CLICpix2 test-beam analysis

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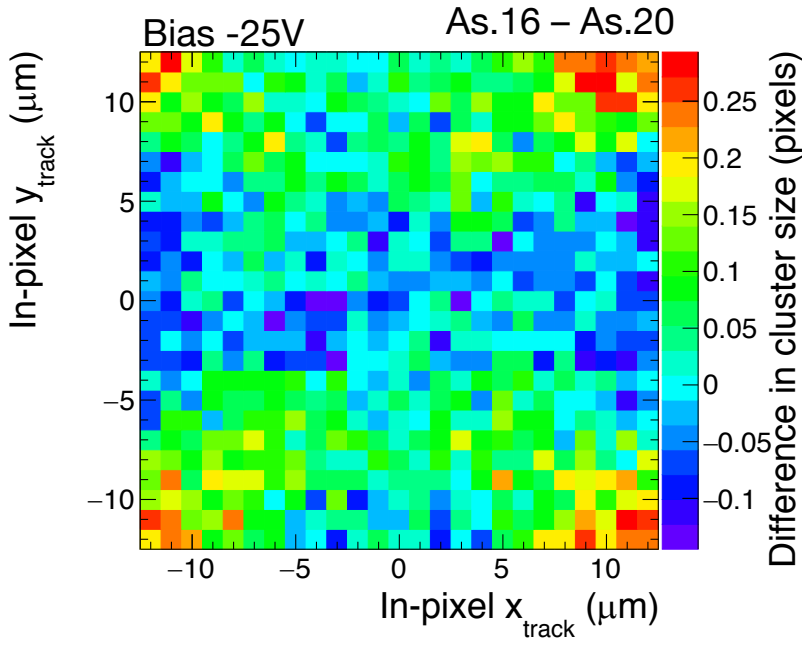
Recap

- When comparing CLICpix2 planar sensor assemblies 16 and 20, large difference in trend between Y and X axes: larger cluster sizes along Y, smaller along X for assembly 16

  → asymmetry observed in in-pixel cluster size, total residual widths, residual width for different cluster widths, effective pitch of 1-pixel clusters, MIP peak

- Also saw 1um offset to positive Y values for assembly 16

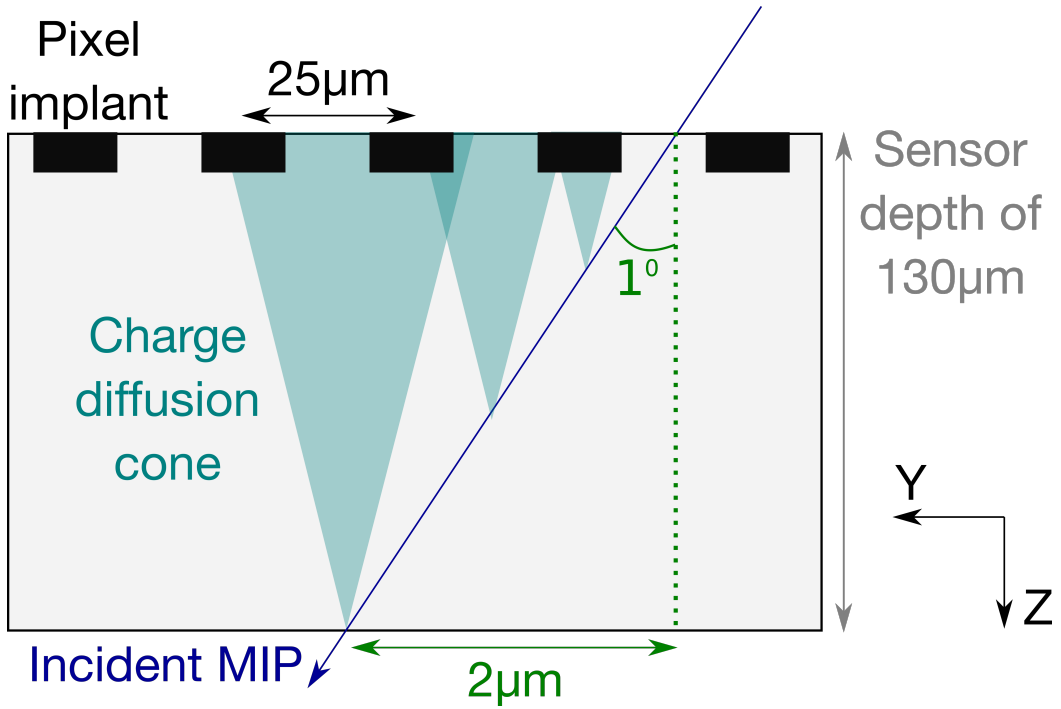
  → observed in all in-pixel plots and 1-pix cluster residual in Y



	Residual width X (um)	Residual width Y (um)
As 16	4.0	3.4
As 20	4.1	4.1

Recap

- Hypothesis: 1deg rotation observed in alignment could case different levels of above threshold charge sharing along X and Y axes, owing to the large ratio between pitch and sensor thickness (pure geometry)
- Only theory we had that could explain all the effects seen…
- … but relies on small angle creating a big effect → need simulation to verify



Simulations

Three Allpix^2 simulations of CLICpix2 DUT performed by Simon, then reconstructed in Corryvreckan:

1. SPS telescope + DUT at an angle of (1,0,0) → assembly 16 case
2. SPS telescope + DUT at an angle of (0,0,0)
3. DESY telescope + DUT at an angle of (0,0,0) → assembly 20 case

Expect one of two outcomes:

A) See no 1um offset or residual width XY asymmetry in any simulation → hypothesis not validated
B) See 1um offset and residual width XY asymmetry in simulation 2 only → hypothesis validated

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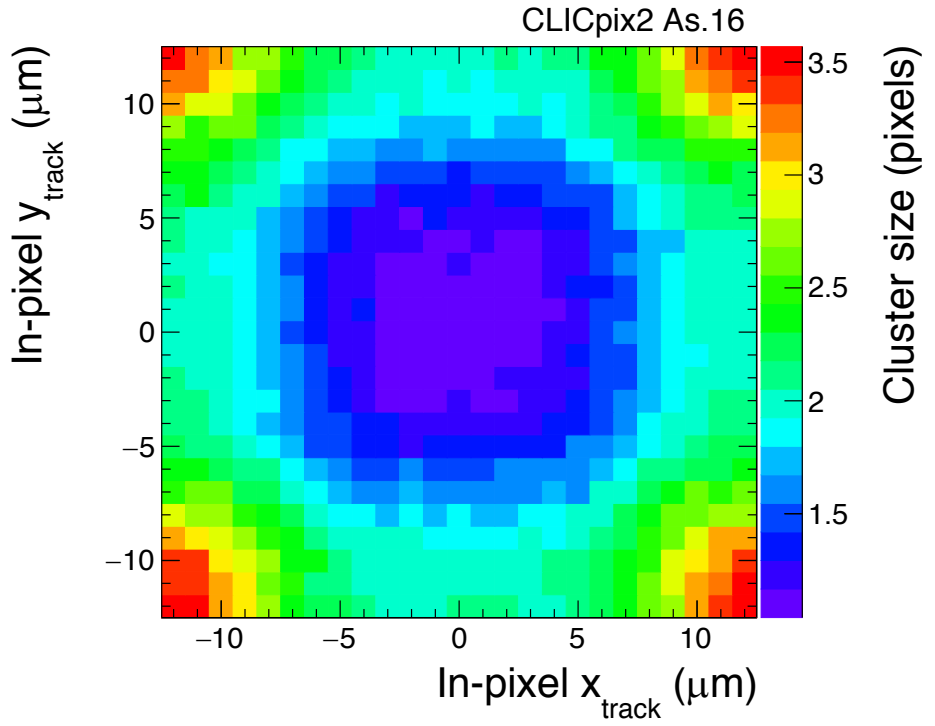
B) See 1um offset and residual width XY asymmetry in simulation 2 only → hypothesis validated

Outcome = option C): see no XY asymmetry in any simulation but see 1um offset in both SPS simulations.

	Residual width X (um)	Residual width Y (um)
SPS non-rotated	3.8	3.8
SPS rotated	3.8	3.8
Assembly 16 data	4.0	3.4



In-pixel cluster size SPS non-rotated simulation

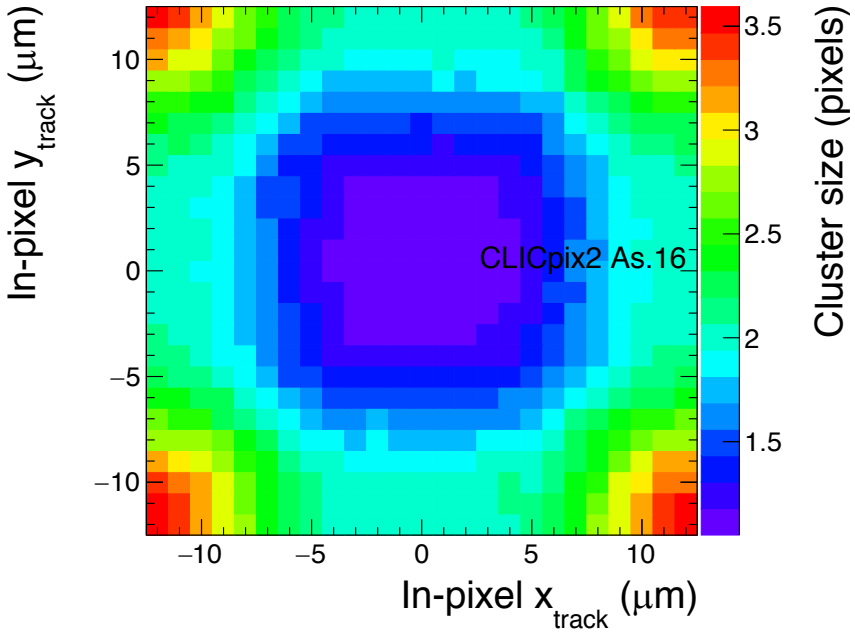
Cause of 1um Y offset in simulation

Track model used in Corry:

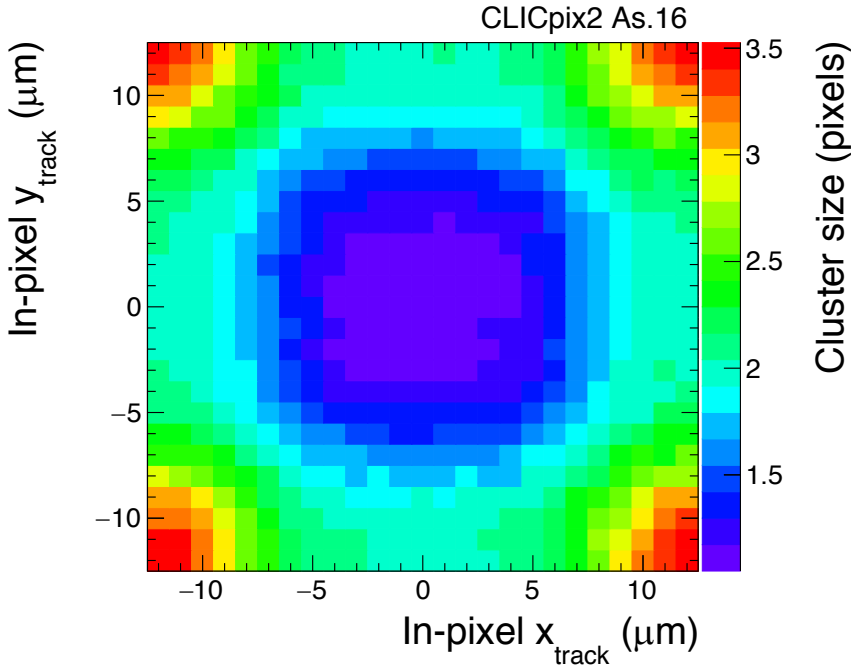
- Previously used to use a straight-line track model for reconstruction of SPS data to obtain a better constrained DUT alignment, as rotational alignment with GBL can be difficult, and as the kink angles at SPS are near 0°.
- Had used straight-line track model to reconstruct the simulated data for consistency.
- Changing to a GBL track model reduced the offset in Y in the simulated data to the point where it is not visible in in-pixel cluster size plot.

Cause of 1um Y offset in simulation

→ implies GBL track model should be used for SPS data reconstruction



In-pixel cluster size SPS non-rotated simulation with GBL



In-pixel cluster size SPS 1deg rotated simulation with GBL

SPS data with GBL

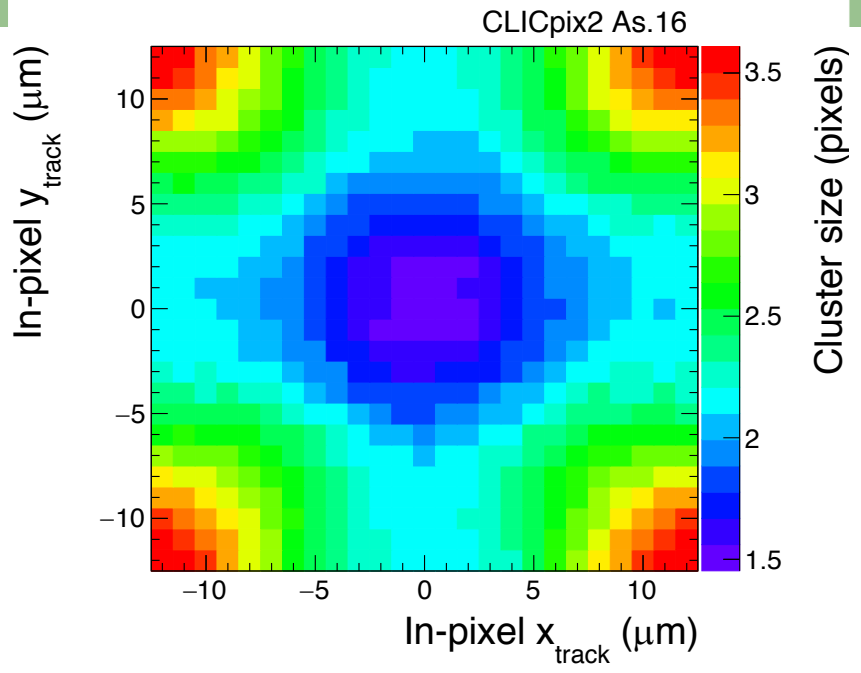
Changing to a GBL track model in data:

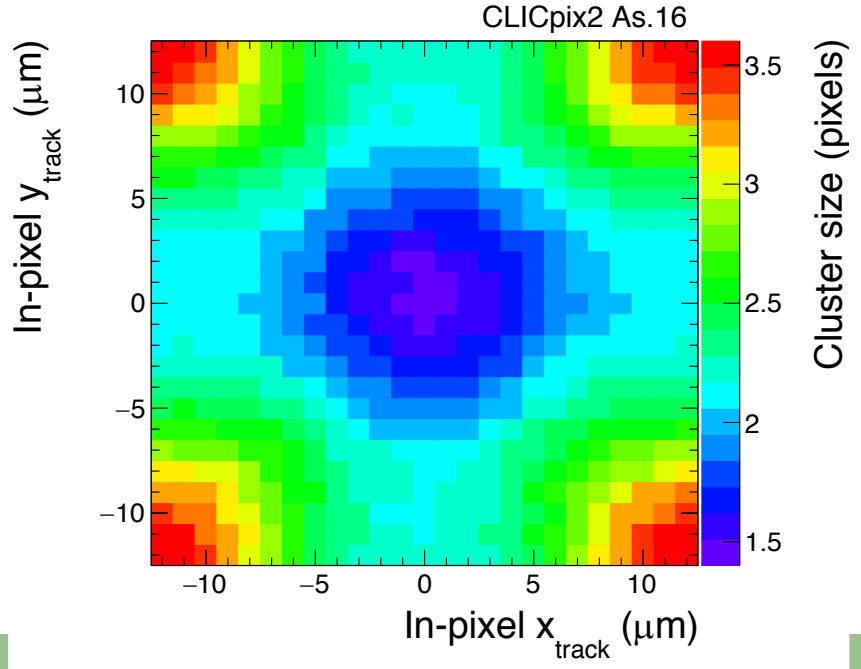
- 1um Y offset in in-pixel plots remains
- XY asymmetry remains in all plots

	Residual width X (um)	Residual width Y (um)
Assembly 16 with GBL	4.0	3.5
Assembly 16 with straight-line	4.0	3.4

→ 1um offset and XY asymmetry in data must come from somewhere else

Top: In-pixel cluster size using GBL
Bottom: In-pixel cluster size using straight-line





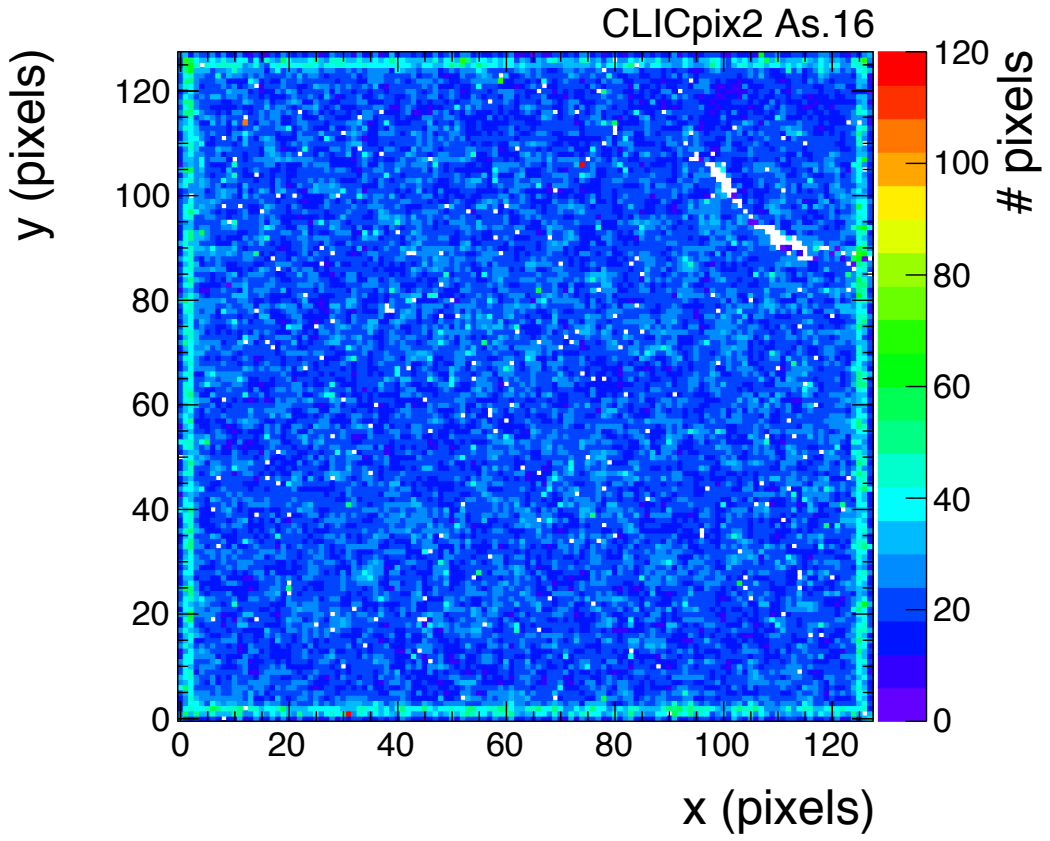
Cause of XY asymmetry in data

Saw ‘hot-edge’ effect in hit-rate of all CLICpix2 assemblies during laboratory testing.

Affects 1st, 2nd, and 3rd columns/rows from matrix edge.

Thought to be due to active-edge and large ratio between pitch and sensor thickness.

Up to now, always left these pixels in the analysis…



Cause of XY asymmetry in data

Applied ROI to the analysis, such that tracks incident within the 1st-3rd columns and rows around the matrix edge are excluded (using GBL track model).

→ XY asymmetry in residual widths is halved, XY asymmetry in in-pixel cluster size greatly reduced, small asymmetry now seen for both assemblies

	Residual width X (um)	Residual width Y (um)	Difference (um)
As.16 (SPS) with straight-line	4.0	3.4	0.6
As.16 (SPS) with GBL	4.0	3.5	0.6
As.16 (SPS) with GBL and ROI	3.4	3.1	**0.3**

	Residual width X (um)	Residual width Y (um)	Difference (um)
As. 20 (DESY) with GBL	4.1	4.1	0.0
As. 20 (DESY) with GBL and ROI	3.8	3.7	**0.1**

Cause of XY asymmetry in data

- Large asymmetry thought to be caused by edge pixels, however a small asymmetry remains for both assemblies

  → could be caused by a combination of the mirrored ASIC design, even-odd column calibration differences, and asymmetric telescope resolution

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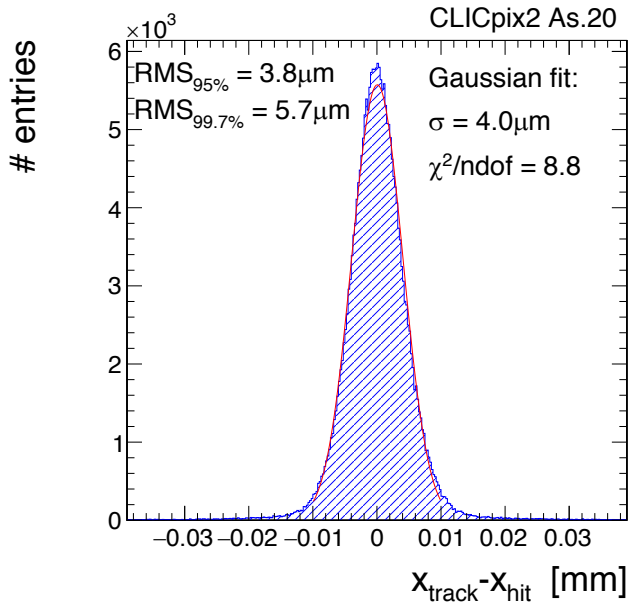
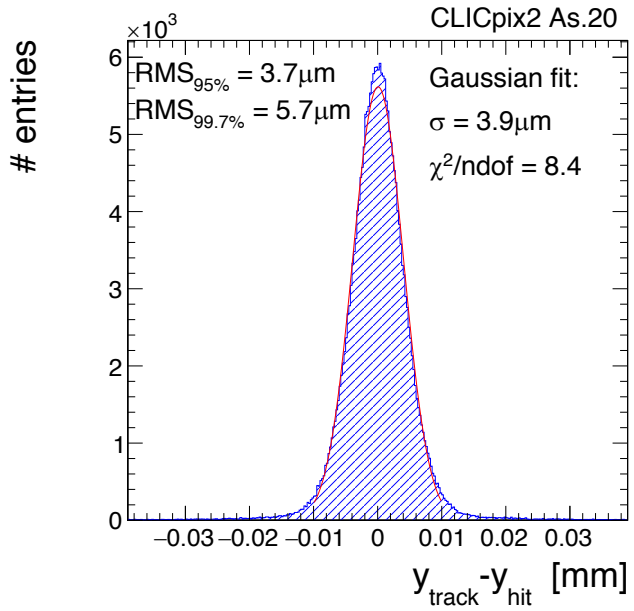
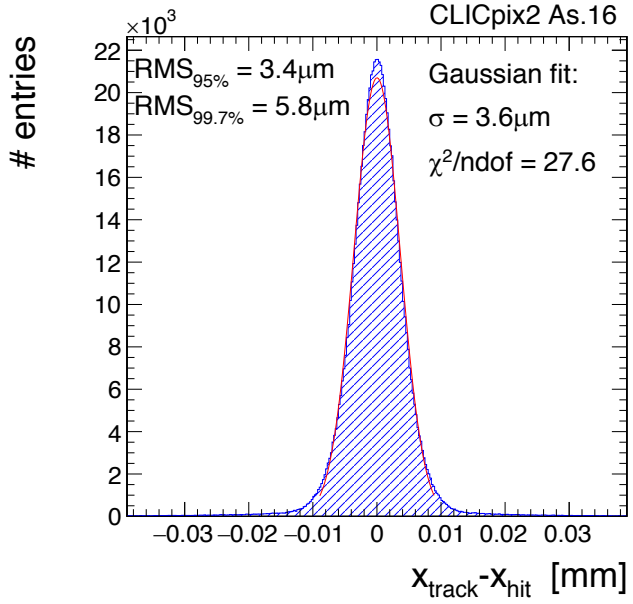
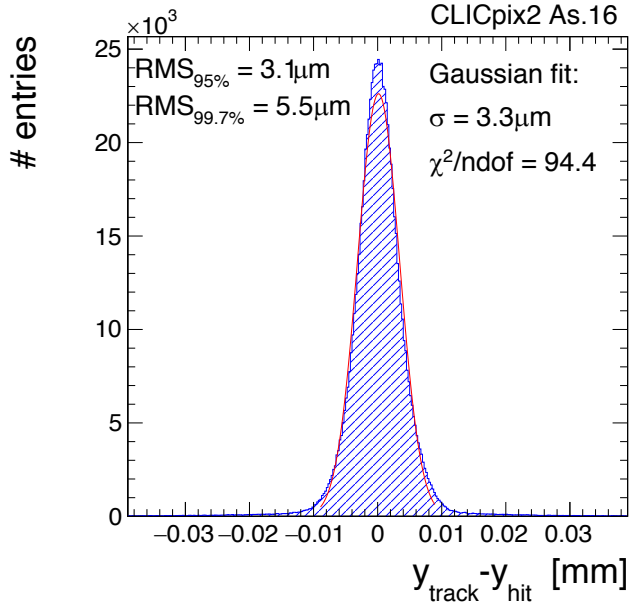
Updated test-beam results

- Intrinsic spatial resolution of both assemblies along both axes is below 3µm





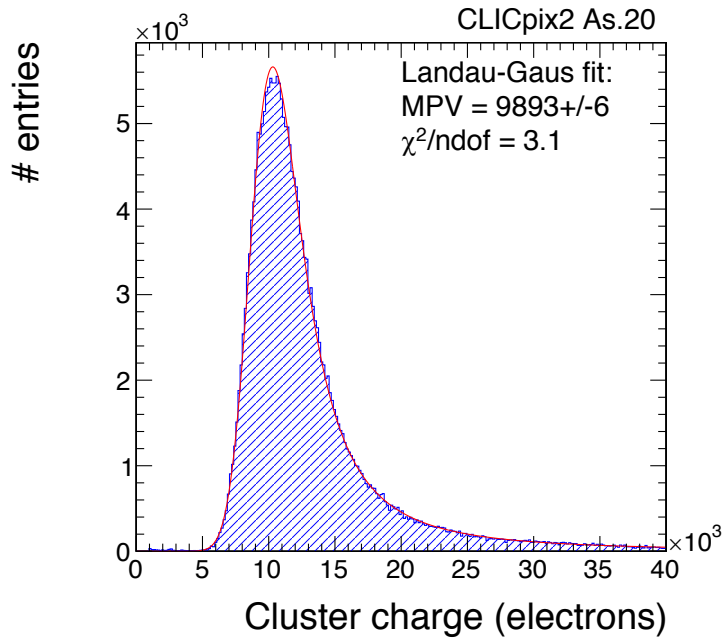


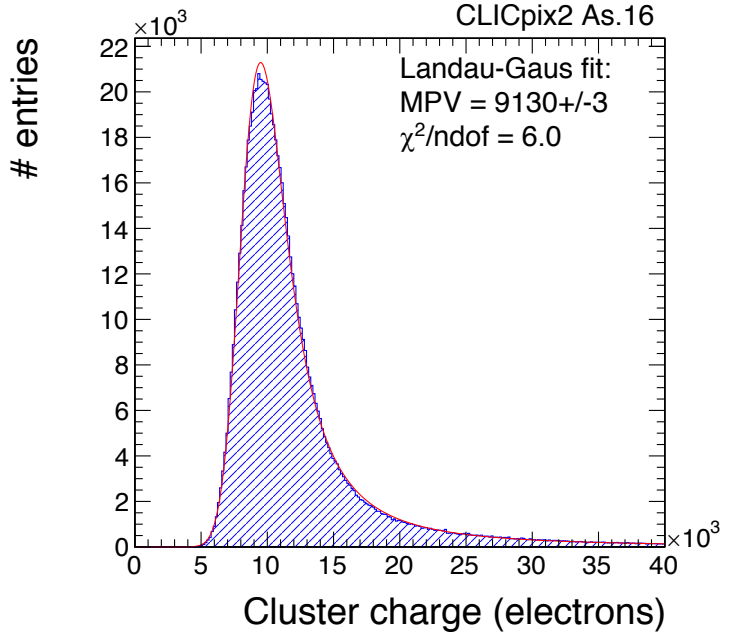


Cluster charge

Measured cluster charge MPV significantly different from theoretical expectation.

	MPV (ke)
SPS data (with GBL and ROI)	9.1
DESY data (with ROI)	9.9
Theoretical expectation	9.6





Cluster charge

Thought to be caused by combination of:

- Different assembly thresholds and threshold uncertainty
- ToT calibration uncertainties from fitting and propagated from threshold calibration, especially between odd-even columns
- Discrete per-pixel ToT measurement causing assembly-dependent systematic uncertainty
- Uncertainty in bias voltage applied

Thought not to contribute:

- Thickness difference - unlikely as both assemblies from the same wafer
- DESY/CERN particle types / energies - should only be a 0.1% effect

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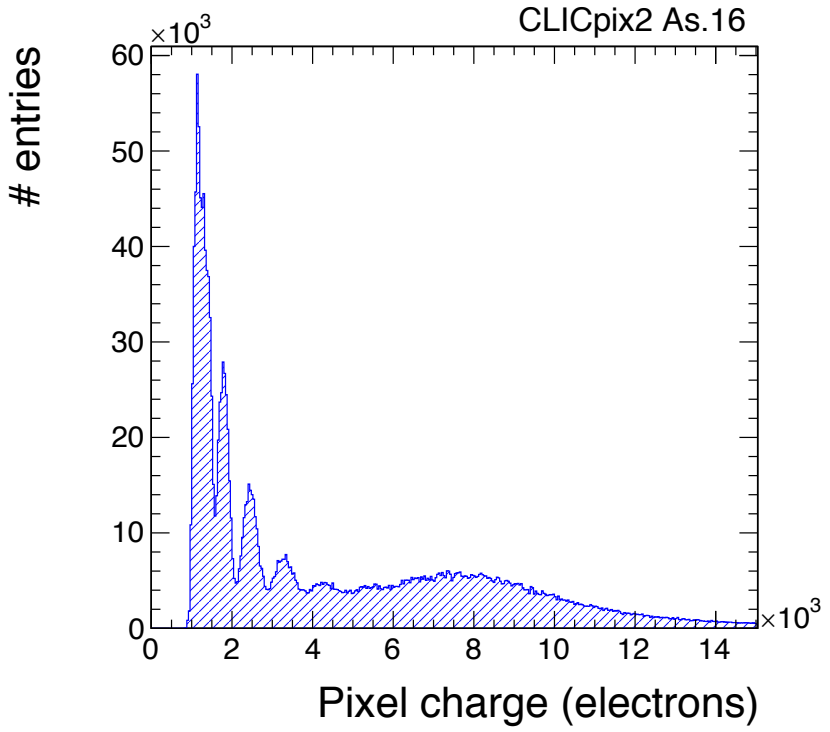


Open questions

- Straight-line vs GBL track model for SPS data

Interesting and not fully understood why straight-line track model caused systematic 1um shift in Y in simulations:

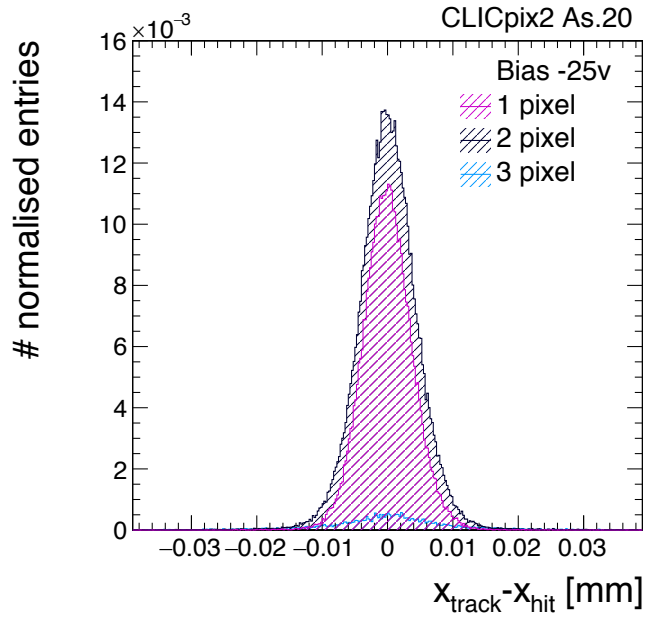
- along Y, not X, and on um scale at the DUT position
- makes visible difference in reconstructed simulation despite kink angles of GBL tracks being near 0
- for CLICpix2 TB data, no clear difference in Y offset when switching to GBL track model (edge pixel effect probably obscures the effect in this case)

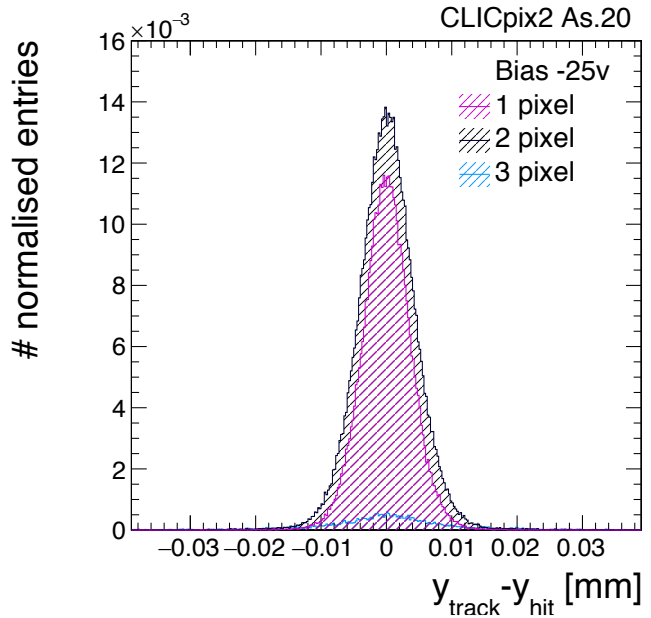
Open questions

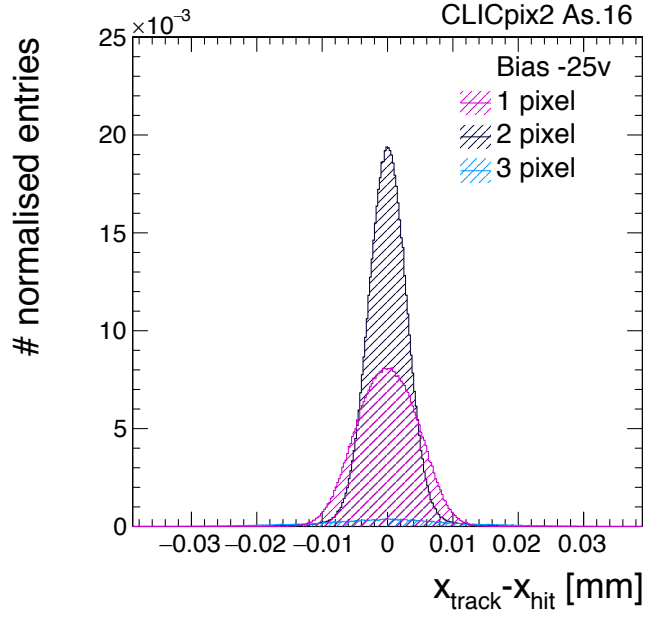
- Residual for different cluster widths:

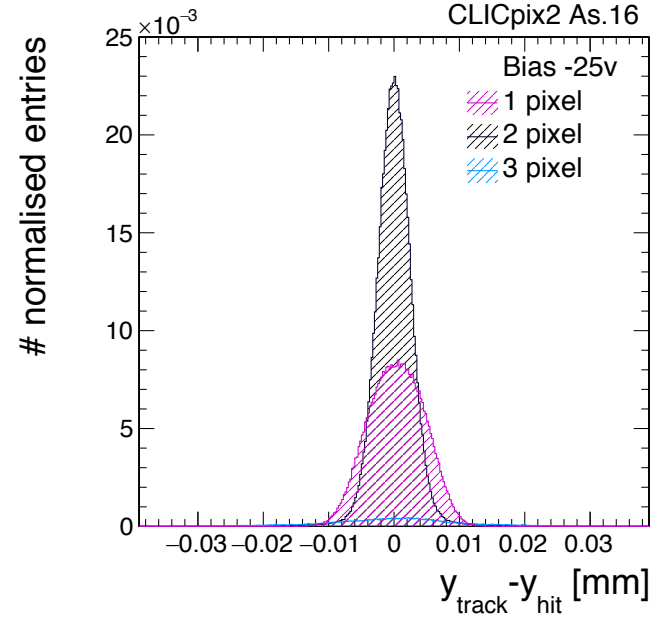
Difference in trend between As. 16 and As. 20 for 1-pixel and 2-pixel wide clusters.

normalised = divided by the total number of track associated DUT clusters









Open questions

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Difference in trend between As. 16 and As. 20 for 1-pixel and 2-pixel wide clusters.

As. 16	X (um)	Y (um)
1 pix	4.4	4.4
2 pix	3.1	2.7
3 pix	10.8	10.4

As. 20	X (um)	Y (um)
1 pix	3.8	3.7
2 pix	4.5	4.5
3 pix	14.4	14.4

normalised = divided by the total number of track associated DUT clusters

width = RMS of central 99.7%

Conclusion

- Allpix^2 simulations performed to assed rotational hypothesis for observed test-beam data trends
- Simulation results were unexpected: no asymmetry, but 1um shift in both rotated and non-rotated DUT cases
- 1um Y offset in simulated data occurred due to straight-line track model not accounting for um order scattering effects
- Majority of XY asymmetry previously observed originated from edge pixels of each assembly, now excluded from the analysis using a ROI cut
- XY residual width asymmetry now similar for both assemblies (0.1-0.3um)

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- XY residual width asymmetry now similar for both assemblies (0.1-0.3um)

→ highlights the importance of simulations in conjunction with test-beam reconstruction, and the importance of having some data for the same assembly at both facilities

Back-up