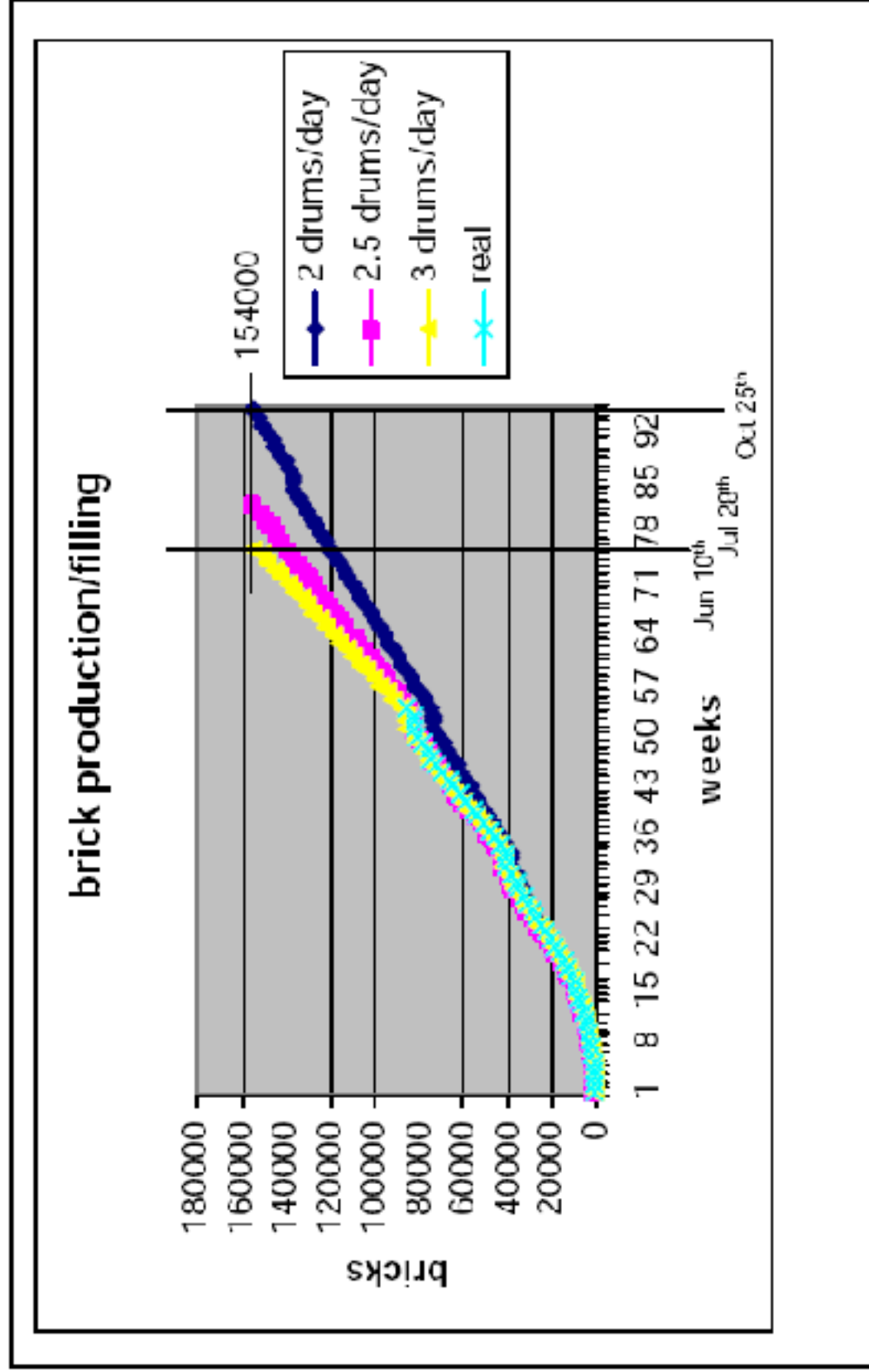
## Status of the detector filling

- The filling of the 1-st SM is completed: 85202 bricks have been produced so far to be compared to 77000 for 1 SM
- BAM production is stabilized at a rate of 3 drums per day (~700 bricks) under normal condition

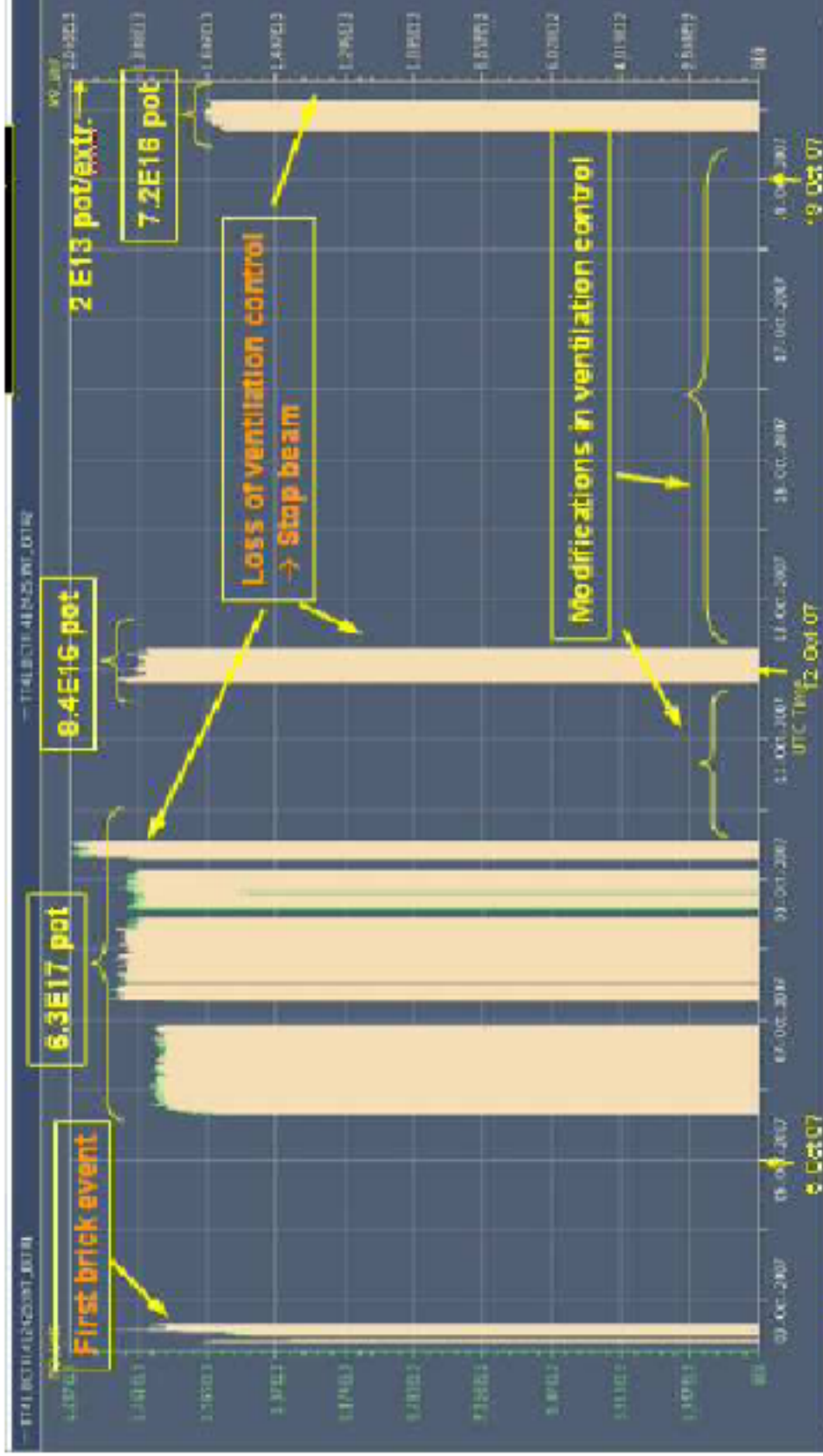




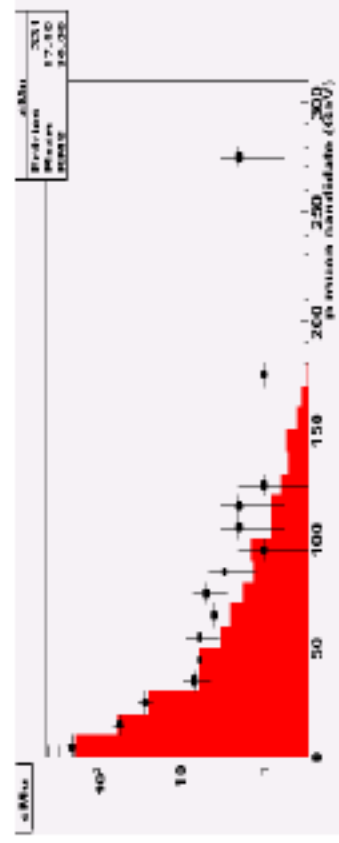
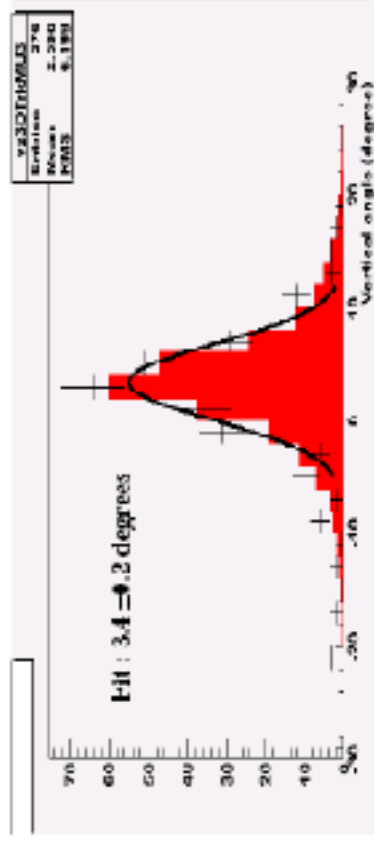
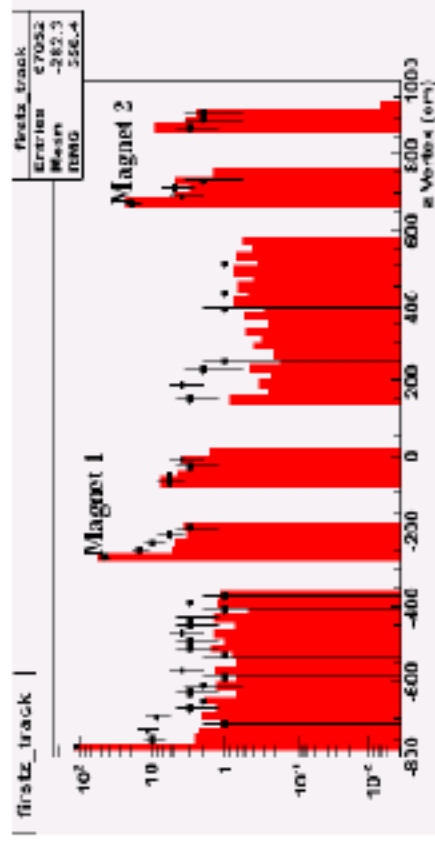
# Status of the detector filling



The 1-st event inside the OPERA target has been observed on October 3-rd.  
 The following figure show the proton delivery onto the CNGS target.



# Data analysis



There were selected and analysed 365 events out of which 331 passed through the analysis cuts. The number of events expected was 303.)

The main physical distributions for those events (in red the expected distribution and in black the data points)

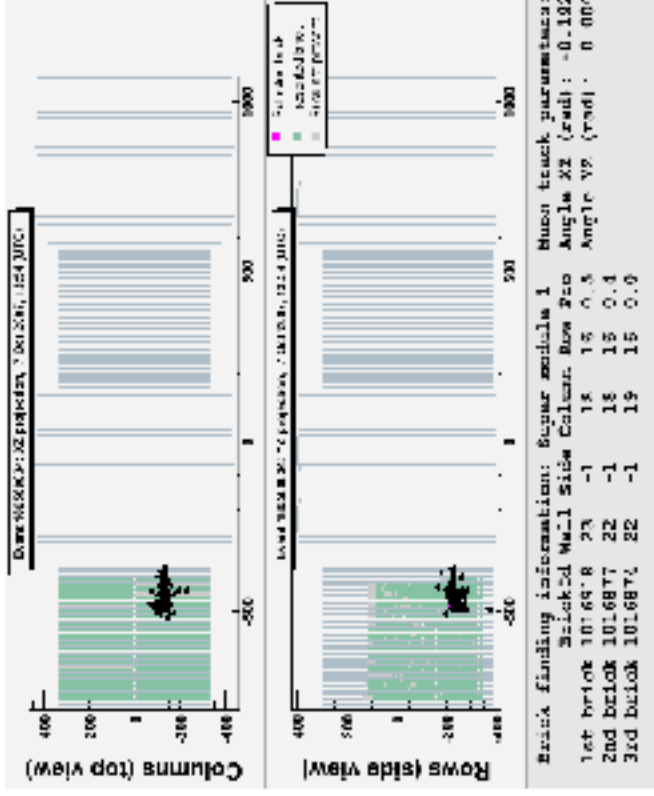
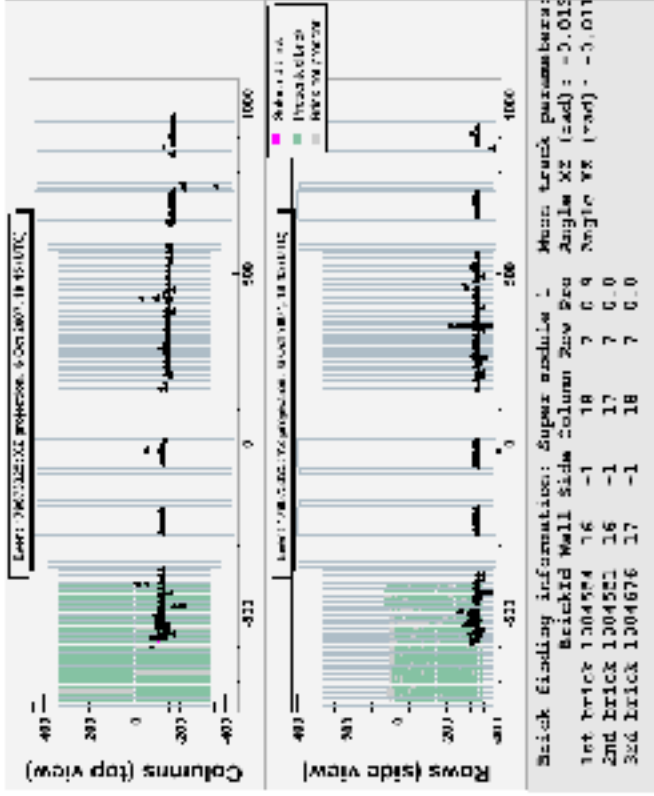
- The vertex location as defined as a 1-st hit of 3D reconstructed track
- The vertical angle of the track
- The energy of the muon as measured with the RPC of the spectrometers

There were observed 38 events (31.5 expected) located in the area of target containing the bricks and 3 events outside the brick area (interactions the TT scintillator). The ratio between CC(29) and NC(9) is compatible with the relative cross section.

The events are analysed through brick finding package which uses the results of the reconstruction package (OPREC). The brick-finding is an iterative process including:

- a neural network algorithm for the wall finding
- the hadronic shower parametrisation
- the exact configuration and alignment of the target at the time of the event (BMM data base) taking into account the wall elongation as a function of the filling
- the probably estimate for the vertex location in each brick





You can see that programm selects bricks with maximal probability of vertex contain.

### The brick processing is organized in 2 steps:

#### Brick confirmation

- Brick extraction with the BMS
- Xray mark between the CSd and the brick for the CSd/brick alignment
- CSd extraction for film development in the CSd facility in the Hall B
- CSd scanning (half in Europe, half in Japan)

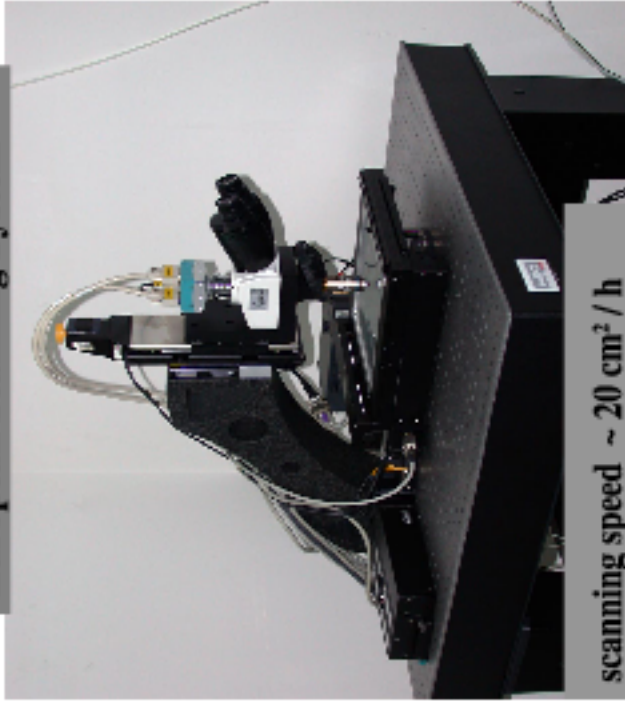
#### Brick processing

- Brick transfer to the OPERA facility
- Lateral Xray marks for the film labelling and alignment inside the brick
- 24 hours cosmic irradiation in the cosmic pit to print enough muons for the inter plates alignment
- Film development with the automatic chains
- Shipment to the scanning lab in Europe and Japan

# Scanning stations

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

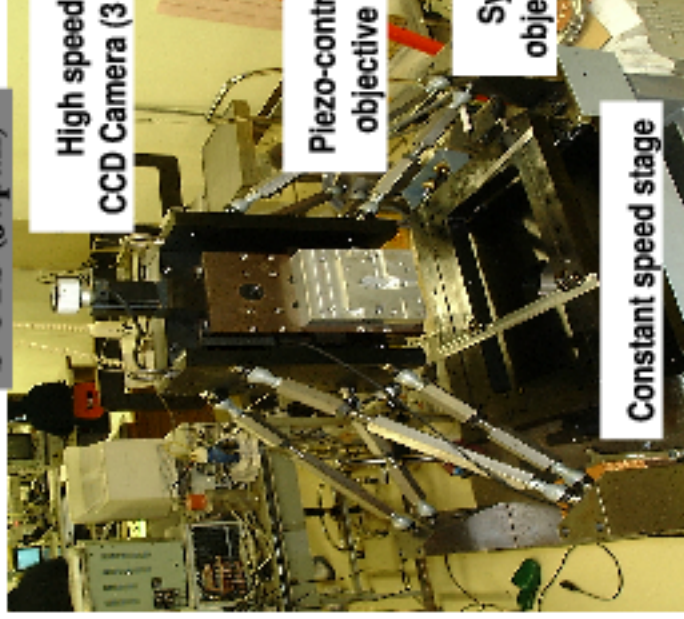
## European Scanning System



scanning speed ~ 20 cm<sup>2</sup> / h

Customized commercial optics and mechanics + asynchronous DAQ software

## S-UTS (Japan)



High speed  
CCD Camera (3 kHz)

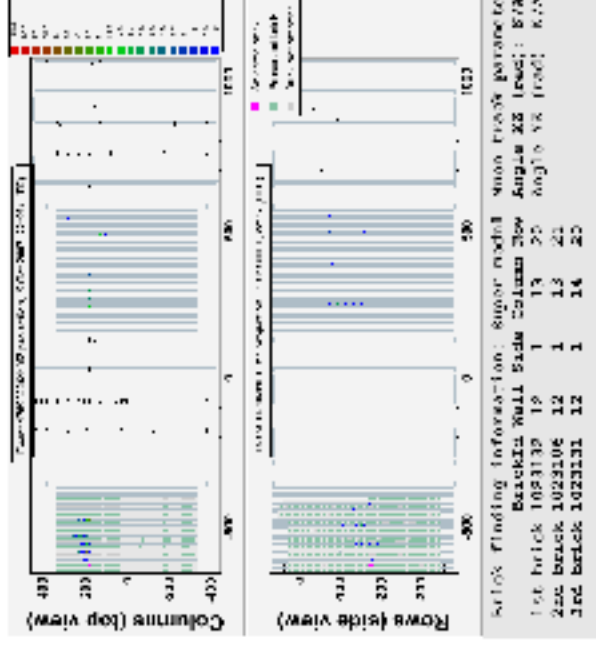
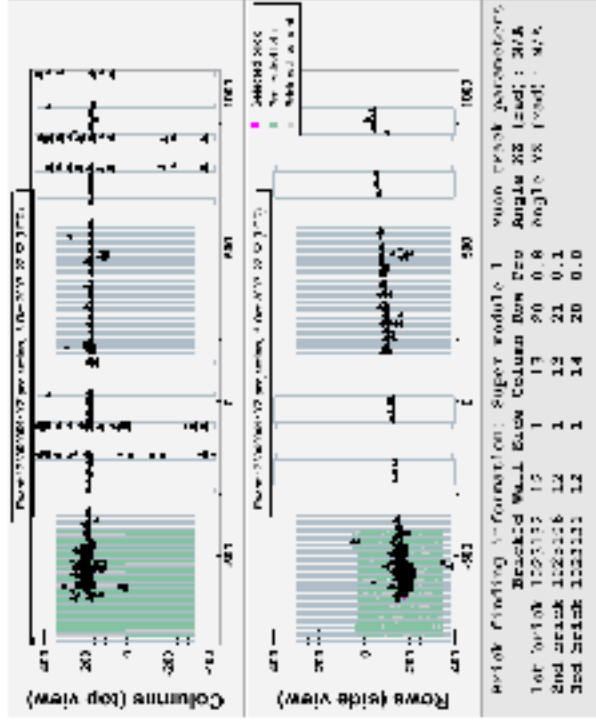
Piezo-controlled  
objective lens

Synchronization of  
objective lens and stage

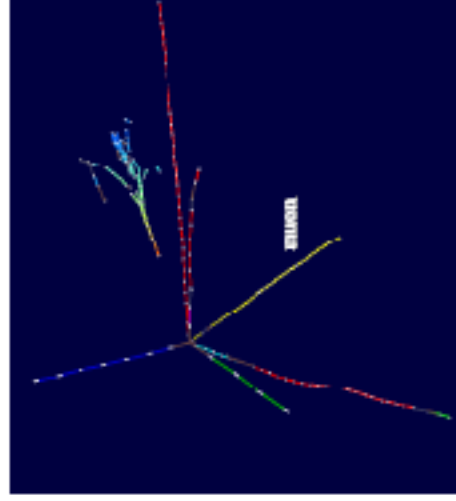
Constant speed stage

Hard-coded algorithms

# Sample of reconstructed CNGS neutrino interactions

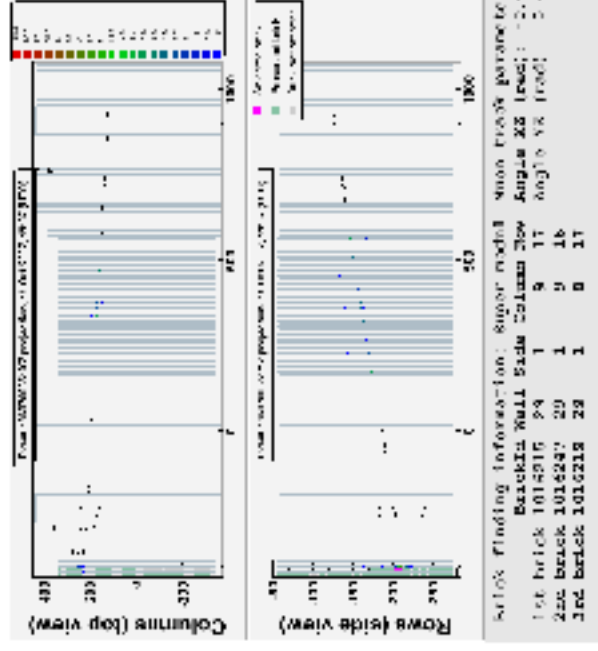
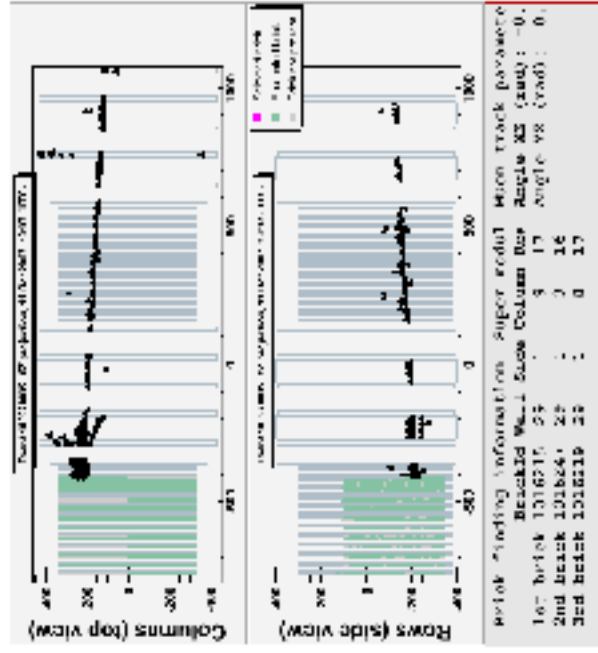


1) Event 178969961

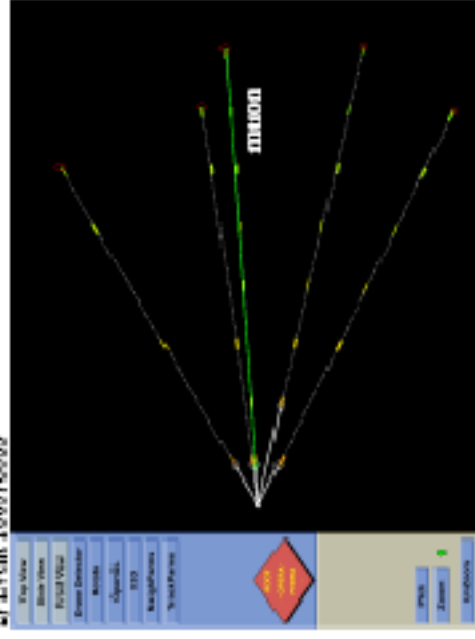


Slopes	IP (microns)
-0.028,0.095	5.2
-0.114,0.143	0.3
0.091,0.039	6.2
-0.166,-0.342	21.4
0.127,0.075	10.4
-0.370,0.430	15.3

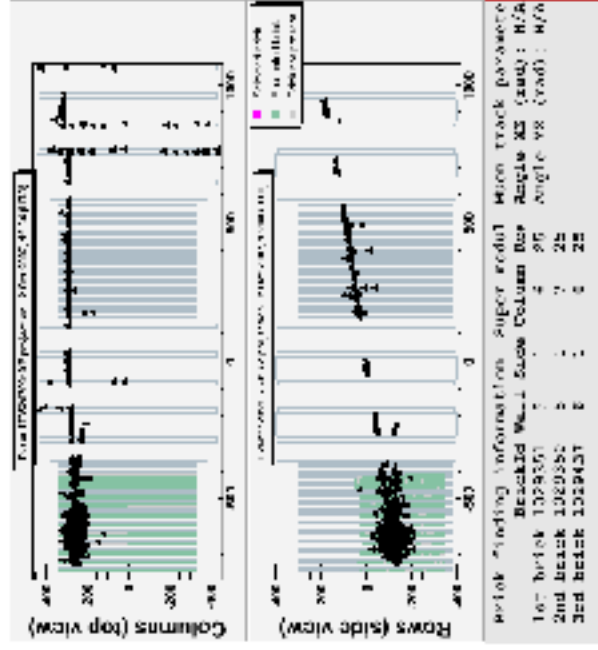
# Sample of reconstructed CNGS neutrino interactions



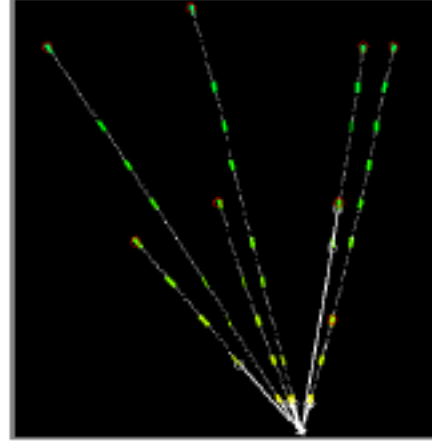
2) Event 186970035



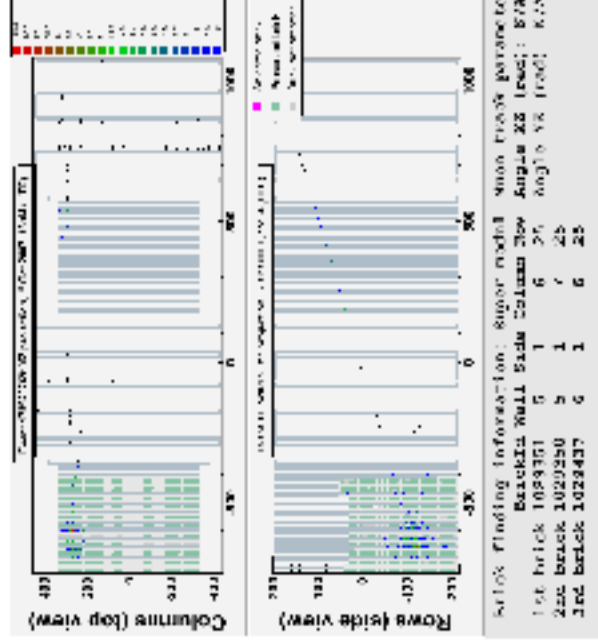
# Sample of reconstructed CNGS neutrino interactions



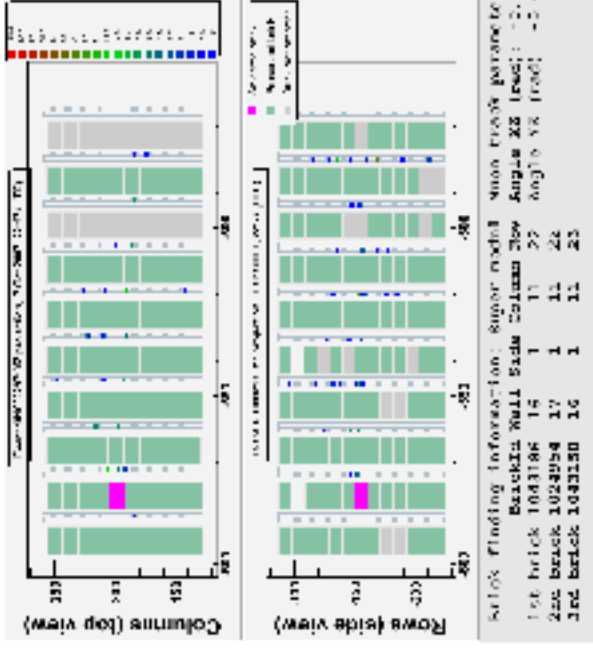
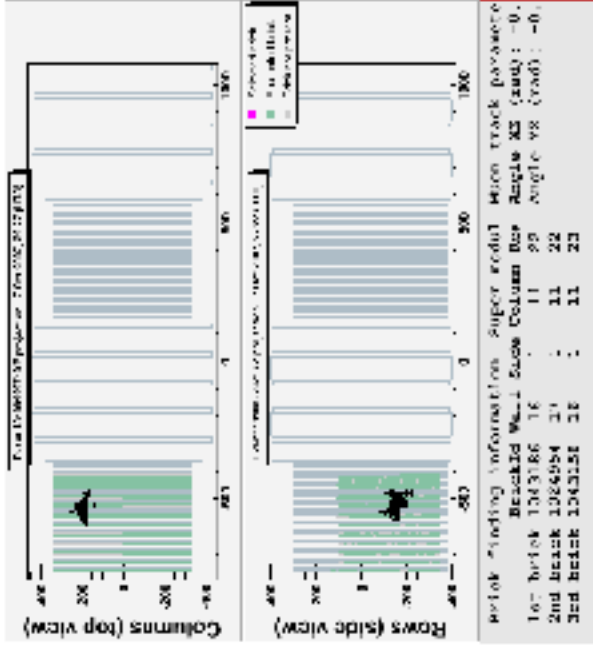
3) Event 173520769



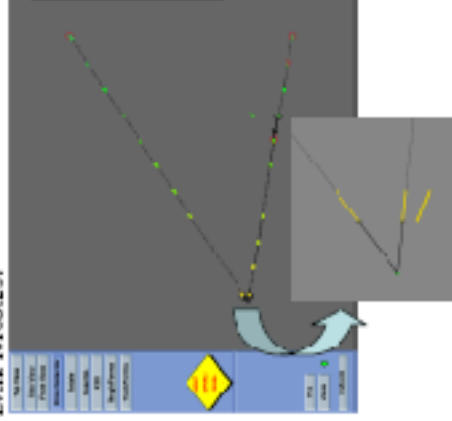
Slopes	IP (micron)
0.012	0.160
-0.033	-0.066
-0.014	0.064
-0.735	0.094
0.035	0.214
-0.100	-0.040



# Sample of reconstructed CNGS neutrino interactions



3<sup>rd</sup> Event 111085297



Slopes IF (micron)

-0.087	-0.070	2.3
0.666	0.335	1.1
-0.323	0.373	1.0

## OPERA request for the 2008 run

The concept of the OPERA experiment has been fully validated during the short run in 2007.

Statistics which could be accumulated for a nominal CNGS year (taking into account the reduced target mass):

Total number of interactions	5200
CC events	3900
NC events	880
Electron events	35
Charm decay	160
Tau candidate (@ $2.5 \cdot 10^{-3} \text{ eV}^2$ )	2

Summary results in comparing with the so-called nominal CNGS year:

	2008	Nominal CNGS
Number of days	147	200
Super Cycle (sec.)	48	27.6
Circulating proton efficiency	$3.8 \cdot 10^{13}$ 70%	$4.5 \cdot 10^{13}$ 80%
Integrated pot	$2.1 \cdot 10^{19}$	$4.5 \cdot 10^{19}$



## Conclusions

During the 2007 OPERA was half filled with the emulsion-lead bricks. First 38 events were registered and successfully located in the nuclear emulsion - so the whole detection conception of the OPERA was validated.

The brick production and the detector filling is well under way, and the whole OPERA is to be filled in time before June 2008, when the new CNGS run will start.

JINR has purchased the components of ESS and will create a scanning station in the middle of 2008 to participate in the scanning along with the other OPERA participants (see the talk of Tereschenko).