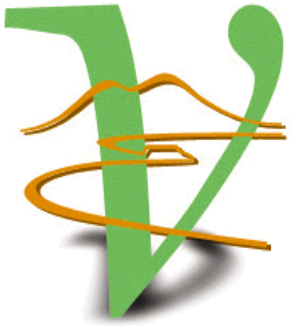


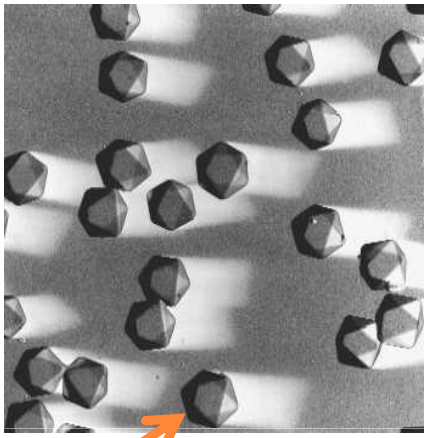
La microscopia automatica ad altissima velocità

Valeri Tioukov

INFN Napoli

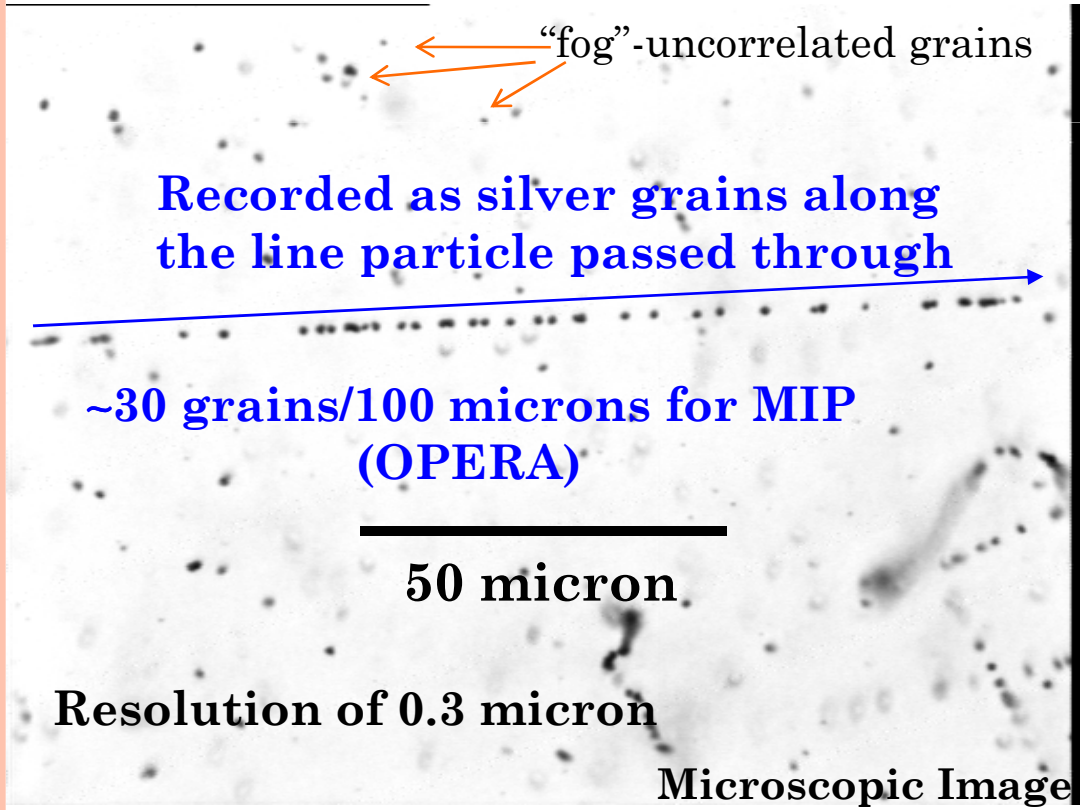
NUCLEAR EMULSION AS SENSITIVE MEDIA FOR CHARGED PARTICLES

After charged particle pass through the emulsion layer the latent image remaining
After the emulsion chemical developing the Ag grains becomes visible with the optical microscope



AgBr crystal, size 0.2-0.3 micron

Is the elementary detection element



Nuclear emulsions used for more them 100 years in Particle Physics

EMULSION ANALYSIS EVOLUTION

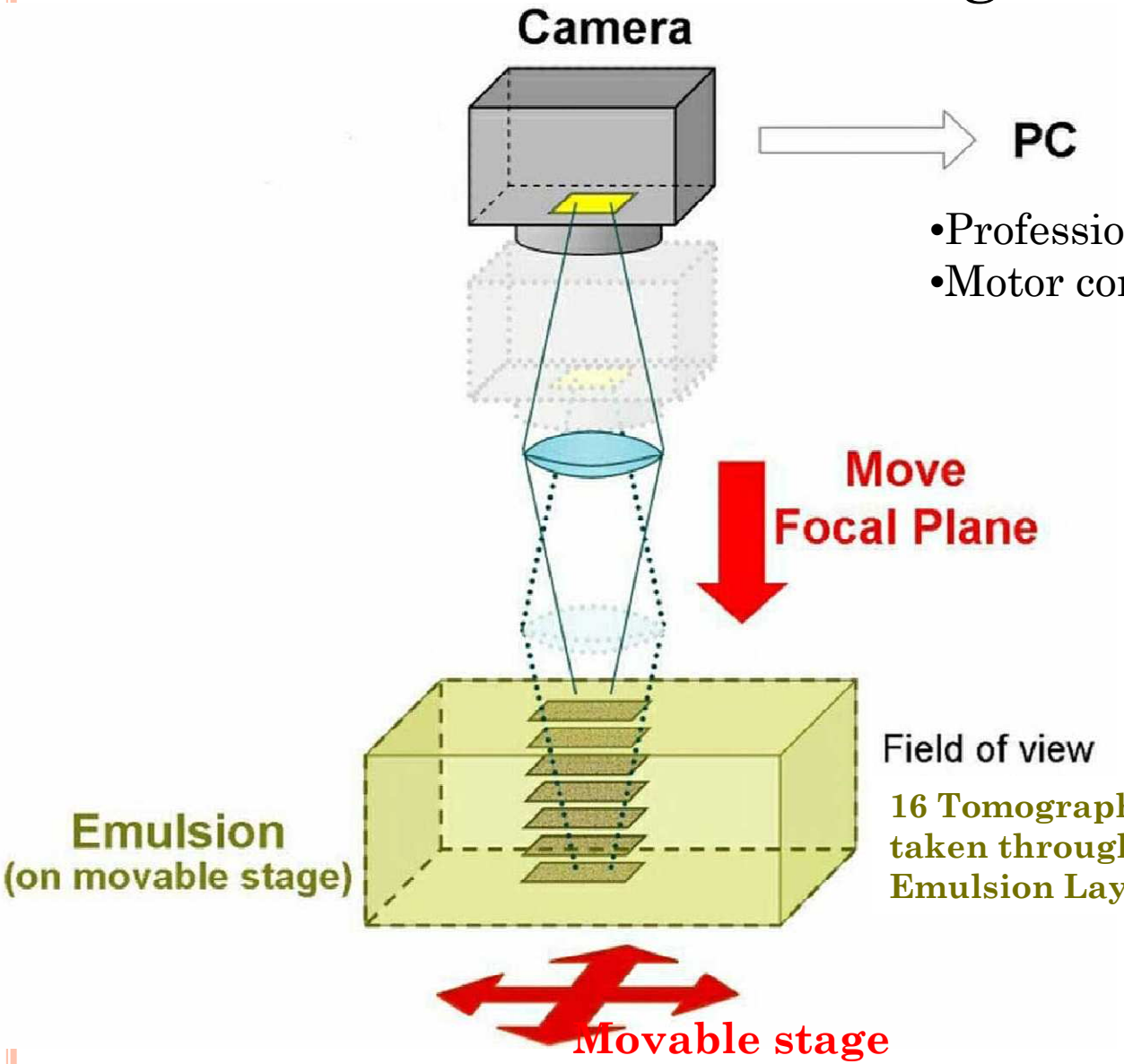
Before 1974 – the only way to find the charged particle tracks and decays in the nuclear emulsions was the eye inspection using manual microscopes

1974 K. Niwa: Track recognition by superimposing tomographic images from different focal planes

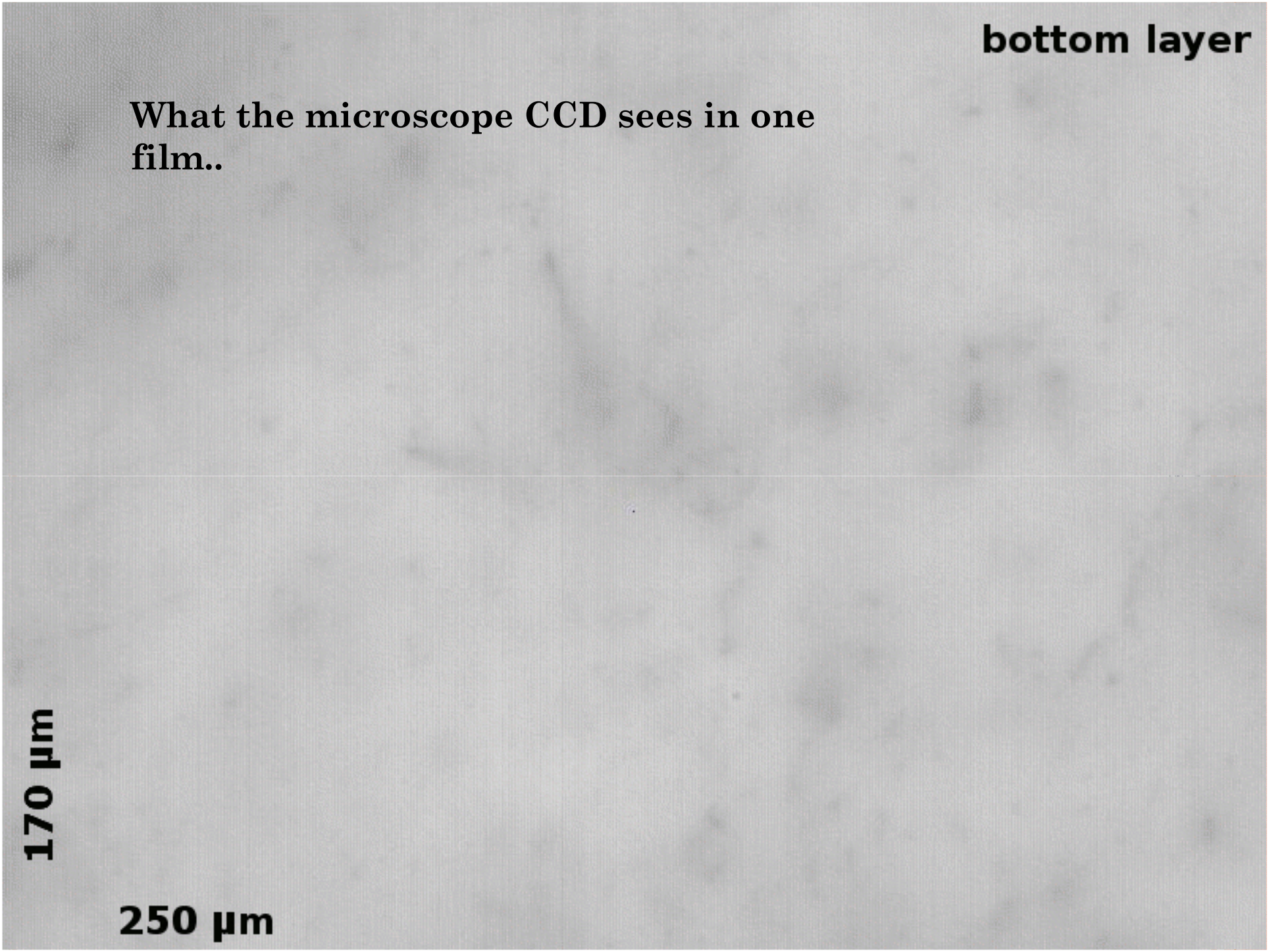
This was the first idea of the automatic scanning but the digital technology was not ready yet in that time
(the first Digital Camera -1975)

- 1980 – First semi-automatic scanning (Nagoya)
- 1985 – "Track Selector" (TS) the first automatic scanning system based on tomographic image processing. Started TS-NTS-UTS-SUTS development line (Nagoya)
- 1994 – CHORUS data analysis – Napoli group enter into scanning business: 2 microscopes equipped with NTS systems arrive to Naples
- 2004 – the first prototype of the European Scanning System dedicated for OPERA scanning operational in Naples, developed in collaboration with other Italian groups

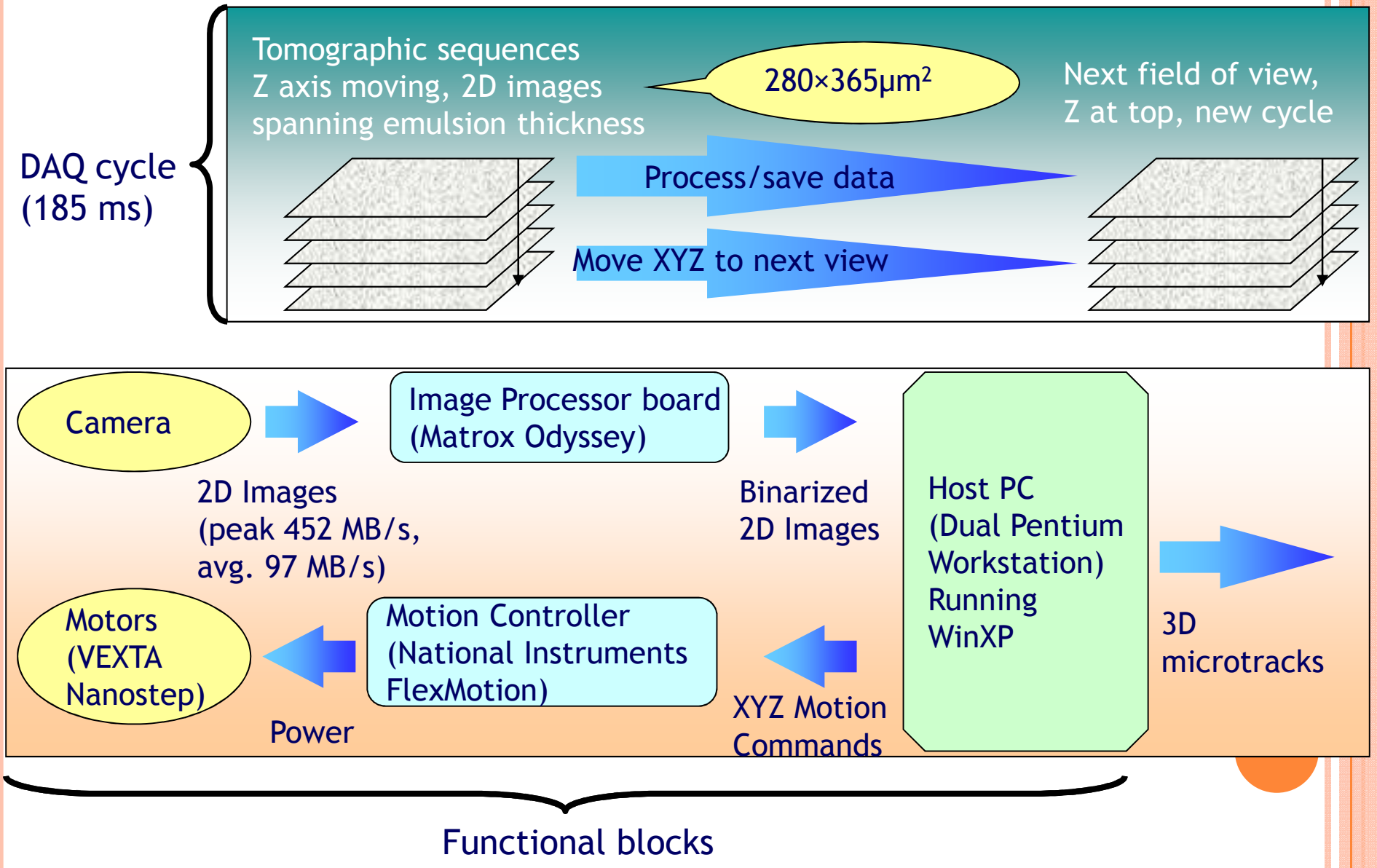
Principle of the automatic emulsion scanning



- Professional Image Processing board
- Motor control card

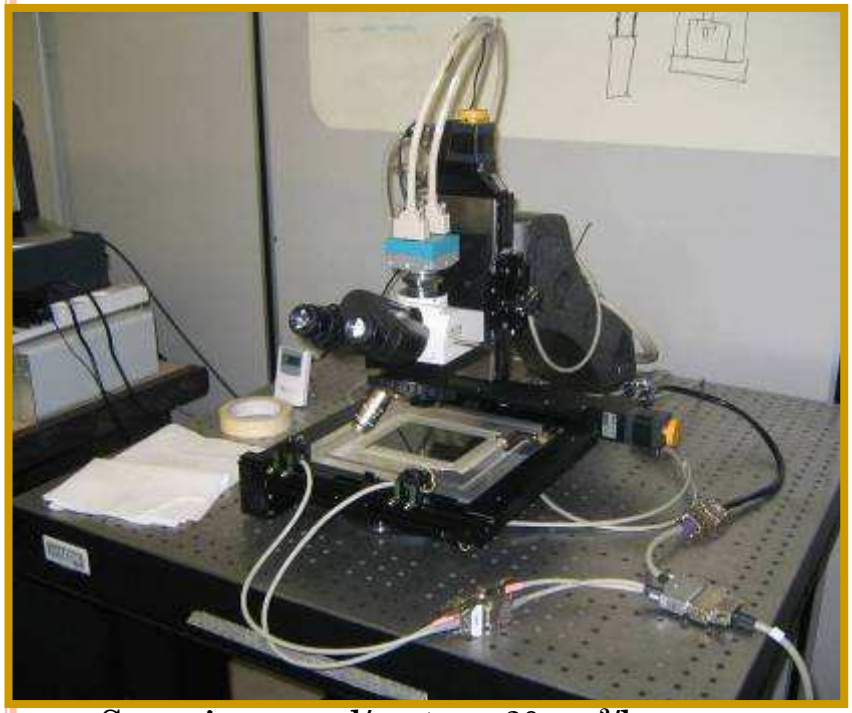

bottom layer
What the microscope CCD sees in one film..
170 µm
250 µm

Data (images) processing and motion control flow in the European Scanning System



OPERA AUTOMATIC SCANNING SYSTEMS

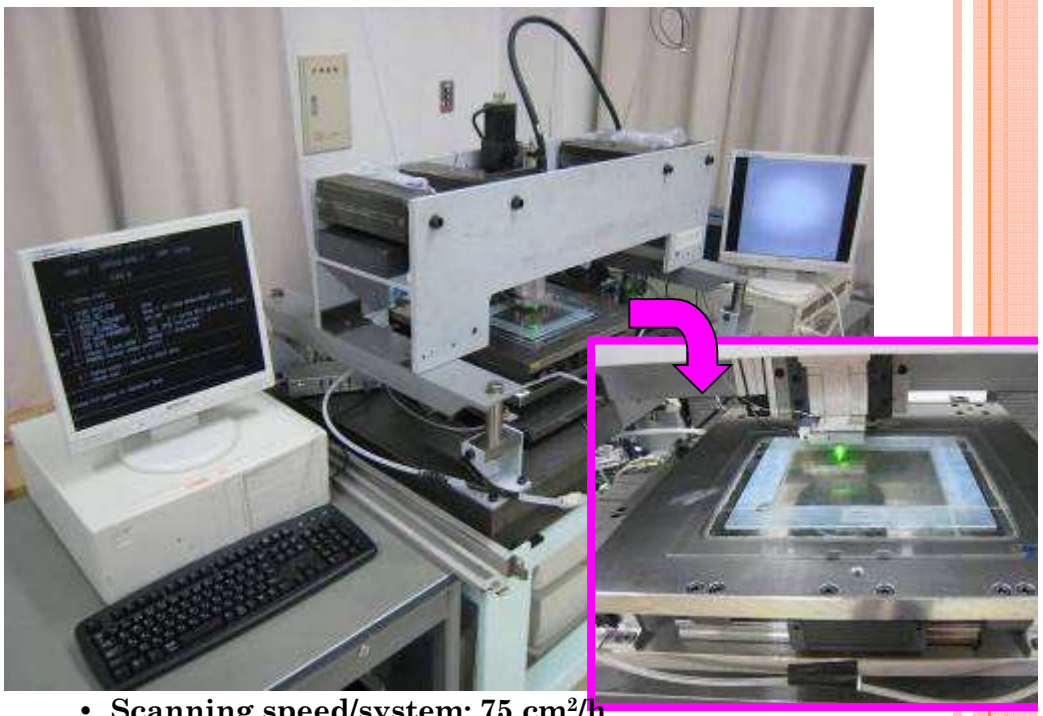
EU: ESS (European Scanning System)



- **Scanning speed/system: 20 cm²/h**
- **Customized commercial optics and mechanics**
- **Asynchronous DAQ software**

Relatively cheap and easy to clone

Japan: SUTS (Super Ultra Track Selector)



- **Scanning speed/system: 75 cm²/h**
- **High speed CCD camera (3 kHz), Piezo-controlled objective lens**
- **FPGA hard-coded algorithms**

Expansive system based on home-made Image processing electronics

Both systems demonstrate:

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

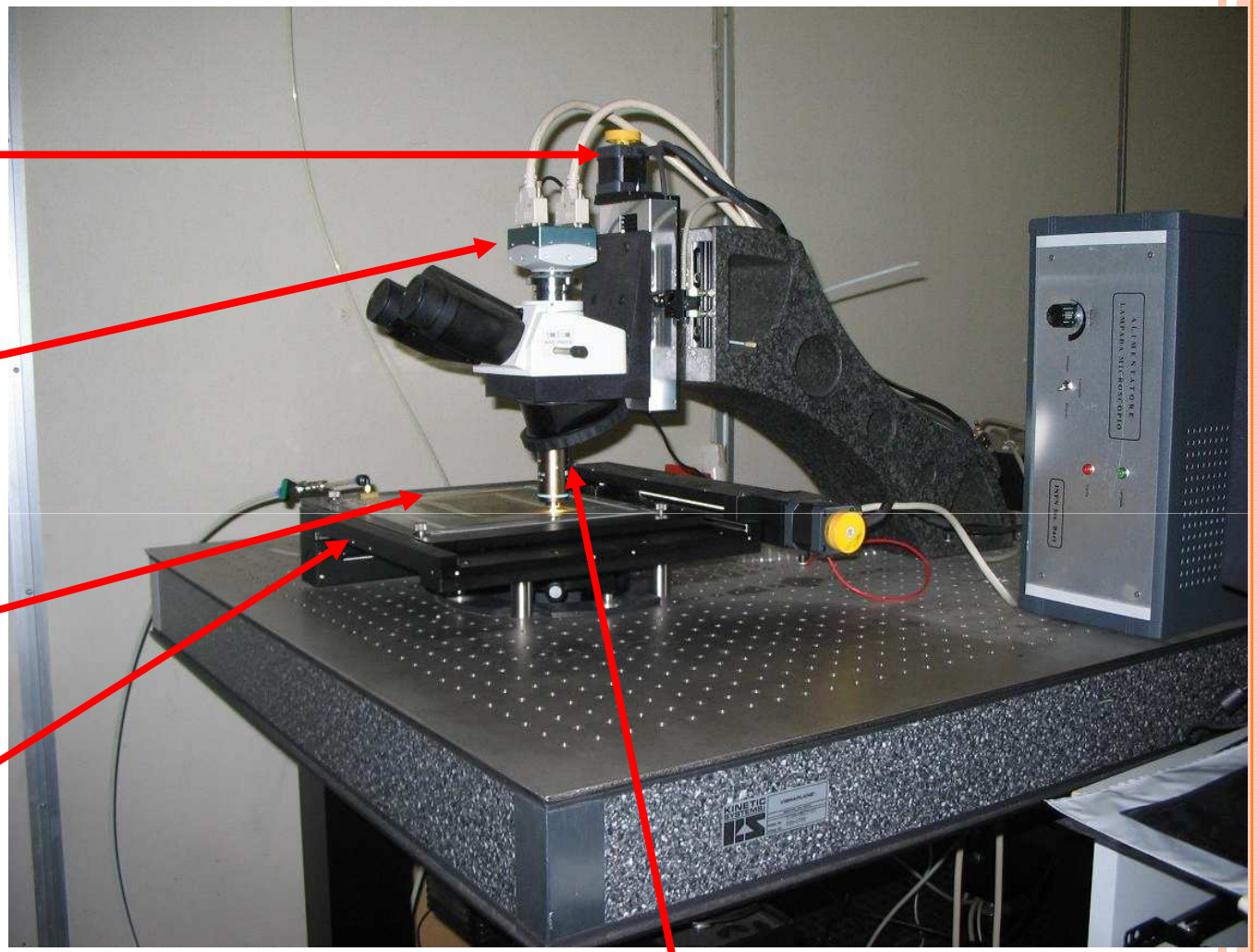
CLOSER VIEW TO THE ESS

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)

OPERA SCANNING SYSTEMS

Napoli: 5, Bern: 5, Bari: 4
Salerno: 4, Bologna: 4
Padova: 1, Frascati : 2
LNGS: 10 (CS interface films scanning)

Total scanning power: ~ 700 cm^2/h

Nagoya: 4 systems (75 cm^2/h)
1 systems (20 cm^2/h)
5 sub systems (1 cm^2/h)

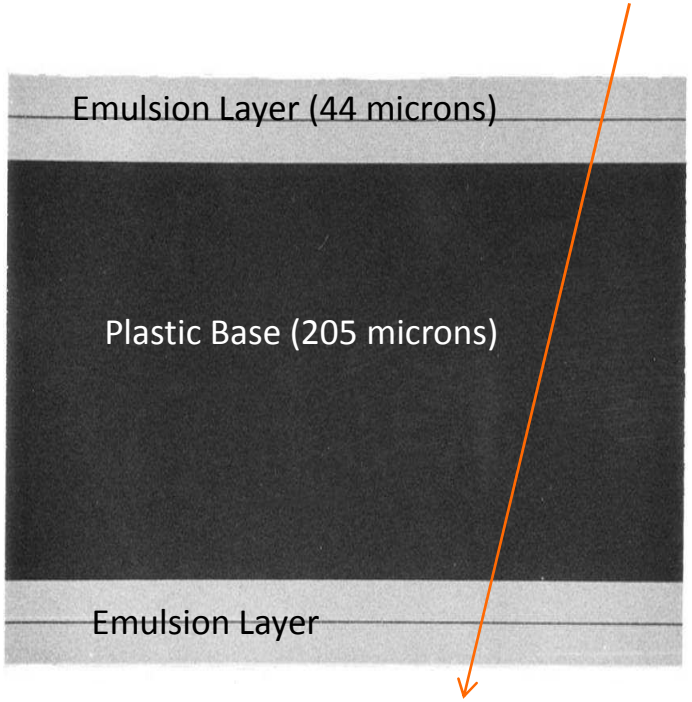
Total scanning power: ~ 350 cm^2/h

OPERA EMULSIONS

OPERA industrial emulsions from FujiFilm

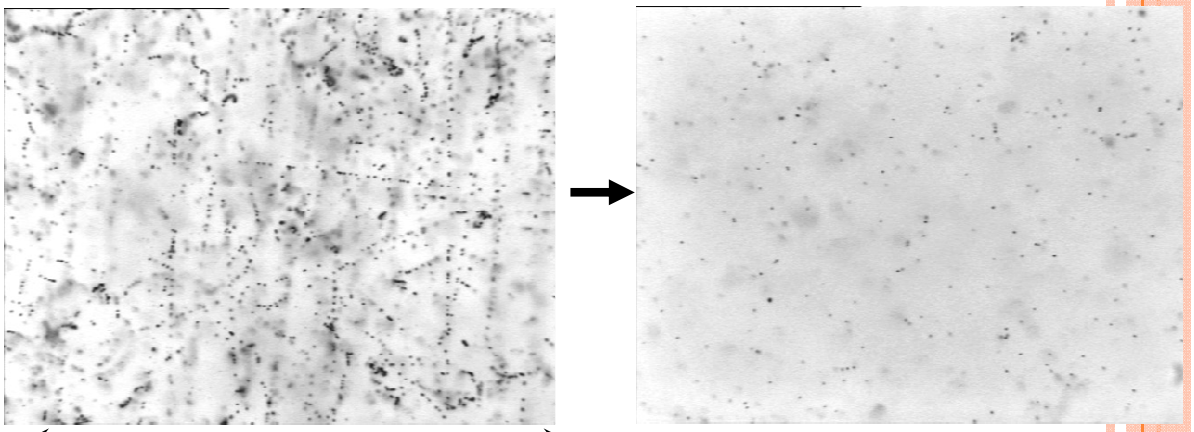
• High sensitivity – tuned for MIP detection
• The AgBr density in the OPERA emulsions is higher in respect to the commercial films
•Special R&D for OPERA: the double pouring procedure

Emulsions are continuously sensitive detector ALL charged particle (cosmic rays, natural radioactivity, etc..) recorded as latent images. They can be partially cancelled by the "refreshing" procedure (high temperature and humidity) applied just before the detector assembling
Refreshing was an R&D for OPERA films



Before refreshing
>30 tracks/mm^2 bg

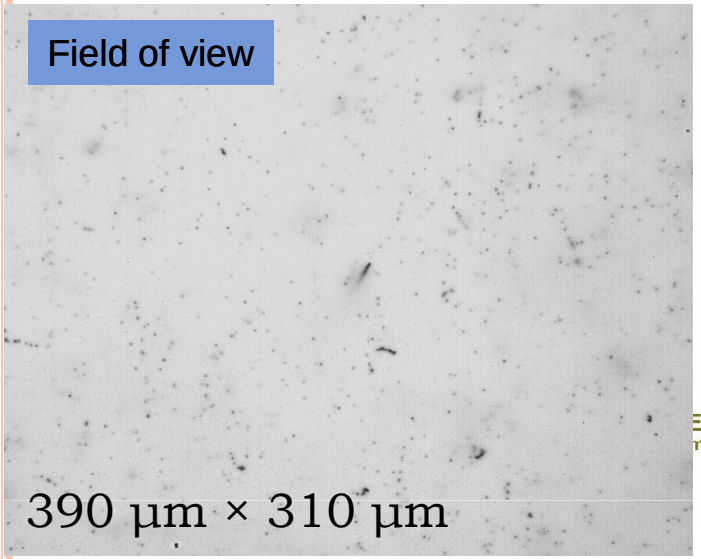
After refreshing
~1 tracks/mm^2 bg

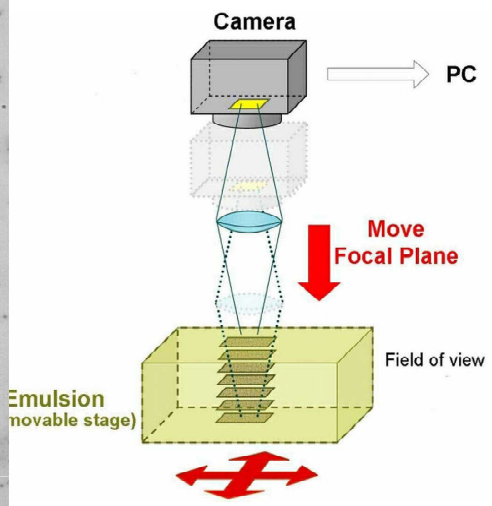


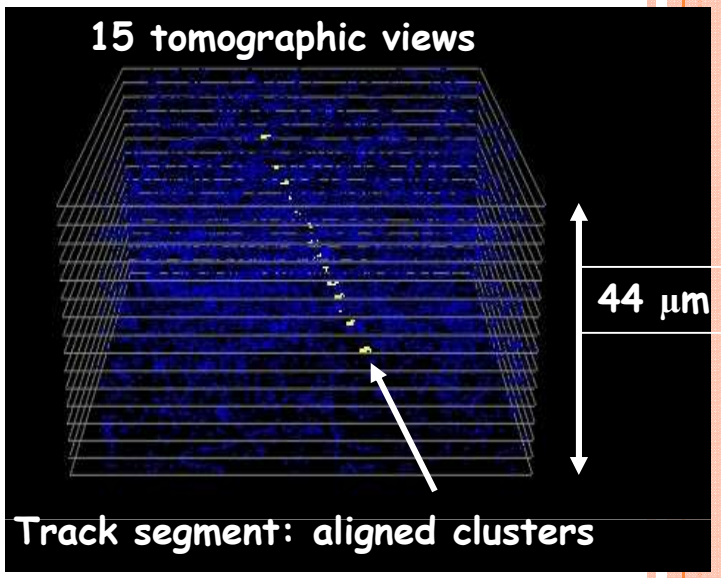
SOME NUMBERS CONCERNING THE OPERA SCANNING

- Emulsion can be considered as a multi-layer optical storage media (like a DVD disk) with the storage capacity of about 1 Tb/100 cm^2 (images level without data reduction)
- The mean area to be scanned per OPERA event is 200 cm^2
- Considering 20000 events to process the full area to be scanned is 400 m^2 of the emulsion surface
- With the old manual scanning the total tracks search in a wide angular range was rarely used. The human scanning performance for this kind of data is ~ 1 mm^2/hour
- So if the lady from the 3-d slide decides to analyze manually the full OPERA data it would takes her about 40000 years

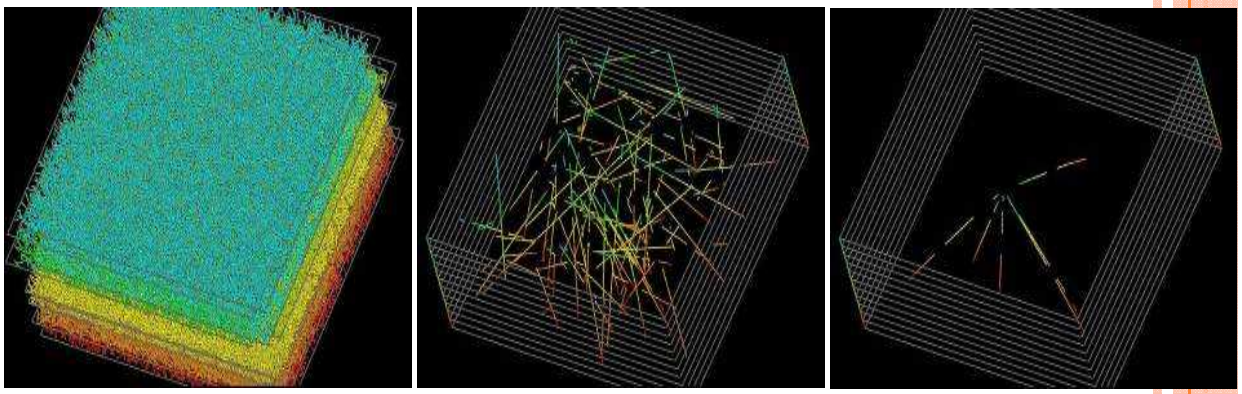
EMULSION DATA ANALYSIS OVERVIEW







- Images -> microtracks
- Microtracks->basetracks
- Plate-to-plate alignment
- Long tracks reconstruction
- Vertex location
- Event analysis



Volume scan data (basetracks)

Passing-through and short tracks rejected

Vertex located in the brick

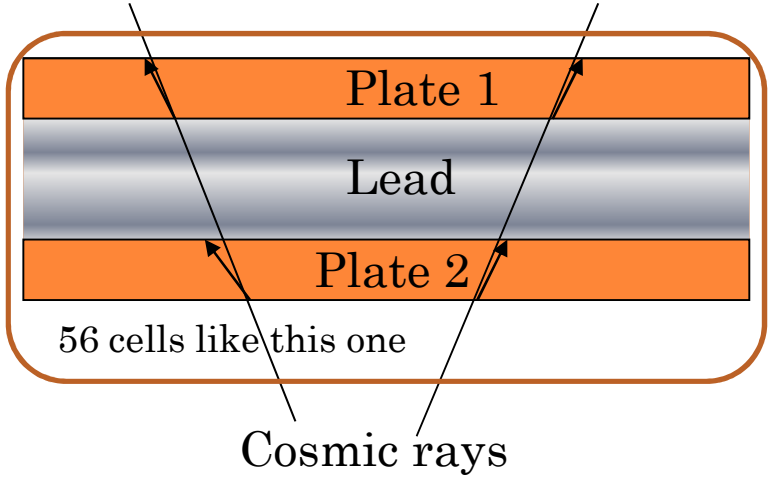
The full offline processing chain for the emulsion data was developed in Napoli (FEDRA system)

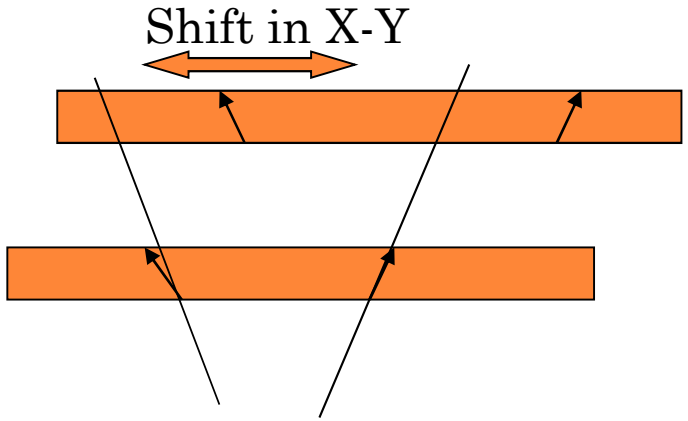
ECC VS ELECTRONICS DETECTOR
FROM THE DATA ANALYSIS POINT OF VIEW

- No time stamp in the emulsion data – all charged particles passing through the emulsion plate leave tracks. How to find the correct one in different emulsions plates?? Main background sources:
  - Cosmic rays accumulated during the transportation from Japan to Italy
  - Environment radioactivity products (present always and everywhere)
  - Instrumental background (random coincidences of the fog grains)
- The signal/noise ratio in one emulsion plate looks extremely low: we are interested in 1-10 segments of the neutrino event over 10000 of the background ones (the typical values)
- The intrinsic emulsion accuracy is extremely high: 0.3 micron but is it really possible to reach this value??
  - The positioning accuracy of the plates in the brick is ~100 microns
  - Emulsions are created with gelatin layers poured on the thing plastic foil – them subject to the mechanical and temperature surface deformations up to 10 microns/cm
- The solution for most of this problems is based on the special cosmic rays exposure of the ***assembled emulsion brick*** after the extraction from the detector

EMULSION PLATES ALIGNMENT USING THE COSMIC RAYS TRACKS

Emulsion plates in the assembled brick





1. Shift in X-Y
2. Shift in Z
3. Small rotation around Z-axis
4. Small expansions
5. Several alignment patterns are possible

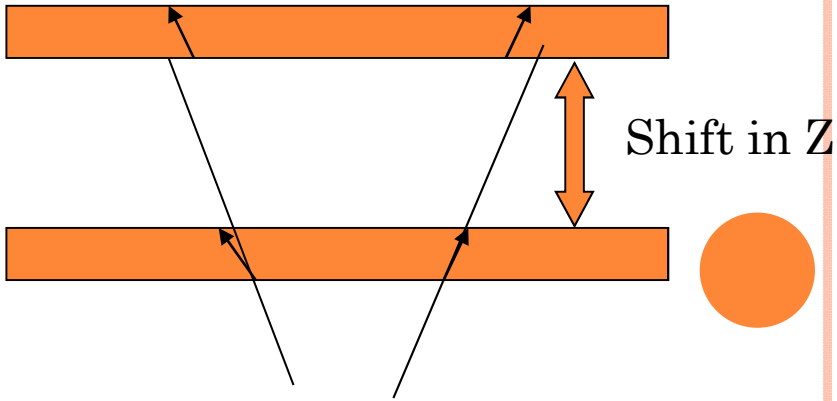
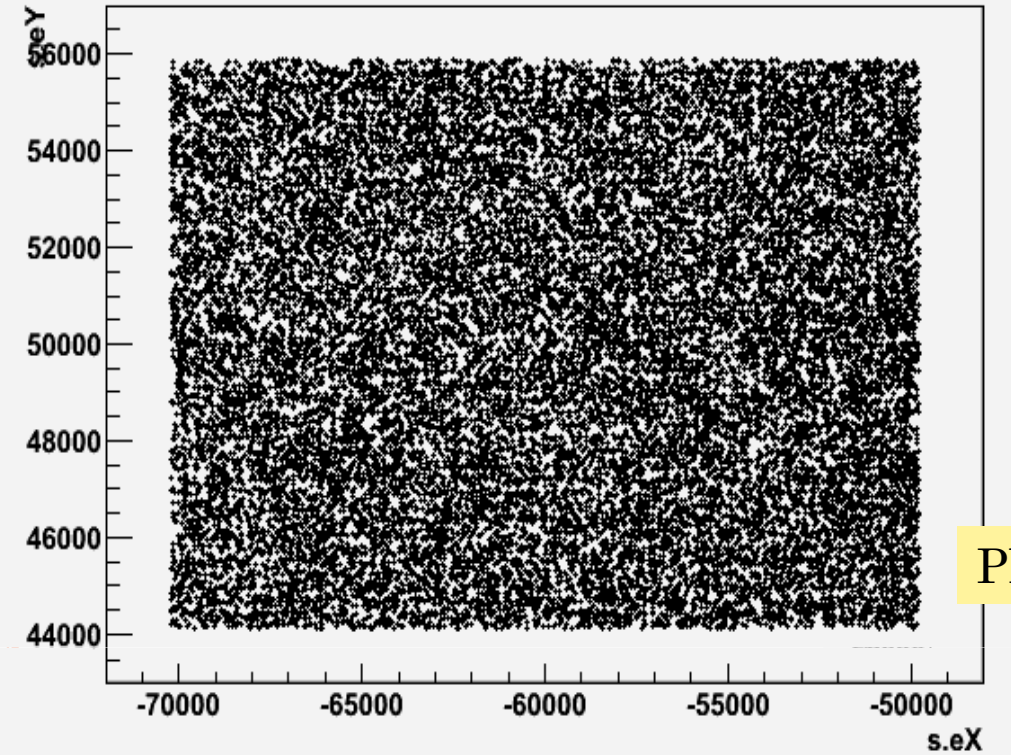


Plate 1 26306 basetracks in 2x2 cm^2



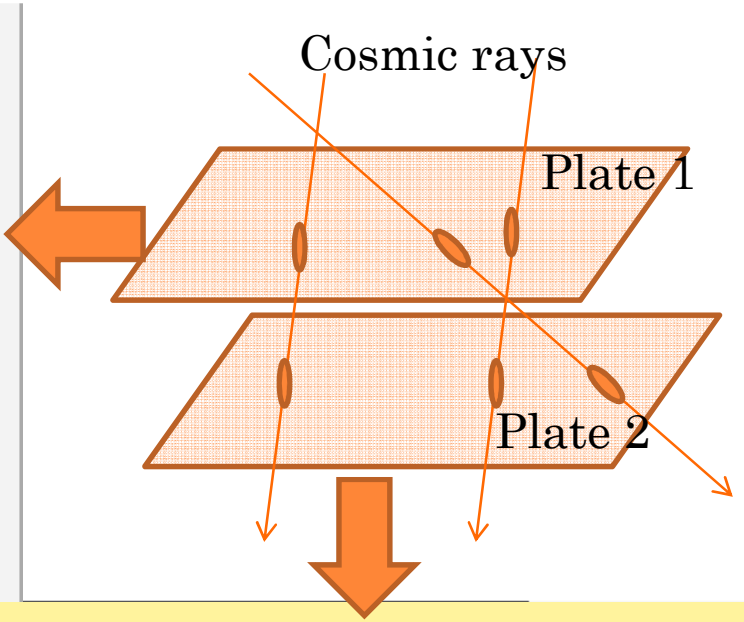
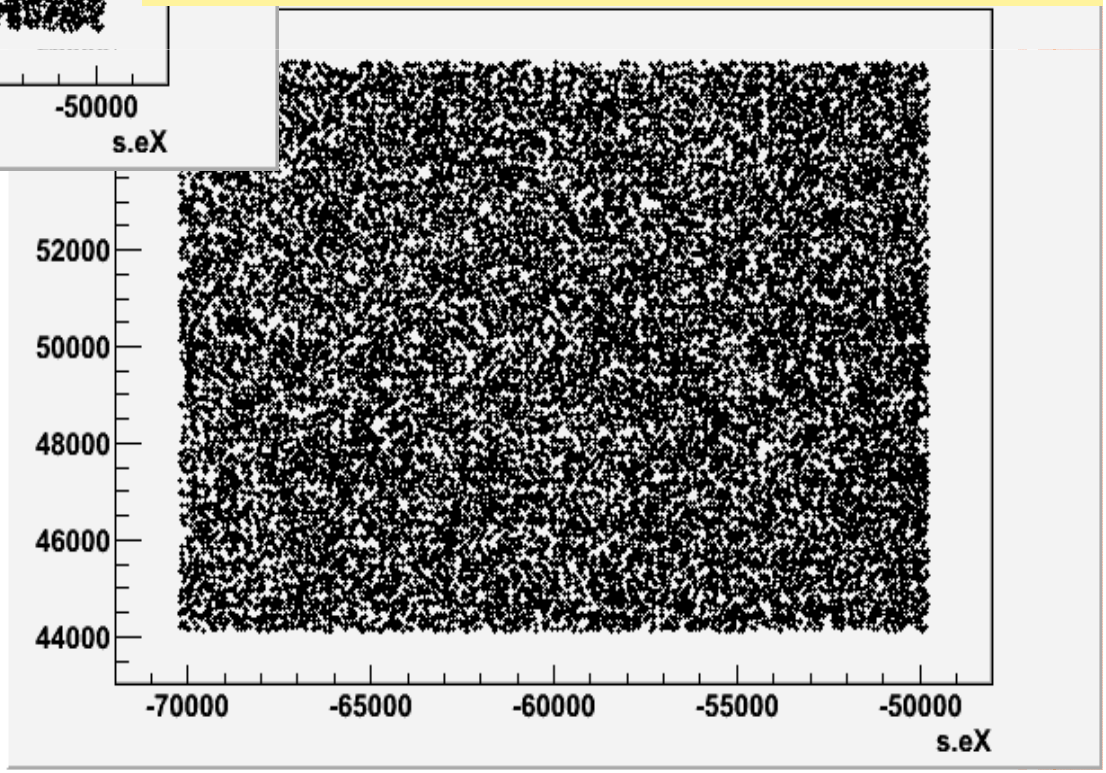


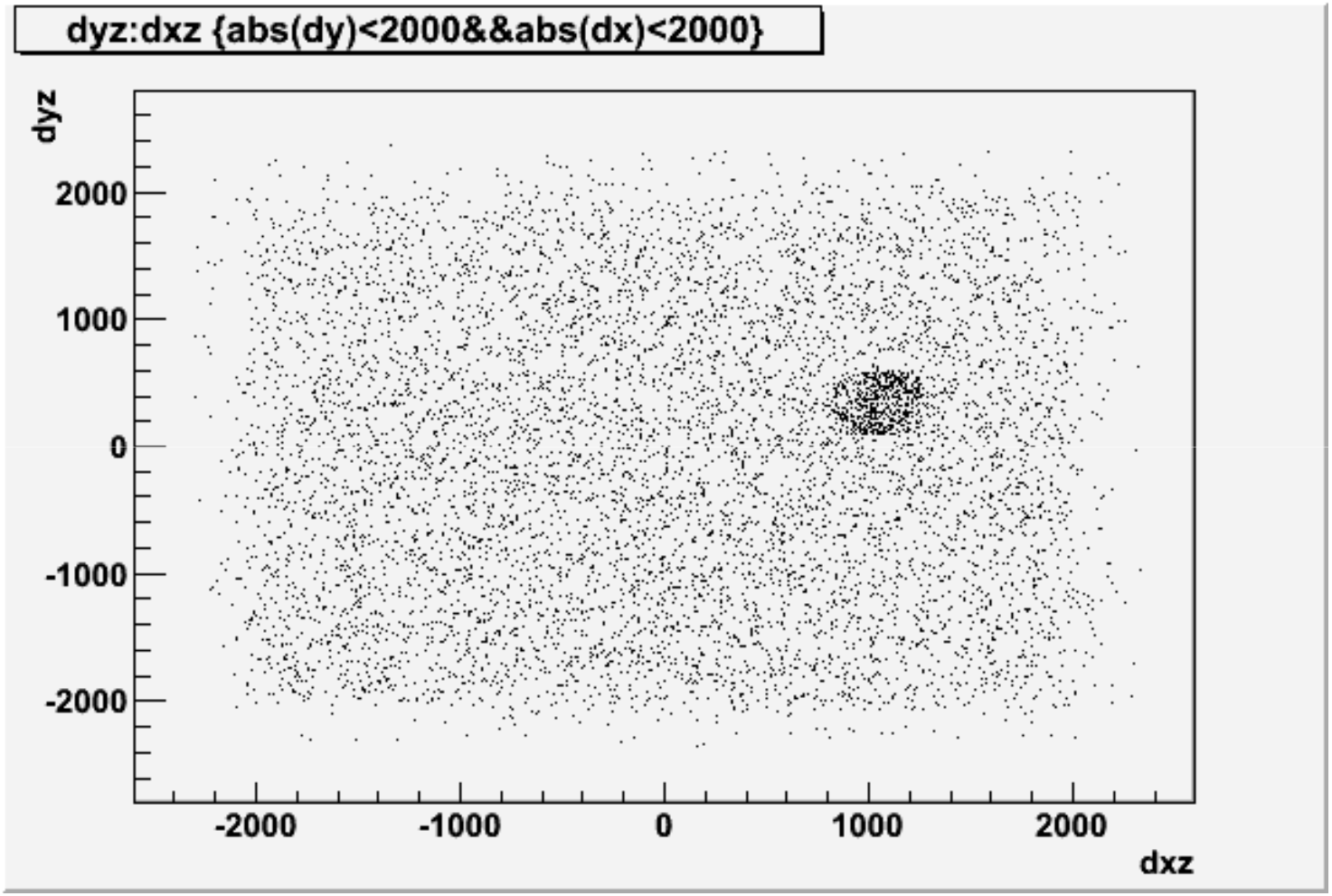
Plate 2 27298 basetracks in 2x2 cm^2

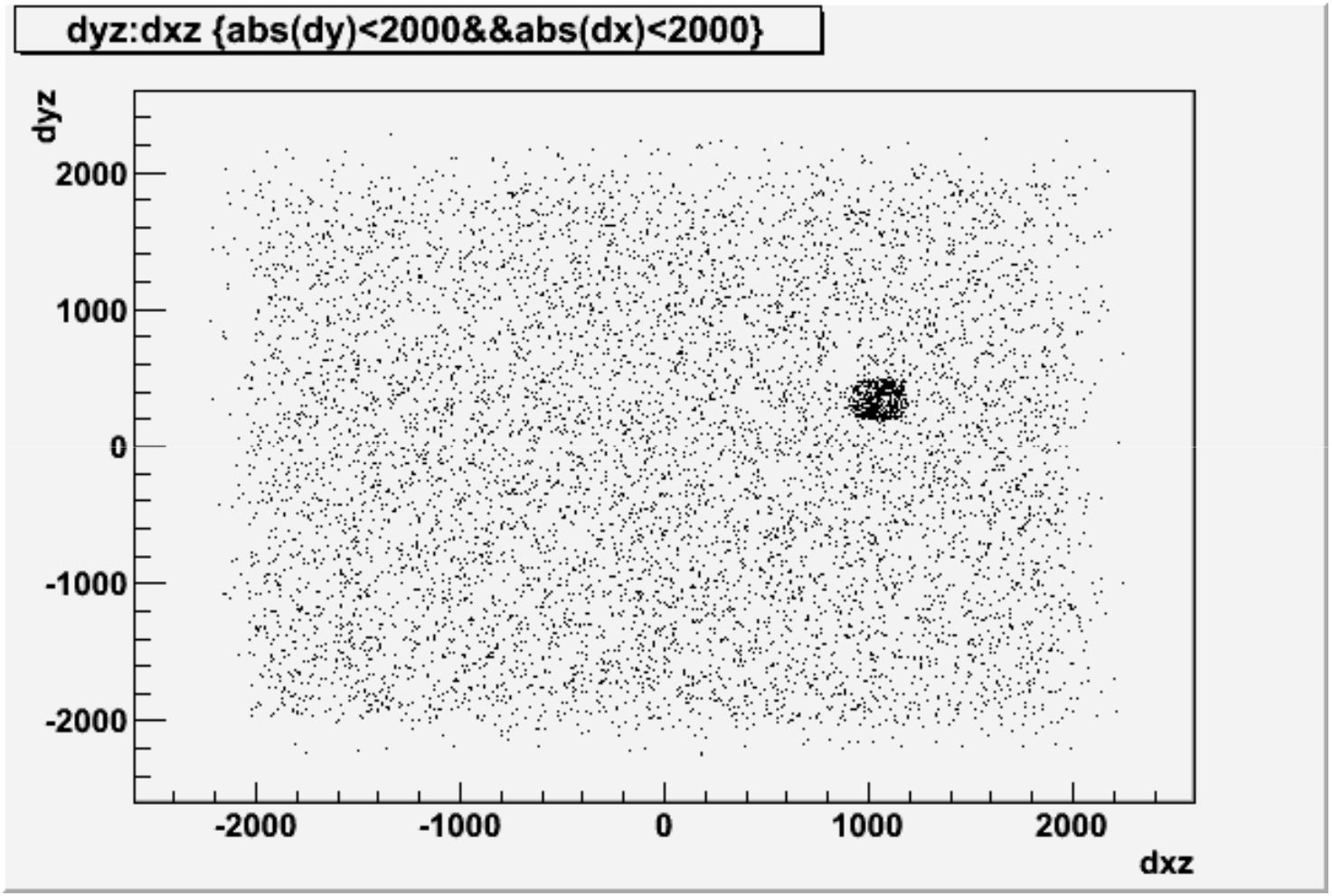


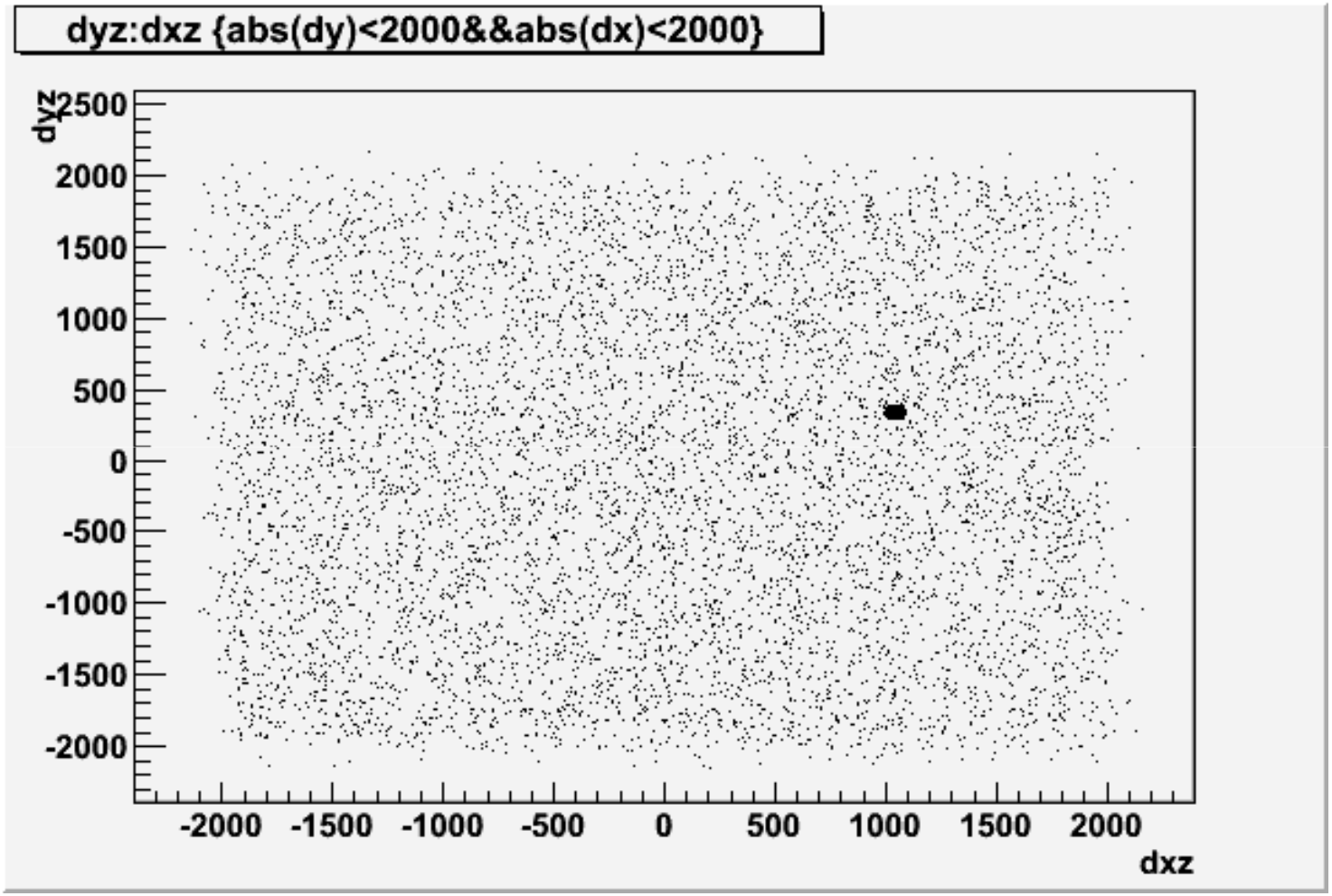
Example of 2 patterns alignment

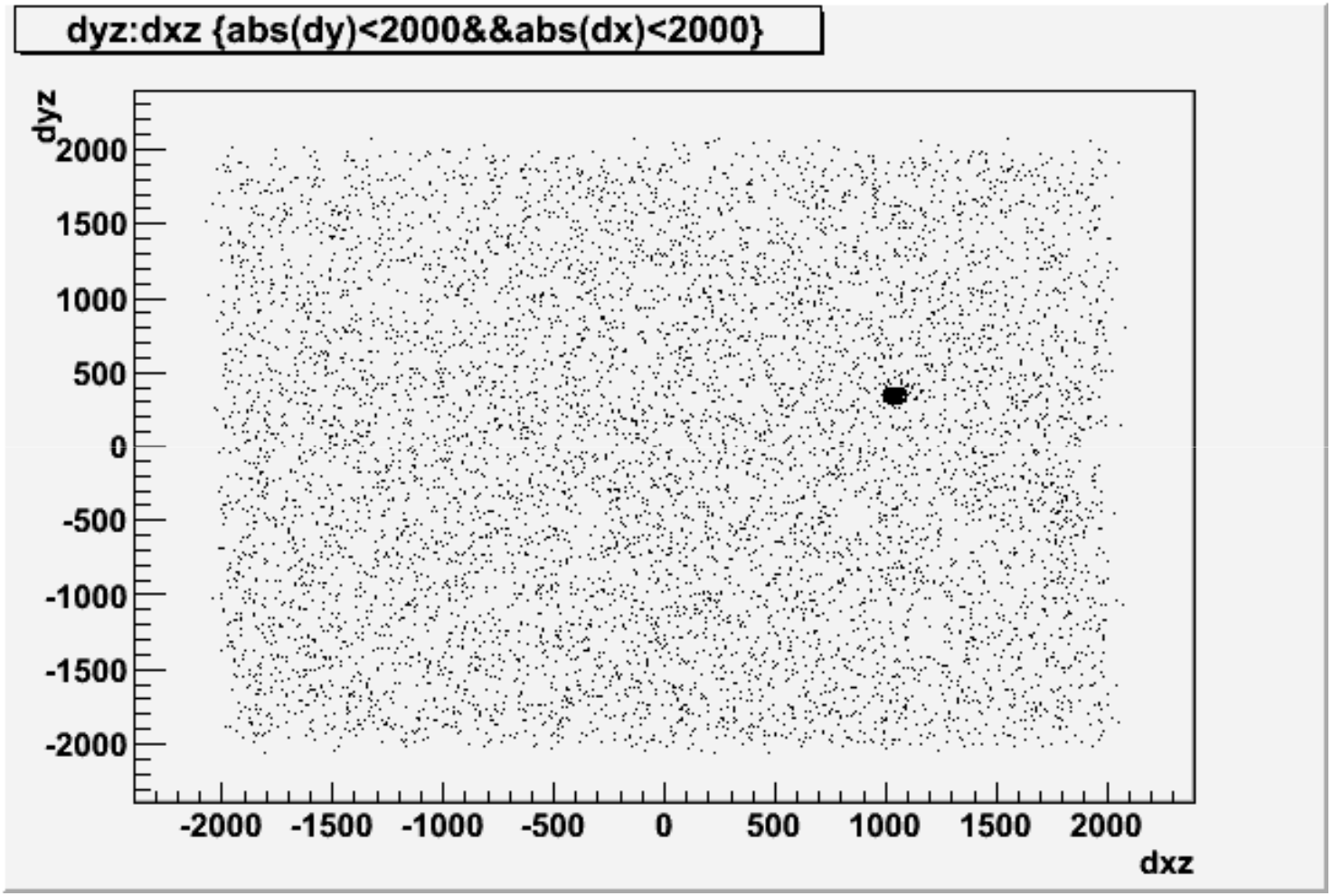
Expected signal: ~ 30 tracks
Possible offsets: up to 3000 microns

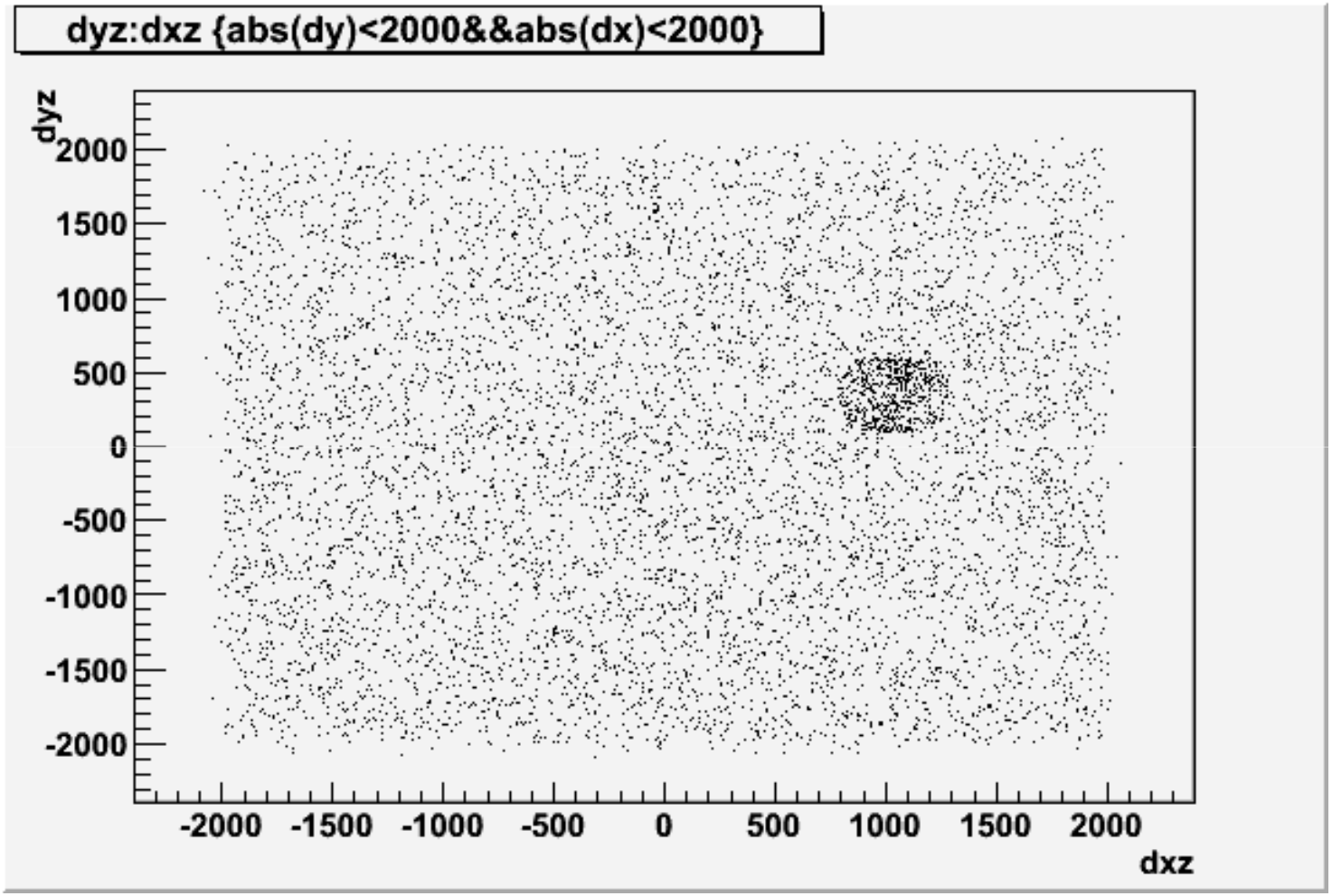
Necessary to find this 30 coincidences using the position and angular information and calculate the Z-offset and Affine transformations between 2 patterns

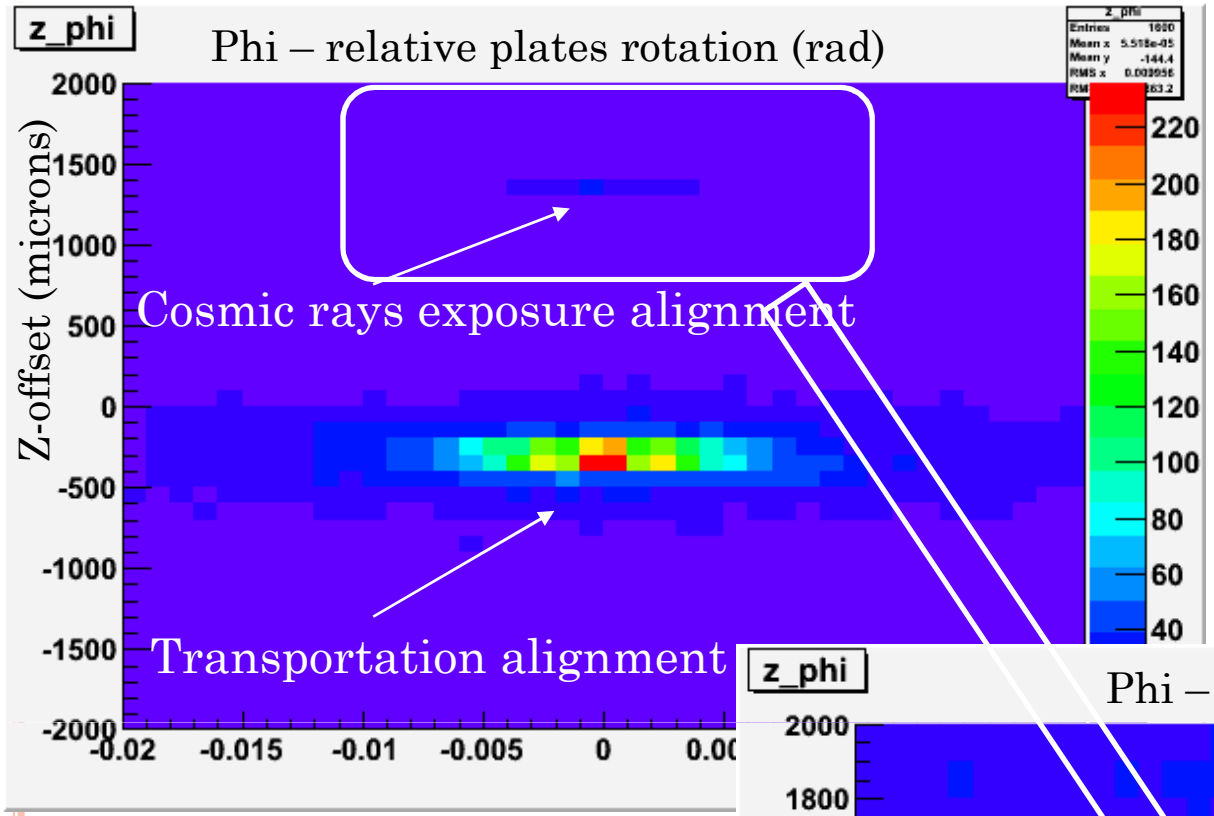

dyz:dxz {abs(dy)<2000&&abs(dx)<2000}
dyz
2000
1000
0
-1000
-2000
-2000
-1000
0
1000
2000
dxz


dyz:dxz {abs(dy)<2000&&abs(dx)<2000}
dyz
2000
1000
0
-1000
-2000
-2000
-1000
0
1000
2000
dxz


dyz:dxz {abs(dy)<2000&&abs(dx)<2000}
dyz
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2000
-1500
-1000
-500
0
500
1000
1500
2000
dxz

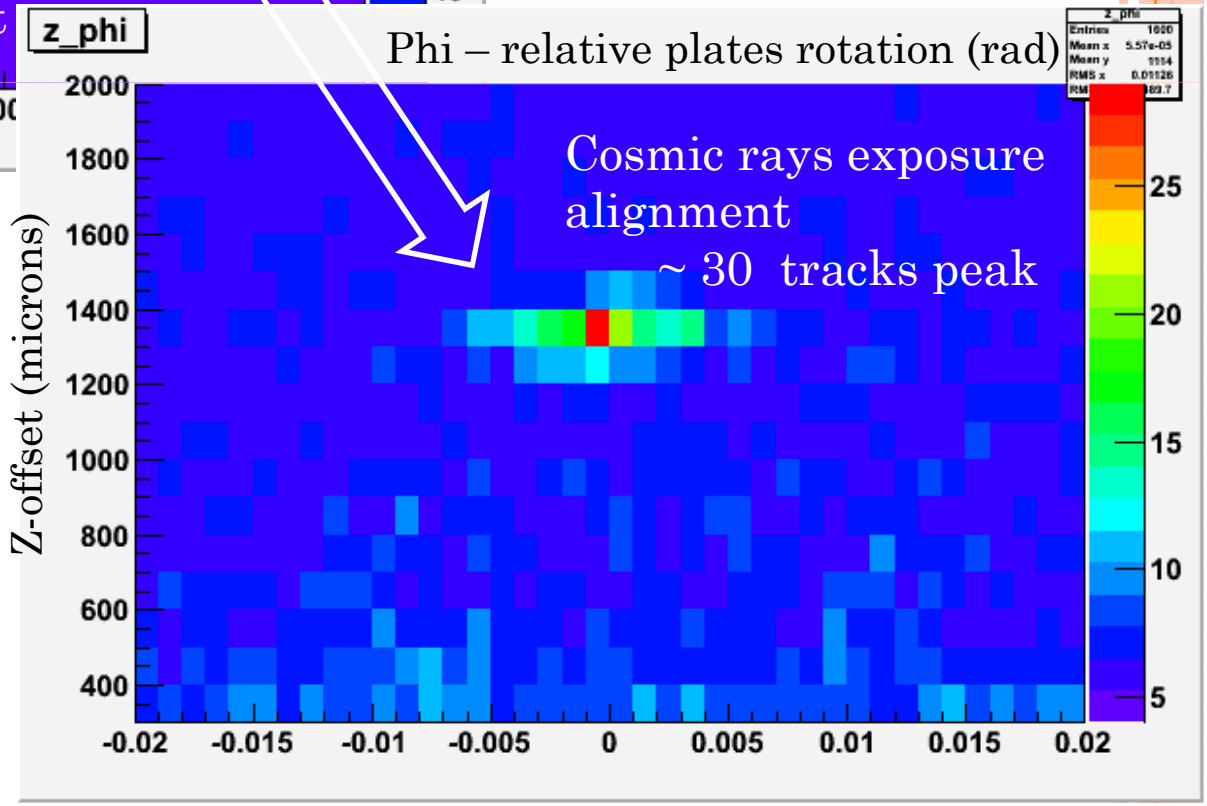

dyz:dxz {abs(dy)<2000&&abs(dx)<2000}
dyz
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2000
-1500
-1000
-500
0
500
1000
1500
2000
dxz


dyz:dxz {abs(dy)<2000&&abs(dx)<2000}
dyz
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2000
-1500
-1000
-500
0
500
1000
1500
2000
dxz



Z-Phi space scanned in limits

- Z: -2000, 2000 with step of 200 microns
- Phi: -0.02, 0.02 with step of 0.001 radian



This procedure provides the position accuracy of about 0.5 -1.5 microns, depending on the zone size and the exposure time

CHANGEABLE SHEET (INTERFACE FILMS)

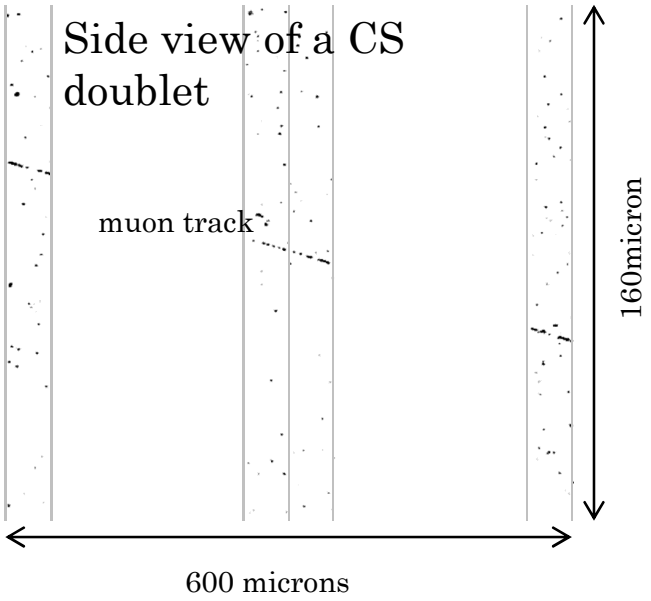
From meters to microns:

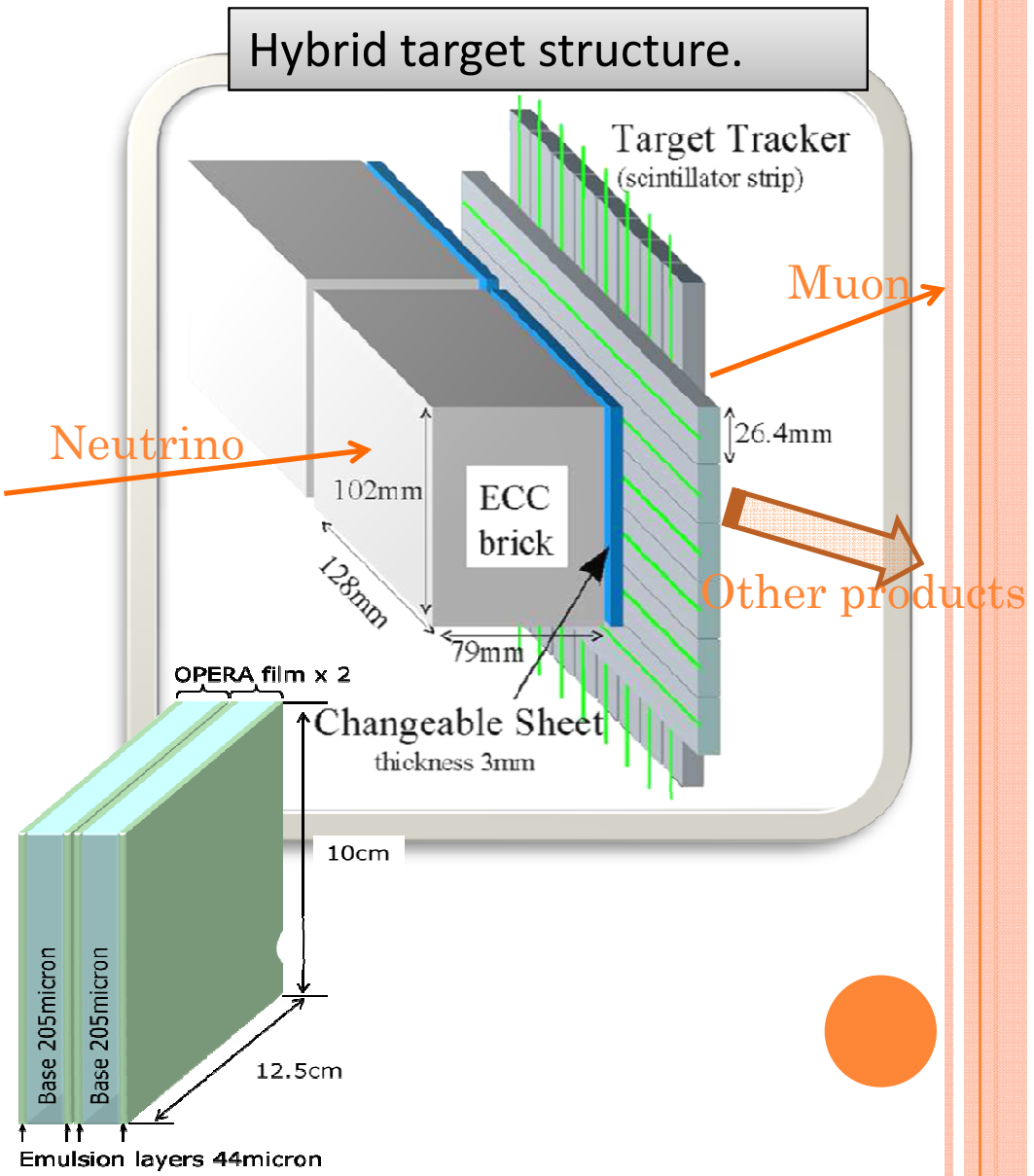
- OPERA: 10x10 m^2
- TT – indicate brick ~ 1 cm accuracy
- CS – ~100 microns
- Inside brick near the vertex ~ 1 micron

- CS background requirements:
  1 track/ 10x10 cm^2

Doublet film for coincidence

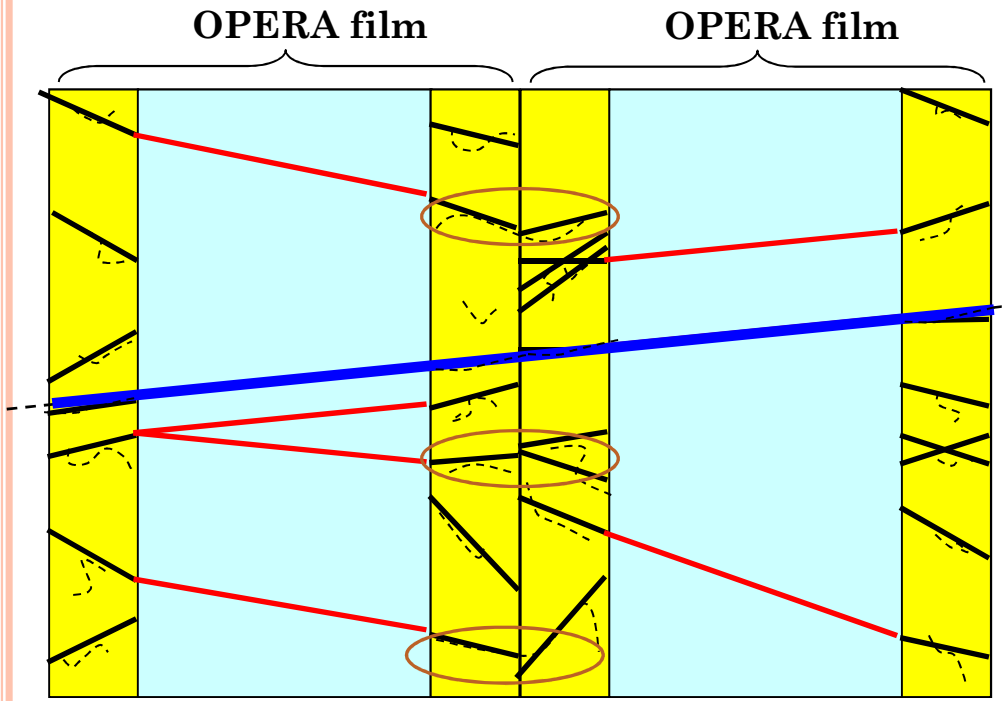
No cosmic rays in CS!





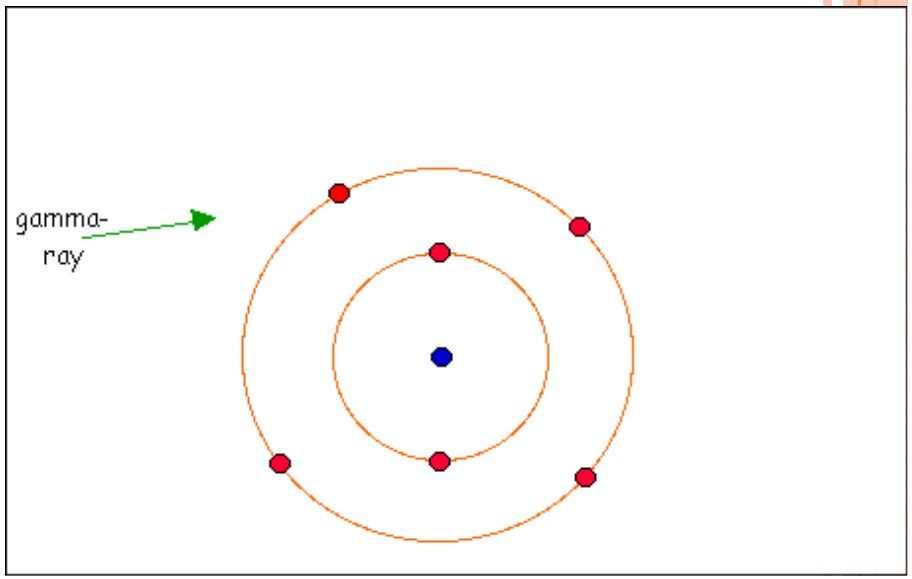
Emulsion deformations and the Compton alignment for Changeable Sheets Doublets

In 1 year of exposure in Gran Sasso accumulated about 10/mm^2 Compton tracks



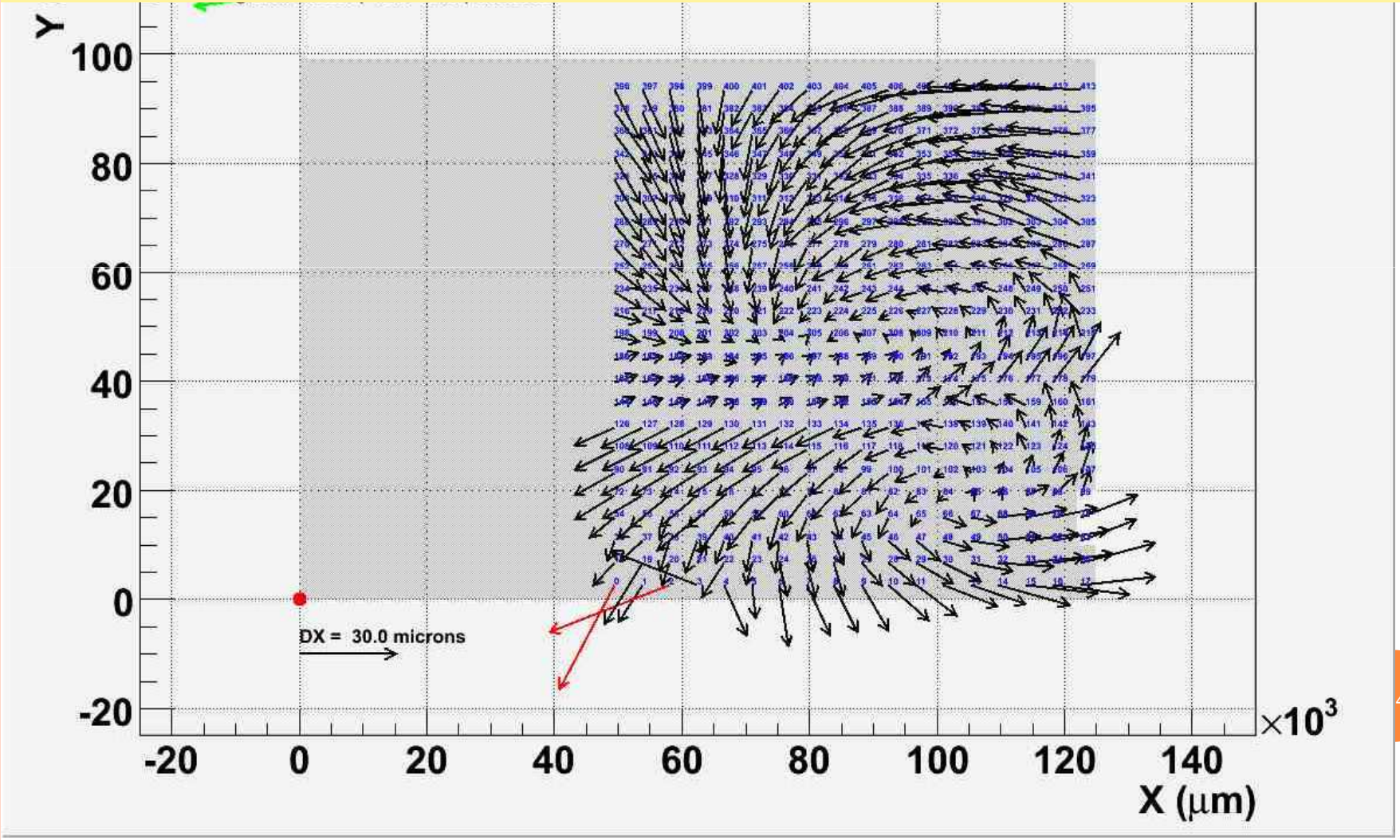
The better the alignment accuracy - the higher background rejection power

We can use the natural radioactivity to improve the plate-to-plate positioning accuracy!

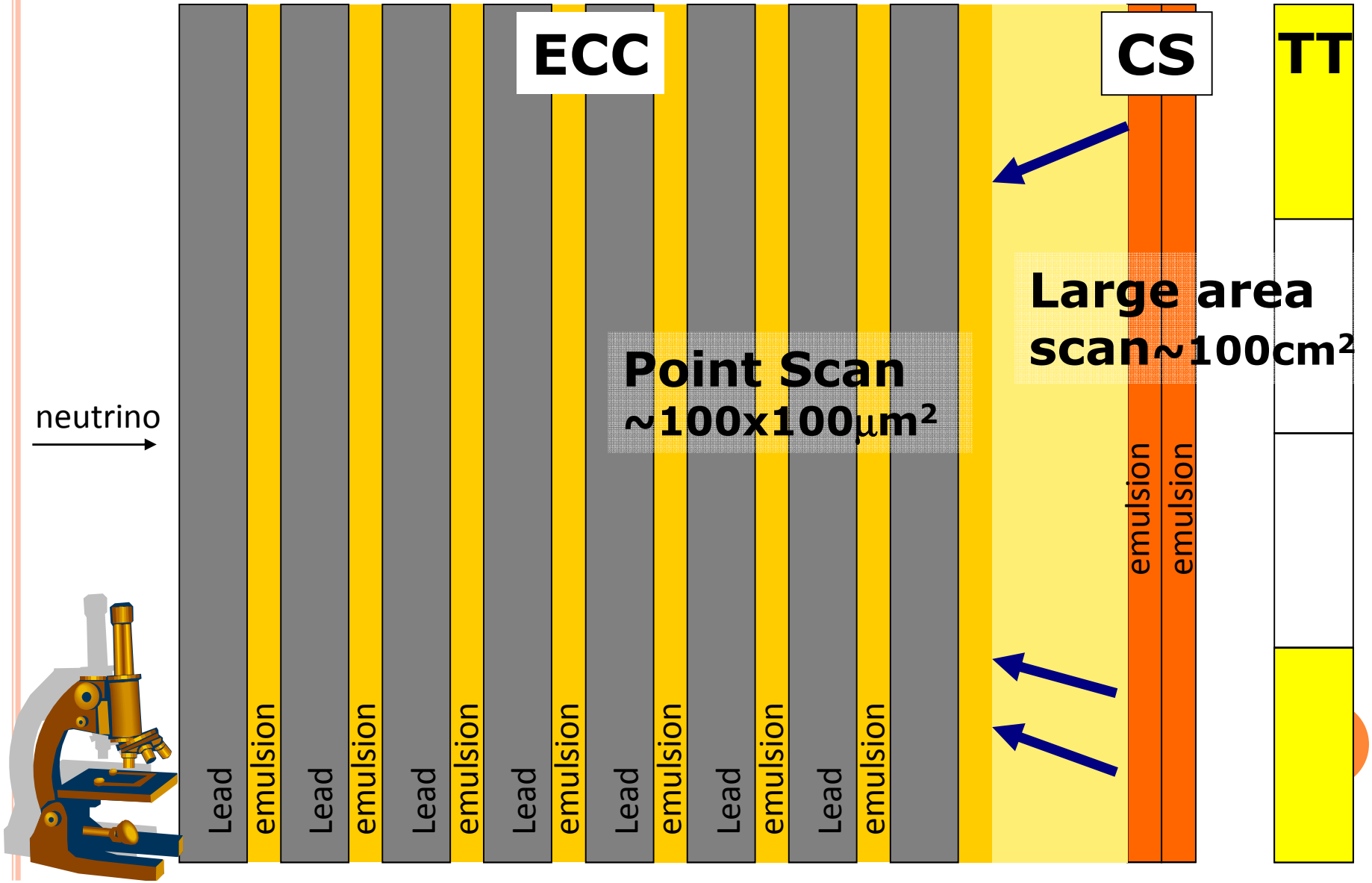


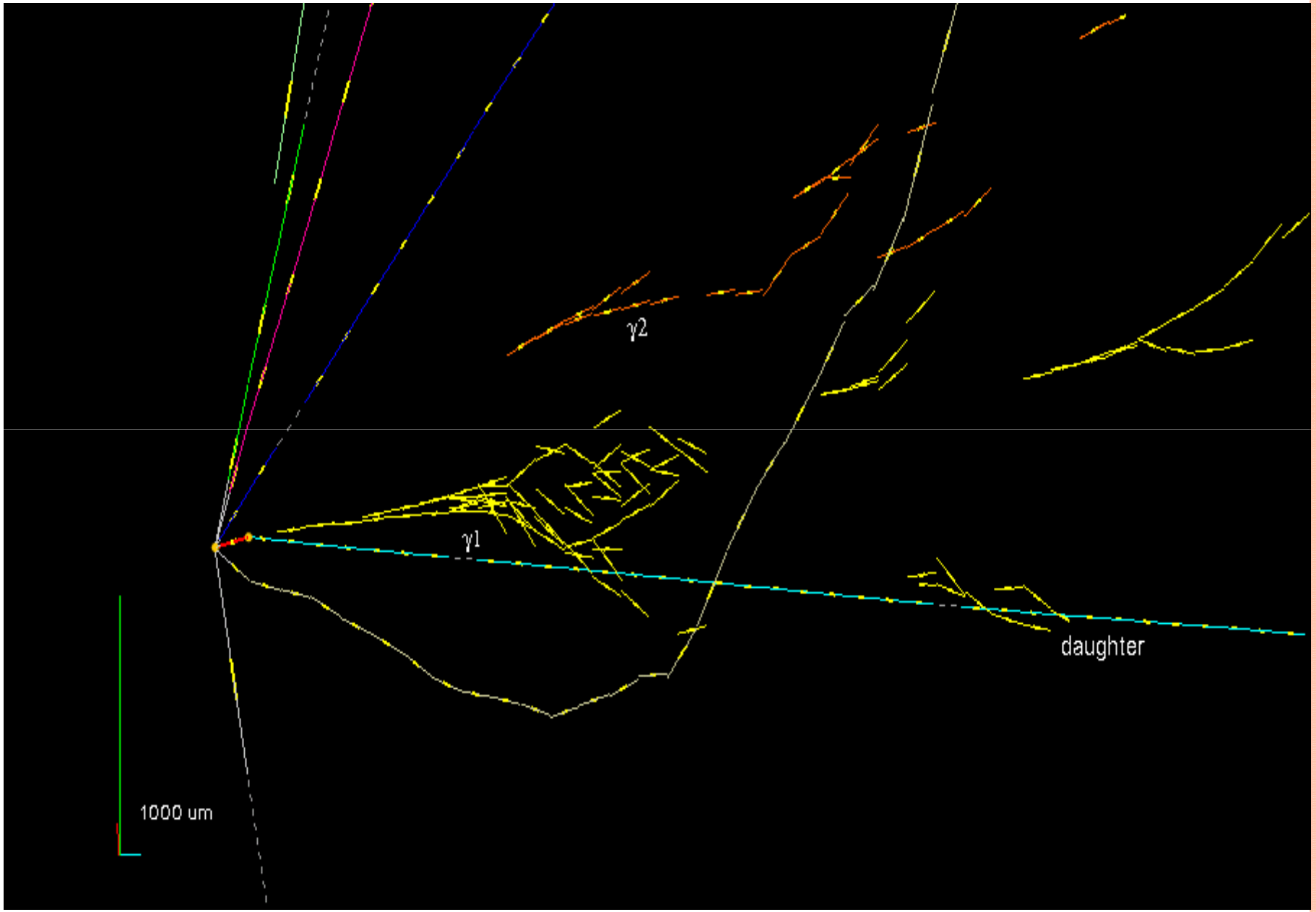
Compton alignment map for one Changeable Sheets doublet
Area of 70 cm^2 fully scanned on both CS
2 millions mt/pattern are divided in 414 zones of 4x4 mm^2,
258750 elementary alignments done to produce this map

Accuracy gain: from 15 microns to 1-5 microns : overall BG reduction is of the factor of 25



Flow of Location – ECC –

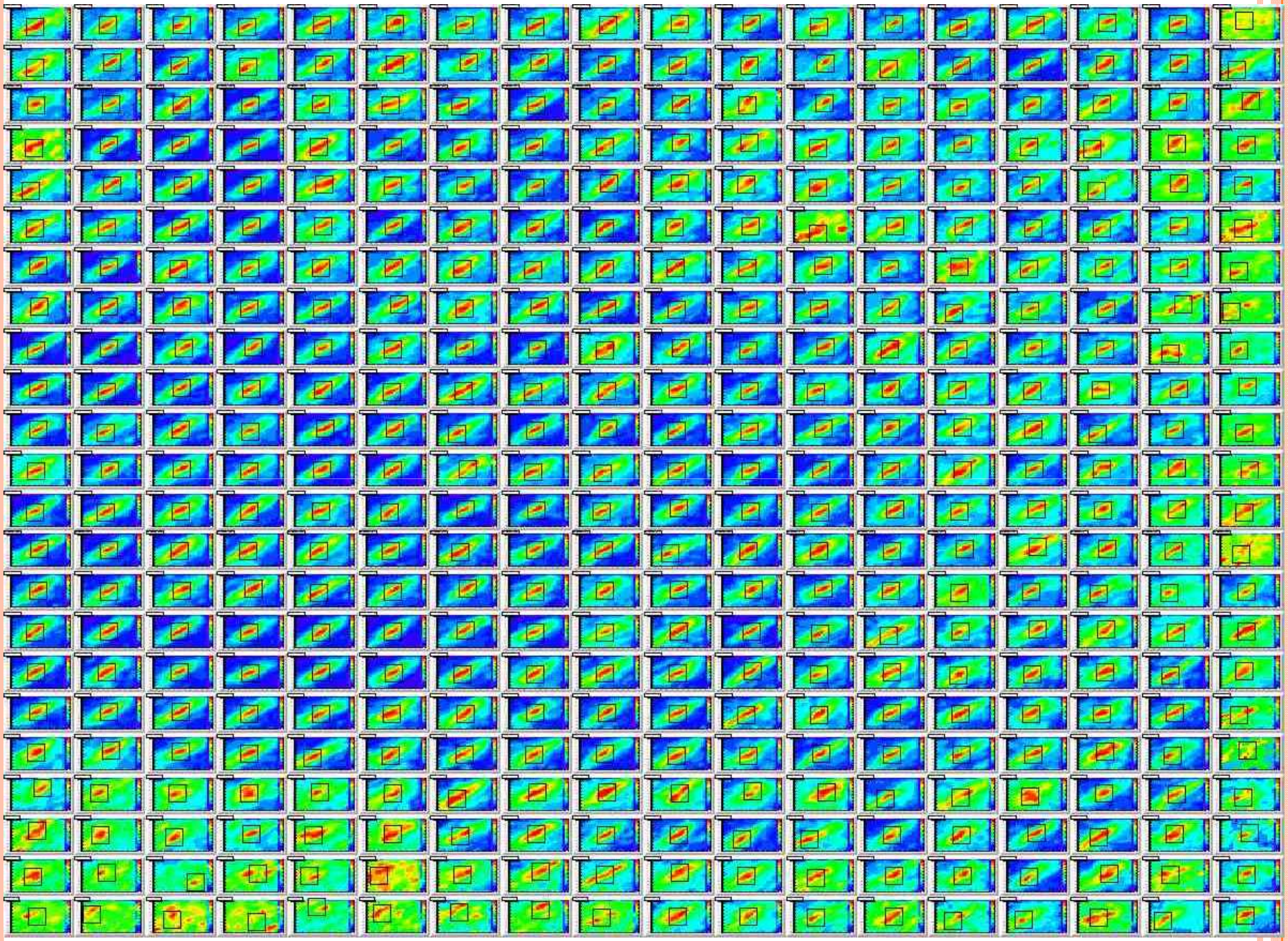


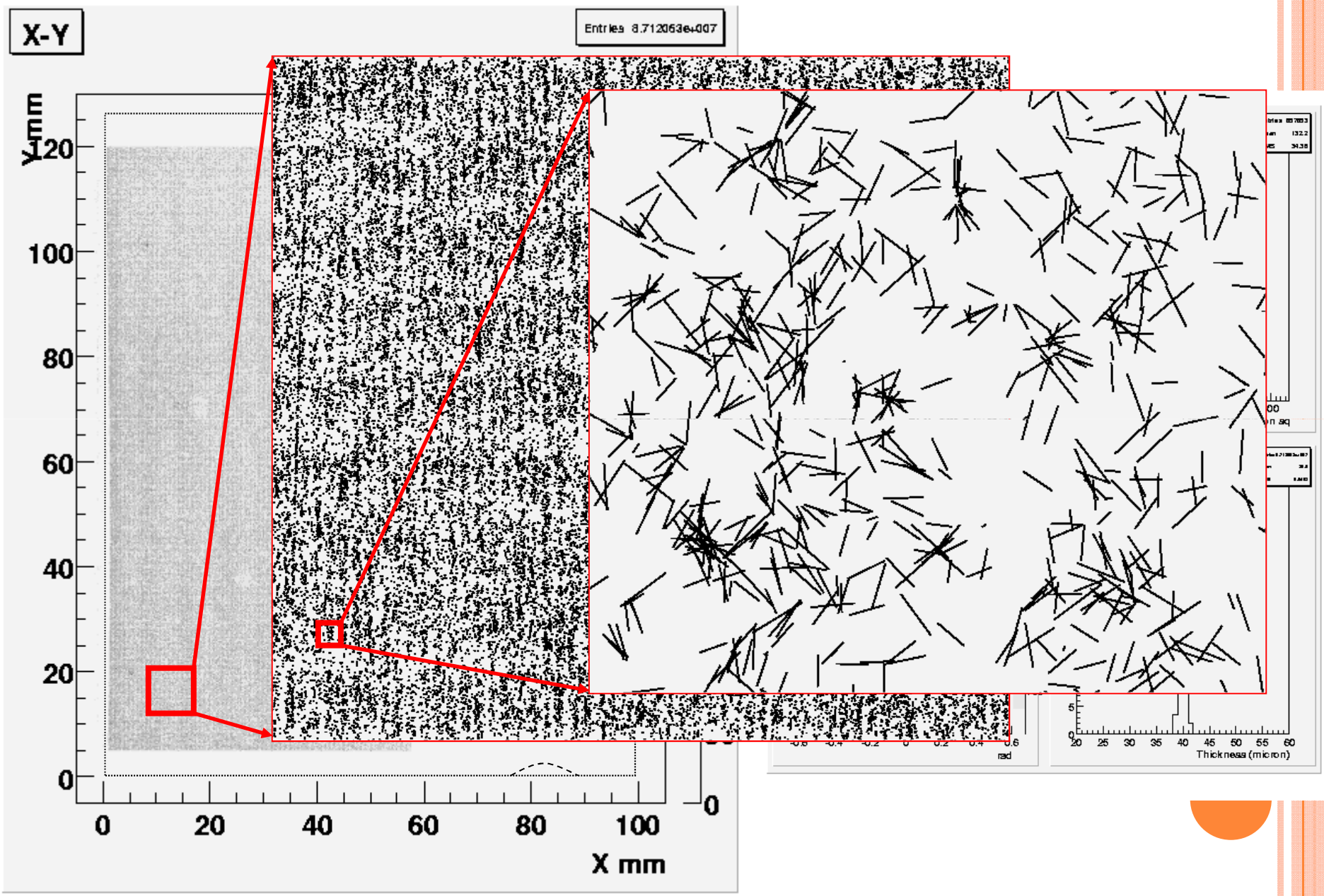

γ2
γ1
daughter
1000 um

CONCLUSIONS

- High speed automatic emulsion scanning makes possible the large scale ECC experiments like OPERA where thousand ton detector coexist with the submicron resolution
- INFN Napoli scanning laboratory has the key role in the developing of the European Scanning System (the first prototype was build in Naples). Now about 30 ESS works in many European labs
- Sophisticated off-line processing algorithms specific for the emulsion data are developed in our group
- Follow the technological progress of last 20 years in computing, image processing and automation, the emulsion systems gains approximately one order of magnitude in scanning power each 5 years – this opens interesting prospective also for future applications of this technology

Backup slides




X-Y
Entries 8.712063e+007
Y mm
120
100
80
60
40
20
0
0
20
40
60
80
100
X mm
rad
Thickness (micron)