UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

Update on DECAL studies for future experiments

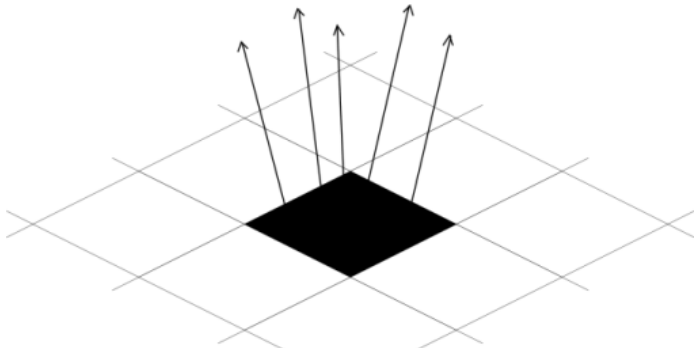
T. Price, A. Winter, N. K. Watson, L. Gonella, K Nikolopolous, S. Worm, I. Sedgwick, J. Dopke, Z. Zhang, G. Villani, and P. Allport

Contents

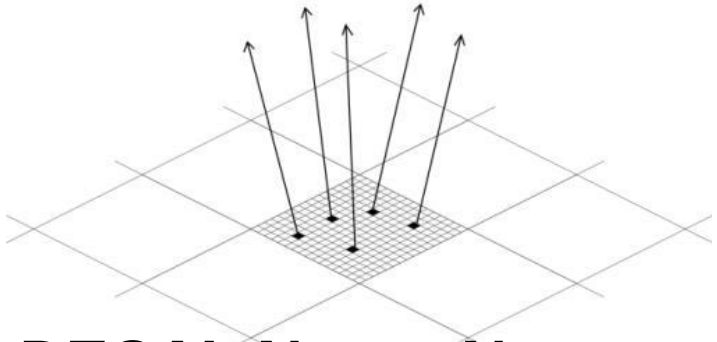
- Summary of beam test results
- Simulations within Mokka with added realism
- Overview of studies for DECAL in high radiation environments

Digital Calorimetry: The Concept

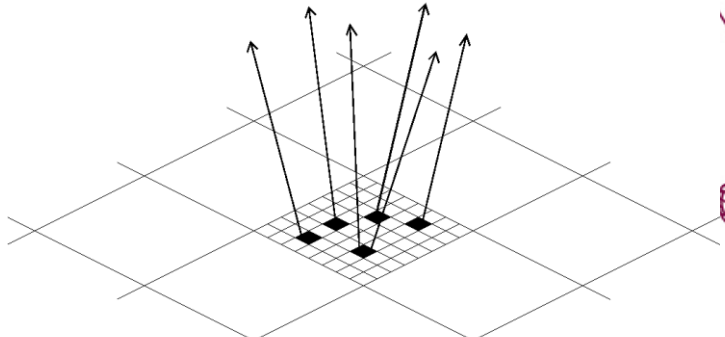
- Make a pixelated calorimeter to count the number of particles in each sampling layer
- Ensure that the pixels are small enough to avoid multiple particles passing through a single pixel to avoid undercounting and non-linear response in high particle density environments
- Digital variant of ILD ECAL would require 10^{12} channels



Analogue ECAL



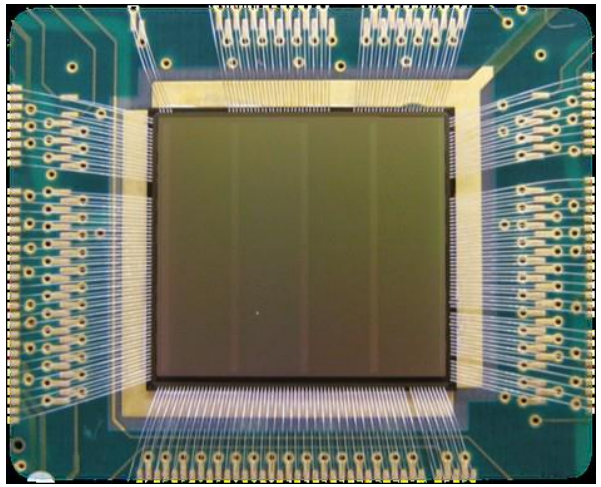
DECAL $N_{pixels}=N_{particles}$

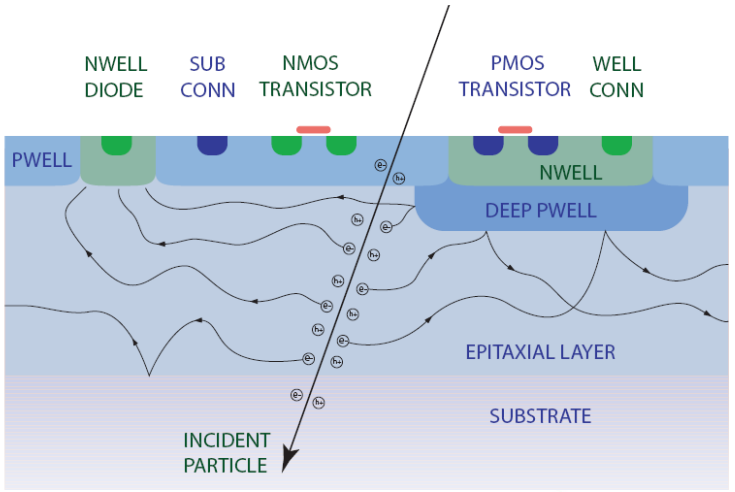


DECAL $N_{pixels}<N_{particles}$

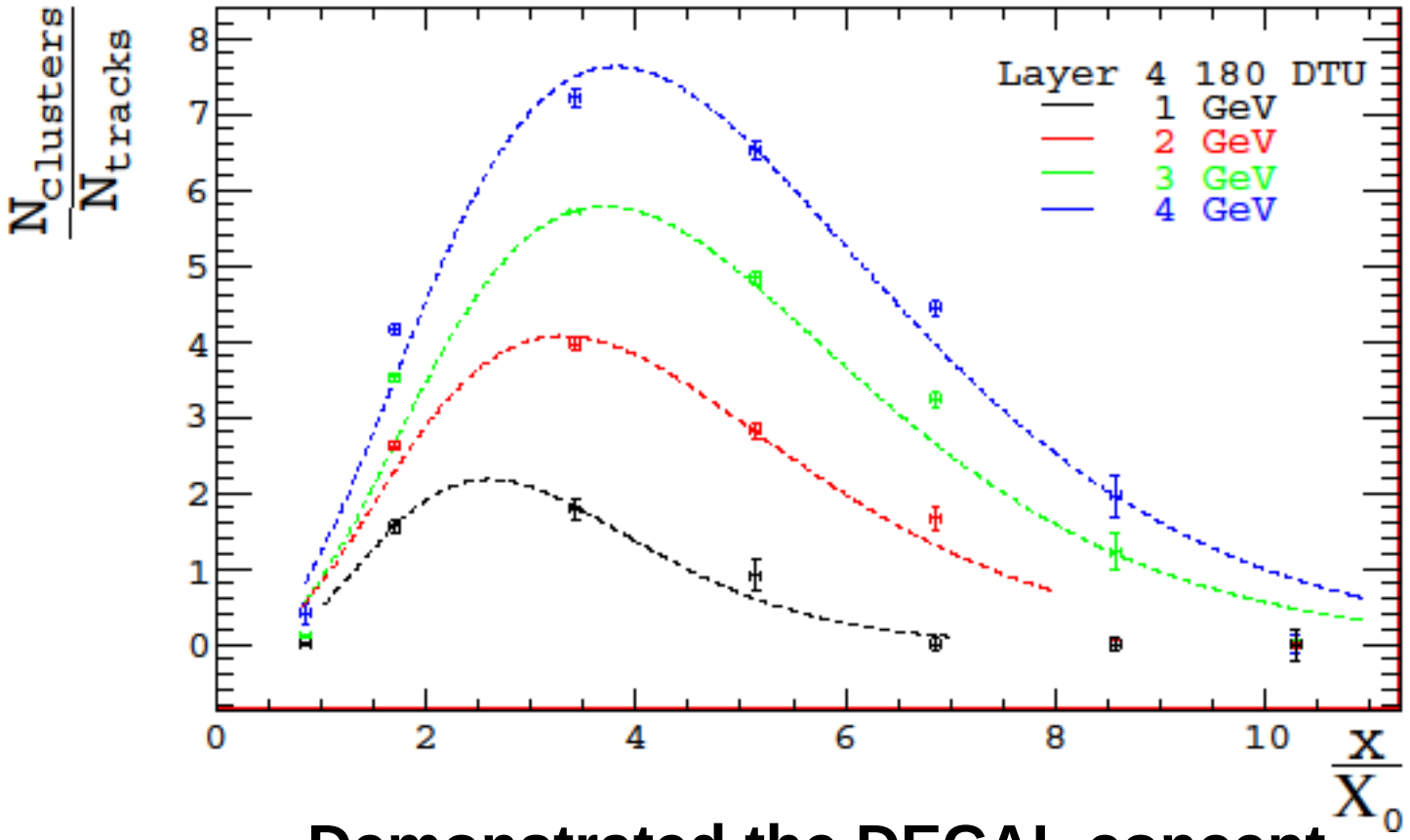
TPAC Sensor

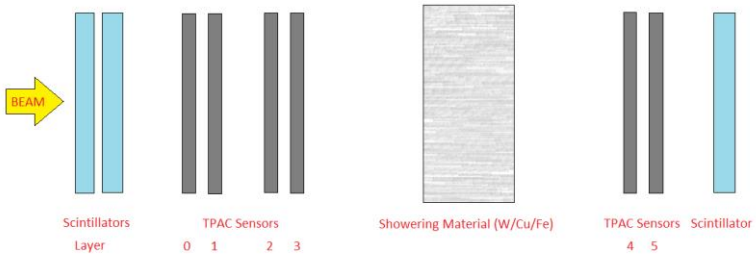
- CMOS MAPS
- 168x168 pixel grid, 50x50 micron pitch
- Digital readout
- Low noise
- Utilise the INMAPS process to reduce parasitic charge collection
- Collect charge by diffusion to signal diodes
- Sampled every 400 ns (timestamp)
- Readout every 8192 timestamps (bunch train)





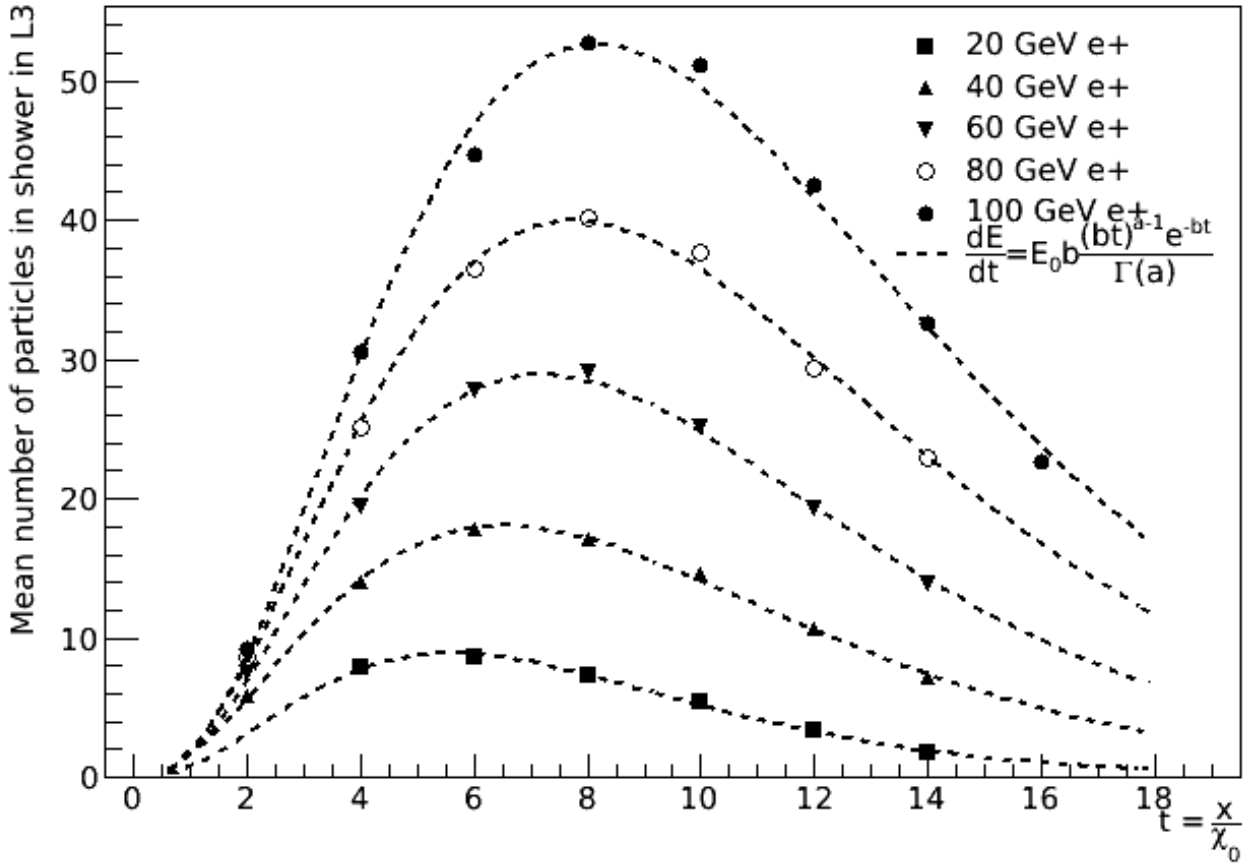
DESY TB March 2010: Shower Multiplicity in TPAC Stack

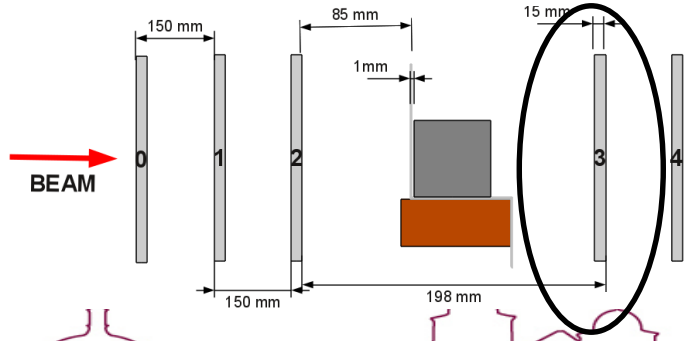




Demonstrated the DECAL concept

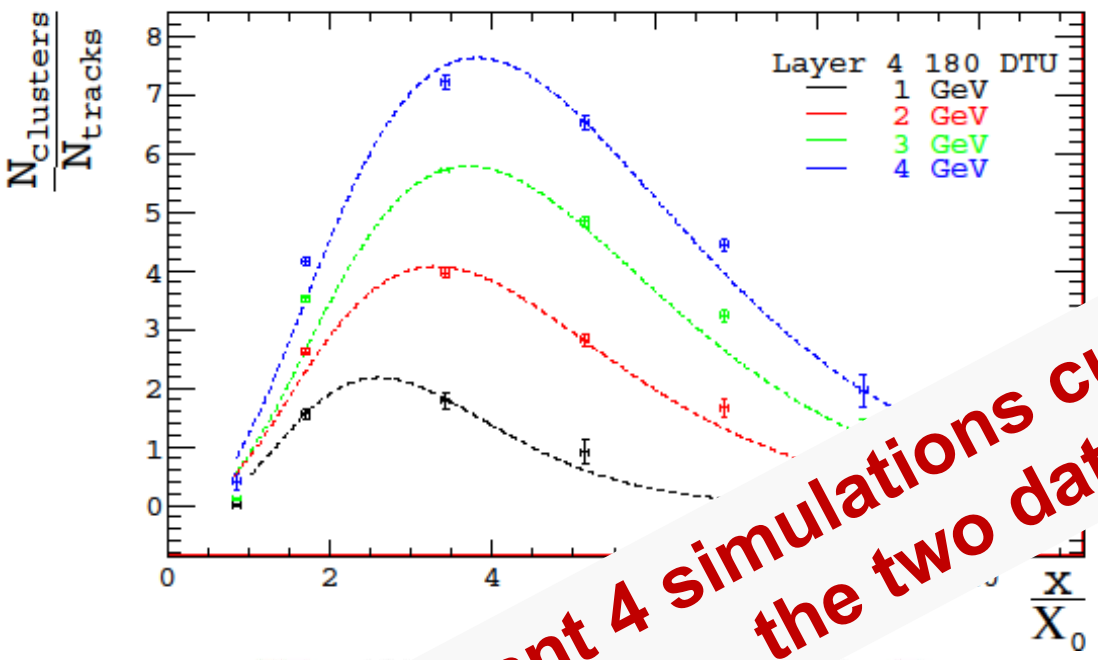
CERN TB September 2010: Shower Multiplicity in EUTelescope

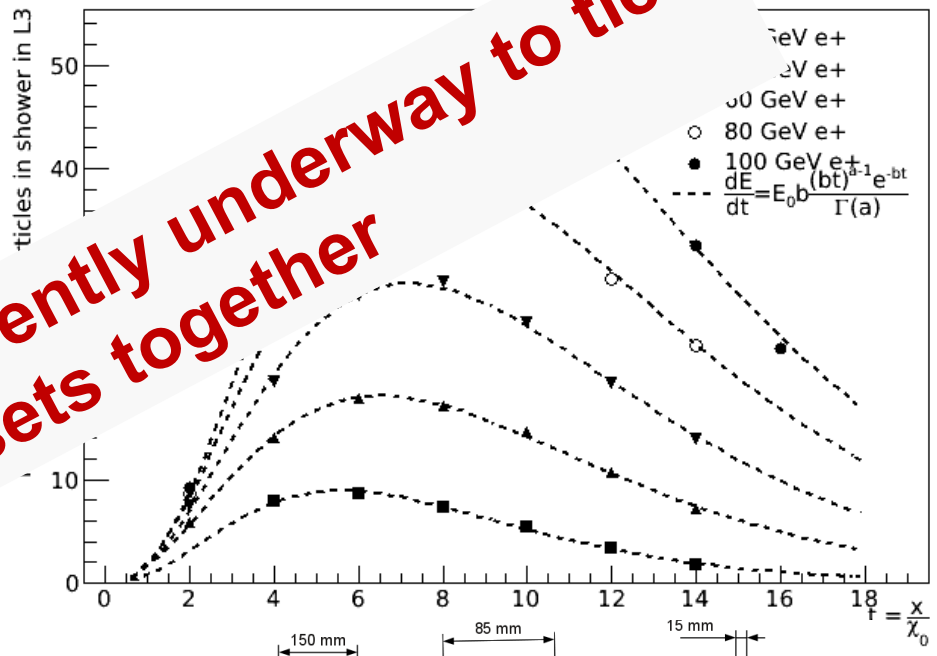


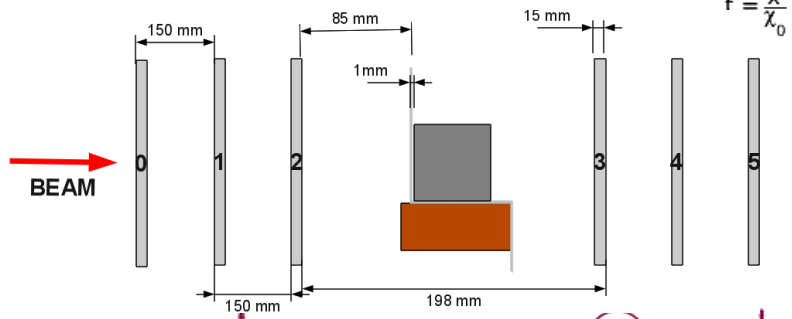


DECAL concept holds to higher energies

TB: Shower Multiplicities



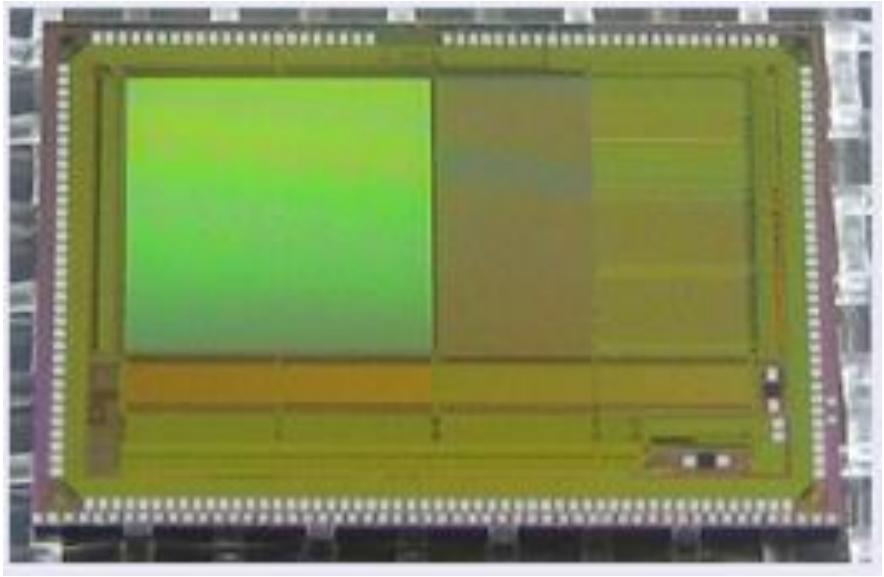




Geant 4 simulations currently underway to tie the two datasets together

Cherwell Sensor

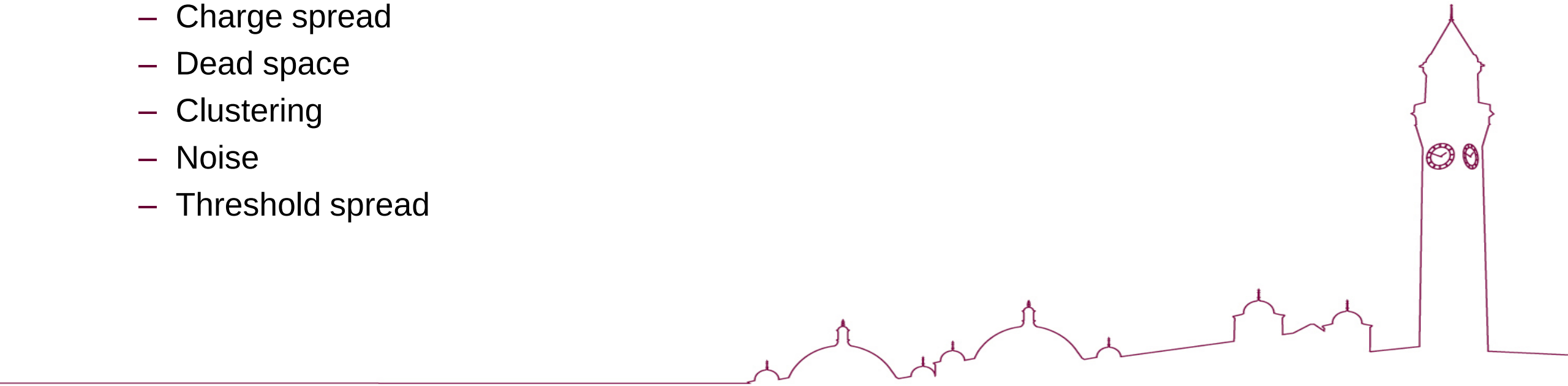
- Spin-off from TPAC and FORTIS
- CMOS for Calorimetry/Tracking/Vertexing
- 4 test structures
  - DECAL25 : 48x96 25um pixels with 2x2 reconfigurability
  - DECAL50 : 24x48 50um pixels
  - Reference: 48x96 25um pixels with ADC at column base
  - Strixel : 48x96 25um pixels with ADC embedded in pixel
- 180nm process
- 4T structures
- CDS
- 12-bit ADC, rolling shutter
- Global shutter for DECAL
- Supports power pulsing



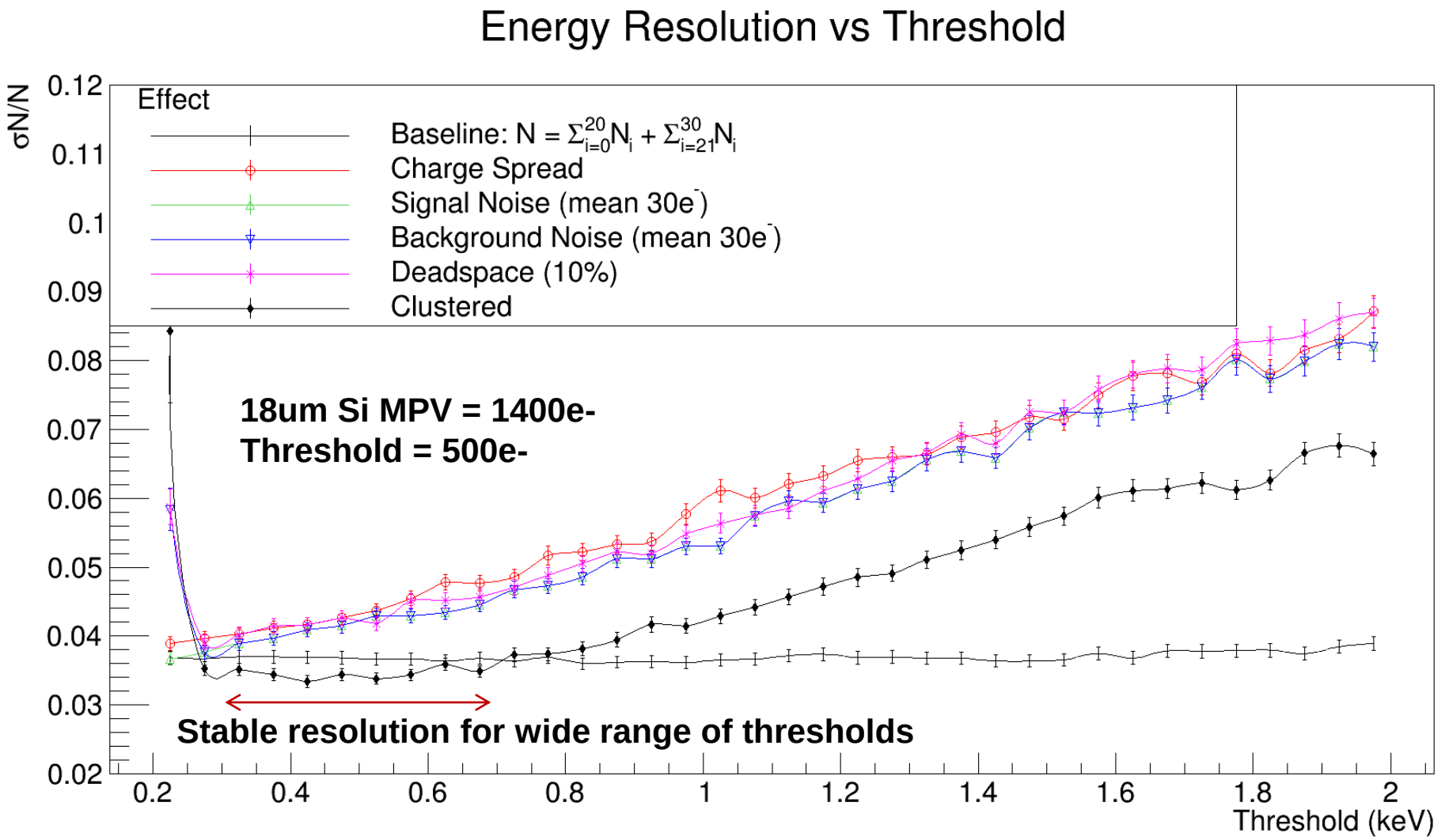
Firmware issue solved
Readout stability issues solved
Reconfigurability and PP can finally be studied over the coming months

DigiMAPS Package

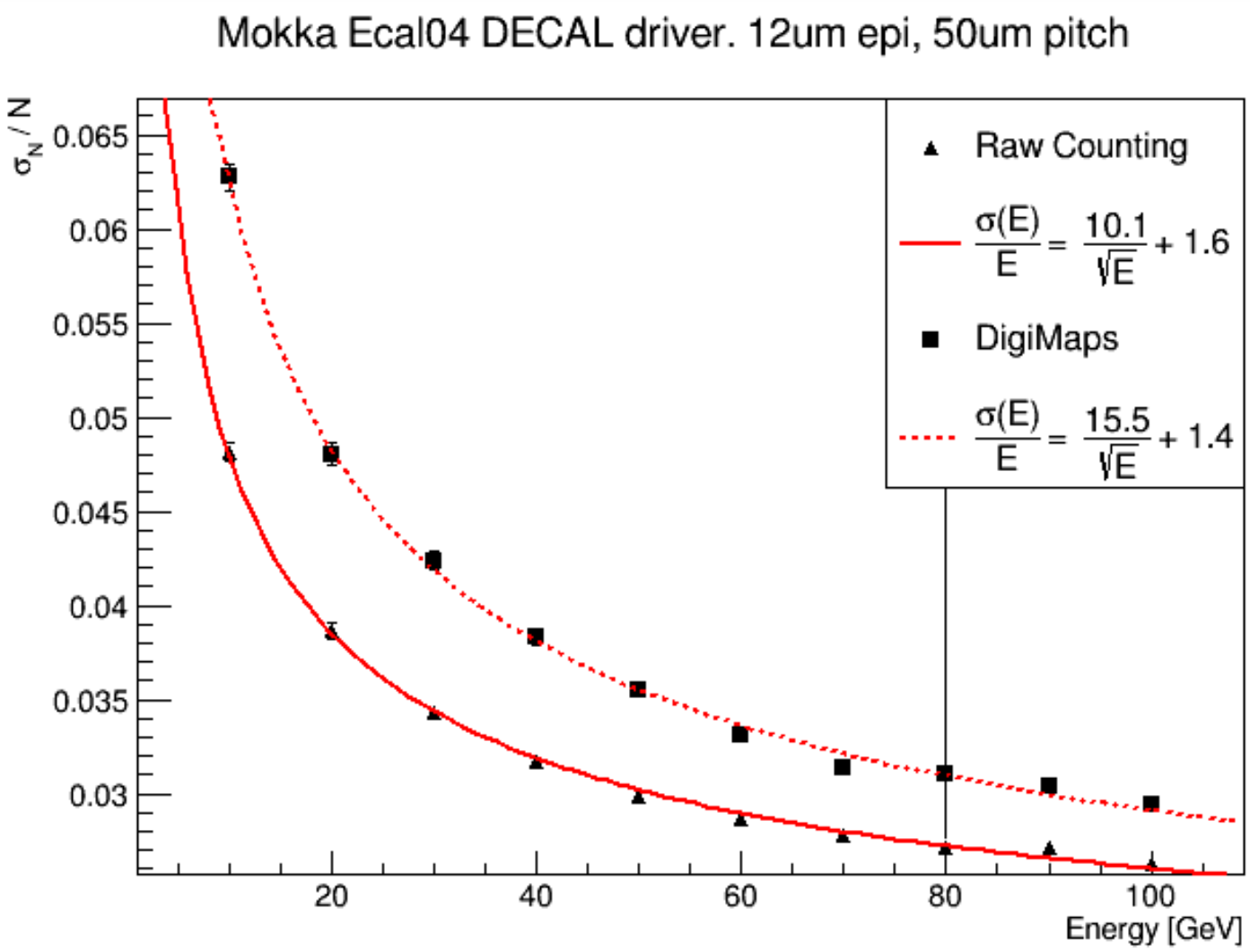
- Tool for adding additional levels of realism to simulations
- Developed for CALICE in 2008 by Anne-Marie Magnan (Imperial,CMS)
- Resurrected and adapted by Alasdair Winter (PhD UoB)
- Accounts for numerous effects not dealt with by Mokka:
  - Charge spread
  - Dead space
  - Clustering
  - Noise
  - Threshold spread



DigiMAPS Package

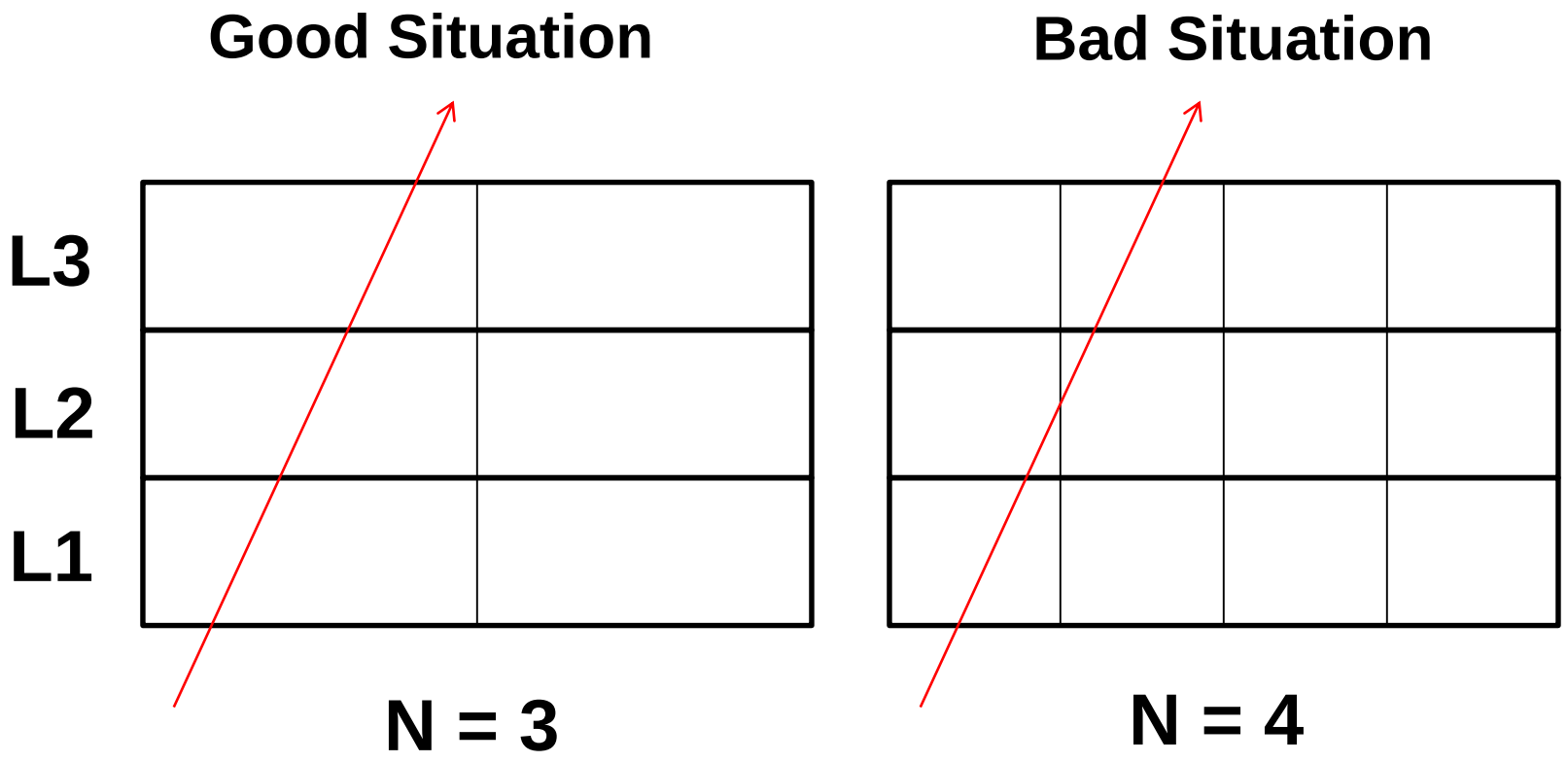


DigiMAPS Package

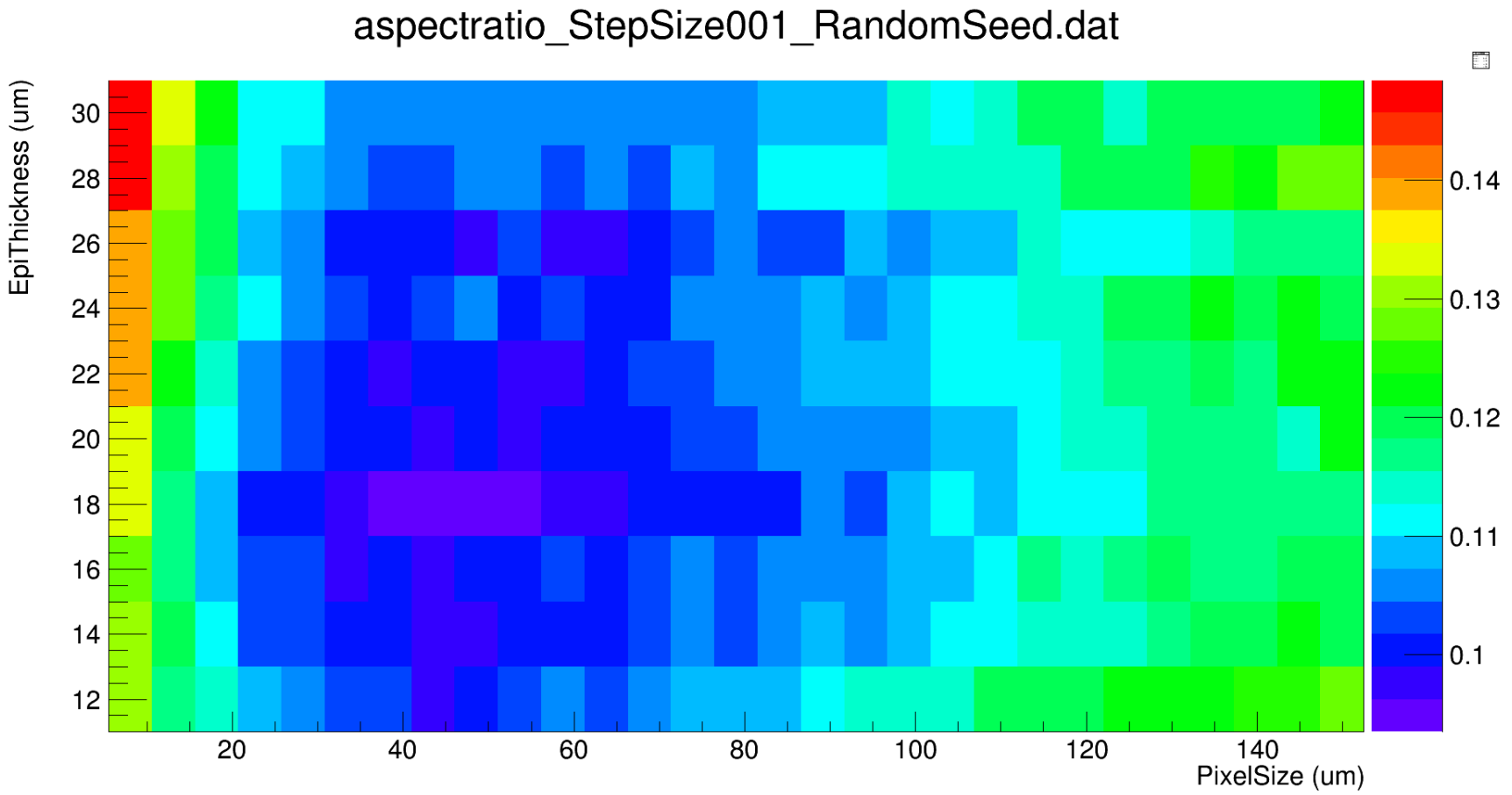


- Full MOKKA Simulation with DECAL adaptation of ECAL04 (digital readout of 50x50um pixels)
- Single particle resolution degraded when all effects of DigiMaps added

Pixel Aspect Ratios



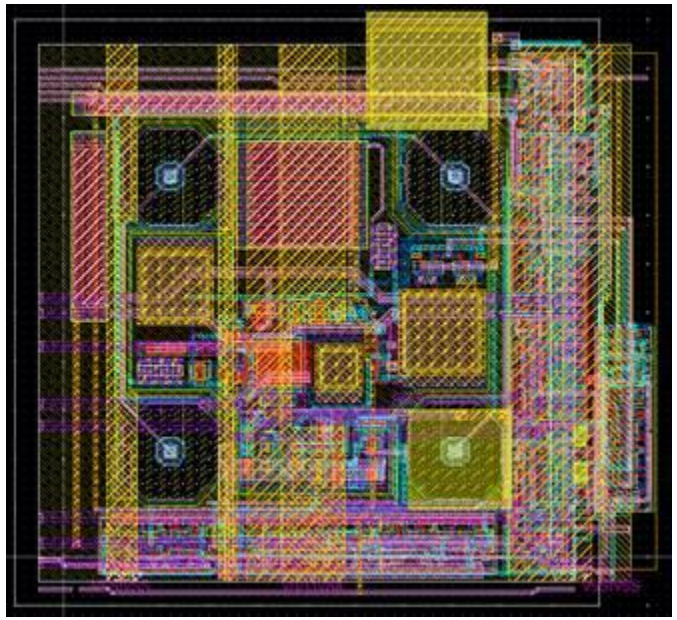
Pixel Aspect Ratios



- Full MOKKA ECAL04 DECAL simulation
- 5um pixel pitch rebinned using DigiMAPS
- 1um max step in epi
- Random Seed corrected in MOKKA
- Each bin is stochastic term fitted up to 100 GeV e-
- No threshold applied
- No DigiMaps effects

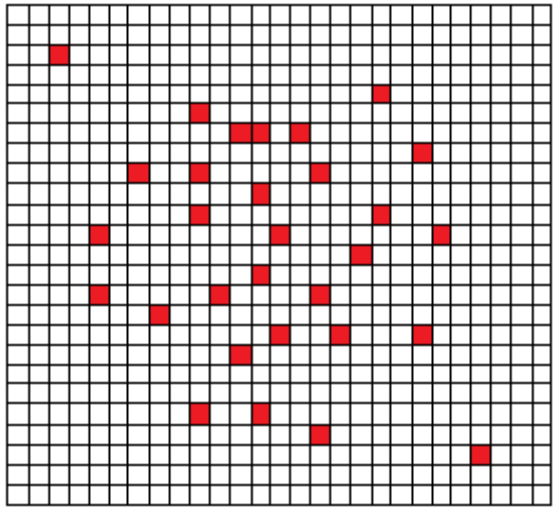
DECAL for higher radiation environments

- Currently developing radiation hard, reconfigurable CMOS MAPS devices for future experiments
- Applications for tracking, calorimetry and medical applications
- Investigating their applications within the FCC-hh ECAL Barrel
- Architecture designed for high rate (25ns BX), also relevant to other applications (hadron therapy at cyclotrons)
- Prototyping with same foundry as used for ALICE ALPIDE sensor
- Recent results shown at recent “Trento” workshop have show modified process can deliver excellent radiation hardness https://indico.cern.ch/event/587631/contributions/2467389/attachments/1415291/2166554/CMOS-TJ-Trento-Pernegger.pdf
- Following results are obtained with DECAL in FCCSW framework. Basic cylindrical 18um Epitaxial (sensitive layer), 450um Substrate, 2.1mm W, 50 layer calorimeter.



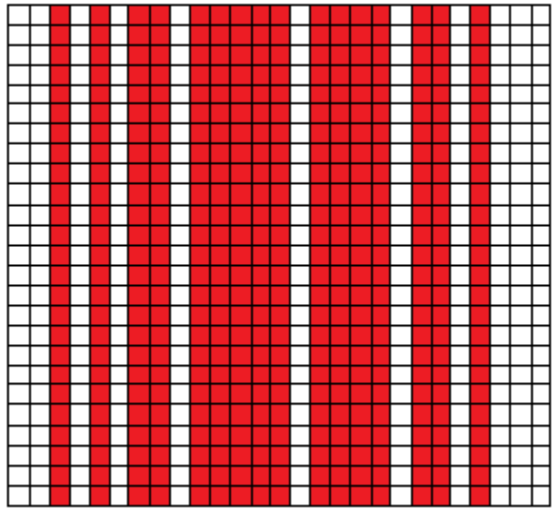
Reconfigurability

- Cannot read out every pixel location, every 25ns due to data rates so need to reduce
- Reconfiguring the pixel matrix to read out column IDs (applications in tracking and possibly pre-shower)
- Sum the # of hits in 5x5mm^2 pad and readout this value (calorimetry)



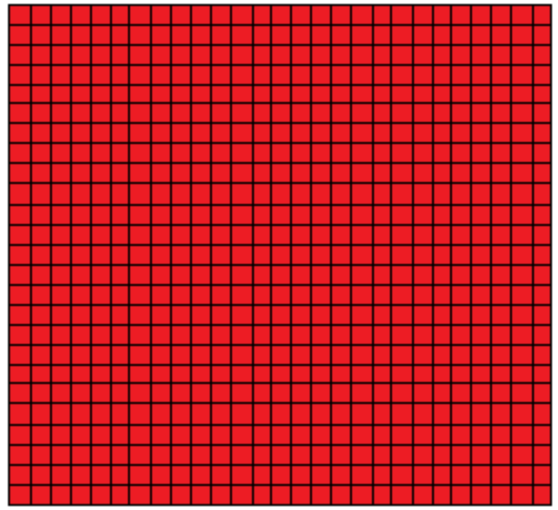
Pixel Mode

N pixels fired
N positions read out



Strixel Mode

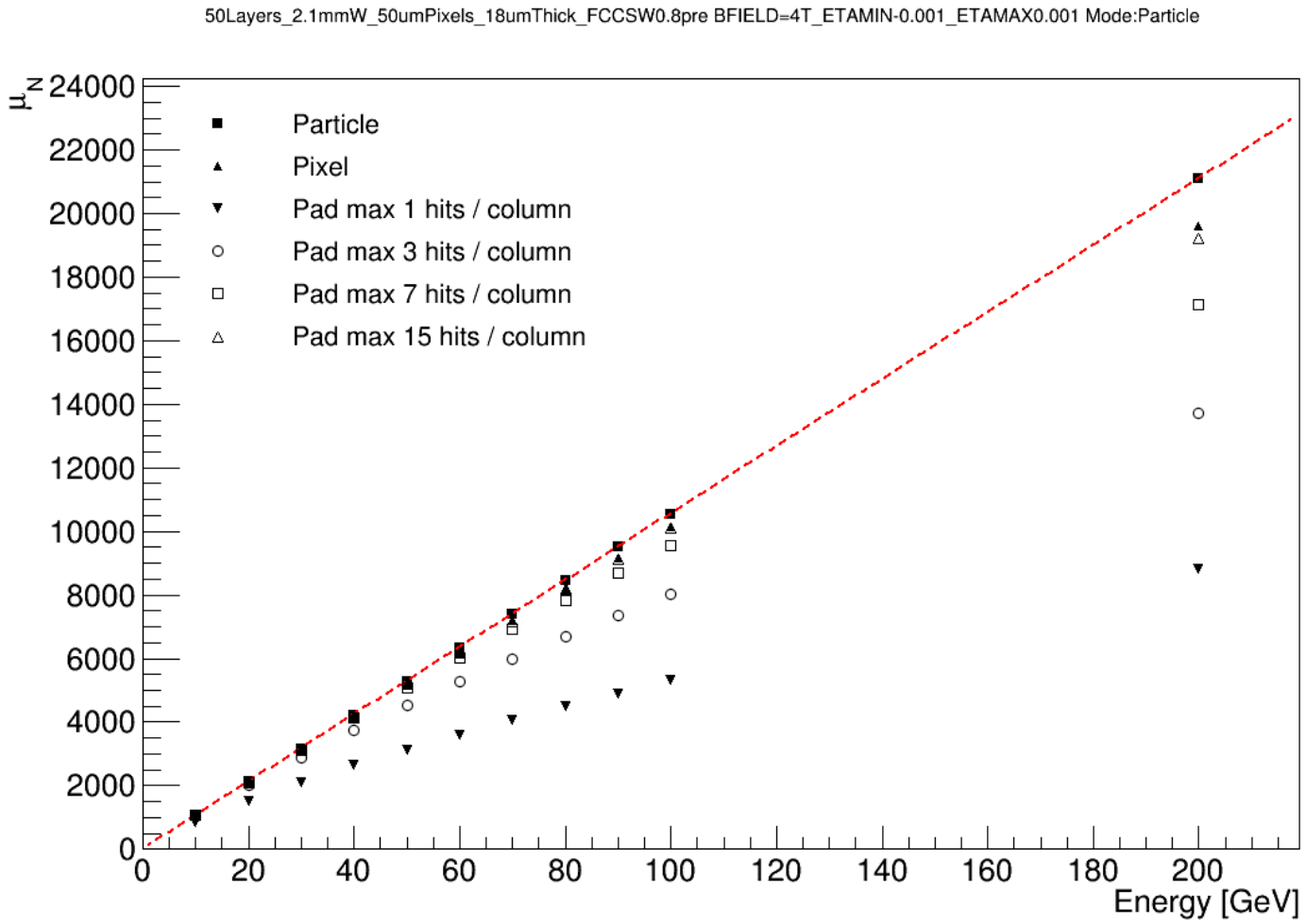
hit column IDs read out



Pad Mode

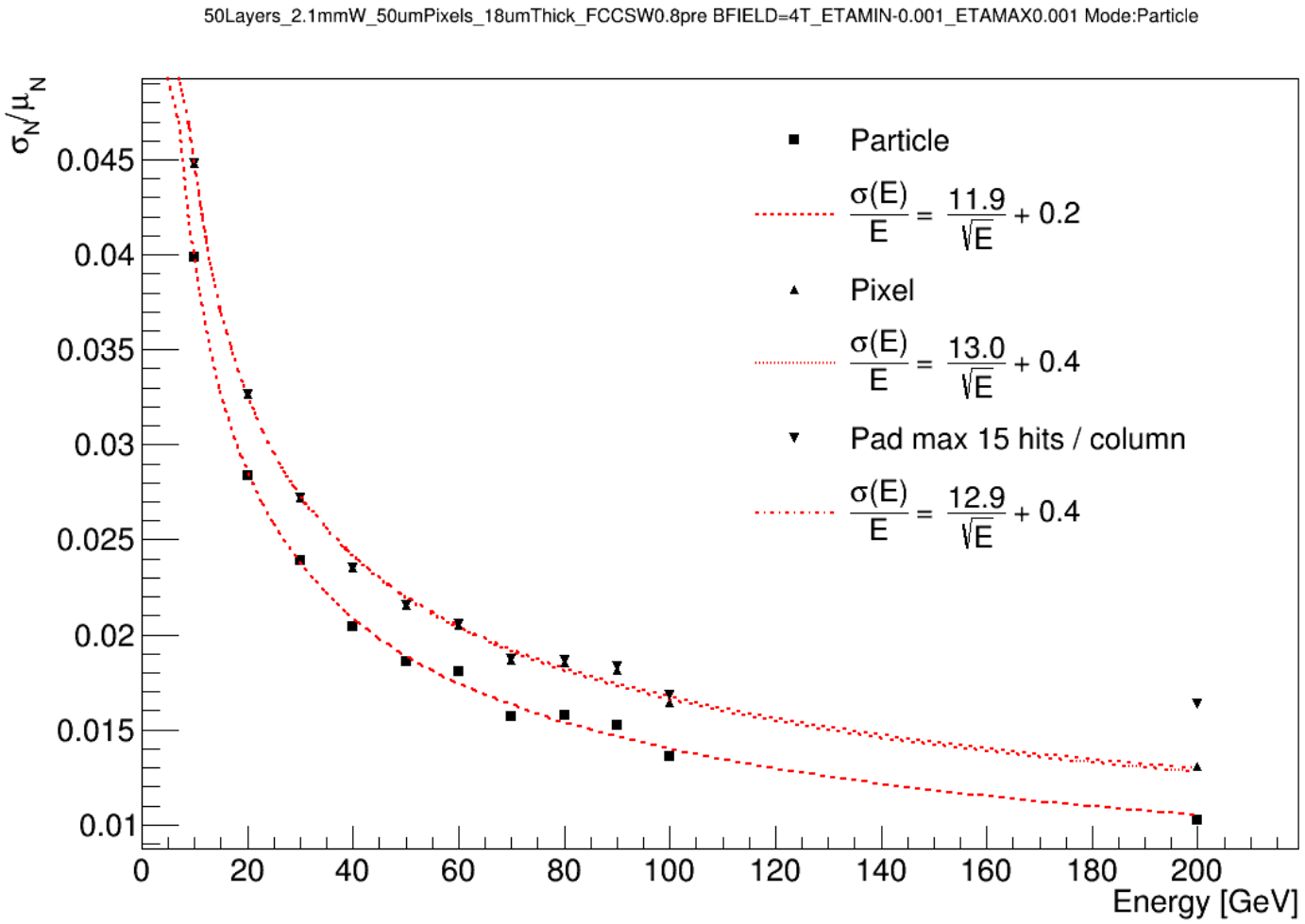
Sum hits in all columns
hits and Pad ID read out

Impact of Column Readout on Linearity



- In pad model the columns are added together with a series of HA and FA
- Due to finite space within the pixel and matrix there is a limited amount of logic possible
- Number of hits allowed in a column can seriously impact the physics
- The DECAL chip will be able to count 15 + 1 along each 5mm column

Impact of Column Readout on Resolution



- Pad mode with 15 hits / column sees no degradation in performance up to 100 GeV
- Higher energies require more hits / column but initial results look promising
- Pad mode read out could be a viable option for a collider with LHC/FCC bunch timing
- Pad mode readout could also reduce the power required at LC but at the detriment of losing granularity

Conclusions

- Beam test data shows that the principle of particle counting for electromagnetic calorimetry is valid
- Currently working on simulations to evaluate shower properties at tungsten exit
- Reconfigurability and Power Pulsing of CMOS to be investigated with Cherwell chip in the coming months
- A new DECAL chip is currently being designed for future high radiation environments
  - Radiation hard
  - Reconfigurable for use in tracking, calorimetry, and medical applications
  - Able to be read out every 25 ns
- Counting # of particles in a 5x5mm2 Pad is an option to do this
- Read out architecture at LC would be very different to hadron machine
- Pad mode would lose some of the benefits of ultra high granularity but could further reduce power consumption

Any Questions?