

INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS



06 - 10 OCTOBER '14

INN VINCA

BELGRADE

SERBIA

EUROPE

EARTH

ПЦБС14
LGWS14

B E L G I E

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



Sophie Redford on behalf of the CLICdp collaboration



CLIC vertex detector requirements

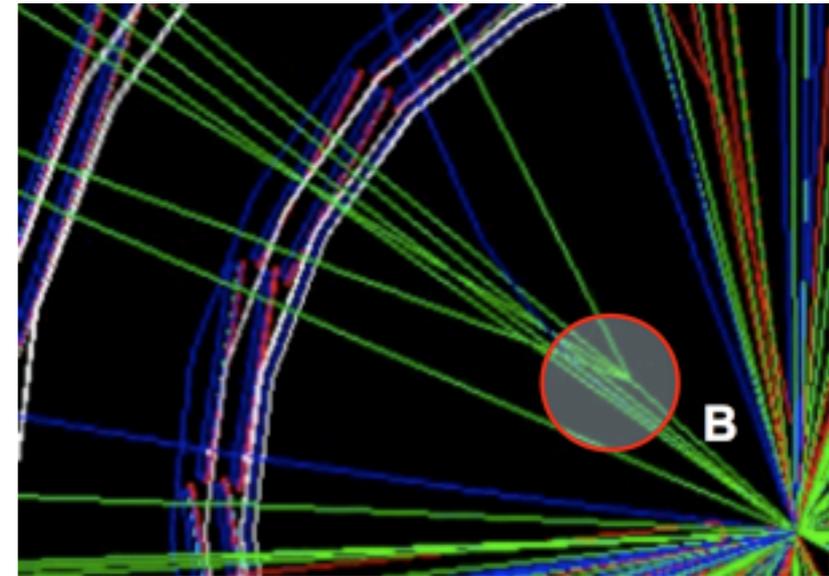
Goal

Efficient tagging of heavy quarks through a precise determination of displaced vertices



Multi-layer barrel and endcap pixel detectors

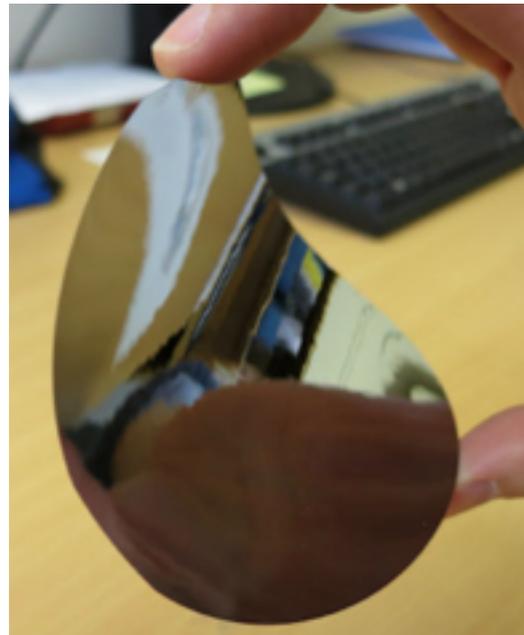
- ▶ 560 mm in length
- ▶ Barrel radius from 30 mm to ~70 mm



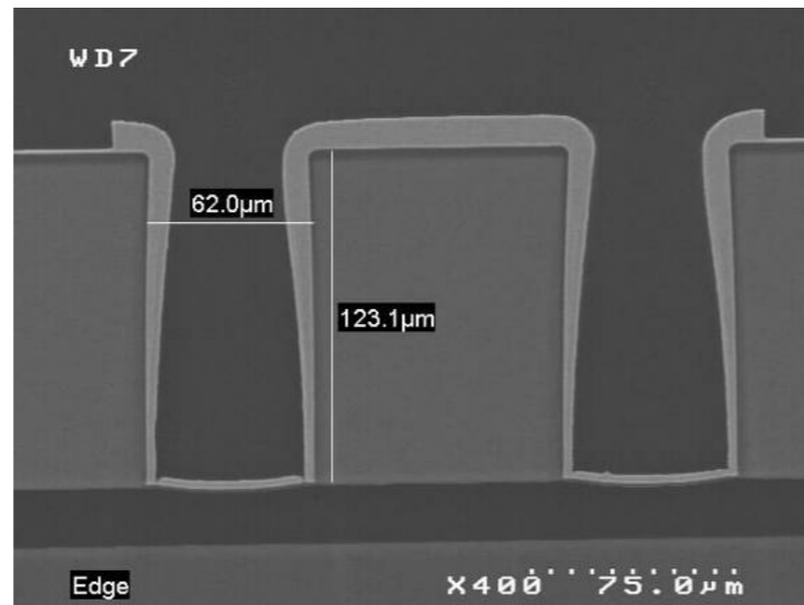
- Single point resolution of 3 μm
- Material budget of $< 0.2\%$ of a radiation length per layer
- No active cooling elements - use forced air flow cooling
- Limit the power dissipation to 50 mW/cm^2 in sensor area
- Hit time slicing of 10 ns

Sensor assembly R&D

- Hybrid planar pixel technology: sensor + read out chip
- Ultimate goal: 50 μm sensor on 50 μm ASIC with 25 μm pitch
- Thin edge sensors using Through-Silicon-Vias



50 μm thick silicon wafer



TSV with Cu liner cross section



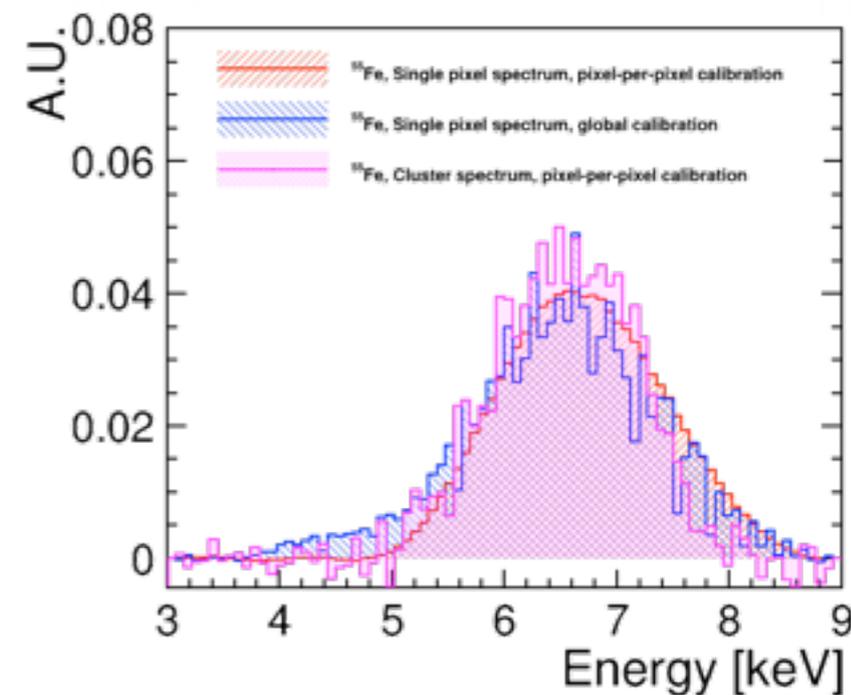
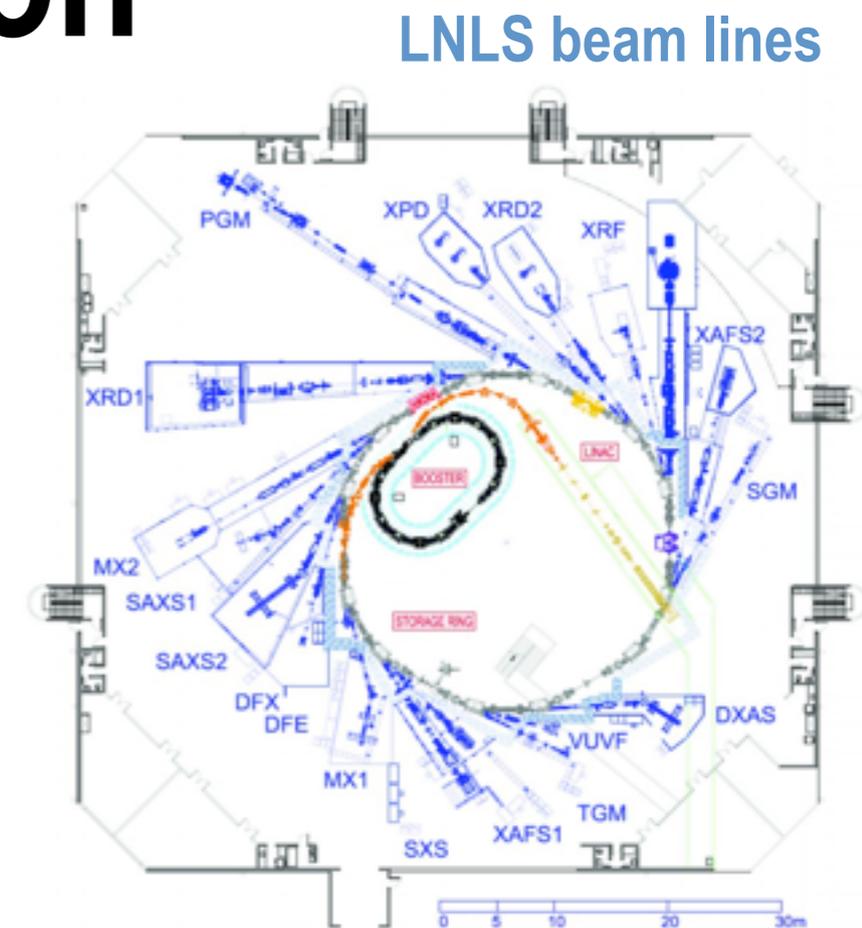
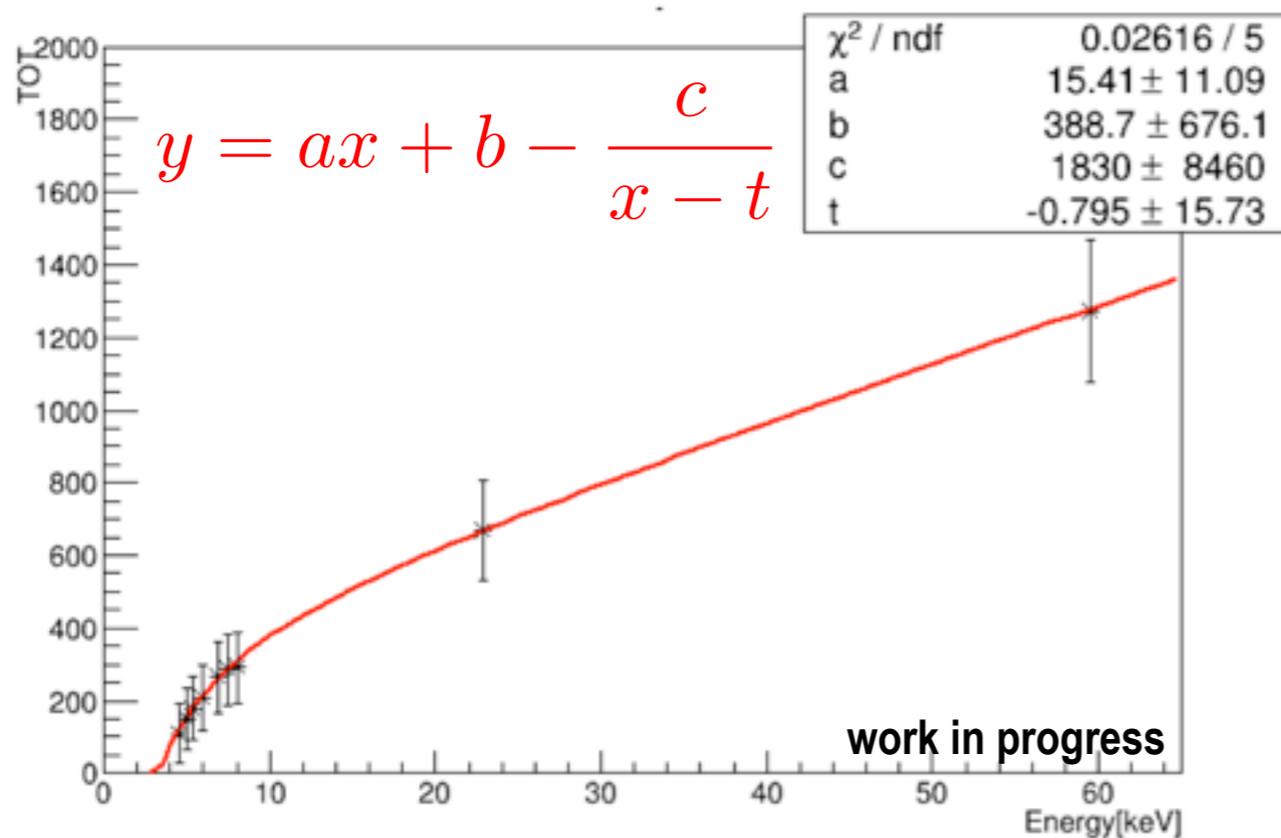
First Medipix3 image using TSV

Using the Medipix/Timepix family of read out chips:

- Timepix: DESY test beam 2013, lab tests CERN, LNLS
- Timepix3: CERN PS test beam 2014
- CLICpix: CCPDv3 (capacitive coupling) in CERN PS test beam 2014, future bump-bonding trials at SLAC

Sensor calibration

- Calibrate TOT values by measuring response to photons of known energy
- Fit accounts for non-linearities in response
- Extra data points from LNLB added since LCWS13



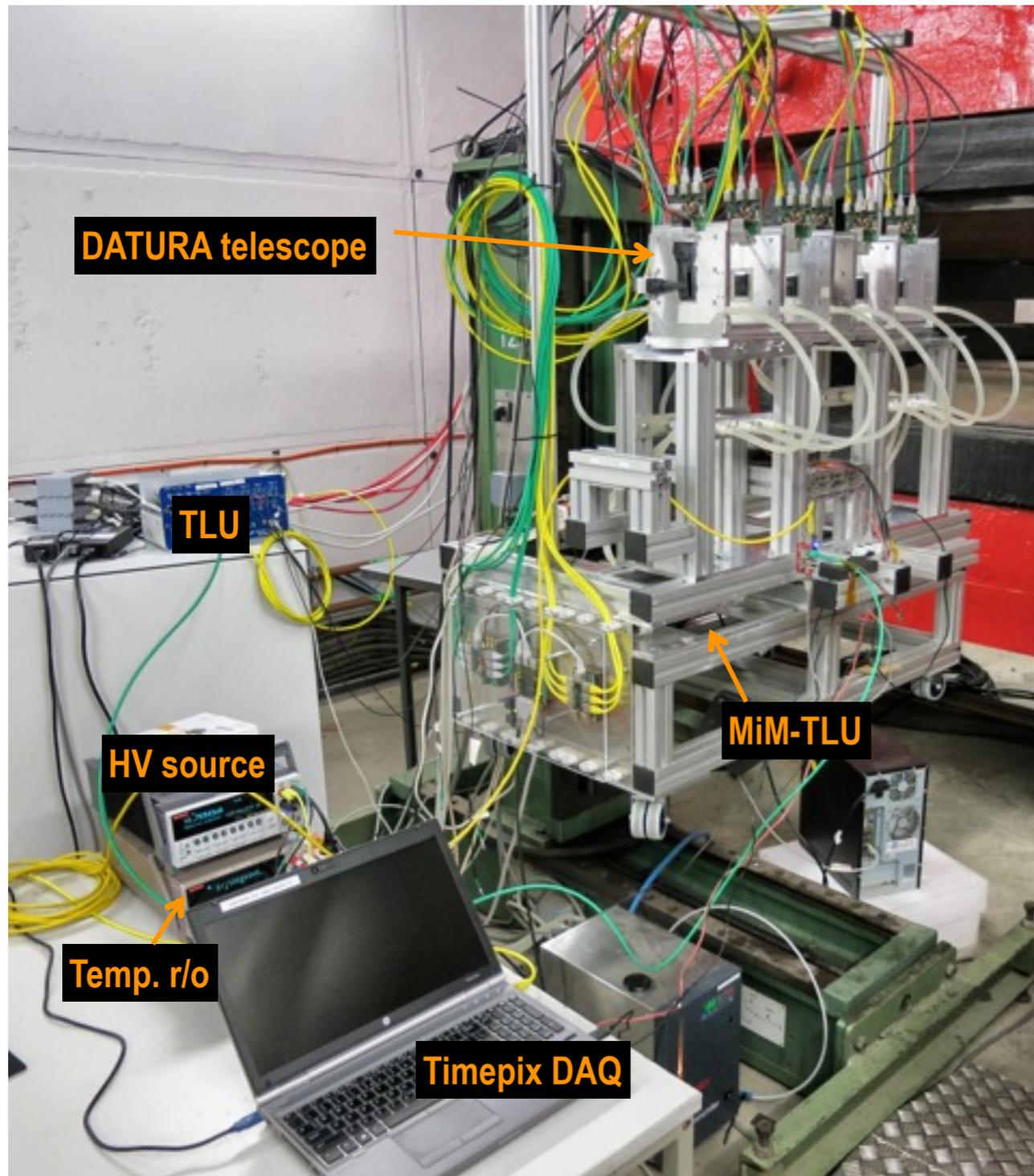
Target/Source	^{55}Fe	Brass	^{09}Cd	Indium	^{241}Am	^{241}Am
E (α) in keV	5.8	8.1	22.9	24	26.2	60

CERN

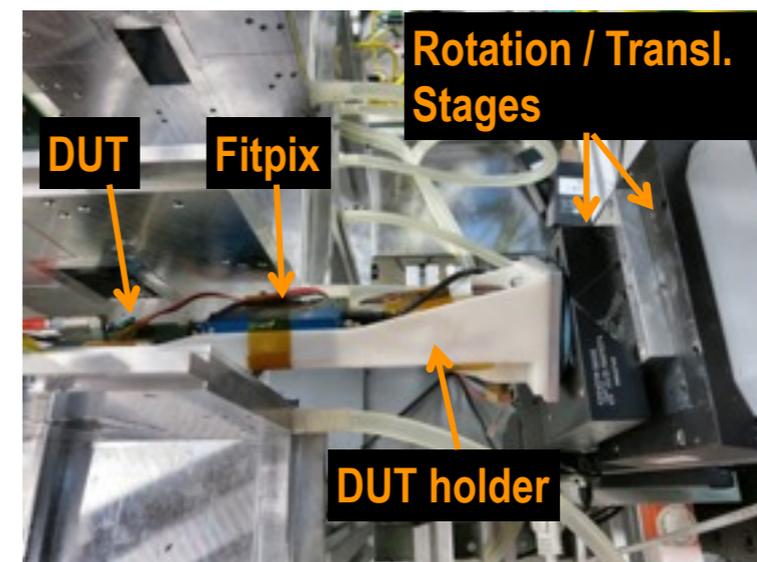
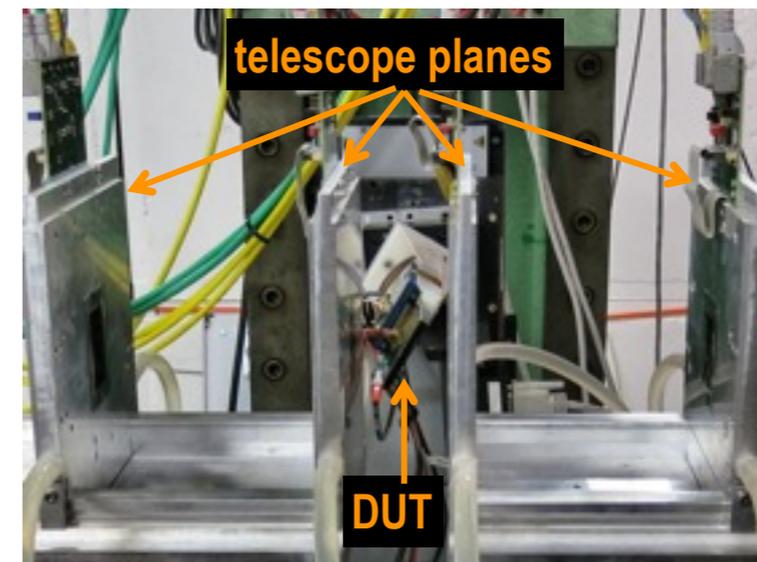
Target	Co	Cr	Cu	Fe	Mn	Ni	Ti	V	Zn
E (α) in keV	4.51	4.95	5.414	5.89	6.4	6.93	7.47	8.04	8.63

LNLB

DESY test beam and EUDET telescope



5.6 GeV electron beam

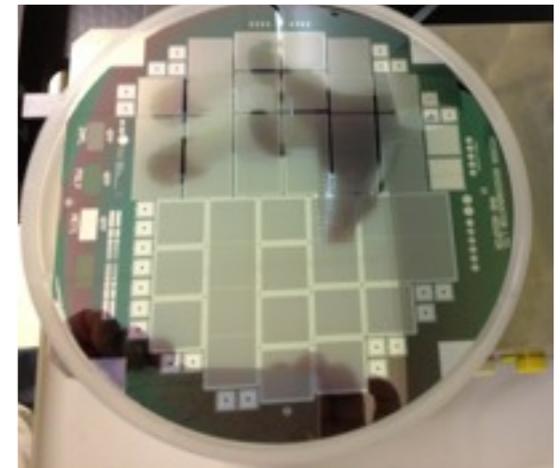


Test beam data

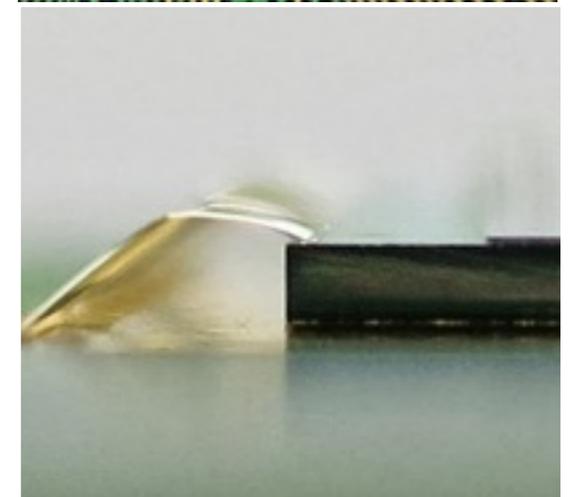
- 7 weeks of test beam at DESY between Feb 2013 and Feb 2014
- Data recorded with 17 different sensors:

Assembly	Sensor producer	Sensor thickness [um]	Sensor type	Sensor edge design	ASIC thickness [um]
B04-W0110	Advacam	50	p-in-n	50 um active	750
A06-W0110	Advacam	50	p-in-n	20 um active	750
C04-W0110	Advacam	50	p-in-n	50 um active	750
C06-W0110	Advacam	50	p-in-n	20 um active	750
J09-W0110	Advacam	50	p-in-n	50 um active	750
C06-W0126	Micron	100	p-in-n		100
D05-W0126	Micron	100	p-in-n		100
D09-W0126	Micron	100	p-in-n		100
L04-W0125	Micron	100	p-in-n		750
L05-W0125	Micron	100	p-in-n		750
D04-W0125	Micron	150	n-in-p		750
D05-W0125	Micron	150	n-in-p		750
D08-W0125	Micron	150	n-in-p		750
B06-W0125	Micron	200	n-in-p		750
<i>B07-W0125</i>	<i>Micron</i>	<i>300</i>	<i>p-in-n</i>		<i>750</i>
I10-W0015	Canberra	300	p-in-n		750
D03-W0170	Canberra	500	p-in-n		750

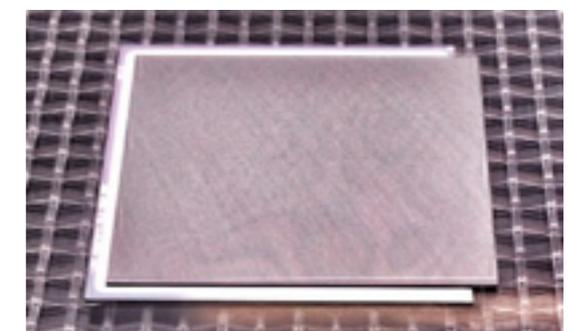
~175M events recorded



200 um thick Sensor wafer



50um Sensor on 750um ASIC functional Timepix assembly

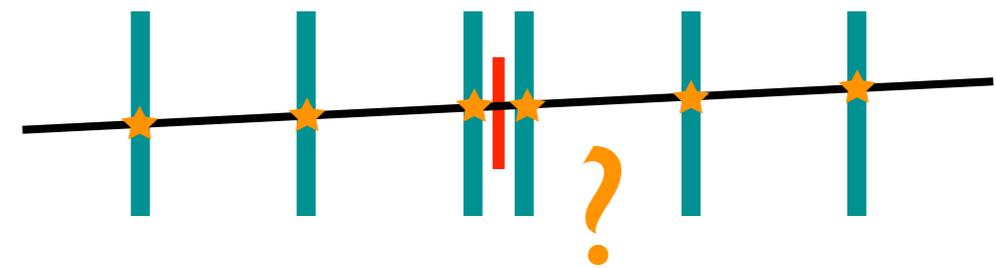
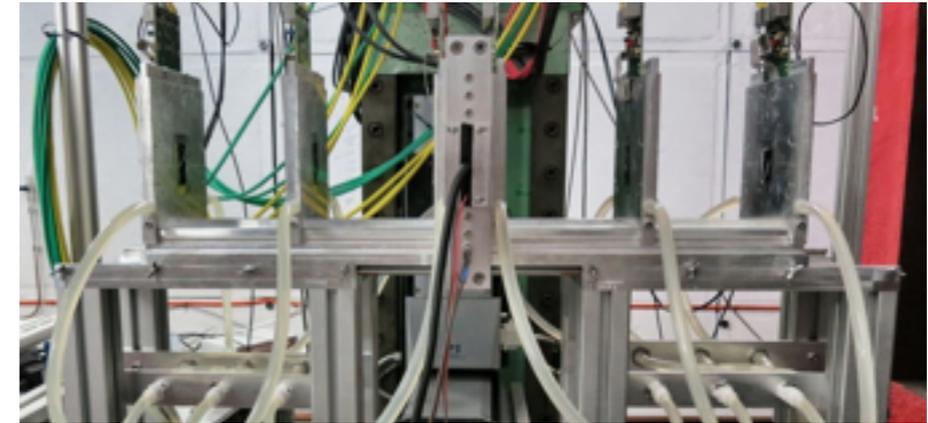
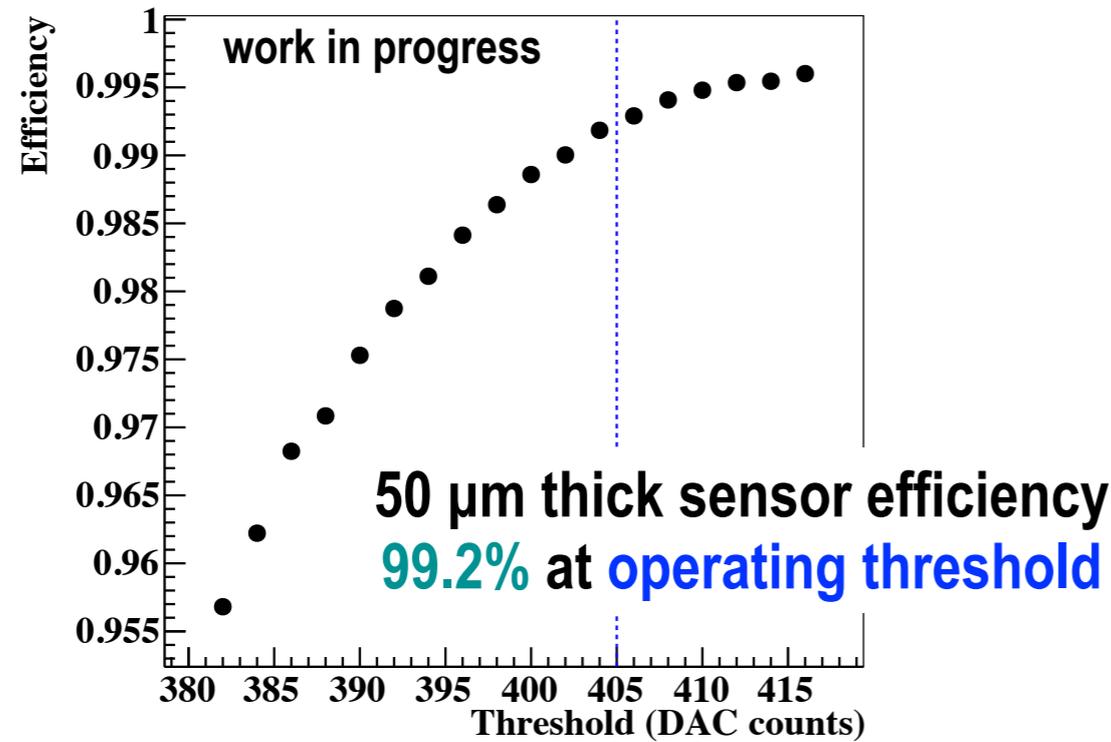


100um ASIC -on-100um Sensor functional Timepix assembly

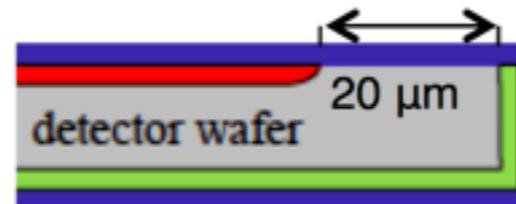
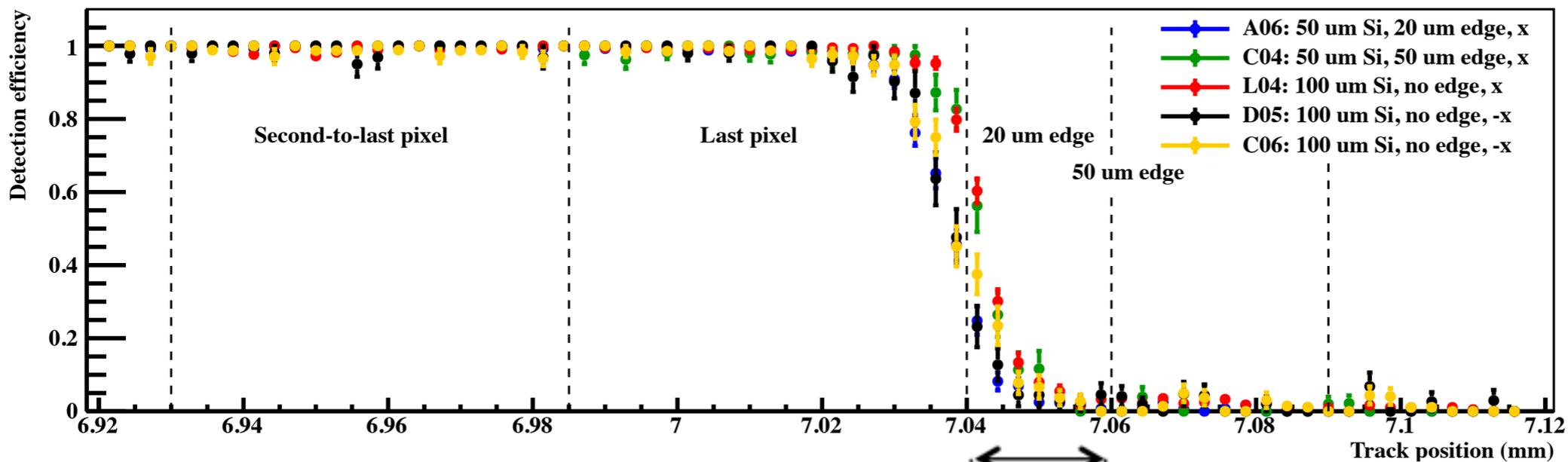
- Characterise thin sensor assemblies with 55 um pixels
- Validate simulation and extrapolate to 25 um pixels

Detection efficiency

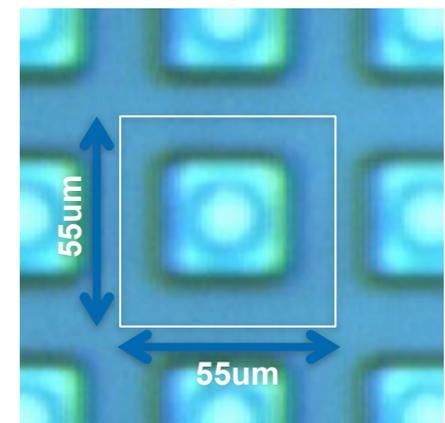
- Is a hit detected where we expect from using the telescope to extrapolate track to DUT?



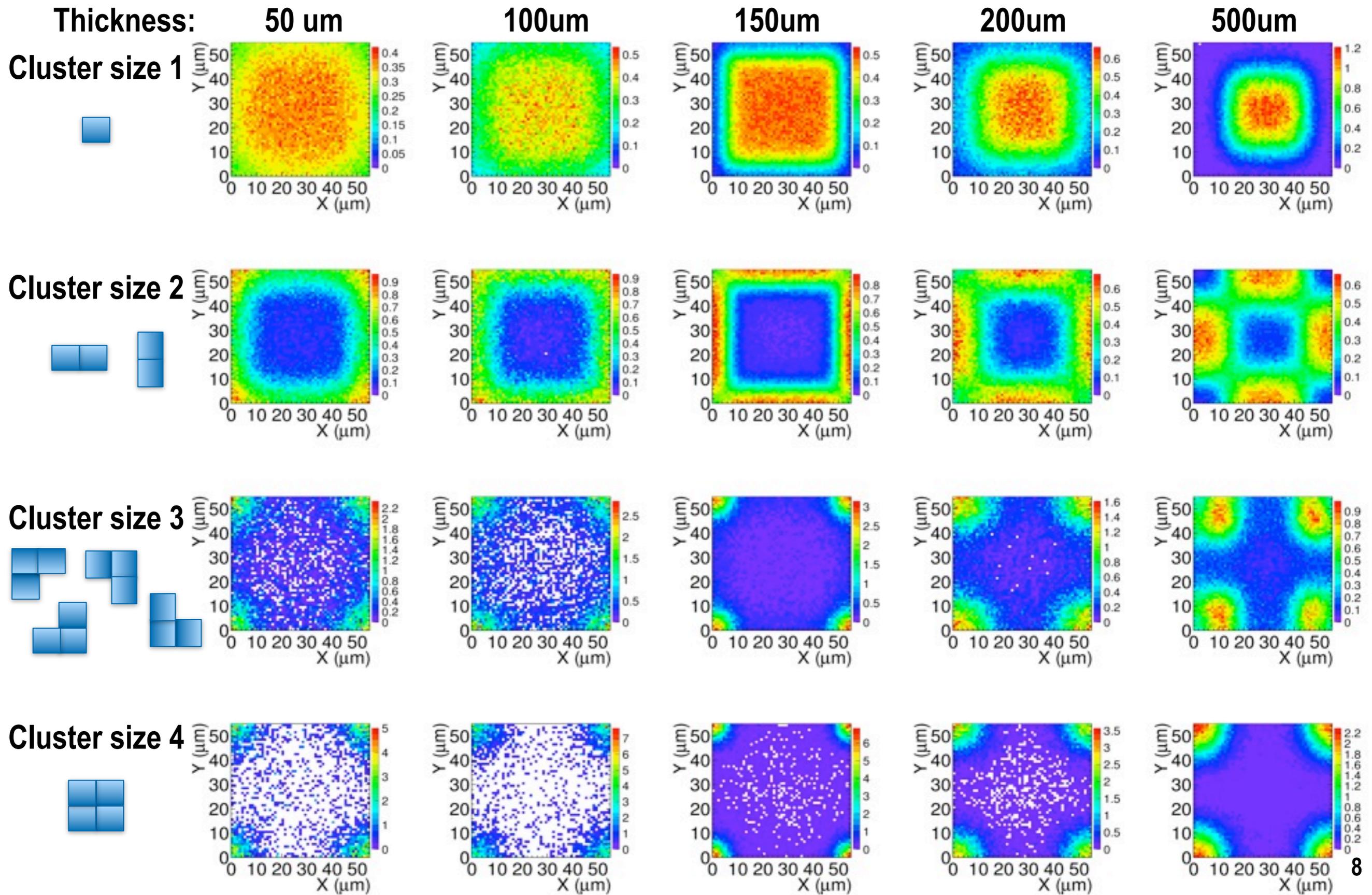
- Edge efficiency: how does the detection efficiency vary at the edge of the sensor?



Implant size vs pixel size



Charge sharing

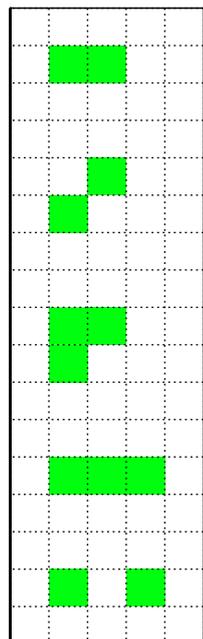


Clustering and hit-making

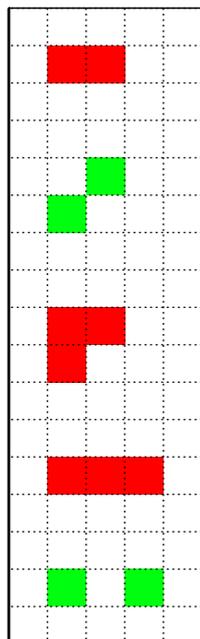
Clustering performed by scipy 'fclusterdata'

- ▶ Distance determines allowed cluster shapes
- ▶ Current algorithm uses distance $=\sqrt{2}$

Pixel hits



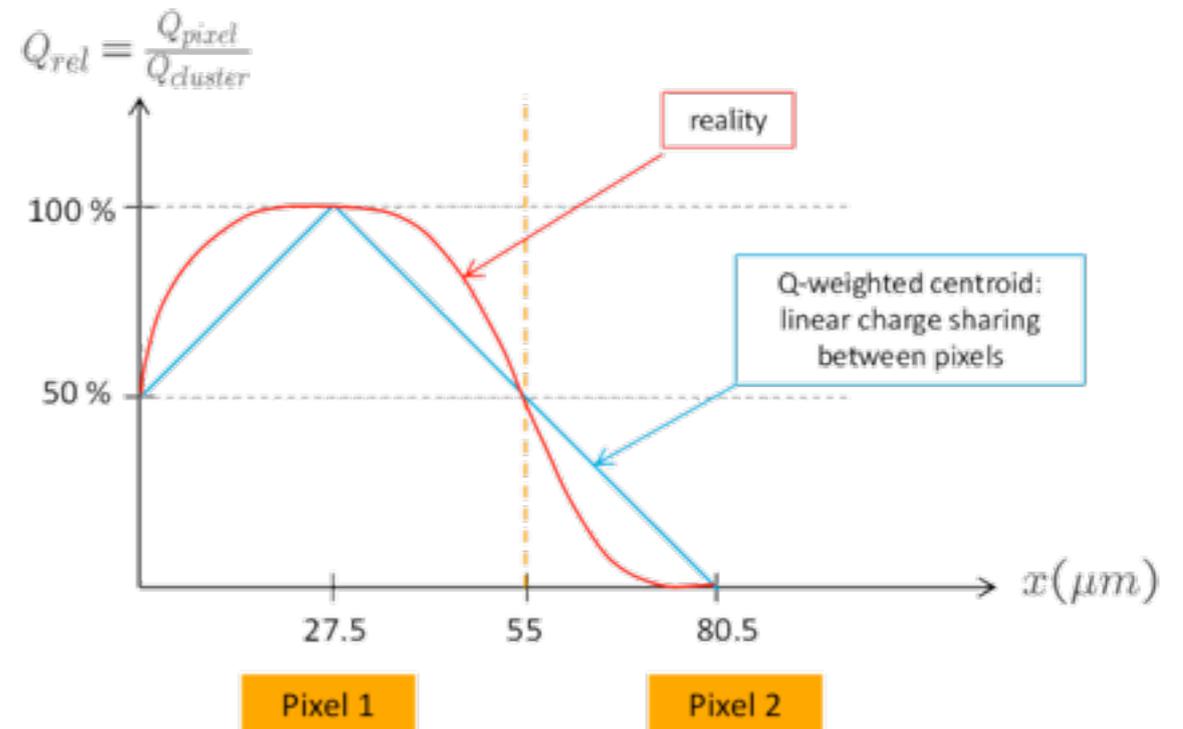
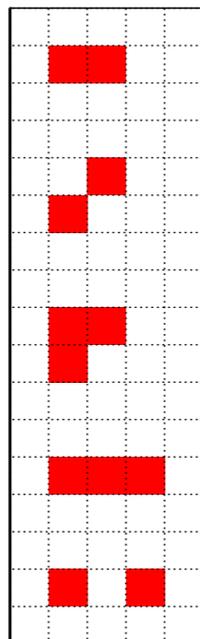
d=1



d=√2

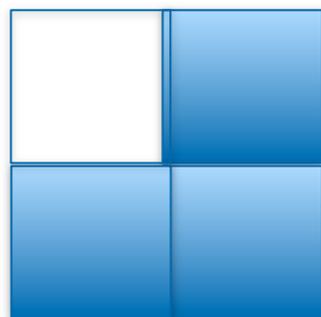


d=2



Compute cluster centroid using Eta Correction method

- ▶ Like charge weighting
- ▶ But uses non-linear diffusion model



Three-hit clusters:

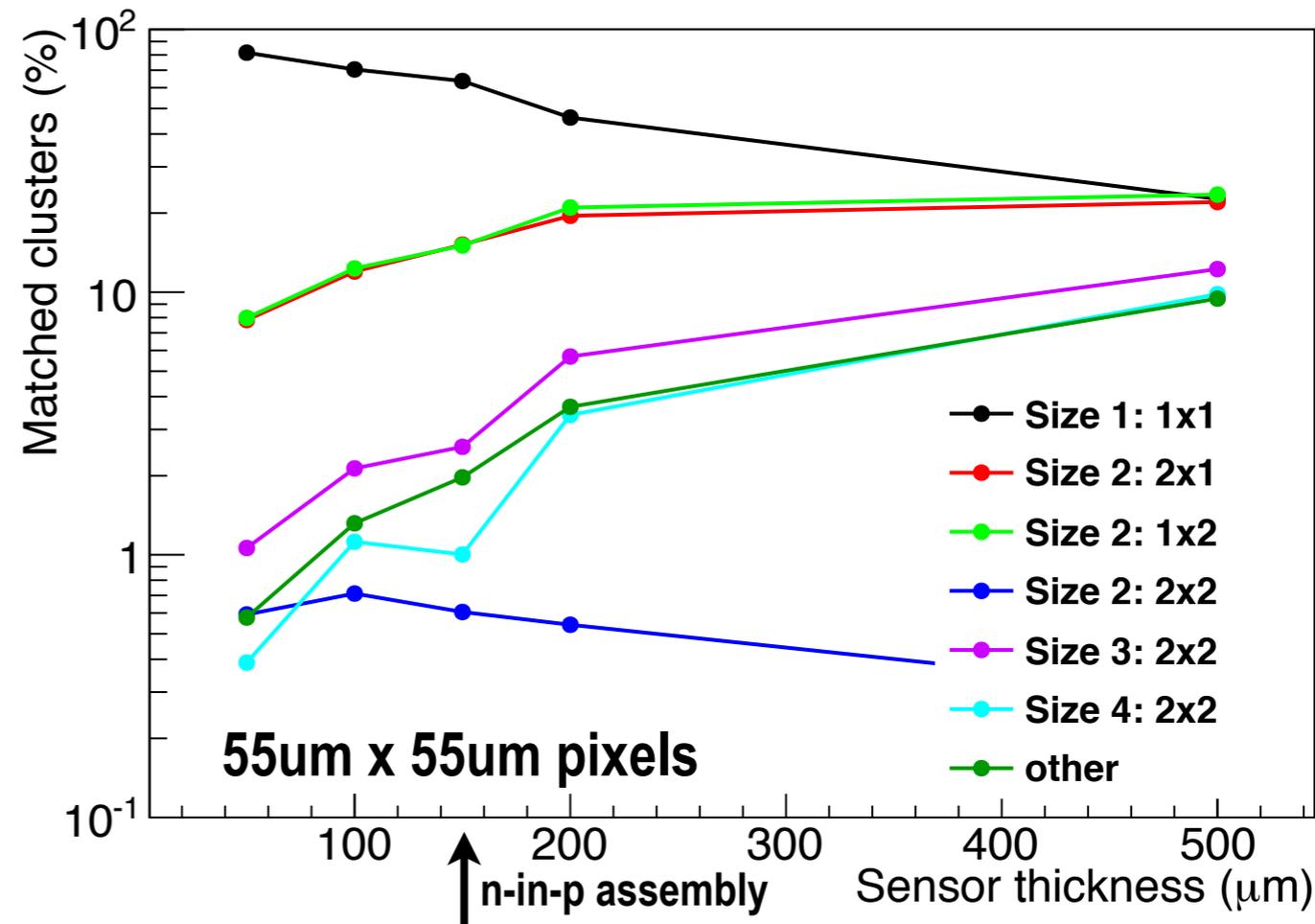
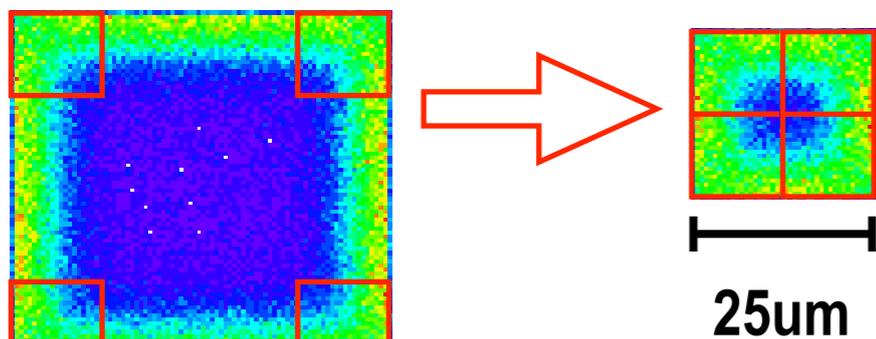
- ▶ Caused by charge sharing below TOT
- ▶ Artificially add 4th pixel to compute centroid
- ▶ Optimisation ongoing

New technique inspired
by Peter KODYS (Belle II)

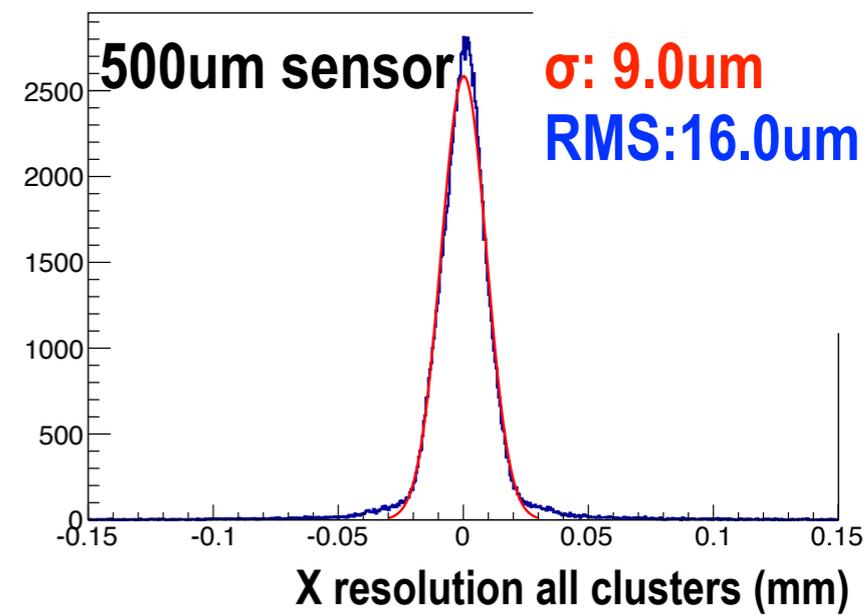
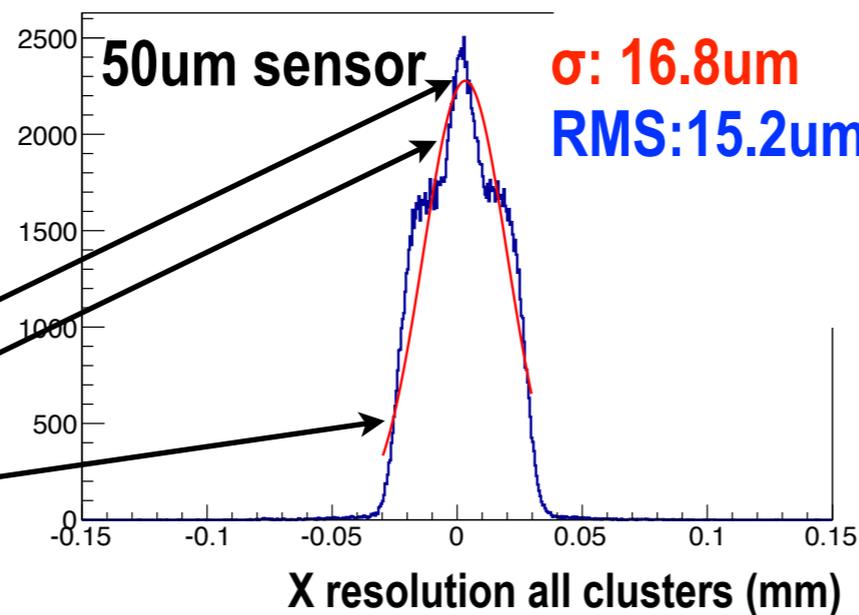
Hit resolution

- Overall hit resolution depends on fraction of multi-hit clusters
- Thinner sensors exhibit less charge sharing
- Smaller pixels will increase charge sharing considerably

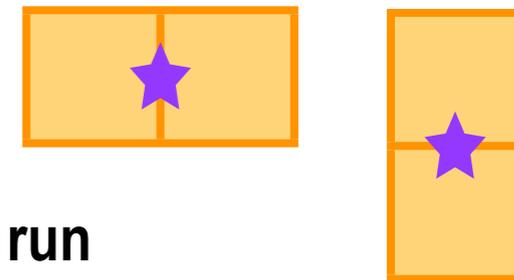
Two hit cluster track position



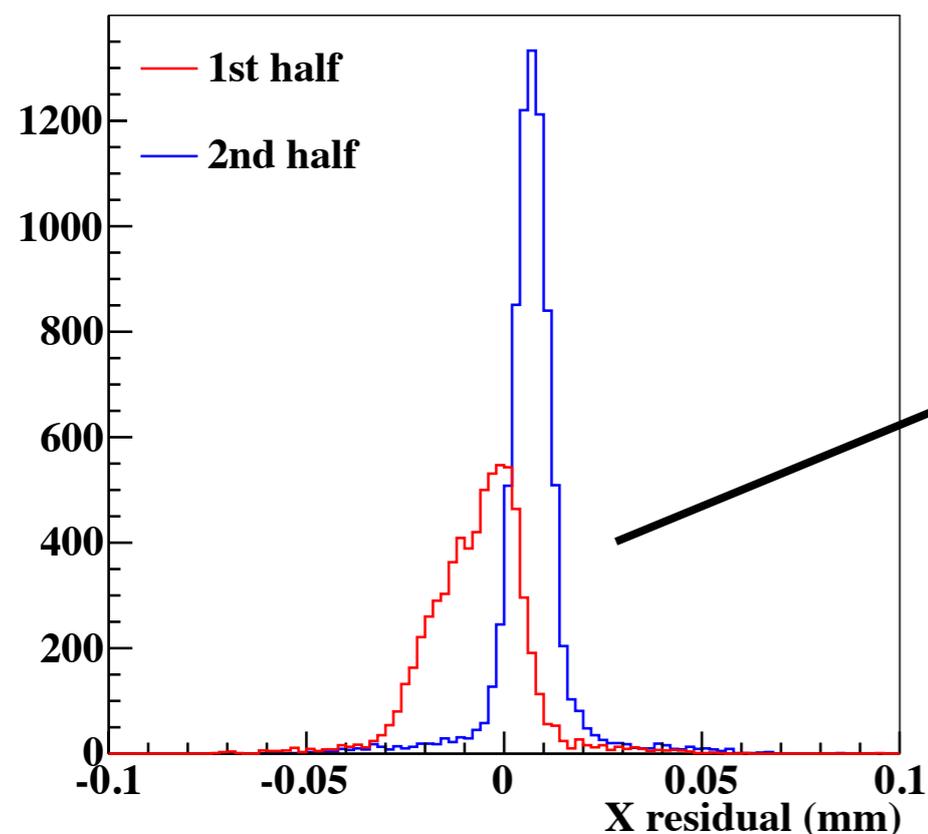
Approximate resolutions:
 55um x 55um pixels
 50um thick sensor
 4 hit cluster: $\sigma \sim 4.6\mu\text{m}$
 2 hit cluster: $\sigma \sim 4.1\mu\text{m}$
 1 hit cluster: RMS $\sim 18\mu\text{m}$
 including telescope res. ($\sim 3.5\mu\text{m}$)



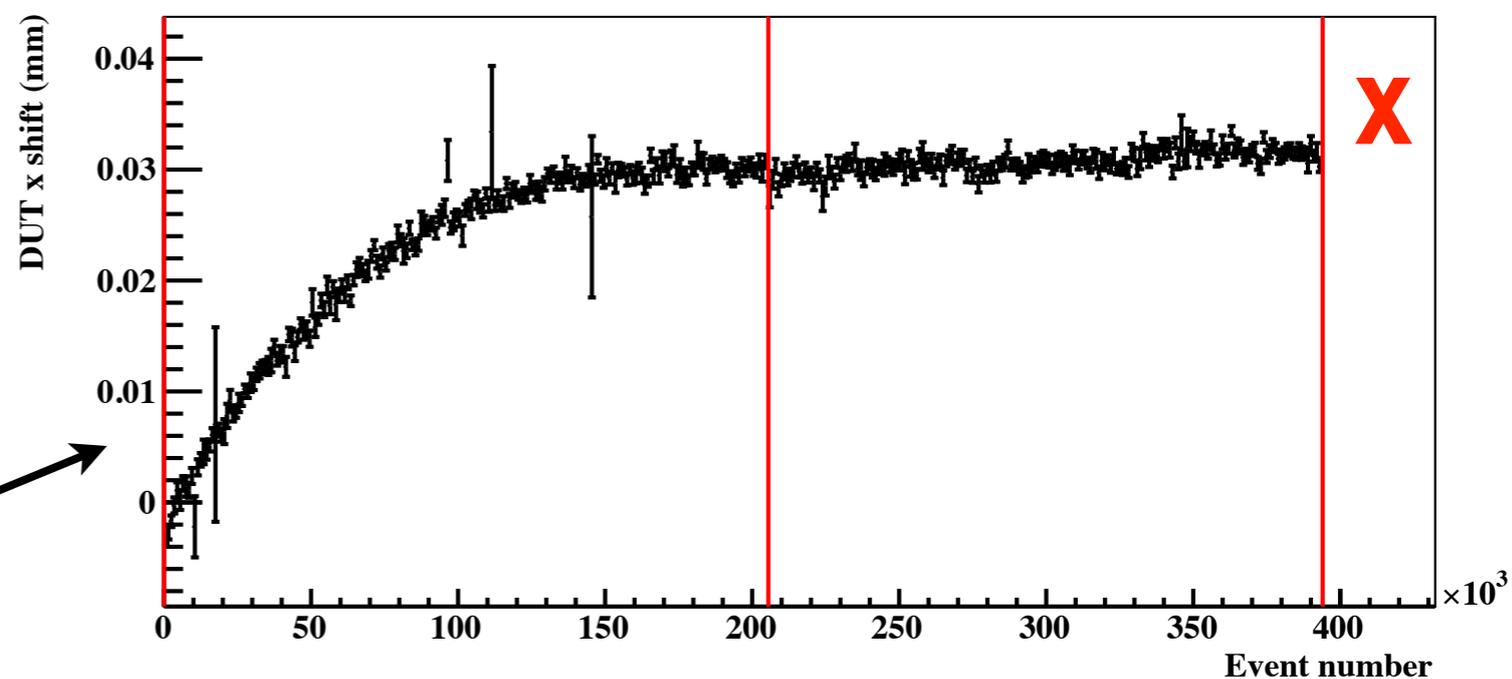
DUT drift



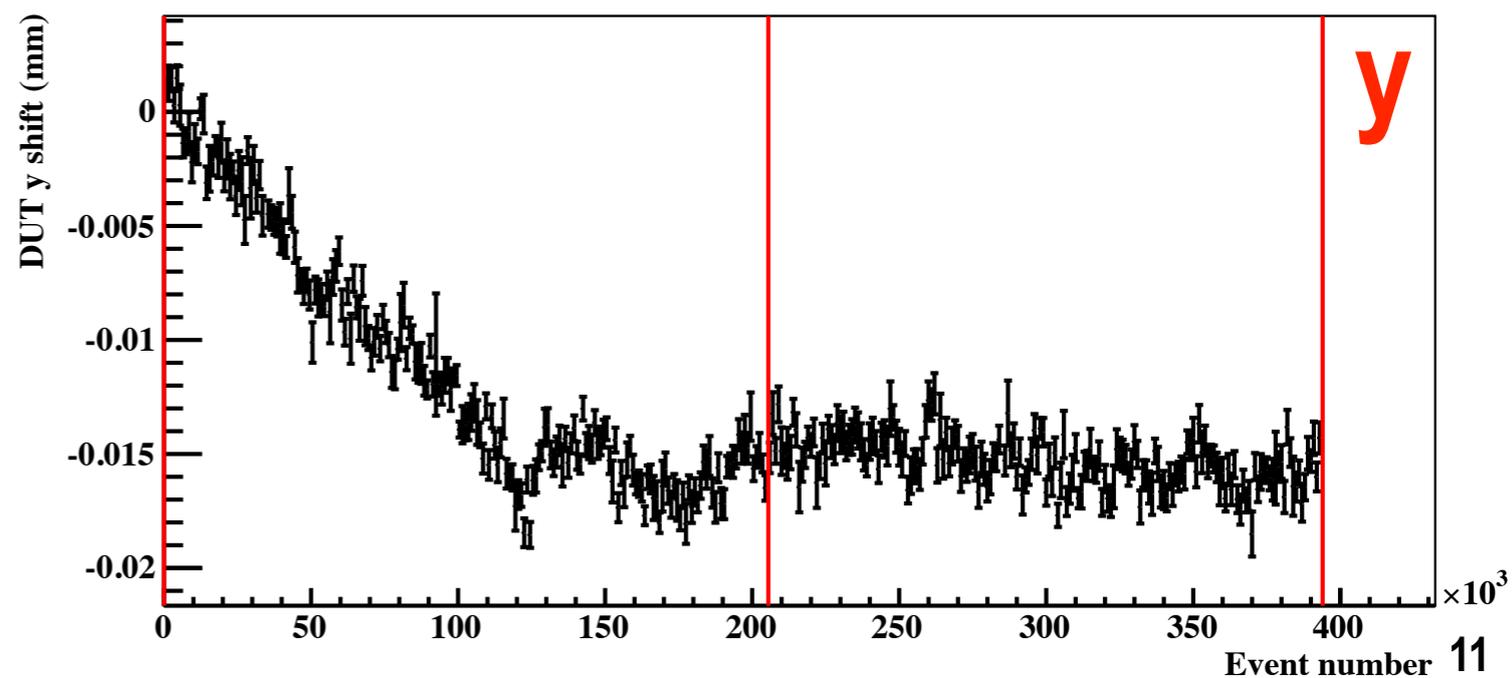
- The mean of the two-hit cluster residual peak moves during the course of a run
- The DUT drifts within the reference frame of the telescope
- This can be corrected for



Run 1110-11

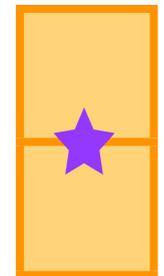
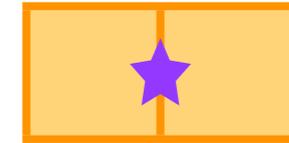


Run 1110-11

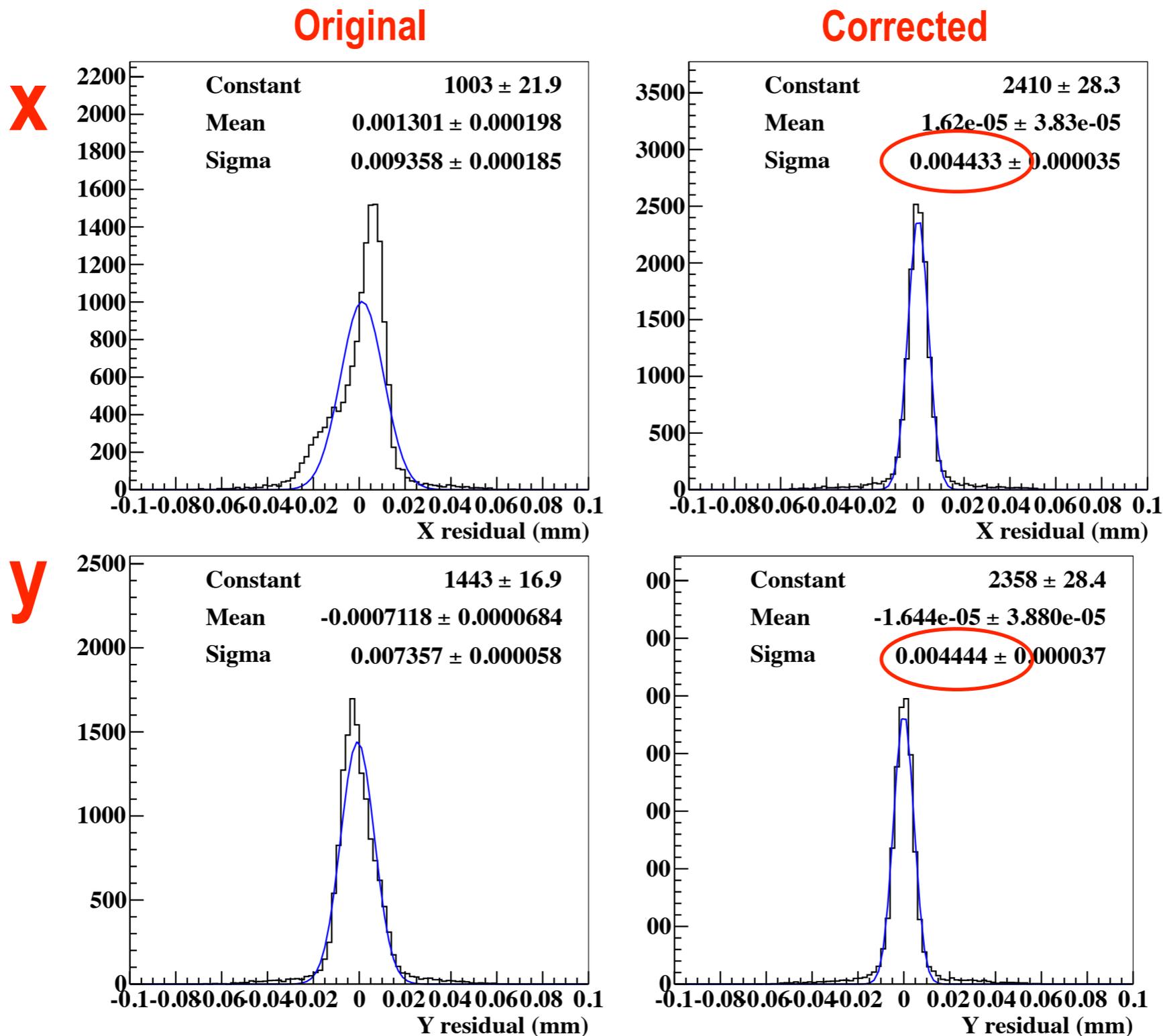


One particularly bad run:
large shifts of 20 - 30 μ m, with a resolution
of 3 μ m. Run unusable without correction

Correcting DUT drift



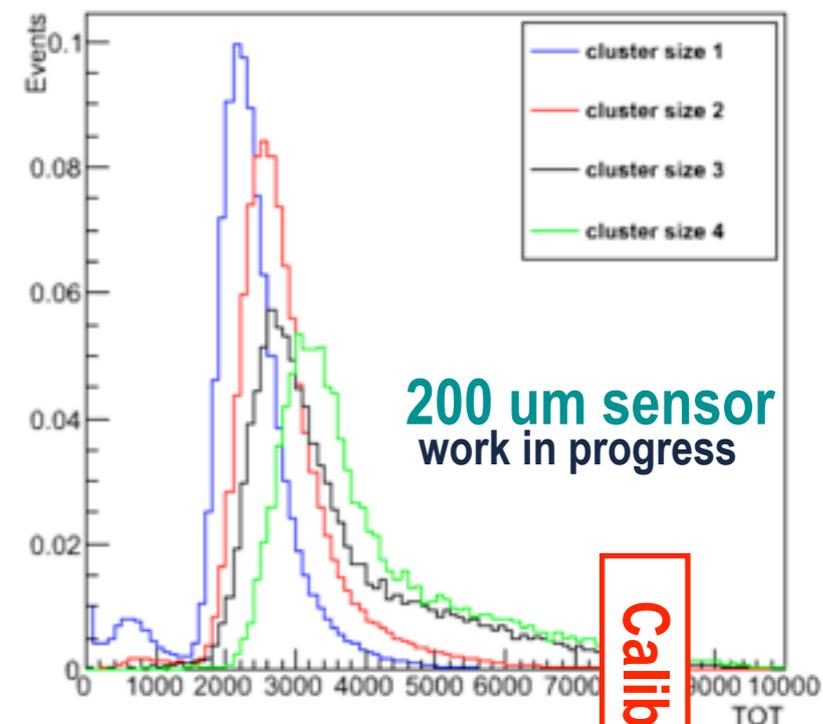
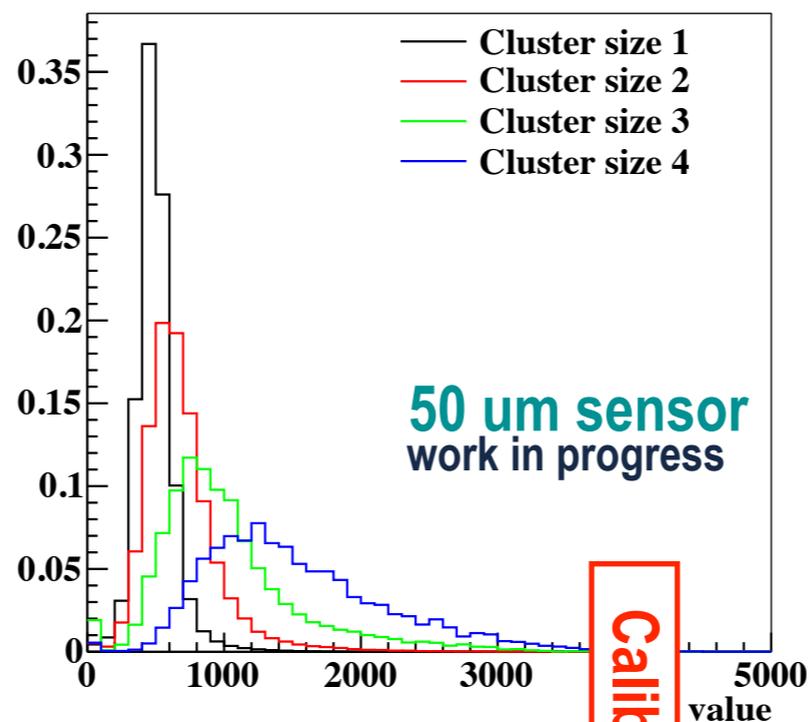
- Corrected two-hit resolutions of 4-5um
- Equivalent to resolutions achieved in stable runs with similar sensor thickness



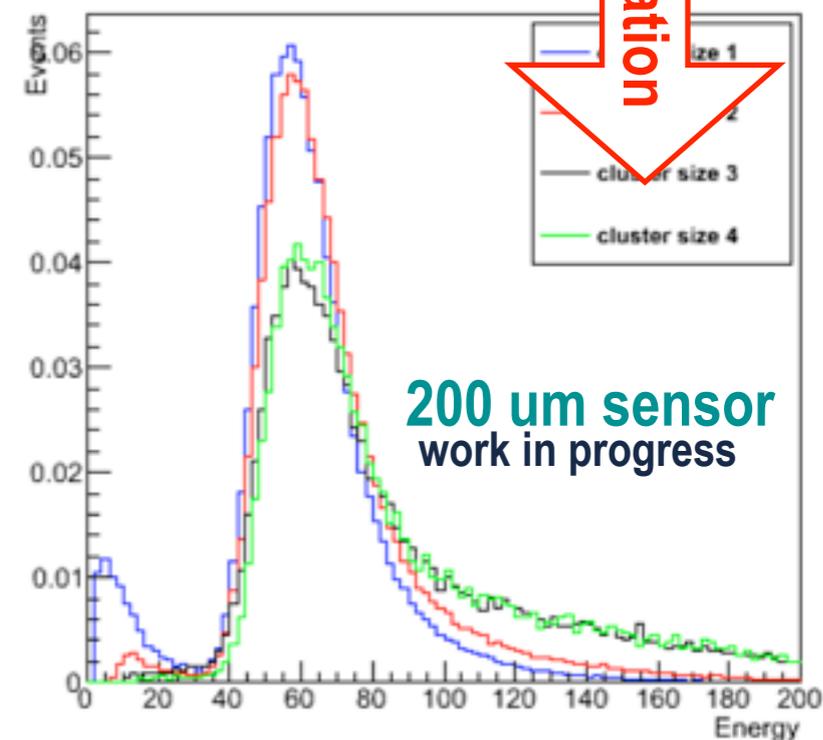
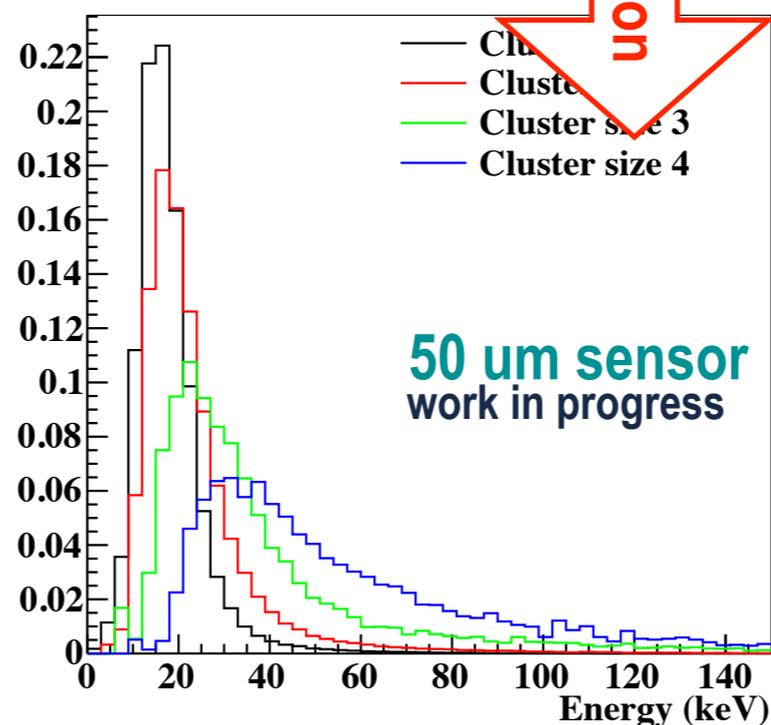
Calibrated test beam data

- Using calibration from CERN, LNL
- Apply to DESY test beam data
- 50um sensor: charge loss below threshold?
- 200um sensor: delta rays in multi hit clusters?

No calibration

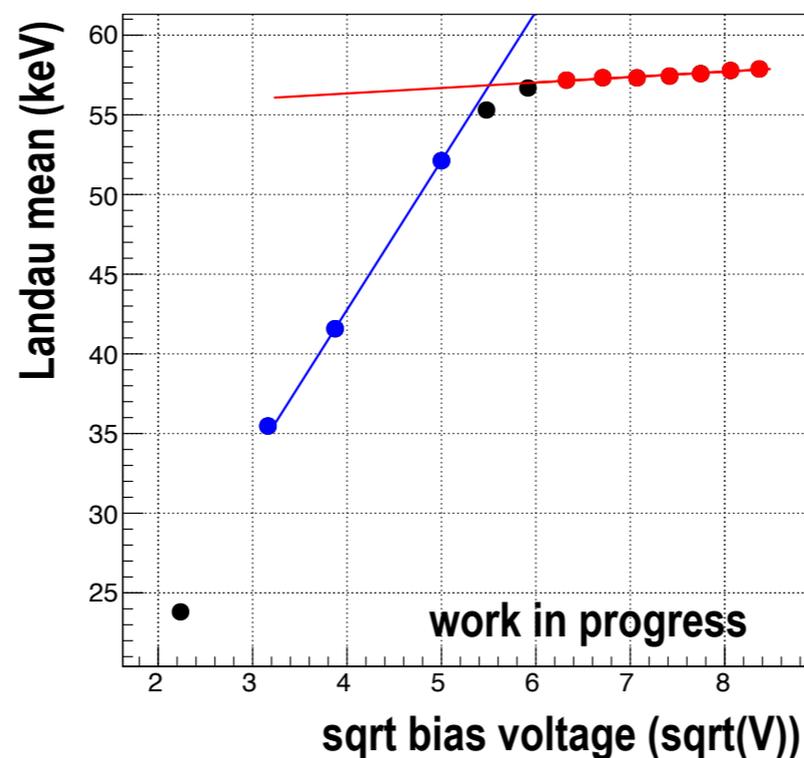
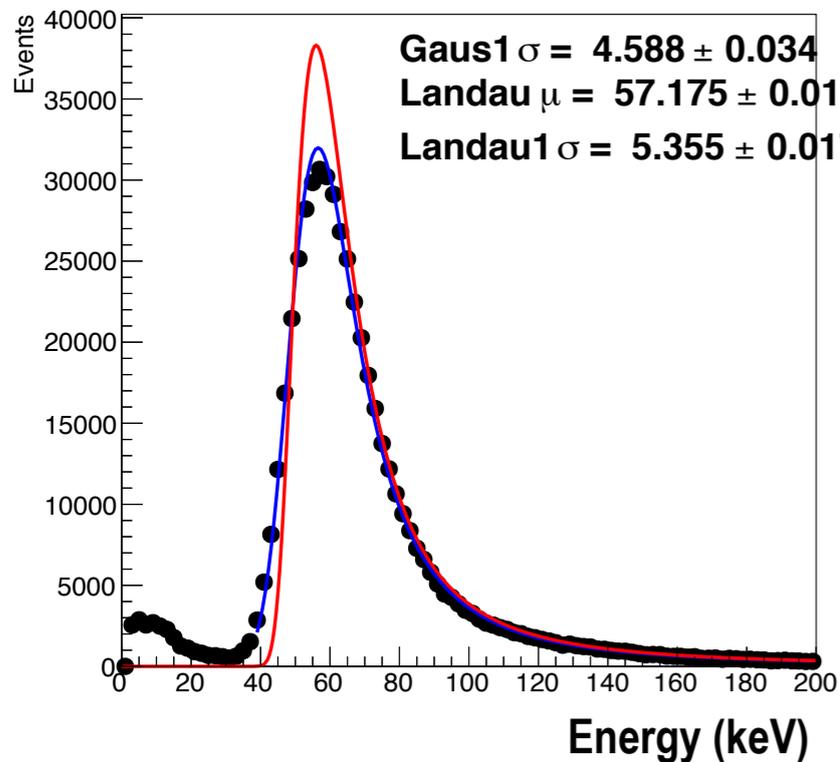
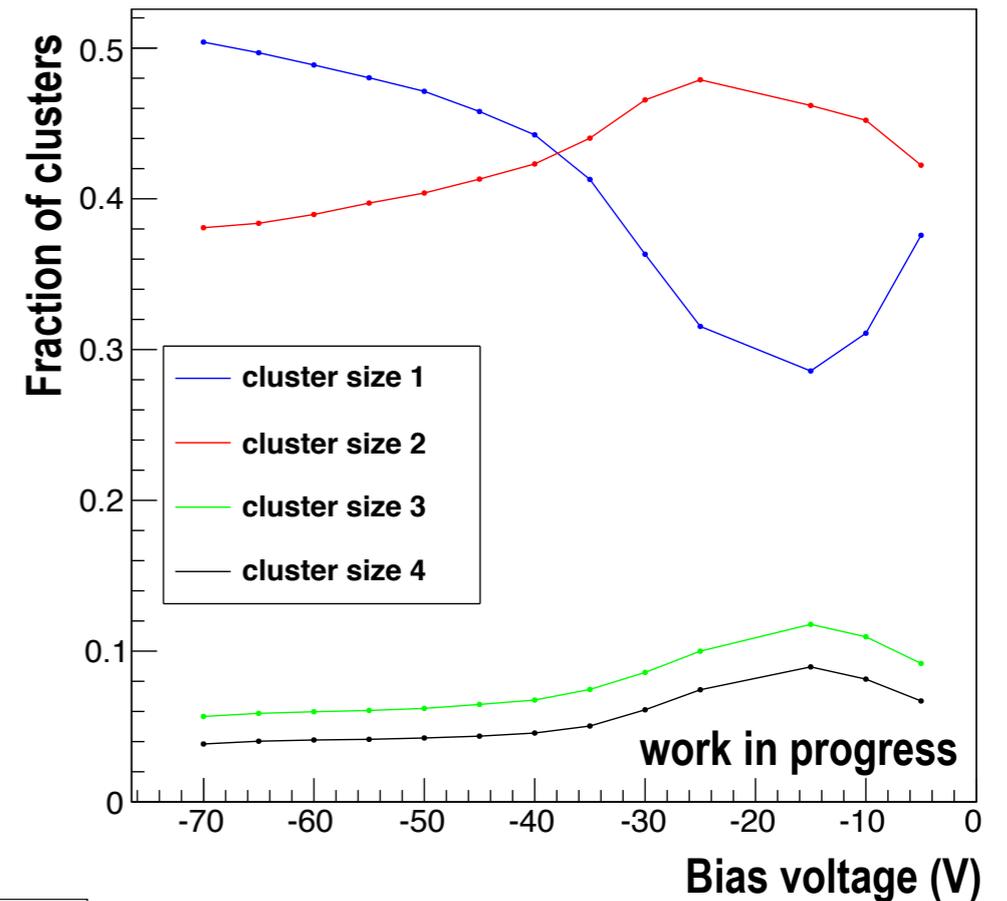


Global calibration



Bias voltage scan

- Altering the bias voltage affects cluster size
 - ▶ More charge collected vs stronger E field
 - ▶ Increase charge sharing for same efficiency with lower bias voltage
- Bias voltage also affects collected charge
 - ▶ Determination of depletion voltage
 - ▶ ~30V for a 200um thick sensor

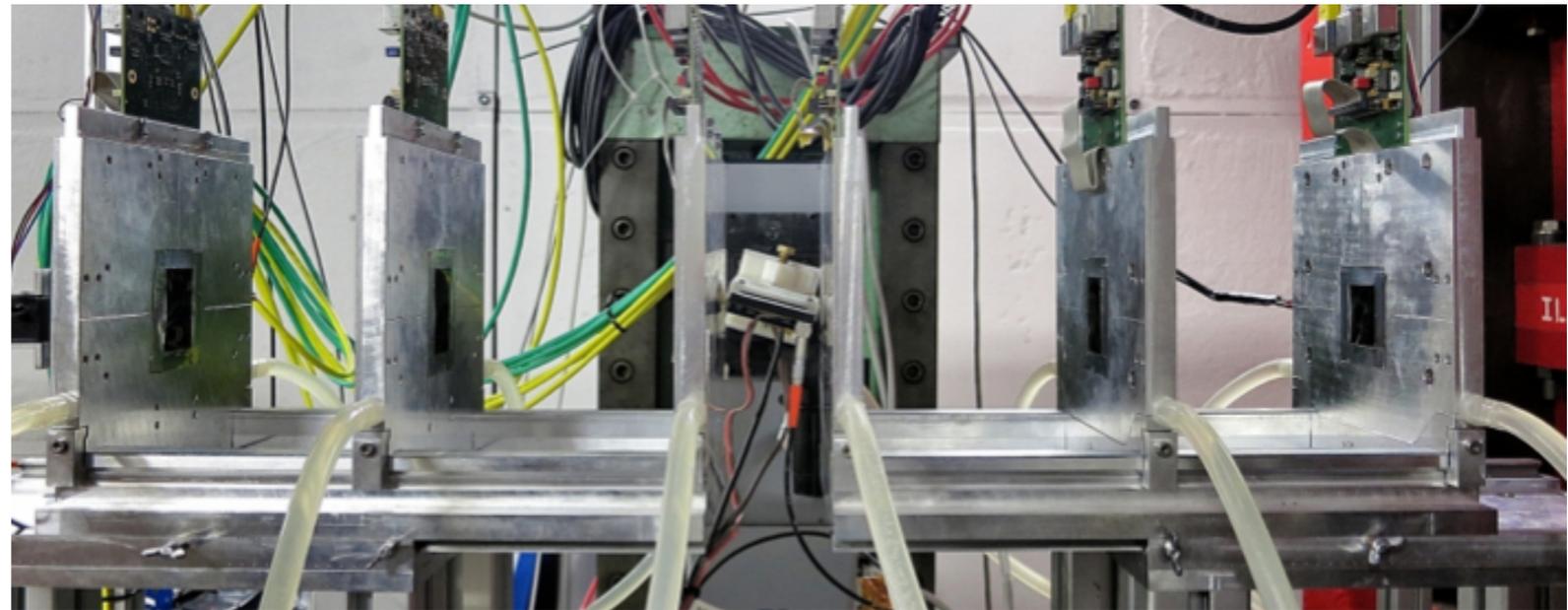


$$V_d = \frac{eNT^2}{2\epsilon}$$

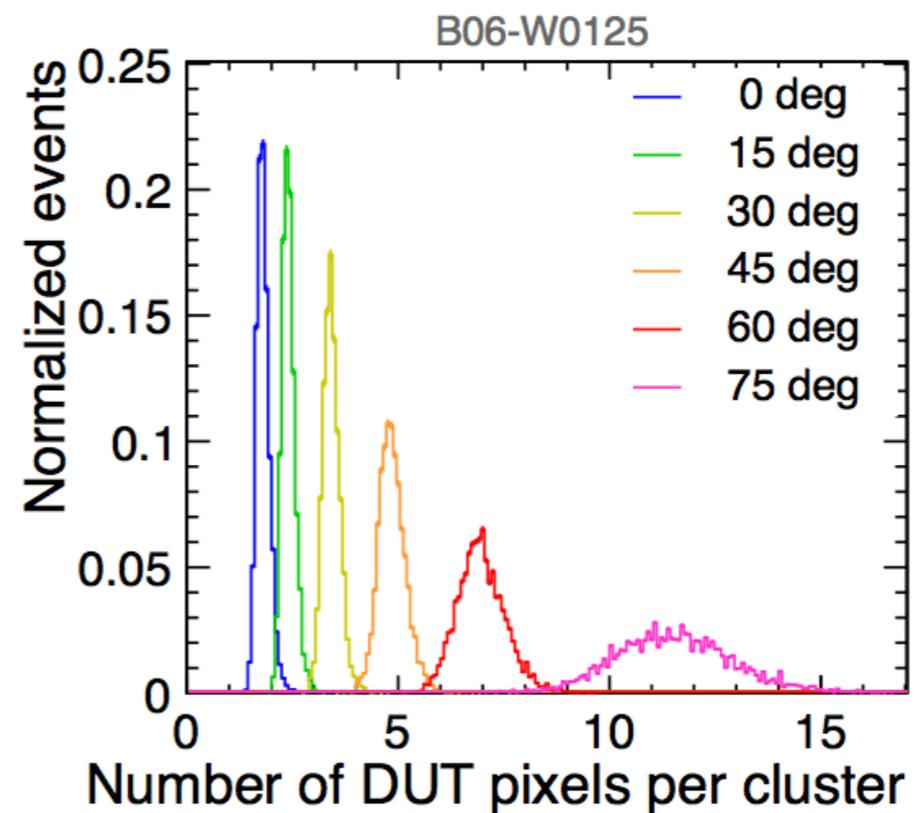
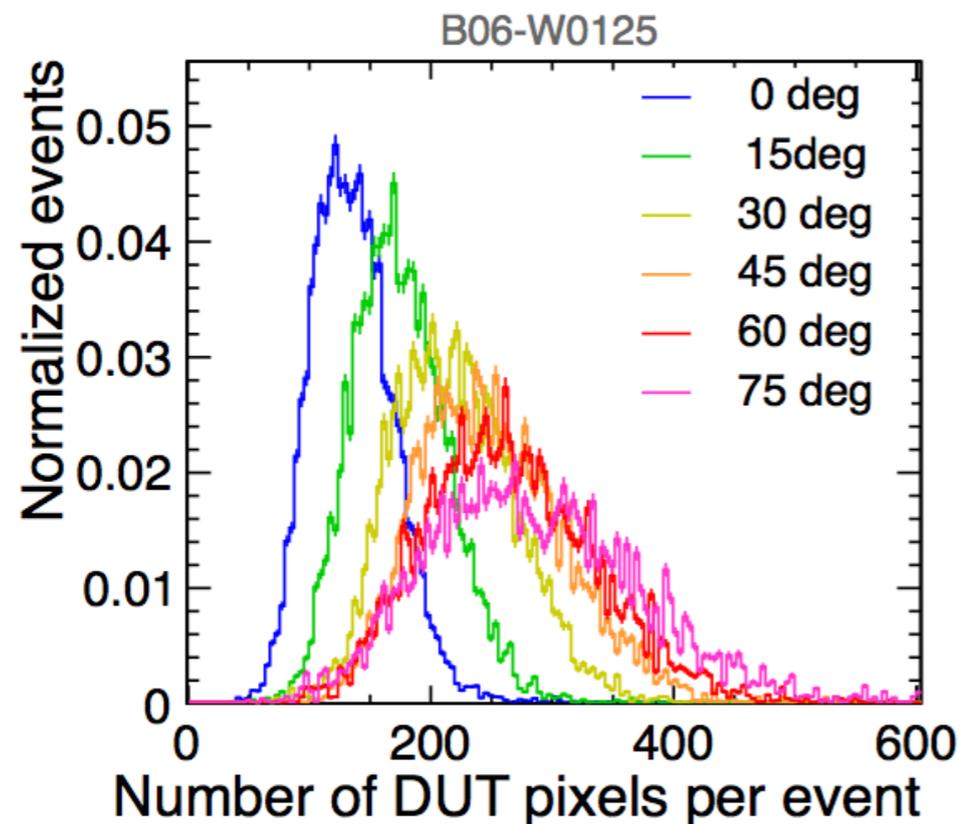
V_d = depletion voltage
 e = electric charge
 N = dopant concentration
 T = thickness
 $\epsilon = \epsilon_0\epsilon_{Si}$

Angle scans

- Rotate DUT within telescope
- Simulates tracks in forward direction
- Hits produce larger cluster sizes
- In line with geometrical expectations
- Need a new cluster centre method

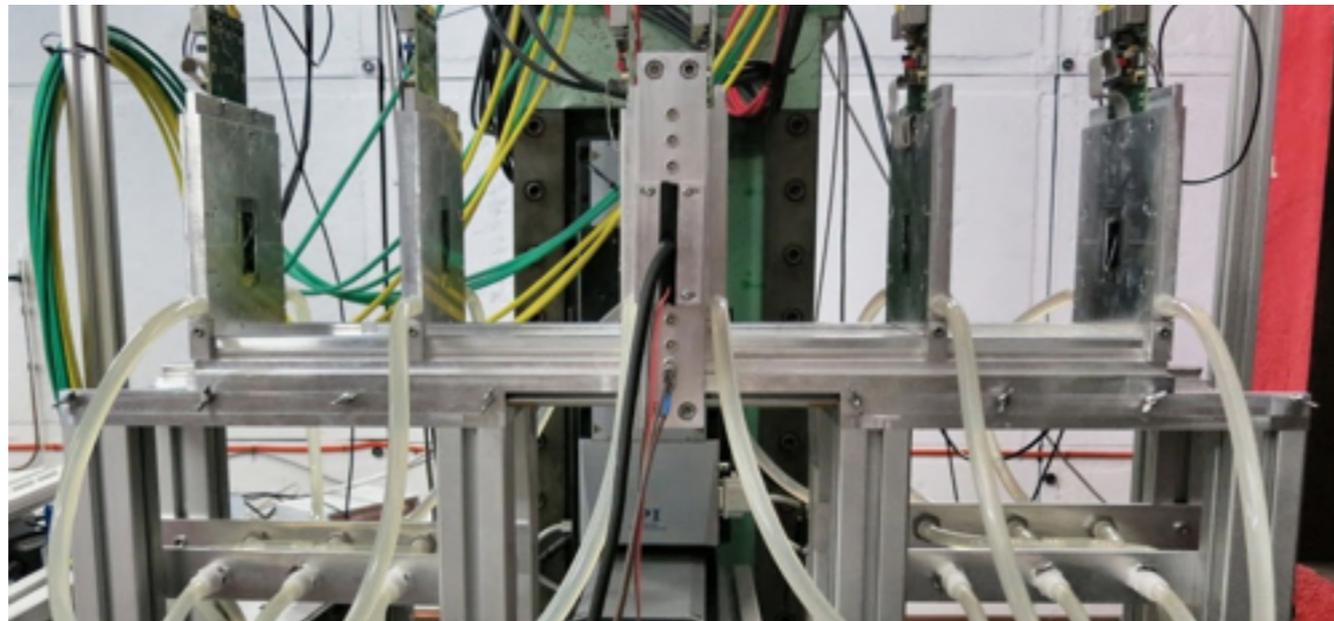


75 degrees rotation



Summary

- **Thin-sensor Timepix assemblies were characterised in test beam and lab measurements**
- **Calibration performed using photons of known energy at CERN and LNL**
- **Test beam data recorded at DESY**
- **Analysis shows thin sensor assemblies have excellent detection efficiencies and spatial precision**
- **Further characterisation performed with bias, threshold, angle scans**



Thanks for your attention!

