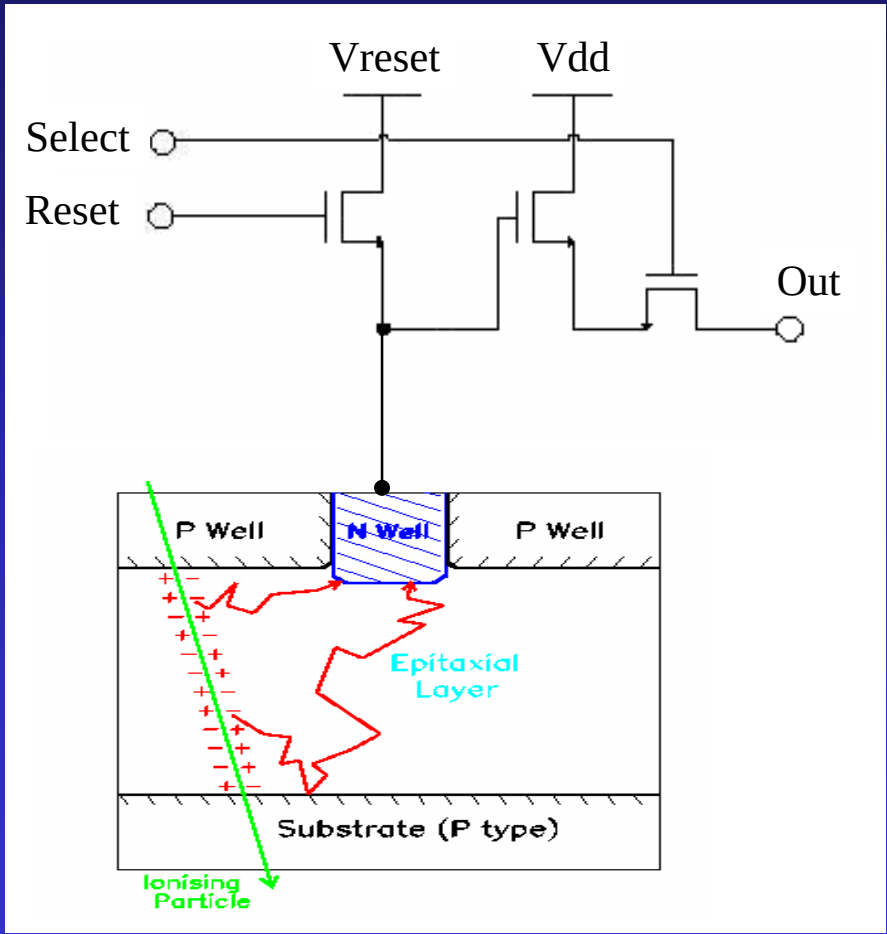
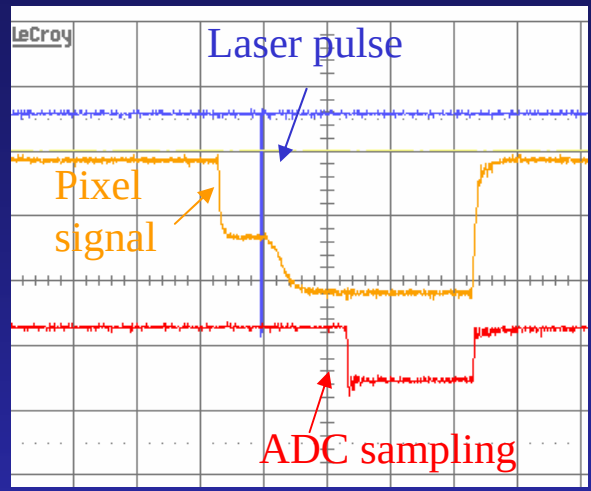
CMOS sensor in 0.25 μm technology

P.P. Allport, G. Casse, A. Evans, R. Turchetta, J.J. Velthuis, G. Villani

- MAPS
- APS1
- APS2
  - Source tests
  - Radiation test
  - FAPS
- APS3 non epi
- Summary & Outlook

Monolithic active pixels





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

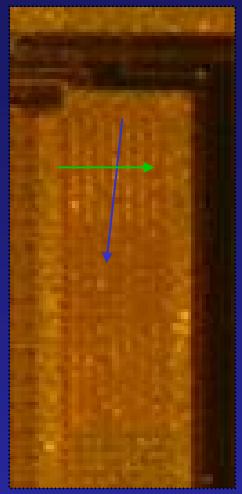
APS1

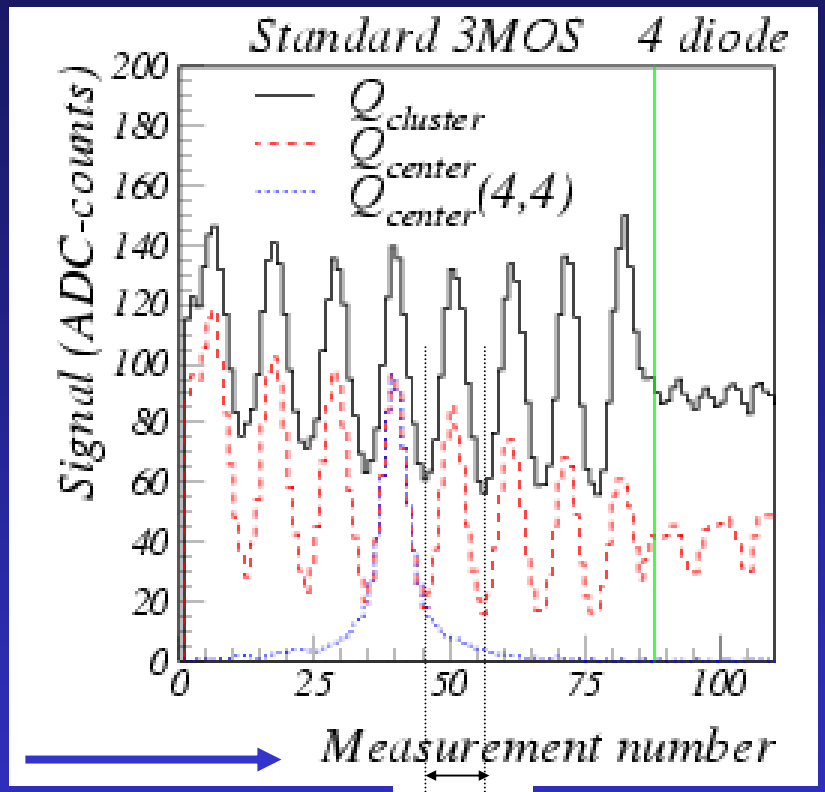
- Eight 8*8 arrays (15 μm pitch)
  - Baseline 3MOS pixel
  - 4 diode
  - 4MOS (CDS)
  - Baseline with cal
  - (4 Photogate pixels)
- 2 μm epi-layer
- 0.25 CMOS IBM

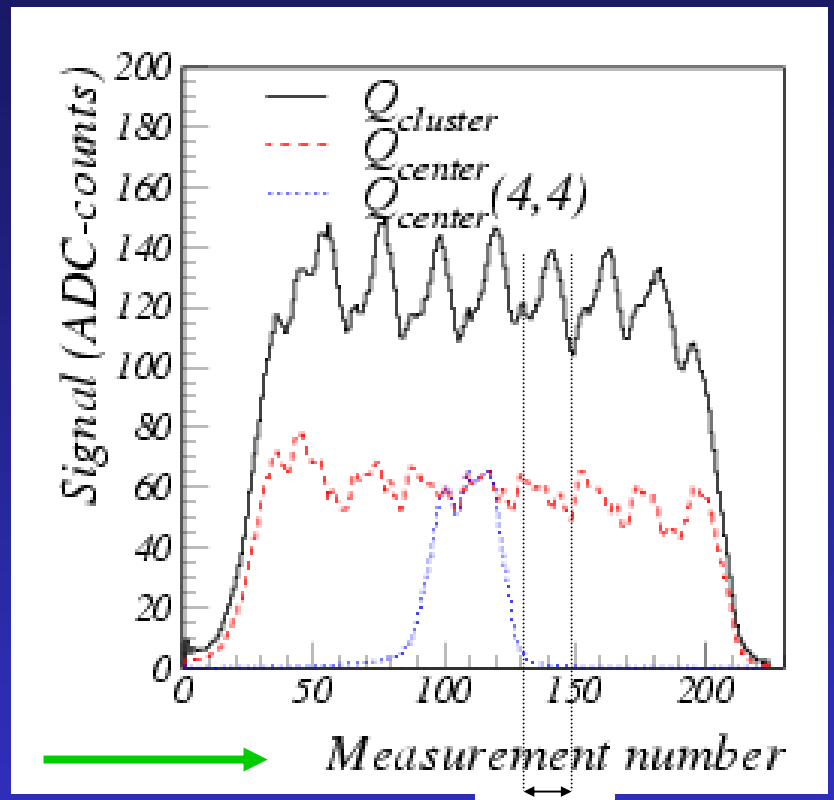
Design: R. Turchetta (RAL)

120 μm

APS1 Laser scan





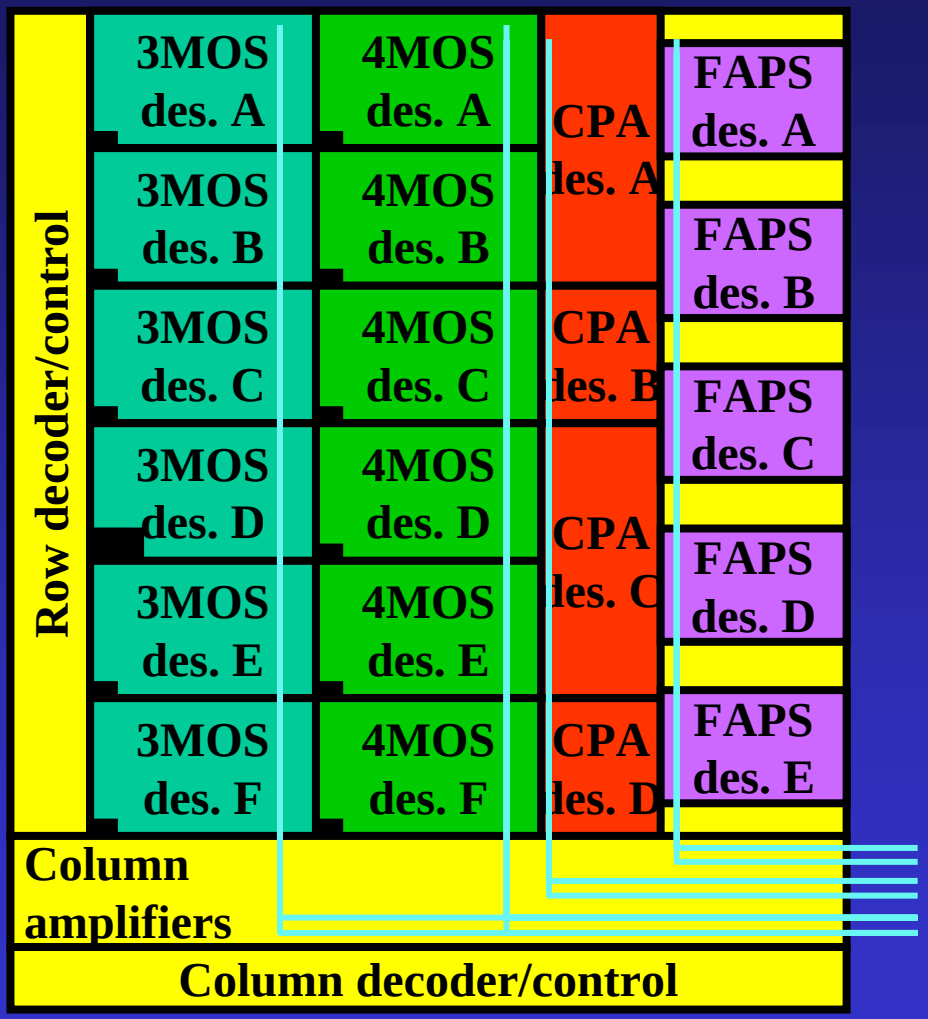


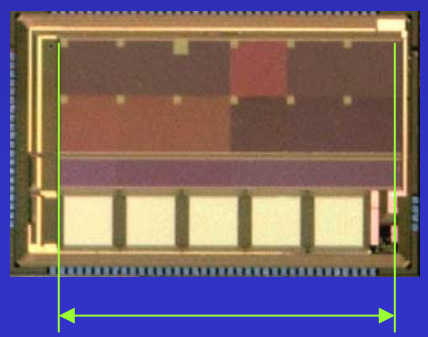
- Scan using laser along arrows
- Laser spot: σ=7µm
- Effects of metal structure clearly visible

APS2

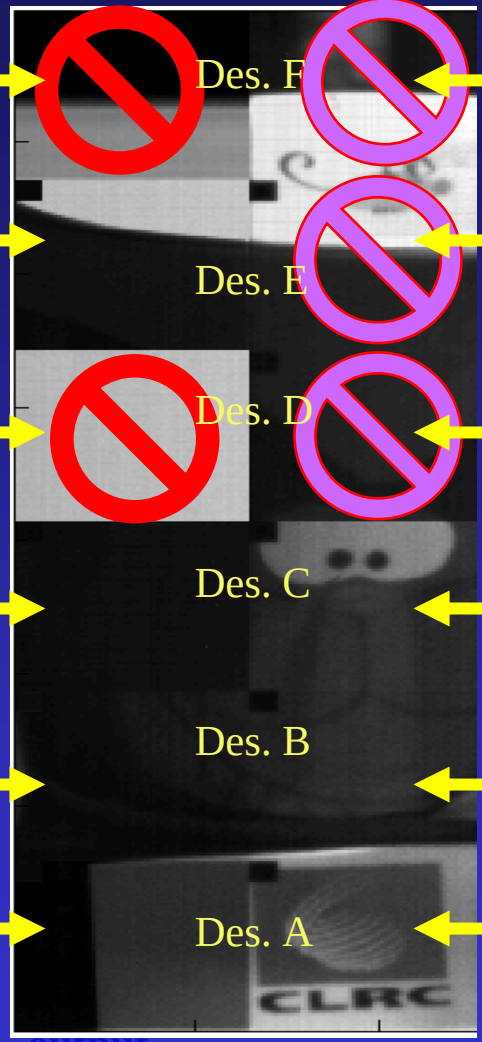
- 4 pixel types, various flavours
  - Std 3MOS
  - 4MOS (CDS)
  - CPA (charge amp)
  - FAPS (10 deep pipeline)
- 3MOS & 4MOS: 64x64, 15μm pitch, 8μm epi-layer ⇒ MIP signal ~600 e-

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)

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

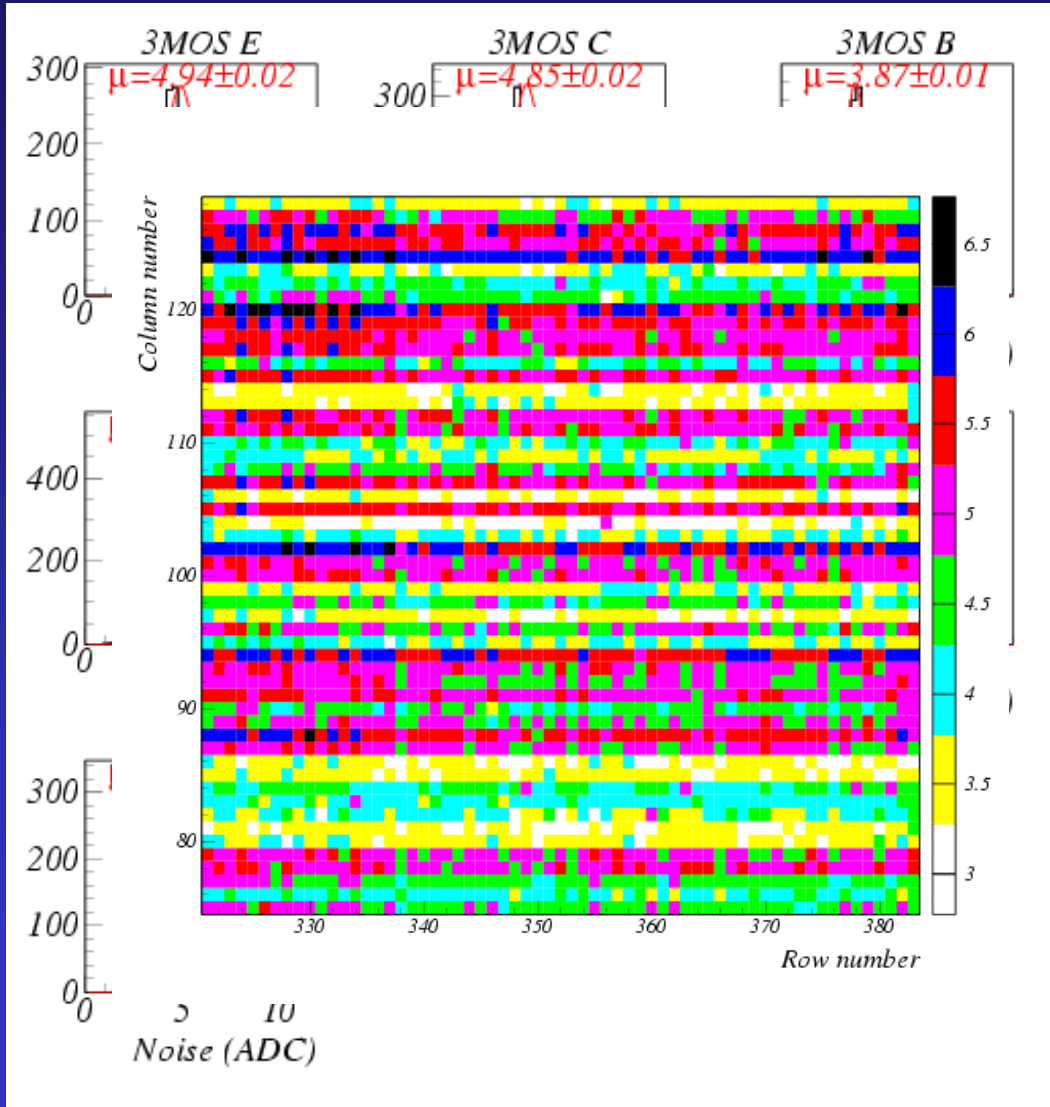
3MOS 4MOS

Production error

Gain too low

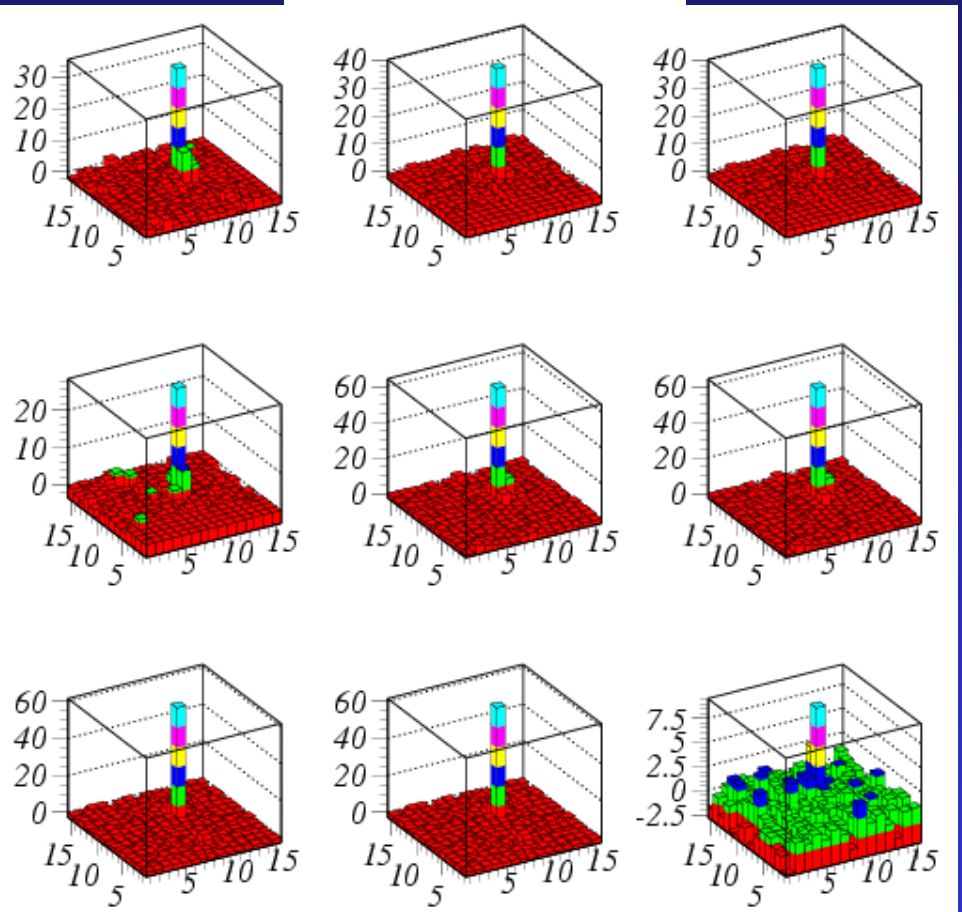
APS2: Source test

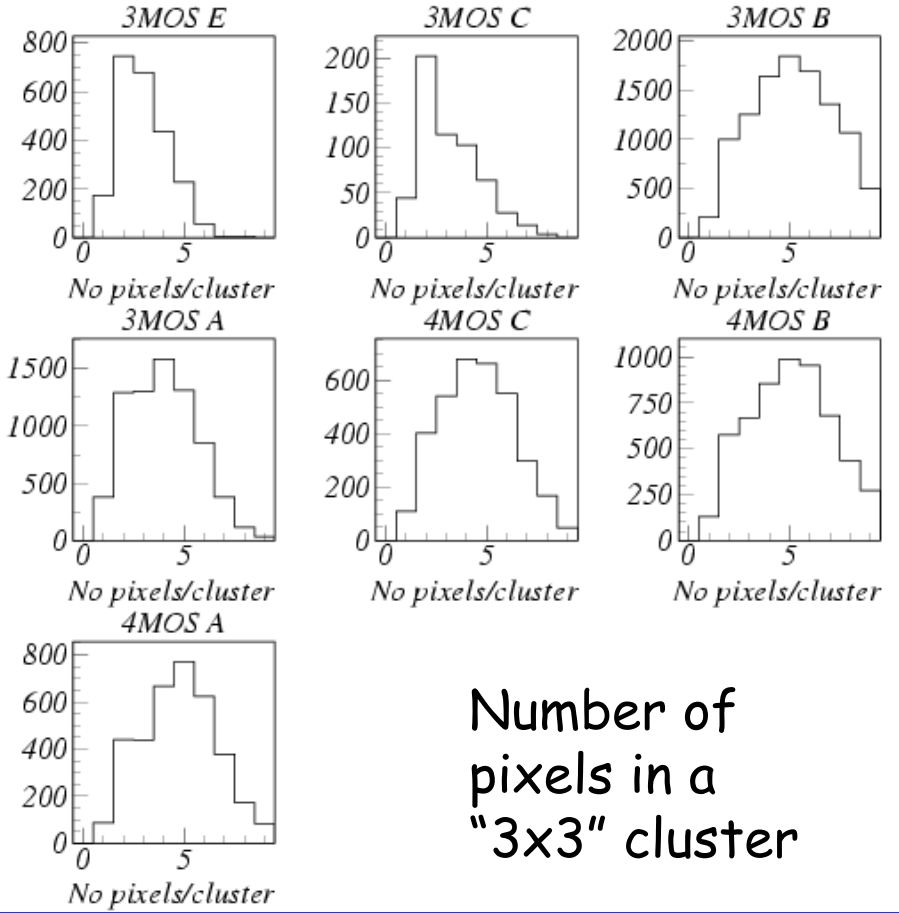
- Here only use 3MOS and 4MOS (no CDS)
- Calculate pedestals
  - Average output after removing hits
- Calculate common mode noise
  - Average pixel type output after pedestal subtraction
- Calculate random noise
  - Sigma of pedestal and common mode corrected output
- Cluster definition
  - Signal >8σ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



APS2: Some Clusters

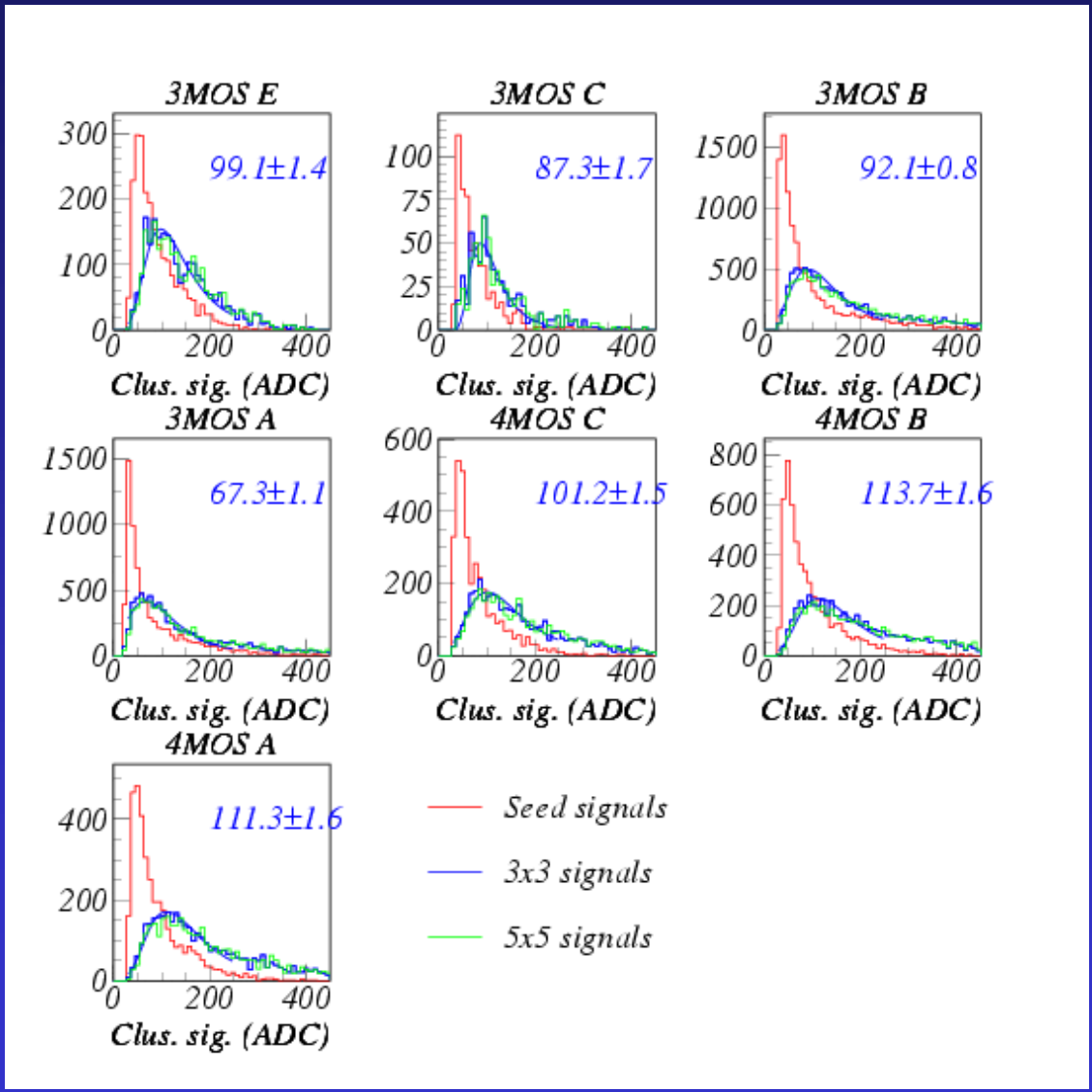
Cluster in S/N





Number of pixels in a "3x3" cluster

APS2: Cluster signals

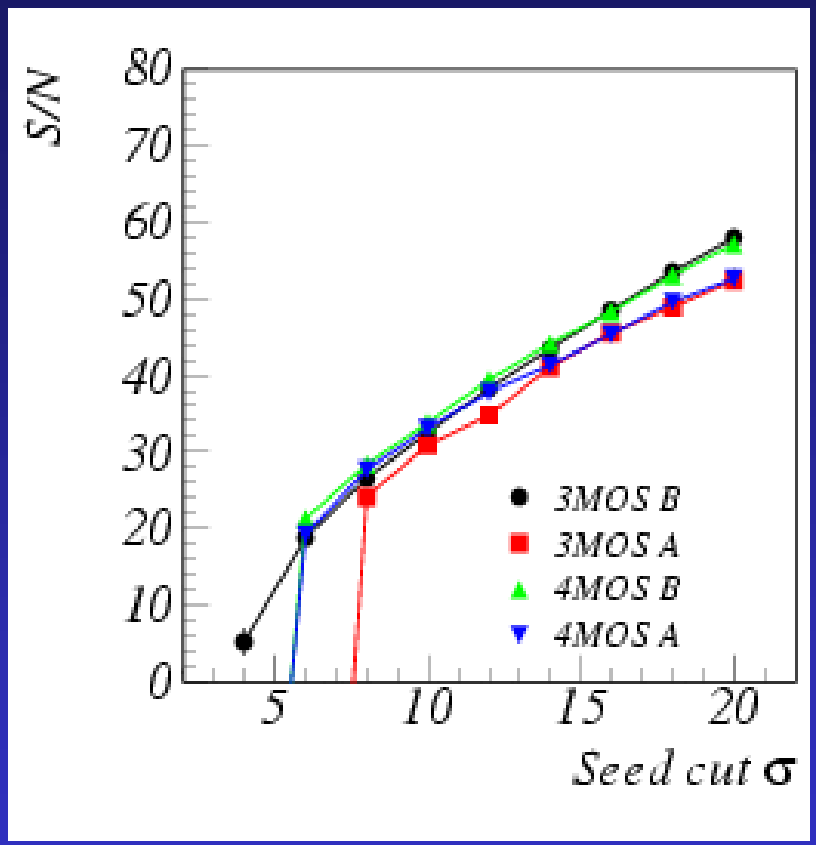


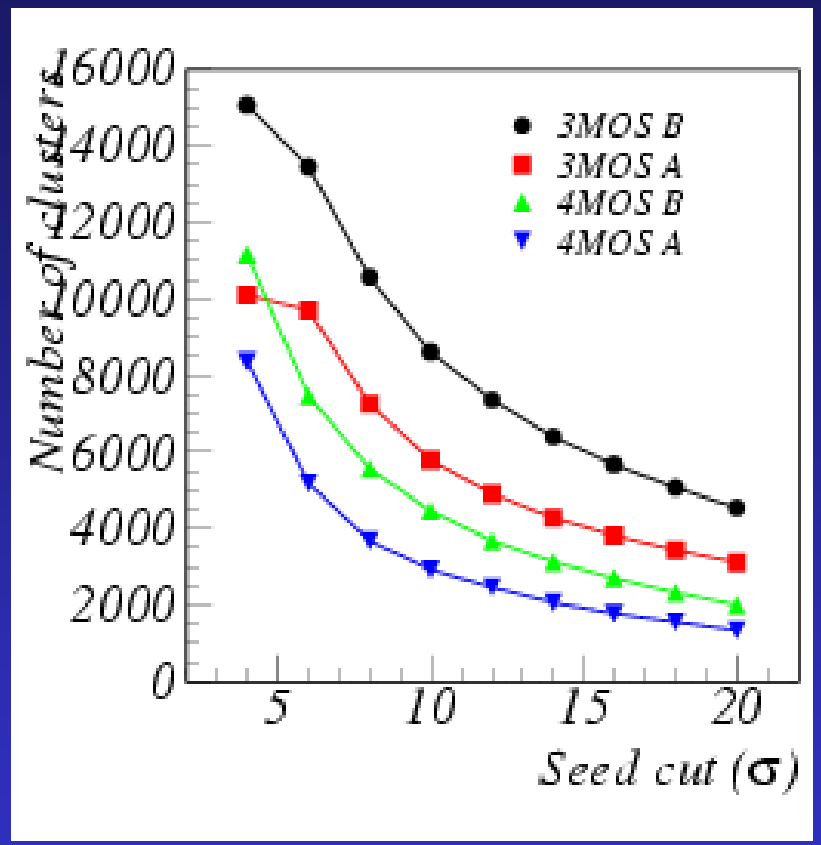
APS2 3&4 MOS summary

Type	Specs	S	N	S/N
3MOS E	4 diodes	99±1	4.94±0.02	20.1 ±0.3
3MOS C	GAA	87±2	4.85±0.02	18.0 ±0.4
3MOS B	Diode 1.2x1.2	92±1	3.87±0.01	23.8 ±0.2
3MOS A	Diode 3x3	67±1	3.31±0.01	20.3 ±0.3
4MOS C	Lower V_T	101±2	4.14±0.02	24.4 ±0.4
4MOS B	Higher V_T	114±2	4.70±0.02	24.2 ±0.4
4MOS A	Reference	111±2	4.45±0.02	25.0 ±0.4

- Out of 12 substructures 7 display good S/N.
- Two structures problems in fabrication.
- 4MOS GAAs have too low S/N for MIPs.
- Need test beam experiment:
  - Seed cut determines S/N result
  - Efficiency not uniform

Effect seed cut on signal

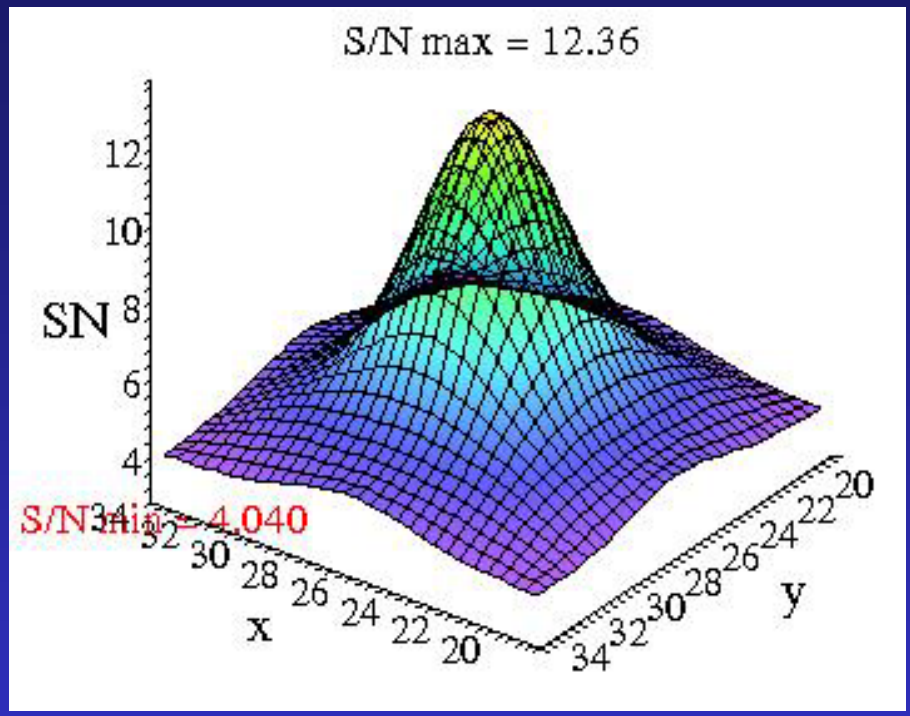


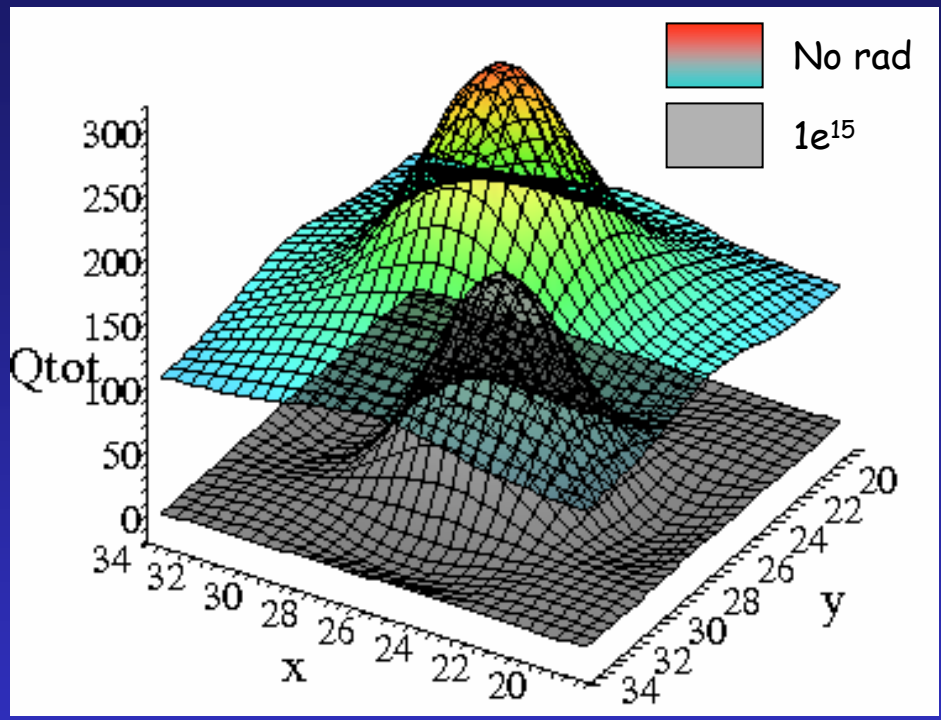


- Measured S & S/N highly dependent on seed cut (efficiency vs purity)

S/N uniformity

Simulation: G. Villani (RAL)





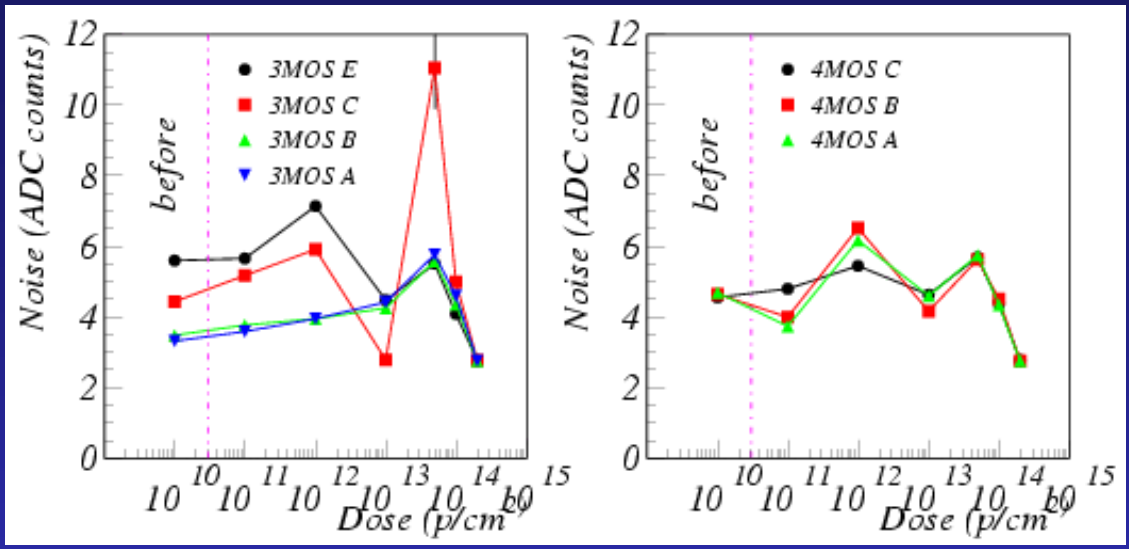
- S/N varies over pixel between 12 and 4 before irradiation.
- S drops to zero at edges after $1e^{15}$ p/cm^2.

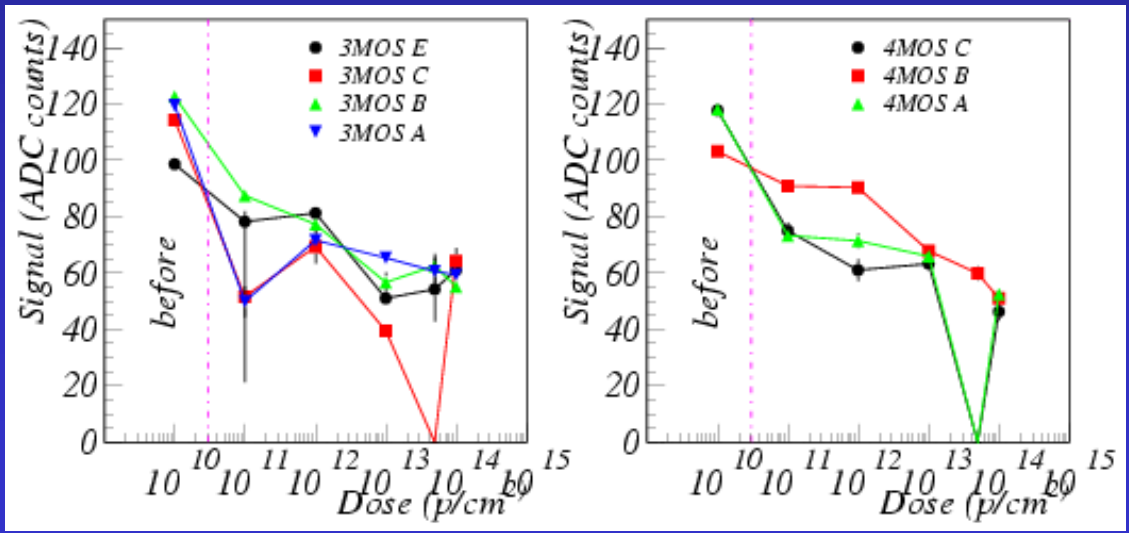
Radiation test

- Irradiated APS2 up to 10^{15} p/cm^2 at CERN.
- So far only time to test 1 chip at each dose.
- Repeat analysis at each dose with same cuts
  - Seed >8σ
  - Neighbour >2σ

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

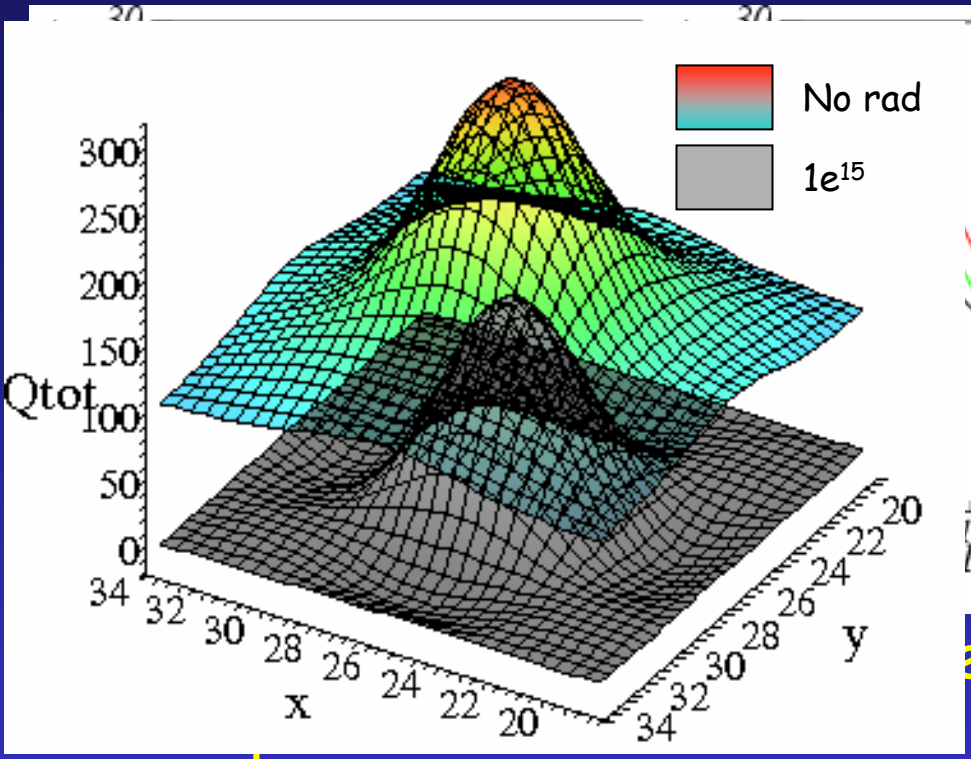
Radiation test (II)

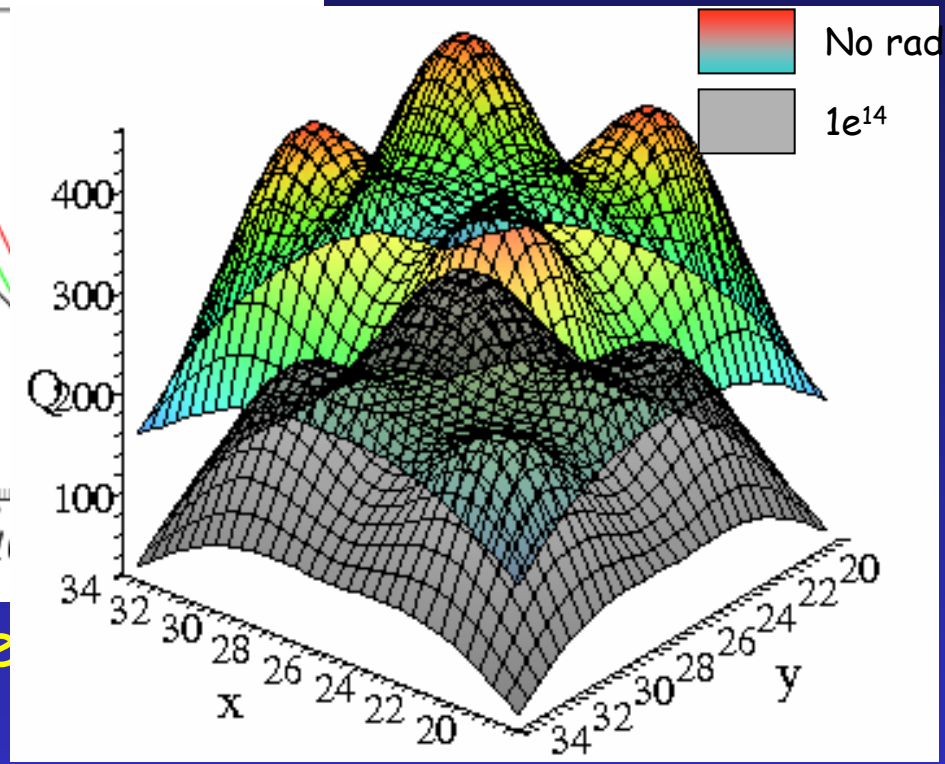




- Noise seems to increase slightly with dose until 5×10^{13} p/cm^2.
  - Noise decrease might be due to decrease in gain.
- Signal decreases with dose.
- Note: 3MOSE (4 diodes/pixel)
  - No noise increase
  - Signal decrease relatively small

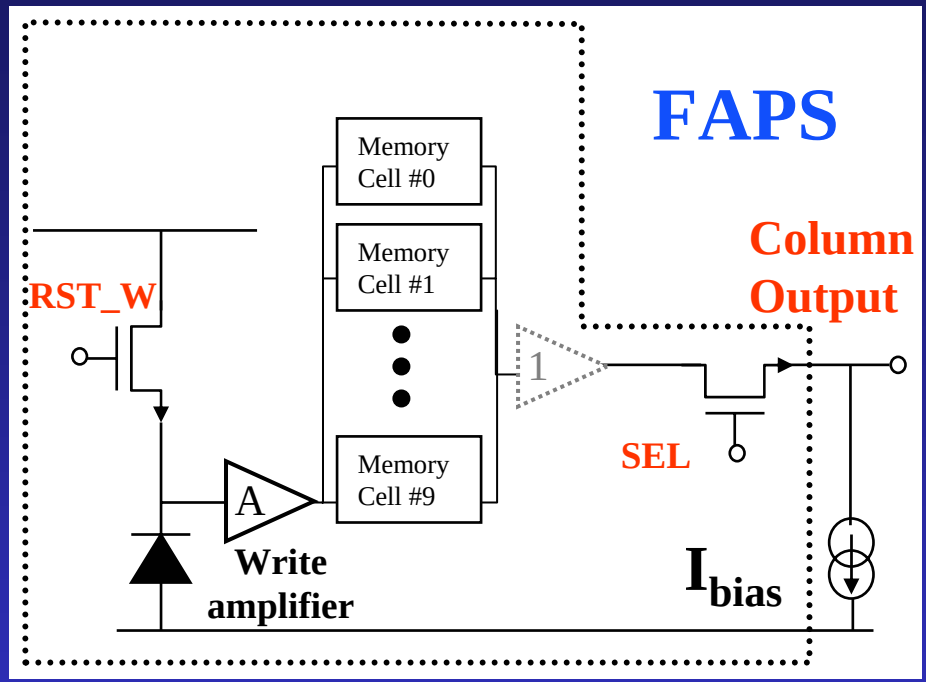
Radiation test (III)

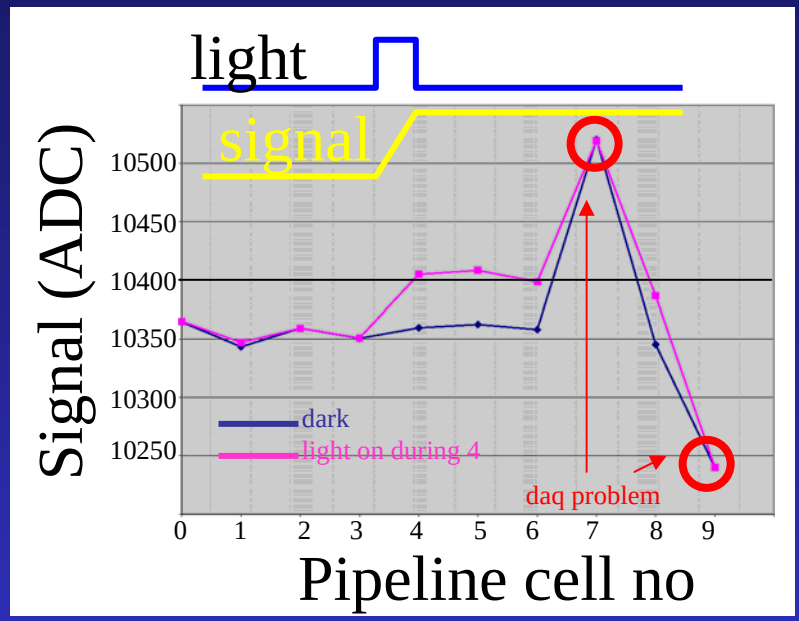




  - No efficiency measurement
- Especially 3MOSE (4 diodes) looks good
  - Larger capacitance yields larger noise
  - But after irradiation larger "sensitive area"
- Need more statistics and testbeam data

FAPS

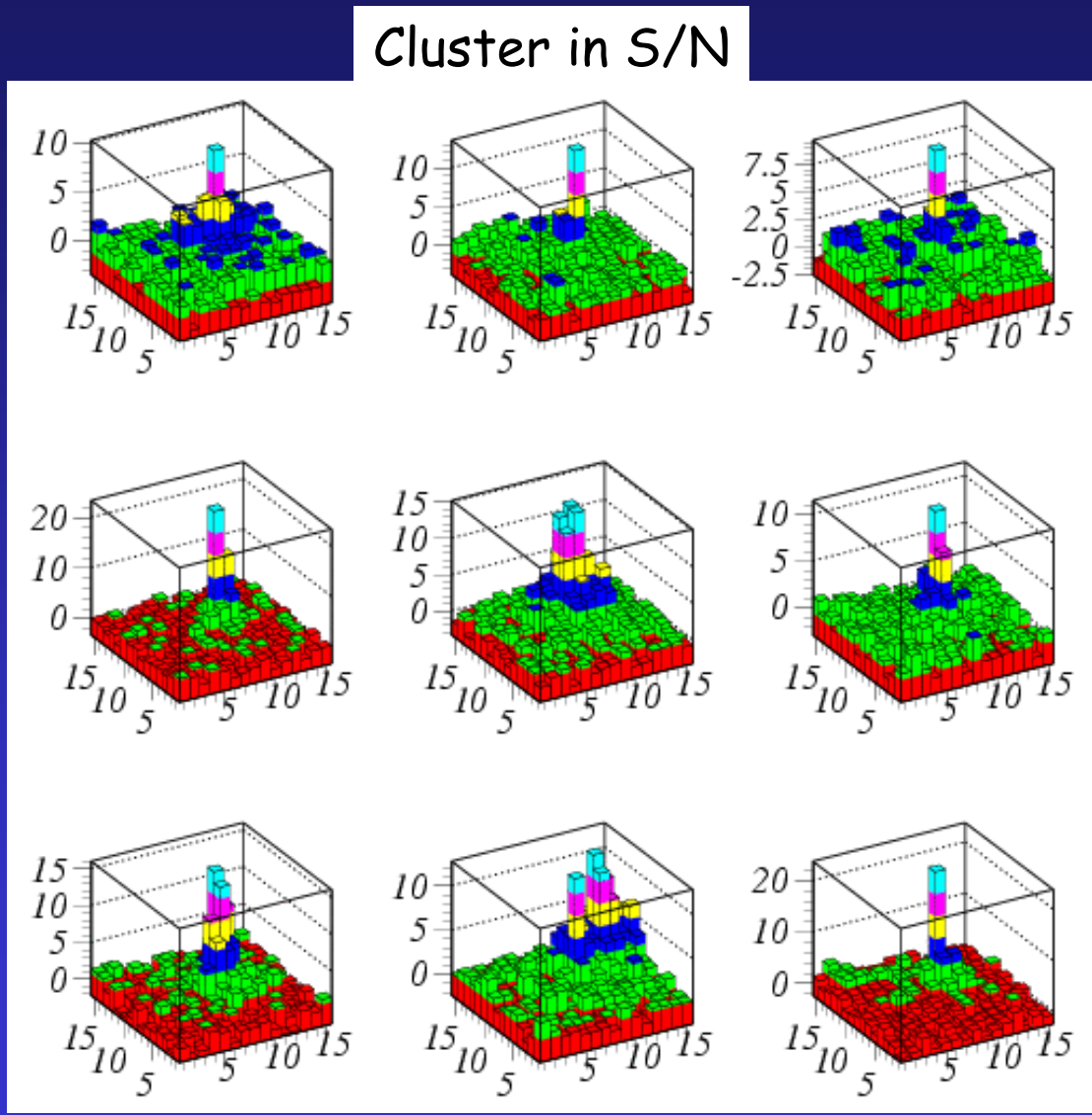




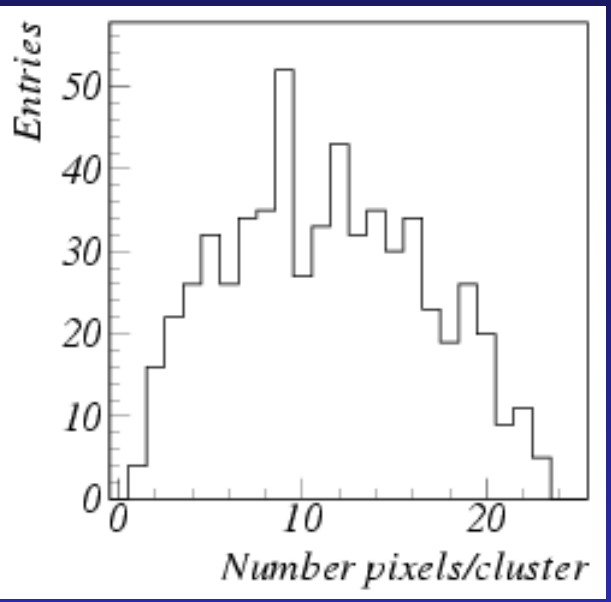
- FAPS=Flexible APS
  - Every pixel has 10 deep pipeline
- Data example using pulsed diode: proof of principle.
- No source results yet.

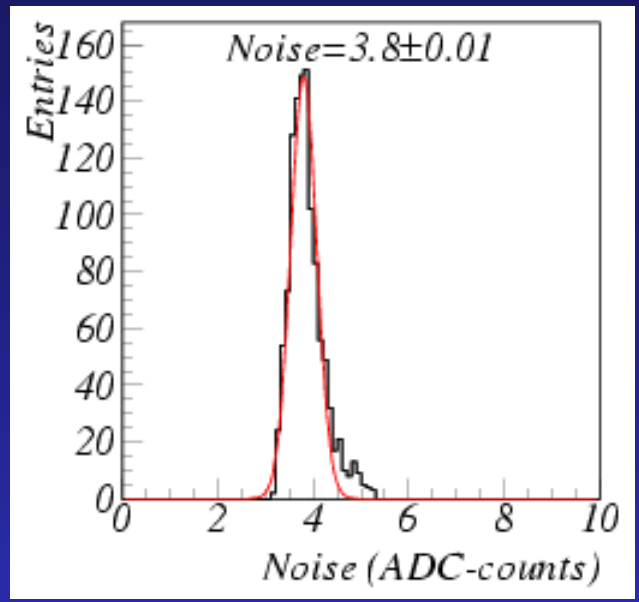
APS3: std 3MOS

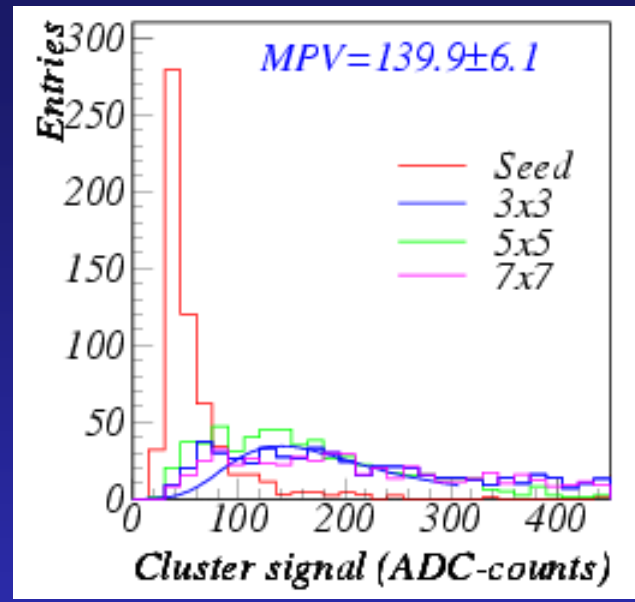
- Designed in TSMC 0.25μm Mixed Signal CMOS.
- Diode 1.8*1.8 μm
- No epi-layer
  - Large clusters
  - Large signals



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
  - $S/N_{3x3}=30.7\pm0.8$
  - $S/N_{5x5}=37\pm2$

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=18-25)
    - 2 have fabrication problem (resubmitted)
    - 3 4MOS GAAs have too low S/N for MIPs
  - Have performed an irradiation test up to 10^{15} p/cm^2. Especially 3MOSE (4 diodes) seems to operate reasonably well up to 10^{14} p/cm^2.
  - Demonstrated proof of principle for FAPS. No source results yet.
- APS3 has no epi-layer
  - Yields large clusters
  - Very high S/N (for 5x5 clusters S/N=37±2)

Outlook

- Different reset and read out techniques (e.g. CDS) are currently under study.
- More irradiation test results to come.
- Will go for test beam in February 2005.
- Source measurements with the FAPS.

- New large(r) scale device is planned for spring 2005.