Nuclear emulsions in FIRST: a first look

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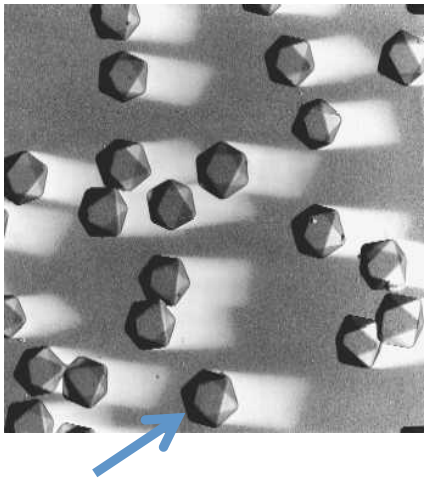
Nuclear emulsion as sensitive media for charged particles

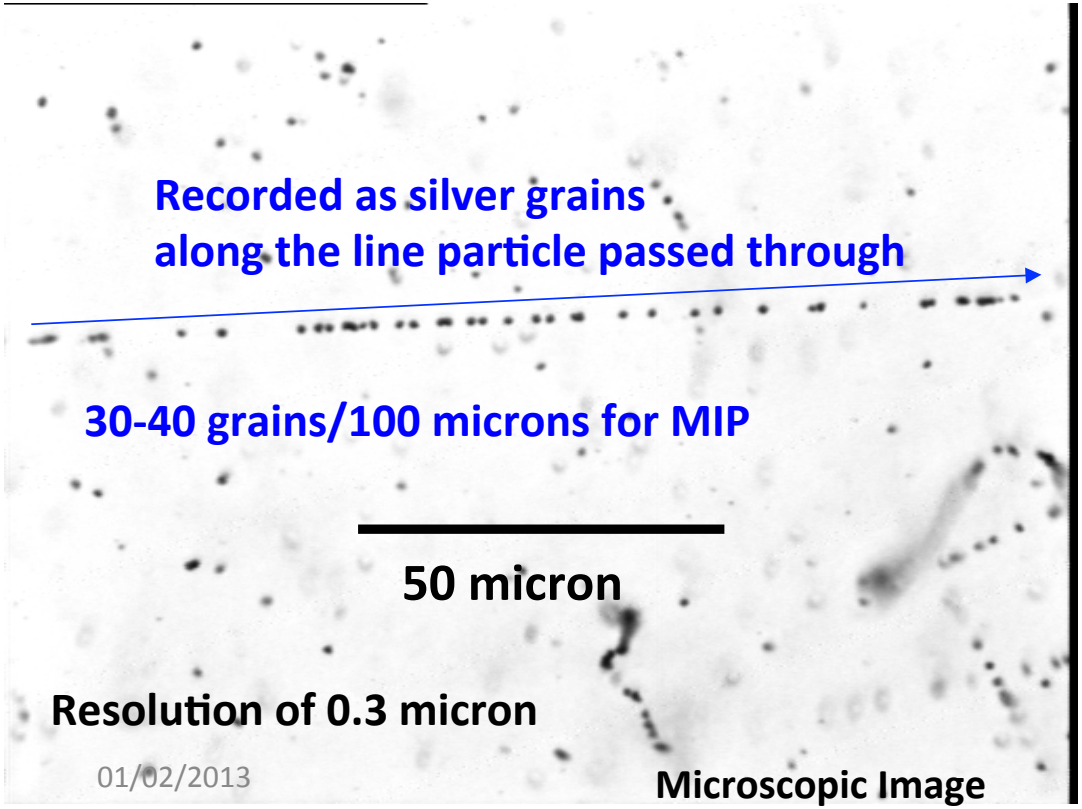
After the passage of charged particles through the emulsion layer, a latent image is produced

After a physical/chemical process known as development, Ag grains become visible with an optical microscope



AgBr crystal, size 0.2 micron

Is the elementary detection element



Microscopic Image

Nuclear emulsions used for more than 100 years in Particle Physics

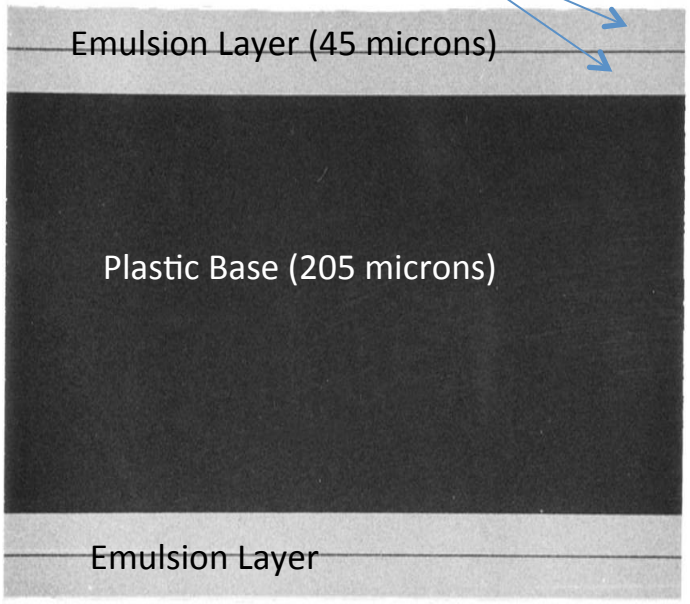
OPERA emulsions

OPERA industrial emulsions from FujiFilm

• The AgBr density in the OPERA emulsions is higher in respect to the commercial films

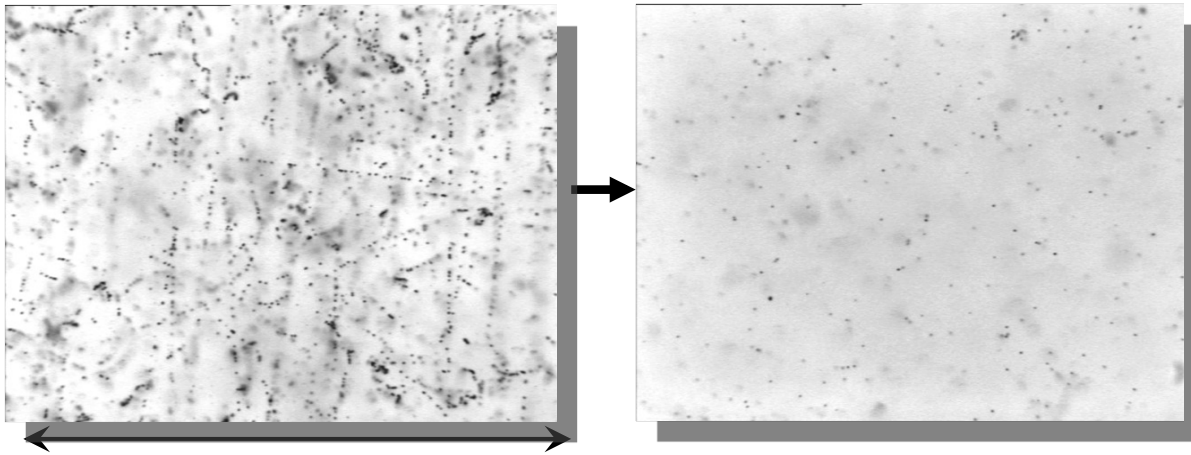
•Special R&D for OPERA: the double pouring procedure

Emulsions are continuously sensitive detector ALL charged particle: cosmic rays, natural radioactivity etc recorded as a latent images. They can be partially erased by a “refreshing” procedure applied just before the detector assembling



Before refreshing
>30 tracks/mm^2 bg

After refreshing
~1 tracks/mm^2 bg

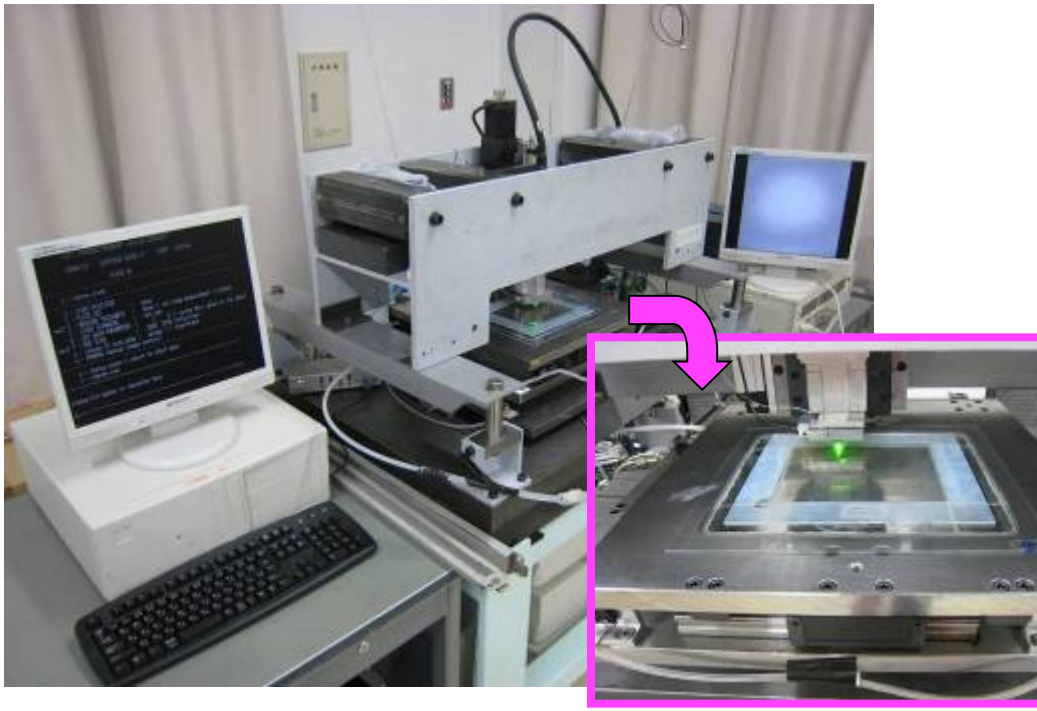


Emulsion Scanning Stations

EU: ESS (European Scanning System)

- Scanning speed/system: 20cm^2/h
- Customized commercial optics and mechanics
- Asynchronous DAQ software

Japan: SUTS (Super Ultra Track Selector)



- Scanning speed/system: 75cm^2/h
- High speed CCD camera (3 kHz), Piezo-controlled objective lens
- FPGA Hard-coded algorithms

Both systems demonstrate:

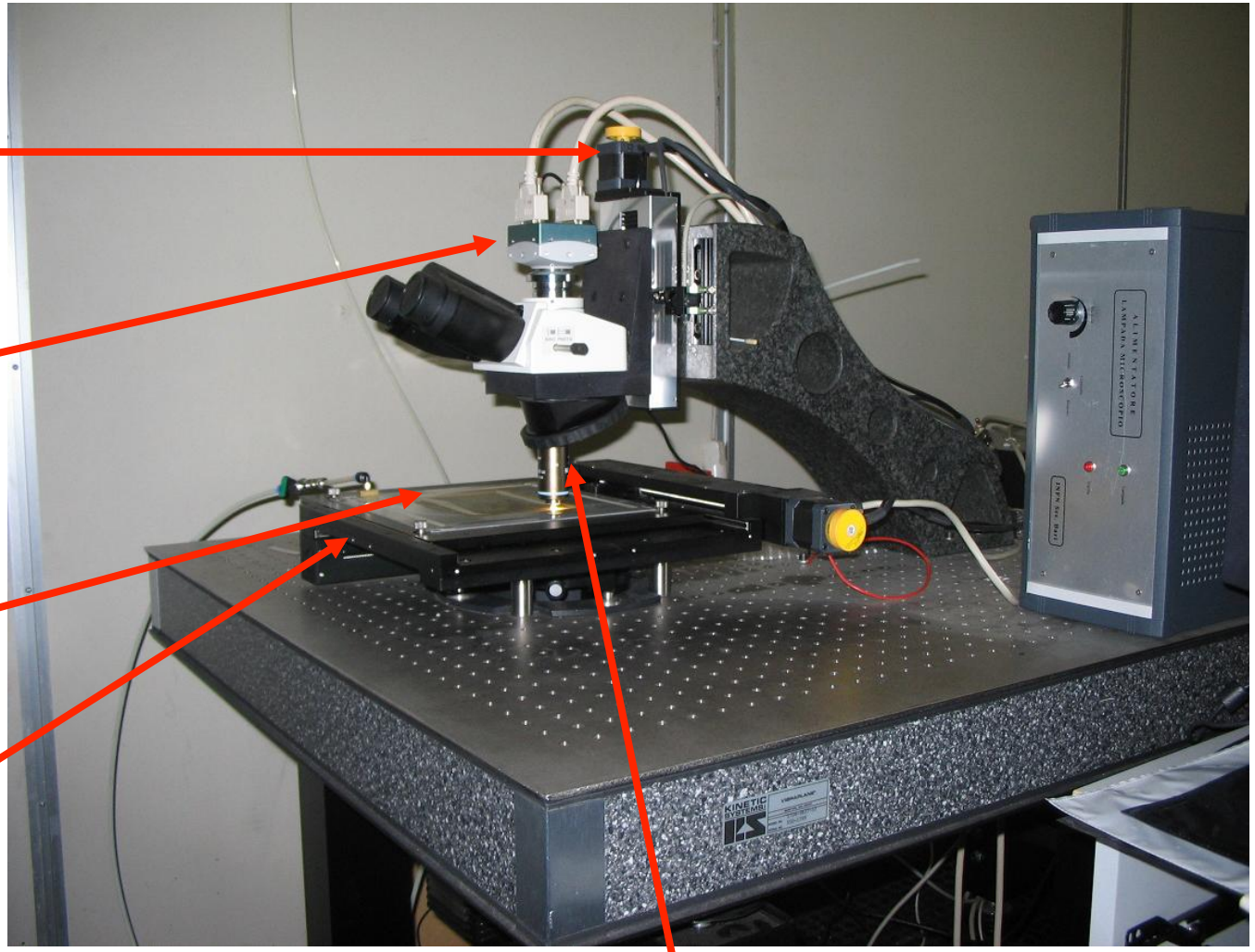
- ~0.3 μm spatial resolution
- ~2 mrad angular resolution
- ~95% base track detection efficiency

Z stage (Micos)
0.05 μm nominal
precision

CMOS camera
1280×1024 pixel
256 gray levels
376 frames/sec
(Mikrotron MC1310)

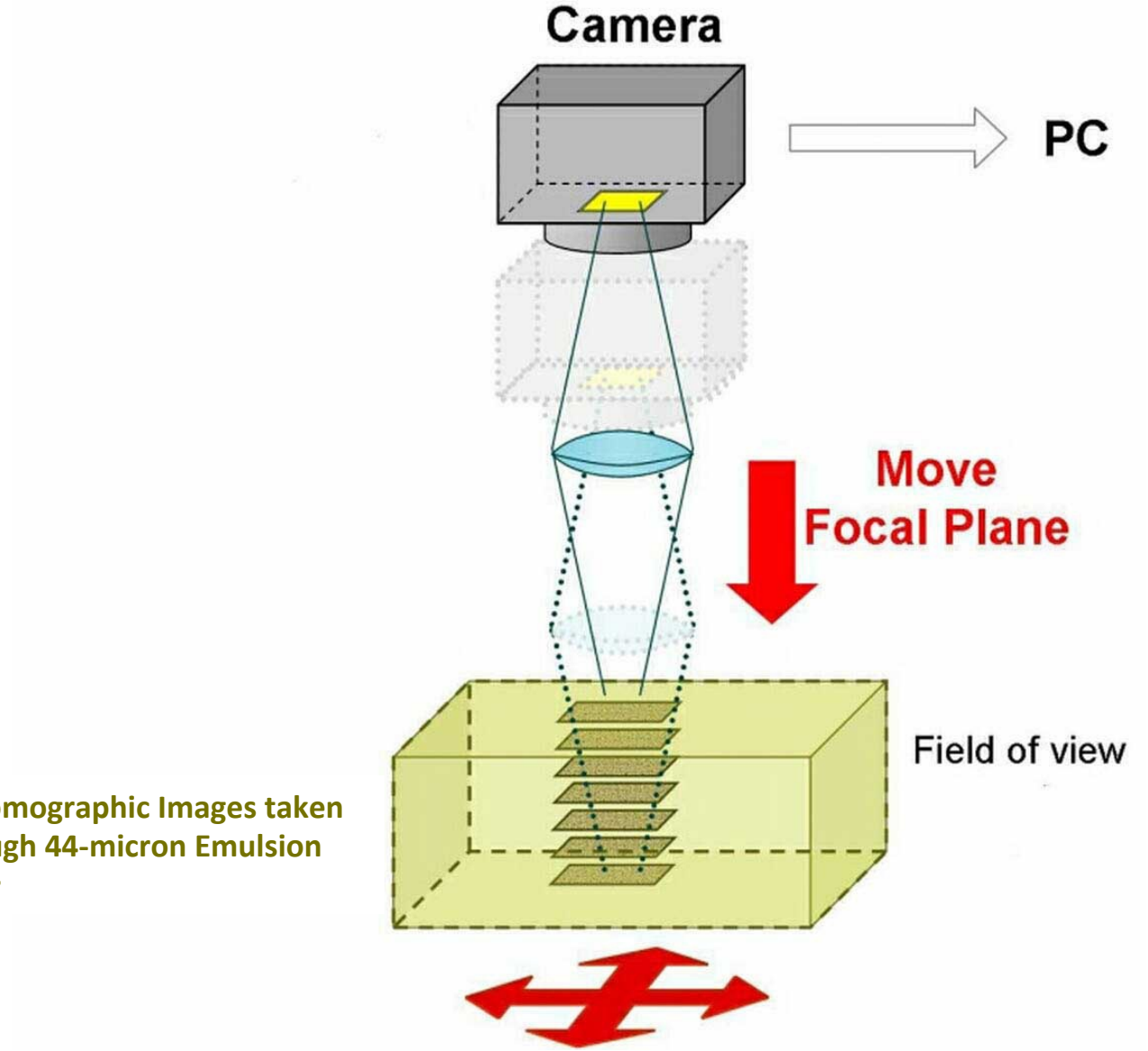
Emulsion Plate

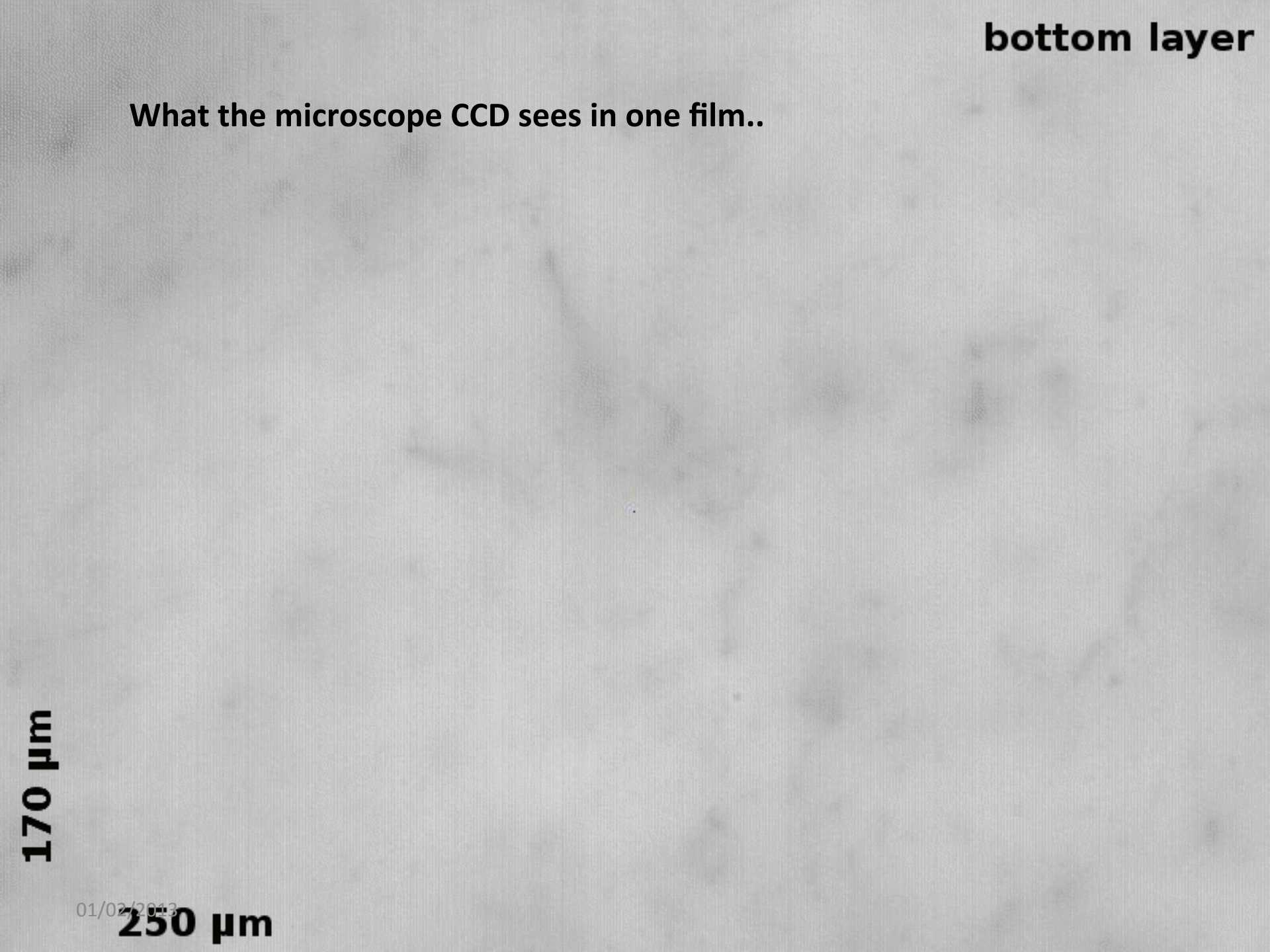
XY stage (Micos)
0.1 μm nominal
precision



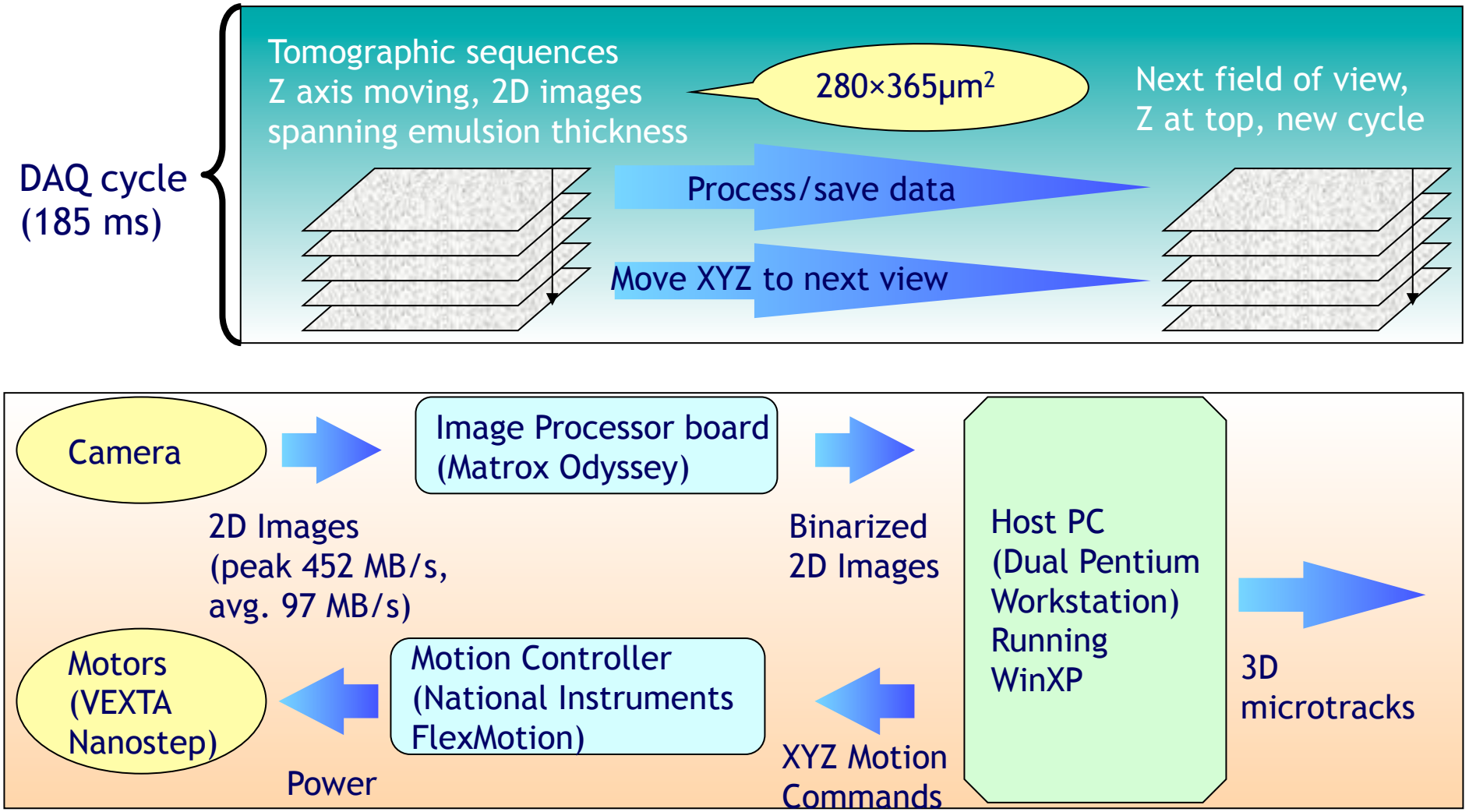
Illumination system, objective (Oil 50× NA 0.85)
and optical tube (Nikon)

Principle of scanning emulsion (European)




bottom layer
What the microscope CCD sees in one film..
170 µm
250 µm

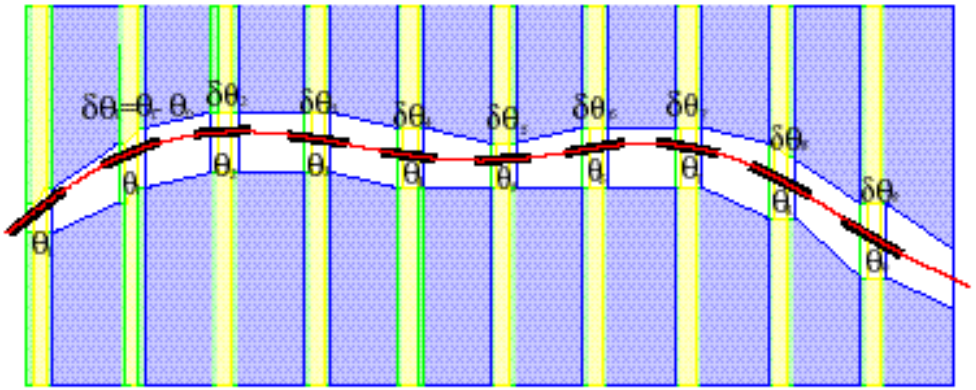
Data (images) processing and motion control flow in the ESS



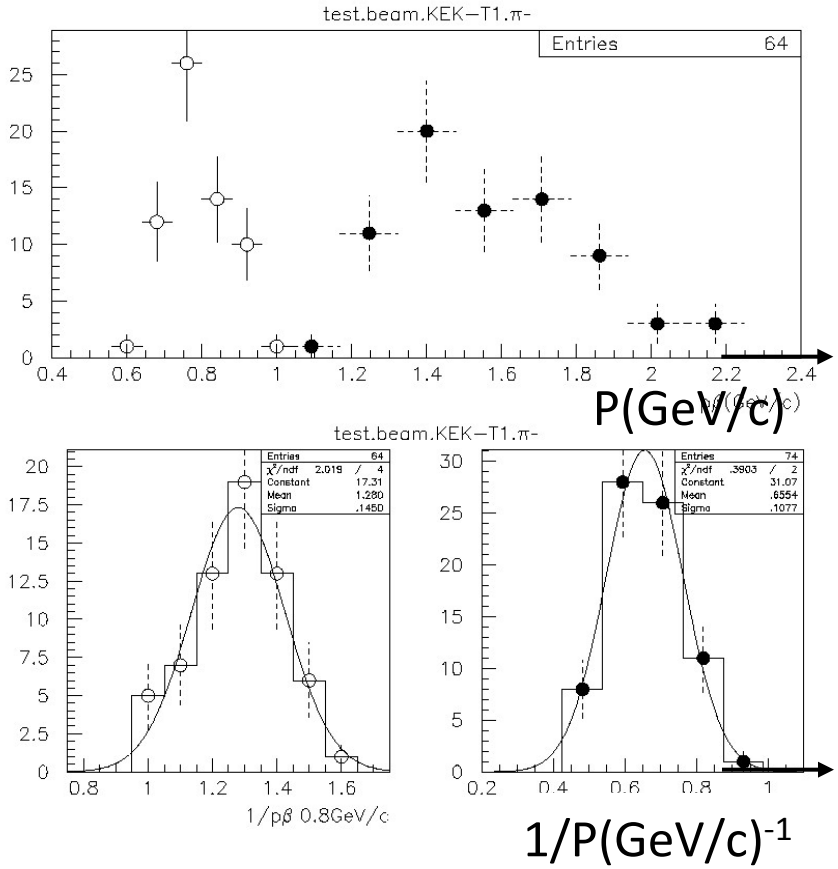
Kinematical measurements

1.Momentum measurement by multiple coulomb scattering

[Angle Method]



$$P\beta = \frac{13.6\ (\mathrm{MeV/c})}{\delta\theta}\sqrt{\frac{x}{X_0}}$$



0.8GeV/c pion : P =0.79(GeV/c), dP/P =**11**%

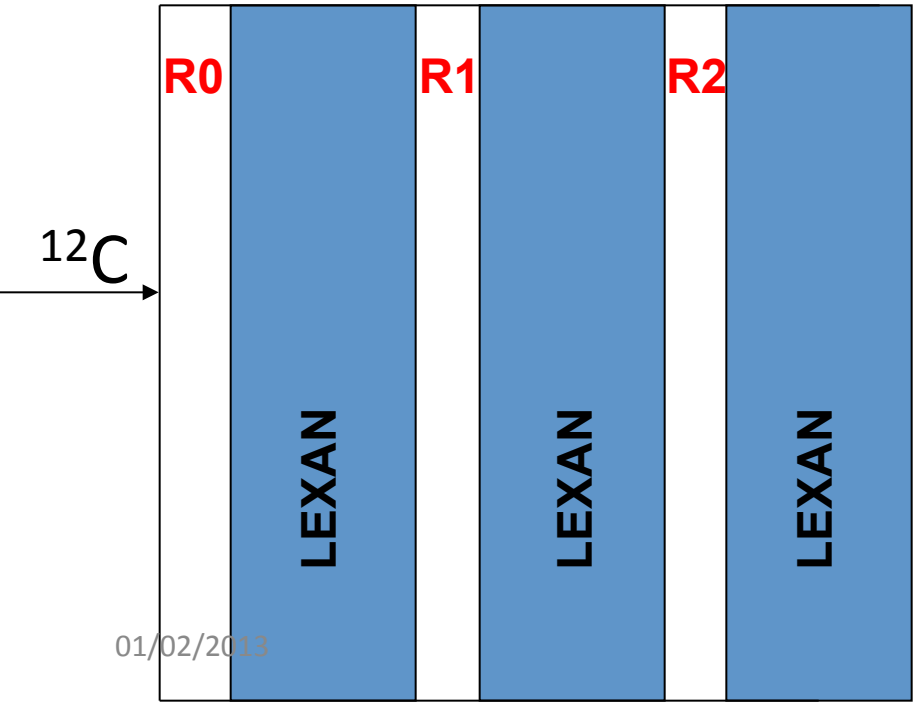
1.5GeV/c pion : P =1.53(GeV/c), dP/P =**16**%

Exposure of an Emulsion Cloud Chamber (ECC) to 400 MeV/u Carbon ions

ECC structure: 219 emulsion films (300 μm thick) and 219 Lexan plates 1 mm thick (73 consecutive "cells")

Lexan: $\rho = 1.15$ g/cm^3 and electron density = 3.6×10^{23}/cm3, e.g. Water 3.3×10^{23}/cm3

Cell structure

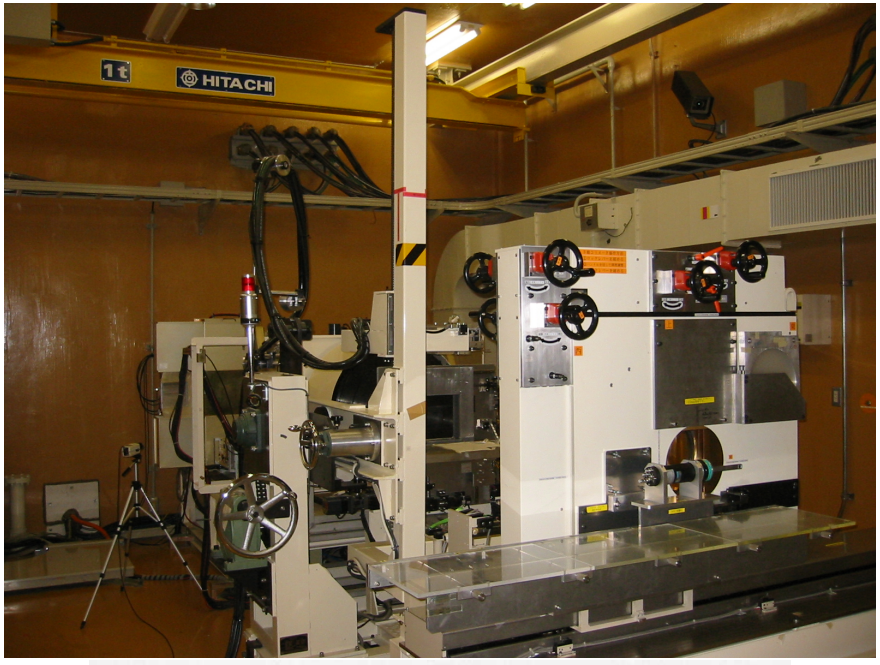


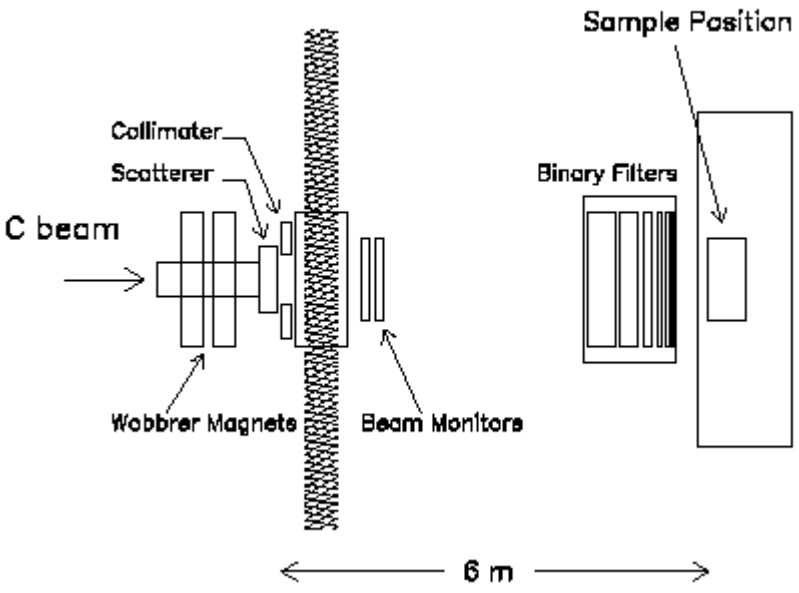
R0: sensitive to m.i.p.

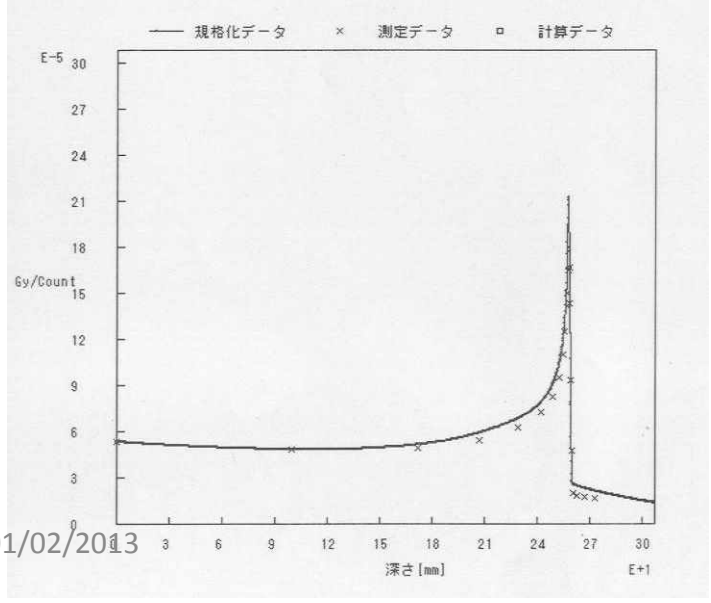
R1: insensitive to m.i.p., sensitive to protons

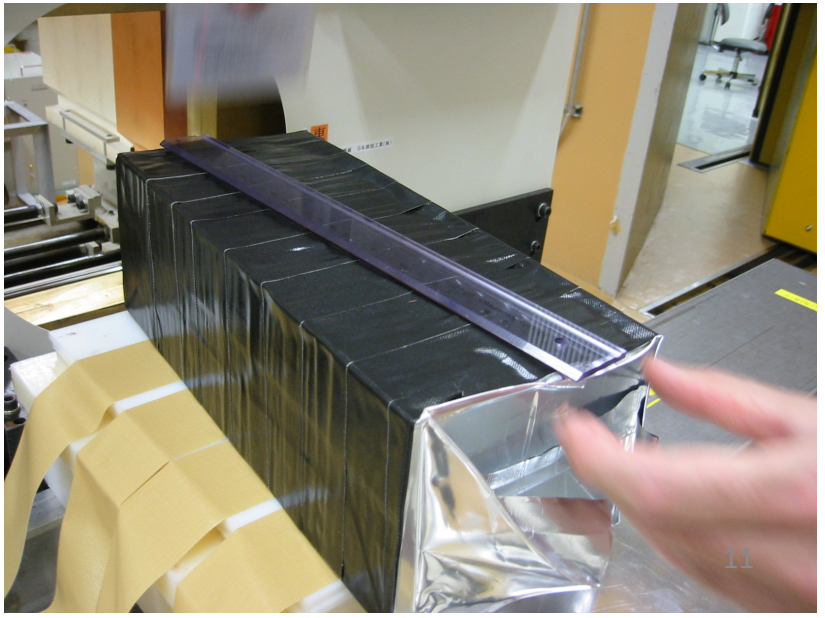
R2: sensitive to He

Carbon exposure at HIMAC (NIRS-Chiba)



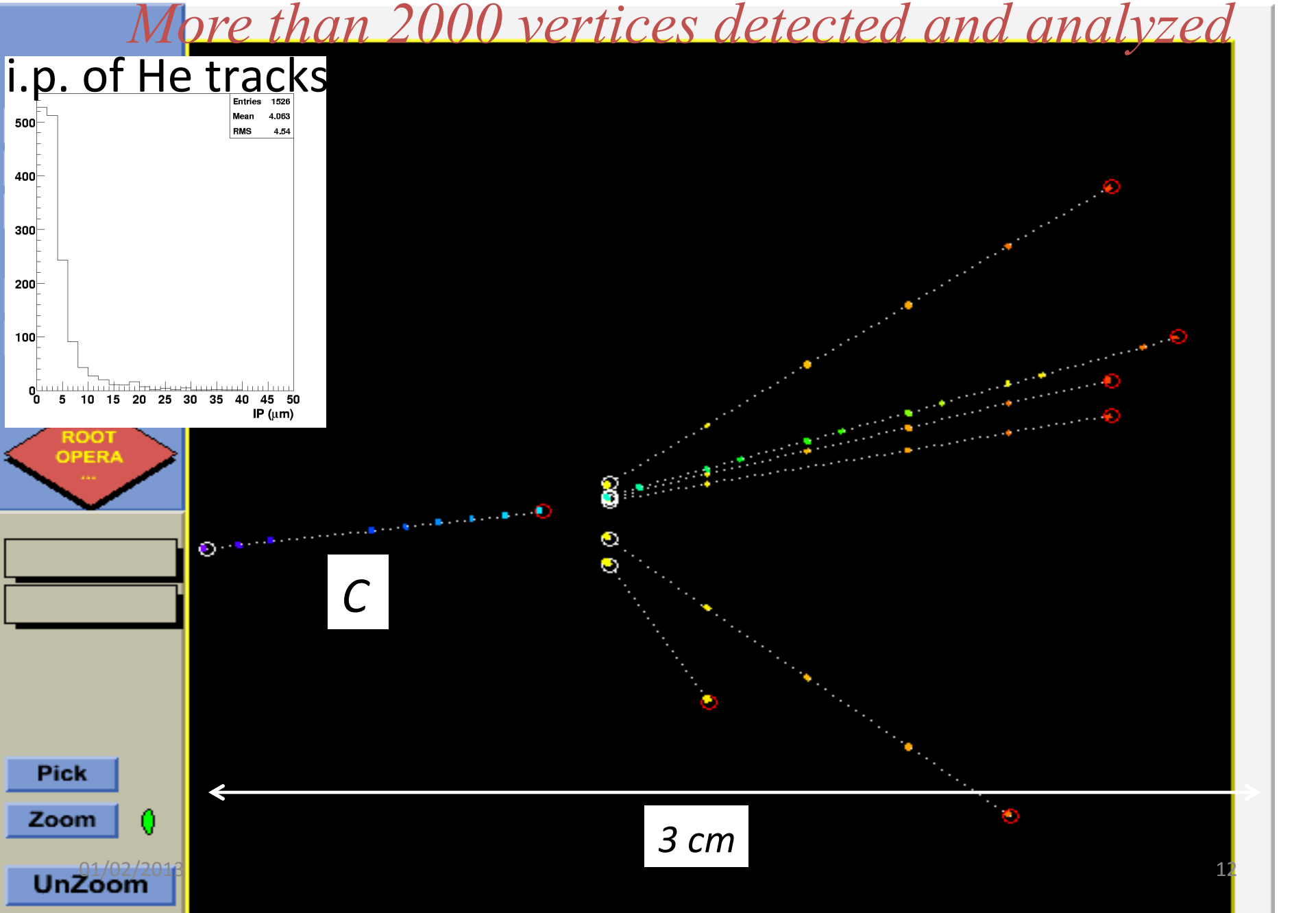




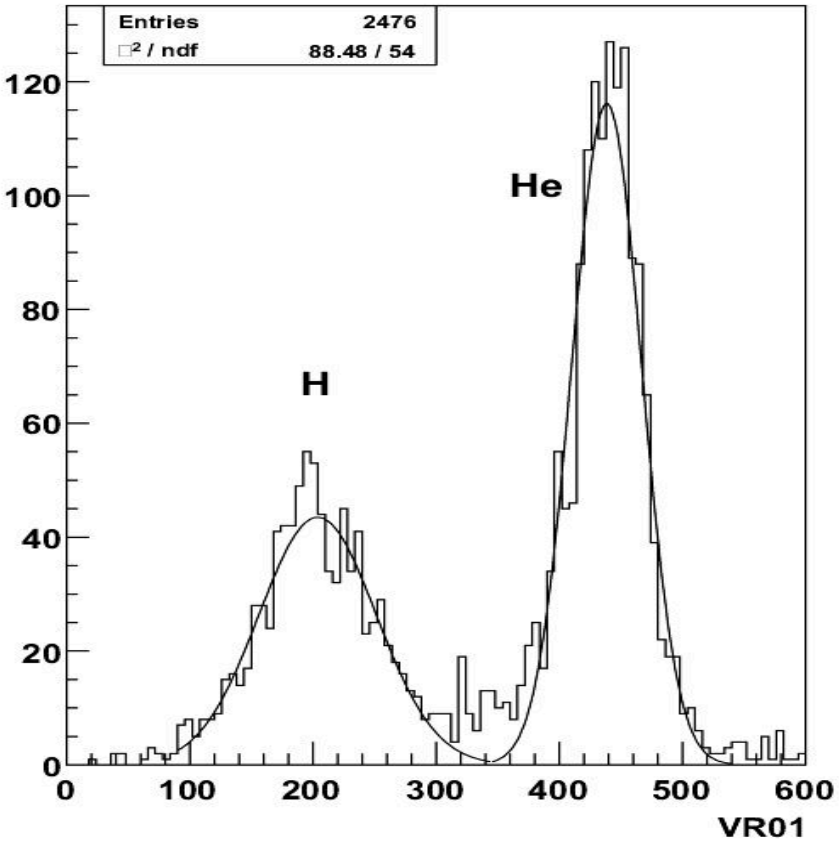


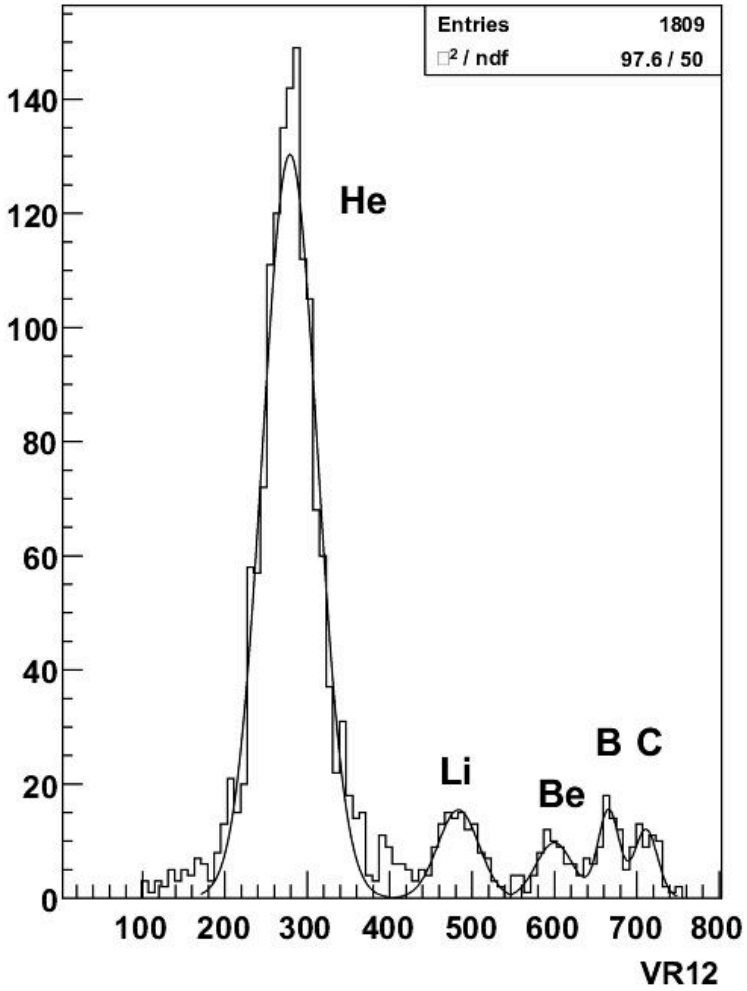
Vertex reconstruction

More than 2000 vertices detected and analyzed



Charge separation





G. De Lellis et al., Journal of Instrumentation 2 (2007) P06004

Charge changing cross-section

G. De Lellis et al. / Nuclear Physics A 853 (2011) 124–134

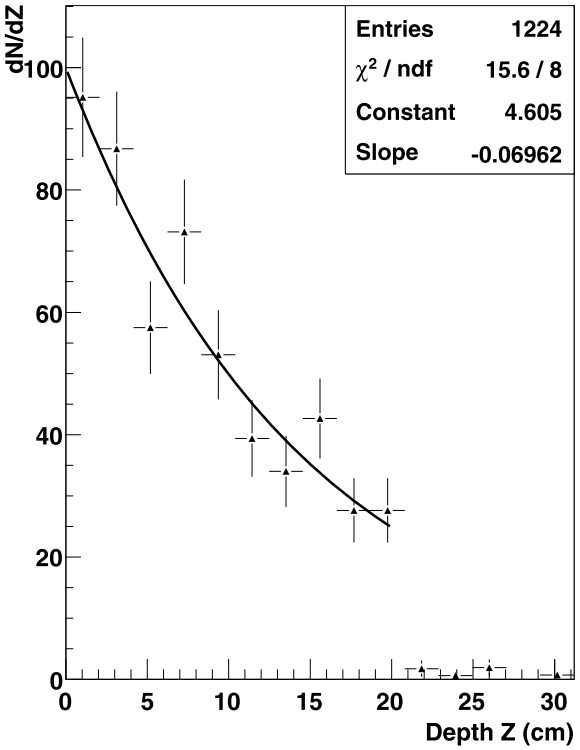


Fig. 2. Fraction of the remnant Carbon beam as a function of the traversed ECC material.

$$\sigma_{tot} = (18420 \pm 380_{stat} \pm 1840_{sys}) \text{ mbarn}$$

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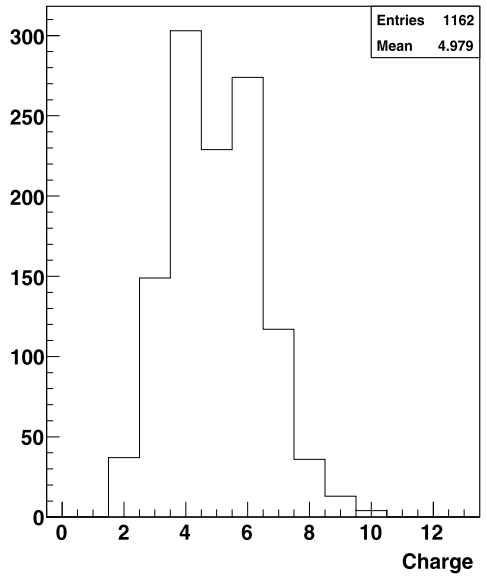


Fig. 4. Distribution of the sum of the absolute values of the electrical charge of the particles associated to multi-pron vertices.

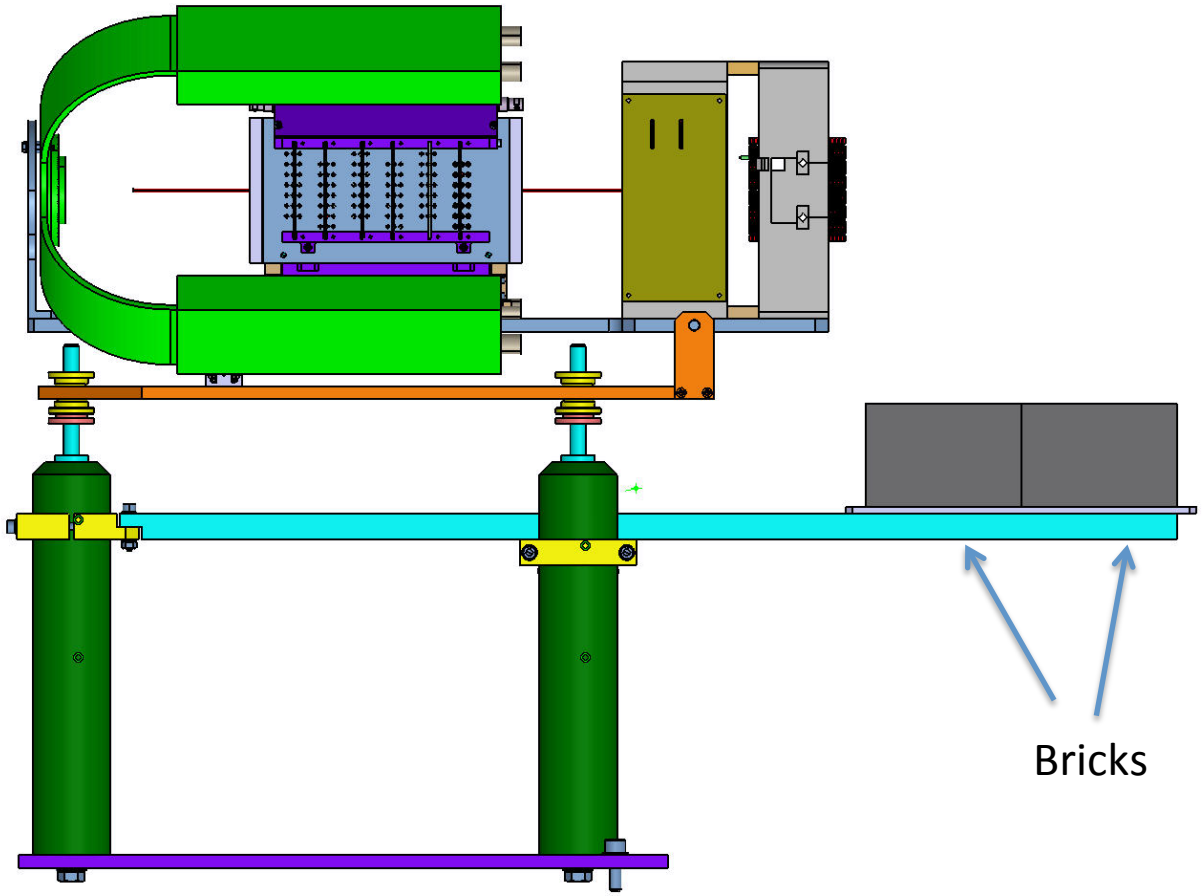
$$\sigma(\Delta z = 1) = (2510 \pm 140_{stat} \pm 250_{sys}) \text{ mbarn}$$

$$\sigma(\Delta z = 2) = (1170 \pm 90_{stat} \pm 120_{sys}) \text{ mbarn}$$

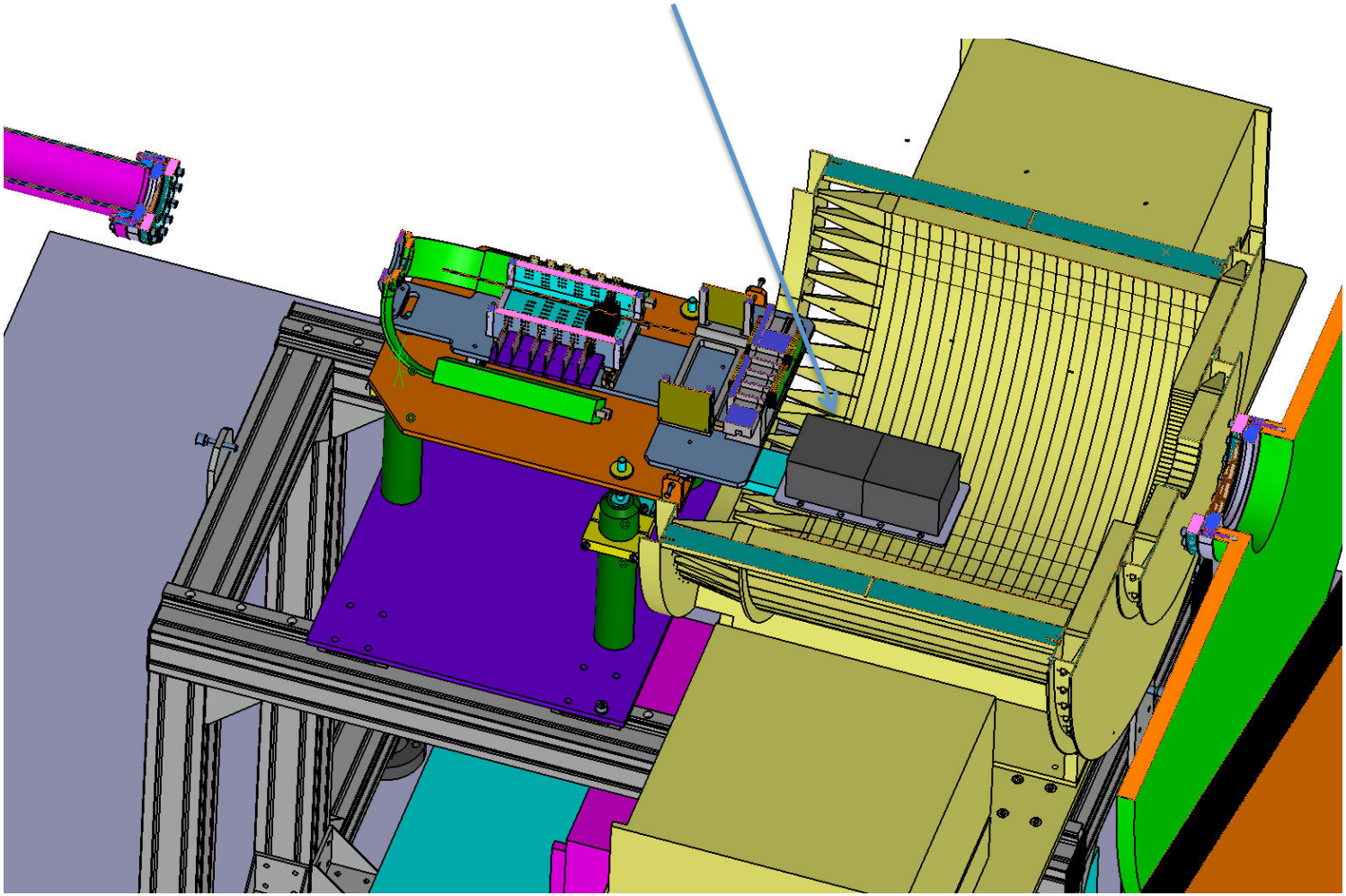
$$\sigma(\Delta z = 3) = (1460 \pm 105_{stat} \pm 150_{sys}) \text{ mbarn}$$

$$\sigma(\Delta z = 4) = (7510 \pm 240_{stat} \pm 750_{sys}) \text{ mbarn}$$

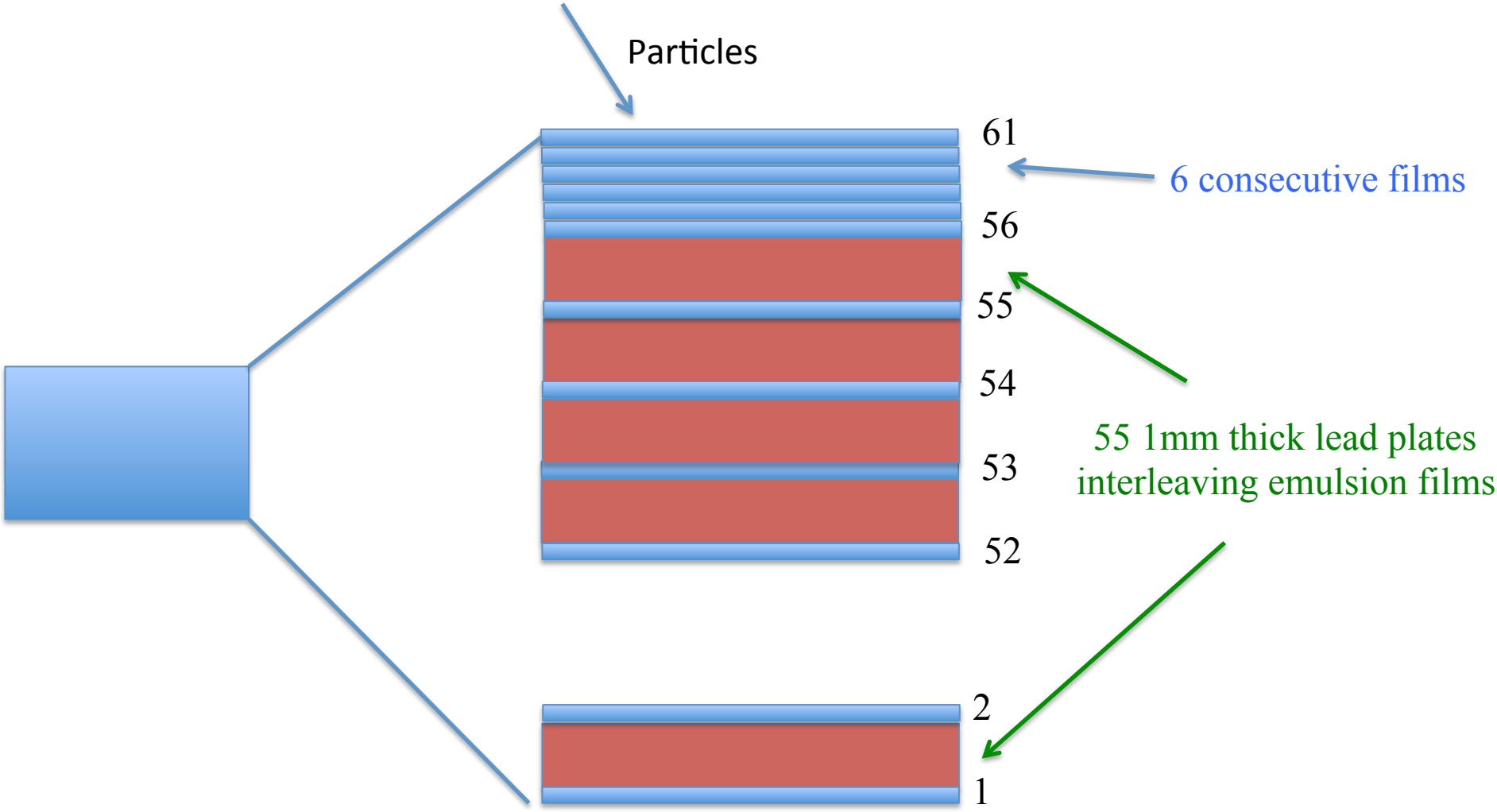
Emulsions in FIRST: Schematic view



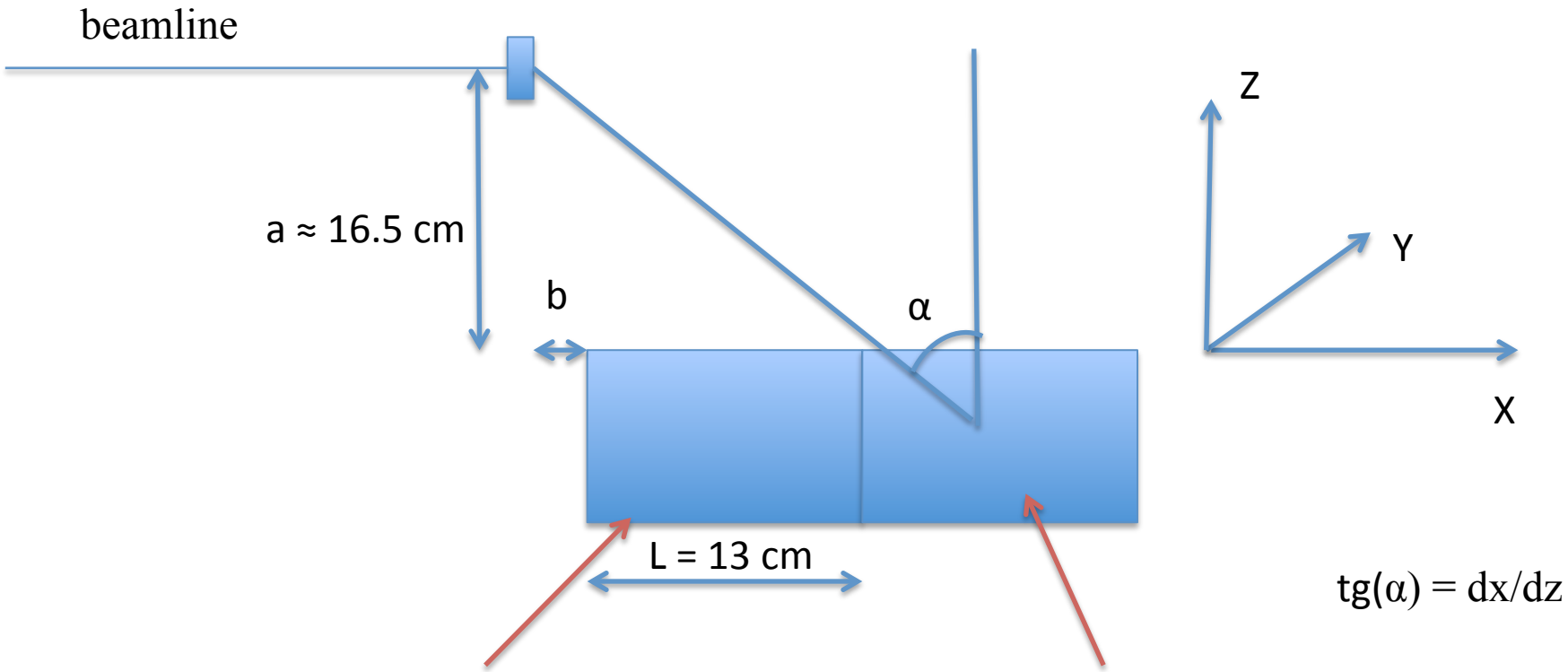
Bricks



Brick structure: 61 films and 55 lead plates



Track slopes expected in emulsion



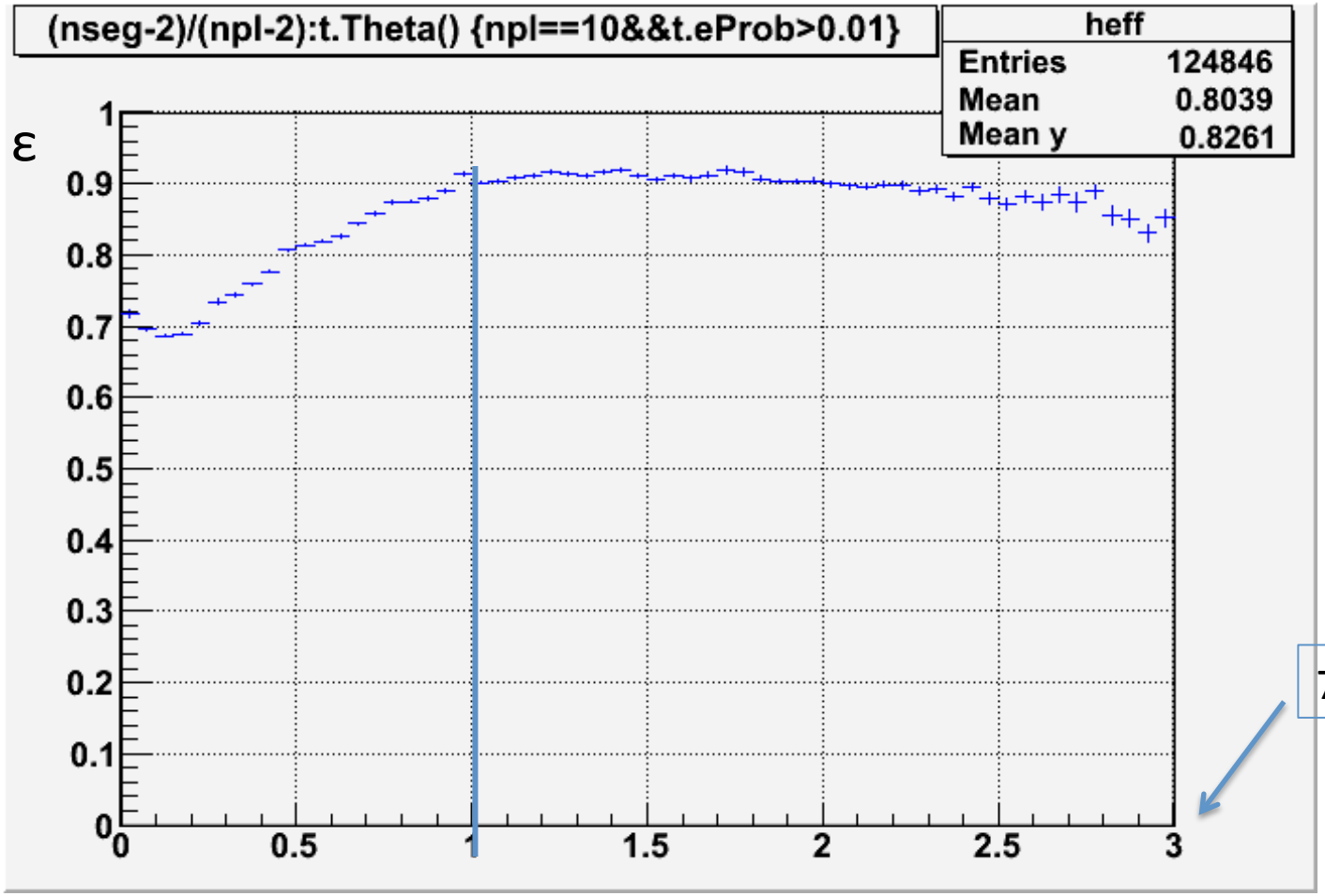
$tg(\alpha) = dx/dz$

brick 2
$b/a \leq tg(\alpha) \leq (b+l)/a$

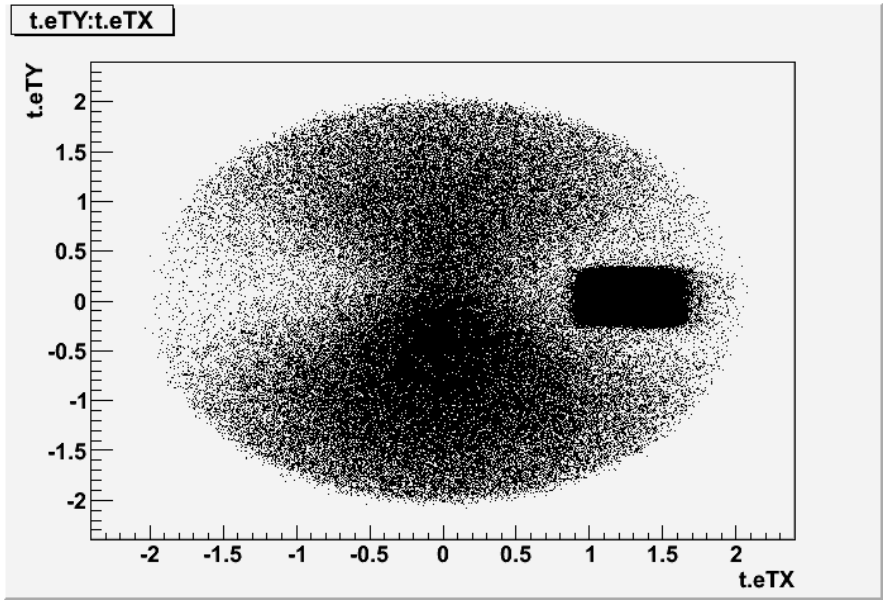
brick 1
$(b+l)/a \leq tg(\alpha) \leq (b+2l)/a$

$tg(\alpha) > 1 \rightarrow \alpha > 45$ degrees
Typical values in high energy physics: $tg(\alpha) < 0.6$

Dedicated study on Large angle track detection



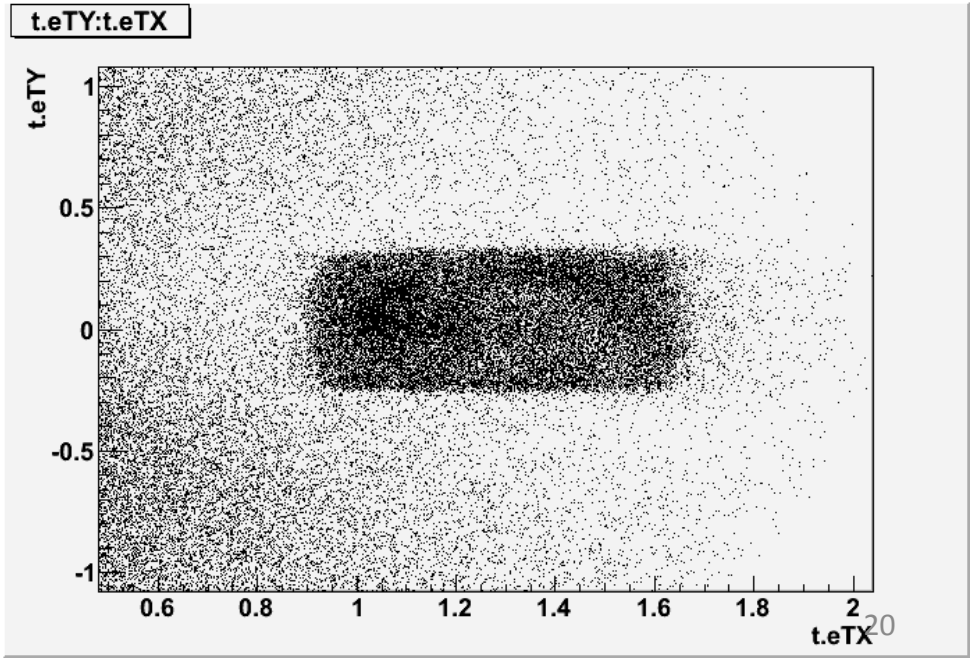
Brick 1: preliminary results



Scanning of 4 emulsion films (slope ≤ 2)

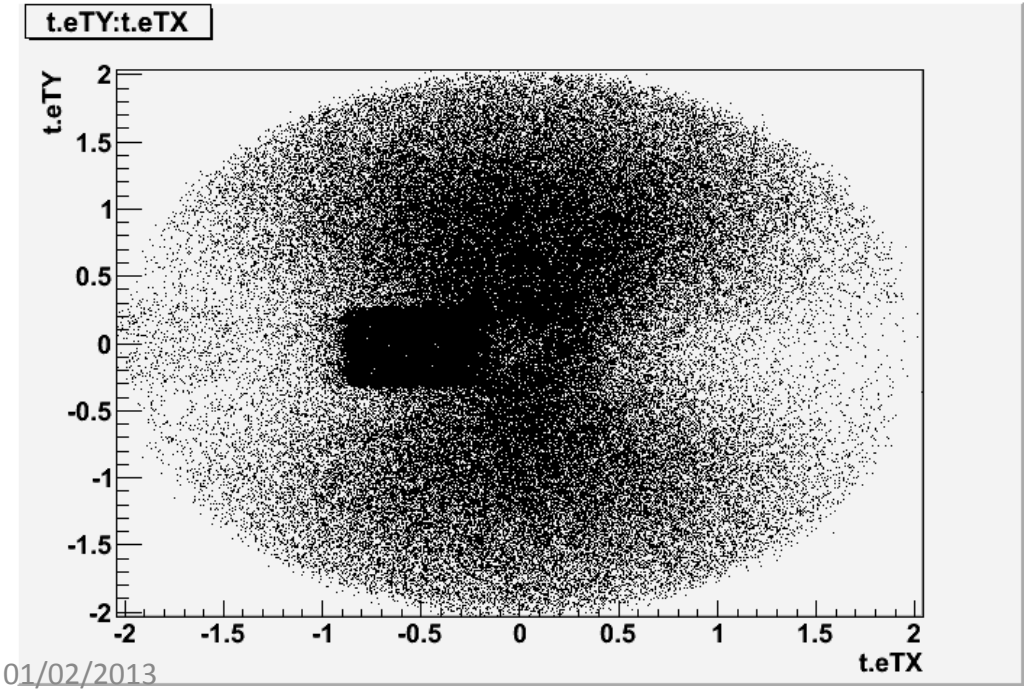
Tracks angular distribution of films 61÷58

Peak signal selection



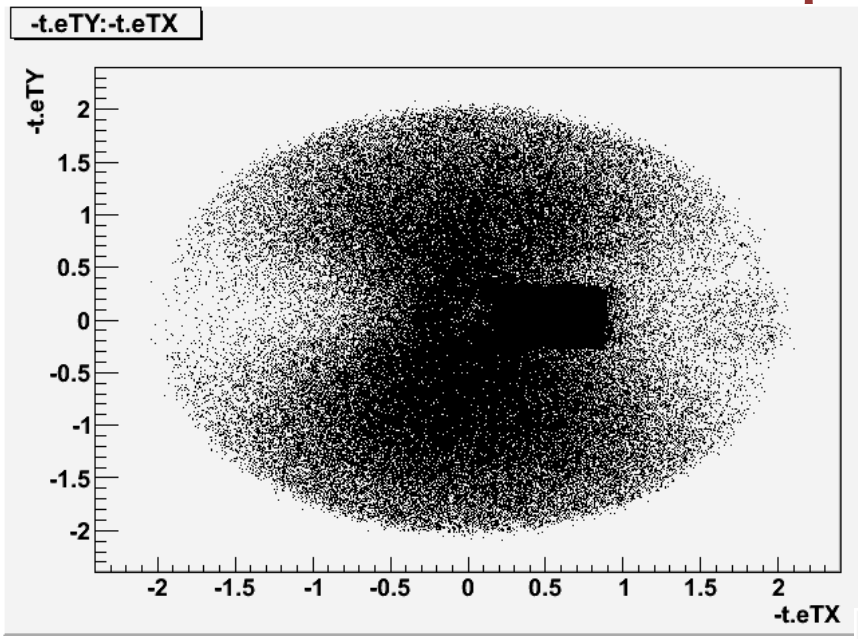
Scanning of brick 2

- 3 most upstream films



brick rotated by 180 degrees
w.r.t. the other one

Brick 2: preliminary results

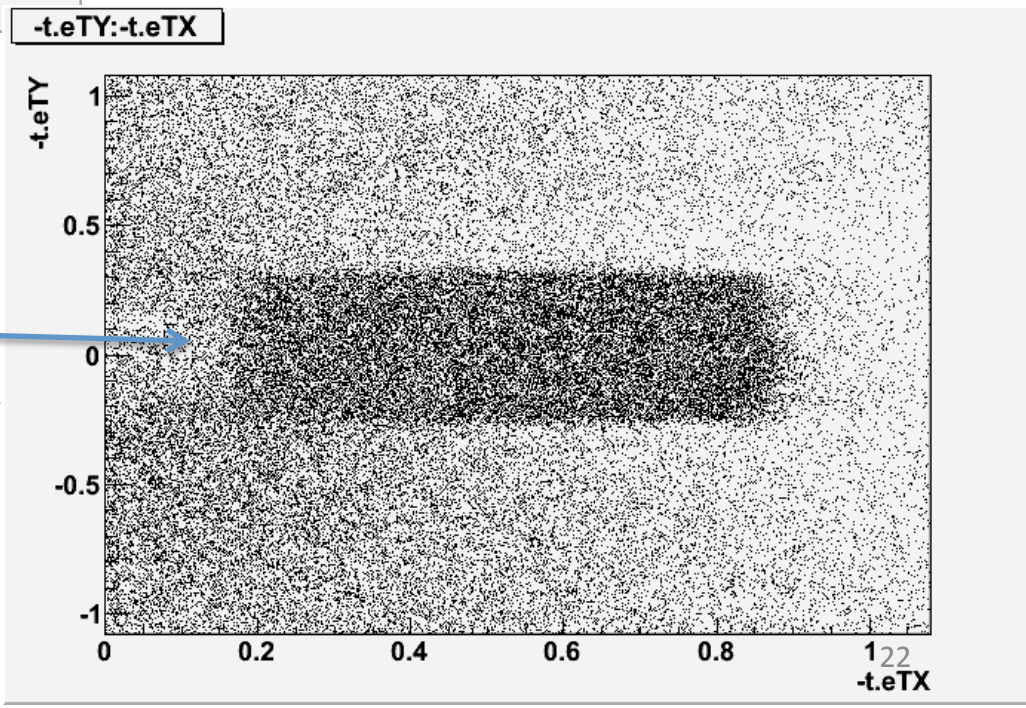


Scanning of 3 emulsion films (slope ≤ 2)

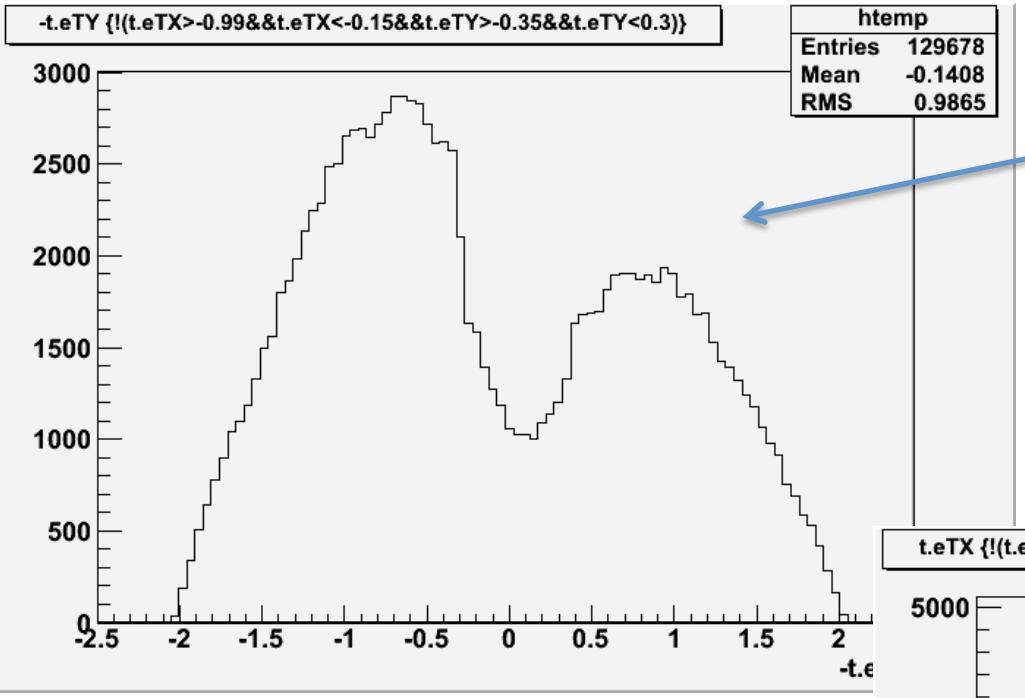
Tracks angular distribution of films 61÷59

274 trks/cm^2 (nseg>=2)

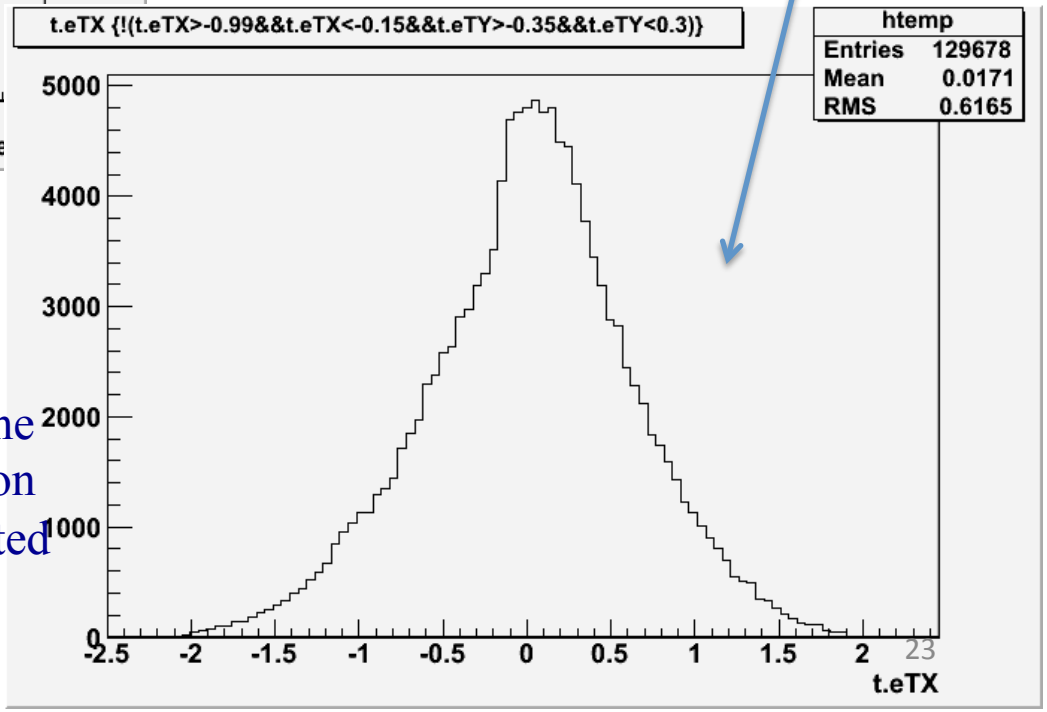
Contribution from cosmic-rays included



Cosmic-ray angular distribution



- Films transported from Gran Sasso to CERN
- Brick assembled at CERN
- Cosmic-ray integrated during the transportation of the brick from CERN to GSI and from GSI to Gran Sasso
- Brick disassembled and film developed at Gran Sasso



Cosmic-rays taken with the films inside the brick in the same geometrical configuration as for the beam at GSI, with the brick rotated by 90 degrees to minimize the flux

Conclusions

- Scanning of very large angle tracks is now routinely done
- First look at the films exposed at GSI in Summer 2011
- To be done:
- Define tracks by the first 6 consecutive films
- Analysis of the films interleaved with lead to measure the properties of these tracks and try the particle identification (proton/alpha)