Super Fast Automated Emulsion Scanning System
~ HTS ~

Masahiro Yoshimoto,

Toshiyuki Nakano and other HTS collaboration

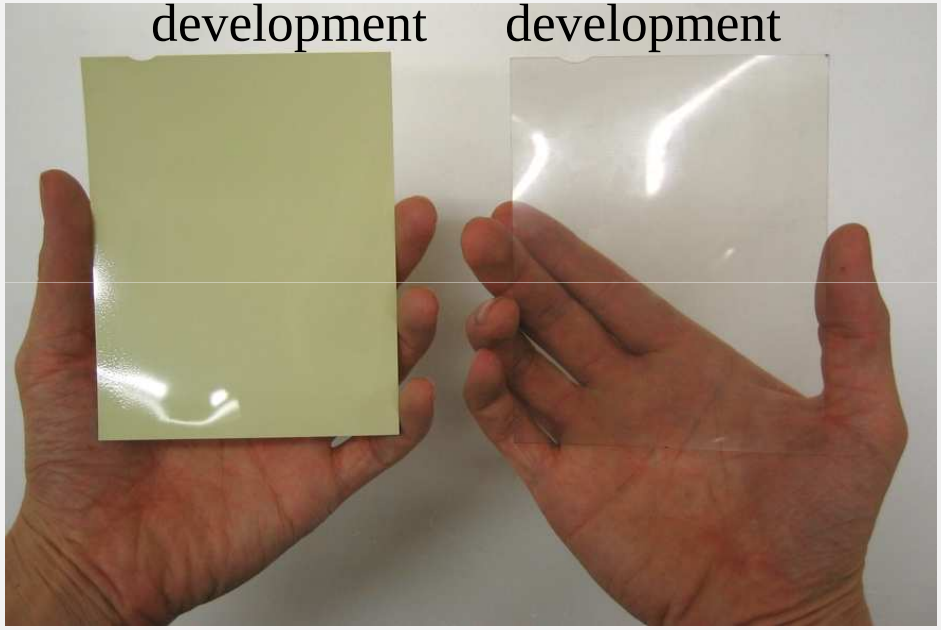
Nagoya University, Japan

Our Emulsion Film

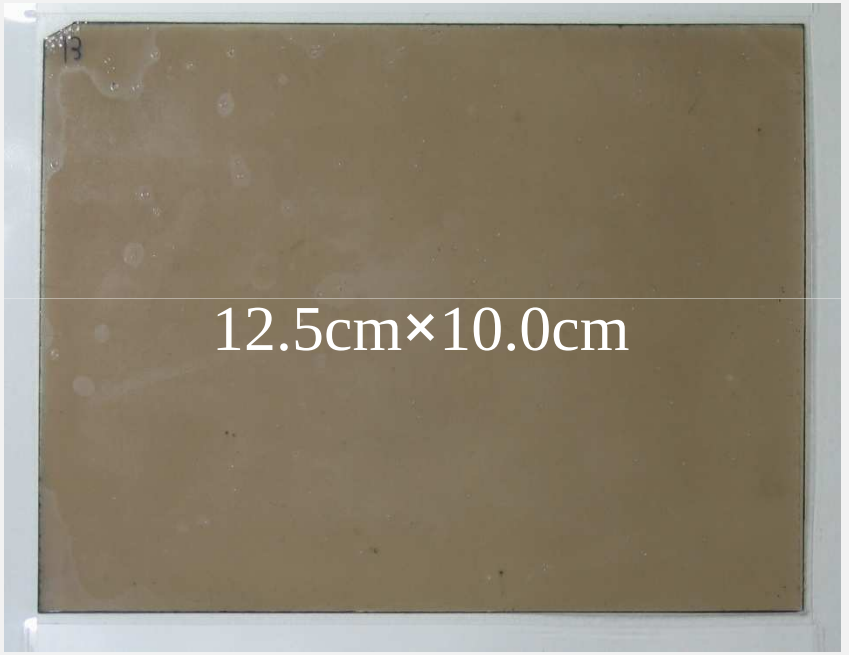
OPERA film

Before development

After development



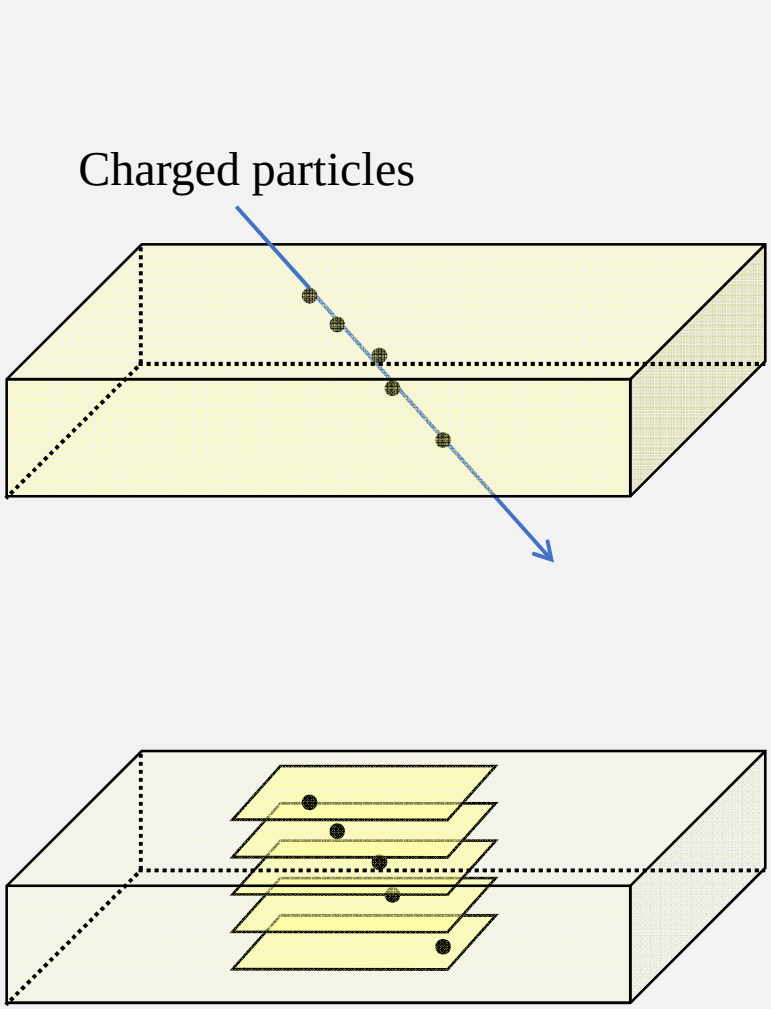
New Emulsion film
(After development)

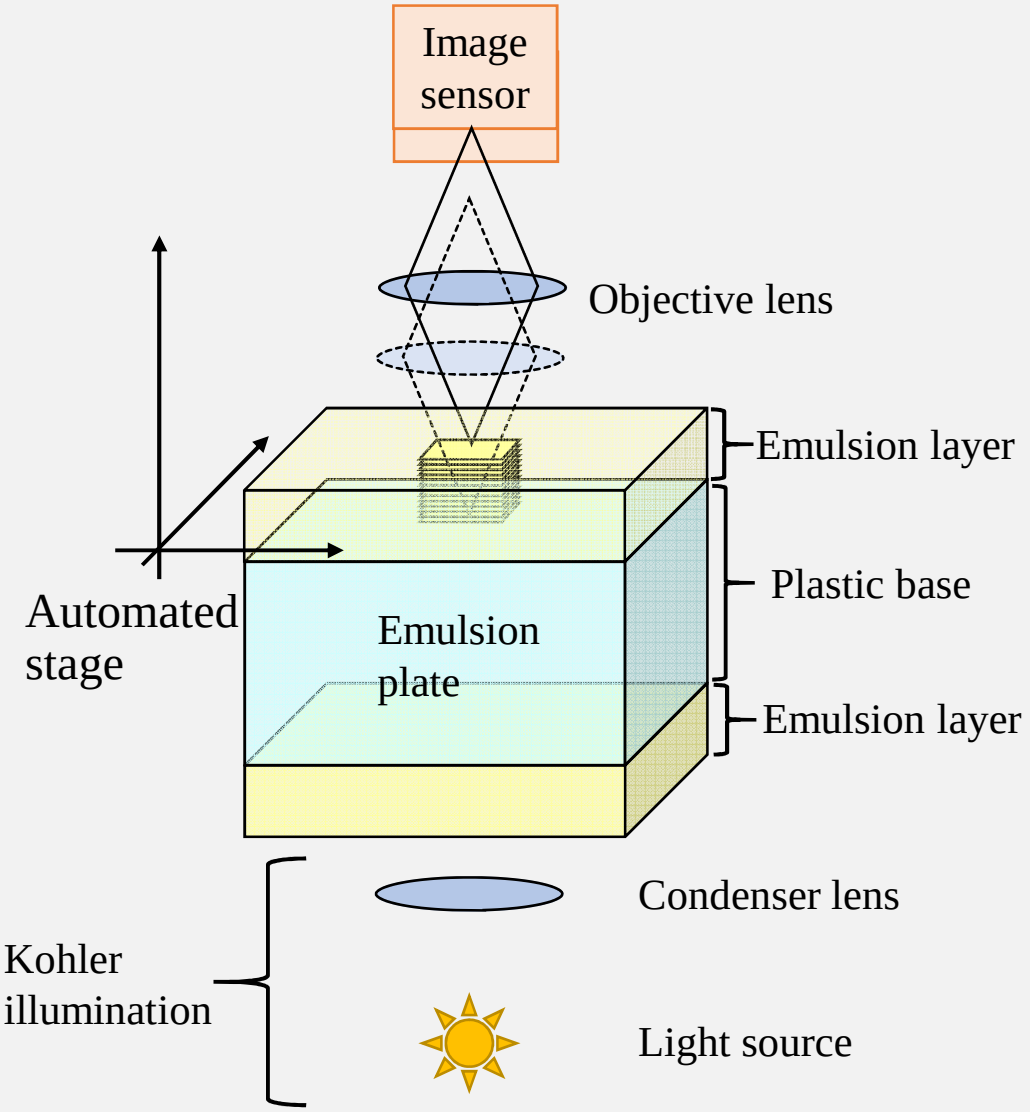


In Nagoya Univ., We have been developing new emulsion film.

- Grain density is much higher.
- Emulsion gel can be produced by ourselves.
- Pouring (coating) facility is under construction.

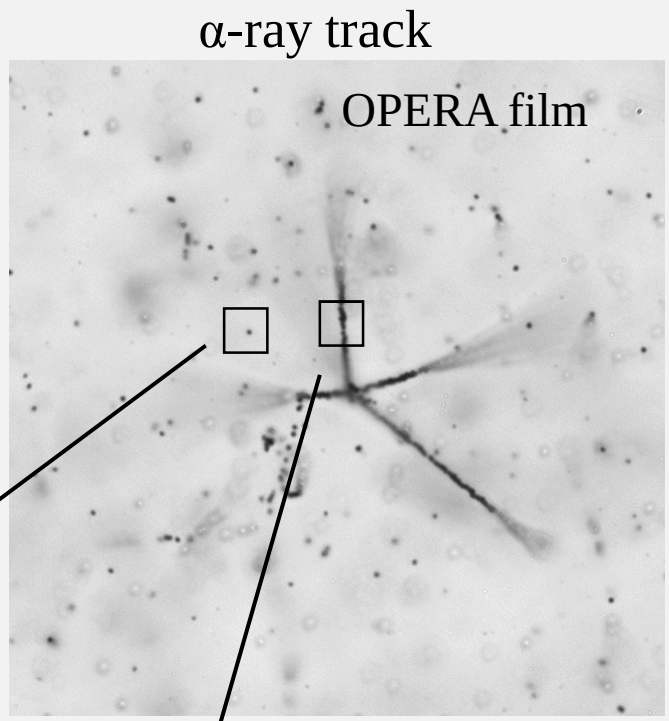
Detecting ionizing particles

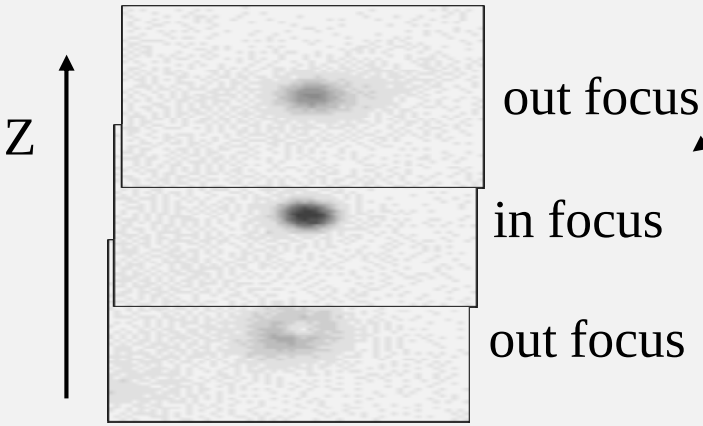


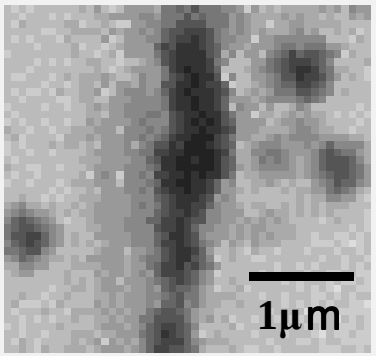


Capturing Emulsion Image

- Thickness of the emulsion layer >50μm
- Depth of field ~3μm
- Size of the silver grain ~0.3μm
- Optical resolution which is required <0.5μm







Stacked image of optical microscope
res. 0.27μm

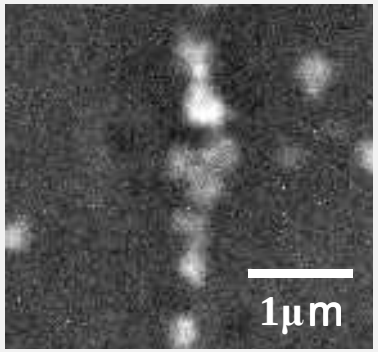


Image of X-ray microscope
DOF is ±~70μm
res. 0.07 μm

Image processing

Raw image which is taken

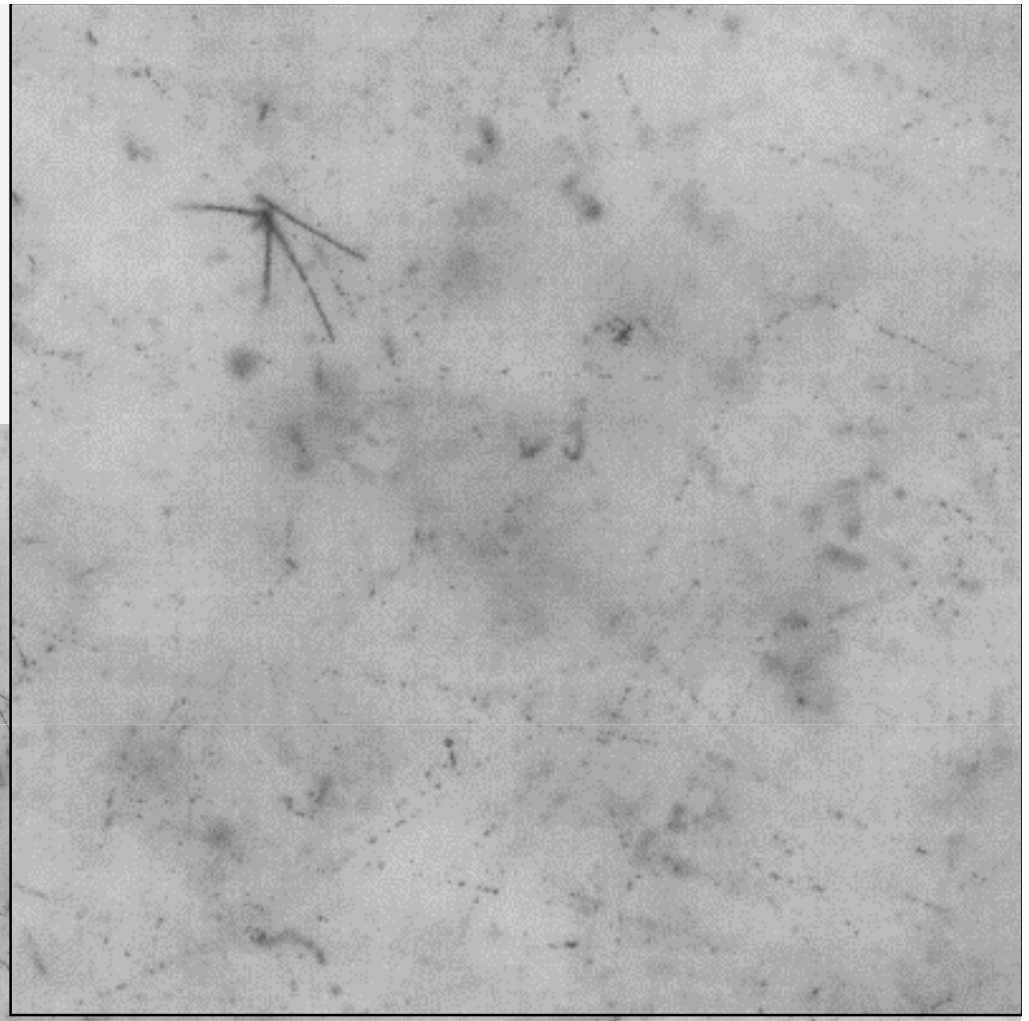
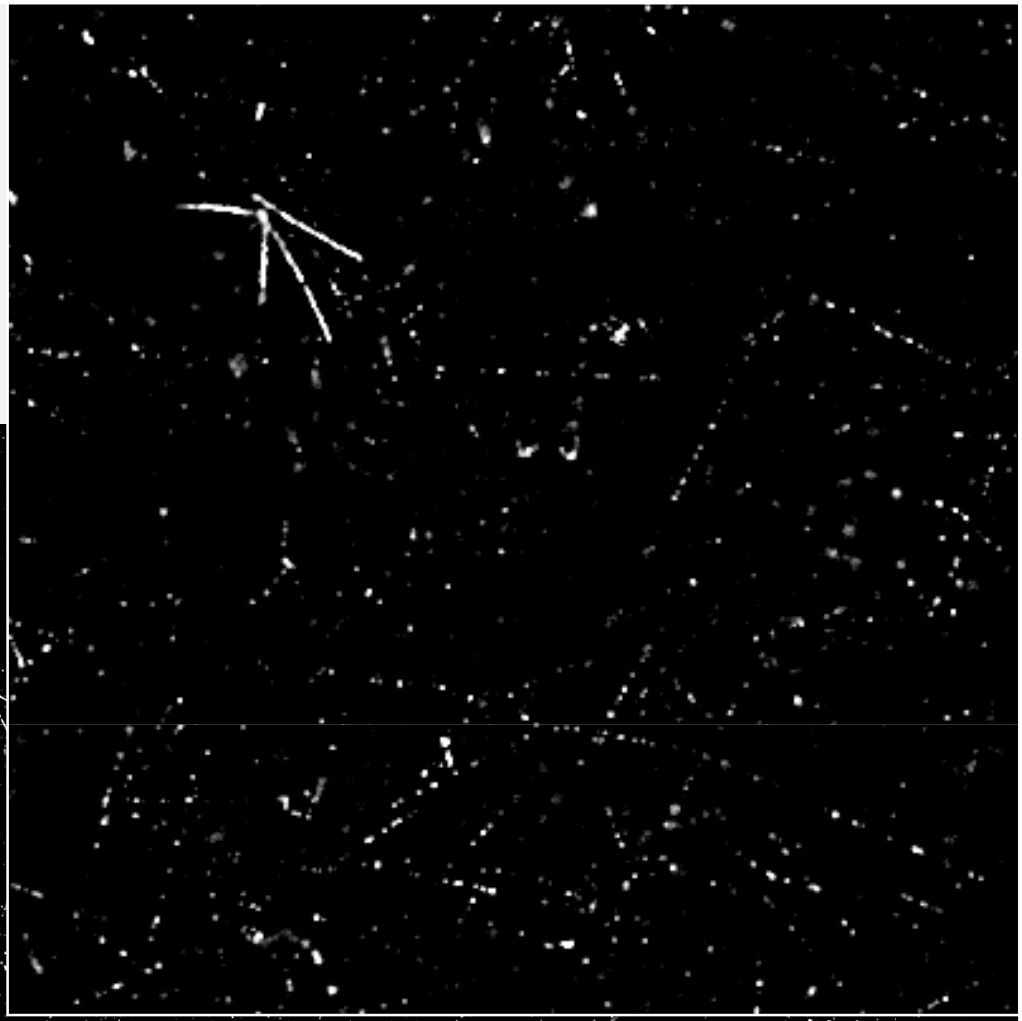
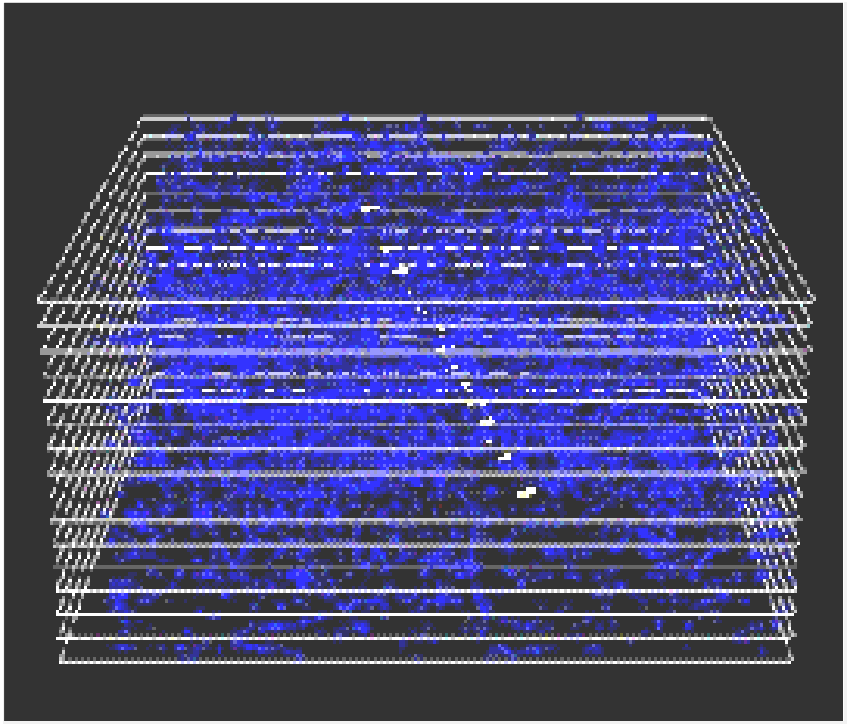
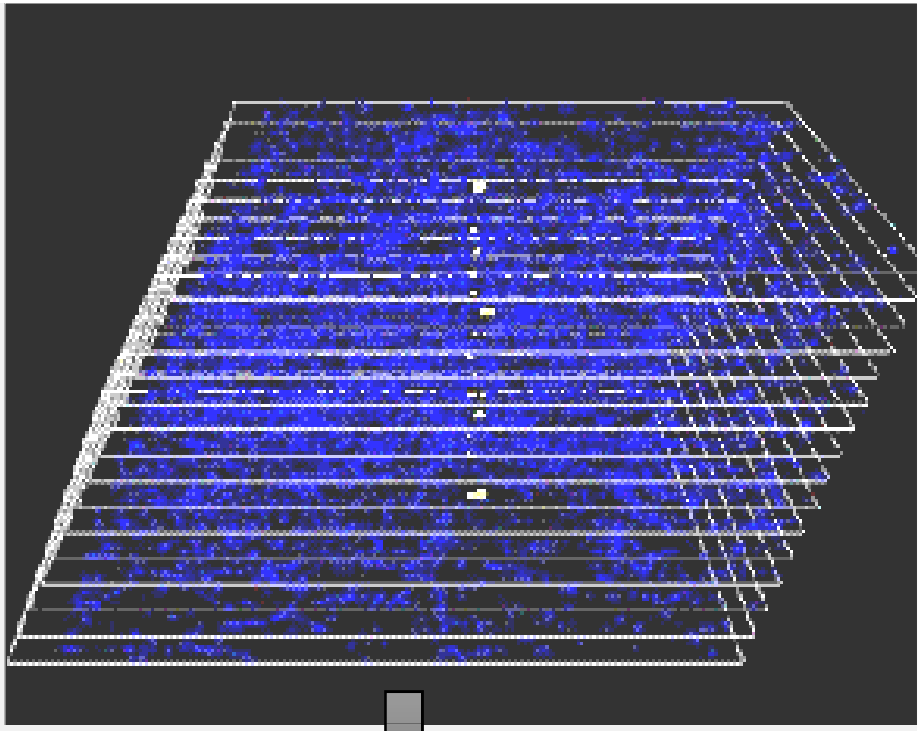


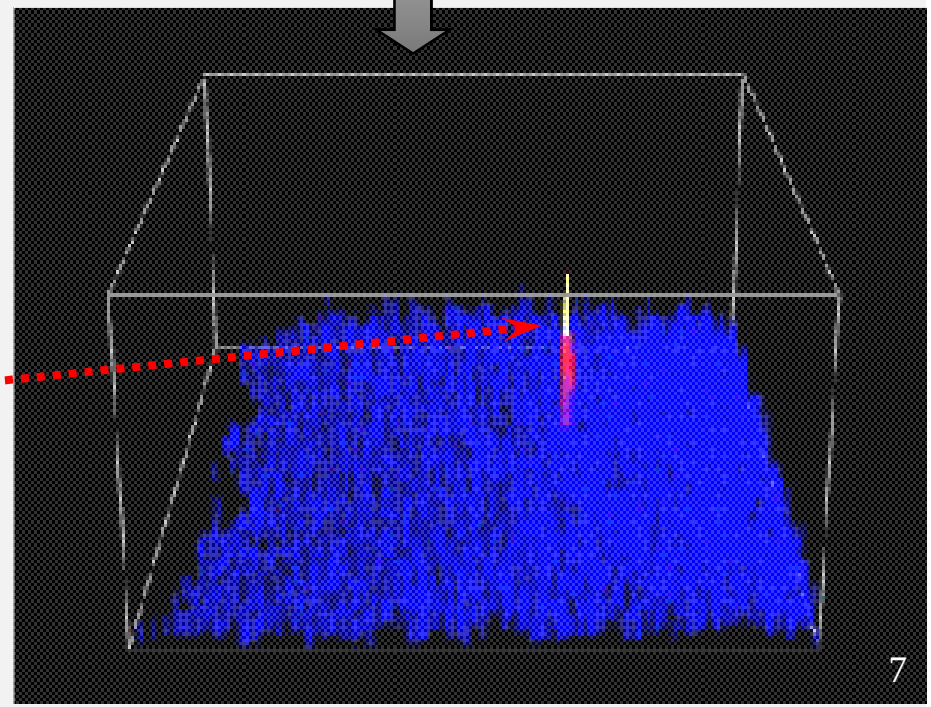
Image processing

Applying 2D-FIR filter
Cut off the background







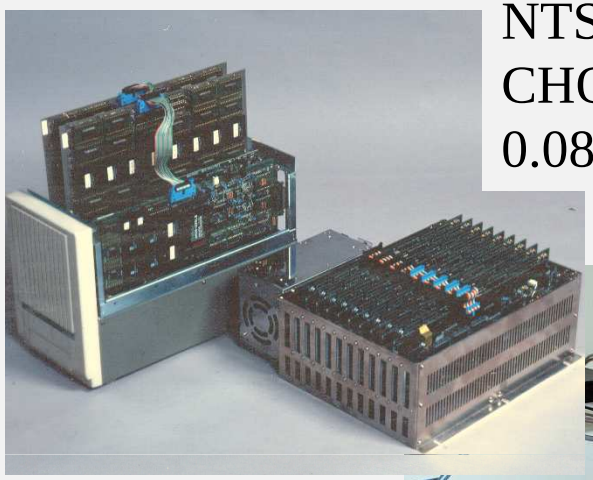


Track recognition method

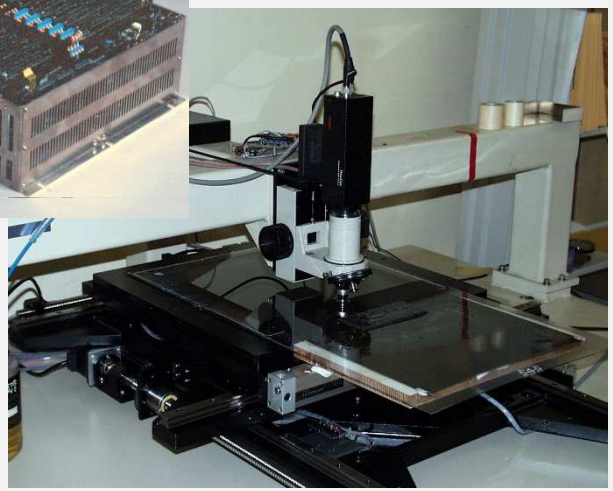
- Take 16 tomographic images by microscope optics.
- Shift images to aim at specific angle tracks.
- Sum up 16 images to examine coincidence.
- Find signal of tracks.
- Repeat for all angles in space, >2000 times

Invented by K. Niwa in 1974

History of emulsion readout system in Nagoya



NTS (CPLD) 1994~
CHORUS
0.082cm^2/h

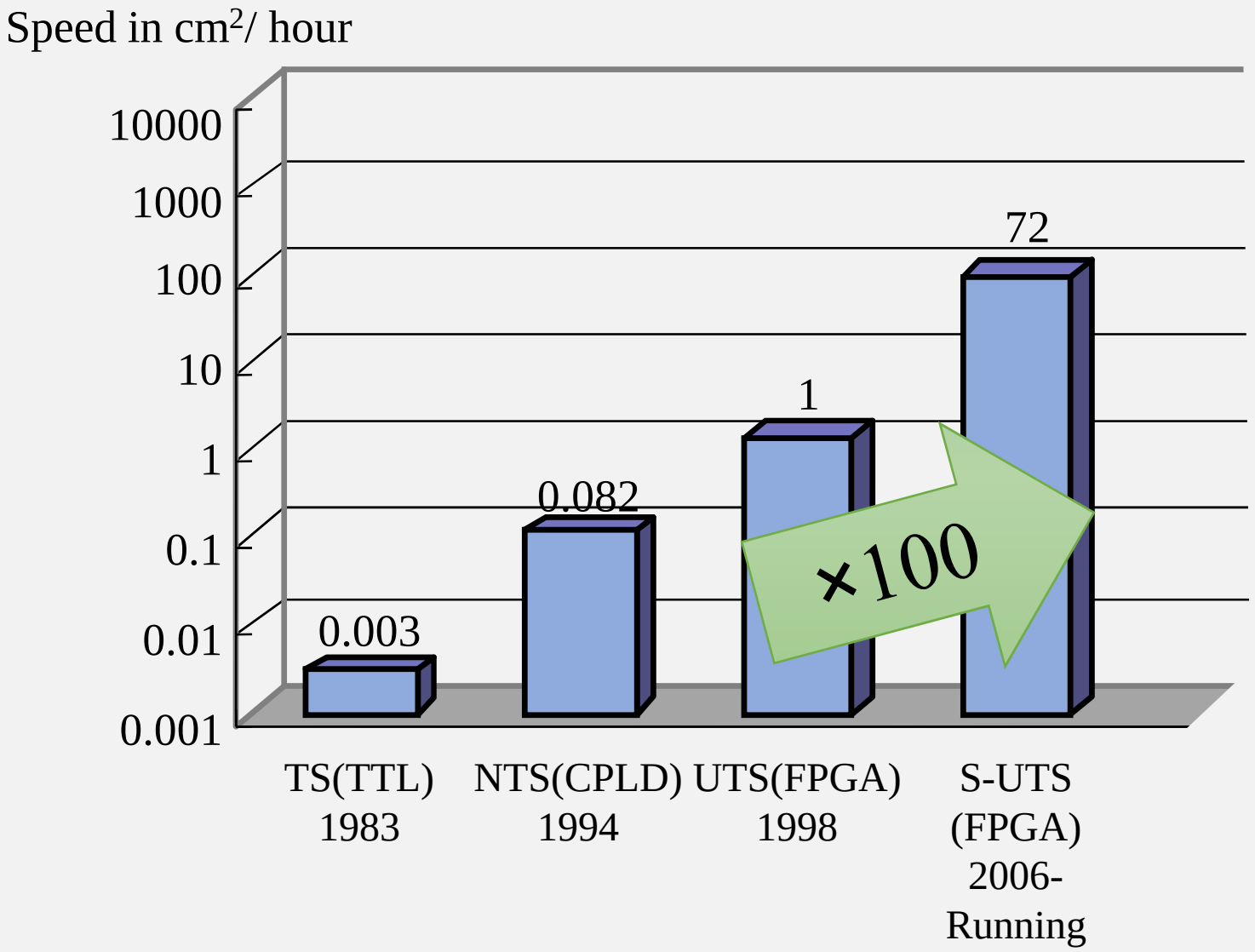


TS (TTL)
1983~
CHORUS(R&D)
0.003cm^2/h

UTS (FPGA)
1998~
DONUT
1cm^2/h

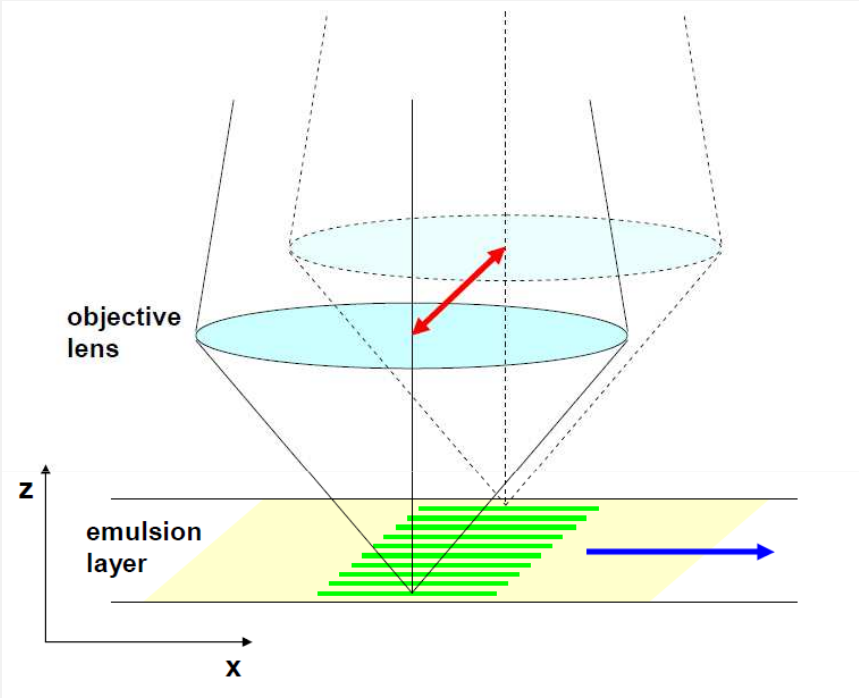
Innovation has been required for the next generation systems.

Evolution of the Scanning Speed



Overcome the Bottle necks of the image acquisition

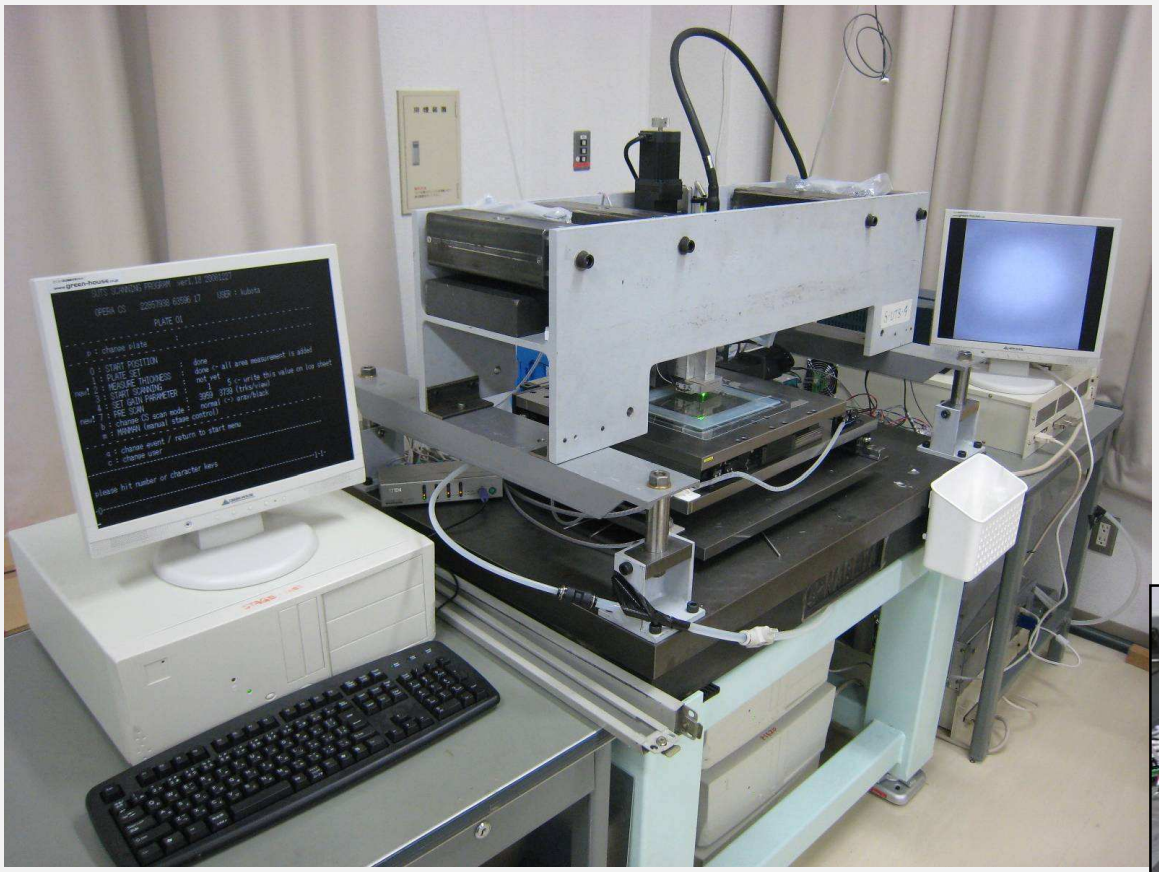
- Use Ultra High Speed Camera
  - Up to 3k frames per second.
  - 60 view/sec (20times)
- Image taking by follow shot
  - No step and repeat operation can avoid a mechanical bottleneck.
  - High speed motion of the objective lens can be done by piezo actuators
- Optimizing Field of View
  - 120mm×90mm -> 200mm×200mm (4 times)

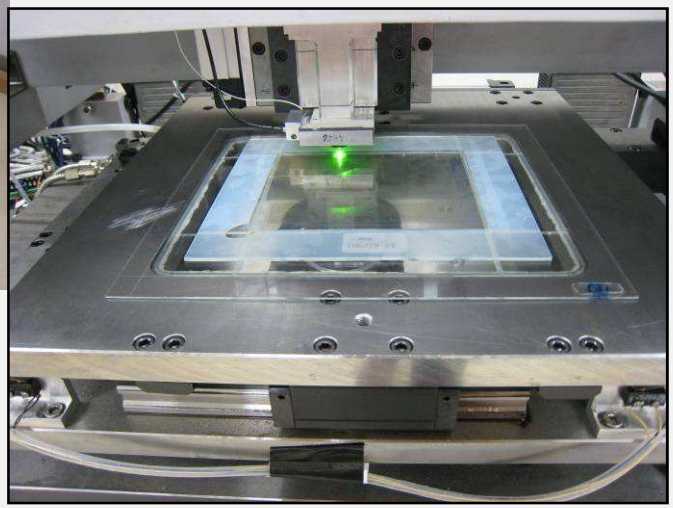


We have achieved 72cm^2/h

Movie of the readout by S-UTS

S-UTS (Super-Ultra Track Selector)

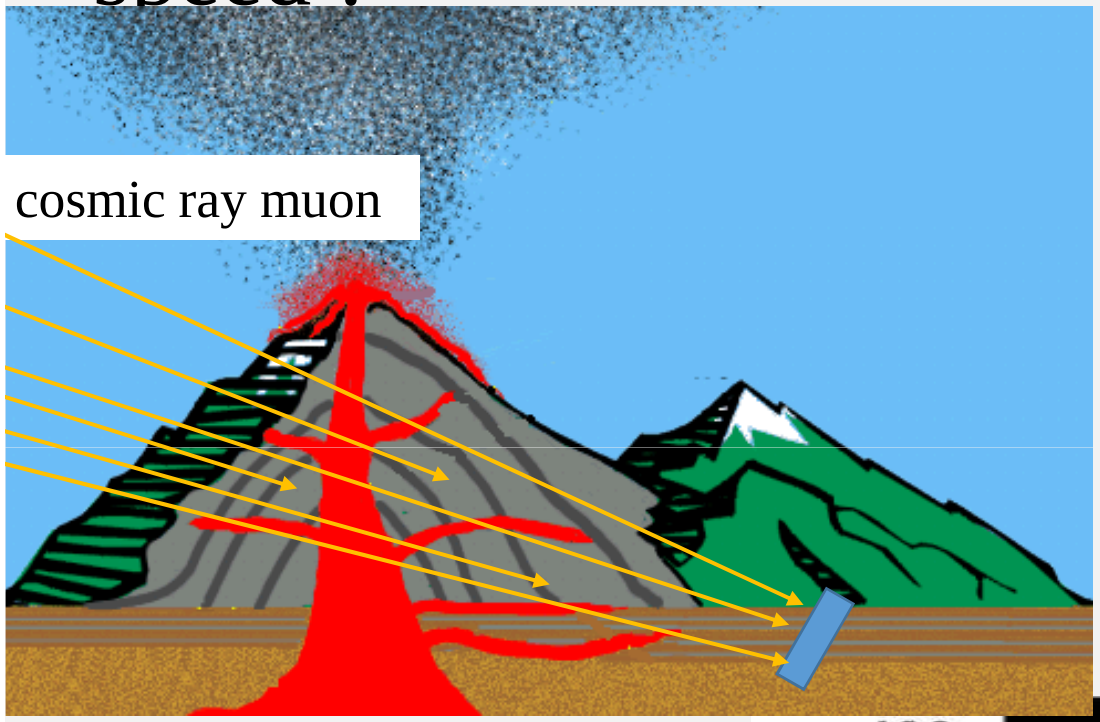




Five S-UTSs were produced in order to perform OPERA experiment.
Readout capability of one S-UTS is 20m^2/year.

Applications of Nuclear Emulsion

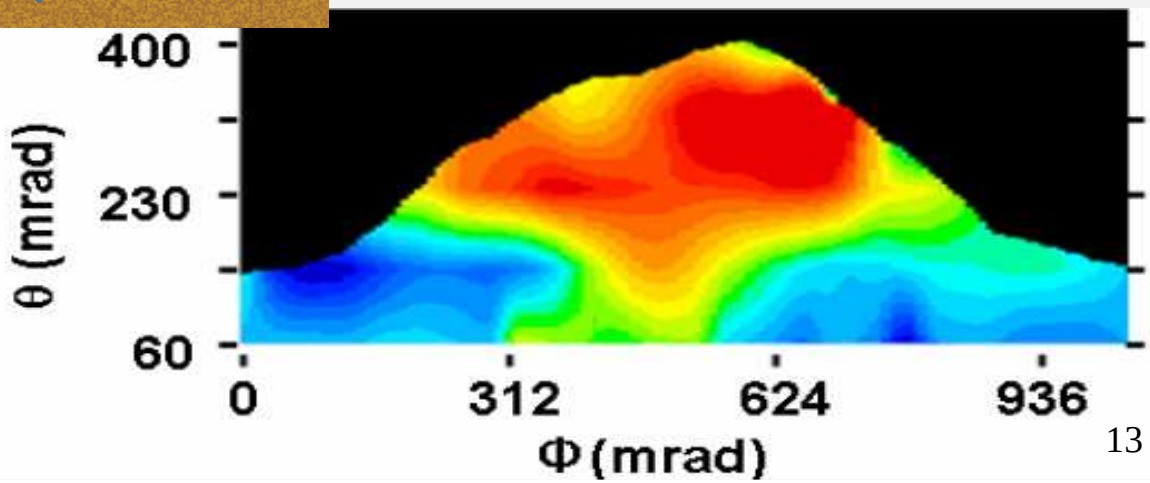
• • • • • need much more speed !



Muon Radiography

100m^2 will be required for one measurement.

→Morishima's talk



Applications of Nuclear Emulsion

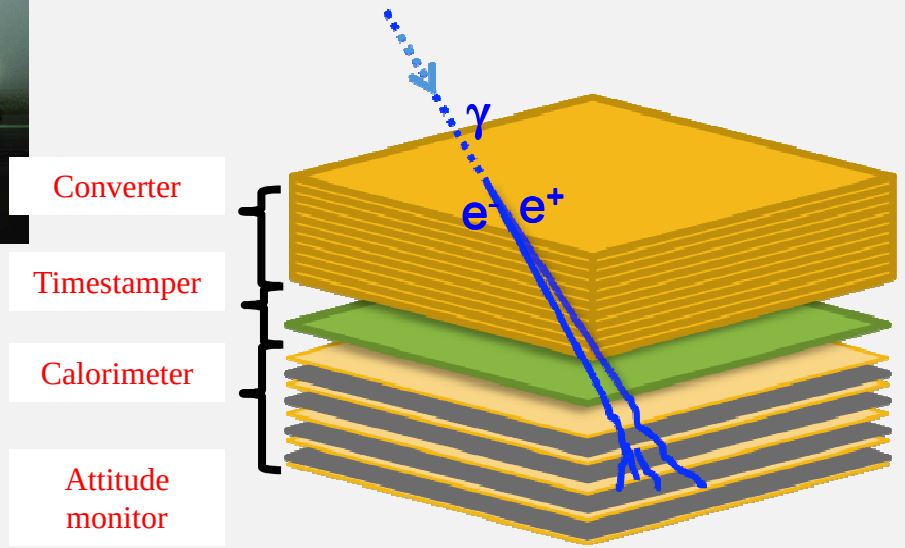
• • • • • need much more speed !

GRAINE project

Gamma-ray Telescope

Several 1000m^2 will be required for scientific observation.

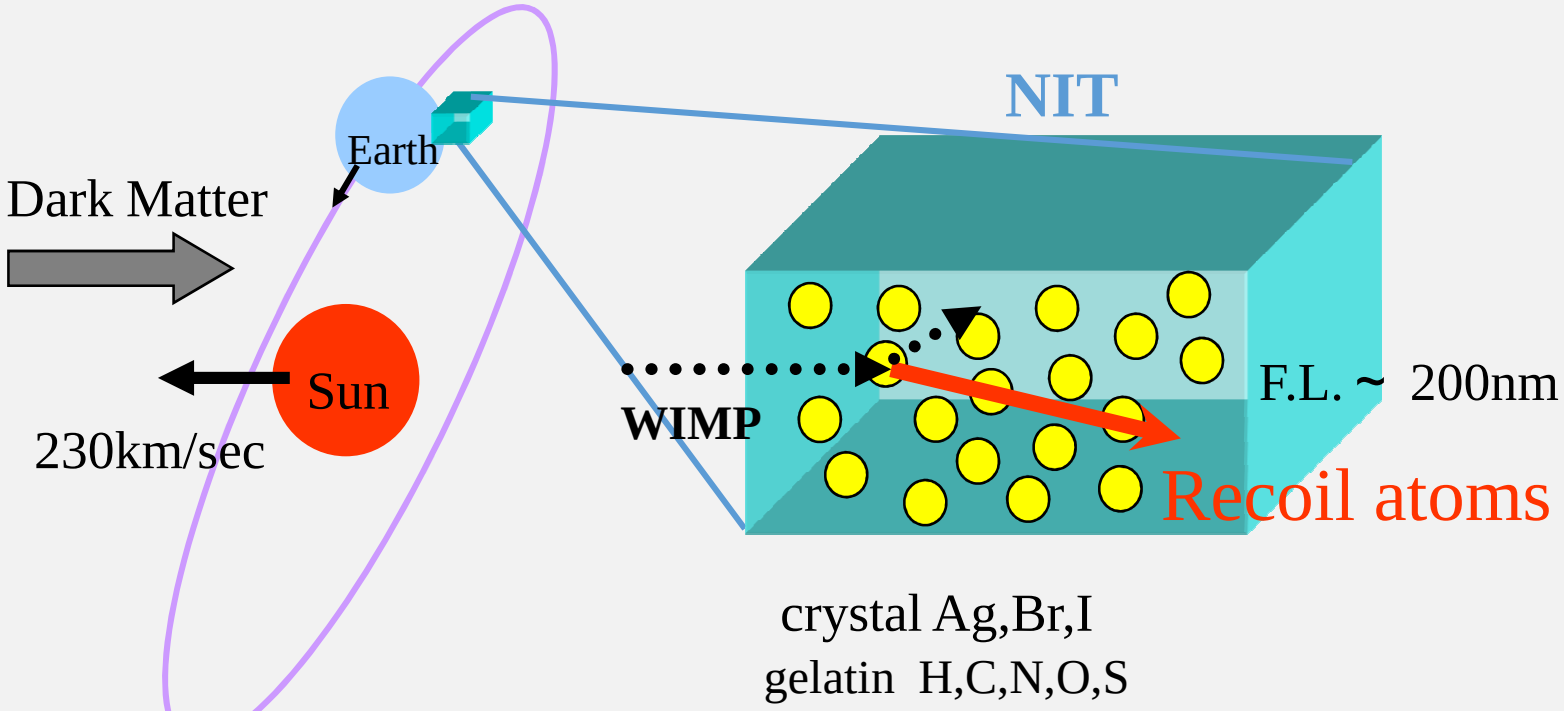
- 2011 Balloon experiment was performed.
- 2014 Planned at Alice Springs.
- 2015- Starting scientific observation



Applications of Nuclear Emulsion

• • • • • need much more speed !

Dark Matter Search



$V_{recoil} = 2 (V_{sun} + V_{WIMP})$

$= 100 \sim 1000 km/sec$

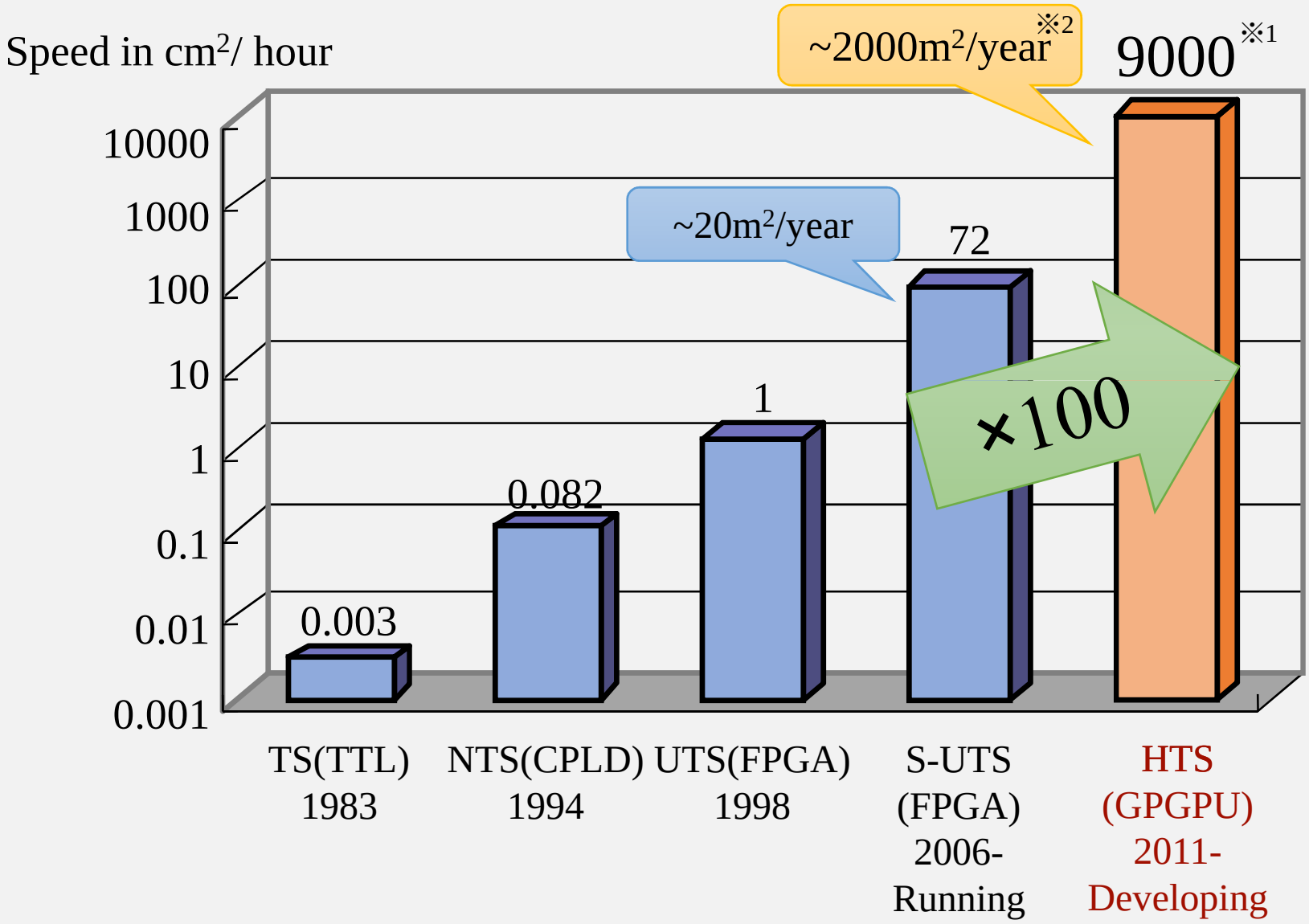
→Asada's talk

We need to readout the target mass of 1 ton (about 4000m^2).

~3g / film
0.0125m^2/film

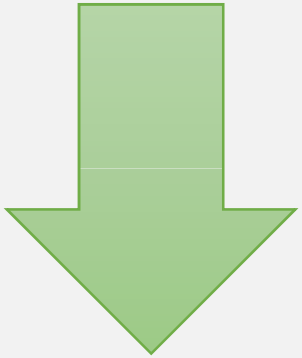
Evolution of the Scanning Speed

※1 Area of each layer
※2 Area of the films



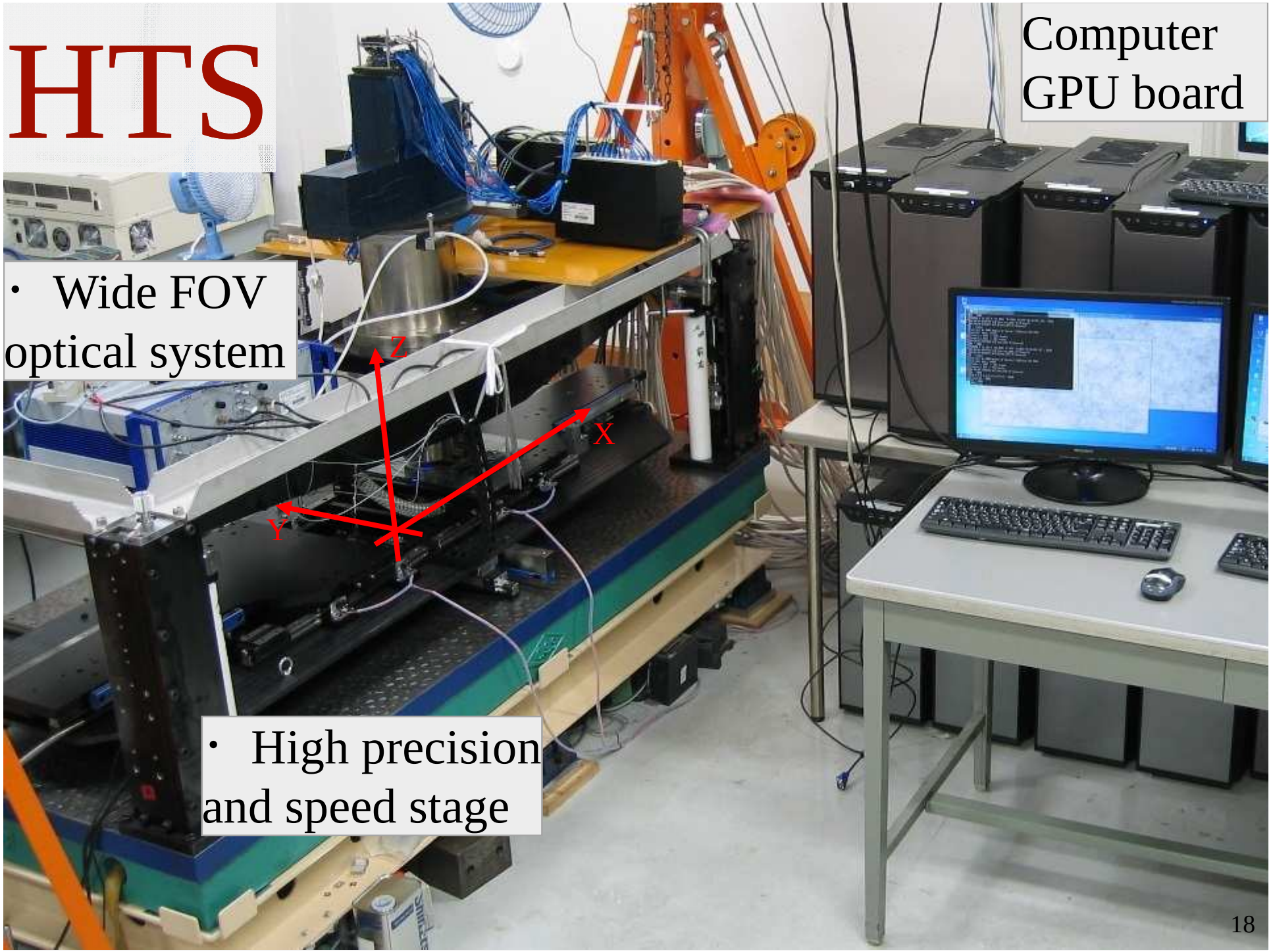
Concept of HTS (Hyper Track Selector)

- It is difficult to drive objective much more quickly.



- Field of view can be a few orders of magnitude larger.

HTS


Computer
GPU board
· Wide FOV optical system
Z
X
Y
· High precision and speed stage

Enormous Objective

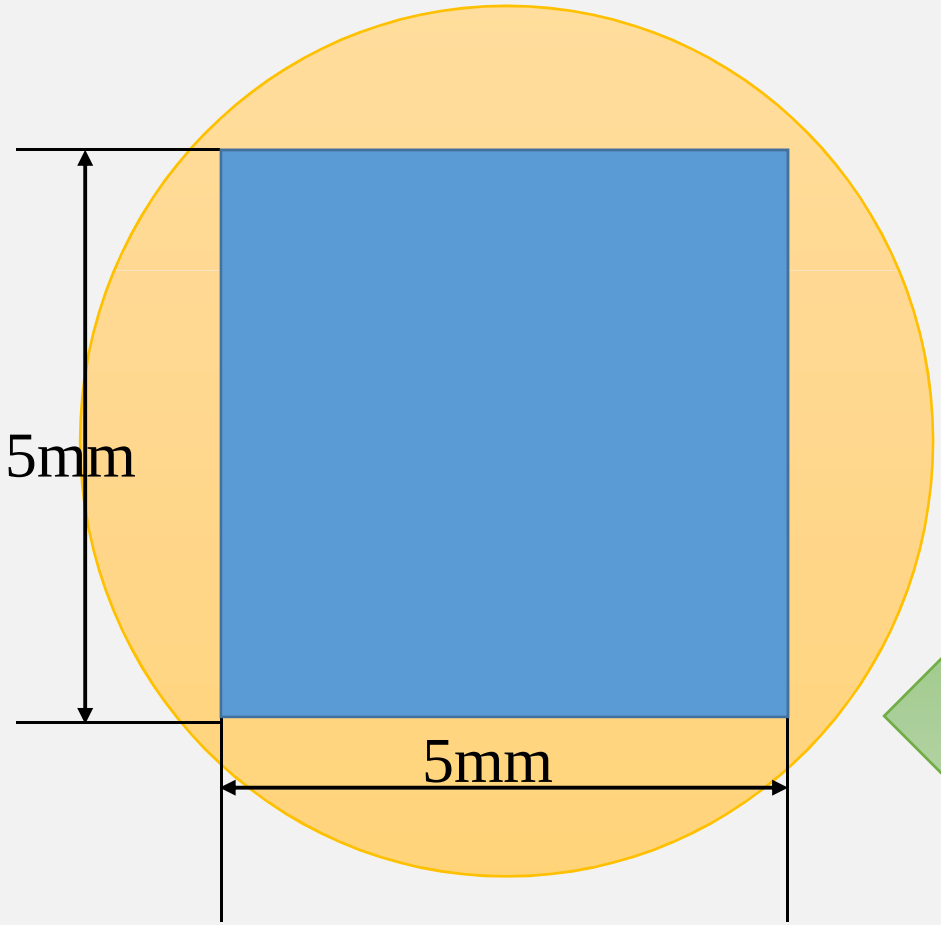
Resolution : ~420nm
N.A. : 0.65
Light source : g-line (436nm)
Magnitude : ×12.2
F.O.V : 5.1 (H)×5.1 (V)mm

#of image plane 6
(by Beam splitter)

Weight : 80kg

Wide field of view

Field of view (FOV) of HTS



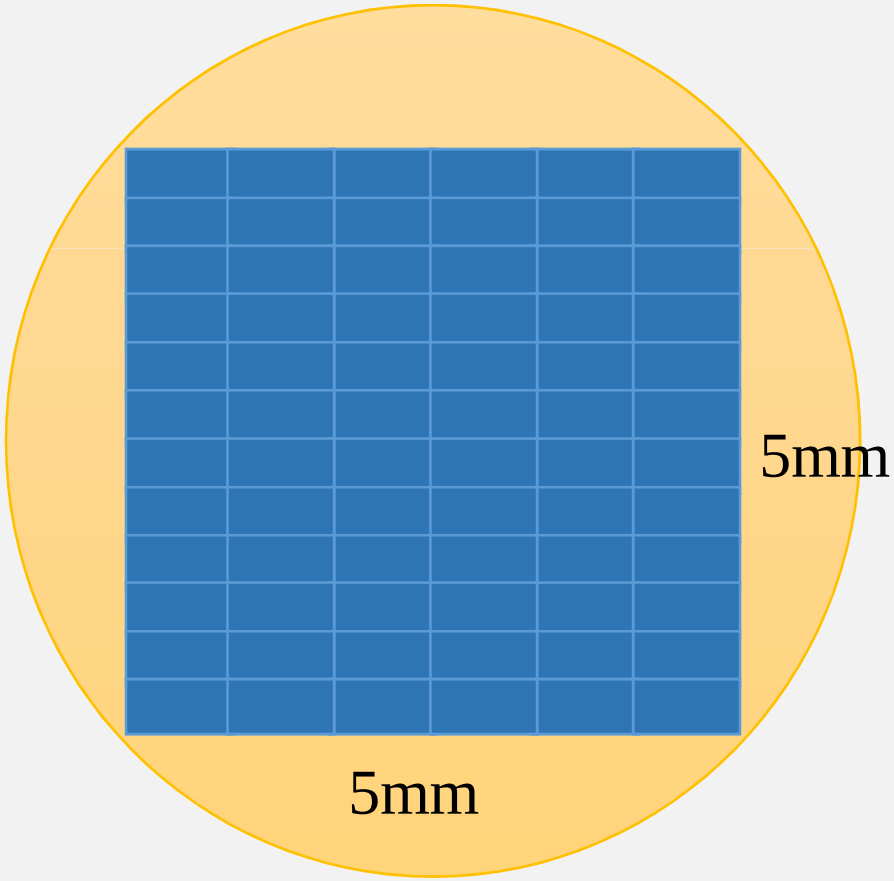
× 600

S-UTS

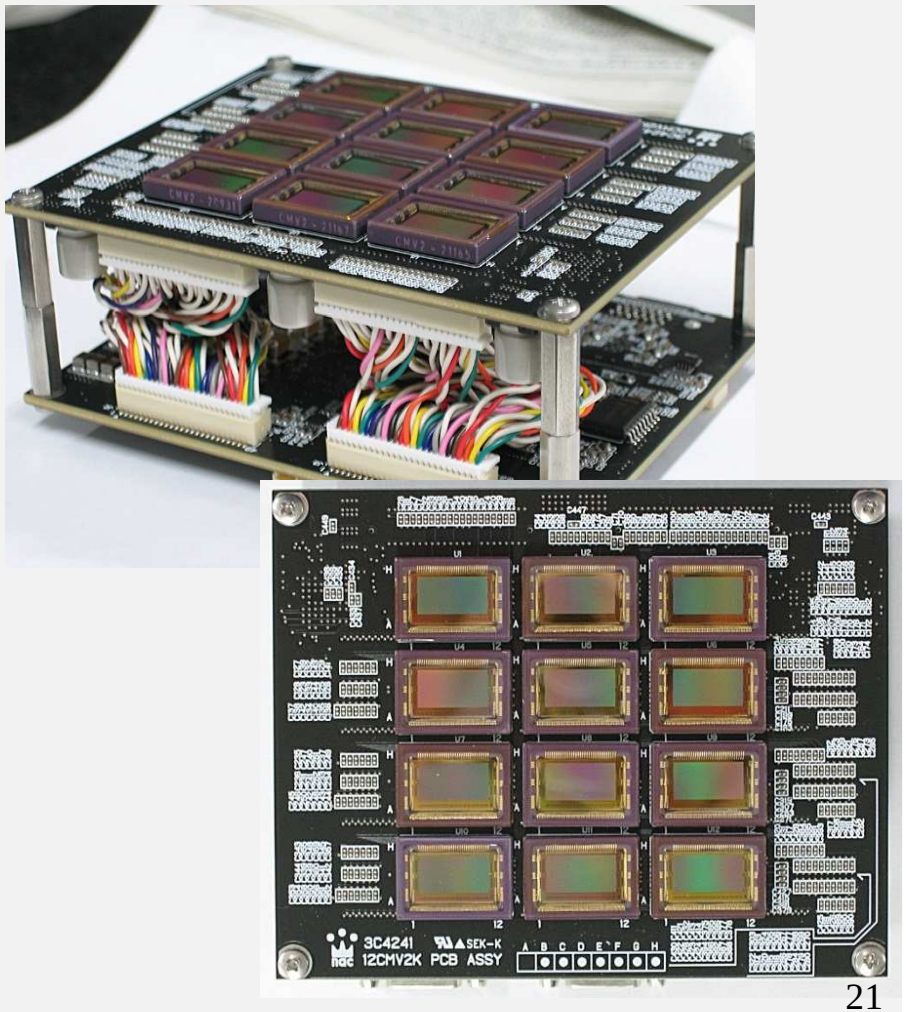
~0.2mm

Speed and Coverage of Mosaic Imager

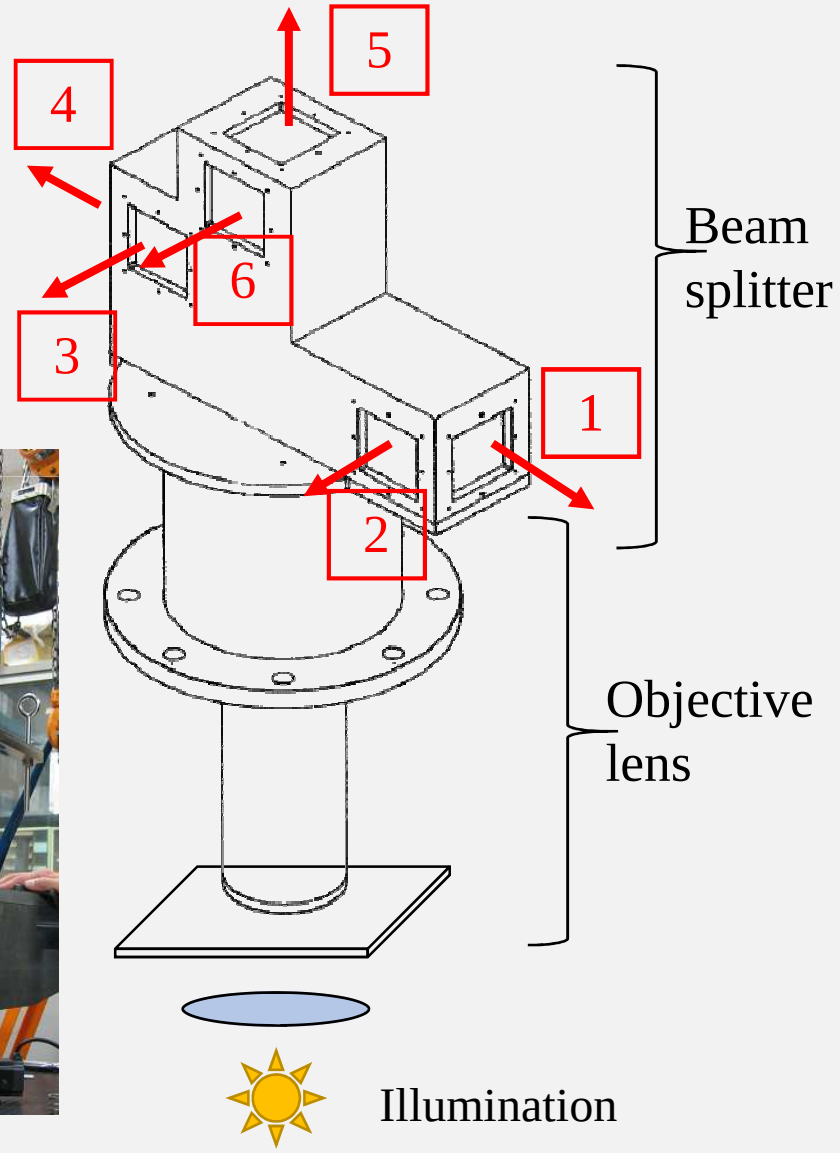
Divide FOV into 72 parts.
Need the sensor of 2M pixel and 340fps.

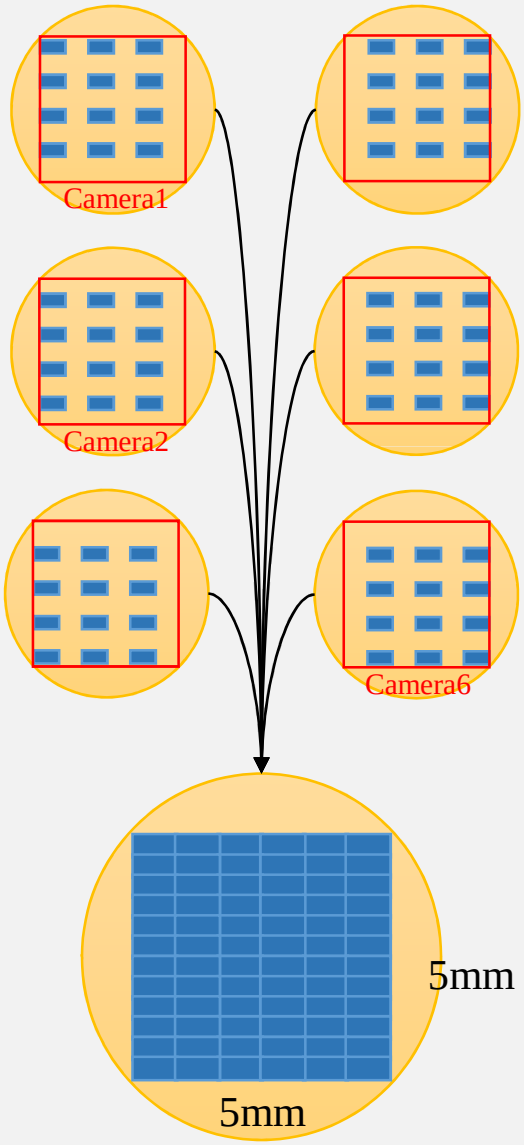


Specially ordered Mosaic Imager



Mosaic Imager system





Movie of the readout by HTS

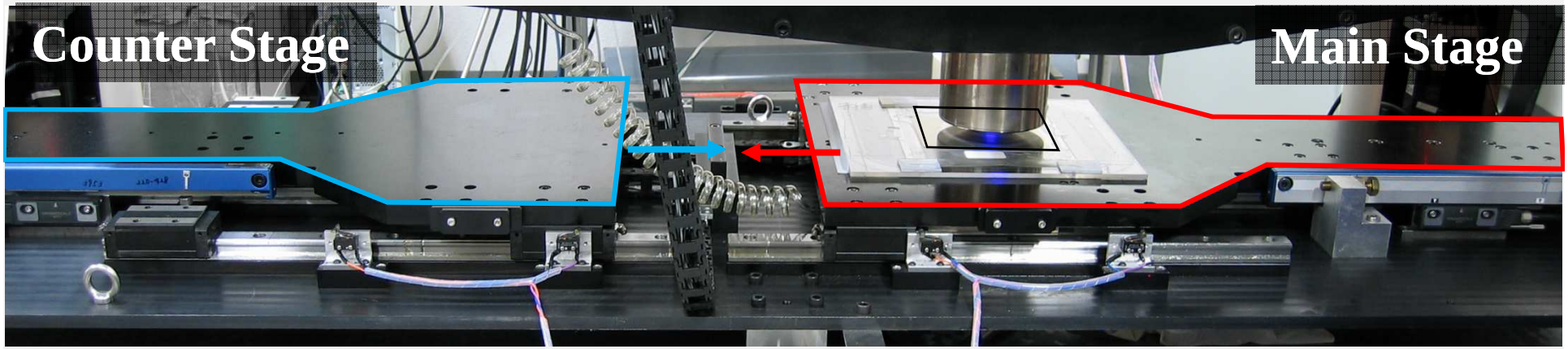
Image capturing at rest

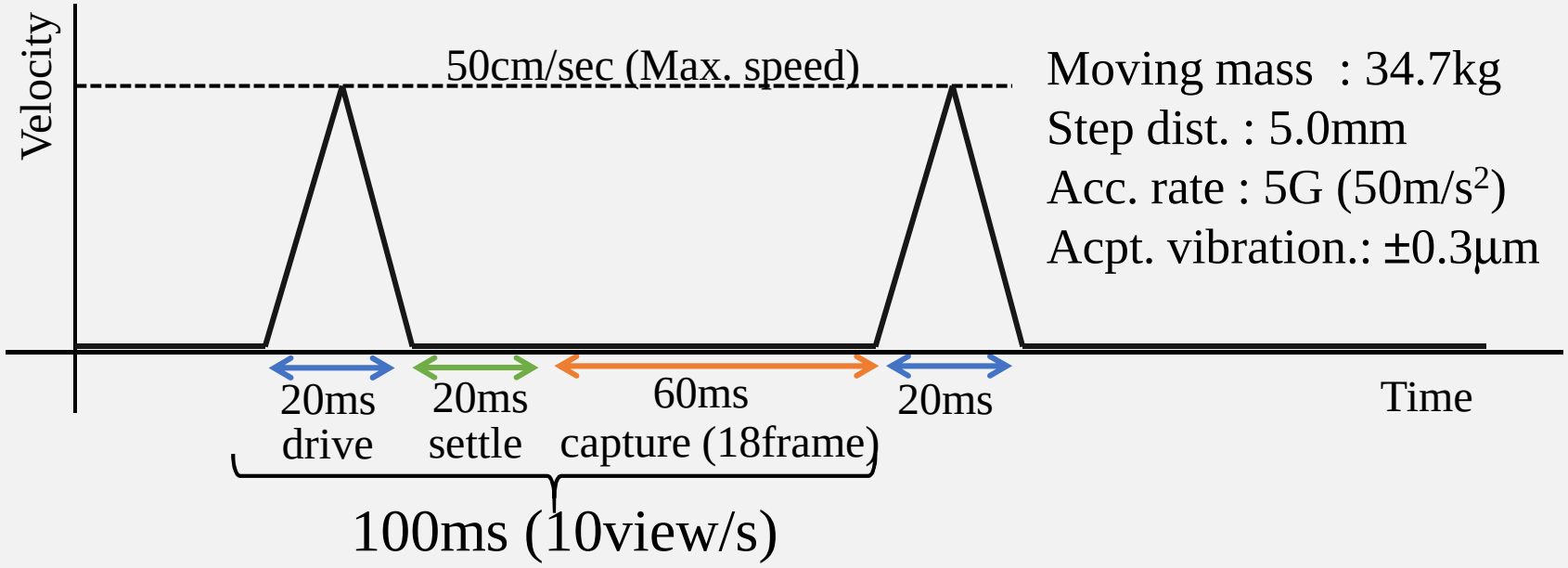
- Stopping accuracy should be 0.3μm.
- HTS takes advantage of Stop & Go in image capturing.
- Key is how to stop quickly and precisely.
- The Z-axis should move at constant velocity.

Throughput = FOV × Repetition freq.
FOV : 600 times larger
To achieve 100 times faster than S-UTS,
Repetition freq. should be >10view/s (1/6 of SUTS)

High precision and speed stage

Under developing



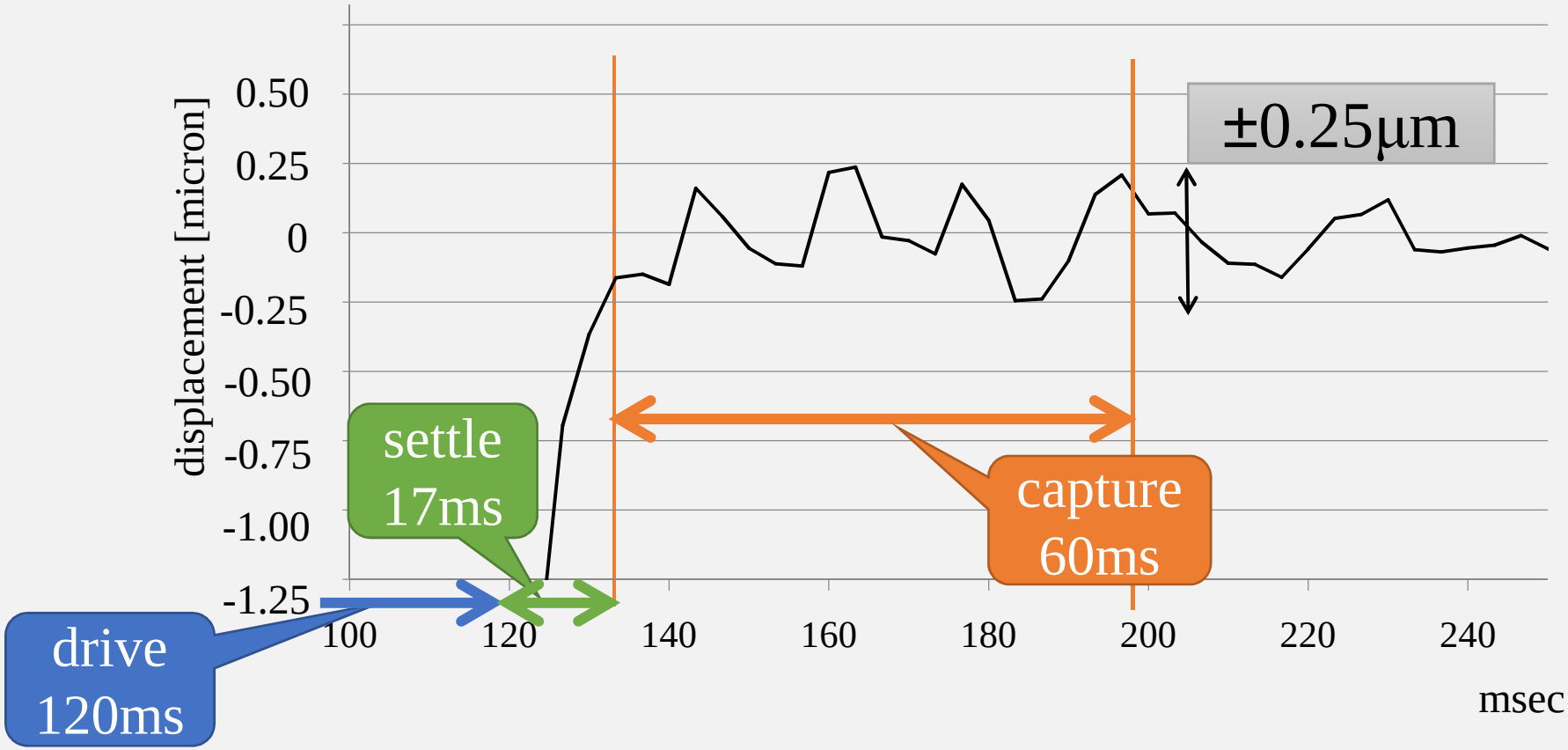


Reaction force is canceled by counter stage

Evaluation of stage settling time

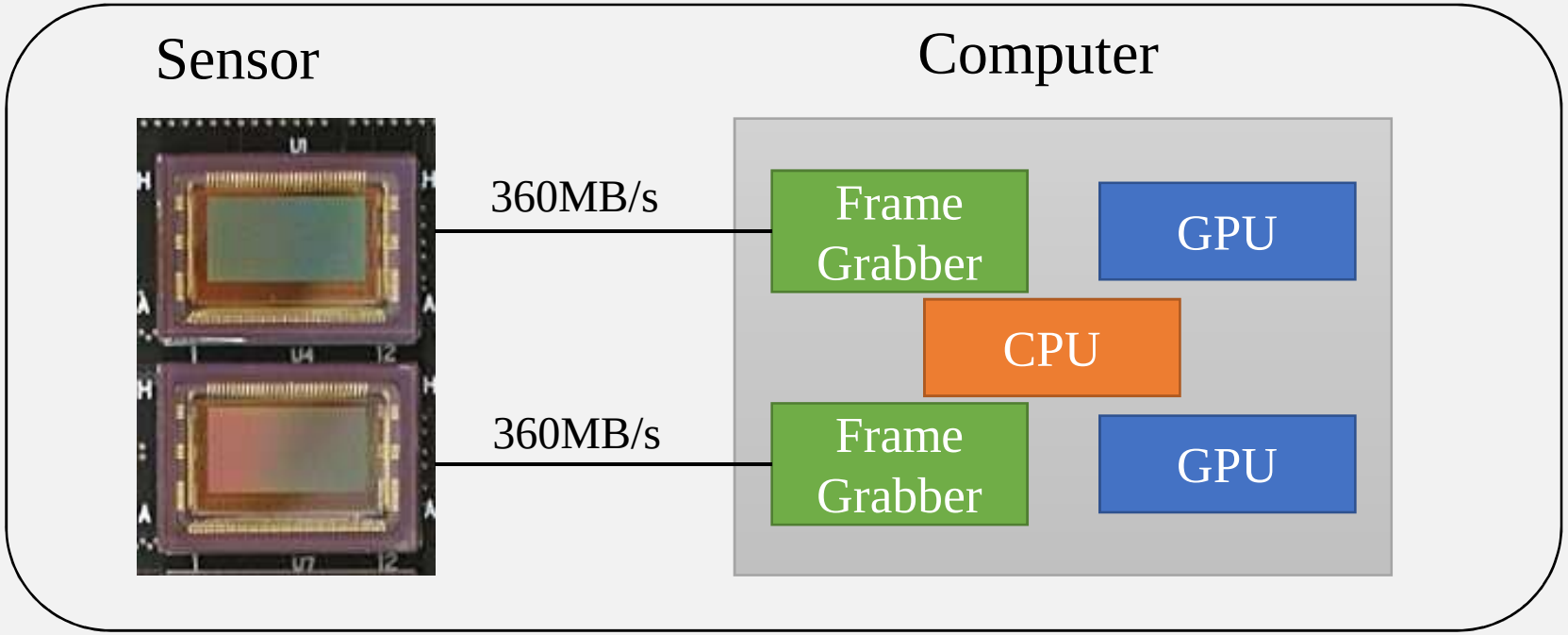
By optimizing the acceleration, 5view/sec was achieved.

The displacement has been measured by using main optics.



Tracking Hardware

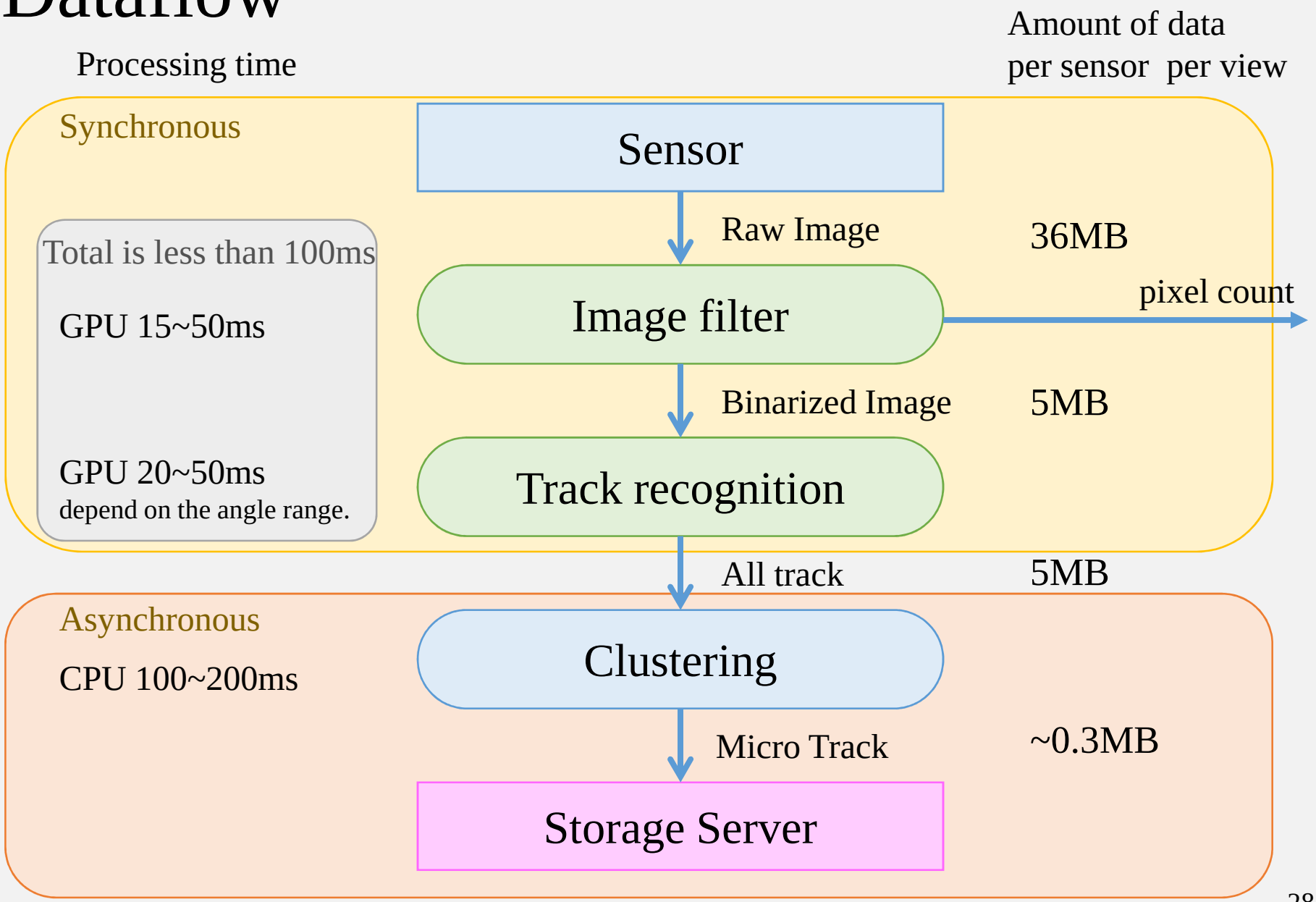
- Sensor 72 × 36Mbyte/view × 10view/s ＝ 26GB/s
- Computer 36, Frame grabber board 72, GPU board72



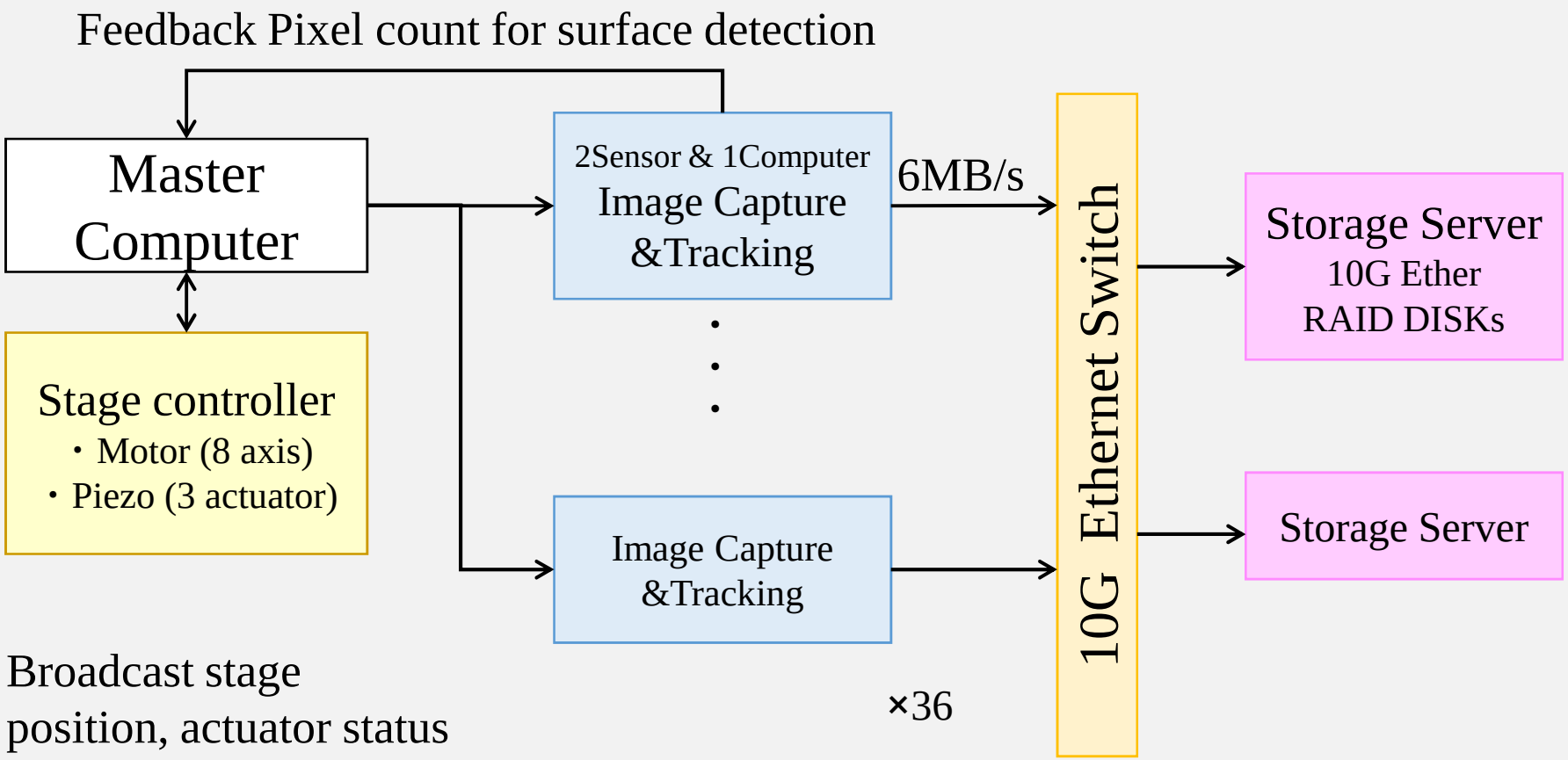
26GB/s/all
2.6TB/plate (OPERA film)

×36

Dataflow


Processing time
Amount of data
per sensor per view
Synchronous
Sensor
Raw Image
36MB
Total is less than 100ms
GPU 15~50ms
Image filter
pixel count
Binarized Image
5MB
GPU 20~50ms
depend on the angle range.
Track recognition
All track
5MB
Asynchronous
CPU 100~200ms
Clustering
Micro Track
~0.3MB
Storage Server

Stage control



Broadcast stage position, actuator status and Trigger timing for image capture

ave. 200MB/s/all
~10GB/plate

Scanning speed and other status

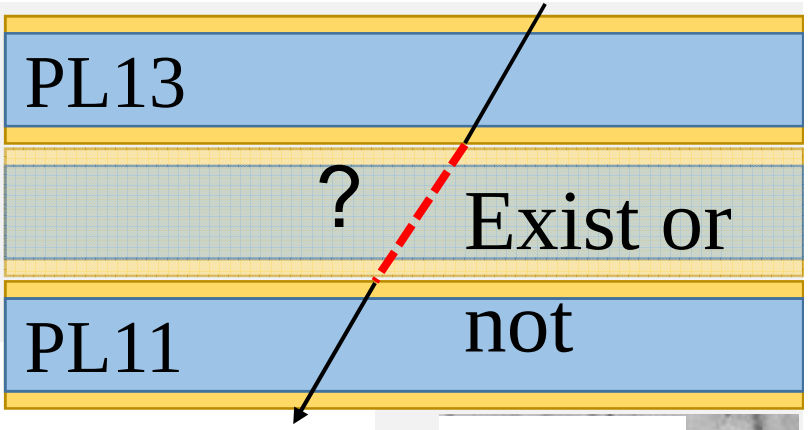
- December 2011 Objective lens and beam splitter were mounted.
- May 2012 All motors for xyz-axis drive began to work.
- November 2012 Piezo actuator for z-axis drive was installed.
- May 2013 Half of cameras and computers became ready.
- May 2013~ Scanning test for various emulsion plates

	Practicable	**Installed**	**Final Goal**
Stage	2 view/s	5 view/s	10 view/s
Camera	1 unit	3 unit	6 unit
Speed	300cm^2/h	2250cm^2/h	9000cm^2/h

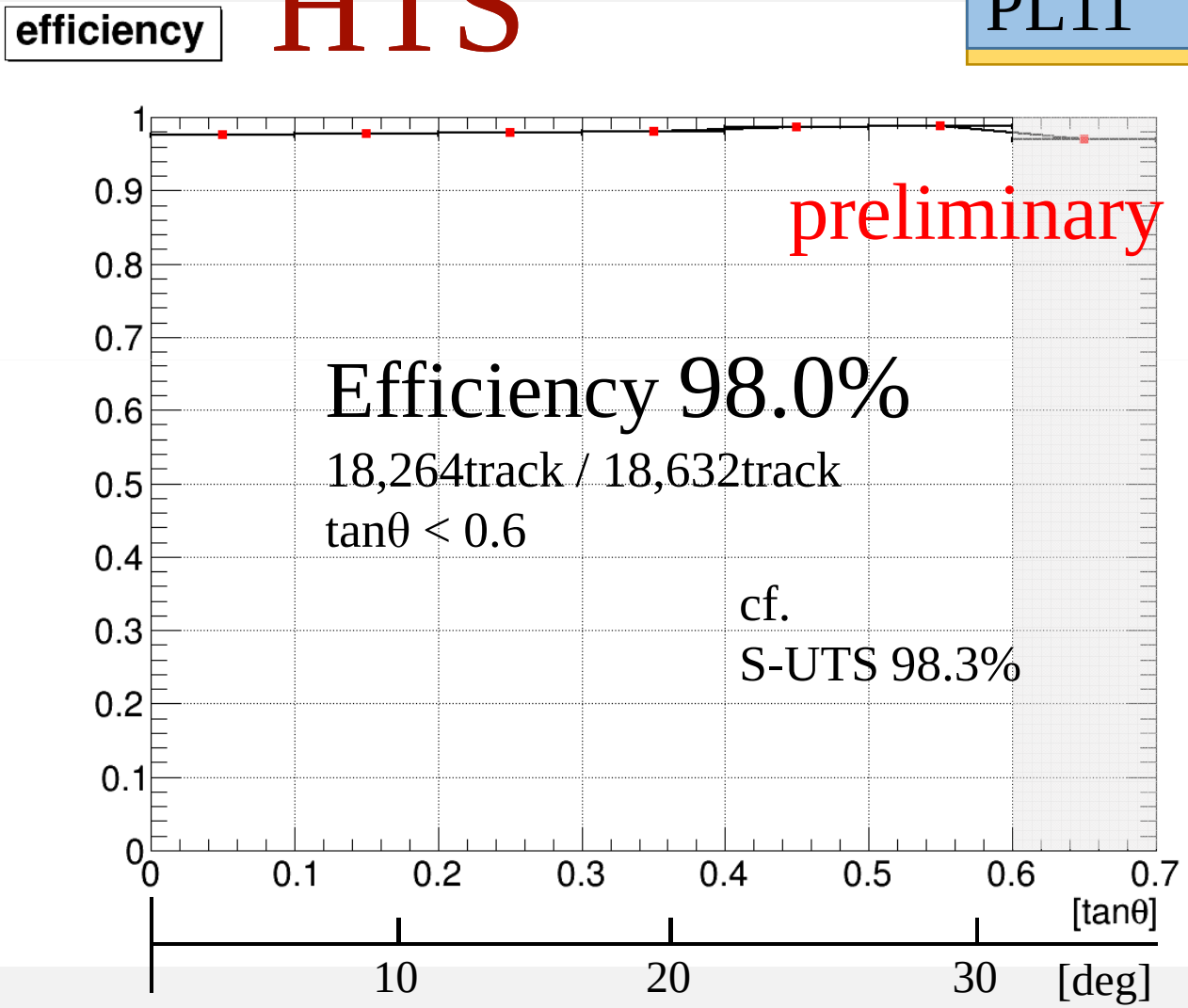
I did scanning test at this speed.

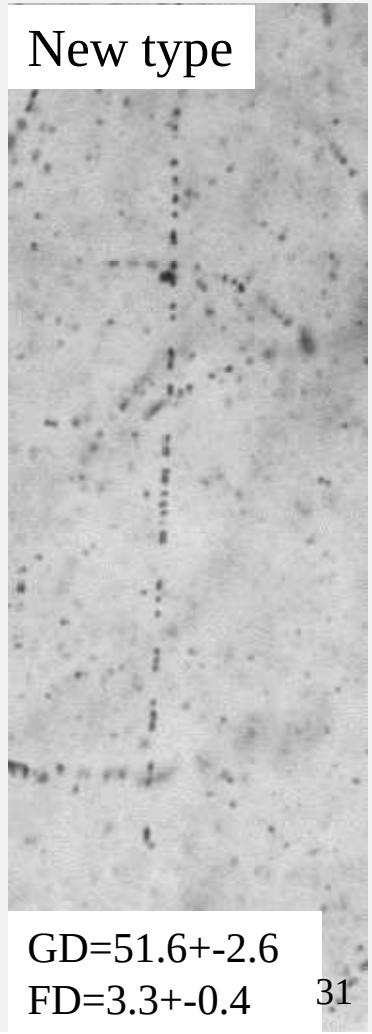
cf. S-UTS 72cm^2/h

New Emulsion Film



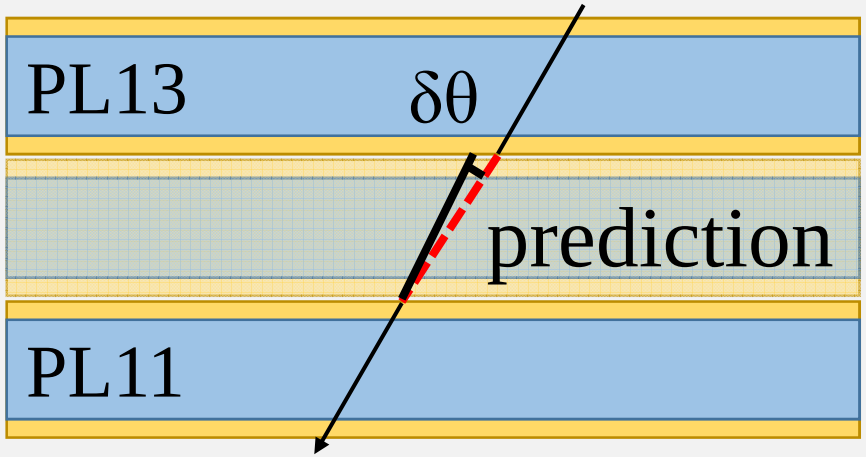
HTS

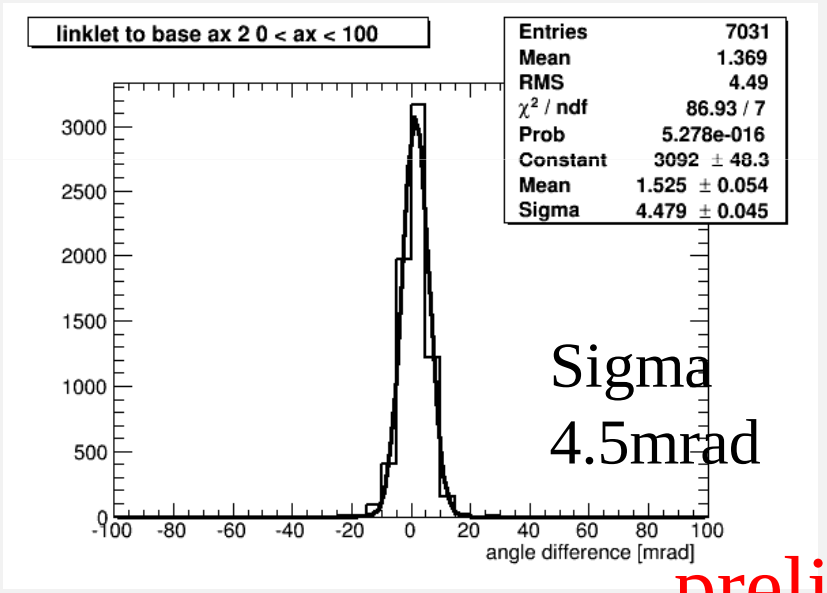




New Emulsion Film

- Angle deviation

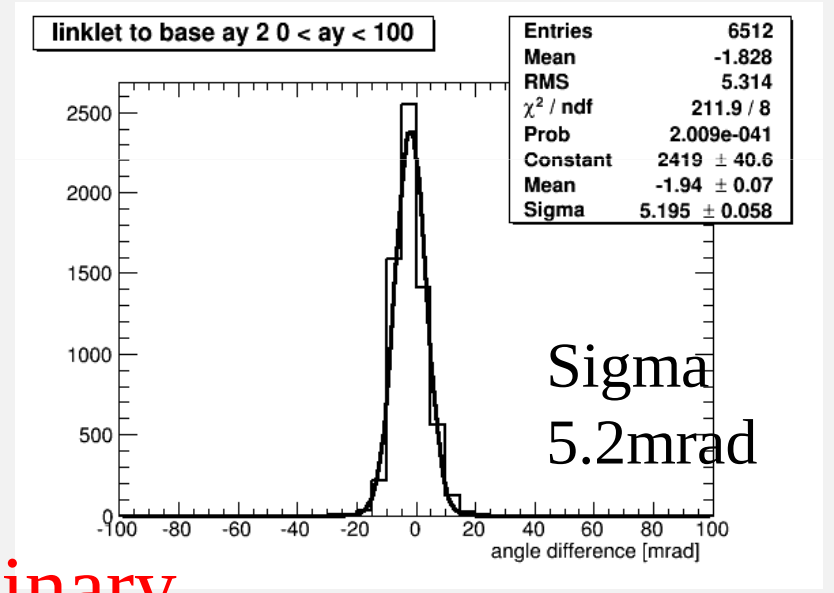




Sigma
4.5mrad

X-projection

cf. S-UTS
4.8mrad



Sigma
5.2mrad

Y-projection

cf. S-UTS
4.3mrad

preliminary

What we can do with HTS?

Emulsion Archives Project

The project is to read all emulsion and convert to the data.

➢In near future we will scan a lot of emulsion with HTS.

Requirement,

- All Emulsion existing around the world.
- Money (and man power) for running
- Unified Specification of track and image

And

- Dream for Science

Summary and Prospect

- We are developing HTS which is 100 times faster.
- Scanning at the speed of 300cm^2/h is practicable.
- The efficiency and angle resolution are almost the same as previous system.

- HTS is working for muon radiography, GRAINE project and dark matter search.
- All cameras and computers will be installed this year.