Status of the UK MAPS

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- UK MAPS program
- Source tests
- Radiation test
- FAPS
- Ladder development
- Conclusions
- Outlook

UK MAPS program

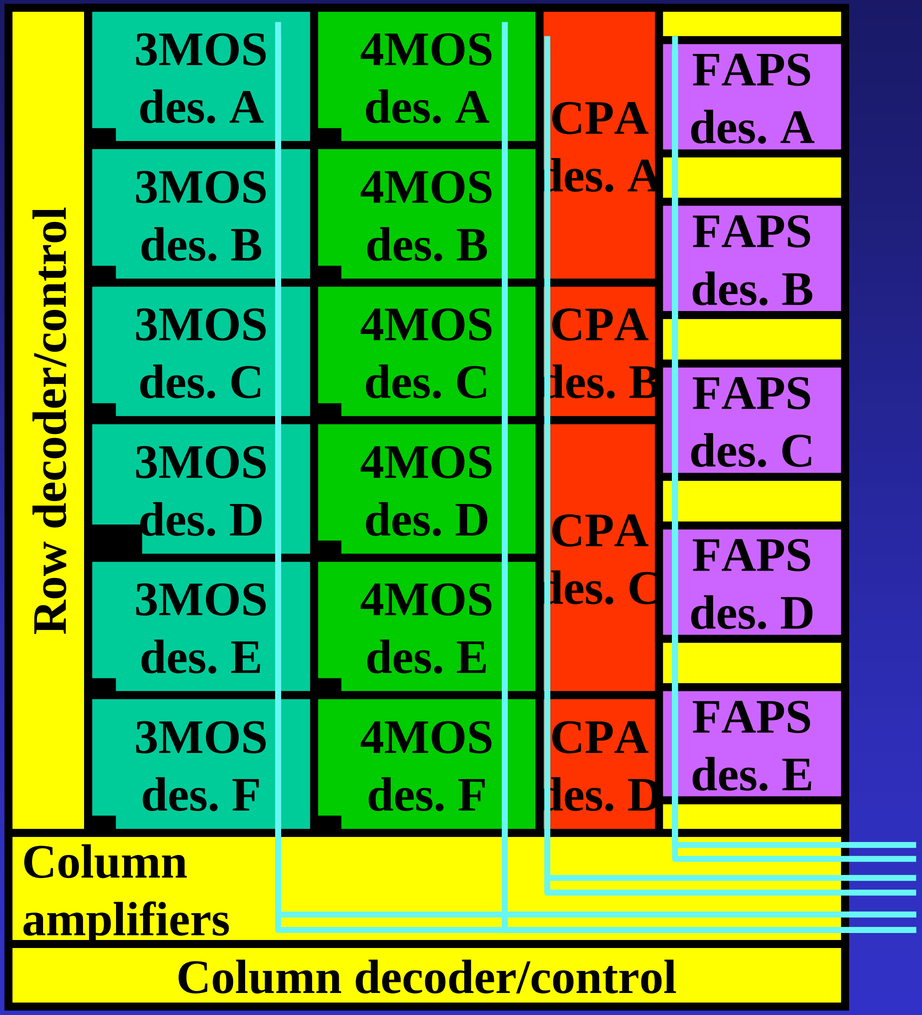
- Successfully produced 3 test structures:
  - RALHEPAPS 1 See LCWS04
    - 0.25 CMOS IBM
    - Eight arrays of 8x8 pixels
    - Pixels 15 μm pitch
    - 2 μm epi-layer
  - RALHEPAPS 2 ⇒ work horse See IEEE04+ VERTEX04
  - RALHEPAPS 3 See VERTEX04
    - 0.25 Mixed Signal CMOS TSMC
    - Pixels 15 μm pitch
    - No epi-layer
- RALHEPAPS 4 to be submitted end of March
  - Large scale structure

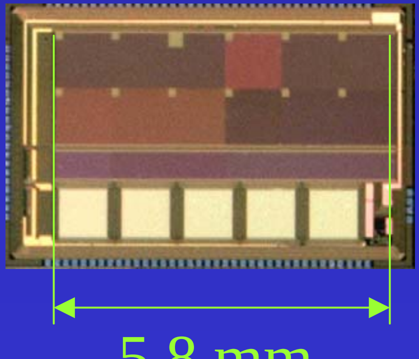
RALHEPAPS 1
Design: R. Turchetta (RAL)

RALHEPAPS 2

- 4 pixel types, various flavours
  - Std 3MOS
  - 4MOS (CDS)
  - CPA (charge amp)
  - FAPS (10 deep pipeline)
- 3MOS & 4MOS: 64x64, 15μm pitch, 8μm epi-layer ⇒ MIP signal ~600 e-

Design: R. Turchetta (RAL)





APS2 3&4MOS: Various flavours

Like E but with p-well as small as possible

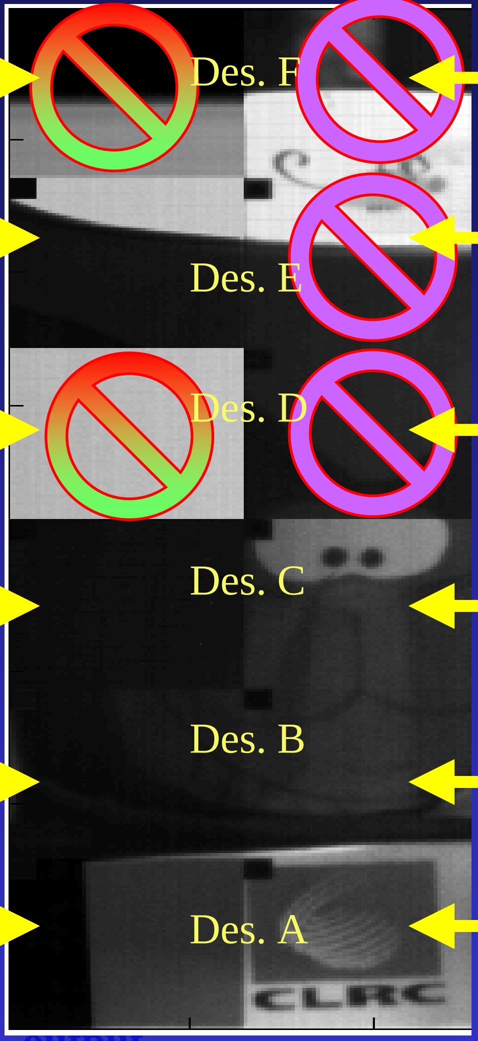
Like B but with four diodes in parallel

Like B but with p-well as small as possible

Like B but with gate-all-around transistors

Like A but with smallest diode (1.2*1.2 μm)

Reference pixel (diode ~ 3*3 μm)



3MOS 4MOS

Like C but with gate-all-around transistors

Like B but with gate-all-around transistors

Like A but with gate-all-around transistors

Like A but the TX transistor has lower Vt

Like A but the TX transistor has higher Vt

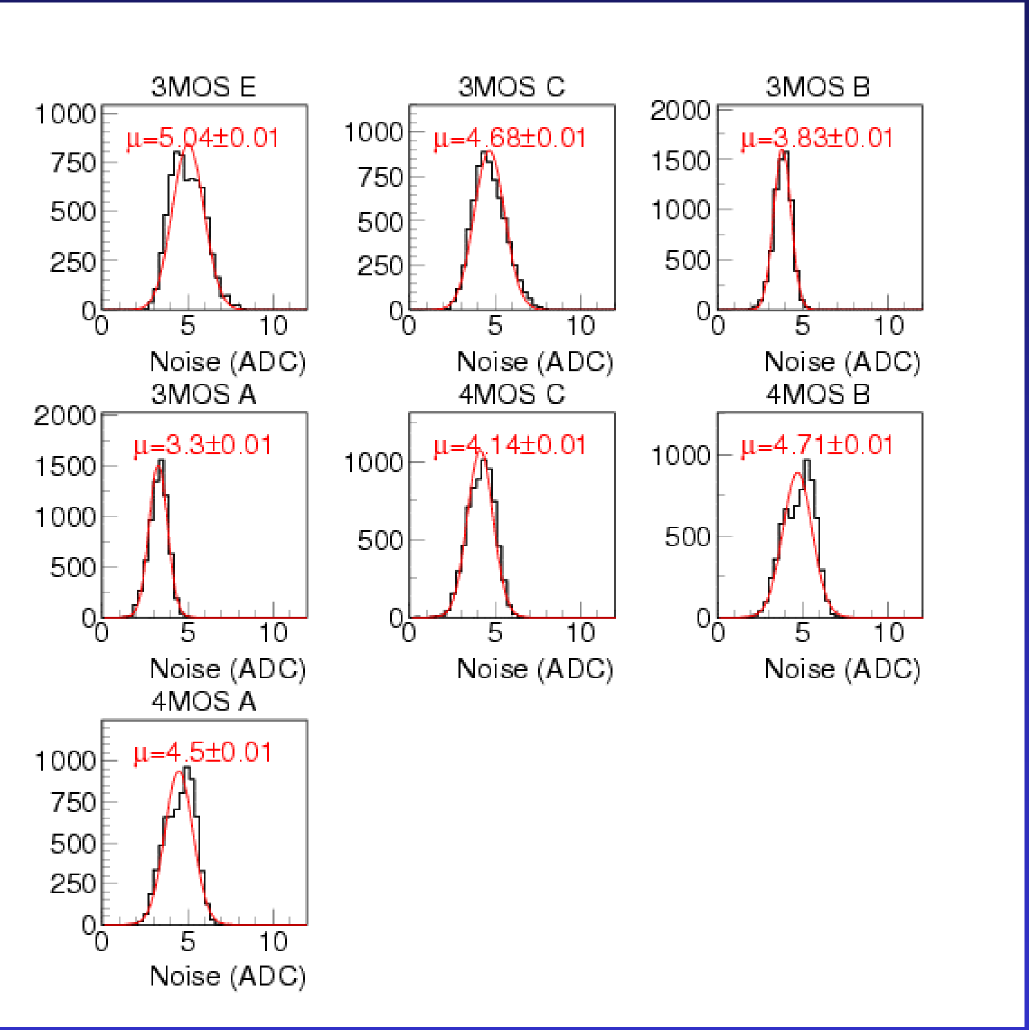
Like 3MOS-A but with the TX transistor

Initial production error, now okay

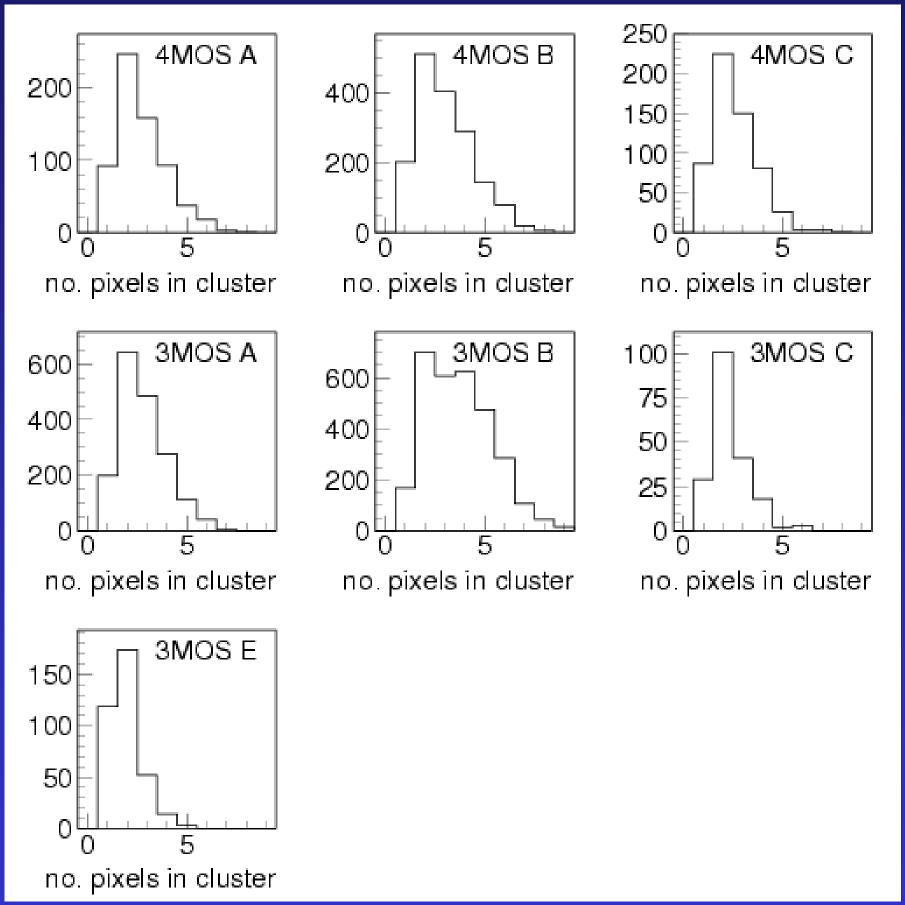
Gain too low

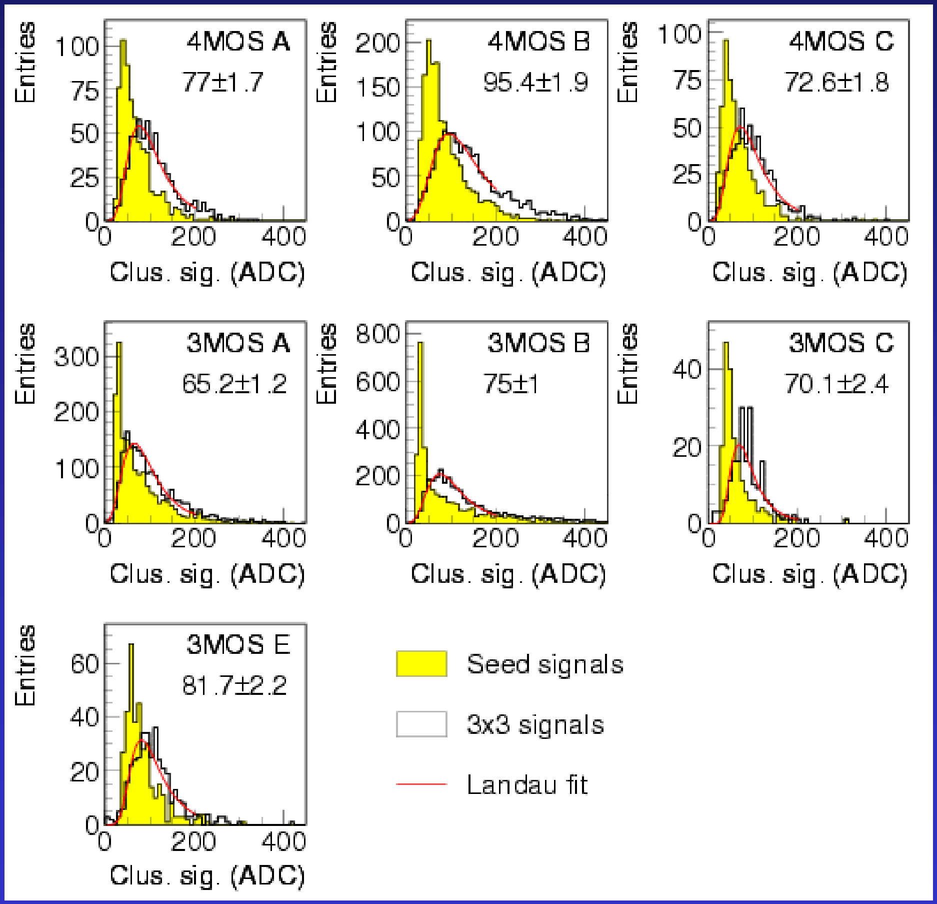
APS2: Source test

- ^{106}Ru-source emitting β-particles
- Here only use 3MOS and 4MOS (no CDS)
- Calculate pedestals
  - Average output after removing hits
- Calculate common mode noise
  - Average pixel type output after pedestal subtraction
- Calculate random noise
  - Sigma of pedestal and common mode corrected output
- Cluster definition
  - Signal >8σ seed
  - Signal >2σ next



APS2: cluster size & signals



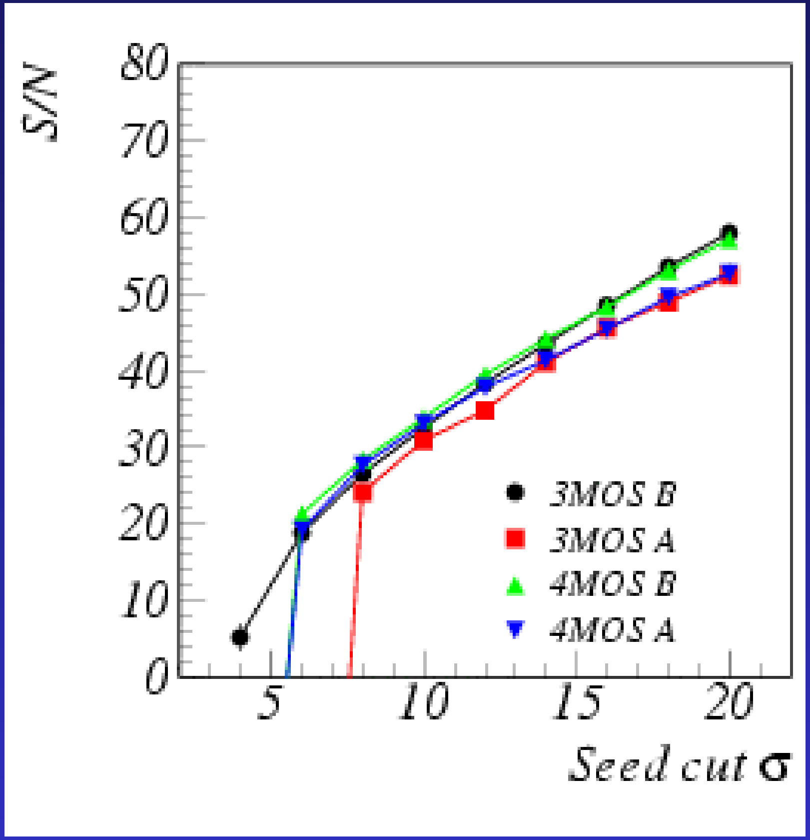


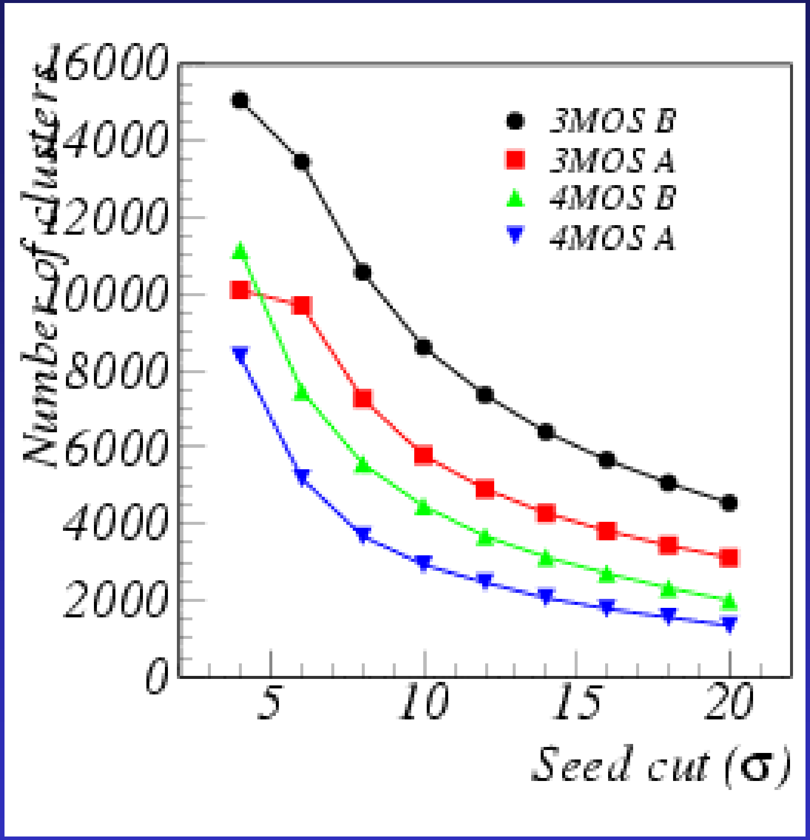
APS2 3&4 MOS summary

Type	Specs	S/N
3MOS E	4 diodes	21±6
3MOS C	GAA	20±6
3MOS B	Diode 1.2x1.2	21±5
3MOS A	Diode 3x3	22±4
4MOS C	Lower V_T	27±7
4MOS B	Higher V_T	16±4
4MOS A	Reference	18±4

- Out of 12 substructures 7 display good S/N.
  - Two structures initial problems in fabrication, but ok now.
  - 4MOS GAAs have too low S/N for MIPs.
  - Variation in S/N between various sensors found to be large.
- Need test beam results:
  - Seed cut determines S/N result
  - Efficiency not uniform
- Have taken testbeam data in February. Analysis is still ongoing.

Effect seed cut on signal

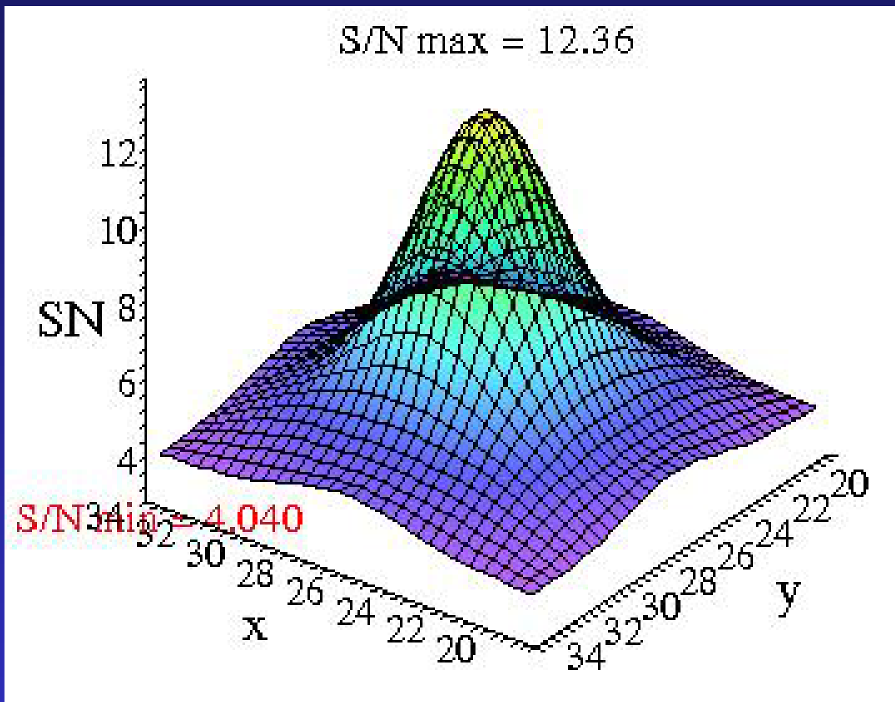


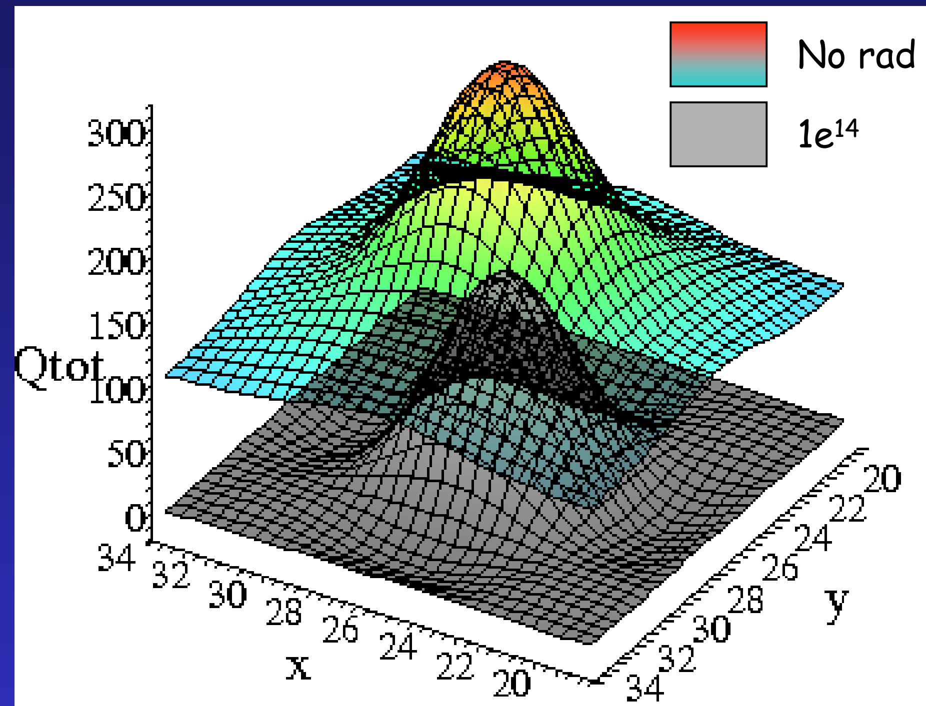


- Measured S & S/N highly dependent on seed cut (efficiency vs purity)

S/N uniformity

Simulation: G. Villani (RAL)





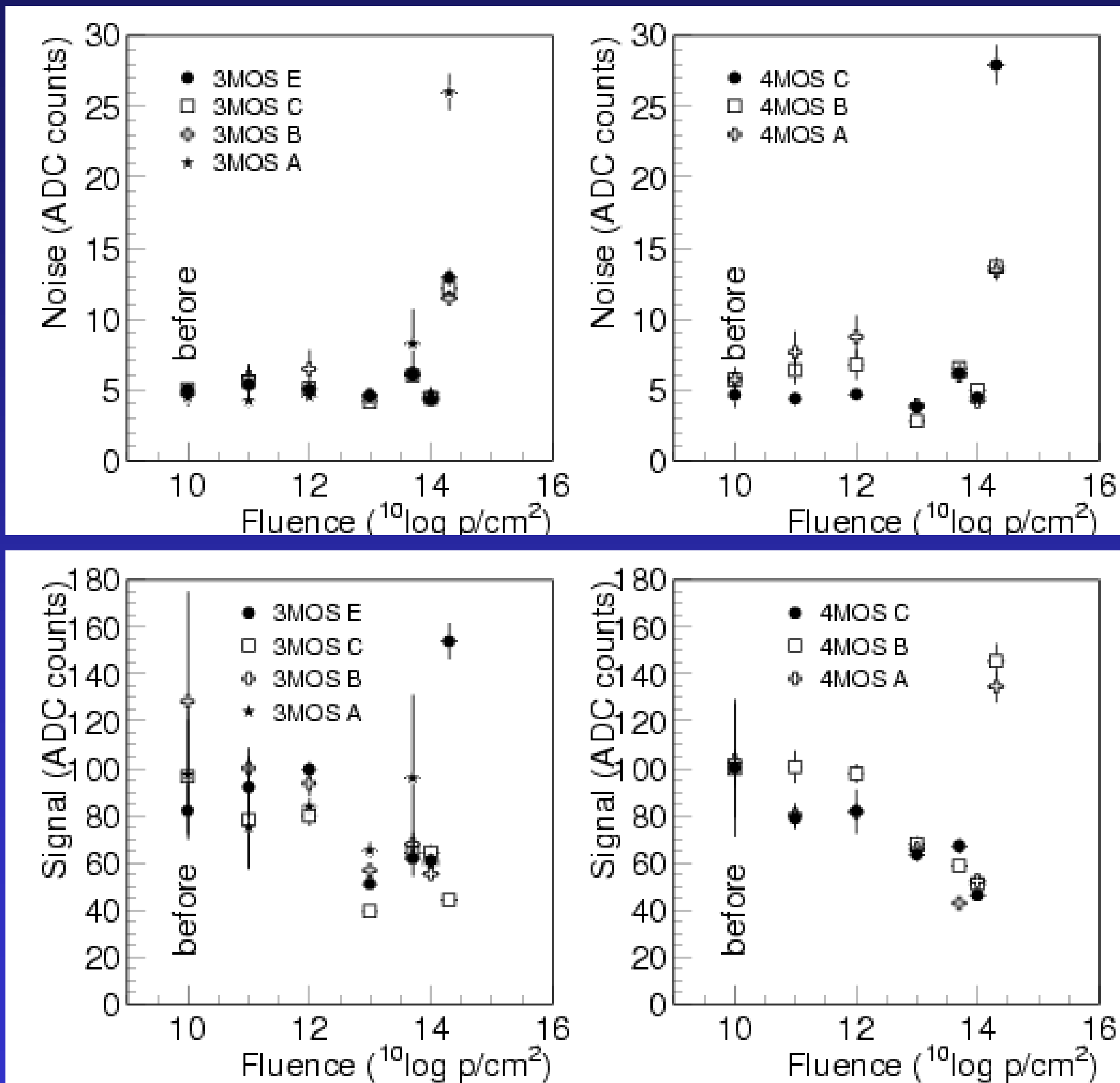
- S/N varies over pixel between 12 and 4 before irradiation.
- S drops to zero at edges after $1e^{15}$ p/cm^2.

Radiation test

- Irradiated APS2 up to 10^{15} p/cm^2 at CERN.
  - 10^{12} p/cm^2 ILC requirement
  - 2×10^{15} p/cm^2 10 years ATLAS pixel layer
- Repeat analysis at each dose with same cuts
  - Seed $>8\sigma$
  - Neighbour $>2\sigma$

Dose (p/cm^2)	#APS2
0	3
1e11	4
1e12	4
1e13	4
5e13	4
1e14	2
2e14	2
5e14	2
1e15	2

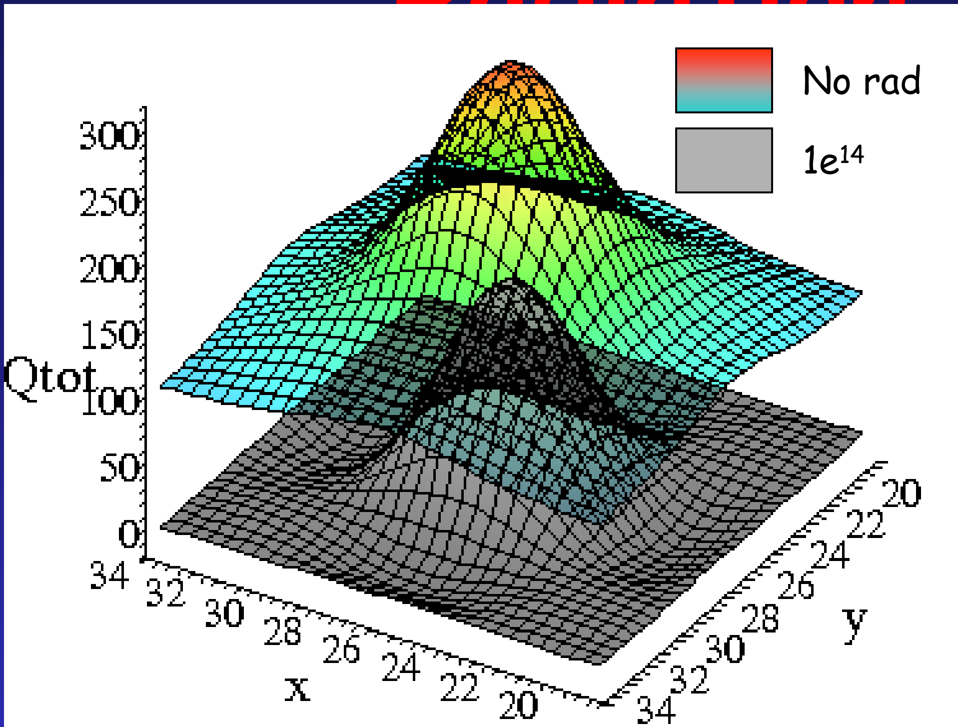
Radiation test (II)

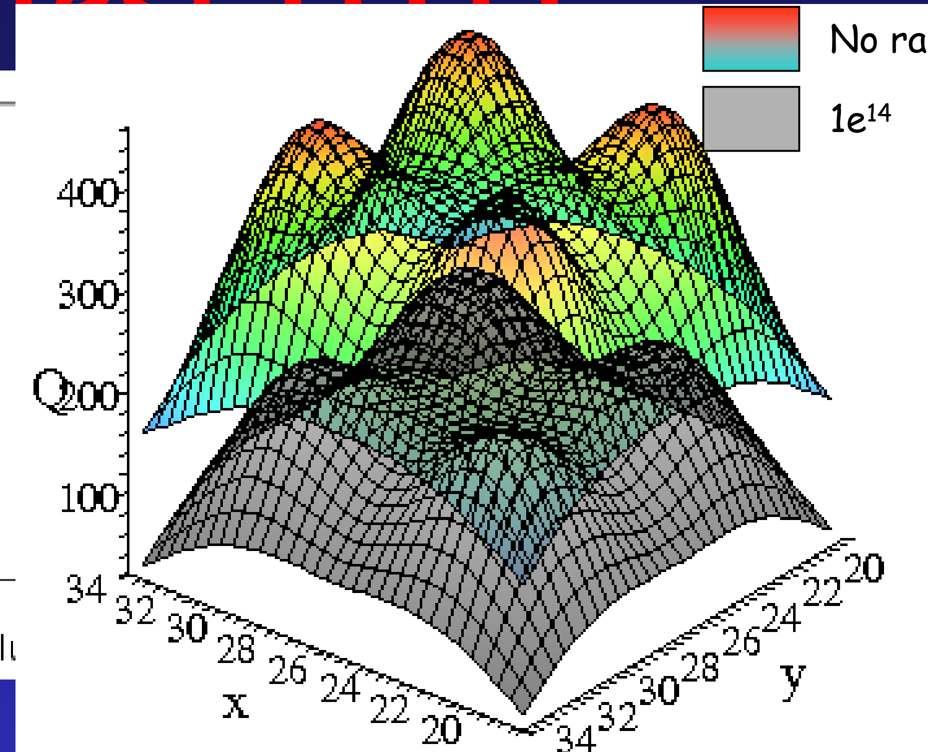


- Noise seems to increase slightly with dose.
- Signal decreases with dose.

3MOSA	3x3 μm^2
3MOSB	1.2x1.2 μm^2
3MOSC	GAA
3MOSE	4 diodes
4MOSA	Reference
4MOSB	Higher V_T
4MOSC	Lower V_T

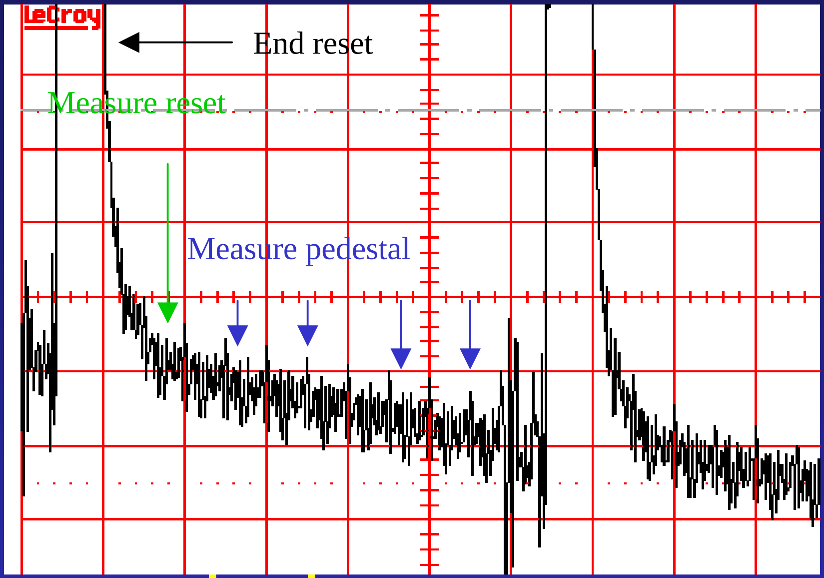
Radiation test (III)





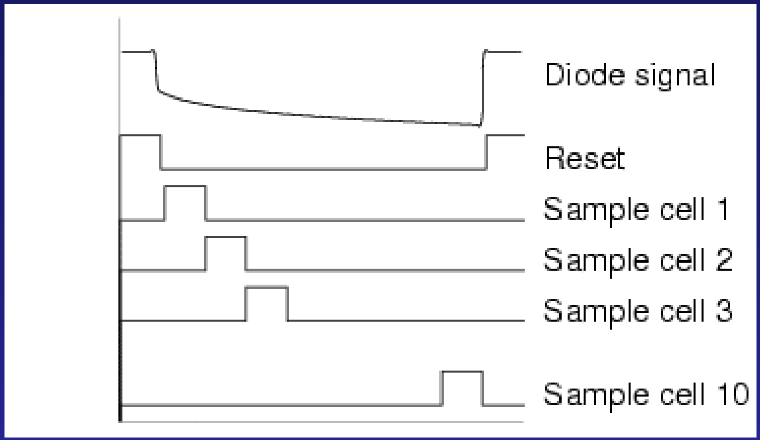
- Sensors yield reasonable S/N even up to 1×10^{14} p/cm^2
  - No efficiency measurement; need testbeam data analysis
- Especially 3MOSE (4 diodes) looks interesting
  - Larger capacitance yields larger noise
  - But after irradiation remains a larger "sensitive area"

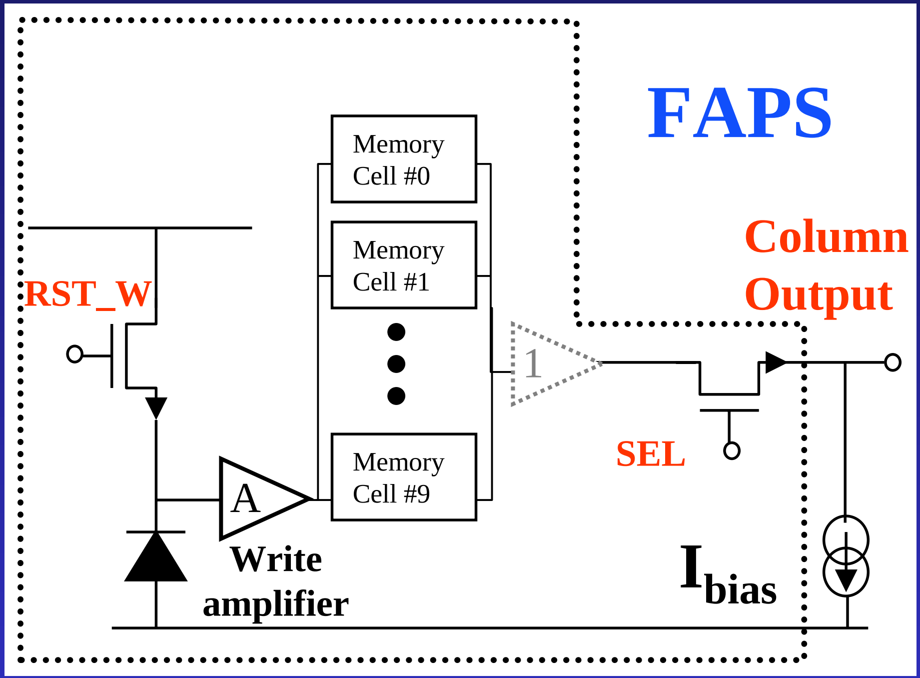
Radiation test (IV)



- Slope is due to leakage current
  - Measure pedestal-reset(time)
  - Fit straight line
  - Plot average slope versus dose
- No significant increase in leakage current.
  - NB. Measured at -20 °C

Flexible APS

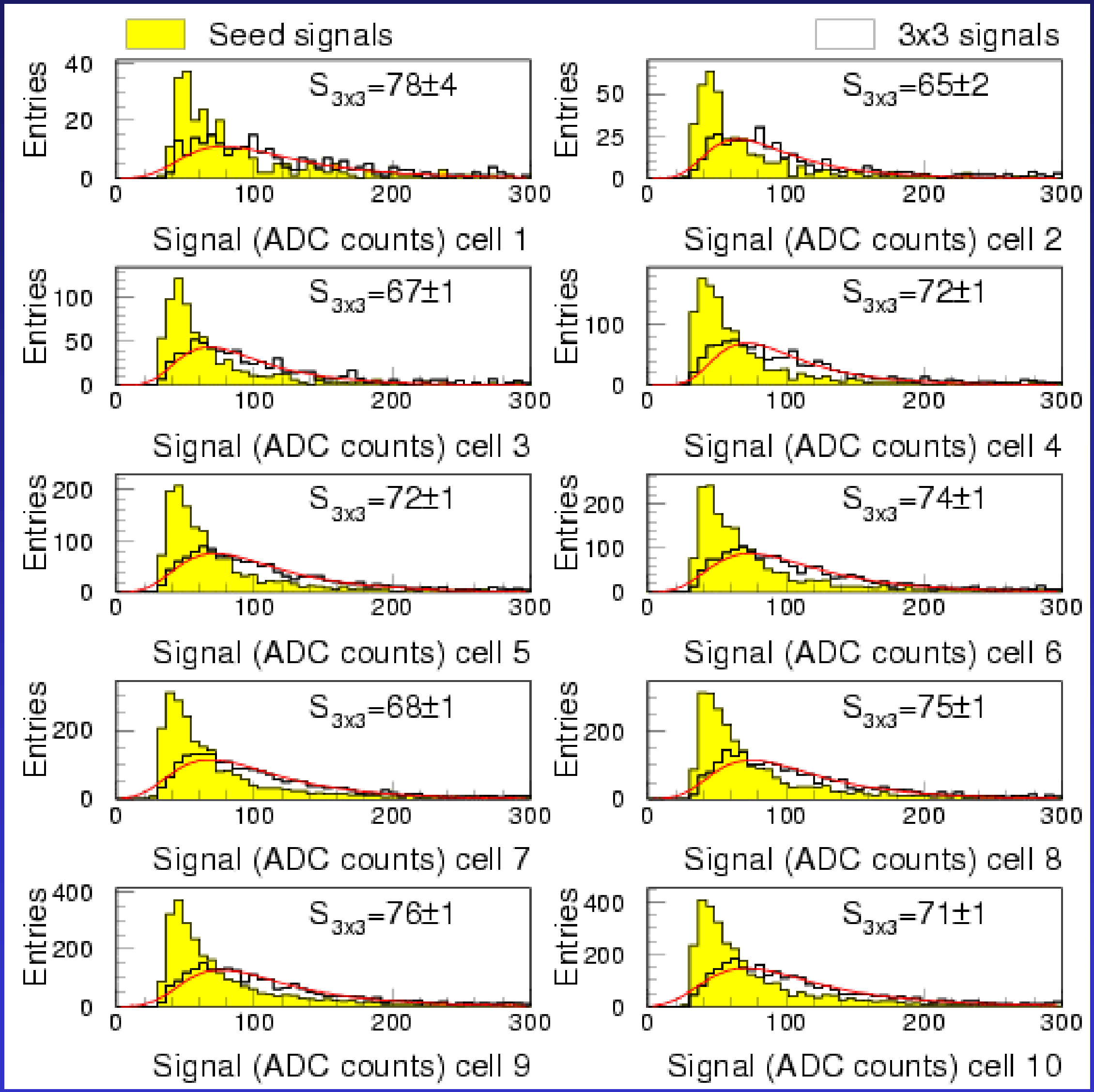




- FAPS=Flexible APS
  - Every pixel has 10 deep pipeline
- Designed for TESLA proposal.
  - Quick sampling during bunch train and readout in long period between bunch trains

FAPS source test

- Correlated Double Sampling readout (subtract $S_{cell\ 1}$)
- Correct remaining common mode and pedestal
- Calculate random noise
  - Sigma of pedestal and common mode corrected output
- Cluster definition
  - Signal >8σ seed
  - Signal >2σ next
- Note hit in cell *i* also present in cell *i+1*.
- S/N_{cell} between 14.7±0.4 and 17.0±0.3
  - Lower than 3MOSB, 19.6±0.3, due to larger noise (reason not yet understood)

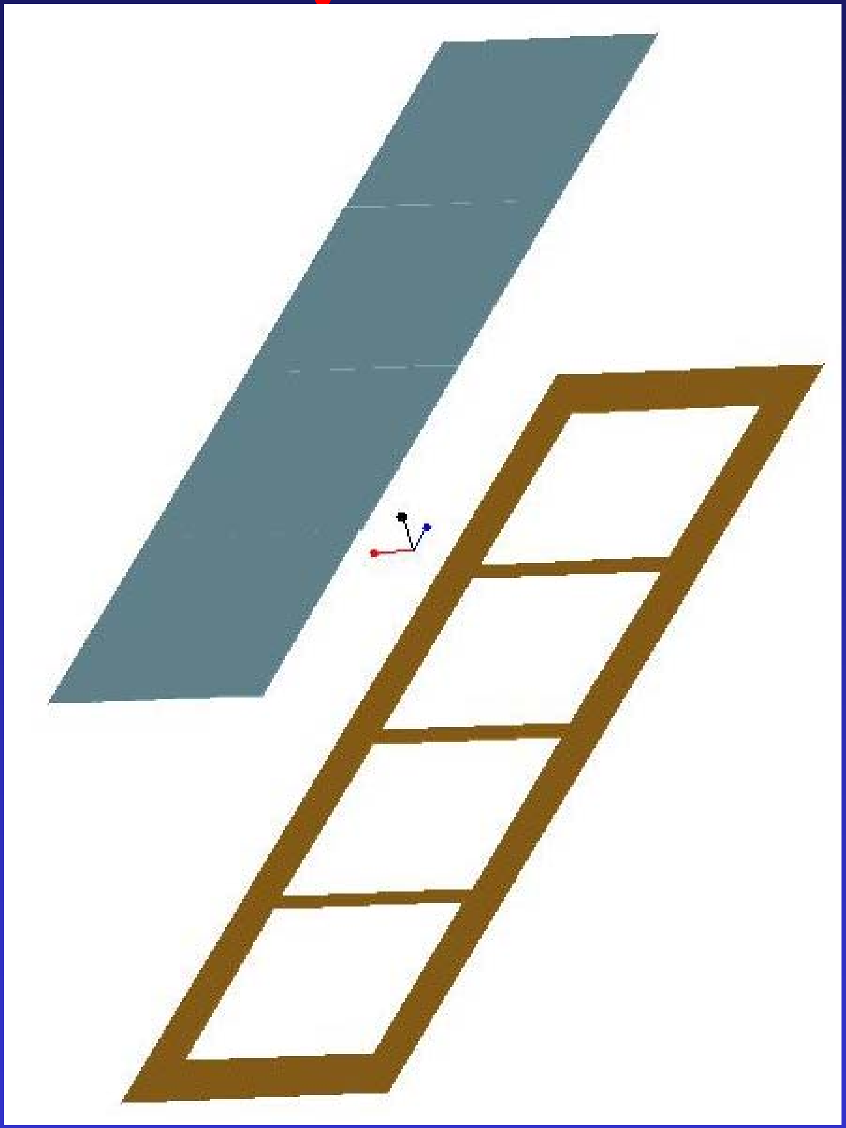


RALHEPAPS 4

- New large scale device will be submitted end of March
  - AMS 0.35 μm CMOS
  - 1024x384 pixels
  - 15 μm pitch (active area 15.4x5.8 mm^2)
  - Two versions because of design rules:
    - 4 small diodes in parallel
    - 2 larger diodes in parallel
  - 10-20 μm epi-layer
  - Readout speed designed for 5-10 MHz

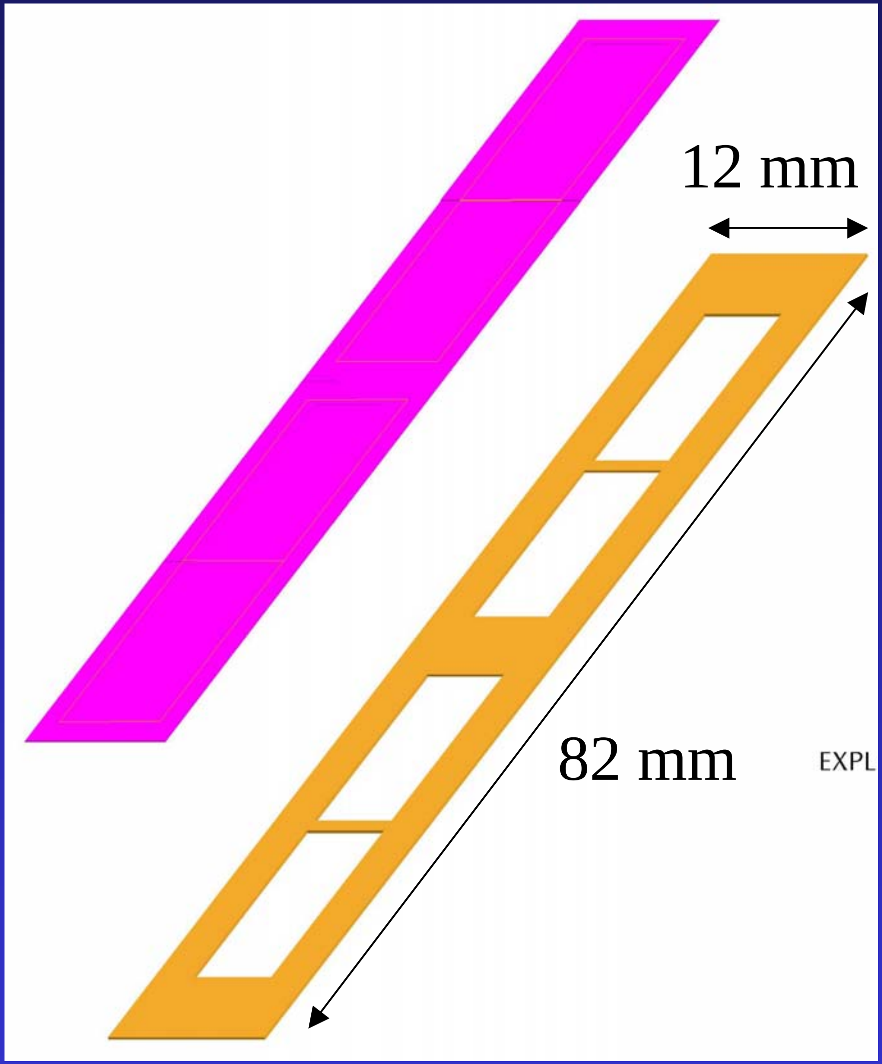
Ladder concept

- Idea:
  - 2 large MAPS sensors (trough stitching)
  - thinned down to 20-30 μm
  - operating close to room temperature on
  - thin CVD diamond ladder
- CVD diamond:
  - Very strong/stiff
  - Light/low radiation length
    - 100 μm thick diamond possible
    - Cut away diamond underneath sensitive area (heat mainly generated in periphery)
  - Excellent heat transport
    - Cooling by cold contact at edge of ladder



Ladder concept (II)

- Complication: CVD diamond available in various qualities (and prices).
  - Working on this with ElementSix (de Beers)
- Have ordered first test ladder to be equipped with APS4 to test idea.
  - Ladder will arrive beginning of May
  - Aiming for thinned APS4s by end of summer (e2v)



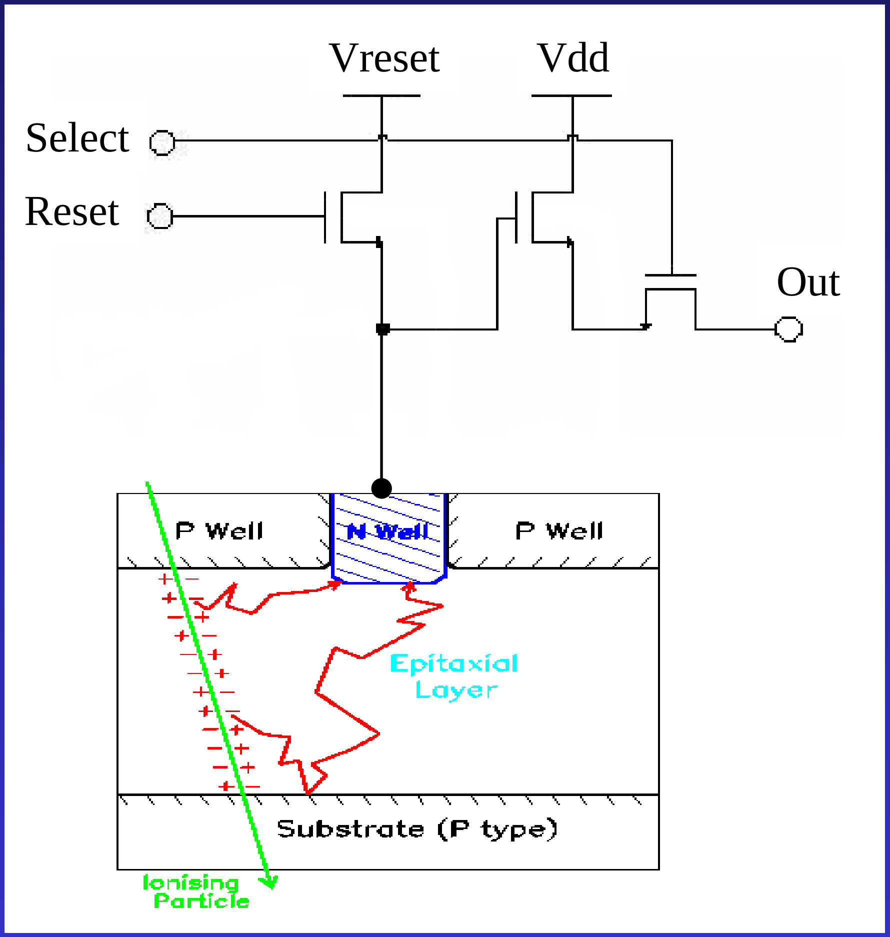
Conclusions

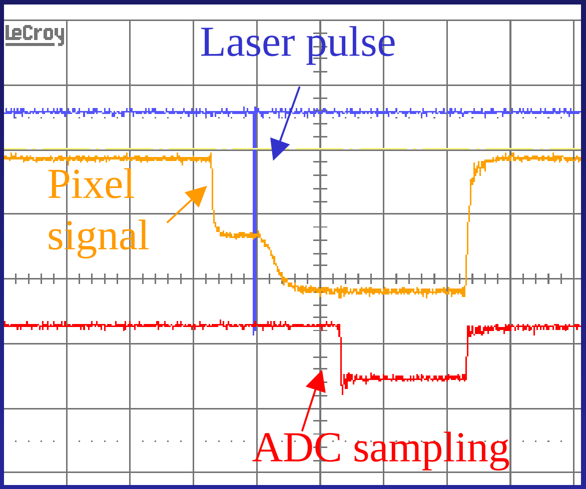
- Have successfully produced 3 test structures.
- On APS2 we have tested the 3MOS, 4MOS and FAPS.
  - Of the 12 3&4MOS structures 7 yield good S/N in source tests (S/N=15-20)
- Have performed an irradiation test up to 10^{15} p/cm^2.
  - 3MOS & 4MOS devices still operational after 10^{14} p/cm^2.
  - Especially 3MOSE (4 diodes) seems to operate reasonably well up to 10^{14} p/cm^2.
  - Observed no significant increase in leakage current (at –20 °C).
- FAPS (10 deep pipeline in each pixel) working fine!
  - S/N_{cell} between 14.7 ± 0.4 and 17.0 ± 0.3

Outlook

- Done a test beam in February 2005. Analysis is still in progress.
- New large scale device RALHEPAPS4 will be submitted soon:
  - 1024x384 pixels
  - 15 μm pitch (active area 15x6 mm^2)
  - >10 μm epi-layer
  - Two versions: 4 and 2 diodes in parallel
- We are working on a ladder concept based on CVD diamond
  - First prototype will be delivered beginning of May

Monolithic active pixels



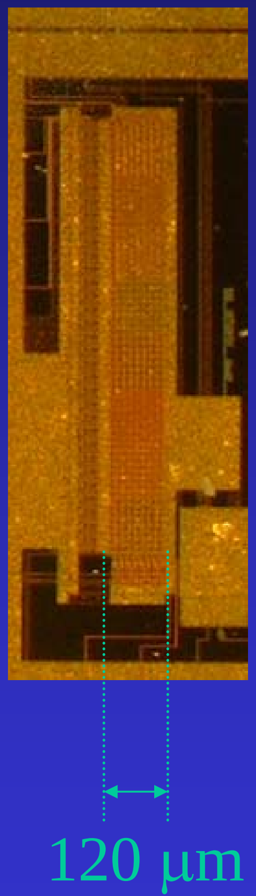


- Epitaxial layer forms sensitive volume (2-20μm)
- Charge collection by diffusion
- Charge collected by N-well

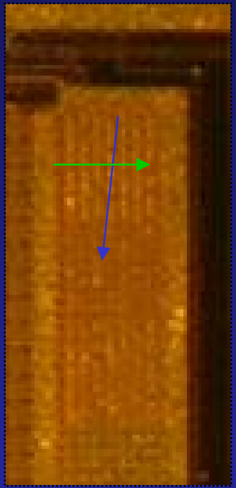
APS1

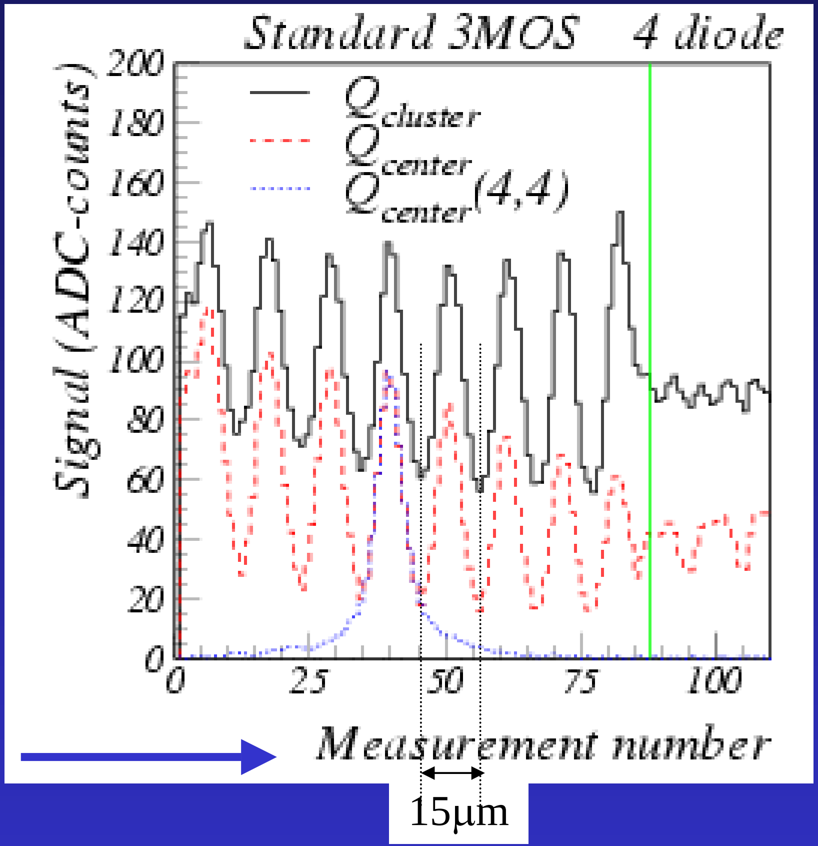
- Eight 8*8 arrays (15 μm pitch)
  - Baseline 3MOS pixel
  - 4 diode
  - 4MOS (CDS)
  - Baseline with cal
  - (4 Photogate pixels)
- 2 μm epi-layer
- 0.25 CMOS IBM

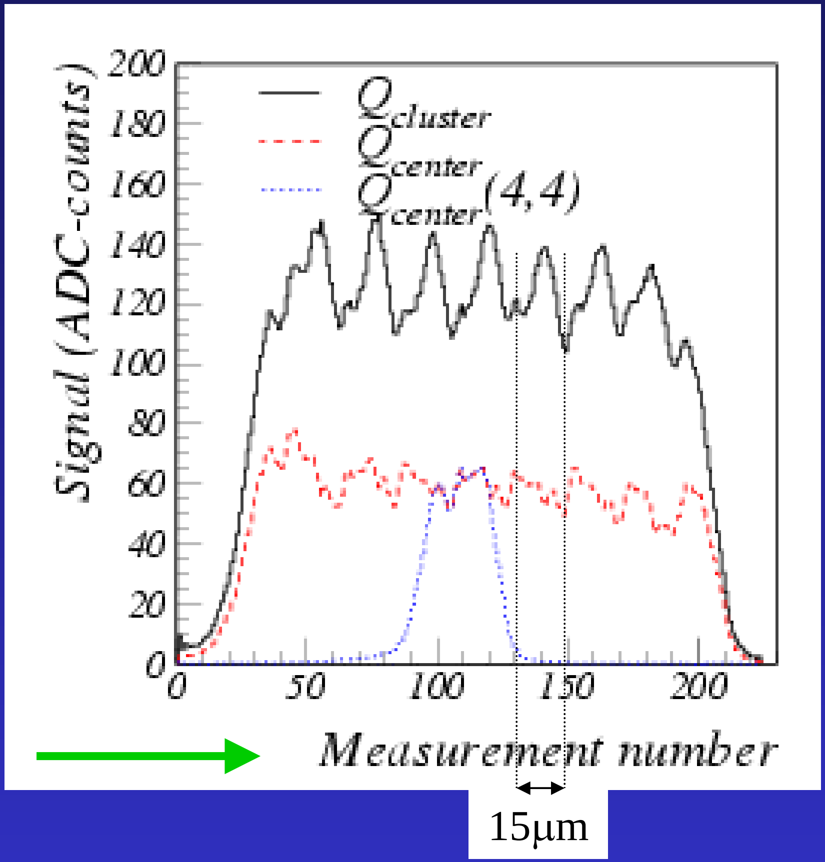
Design: R. Turchetta (RAL)



APS1 Laser scan





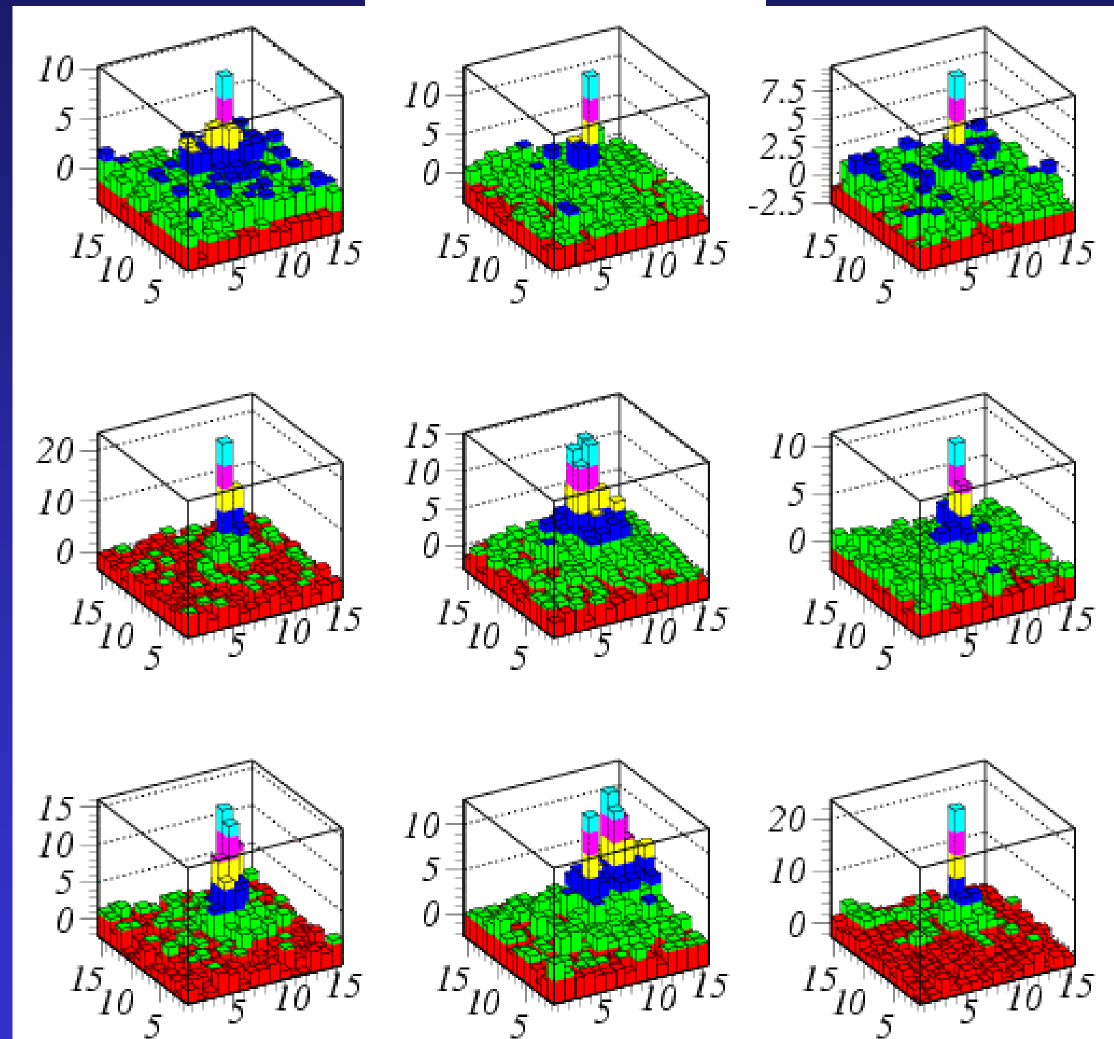


- Scan using laser along arrows
- Laser spot: σ=7μm
- Effects of metal structure clearly visible

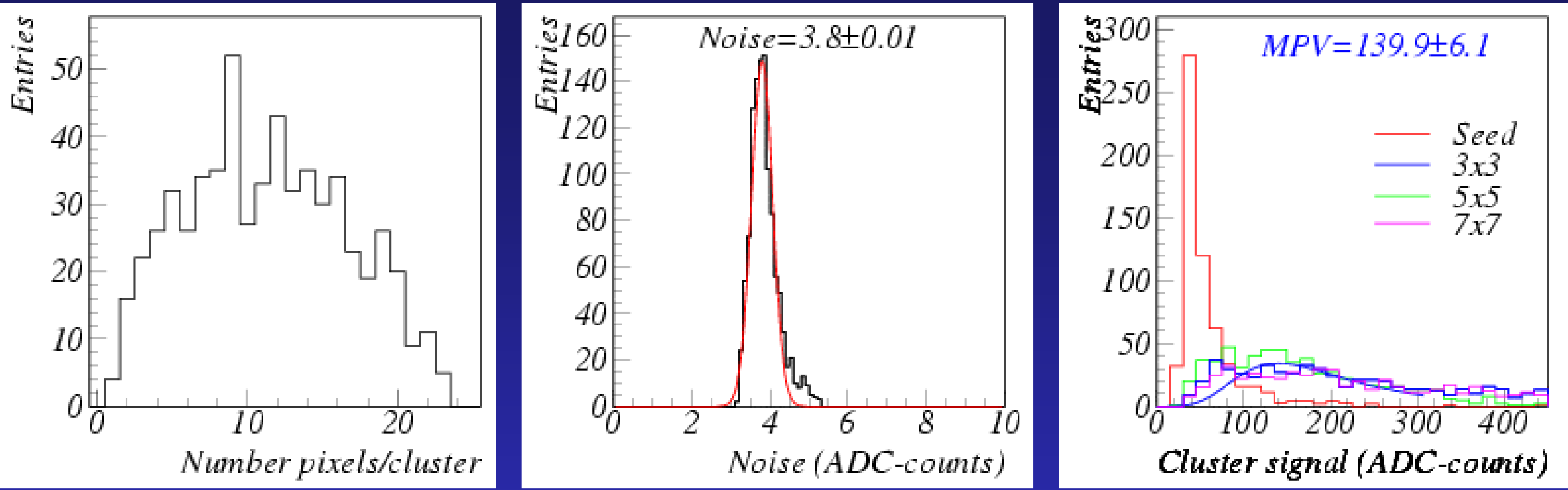
APS3: std 3MOS

- Designed in TSMC 0.25μm Mixed Signal CMOS.
- Diode 1.8*1.8 μm
- No epi-layer
  - Large clusters
  - Large signals

Cluster in S/N



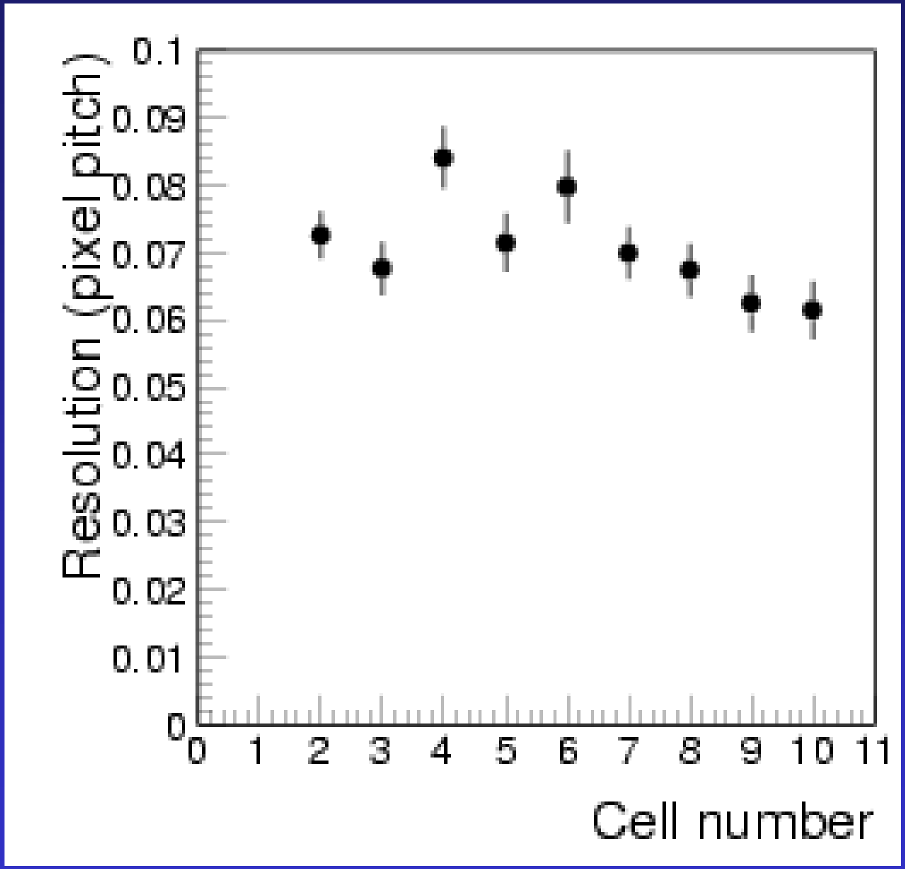
APS3: std 3MOS source test



- Huge cluster size
- Large signals
- Fit does not describe data very well (5x5 clusters) but most probable value estimate reasonable
  - $S/N_{3x3}=30.7\pm0.8$
  - $S/N_{5x5}=37\pm2$

FAPS Hit resolution

- Hit Resolution≠spatial resolution!!!
- Take hits found in cell 2
- Reconstruct x and y each cell using Centre-of-Gravity
- Calculate average hit position
- Determine residual position for each memory cell
- Hit resolution approximately 1.3 μm



FAPS efficiency estimate

- Find hits in all cells
- Plot max S/N_{pixel} in 3x3 area around expected hit position if hit not found
- Define:

$$Missed = \frac{\#\,missed\ seed\ cut}{\#\,seeds\,cell\,(i-1)}$$

- Clearly, strongly dependent on seed cut. Lowering seed cut to 5σ yields inefficiency ranging between 0.08±0.08% and 0.5±0.1%