2009 SPS Pion beam tests of 3D TimePix Detectors

C. Parkes on behalf of Glasgow & CNM

Pion testbeam was conducted by LHCb/Medipix groups, led by Richard Plackett.

See backup slide for full list of participants

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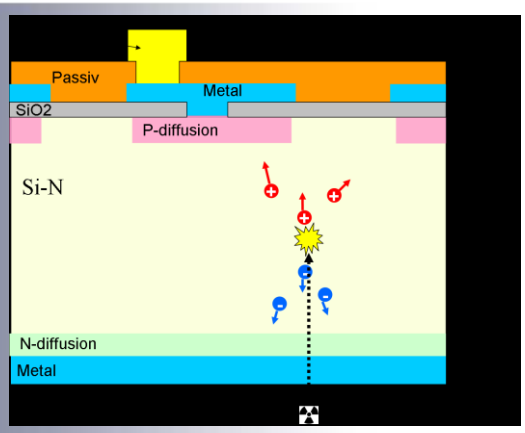
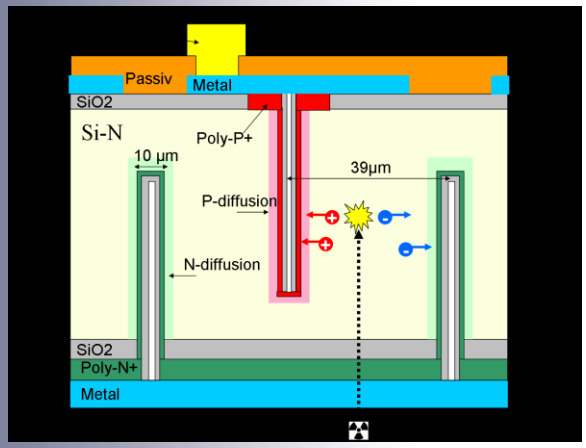
Outline

- Introduction
  - 3D double sided detectors substrates
  - Timepix description
- Pion-beam from SPS
  - Telescope
  - Pulse height spectra
  - Detection Efficiency
  - Cluster size
  - Resolution
- Conclusions

Detector substrates - 3D and Planar

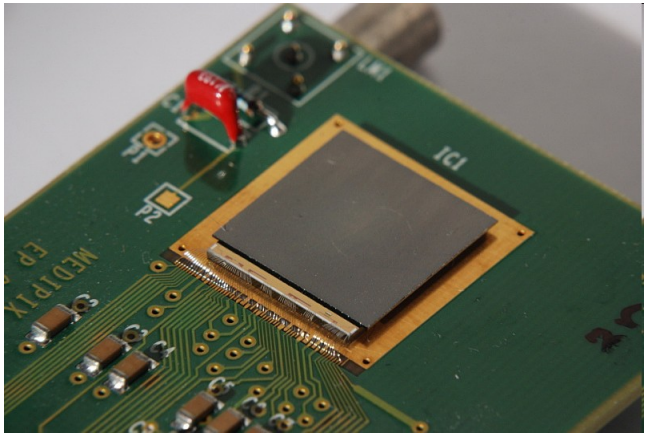




- Detectors designed by Glasgow/CNM and fabricated at Centro Nacional de Microelectronica, Barcelona
- Columns are etched from opposite sides of substrate
- Column fabrication:
  - » Reactive ion etching
  - » Partial filing with polysilicon then doping
  - » TEOS almost fills hole
- Substrate is 285µm thick
- Columns are 250µm deep and dead inside the column
  - » Low field region around top of ohmic columns
- n-type bulk, p-type junction columns connected to electronics
  - » Hole collection
- Square array of ohmic columns with junction column at centre, array pitch of 55µm

Timepix

- 256 x 256 pixel array
  - 65k single-photon counting pixel array
- Square pixel size of 55μm
- Electron or hole collection
- Global and pixel threshold equalisation
- 1 counter per pixel with 14bit depth
- Time over threshold to measure signal size
- 100ns rise time
- Count rate of ~100kHz
- Shutter control – no pipe line
- Readout in 300μs
- High dynamic range

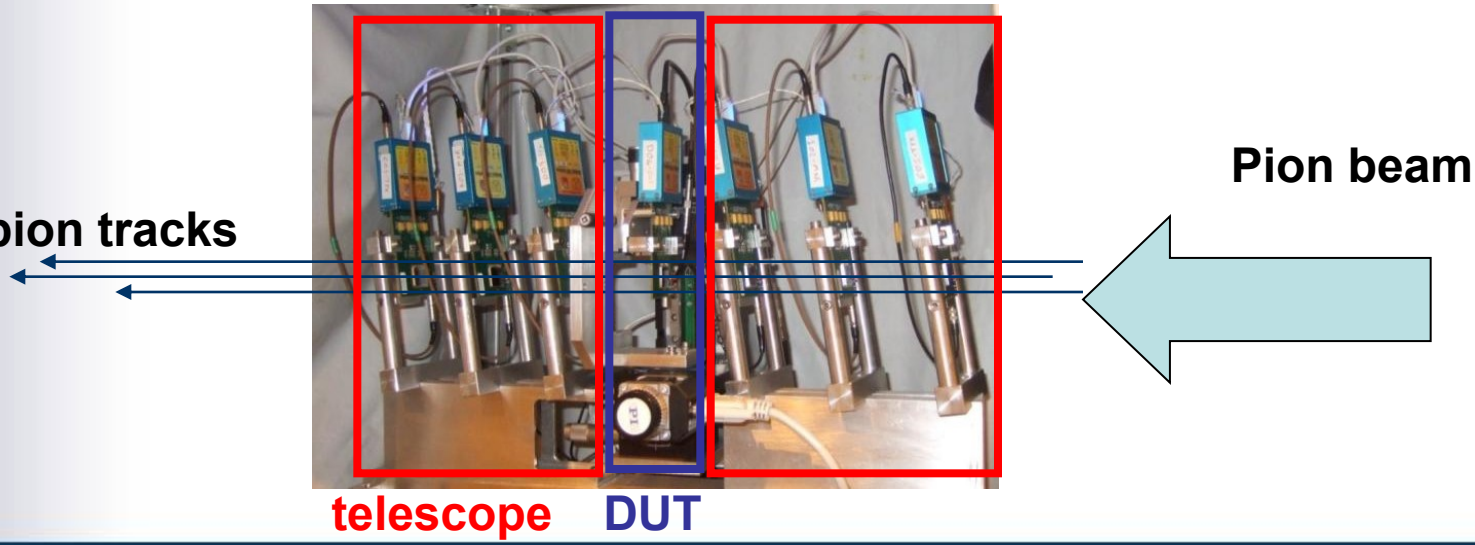


•3D Timepix bump bonded at VTT

MIP beam from SPS

Medipix & LHCb

- Secondary 120 GeV pion beam from SPS
- No B-field, non-irradiated sensors
- USB Interface for Timepix (CTU, Prague)
- 4 Timepix, 2 Medipix planes in telescope
- Angled at 9degs to vertical and horizontal axes to get best resolution
- DUT: double sided 3D N-type sensor from CNM/Glasgow
- Expected track extrapolation error: < 2 μm
- DUT can be rotated to give different angles of incidence.



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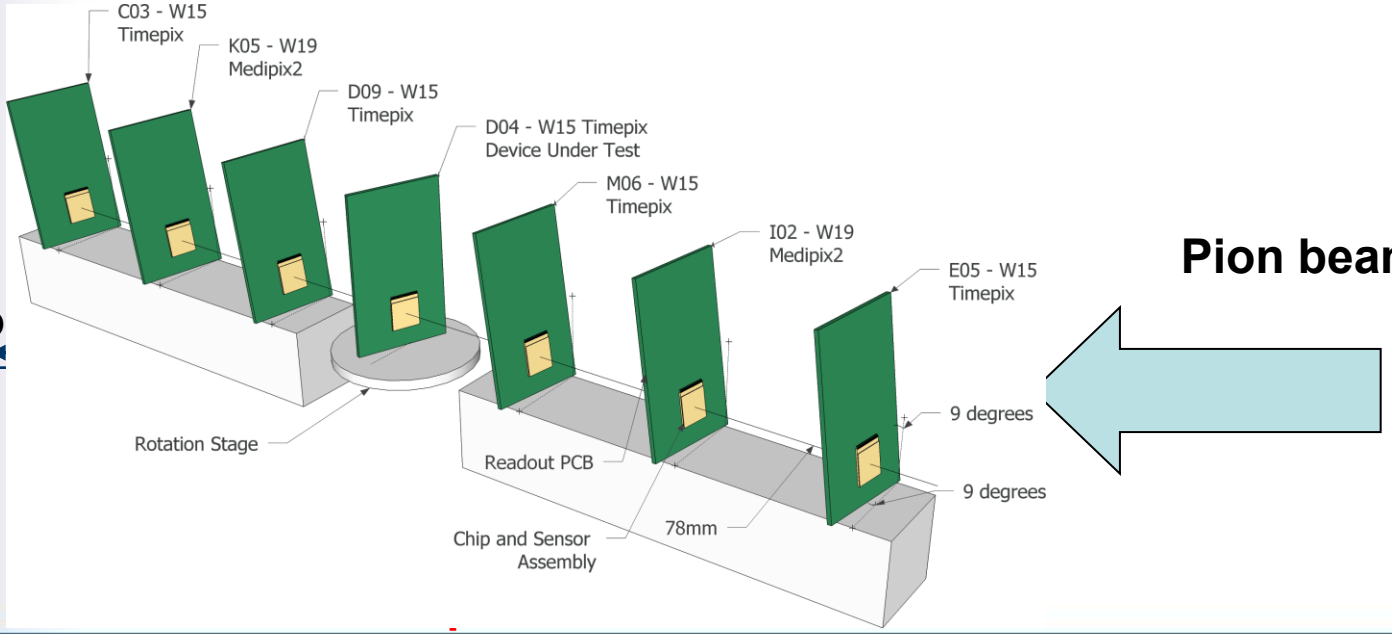
Individual pio



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Testbeam analysis

- Shutter driven DAQ
  - No scintillator trigger
  - No pipeline or event number
- Data collection method
  - Open shutter
  - Collect 100-1000 events - occupancy at 0.2% level or less
  - Close shutter - 10ms later
  - Read out data
- Event rate of 200Hz
- Reconstruct tracks
  - Set threshold on telescope planes to 1600 electrons to reduce noise events
  - Assume that no two hits are in neighbouring pixels
  - Cluster all neighbouring pixel hits
    - Cluster is excluded is exceeds a 3x3 limit
    - Cluster is excluded is there is another hit in a 9x9 region around cluster
    - Centre of cluster is found (C.of.G or Eta)
  - Clusters in all planes are fitted with a straight line tack fit
    - When a cluster is associated with a track it is removed from the data set to prevent re-use.
    - All planes must be used in a track for the track to be valid
  - Typically 64 trackers per 100 clusters per plane (only 85% included due to alignment errors)
  - Minimisation procedure followed to minimise residuals via software alignment of detector planes
- Pointing resolution of the telescope at the position of the DUT of 2μm
- DUT - similar process as with telescope planes

Rotational Alignment of DUT

- X-y-z alignment performed via minimization of residuals between cluster and track
- Angular alignment performed by measuring samples over a wide range of angles and looking for minimums in row width, column width and fraction of 1pixel events

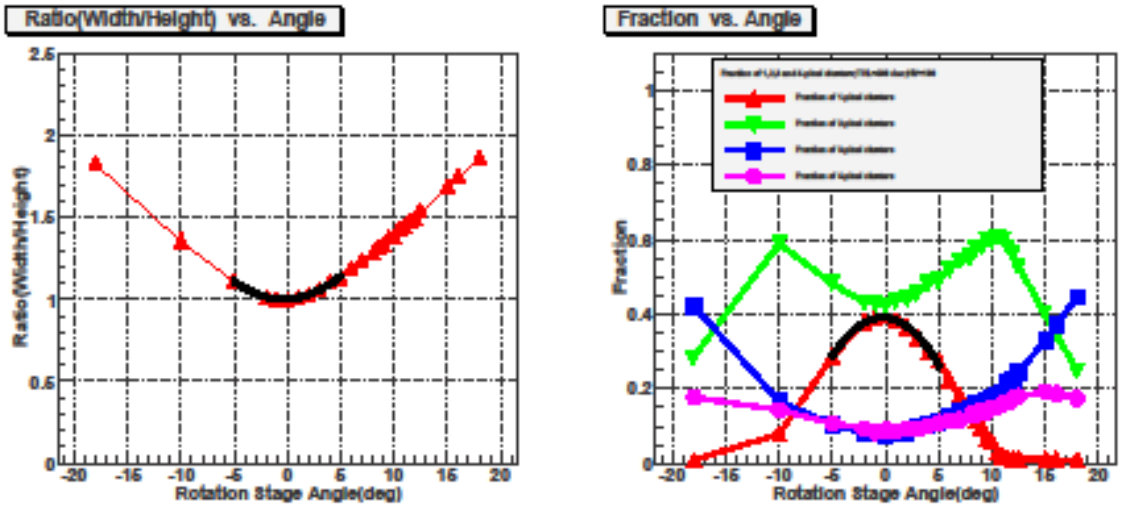


Figure 8: Left plot shows the distribution of the ratio of row width to column width; right plot shows percentage of various sizes of clusters as a function of nominal angle

Scan	Minimum Angle
Cluster Size	-0.205
Cluster Row Width	-0.306
Fraction of 1-pixel Cluster	-0.273
Ratio(Row/Column)	-0.366

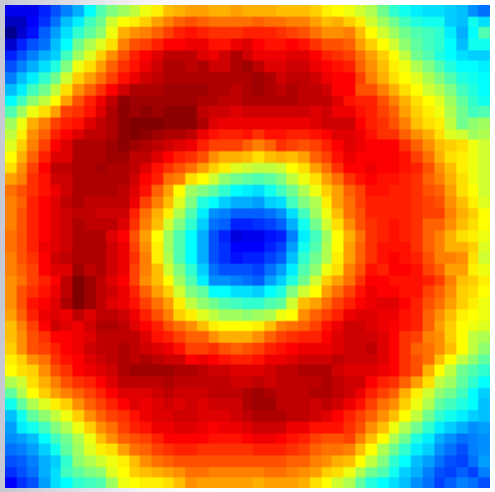
Table 2: The DUT angle at which the specific quantity listed in the left-hand column is minimized.

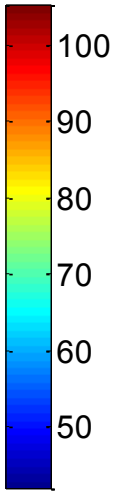
Energy Spectra – TOT Mode

Clusters made and then track associated with them
Can look at pulse height from single pixel at the centre of the cluster or from cluster
Plot “mean” of pulse height as function of track position in a pixel

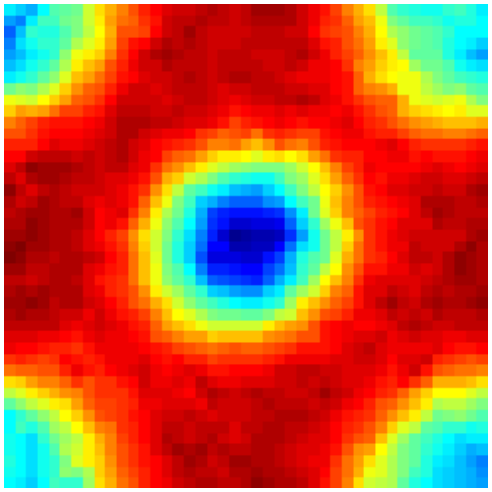
Threshold just above noise level at 1000 electrons

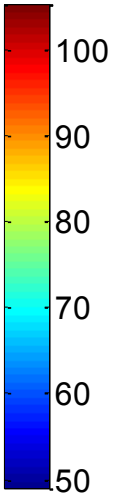
ADC in pixel





ADC in sum of 3x3 pixel



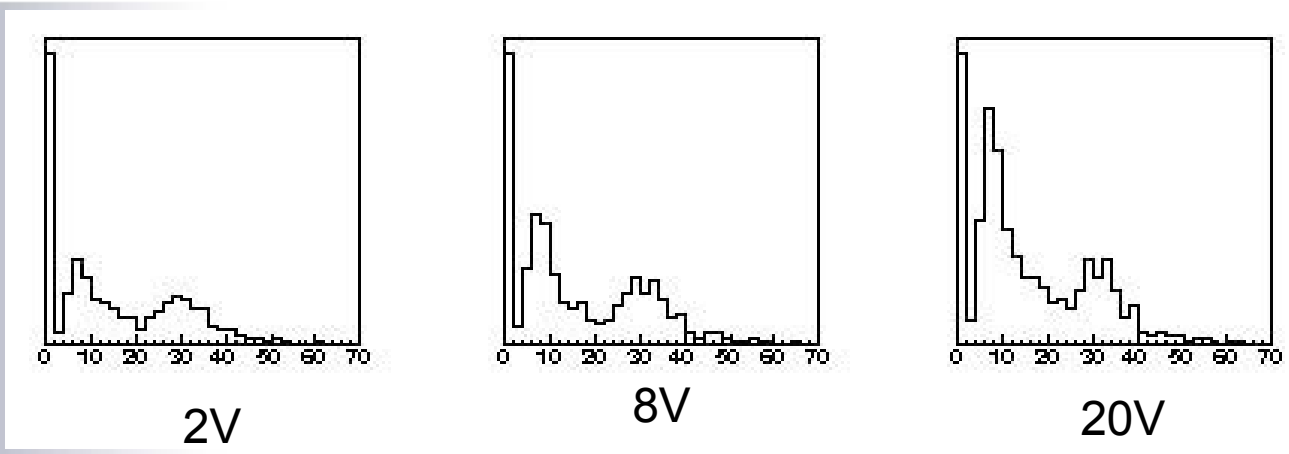


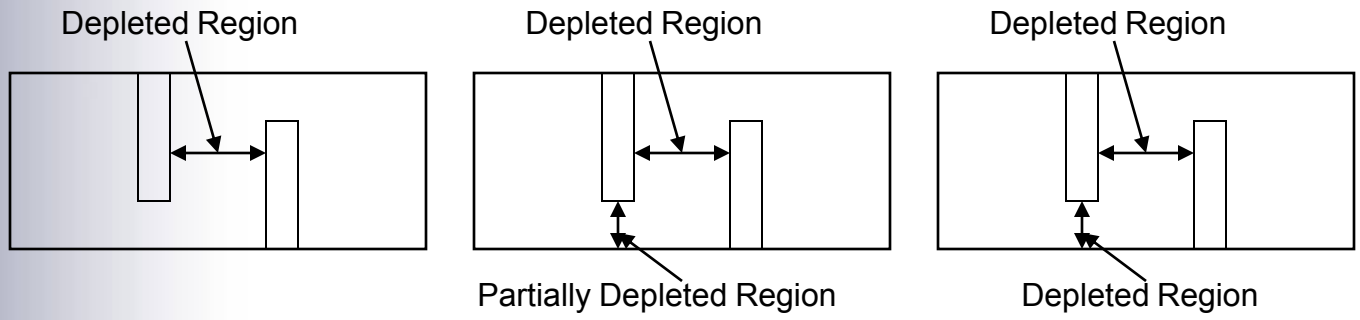
2D Normalised average ADC plot, 20V bias

Normalisation : assume average signal size =100 for a ring around the central column

Energy Spectra at varying Bias Voltages

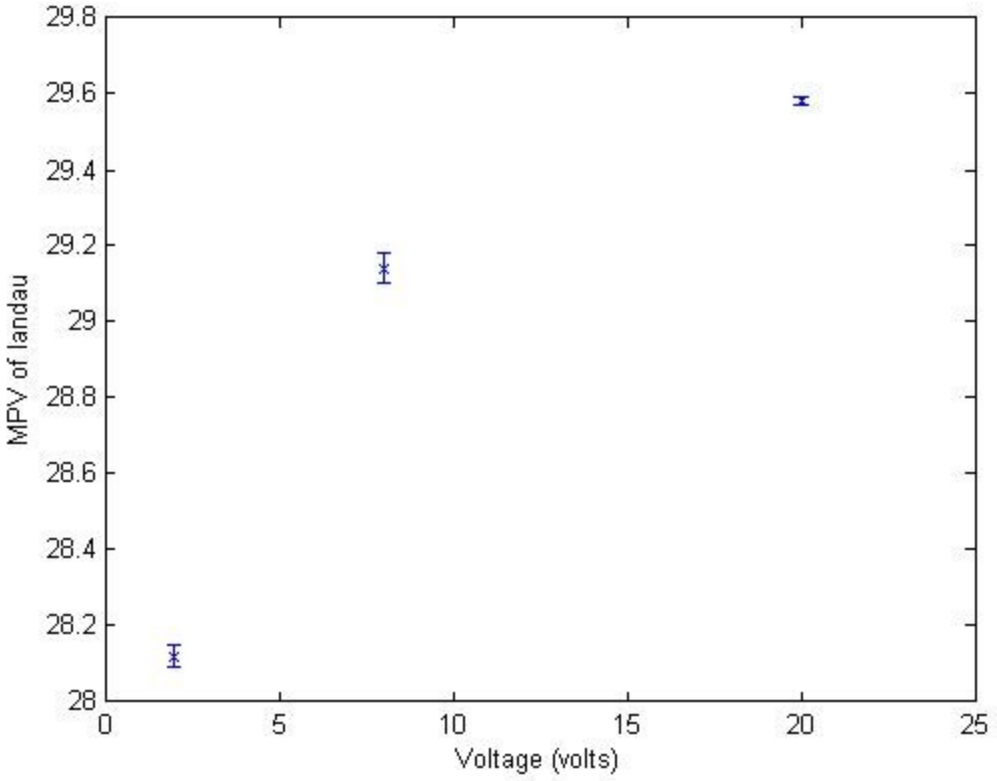
Pulse height spectra for region at centre of pixel





Landau MPV as a function of Bias Voltage

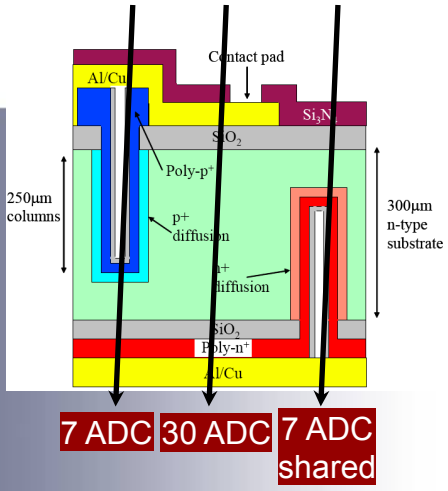
- MPV of deconvolved Landau from fit of Landau convoluted with a Gaussian to the high energy peak in the pulse height spectra from the full charge collection region around the collection column.

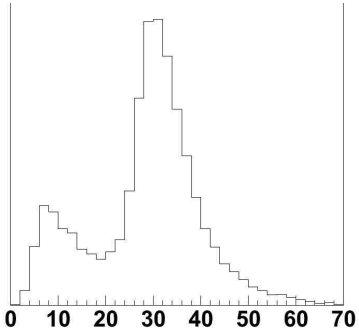


Only 5% increase in MPV

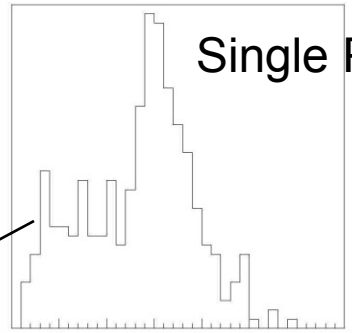
Energy Spectra – ToT mode, Normal incidence, 0°

Overall, from single pixel not cluster

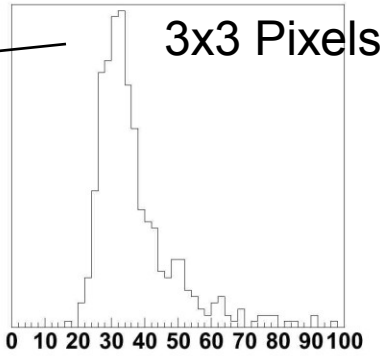




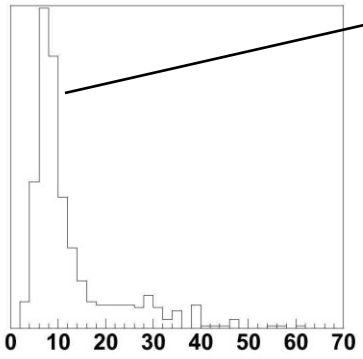
Single Pixel

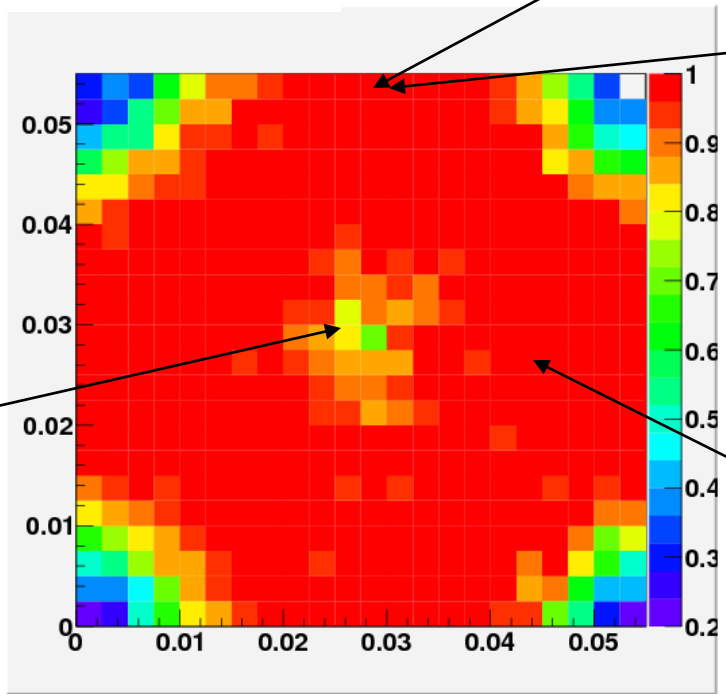


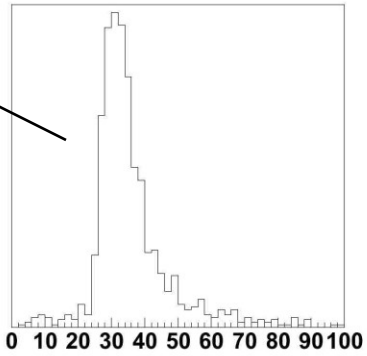
3x3 Pixels



Signal ratios suggests shorter columns, 220 not 250µm deep?

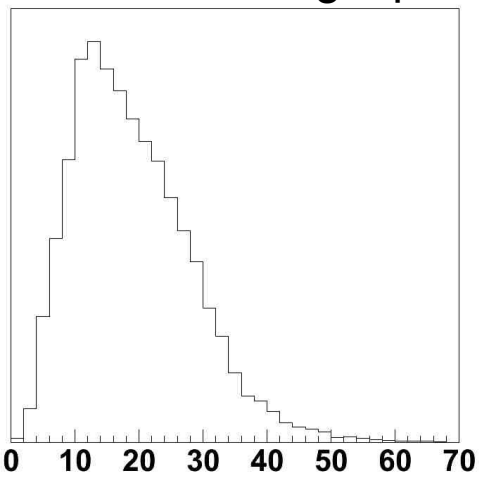




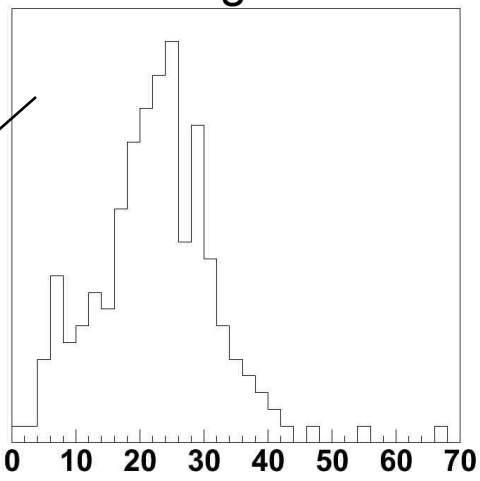


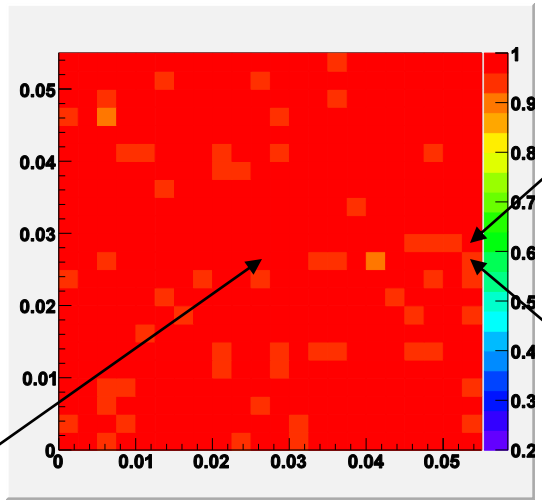
Energy Spectra – ToT mode, 10°

Overall, for single pixel not cluster

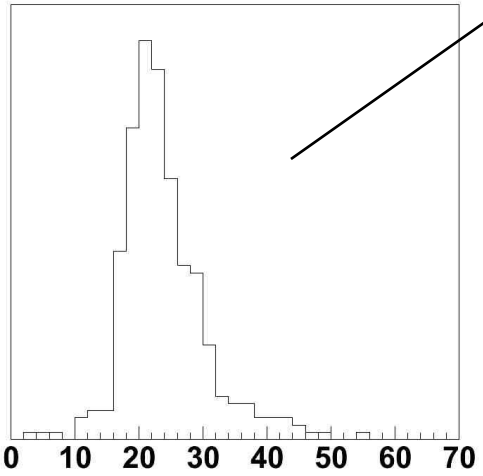


Single Pixel

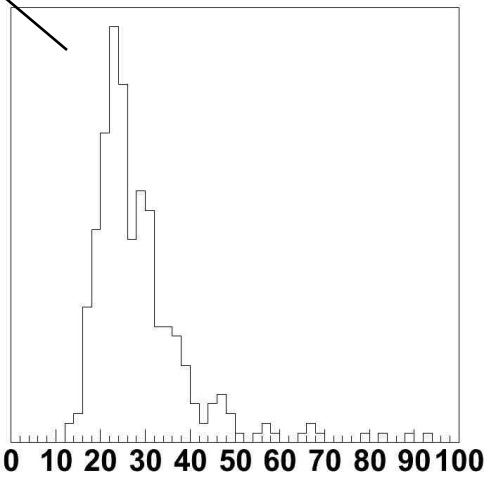




Centre



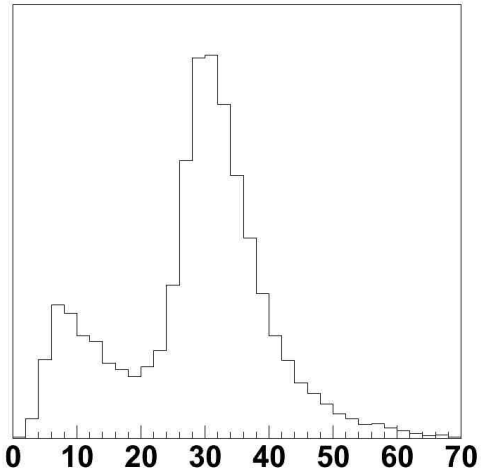
3x3 Pixels



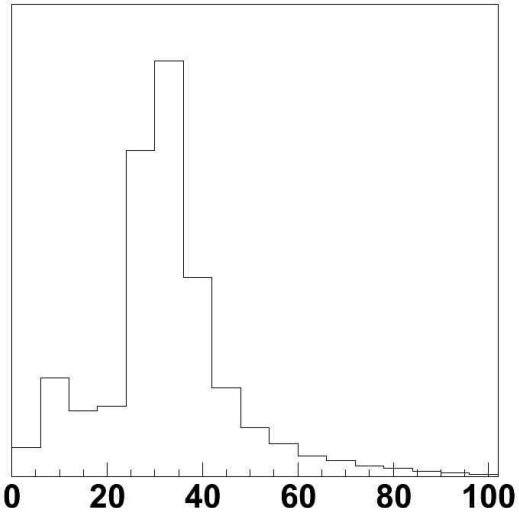
Cluster and single pixel P.H.S.

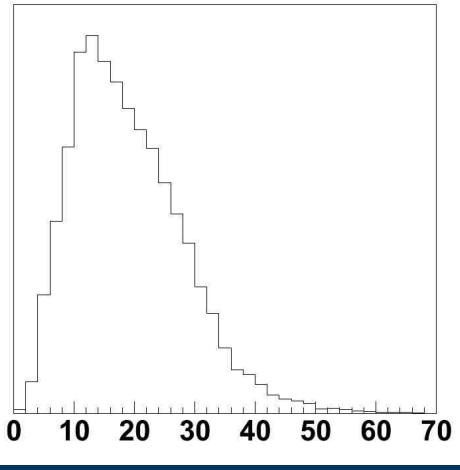
- 0^o incidence
- 10^o incidence

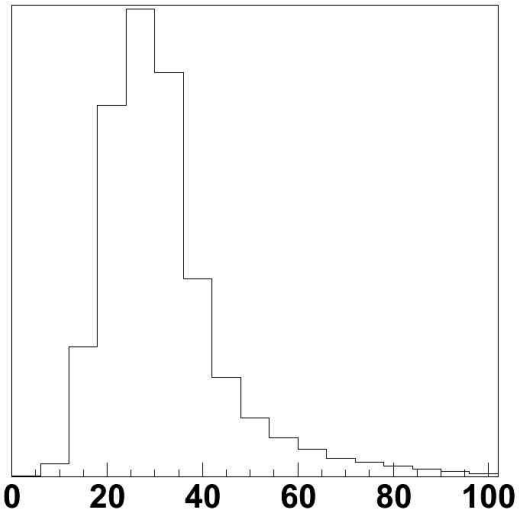
Single pixel P.H.S



Cluster P.H.S



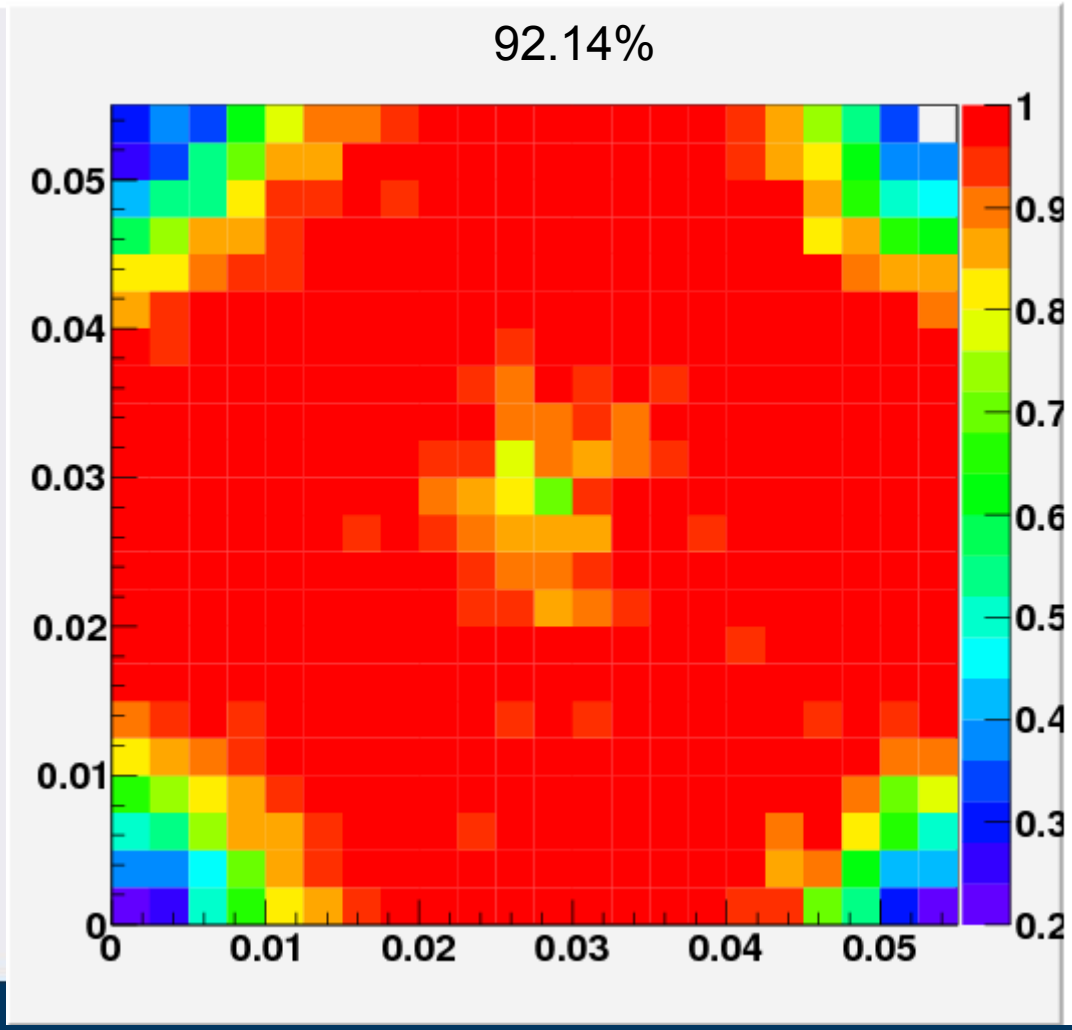




Absolute Detection Efficiency
Normal Incidence, 0°

Cluster in DUT included if in 3x3 pixel array around the track intersection point
Bad pixels are masked : 0.1% noise/dead + 1% due to ASIC

Threshold set just above noise level.



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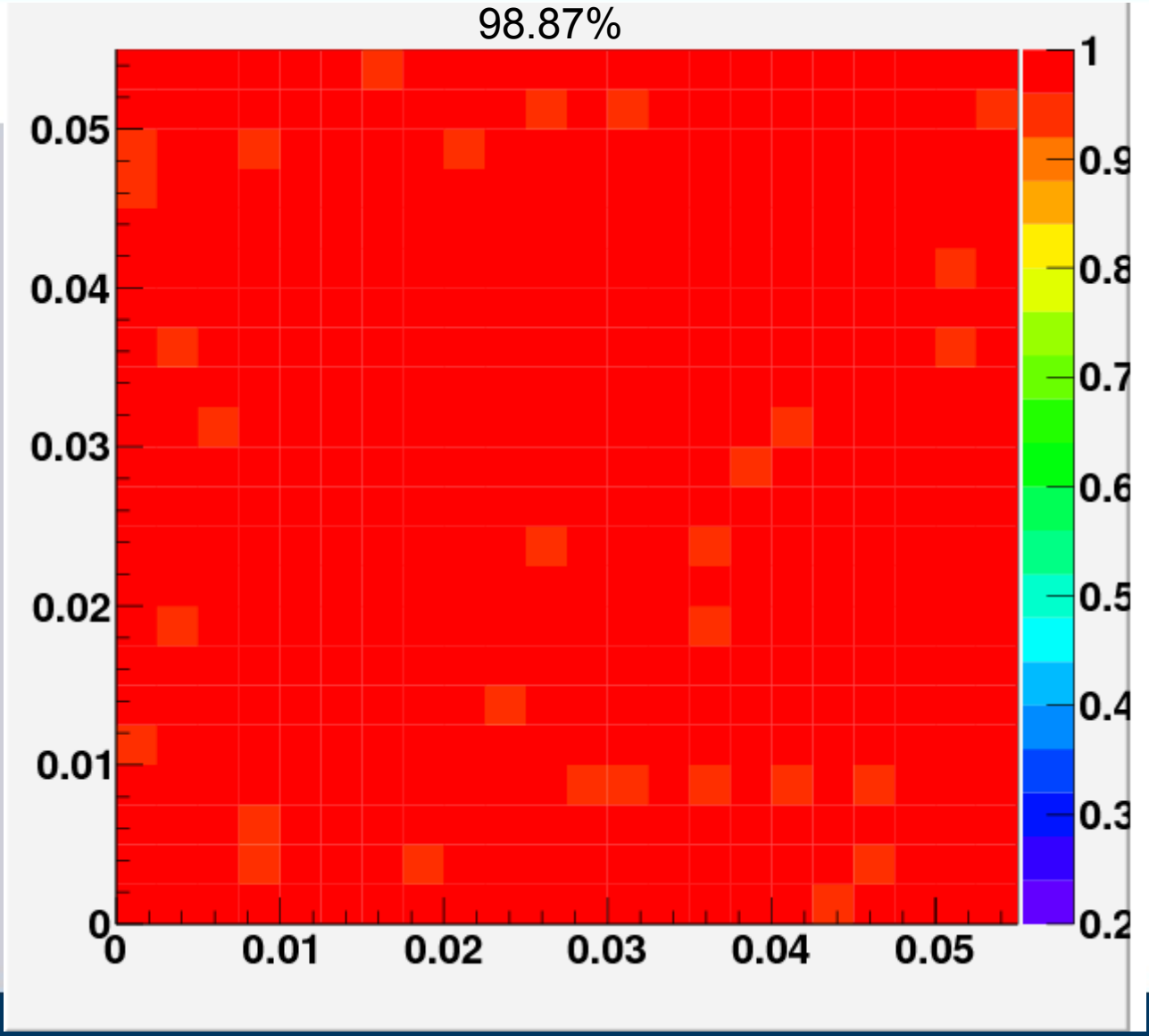
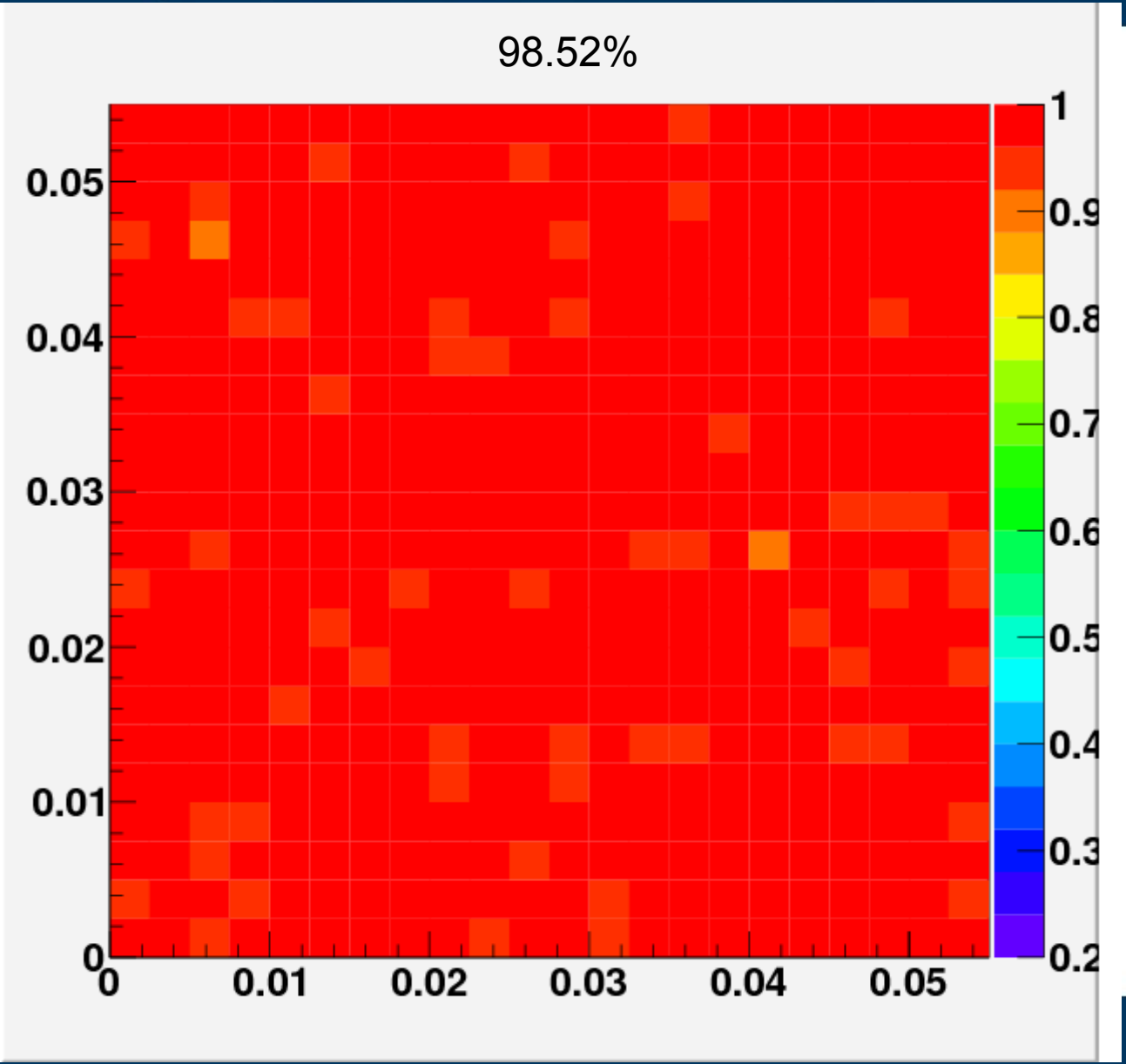
Absolute Efficiency 10°

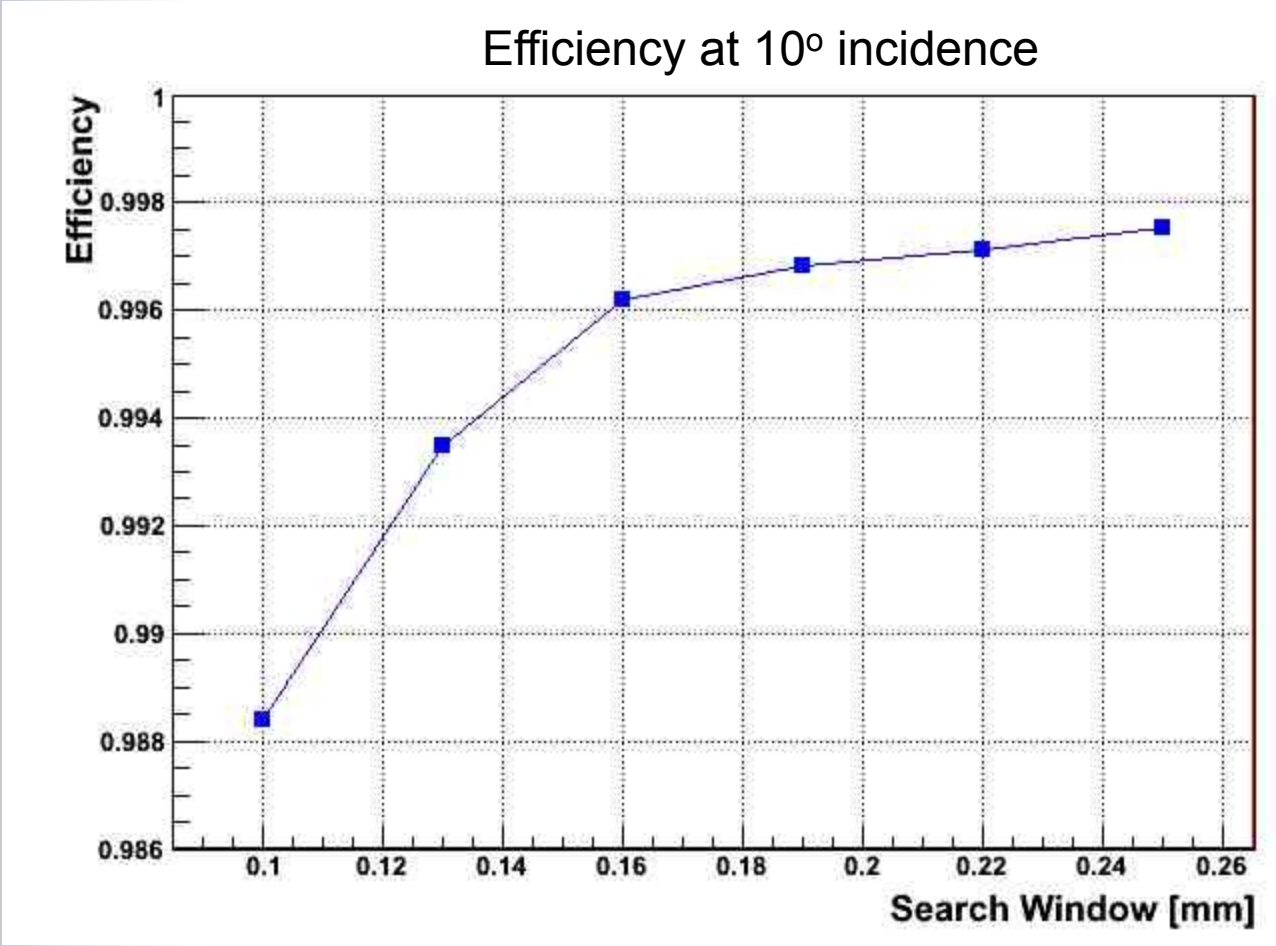


Absolute Efficiency 18°

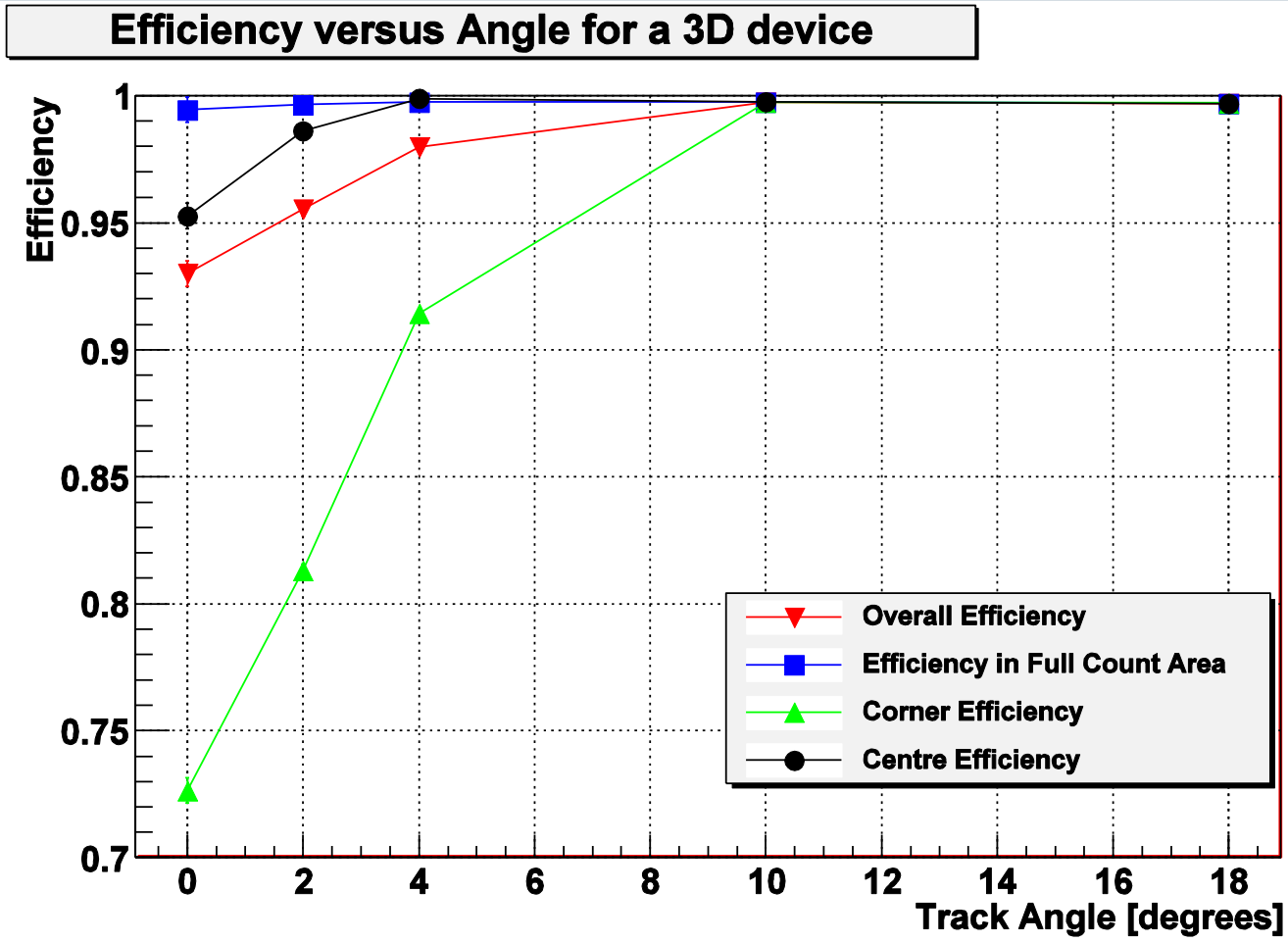


Efficiency – search window

- Increasing the search window increases the efficiency

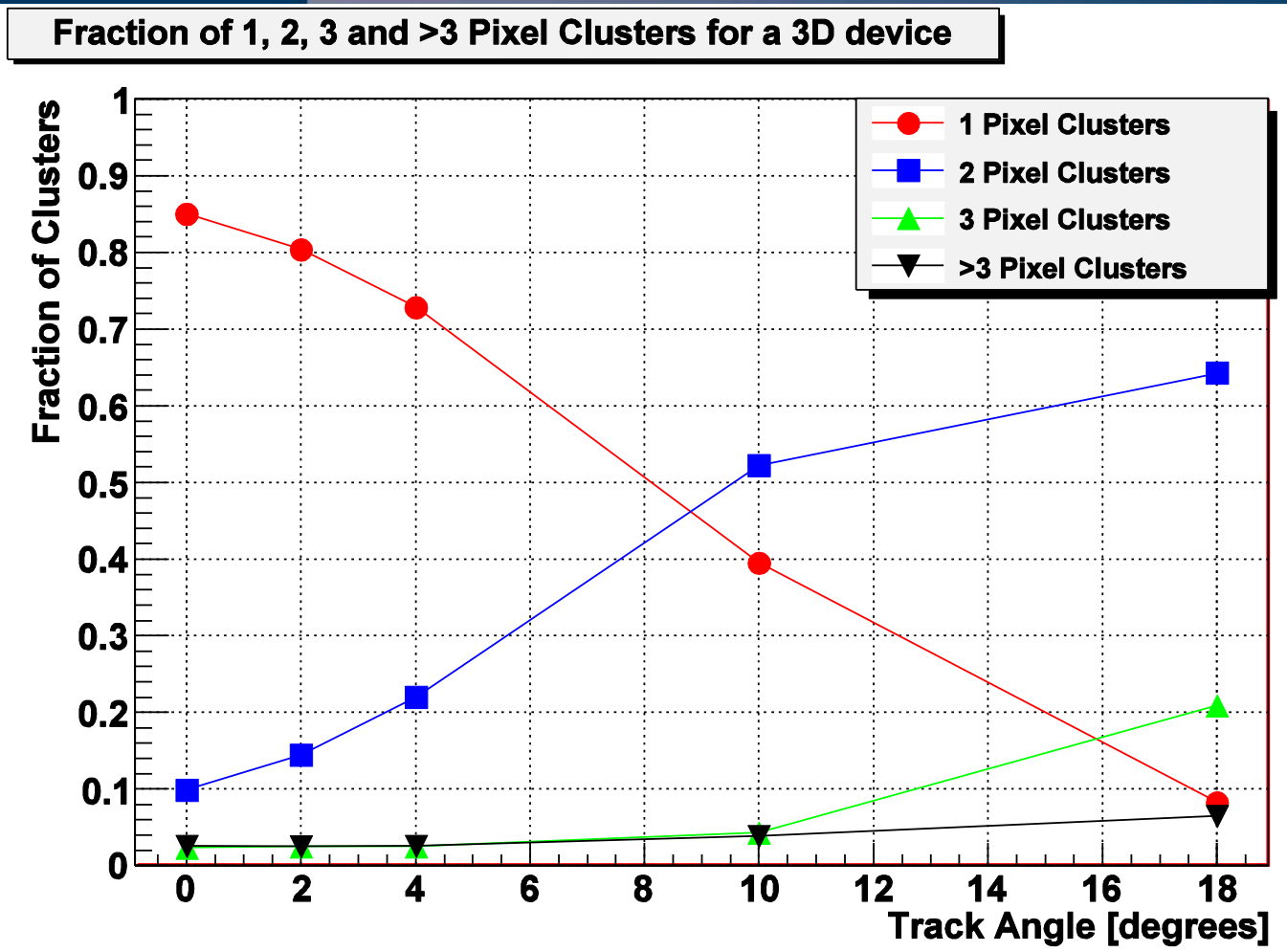


Efficiency with angle



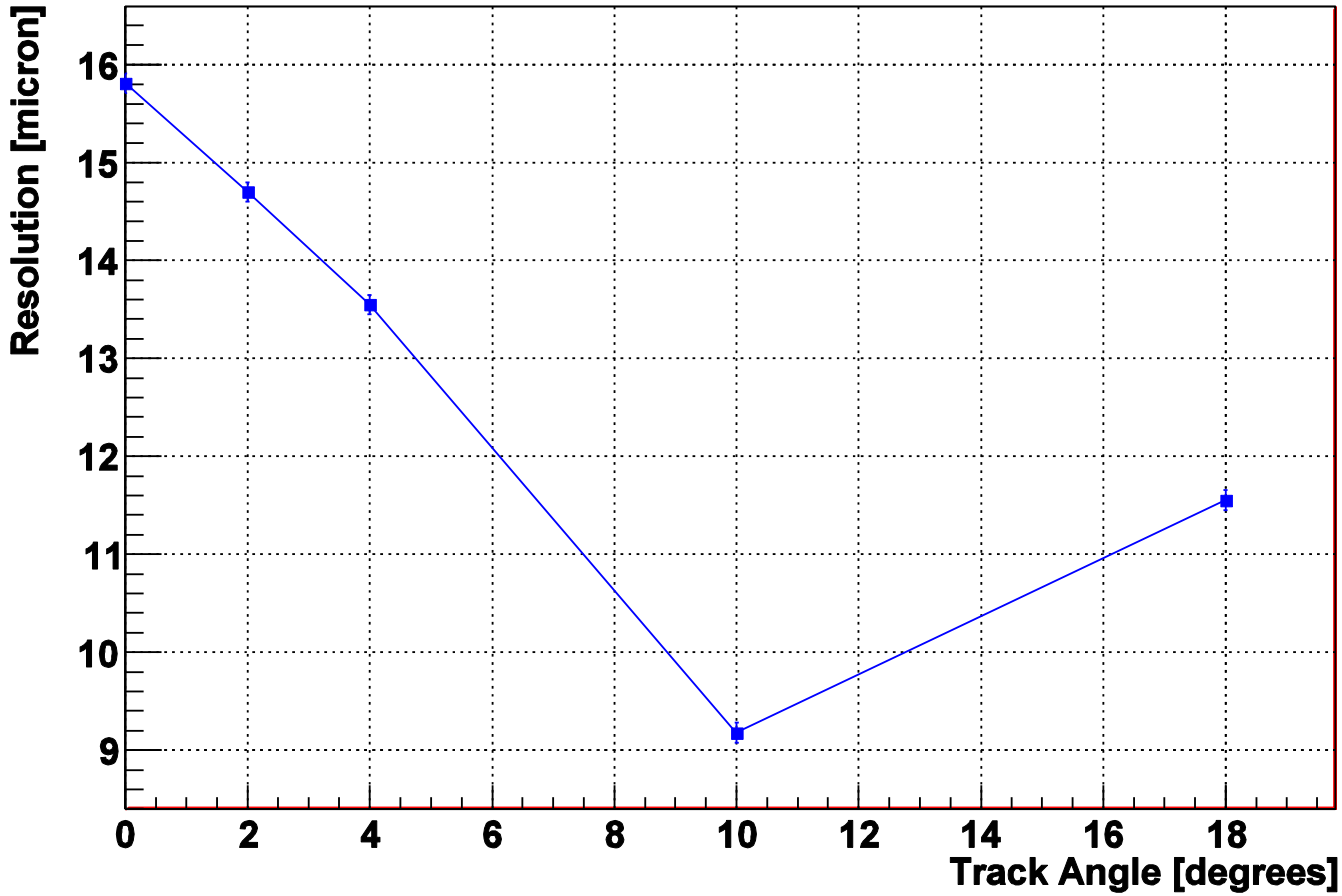
- Highest efficiency of 99.8%
- Efficiencies over device become equal

Cluster size



- The S/N cut is the one from the hardware, 1000e.
- If there is a hit (above hardware Vth) then it is included in the hit histogram.
- Clusters used that are track associated ones

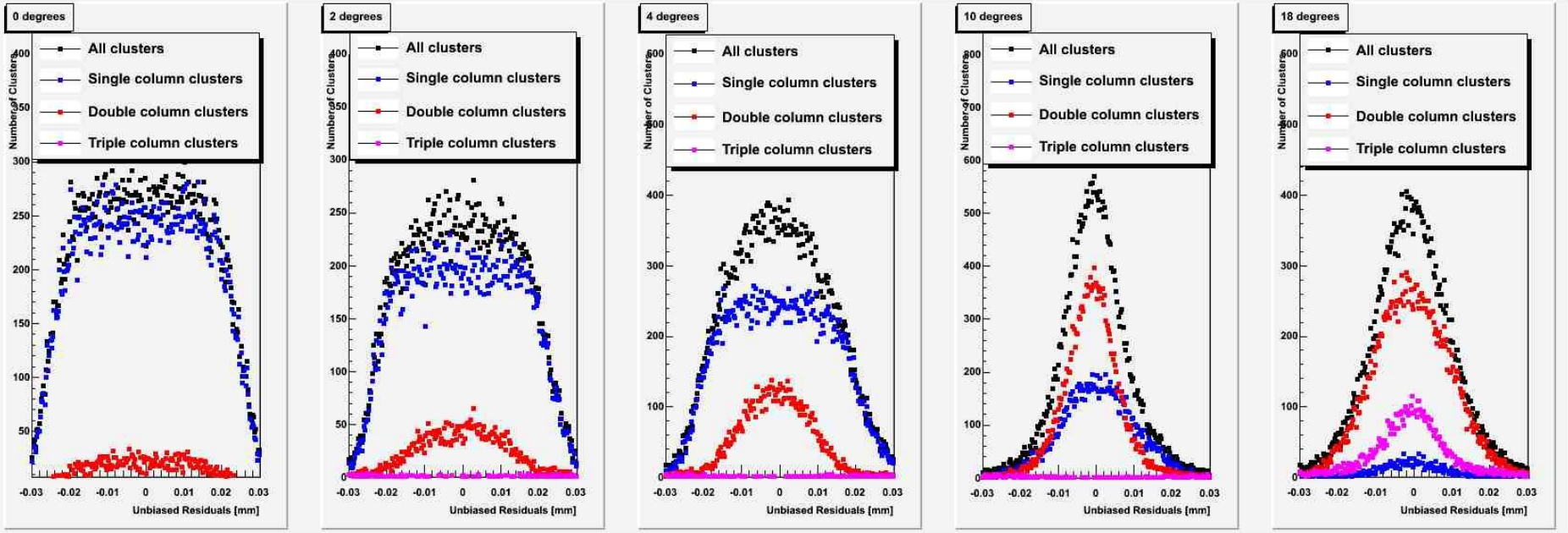
Resolution



- Pitch/ sqrt 12 = 15.9μm
- Resolution improves with angle to 10deg where track travels 50μm laterally
  - Lots of 2 hit clusters with non-equal pulse heights improves resolution
- At 18deg lateral travel is 90μm, and 2 hit clusters have equal pulse heights

Residuals for different cluster sizes

0° 2° 4° 10° 18°



- Red is residuals for 2 hit clusters

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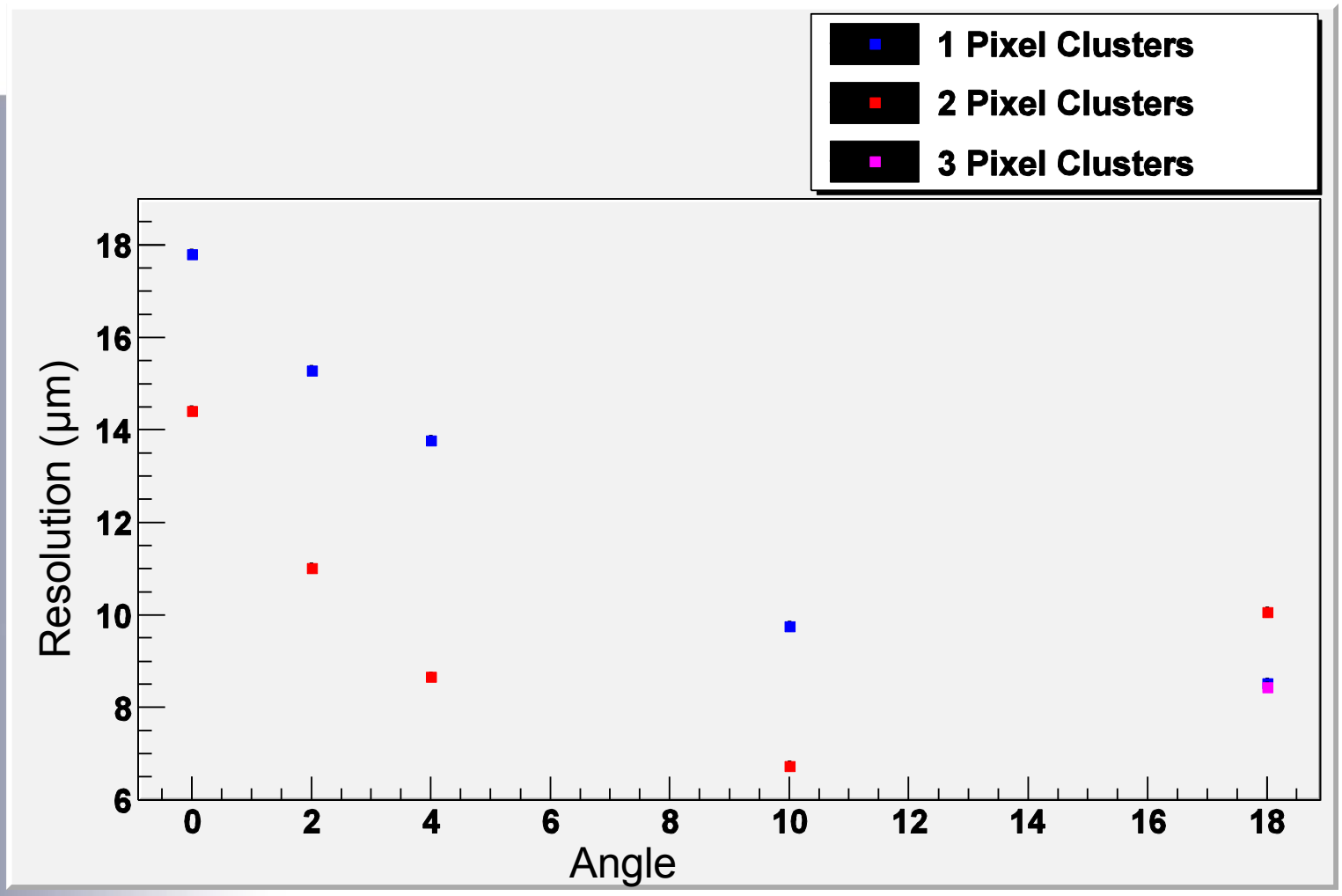
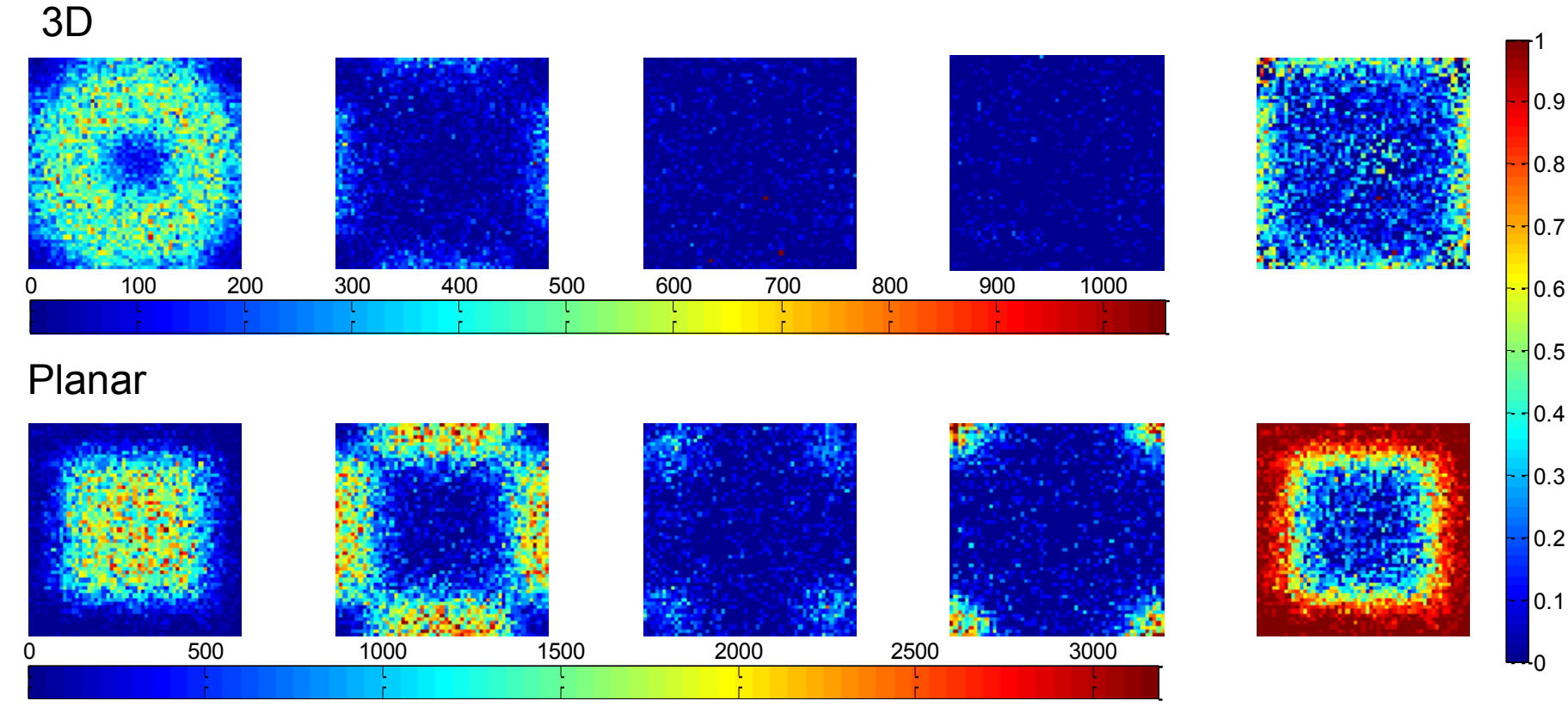
Resolution as a function of cluster size



A study of charge sharing

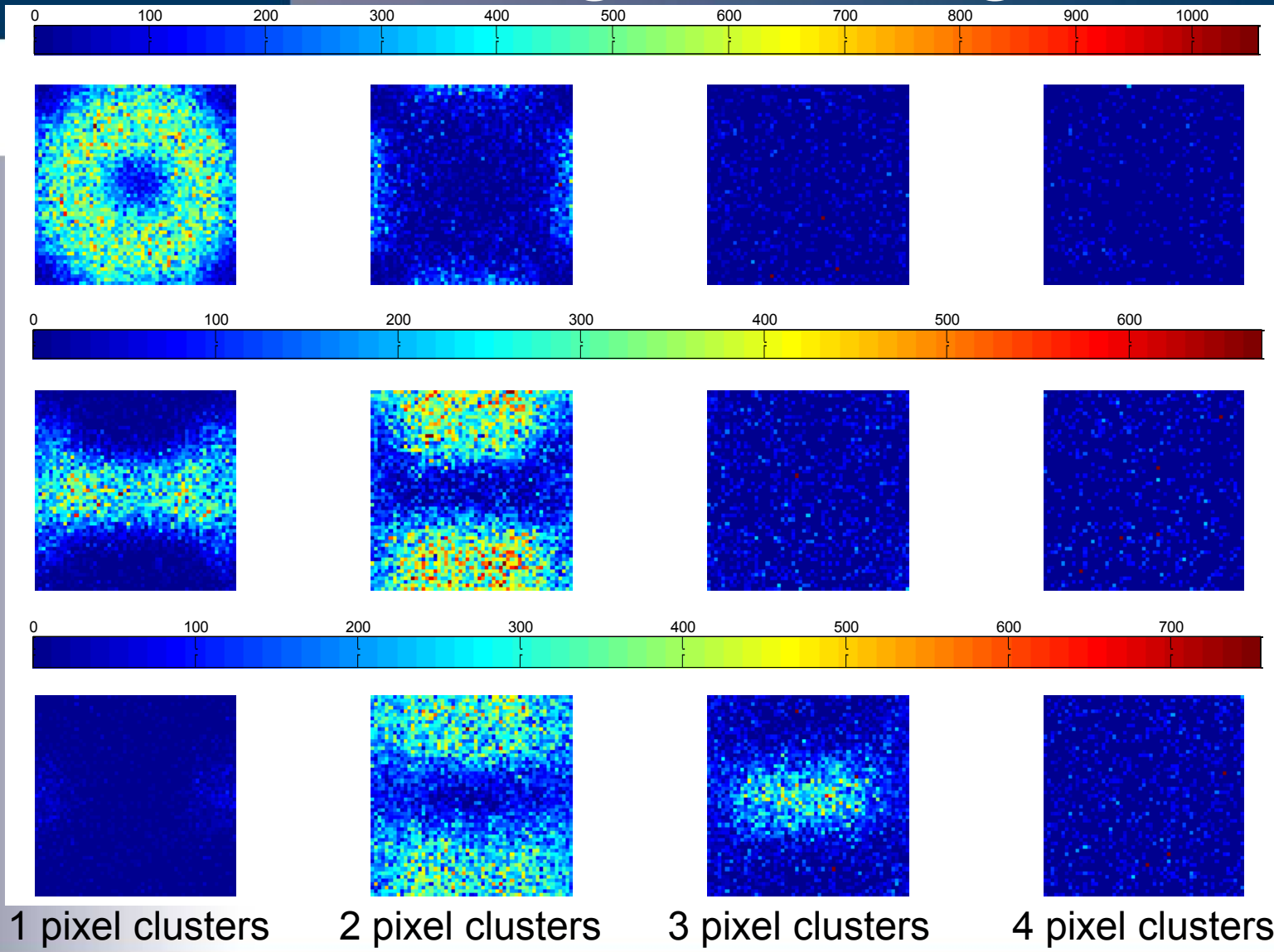
Number of clusters and their positions in the pixel



1 pixel clusters 2 pixel clusters 3 pixel clusters 4 pixel clusters

$$\frac{>1 \text{ pixel clusters}}{\text{Total of clusters}}$$

Charge sharing – 3D



Detector rotated in the vertical direction

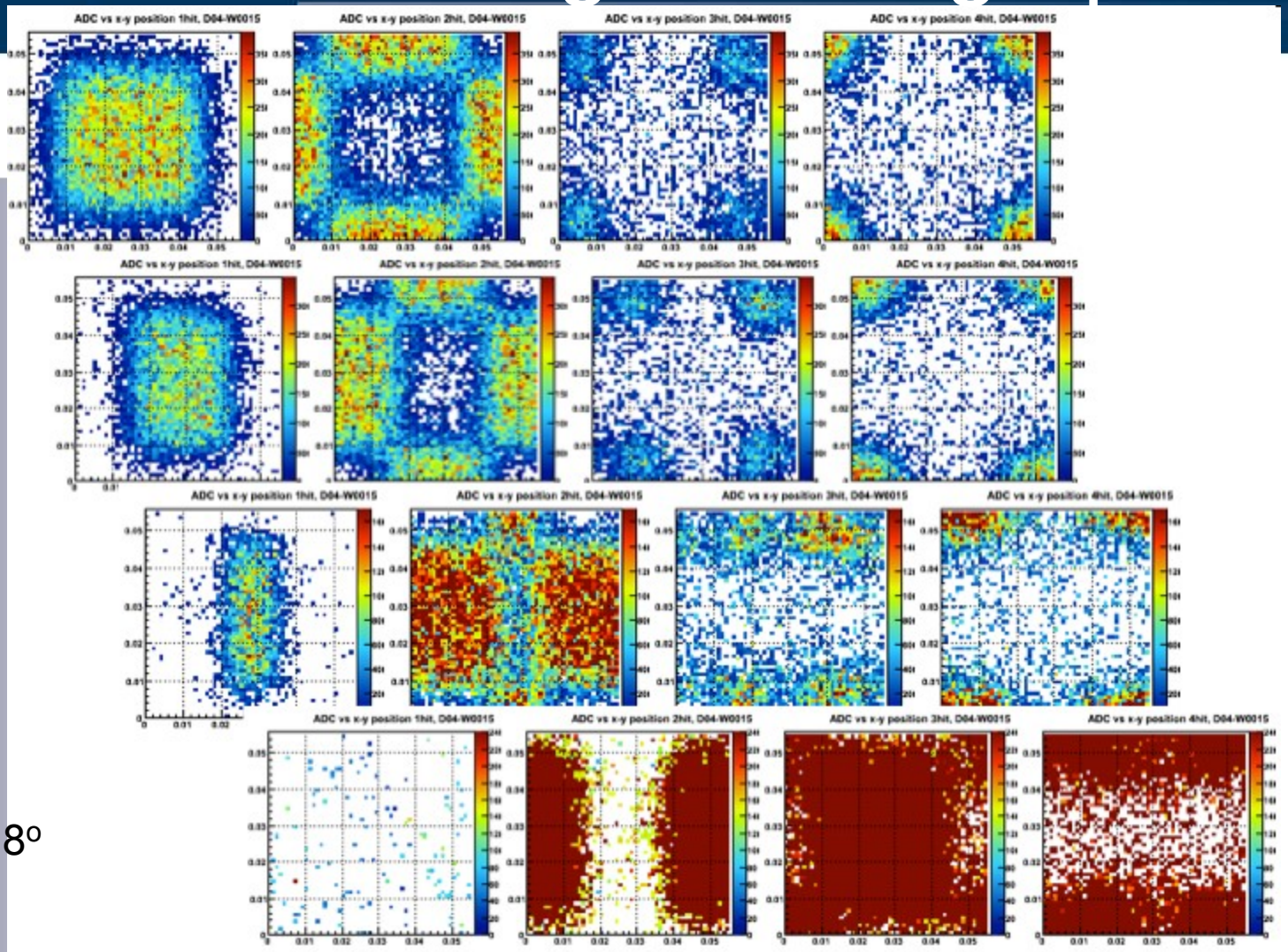
Charge sharing - planar

0°

5°

10°

18°



1 pixel clusters 2 pixel clusters 3 pixel clusters 4 pixel clusters

Detector rotated in the horizontal direction

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Conclusions

- 3D Timepix detector successfully operated in MIP test beam.
- Charge collection observed from both inter-column and column-back plane regions.
  - Charge loss at electrodes observed.
- Reduced average charge collected at 10^{o} track angle due to dead columns
- High (99.8%) and uniform detection efficiency observed at 10^{o} track angle
- Little diffusion charge sharing observed
- Resolution of pitch/square root 12 for normal incidence
- Resolution best at 10^{o} = 9.2μm

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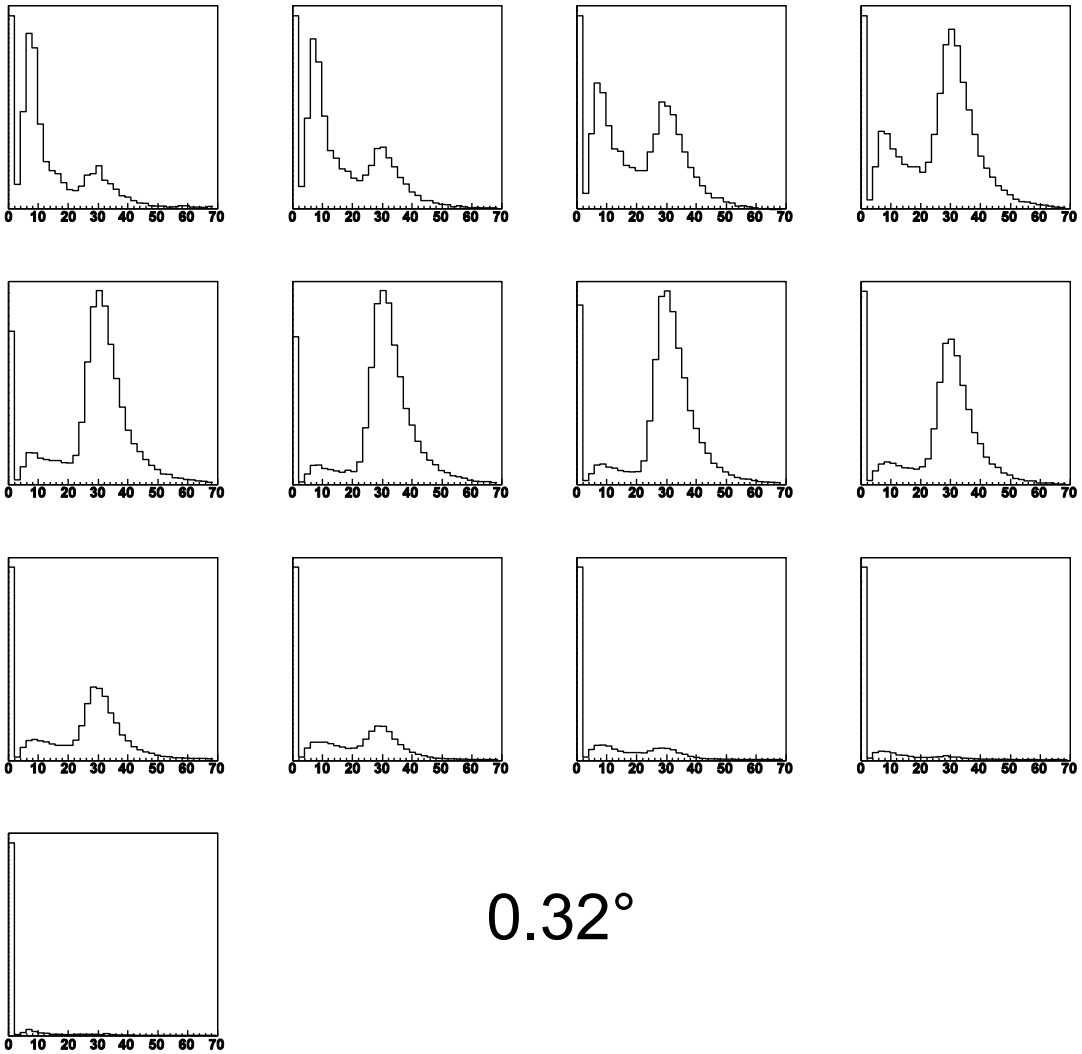
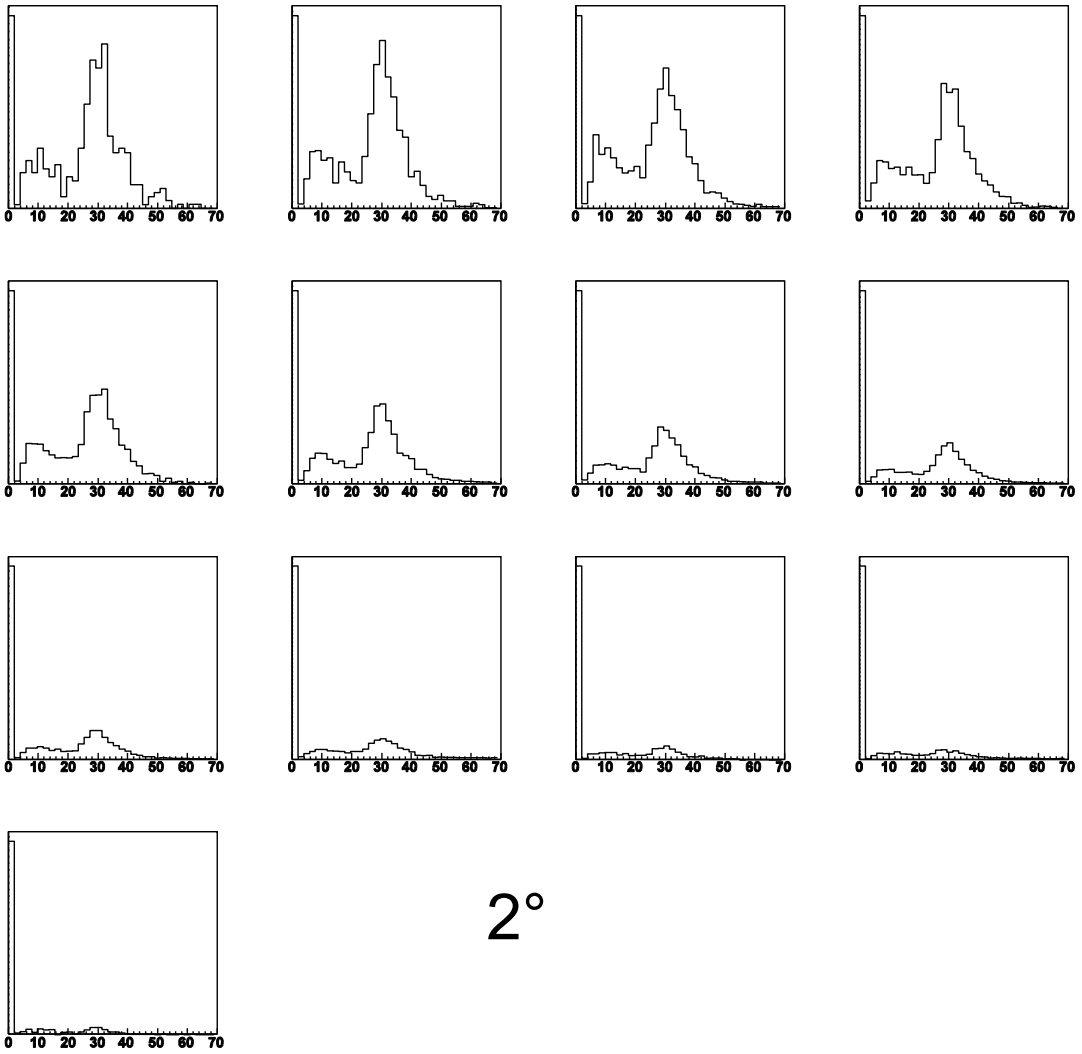
Energy Spectra at varying Angles



0.32°

Energy Spectra at varying Angles



2°

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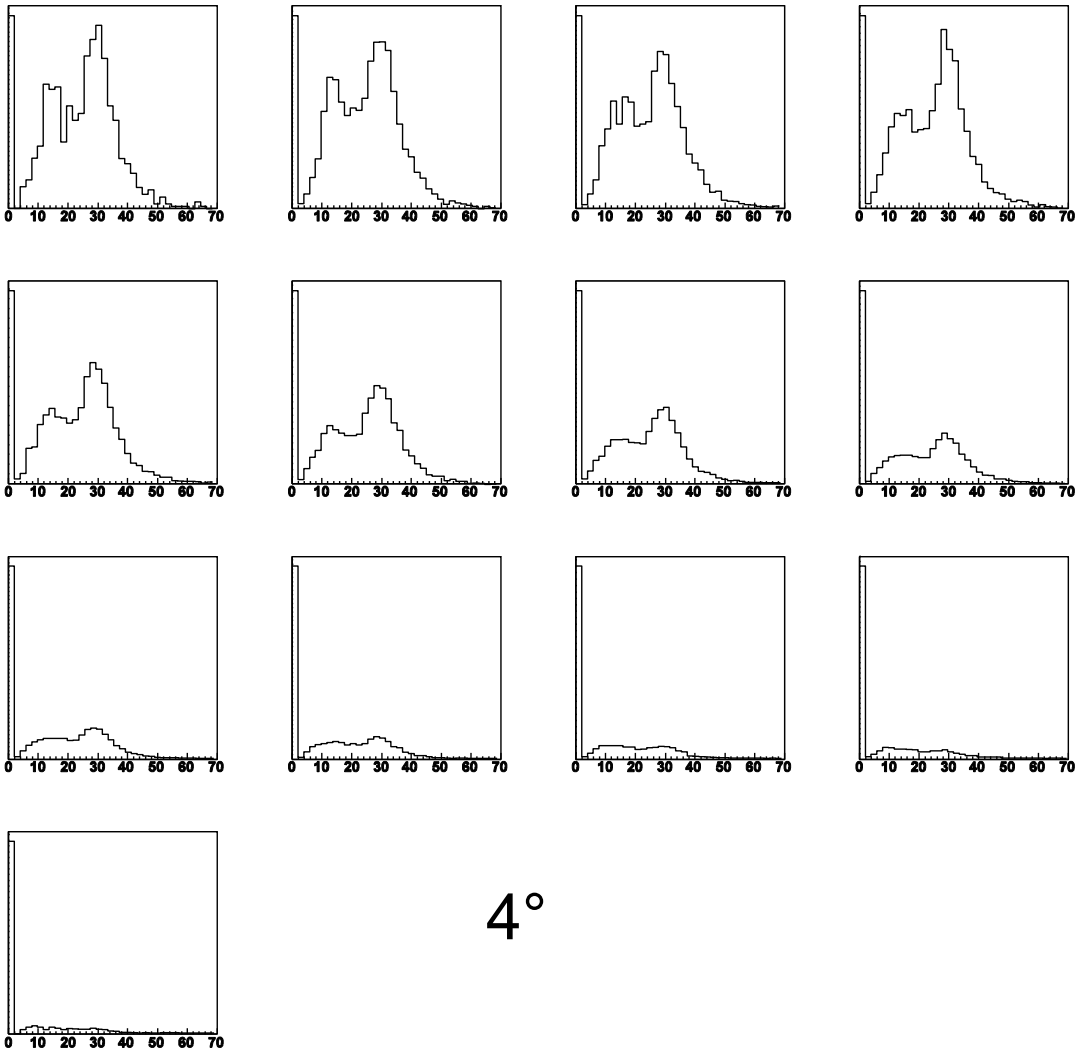
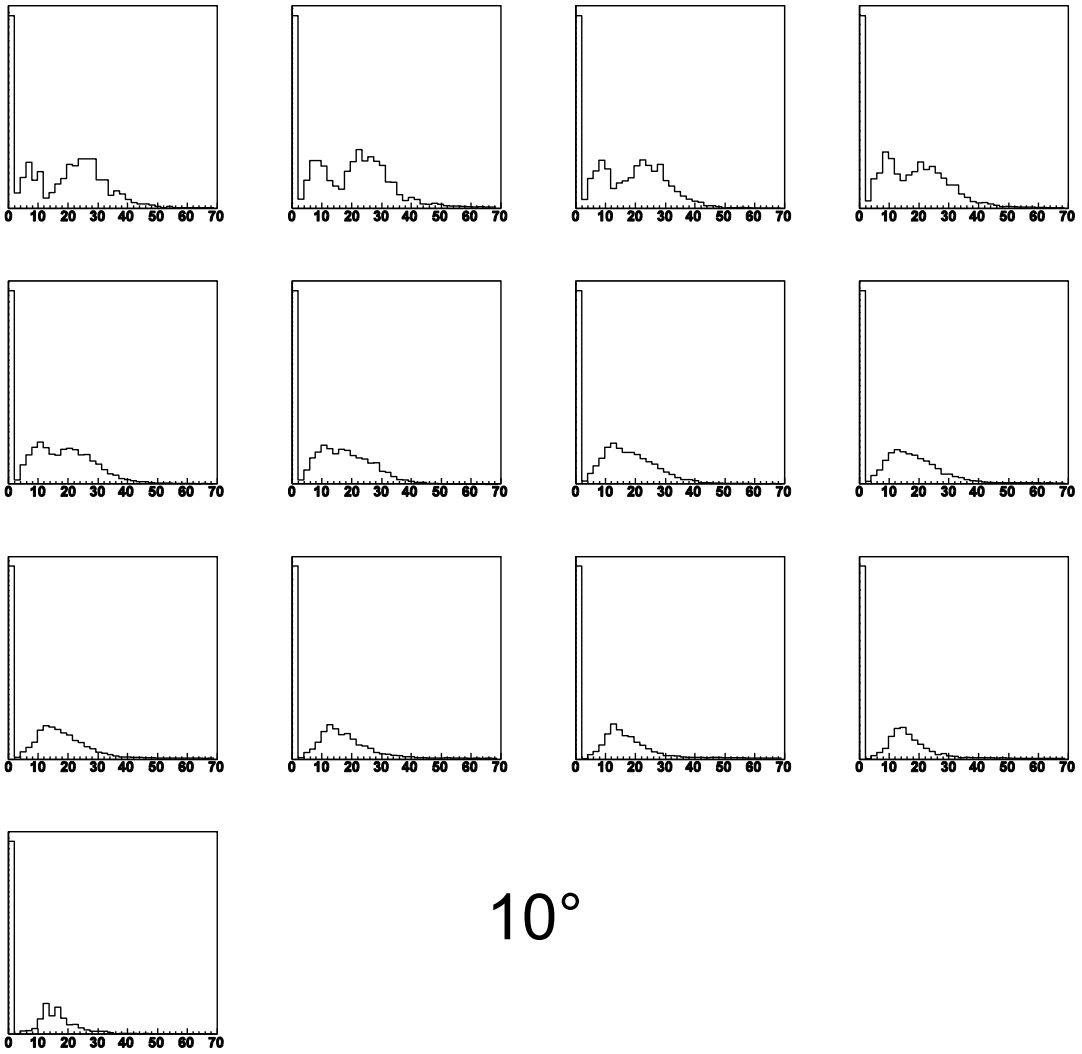
Energy Spectra at varying Angles



4°

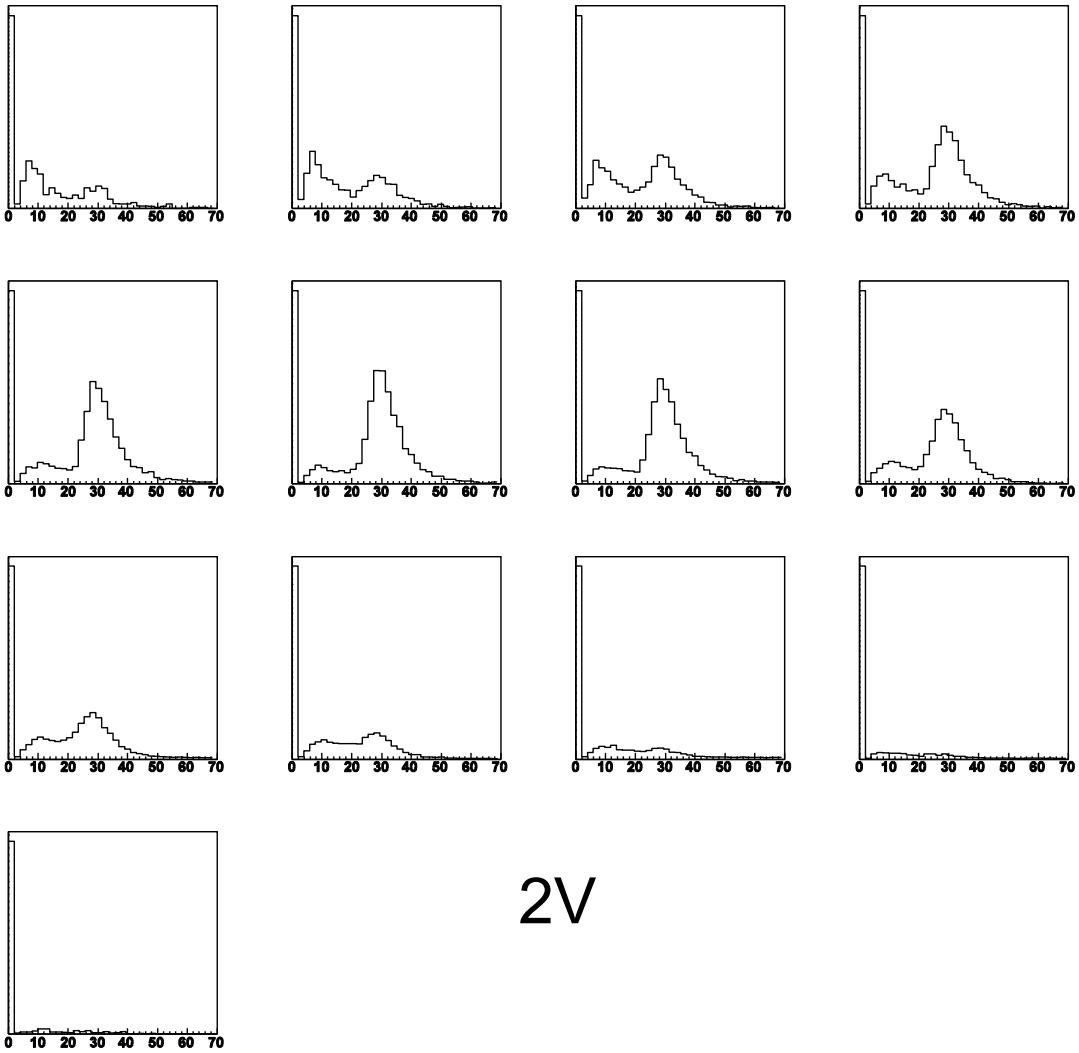
University of Glasgow

Energy Spectra at varying Angles



10°

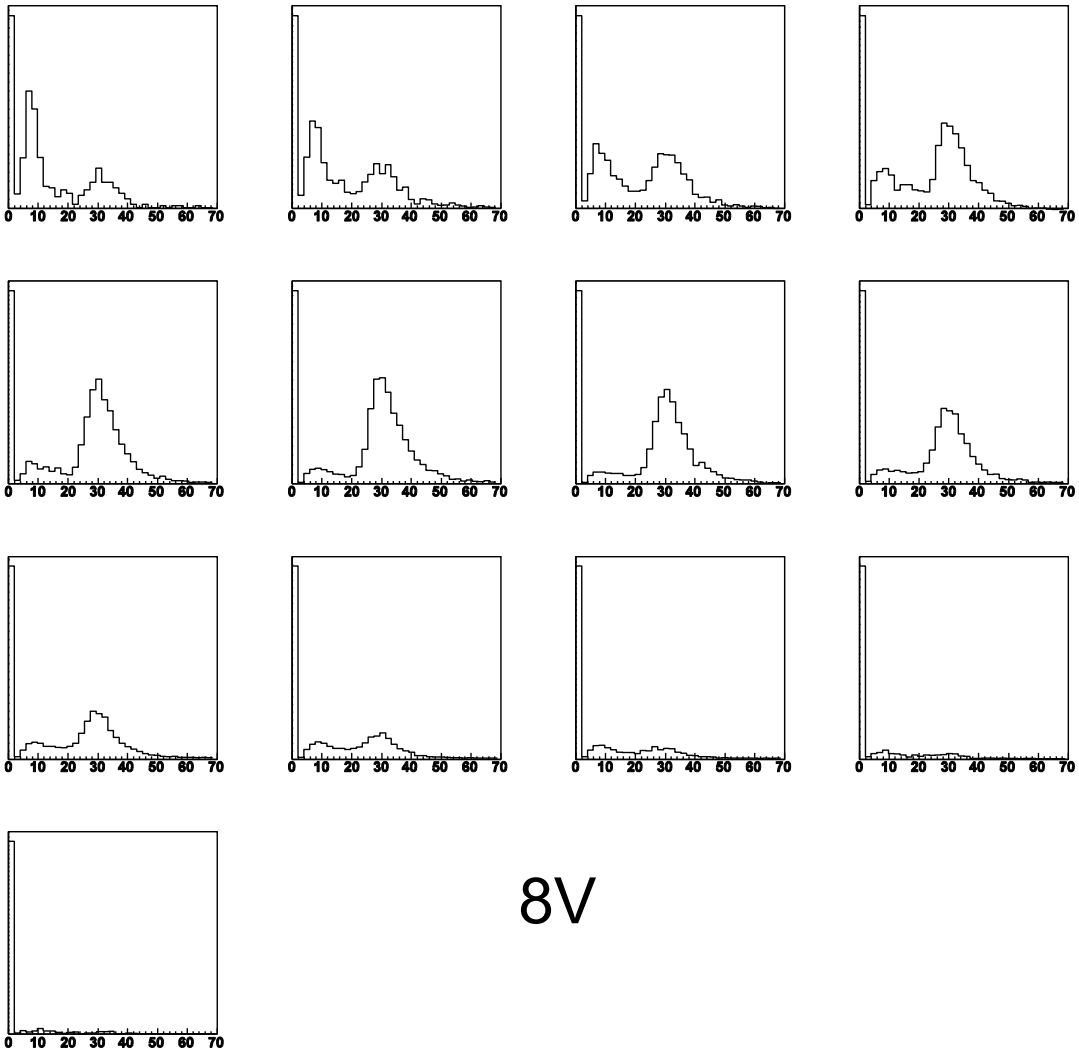
Energy Spectra at varying Bias Voltages



2V

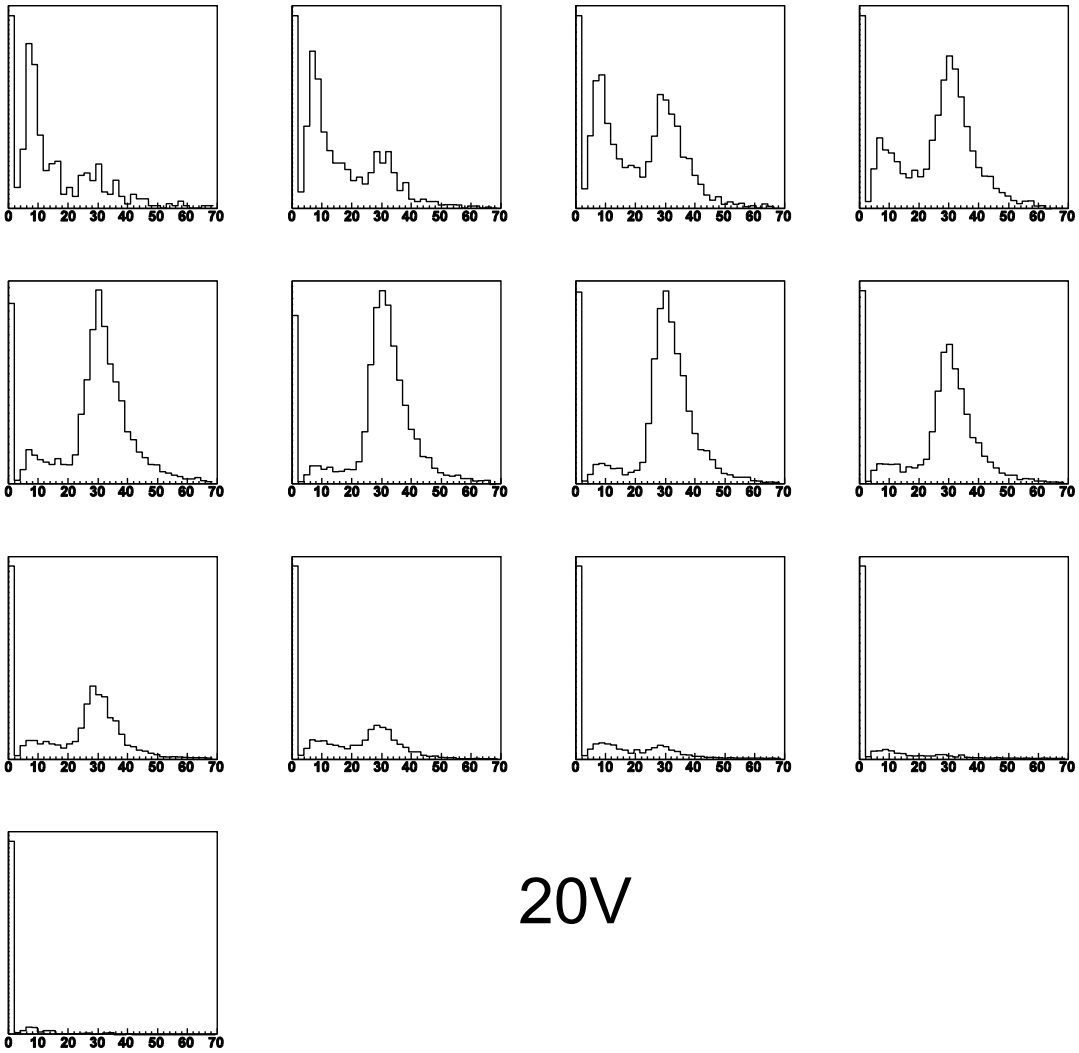
University of Glasgow

Energy Spectra at varying Bias Voltages



8V

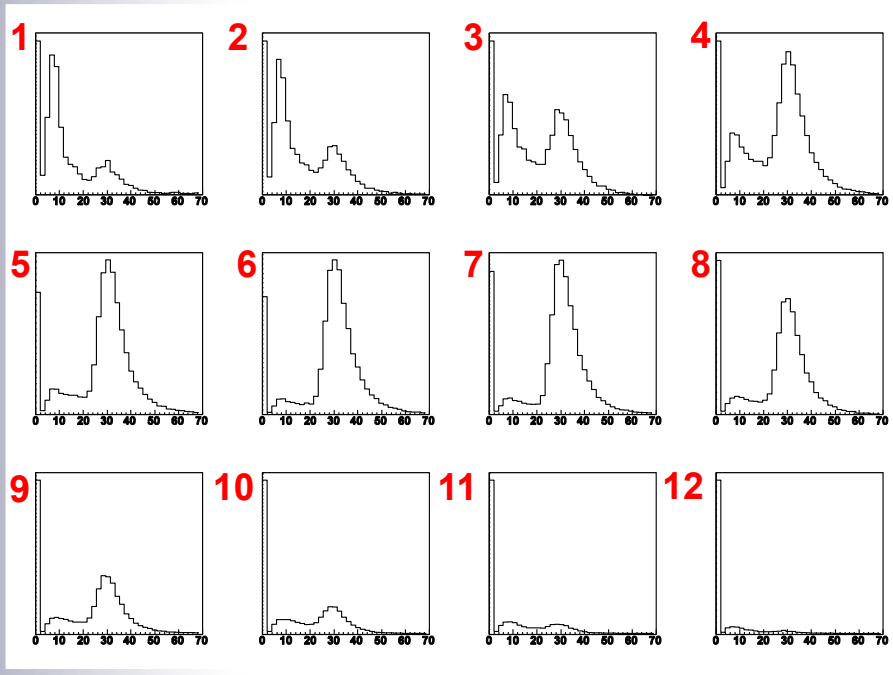
Energy Spectra at varying Bias Voltages



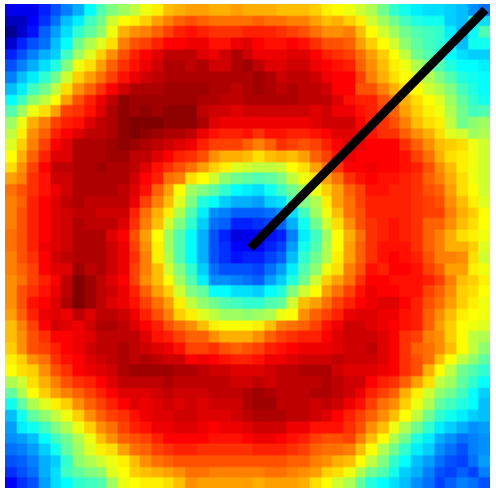
20V

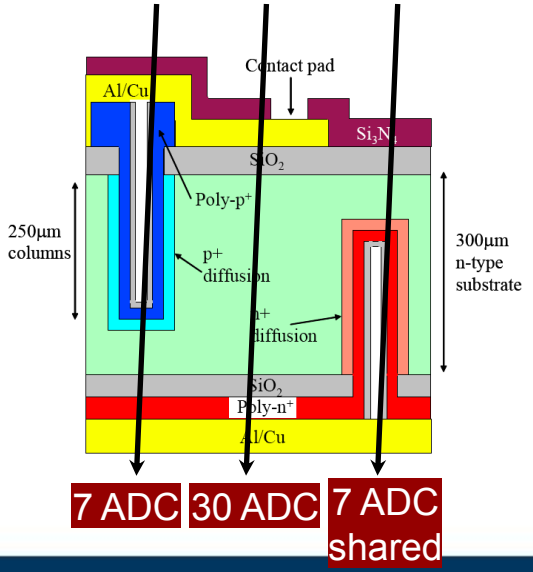
Energy Spectra – ToT mode

1-12 show ADC counts at positions along cross section from centre to the corners



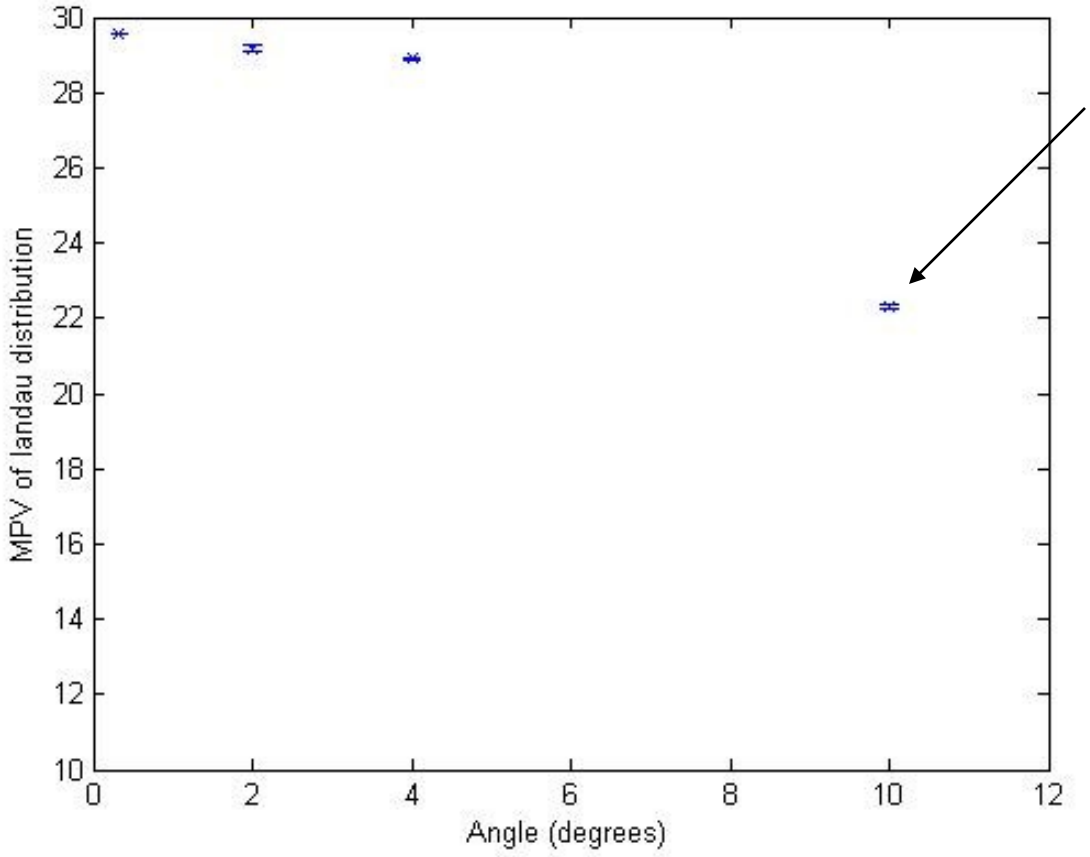
Peaks seen at ~7 and ~30 ADC counts





Energy Spectra at varying Angles

- Position of primary peak in landau distributions.



This can be explained in part as the mip now travels through a hole which is non-sensitive

For a 10^{o} track the mip goes through 1.5% more thickness. Now the mip is more likely to go through the hole. This is 10μm in diameter. Assume that it goes through 10μm then it has a path length of 57μm. So we loose 57/289 = 0.2 (20%) which brings the ADC down from 30 to 24.