High speed 3D track reconstruction in particle physics with GPUs

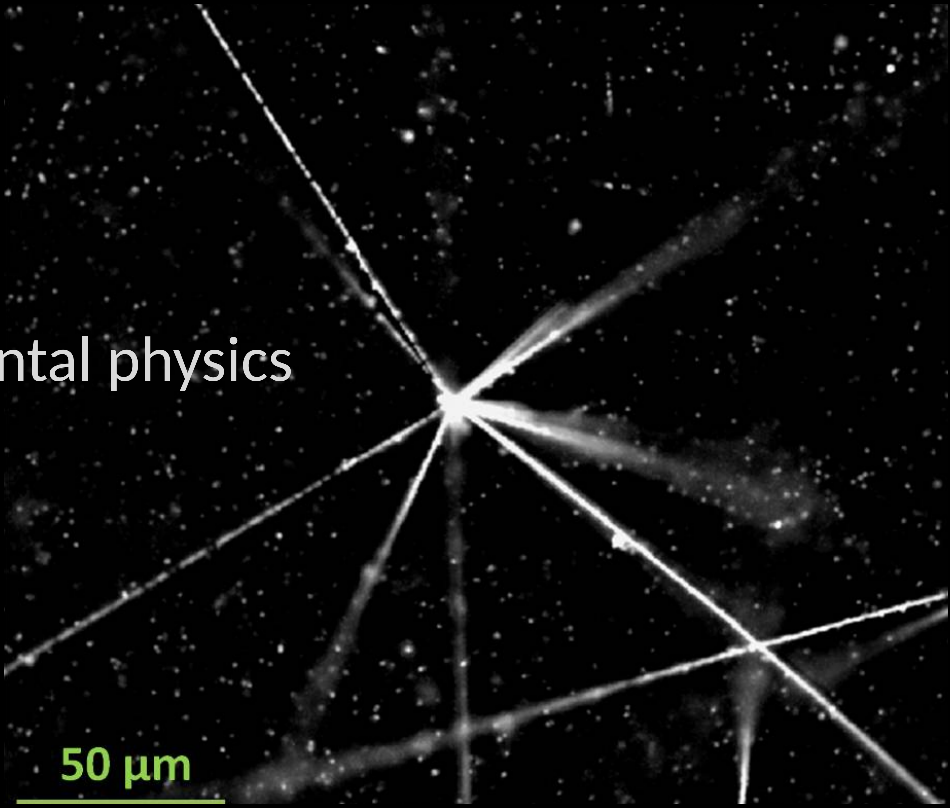
Akitaka Ariga, PhD

Senior staff

Albert Einstein Center for Fundamental physics

Laboratory for High Energy Physics

University of Bern, Switzerland



UNIVERSITÄT BERN

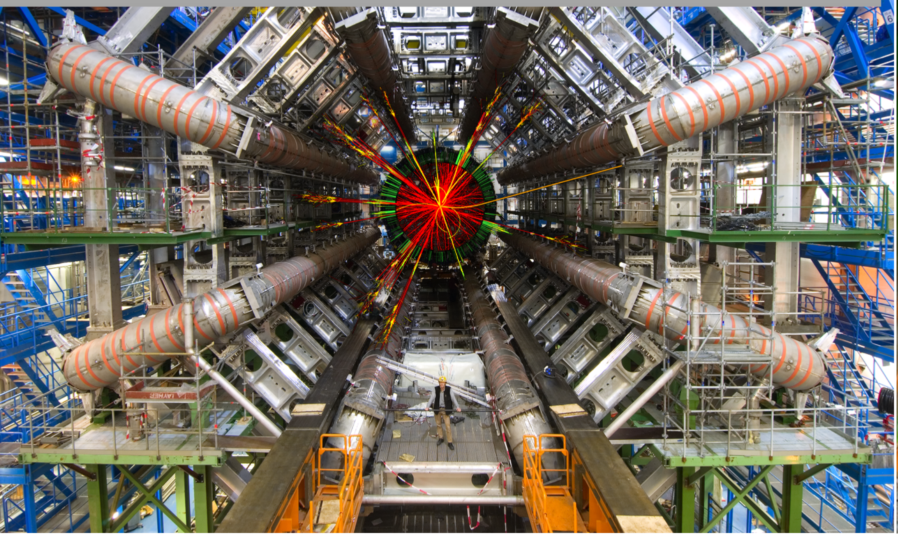
AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

Particle physics needs GPU!

- Particle Physics = Big science
- Large facilities and detectors

100 M channels x 40 MHz



ATLAS experiment

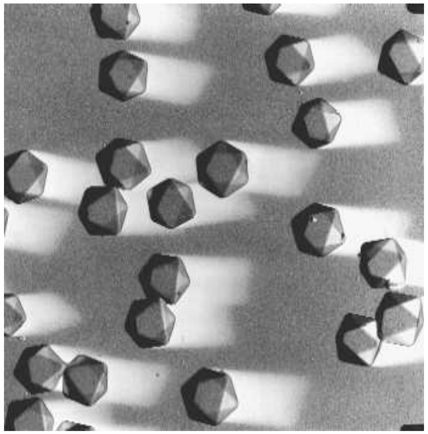
10^{21} channels 3D detector

OPERA experiment
Photographic emulsion detectors

- Huge amount of data from detectors
- **Reconstruction of data needs GPUs!!**

Photographic emulsion particle trackers

The best position resolution among all detectors!

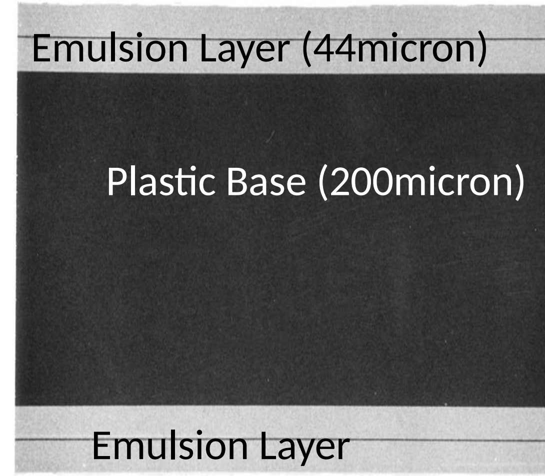


- minimal detectors

AgBr Cristal,

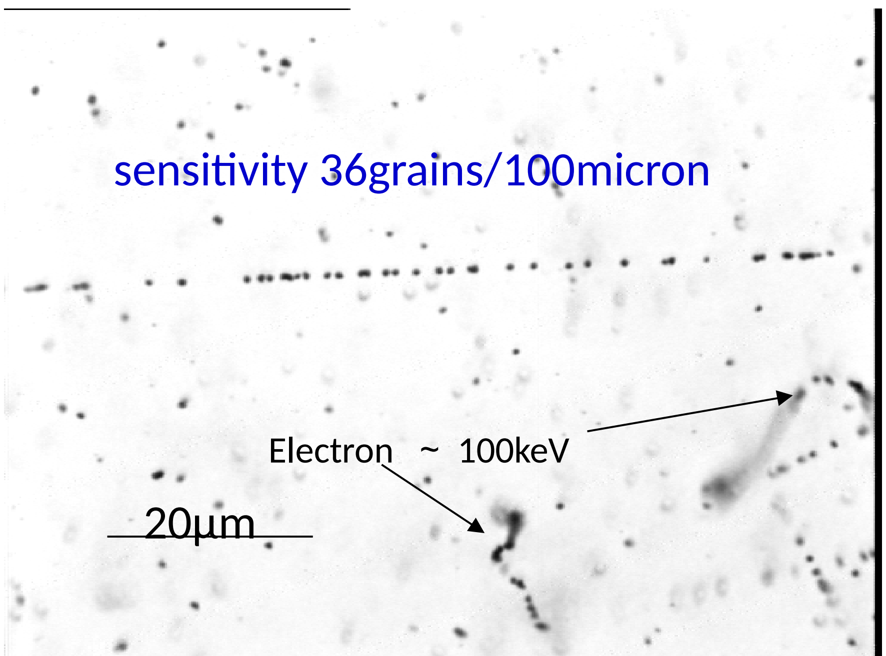
Size = 200 nm

10^{14} crystals in a film



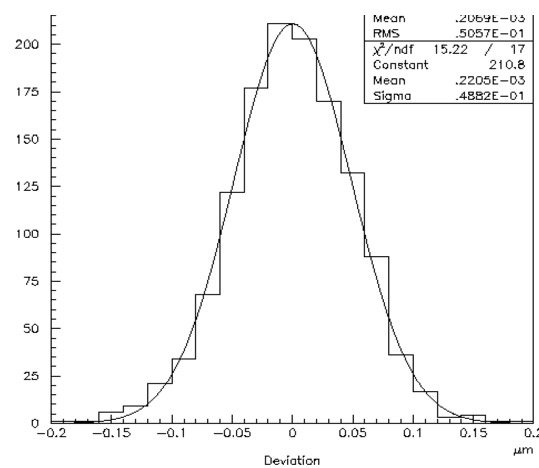
Cross-sectional view (SEM)

π-10GeV/c

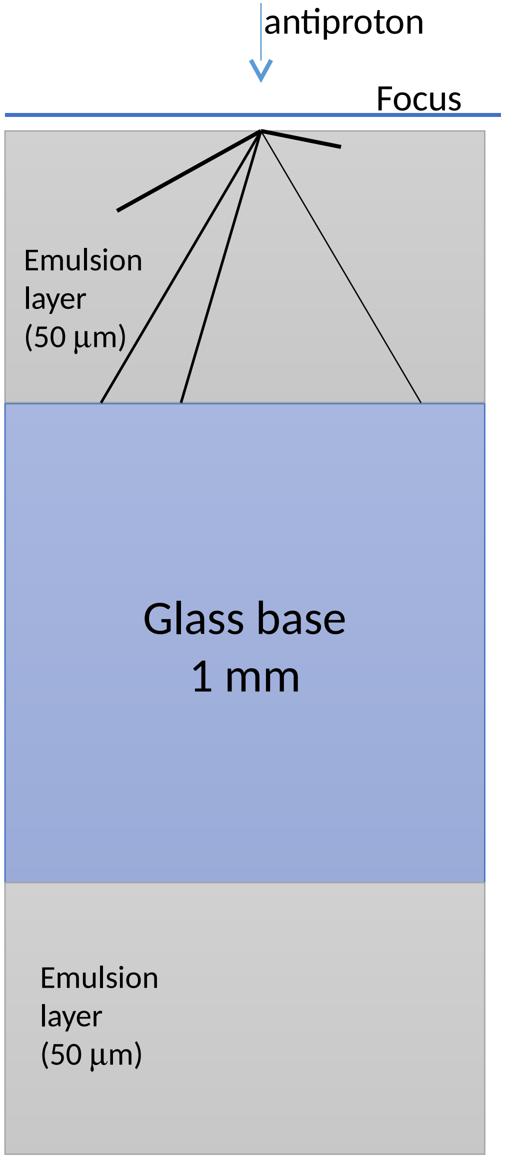


Intrinsic resolution

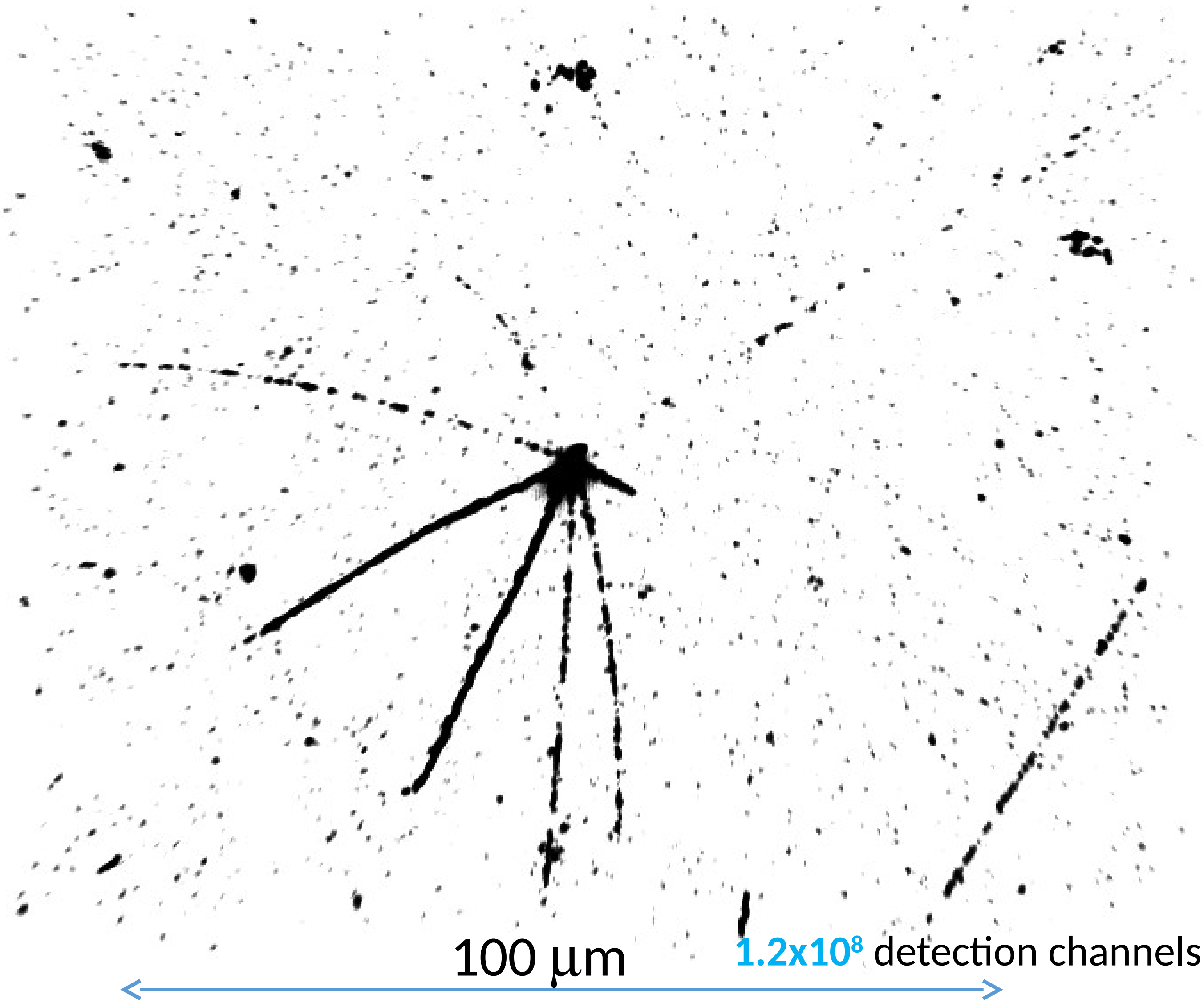
50nm



Antiproton annihilation in the emulsion (AEgIS 2012)



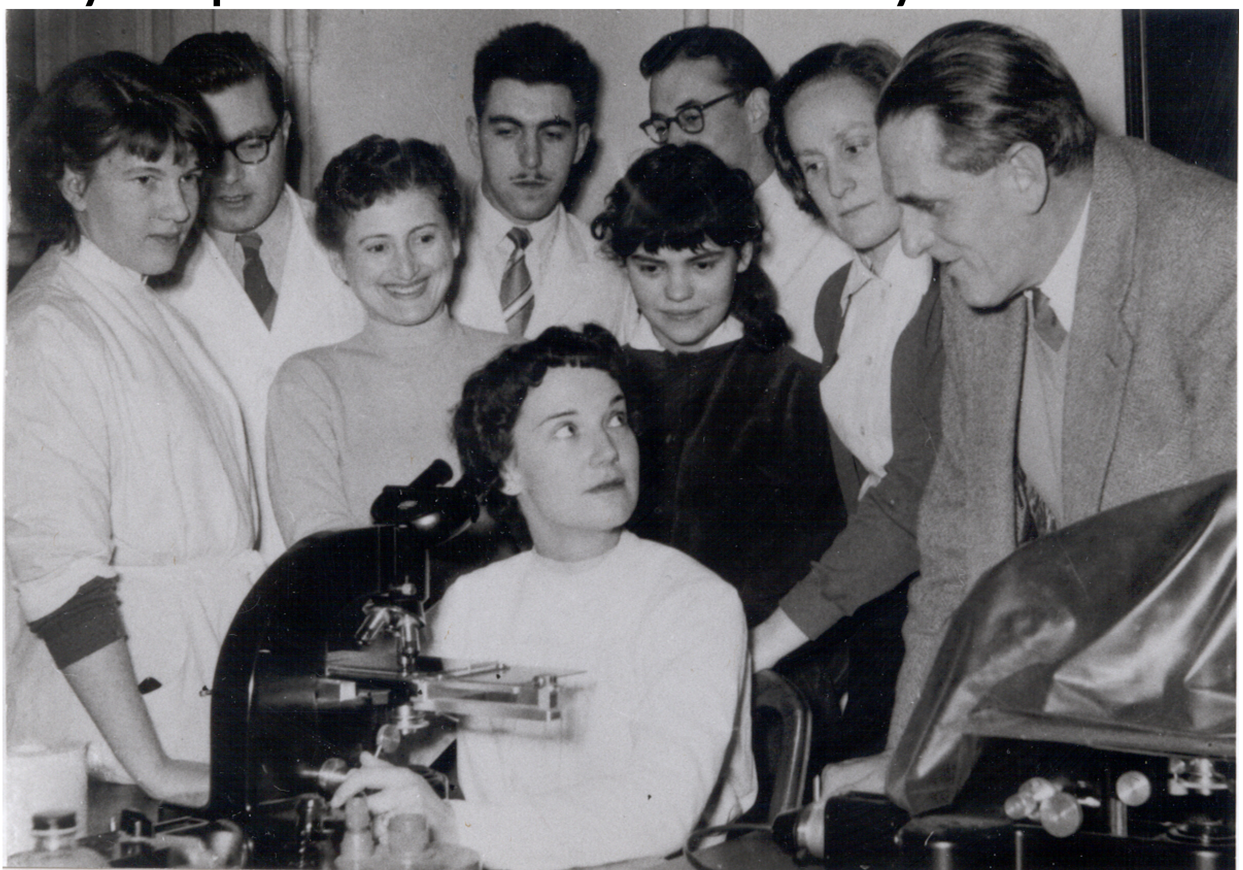
3D view of antiproton annihilation



1.2x10^{8} detection channels in this volume

Nice detector… but some drawbacks…

- **Very high resolution** = **very large data volume**
  - 10 Tbytes / 10cm x 10cm
- No way to process it automatically… till recently.

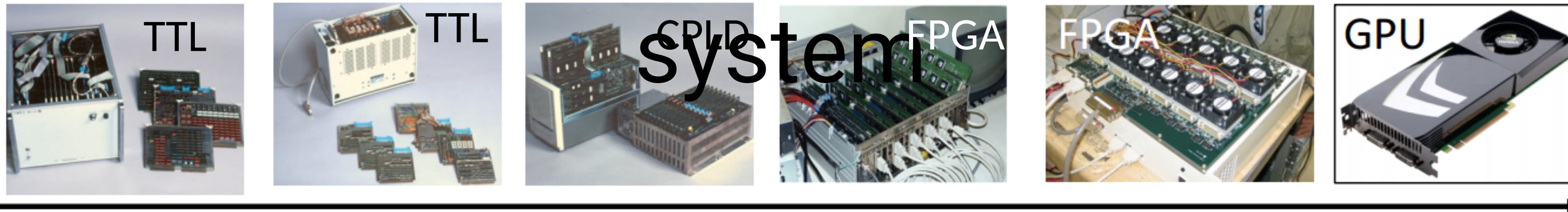


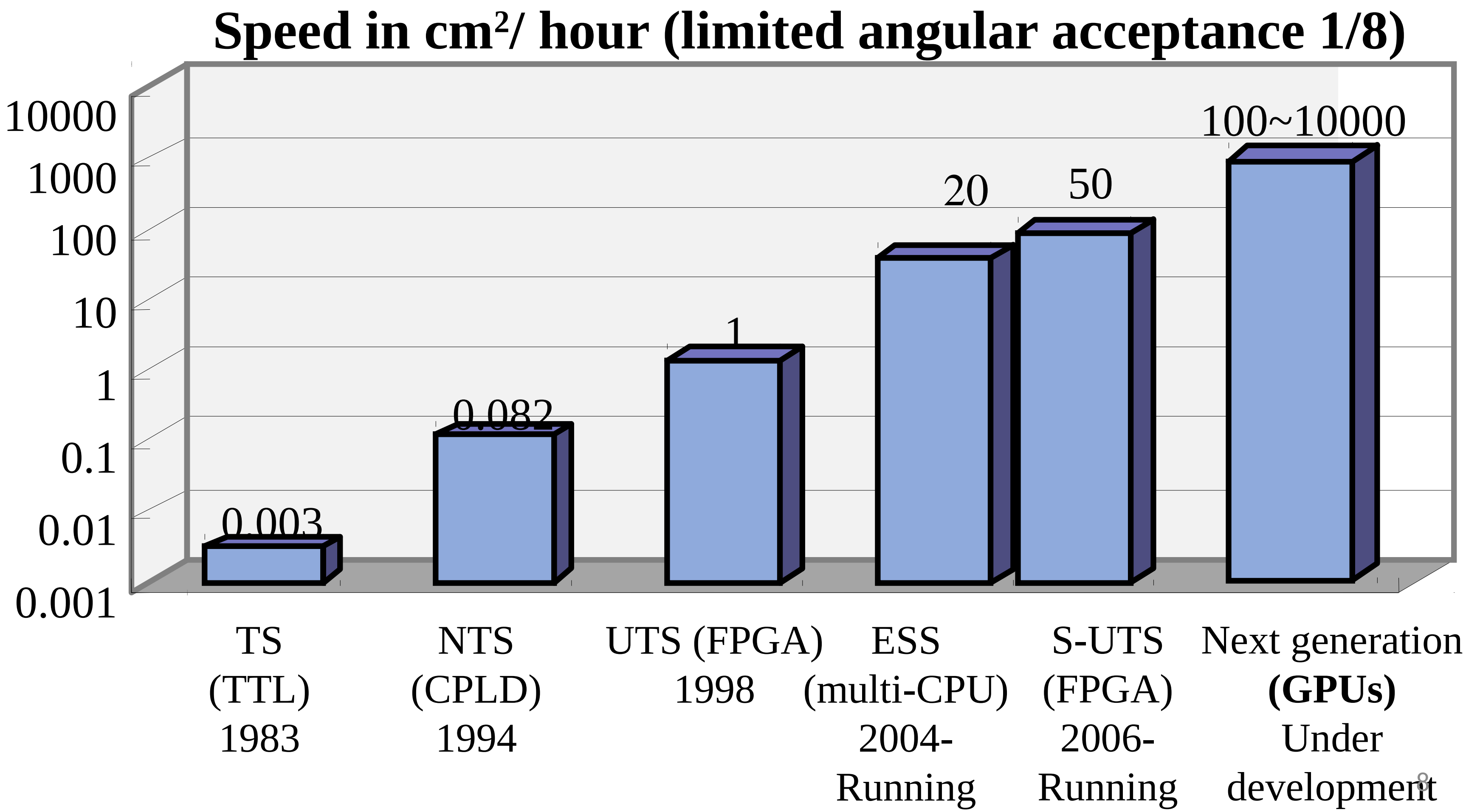
F.G. Houtermans im Kreise seiner Scannerinnen im
Physikalischen Institut Bern 1955/56

Swiss Scanning Station in Bern

Several hundreds of photographic emulsion sheets analyzed every week

Evolution of automated scanning system

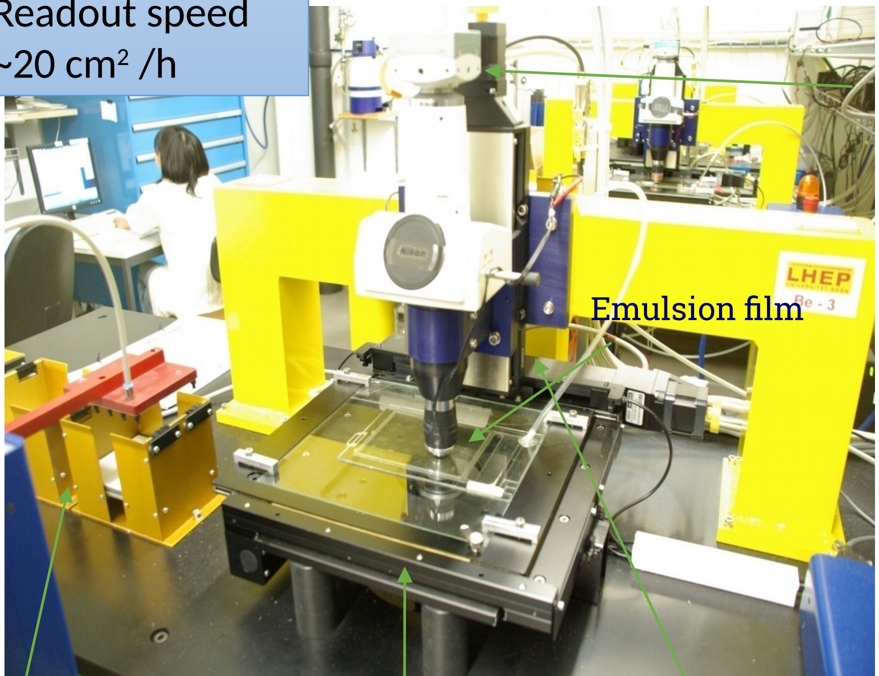




High speed readout system (current generation)

Custom-made real-time scanning microscope.

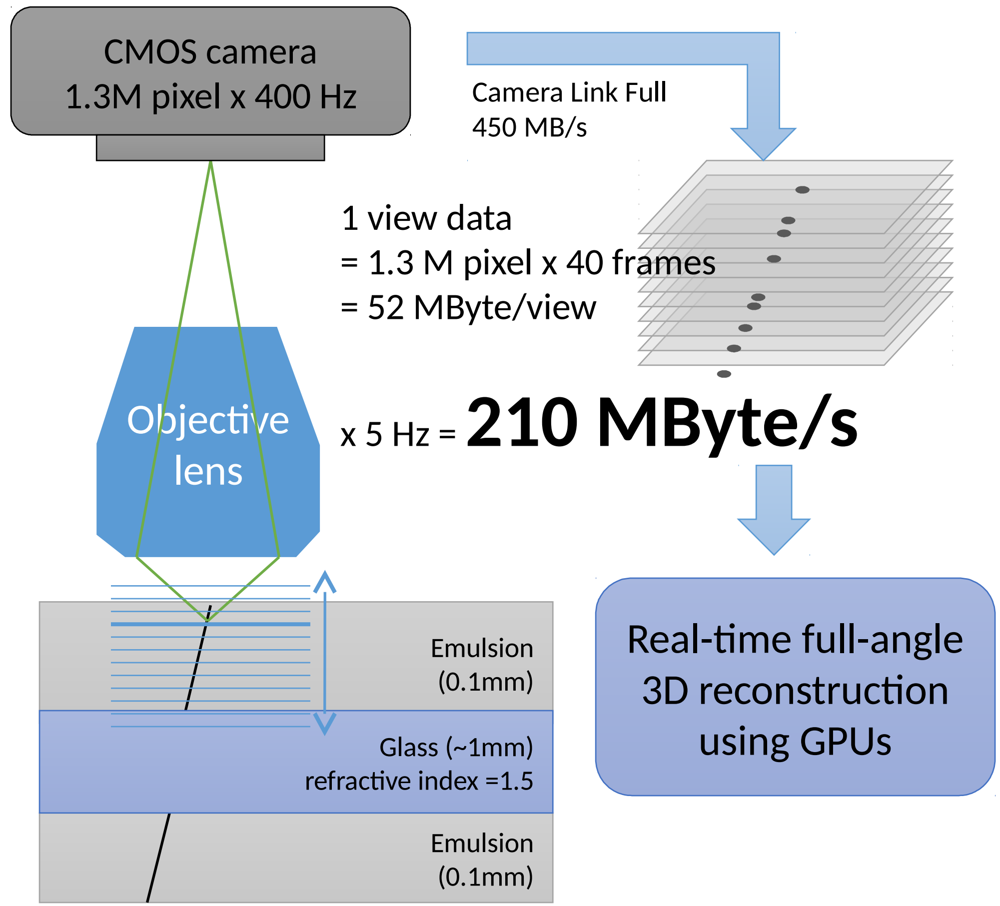
Readout speed
~20 cm^2 /h



Automatic Plate Changer

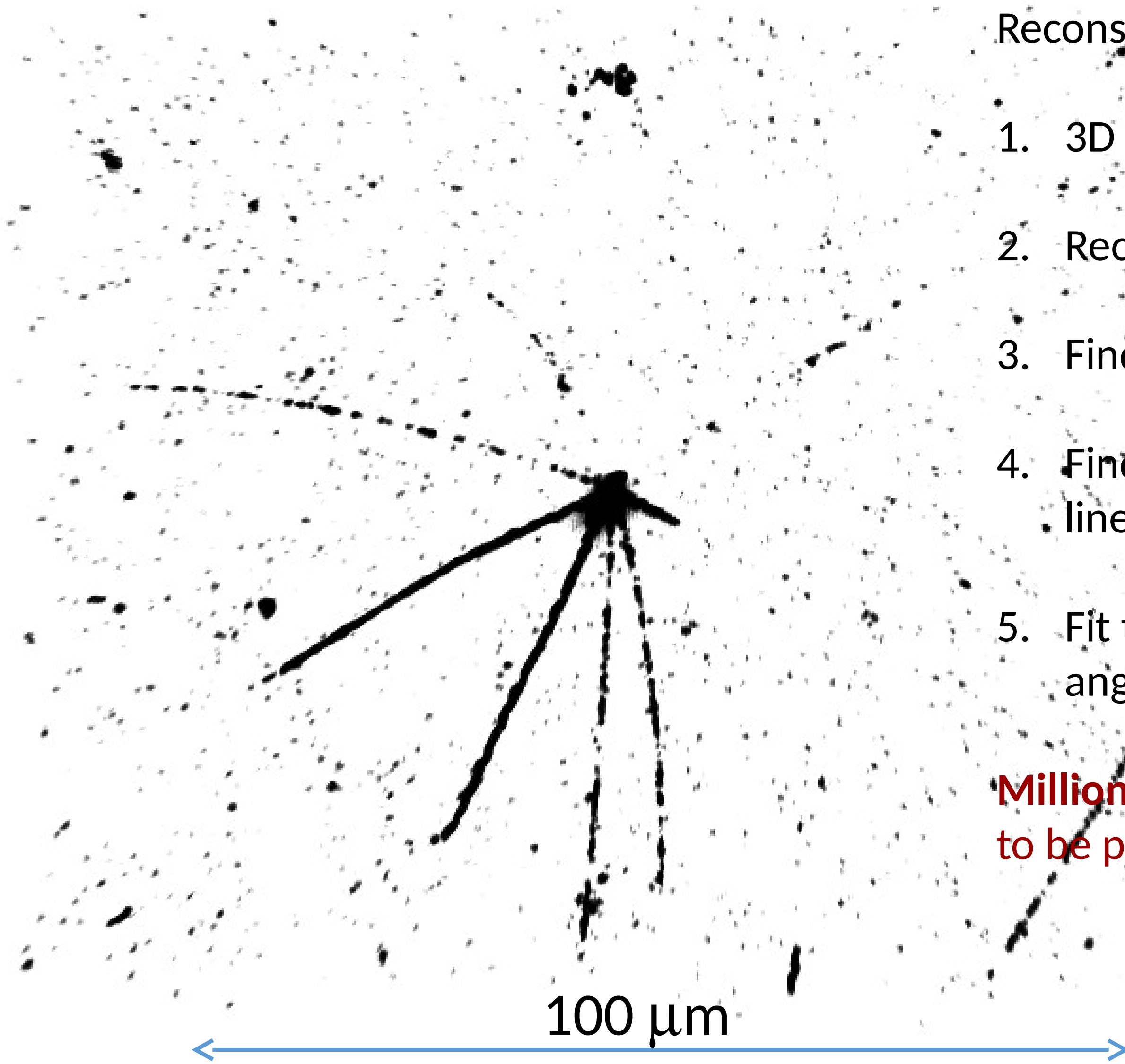
XYZ stage (Micos)
0.1 μm nominal precision

objective (50x)



Need to process in real-time, locally.
See demo of data

Track reconstruction

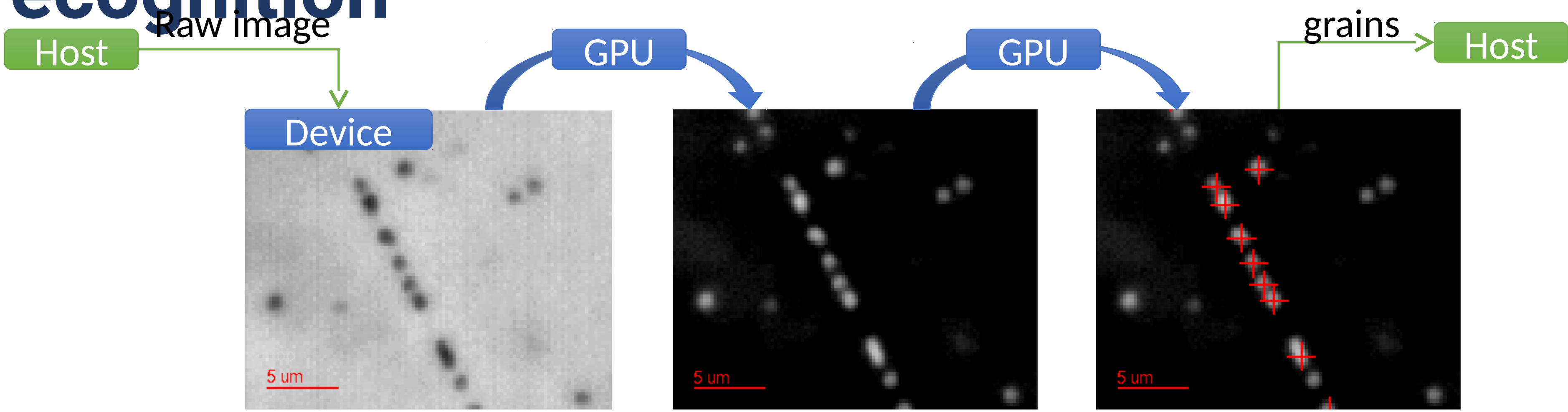


Reconstruction of particle trajectories

1. 3D image filtering
2. Recognize dots (or grains)
3. Find any combination of grains
4. Find sequential grains forming lines
5. Fit track □ 5D (3D position, 2D angles)

Millions of such data unit (view) have to be processed within hours.

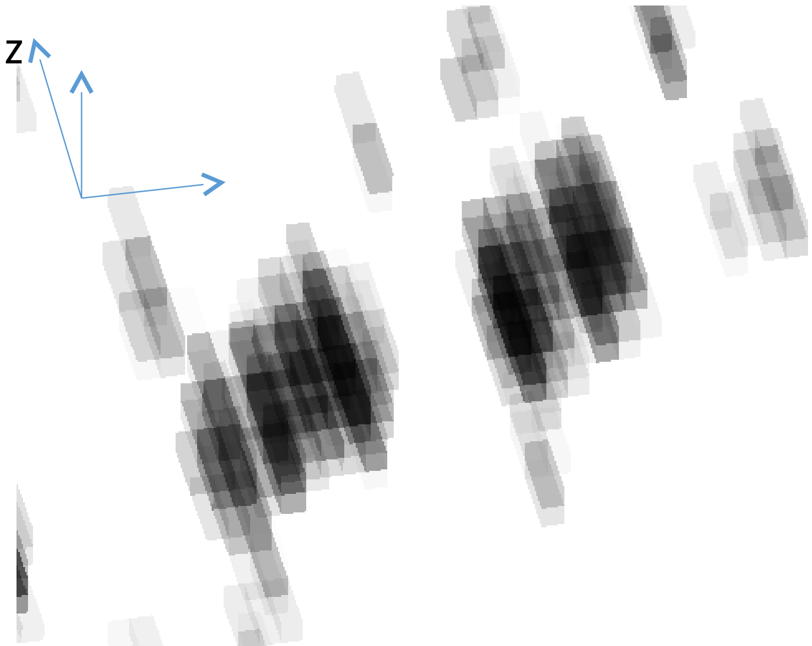
3D image processing and object recognition



zoom of raw image

3D image filtering
(kind of high pass filter)

3D grain recognition
O(10^4) grains / view

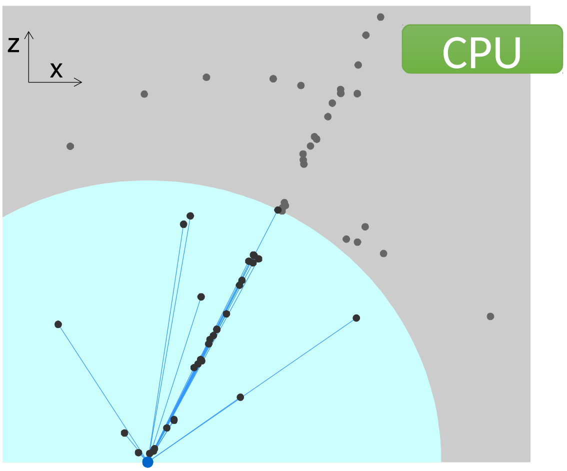


Grains have optical shadow in Z.
Consecutive frames has a strong correlation.
→A 3D image processing.

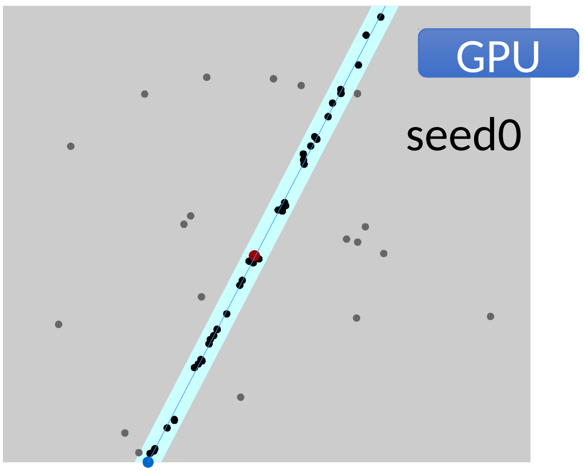
Tracking algorithm

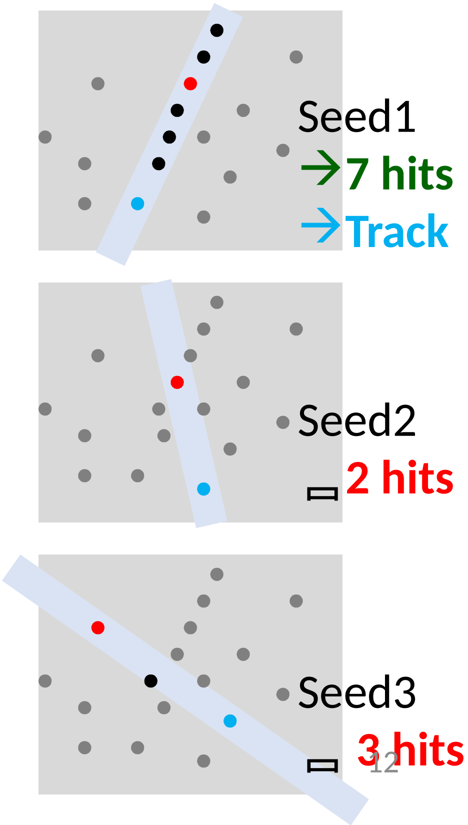
1. Form “seeds” of tracks = 3D line made of **any two combination of grains** (4π solid angle)
2. Count number of grains along the seeds (parallelizable)

Form “seeds”



Process seeds



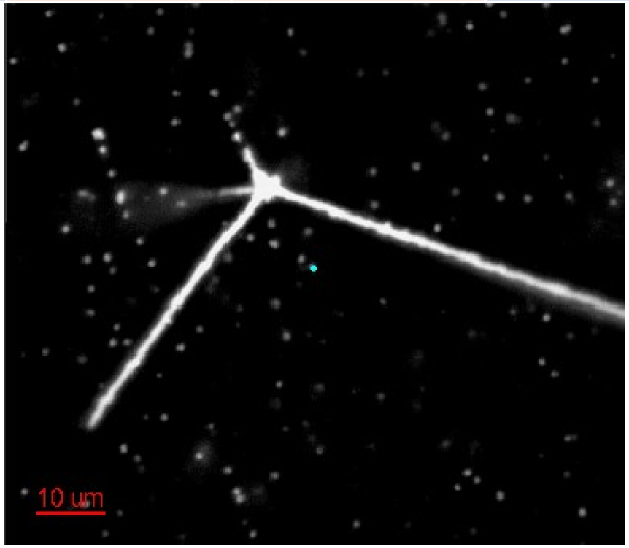


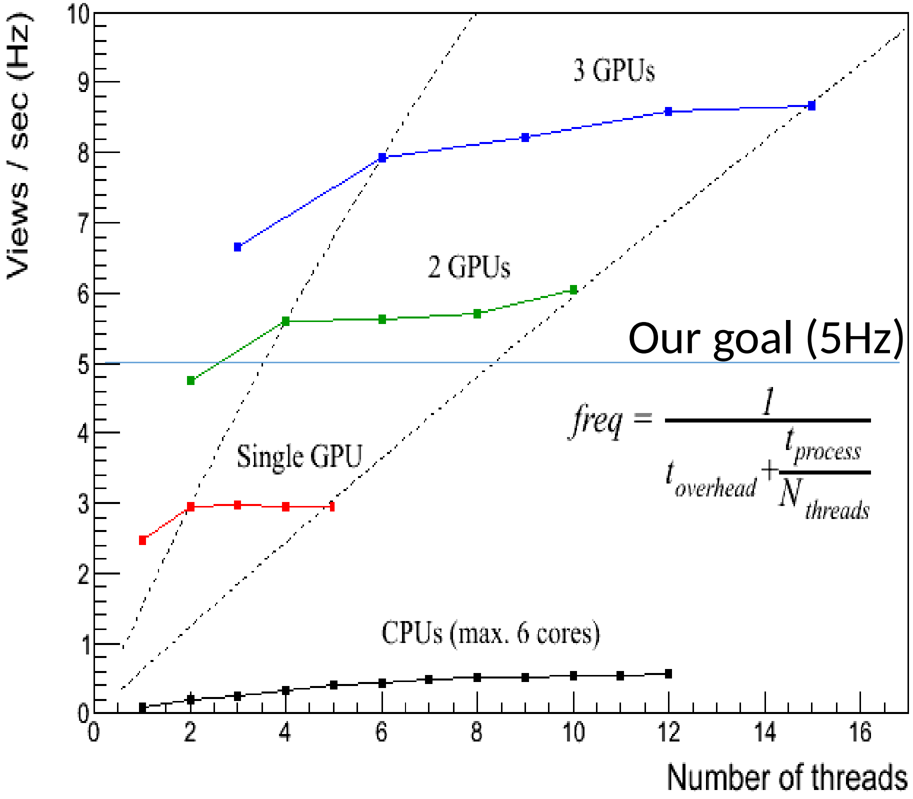
3. Number of grains >= 5 ▭ “track”

Processing speed

- 1 Views = 1280x1024 pixels x 40 frames = 52Mbyte
- CPU :i7- 3930K 6 cores, 12 threads, 3.2 GHz, GPU : Geforce GTX TITAN, 2688 cuda cores

	1 CPU (sec/view)	using 1 GPU (sec/view)	Gain
Image filtering	3.396	0.051	x67
3D grain reco.	0.181	0.023	X8
3D tracking	6.999	0.330	x21

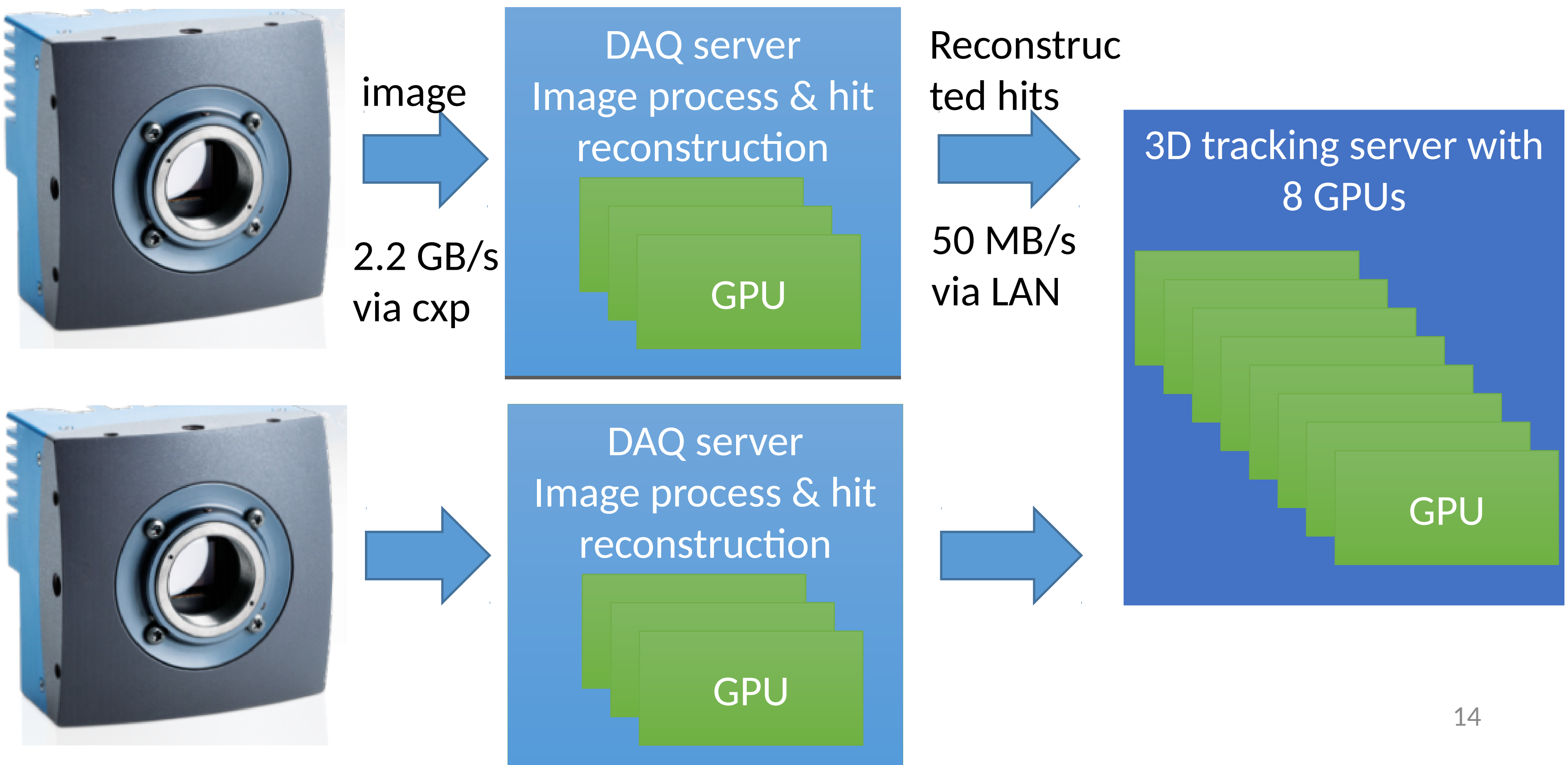




Antiproton sample
High number of grains
Tracking dominant

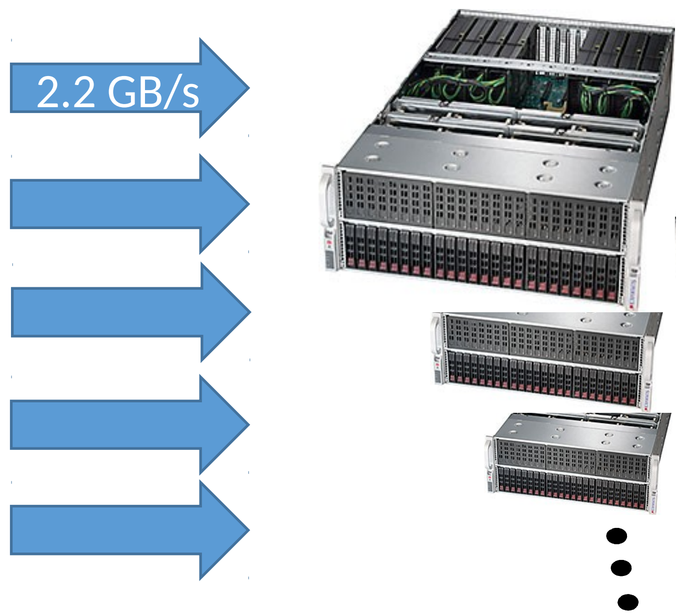
New scanning system under development

- 4 M-pixel x 563 fps camera (throughput 2.2 GB/s)
- Image processing with 3 GPUs
- Track reconstruction with 8 GPUs



PB-level Scanning facility (future)

- 6 microscopes: Data throughput of 13 GB/s, over 1 PB/day
- Real-time processing with a cluster of GPU servers on site

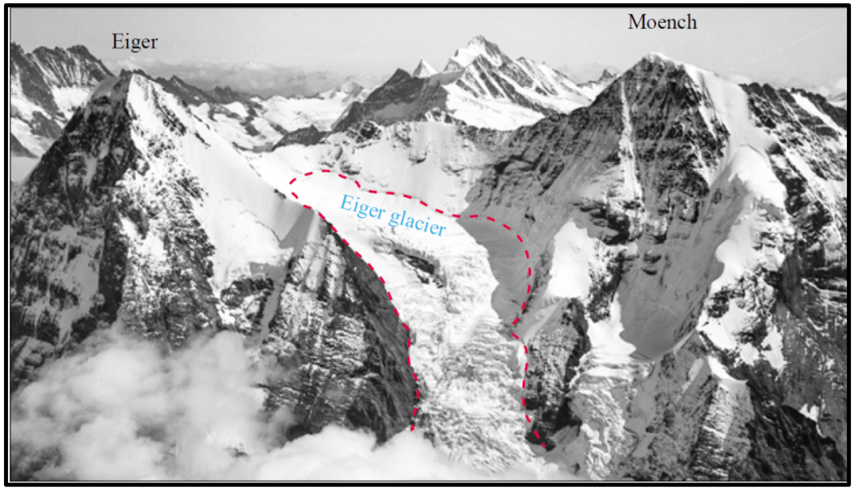


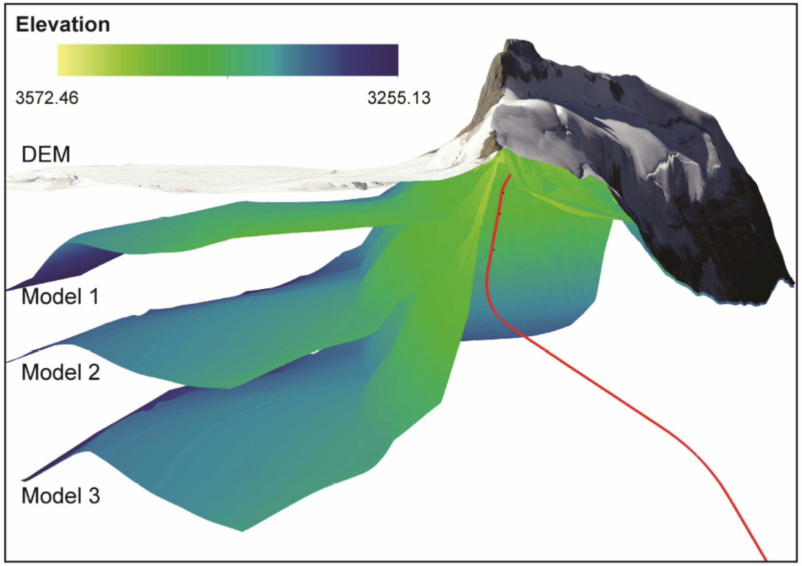
Wide range of application

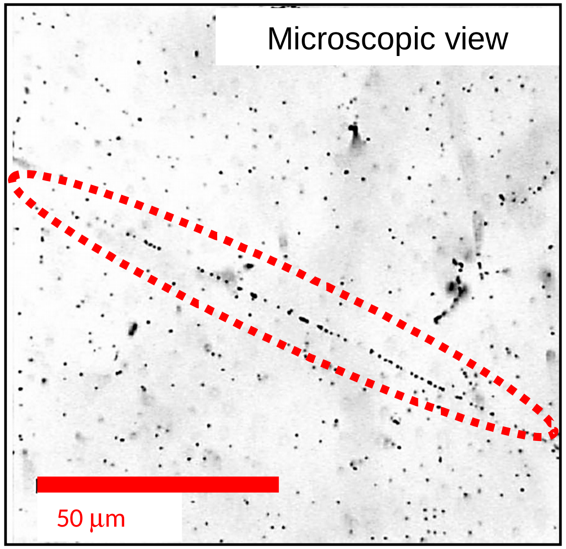
Emulsion detector technology with GPUs

Fundamental Physics	Accelerator	Medical application	Geosciences
• Neutrino physics • Hadron physics • Antimatter • Dark matter	• Beam monitoring • Muon beam study in neutrino beamline	• Neutron source imaging • Proton radiography	• Muon radiography • Volcanoes • Glaciers

Muon tomography of active glaciers



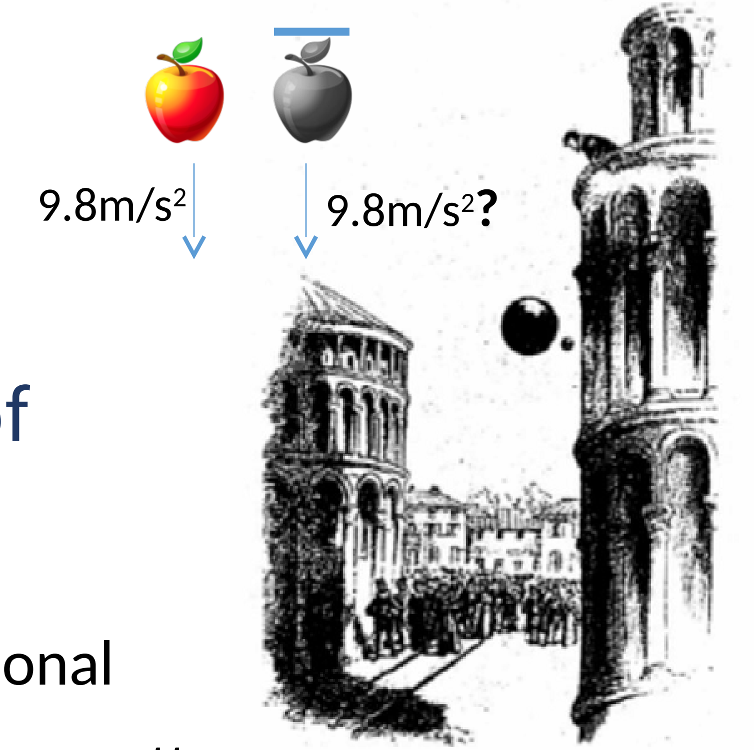




GPU ▭ monitoring of the glacier retreat in Swiss Alps

Summary

- Large amount of data comes from particle detectors. Real-time processing is vital.
- GPUs play essential roles in such tasks.
- Successful application for emulsion detectors
  - Highly parallelizable algorithms
  - O(100) faster wrt CPU
- Preparing a PB-level microscope facility for future projects in physics and applications.

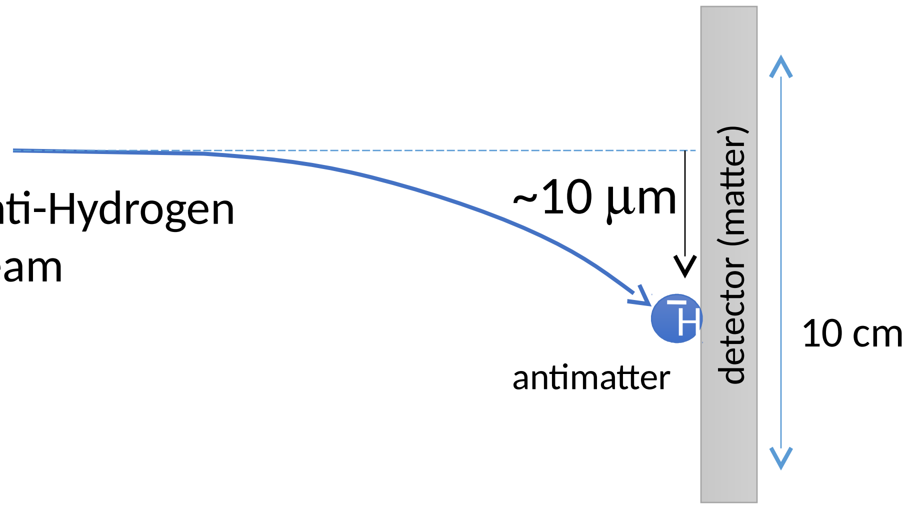


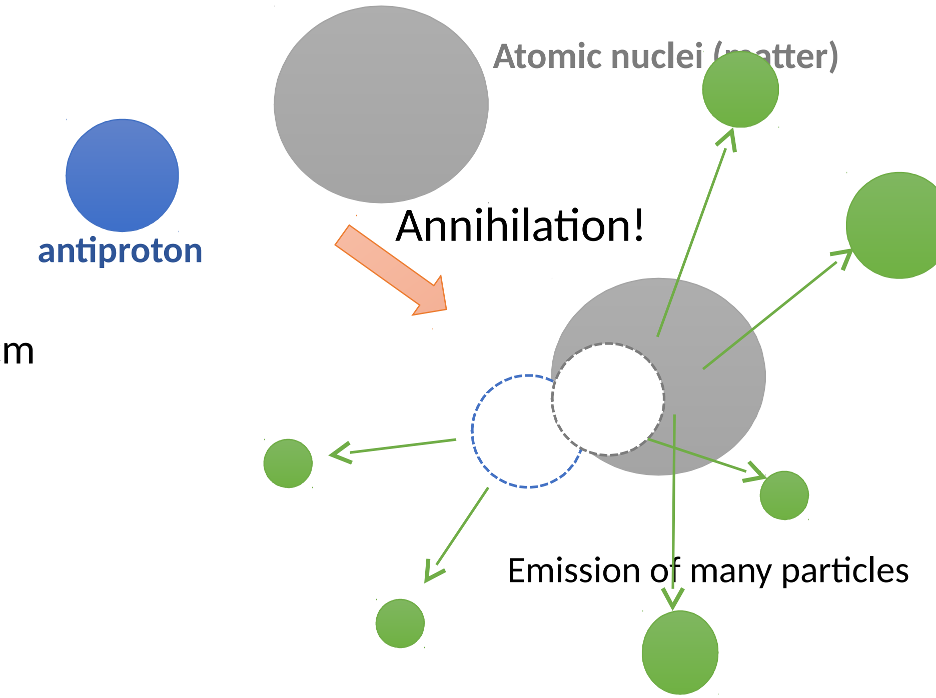
AEgIS experiment

aiming at the first measurement of gravitational force on antimatter

- Principal of equivalence between gravitational and inertial mass ($m_i = m_g$) is measured for matter with a precision of $\mathbf{10^{-13}}$. ($\mathbf{10^{-3}}$ by Galileo)
- **Gravity on antimatter has never measured directly!**
- **AEgIS at CERN is going to measure the gravitational acceleration (g) on a antihydrogen with 1 % accuracy.**

Detection of antiproton annihilation

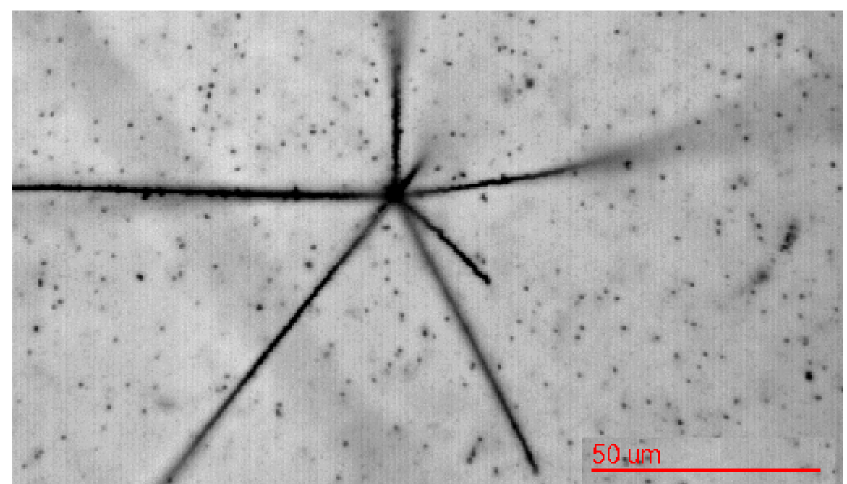




- The scale of free-fall of anti-hydrogen is expected to be **~10 microns**

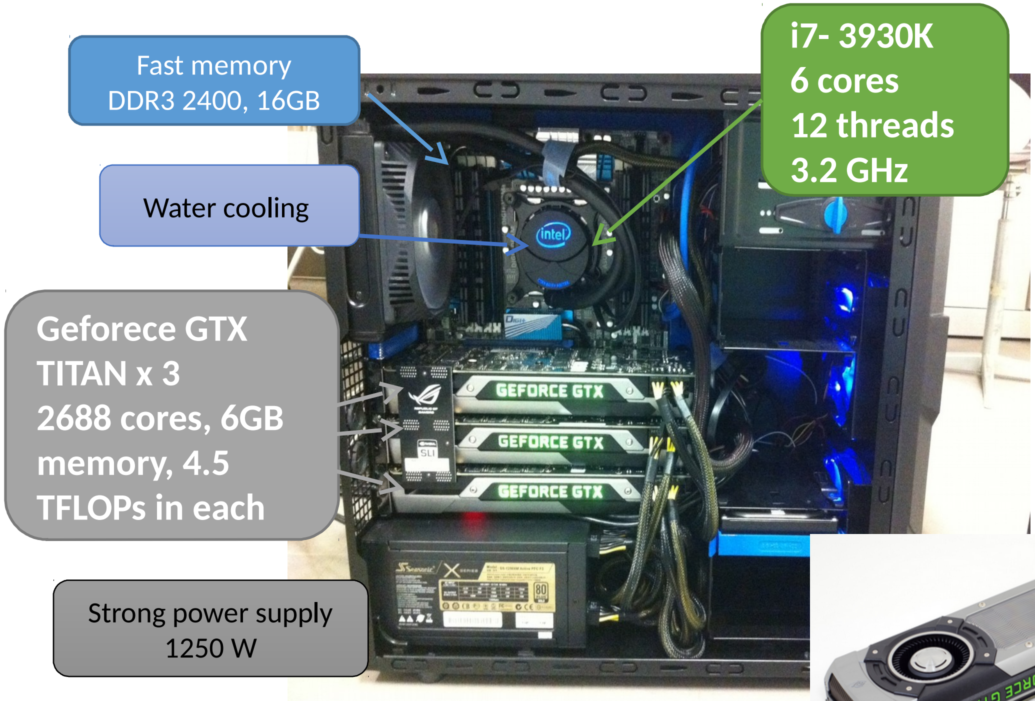
Use of high precision particle detector : **Photographic emulsion detectors**

- 3D tracking of particles
- High position resolution (50 nm)



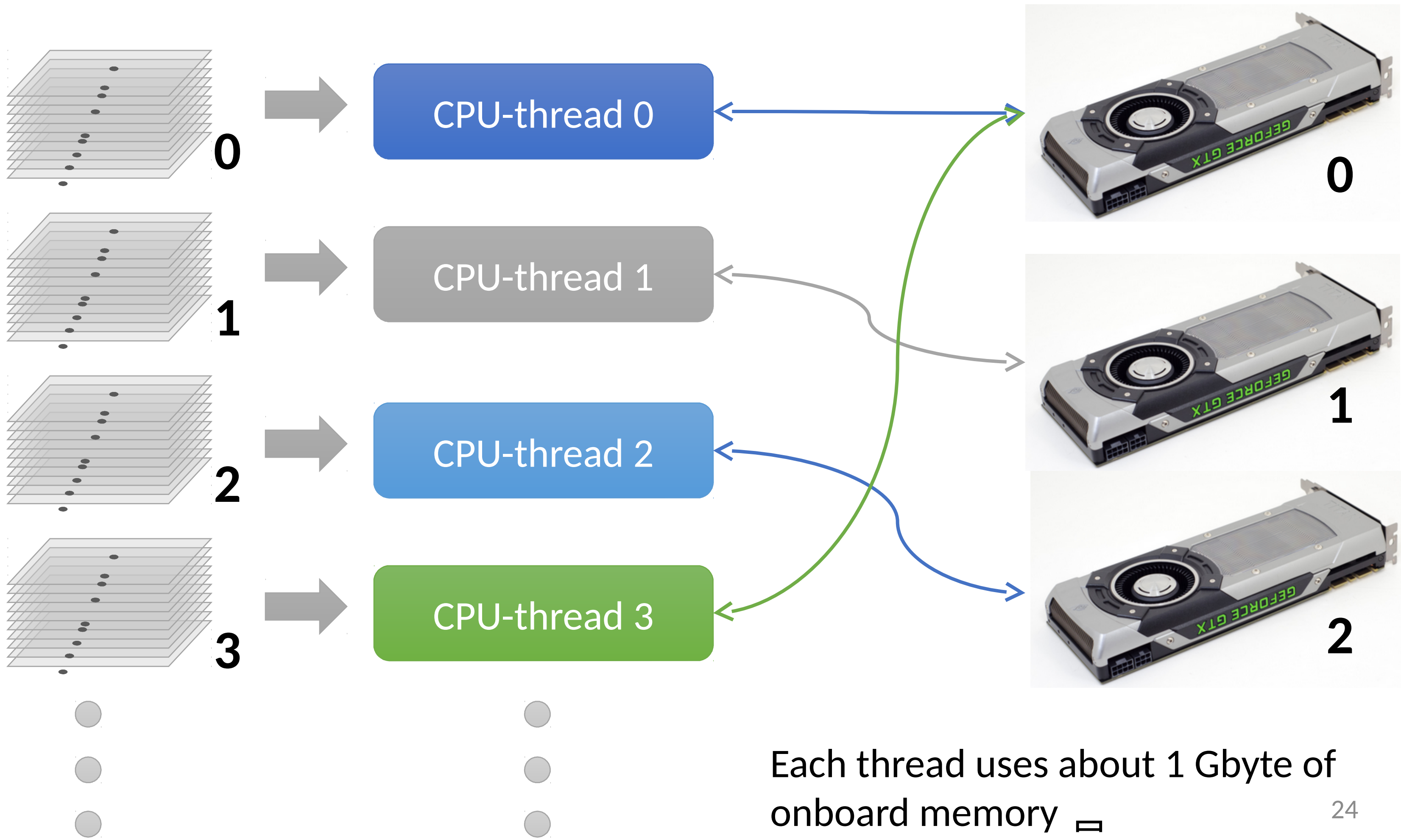
Software and Hardware

- C++, CERN ROOT, CUDA (5.5)
  - CUDA experience since 2008
  - ROOT classes calling CUDA kernels
- CPU: i7-3930K (3.2 GHz, 6 cores)
- GPU: Geforce GTX TITAN x 3
  - Single precision



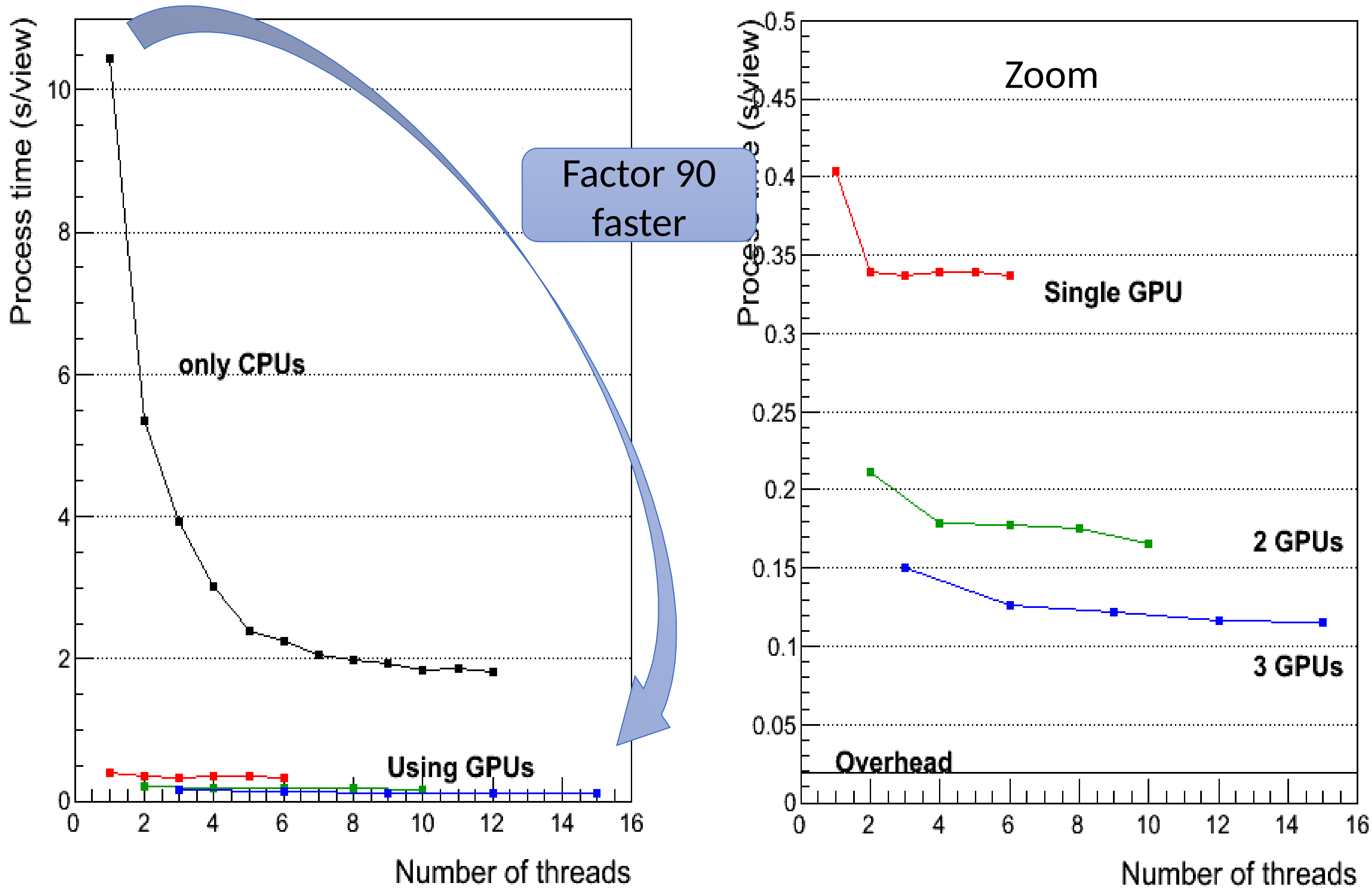
Multi-CPU-thread processing

- Each CPU-thread is responsible of a view
- Each CPU-thread is linked to one of 3 GPUs



Each thread uses about 1 Gbyte of onboard memory

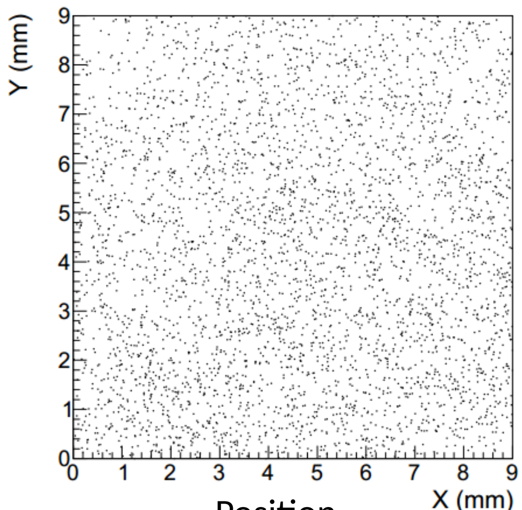
Processing time with “multi-threading” and “multi-GPUs “ (Antiproton sample)



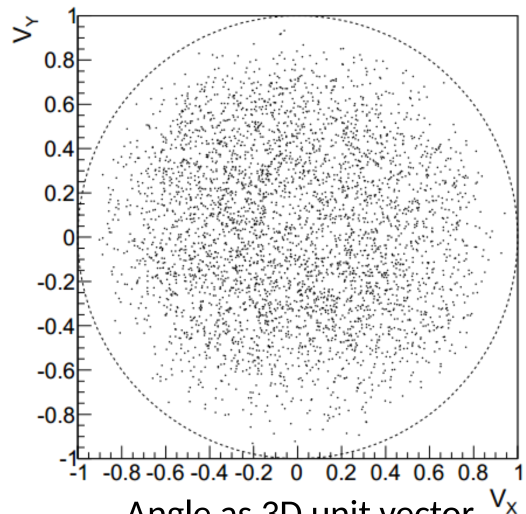
CPU :i7- 3930K 6 cores, 12 threads, 3.2 GHz, GPU : Geforce GTX TITAN, 2688 cuda cores

Reconstructed tracks and detection efficiency

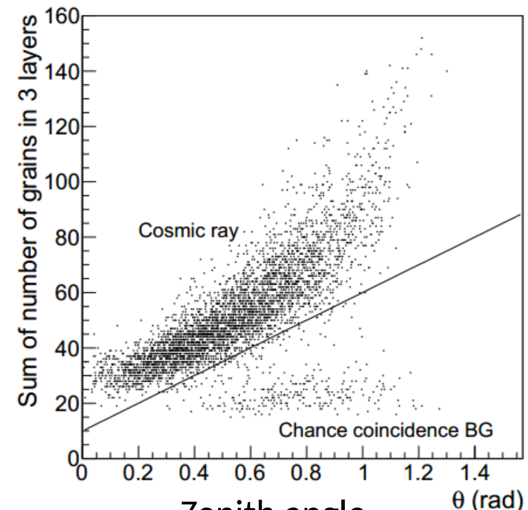
- Performance test with cosmic-ray tracks



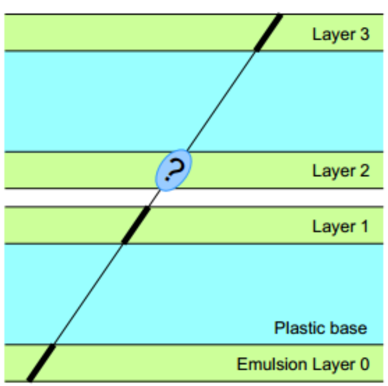
Position

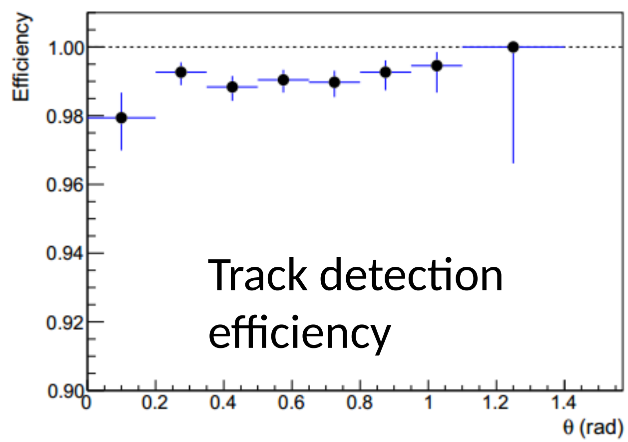


Angle as 3D unit vector



Zenith angle





Some publications

A. Ariga and T. Ariga, *Fast 4π track reconstruction in nuclear emulsion detectors based on GPU technology*,

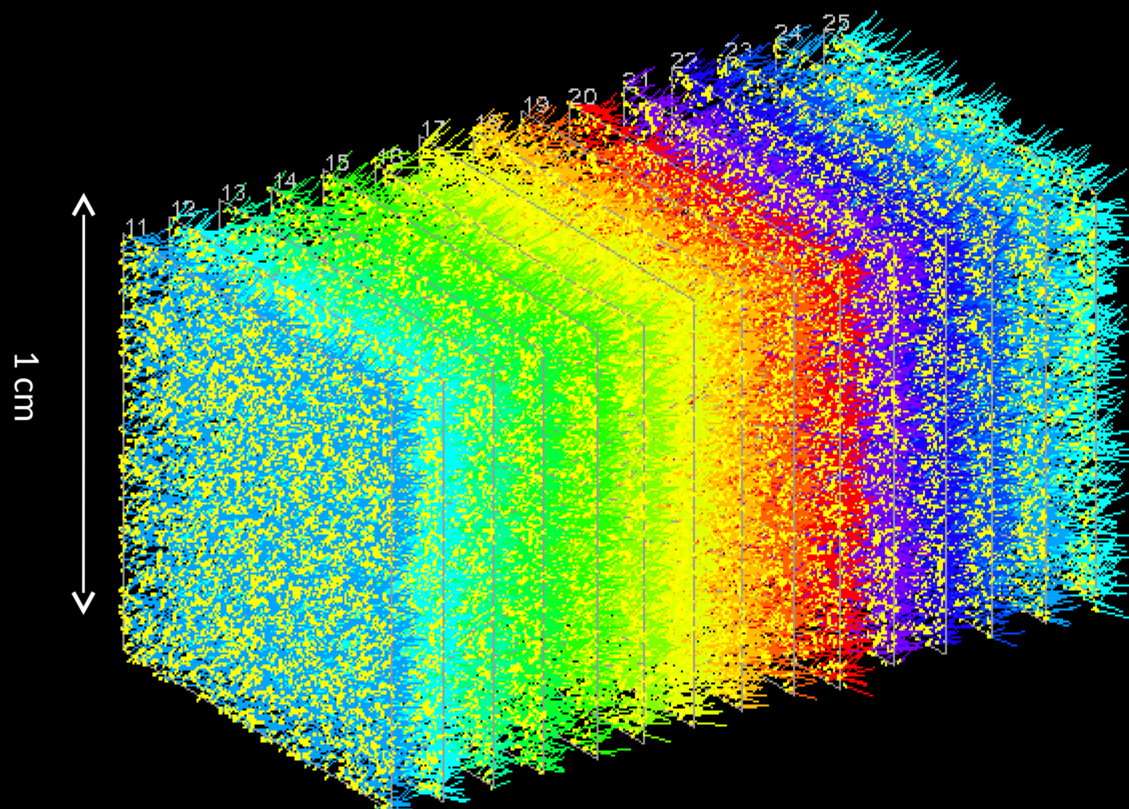
JINST 9 P04002 (2014), arXiv:1311.5334

AEgIS experiment with photographic emulsions

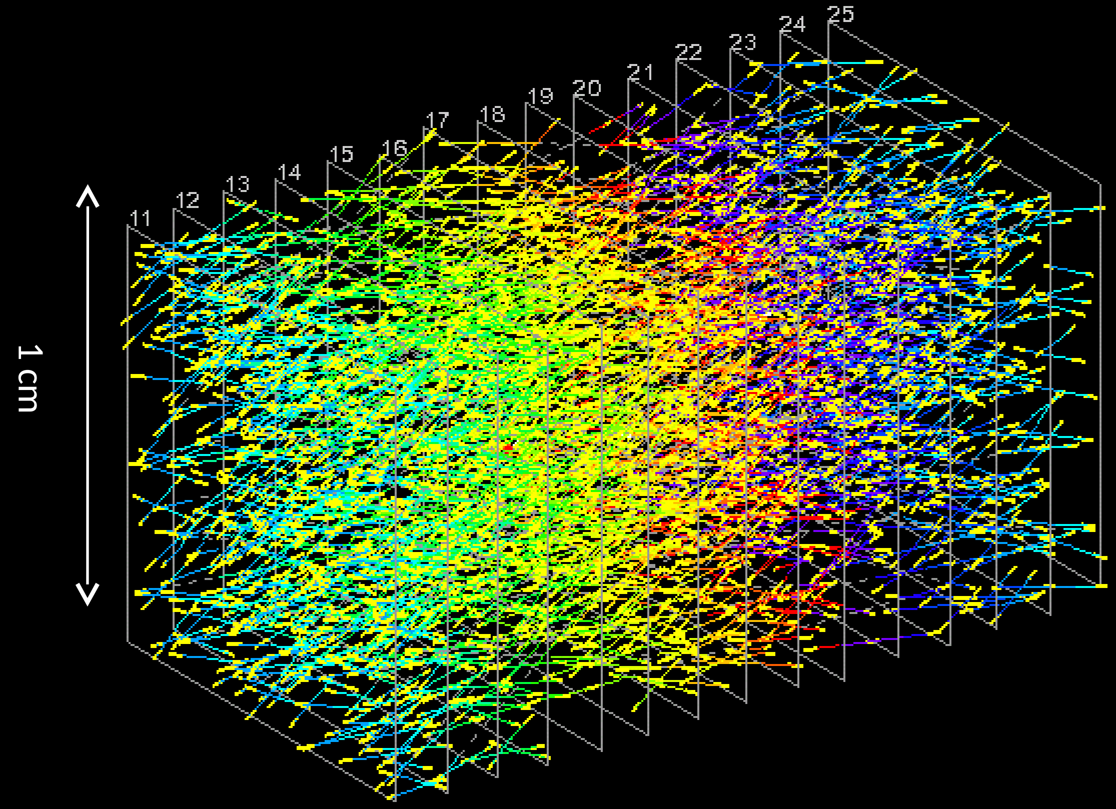
- JINST 8 (2013) P02015
- JINST 8 (2013) P08013

Emulsions give 3D vector data, with micrometric precision.

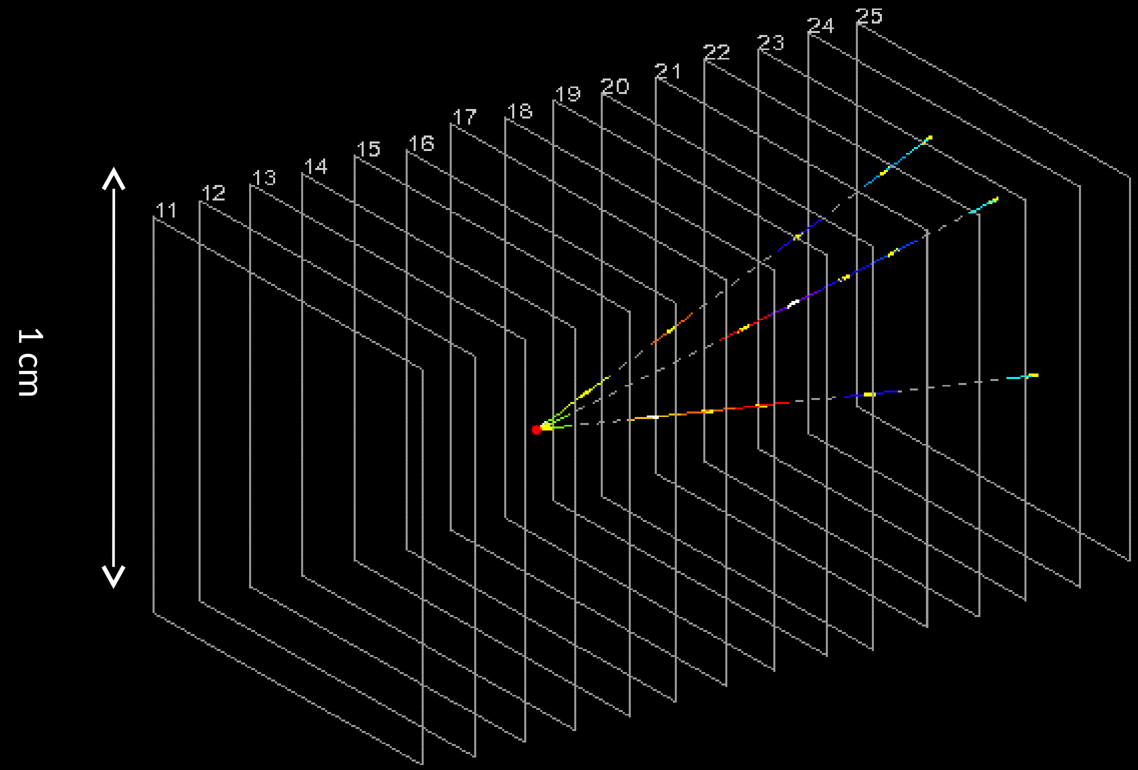
The frames correspond to the scanning area. Yellow short lines □ measured tracks.
Other colored lines □ interpolation or extrapolation.



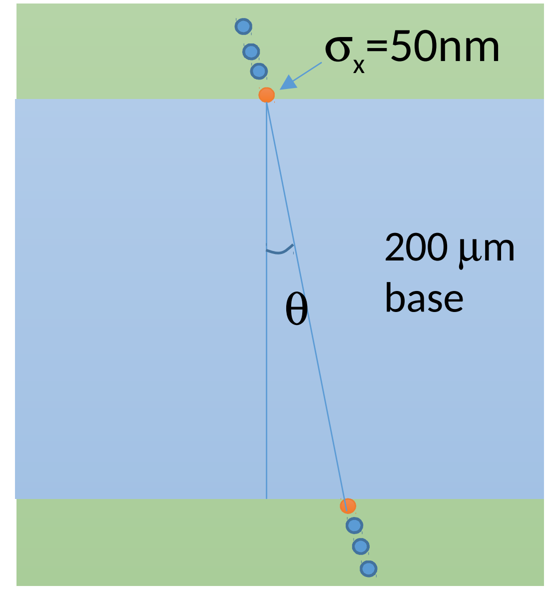
Film to film connection



LOCATED NEUTRINO INTERACTION



High precision measurement system



- Intrinsic resolution of each grain = 50nm
  - Two grains on top and bottom of 200 µm base ⇒ **350 µrad**
- Conventional systems spoil it due to mechanical vibration of Z axis (about 0.2µm, corresp. 1.5 mrad)
- ⇒ Need high precision Z-axis
- Piezo objective scanner under testing ⇒ Z axis systematics to be kept below 60 µrad
- By fitting a series of grains, the angular resolution would reach **200 µrad**

Piezo objective scanner

- Angular alignment between films to be done by using dense 400 GeV proton tracks
  - 400 GeV proton scatters 2 µrad between emulsion trackers
  - 10^5 tracks/cm^2 = 100 tracks in each microscope view