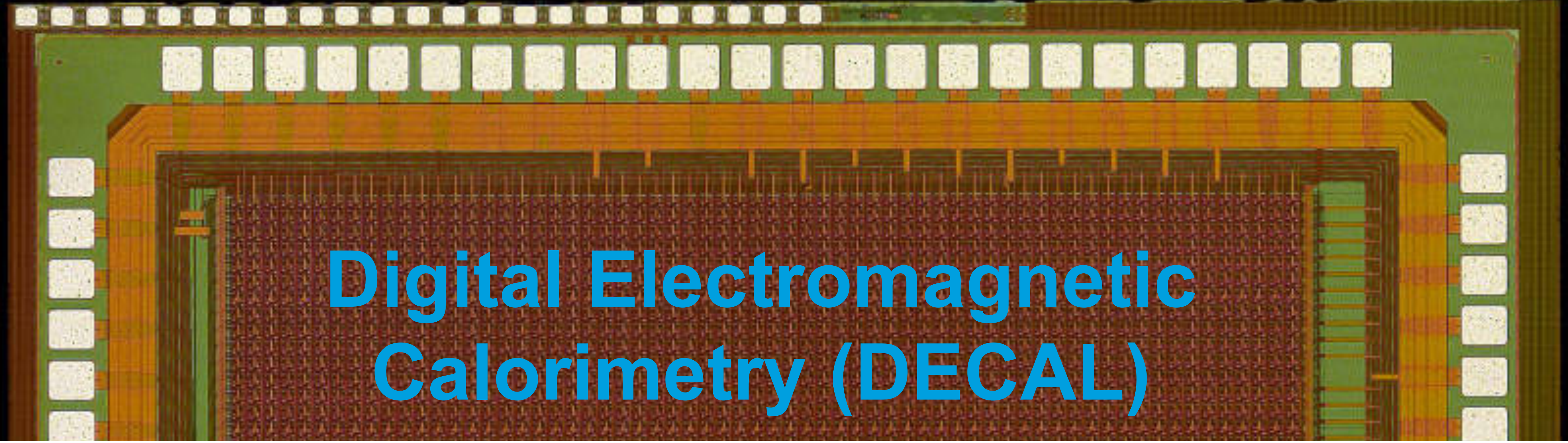

Digital Electromagnetic Calorimetry (DECAL)

A reconfigurable CMOS sensor for digital EM calorimetry (AP 3.2)

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22nd February 2022

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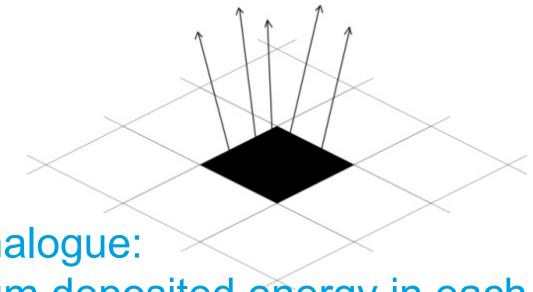
In collaboration with Rutherford Appleton Laboratory and University of Birmingham, UK

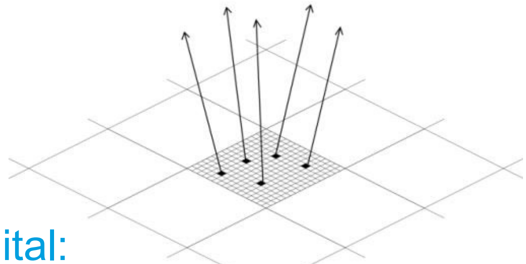
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Digital EM calorimetry

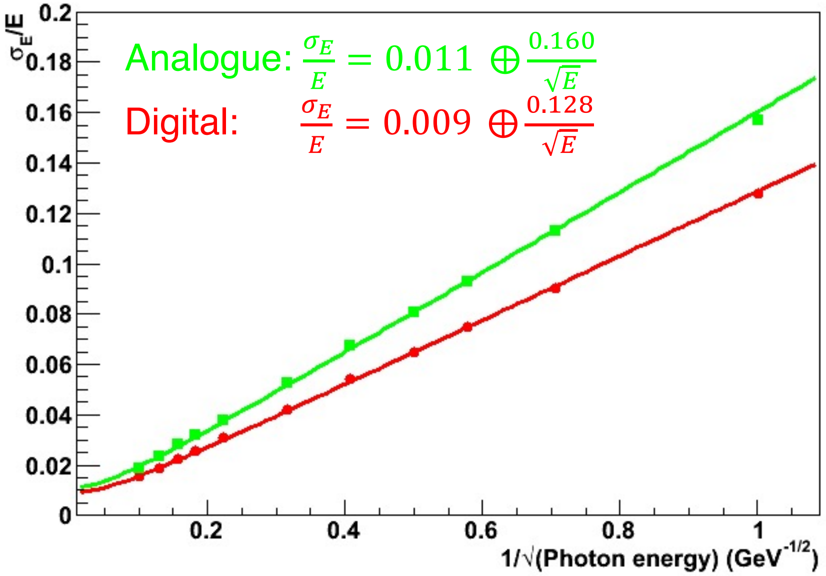
Comparison with conventional analogue ECAL



Analogue:
Sum deposited energy in each layer



Digital:
Sum number of particles in each layer
Requirement: High granularity to avoid saturation



Simulated digital ECAL shows better σ_E/E than analogue one

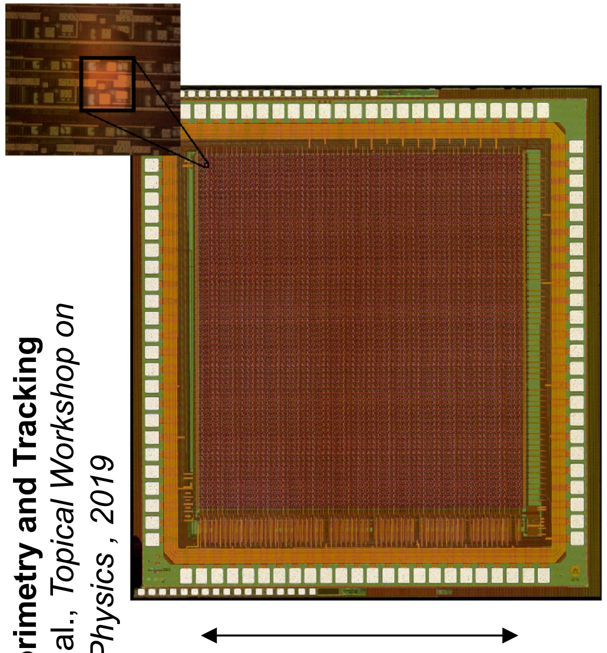
- Bethe-Bloch formula gives mean energy loss
- Deposited energy in detector fluctuates, following Landau-distribution for thin absorbers
- Stochastic term reduced by 20% as landau fluctuation from energy deposition vanishes
- High granularity benefitial for particle flow algorithms and identification of pileup

P. Dauncey et al. (2011) *Performance of CMOS sensors for a digital electromagnetic calorimeter,* Proc. 35th International Conference on High Energy Physics, July 22–28 2010, Paris, France.

The DECAL chip

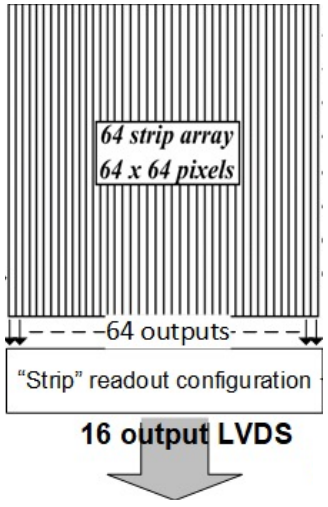
A monolithic active pixel sensor prototype

DECAL: A Reconfigurable Monolithic Active Pixel Sensor for use in Calorimetry and Tracking
Seddik Benhammadi et al., *Topical Workshop on Electronics for Particle Physics , 2019*

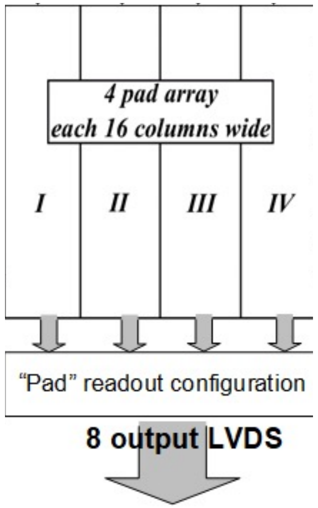


3,5 mm

- $55\times55\ \mu\mathrm{m}^2$ pixels in a 64×64 pixel matrix
- Fabricated in the TowerJazz 180 nm CMOS optical process using 18 um epitaxial Si layer
- Reconfigurable digital readout logic as:
  - 1x64 pixel strips for tracking
  - 16x64 pixel pads for calorimetry
- One pixel with analogue readout in top left corner



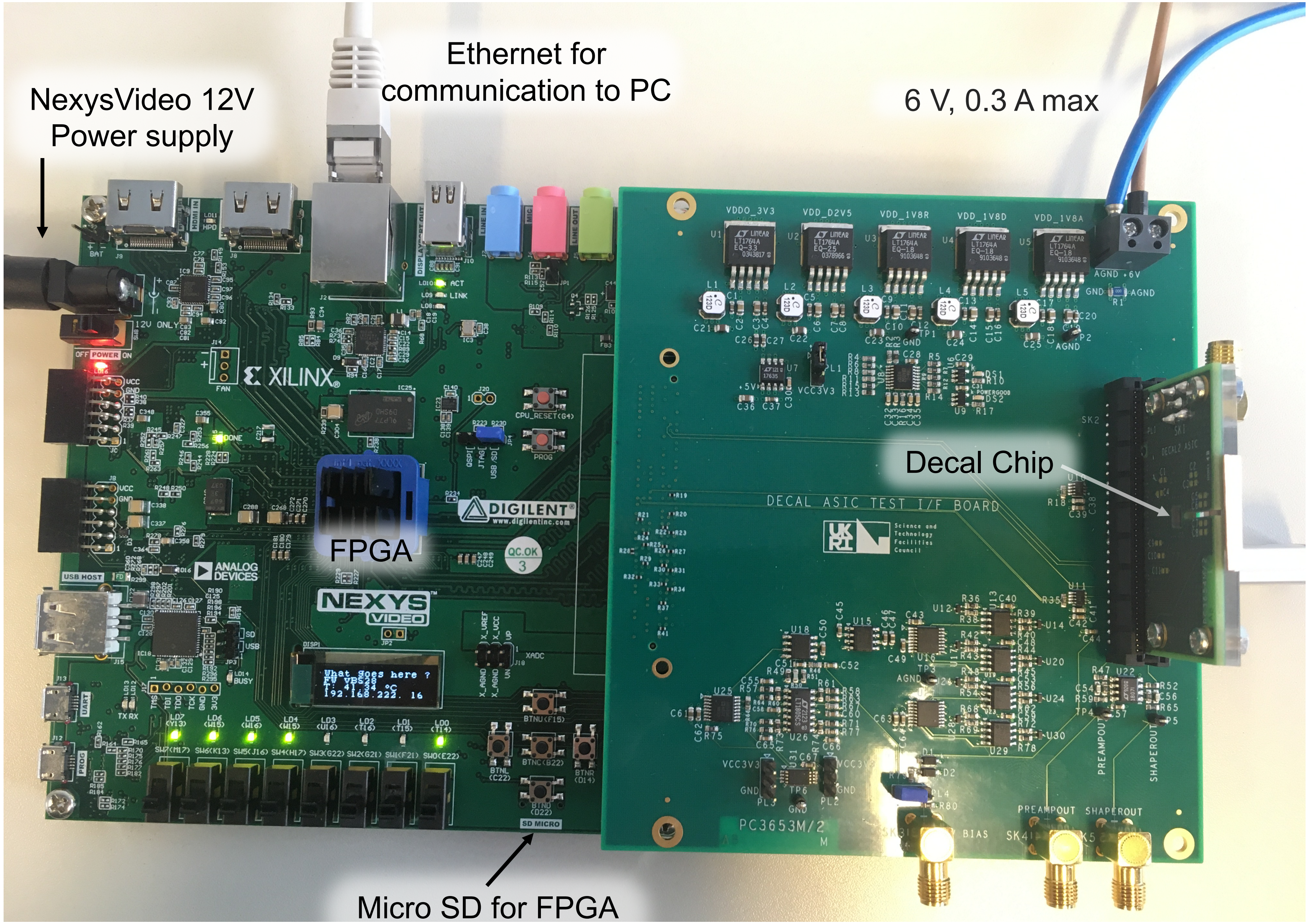
- Max 3 hits/strip
- Higher granularity

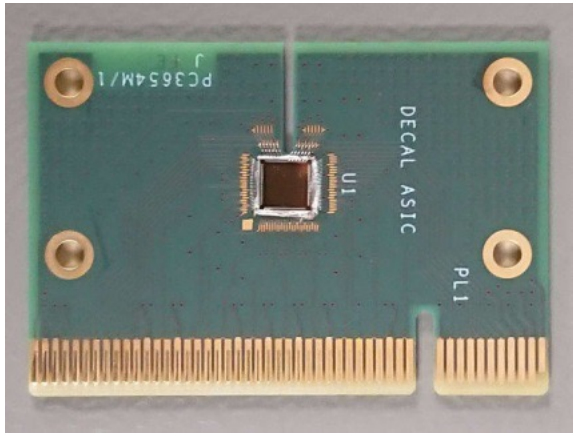


- Max 15 hits/strip
- 240 hits/pad
- More counts per strip while maintaining lower data rate

DECAL setup

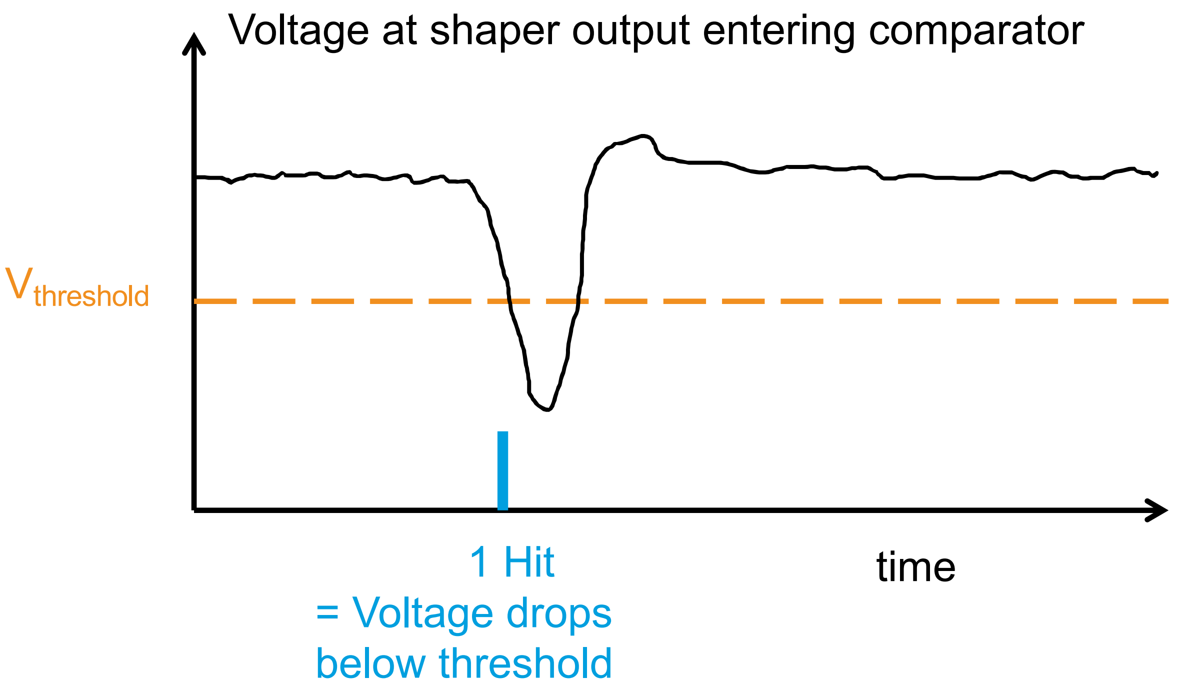
- 4 chips and motherboard schematics received from Jens Dopke (RAL, UK)
- Motherboard produced at DESY Zeuthen
- Digilent Nexys Video Board
- Data acquisition via ATLAS ITSDAQ software
- 40 MHz readout



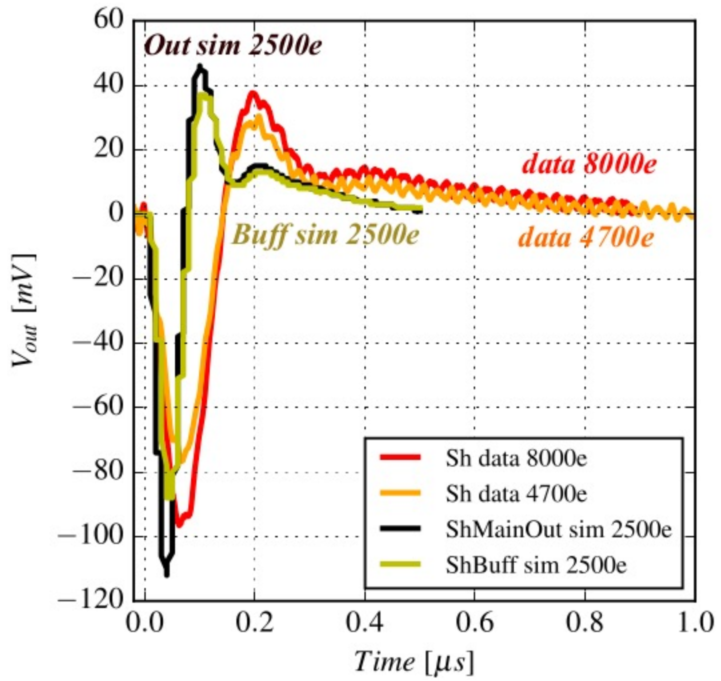


Measurement procedure

Sketch and measurement of laser illumination



Shaper Signals

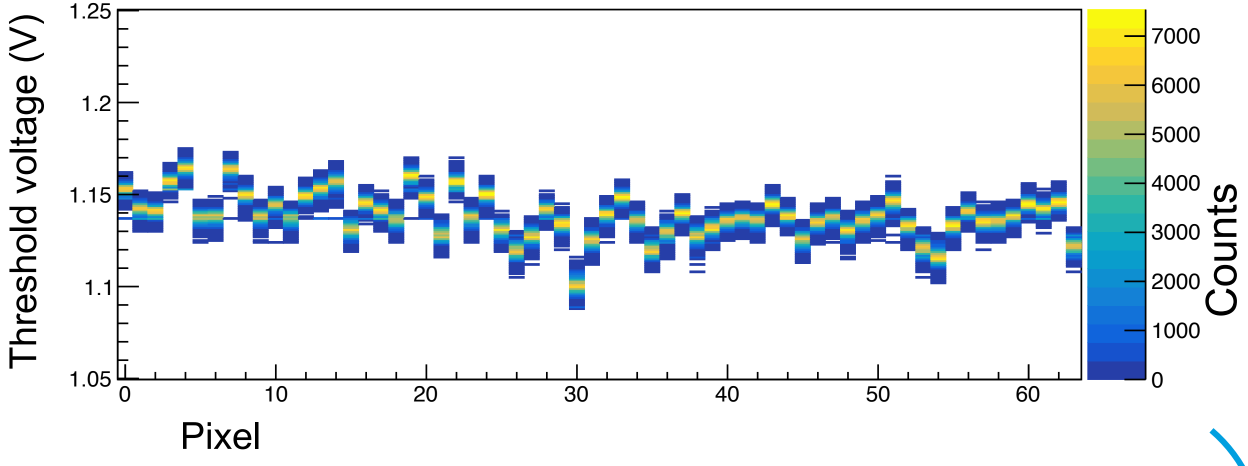


P. Allport et al., First tests of a reconfigurable depleted MAPS sensor for Digital Electromagnetic Calorimetry, Nucl. Inst. and Meth. A, 958:162654, April 2020

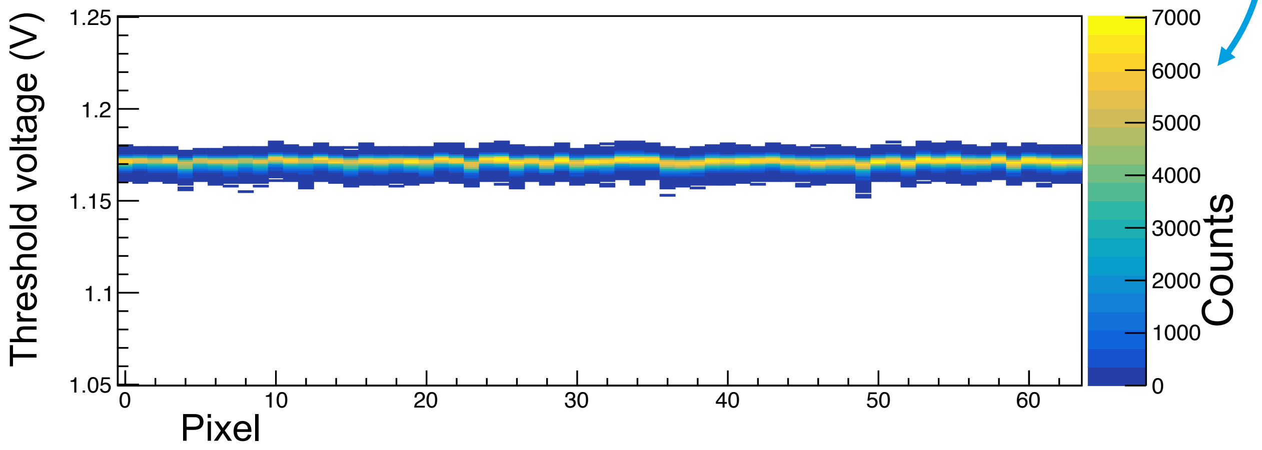
- Despite digital readout, one pixel has analogue as well
- Signal from defocused 10x10μm^2 TriLite laser (pJ/pulse, λ=1064 nm)

Finding noise level per pixel

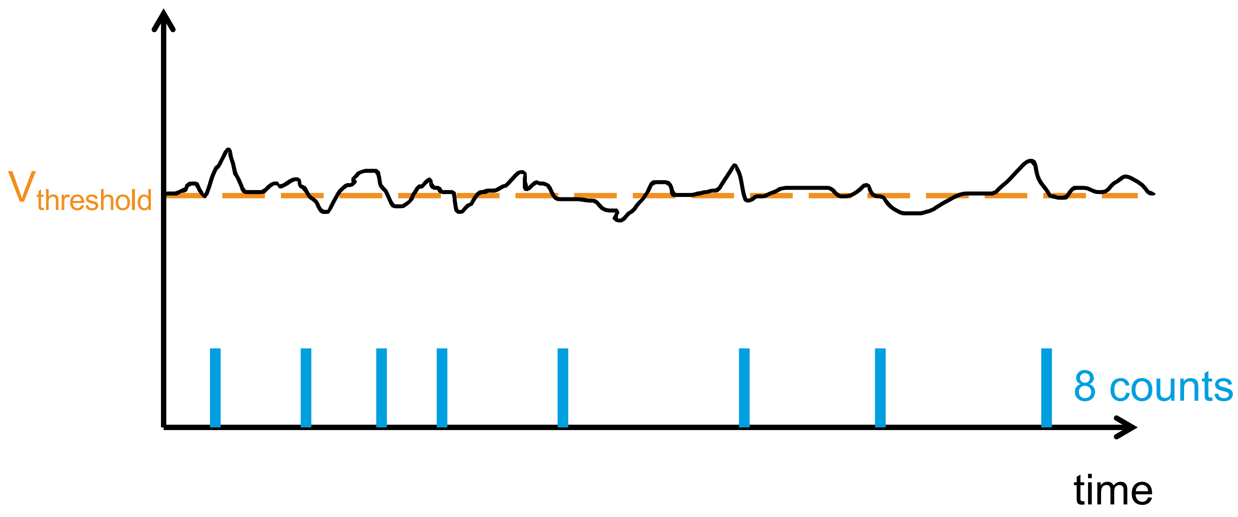
Threshold scan of one row with untuned and tuned pixels



Tuning via 6 bit calibration DAC
(Details next slide)



Voltage at shaper output entering comparator



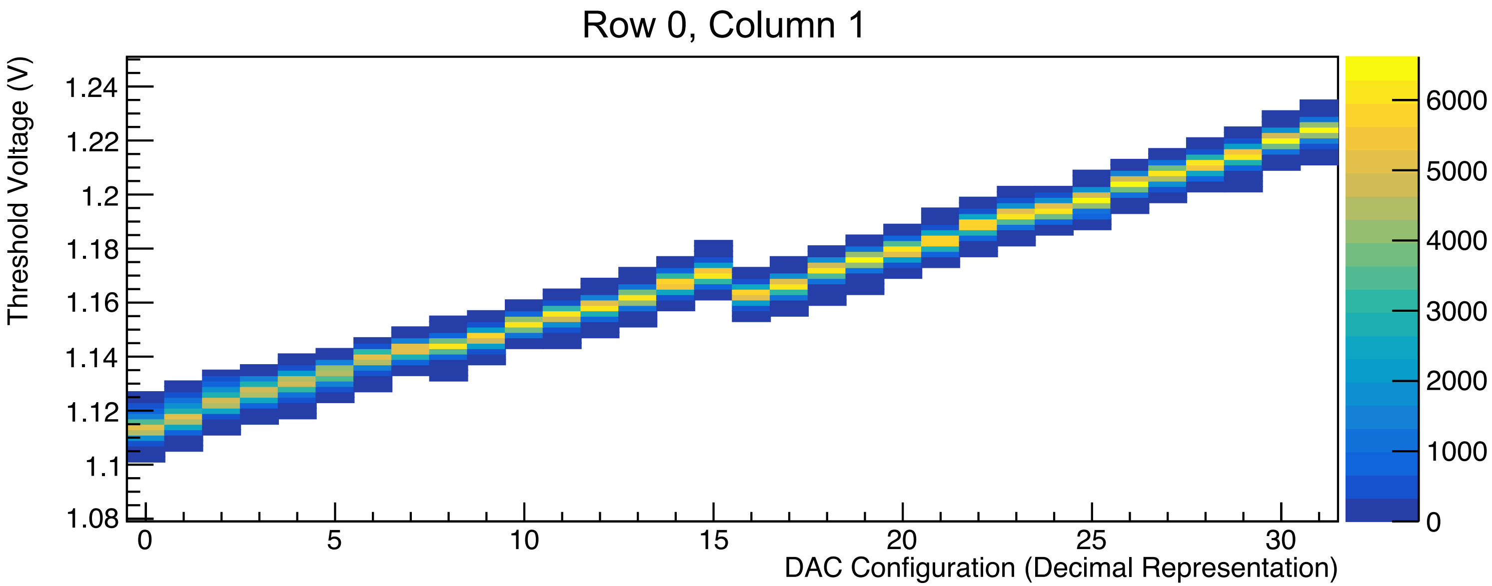
- Noise measurement, no signal yet
- Broad distribution of untuned pixels with means varying within 100 mV
- Each pixel has 6 bit calibration DAC for tuning
- Means of tuned pixels lie within 7 mV
- Threshold is globally defined for all pixels

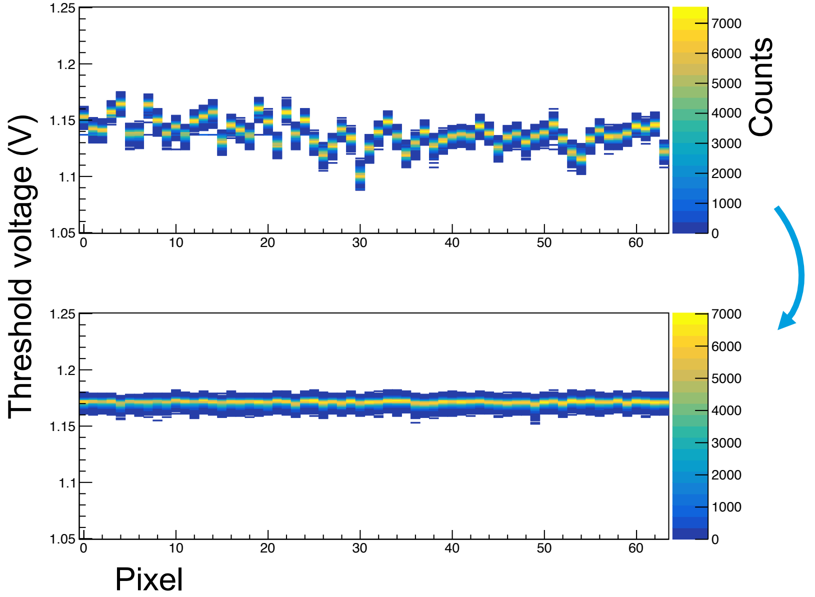
Tuning each pixel with 6 Bit calibration DAC with bias current of 100 µA

- Each pixel has 6 bit calibration DAC for tuning

Masked	**+/-**	**31mV**	**15.5mV**	**7.75mV**	**3.875 mV**

- Calibration DAC has input/ bias current (here 100 µA)
    - defines value of last 4 bits → range and resolution of tuning
- Aim is narrow distribution of means around nominal value



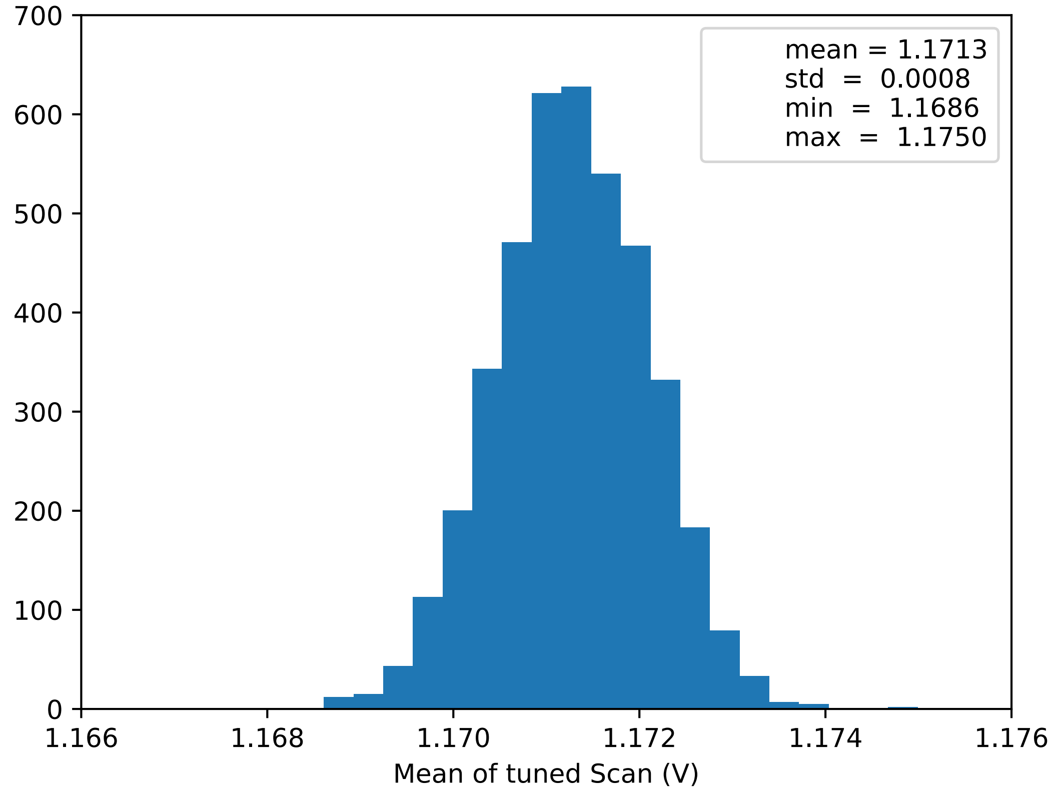


Mean values of pixels tuned to 1.17 V

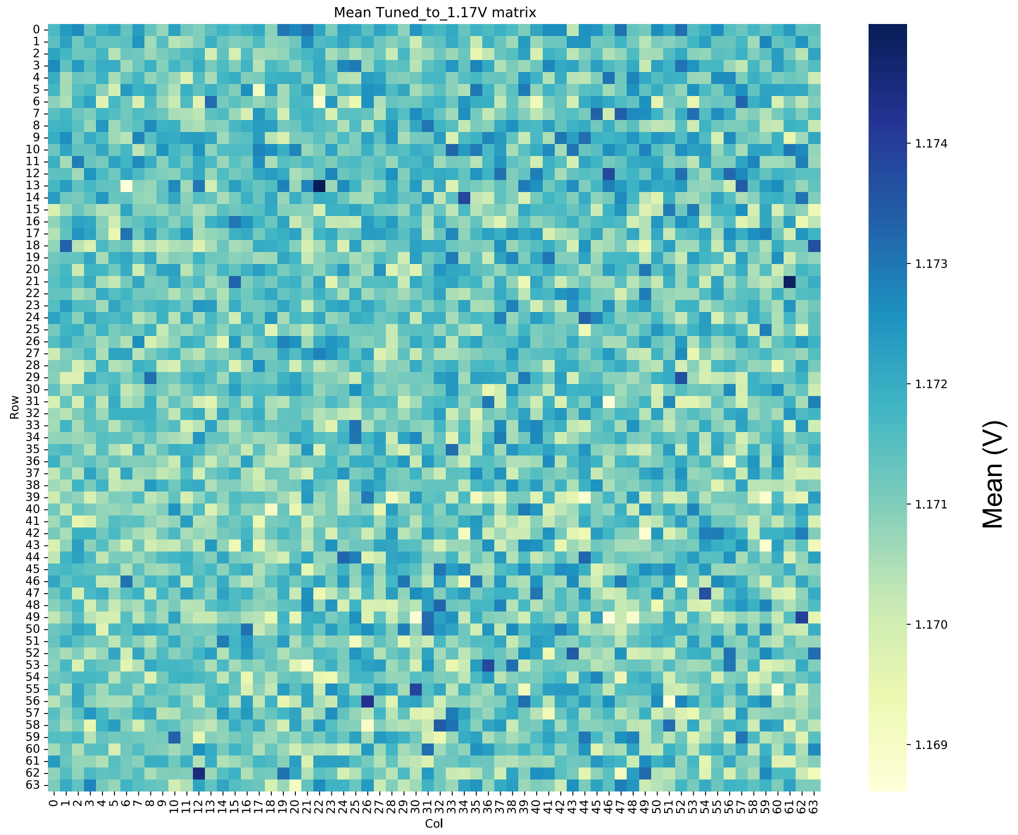
DAC bias current of 75μA sufficient to tune all pixels

untuned pixel within 100 mV
tuned pixel within 7 mV and FWHM = 2 mV

Histogram of all 64 x 64 means after tuning



Homogeneous distribution of means over pixel matrix after tuning

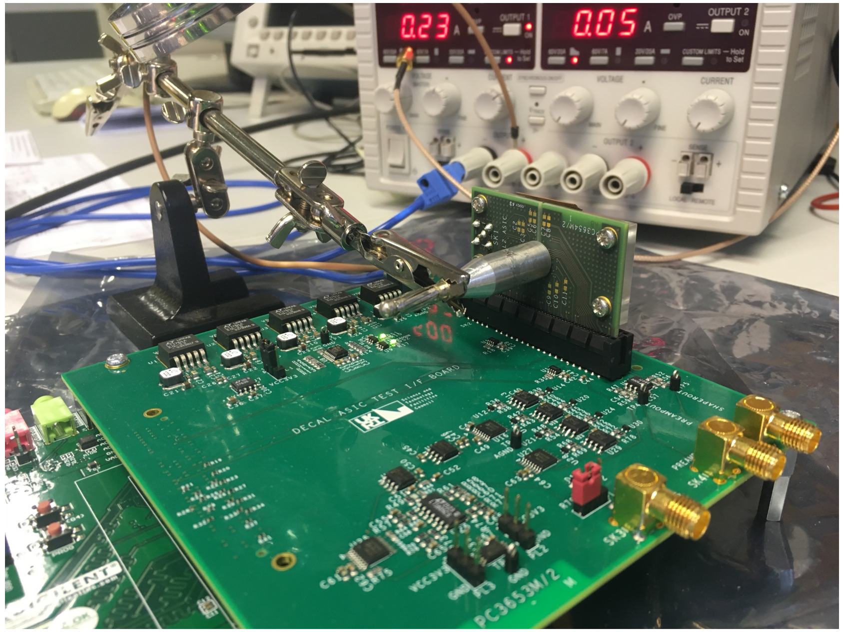


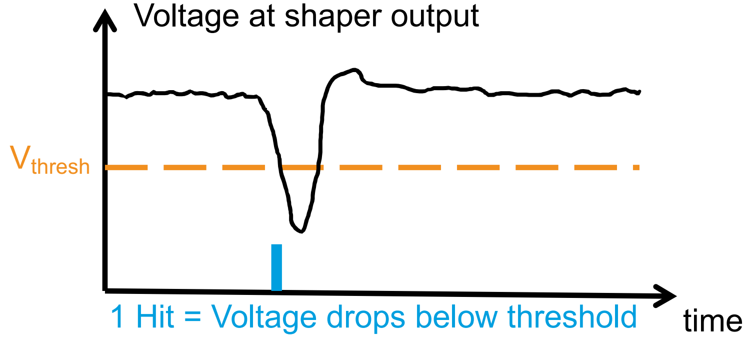
Pixels tuned to internal noise allows looking into signal from laser light, X-rays or <u>radioactive sources</u>

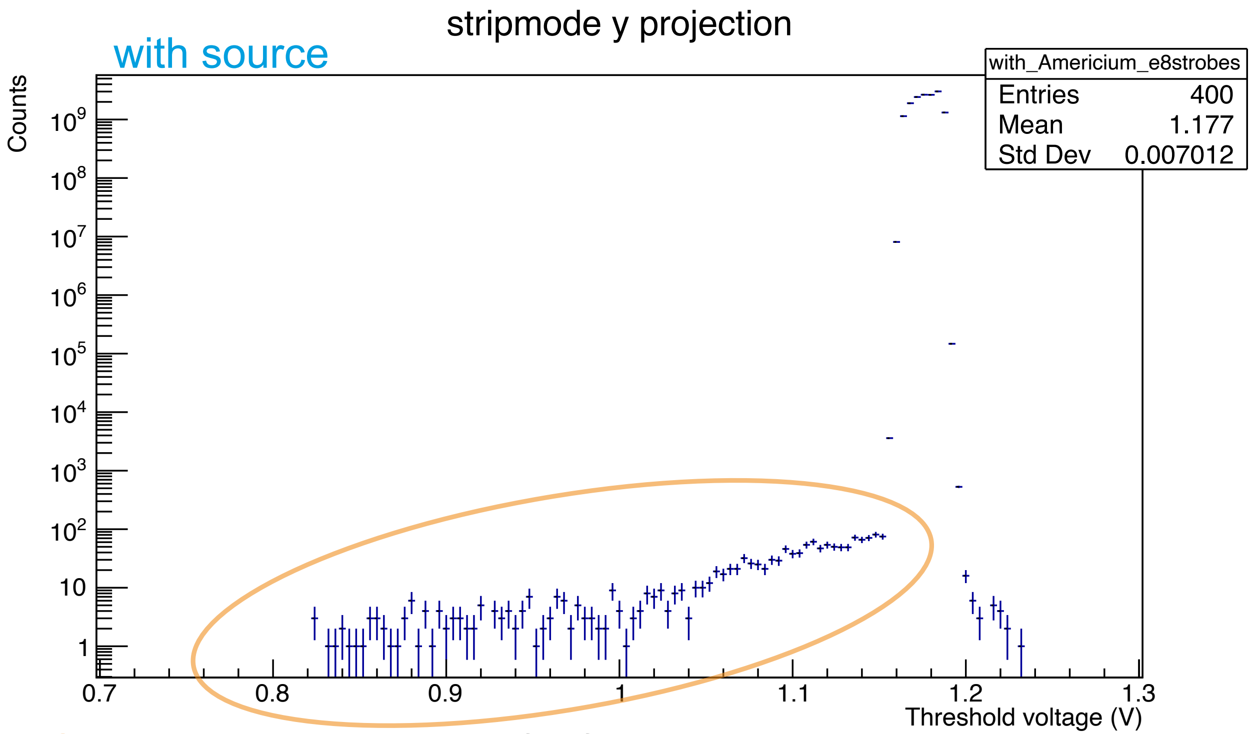
^{241}Americium source measurement

Measurement in the proximity of the noise peak with the DECAL sensor at HU

- Low activity of 300 kBq of 60 keV photons→ activate whole chip for higher statistics







- Signal shoulder on the left of noise peak
- Shoulder height expected to scale with activity
- Higher statistics allows energy calibration of signal width
- Broad noise peak when whole chip activated (still studying this impact)
- Too low activity source for pixelwise measurement, that has narrow noise peak

Summary and outlook into the next 6 months:

- DECAL has potential to improve energy resolution
- DECAL test stand was set up at HU in collaboration with DESY ✓
- Tuning to noise peak
  - Successful pixelwise tuning ✓
  - Improved strip mode tuning → Identification of Americium shoulder ✓
  - Further investigation of strip mode calibration
- Energy calibration to be done with higher statistics of signal
  - Higher activity gamma sources at DESY or X-ray source at UK
  - Laser illumination of individual pixels
- Give feedback to chip designers for a revision of the chip

In collaboration with:

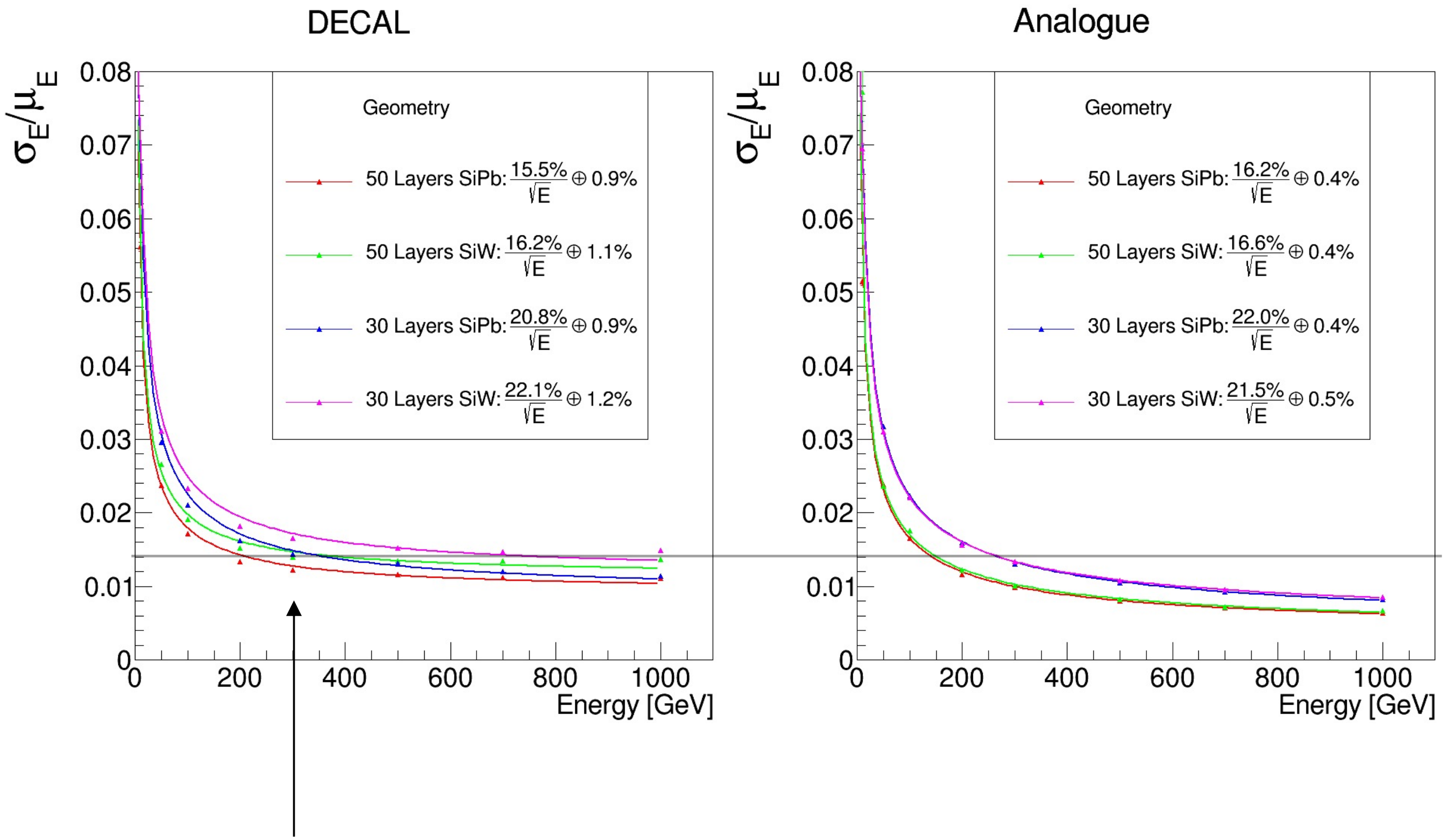
P. Allport[1], S. Benhammadi[2], R. Bosley[1], J. Dopke[2], S. Flynn[1], N. Guerini[2], L. Gonella[1], I. Kopsalis[1], K. Nikolopoulos[1], P. Philips[2], T. Price[1], A. Scott[2,] I. Sedgwick[2], E. G. Villani[2], M. Warren[3], N. Watson[1], F. F. Wilson[2], A. Winter[1], Z. Zhang[2]

[1] School of Physics and Astronomy, University of Birmingham, UK
[2] STFC Rutherford Appleton laboratory, Didcot, UK
[3] Department of Physics and Astronomy, University College London, UK

Comparison with conventional EM calorimetry 2

Simulation of four different geometries

CLICdp Meeting (27/08/2019) Robert Bosley
https://indico.cern.ch/event/792656/contributions/3518934/attachments/1897941/3131887/RBosley_CLICdp_27_08_2019.pdf



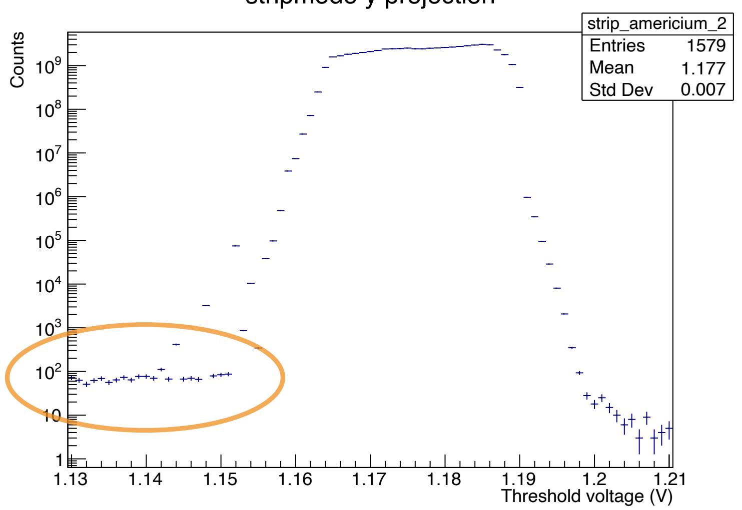
Saturation in pixels begin

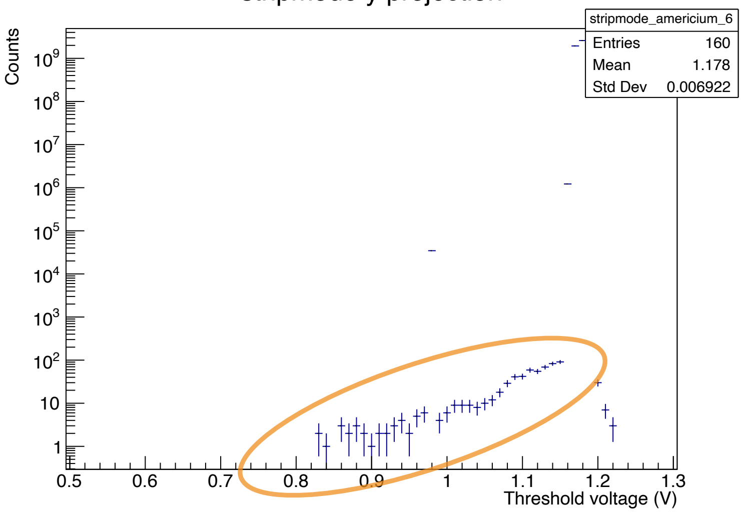
- 4 different geometries simulated for digital and analogue
- Similar performance of DECAL up to 300 GeV
- above 300 GeV saturation leads to undercounting
- Lead improves saturation as its larger Moliere Radius makes EM shower wider

^{241}Americium source (left) and background (right) measurement

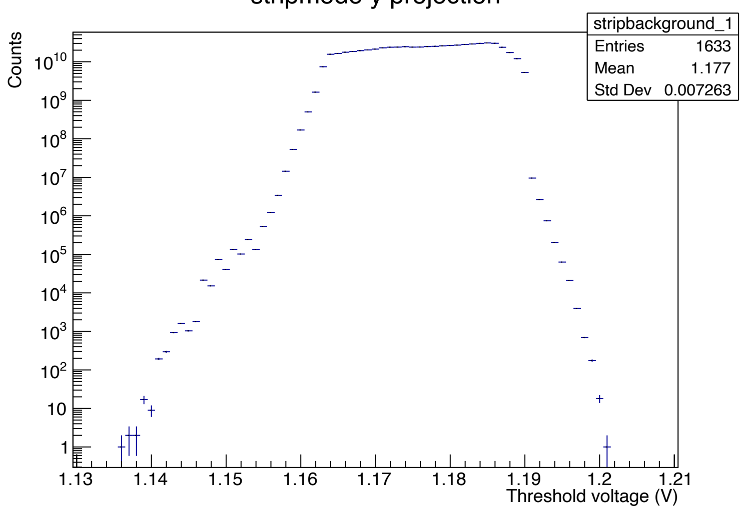
Measurement in the proximity of the noise peak with the DECAL sensor at HU

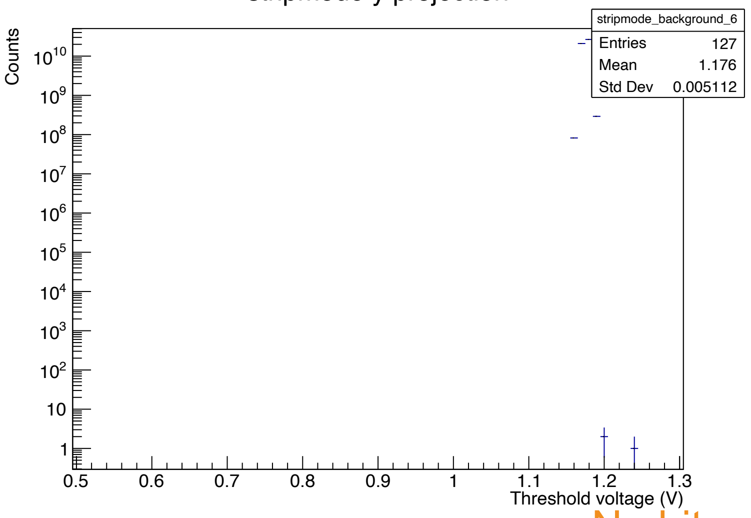
with source

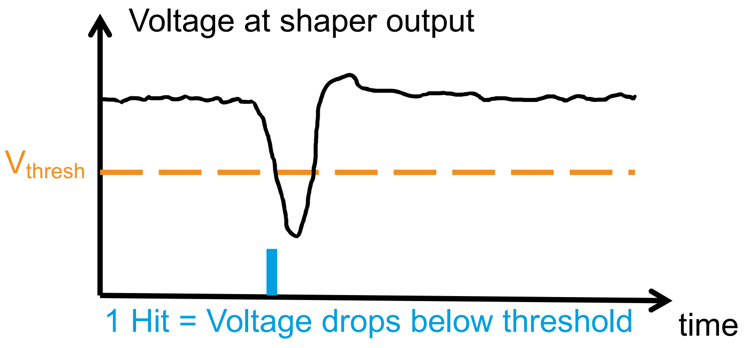




without source







- Signal shoulder on the left of noise peak
- Higher statistics allows energy calibration of signal width
- Broad noise peak when whole chip activated (still studying this impact)
- Too low activity source for pixelwise measurement, that has narrow noise peak
- No source measurement has flat background outside of noise peak

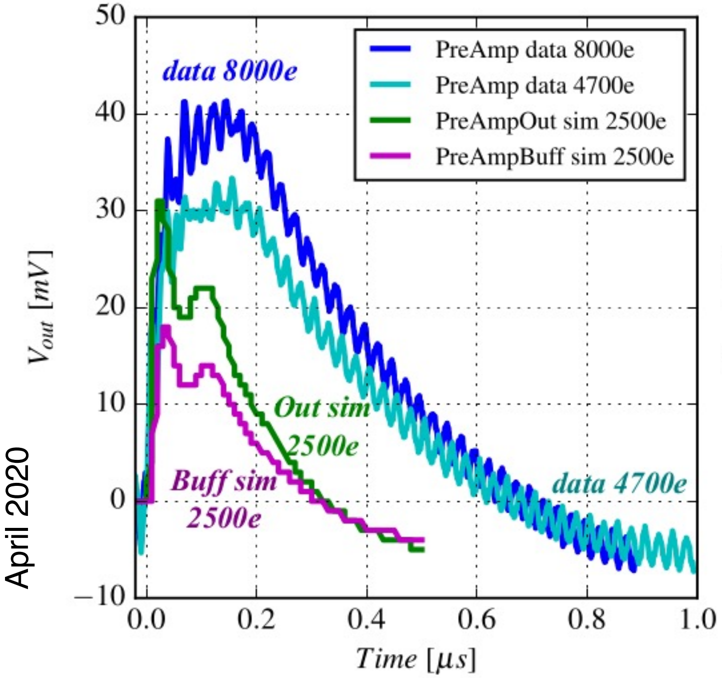
No hits outside of noise peak without source

Analogue readout for one pixel

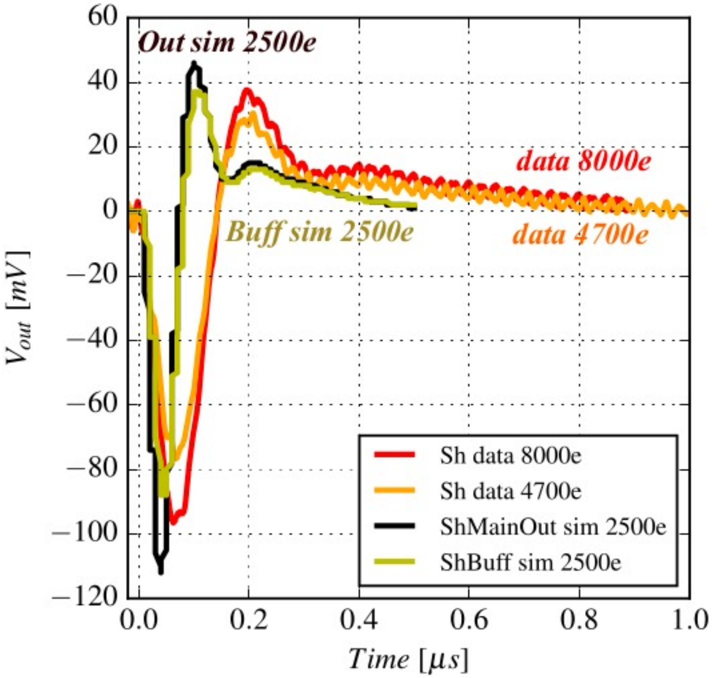
Simulation and measurement

P. Allport et al., First tests of a reconfigurable depleted MAPS sensor for Digital Electromagnetic Calorimetry, Nucl. Inst. and Meth. A, 958:162654, April 2020

PreAmp Signals



Shaper Signals



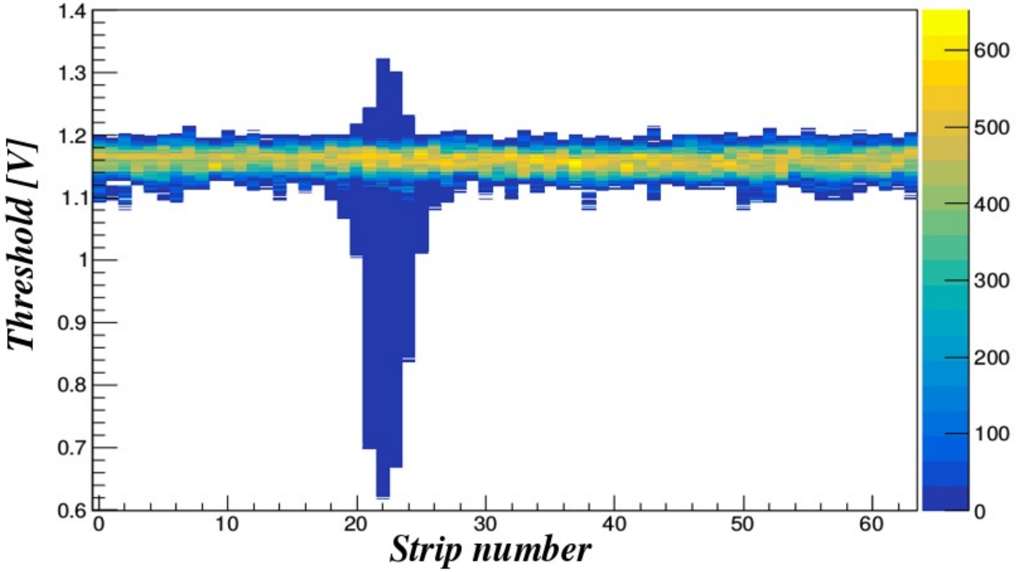
Some delay in measured response time with respect to FE simulation (but expect ~10ns signal collection)

Signal from:
10x10µm^2 TriLite laser (pJ/pulse, λ=1064 nm)

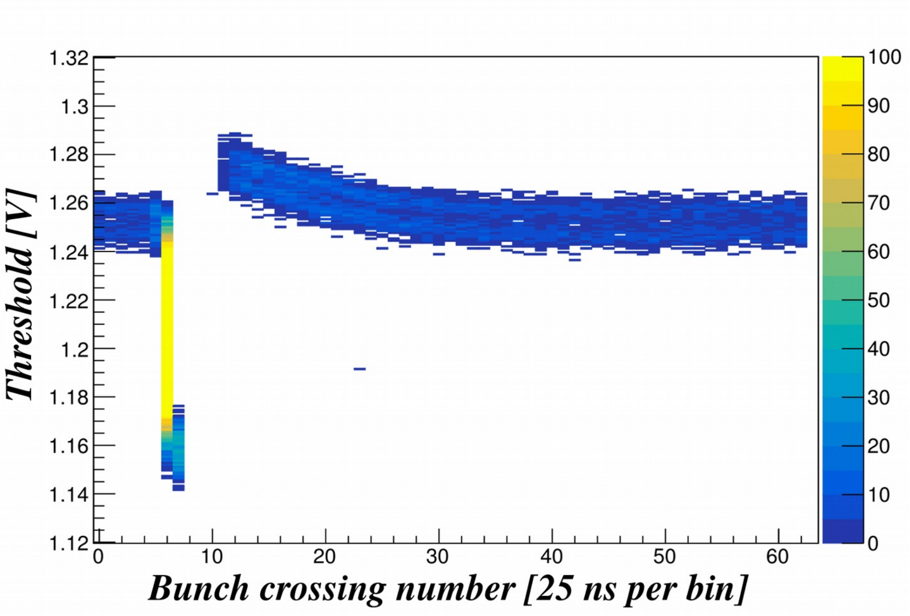
Threshold scan under laser illumination

Defocused IR laser (1064nm) with pulse frecuency of 100 kHz

P. Allport et al., First tests of a reconfigurable depleted MAPS sensor for Digital Electromagnetic Calorimetry, Nucl. Inst. and Meth. A, 958:162654, April 2020



- Signal below and above noise peak detected
- Shape reflects gaussian profile of defocused laser beam
- Broad noise band for strip mode

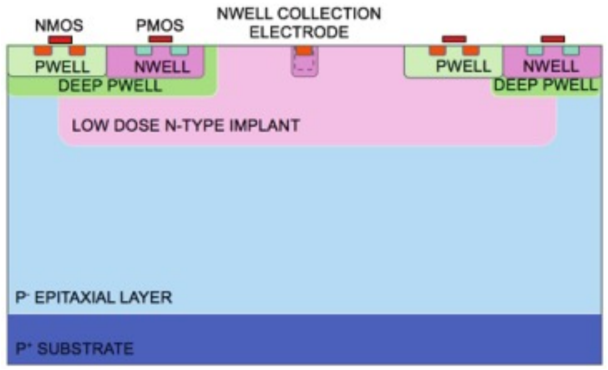


- Time response within one bin of 25 ns
- For detector application: measurement just for one threshold value and not threshold scan

Towerjazz modified process and pixel architecture

Preamplifier, shaper, discriminator, comparator and tuning logic integrated in each pixel

- Threshold depends on inputs, e.g. variations in the input currents to preamplifier, shaper and feedback circuits
- Tuning logic through 6 Bit DAC
- Towerjazz modified process with gap in the n- layer
  - Improved radiation hardness and faster charge collection



H. Pernegger, Depleted CMOS sensors for HLLHC, Proceeding of Science, (VERTEX 2018)

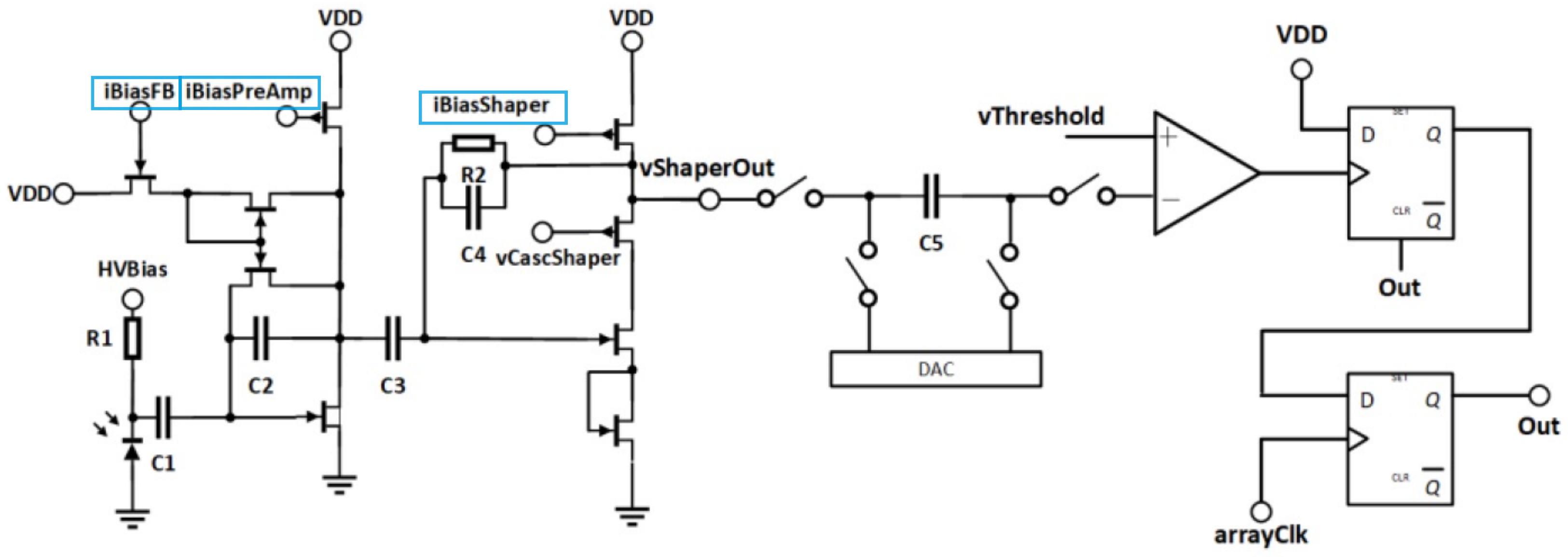


Figure 2 Overview of the architecture of the pixel.

DECAL: A Reconfigurable Monolithic Active Pixel Sensor for use in Calorimetry and Tracking

S. Benhammadi, J. Dopke, N. Guerrini, P. Phillips, I. Sedgwick, G. Villani, F. Wilson, Z. Zhang, M. Warren, P.P. Allport, R. Bosley, S. Flynn, L. Gonella, I. Kopsalis, K. Nikolopoulos, T. Price, N. Watson, A. Winter and S. Worm*