7th International Conference on Position Sensitive Detectors – PSD7

Liverpool (UK), 12-16 September 2005

R&D on MAPS for High Energy Physics

P.P. Allport[b], R. Bates[c], G. Casse[b*], J. Crooks[a], A. Evans[b], L. Jones[a], V. O'Shea[c], R.Turchetta[a*], M.Tyndel[a], J.J. Velthuis[b], G. Villani[a], F. Zakopoulos[a]

[a] Rutherford Appleton Laboratory, United Kingdom

[b] University of Liverpool, United Kingdom

[c] University of Glasgow, United Kingdom

Presented by Renato Turchetta

CCLRC - RAL

Outline

Introduction. *Monolithic Active Pixel Sensors (MAPS) aka CMOS sensors* for imaging.

Requirements

Results

- **Noise**
- **Radiation hardness**
- **CMOS sensors with in-pixel storage: Flexible APS (FAPS)**

Conclusions

CMOS Image Sensors aka Monolithic Active Pixel Sensor (MAPS)

CMOS sensors for imaging, introduced in early '90s.

At the beginning, CMOS sensors used for low-end applications

Constant improvement in the technology: noise, QE, … → CMOS sensors widely used in high-end consumer and prosumer cameras

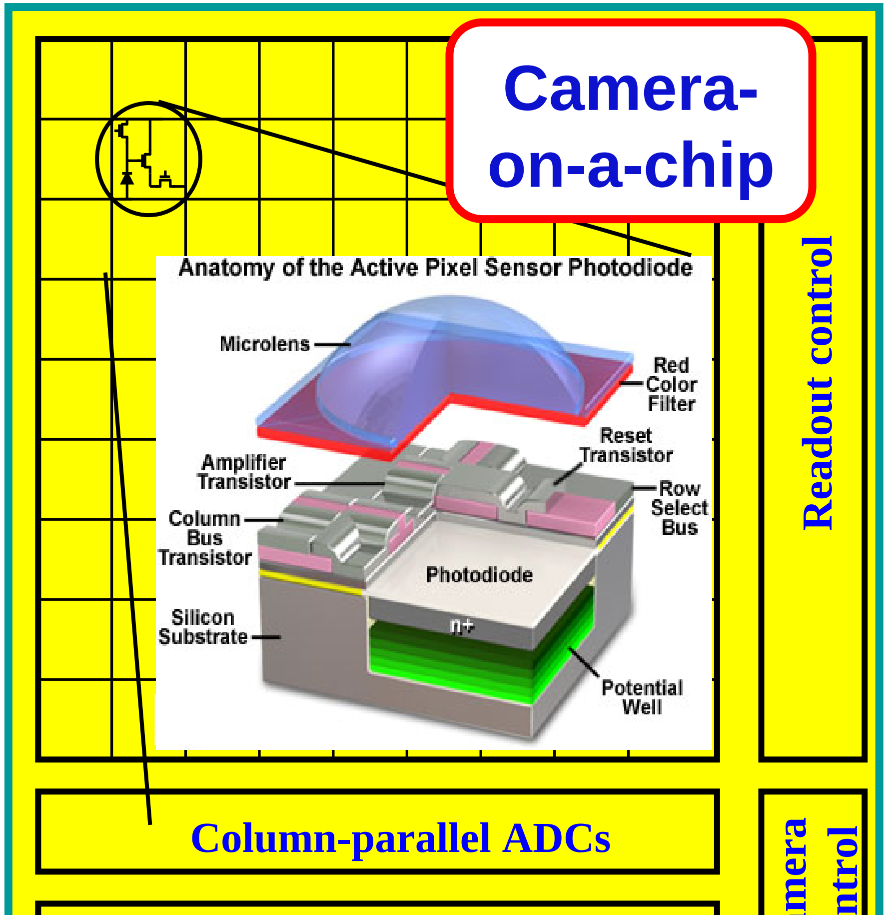
For high-speed imaging (industrial, HDTV, …) CMOS sensors have already the best performance in terms of noise.

All major players in imaging field are improving the technology.

IEEE Workshop on CCD and Advanced Image Sensors → IEEE Workshop on Image Sensors

CMOS Monolithic Active Pixel Sensor

- **Standard CMOS technology**
- **all-in-one detector-connection-readout = *Monolithic***
- **small size / greater integration**
- **low power consumption**
- **radiation resistance**
- **system-level cost**
- **Increased functionality**
- **increased speed (column- or pixel- parallel processing)**

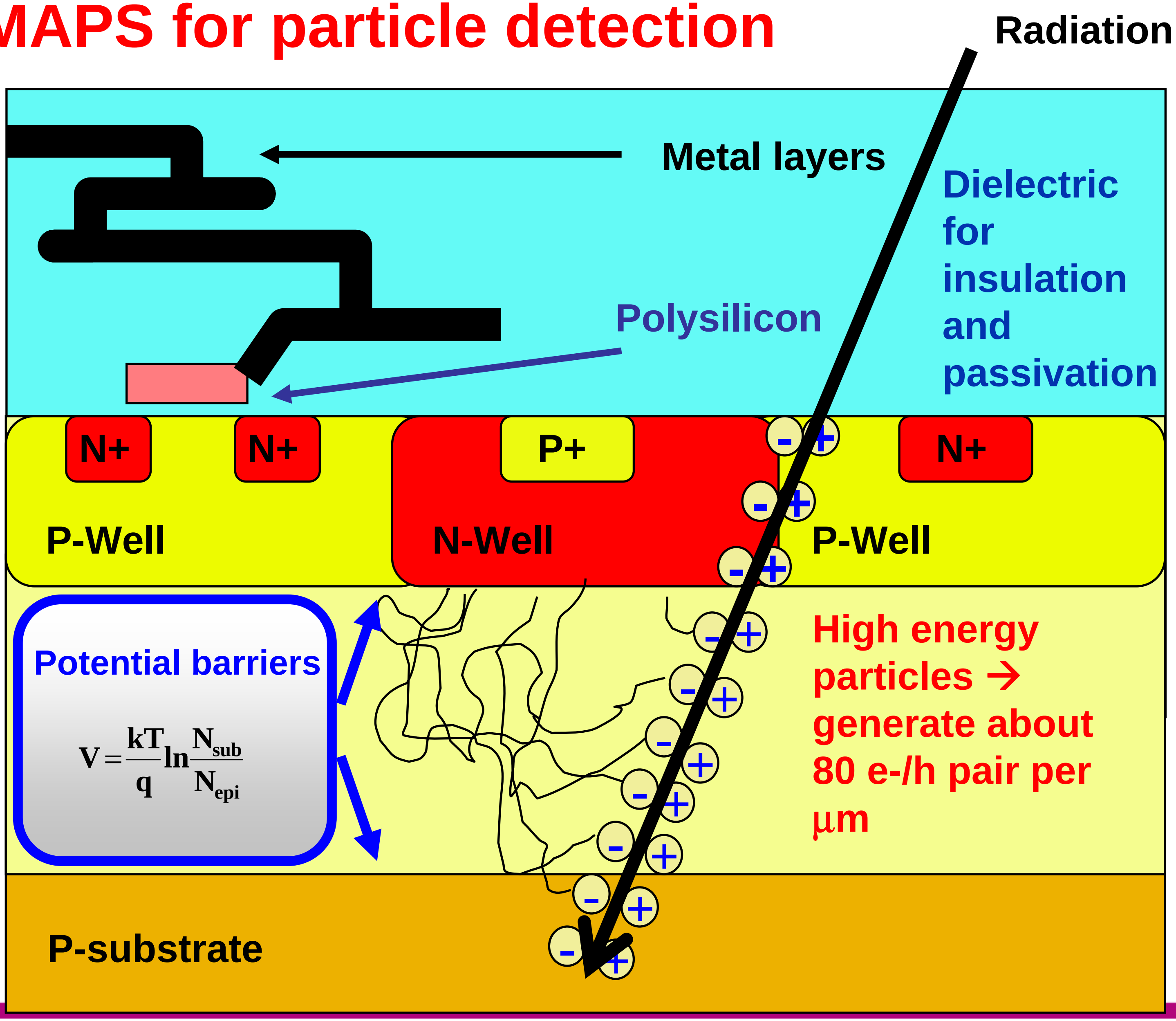


What is needed for Particle Physics ?

MAPS for particle detection

Requirements

1) Efficiency: 100% or close
2) Noise: signal ~ 100s e-/h pairs
3) Radiation hardness: Mrad and beyond
4) Speed: 'frame rate' > 10^6/sec
5) Large area: side ~ cm's



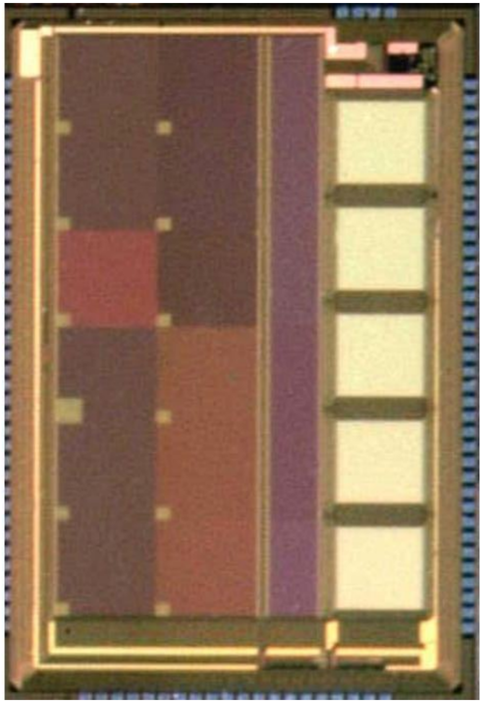
RAL Sensors for Particle Physics

UK collaboration to develop MAPS for Particle Physics and Space Science (also Leicester/Brunel, Birmingham)

Parametric test sensor: RAL_HEPAPS family

RAL_HEPAPS1: 0.25 µm, 2 µm (!) epitaxial layer, 64*8 pixels, 15 µm pitch: 3MOS, 4MOS

RAL_HEPAPS2: 0.25 µm CIS, 8 µm epitaxial layer, 384*224 pixels, 15 µm pitch: 3MOS, 4MOS, ChargePreAmplifier (CPA), Flexible APS (FAPS, 20 µm pitch)

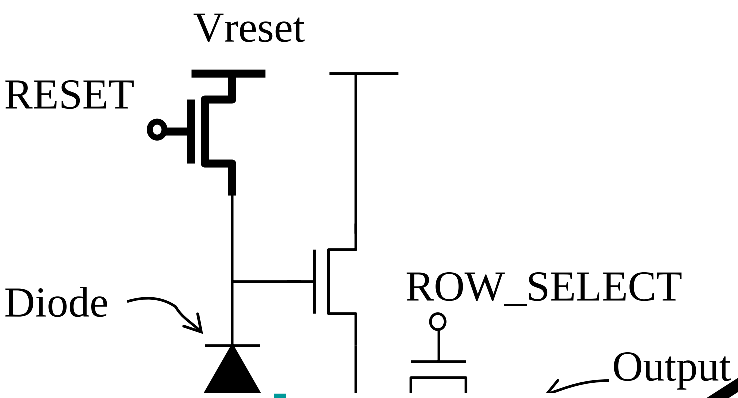


RAL_HEPAPS3: 0.25 µm MM, no epitaxial layer, 192*192 pixels, 15 µm pitch: 3MOS, 4MOS, Deep N-well diodes

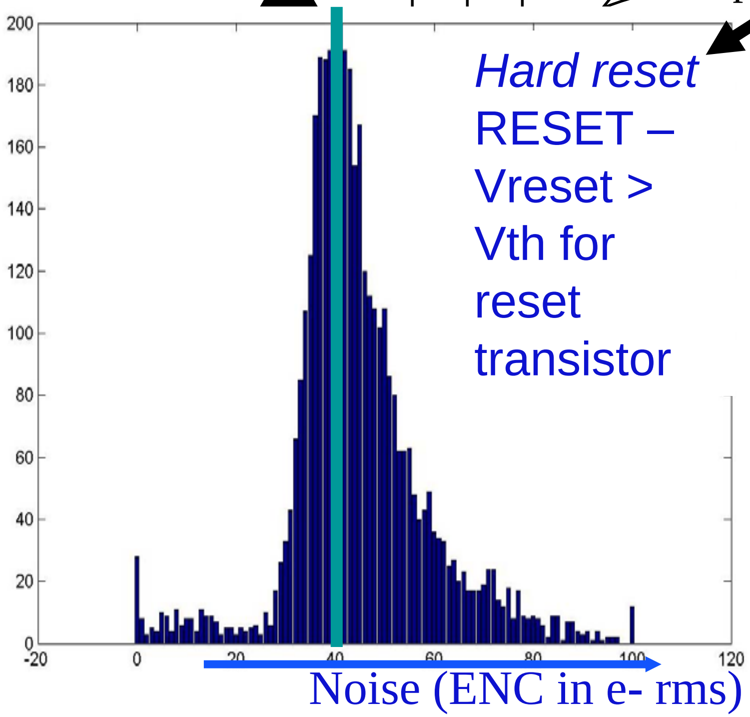
Test sensors

RAL_HEPAPS4: 0.35 µm CIS, 20 µm epitaxial layer, 1026*384 pixels, 15 µm pitch. 3 versions: 1, 2 or 4 diodes per pixel. Rad-hard, 5MHz row rate (manufactured, preparing tests)

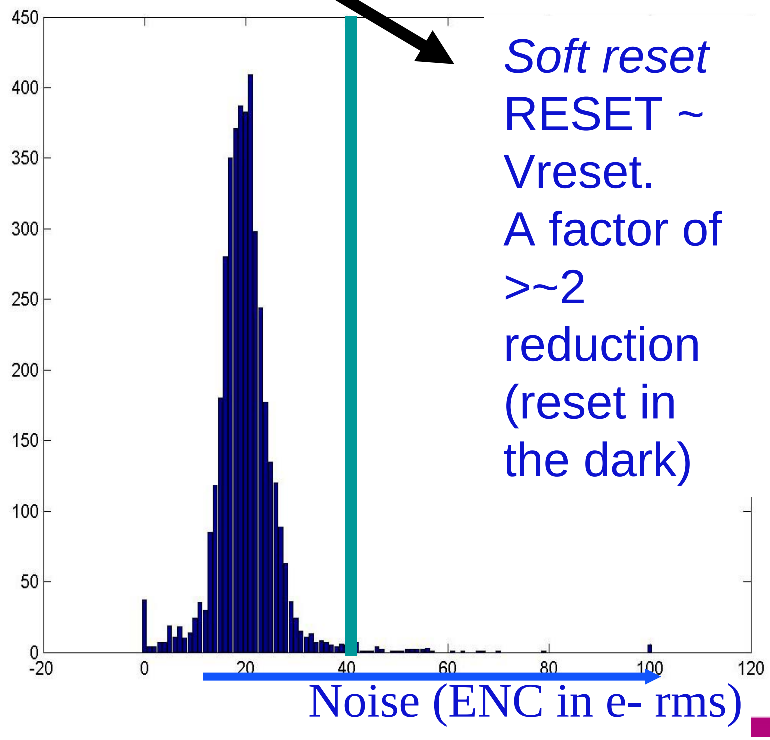
Soft **and** ***hard*** **reset**



Measured noise distributions for a 64x64 pixel test structure.
Not corrected for system noise



Hard reset
RESET – Vreset > Vth for reset transistor



Soft reset
RESET ~ Vreset.
A factor of >~2 reduction (reset in the dark)

Radiation hardness

Transistors.

Threshold shift: reduces with shrinking feature size

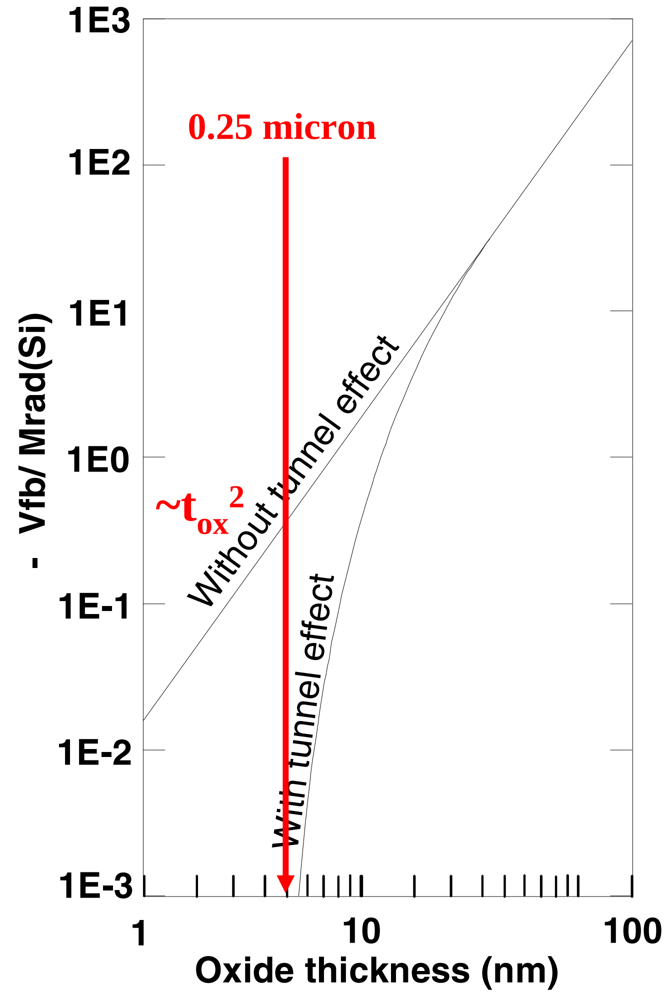
Bird's beak effect: use enclosed geometry transistors

Transistor leakage current: use guard-rings to separate transistors

Diodes.

Radiation damage increases leakage current

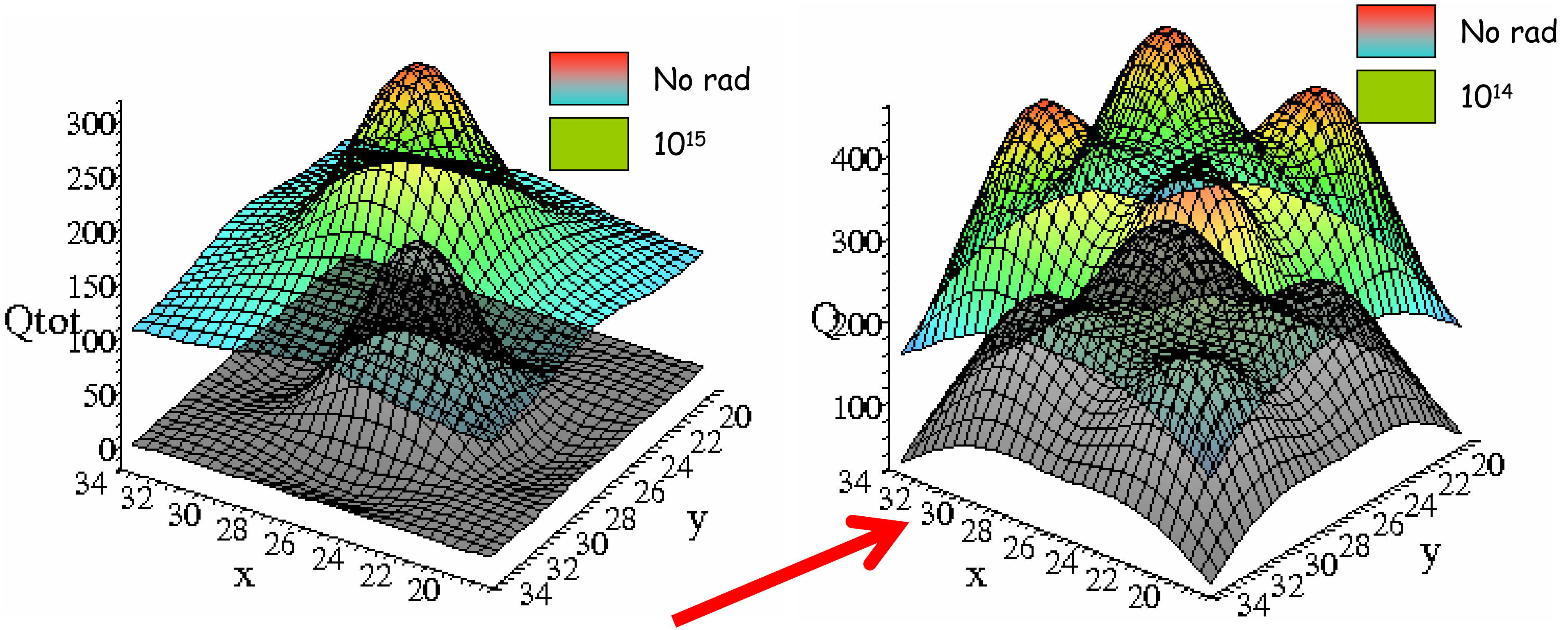
Radiation damage reduces minority carrier lifetime → diffusion distance is reduced



Single pixel S/N dependence on impact point

Device simulation.
Single diode 15 µm pixel

Device simulation.
4-diode 15 µm pixel



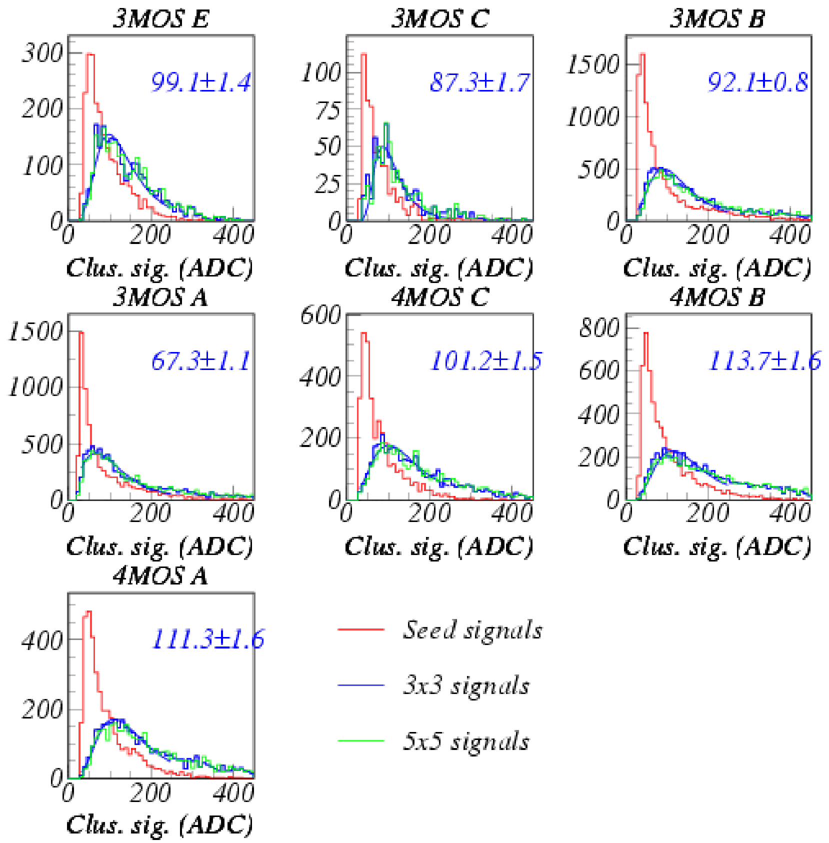
- Less variation in S/N varies over pixel before and after irradiation.
- S at edges still usable after 10^{15} p/cm^2.

G. Villani (RAL)

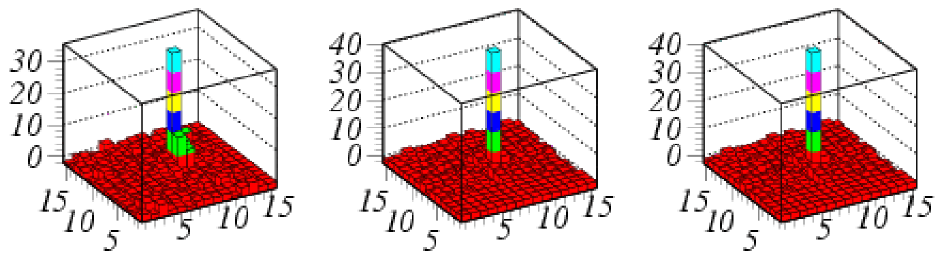
Landau Distributions

Beta source (Ru106) test results. Sensors HEPAPS2.

Landau distributions



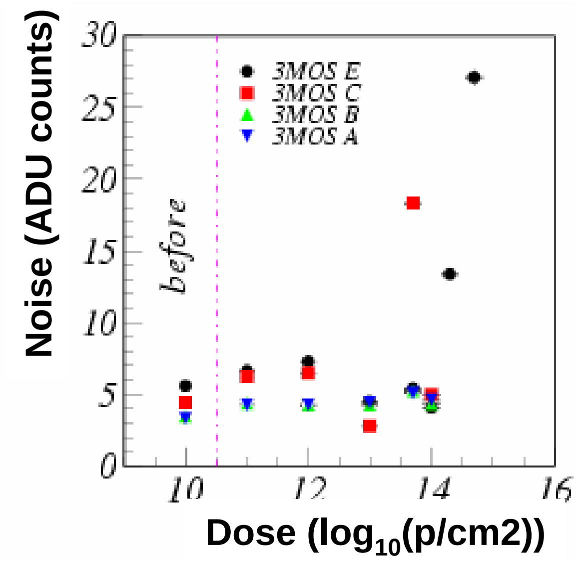
Examples of clusters. S/N per pixel

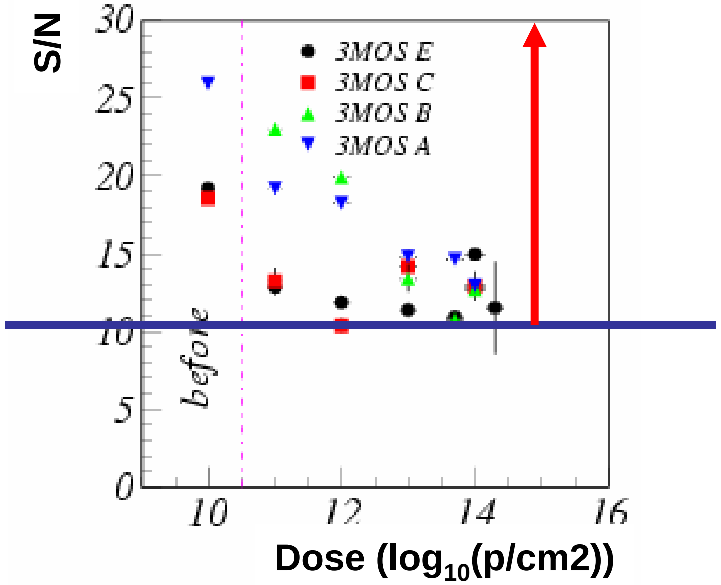


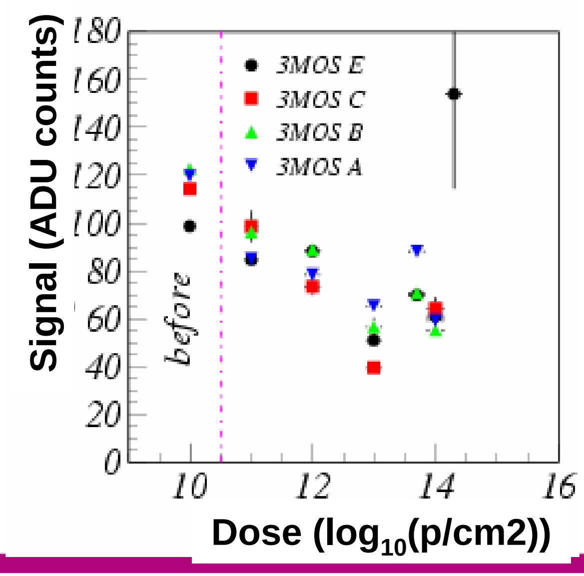
Summary table

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

Radiation test. Summary

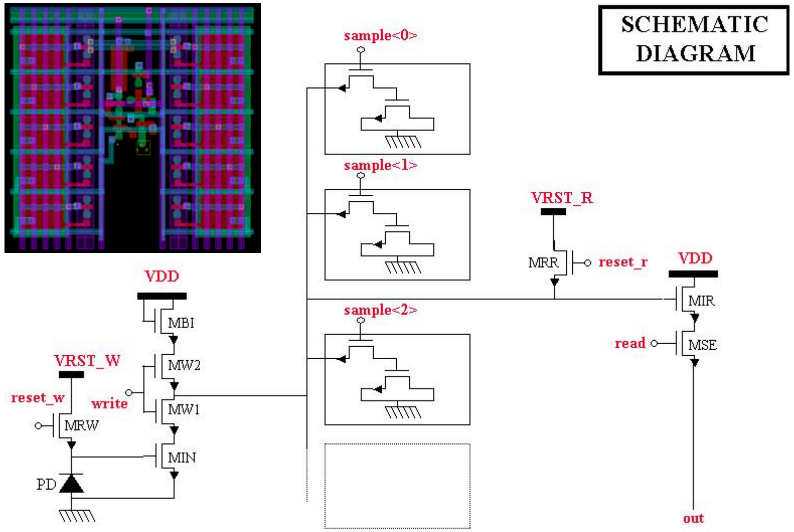




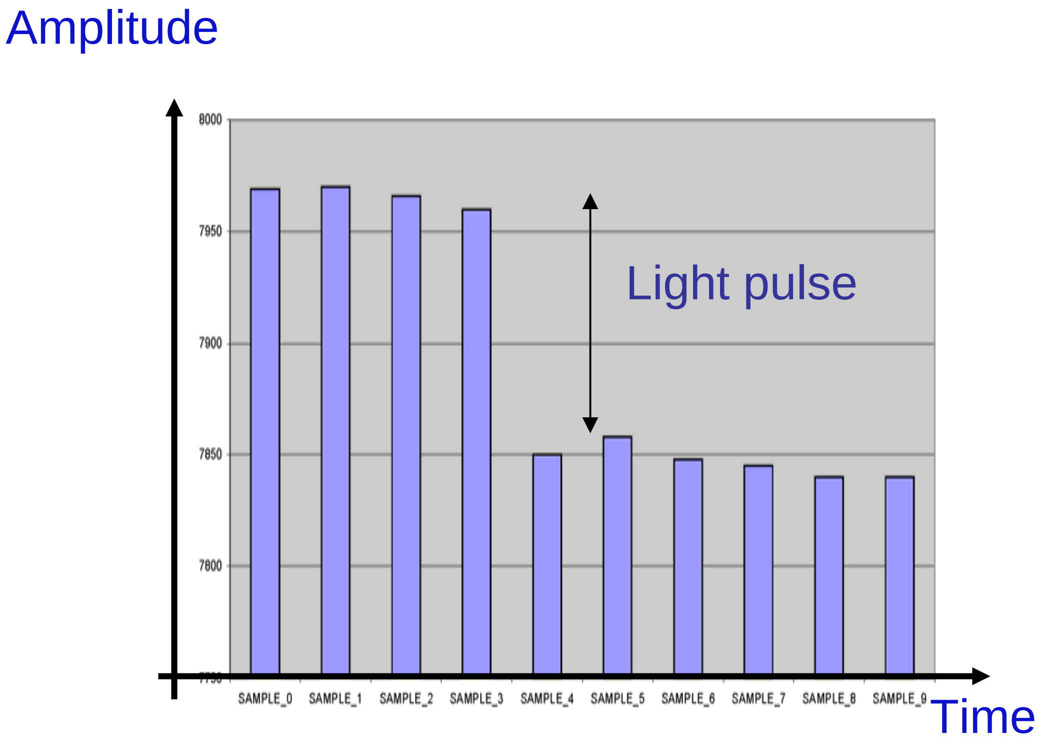


- Sensors yield reasonable S/N up to 10^{14} p/cm^2
- 0.35 µm technology in the pixel transistors. Enclosed layout in 3MOS_E
- S/N reduction seems to be dominated by charge collection

Flexible Active Pixel Sensor



Pulses LED test (single pixel)



10 memory cell per pixel

28 transistors per pixel

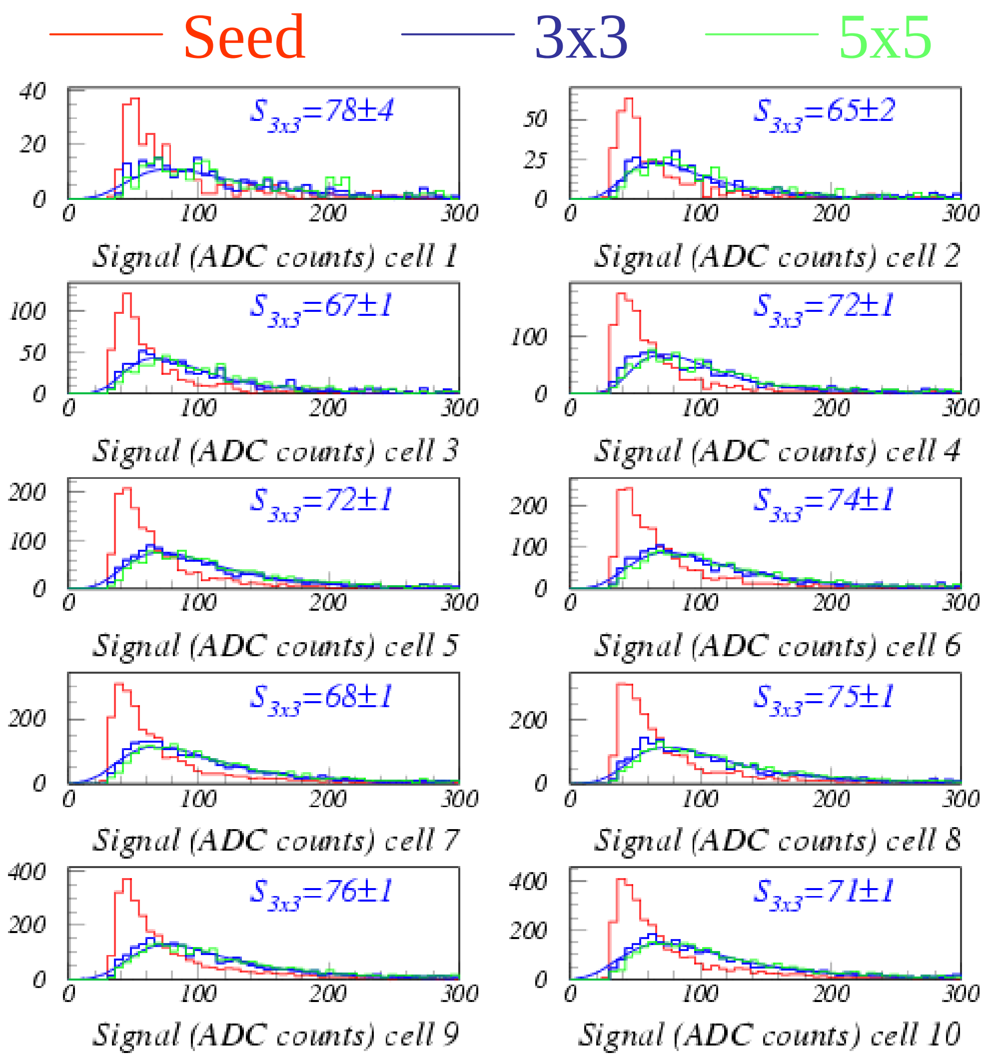
20 µm pitch

40x40 arrays

Design for the Vertex detector at the International Linear Collider

FAPS. Landau distribution

- Test with source
- 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**



J. Velthuis (Liv)

Conclusions

Parametric test sensors used to study noise, radiation hardness, new designs.

Radiation hardness → 10^{14} p/cm^2

Noise < 20 e- rms (soft reset in dark)

Three versions for radiation hardness of **fast (5MHz/line**), rad-hard, large (1024*384) sensor (RAL_HEPAPS4) manufactured

FAPS architecture developed for vertex detector at ILC

Digital pixel architecture (R&D within MI3 collaboration, N. Allinson et al.) in development for CALICE Electromagnetic Calorimeter at ILC (P. Dauncey, Imperial College et al.).

Would require large area coverage → 10^4 m^2, stitched sensors

CMOS technology could provide the solution for coverage of large areas with pixel detectors