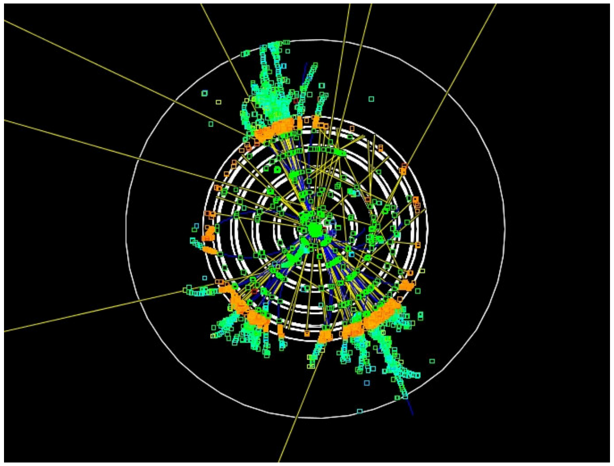
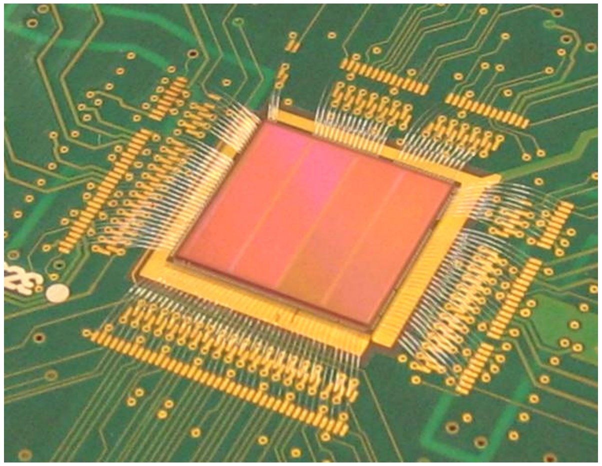
The MAPS ECAL





ECFA-2008; Warsaw, 11th June 2008

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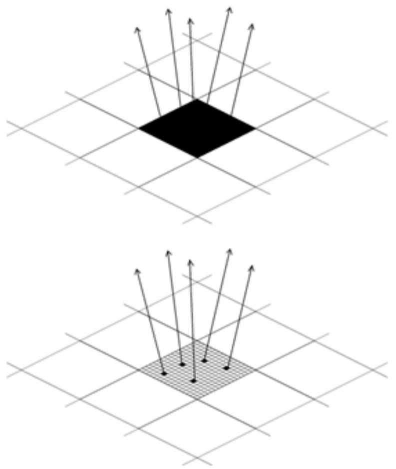
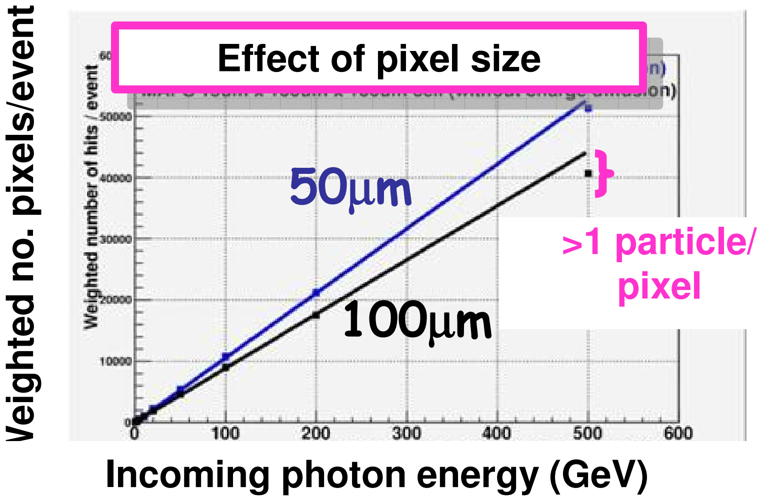
Using pixels in calorimeters?

- Determine energy by counting tracks in a shower rather than measuring the pulse heights produced in the samples.
- Swap ~0.5x0.5 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.



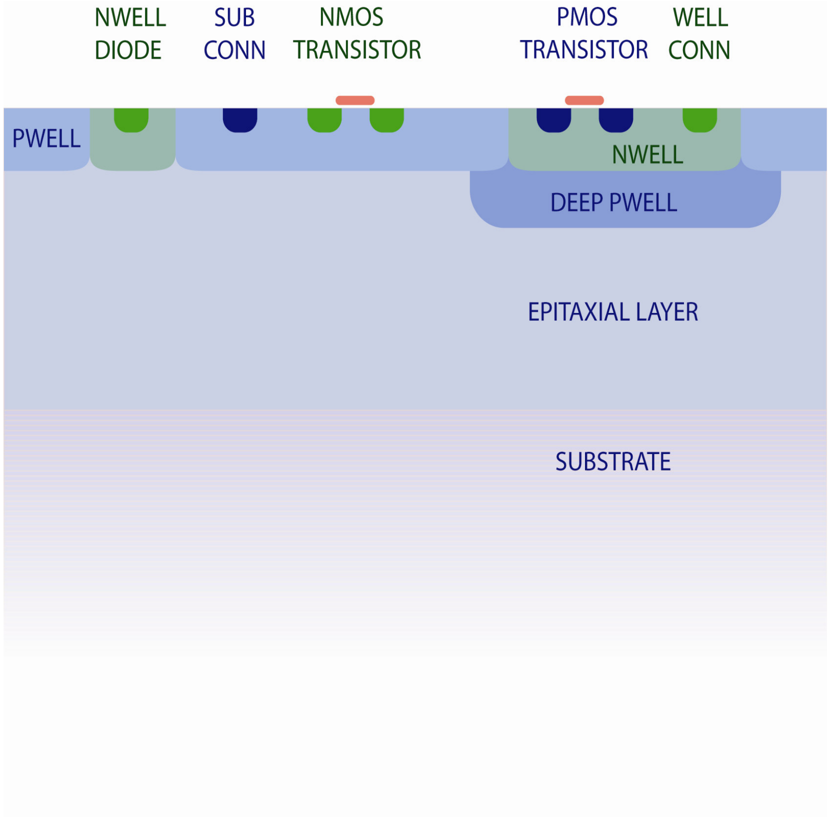
- At 500 GeV, shower core density is ~100/mm^2 (1 particle per 100 x 100 μm^2)

→ pixel size = 50 x 50 μm^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

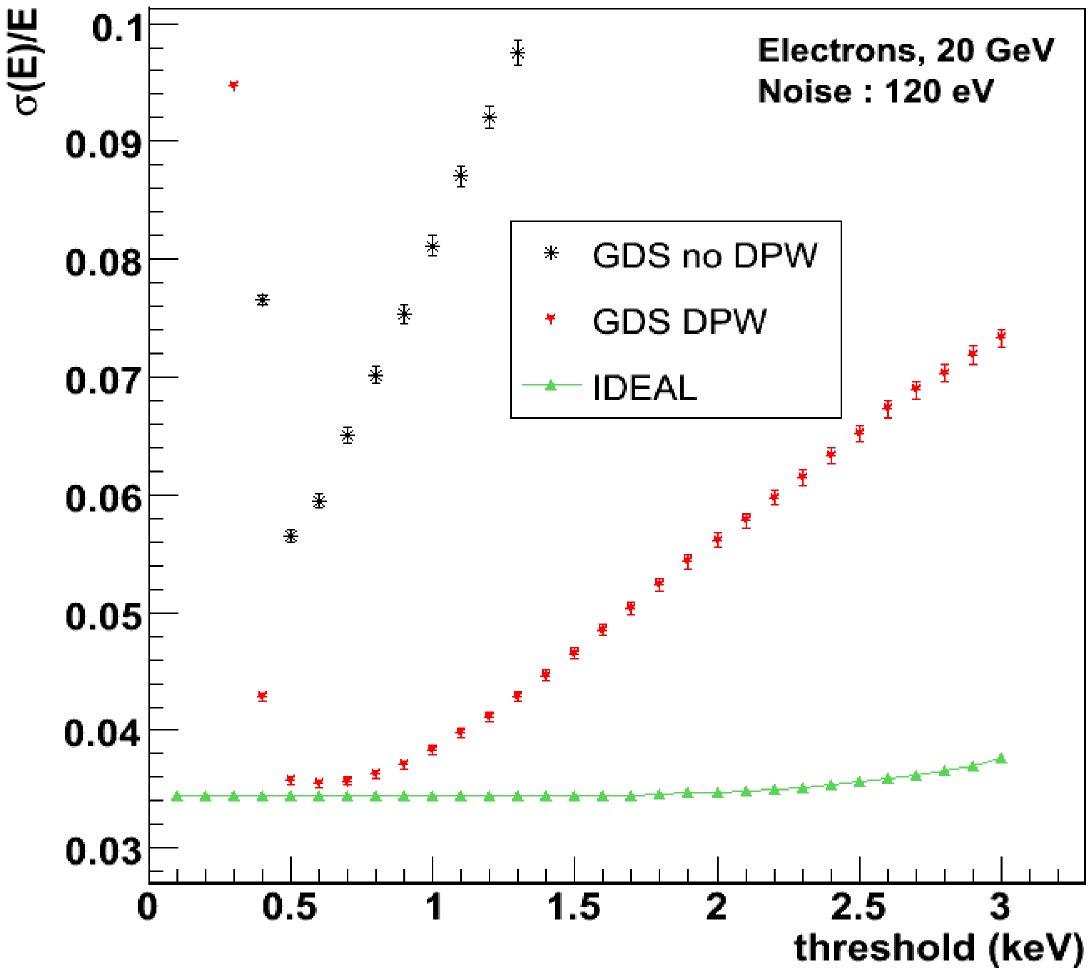


- Use 0.18µm CMOS technology;
- Readout electronics on surface of pixel;
- 12 micron epitaxial layer (ionisation deposited here is collected);
- 300 micron substrate (mechanical support only; ionisation here is not collected);
- Electrons collected by N wells (diodes AND N wells beneath PMOS electronics).

- 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 ⟶ 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**

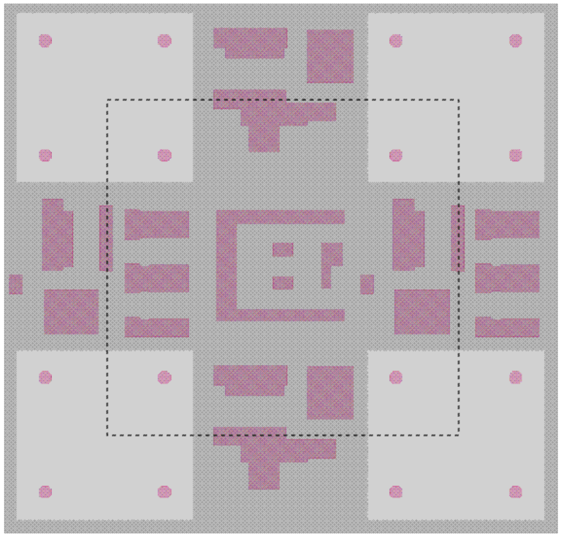


Deep P well implementation

- 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:

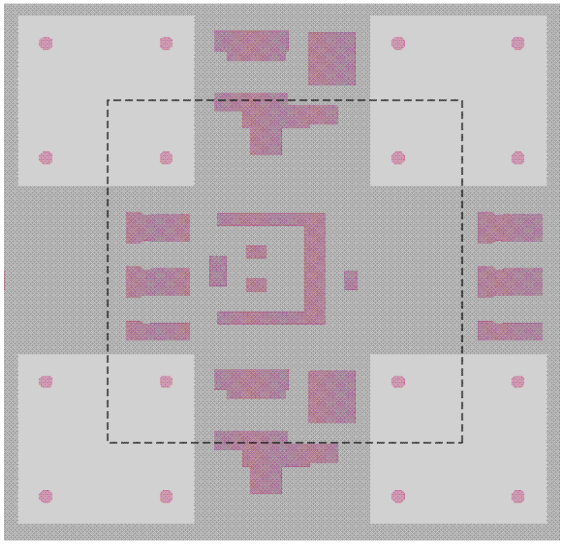
- two variants of Capas and same comparator logic
- Mask bit
- 4 Trim bits



Shaper

pink = nwell (absorbing charge)

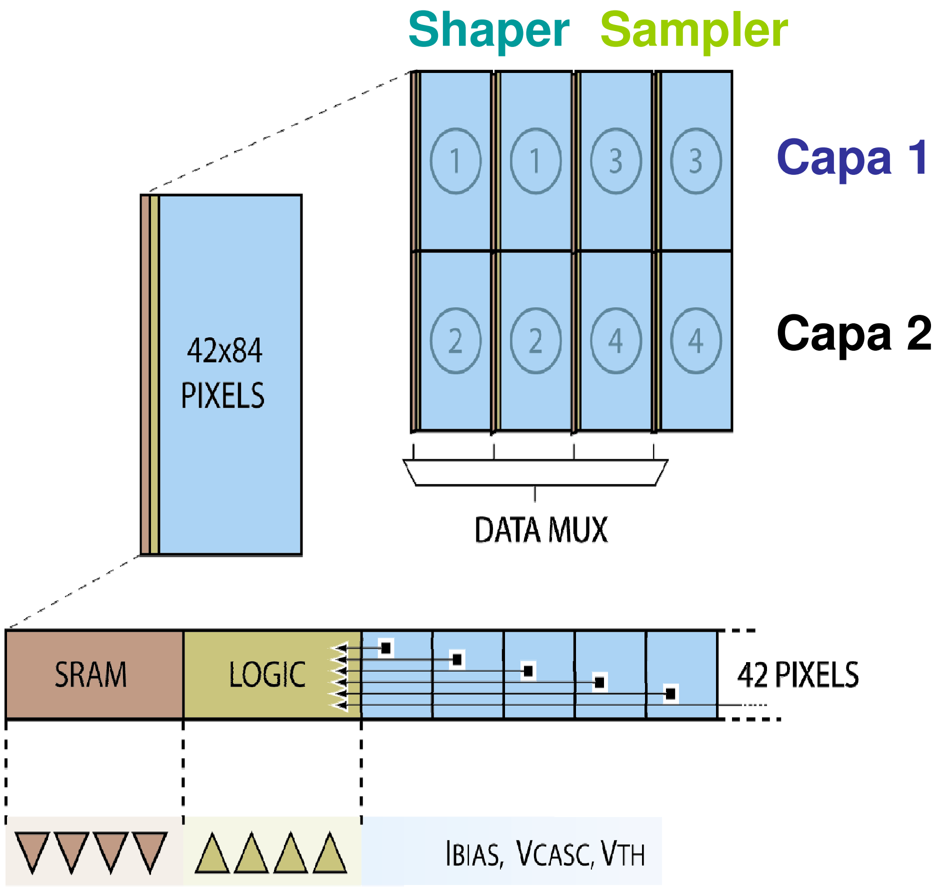
grey = deep p-well added to block the charge absorption (INMAPS process)

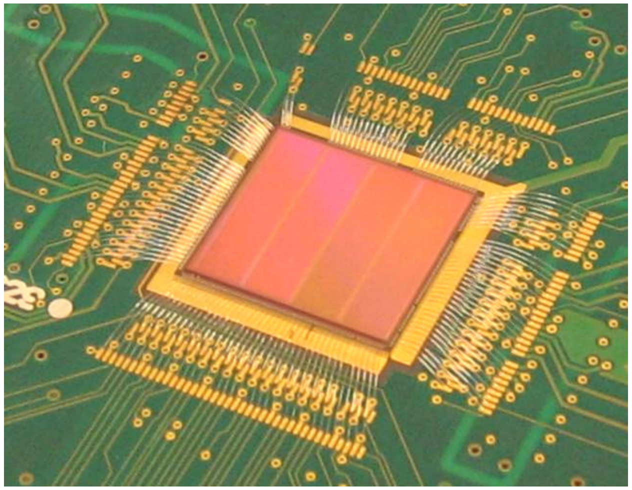


Sampler

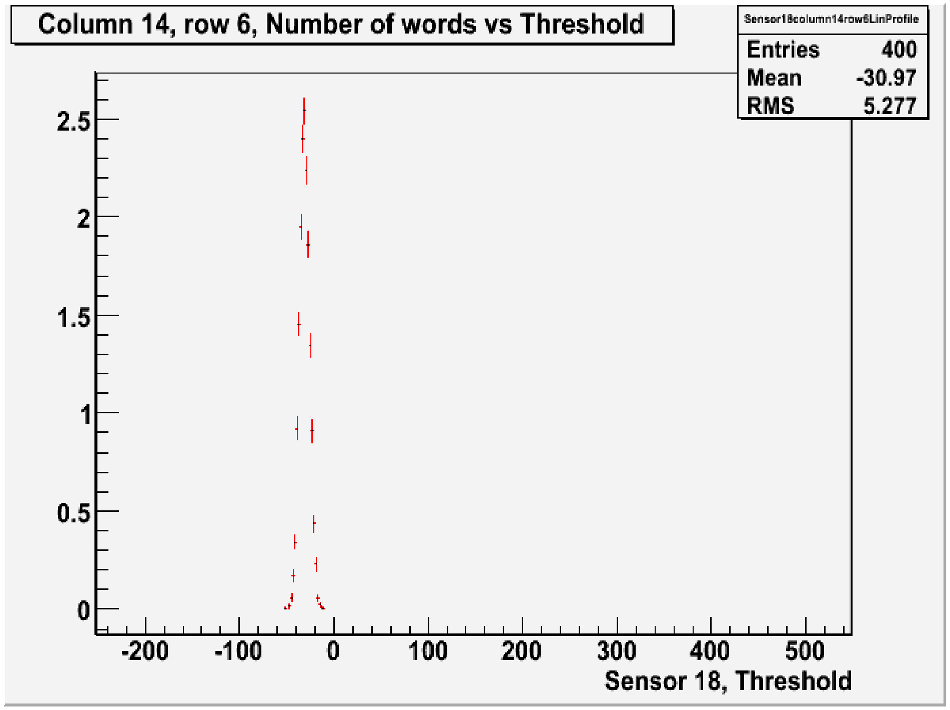
ASIC 1.0

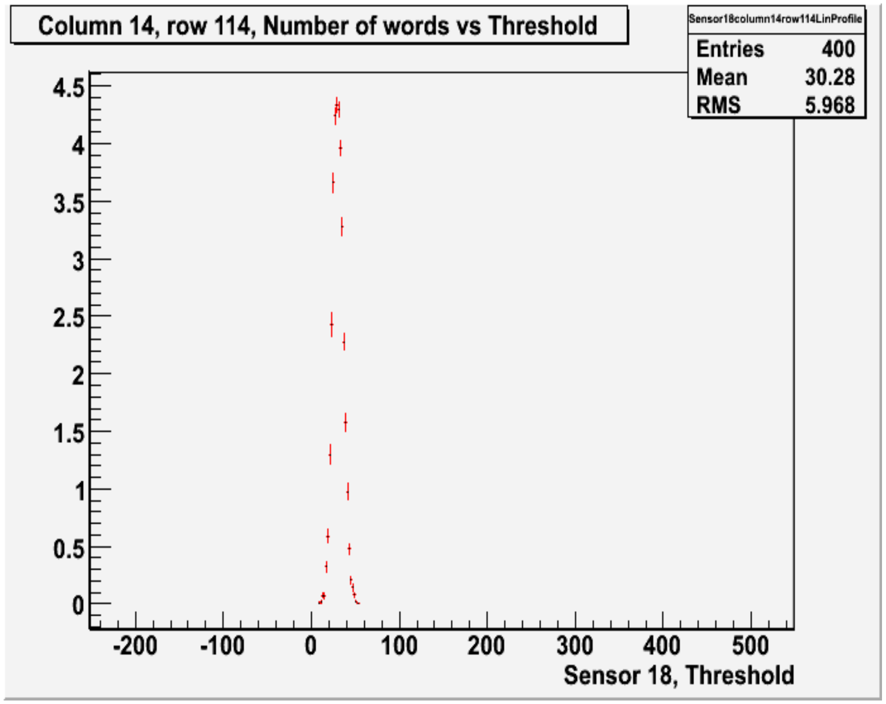
- 168 x 168 pixels
- 10mm x 10mm
- 79.4 mm2 sensitive area
- of which 11.1% is dead (*logic etc*)
- ordered April 2007; delivered July 2007.
- As a binary device, we can investigate noise, pedestal etc by carrying out threshold scans: i.e. varying the global comparator threshold and counting the number of hits per pixel.





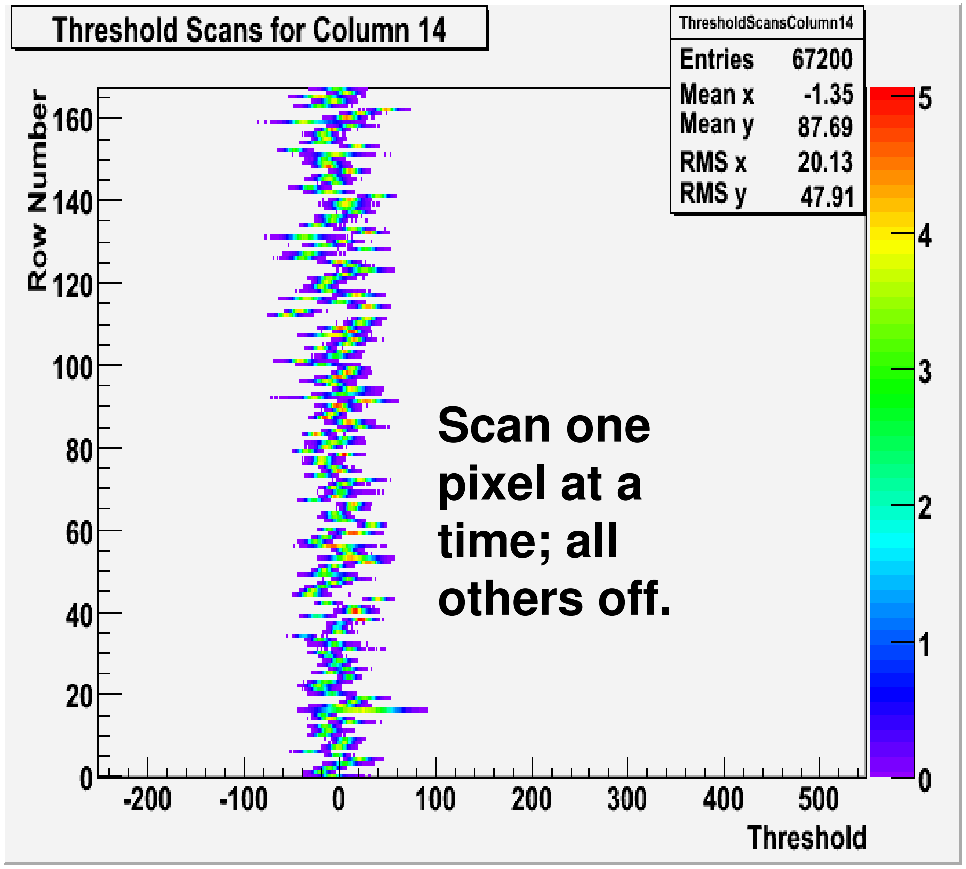
Threshold scans of individual pixels



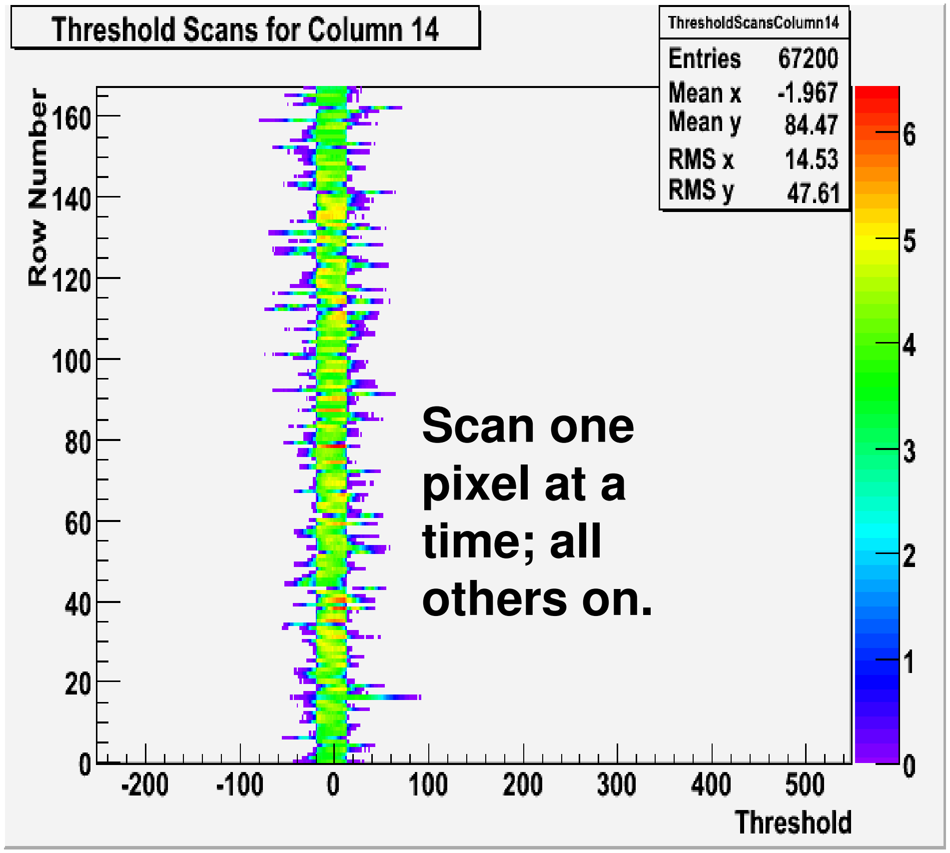


- Means significantly different but RMS is similar
- RMS of theshold peak → Noise
- 5 Threshold Units → 40 electrons – as expected

Crosstalk between pixels



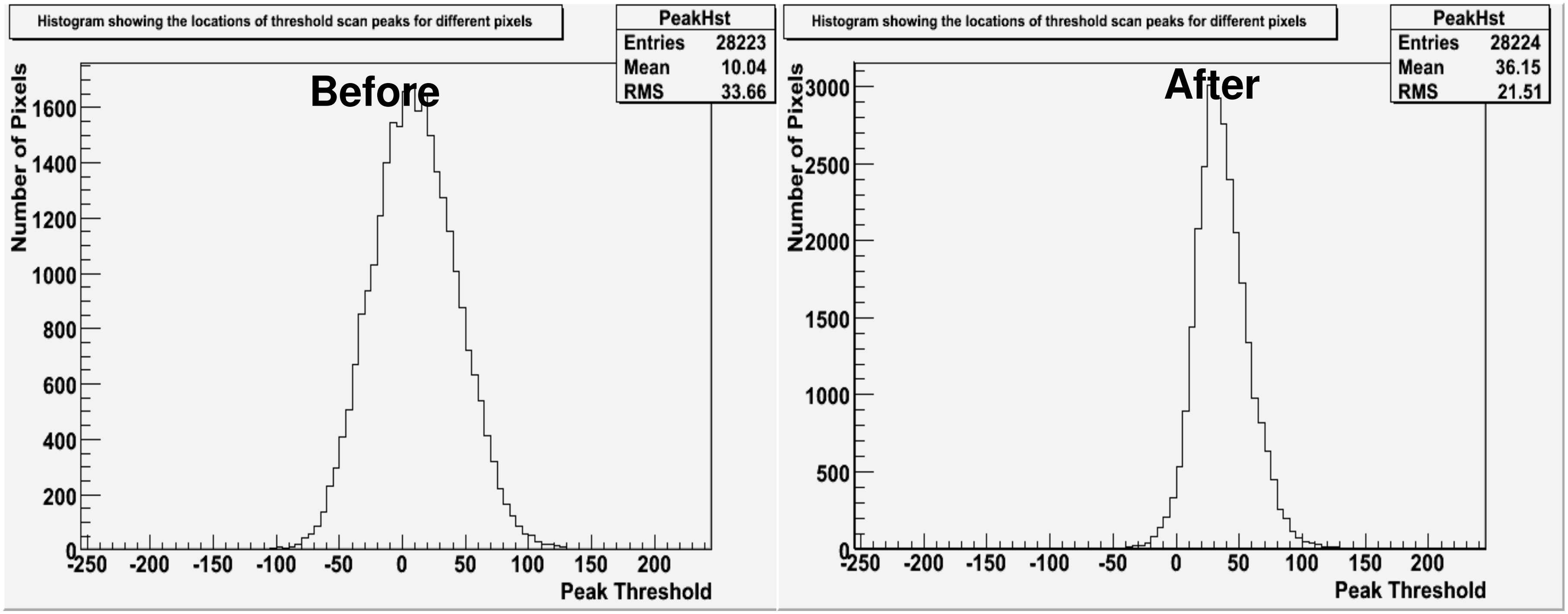
Scan one pixel at a time; all others off.



Scan one pixel at a time; all others on.

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

Trimming the thresholds

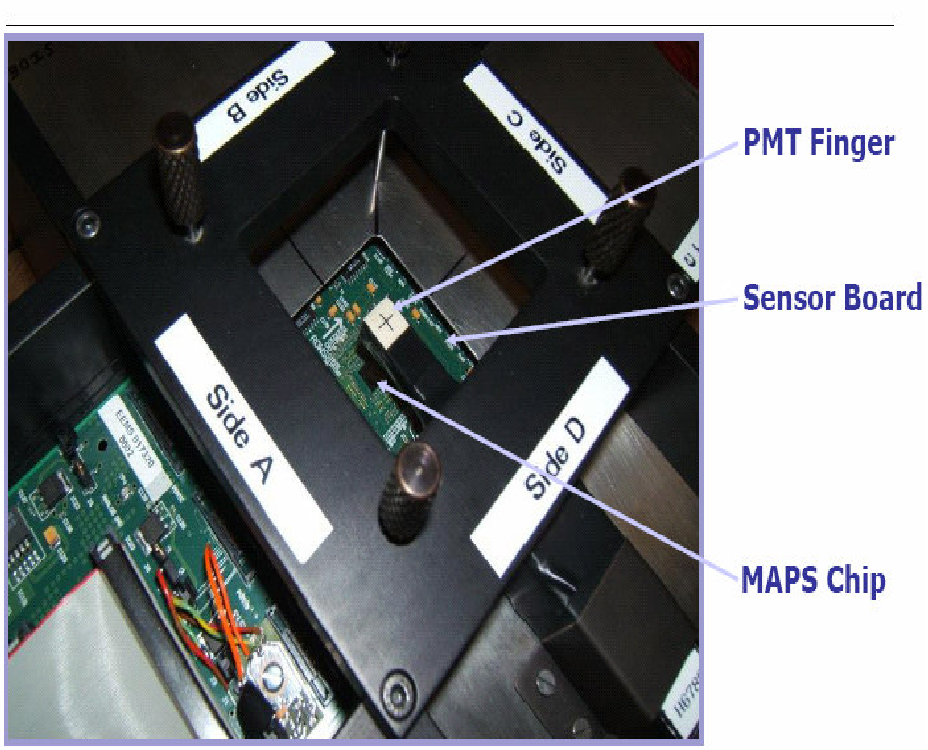


- Trimming reduces the range of pixel thresholds but not enough. (The spread in thresholds is still much larger than the width of a typical threshold scan).
- More dynamic range is required (i.e. 6 trim bits) in order to bring all thresholds into close proximity.
- Difficult to find a global threshold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

Beam tests at DESY

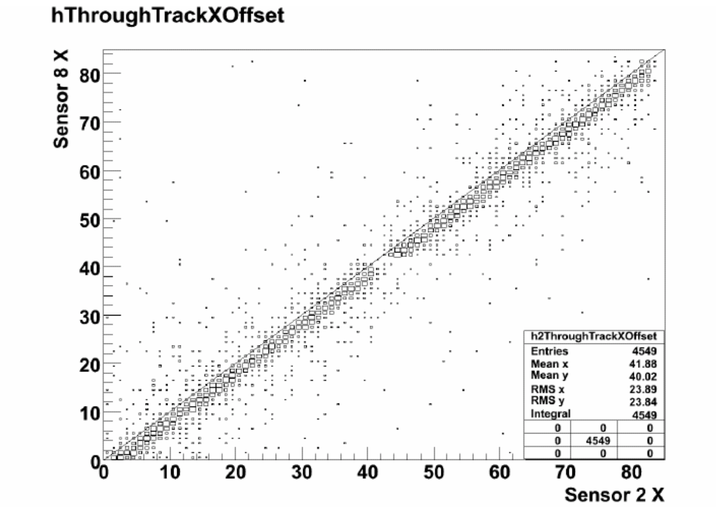
- < one week in mid-December 2007; very tight schedule; last opportunity before long shutdown.
- Electron beam: 2-6 GeV
- 4 sensors plus up to 10 absorber sheets (W; 3mm) all aligned precisely
- Signals from small scintillators upstream and downstream recorded also.

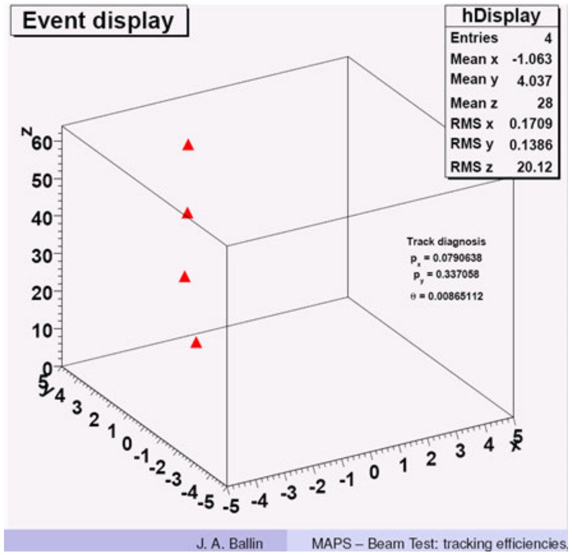
Test beam at DESY



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



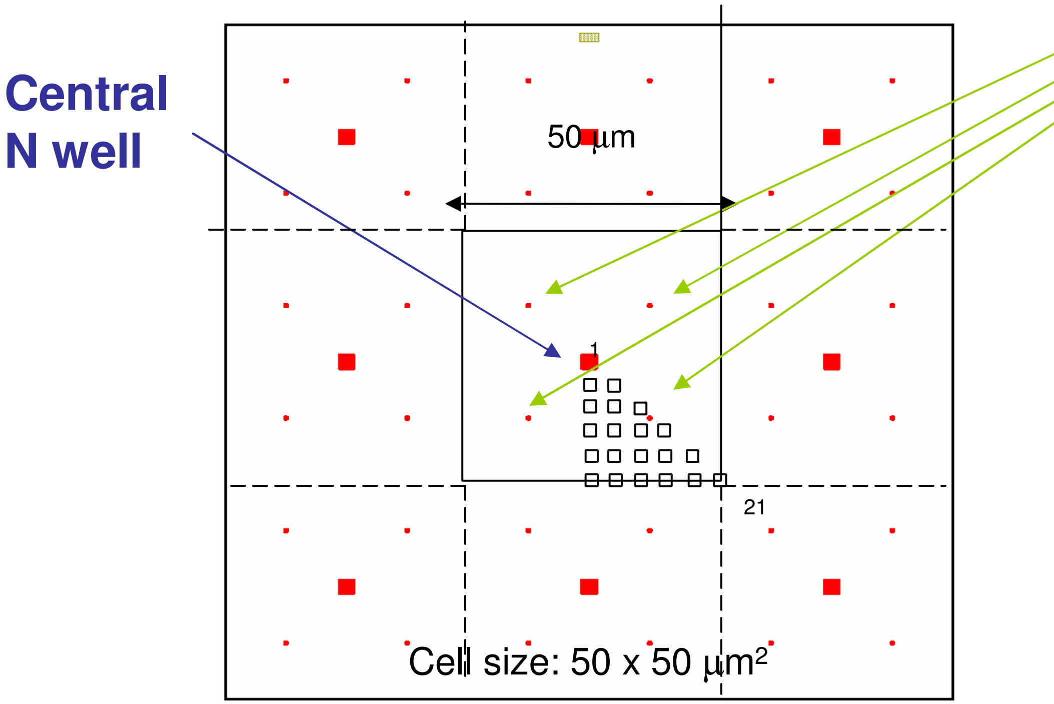


Other tests (ongoing)

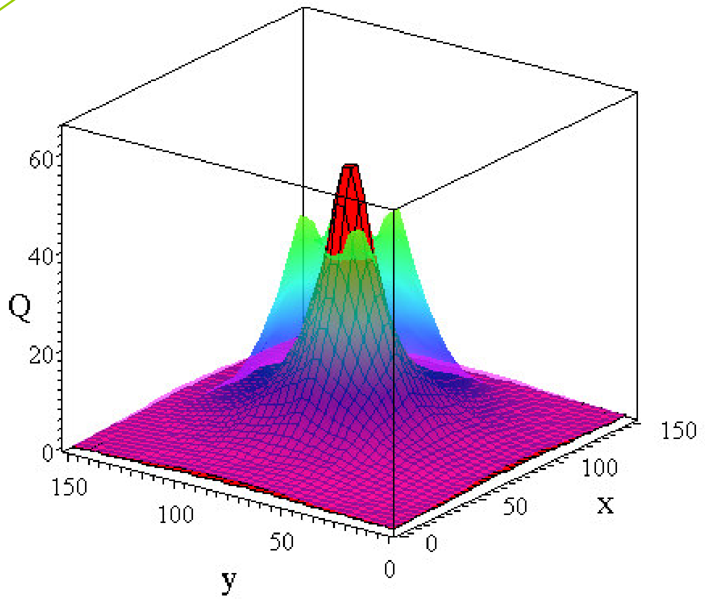
- Radioactive sources : Fe-55 (5 keV X-rays) and
  Sr-90 (>2MeV electrons)

  → 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



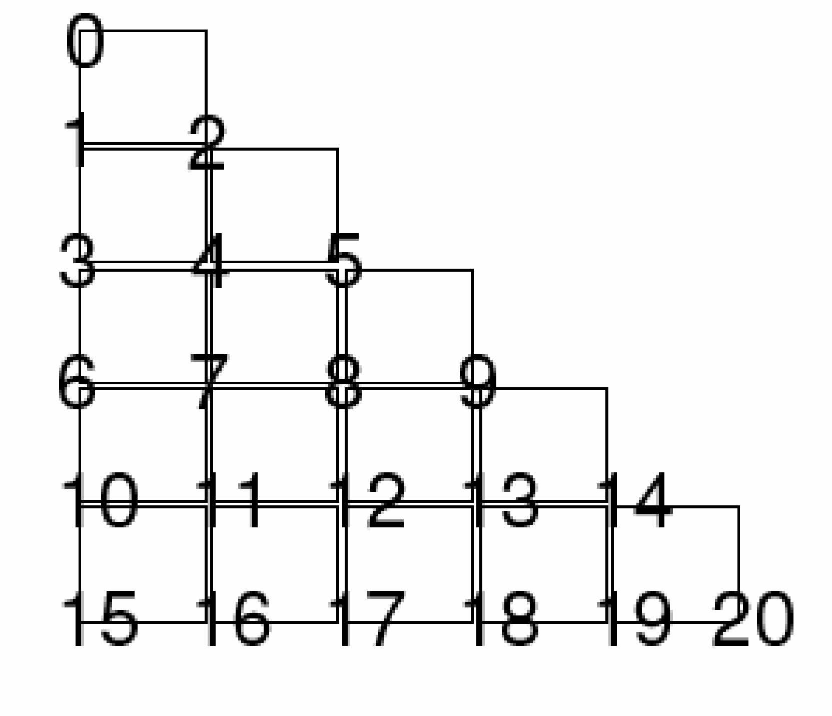
Whole 3*3 array with neighbouring cells is simulated, and the initial MIP deposit is inputted on 21 points (sufficient to cover the whole pixel by symmetry)



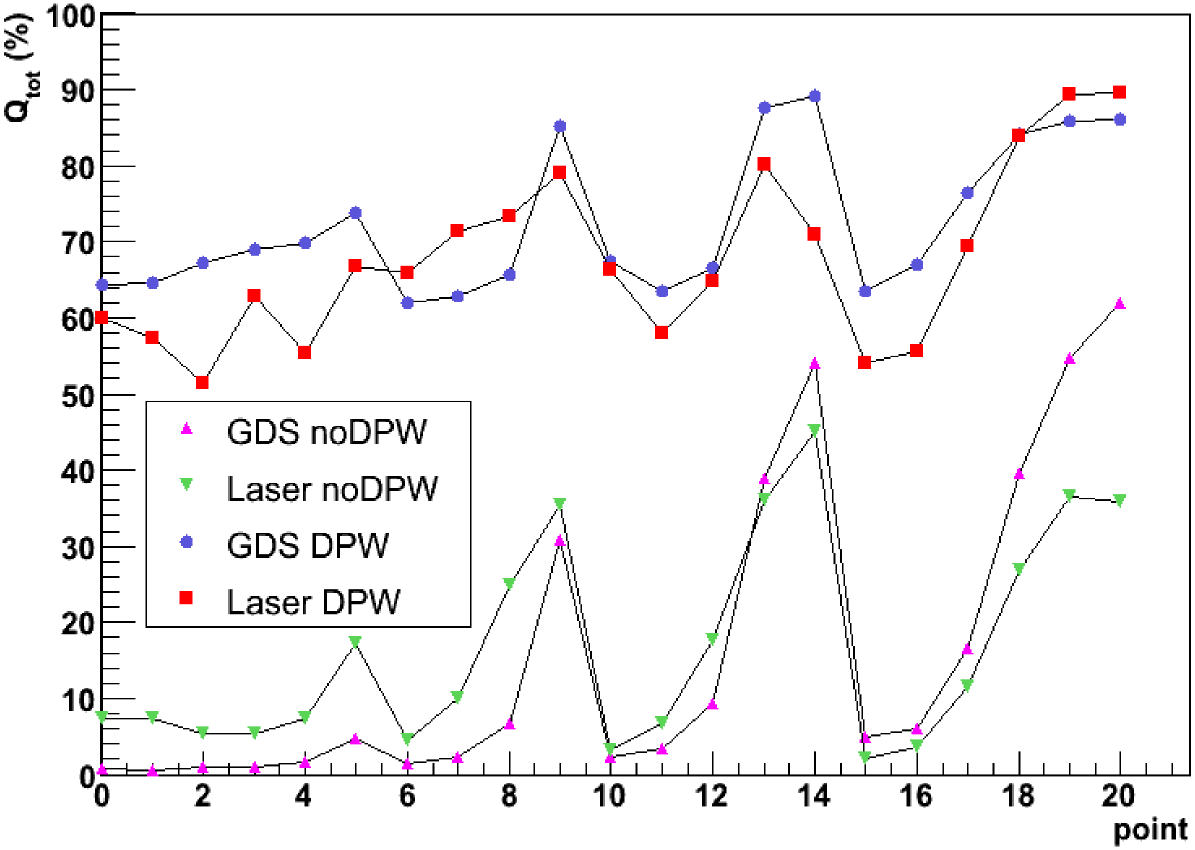
Example of pessimistic scenario of a central N-well eating half of the charge

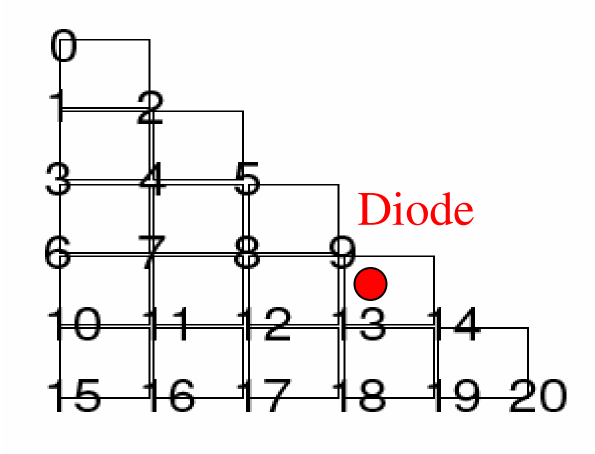
Charge sharing between pixels

- 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.



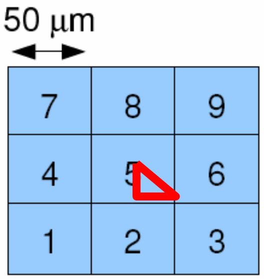
Charge diffusion: summing 3x3 pixels

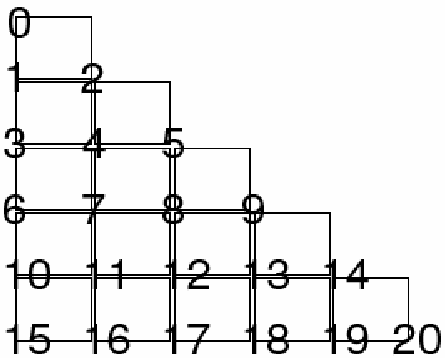


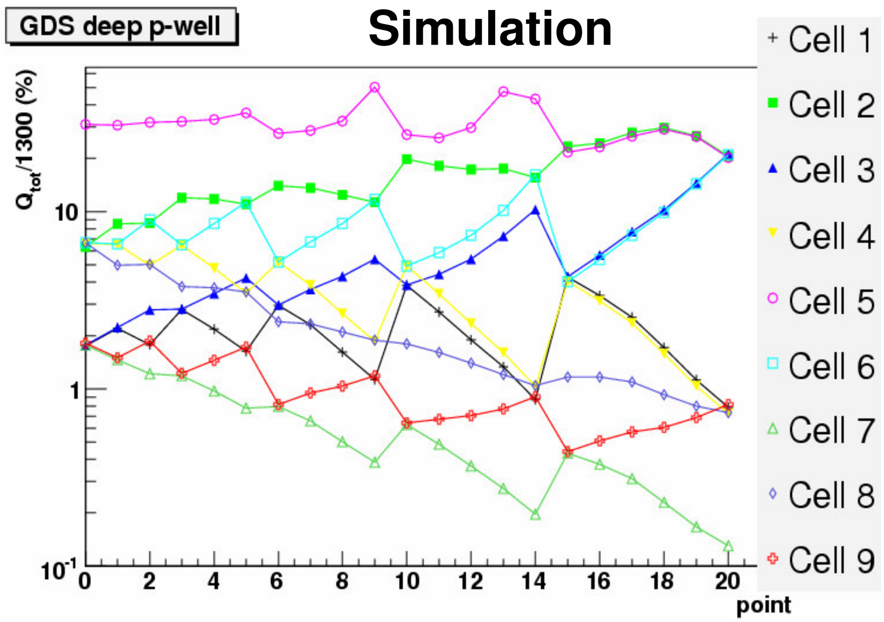


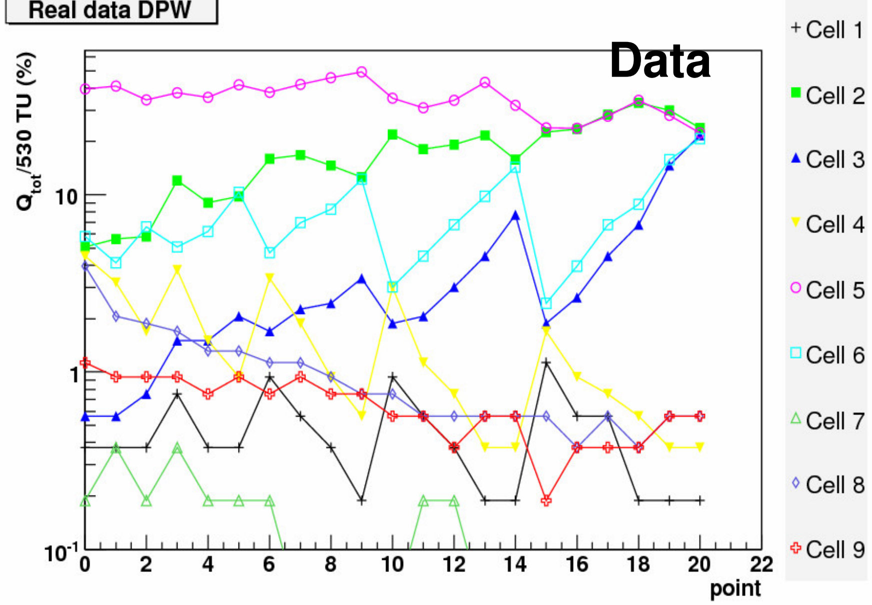
- Excellent agreement between data and simulation both with and without the deep P well.
- With no deep P well, the diodes see signal predominantly from locations nearest to them (i.e. 9,13,14,18, 19, 20 – all near a group of diodes and furthest from the N well.

Charge sharing: deep P well



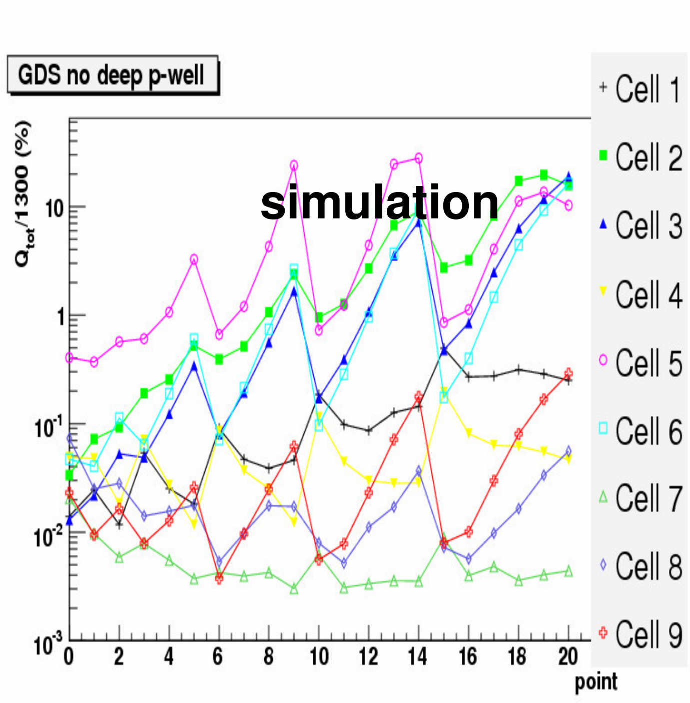


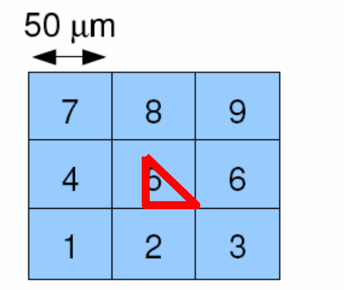


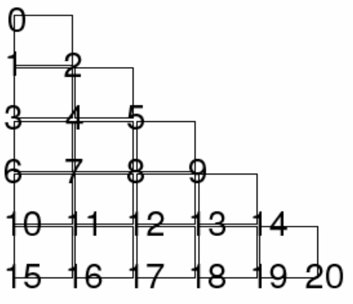


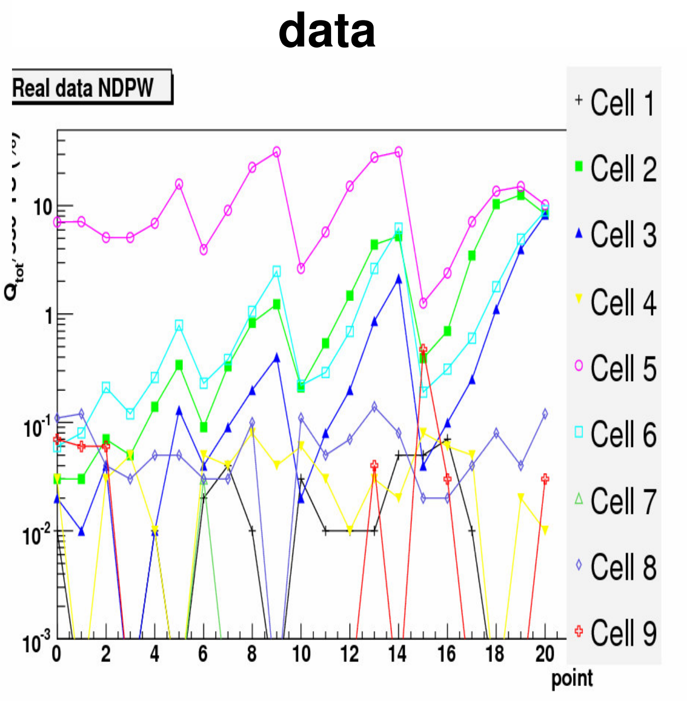
- Reasonable qualitative agreement; e.g. cell 4 has peaks at 3,6,10,15 (all locations closest to the cell)
- Cells 2, 3, 5 and 6 all have the same response at location 20 since this point is on the corner of the 4 cells,

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

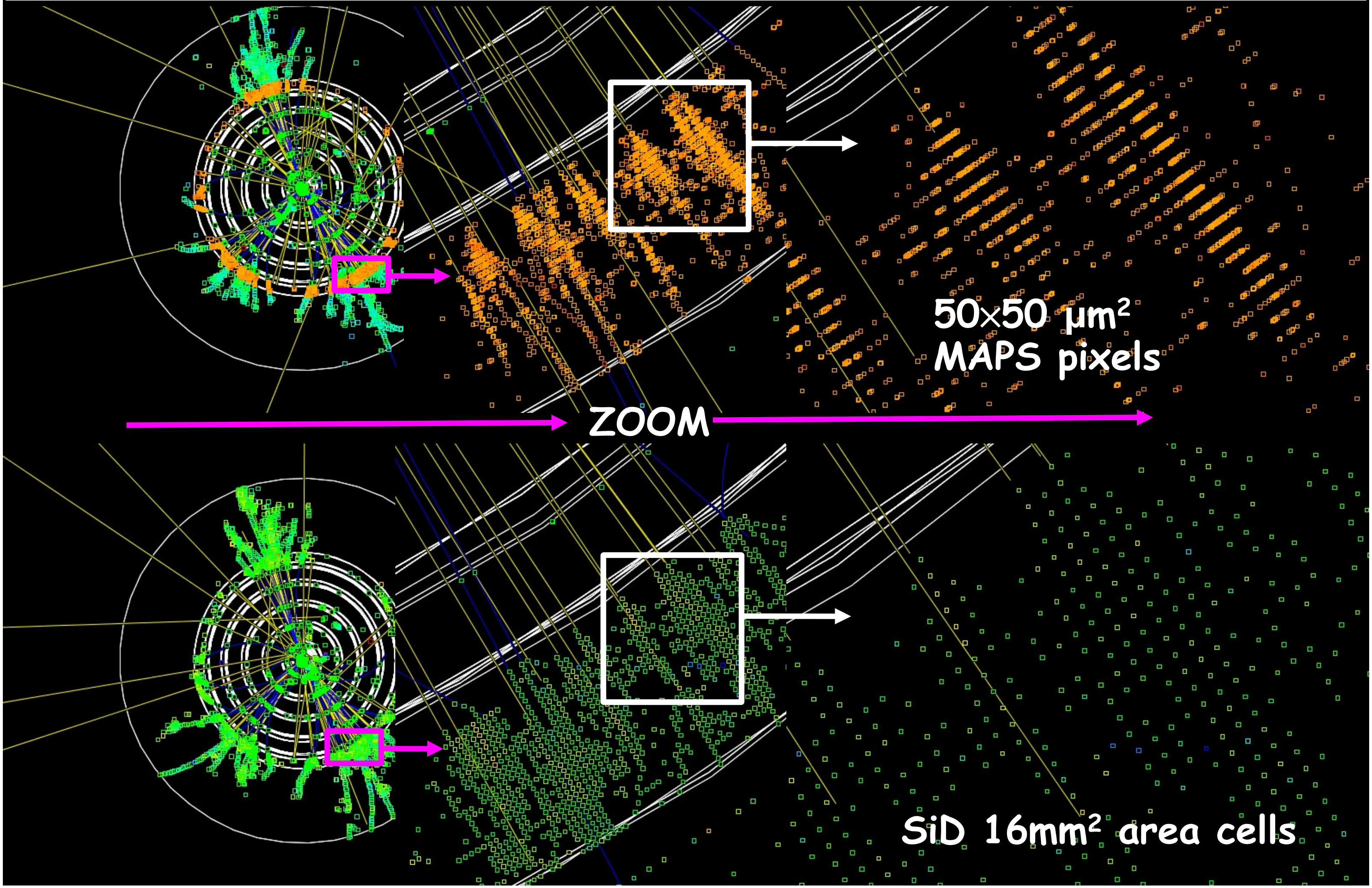
- Design ASIC 1.1 :

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

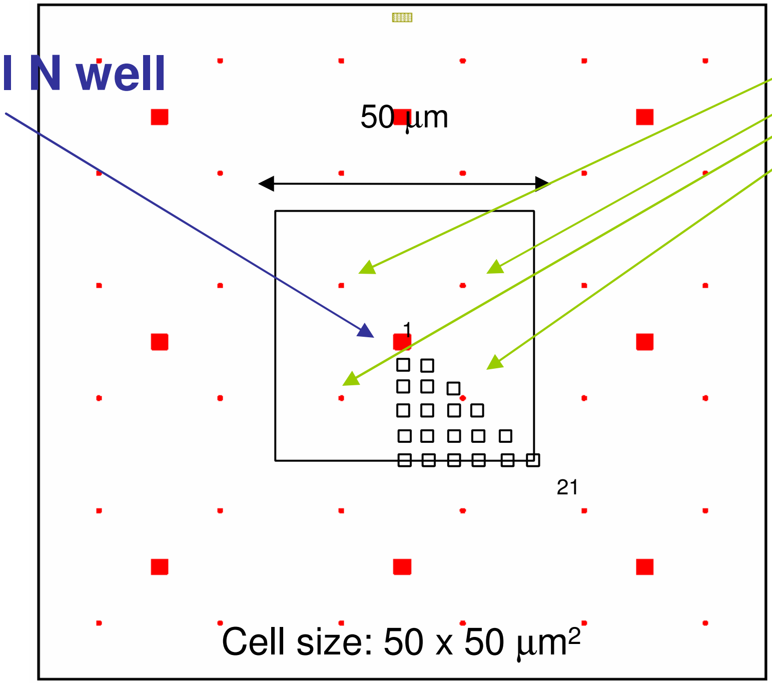
- Submit to foundry by mid-July; expect to receive chips by August/September 2008.

Backup slides

Tracking calorimeter



Simulation of charge diffusion



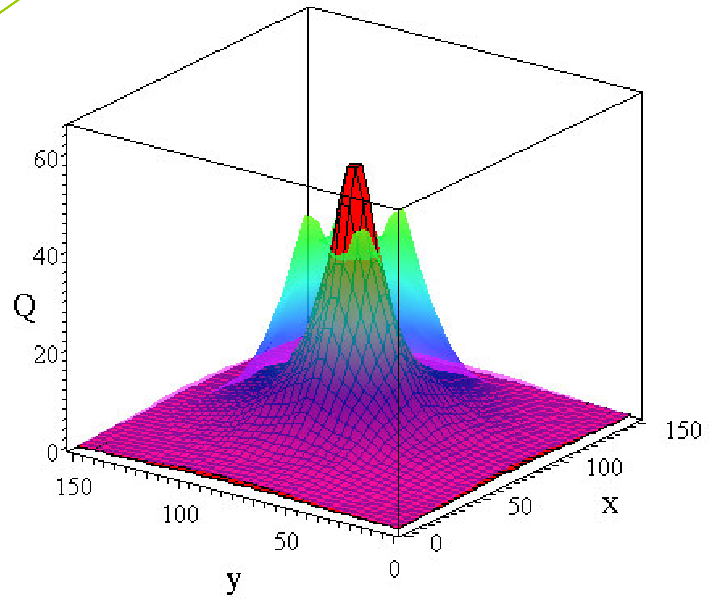
Central N well

Diodes

50 µm

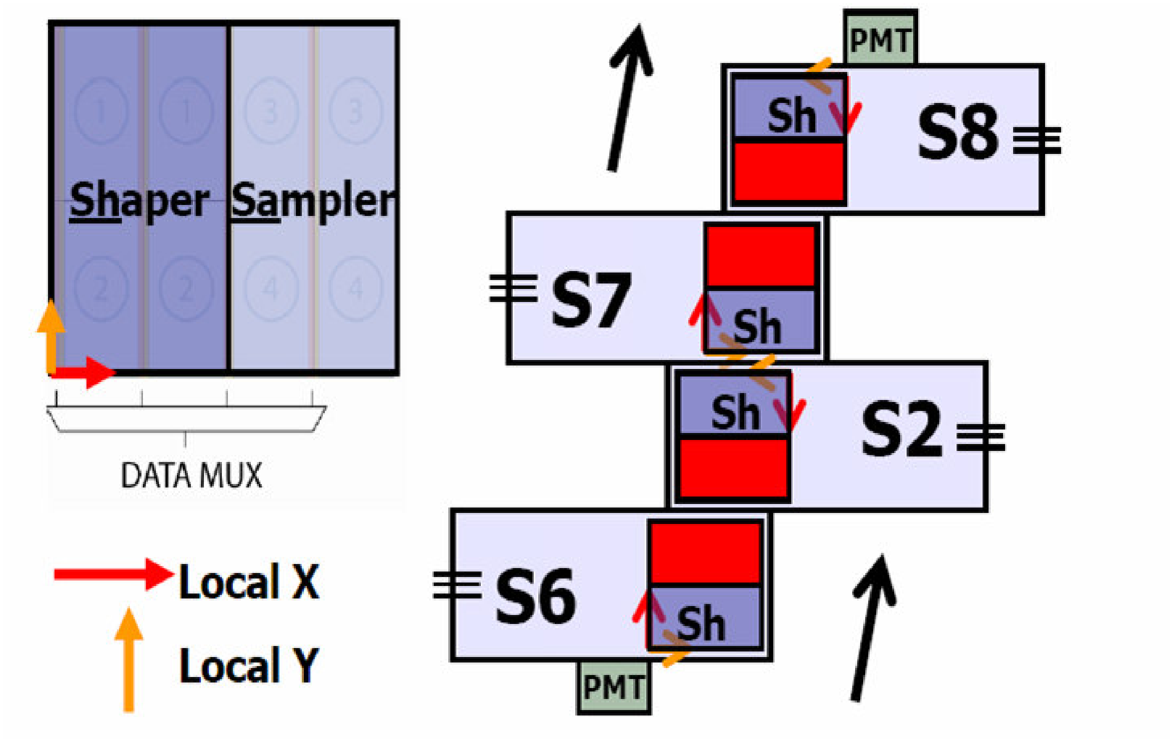
Cell size: 50 x 50 µm²

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

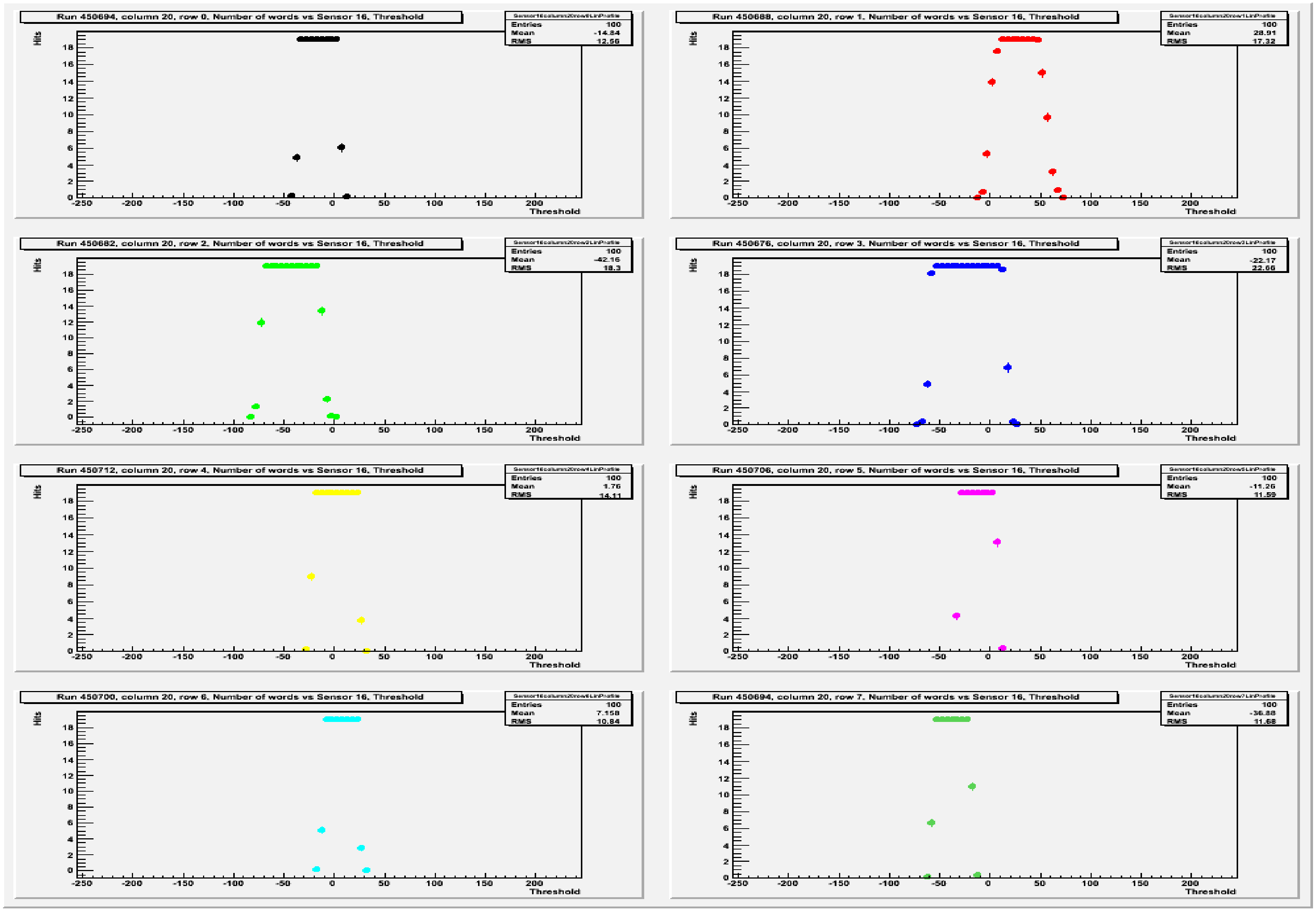
Sensors in test beam



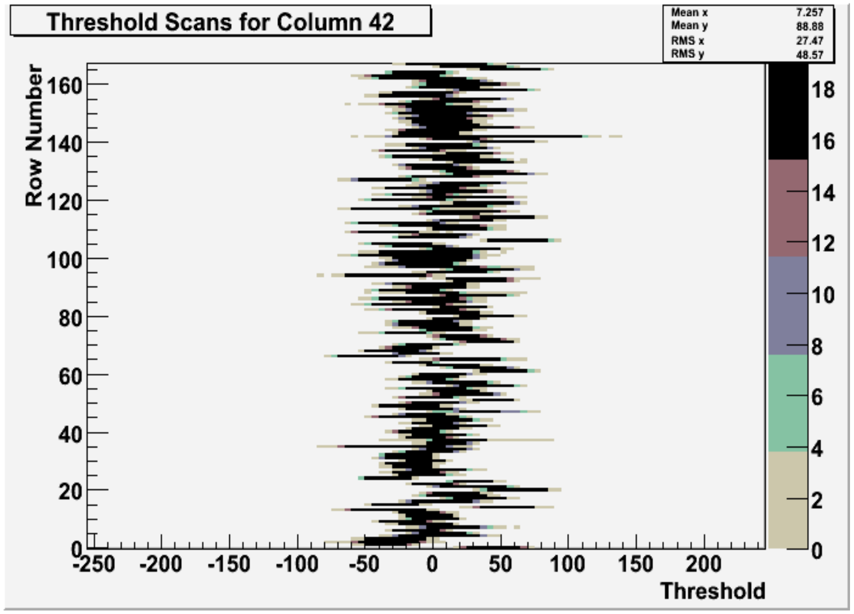
- Beam traverses triggering scints, then 2 + 2 preshapers and presamplers
- mixture of shapers and samplers

⟶ trimming to a consistent threshold very difficult

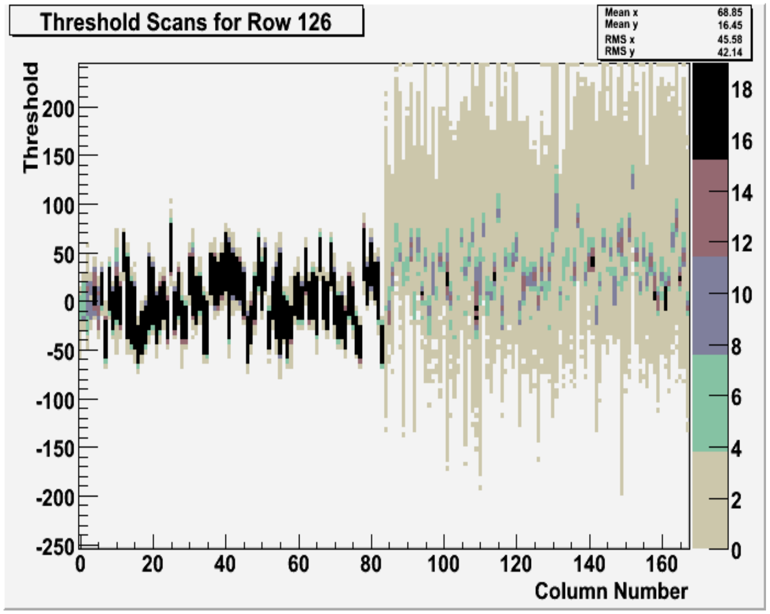
Individual pixel threshold scans



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.