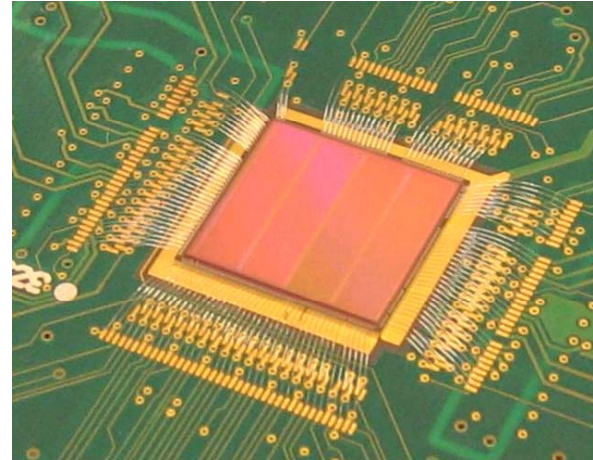
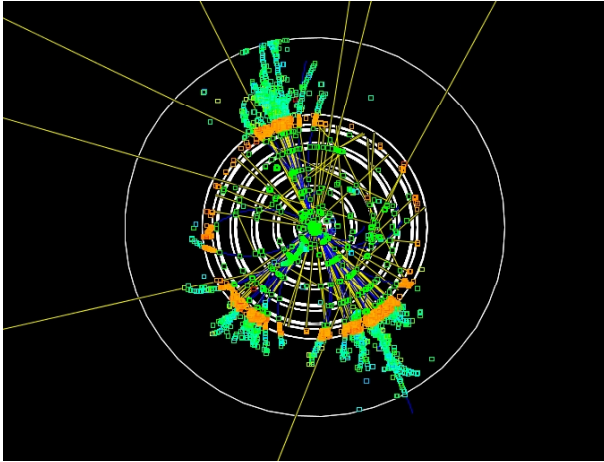


# The MAPS ECAL



ECFA-2008; Warsaw, 11<sup>th</sup> June 2008

John Wilson (University of Birmingham)

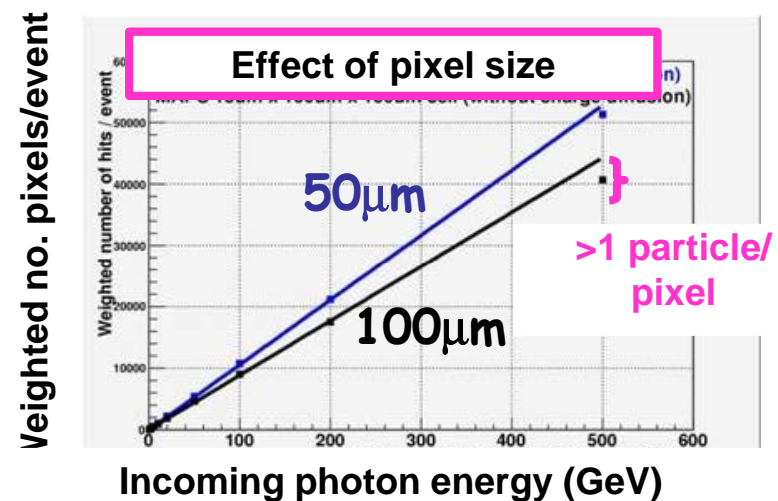
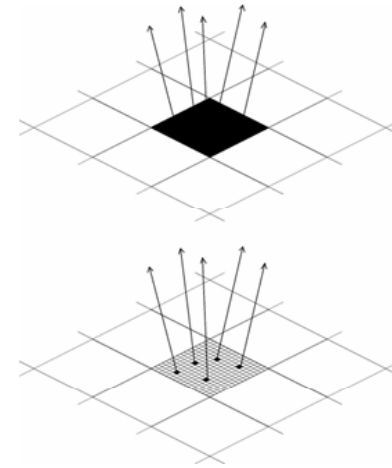
On behalf of the CALICE MAPS group:

- J.P.Crooks, M.M.Stanitzki, K.D.Stefanov, R.Turchetta, M.Tyndel, E.G.Villani (STFC - RAL)
- J.A.Ballin, P.D.Dauncey, A.-M.Magnan, M.Noy (Imperial)
- Y.Mikami, T.Martin, O.D.Miller, V.Rajovic, N. Watson, JAW (Birmingham)

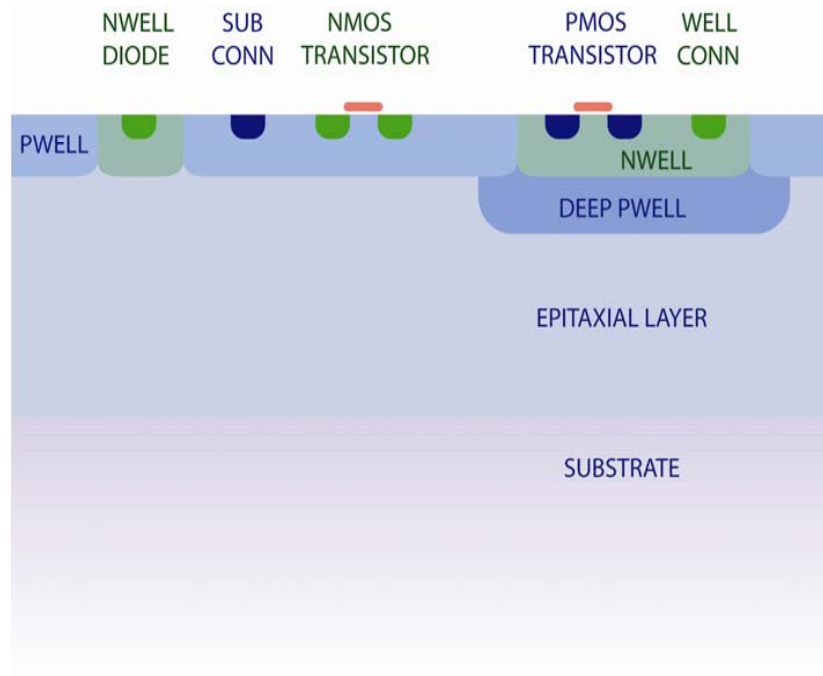
# Using pixels in calorimeters?

- Determine energy by counting tracks in a shower rather than measuring the pulse heights produced in the samples.
  - Swap  $\sim 0.5 \times 0.5 \text{ cm}^2$  Si pads for pixels
  - at most one particle per pixel if linearity is to be preserved
  - binary readout: 1 if input pulse exceeds a comparator threshold.
- At 500 GeV, shower core density is  $\sim 100/\text{mm}^2$  (1 particle per  $100 \times 100 \mu\text{m}^2$ )  
→ pixel size =  $50 \times 50 \mu\text{m}^2$  ensures a low probability of  $>1$  hit in pixel.

General advantages with **MAPS** (Monolithic Active Pixel Sensors): readout electronics is an integral part of sensor → high density – excellent for sampling calorimeters?



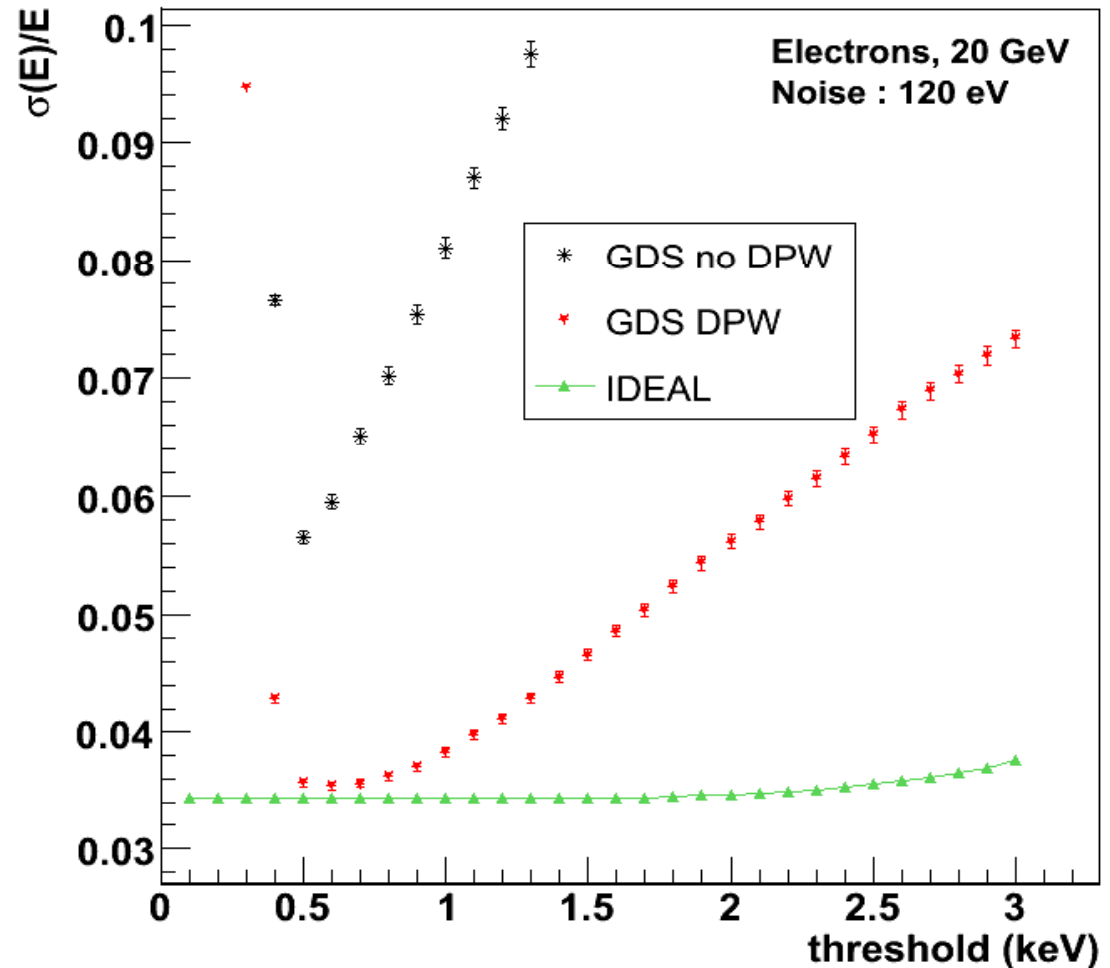
# MAPS charge collection



- Use 0.18 $\mu\text{m}$  CMOS technology;
  - Readout electronics on surface of pixel;
  - 12 micron epitaxial layer (ionisation deposited here is collected);
  - 300 micron substrate (mechanical support only; ionisation here is not collected);
  - Electrons collected by N wells (diodes AND N wells beneath PMOS electronics).
- 
- Avoid absorption in N wells by surrounding them with a deep P well (which reflects electrons back into the epitaxial layer)
  - **INMAPS process**
  - Charge collected by diffusion (not drift)
  - Depletion layers near diodes are tiny (1.8V applied  $\longrightarrow$  few microns)

# Simulating the deep P well

- Central N well absorbs half charge leading to difficult operation; serious degradation
- Deep P well gives reasonable range of threshold.
- Clear advantage in implementing deep P well
- **BUT novel process**

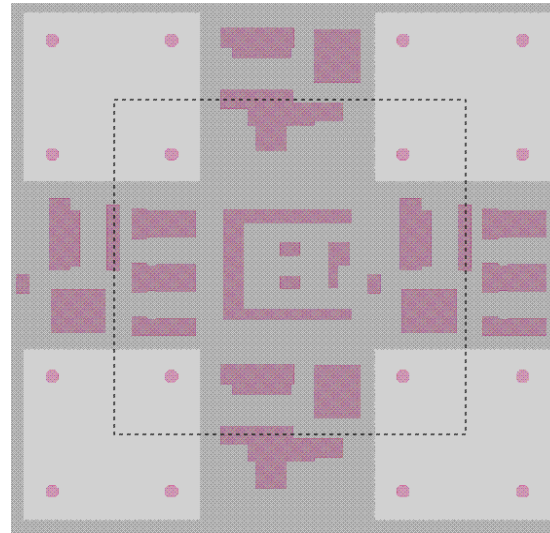


# Deep P well implementation

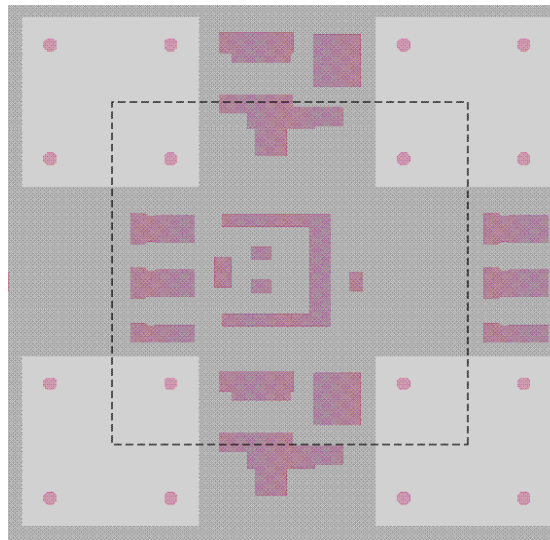
- All pixels contain 4 collection diodes, each 1.8micron diameter and located 8.5 microns from corner along a diagonal
- preShape RC shaping; recovers before next hit)
- preSample (self reset before next hit)

Each with:

- two variants of Capas and same comparator logic
- Mask bit
- 4 Trim bits



**Shaper**

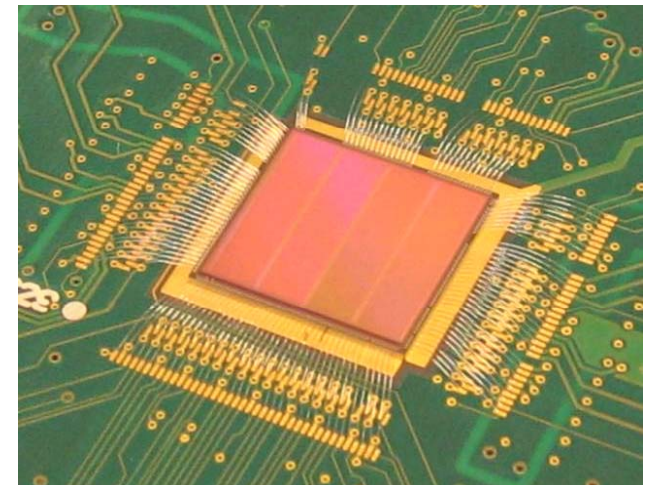
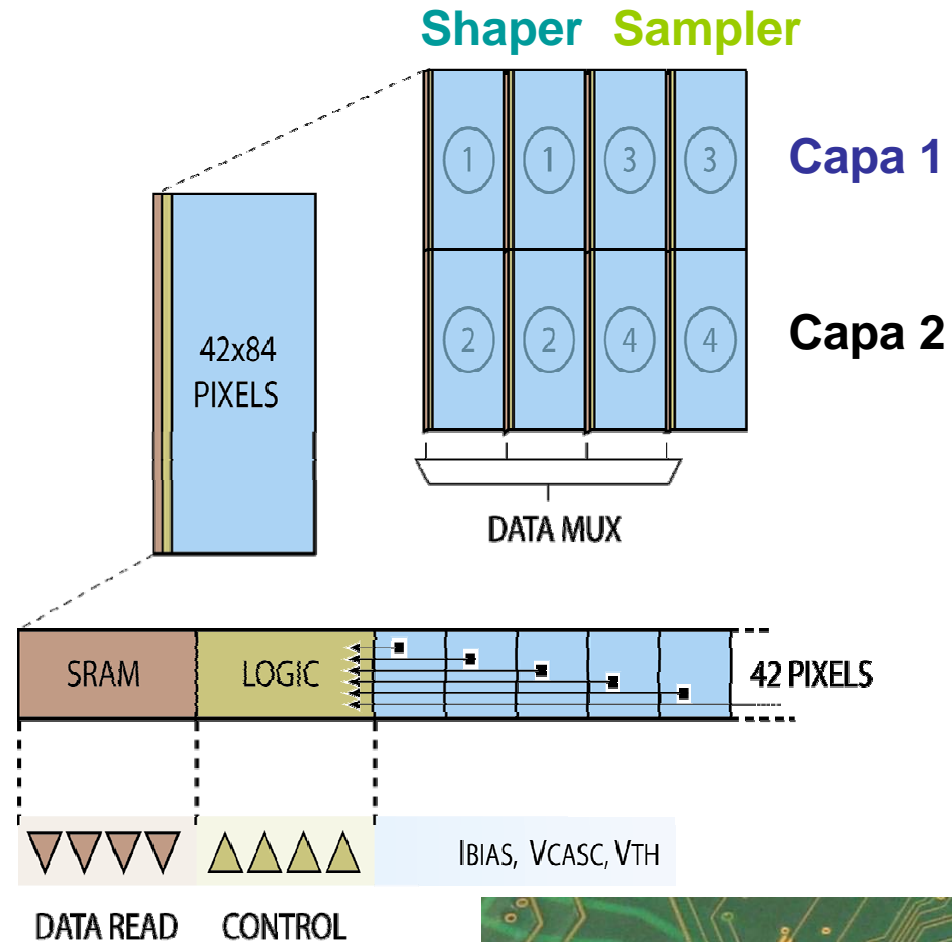


**Sampler**

pink = nwell  
(absorbing charge)  
grey = deep p-well  
added to block the  
charge absorption  
(INMAPS process)

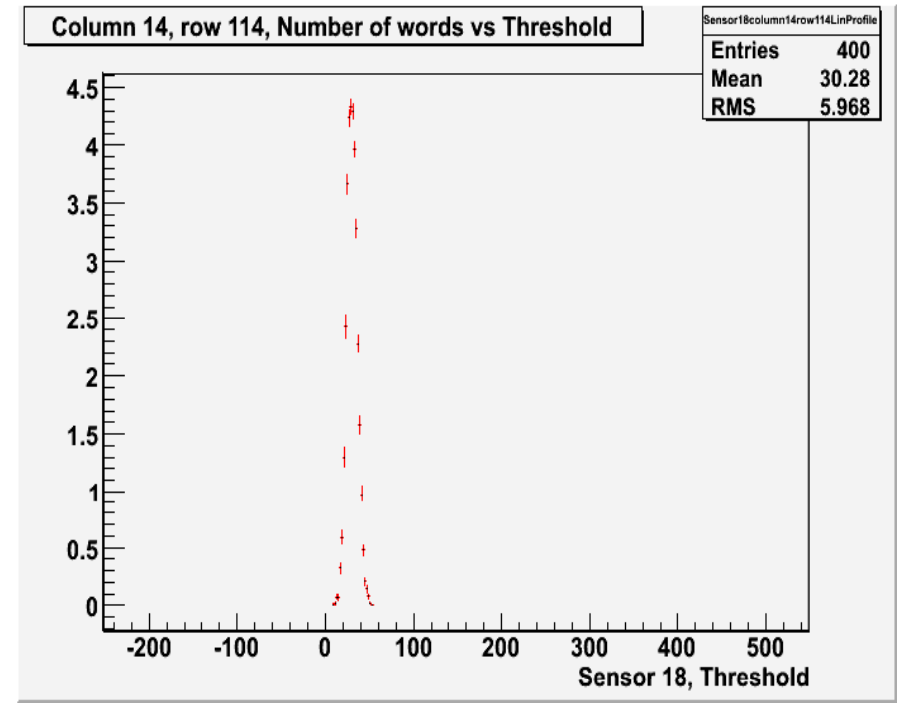
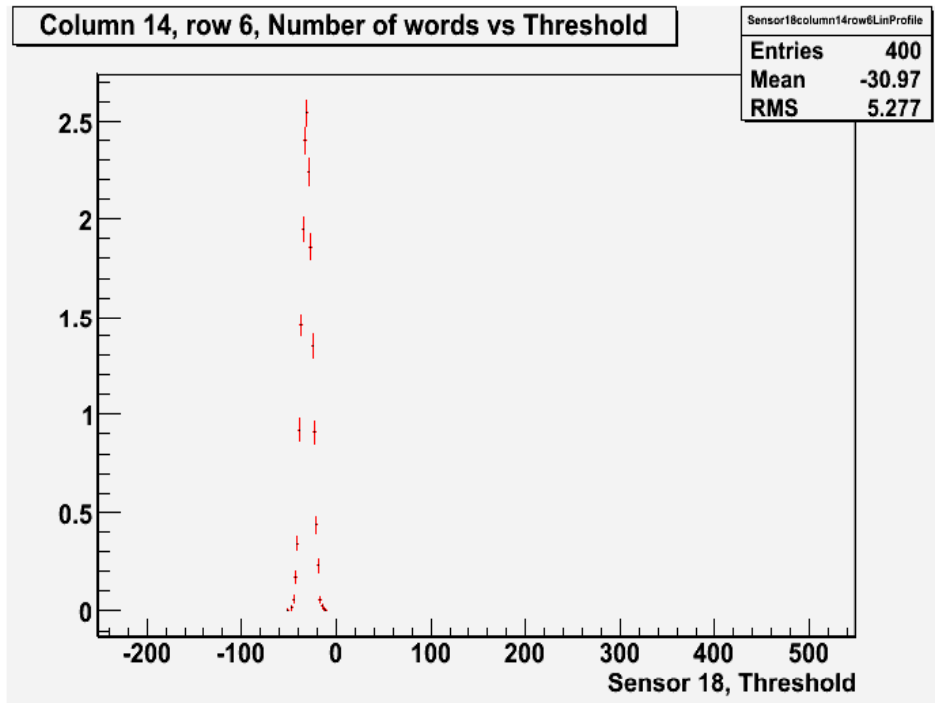
# ASIC 1.0

- 168 x 168 pixels
- 10mm x 10mm
- 79.4 mm<sup>2</sup> sensitive area
- of which 11.1% is dead (*logic etc*)
- ordered April 2007; delivered July 2007.
- As a binary device, we can investigate noise, pedestal etc by carrying out threshold scans: i.e. varying the global comparator threshold and counting the number of hits per pixel.



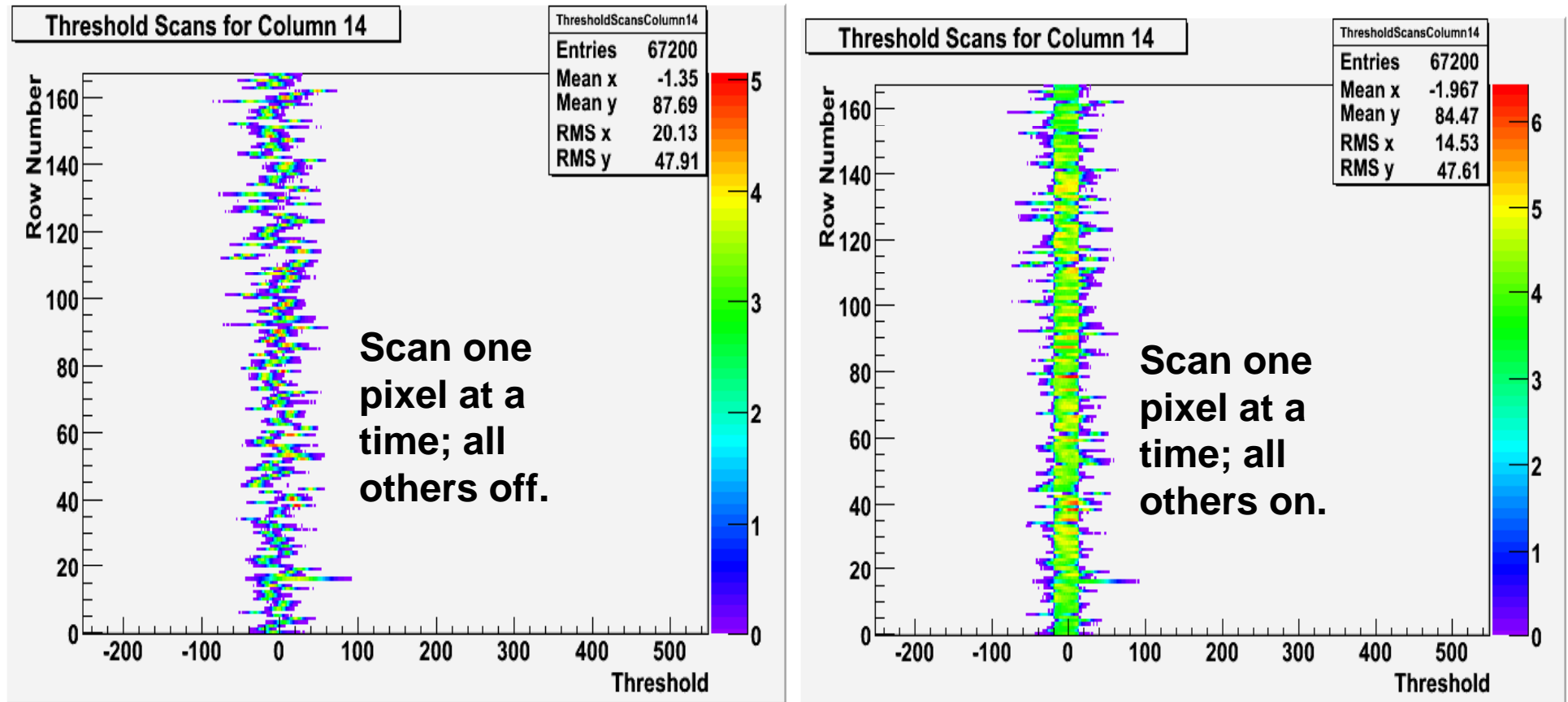


# Threshold scans of individual pixels



- Means significantly different but RMS is similar
- RMS of threshold peak  $\longrightarrow$  Noise
- 5 Threshold Units  $\longrightarrow$  40 electrons – as expected

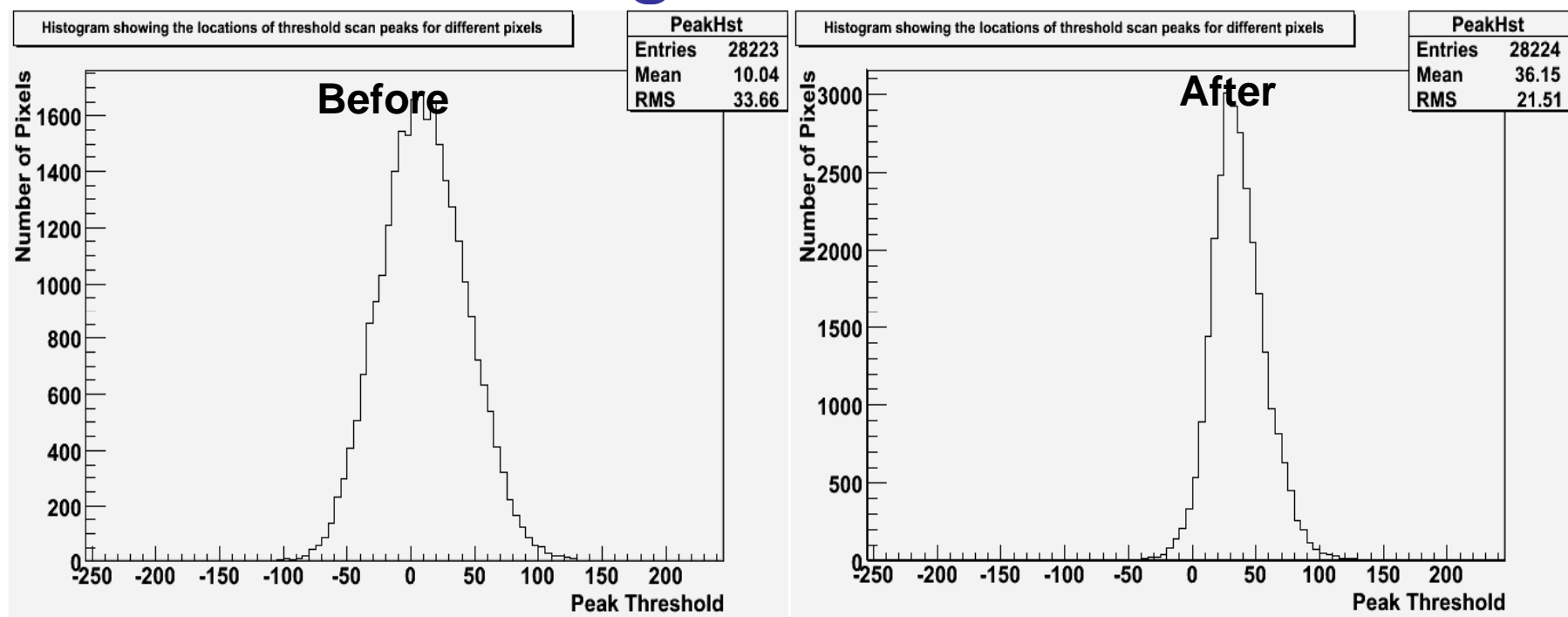
# Crosstalk between pixels



- Effect of all pixels (other than the one being scanned) is to increase the general noise around zero.



# Trimming the thresholds



- Trimming reduces the range of pixel thresholds but not enough. (The spread in thresholds is still much larger than the width of a typical threshold scan).
- More dynamic range is required (i.e. 6 trim bits) in order to bring all thresholds into close proximity.
- Difficult to find a global threshold to allow reliable efficiency measurements → complicated test beam analysis

# Beam tests at DESY

- < one week in mid-December 2007; very tight schedule; last opportunity before long shutdown.
- Electron beam: 2-6 GeV
- 4 sensors plus up to 10 absorber sheets (W; 3mm) all aligned precisely
- Signals from small scintillators upstream and downstream recorded also.

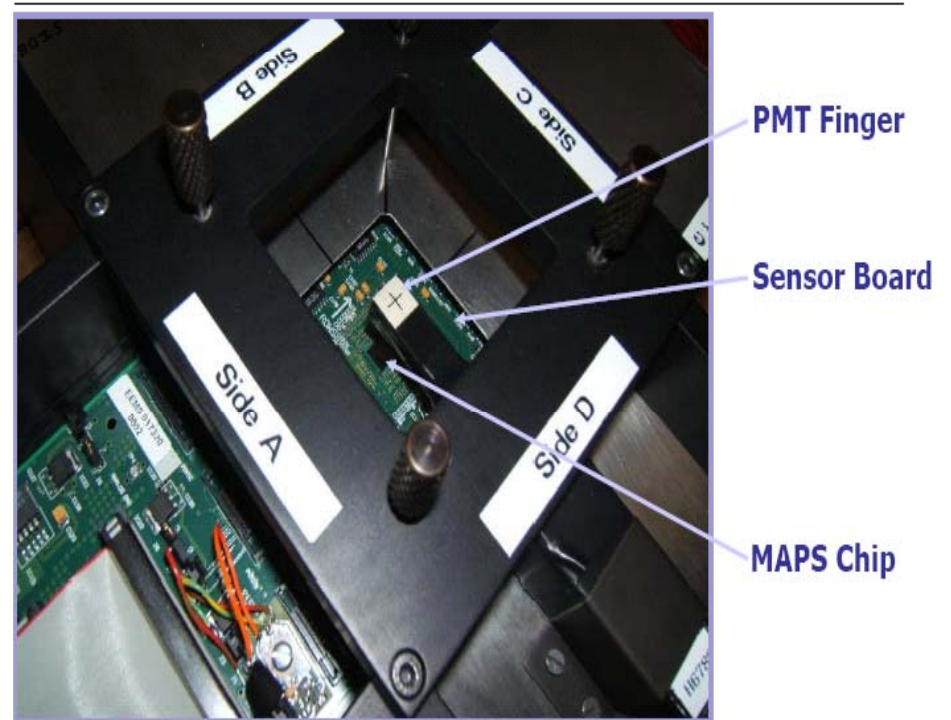
# Test beam at DESY



Science & Technology Facilities Council  
Rutherford Appleton Laboratory

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Marcel Stanitzki

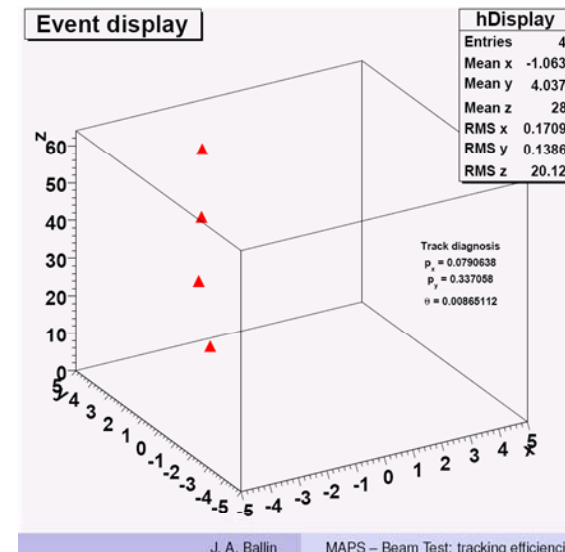
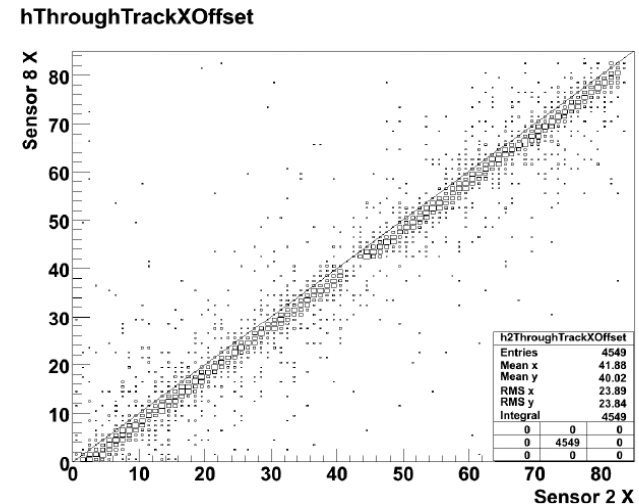


JAW; ECFA 2008, WARSAW

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# Test beam results: tracks seen

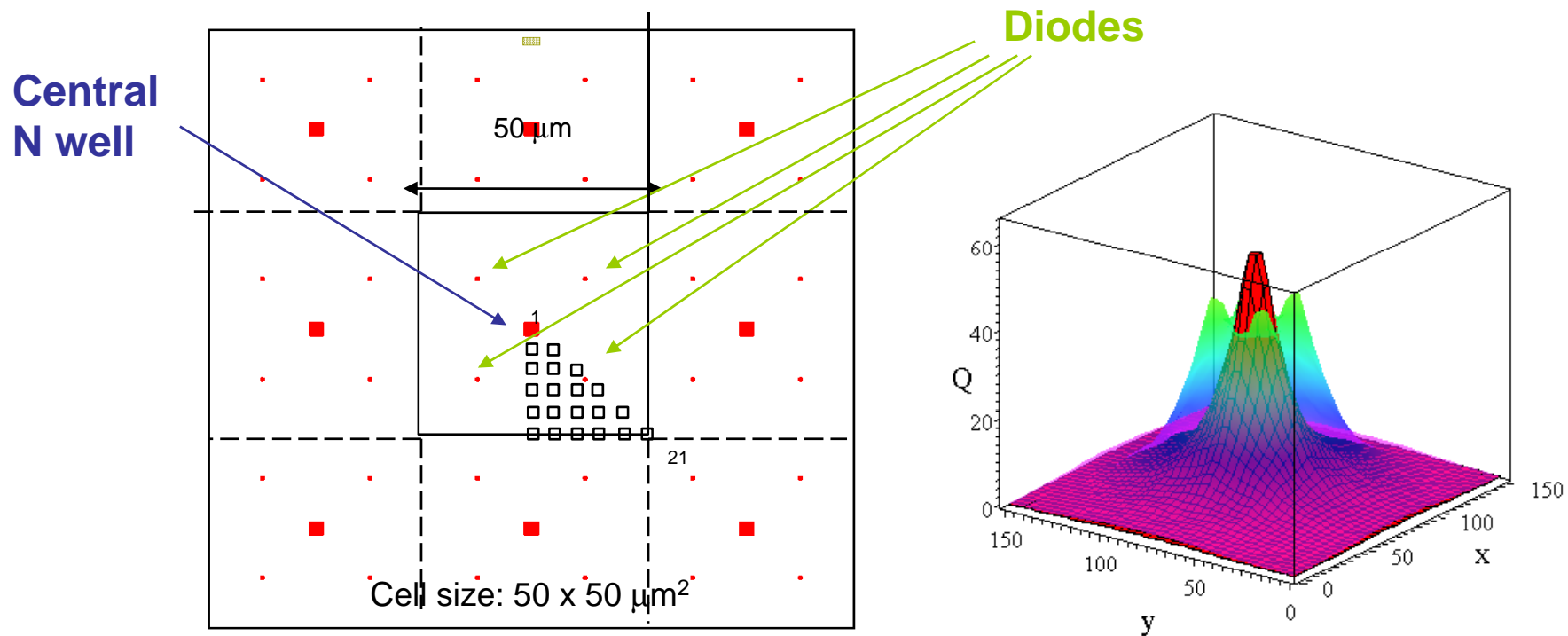
- Observe strong correlations in x and y in adjacent planes
- Tracks picked out by event display
- Due to large natural spread in thresholds, it was not feasible to trim the pixels to a uniform response
- as the global threshold was set too high (to keep the hit rate reasonable), the estimated efficiency is very low
- With all pixels set with the appropriate trims, the efficiency is expected to be high



# Other tests (ongoing)

- Radioactive sources : Fe-55 (5 keV X-rays) and Sr-90 (>2MeV electrons)  
→ uniformity (e.g. of efficiency vs threshold) over the whole sensor; uniformity of threshold and gain.
- Cosmic rays → absolute mip calibration.
- Lasers → uniformity of gain from pixel to pixel; charge diffusion and crosstalk; comparison with simulation.

# Simulation of charge diffusion

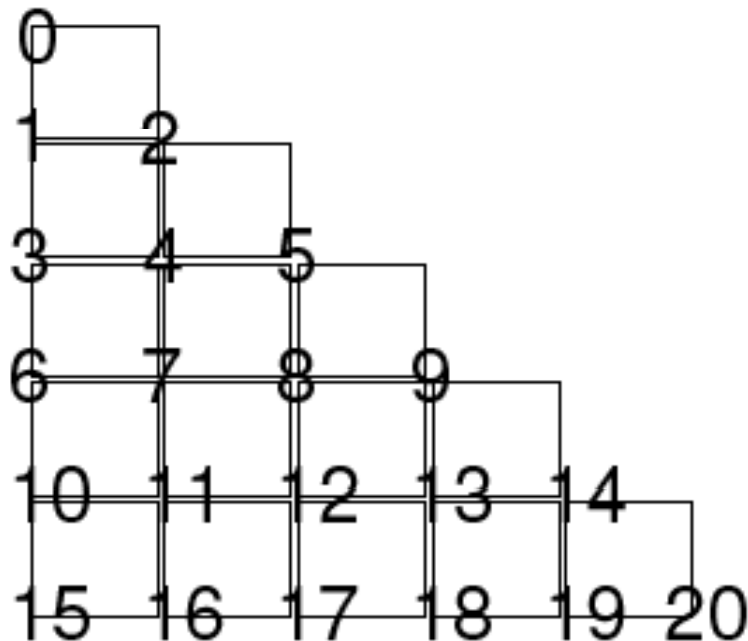


Whole 3\*3 array with neighbouring cells is simulated, and the **initial MIP deposit** is inputted on 21 points (sufficient to cover the whole pixel by symmetry)

Example of pessimistic scenario of a central N-well eating half of the charge

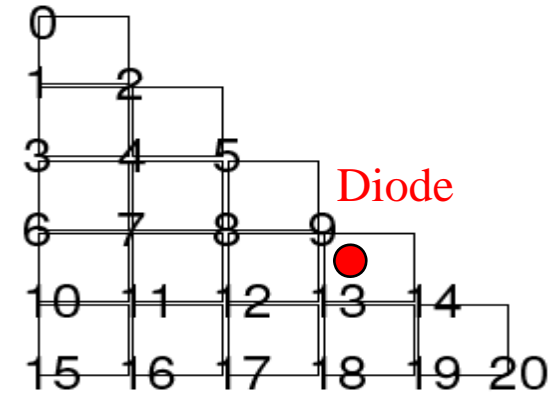
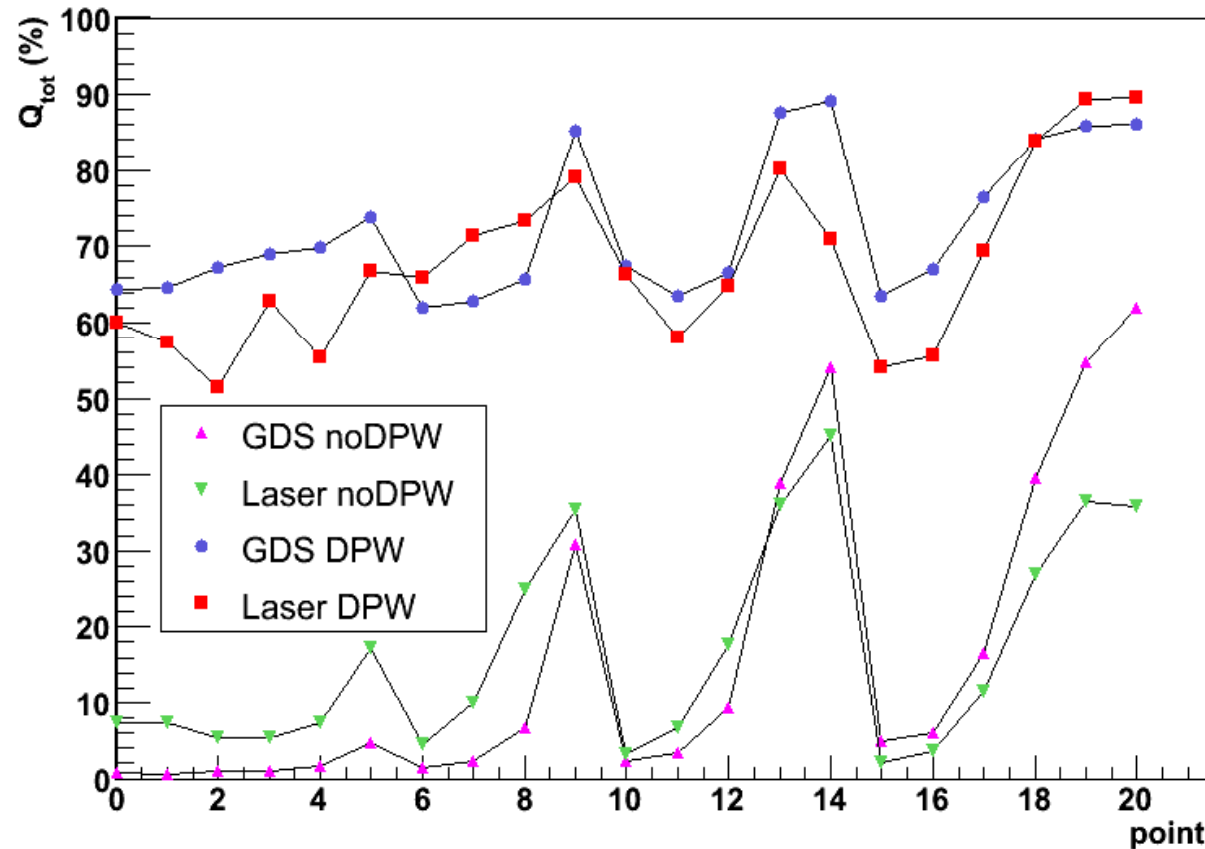
# Charge sharing between pixels

- Infra red laser (spot size: few microns) illuminates grid of 21 points (5 micron spacing) in the central pixel of a set of 3 x 3 pixels. [Same grid as used by simulation, discussed earlier].
- For each position of the laser, take threshold scans of the 3x3 pixels.



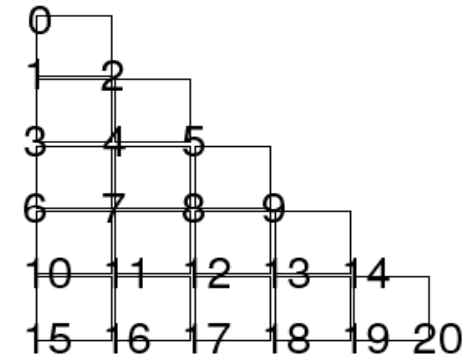
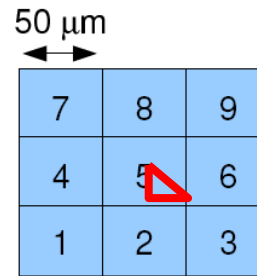


# Charge diffusion: summing 3x3 pixels



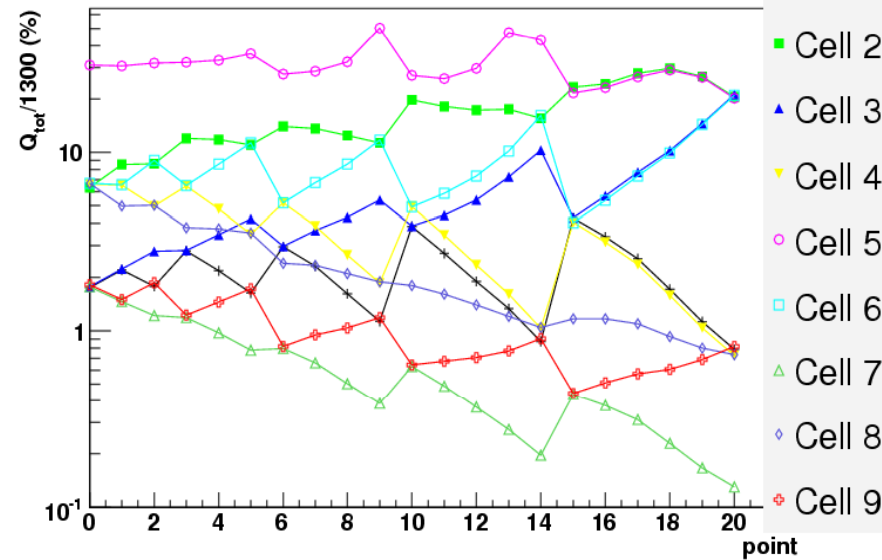
- Excellent agreement between data and simulation both with and without the deep P well.
- With no deep P well, the diodes see signal predominantly from locations nearest to them (i.e. 9, 13, 14, 18, 19, 20 – all near a group of diodes and  $q_6$  furthest from the N well).

# Charge sharing: deep P well



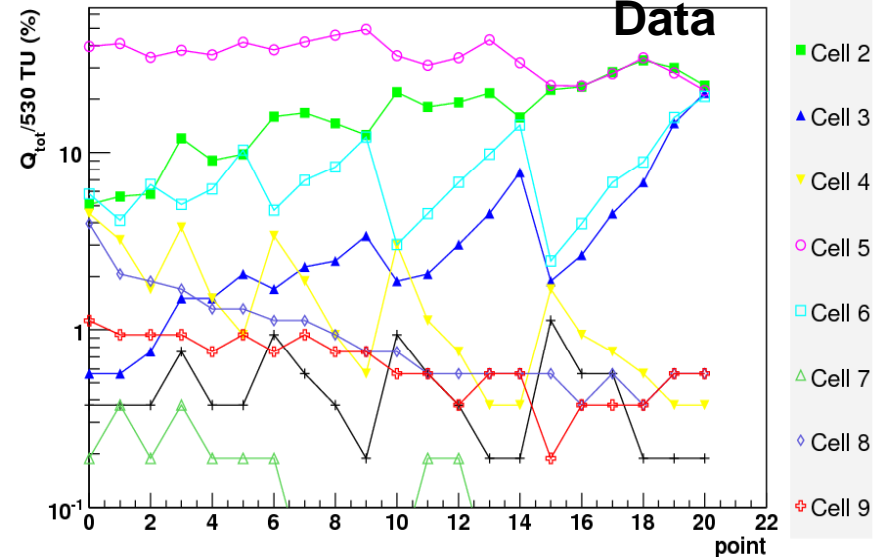
GDS deep p-well

Simulation



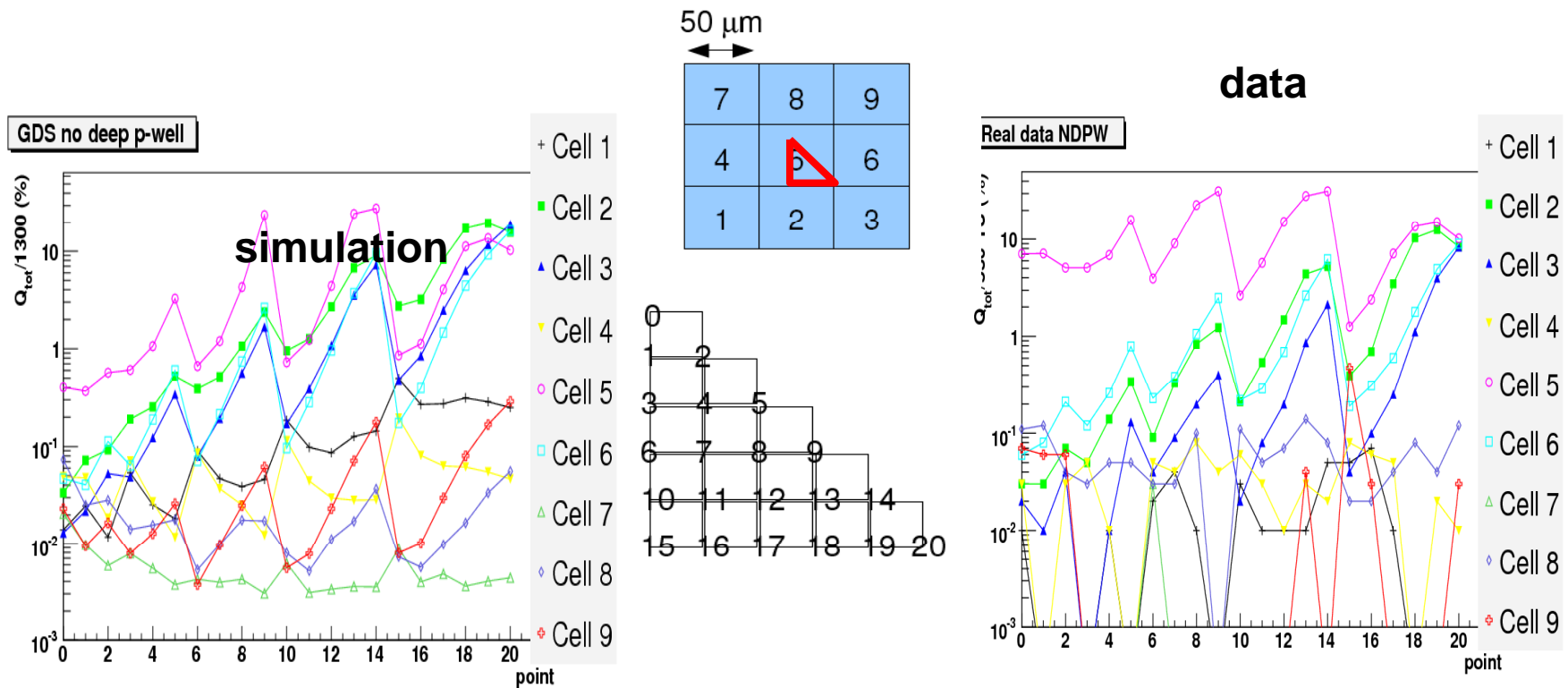
Real data DPW

Data



- Reasonable qualitative agreement; e.g. cell 4 has peaks at 3,6,10,15 (all locations closest to the cell)
- Cells 2, 3, 5 and 6 all have the same response at location 20 since this point is on the corner of the 4 cells,

# Charge sharing: no deep P well



- Much greater variation with position of laser spot as ionisation is lost unless near a diode.

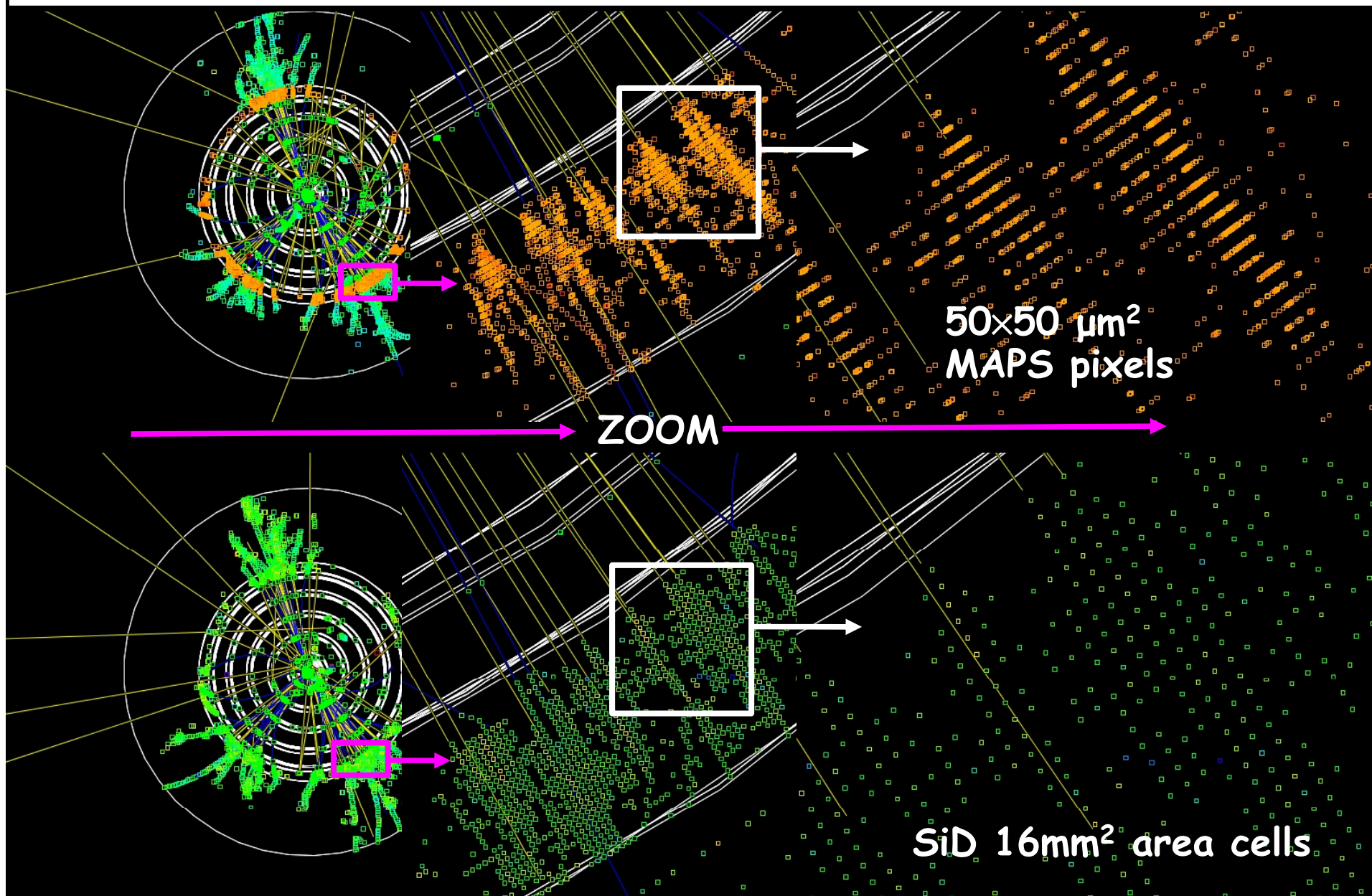
# Conclusions

- Reasonable agreement between data and simulation → gives confidence in predicted performance
- Sensors are being tested at three labs
  - gaining experience with binary system
  - INMAPS sensors look encouraging
  - way forward has become clear

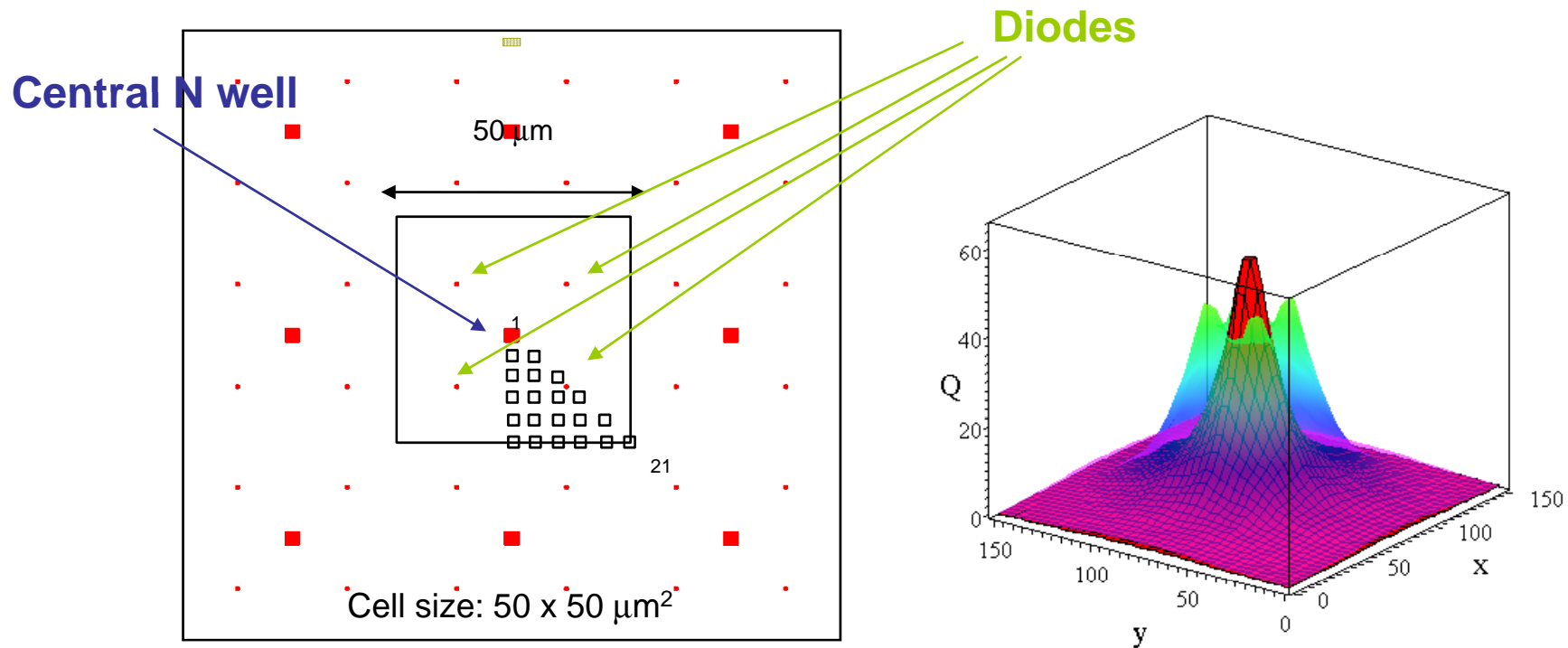
# Next steps

- Design ASIC 1.1 :
  1. dispense with presamplers; preshapers only but still with the two capacitance variants
  2. Implement a 6 bit trim (though space is tight on pixel)
  3. Adjust the power distribution to reduce crosstalk,
  4. Fix three minor faults in original version
- Submit to foundry by mid-July; expect to receive chips by August/September 2008.

# Tracking calorimeter



# Simulation of charge diffusion

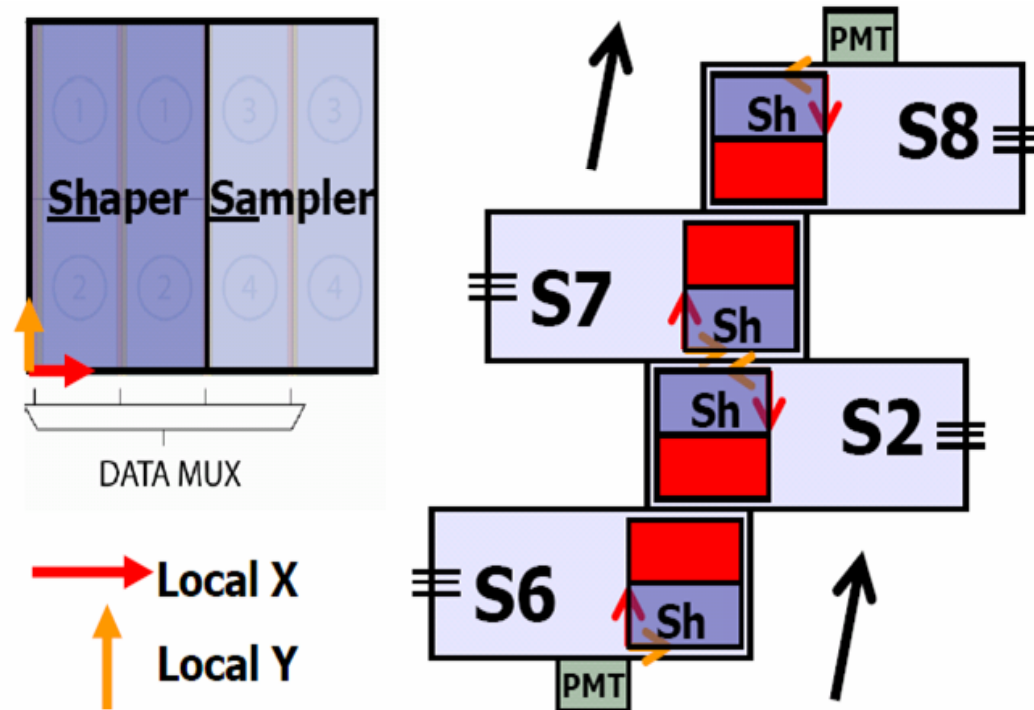


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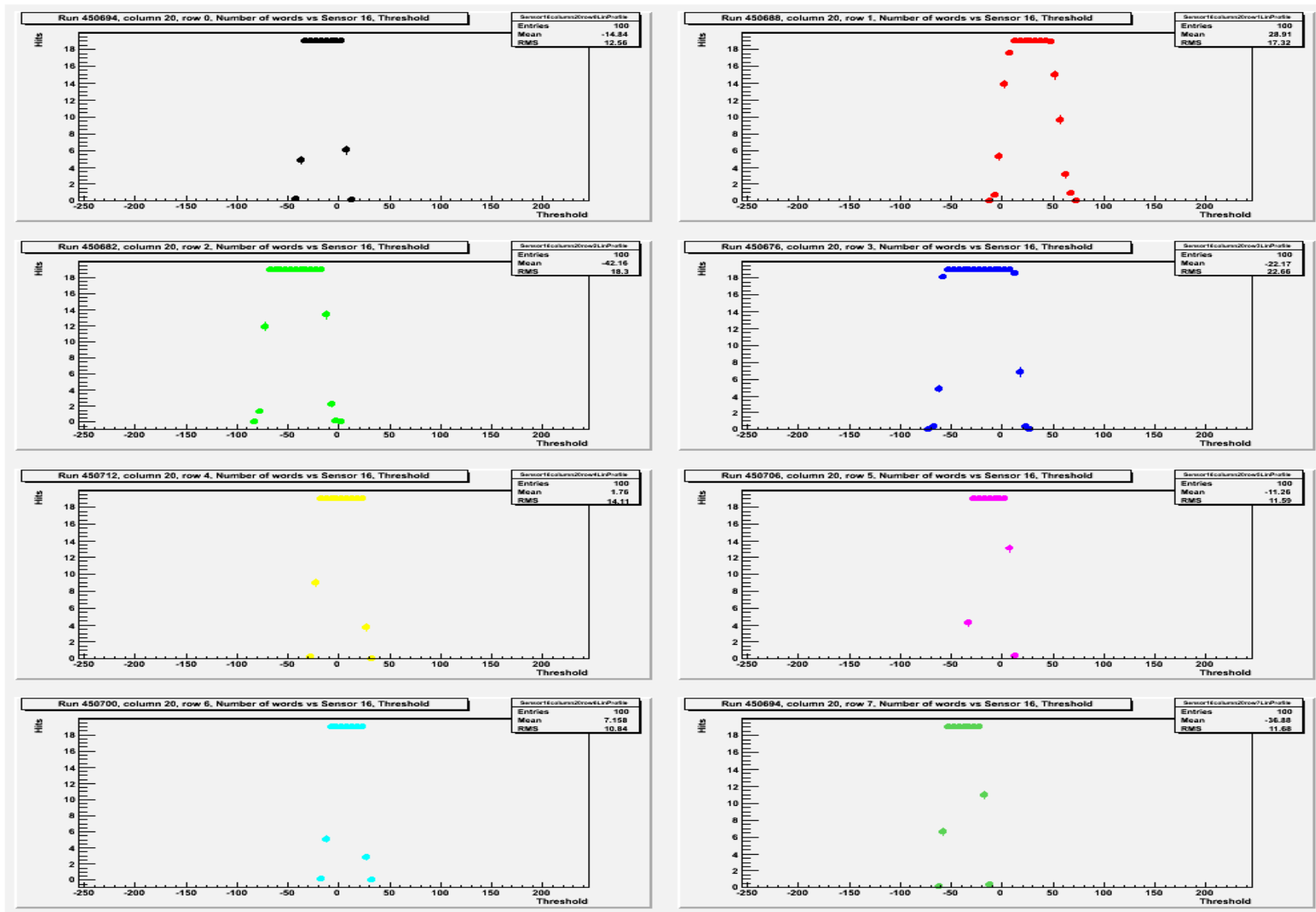


# Sensors in test beam

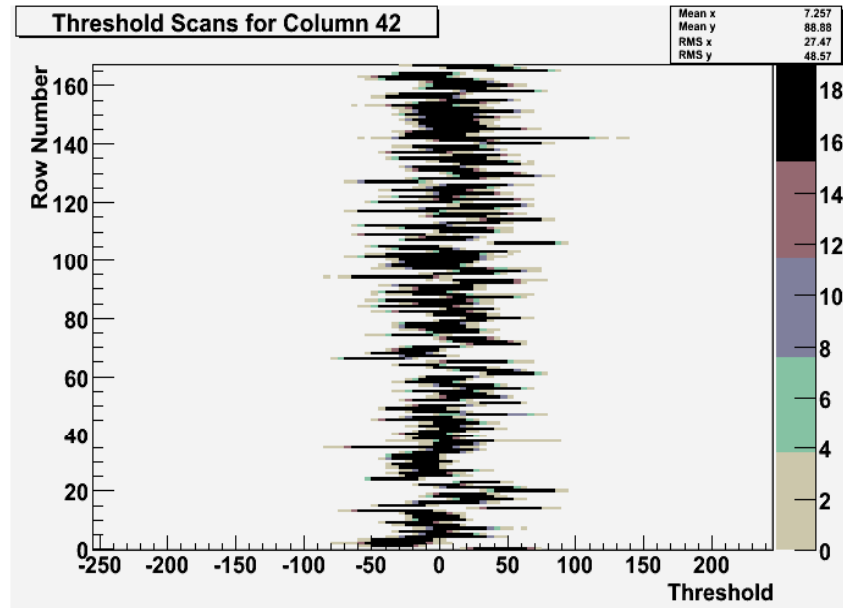


- Beam traverses triggering scints, then 2 + 2 preshapers and presamplers
- mixture of shapers and samplers
  - trimming to a consistent threshold very difficult

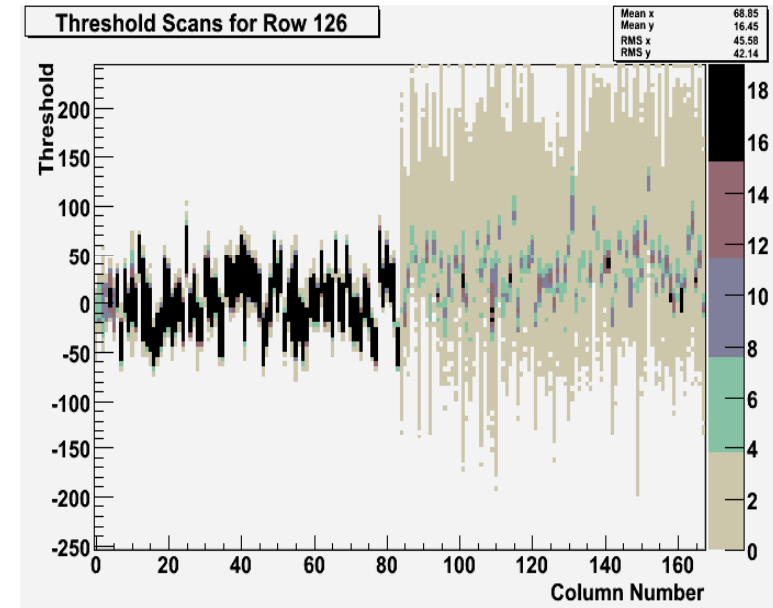
# Individual pixel threshold scans



# Thresholds for groups of pixels



Shapers



Shapers

Samplers

- We see considerable variation in position of the threshold; also a marked difference between shapers and samplers.
- Since a global threshold is applied to all pixels and each has its own distinct threshold, a 4 bit trim is provided for each pixel to bring its threshold into line.