Update on Analysis & Simulations of CLICpix+CCPDv3 Assemblies

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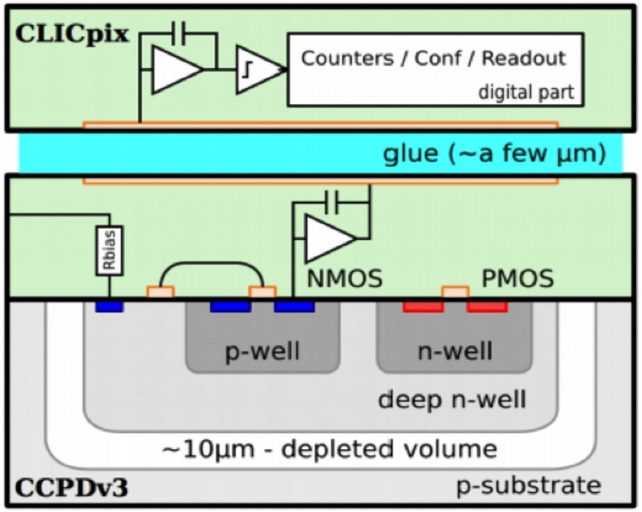
HV-CMOS for CLIC

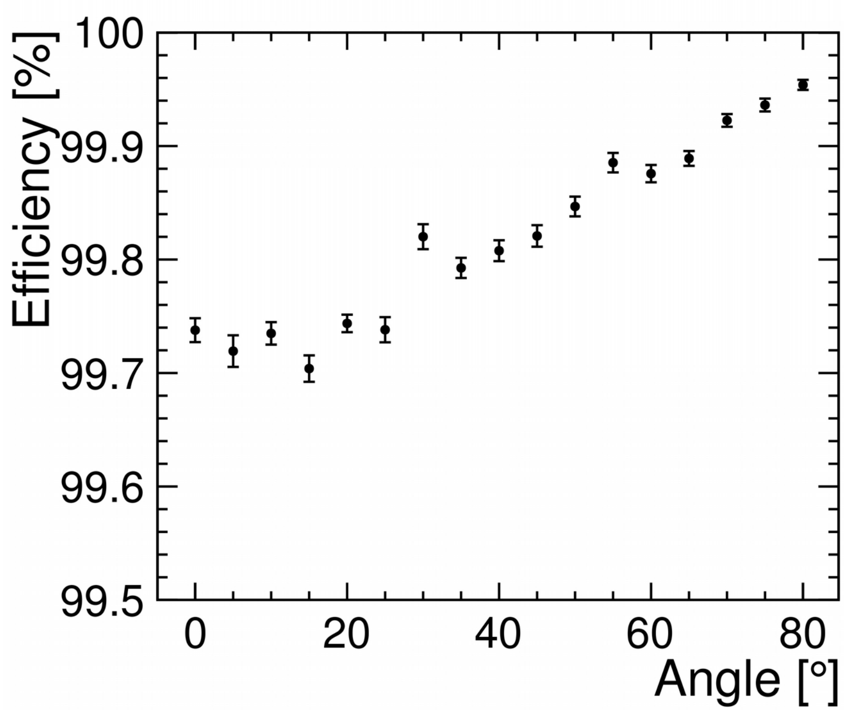
- One option for the vertex detector is a capacitively coupled pixel detector (CCPD), using a High-voltage CMOS (HV-CMOS) sensor
- HV-CMOS has a deep n-well implant which contains the in-pixel electronics
- This well provides shielding from the p-type substrate allowing a high bias => fast signal, larger depletion
- The CCPDv3 has a 2 stage amplifier => capacitive coupling => small pitch (25µm), no bump-bonding
- The sensor is coupled to the CLICpix readout ASIC, simultaneous 4-bit time over threshold (ToT) and 4-bit time of arrival (ToA) measurements
- Tests of these chips have been carried out, showing proof of concept
- The analysis is being finished off in order to compare with simulations to gain a better understanding of the chip and the simulations
- There is now a new generation of chips: the C3PD and the CLICpix2, see later talks by Iraklis and Andreas

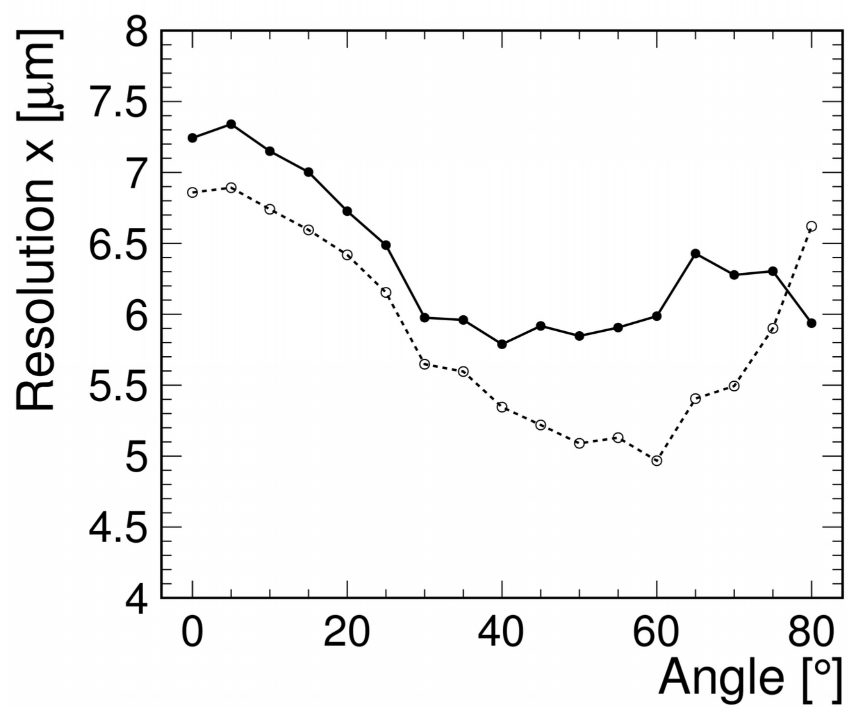


Testbeam Analysis

Testbeam results

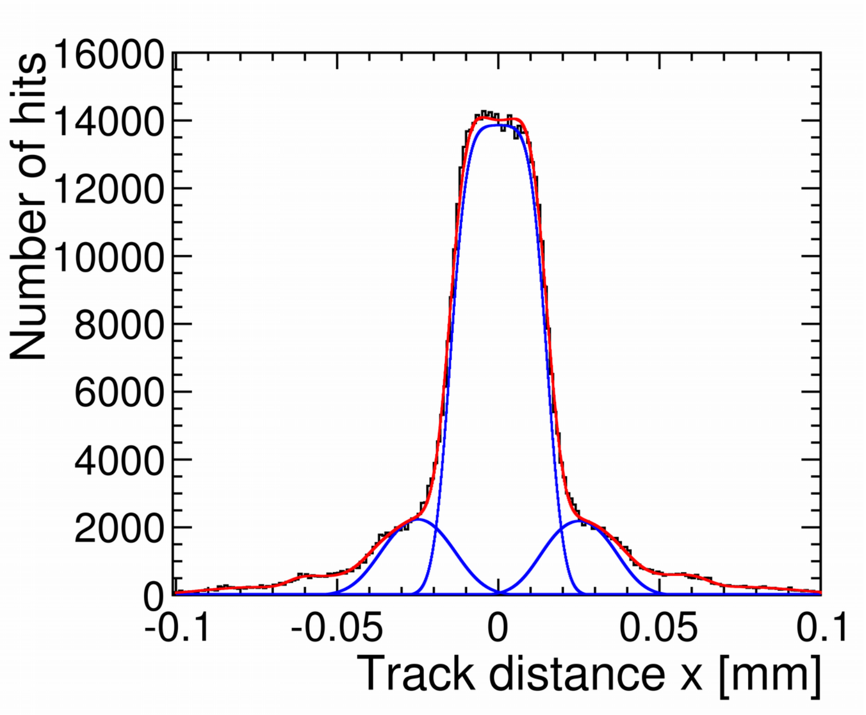
- Initial measurements of the CCPv3+CLICpix assemblies have been carried out
- They show a very good efficiency > 99.7% and a good resolution of 5-7 µm over all angles
- This is still not at the target of 3 µm, so want to understand the results more, especially those related to cross-coupling

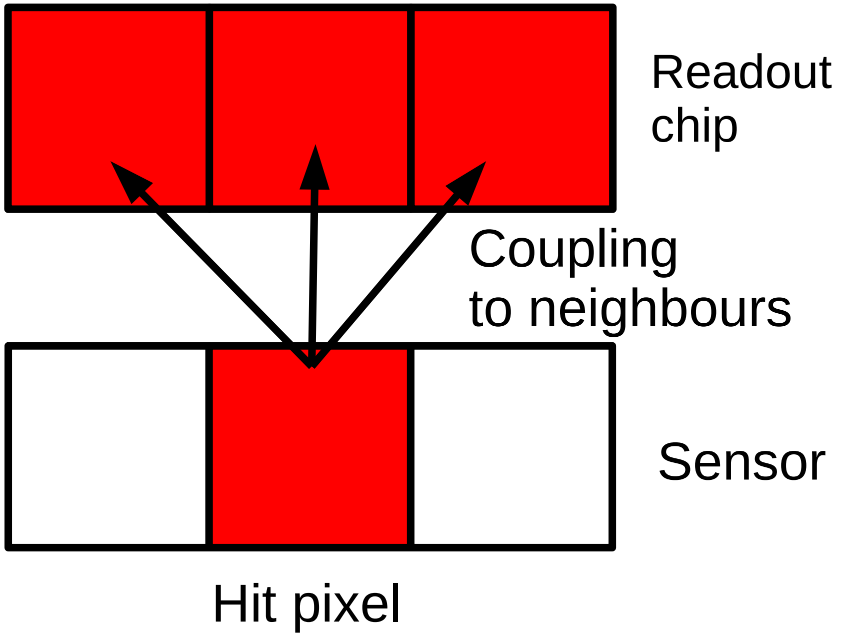




Cross-coupling

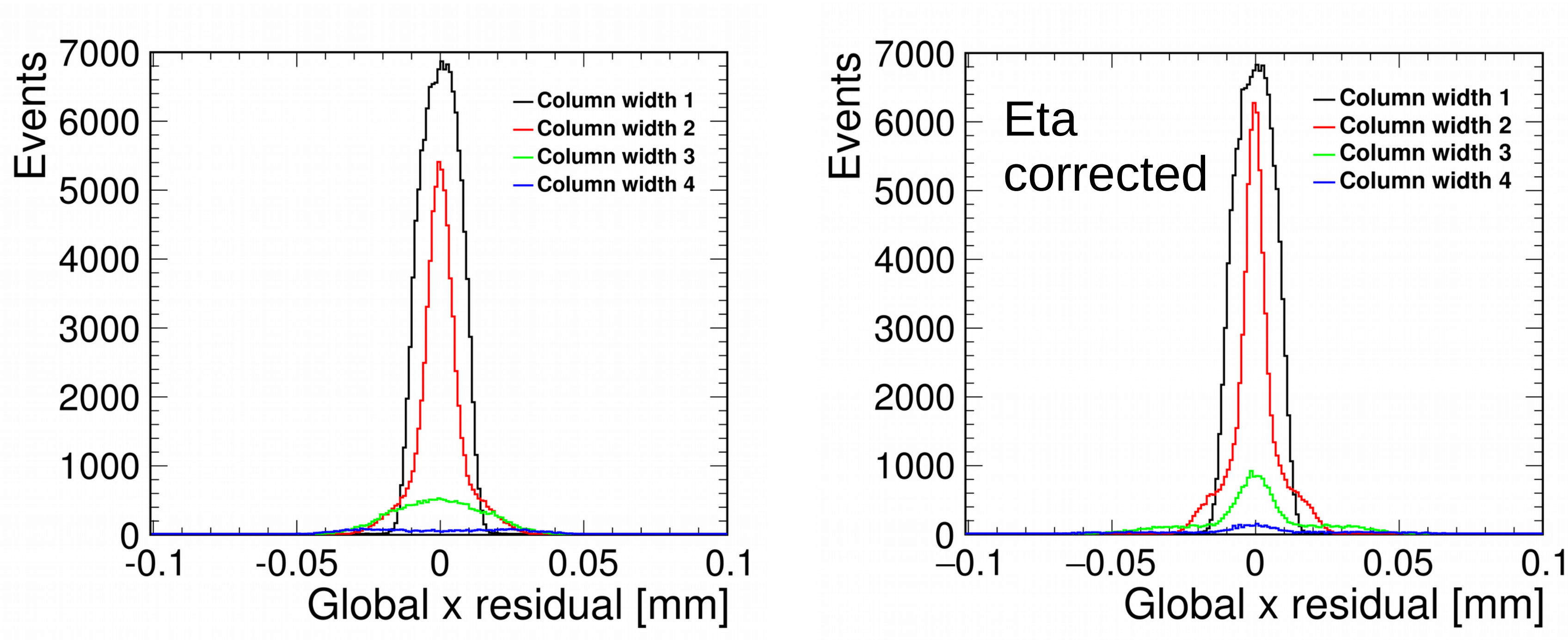
- Signal is capacitively transferred, capacitance to neighbours could be non-zero
- Signal on one HV-CMOS pixel could be transferred to multiple pixels on the readout side, cross-coupling (CC)
- This spoils the position finding algorithm and hence resolution by artifically increasing cluster size and cluster charge
- CC can be seen by scanning the beam along matrix to see when the pixel responds, produces a central peak from “real” charge collection and additional peaks from cross-coupling





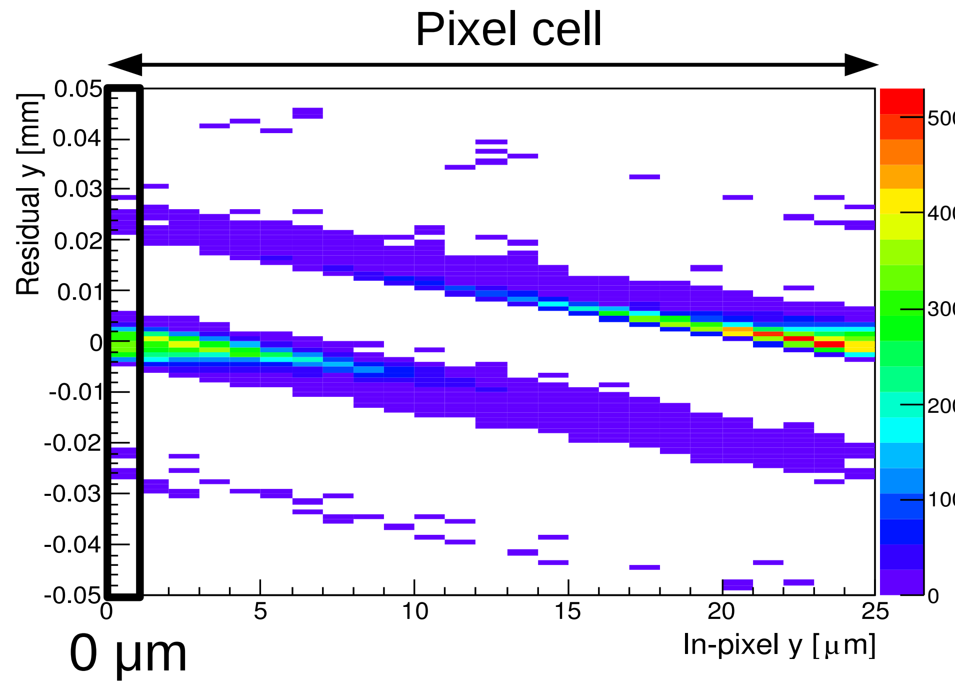
Hints of CC hits from the residuals

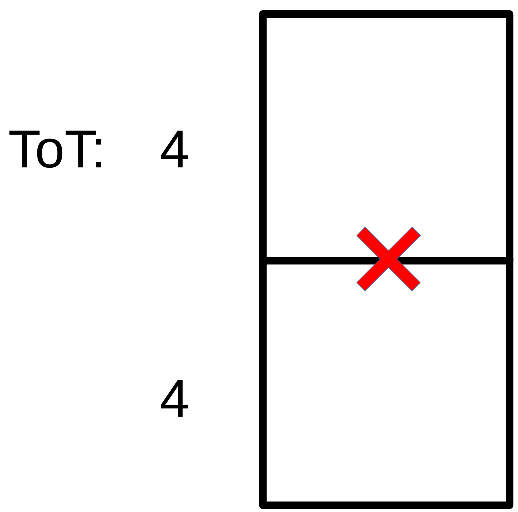
- Residuals are the difference between the position on the sensor and the track position from the telescope
- From the residuals the resolution is obtained
- After eta correction there are two distinct distributions in multi-pixel clusters
  - A thin distribution from “real” hits around 0 mm
  - A broad distribution from uncorrelated tracks, suspected cross-coupled hits
- This is due to the eta correction not improving the residual of the CC hits

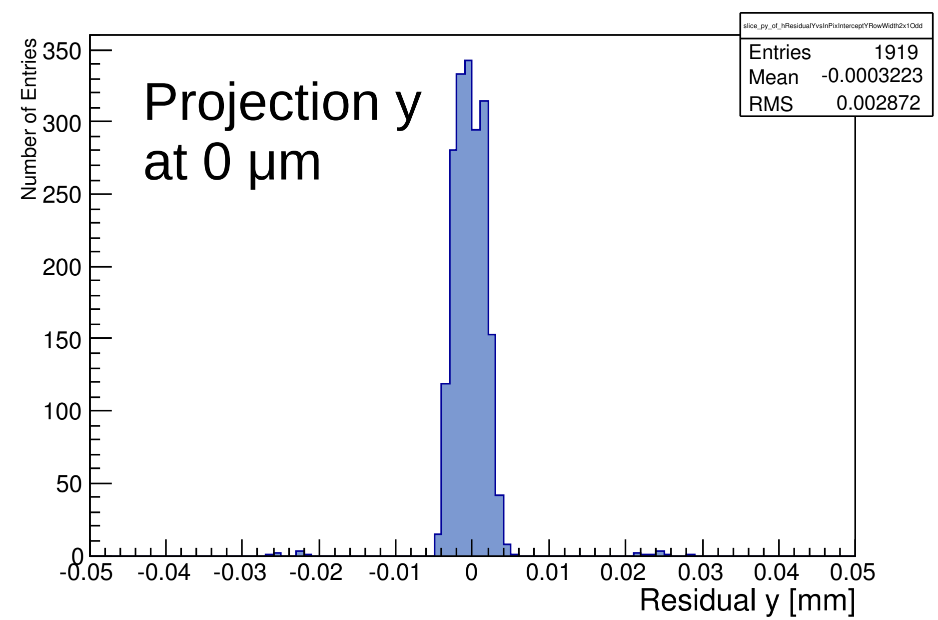


Effect of CC hits on residuals

- Pixel pitch 25μm, centre at 12.5μm
- Look only at clusters with row width 2 and col width 1, 1x2 clusters
- For an in-pixel track intercept at the edges, should get mostly “real” 1x2 clusters
- e.g. at 0 μm, the charge is shared between the two pixels
- The reconstructed sensor position is very similar to the track position therefore the residual is thin

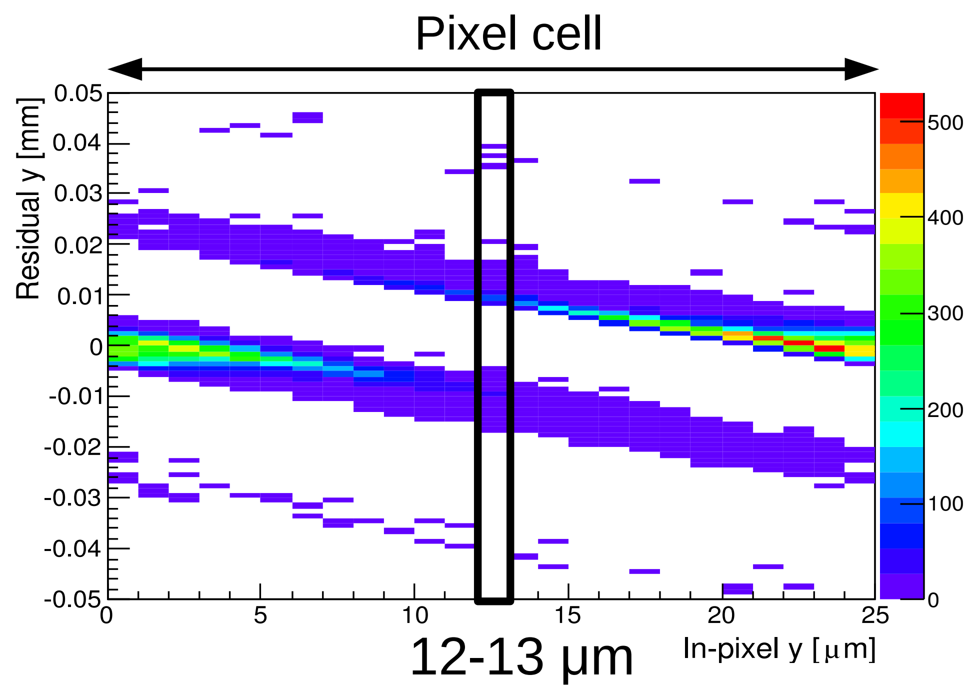


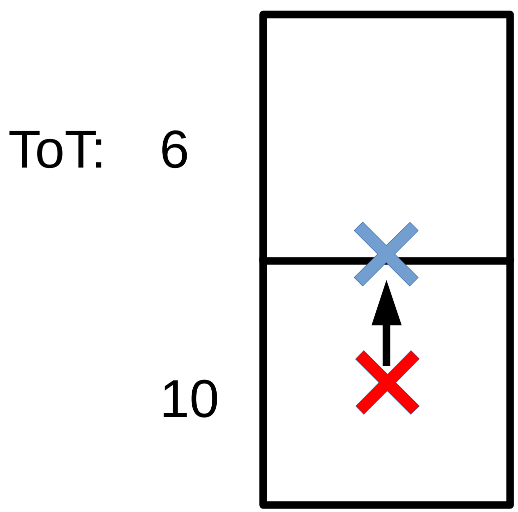


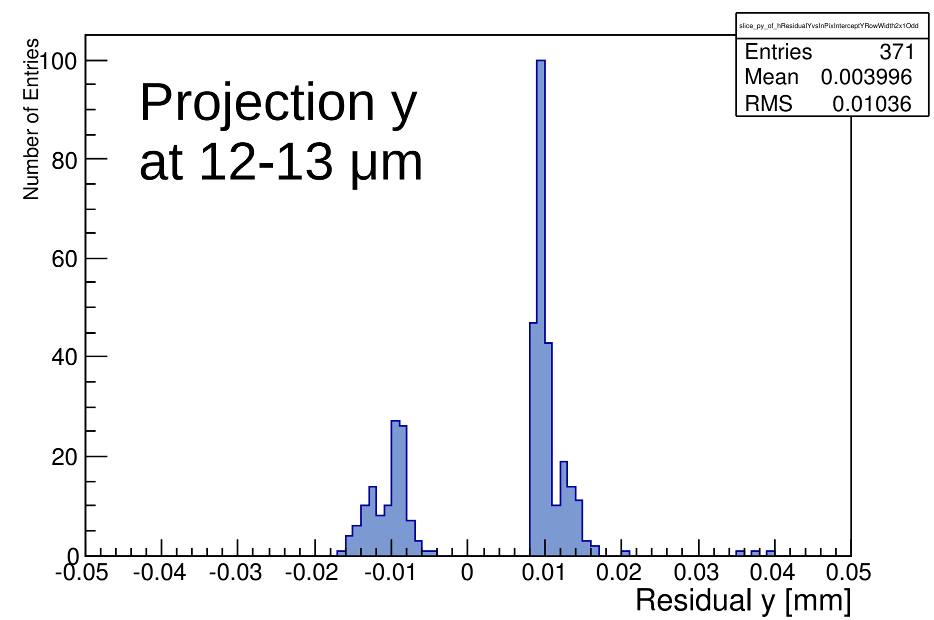


Effect of CC hits on residuals

- Pixel pitch 25μm, centre at 12.5μm
- Look only at clusters with row width 2 and col width 1, 1x2 clusters
- For an in-pixel track intercept at 12-13 μm (centre), the 1x2 clusters are mainly due to cross-coupling
- A cross-coupled hit drags the sensor position (blue) away from the track intercept (red)
- This produces bad a residual with two peaks at +/- 0.01 mm

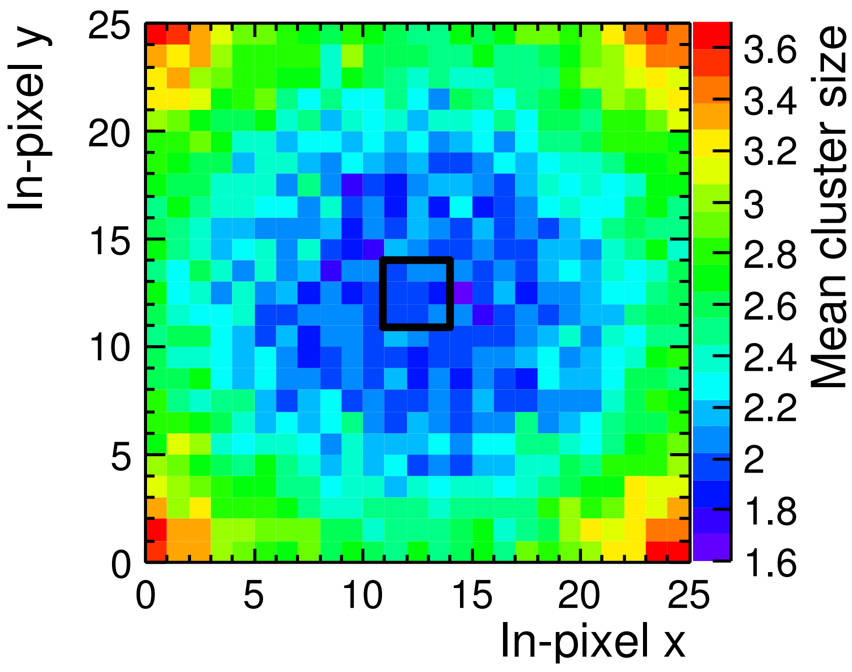


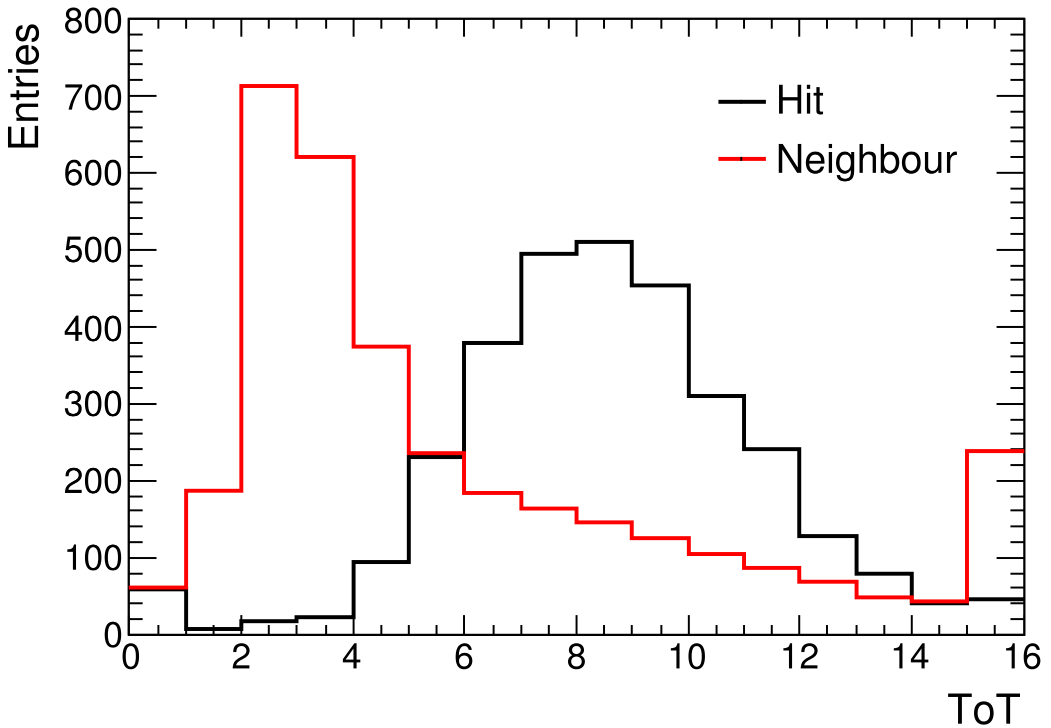




Effect of CC hits on pixel ToT

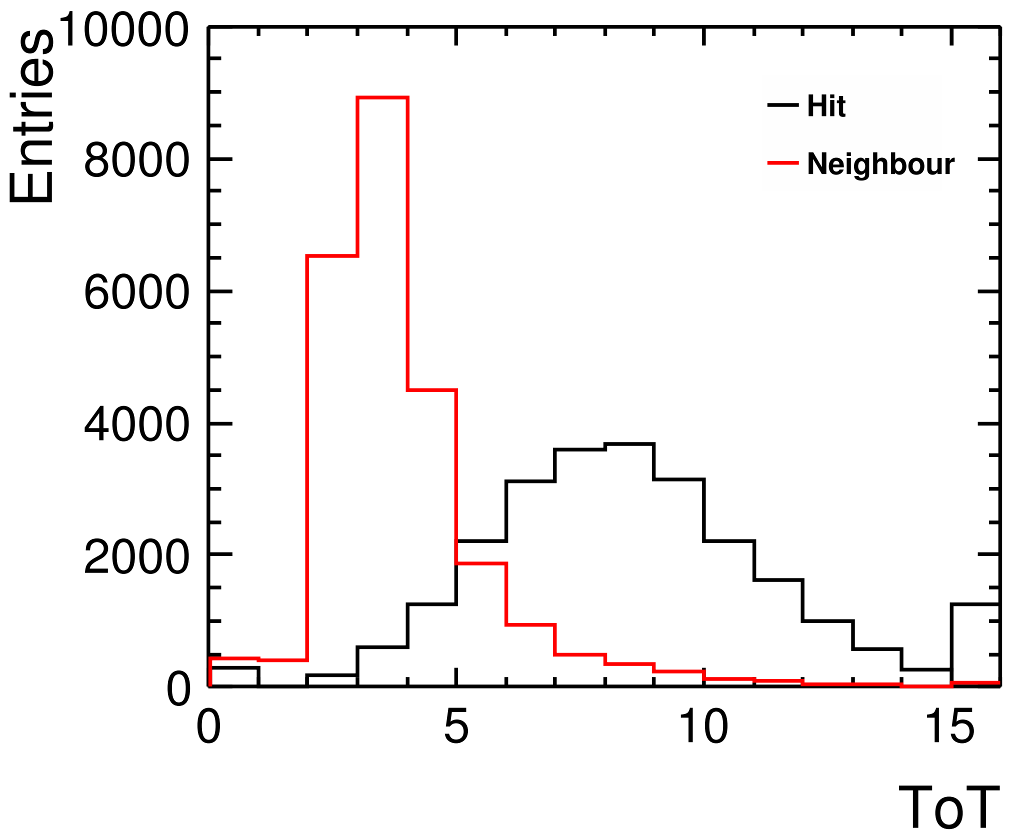
- Look at clusters whose hit intercept is within a 3x3 square at the centre of the pixel, expect mainly single pixel clusters
- From the pixel ToT, see two distinct peaks: one at 8 for the hit pixel and one at 2 for the neighbour pixels
- This is potentially due to charge sharing, need to cross-check





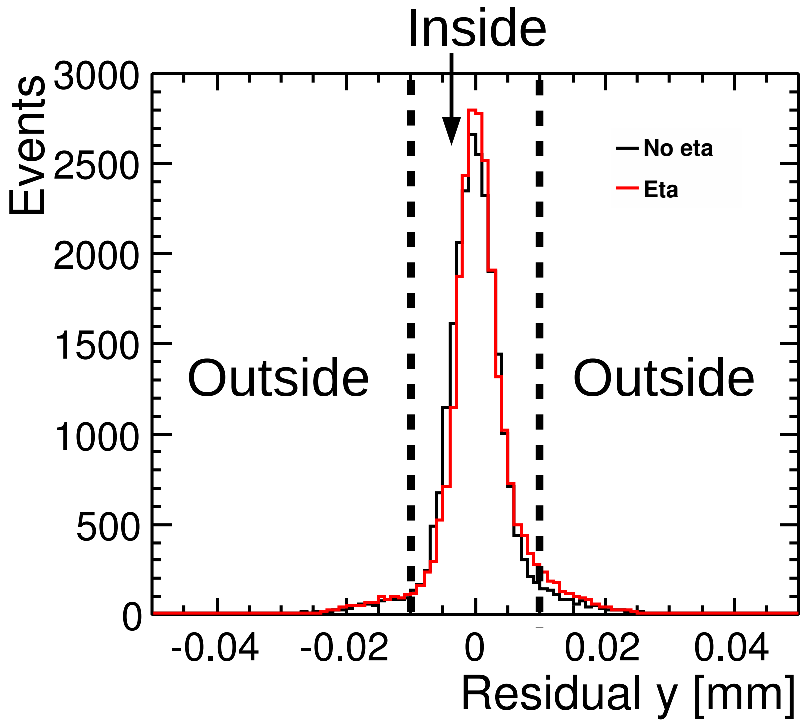
Effect of CC hits on pixel ToT

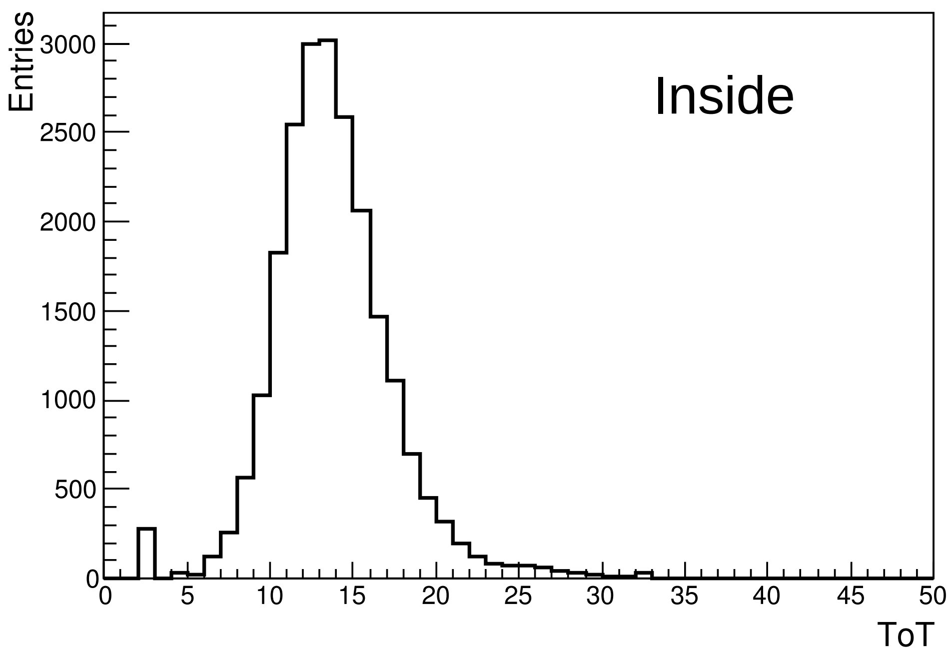
- Look only at clusters with row width 2 and col width 1, 1x2 clusters
- Again see two distinct peaks
- This time at 8 for the hit pixel and at 3 for the neighbour pixel
- Therefore CC hits mainly induce a ToT of 2-3

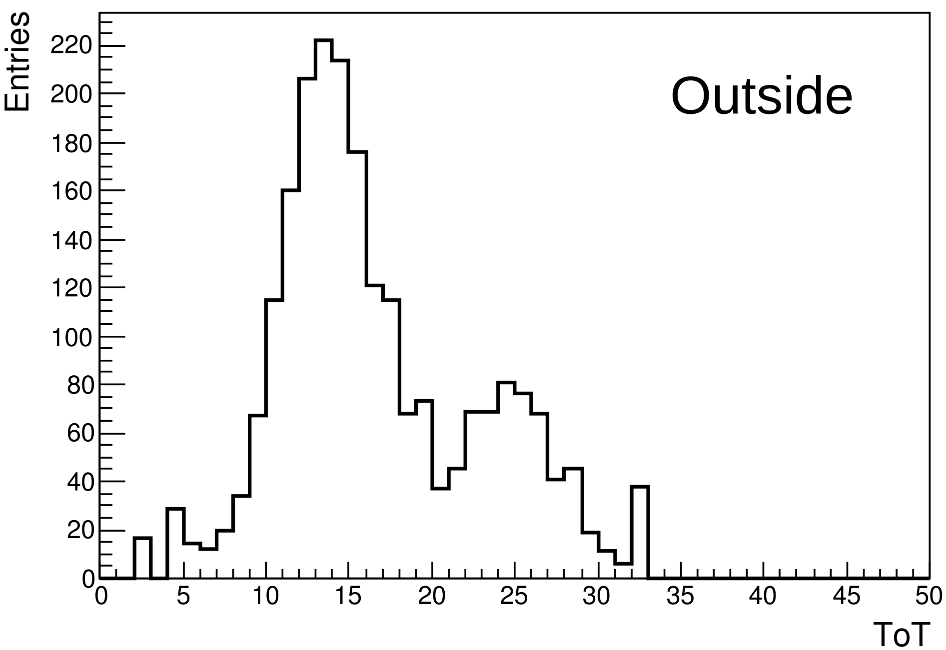


Effect of CC hits on cluster ToT

- Look only at clusters with row width 2 and col width 1, 1x2 clusters
- Cut on residual, -0.01 mm to 0.01 mm
- See two peaks in ToT for outside the cut
- The 2nd peak is possibly from cross-coupling due to the need for higher ToT to produce coupling
- The signal is added to the “real” ToT in cross-coupled hits hence a larger cluster ToT

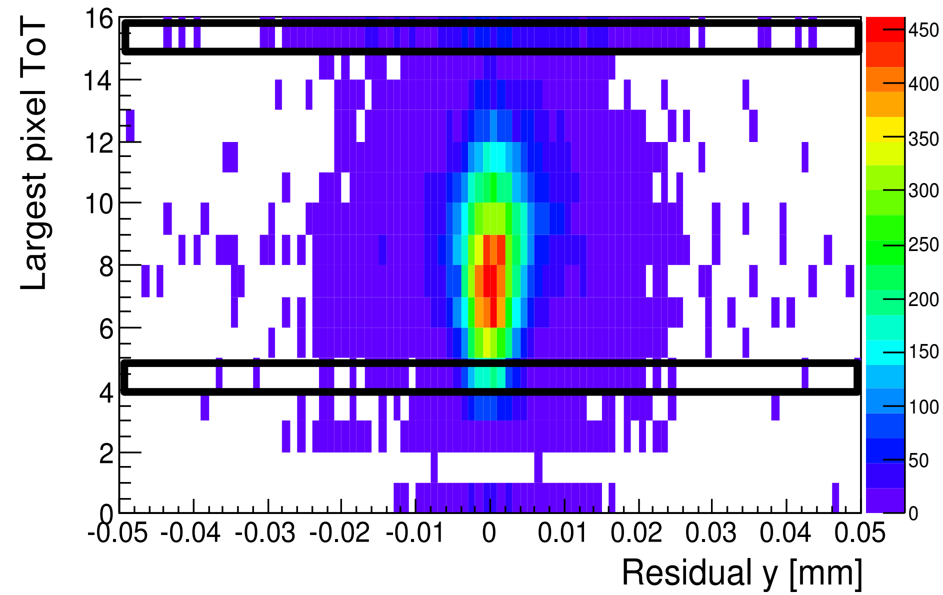


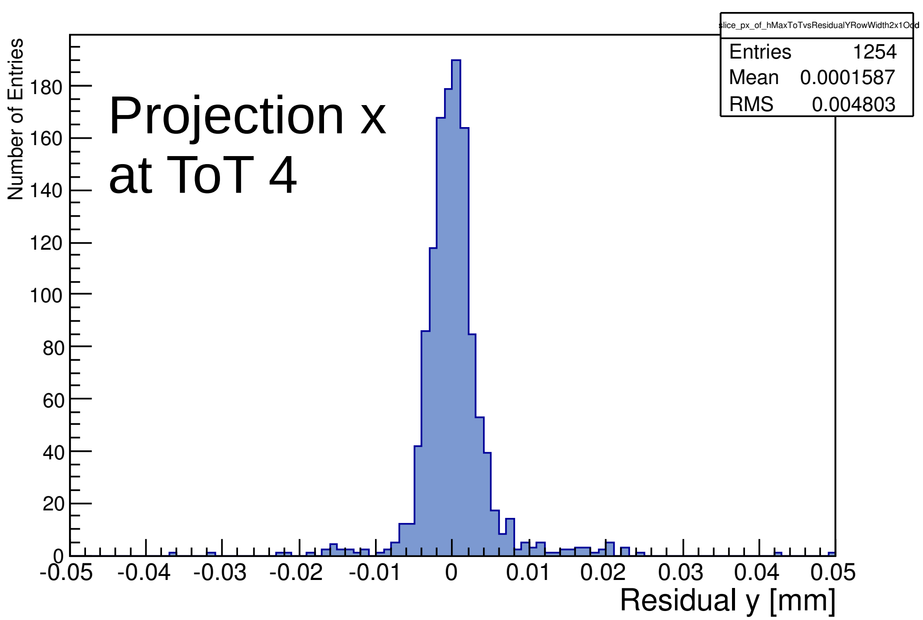


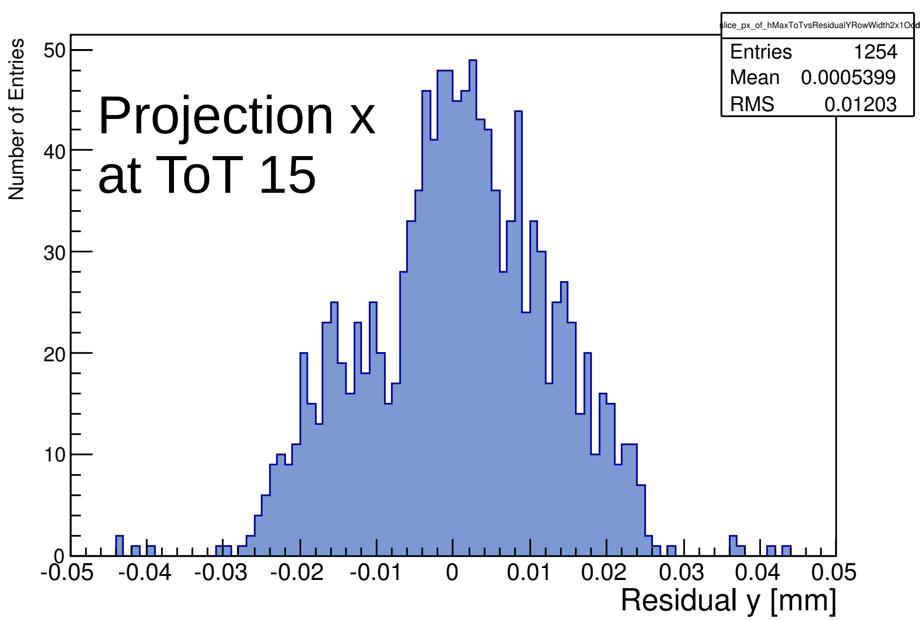


Effect of pixel ToT on residual

- Look only at clusters with row width 2 and col width 1, 1x2 clusters
- Plot the largest pixel ToT in the cluster
- The lower largest pixel ToTs don't couple strongly to neighbour => thin residual
- The higher largest pixel ToTs have stronger cross-coupling => broad residual

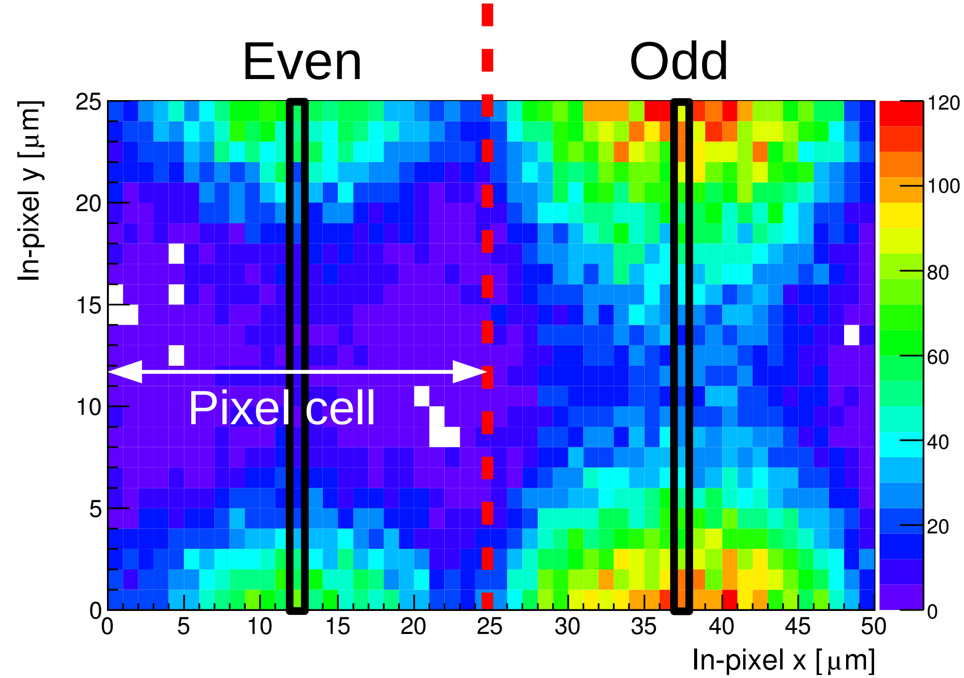


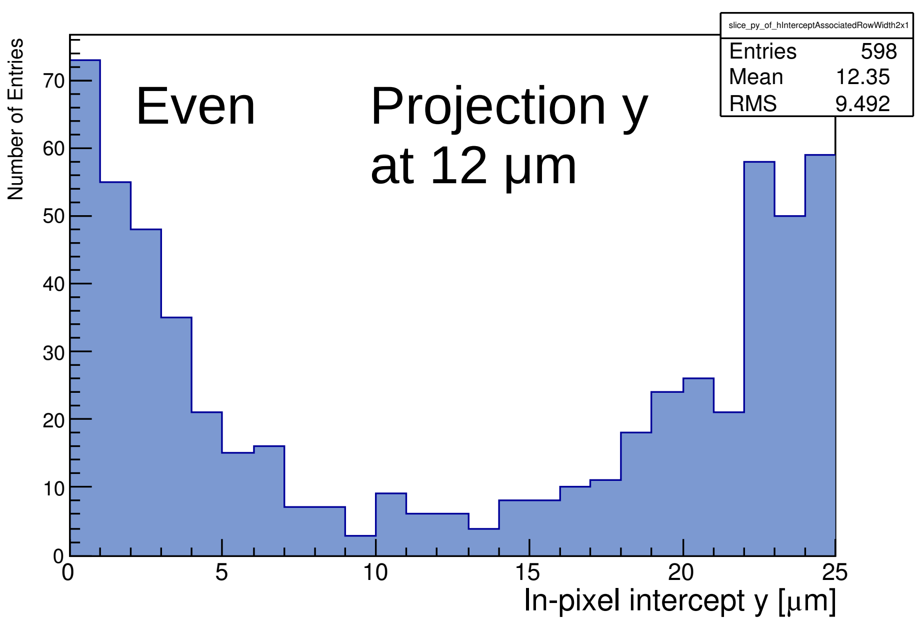


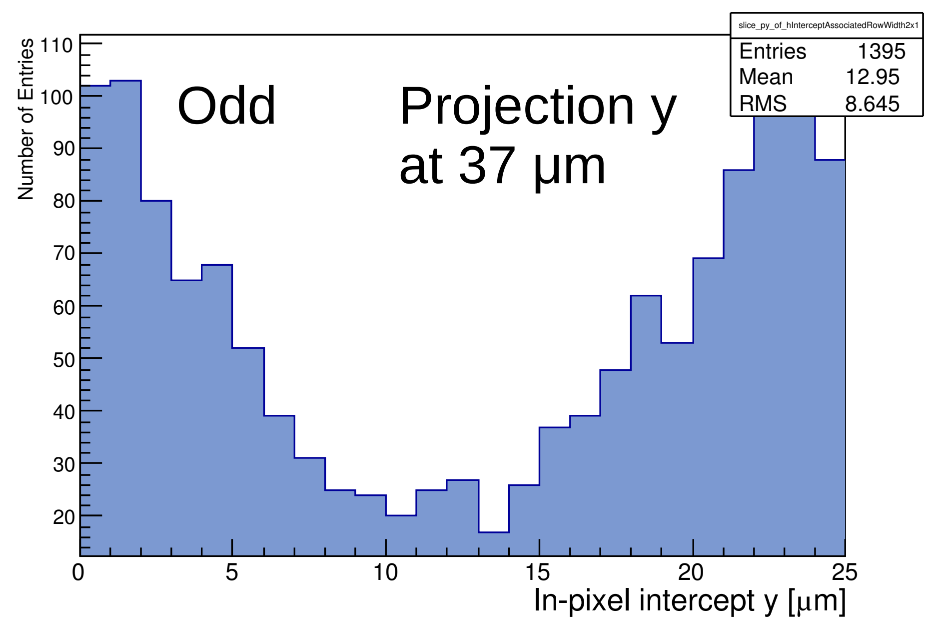


In-pixel intercept

- Look only at clusters with row width 2 and col width 1, 1x2 clusters
- Data is split into odd and even columns, due to known bug in CLICpix
- See that a majority of these clusters are at sides in y and near the centre in x
- But still have some hits in the centre of pixel, due to cross coupling

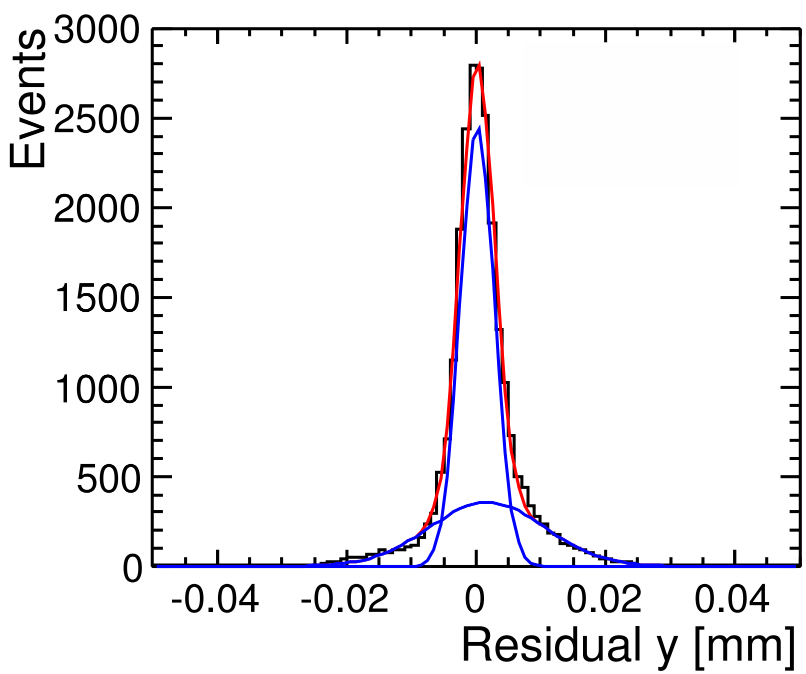


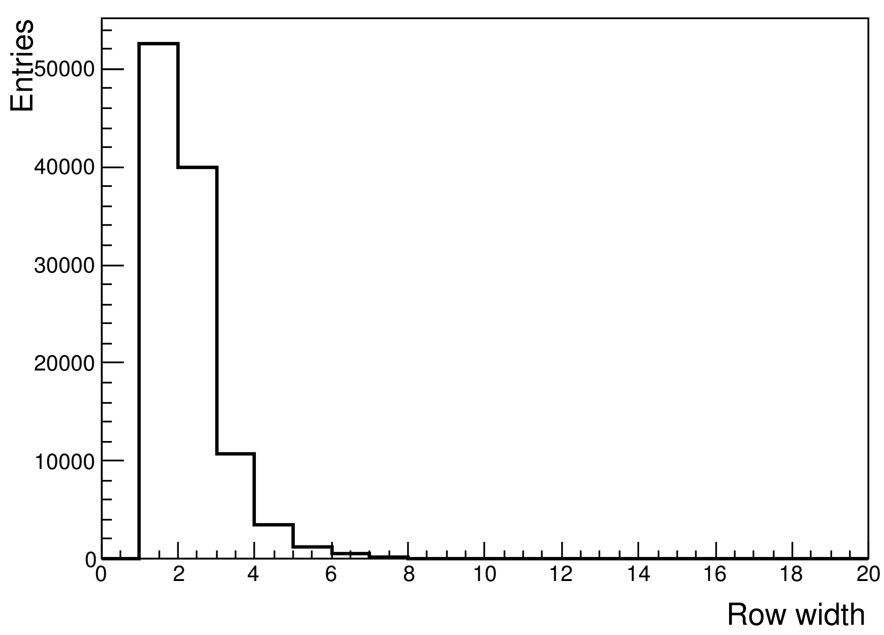




Back of envelope calculation of CC

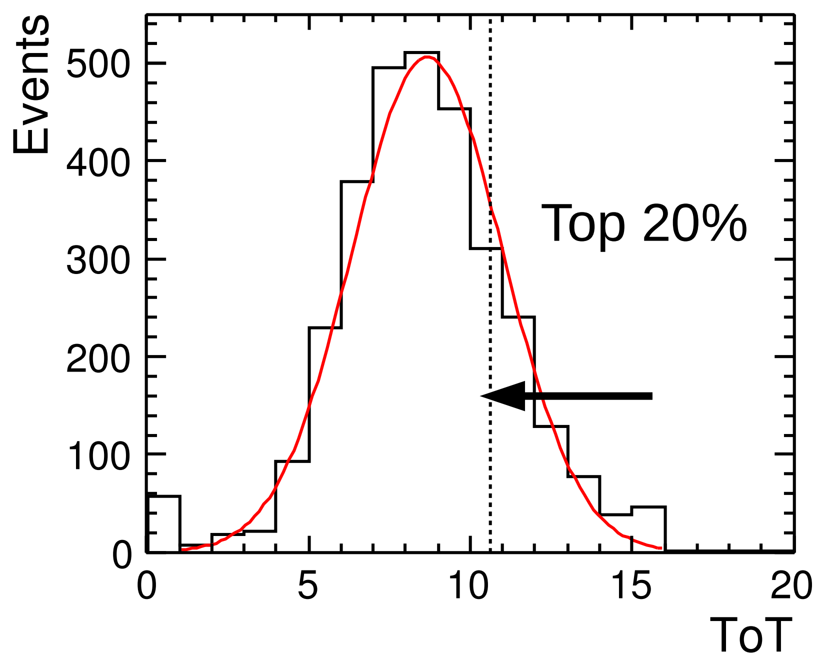
- Look only at clusters with row width 2 and col width 1, 1x2 clusters
- As mentioned previously residuals comprise of two distributions
- Fit a thin Gauss for the "real" hits and a broad Gauss for the CC hits => ≈ 33% of these types of cluster are from CC
- Use this and the number of clusters with row width 1 and 2 to estimate the number of single pixel clusters giving CC hits: ≈ 20%





Quantitative estimate of CC

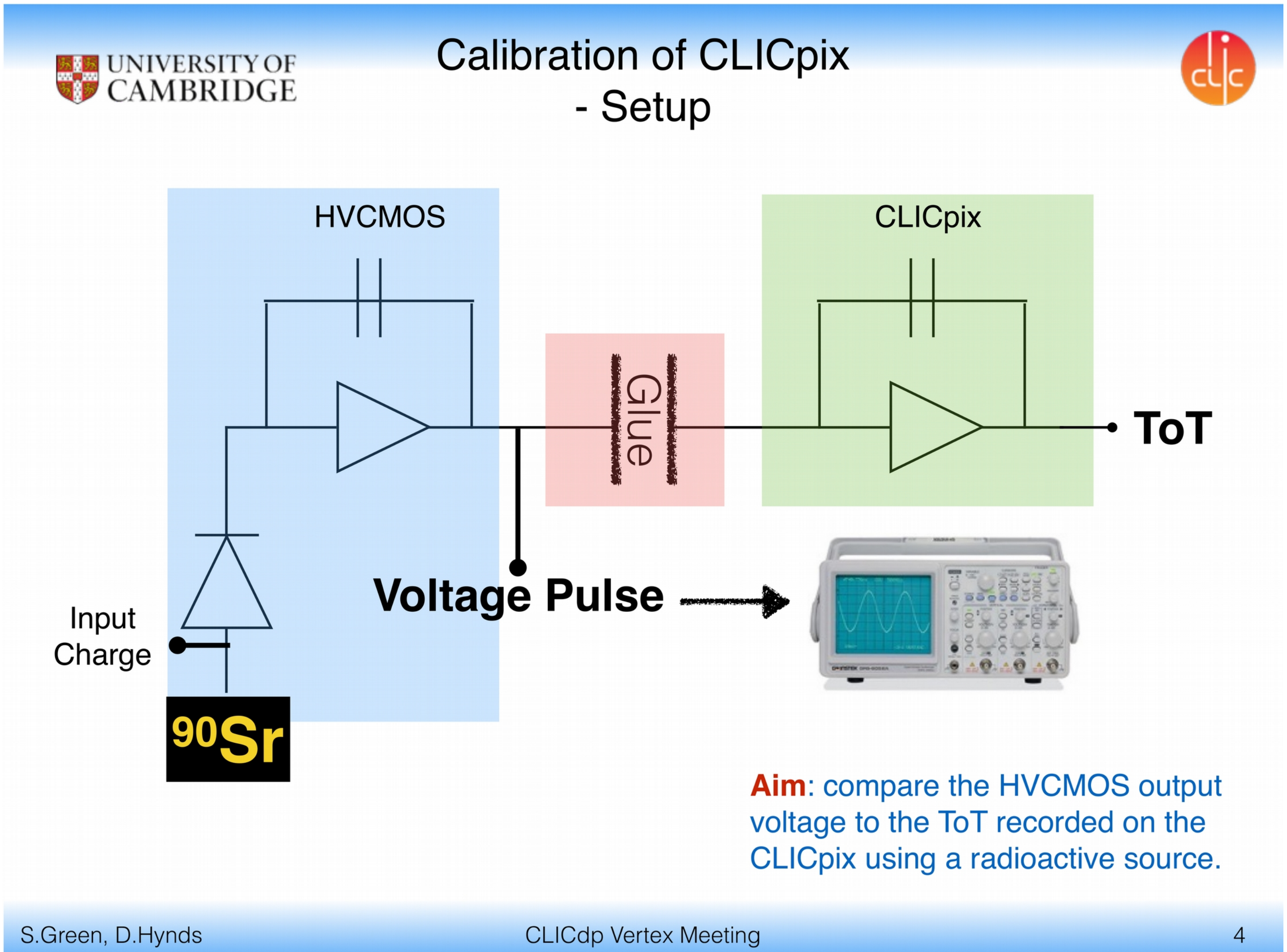
- Calculate the charge deposited by the top 20% of pixels, this is effectively the threshold for CC hits at around 10.6 ToT
- Compare this threshold to the threshold on the chip and get $\approx 4.7\%$
- This is the ratio of the coupling of the neighbour with the coupling to the hit pixel
- From simulations (M. Vincente) this is around 3%



Calibration of CCPDv3+CLICpix

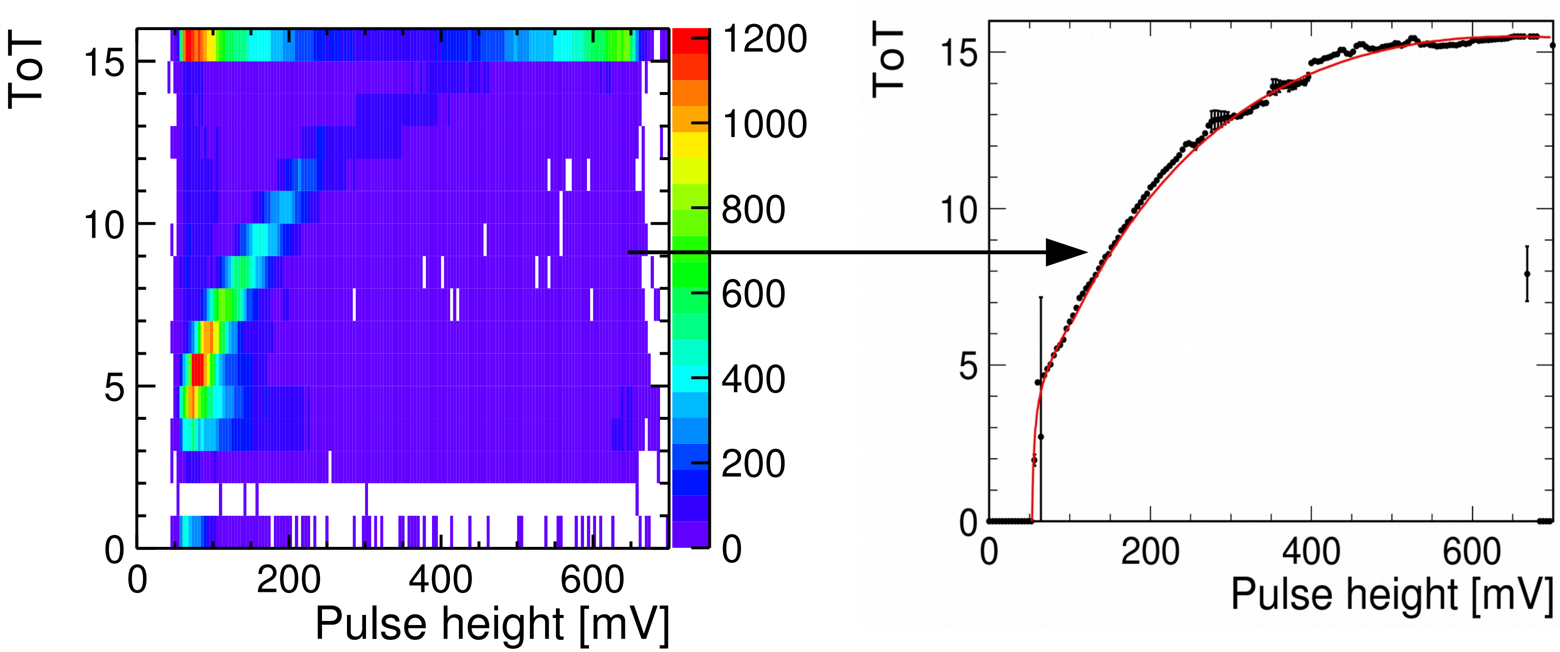
Calibration with radioactive source

- Important for comparing simulation to data
- Calibration done by S. Green



Calibration with radioactive source

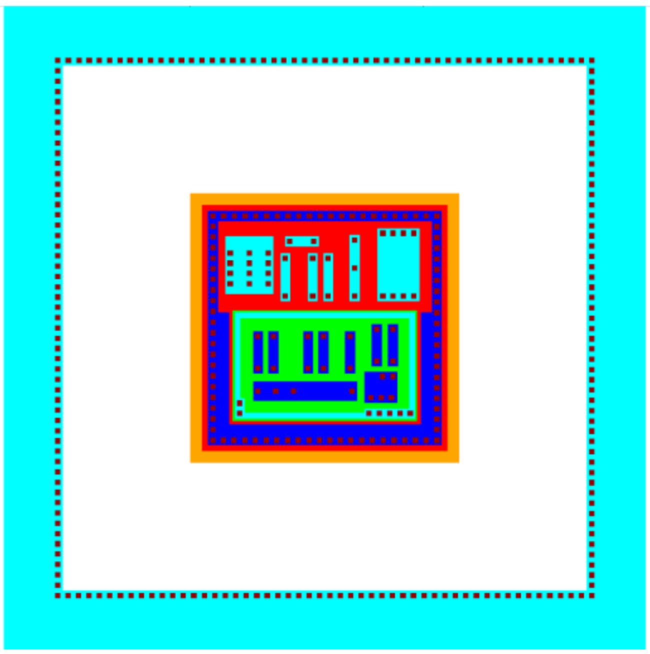
- It is difficult to fit the curve over the whole range with the typical surrogate function:
$$y = ax + b - \frac{c}{x-t}$$
- See very steep turn off at ≈ 60 mV, possibly due to threshold on oscilloscope (50 mV)
- This produces an artificial turn off at low ToT
- Don't see this large non-linear part in the test pulse calibrations
- Measurements will be repeated in the next few days

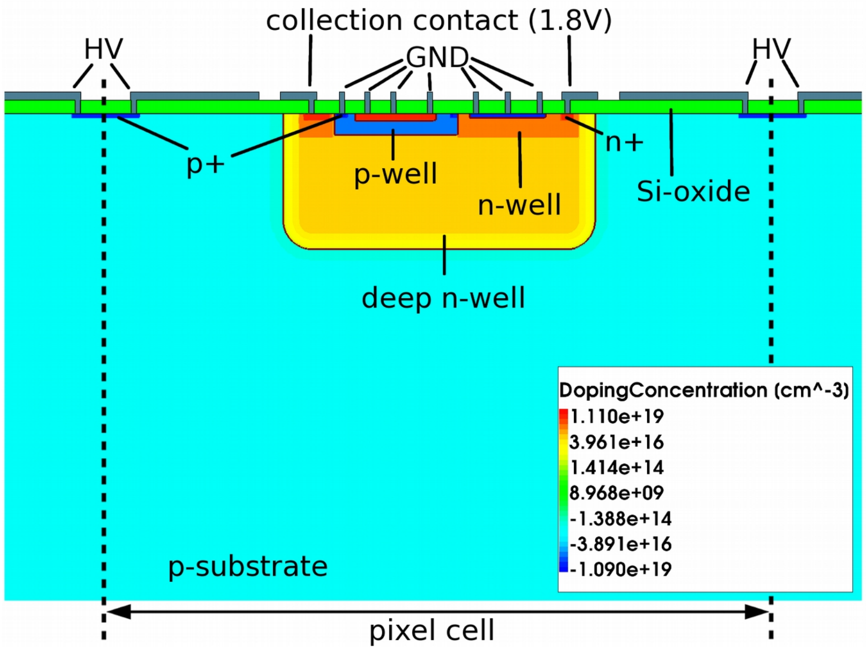


Comparison of simulation and testbeam data

TCAD simulations

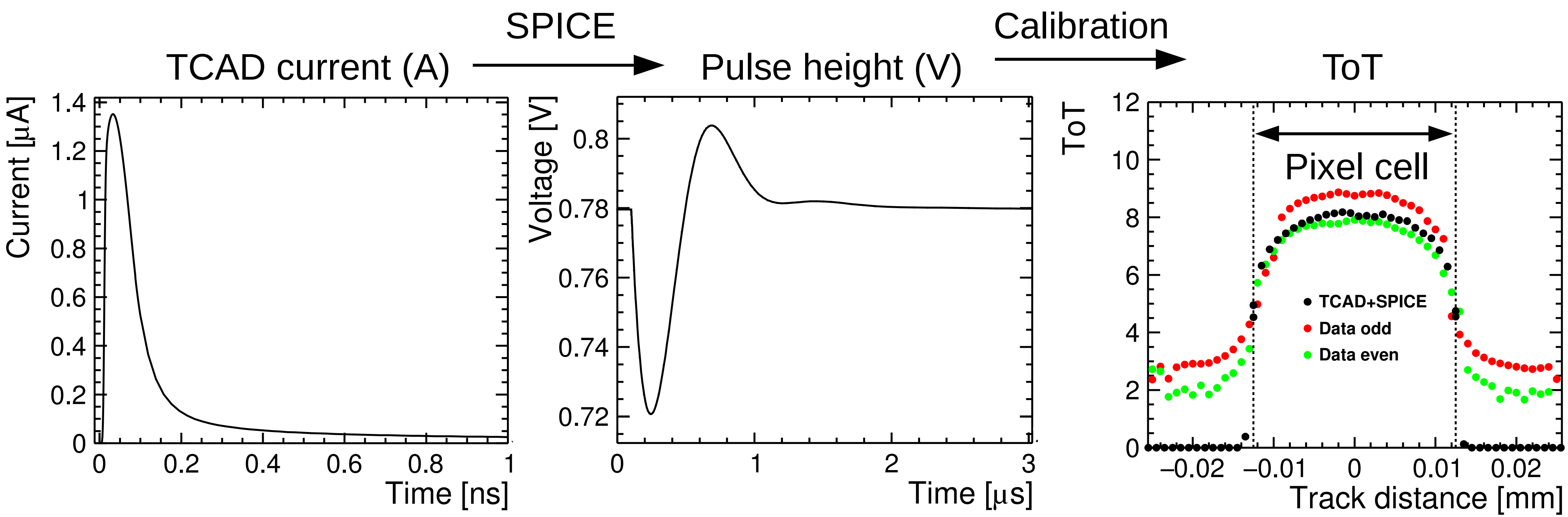
- The simulations can help to understand features of the sensor:
  - Current-voltage characteristics and breakdown
  - Depletion region
  - Signal collection
- Using the design file (gds) of the chip can produce structures in TCAD
- Extraction of the relevant implant layout is used to create a mask for the simulations





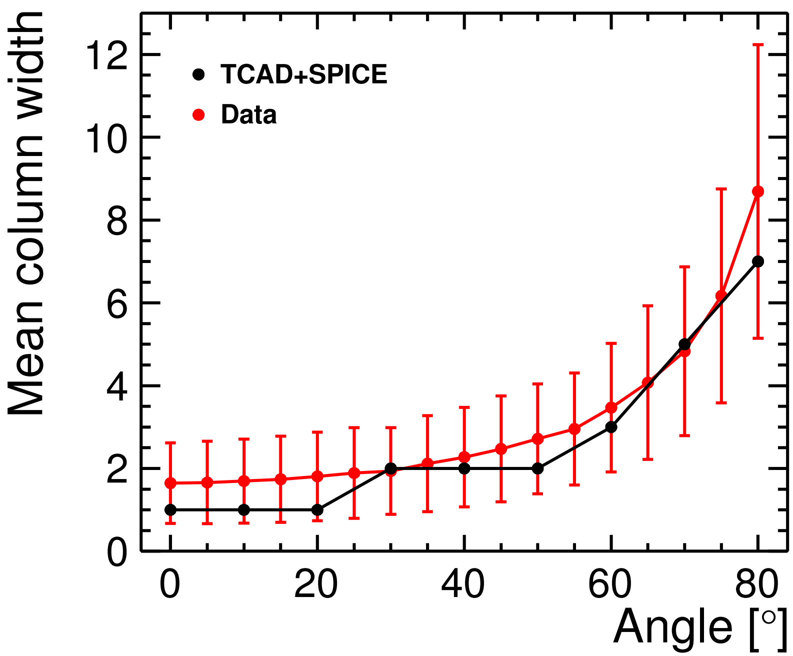
Comparison of TCAD to data

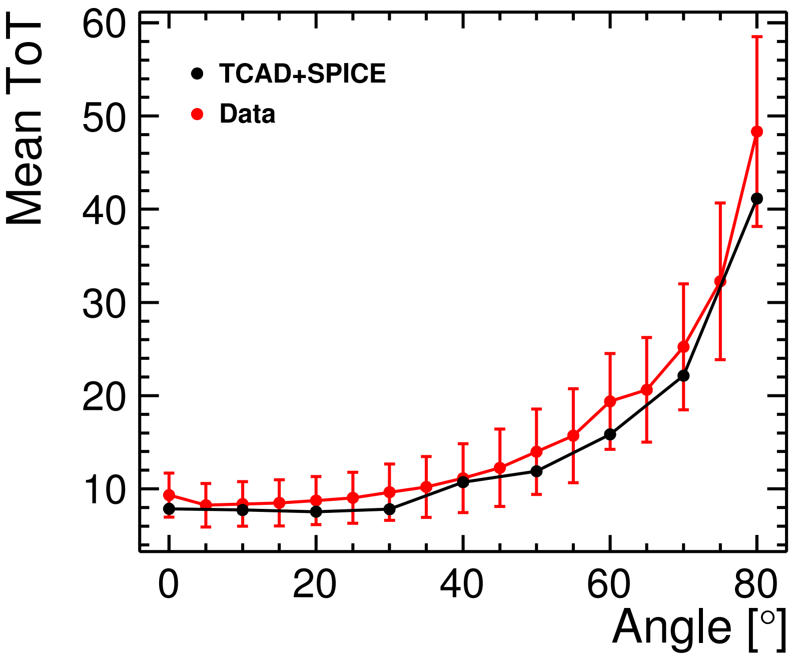
- Obtain a current pulse from TCAD then put this into a SPICE simulation of the CCPDv3 (I. Kremastiotis)
- This gives the 2nd stage amplifier output => obtain a pulse height
- Use the calibration curve to convert to a ToT
- Good agreement to data within the pixel cell
- Disagreement outside is due to the calibration not covering low pulse height voltages
- Also due to cross-coupling, not put into the simulation as of yet



Comparison of TCAD to data

- Have a good agreement over the full angular range in the mean column width and the mean ToT

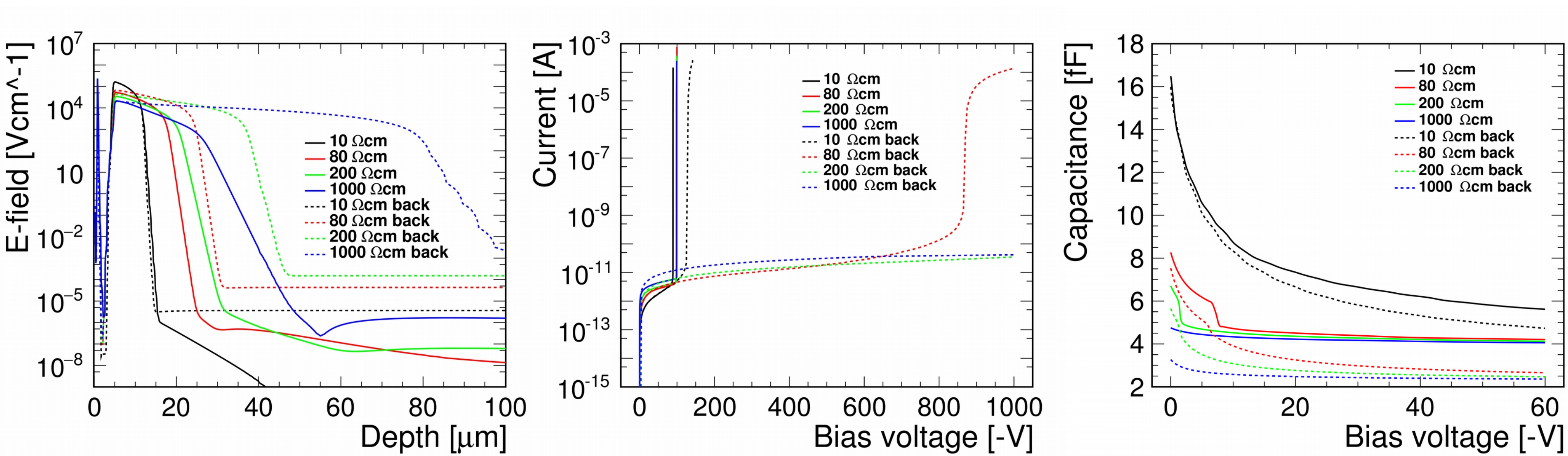




Prospects for improved performance

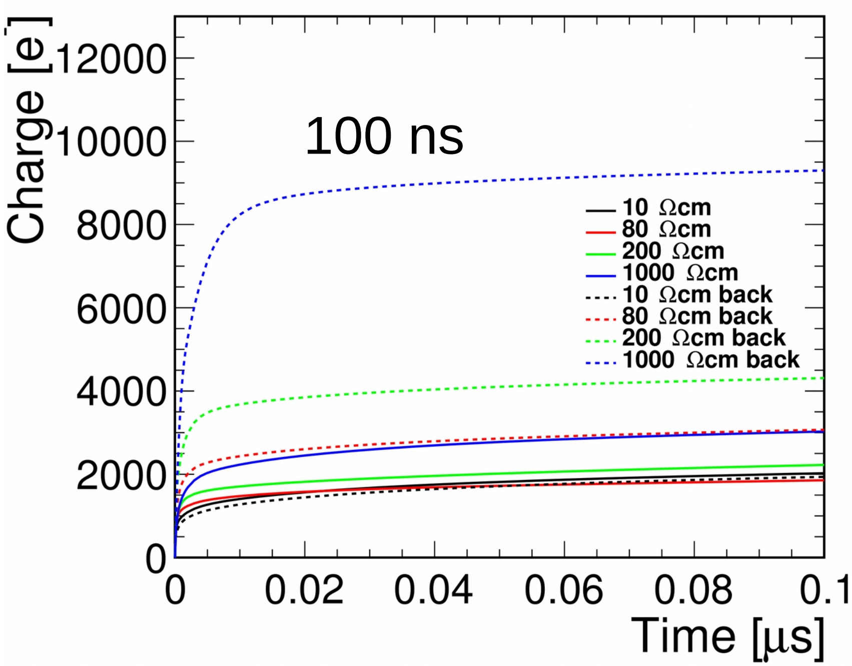
Topside vs. backside biasing

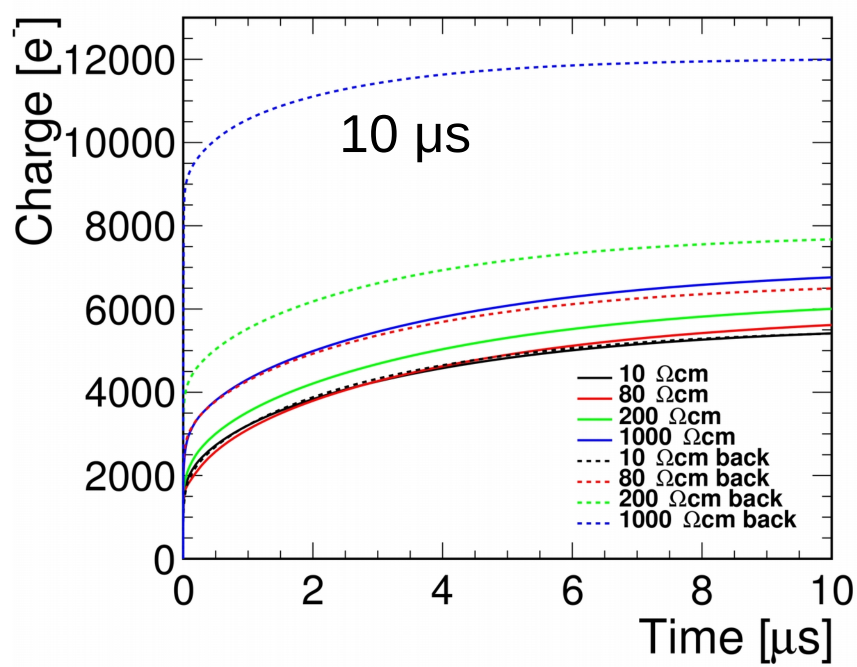
- Two methods of biasing: from the topside and from the backside
- See a larger electric field depth for backside
- Difference in depletion depth at 1k Ωcm is ≈ 40 μm
- Also have an improvement in the breakdown voltage and deep n-well to bulk capacitance
- 1k Ωcm produces the largest improvement between the two biasing schemes



Topside vs. backside biasing

- For the topside there is a larger and faster charge collection => improved timing performance
- Very small difference at 10 Ωcm
- Again 1k Ωcm produces the largest improvement





Summary

- Testbeam analysis:
  - Majority of cross-coupled hits have large residual values
  - See more cross-coupling in hits with higher ToTs, broader residuals
  - Still can't entirely disentangle CC multi-pixel hits from “real” ones
- Calibration:
  - Slight improvement from previous fit
  - Need to retake the data to properly cover low pulse heights
- Simulation:
  - Improved agreement with the SPICE and new calibration curve
  - It needs the low pulse height calibration for agreement outside the pixel cell
  - Backside biasing produces more desirable characteristics, still need to check the cluster size

Backup

CC hits in calibration

- See CC hits in the calibration with ToT of 3-4