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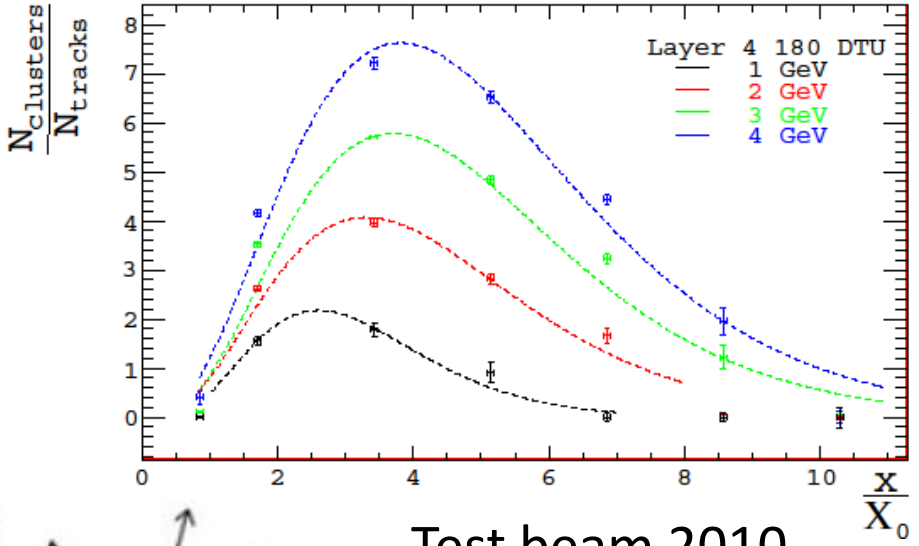
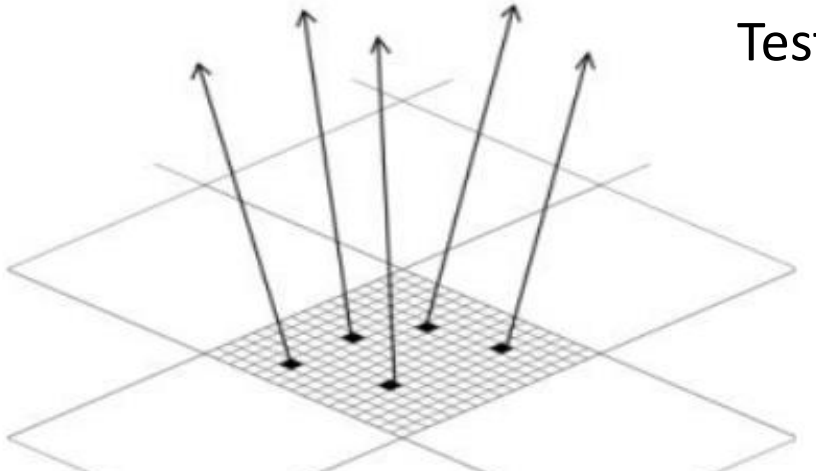
Digital Calorimetry for Future Colliders

Robert Bosley, Phil Allport, Ioannis Kopsalis, Tony Price, Nigel Watson, Alasdair Winter.

- Simulations (FCC-hh/CLIC)
- Reconfigurable Sensor Studies
  - Multiple applications
- Future Outlook

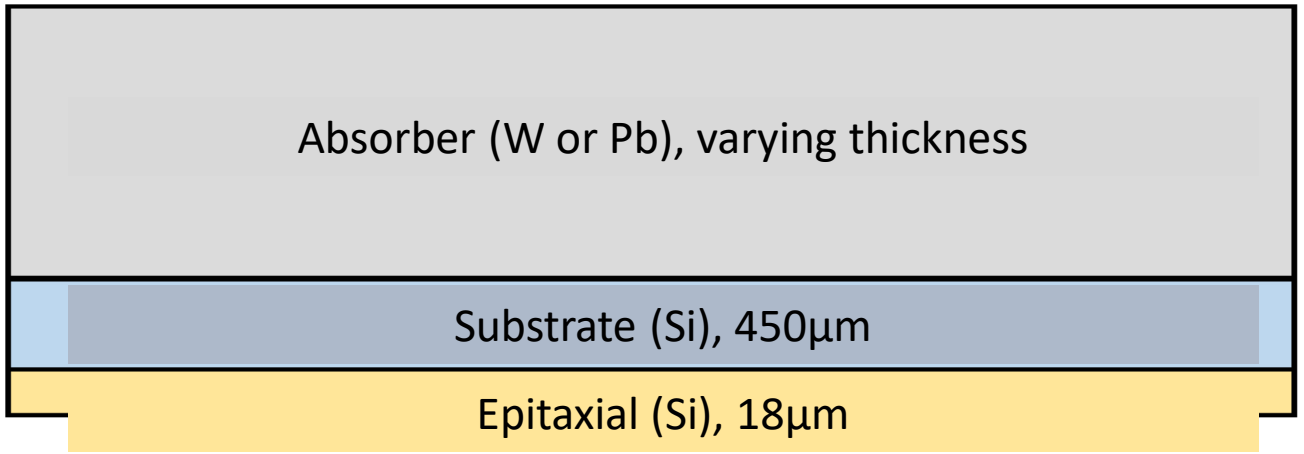


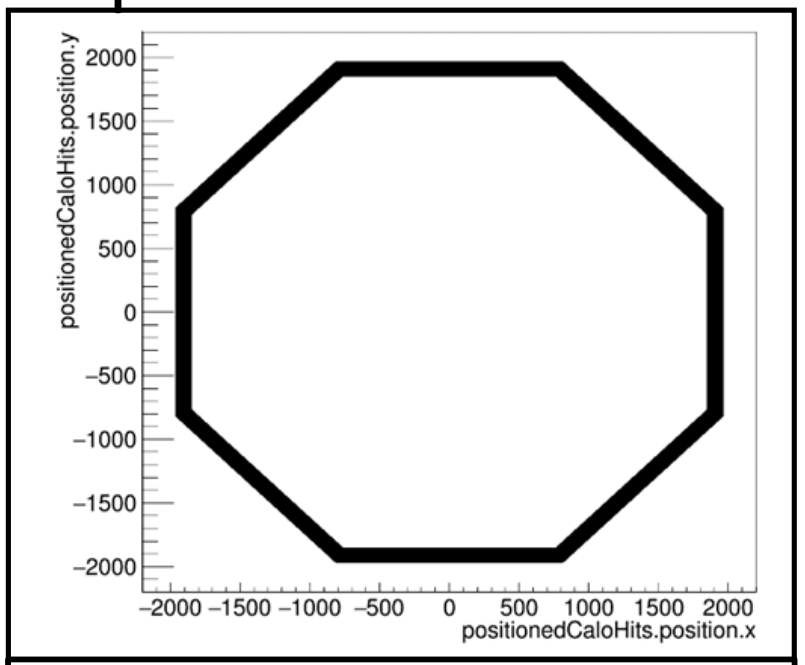
Test beam 2010

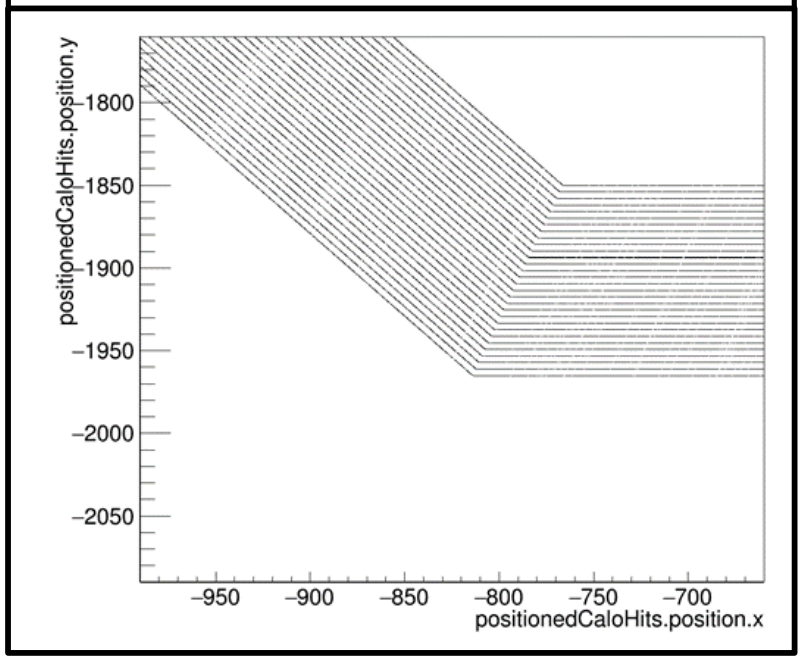


FCC-hh Geometry Implementation

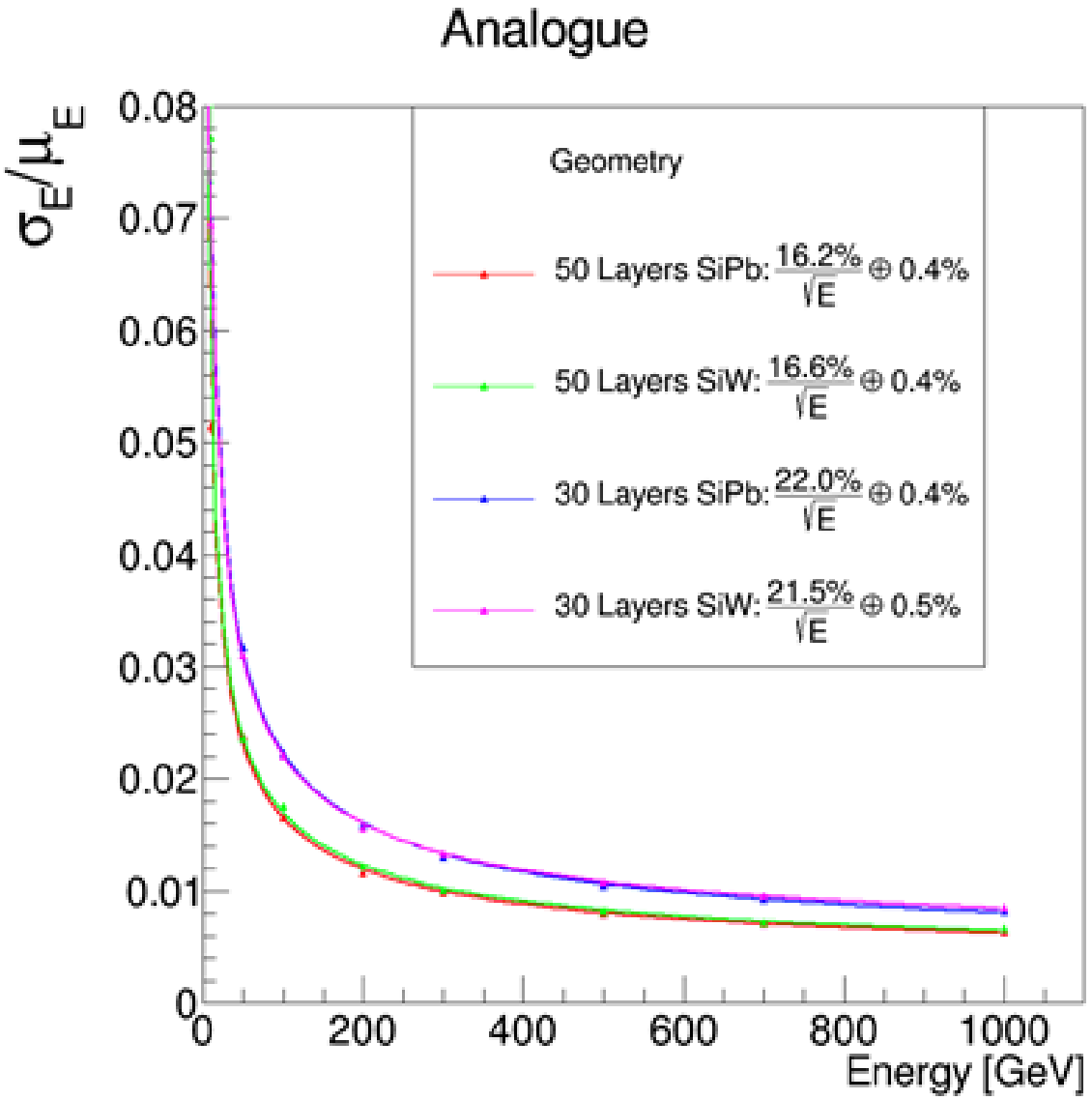
- Flexible geometry implemented in FCCSW
- Simulated 4 different geometries:
  - 30 Layers, 3.5mm W ($30 \times 1.0\ X_0$)
    5.6mm Pb
  - 50 Layers, 2.1mm W ($50 \times 0.6\ X_0$)
    3.4mm Pb





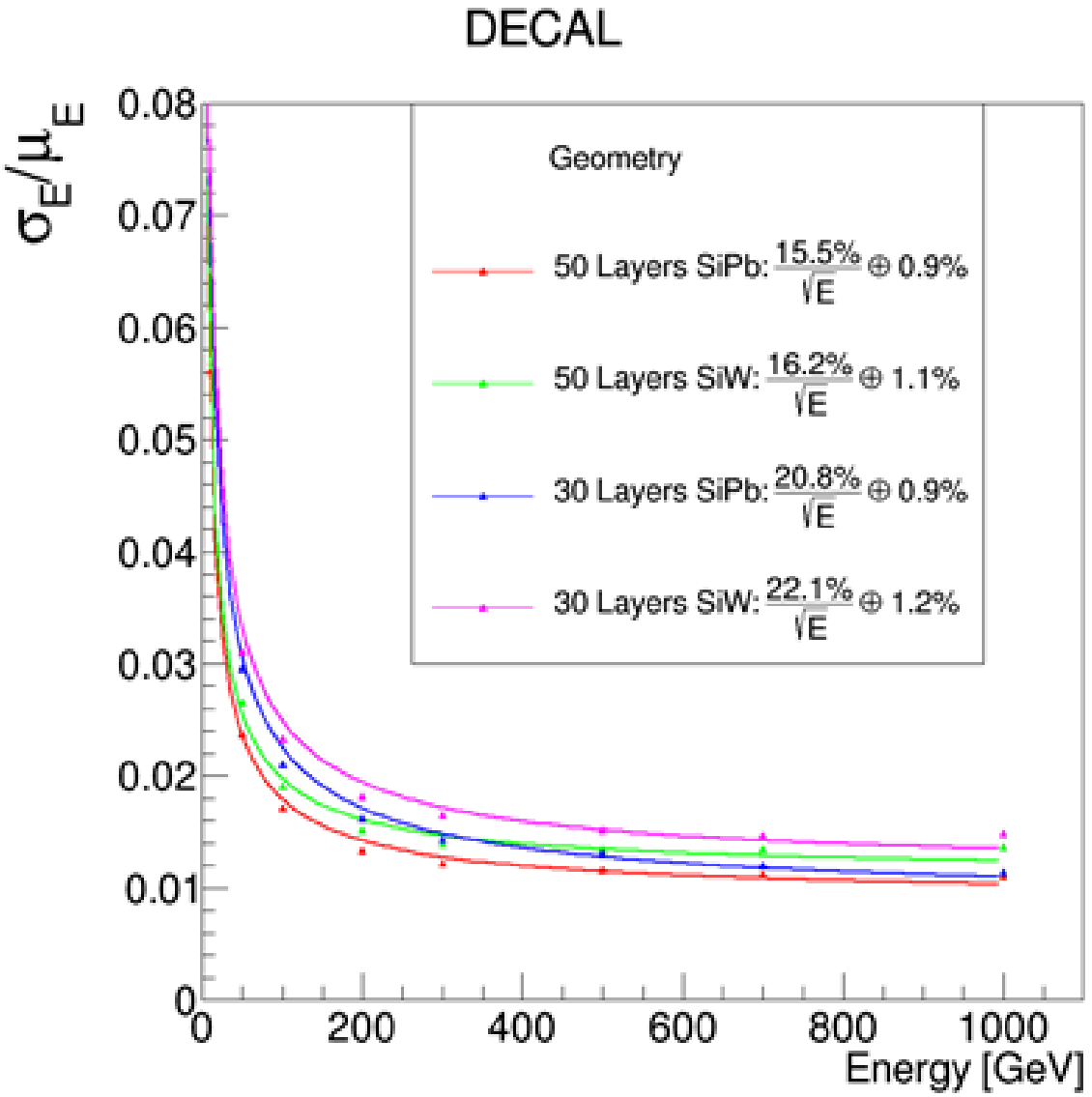


FCC-hh Geometry Optimisation



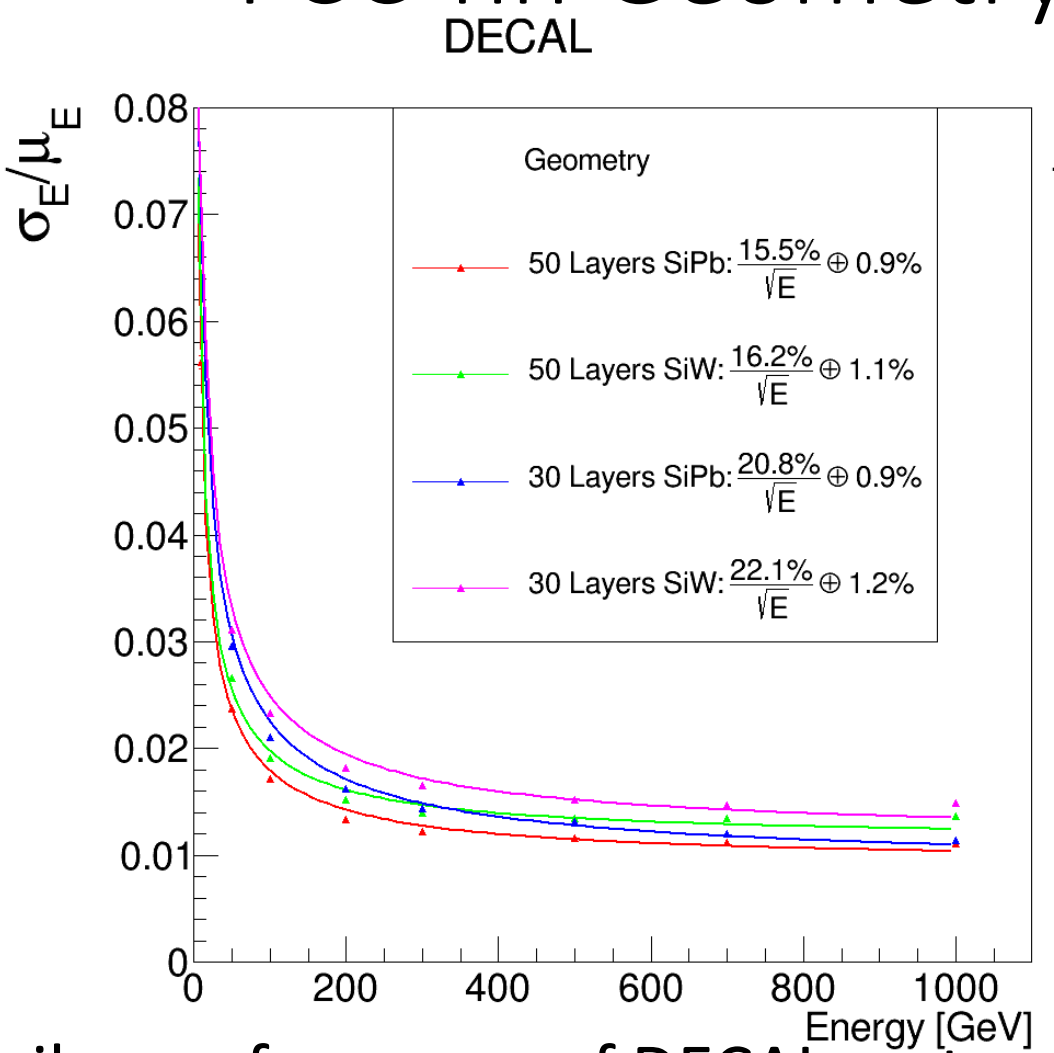
- Analogue performance dominated by sampling fraction
- Almost no difference in performance between choices of material

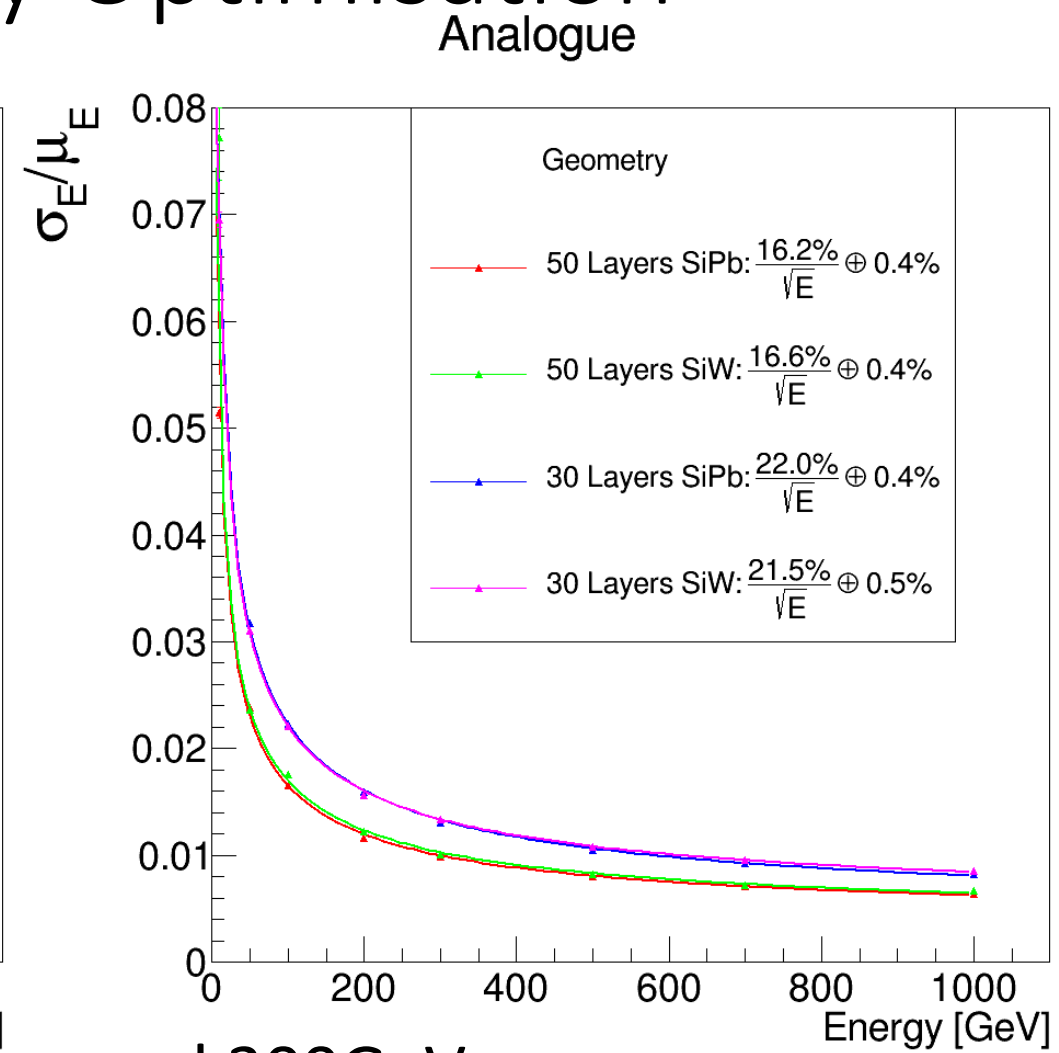
FCC-hh Geometry Optimisation



- Performance at low energies dominated by sampling fraction, similar to analogue case – clustering of similar number of layers
- Performance at high energies dominated by saturation – clustering of similar passive material
- Lead improves saturation as larger Moliere Radius causes greater spread of the shower

FCC-hh Geometry Optimisation

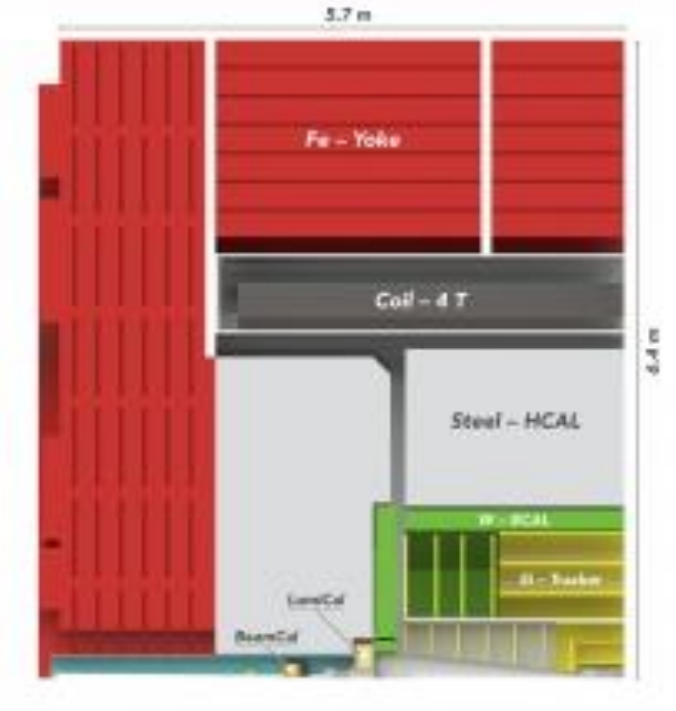


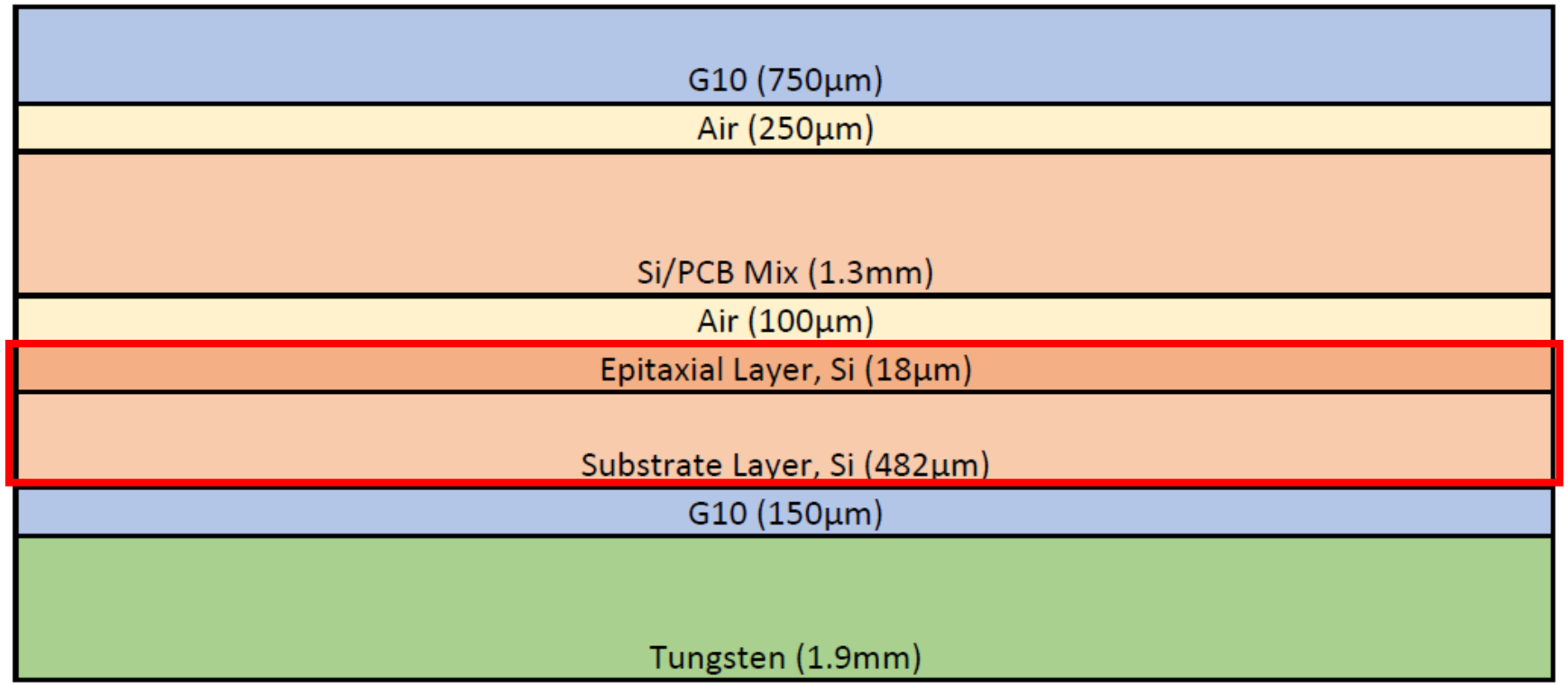


- Similar performance of DECAL up to around 300GeV
- Above this level, saturation significantly impacts performance of DECAL

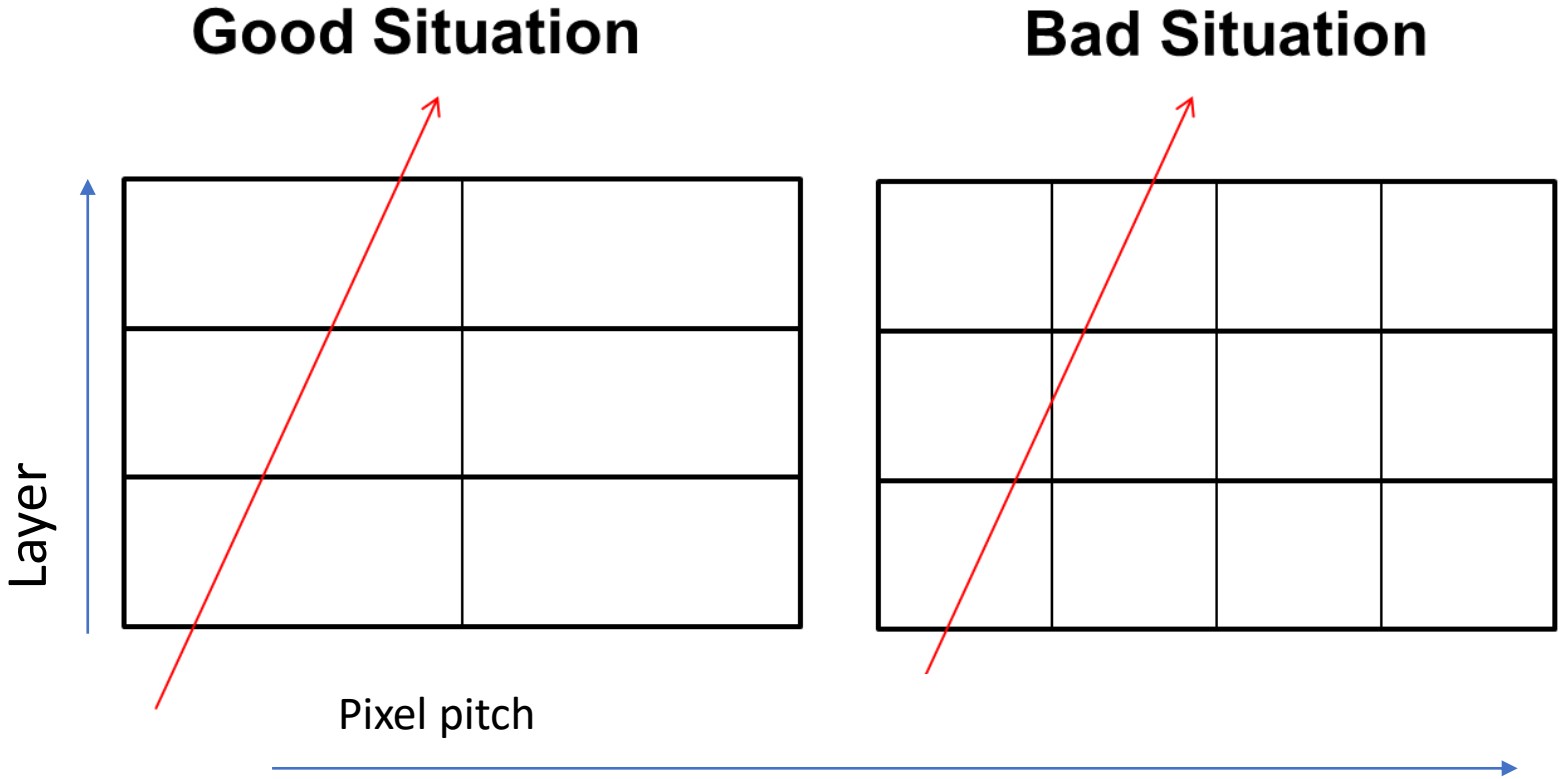
CLIC Geometry Implementation

- From CLICdet (CLIC_o3_v14), modified ECAL segmentation, 18µm epi, 50×50µm pixels
- Committed soon
- Pandora PFA already includes DECAL options





Pixel Aspect Ratio Optimisation



https://etheses.bham.ac.uk/id/eprint/8458/

Nominal 50GeV Energy:
30µm pitch, 12µm epi:

$$\frac{\sigma_E}{E} = \frac{16.1\%}{\sqrt{E}} \oplus \frac{0.5\%}{E} \oplus 0.4\%$$

- Trade off boundary crossing vs multiple occupancy
- Study performed using Mokka v08-05

- Model per-pixel effects (DigiMAPS custom package)
  - Charge collection efficiency / charge spread
  - Electronic noise
  - Dead area
  - Non-uniformity of threshold
  - Clustering algorithm at pixel level

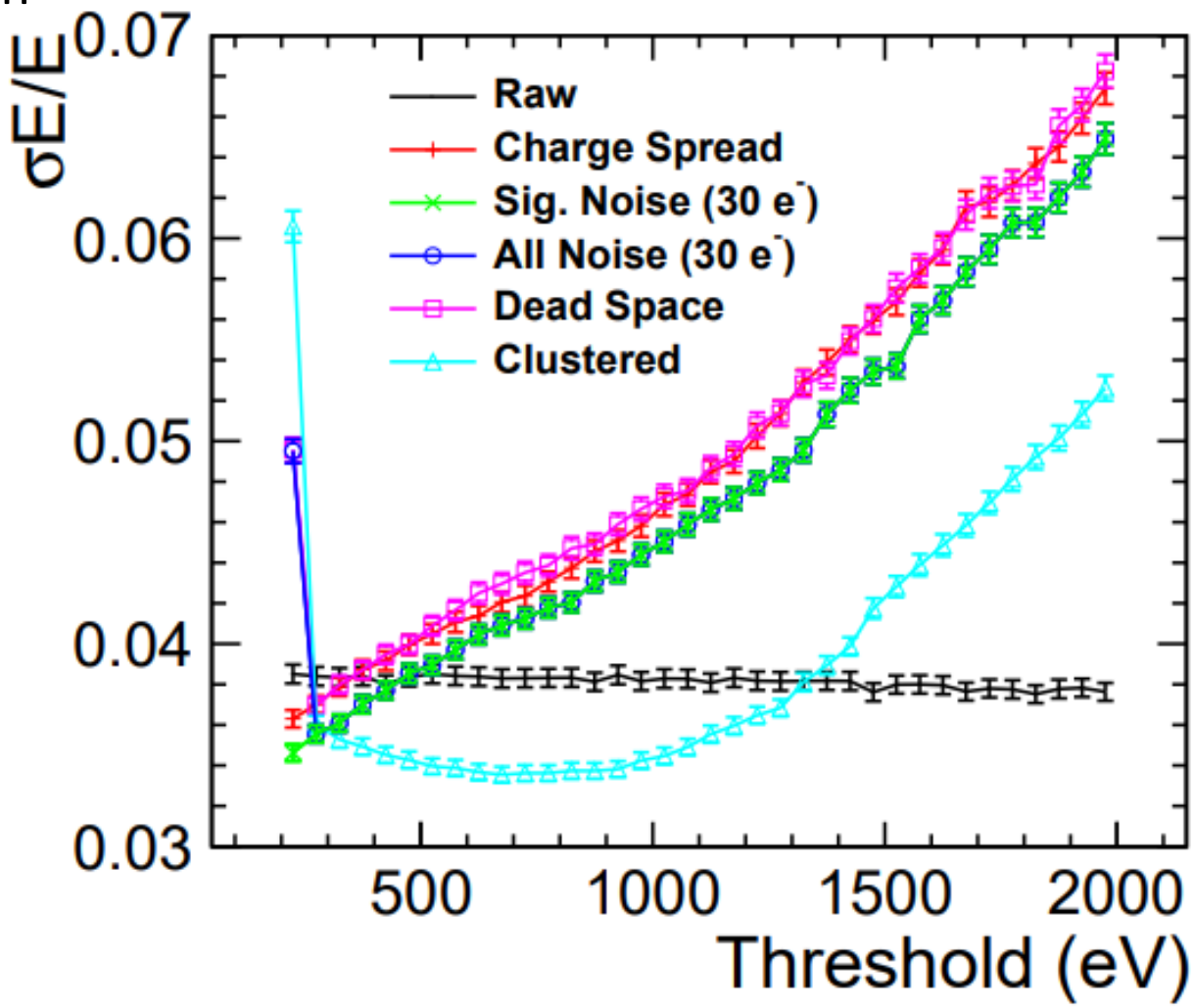
Pixel Aspect Ratio Optimisation

- Illustrated using: 20 GeV γ in full Mokka simulation

  50µm pitch, 18µm epi

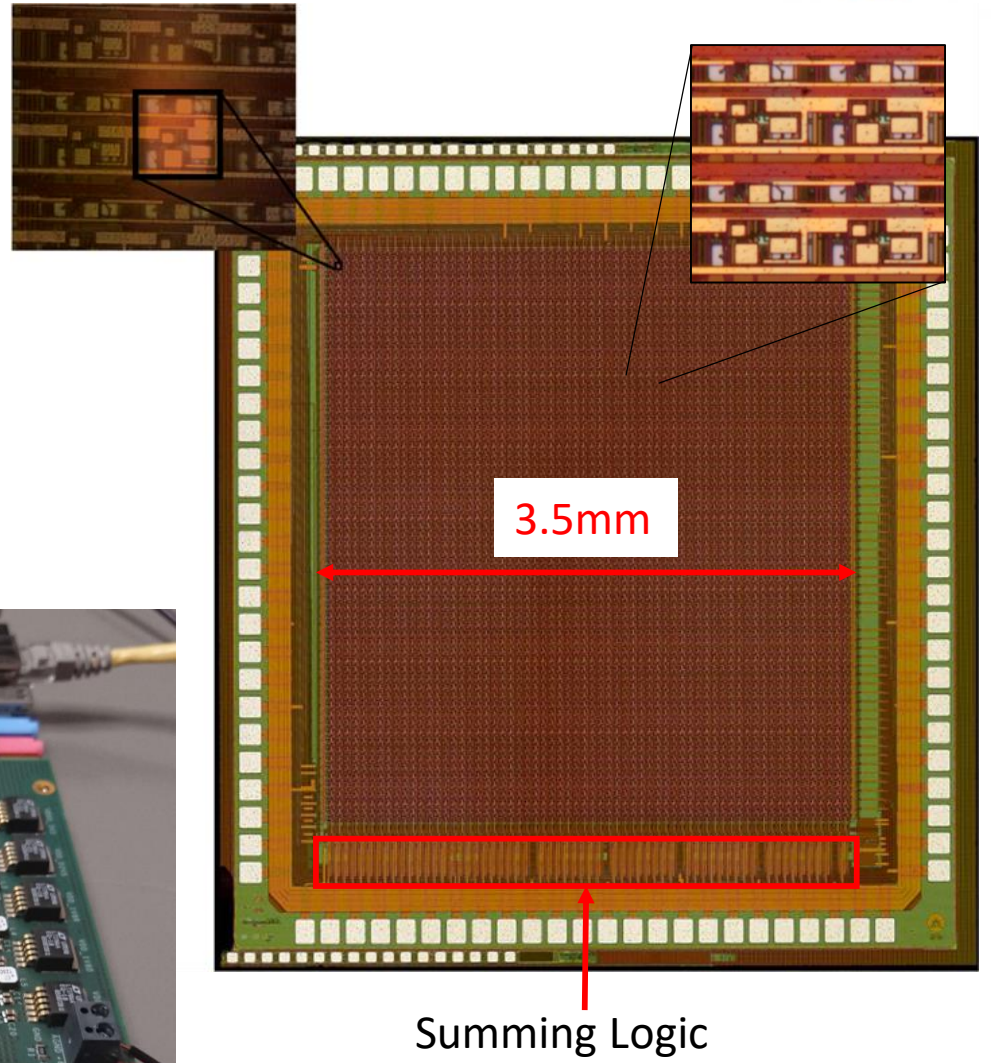
- Each contribution to σ_E/E added in sequence

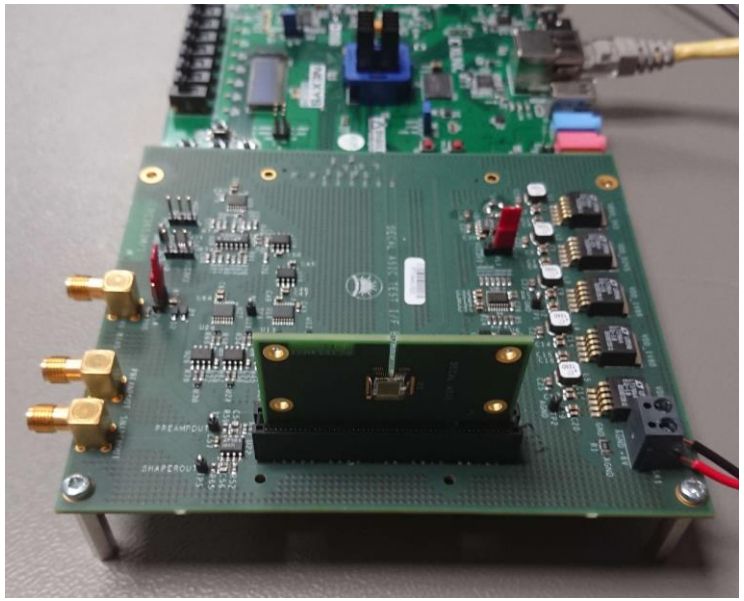
- **Raw** – no noise, 100% charge collected
- **Charge Spread** – diffusion of e-h pairs to diodes
- **Signal Noise** – add thermal/electronic noise to pixels with hits
- **All Noise** – adding noise **as above** but to all pixels
- **Dead space** – area of chip for logic, memory, …
- **Clustered** – simple, mitigate effects of charge spread / boundary crossing



Reconfigurable CMOS Sensor

- Use in either tracker or calorimetry – e.g. reduced cost, homogenous behaviour
- Very fine granularity required for DECAL
- Radiation hard
- Readout rate sufficiently high –ILC/CLIC/FCC-hh bunch crossing timing

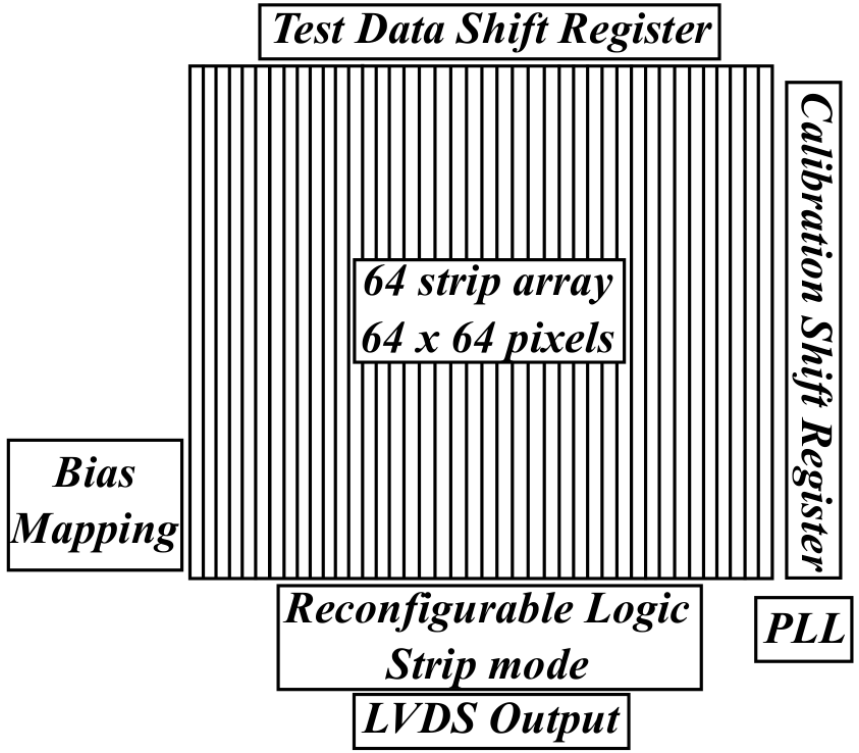




Reconfigurable Depleted CMOS MAPS Sensor

- Prototype built in TowerJazz 180nm
- Configurable as strip sensor (tracking)
  pad sensor (calorimetry)

- 64×64 pixels, 55µm pitch, 18µm thick
  Strip mode, record up to **3 hits/strip**
  Pad mode, 15 hits/strip, 240 hits/pad



40MHz readout, compatible with ATLAS ITSDAQ

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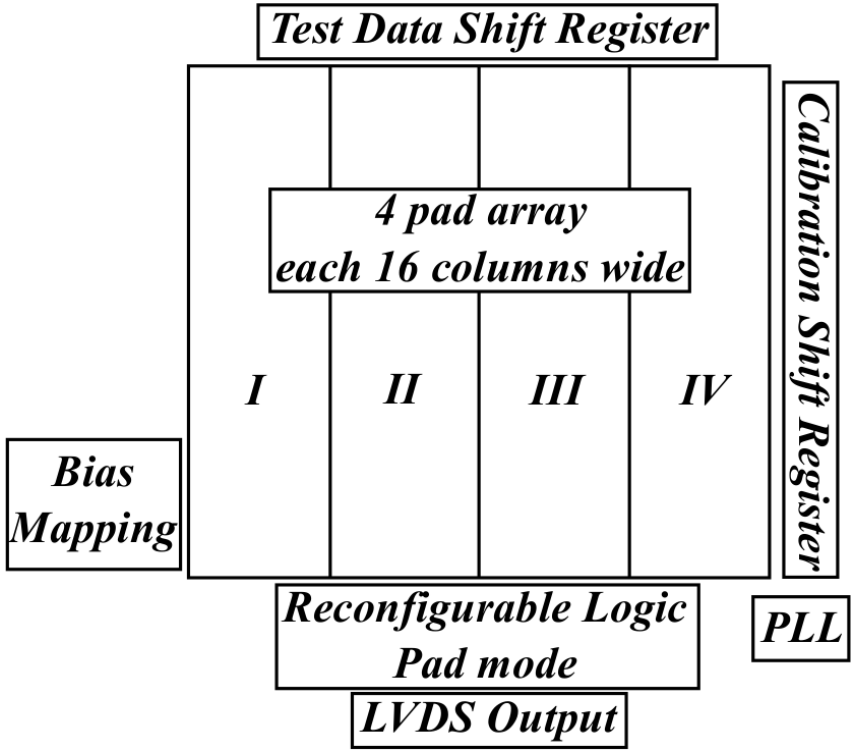
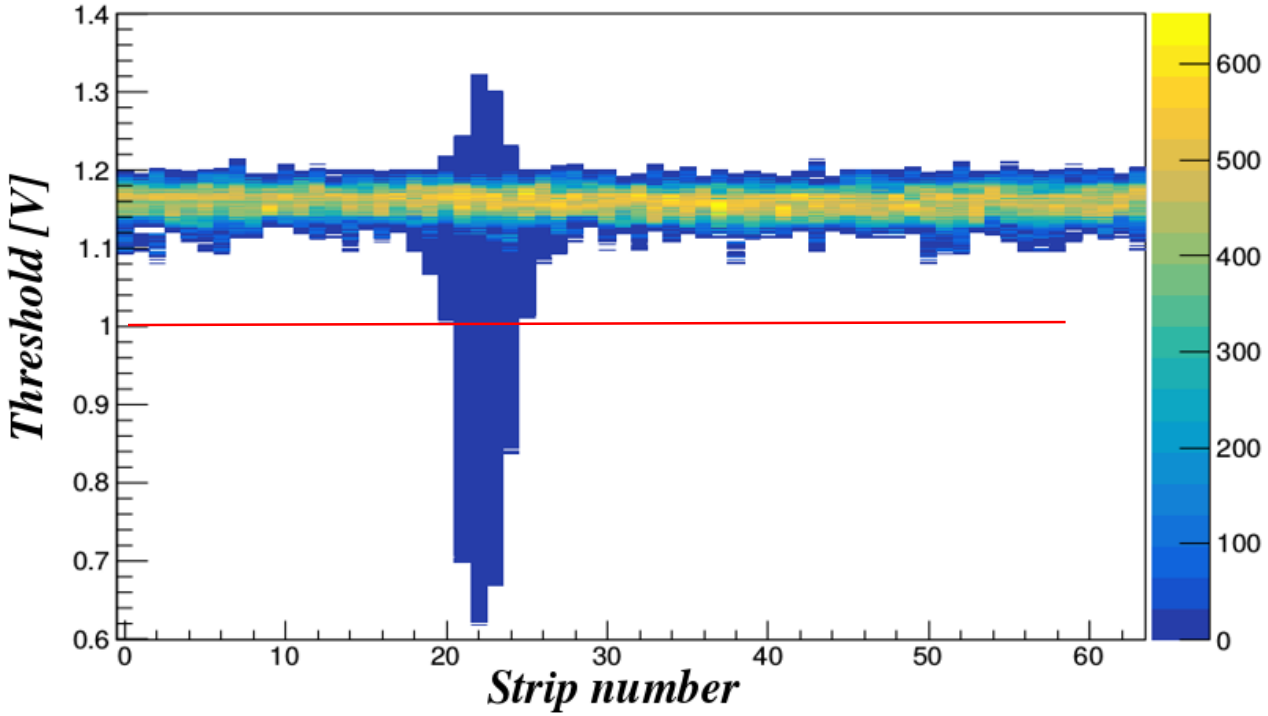
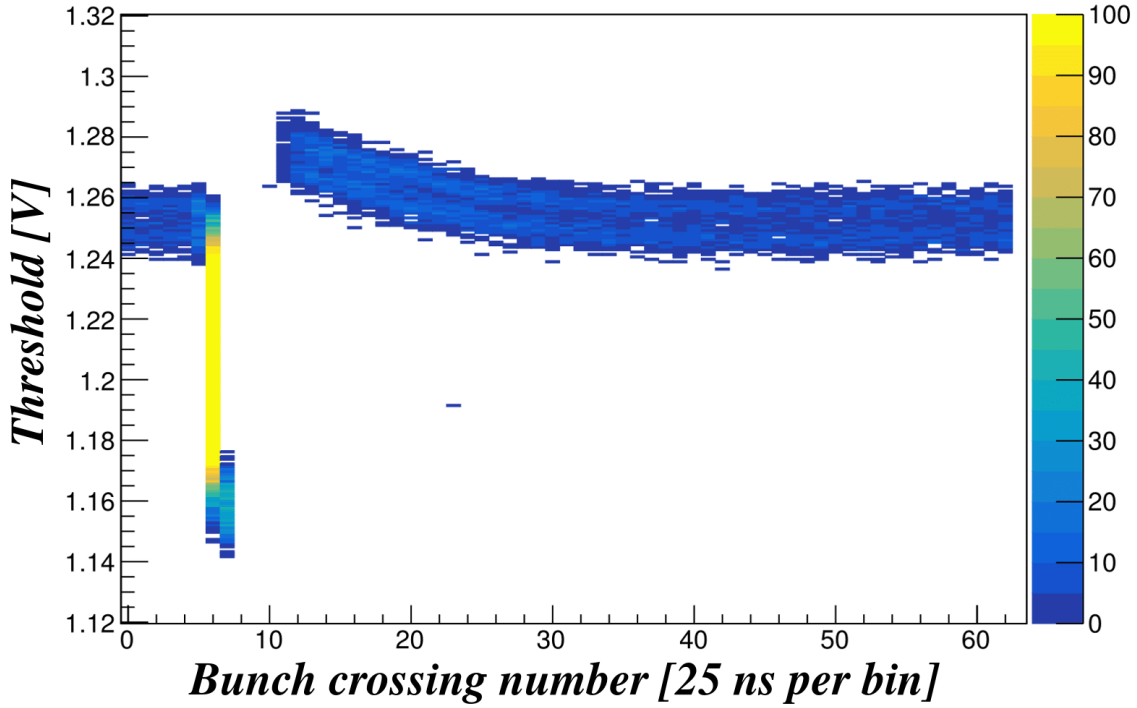


40MHz readout, compatible with ATLAS ITSDAQ

Threshold Scans (Preliminary)

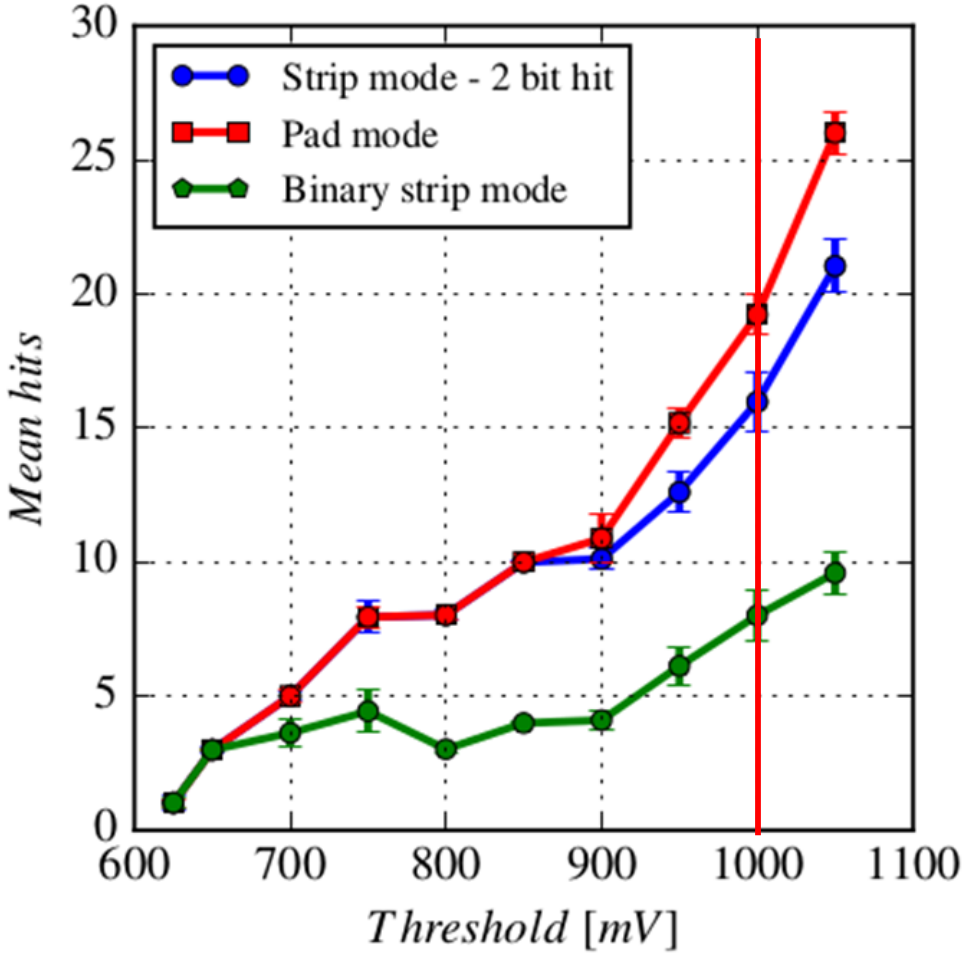
- Used defocused IR laser, 1064nm, 100kHz
- Noise band around the shaper (1.15V)
- Clear signal gaussian around strip 22
- 25ns response time
- Shaper only registers negative gradients

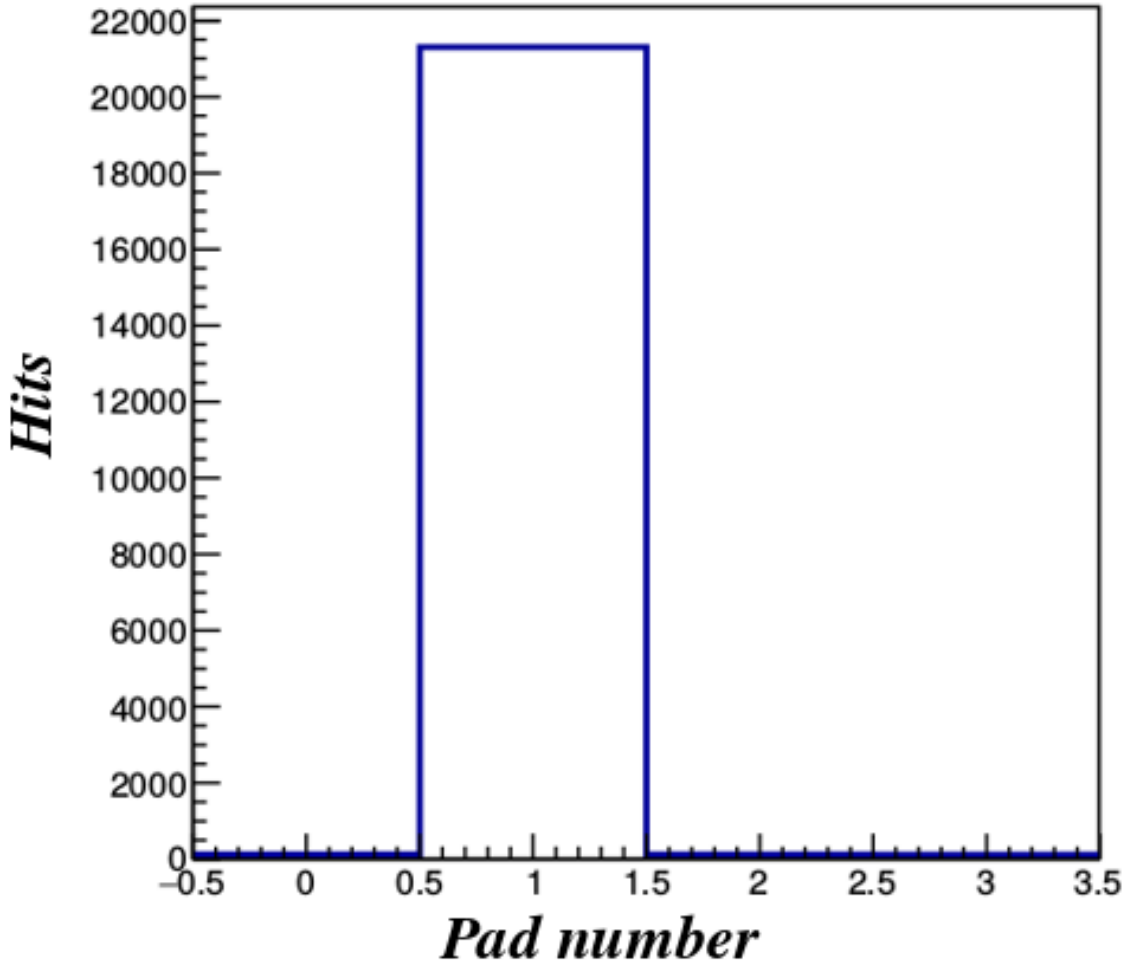




Threshold Scans (Preliminary)

- Compare mean no. hits measured vs. threshold
- Less saturation in **pad mode**, more position information in strip mode





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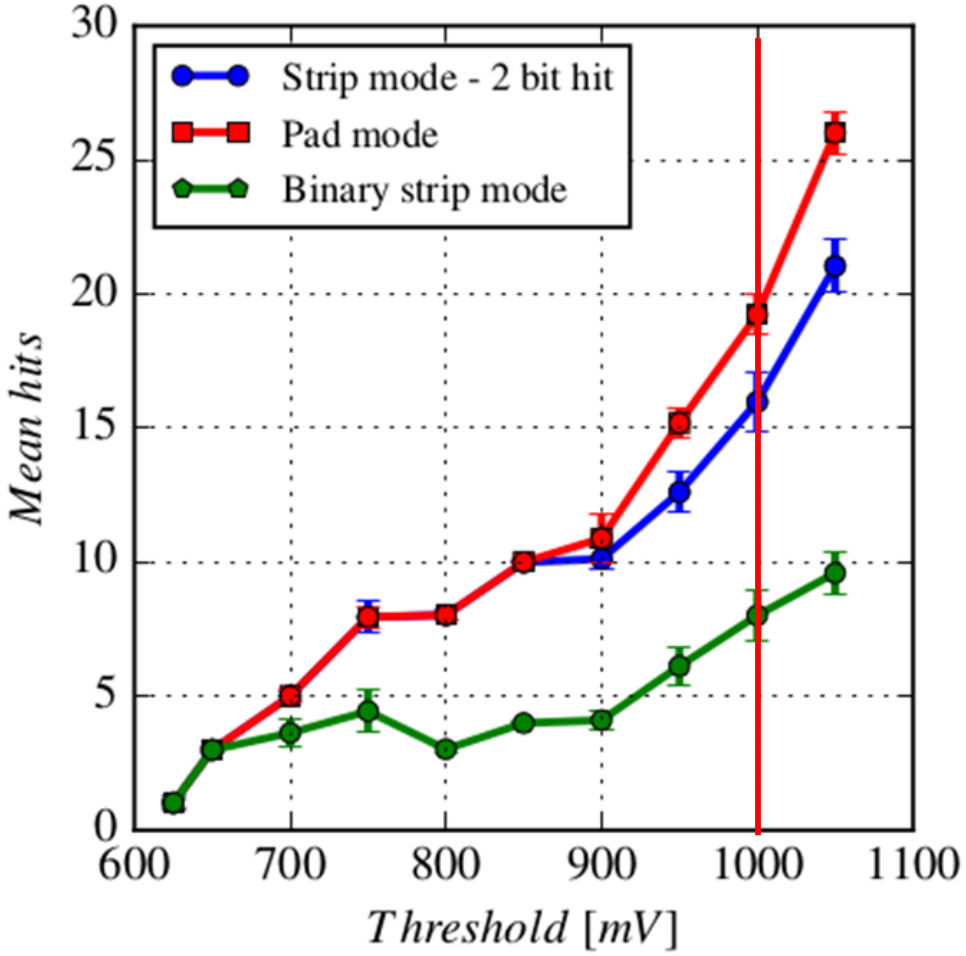
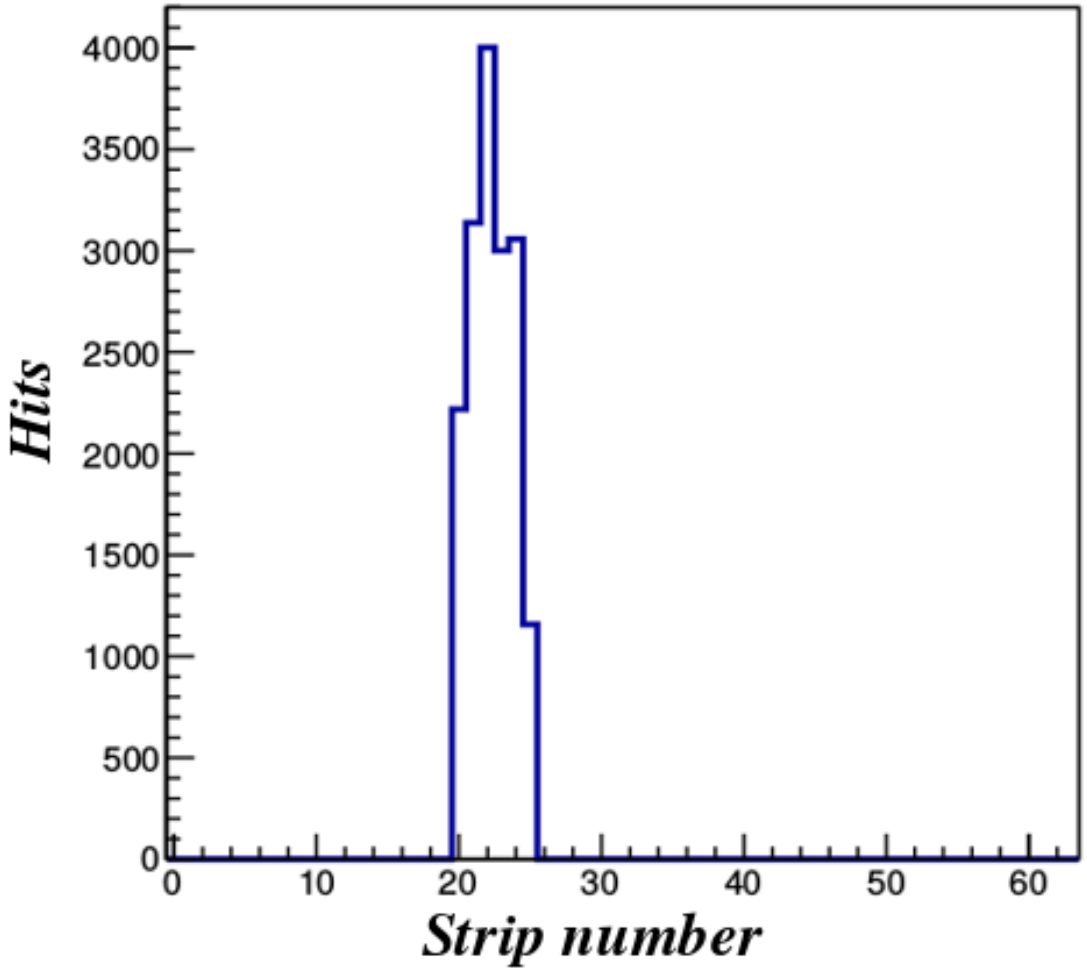
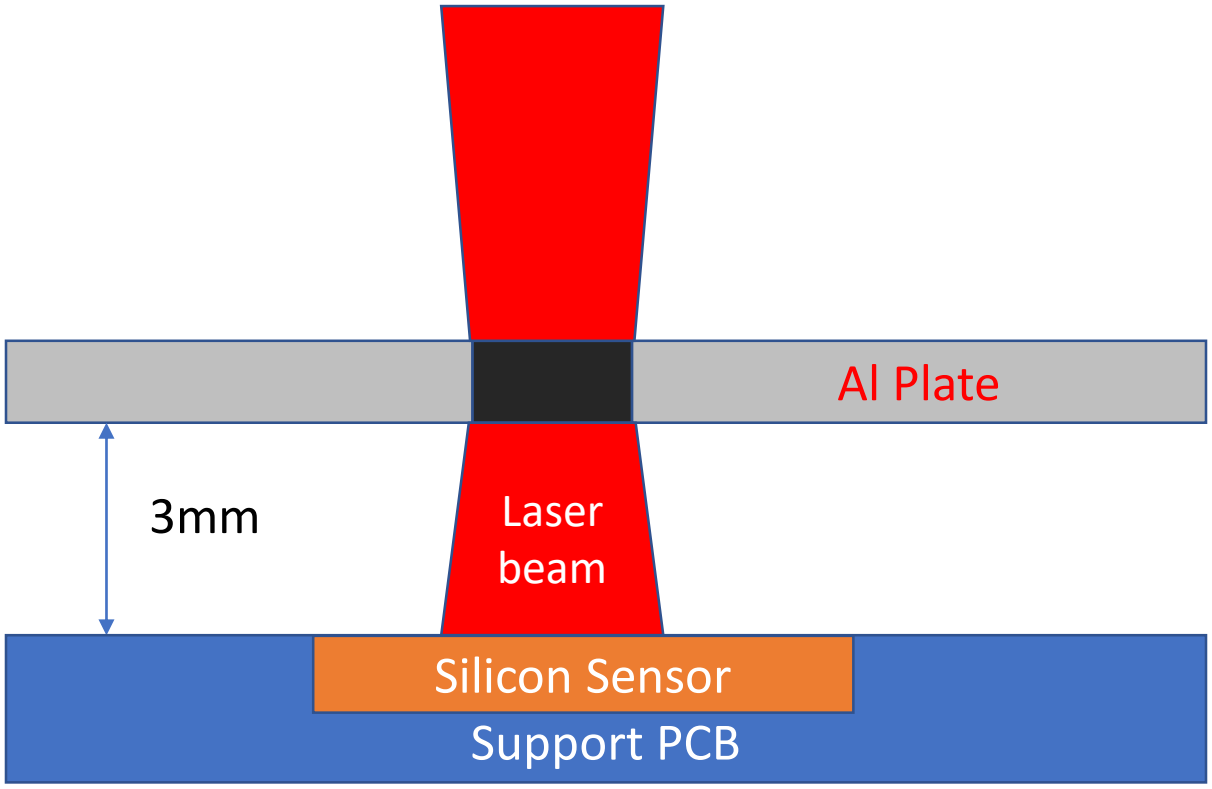
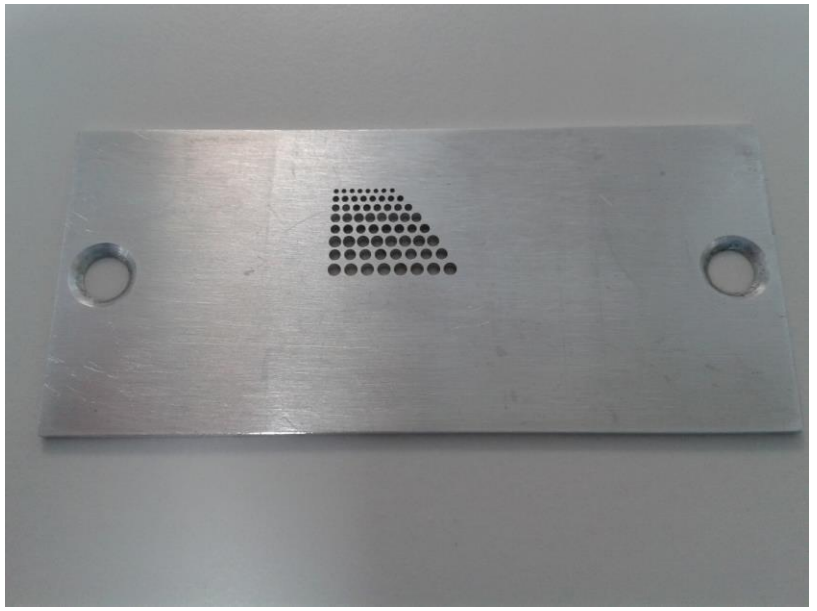


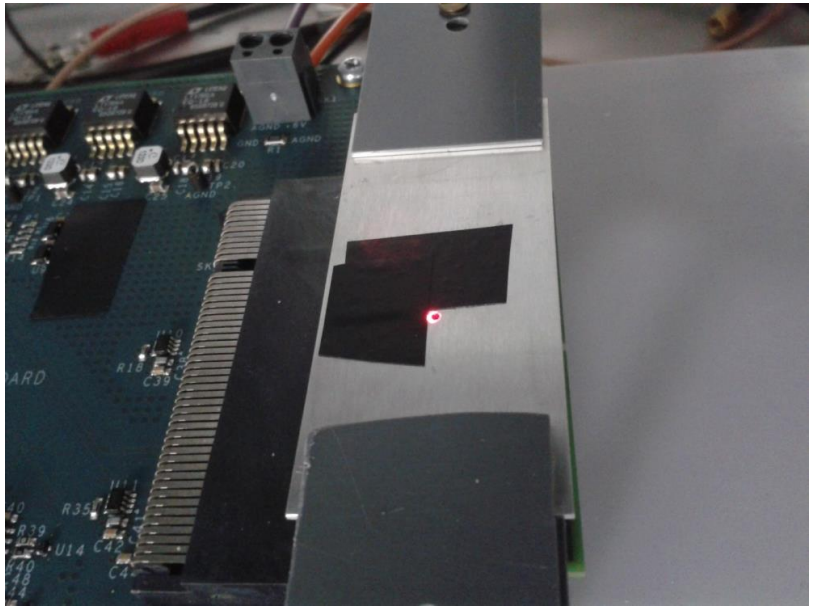


Aperture Tests (Preliminary)

- 1mm thick Al plate, holes from 400µm to 1100µm
- Use this as effective control of illuminated area







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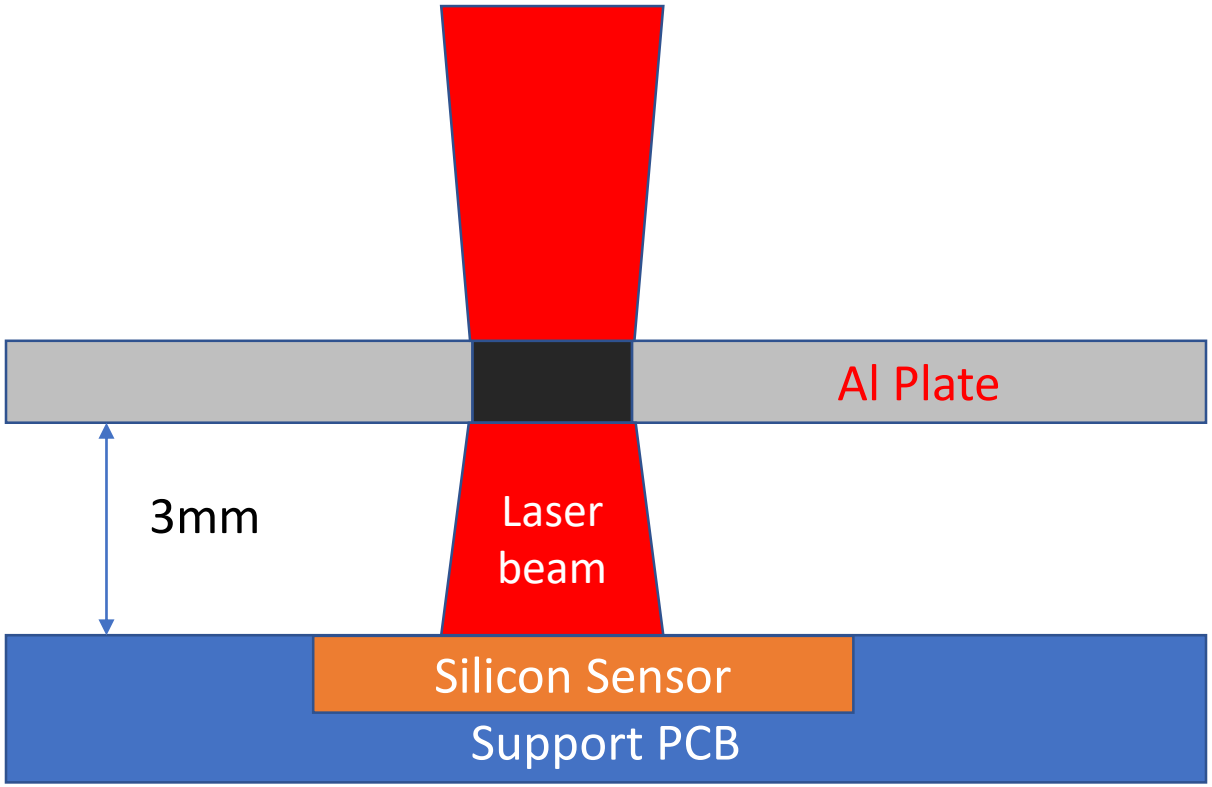
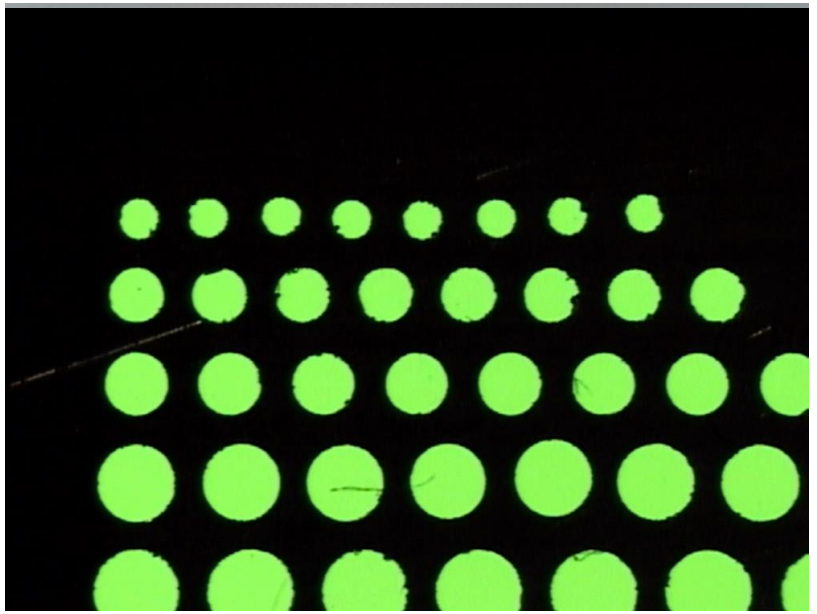
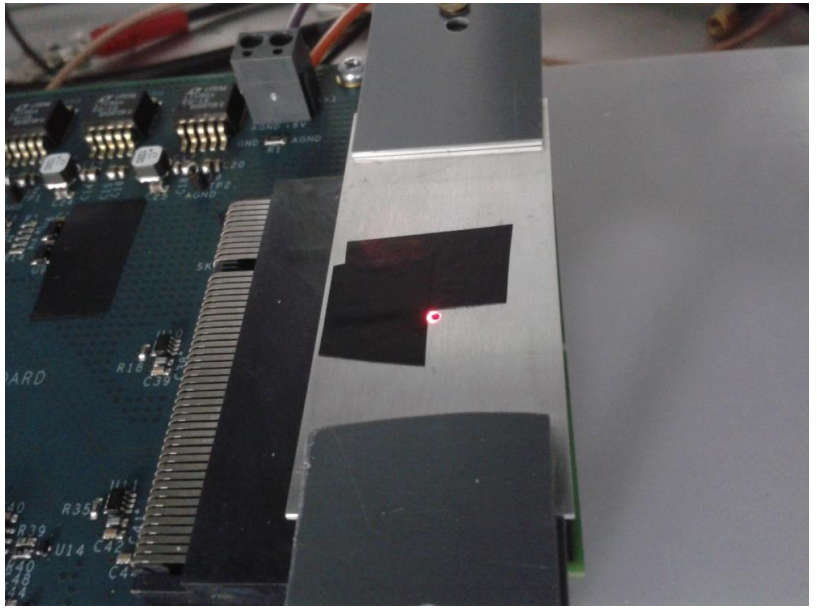
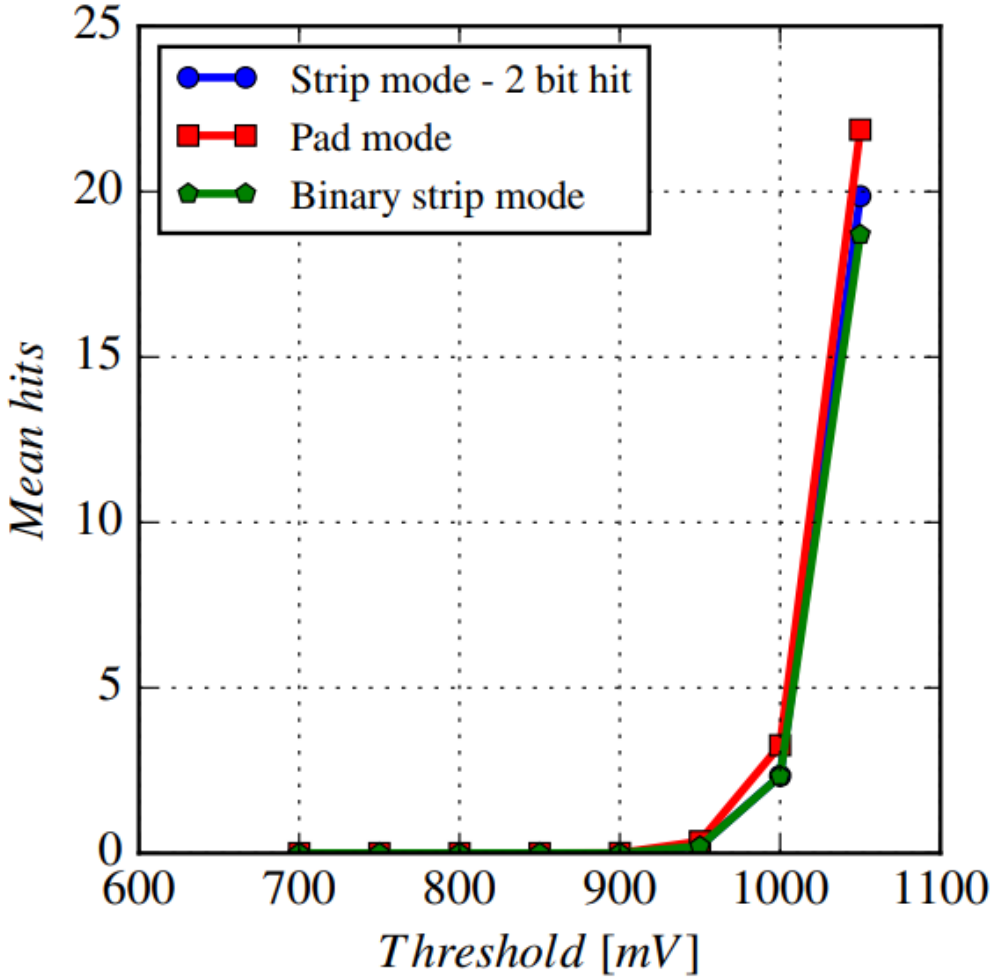


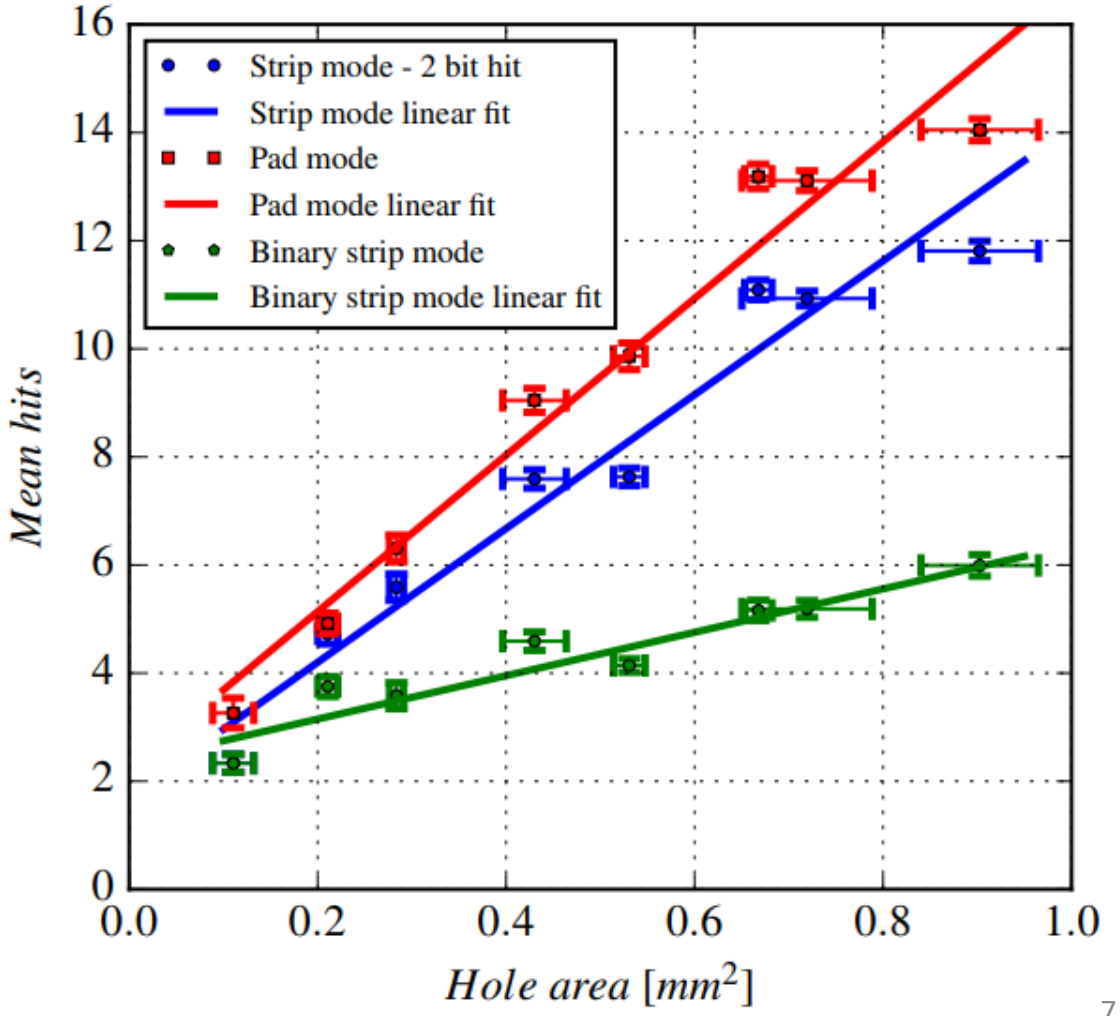




Aperture Tests (Preliminary)

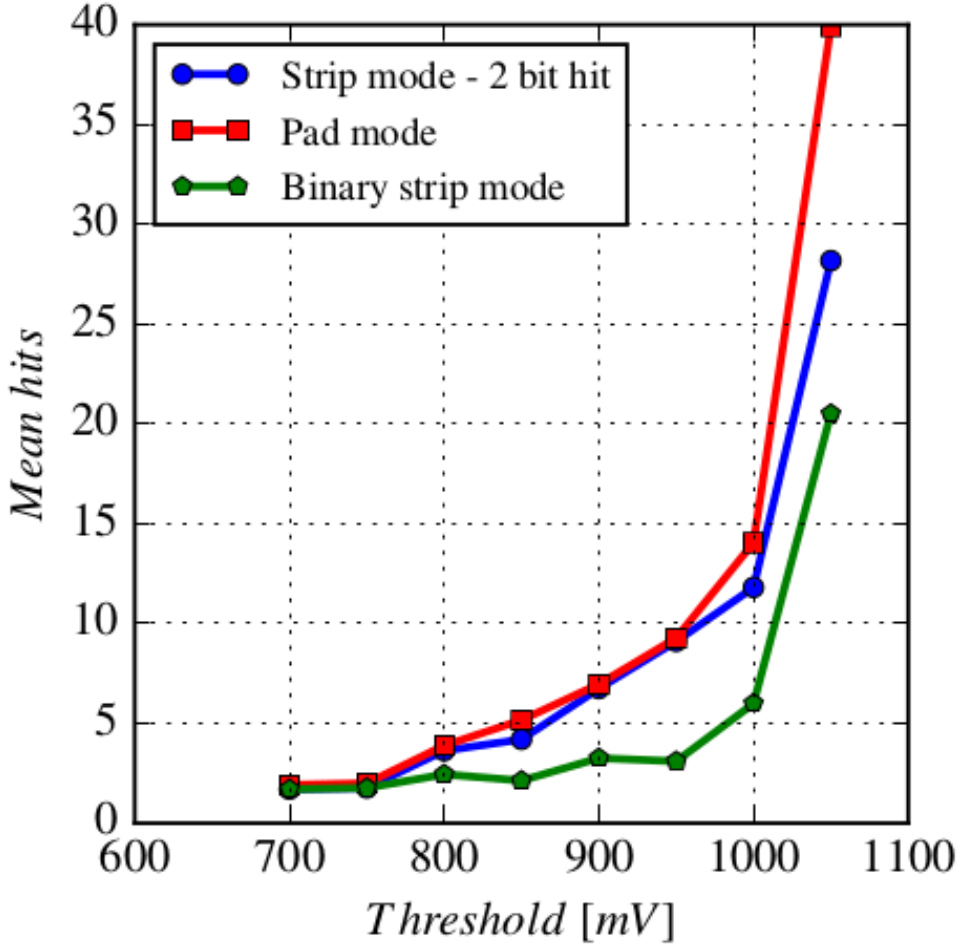
- Calibration proof of principle – can reconstruct illuminated area from number of hits
- Small aperture – noise dominates

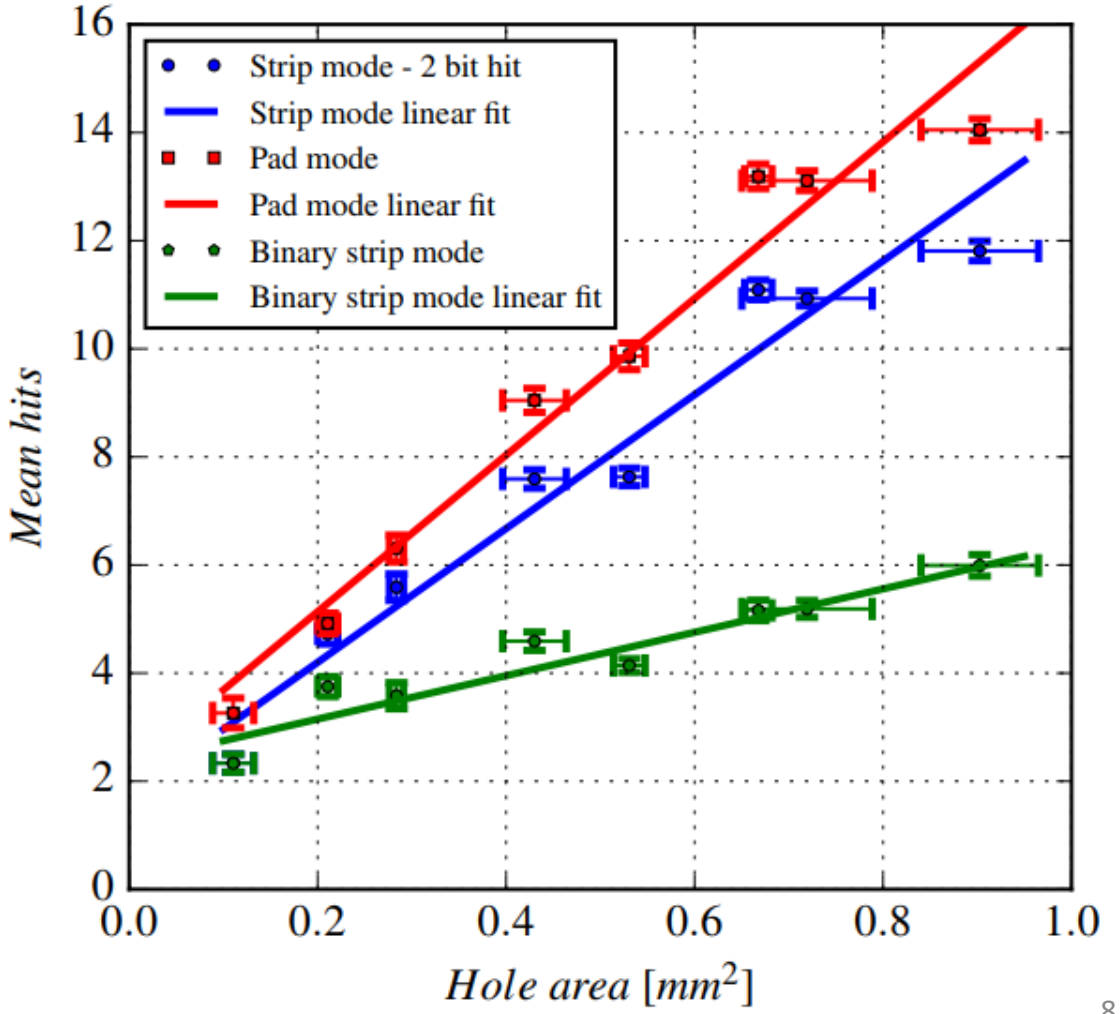




Aperture Tests (Preliminary)

- Calibration proof of principle – can reconstruct illuminated area from number of hits
- Large aperture – signal hits visible





Future Outlook

- Make DECAL geometry available in CLICdet for wider use
- Move from DigiMAPS to Allpix^2 to simulate charge spread etc. in pixel configuration simulations
- Investigate impact of number of bits for strips, summing logic
- More detailed sensor characterisations

- Design improvement on current CMOS sensor
- Implement in more rad hard process
- Conceptual design of wafer scale array

Backup

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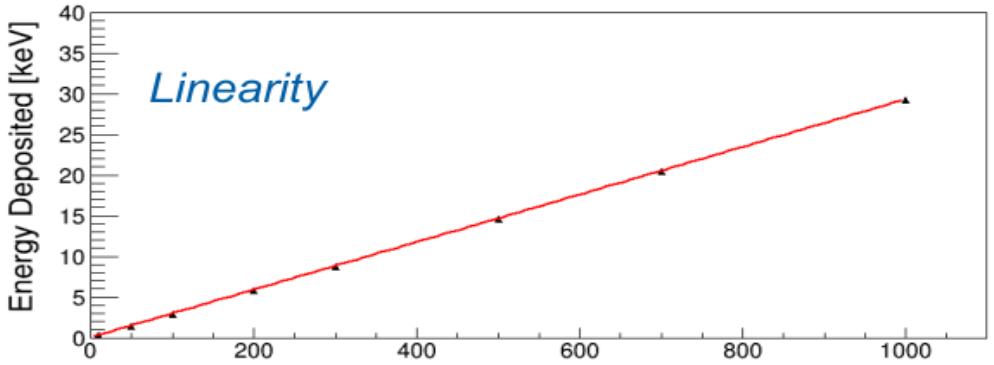
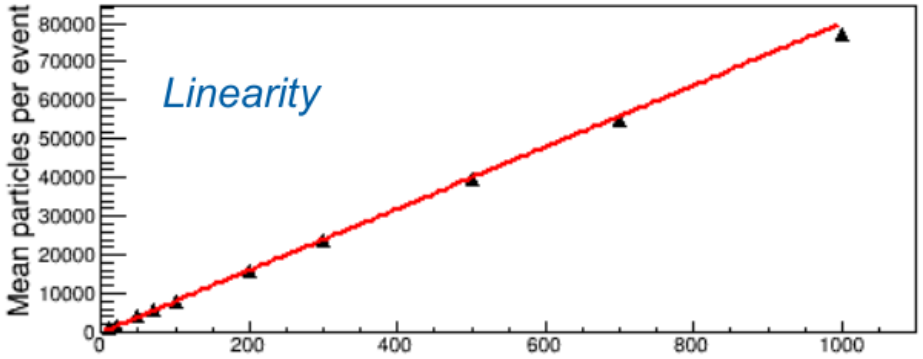
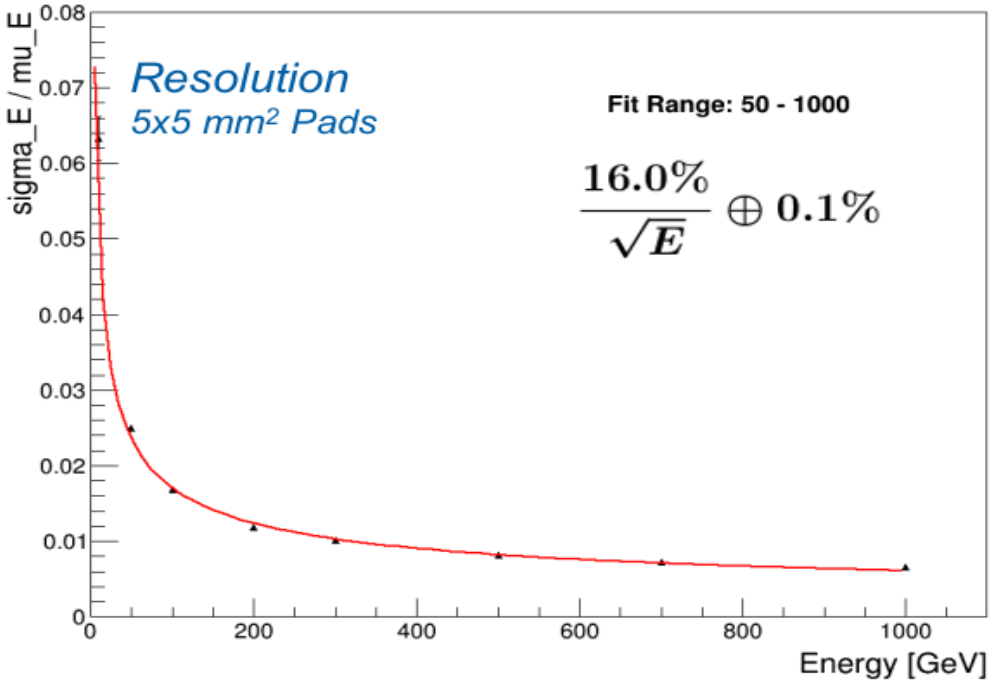
Aperture Test

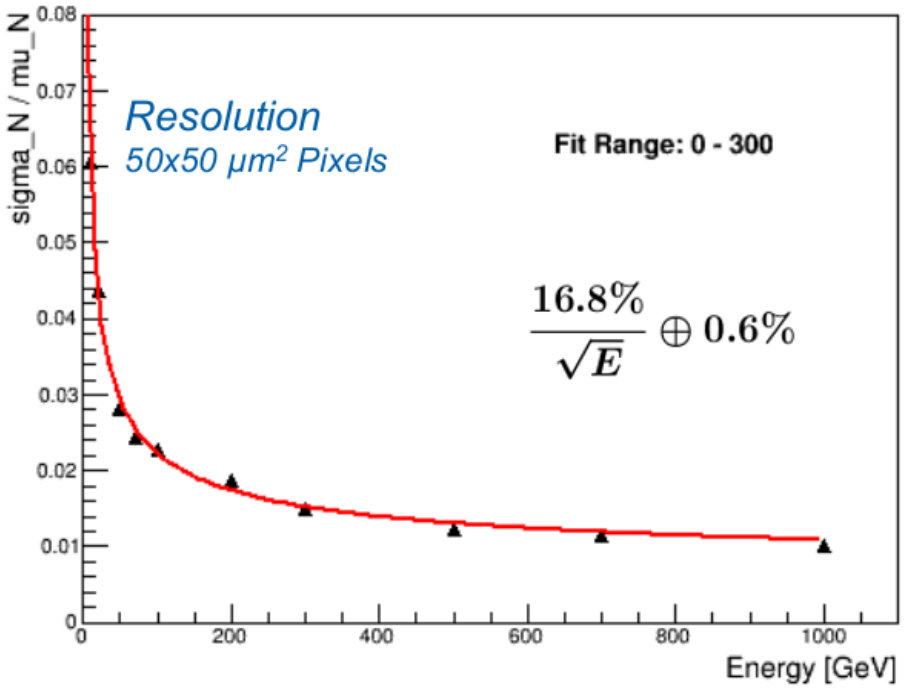
- 3mm gap between aperture and sensor
- Laser λ=1064nm, E_γ~1.2eV, f=100kHz
- Phonon-assisted e-hole production

FCC Results (50 X 0.6X_0, W)







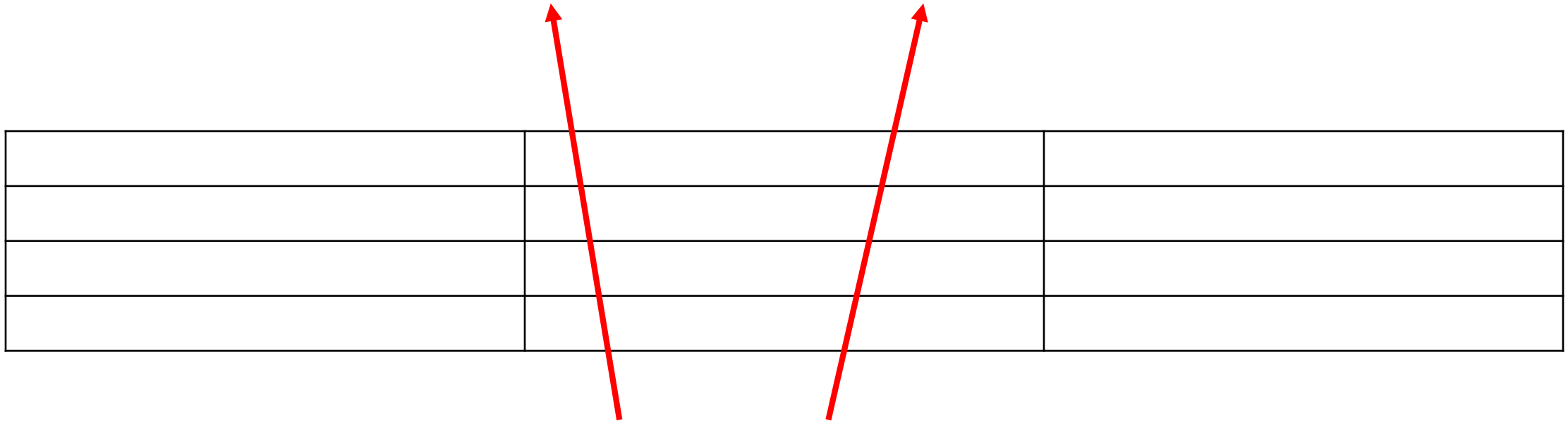


Analogue

Digital

https://indico.cern.ch/event/656491/contributions/2939182/

Multiple Occupancy



- Two particles, only count 1 in each pixel.
- Effective undercount of hits

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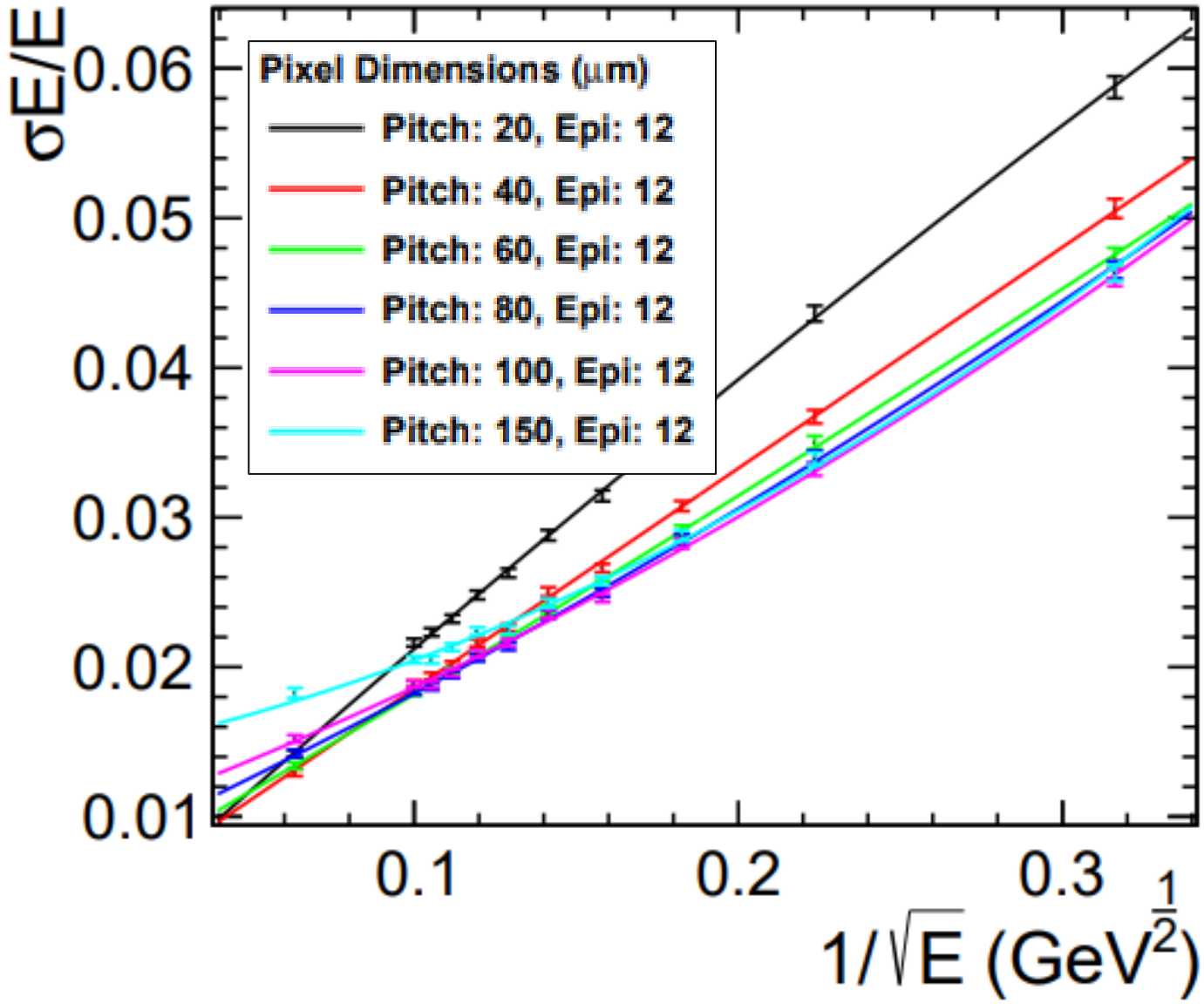
Resolution vs pixel pitch



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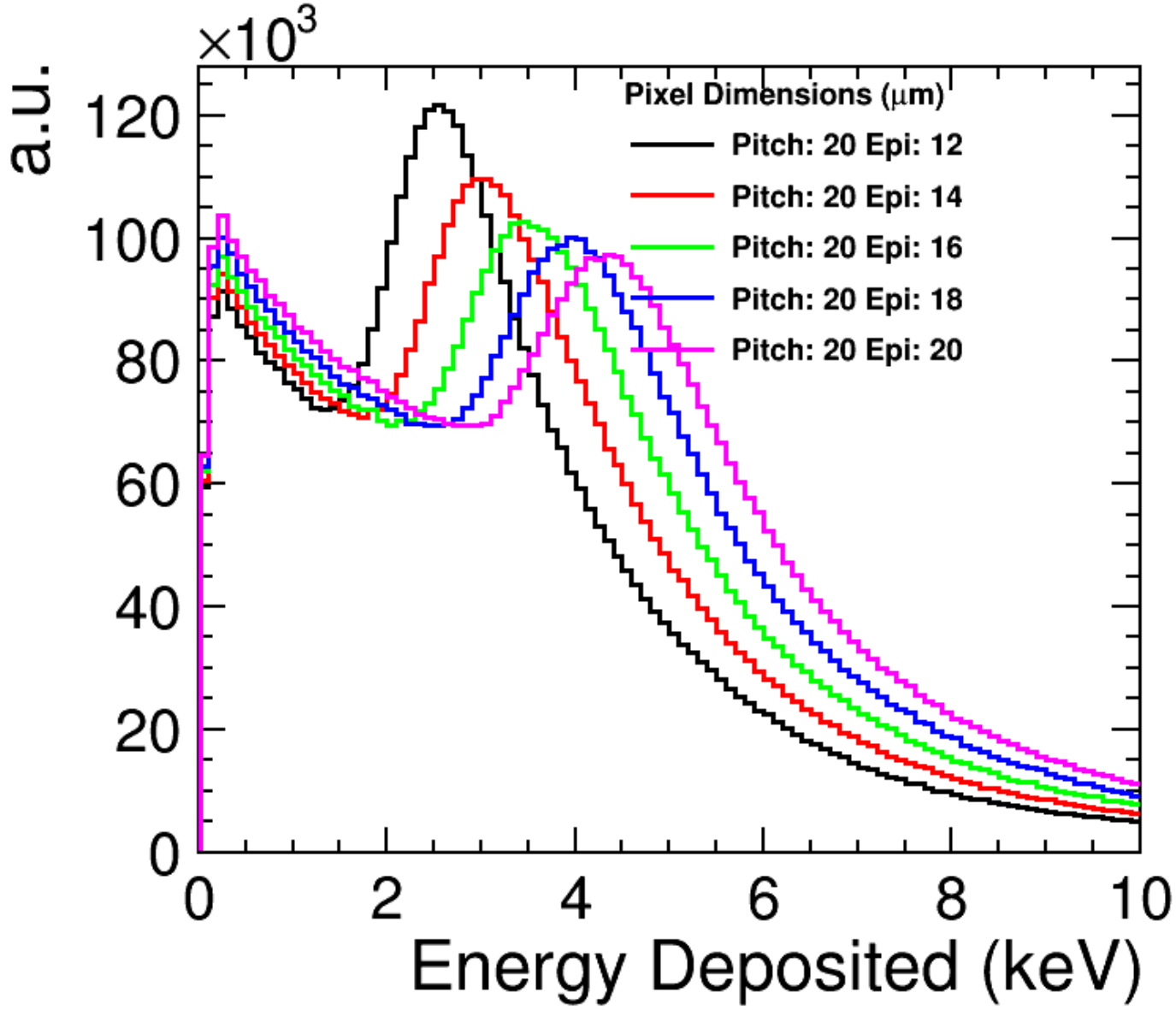
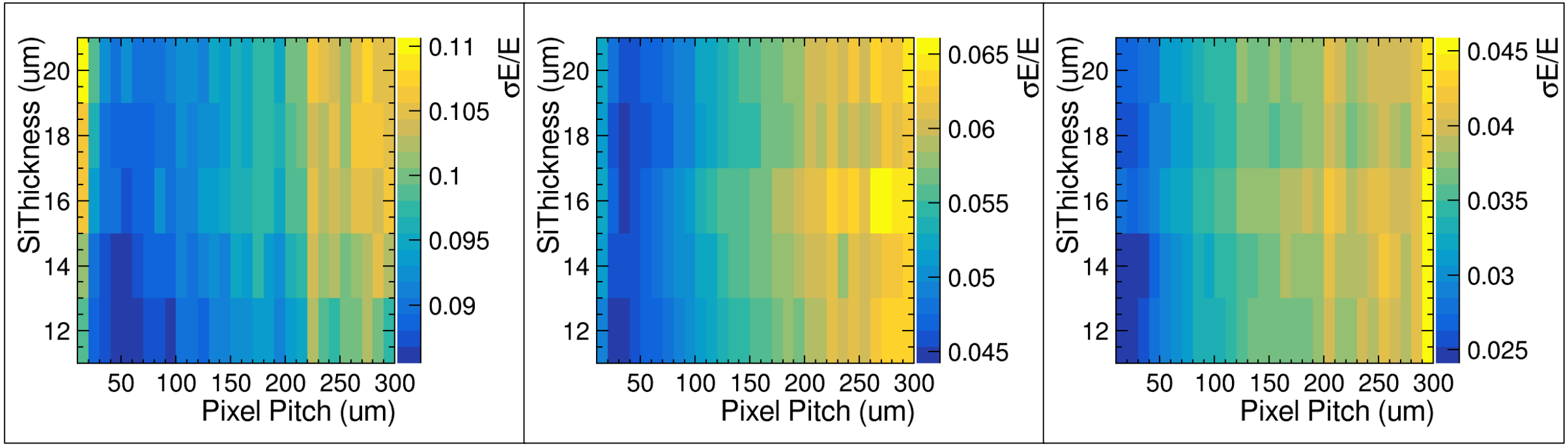
Resolution vs Epi thickness



Pixel Configuration Studies (Preliminary)



10GeV 50GeV 250GeV

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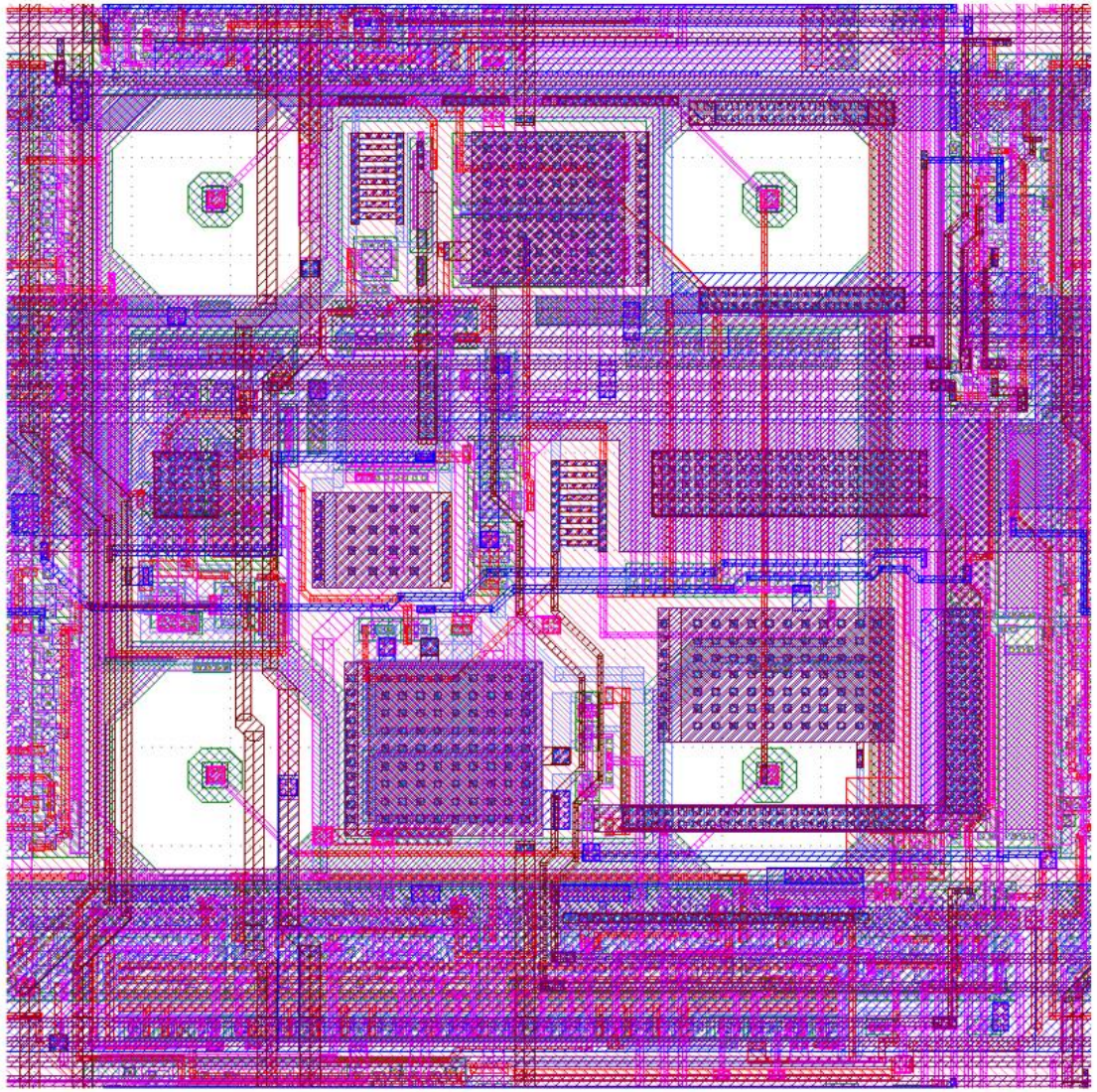
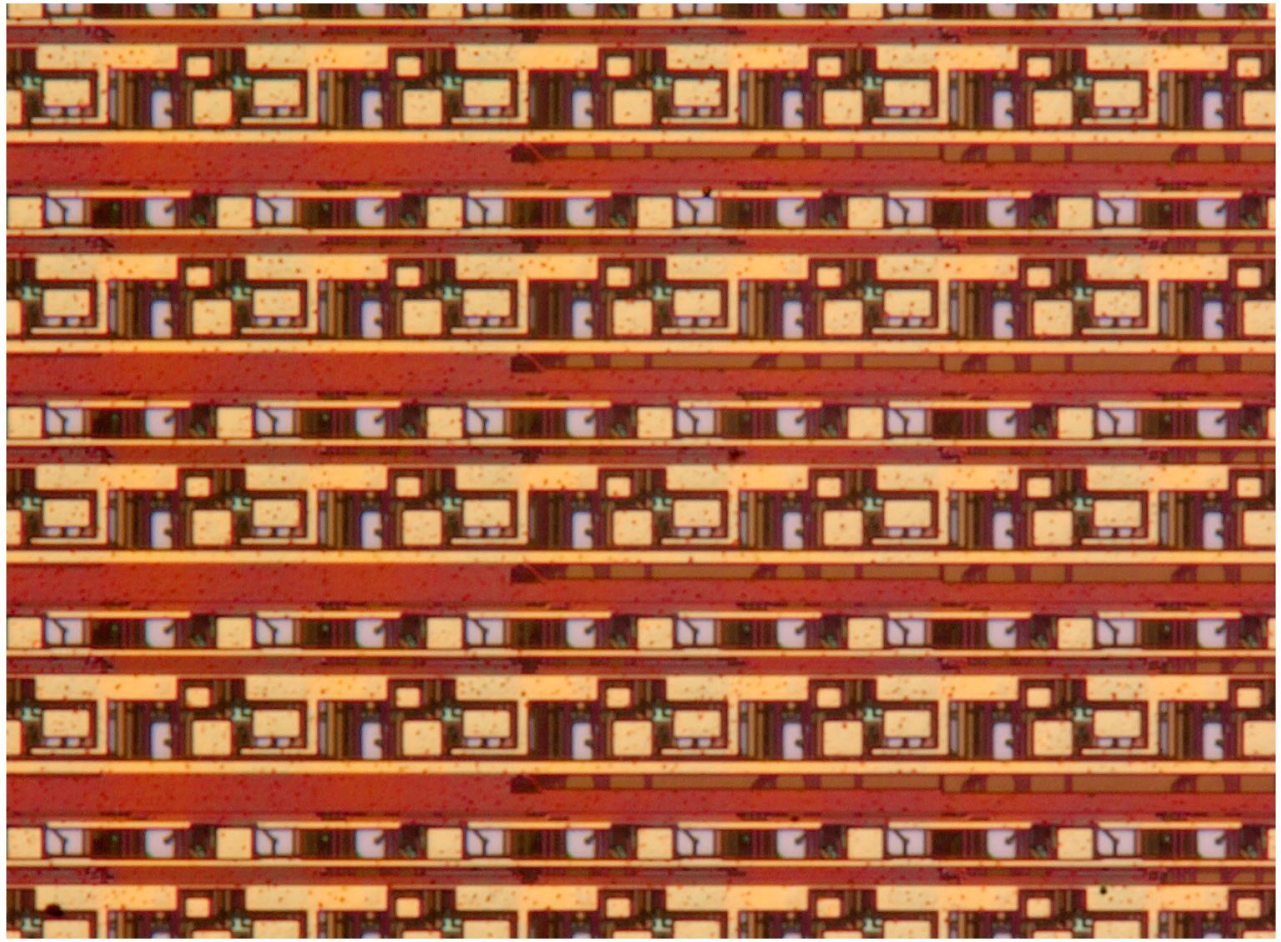
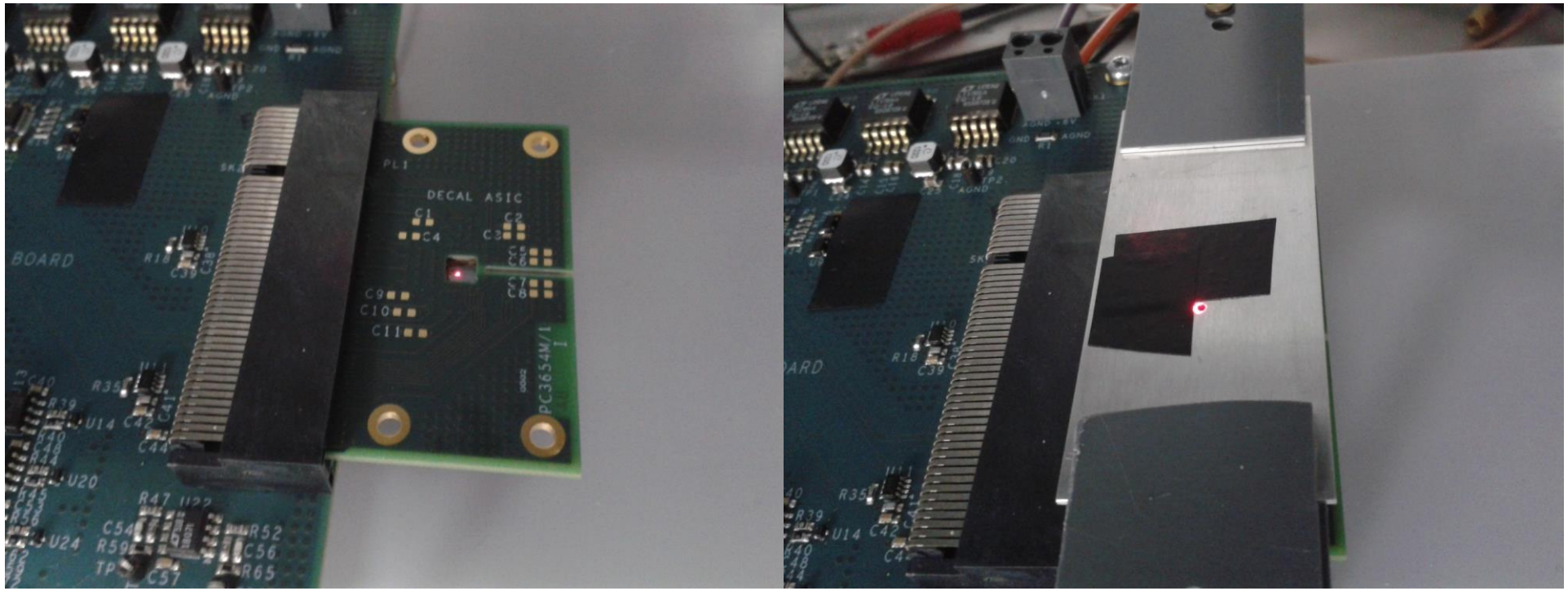
Digital Pixel





Pictures of DECAL aperture test



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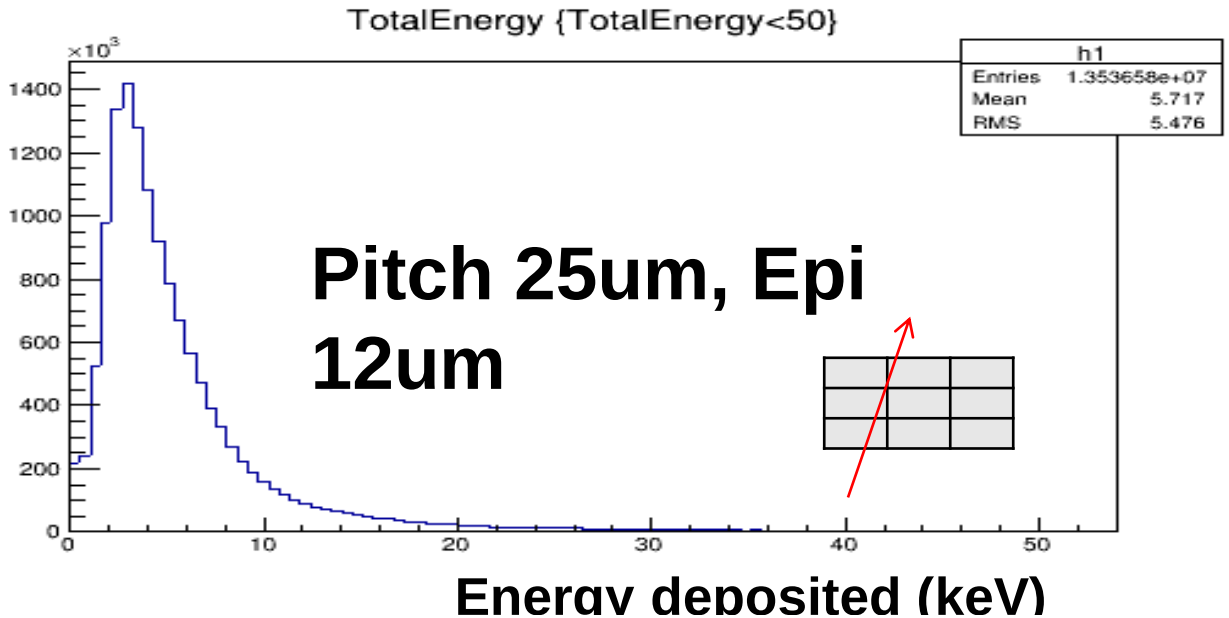
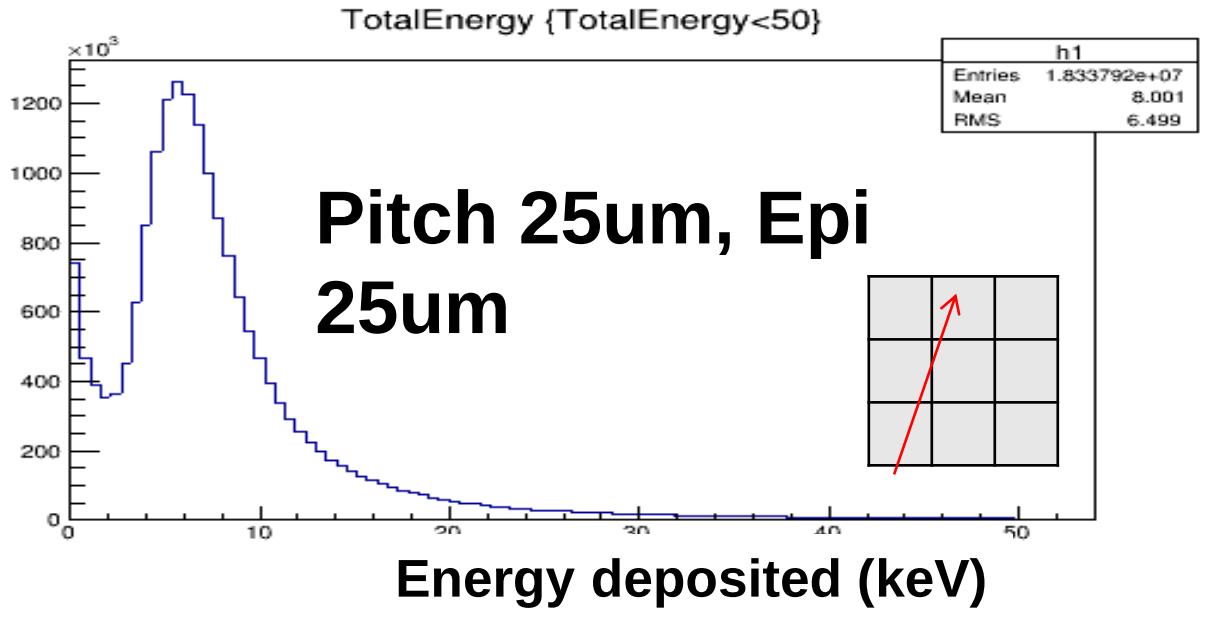
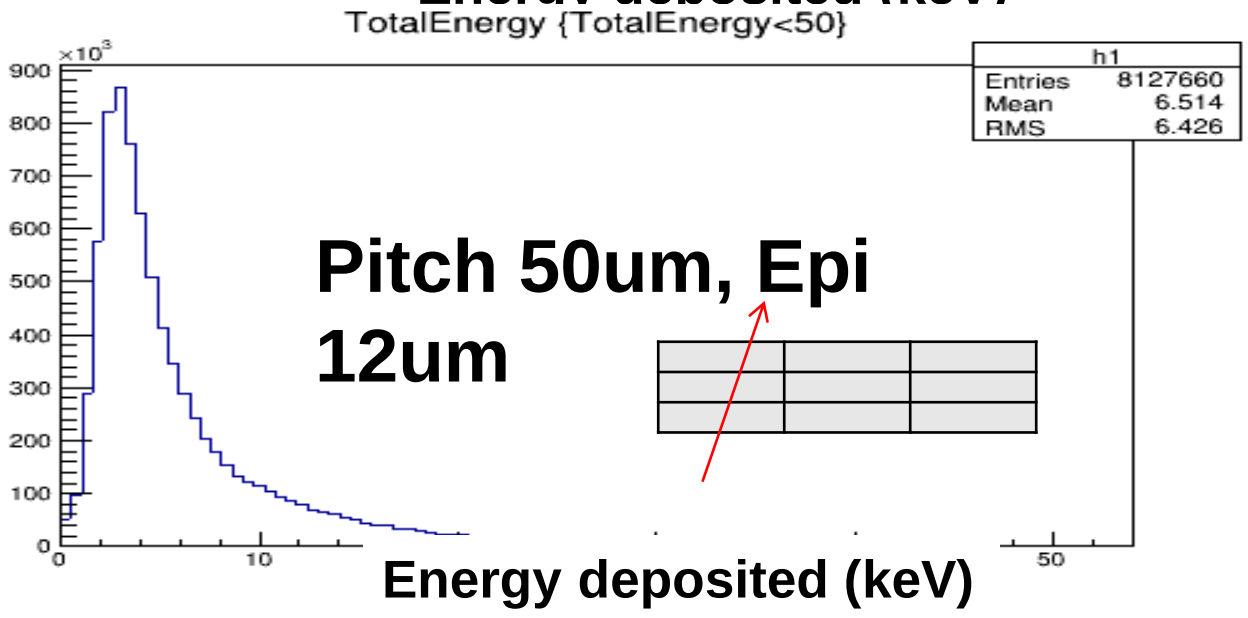
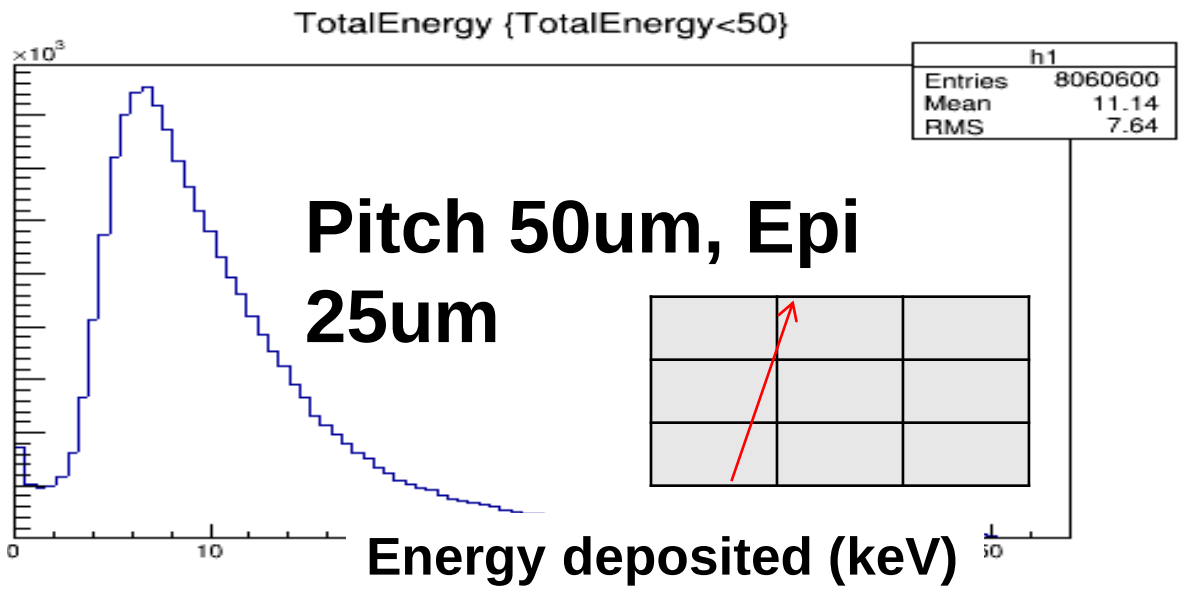
Boundary Crossing Effect

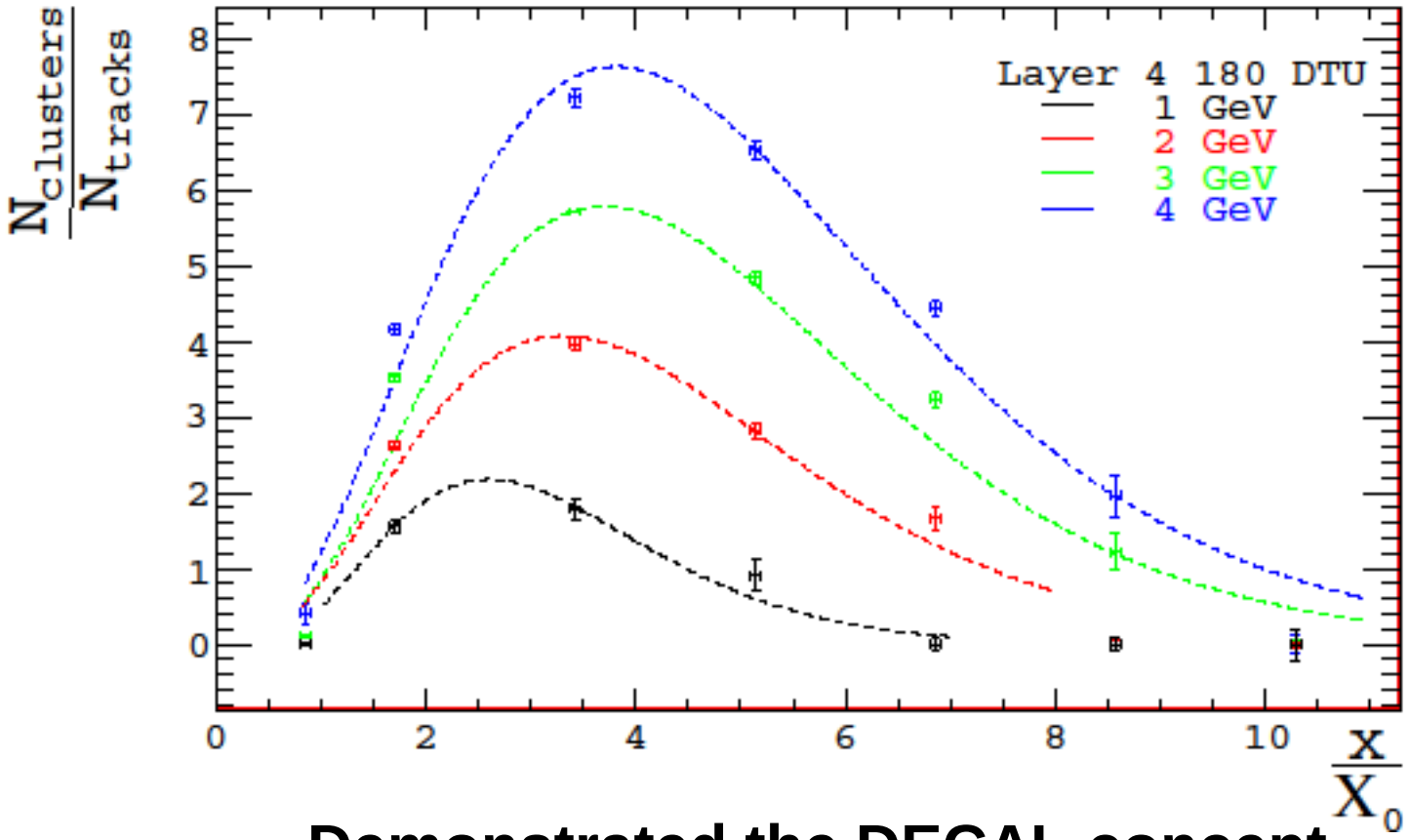


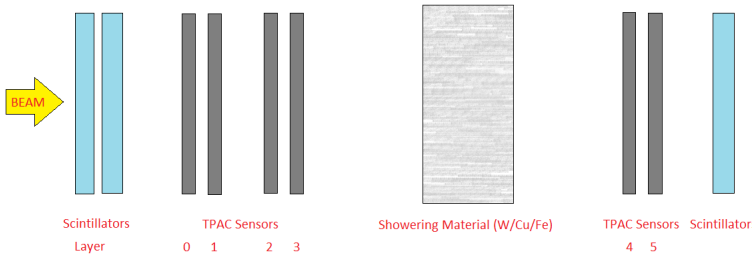






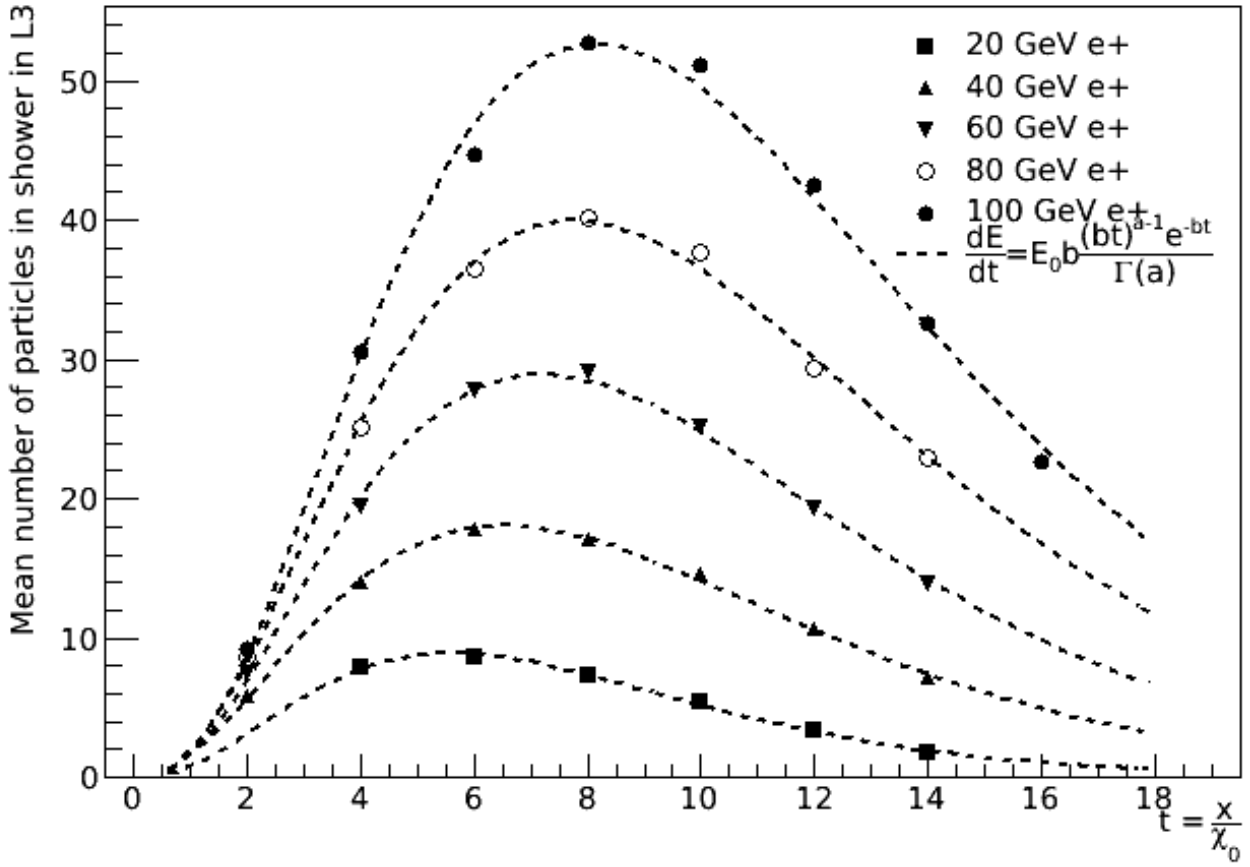
DESY TB March 2010: Shower Multiplicity in TPAC Stack

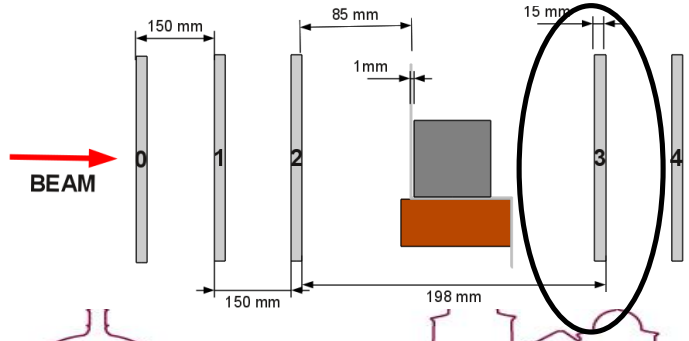




Demonstrated the DECAL concept

CERN TB September 2010: Shower Multiplicity in EUTelescope





DECAL concept holds to higher energies