Emulsion analysis status and prospects

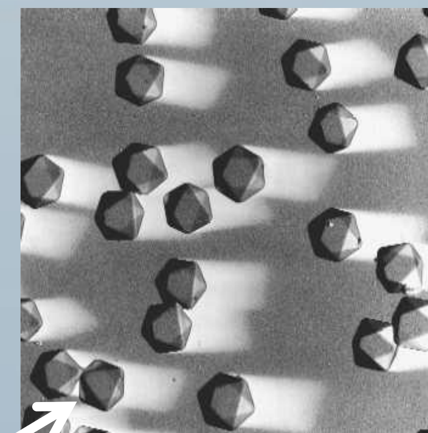
Valeri Tioukov, INFN Napoli

Outlook

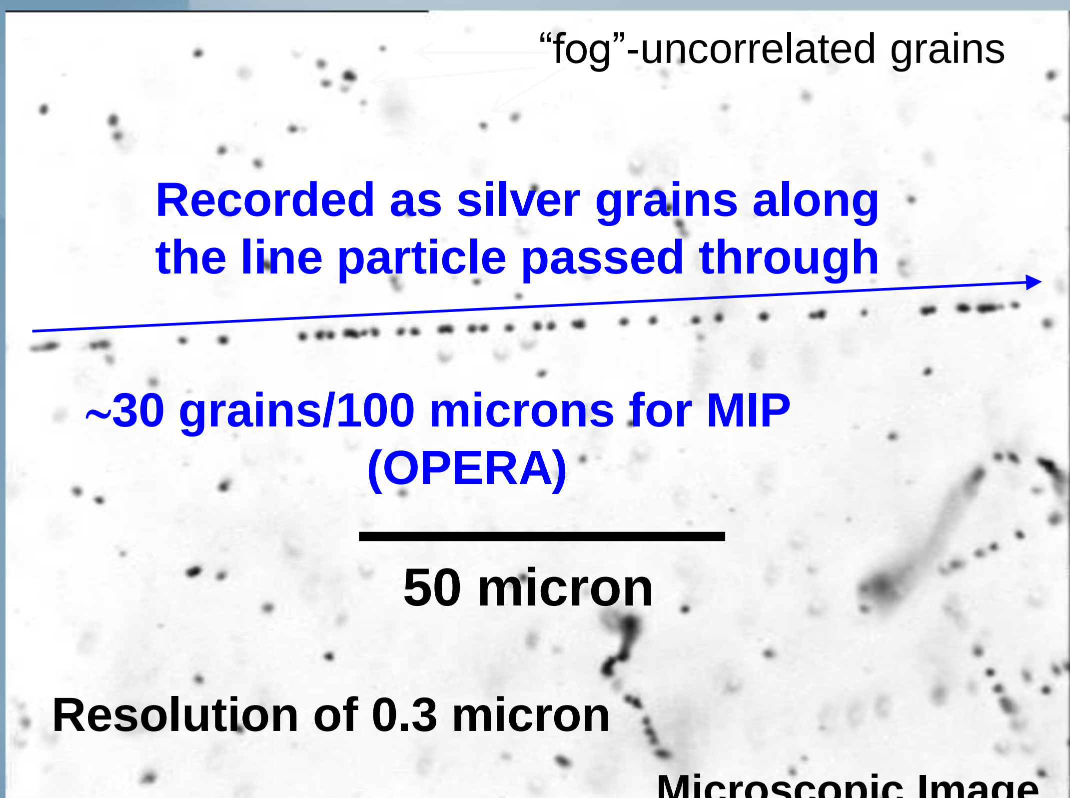
- History of automatic scanning
- OPERA (20cm/h)
- R&D in Europe
- R&D in Japan
- Estimations for SHIP

Nuclear emulsion as sensitive media for charged particles

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



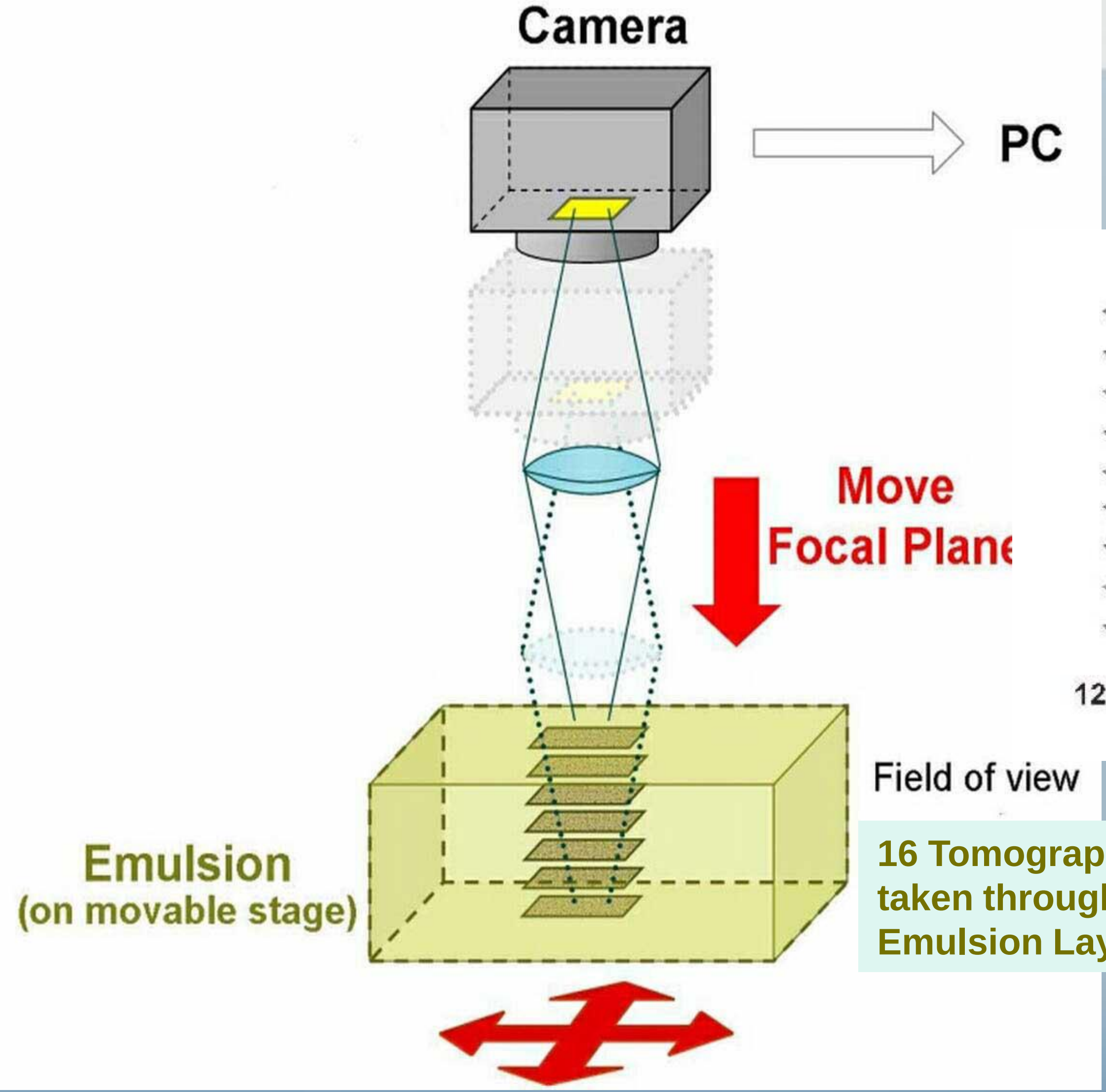
AgBr crystal, size 0.2-0.3 micron. It's the elementary detection element



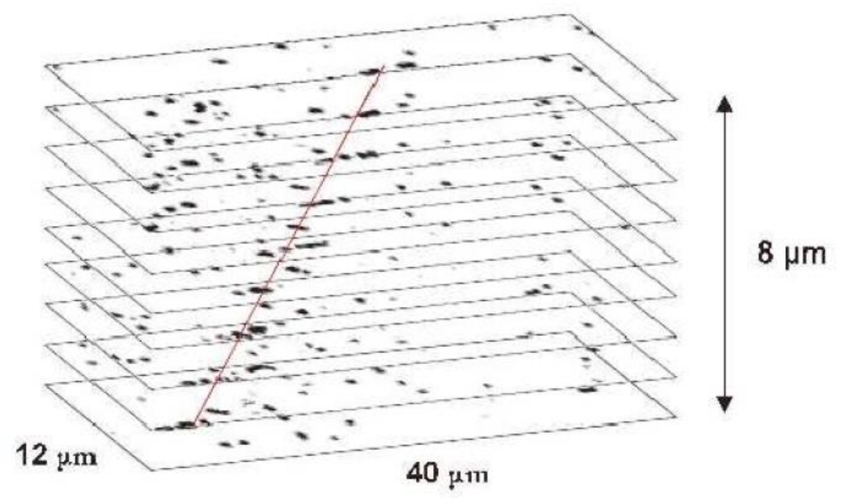
Microscopic Image

Nuclear emulsions used for more them 70 years in Particle Physics.
Since 1980th – automatic scanning systems development started

Principle of the automatic emulsion scanning



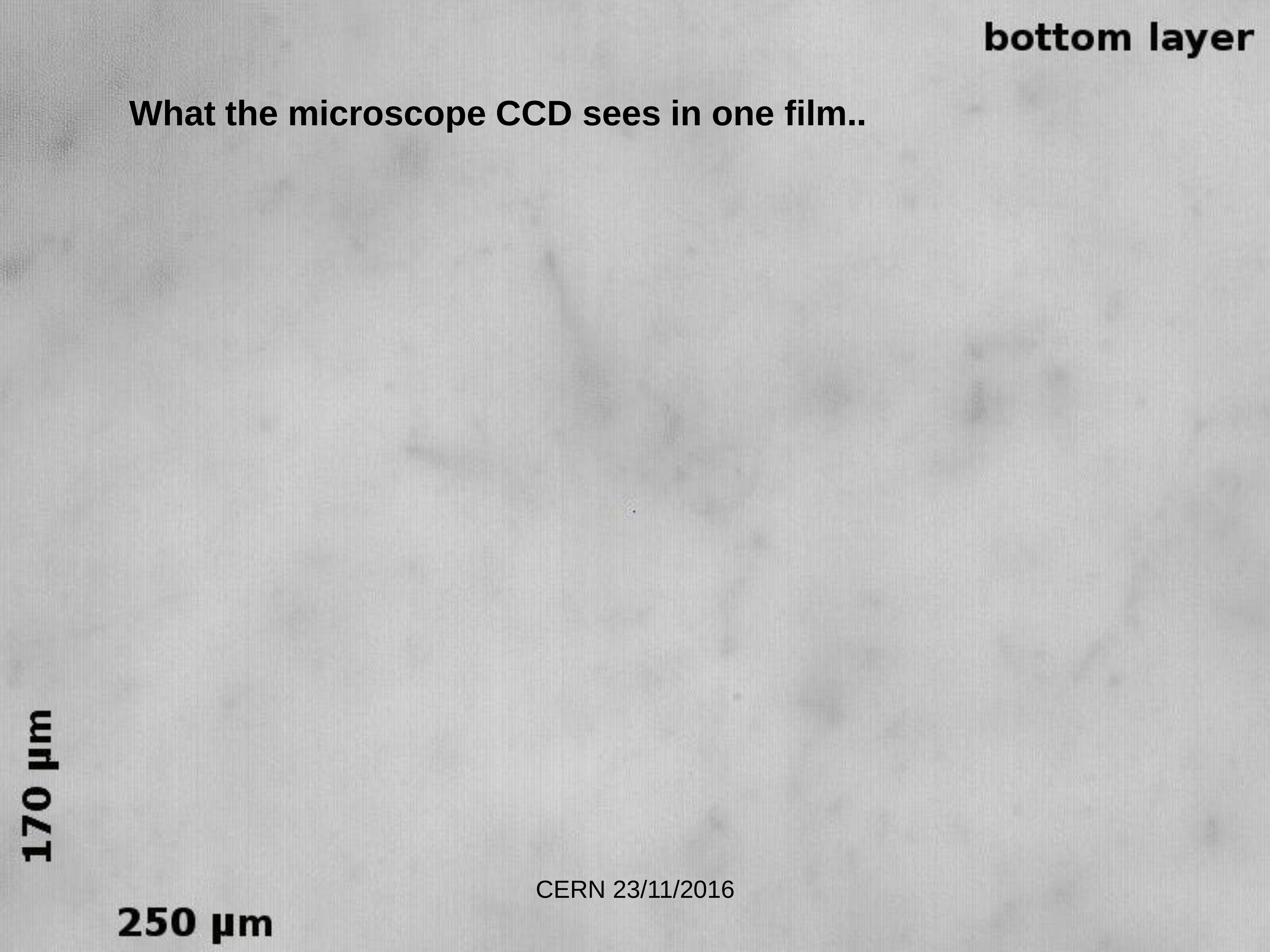
- Professional Image Processing board
- Motor control card



16 Tomographic Images taken through 44-micron Emulsion Layer

Movable stage

What the microscope CCD sees in one film..



OPERA ESS

20 cm²/h (2004 year components)

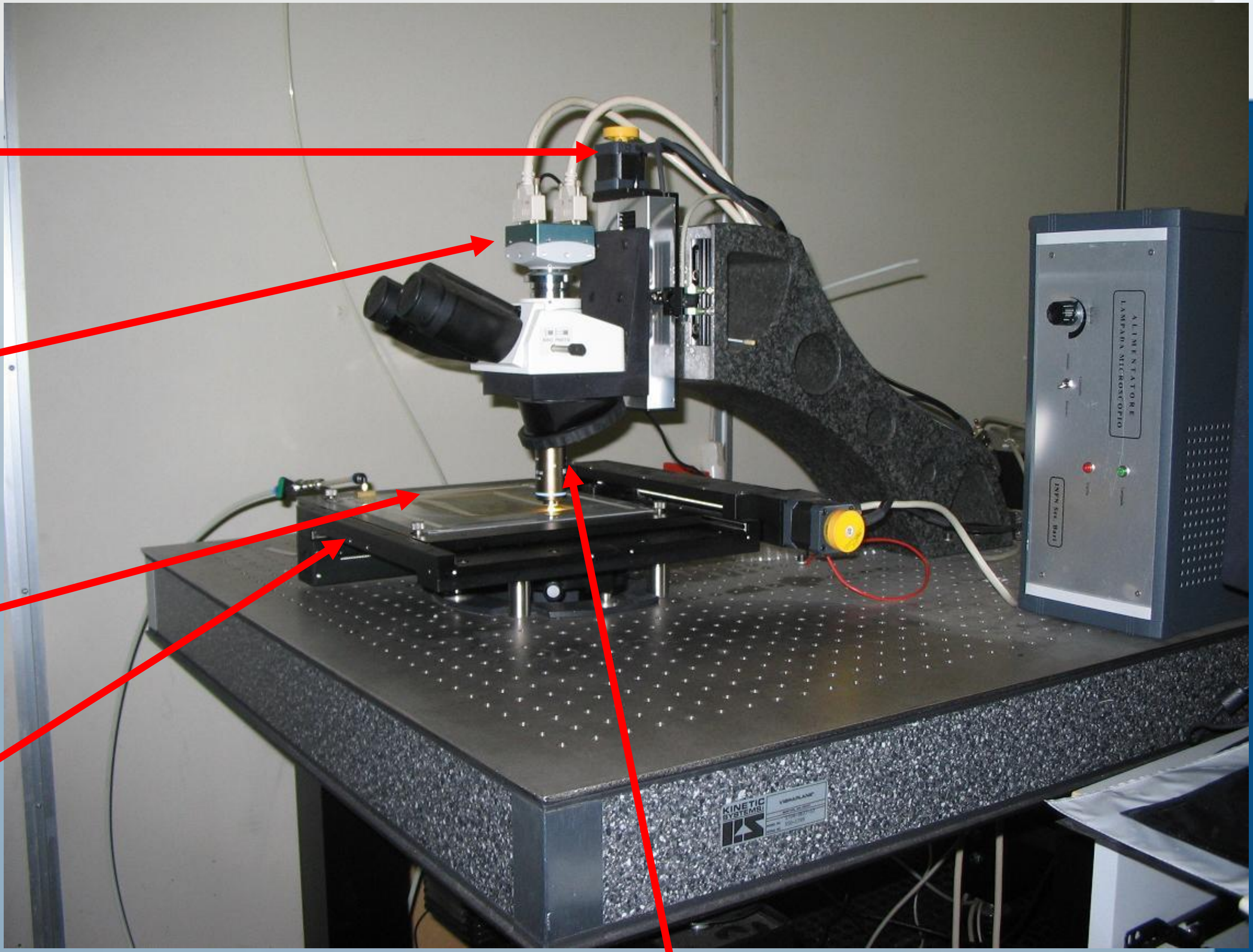
Hardware performance of a scanning system for high speed analysis of nuclear emulsions NIMA568 (2006)

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

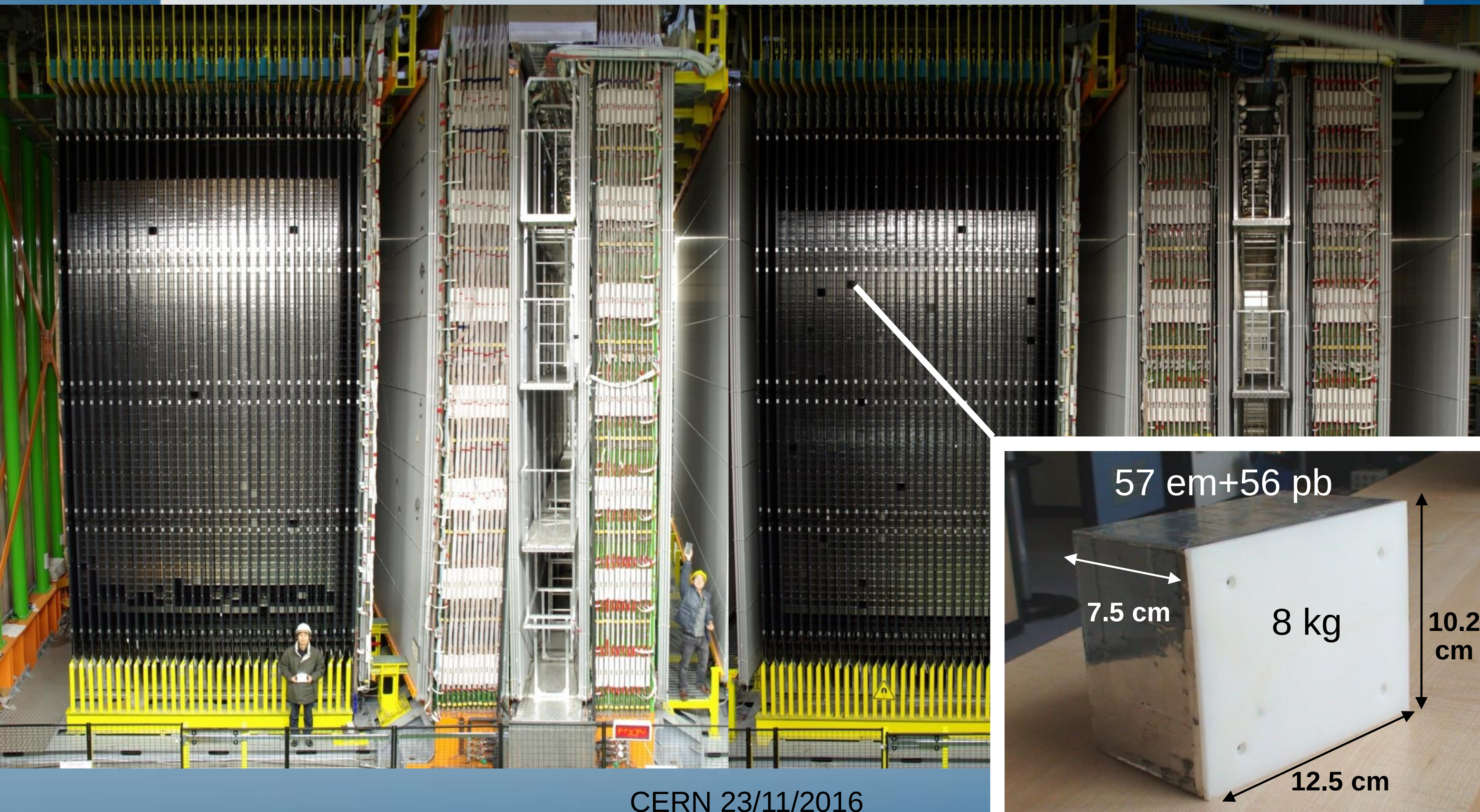


Illumination system, objective (Oil 50× NA 0.85) and optical tube (Nikon)

The OPERA detector: 9 mln films with the total surface of 111,000 m^2

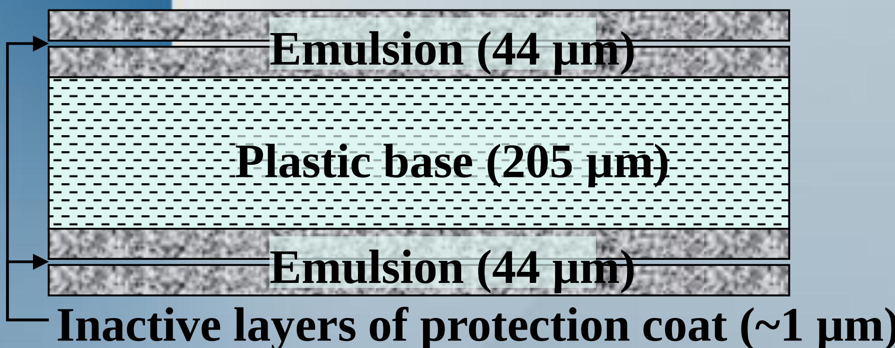
10x10x50 meters construction

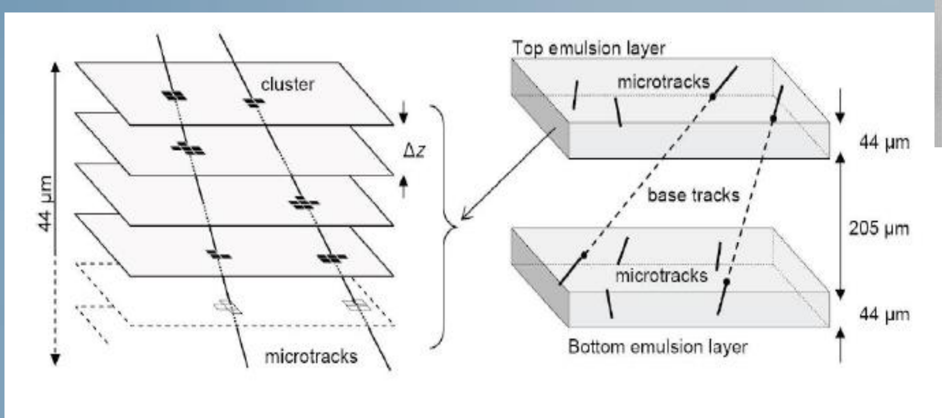
SM1 **SM2**



OPERA emulsion films

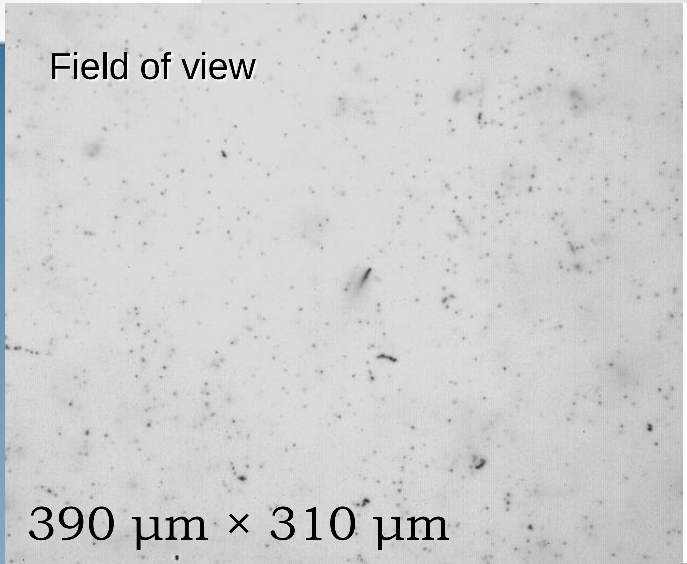
The OPERA film: New nuclear emulsion for large-scale, high-precision experiments NIMA556 (2006)

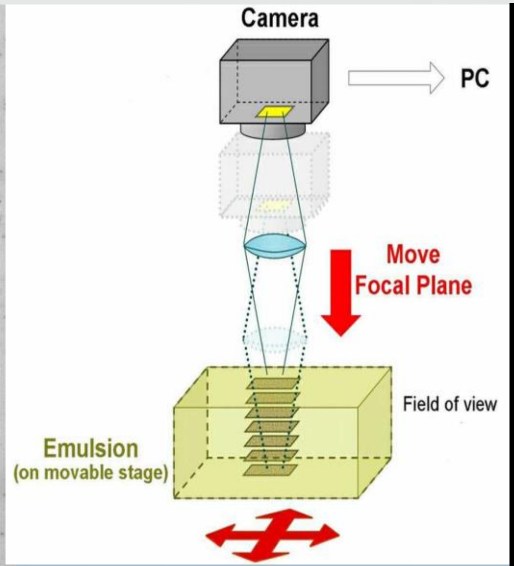


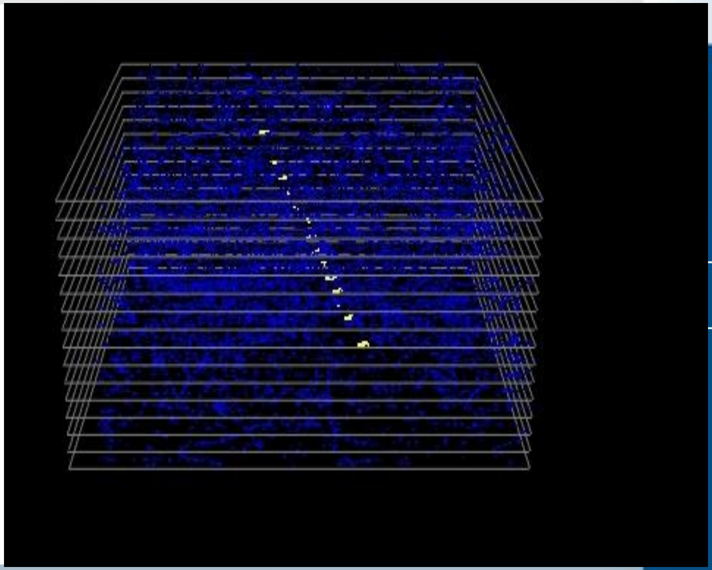


OPERA emulsion gel parameters	
Crystal diameter	200 ± 16 nm
Crystal density	230 / 100 μm
Detection efficiency	0.17 / crystal
Grain density for MIP	36 / 100 μm

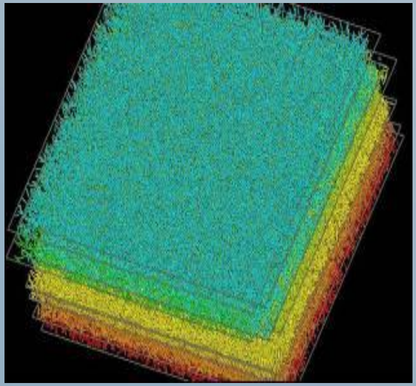
Tracks&vertices reconstruction in ECC



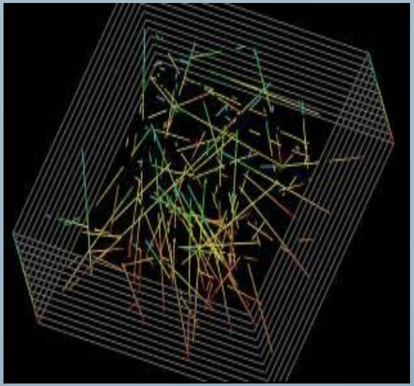




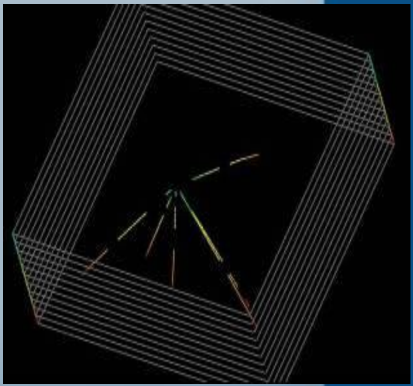
- Images -> microtracks
- Microtracks->basetracks
- Plate-to-plate alignment
- Long tracks reconstruction
- Vertex location
- Event analysis



Volume scan data (basetracks)

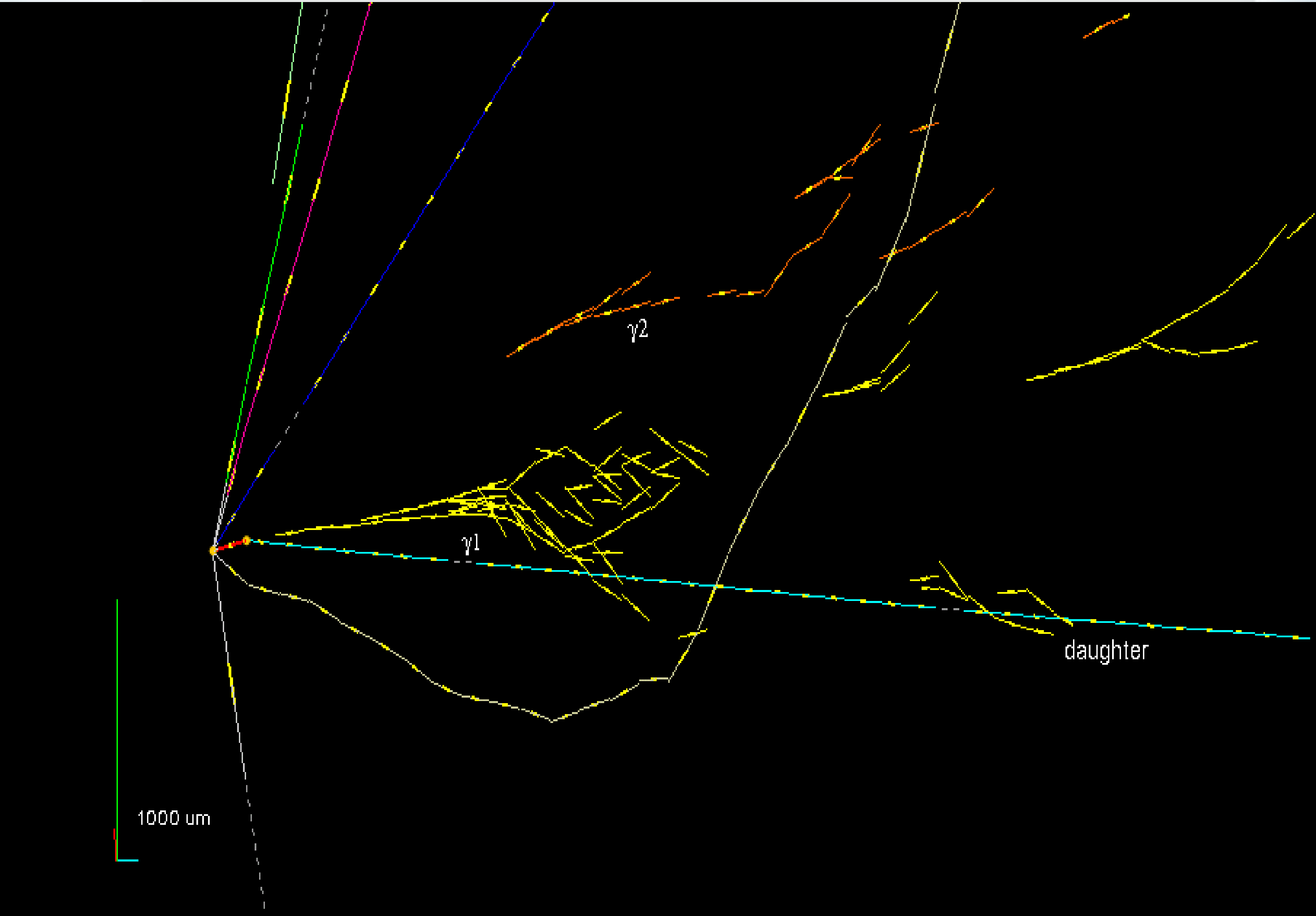


Passing-through and short tracks rejected



Vertex located in the brick

OPERA tau event



ECC as a particle detector

- Any charged particles leave trace in emulsion
- The trace reconstruction accuracy is typically better then 1 micron and 1-2 mrad
- Any direction (4π) tracks reconstruction is possible
- Particles/Interactions properties normally studied with ECC:
  - Vertices and kinks (Tau, Charm) precise reconstruction
  - Ionization: Pi/Mu/P separation
  - Electromagnetic showers reconstruction
  - Gamma (e+ e-) forks recognition
  - Momentum reconstruction using multiple scattering method (resolution is better then 30% up to 8 GeV)

Some methodical publications dedicated to ECC performance

- **Momentum measurement by the Multiple Coulomb Scattering method in the OPERA lead emulsion target New J.Phys. 14 (2012)**
- **Momentum measurement of secondary particle by multiple Coulomb scattering with emulsion cloud chamber in DONuT experiment NIM A574 (2007)**
- **Electron/pion separation with an emulsion cloud chamber by using a neural network JINST 2 (2007)**
- **Charge identification of highly ionizing particles in desensitized nuclear emulsion using high speed read-out system NIMA556 (2006)**
- **pi / p separation at 1.2-GeV/c by an emulsion cloud chamber NIMA516 (2004)**

Recent emulsions applications

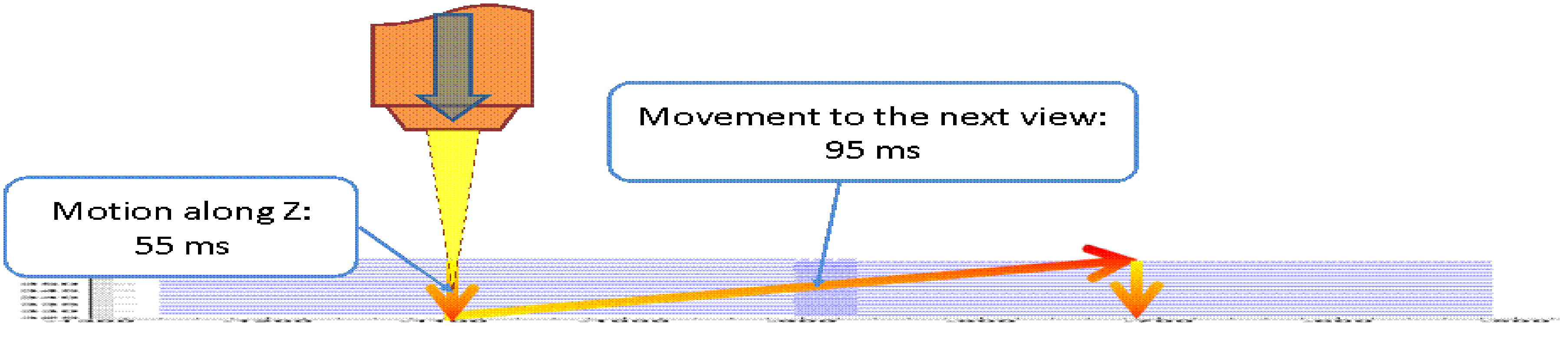
- HEP – DONUT, CHORUS, OPERA (1990-2014)
- Muon Radiography (since 2011 started in Europe) now actively developing
  - Volcanoes radiography&tomography (Stromboli, Unzen, Teide, etc)
  - Geological and industrial applications are possible
- Medical applications (Carbon ions fragmentation study, etc)
- Dark matter search using NIT (NEWS project)

All these tasks has triggered the new SS R&D cycle started in 2011

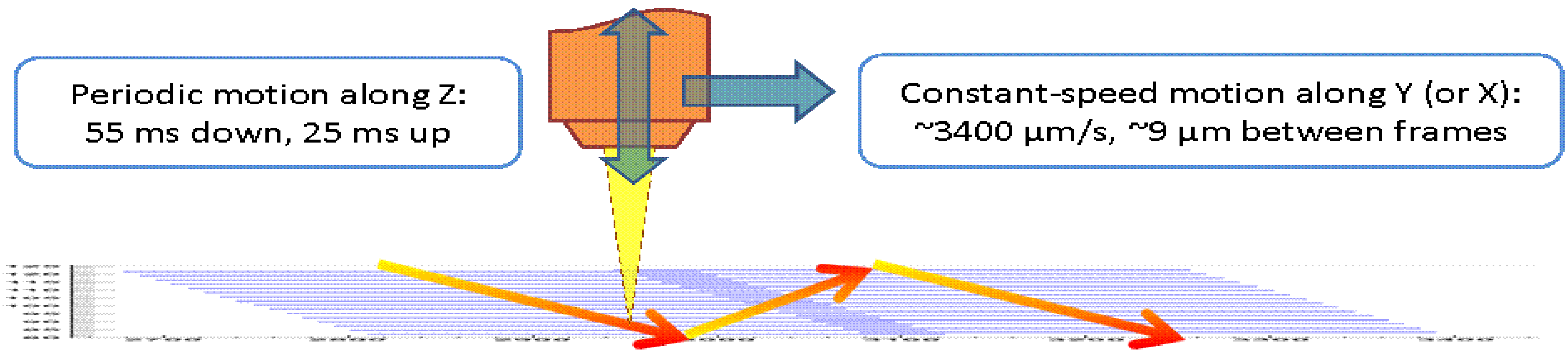
R&D milestones

- 2011-2012 new scanning technique “continuous motion” scan was proposed and implemented with standard ESS hardware **x2 scanning speed increase**
- 2012 Piezo-drive is proposed and tested for Z-motion – drastic reduction of dead time **(another x1.4 gain in speed)**
- 2012-2013 new SW developed for handling higher data flow and Large Angle Tracking (GPU-based calculations are implemented)
- 2012-2014 intensive market research and new hardware test. New components allows **another factor 3-5 acceleration** by just direct system upgrade
- New for ESS multi-camera approach can provide linear performance increment **x2 or x4** (no principle problems expected up to 4 heads)

Stop&Go vs Continuous motion
(20 -> 45 cm^2/h)



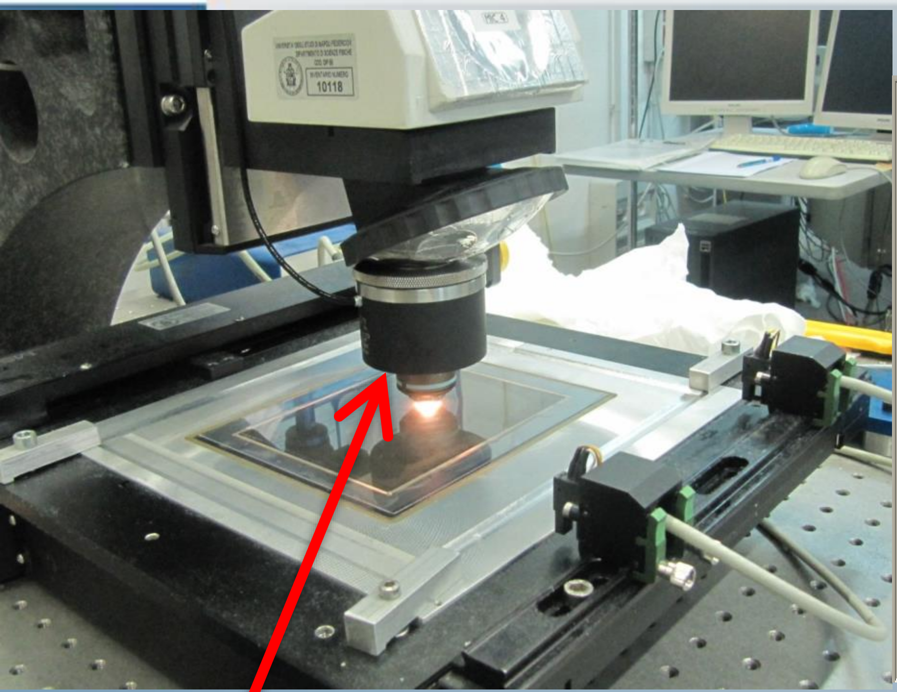
55 ms data acquisition + 95 ms back motion = 150 ms duty cycle



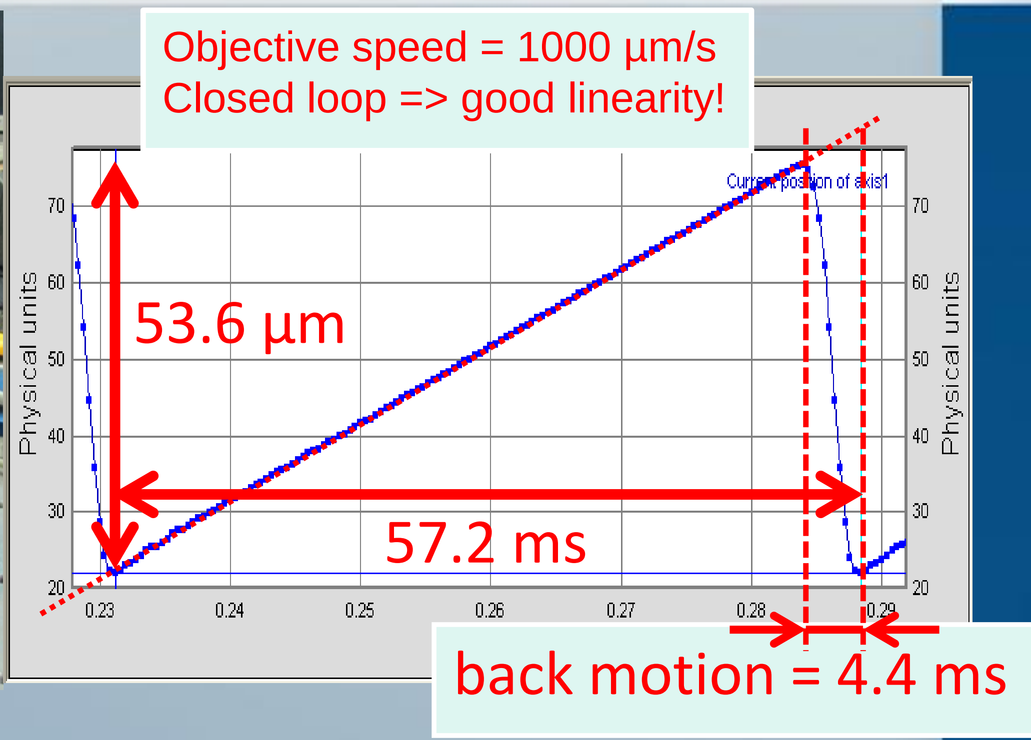
55 ms data acquisition + 25 ms back motion = 80 ms duty cycle

Piezo-driven Z-motion

(45 -> 60 cm^2/h)



PIFOC Pi-726Piezo nano-positioner

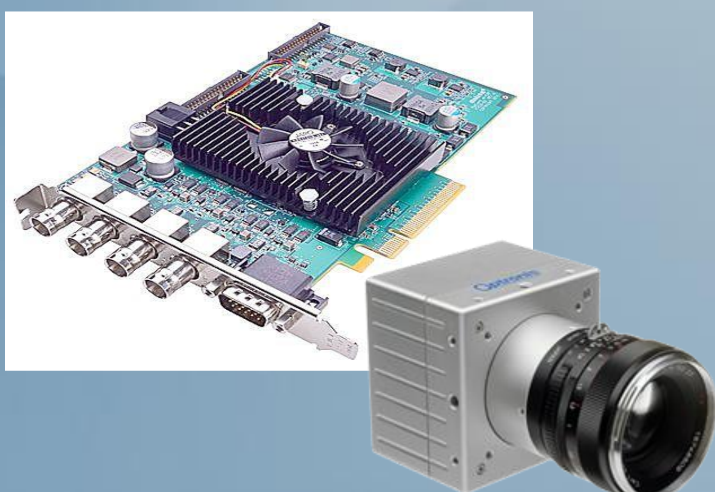


- Back motion is reduced from 25 (LS-110) to 4.4 ms
- Scanning speed increase: 1.4
- Significant vibrations reduction
- Heavy multy-head Z-group becomes possible

New Objective, Cameras and Framegrabbers

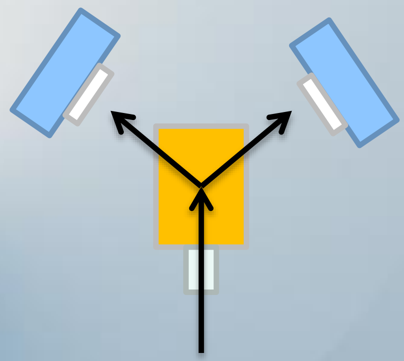
x5

Passing to new 4Mpix camera and 20x objective will allow to **triple the field of view area** keeping the pixel size at the same value which will allow to use already existing image processing modules. The speed of Camera Link interface is a limiting factor here



New (from 2013 on the market) 4 and 12 Mpix cameras and frame-grabbers with **CoaXPress interface permits factor of 3 band increasing.** The scanning speed in this configuration reach **300 cm^2/h**

Multi-camera approach
x2 or x4

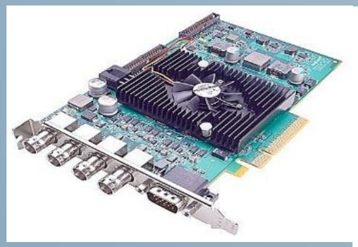


It is possible to split optically the data coming from microscope and send it to 2 or 4 cameras, each with independent processing chain. This gives the liner gain in the scanning speed proportional to the number of heads.

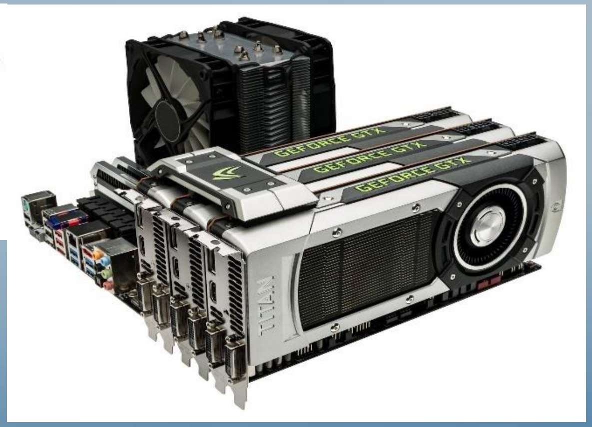
Image processing chain to be multiplied:

Camera

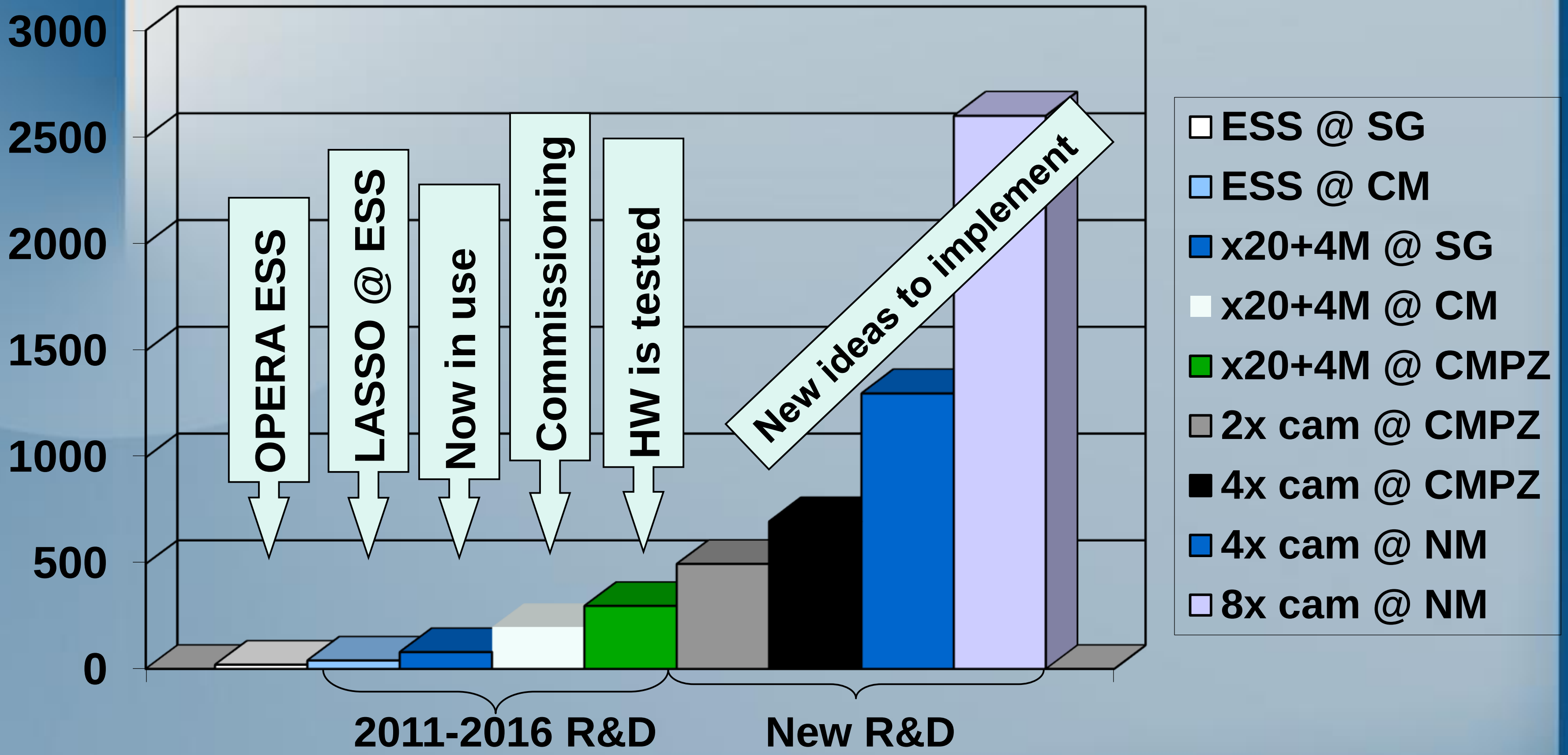
Framegrabber



GPU + CPU



How fast ESS can become?



Scanning Systems cost estimation

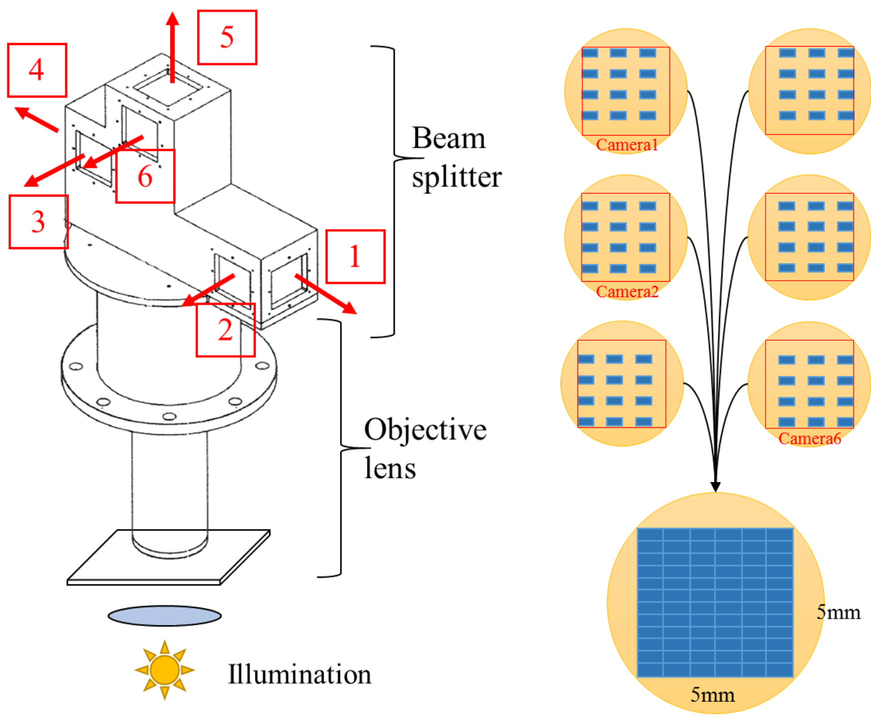
- 50 k€/system – basic part (optics&mechanics already invested for OPERA systems)
- 5 k€/system new optics
- 15 k€/head for Camera+FG+GPU+CPU
- 20 k€/system for piezo drive
- Total (1 head): 90 k€/system (300 cm^2/h)
- Total (4 head): 145 k€/system (1200 cm^2/h)

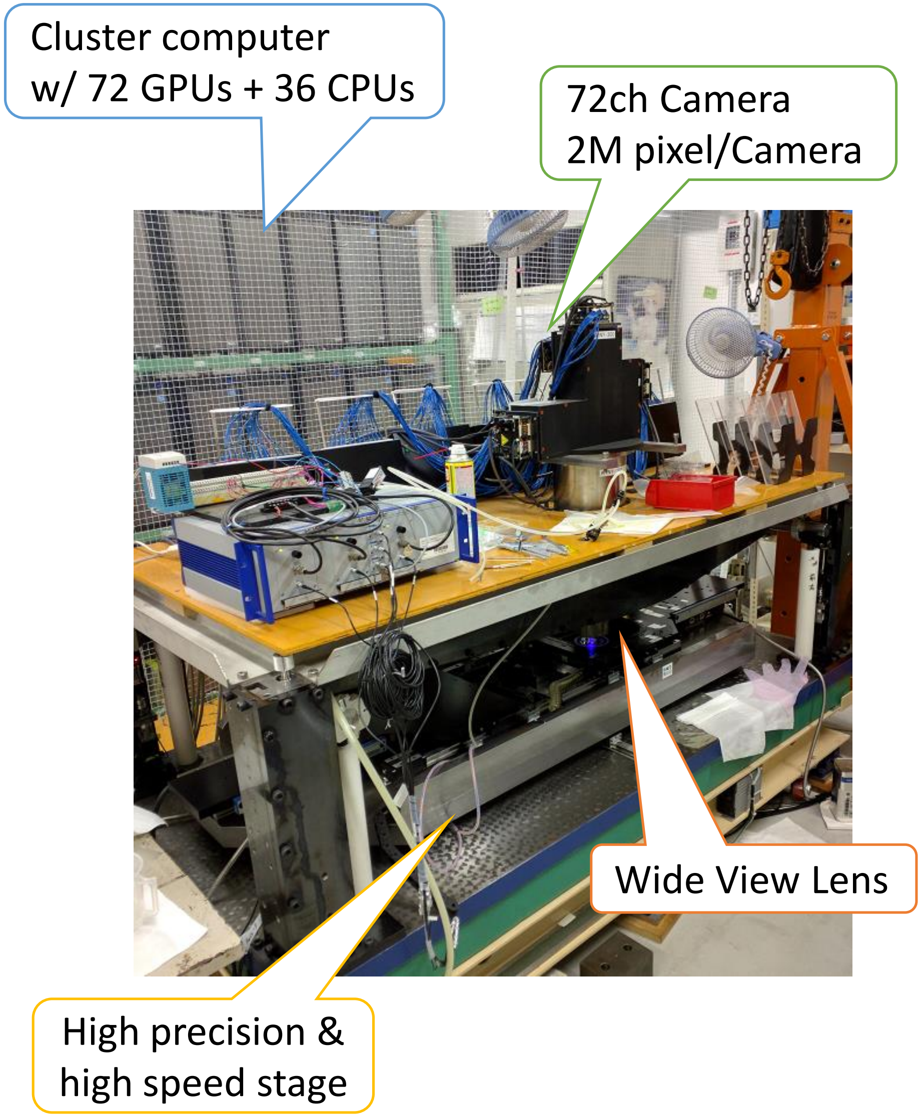
- In the Italian laboratories involved in SHIP we have more then 20 OPERA ESS. The upgrade cost is about 20/40/95 k€ per 200/300/1200 cm^2/h system

Concept of HTS

M.Komatsu

- Wide view objective lens
  - The field of view is ~500 times larger
- Mosaic Imager system
  - Parallel read-out from 72 image sensors

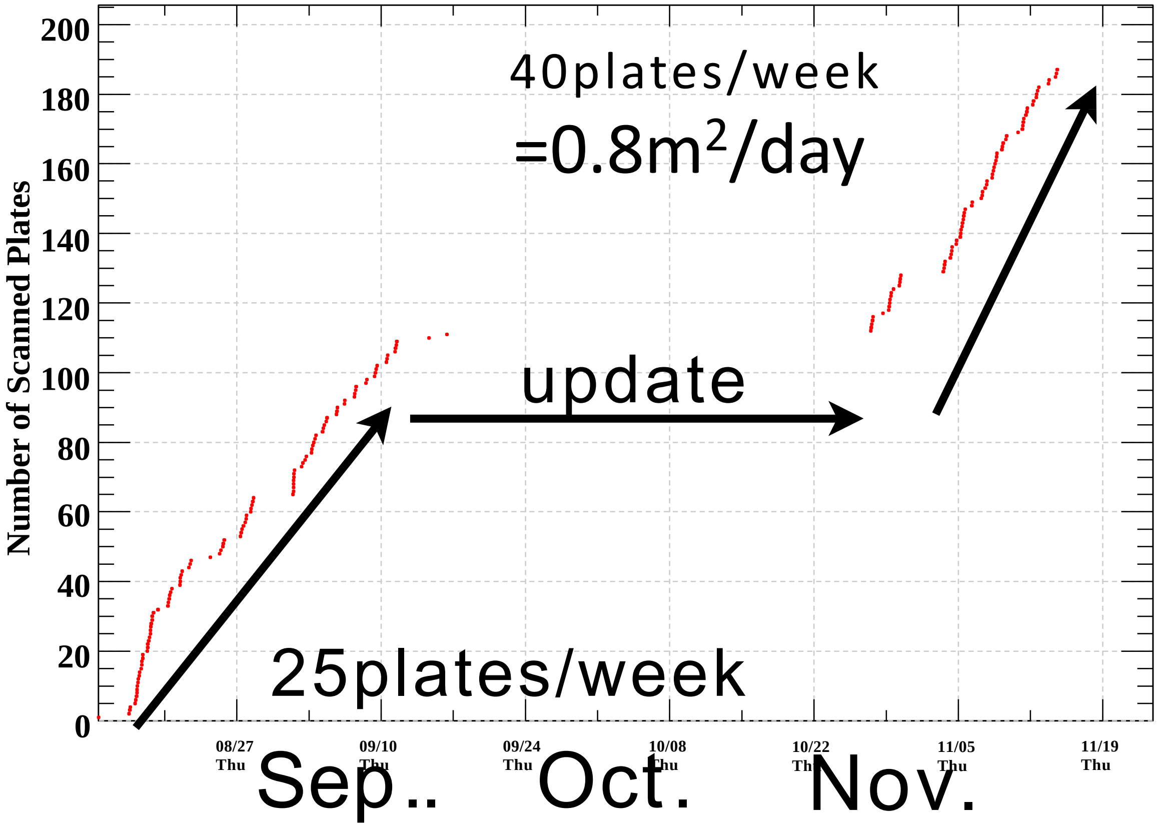




Read-out records

M.Komatsu

- Completed read-out GRAINE2015 flight converter section with the area of ~40m^2

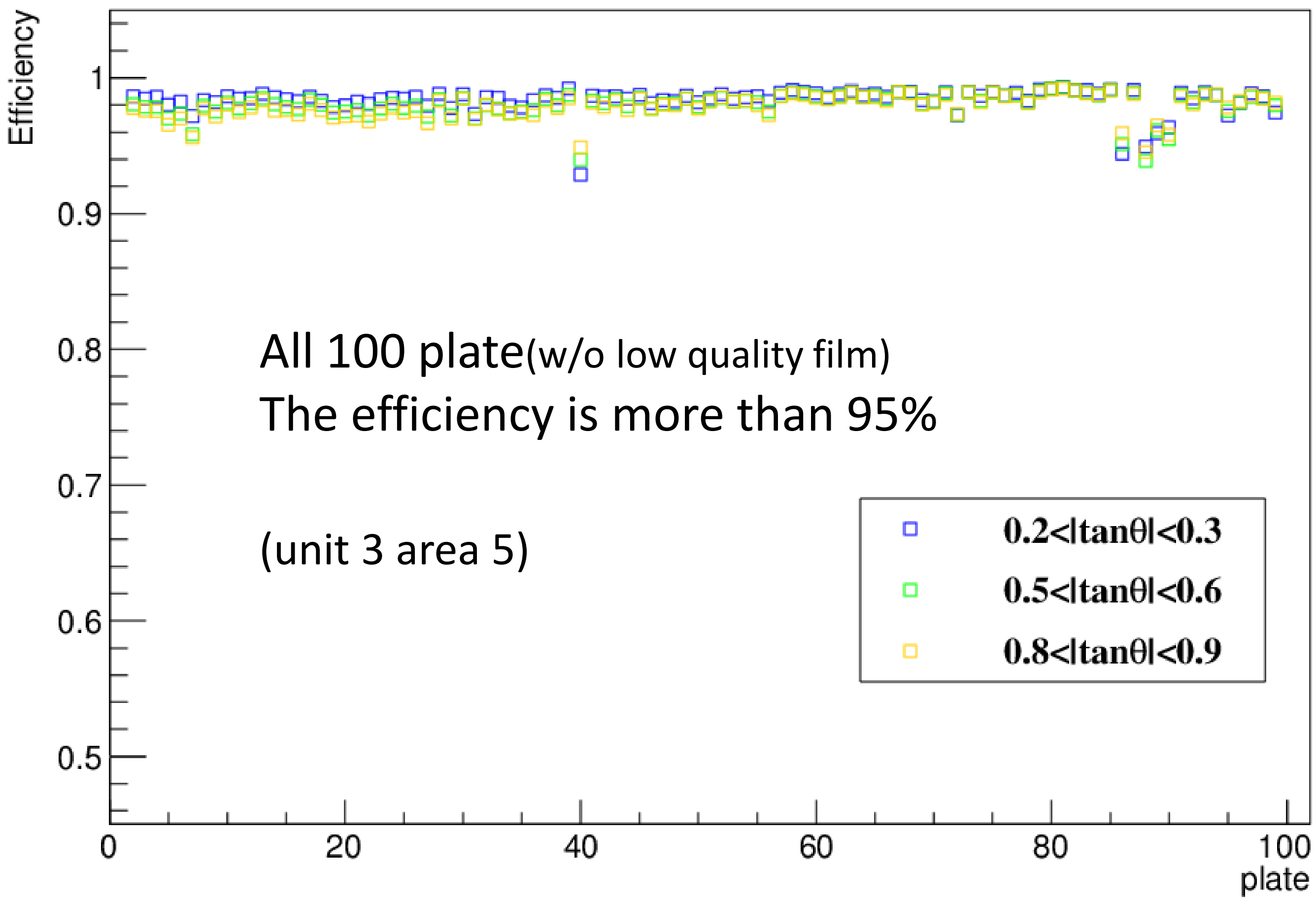


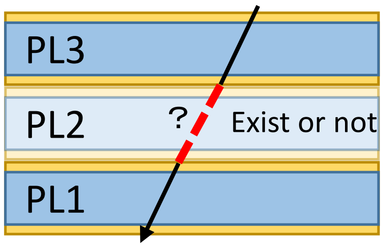
1 plate = 0.1m^2

Track finding efficiency

M.Komatsu

- Achieved stable detection efficiency over 100 plates

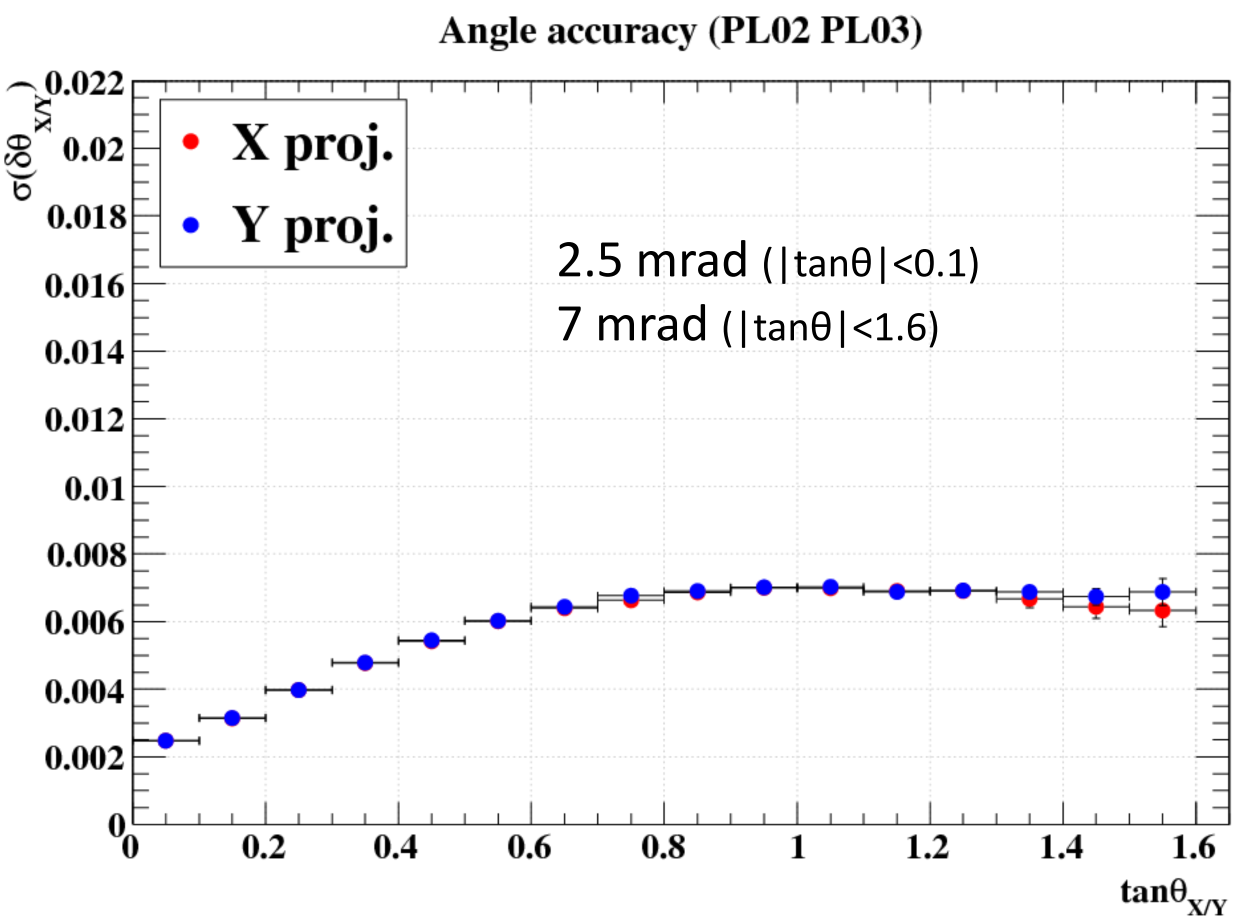


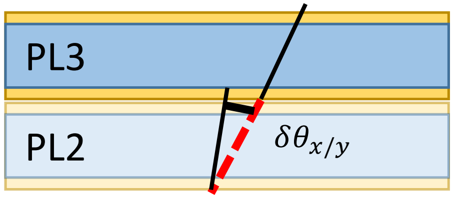


Angle accuracy

M.Komatsu

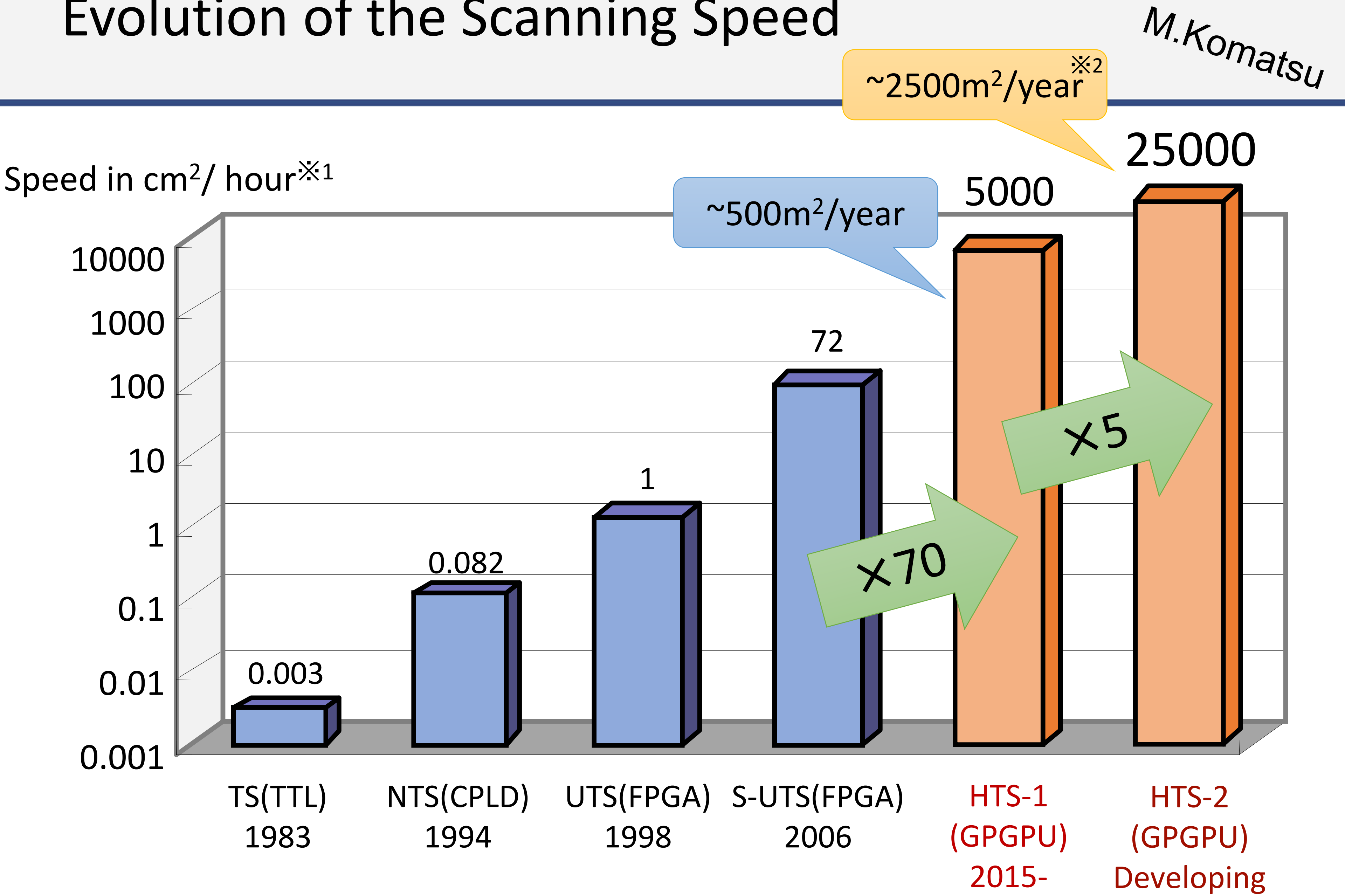
- Achieved 2.5 mrad angular accuracy with vertical track





Evolution of the Scanning Speed

※1 Area of emulsion layer
※2 Area of the films with 24 hour shift



Estimation of scanning power for SHIP data analysis

- About 1000 OPERA-like bricks has to be extracted each 6 months
- This require the scanning rate of 1400m^2/180day = 8 m^2/day
- Assume 300 cm^2/h scanning speed of one SS => 6/24/0.03 = 11 systems required
- **15 upgraded European scanning systems can sustain this load**
- **HTS2 system in Nagoya can sustain this load as well**
- **We have sufficient margins for doubling the scanning rate if needed, with already developed technology**

- **Another factor 2-5 in SS speed improvement is expected in near future**

Conclusion

- The performance of scanning systems growing fast thanks to intensive R&D and technological progress
- There are 2 different approaches for high-performance scanning in Japan and in Europe:
  - One (two) huge multy-camera system in Nagoya
  - Many smaller 1-few camera systems in Italy
- Both approaches results in comparable as cost/area scanning power with an overall performance of several m^2/day/laboratory
- Using already developed technology the performance of scanning laboratories is adequate for SHIP requirements
- The scanning systems development is far from saturation, another factor 2-5 is achievable in a few years