Calibration, simulation and test-beam characterisation of Timepix hybrid-pixel readout assemblies with ultra-thin sensors

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Outline

- Thin Timepix assemblies
- DESY test beam setup and infrastructure
- Test beam data-taking
  - reconstruction
  - analysis
  - results
- Simulation and reconstruction of test beam data
- Assemblies calibration
- Summary

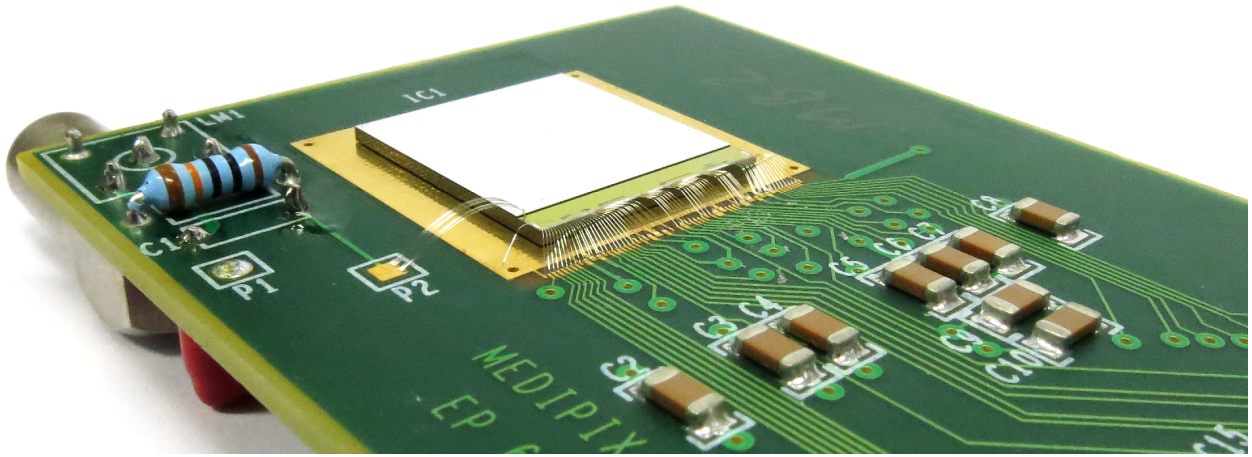
Thin sensor assemblies

Advacam

- **50 µm** thin with **20 µm and 50 µm active-edge** assemblies on standard thickness Timepix ASIC *(delivered July 2013)*
- **Excellent sensor quality**, few (<8) unconnected bumps
- Depletion at **15 V**
- *5 x assemblies tested at DESY*

Micron Semiconductor + IZM

- **100, 150, 200, 300 µm** pixel sensor (Timepix compatible)
- *3 x 100 um assemblies tested at DESY*

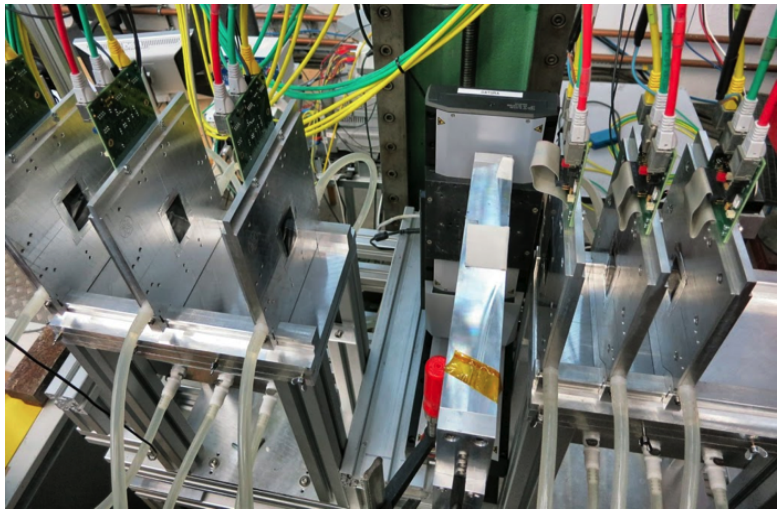


> 2 x 10^9 tracks recorded in 2013!

DESY test beam infrastructure

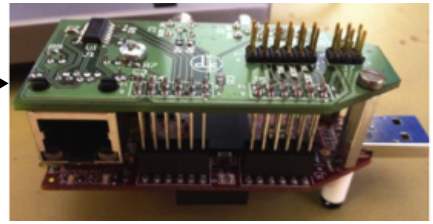
Test beam infrastructure @ DESY:

- **Electron** beam (energies **up to 6 GeV**)
- **Telescope** based on MIMOSA detectors
- **DAQ** framework provided:
- EUDAQ (software)
- Trigger Logic Unit (hardware)
- **Reconstruction** and analysis **software**
- Very good **user support**

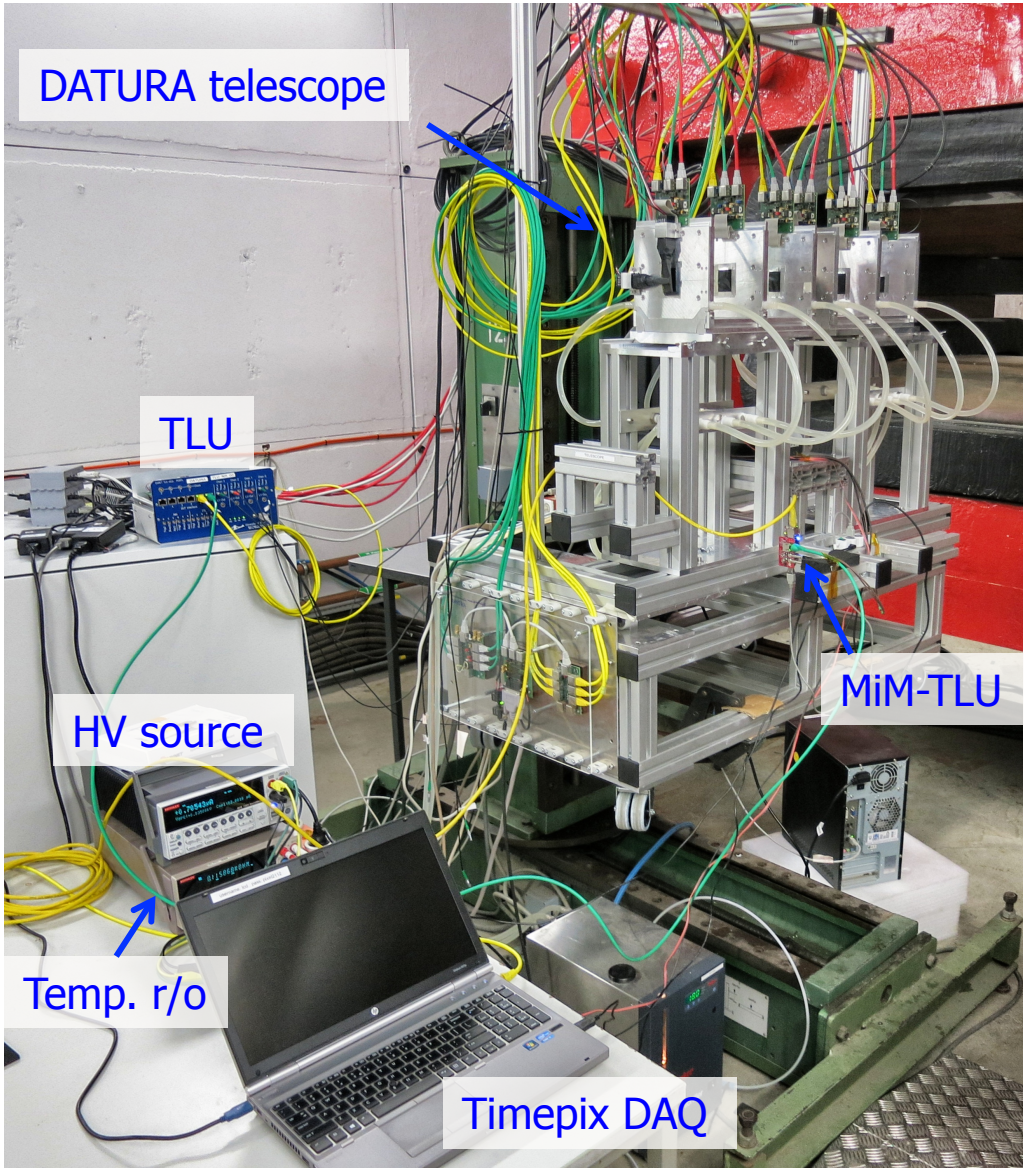


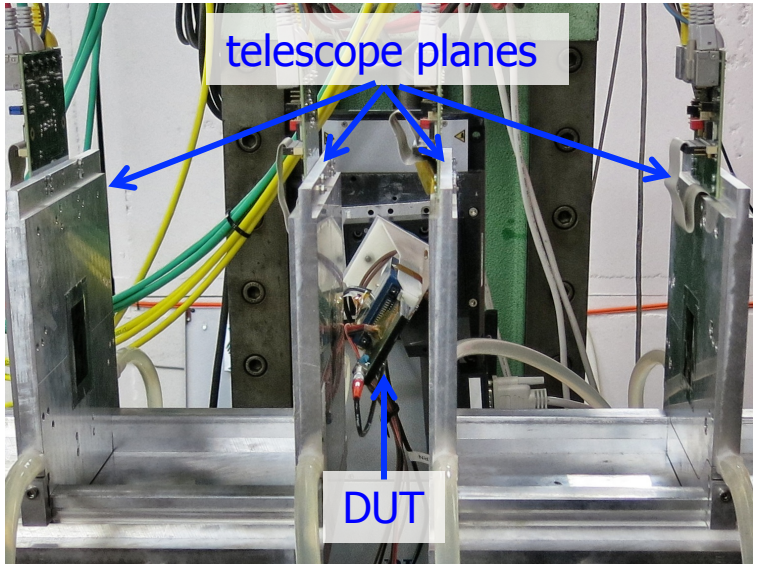
Test beam setup for thin sensor assemblies studies:

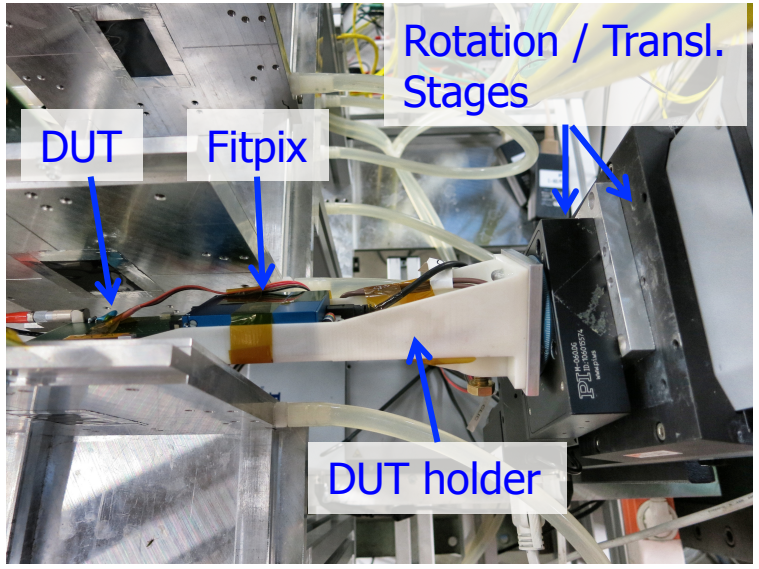
- **Optimization** of telescope **geometry** (distances between planes)
- Assemblies (Device Under Test, DUT) mounted on translational and rotational stages
- FITpix readout for Timepix
- **Man in the middle TLU** FPGA device (MIM TLU)
  - synchronization with the telescope
  - increase track rate
- Dedicated **data producer** (plug-in to EUDAQ framework)
- Extensions to the reconstruction and **analysis software**



DESY test beam setup

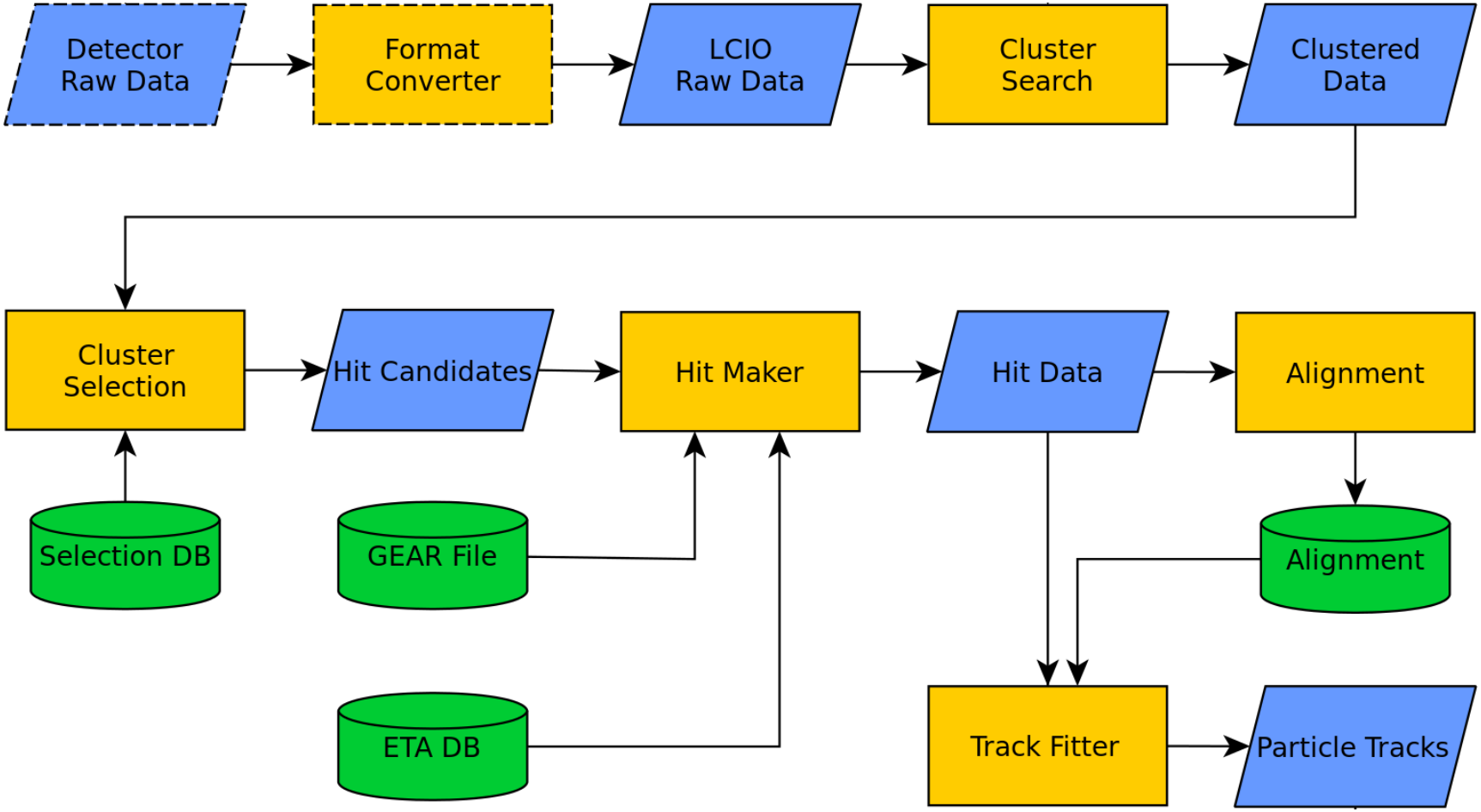






Eutelescope reconstruction framework

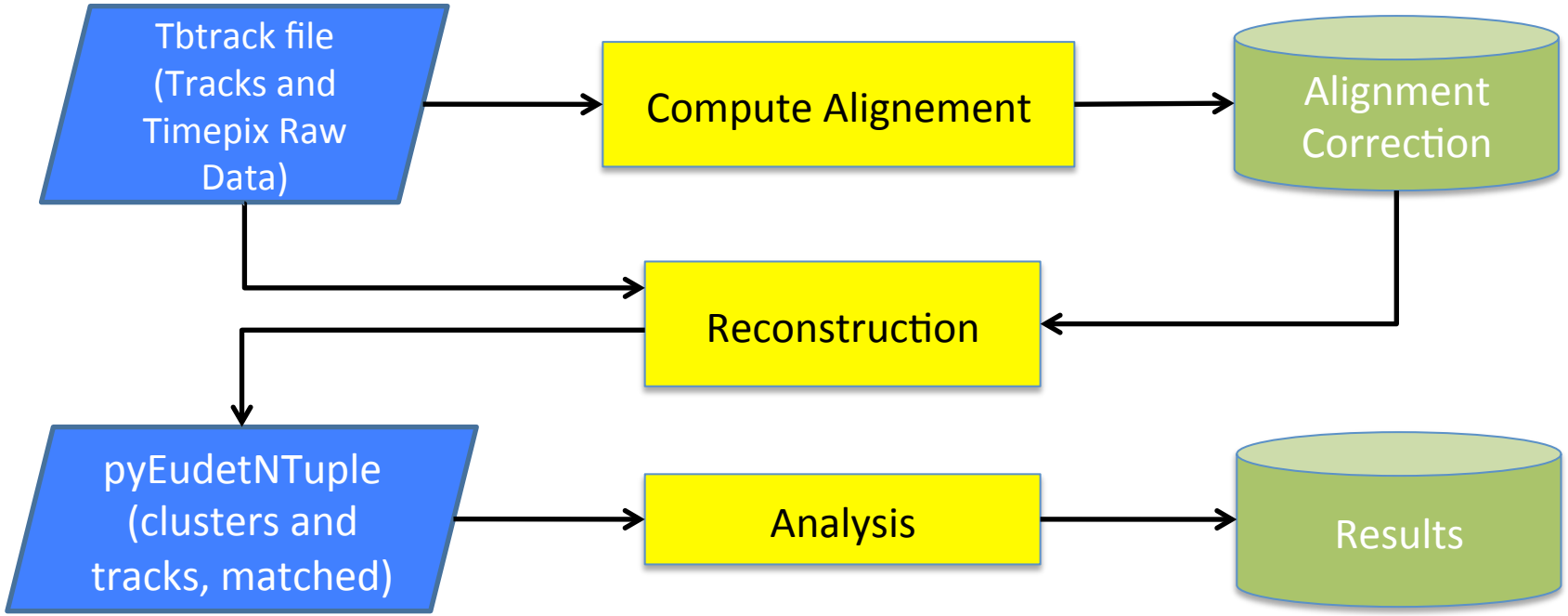
http://eutelescope.web.cern.ch/



pyEudetAnalysis framework

- Standalone test beam analysis framework developed at CERN
  - alignment of telescope and DUT planes
  - clustering
  - track-cluster matching

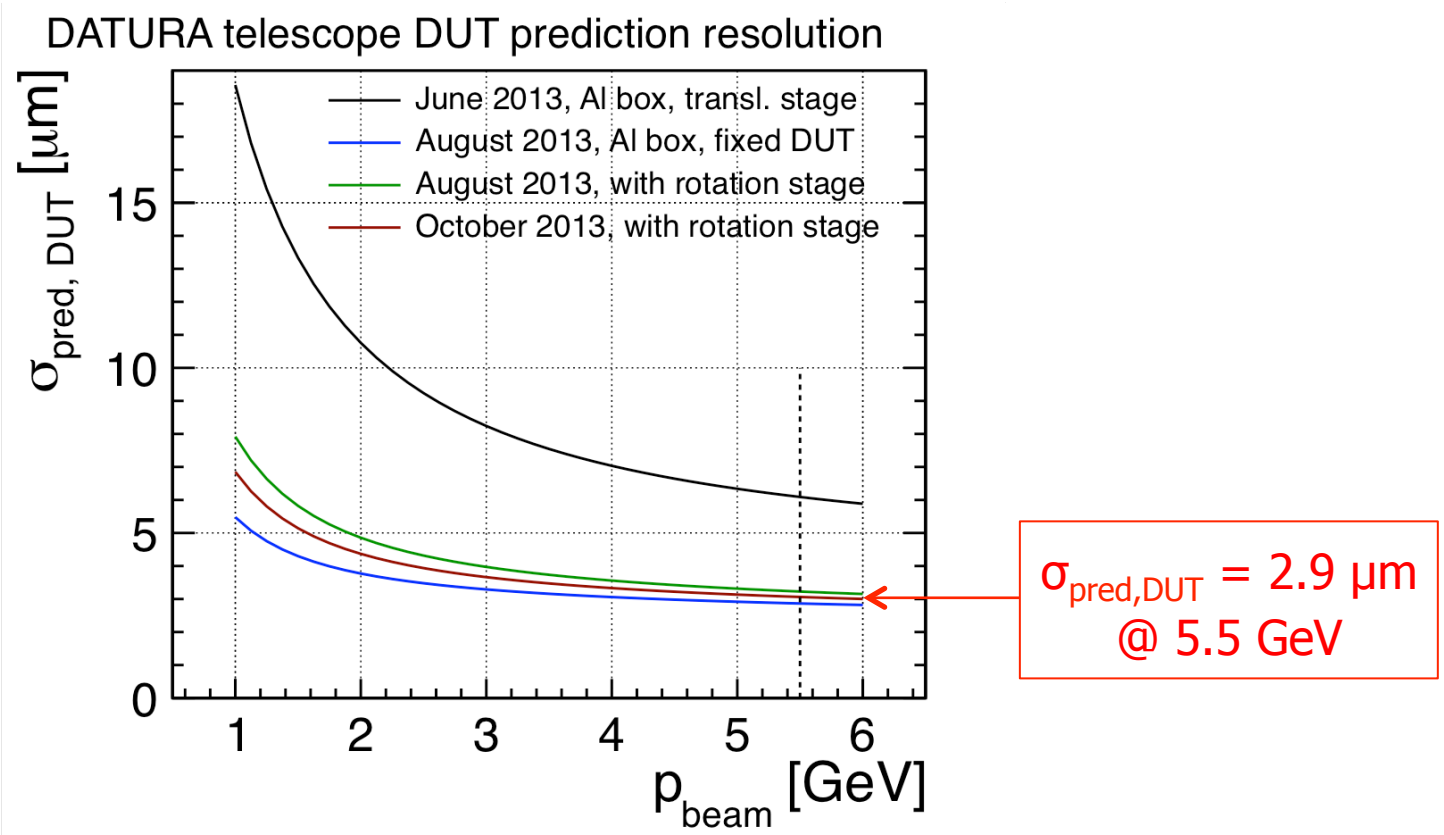
http://pyeudetanalysis.web.cern.ch/pyeudetanalysis/



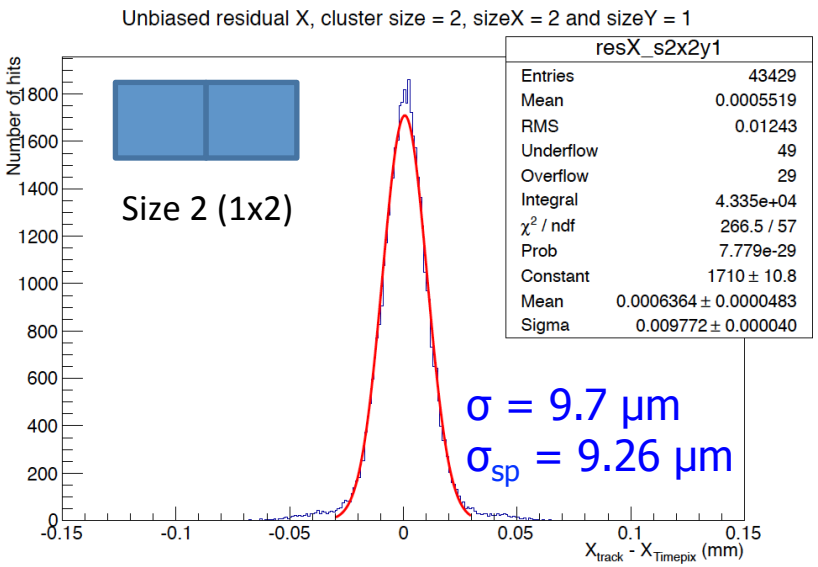
Predicted resolution

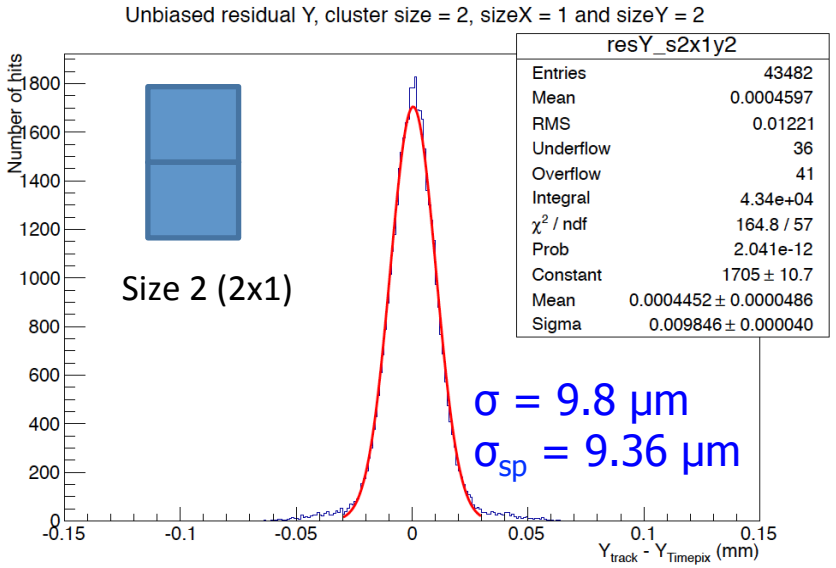
An analytical track fitting method has been implemented in order to predict tracking resolution at the DUT from basic geometrical parameters (e.g. plane positions, thicknesses, position measurement resolution, …)

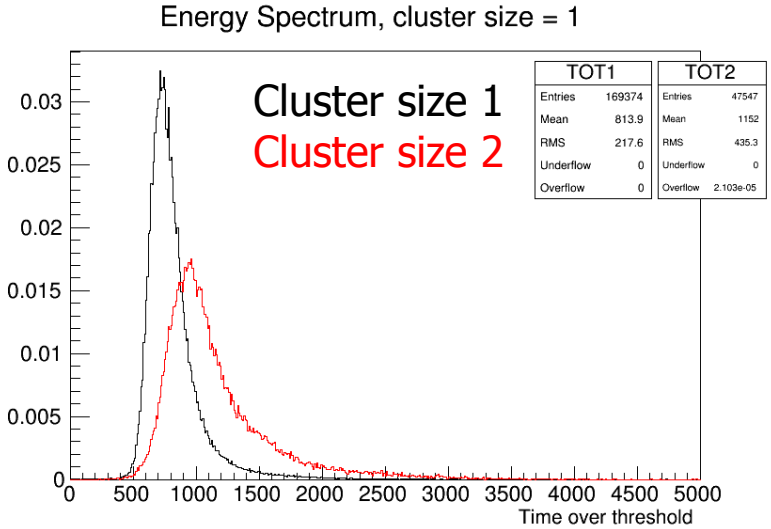
http://www.eudet.org/e26/e27/e295/eudet-report-2007-01.pdf



Test beam results





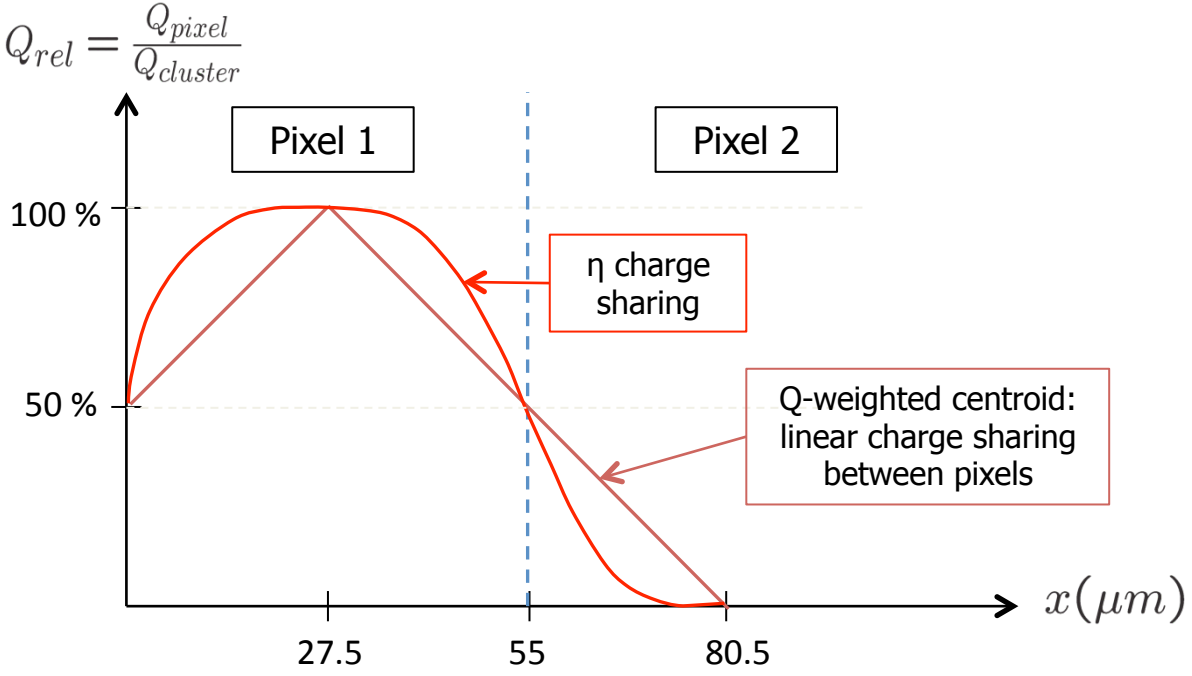


$\sigma^2 = \sigma_{tracking}^2 + \sigma_{singlepoint}^2$
with $\sigma_{tracking} = 2.9$ µm

TOT distributions for different cluster sizes are not aligned
- this is due to non-linearity of the charge amplifier
- **need to calibrate energy response of Timepix assemblies**

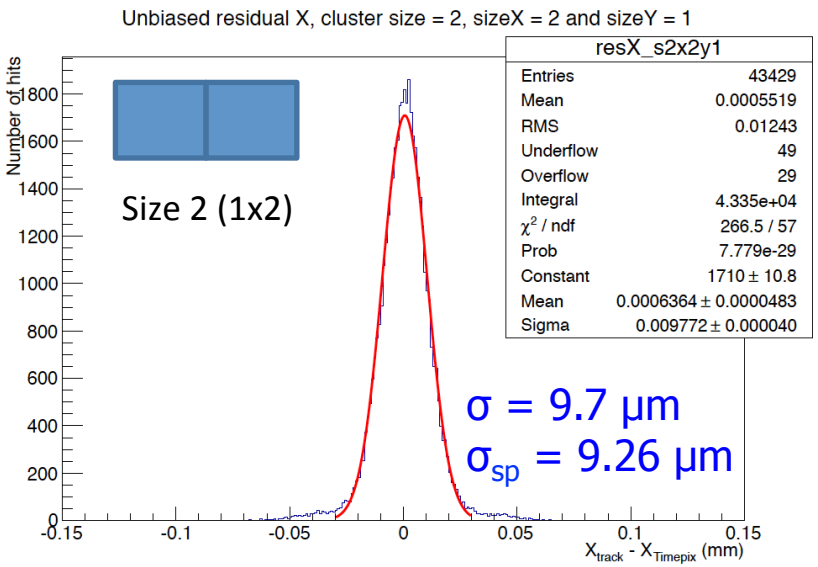
Eta correction

The η function describes the charge sharing distribution:

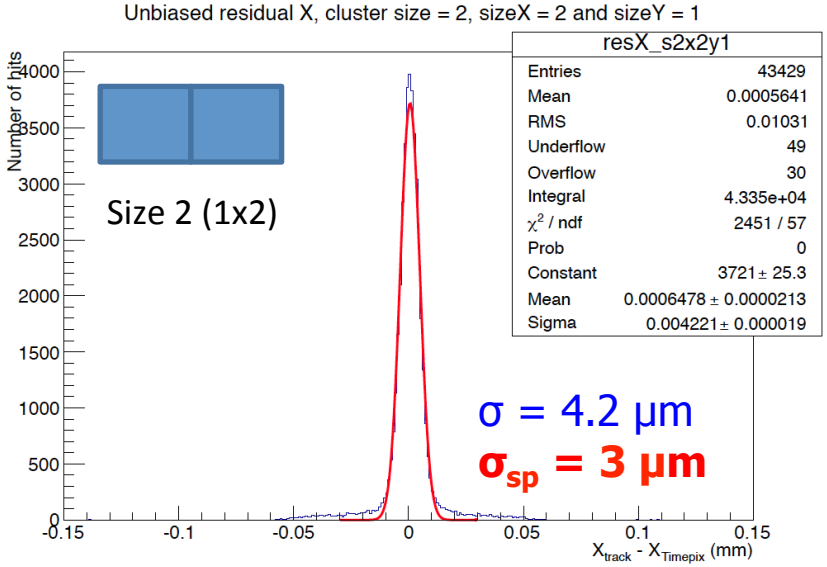


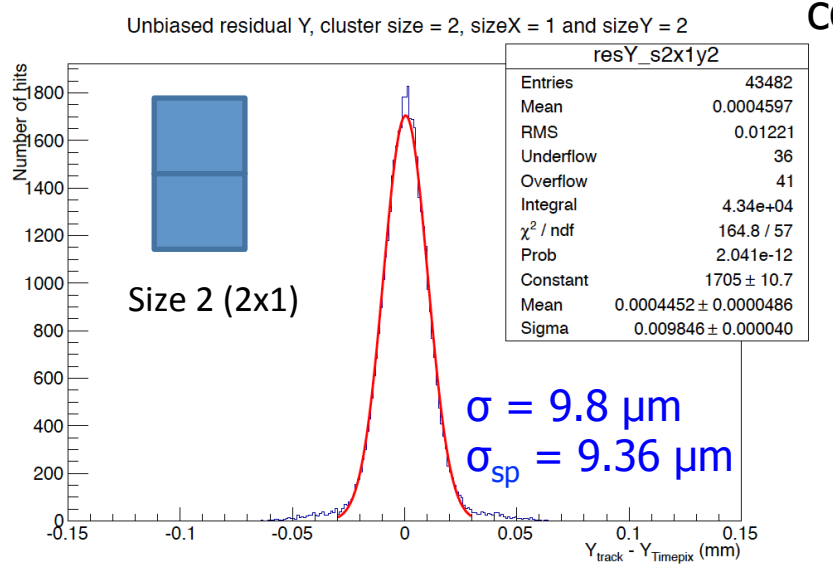
$$\begin{cases} \eta(x) = Q_{cluster} \times \frac{erf(\frac{x}{\sigma})+1}{2} & if\ x < pitchX/2 \\ \eta(x) = Q_{cluster} \times \frac{erf(\frac{pitchX-x}{\sigma})+1}{2} & if\ x > pitchX/2 \end{cases}$$

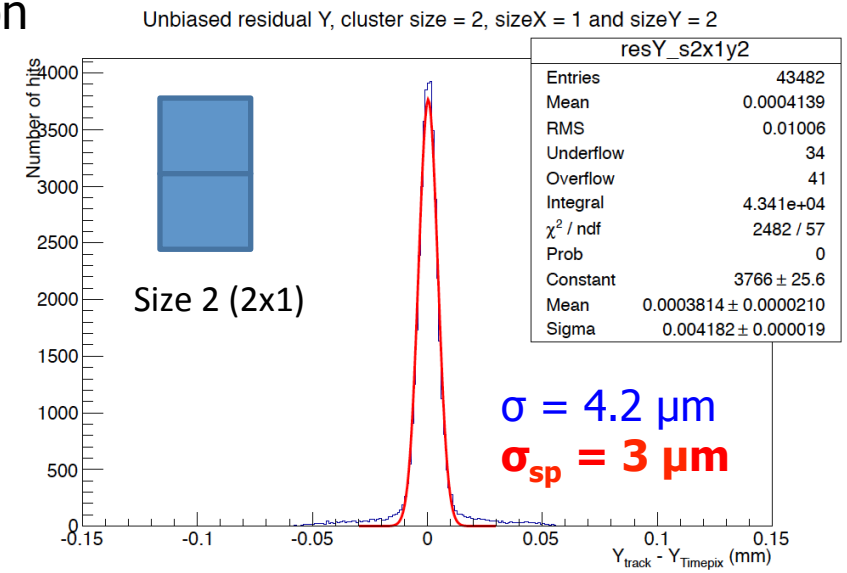
Impact of Eta correction



Eta correction

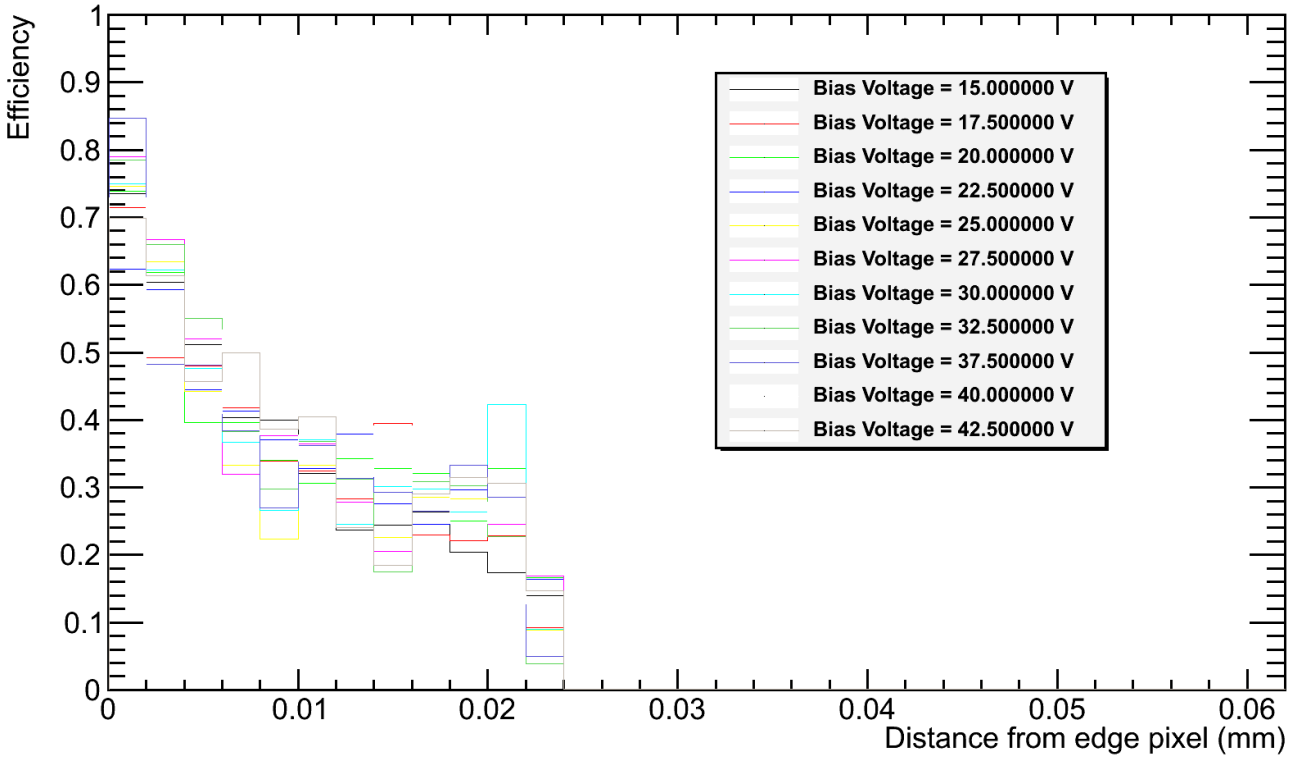


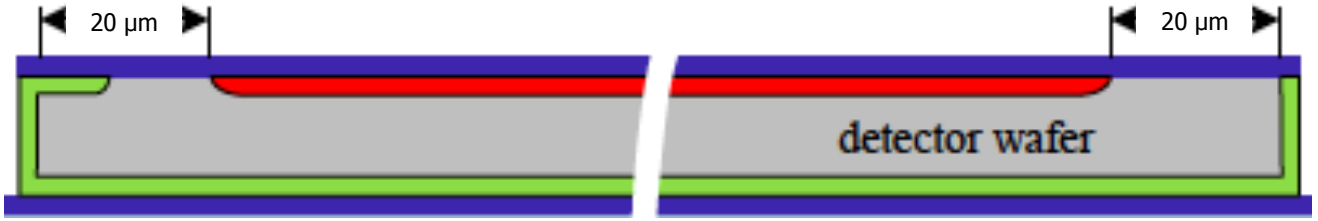




Edge efficiency

Advacam p-in-n 50µm thin Timepix Assembly, 20µm edges, leakage ~100nA@15V



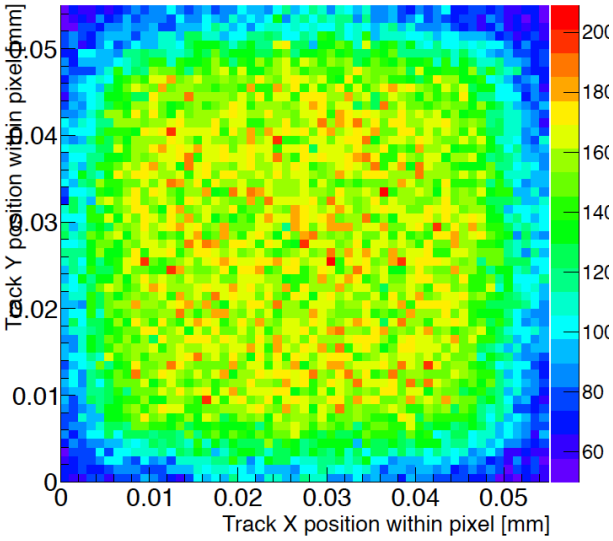


Track position inside pixel

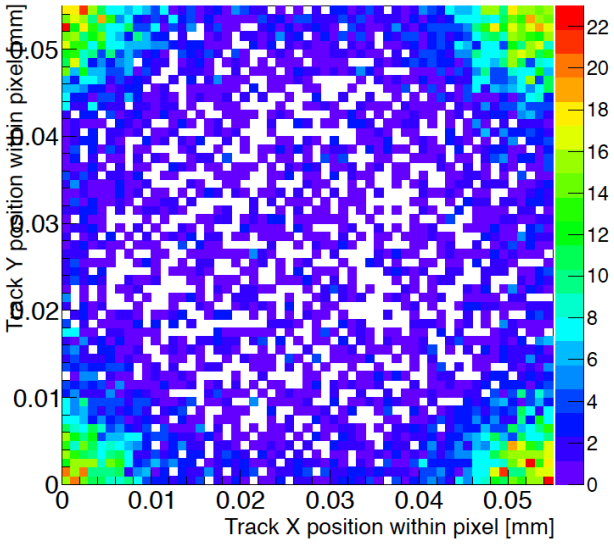
Size 1 (1x1)

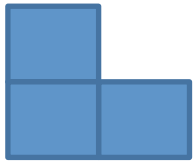
75%

Hit probability, cluster size 1



Hit probability, cluster size 3





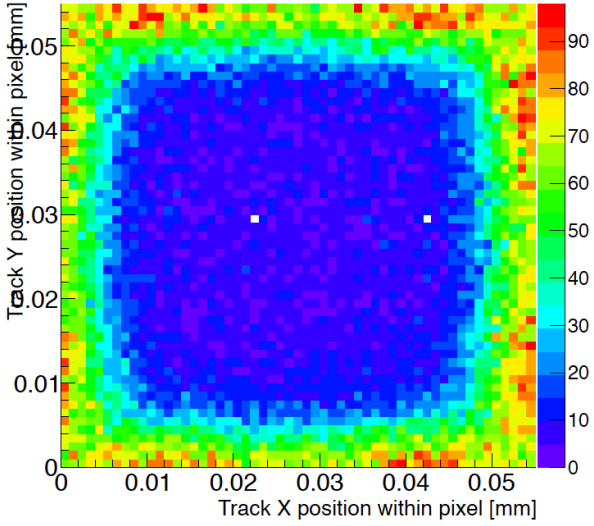
Size 3 (2x2)

2%

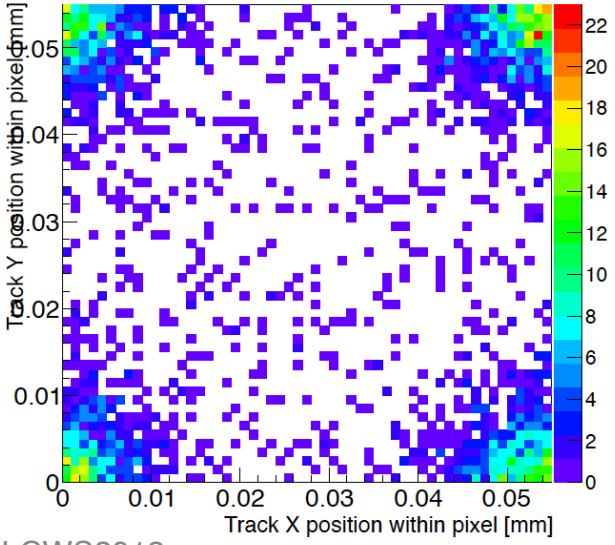
Size 2
(2x1+1x2)

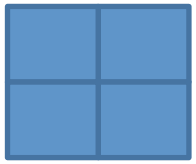
20%

Hit probability, cluster size 2



Hit probability, cluster size 4



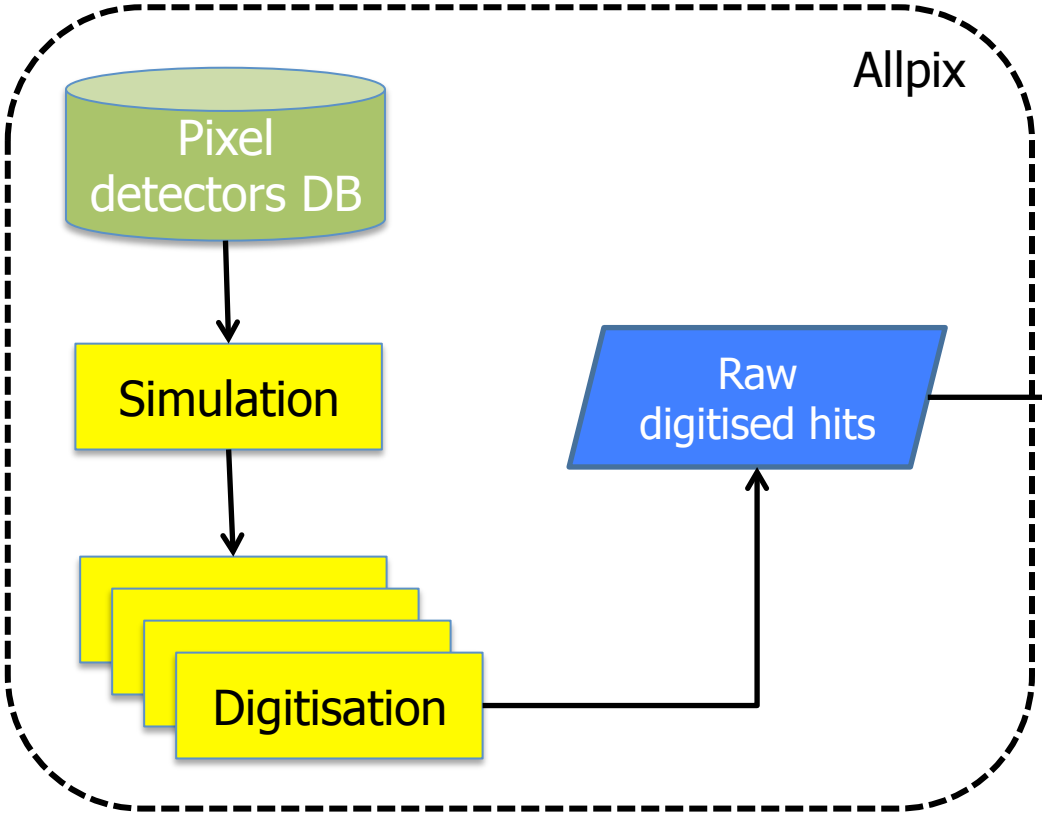


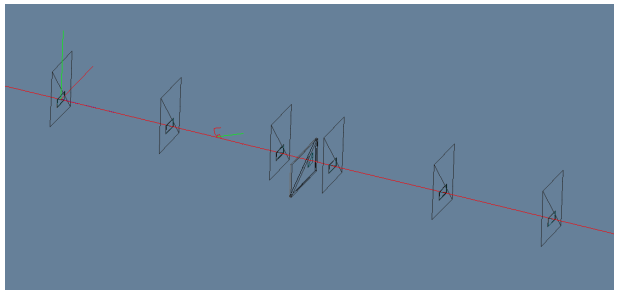
Size 4 (2x2)

0.5%

Allpix simulation

General purpose pixel detector simulation and digitisation framework
https://twiki.cern.ch/twiki/bin/view/Main/AllPix





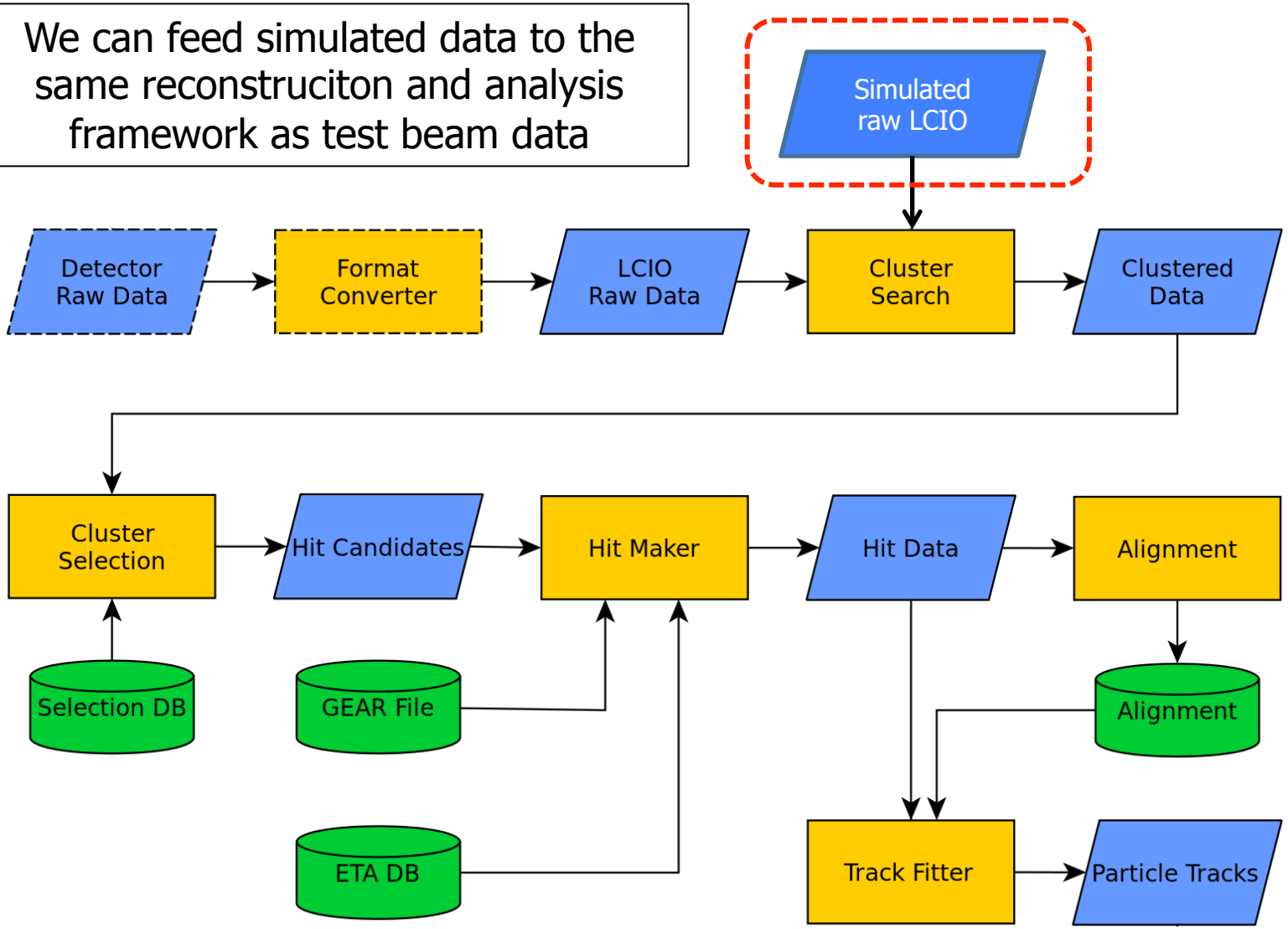
pyLCIO converter

LCIO Raw digitised hits

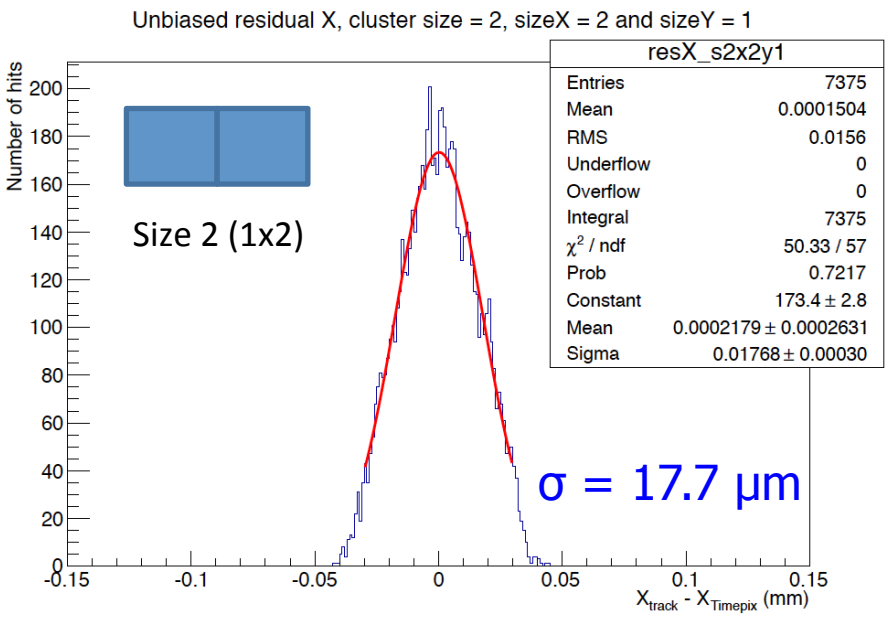
Eutelescope

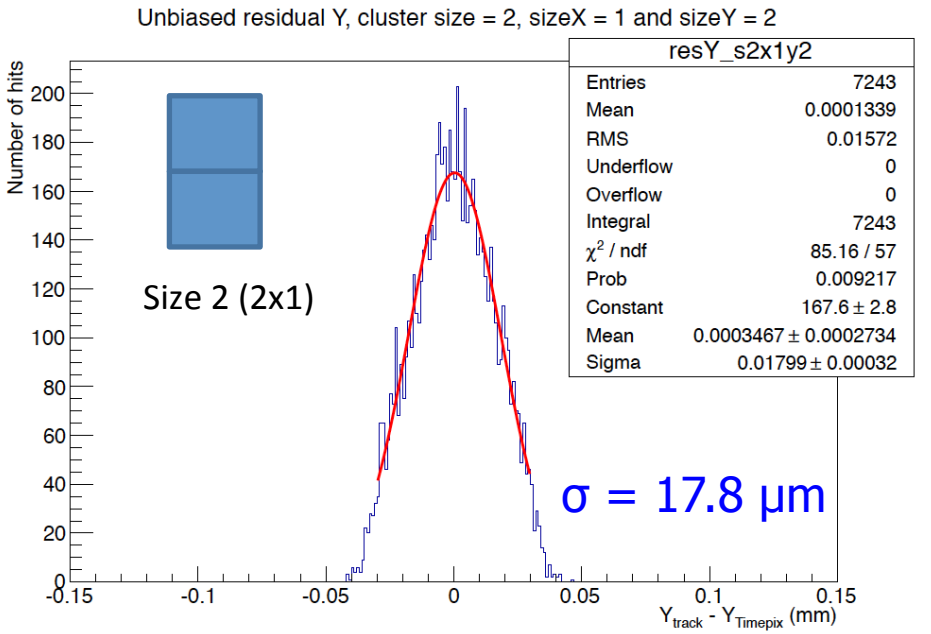
From simulation to reconstruction

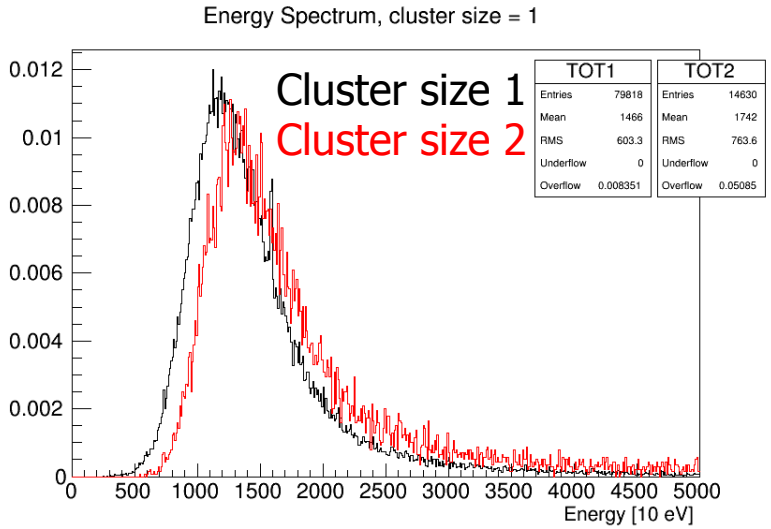
We can feed simulated data to the same reconstruciton and analysis framework as test beam data



Results from simulation



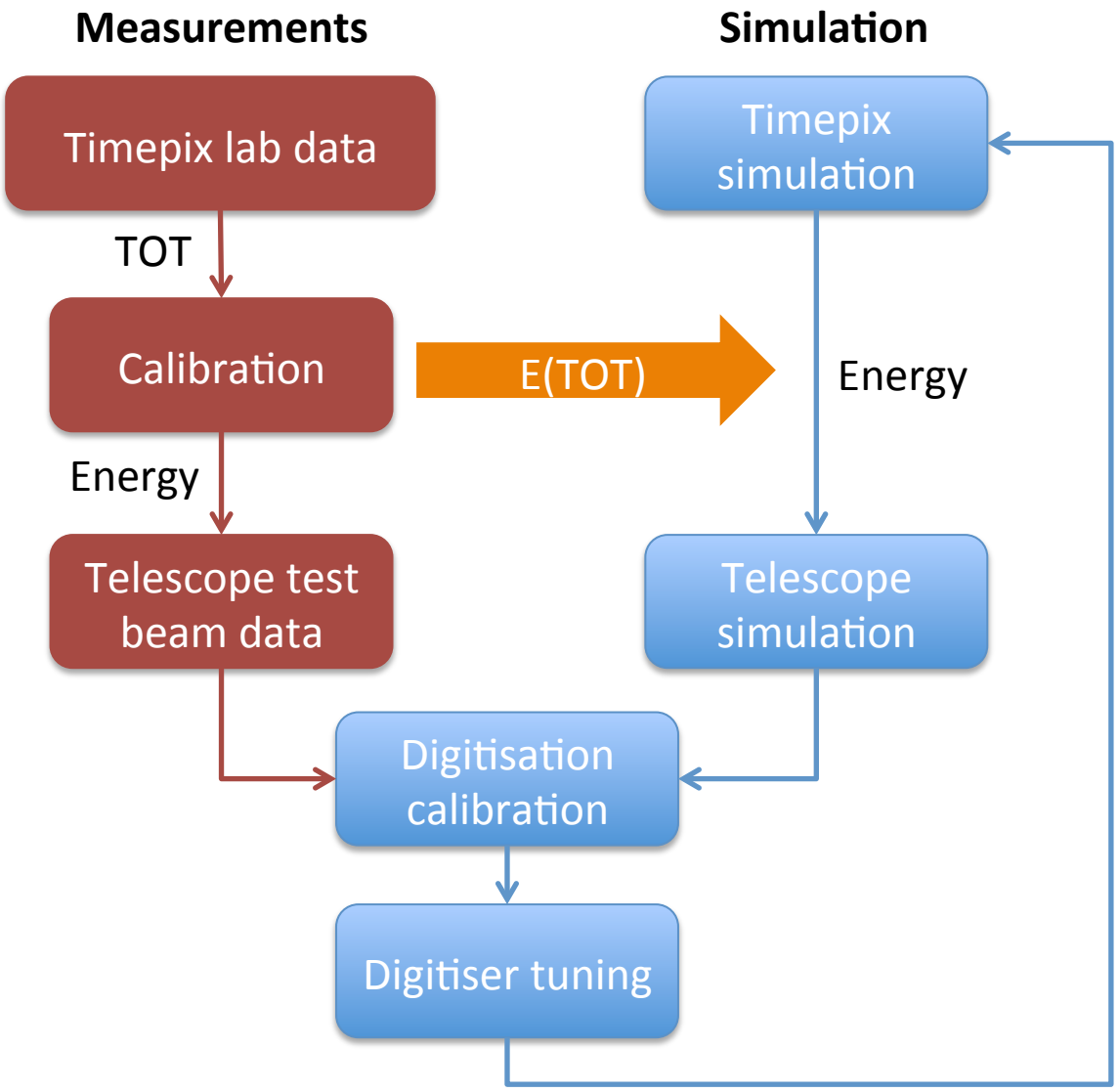




Before comparing with test beam data:

- tune digitisation parameters
- introduce E(TOT) dependence from assemblies calibration into digitisation

Calibration and simulation tuning



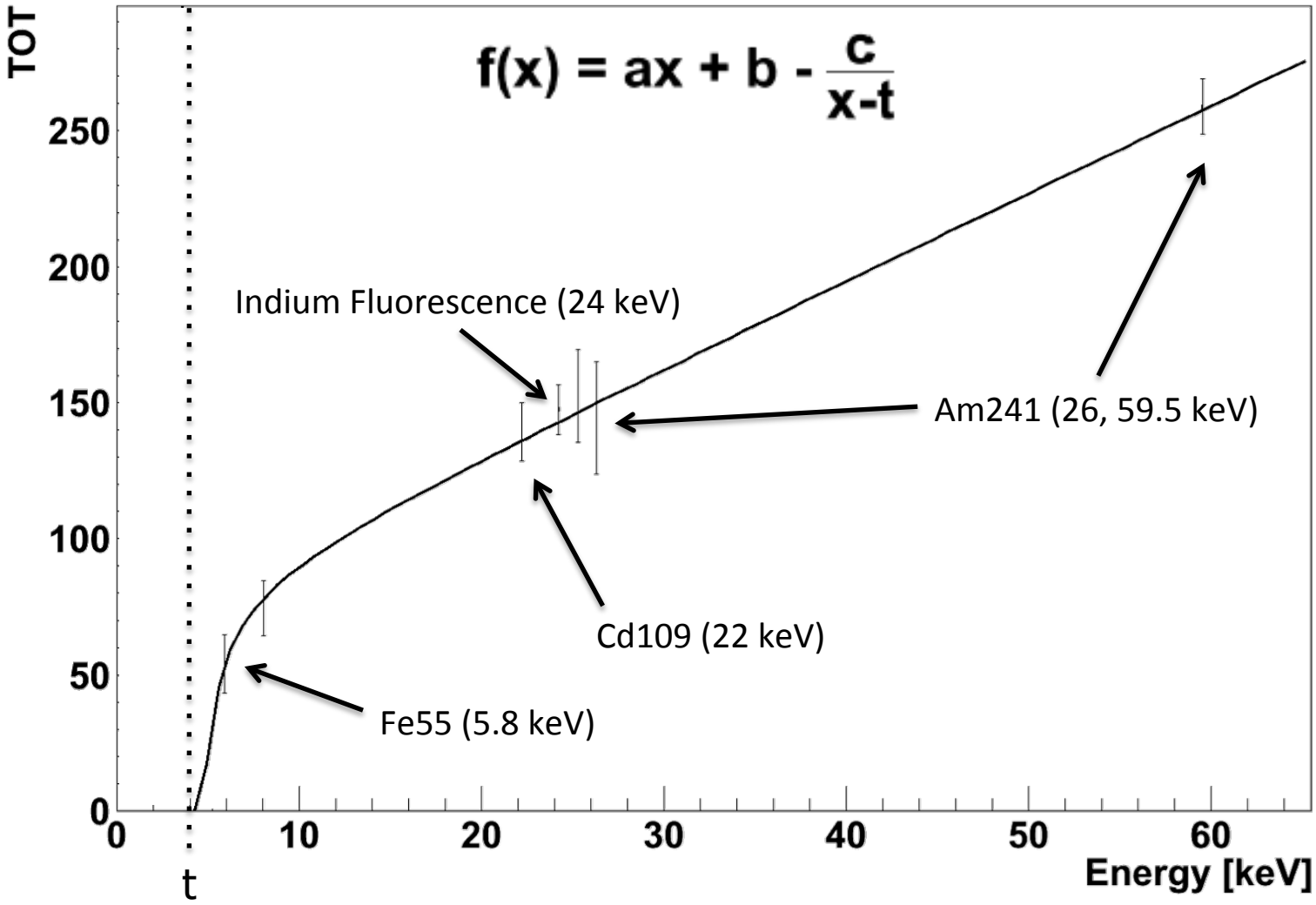
Timepix calibration and digitisation tuning

Calibration of Pixel detector plays an important role for:

- Tuning of digitization model
  - **E vs. TOT relation is non-linear**
  - Simulation output is in Energy (Geant4 deposits)
- Optimise tracking resolution
  - Energy weighting improves reconstruction of hit position in multi-pixel clusters
- Calibration method procedure:
  - **Acquire TOT spectra** for each pixel with reference energy deposits (e.g. radioactive sources, fluorescences)
  - **Determine peak TOT** for each energy and pixel
  - **Fit the preamplifier characteristic response** function to data (4 parameters)
  - Use fitted parameters **to translate TOT to energy**, pixel-by-pixel

Timepix calibration and digitisation tuning

Experimental TOT(E) for one pixel, i.e. « Surrogate function »



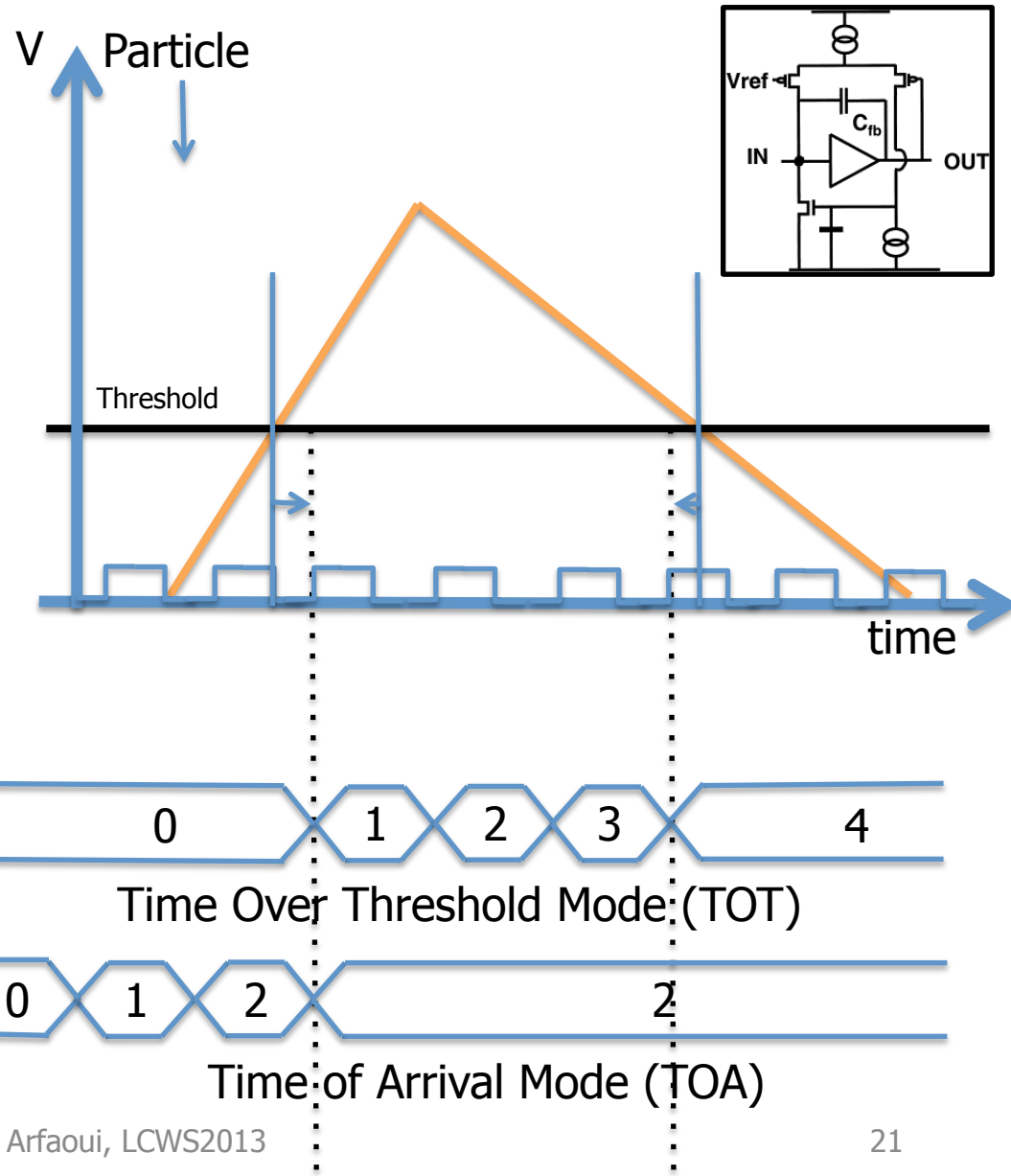
Summary

Characterisation of ultra-thin hybrid pixel sensor assemblies is performed using **three handles**:

- **Test beam data-taking**
  - DATURA Telescope for tracking
  - Eutelescope & pyEudetAnalyis frameworks for reconstruction
  - With Eta correction, single point resolutions of the order of **3µm** are achievable
- **Simulation**
  - Allpix standalone general purpose framework
  - Can do through same reconstruction framework as test beam data
- **Detector calibration**
  - Determine energy response of assemblies in the lab
  - Crucial for digitisation and data-MC comparisons

The Timepix Readout Chip

Timepix	MIMOSA26
Hybrid Pixel Sensor • 256x256 55x55um^2 pixel • 14.08x14.08mm^2 active surface • 11810 count TOA or TOT measurement up to 96MHz • Shutter based, readout rate (FITPIX) ~50Hz	MAPS • 576x1172 18.3x18.5um^2 pixel • 10.54x21.447 mm^2 active surface • Binary Measurement • Rolling shutter readout scheme • Readout time ~115.2us • Realistic readout rate ~(1-2KHz)



96 MHz Clock
- 10.41ns timestamp
- Maximum 230 us shutter