European Scanning System

Andrey Alexandrov

Toward the automatic emulsion scanning

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

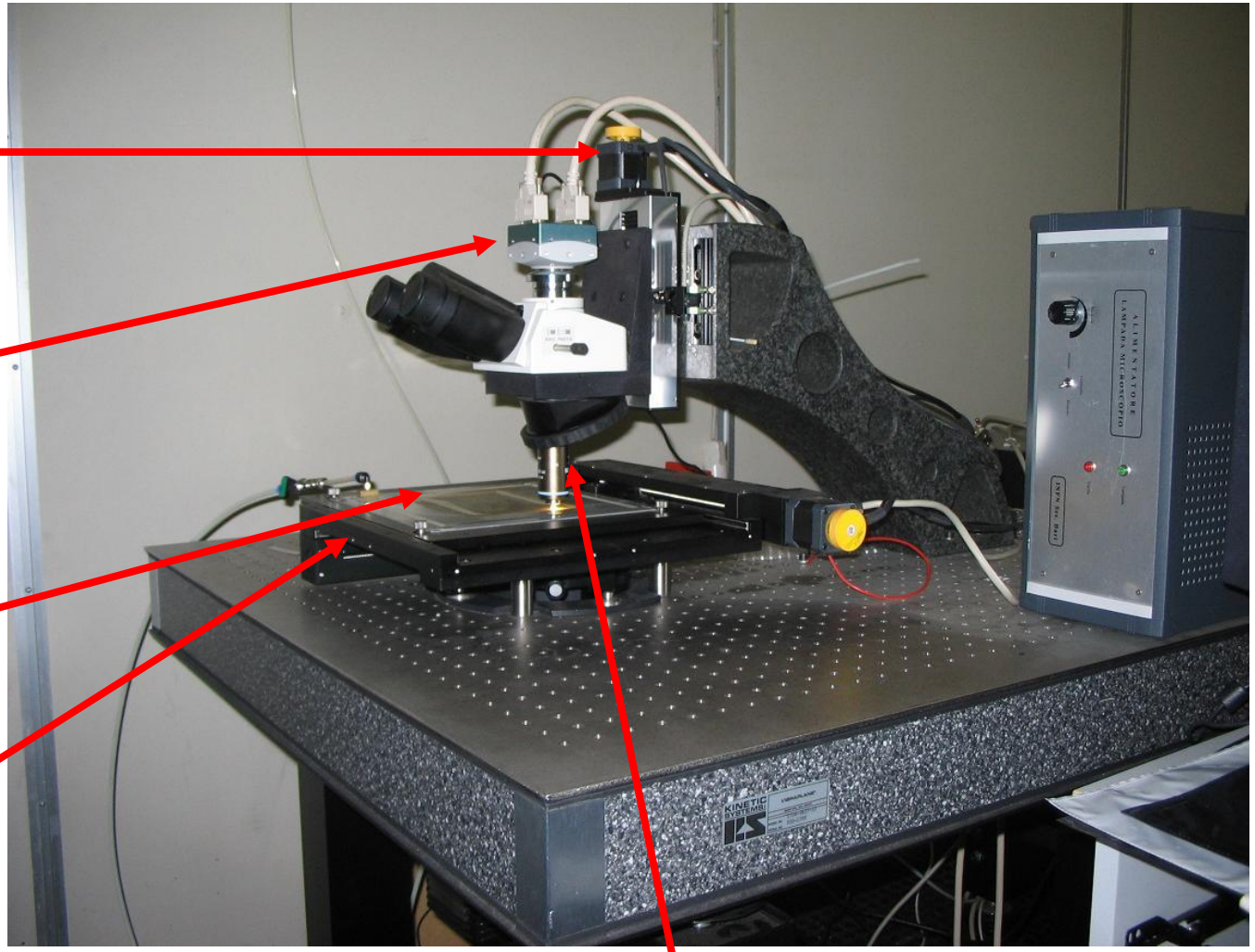
This was the first idea of the automatic scanning but the digital technology was not ready yet in that time (the first Digital Camera prototype from Kodak -1975)

- 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 – *Italian groups enters into scanning business: two microscopes equipped with NTS systems arrived 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*

OPERA ESS

20 cm^2/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

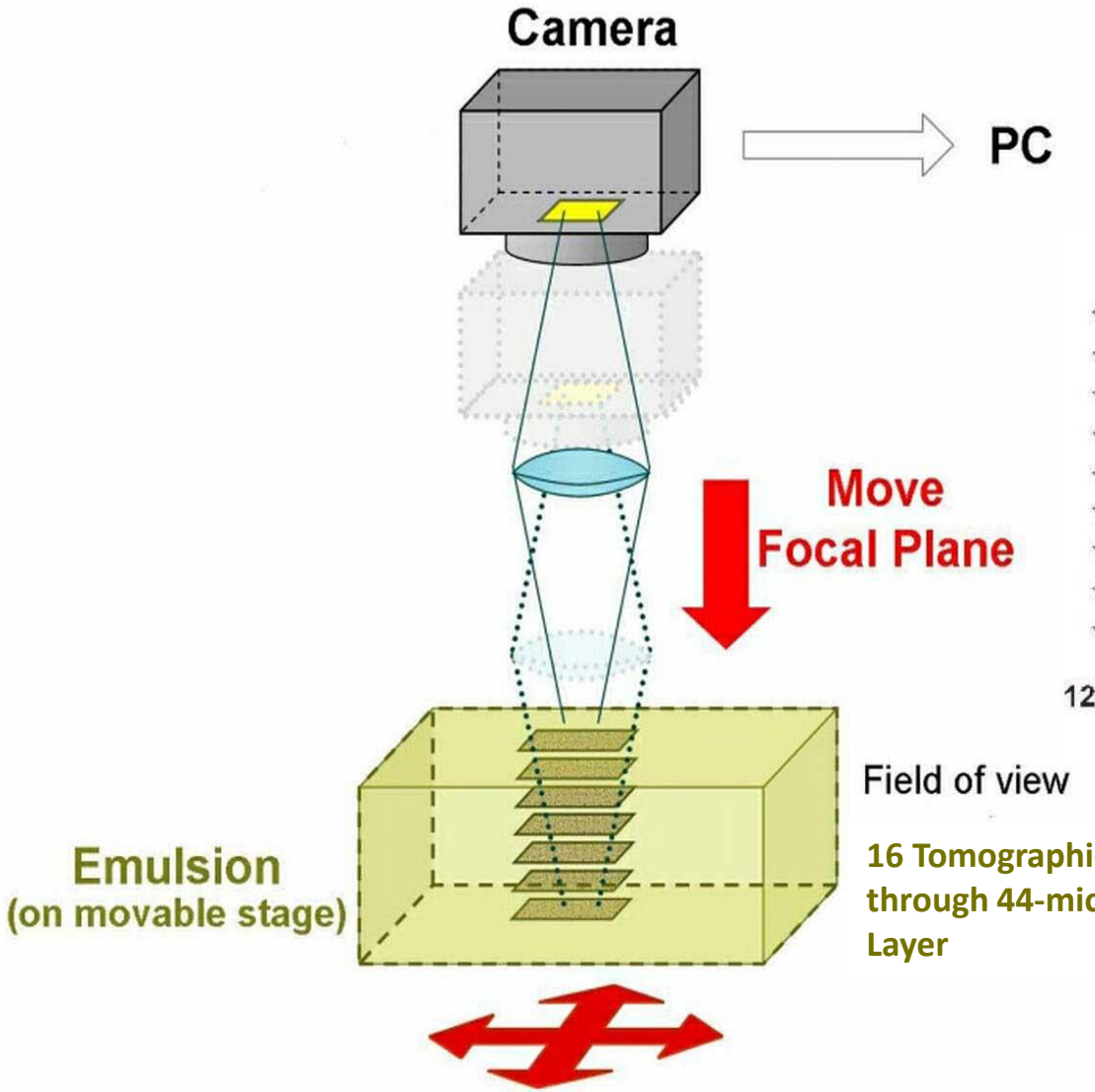
CMOS camera
1280×1024 pixel
256 gray levels
376 frames/sec
(Mikrotron MC1310)

Emulsion Plate

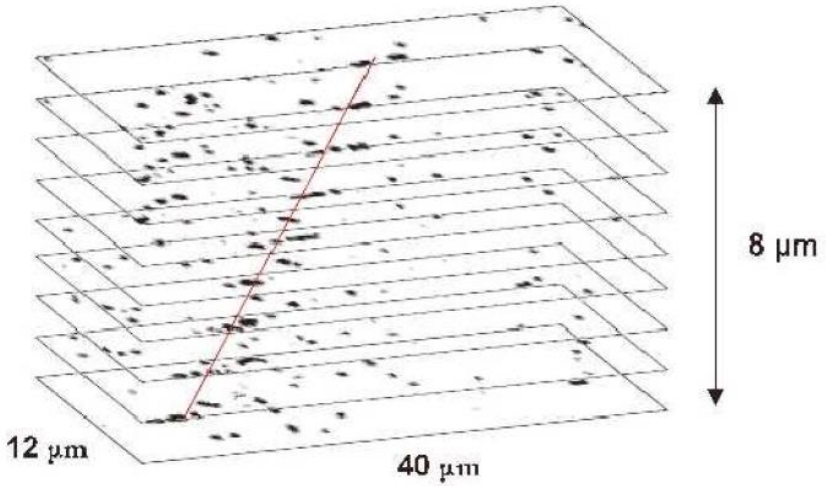
XY stage (Micos)
0.1 μm nominal precision

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

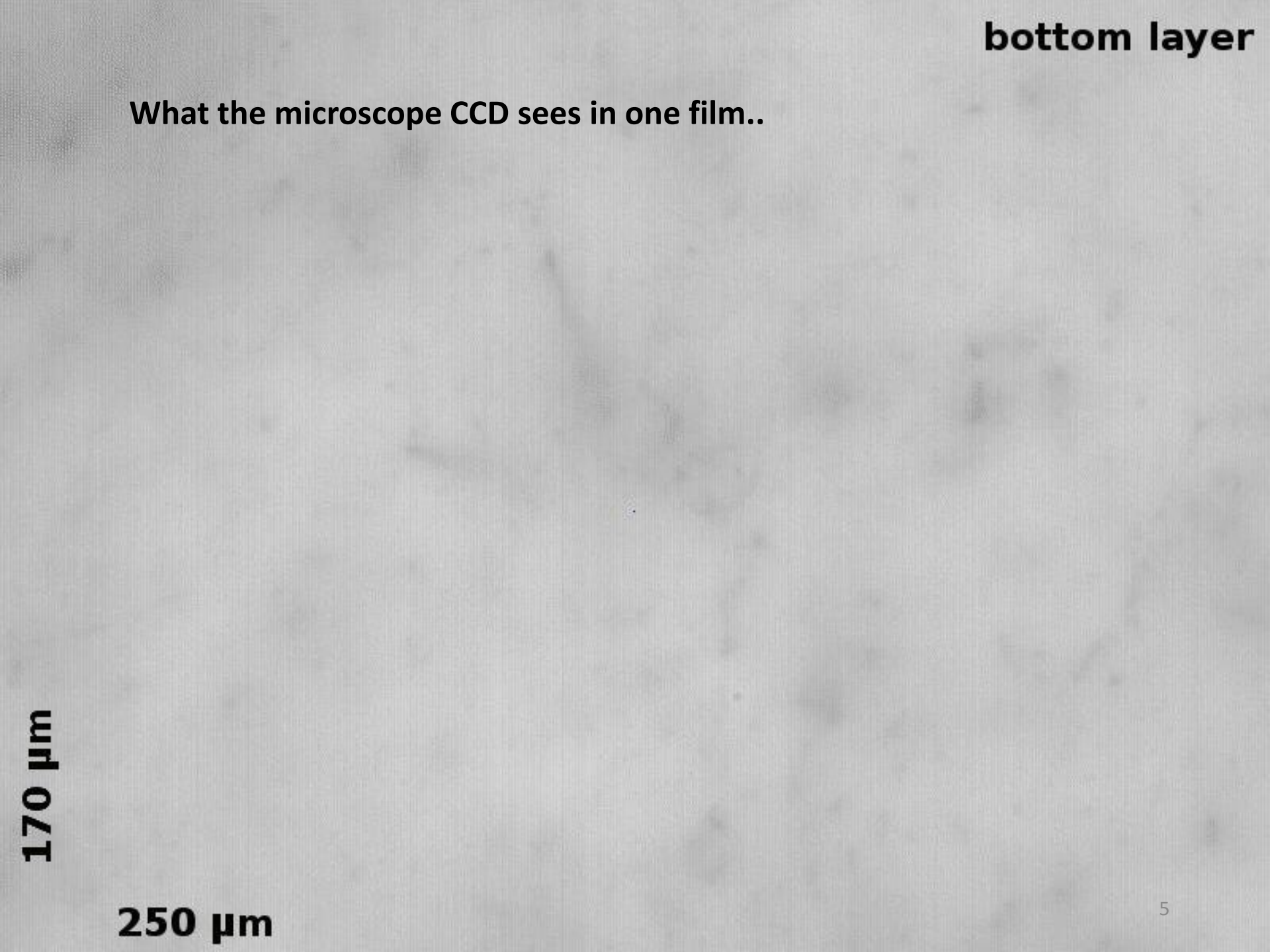
Principle of the automatic emulsion scanning



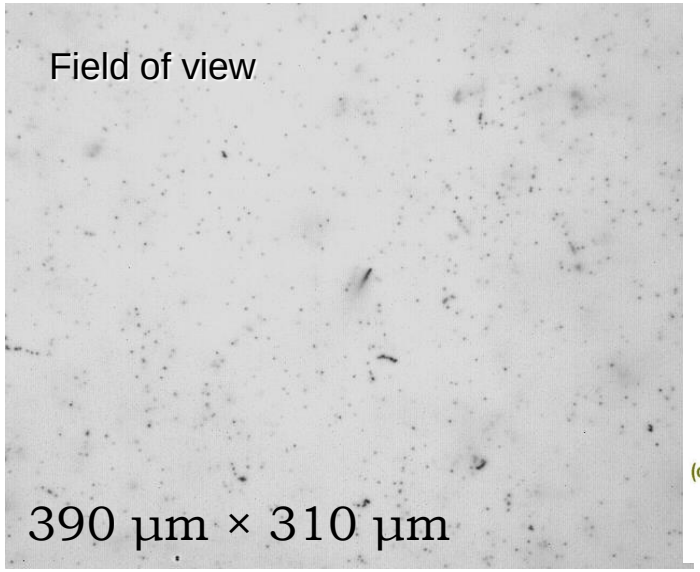
- Professional Image Processing board
- Motor control card

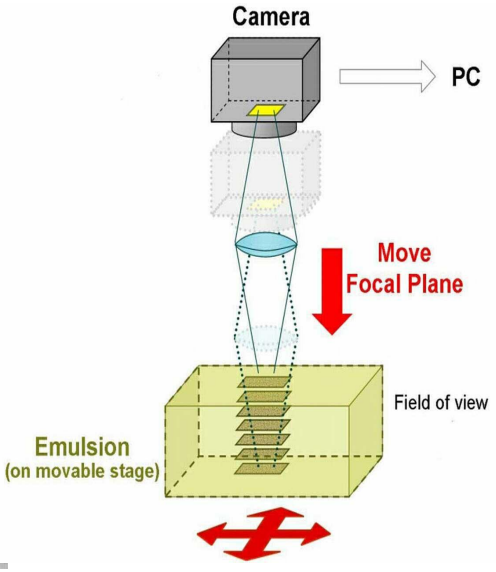


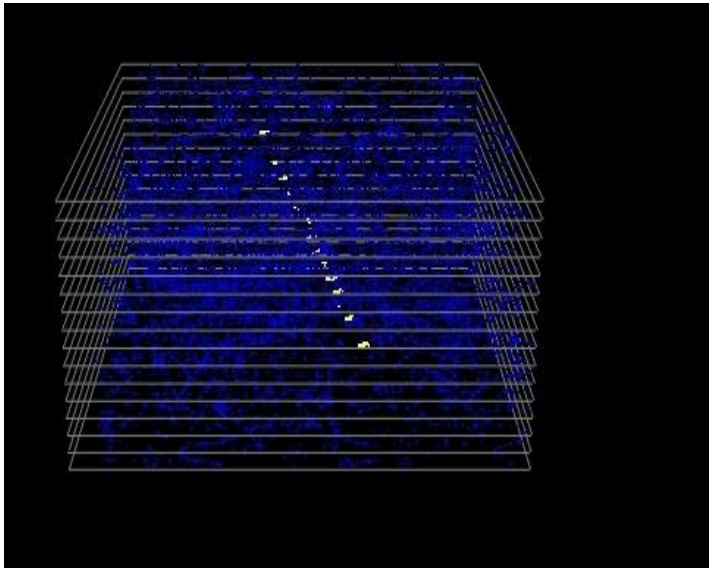
16 Tomographic Images taken through 44-micron Emulsion Layer


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

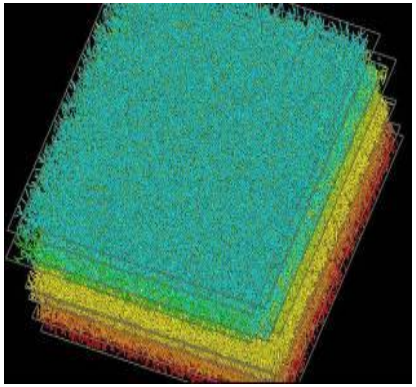
Tracks&vertices reconstruction in ECC



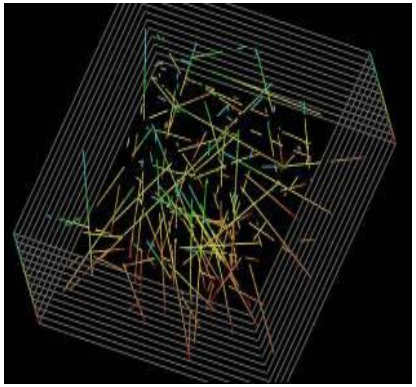




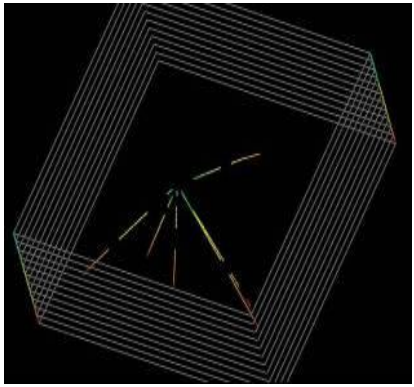
- Images -> microtracks
- Microtracks->basetracks
- Plate-to-plate alignment
- Long tracks reconstruction
- Vertex location
- Event analysis



Volume scan data (basetracks)

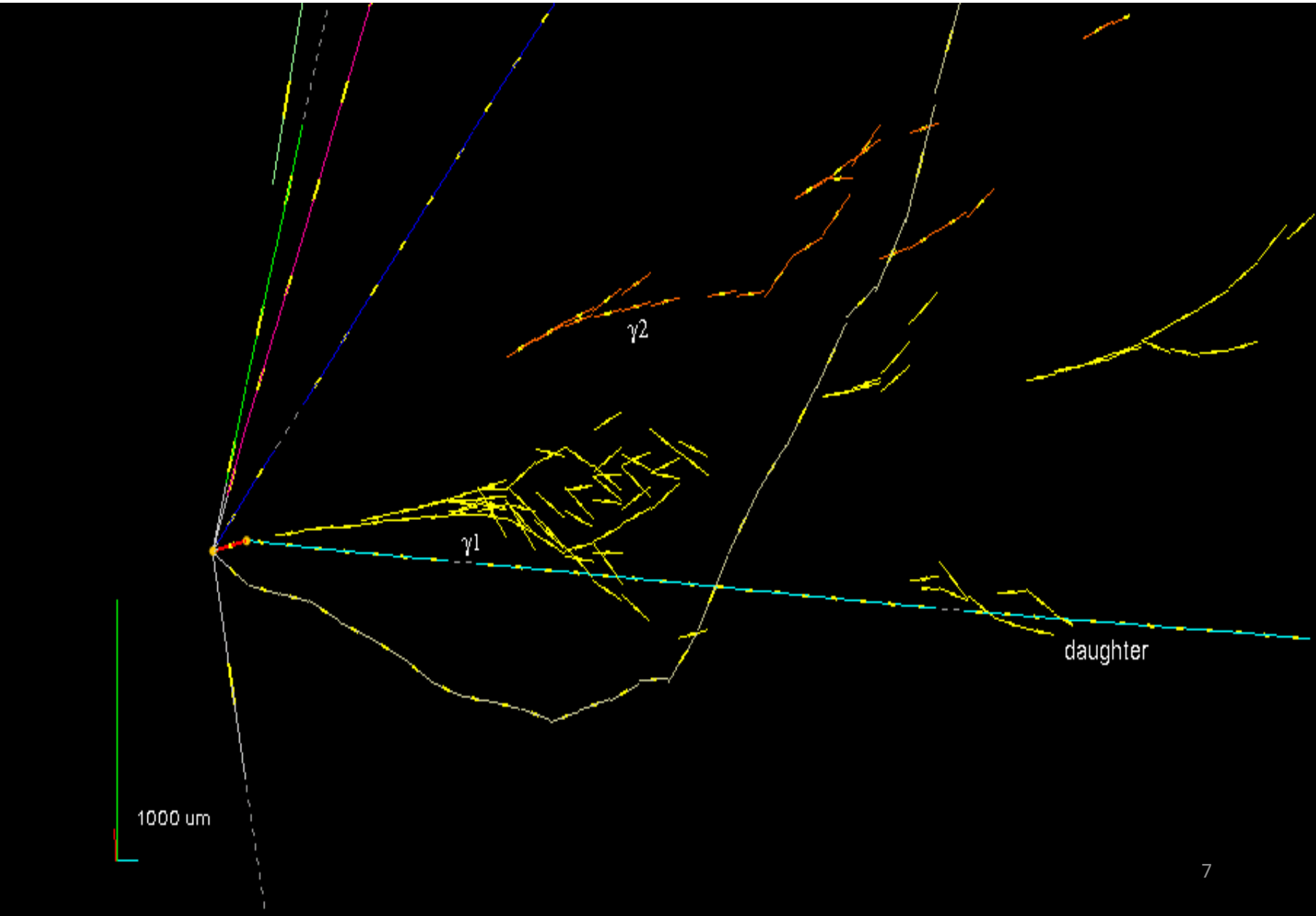


Passing-through and short tracks rejected



Vertex located in the brick

OPERA tau event



2014 HW upgrade: ESS -> NGSS

Matrox Odyssey Xpro SFCL

PCI-X interface
up to 680 MB/sec

SiliconSoftware mE5

PCIe 8x interface
up to 2200 MB/sec

Mikrotron MC-1310

SFCL interface
1280 x 1024 pixels
1.2 Mpixel @ 376 fps

Mikrotron MC-4082

DFCL interface
2336 x 1728 pixels
4 Mpixel @ 563 fps

Nikon Plan

50X Oil
0.9 NA

0.31 µm/pix
396x317 µm

Nikon Plan Fluor

20X Oil
0.75 NA

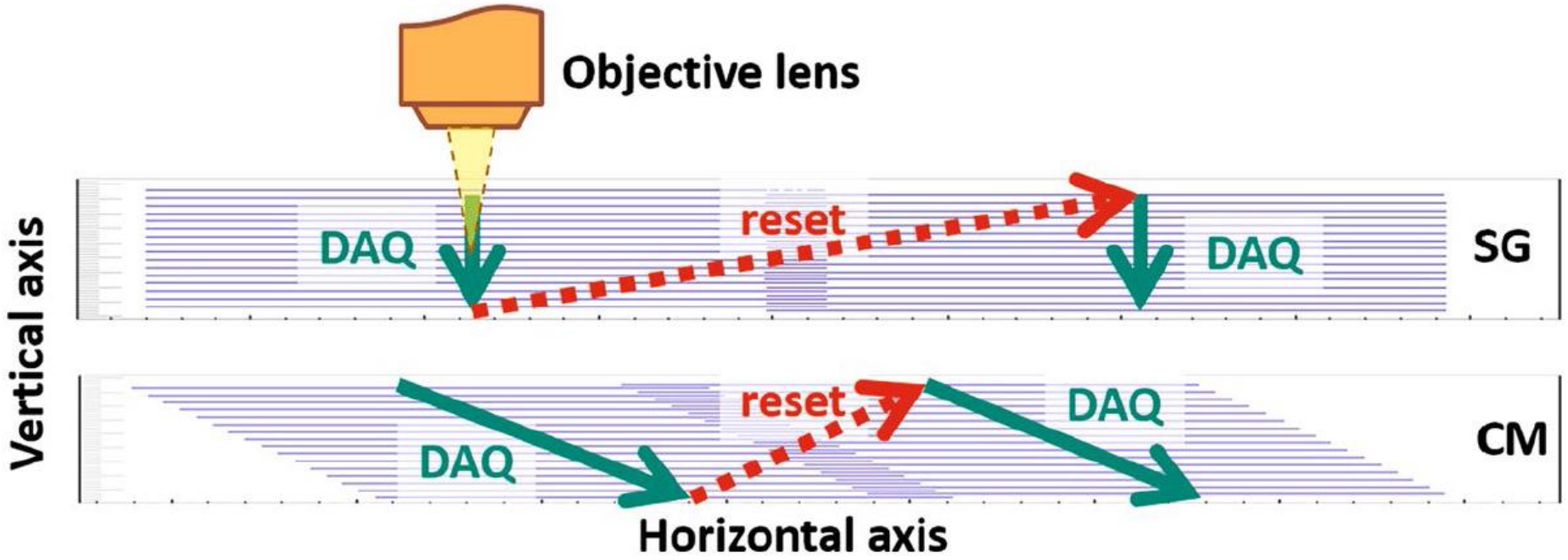
0.34 µm/pix
794x586 µm

3.7x larger FoV

Scanning speed: 20 cm^2/h → 84 cm^2/h

"**A new generation scanning system for the high-speed analysis of nuclear emulsions**" in JINST 11 P06002 2016, doi:10.1088/1748-0221/11/06/P06002

Continuous Motion scanning technique

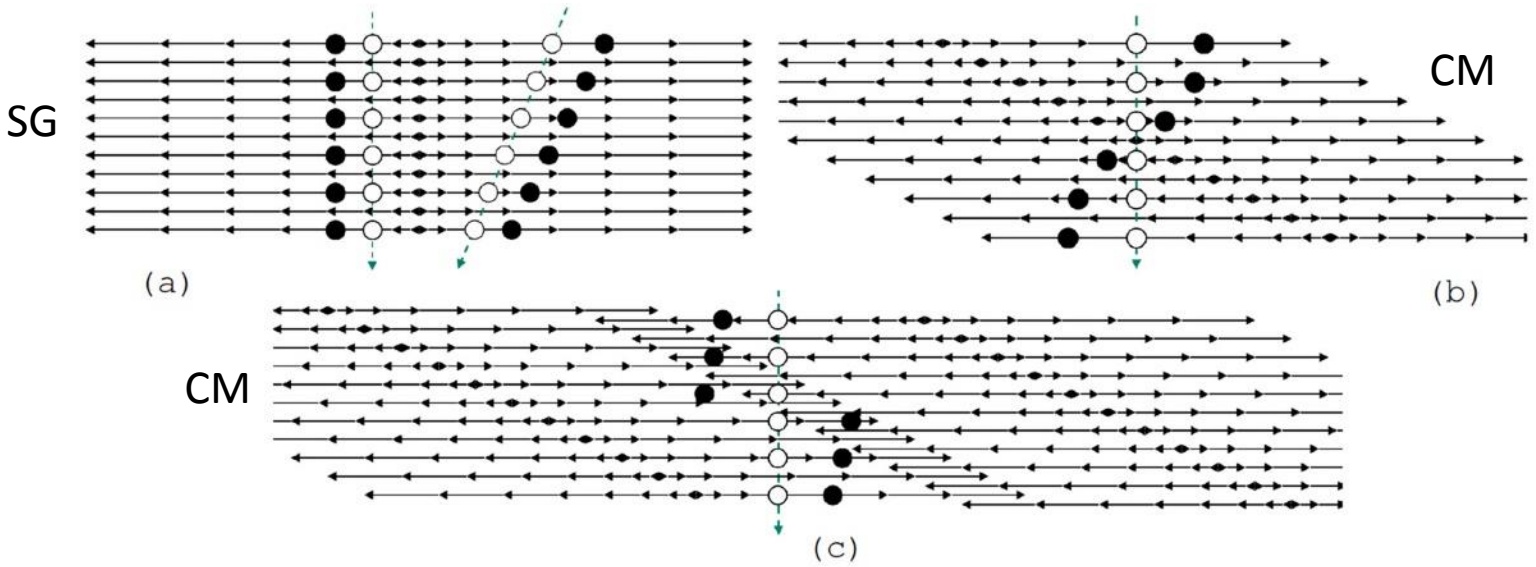


Proposed in 2011.

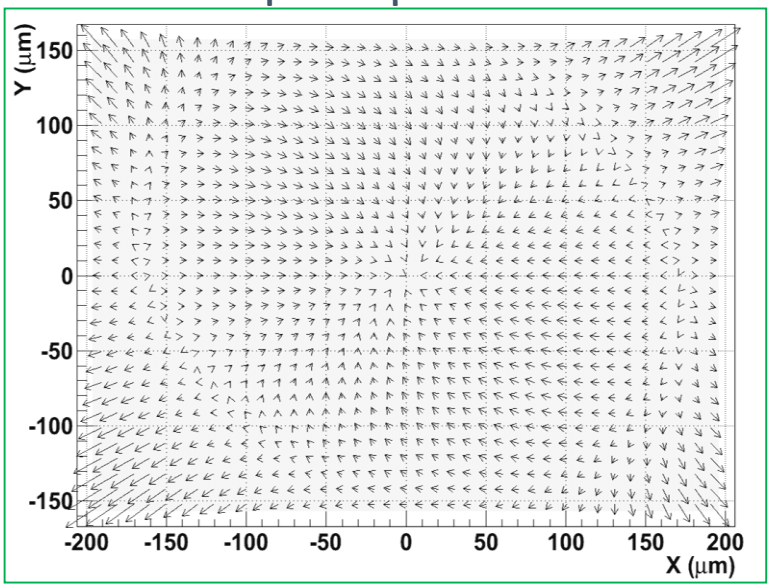
First published in NIM A 718 (2013) 184–185 .

“A novel approach for fast scanning of nuclear emulsions with continuous motion of the microscope stage ”

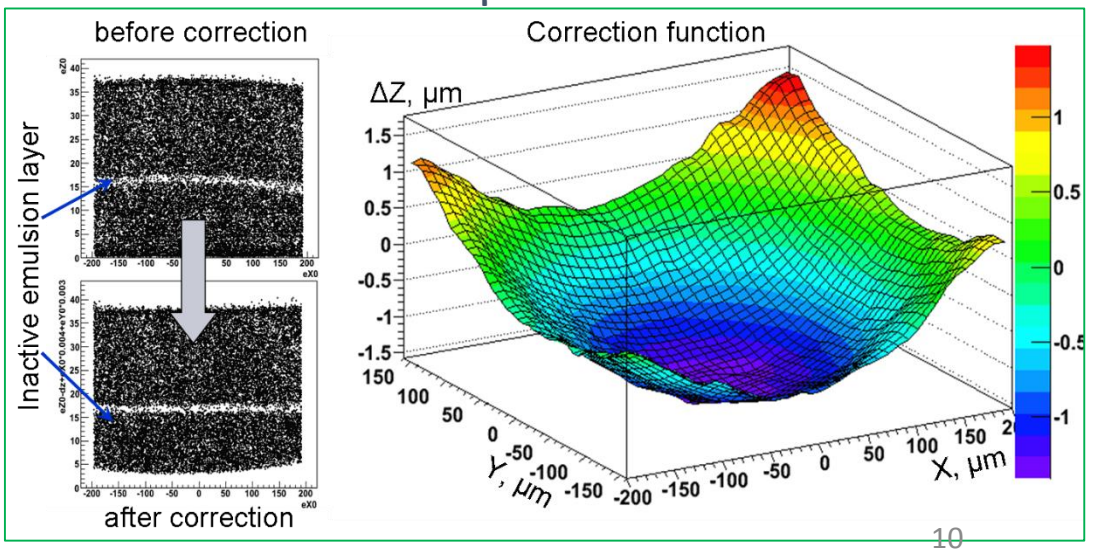
Distortion corrections for CM



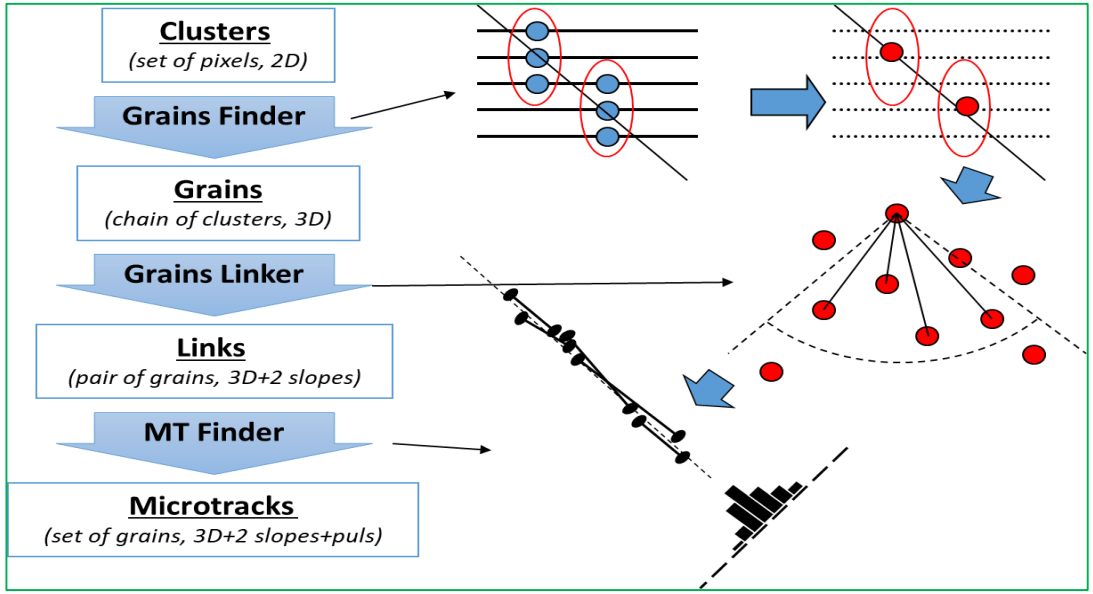
XY-corrections: up to 1.5 μm near the view corners



Z-corrections: ~3 μm near the view corners

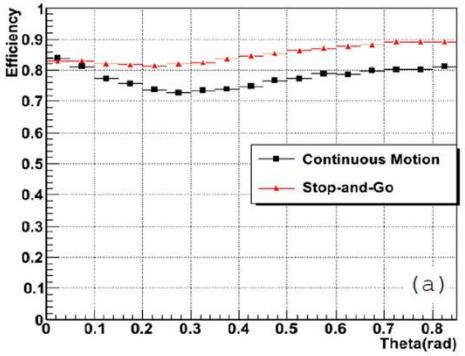


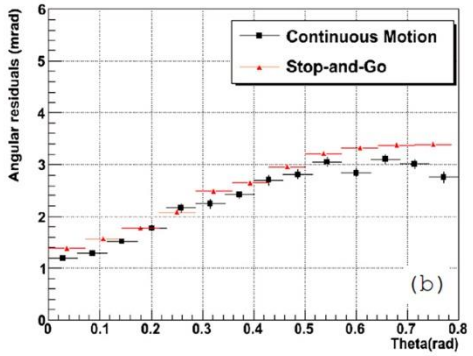
Microtracking performance in CM

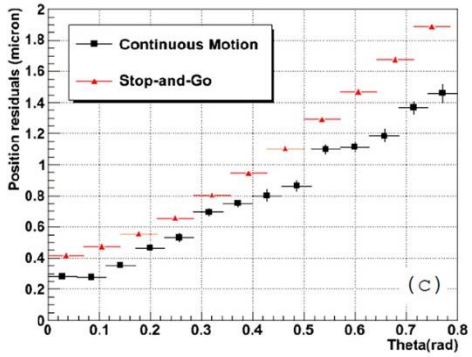


Scanning speed:

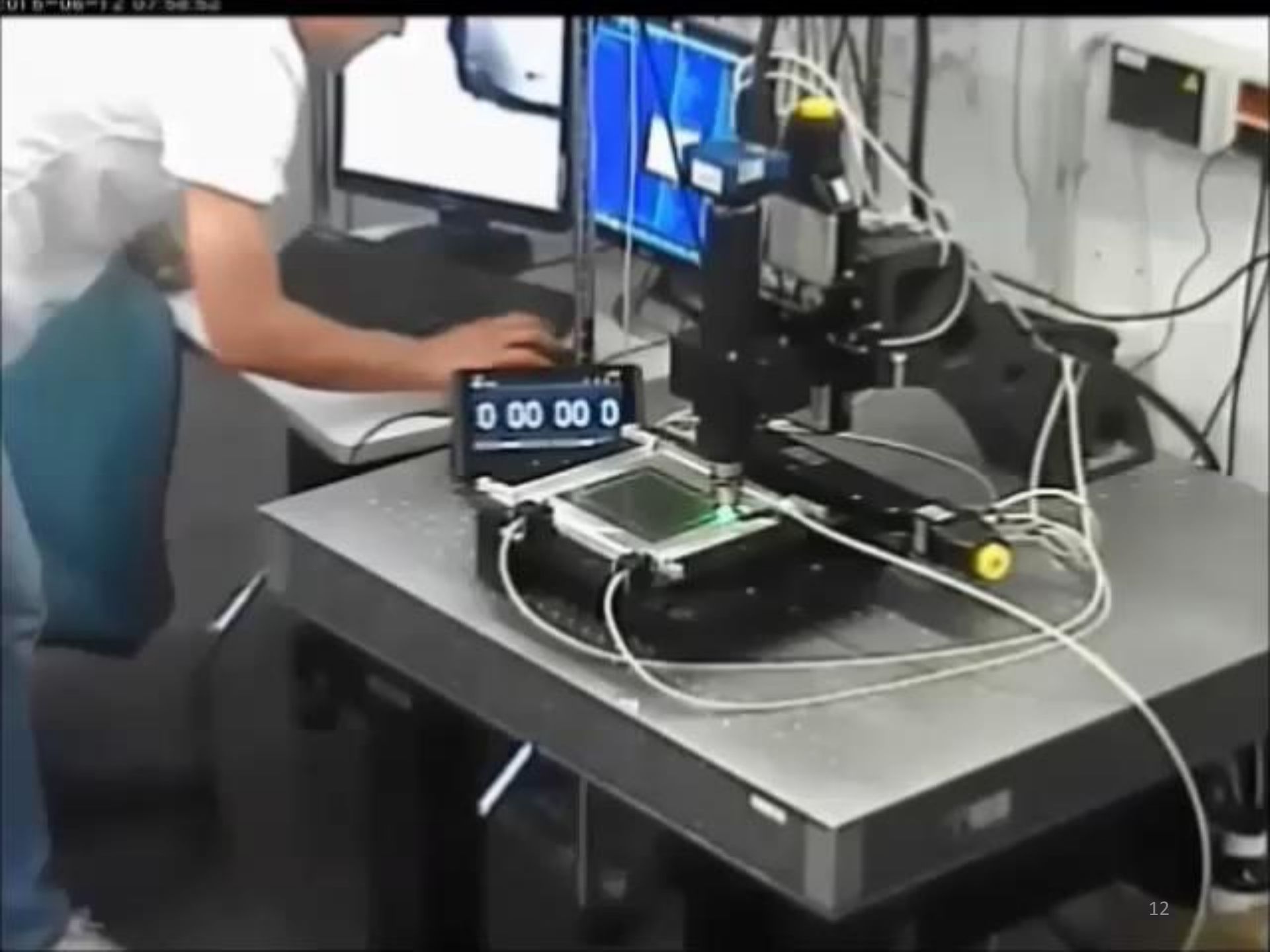
84 → 190 cm^2/h



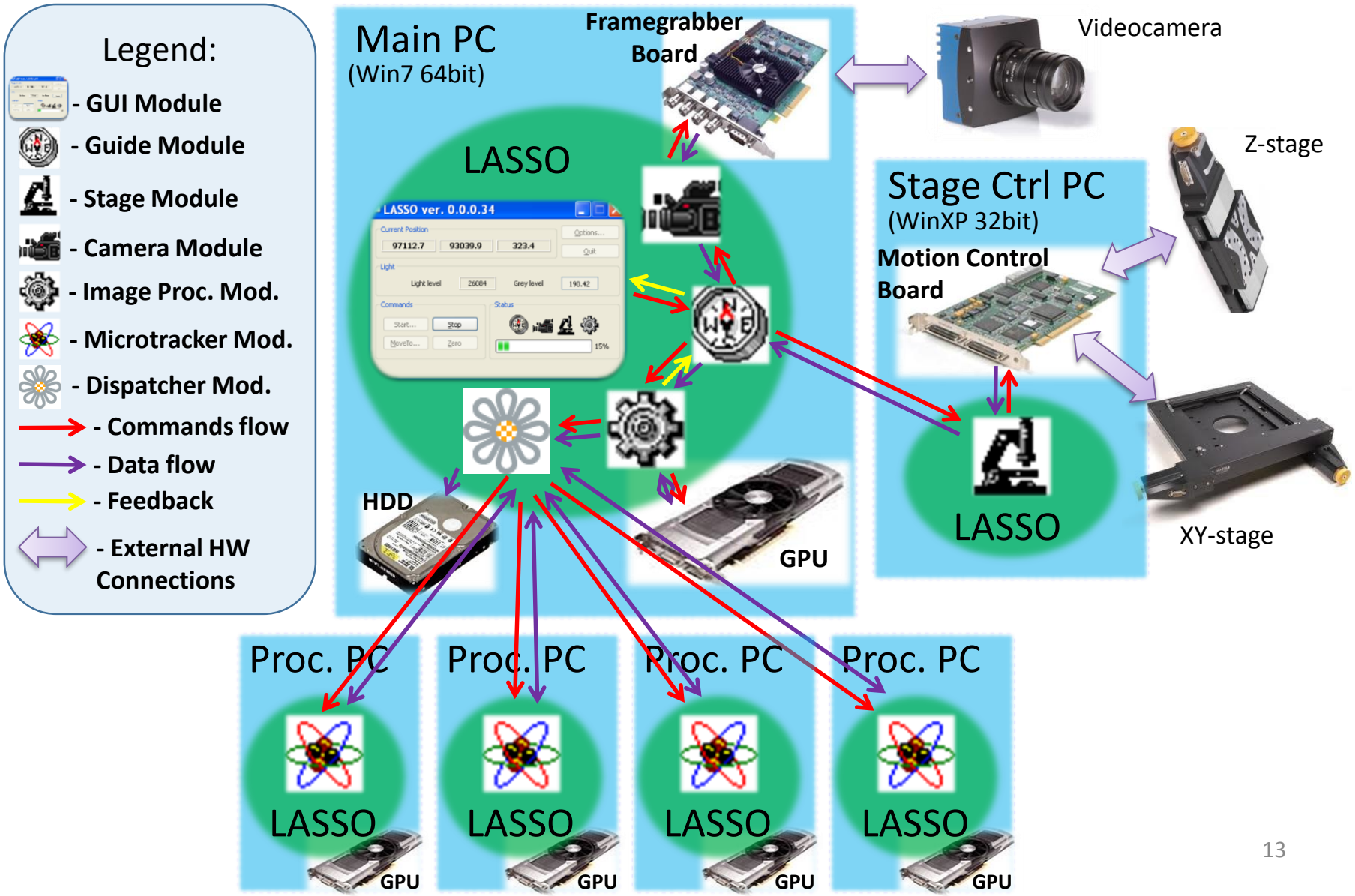




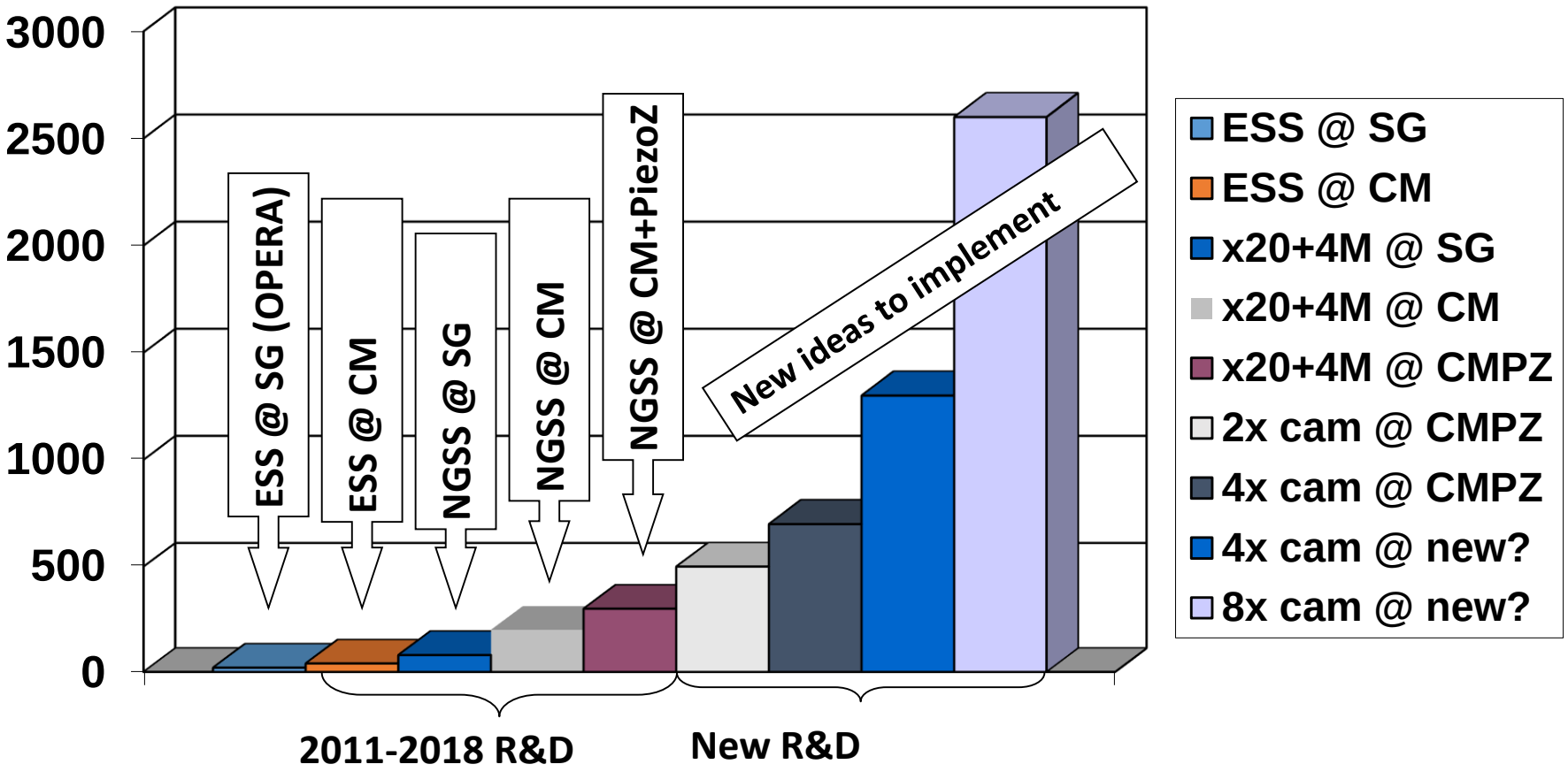
"The Continuous Motion Technique for a New Generation of Scanning Systems"
in Scientific Reports 7: 7310 2017, DOI:10.1038/s41598-017-07869-3


0 00 00 0

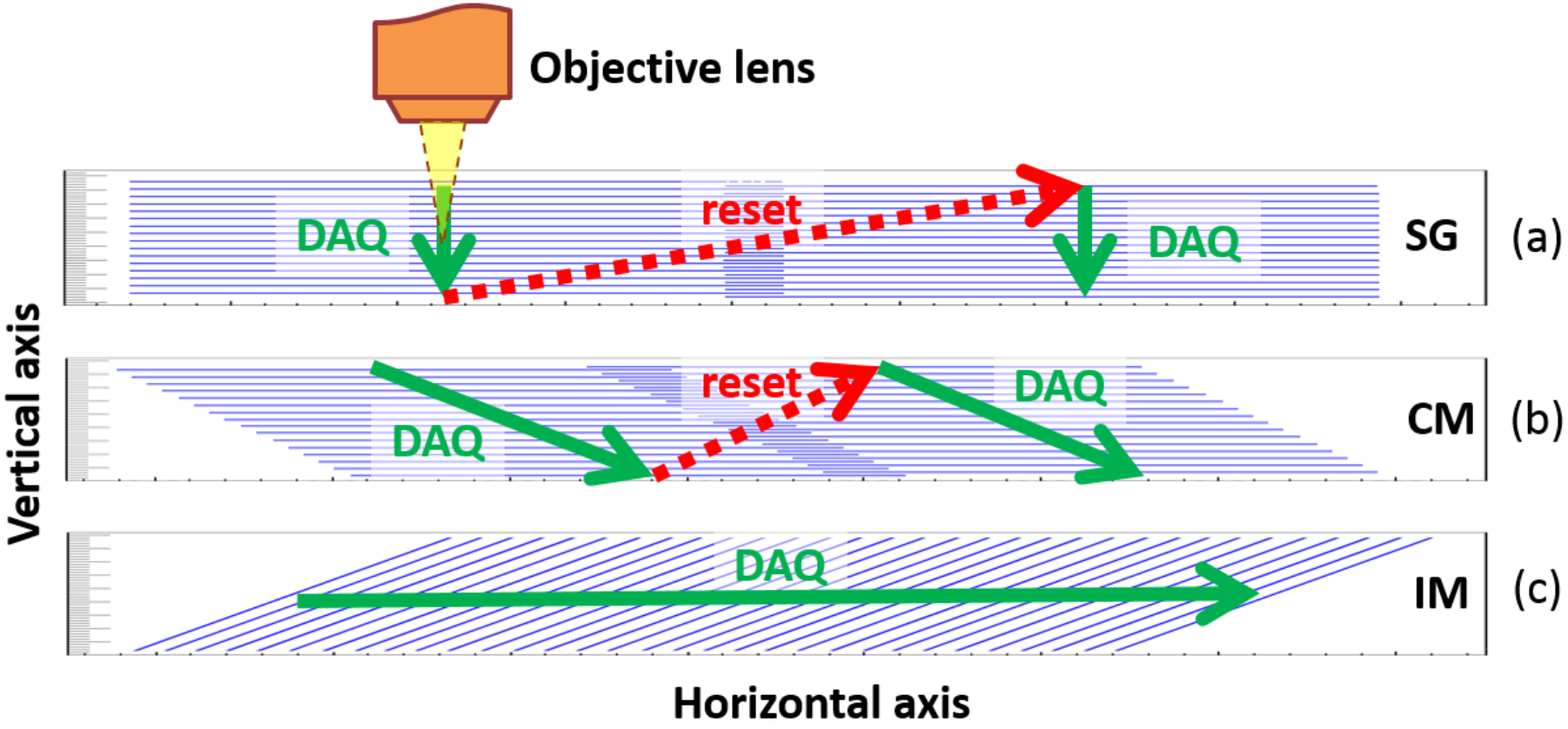
LASSO
Large Angle Scanning System for OPERA



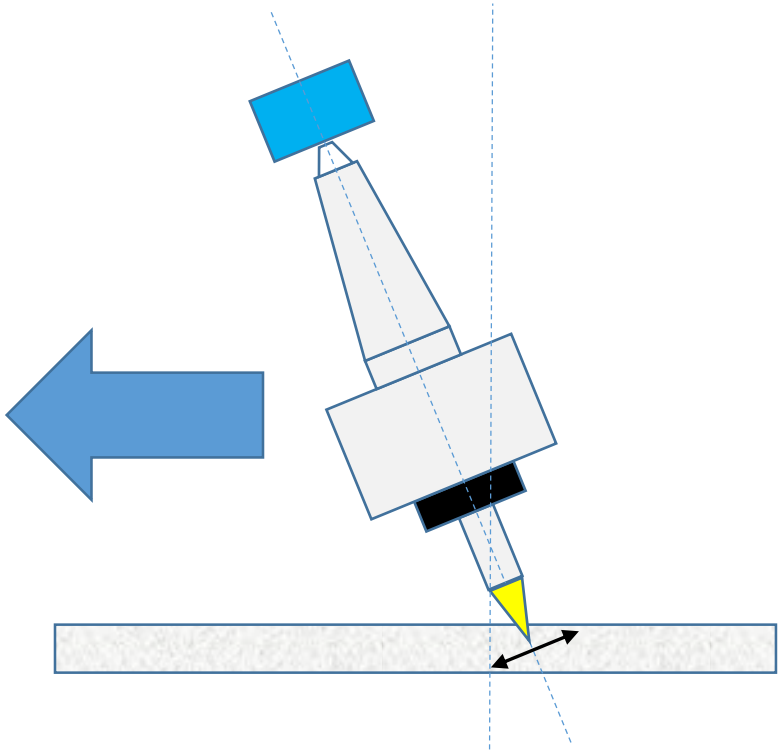
How fast ESS can become?



Inclined Focal Plane Motion (IM)

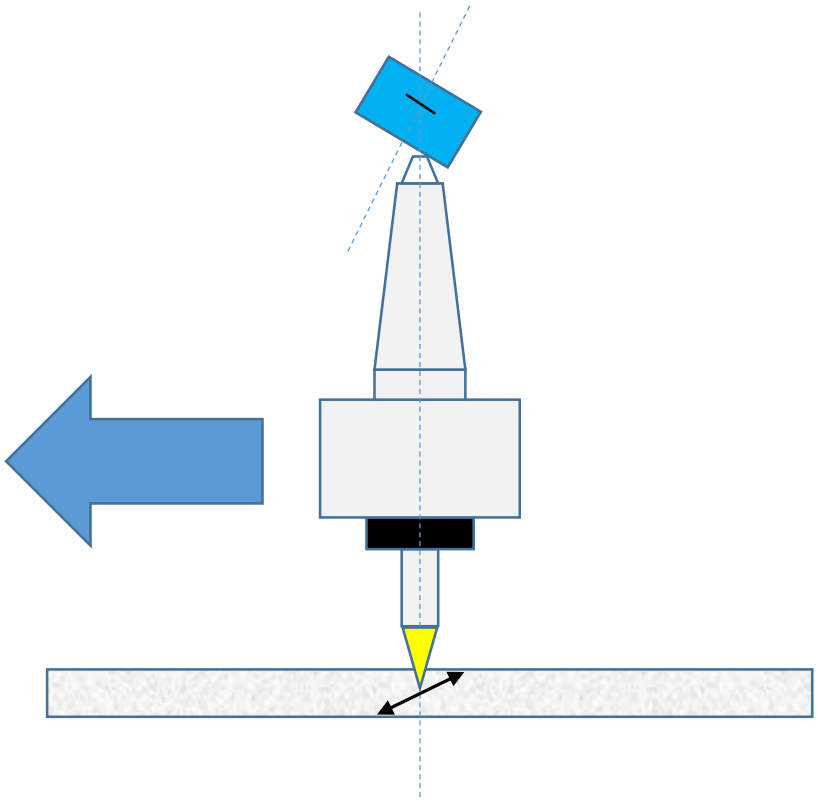


Possible IM implementations



Pros: Easy to implement

Cons: An objective must have the WD > 0.5 mm -> dry objectives only

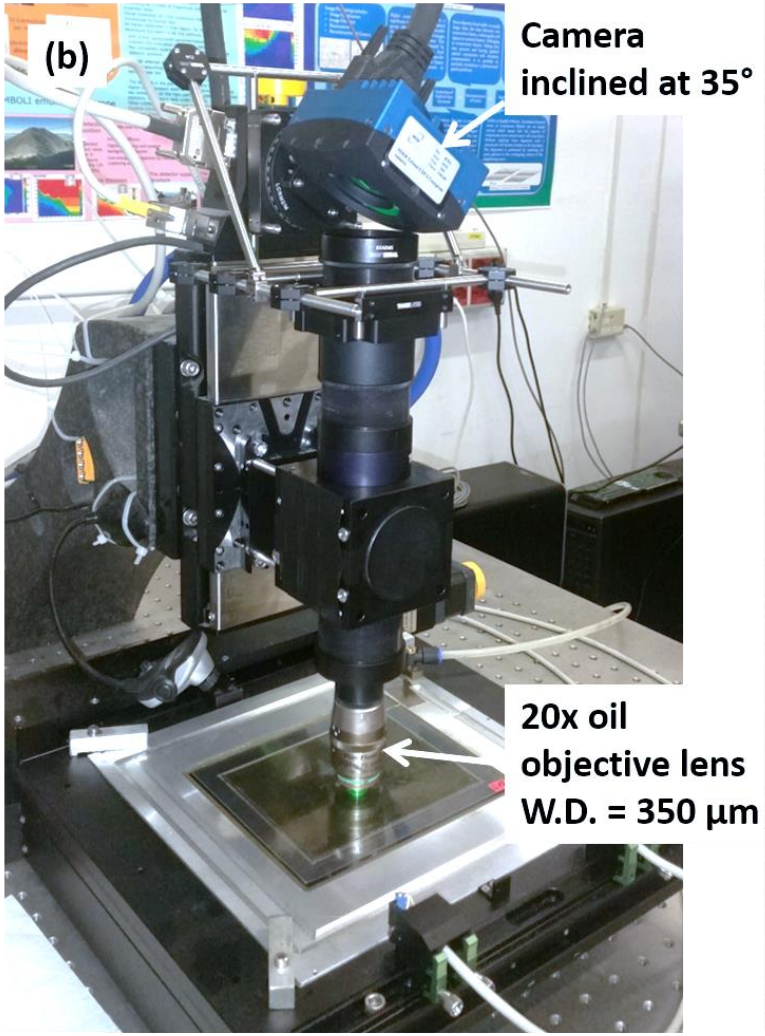


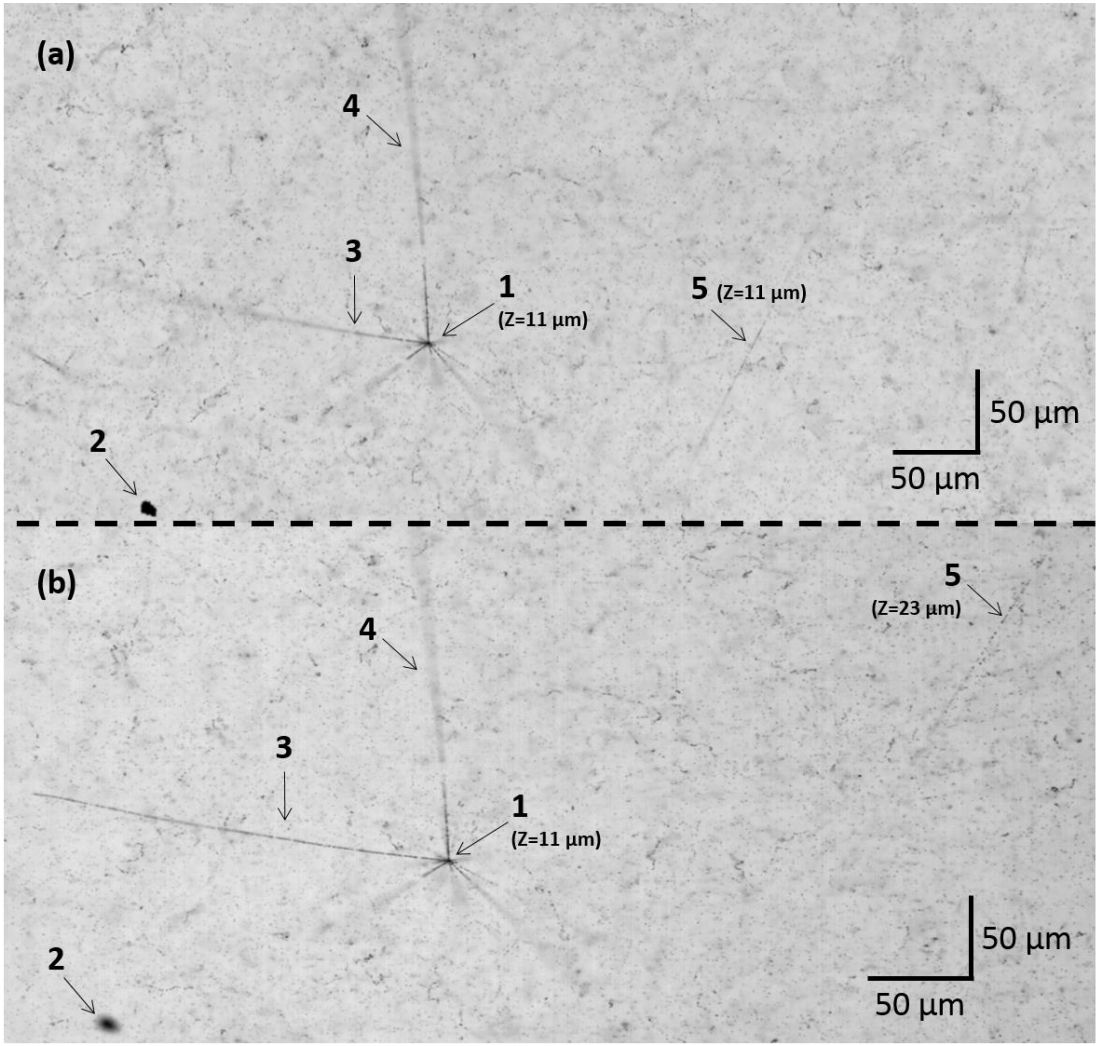
Pros: Suitable for any objective type!

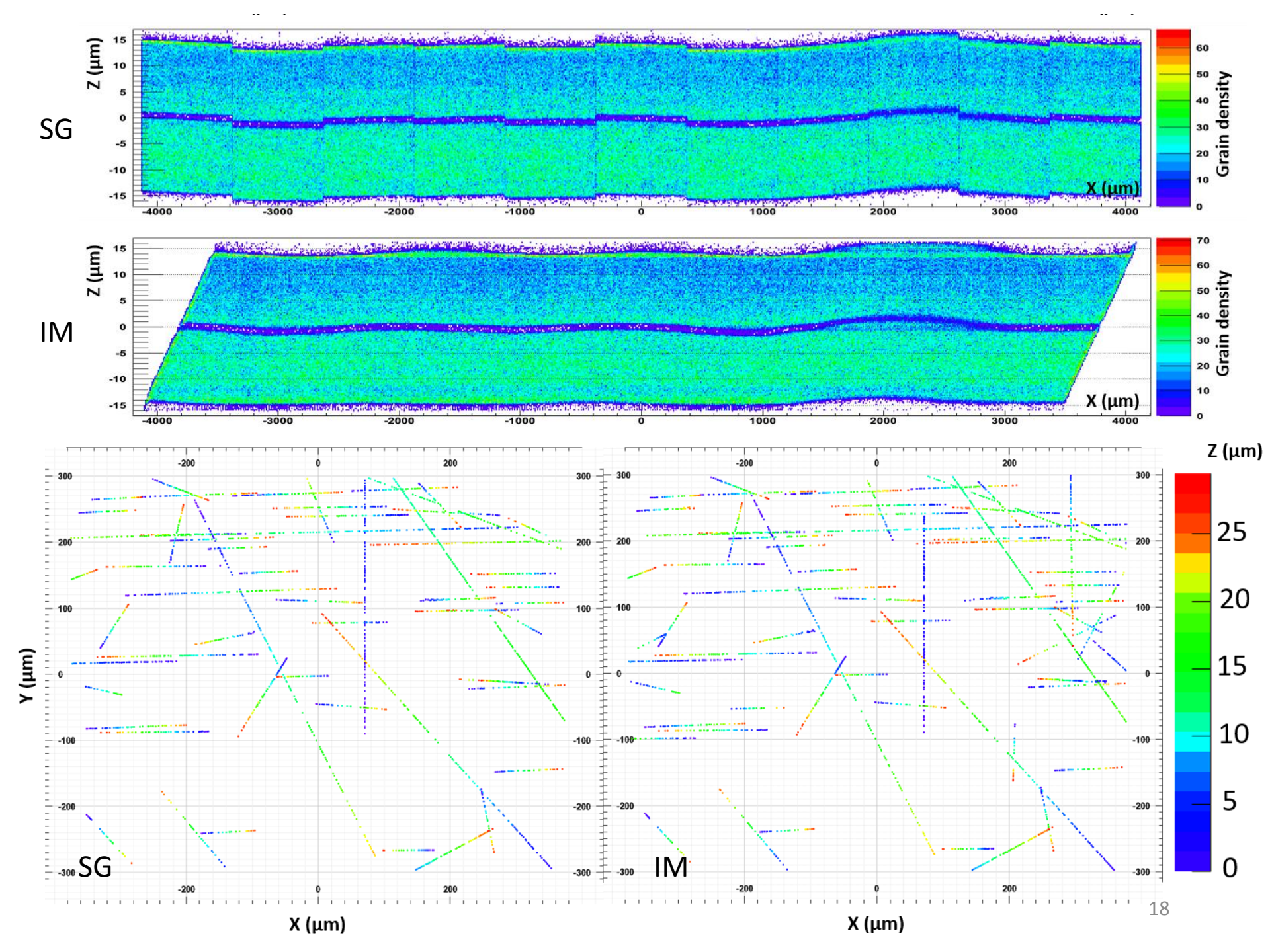
Cons:

1) The camera must be inclined at a relatively large angle
2) Pixel size may vary across the image

Test setup

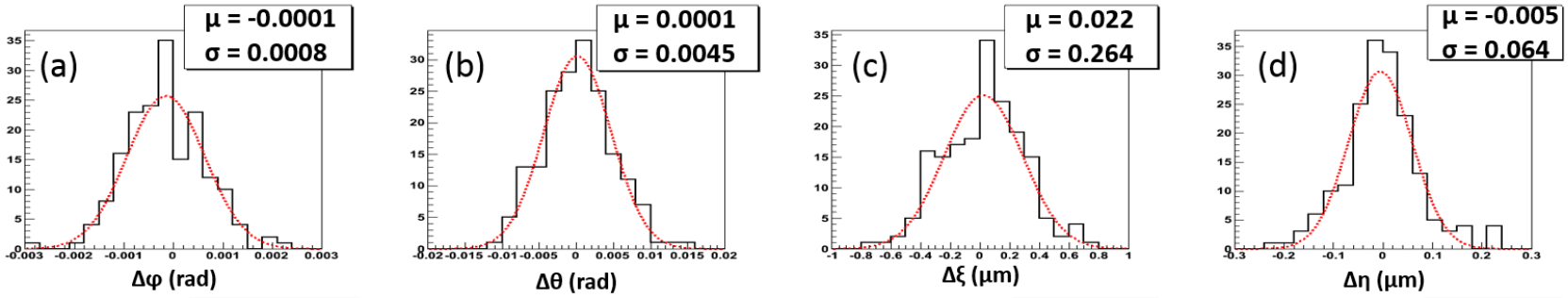

(b)
Camera inclined at 35°
20x oil objective lens W.D. = 350 µm


(a)
4
3
1 (Z=11 µm)
5 (Z=11 µm)
2
50 µm
50 µm
(b)
5 (Z=23 µm)
4
3
1 (Z=11 µm)
2
50 µm
50 µm

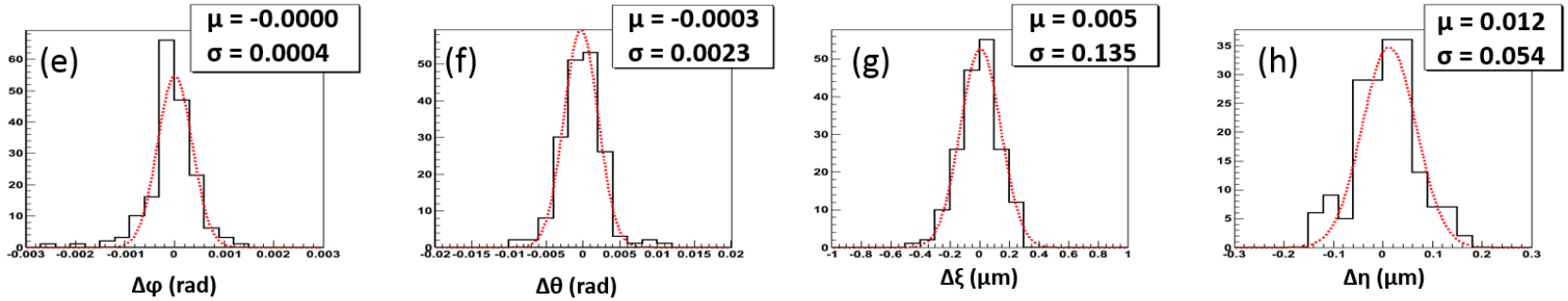

SG
IM
Z (µm)
X (µm)
Grain density
Y (µm)
Z (µm)

SG-IM microtracks matching

IM-SG



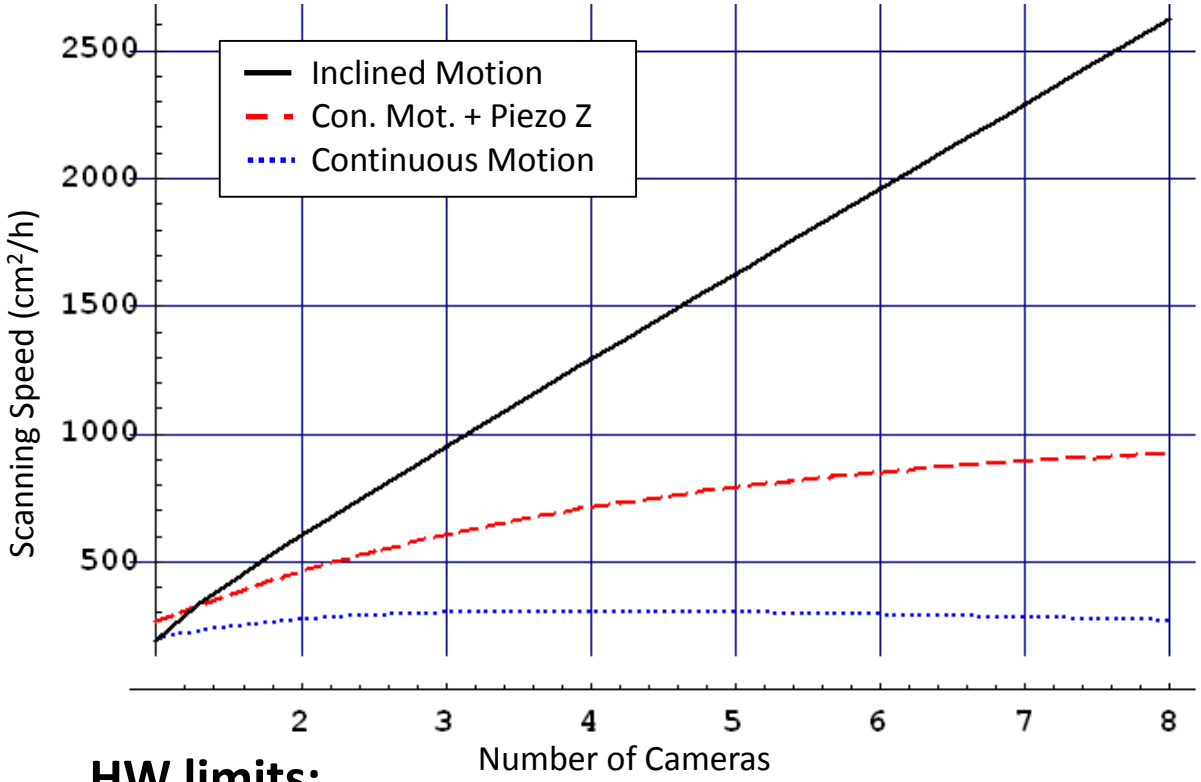
SG-SG



Microtracks selection:
Theta > 1.25 rad
Length > 90 μm

Dataset	Microtracks found
SG1+SG2+IM	187
SG1+SG2	185
IM	184

Scanning Speed vs Number of Cameras



4M camera @ 563 fps

50 µm thick emulsion

30 µm overlap (X&Y)

$$v_{IM} \approx w \frac{s\ f\ R}{\delta\ M} N_{cam}$$

HW limits:

Continuous illumination: 2 µs camera exposure -> 3500 cm²/h

Stroboscopic illumination: 30 cm/s stage speed -> 6000 cm²/h

XY-stage upgrade: 2 m/s stage speed -> 40000 cm²/h = 4 m²/h

Holographic Microscopy

- Collaboration with Institute of Applied Sciences and Intelligent Systems (ISASI)
- Advantages
  - Laser beam -> very strong illumination
  - Includes phase information
  - No need to move along Z or incline camera
- Disadvantages
  - Speckles generated by coherent laser light

Summary

- Successful 14 years history
- 20 cm^2/h -> 190 cm^2/h in last 7 years
- Ongoing R&Ds
  - High speed
  - Super-resolution
- Applications:
  - OPERA
  - FOOT & biomedical app (Cristina's talk)
  - SHiP (Antonia's talk)
  - Muography (Valeri's talk)
  - Directional DM search (Naka's talk)

Thank You!