Test-beam results of CLICpix2 planar sensor assemblies

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Content

Introduction to assemblies

Test-beam analysis:

- cluster size
- cluster charge
- positional resolution
- timing resolution

Summary

CLICpix2 planar sensor assemblies

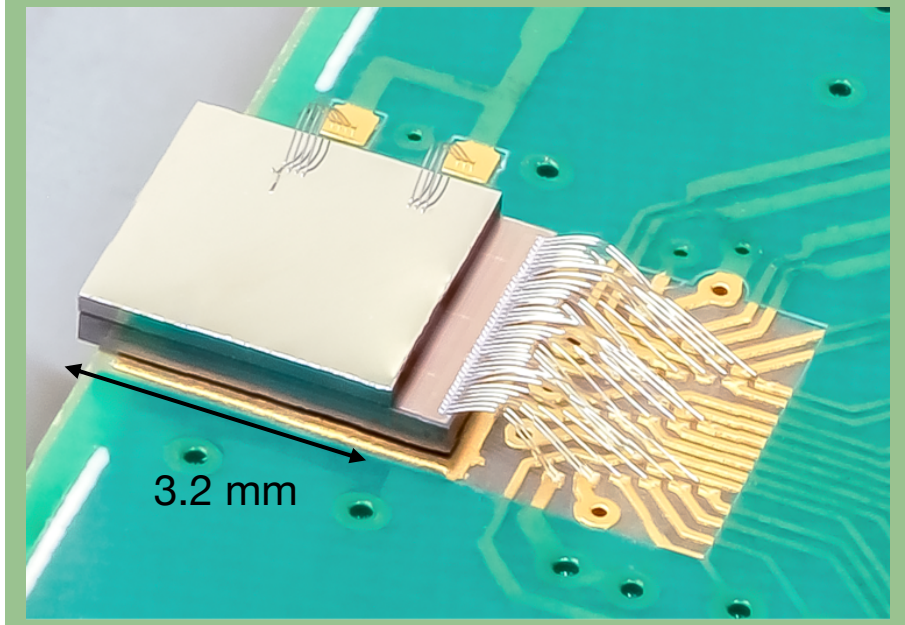
- Aim to fulfil CLIC vertex detector requirements

- Test-beam data recorded for the two highest quality assemblies:

	Interconnect yield	Sensor thickness	Nominal threshold	Pixel pitch
Assembly 16	99.6%	130μm	(769 +- 8) e	25x25μm
Assembly 20	9.7.9%	130μm	(1064 +- 9) e	25x25μm

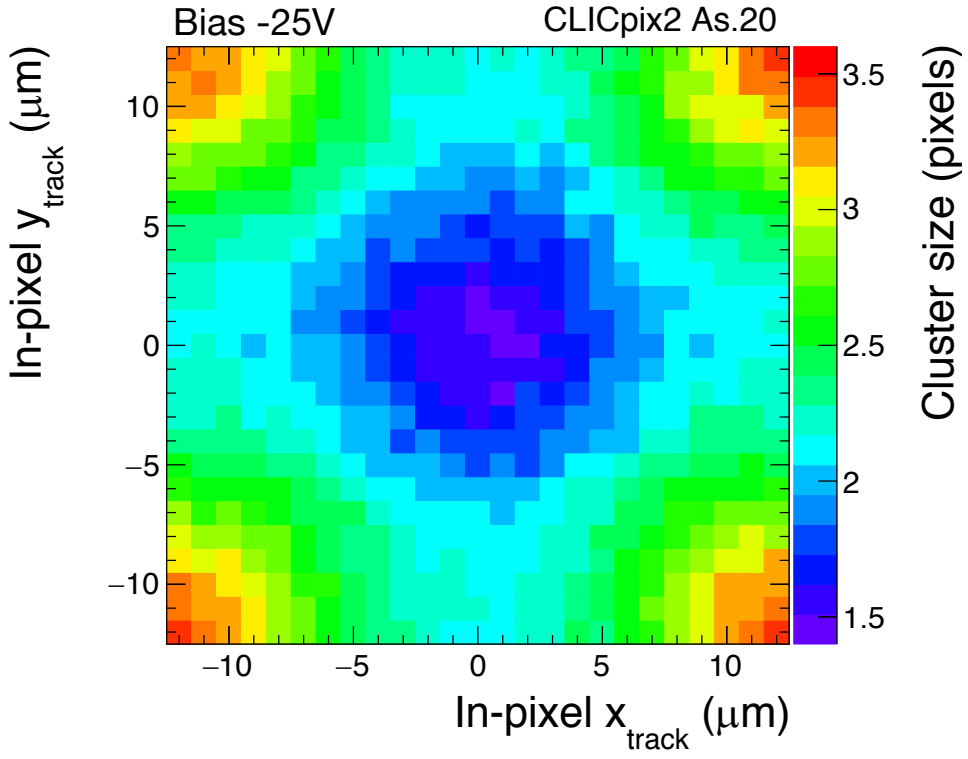
All results shown will be for an applied bias voltage of -25V, the optimal for charge sharing.

Parameter	Requirement
Single point resolution	3 μm
Material budget per layer	0.2 % X_0
Timing resolution	5 ns
Hit efficiency	99.7 - 99.9 %
Average power dissipation	< 50m Wcm^{-2}



CLICpix2 readout ASIC bump-bonded to a planar silicon sensor

In-pixel cluster size

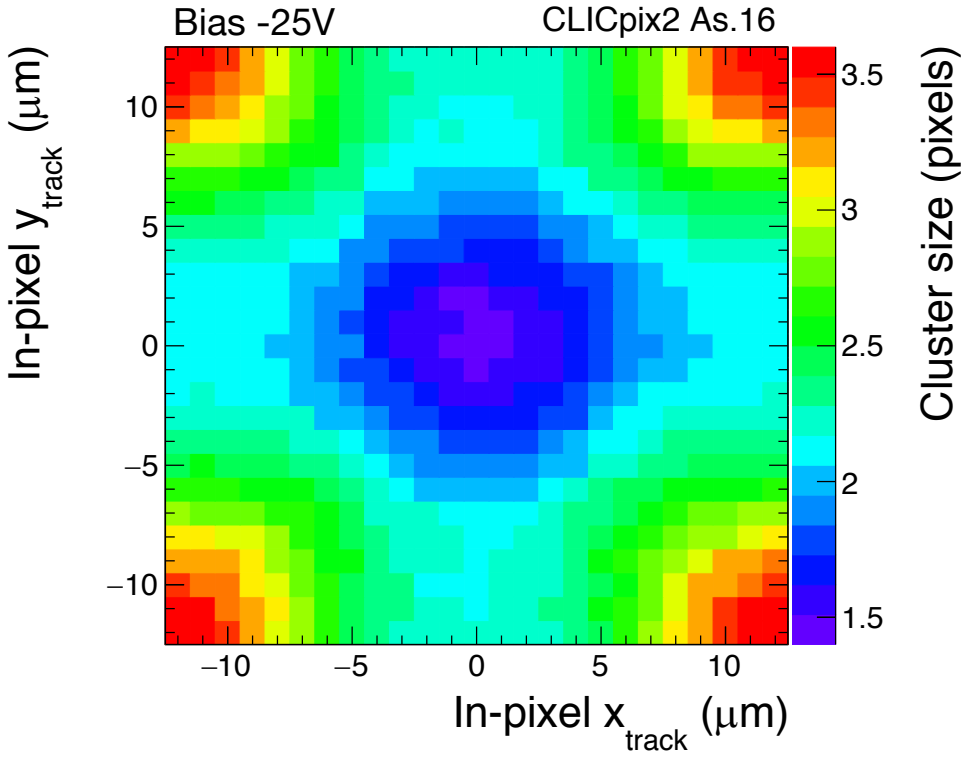


See expected symmetric pattern for As. 20:

particle incident in pixel centre
→ unlikely that diffusion causes detectable charge sharing in neighbouring
→ smaller cluster size

particle incident close to pixel edges
→ diffusion range of charges encompasses larger area of neighbouring pixels
→ larger cluster size

In-pixel cluster size



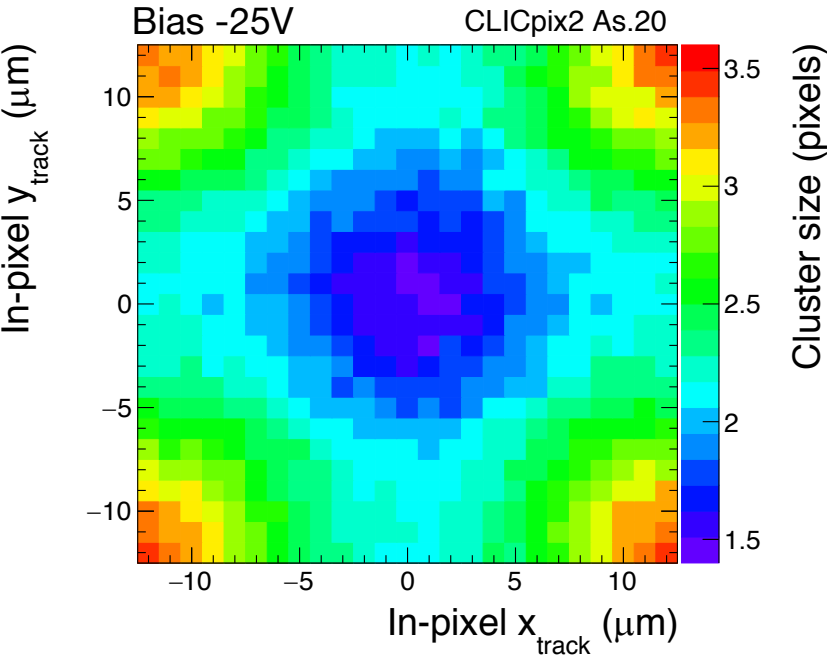
Unexpected distribution for As. 16:

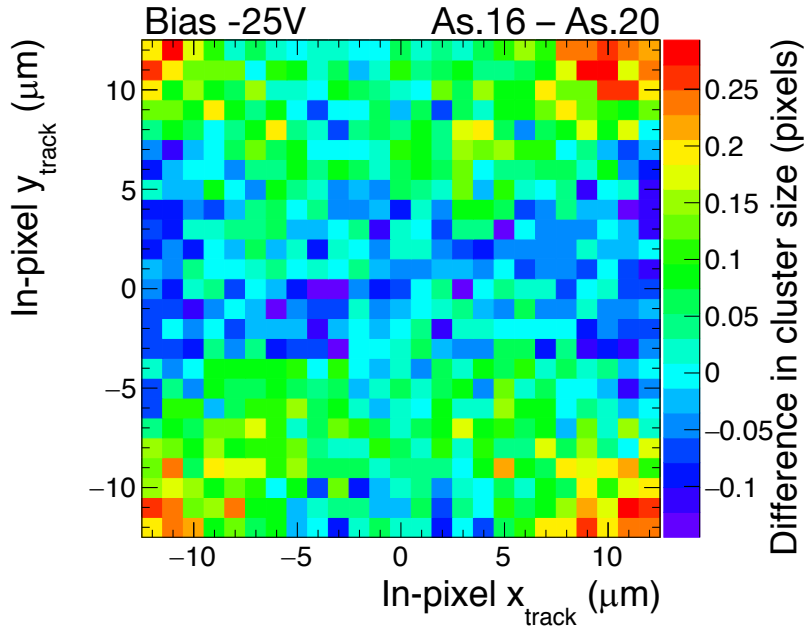
As. 16 has XY asymmetry in in-pixel cluster size
→ not expected as have symmetric pixel pitch

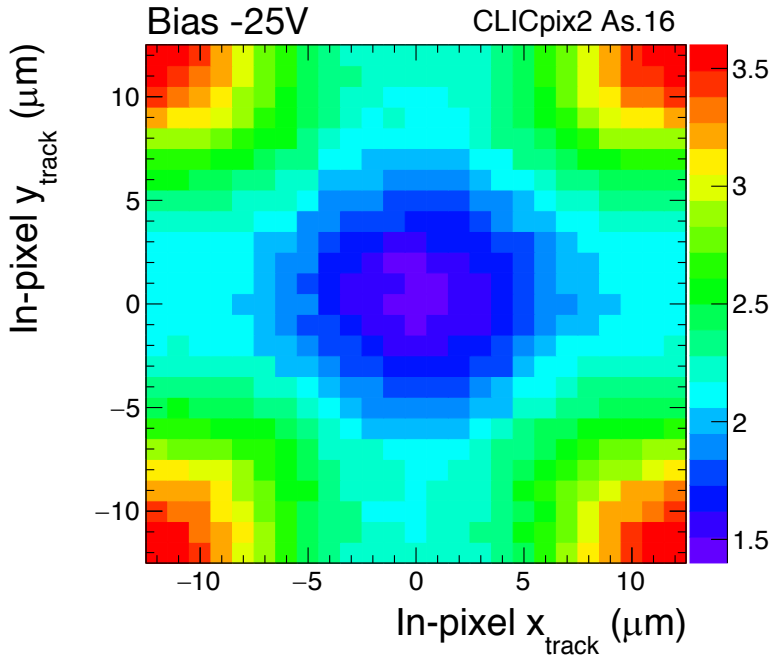
Distribution centre at (0um, 1um)
→ distribution is offset along the Y axis

When comparing the assemblies:

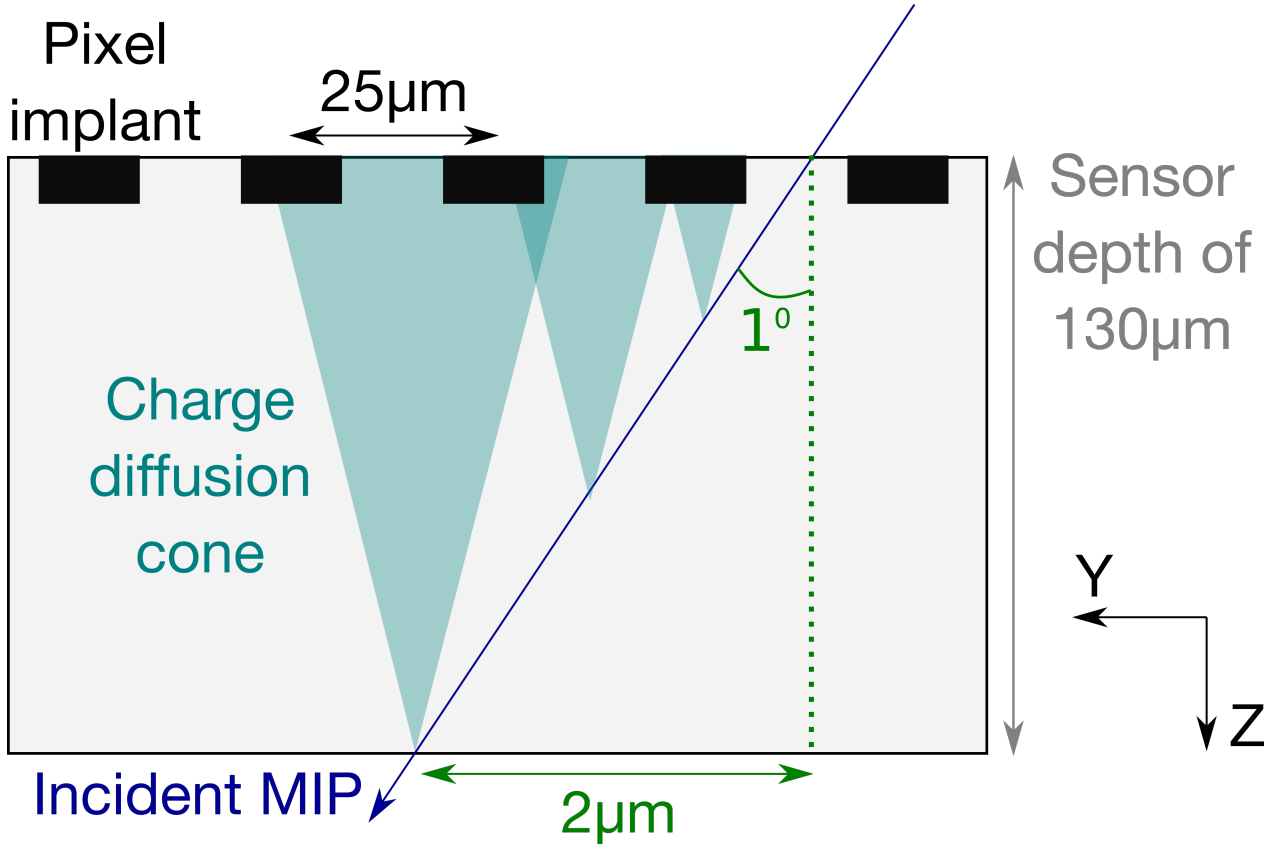
- As. 16 X axis has smaller cluster sizes than As. 20 X axis
- As. 16 Y axis has larger cluster sizes than As. 20 Y axis







Rotations and charge sharing



As. 16 rotated by 1deg around X axis from alignment

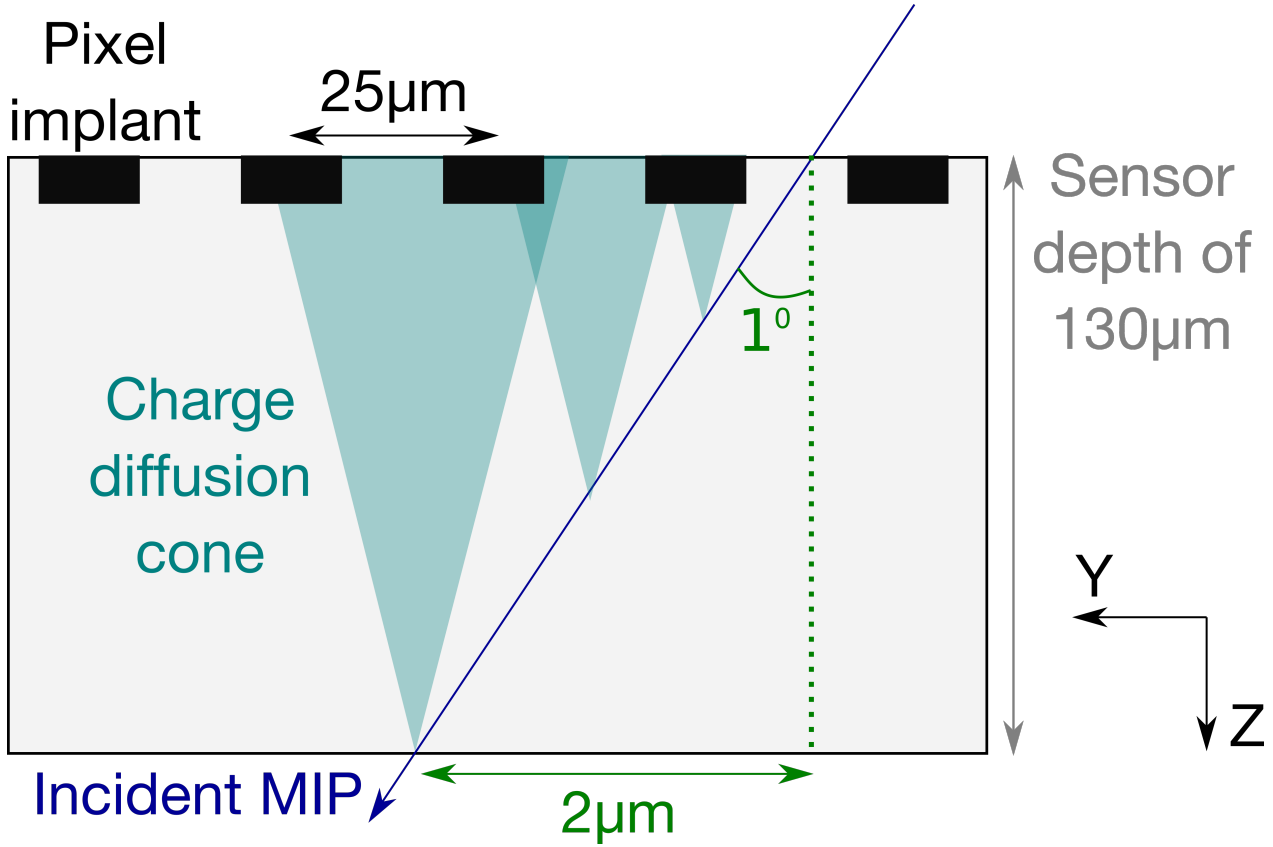
By geometry (see sketch) charges deposited at different points along Y axis over 2um range, significant effect as 8% of the pixel pitch

- → Angle increases likelihood of above-threshold signals along Y axis.

But charge carriers diffuse over a wider area of the pixel matrix, significant effect as 130um>>25um

- → reduces likelihood that signal induced on each pixel is above threshold

Rotations and charge sharing



For the Y axis:

rotation increases likelihood of above-threshold signals

large diffusion decreases likelihood of above-threshold signals

→ overall effect is larger cluster sizes

For X axis:

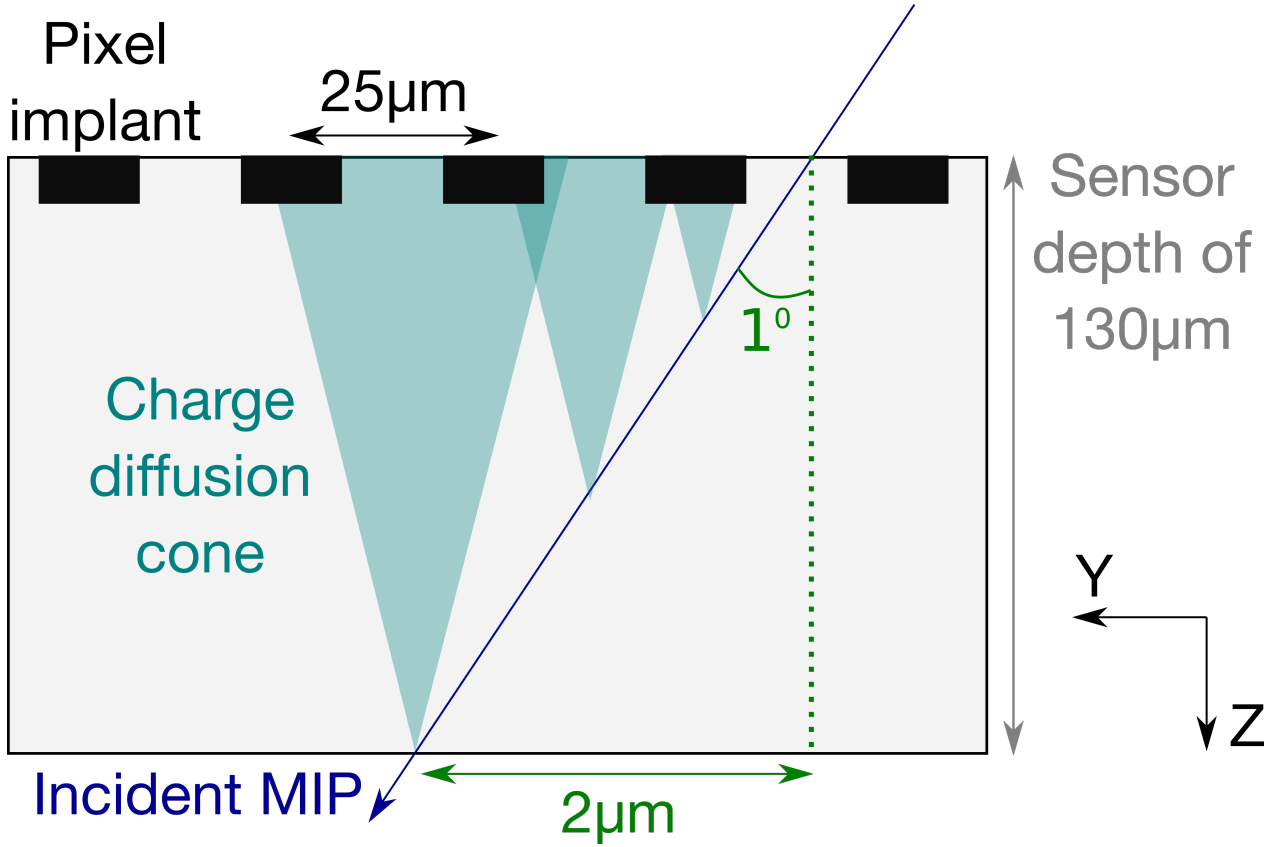
no rotation

large diffusion decreases likelihood of above-threshold signals

→ overall effect is smaller cluster sizes to be smaller.

→ consistent with the in-pixel cluster size distribution observed for assembly 16

Rotations and charge sharing



Why a 1um offset in Y?

Charges deposited over 2um range in Y, then diffuse over larger area

→position of detected charge is offset with respect to true track incidence position

Charge carriers from bottom part of sensor diffuse more, therefore signals more likely to be under threshold

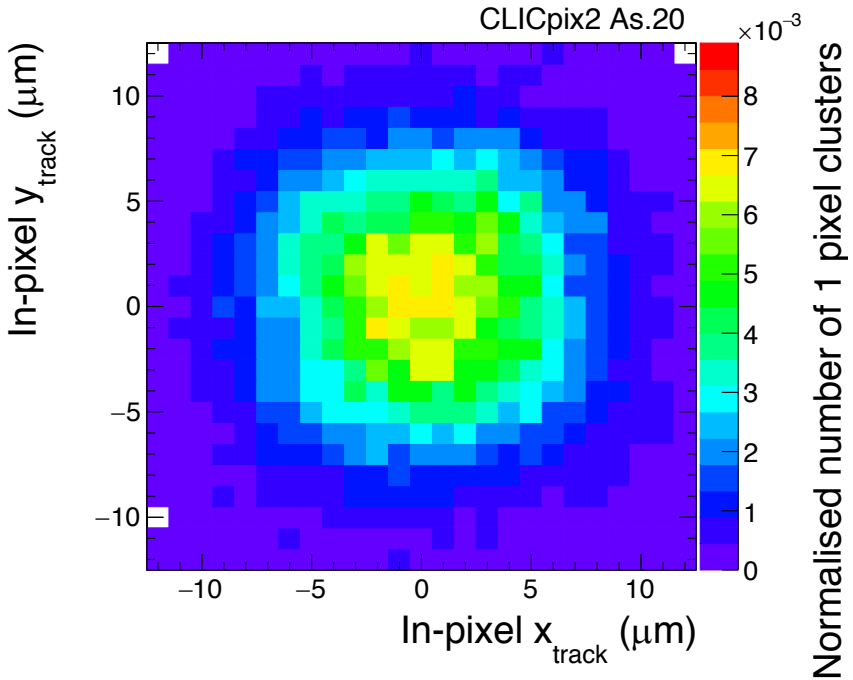
Charges deposited closer to pixel matrix diffuse less and signals more likely to be above threshold

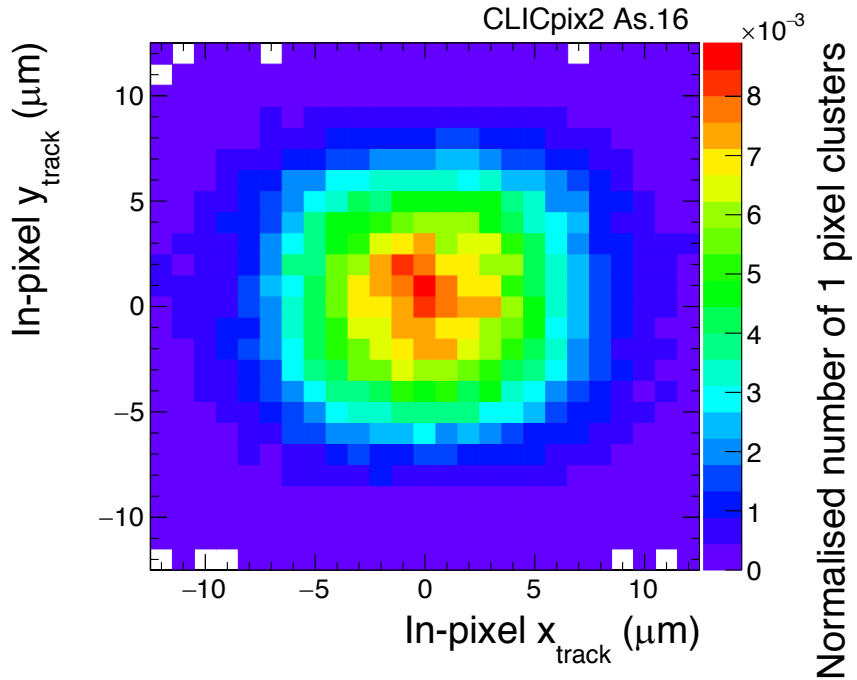
→ overall effect seen for As. 16 is 1um offset

In-pixel position of one-pixel clusters

Area within a pixel where one-pixel sized clusters occur is significantly smaller than the total pixel pitch.

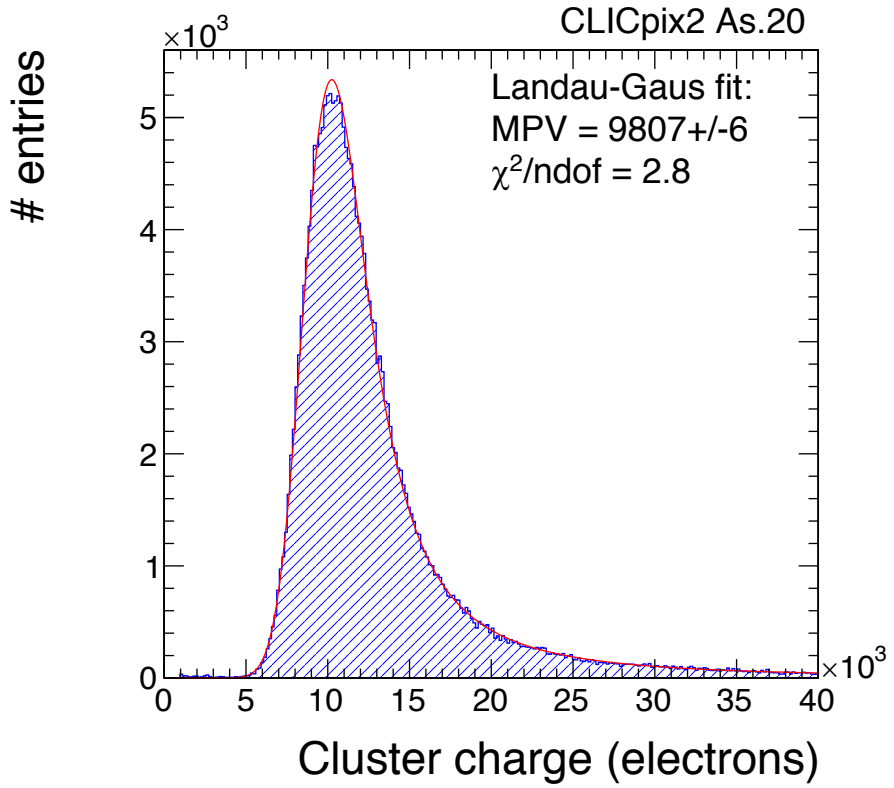
Again see XY asymmetry and 1um offset along the Y axis for assembly 16.

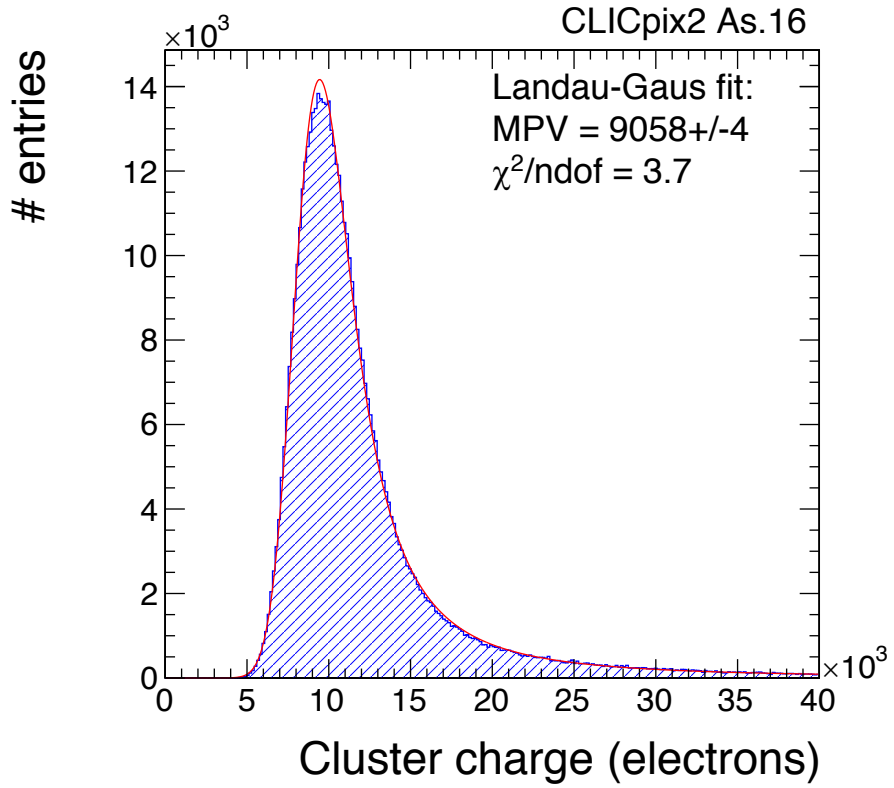




Cluster charge

Theoretically expected MIP peak = 9.6ke
As. 20 MIP peak within 2.2% of theoretical value
As. 16 peak 5.6% smaller than predicted value, despite having an ~300e lower threshold
→ suggests significant number of pixels with signals below-threshold, agreeing with rotation explanation





Spatial resolution

Spatial residual width measured as RMS of central 96%, Gaussian width also quoted for comparison.

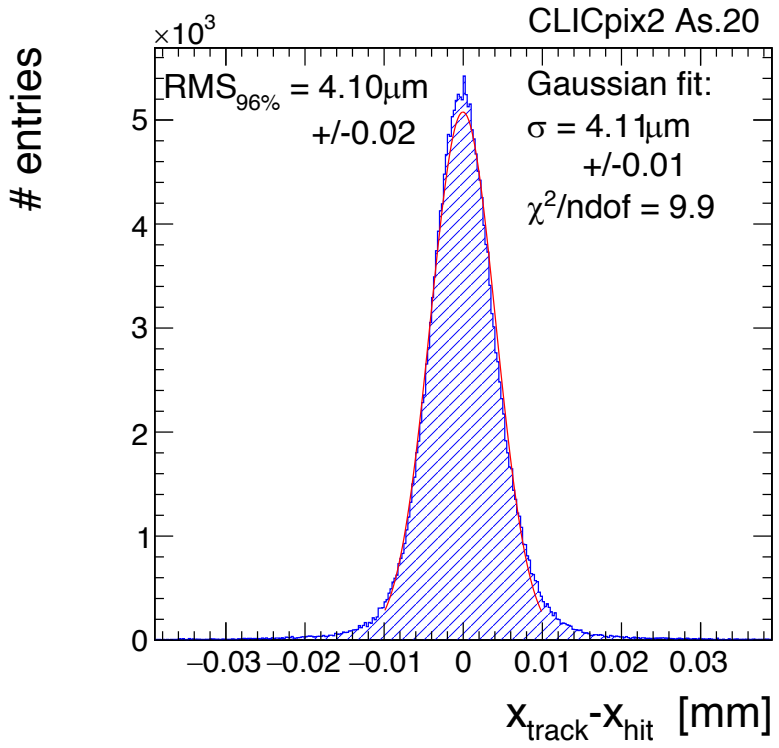
Spatial residual width measured is a combination of the intrinsic resolution of the DUT and the track resolution from the test-beam telescope

$$\sigma^2_{meas} = \sigma^2_{intrinsic} + \sigma^2_{track}$$

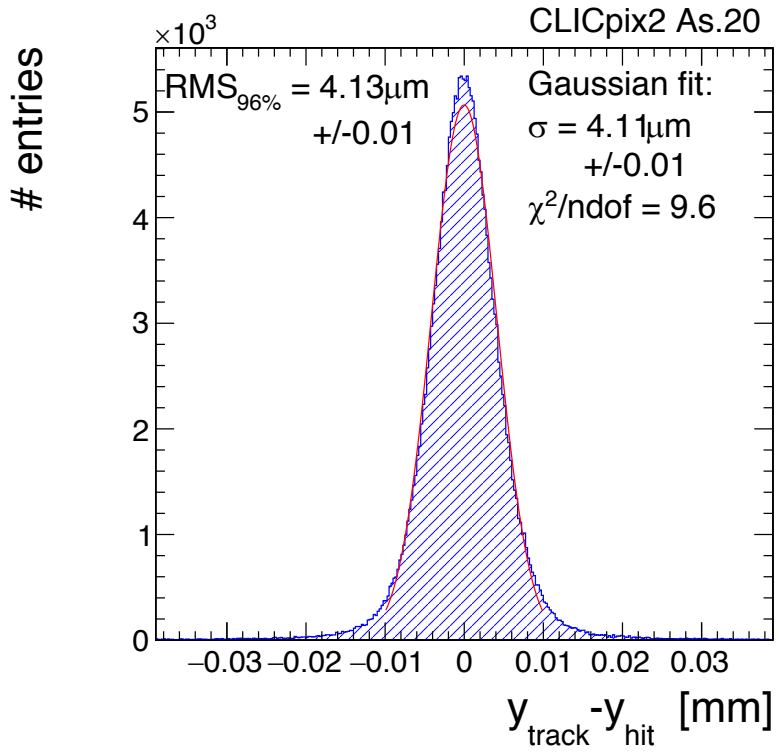
DESY telescope resolution = 2.65um, used for As. 20
CLICdp telescope resolution = 1.85um, used for As. 16

Spatial resolution

- Start with As. 20: expect intrinsic resolution of X and Y axes to be similar as no asymmetry observed.
- Quoted intrinsic resolution is (3.14+-0.02) um → close to 3um required for CLIC vertex detector, though with a sensor of 130um that has a material budget larger than the 0.2%X_0 required



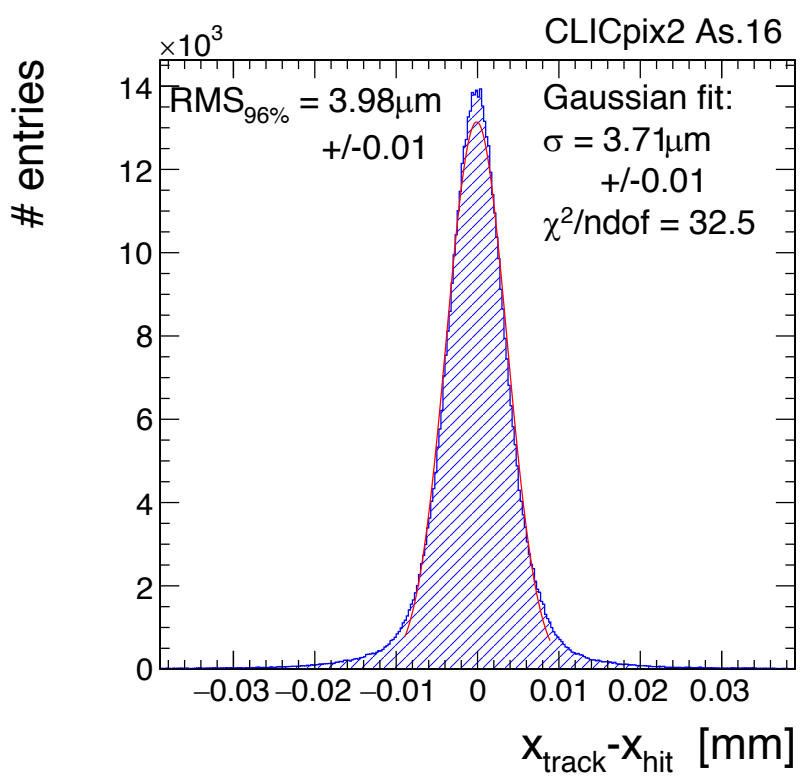
Width = (4.10 +- 0.02) um
Intrinsic resolution = (3.14 +- 0.02) um

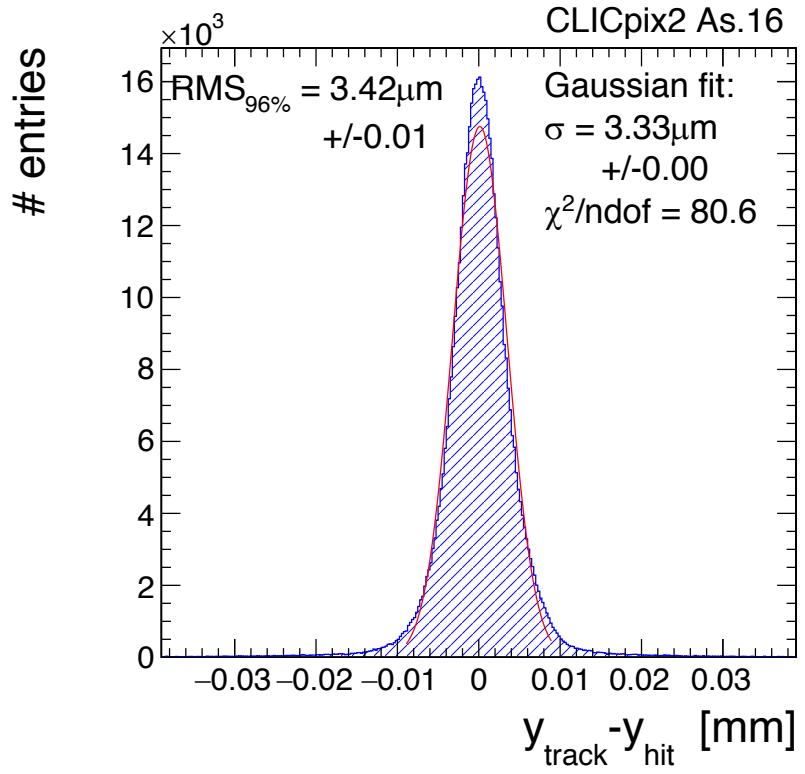


Width = (4.13 +- 0.01) um
Intrinsic resolution = (3.18 +- 0.01) um

Spatial resolution

As. 16: expect intrinsic resolution along X to be worse than As. 20, and along Y to be better than As. 20.



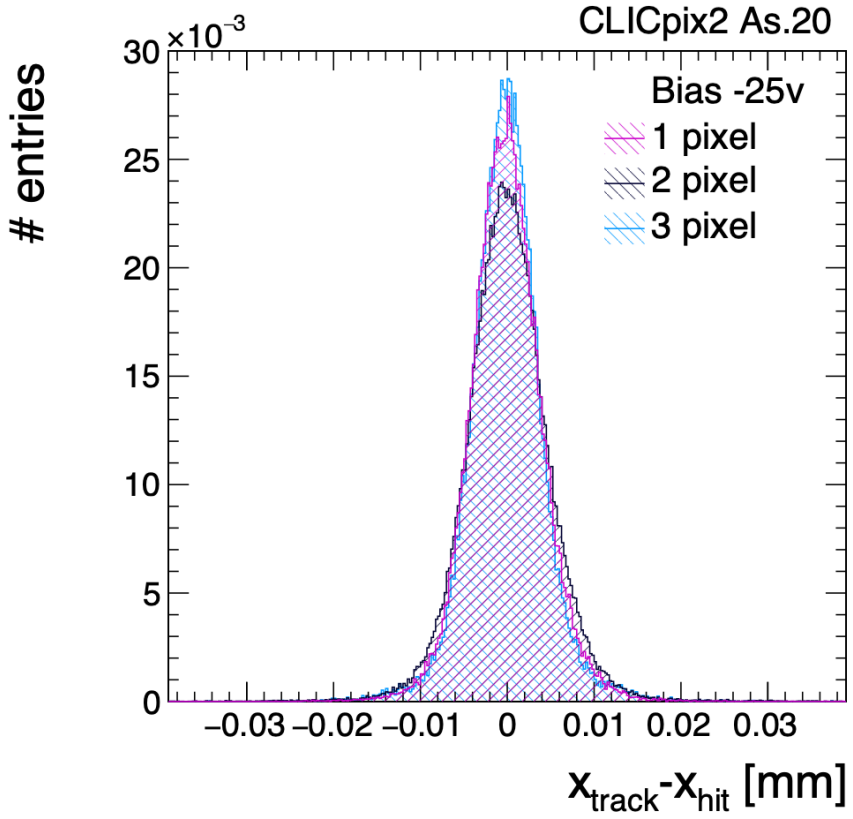


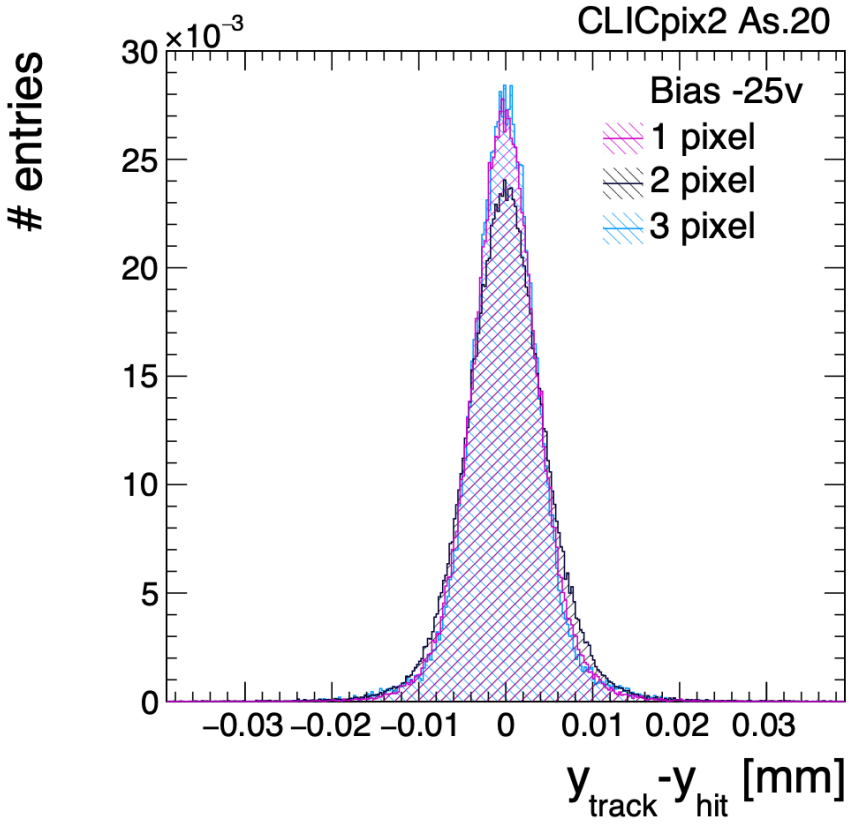
Width = (3.98 +- 0.01) um
Intrinsic resolution = 3.52um → ~8% improvement

Width = (3.42 +- 0.01) um
Intrinsic resolution = 2.88um → ~12% degradation

Spatial resolution for different projected cluster widths

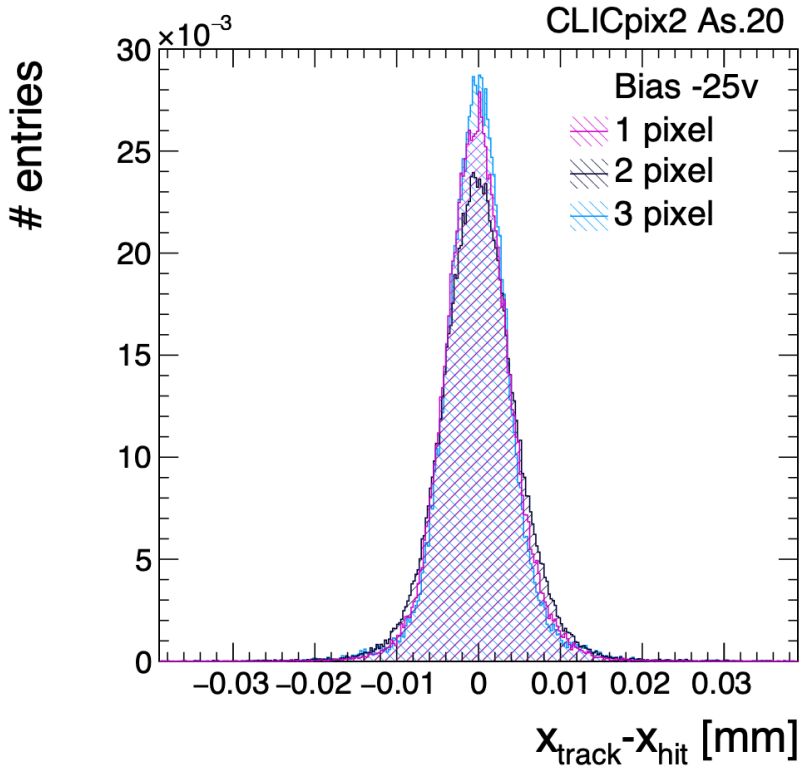
- Start with As. 20: naively expect residual width to be wider for one-pixel width clusters compared to multipixel clusters, where the latter benefits from charge weighted cluster position.
- This is not what we see: all residuals ~the same width

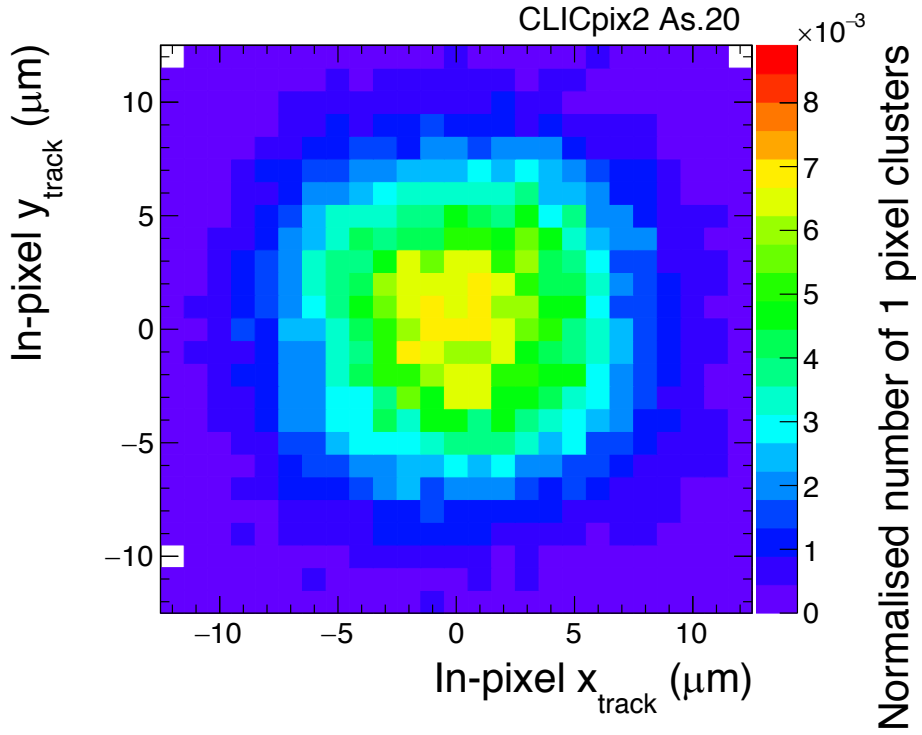




Spatial resolution for different projected cluster widths

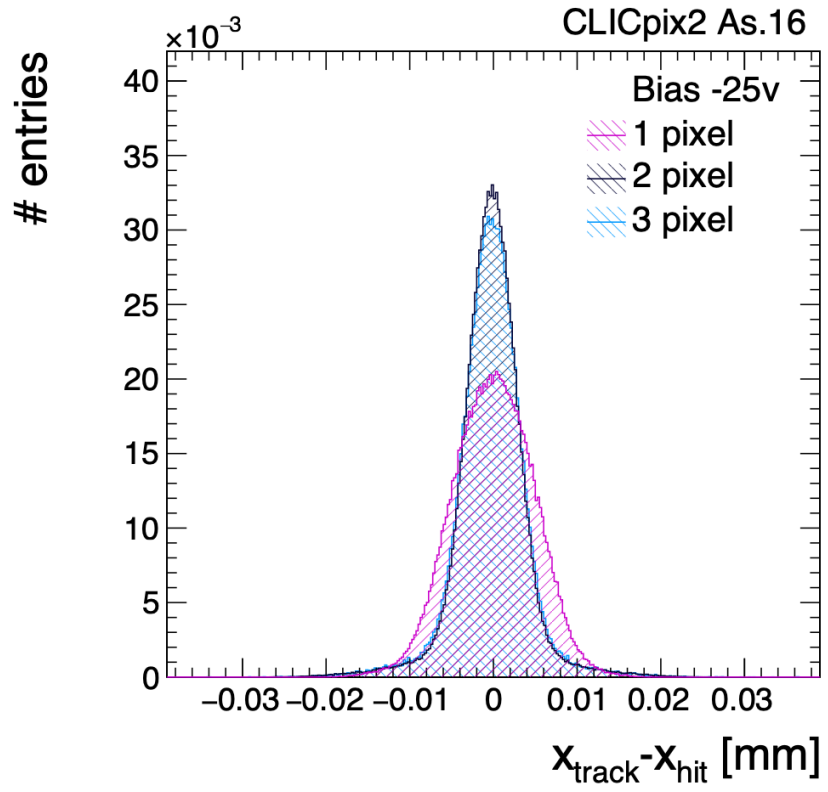
- Explanation comes back to the in-pixel distribution of one-pixel sized clusters: one-pixel clusters only occur within a small area of the total pixel, therefore the pixel pitch is effectively reduced.
- Multipixel wide clusters occur across the full 25um pixel pitch, but benefit from charge weighting
  → results in a similar width to one-pixel wide clusters

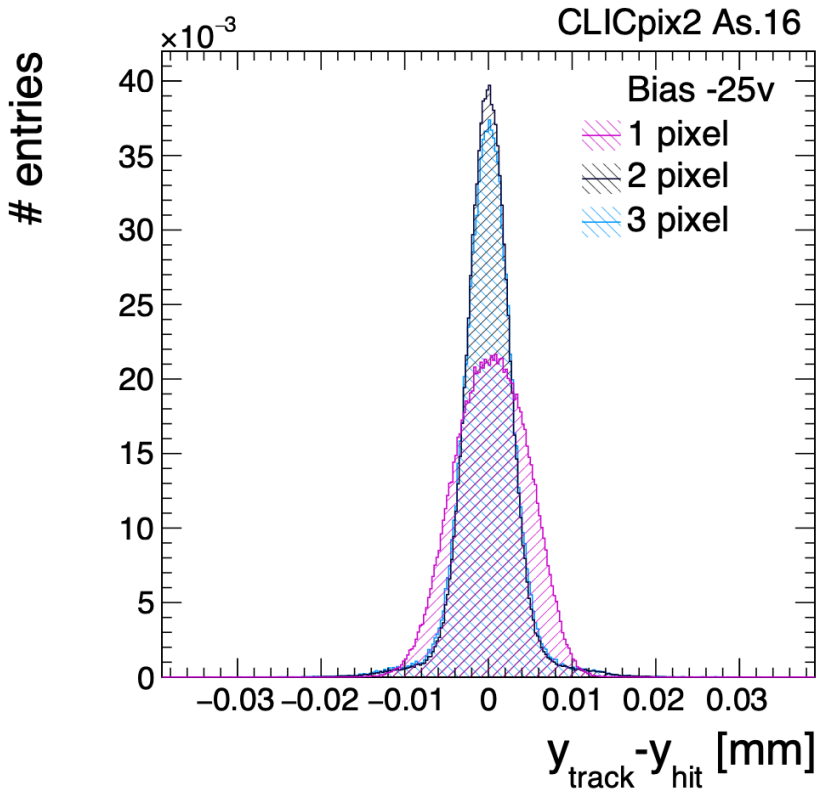




Spatial resolution for different projected cluster widths

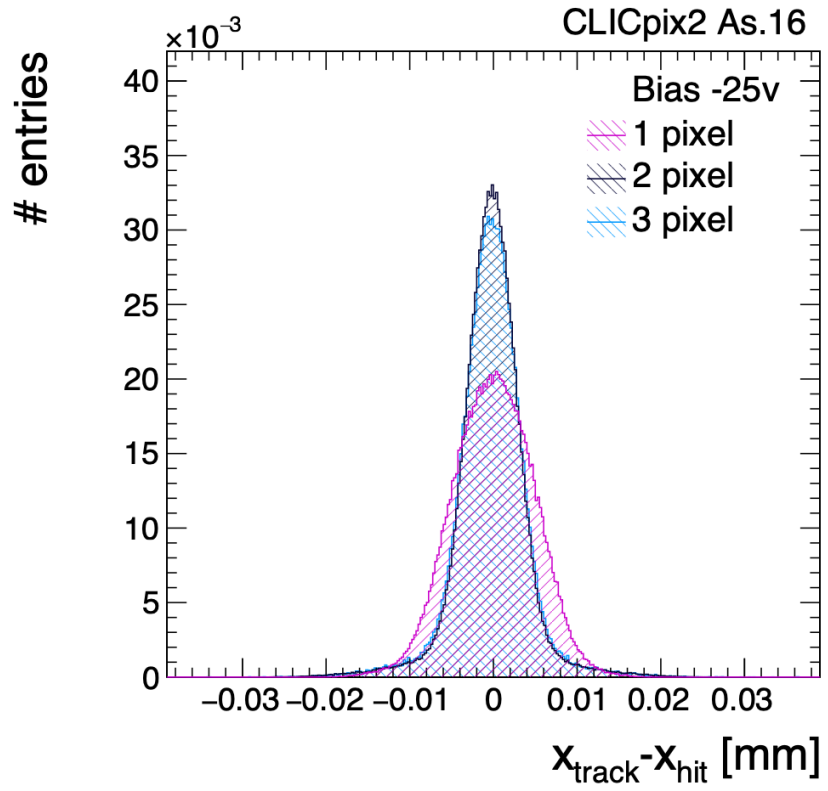
- For As. 16 we see a different trend: one-pixel wide clusters have a larger residual width than for multipixel wide clusters, along both axes

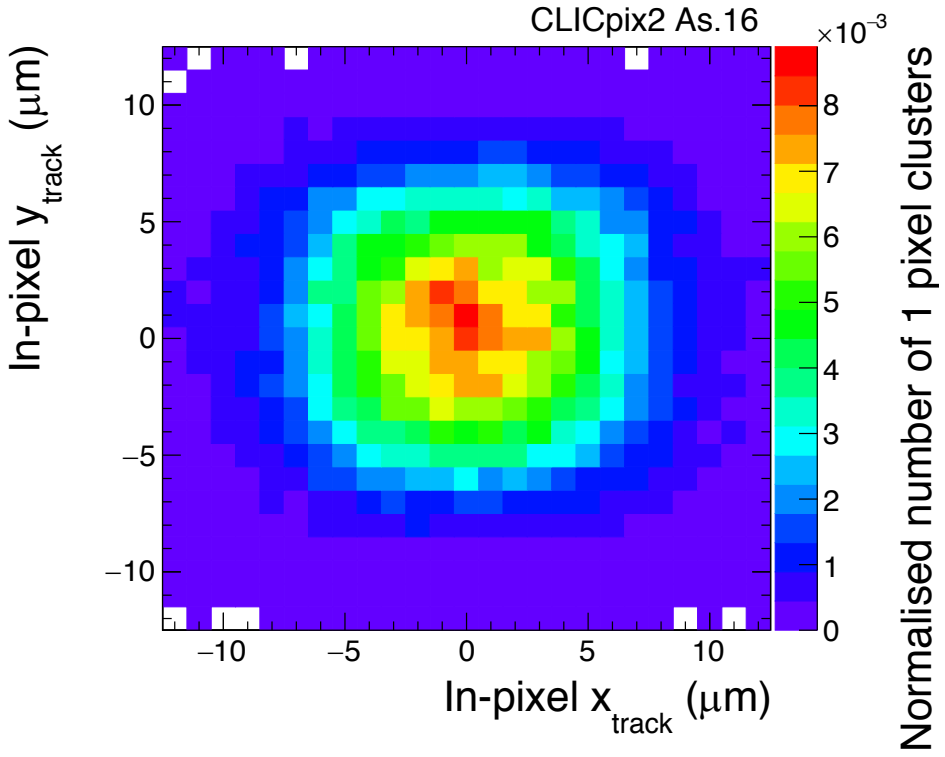




Spatial resolution for different projected cluster widths

- Along the X axis, the residual width of one-pixel wide clusters is larger for As.16 than for As.20
- This makes sense as the effective pixel pitch for one-pixel wide clusters is larger





Spatial resolution for different projected cluster widths

- Effective pixel pitch is smaller along the Y axis of As.16, so why is one-pixel wide cluster residual width larger than expected?

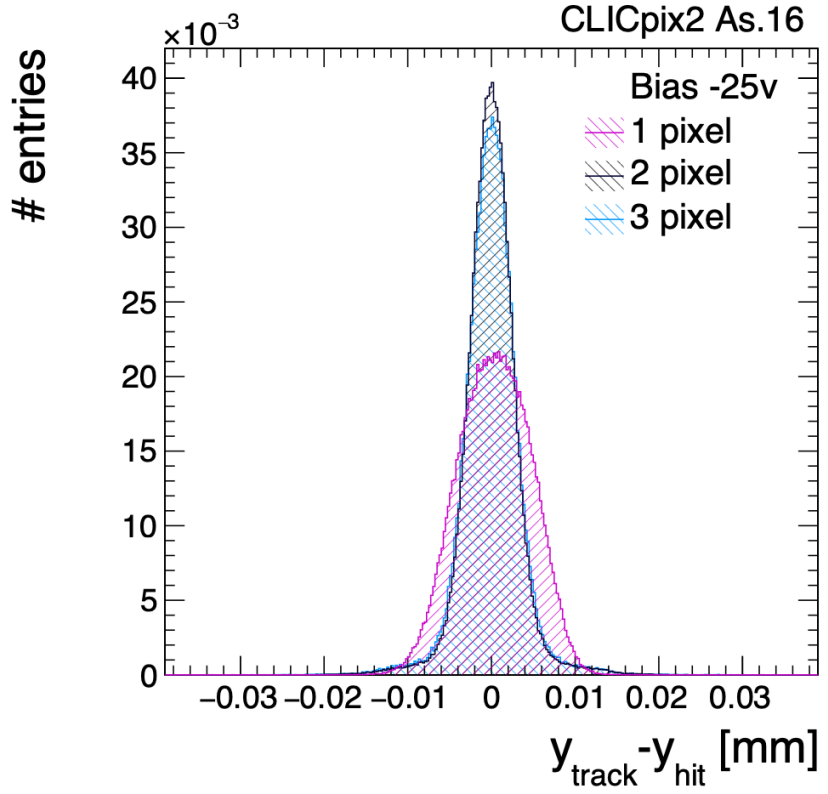
Two reasons:

1) Distribution of one-pixel wide clusters not centred at 0um.

For one-pixel wide clusters, the cluster position is always the pixel centre. For multipixel wide clusters, charge information used to weight cluster position closer to true track position

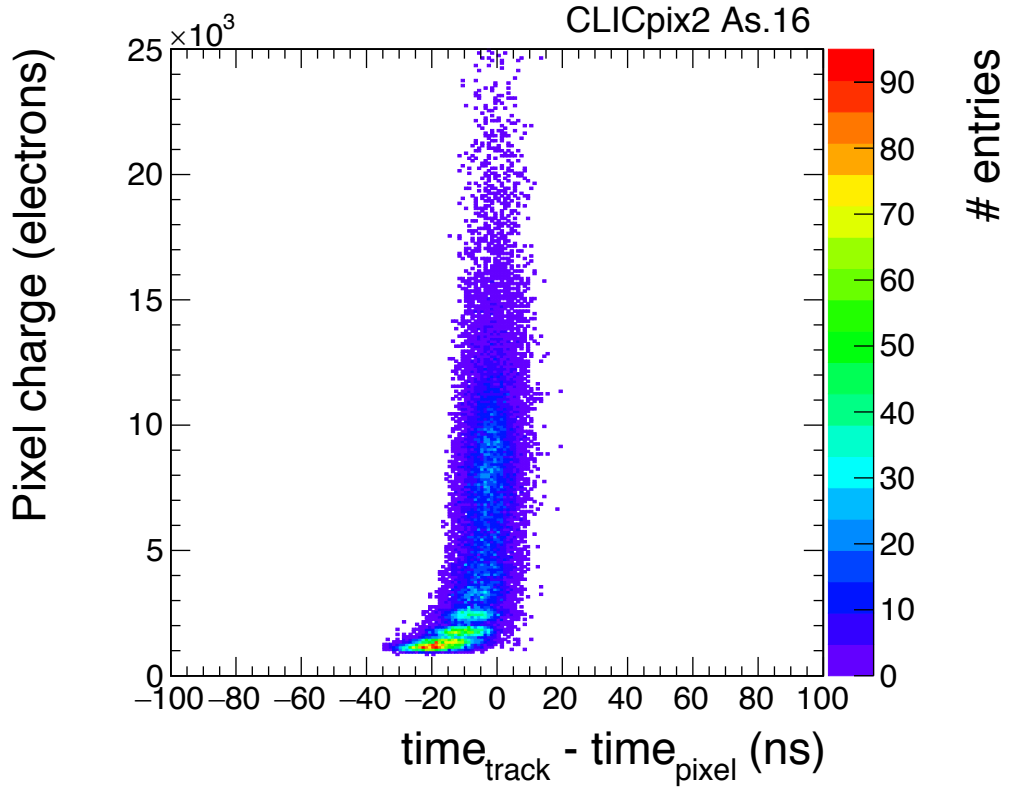
2) The offset described is not constant.

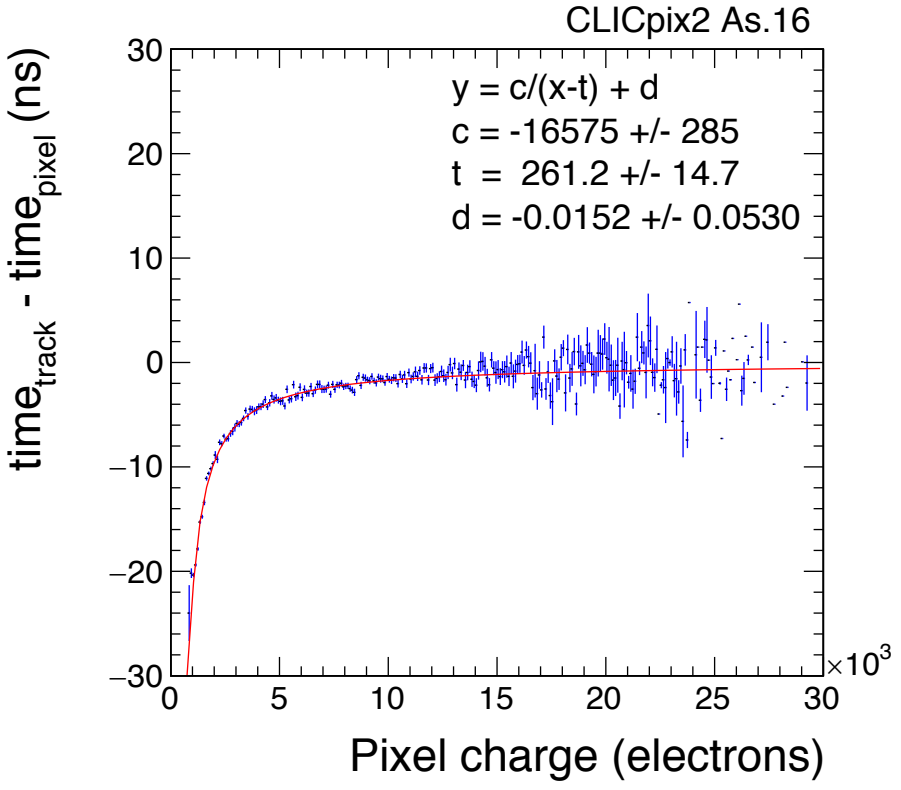
Average offset is 1 μm but this value fluctuates, causing a broader distribution.



Timing residual

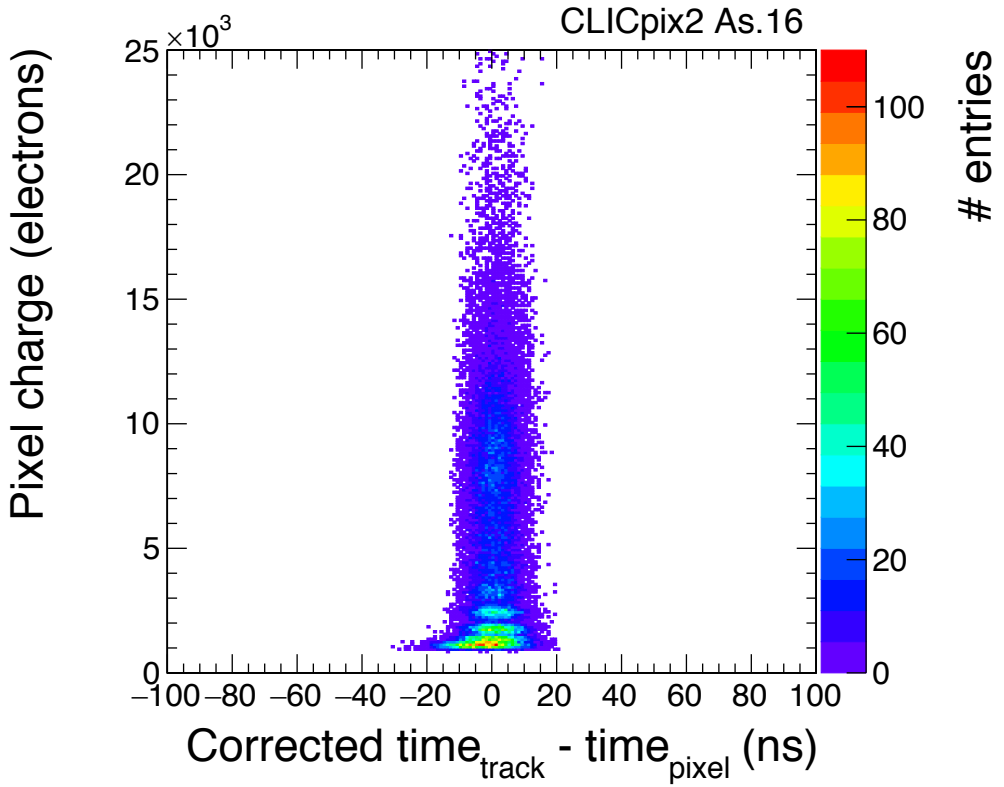
Time-walk correction curve for CLICpix2 planar sensor assembly test-beam data taken in ToT+ToA mode.

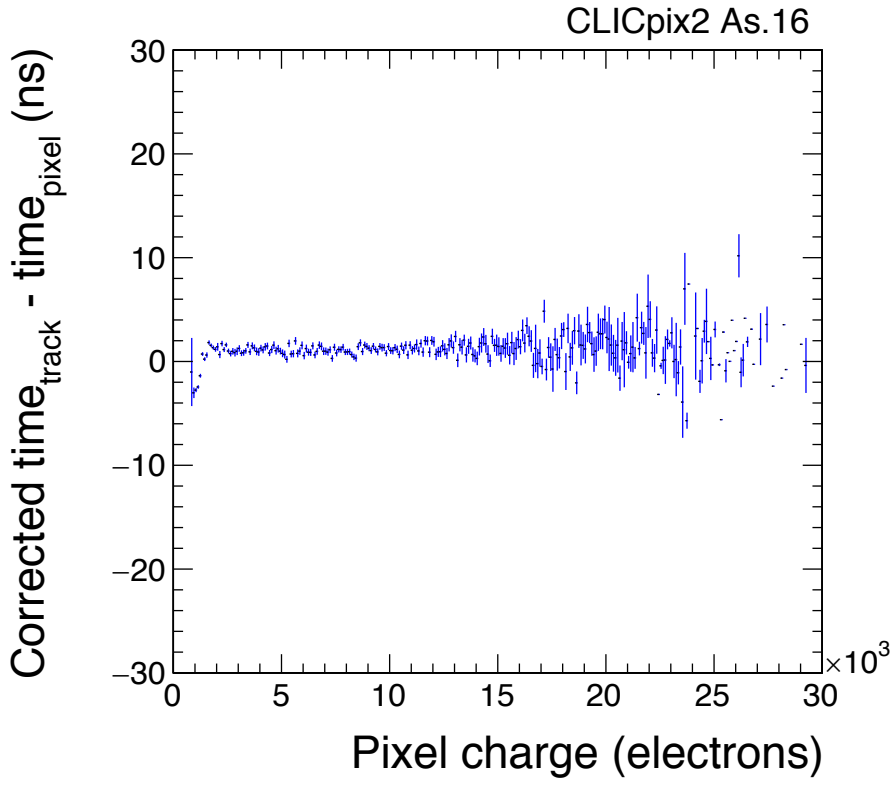




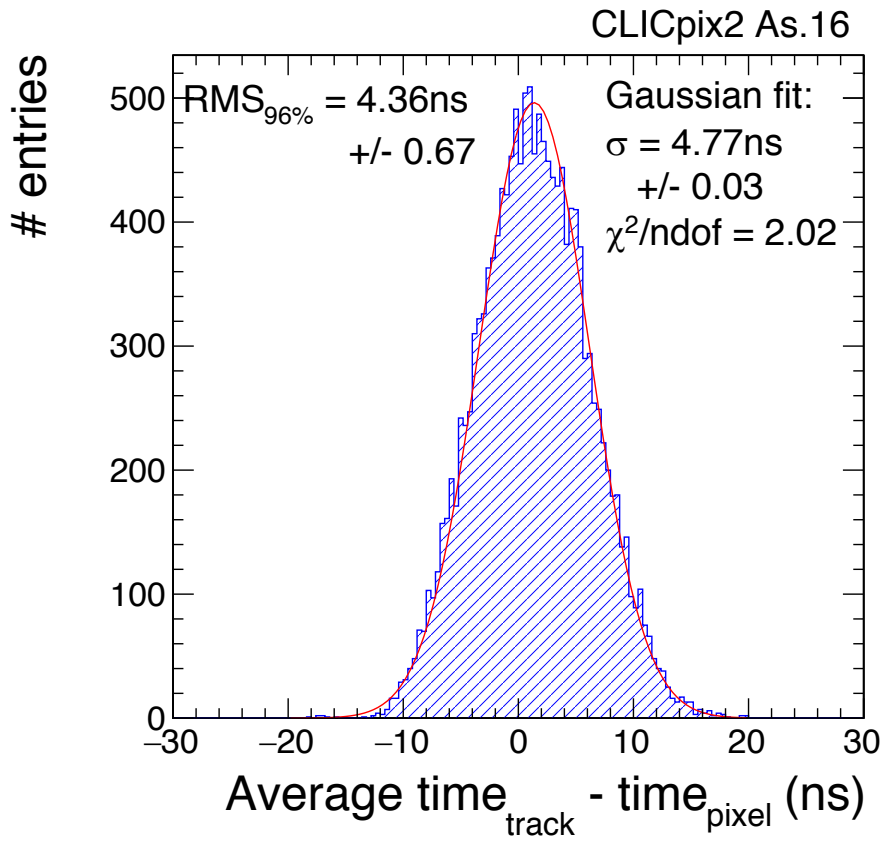
After time-walk correction

Using parameters of fit function shown, pixel time was corrected for time-walk.
Resultant distributions have reduced tails to lower time values, but a small tail to lower values still remains





Timing resolution



- Residual width measured as (4.36 +- 0.67) ns
- Mean of distribution ~0.5-1ns, explanation is currently unknown.
- Even with offset, timing resolution is under the 5ns required for the CLIC vertex detector.

Summary

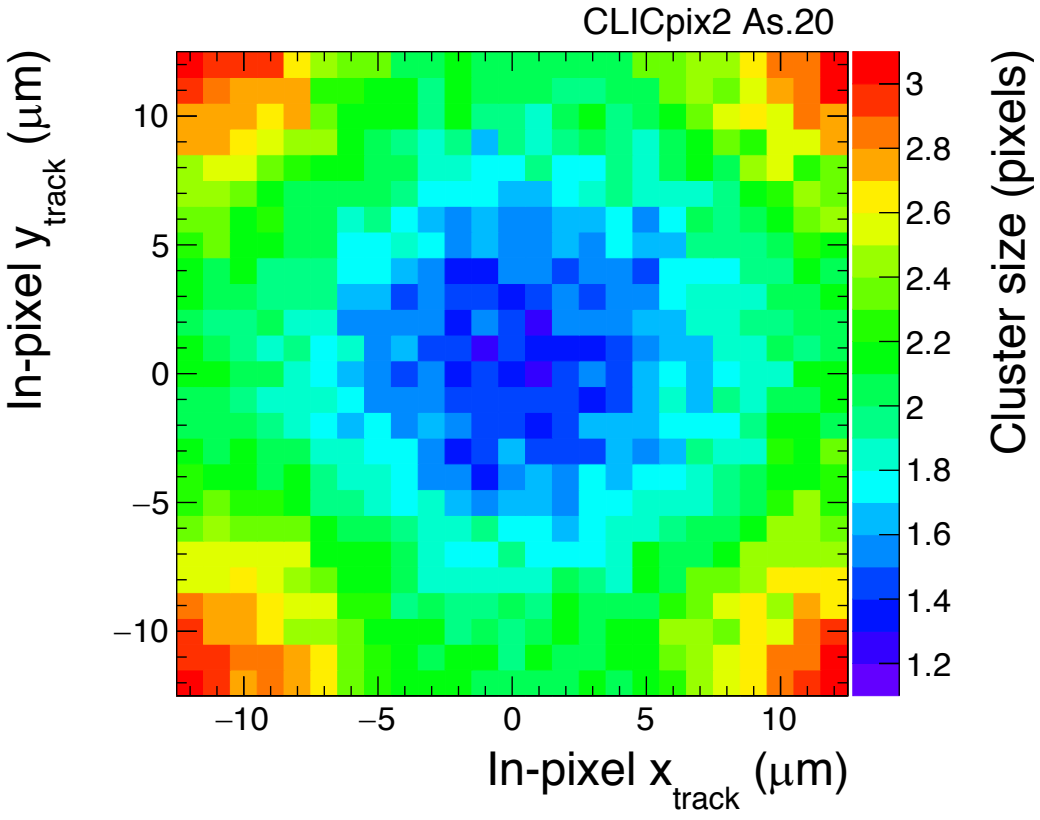
- Observed effect of a 1degree rotation of assembly 16 on the above-threshold charge sharing
- Quoted intrinsic spatial resolution of CLICpix2 planar sensor assemblies is 3.14um
- Rotation around the X axis of 1 degree improves the intrinsic spatial resolution by 8% along the Y axis, but simultaneously degrades it along the X axis by 12%.
- Timing resolution measured to be <5ns
- Efficiency (shown previously) is higher than 99.95% for optimal operating conditions

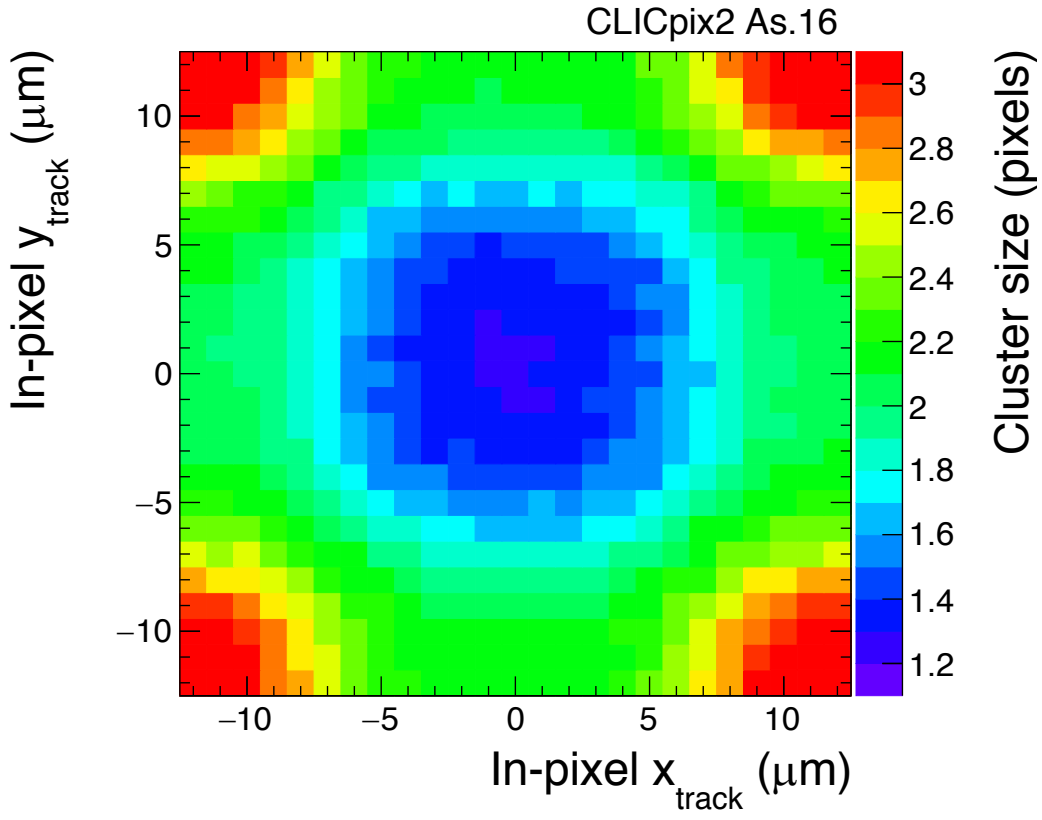
→ CLICpix2 planar sensor assemblies very close to meeting requirements of CLIC vertex detector, apart from material budget

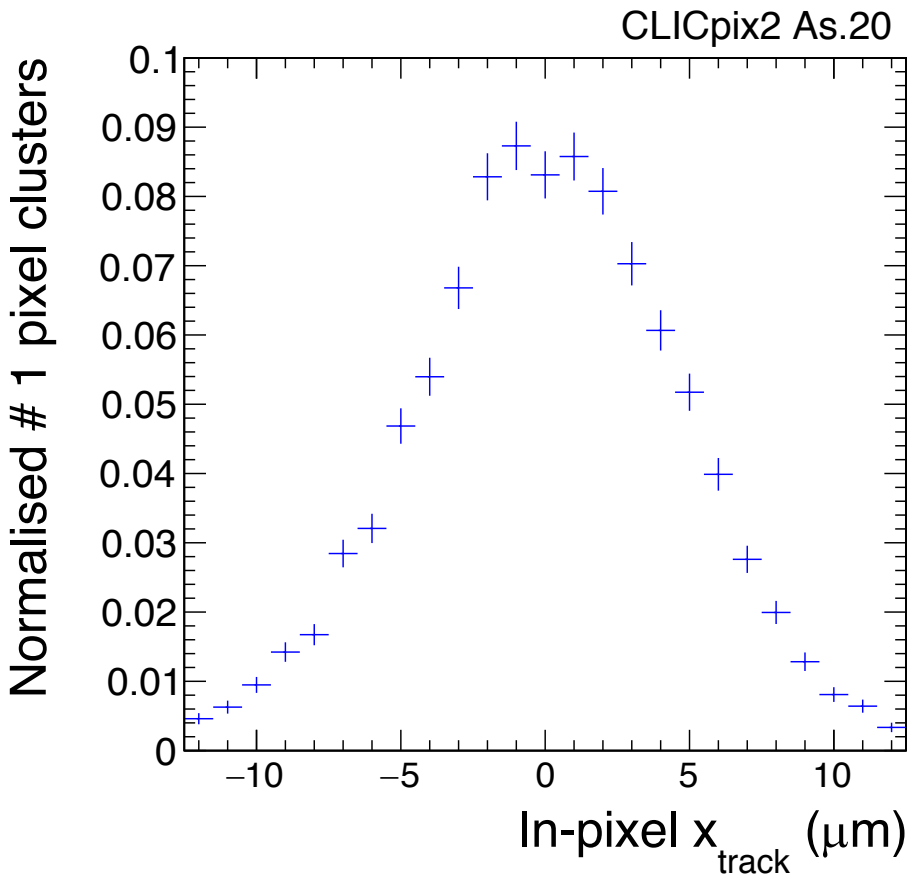
Thank you for your attention

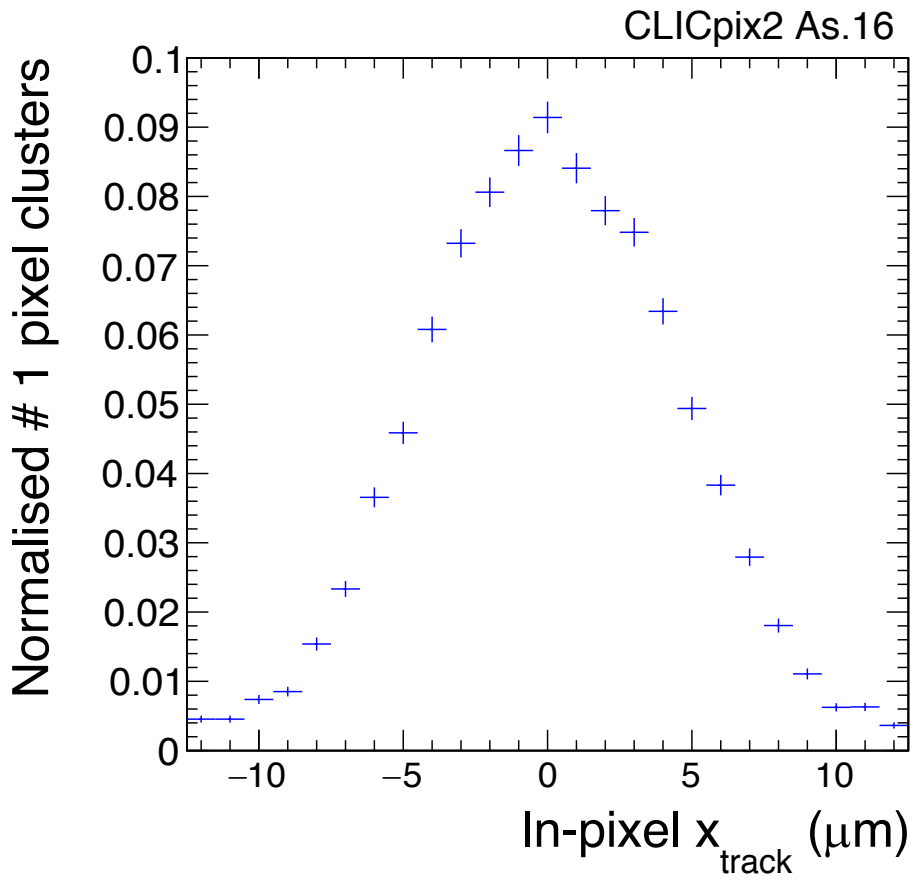
Back-up slides

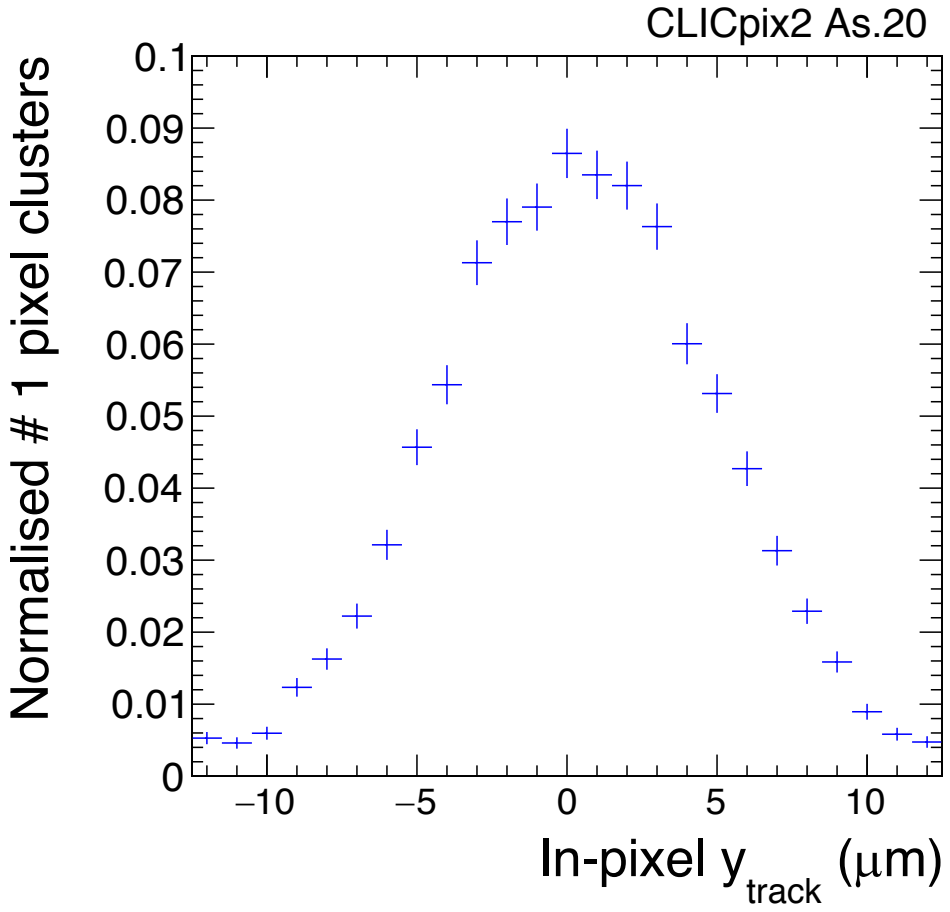
For higher bias voltage of -60V, difference between assemblies is less apparent

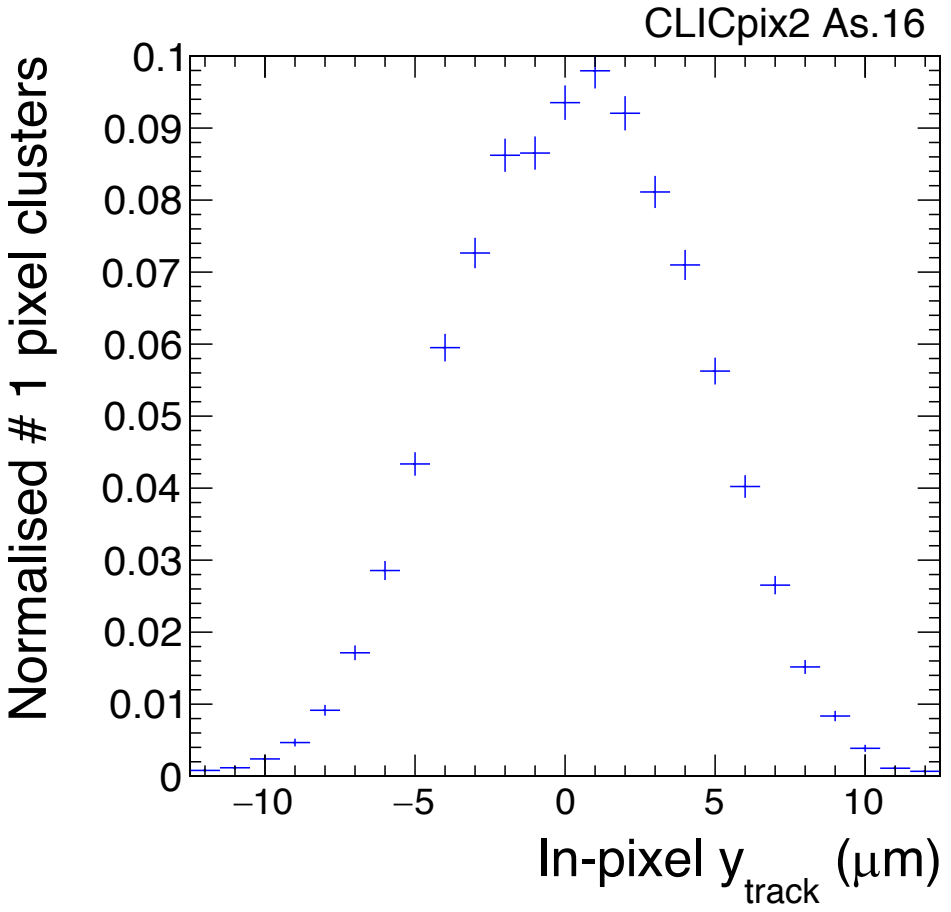


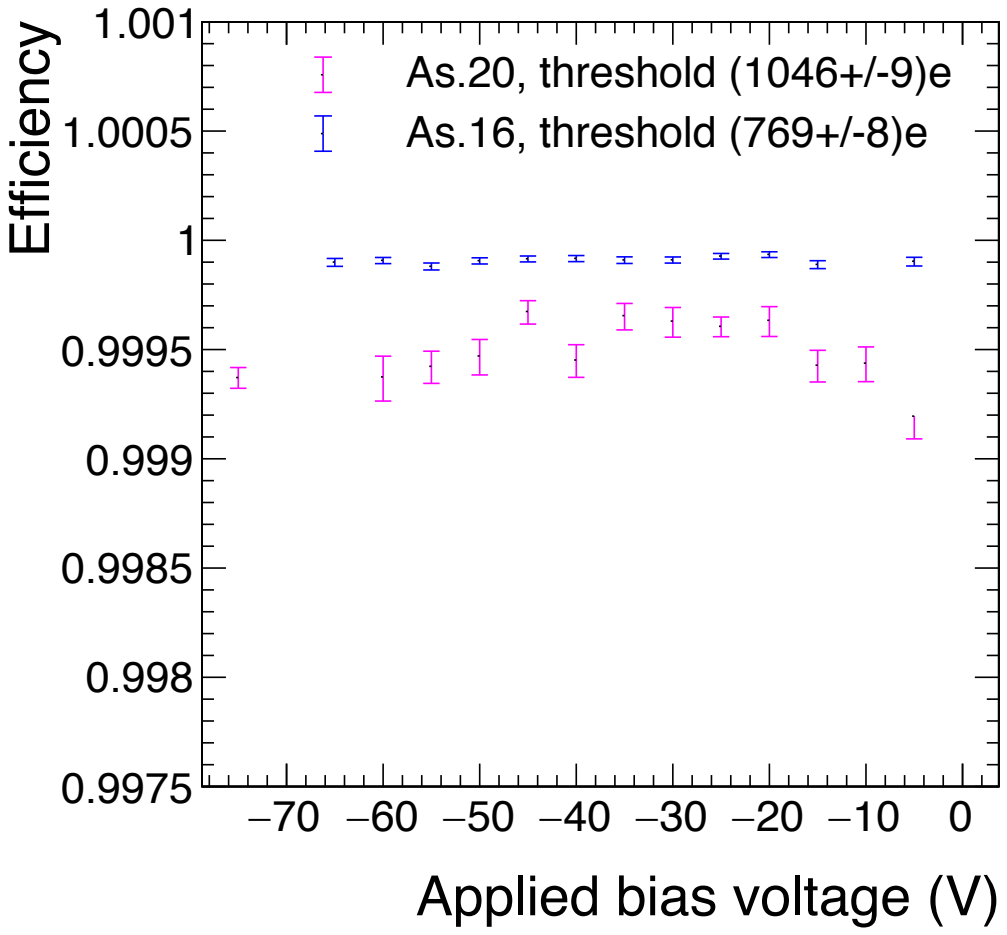


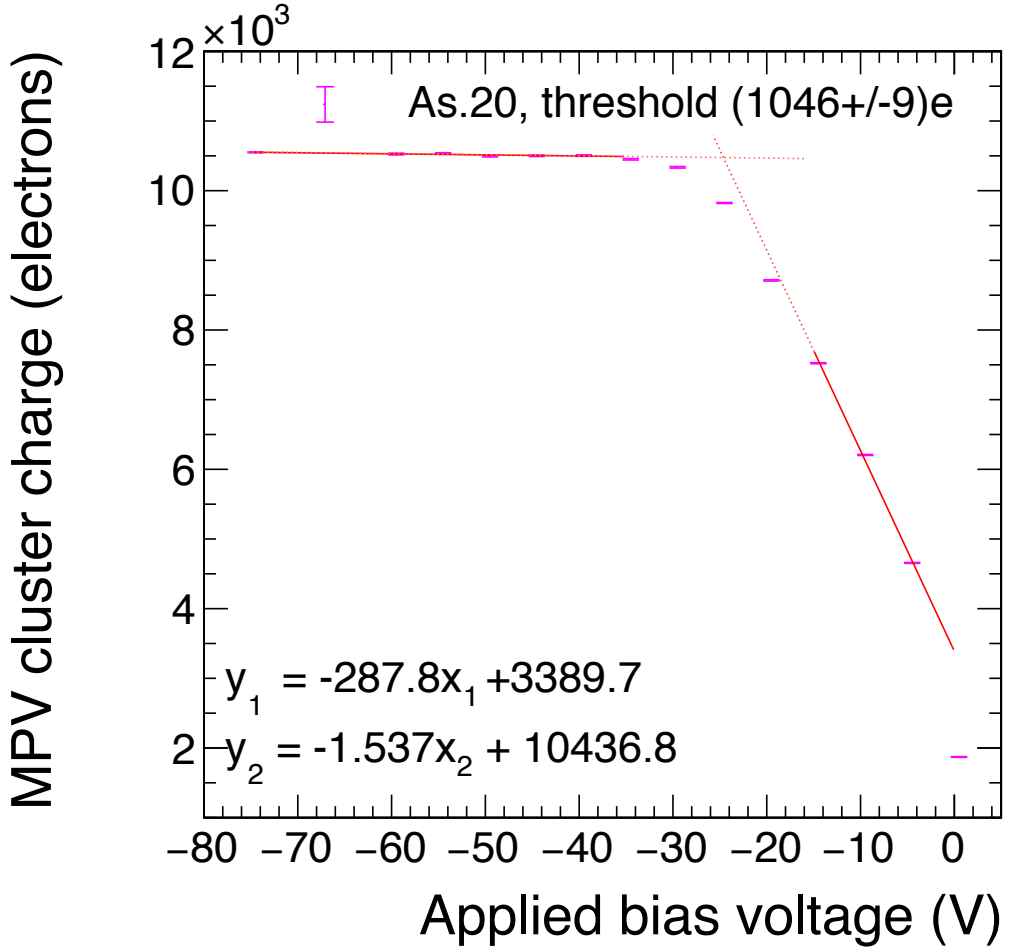

CLICpix2 As.20
Normalised # 1 pixel clusters
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−10
−5
0
5
10
In-pixel x track (μm)

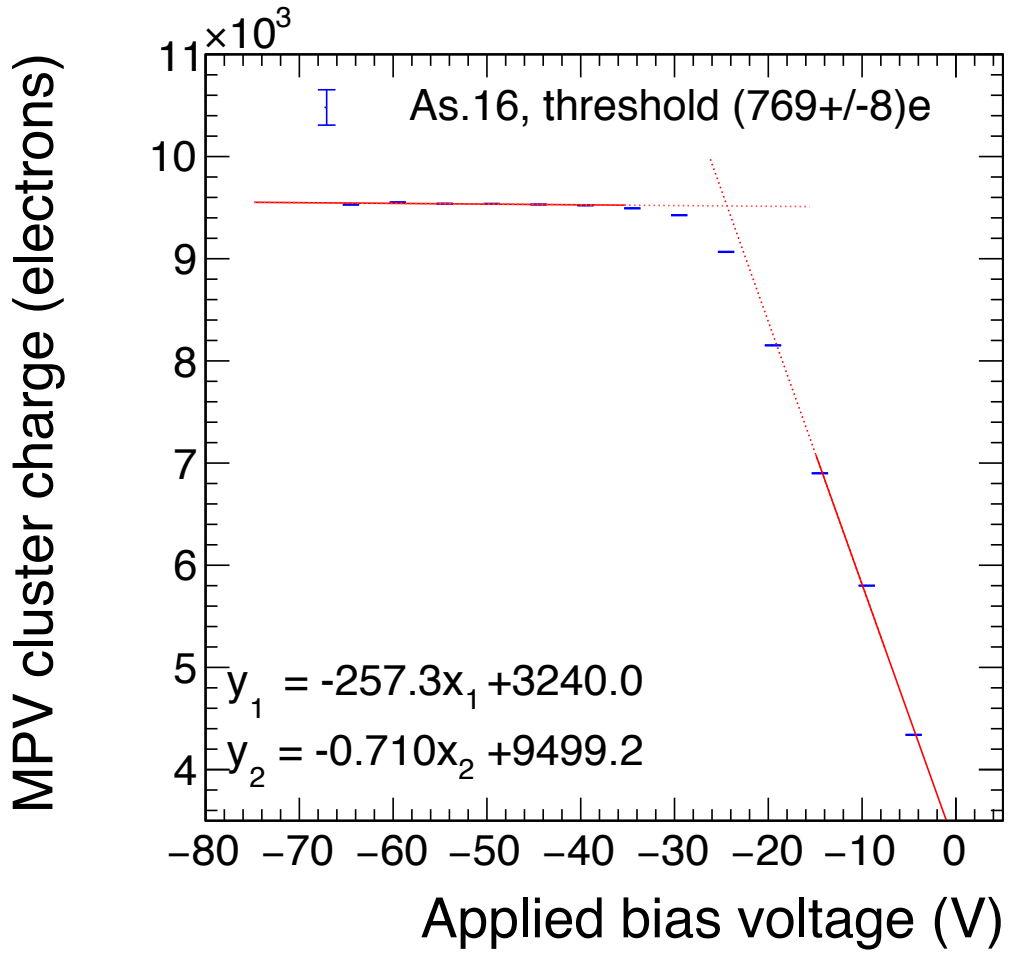

CLICpix2 As.16
Normalised # 1 pixel clusters
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−10
−5
0
5
10
In-pixel x track (μm)


CLICpix2 As.20
Normalised # 1 pixel clusters
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−10
−5
0
5
10
In-pixel y_{track} (μm)


CLICpix2 As.16
Normalised # 1 pixel clusters
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−10
−5
0
5
10
In-pixel y_{track} (μm)


Efficiency
1.001
1.0005
1
0.9995
0.999
0.9985
0.998
0.9975
As.20, threshold (1046+/-9)e
As.16, threshold (769+/-8)e
−70
−60
−50
−40
−30
−20
−10
0
Applied bias voltage (V)


×10^3
12
10
8
6
4
2
As.20, threshold (1046+/-9)e
y_1 = -287.8x_1 +3389.7
y_2 = -1.537x_2 + 10436.8
−80 −70 −60 −50 −40 −30 −20 −10 0
MPV cluster charge (electrons)
Applied bias voltage (V)


×10^3
11
10
9
8
7
6
5
4
As.16, threshold (769+/-8)e
y_1 = -257.3x_1 +3240.0
y_2 = -0.710x_2 +9499.2
−80 −70 −60 −50 −40 −30 −20 −10 0
MPV cluster charge (electrons)
Applied bias voltage (V)