Pixel detectors for Photon Counting

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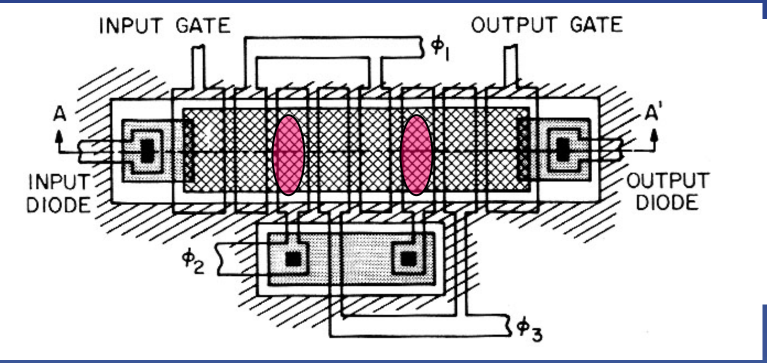
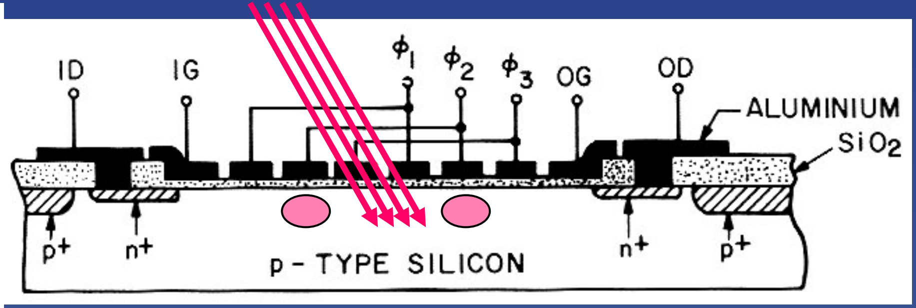
Charge integration vs photon counting

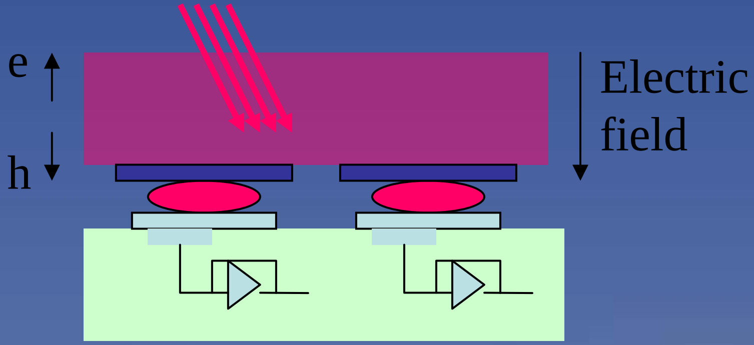
Pixel functionality for added performance

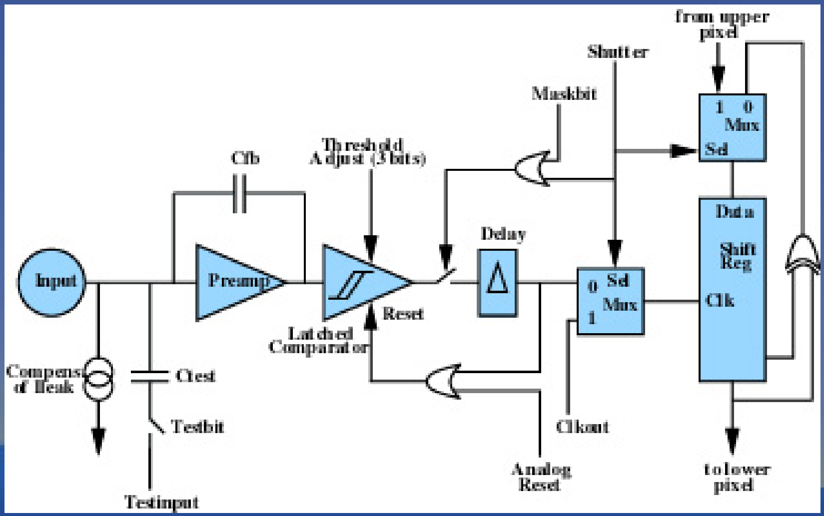
CCD system: charge integration, affected by leakage currents





Photon counting: count individual incoming photon, no leakage effects



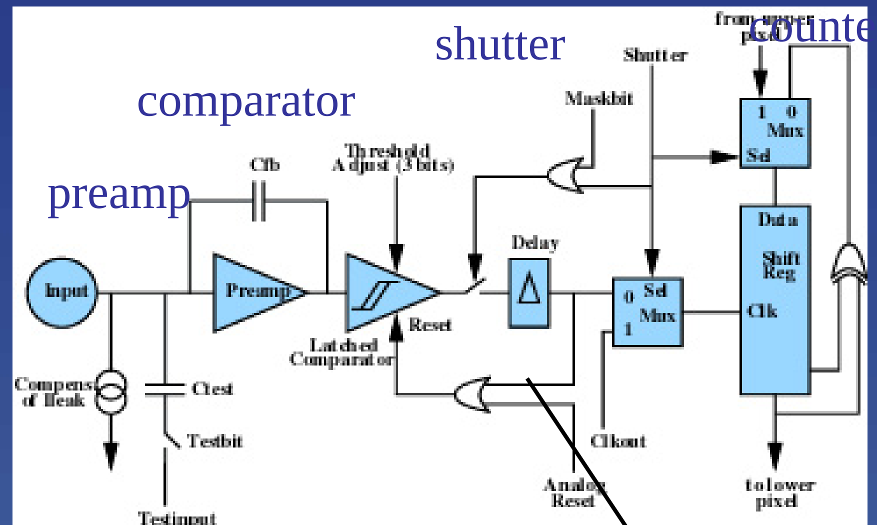


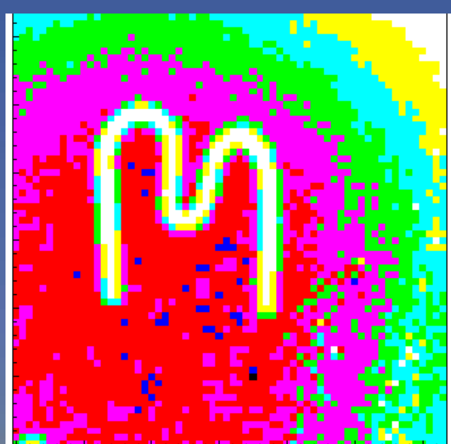
Photon counting system - Medipix1

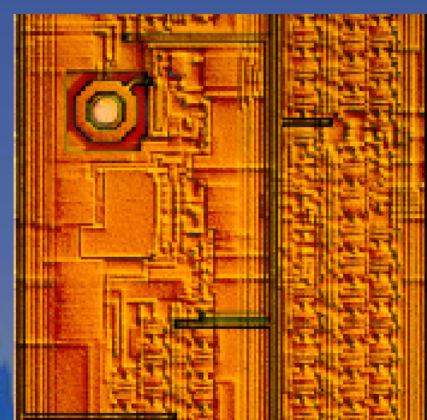
CERN, Freiburg, Glasgow & Pisa - 1997

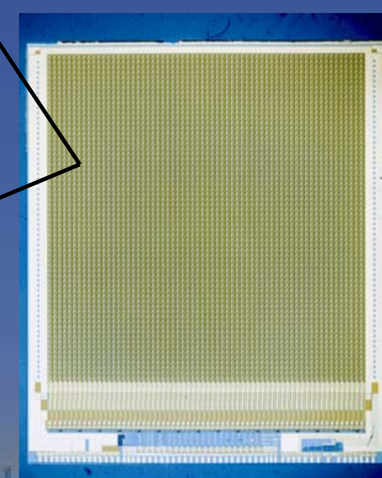
Features:

- 1 μm gate length SACMOS
- 170×170 μm² pixels
- 64×64 pixel array
- sensitive to positive charge
- ~500 transistors per pixel
- single discriminator (energy threshold) with 3-bit adjust
- 15 bit counter
- readout time 384 ms



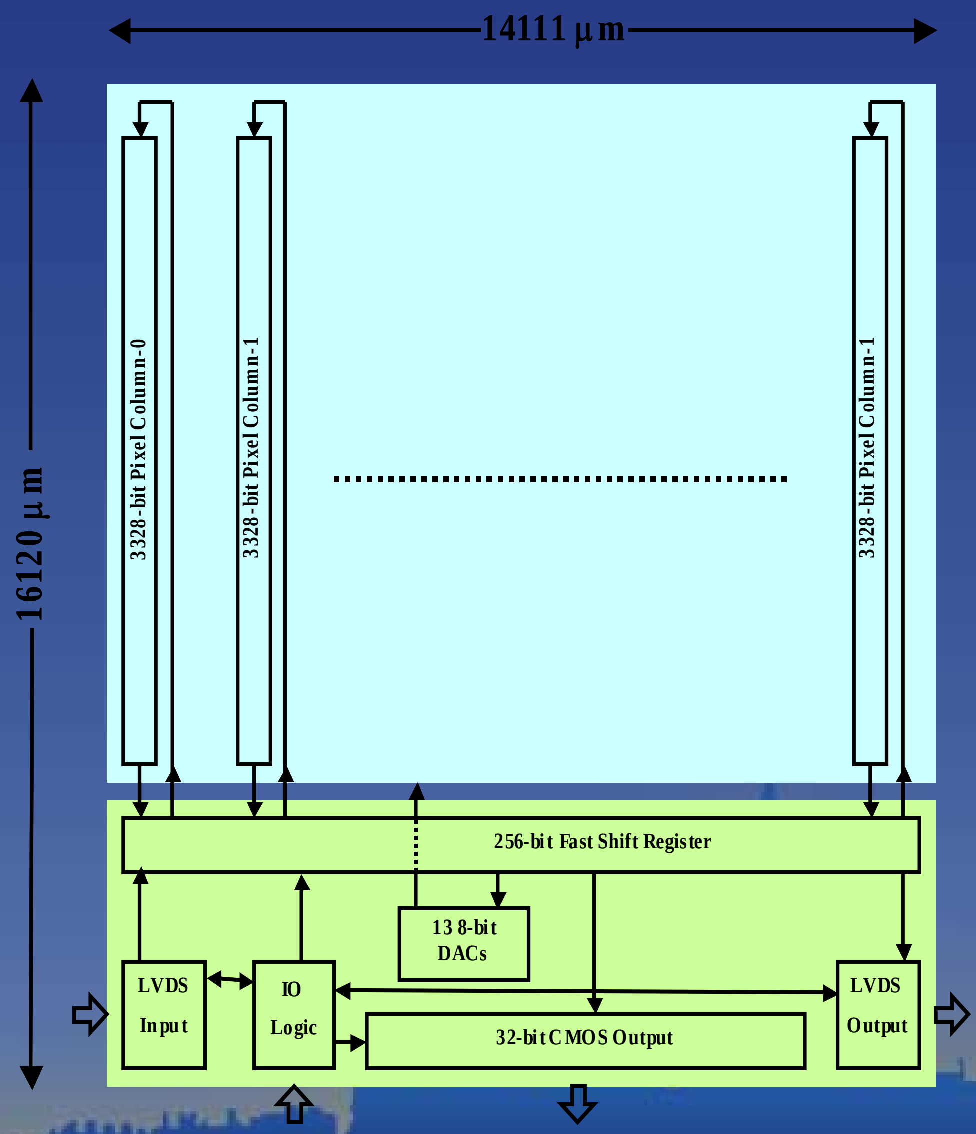






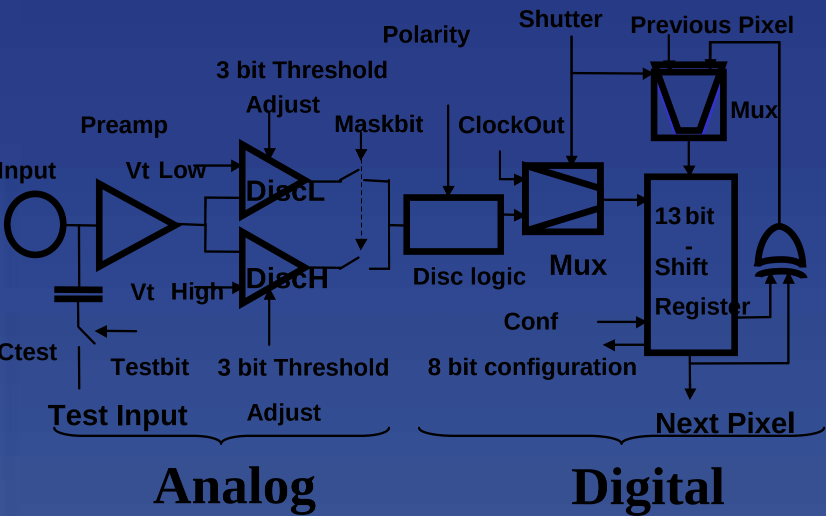
Medipix2 Chip Architecture (I) 2001

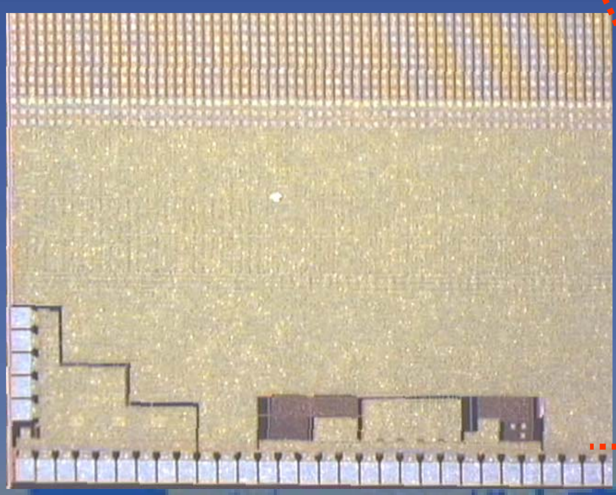
16 Collaborating Institutes

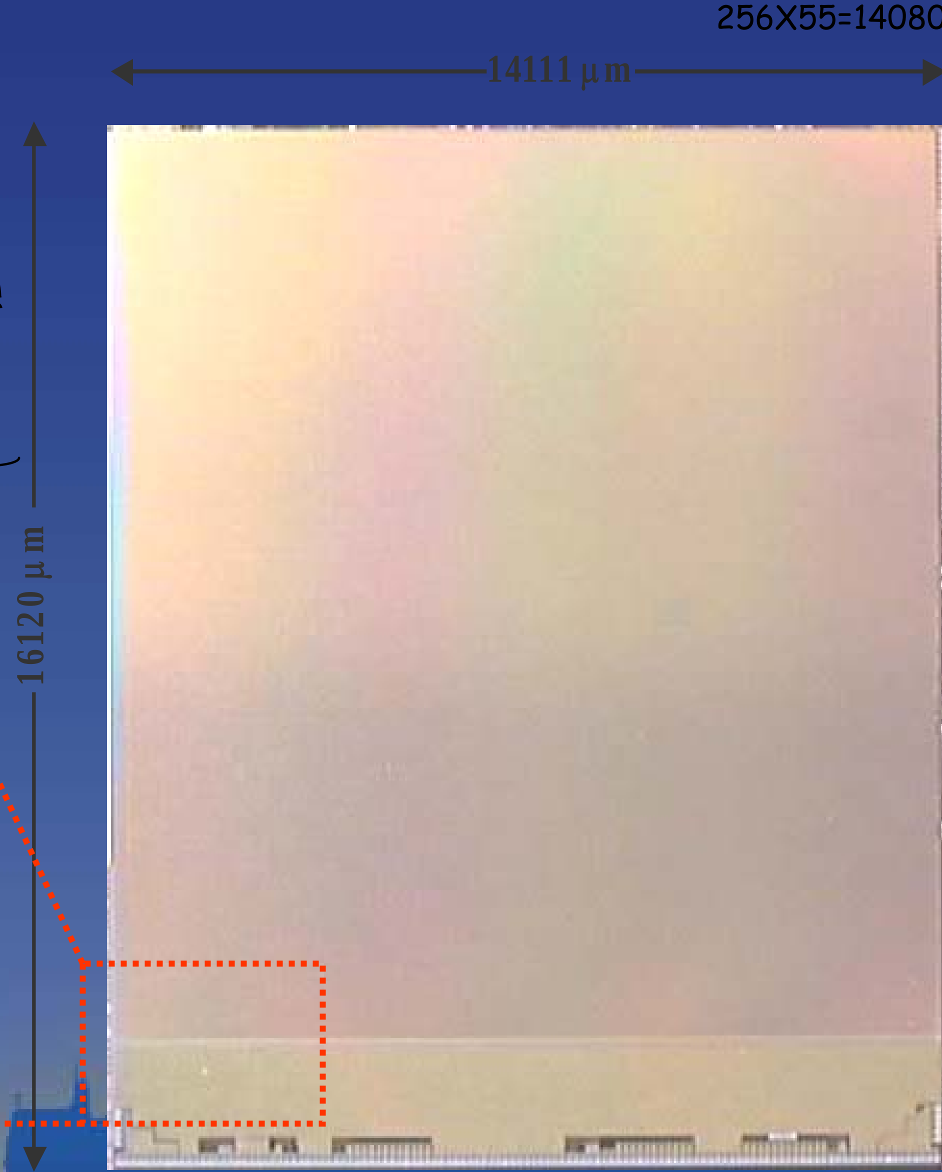


256X55=14.080

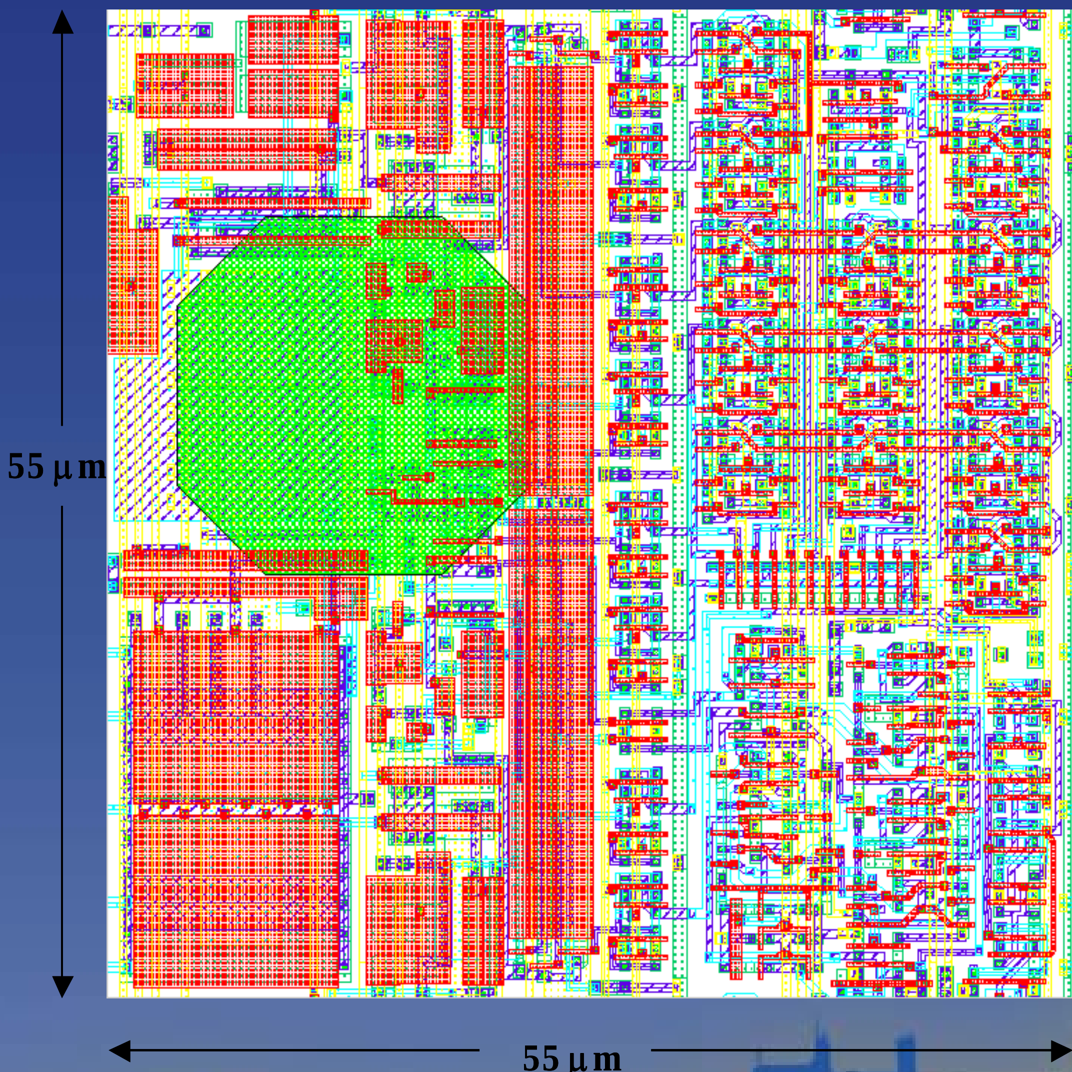
Medipix2 Chip Architecture (II)





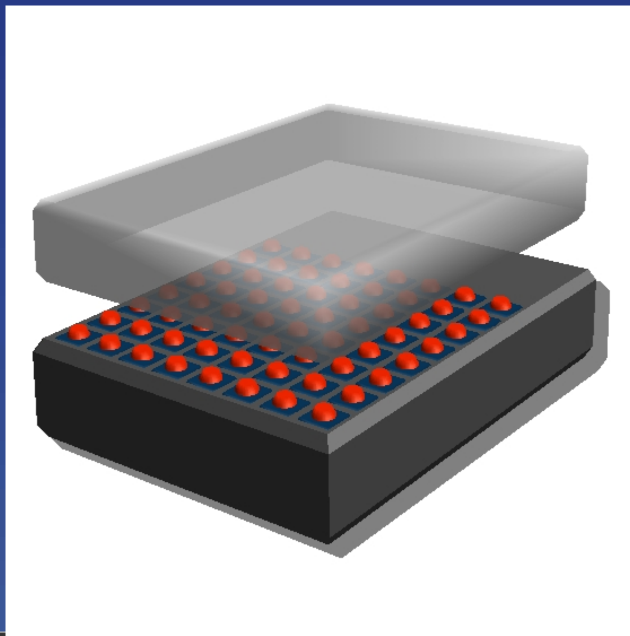


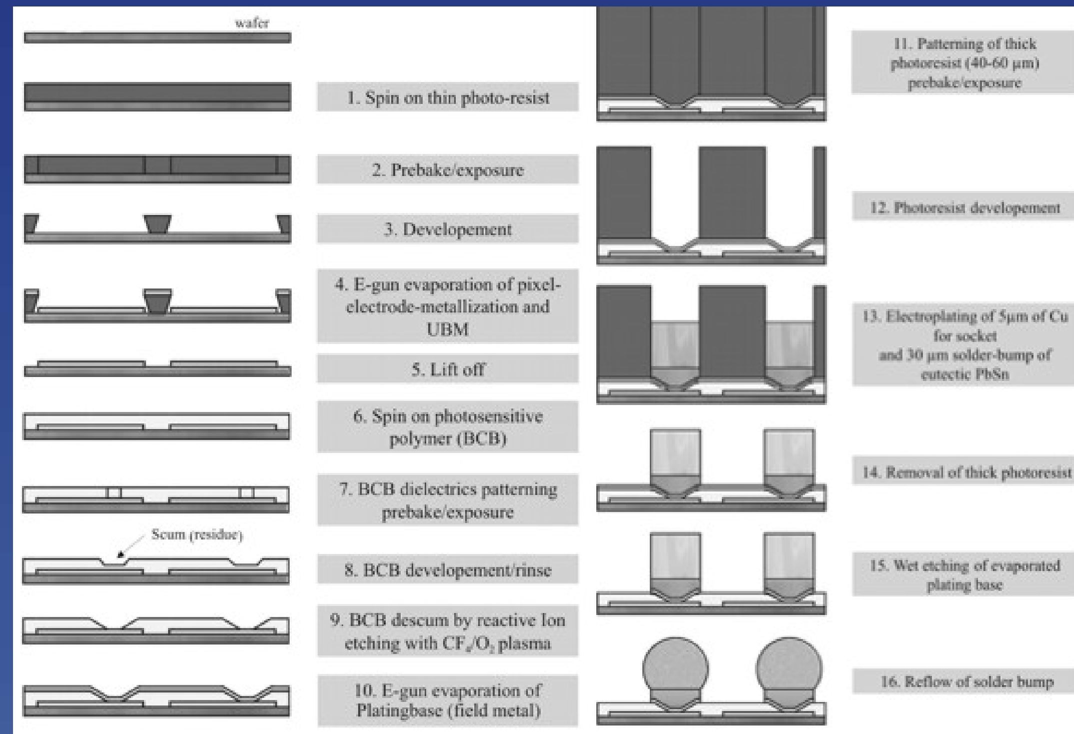
Medipix2 Pixel Cell Layout

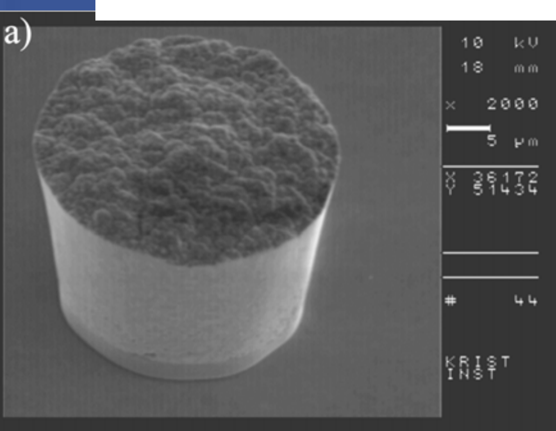


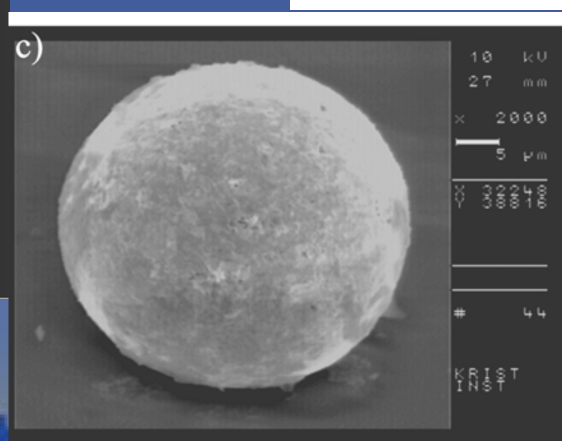
- ~500 transistors per pixel
- ~33 million transistors per chip
- ~8 µW per pixel (@2.2V)
- ~500 mW per Chip
- 13 internal 8-bit DAC
- <10 ms readout serially @100 MHz Clock
- <300 µs readout using the 32bit CMOS parallel port
- 87.5% active area

Bump Bonding

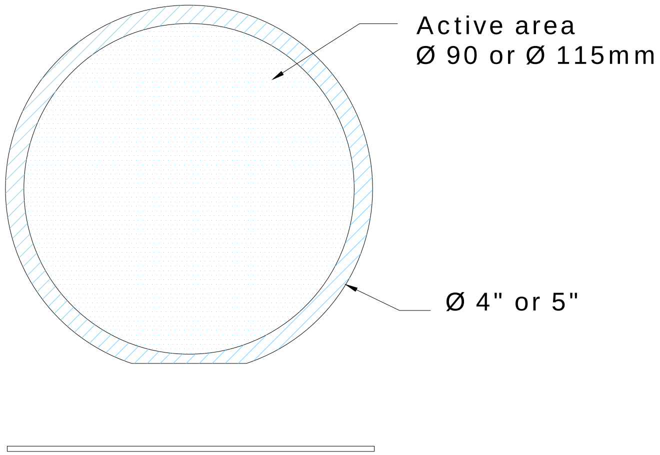


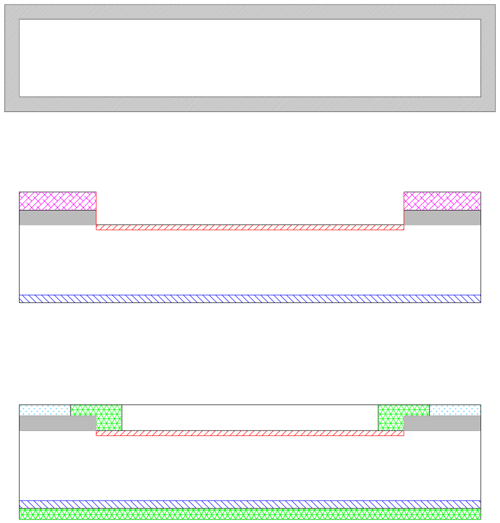






Materials - Silicon





Start with a clean wafer (N-type)
oxidation at 1000°C (200nm)

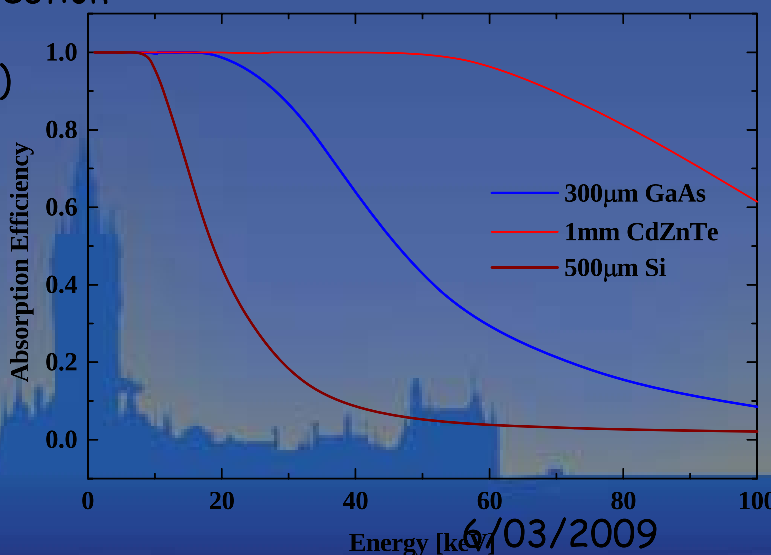
Photo-resist and masking
Etching of the Oxide
Implantation with Boron
and Phosphorus
annealing at 850°C

Contact with Aluminium
Front and backside
Passivation

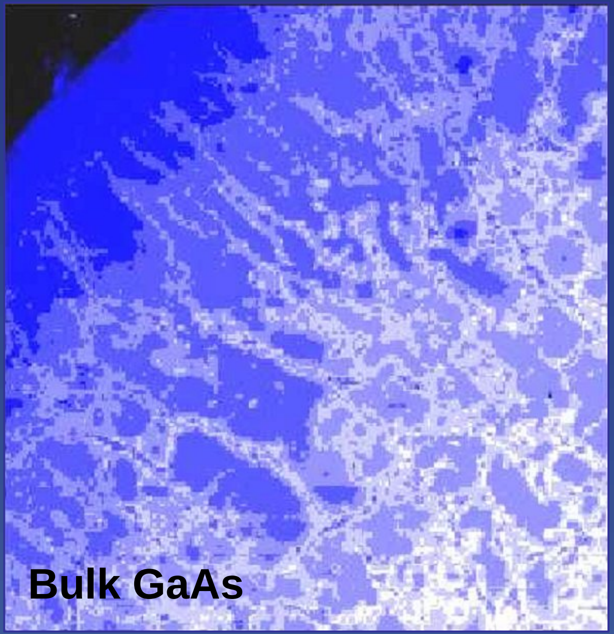
Thickness (150), (200), 300, 500, 700, (1000), (1500) μm

Technologically the most advanced of materials for radiation detection

- Thickness limited by crystal purity (intrinsic Si ~ 1.5 10^{10} cm^{-3})
- Not suited to X-ray imaging above ~ 20 kV
- Hi Resistivity wafers limited to 125 mm diameter
- Many device variants such as CCD's and CMOS imagers using technology push of the IC industry



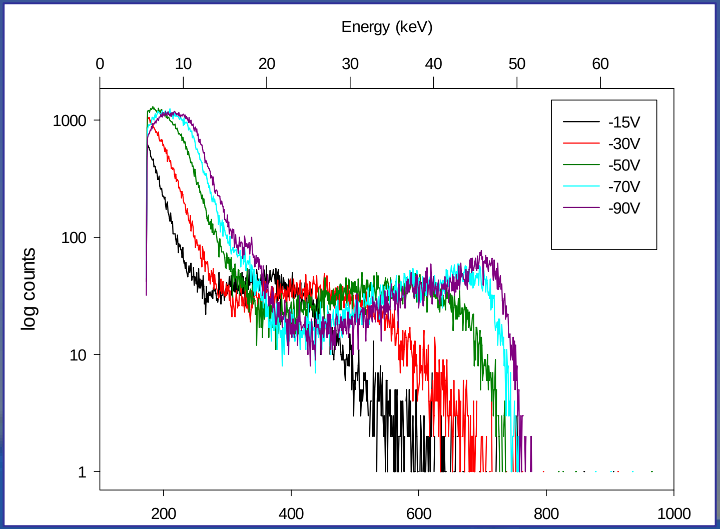
Materials - GaAs



Complicated by stoichiometry – results in large variations through crystal

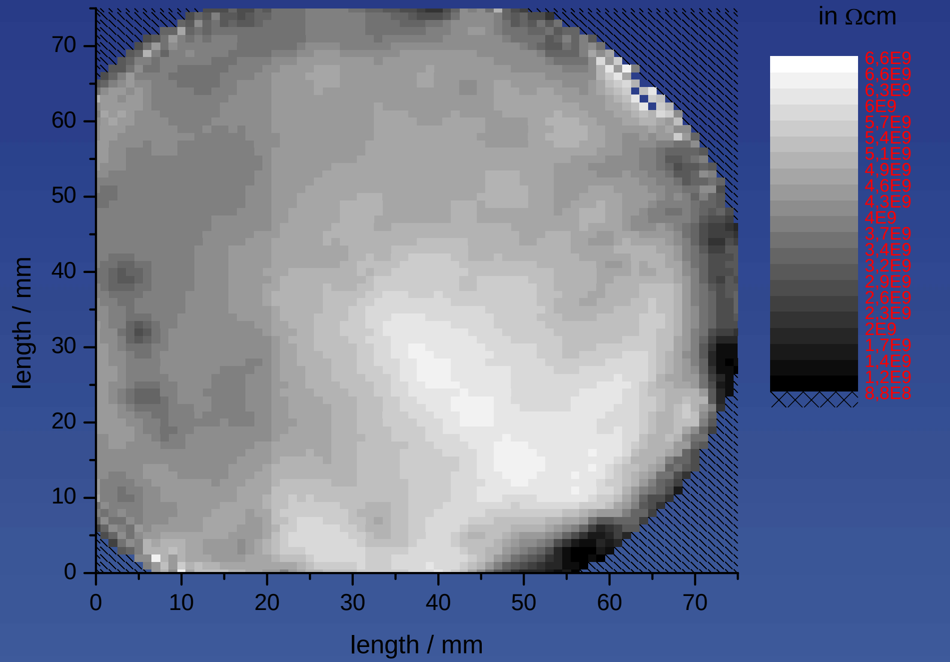
- Hi Z but inhomogeneities lead to images needing compensation
- Technology still being developed for 125 mm
- Thick epi layer are expensive and too highly doped

Depth-dependent CCE produces poorly resolved gamma spectra:



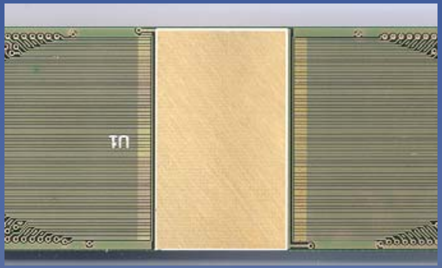
Materials – Cd(Zn)Te

CdZnTe wafer **grown with** modifications



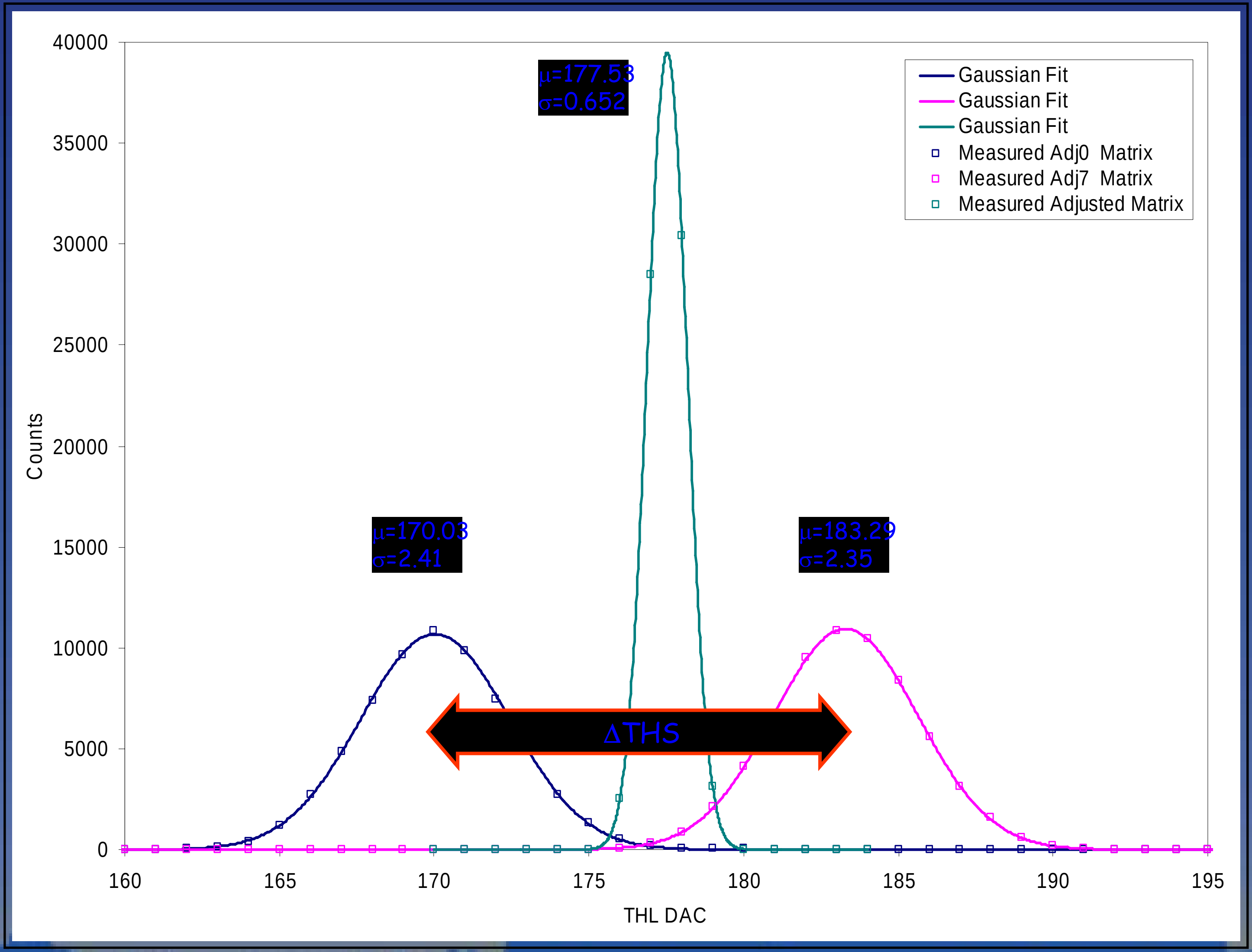
Same problems with stoichiometry – single crystals difficult

- Processing much more difficult than other materials
- Technology still being developed for 75 mm
- Detectors on single crystals by selection



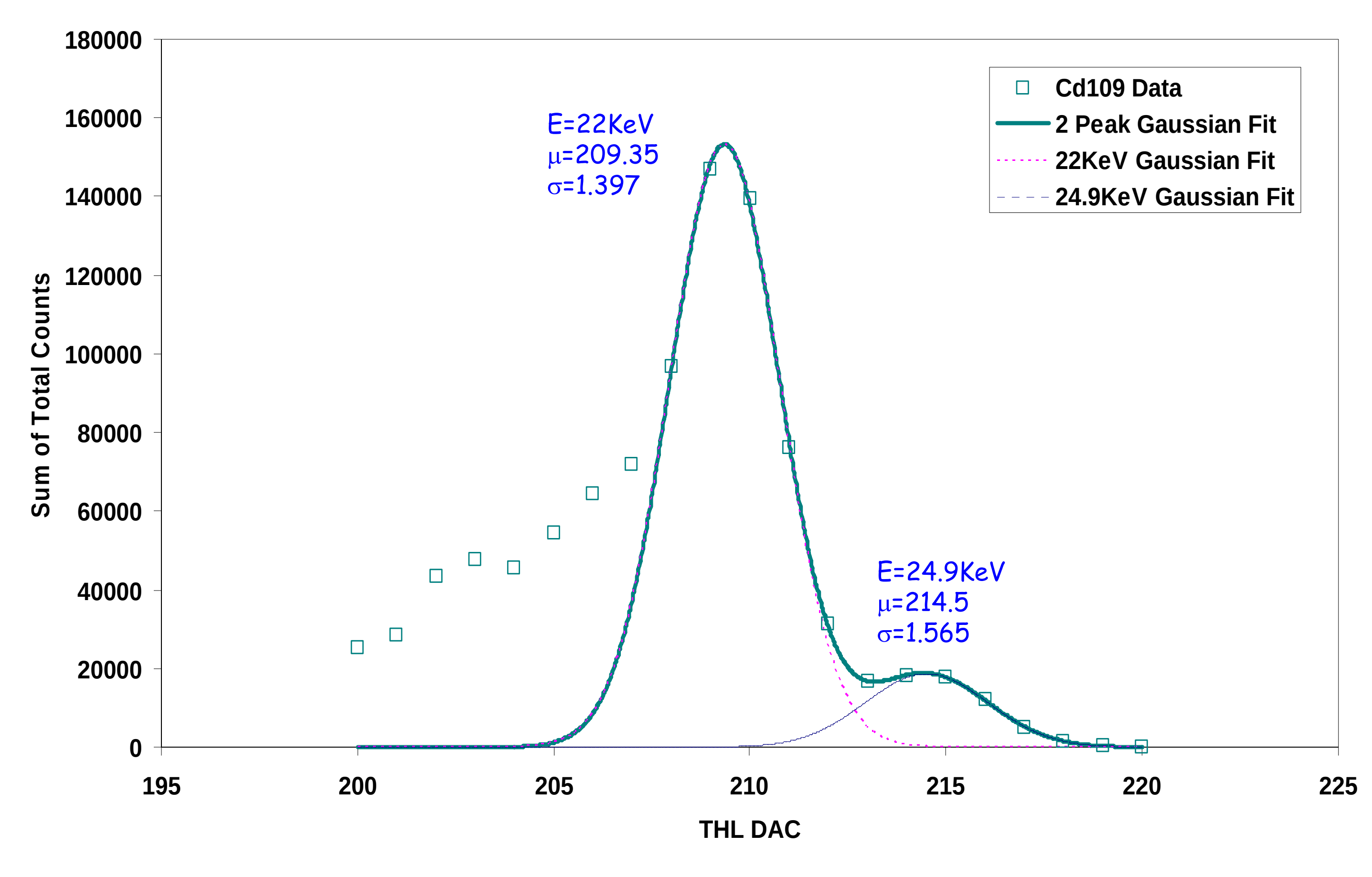
14 x 24 mm CdZnTe strip detector

Low Threshold Equalization



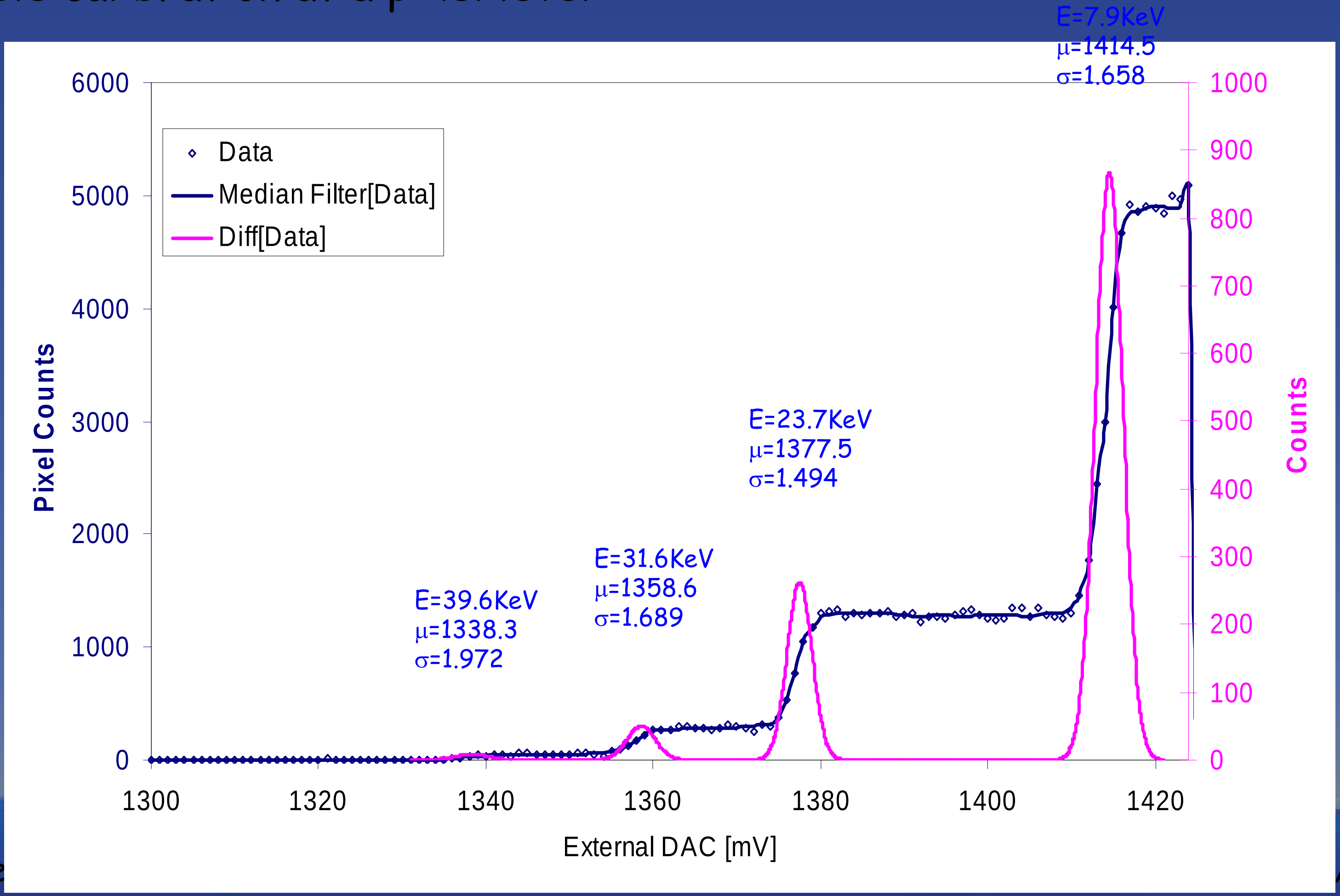
Cd^{109} spectrum

- Threshold scan using the same equalization mask with Cd^{109}
- Acquisition time per point was 1min ⇒ very low statistics !
- All the matrix unmasked

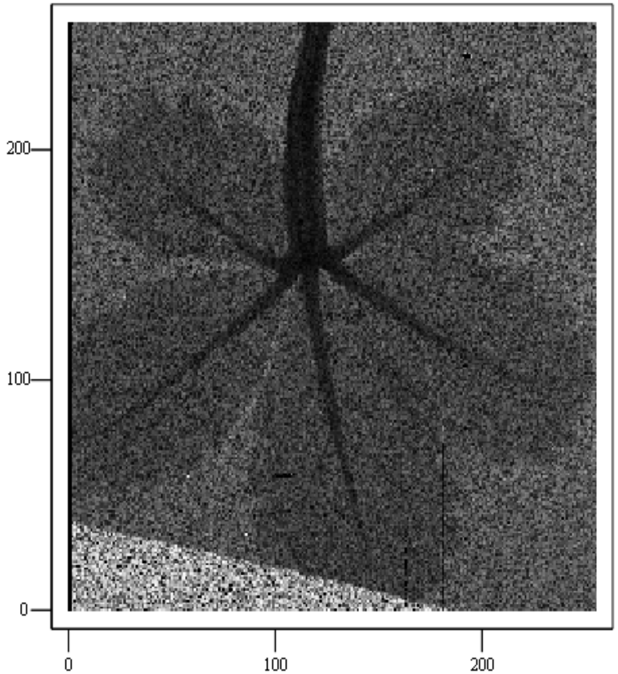


A 'dirty' 7.9KeV pencil beam…

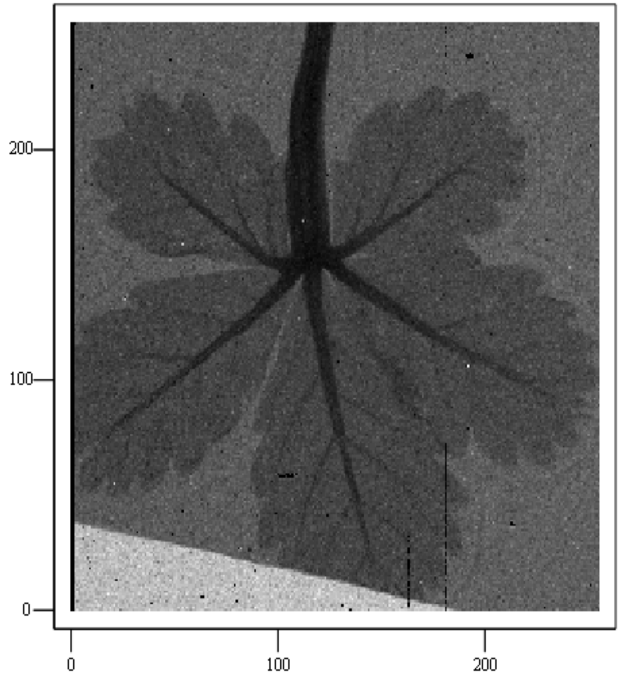
- Pencil beam of 10x10 μm^2 hitting the center of pixel (126,93) of chip S3-D3
- A 7.9KeV beam with its 23.7, 32.6 and 39.5 KeV harmonics allowed a simple calibration at a pixel level



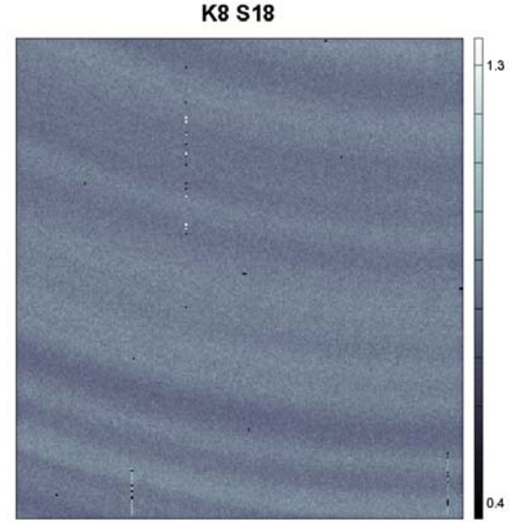
Flat Field Correction



Uncorrected image

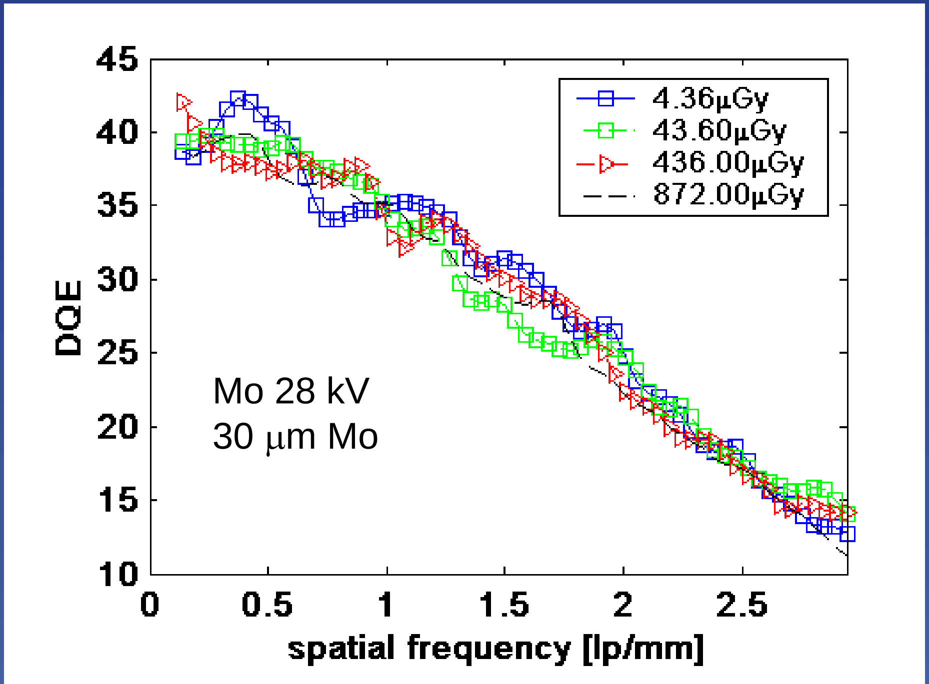


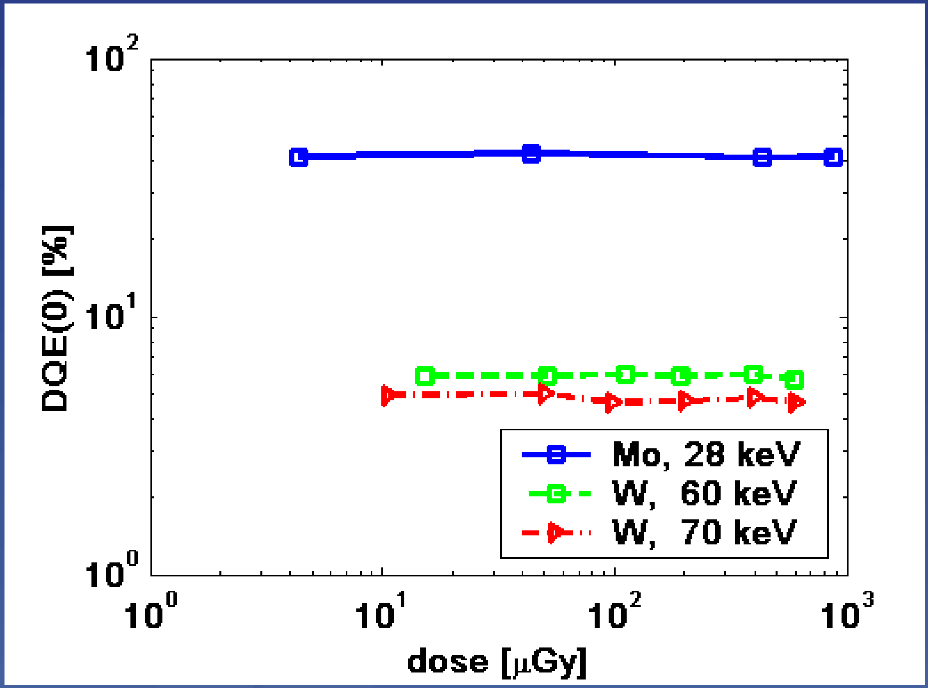
Corrected image



- Original image take during 10min with Fe^{55}
- 7 flood field images (2 hours each) were taken in order to find a flat field correction matrix

DQE flatfield corrected



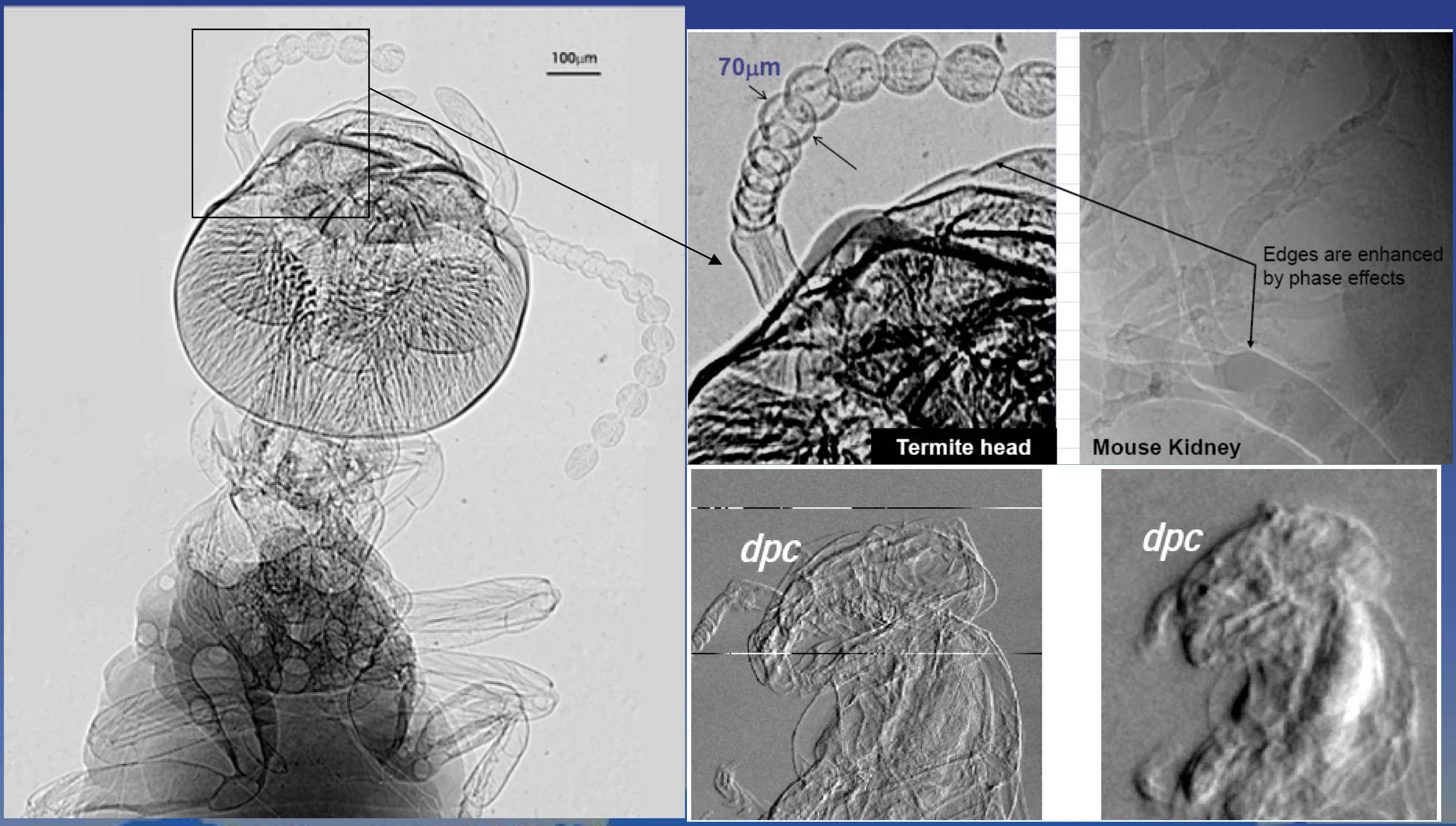


Imaging performance ± dose independent

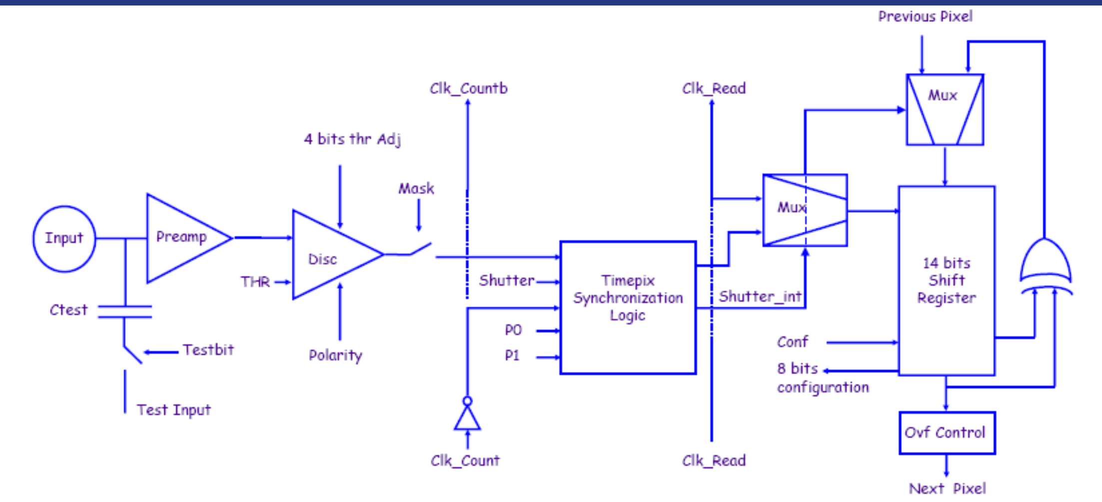
approaching Poisson limit

- Potential for dose reduction in radiographic applications
- Time resolved measurements

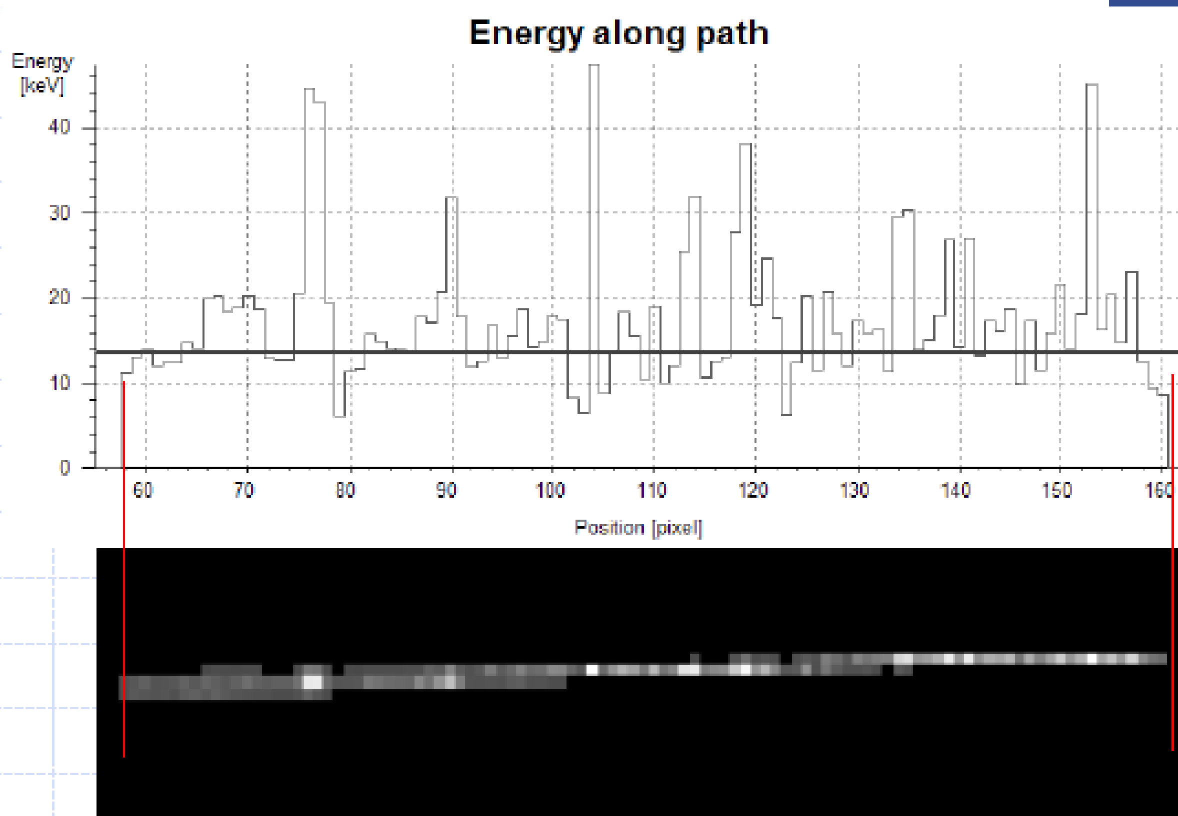
Imaging capability

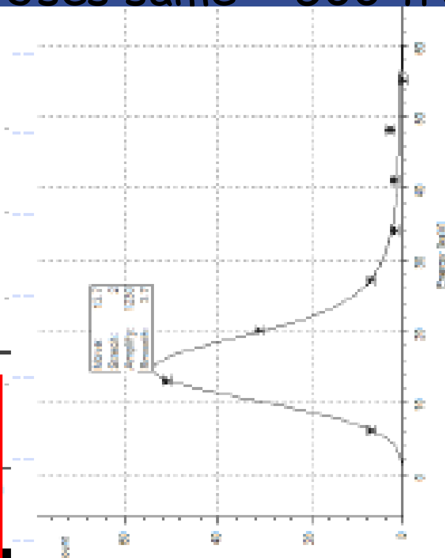


TimePix

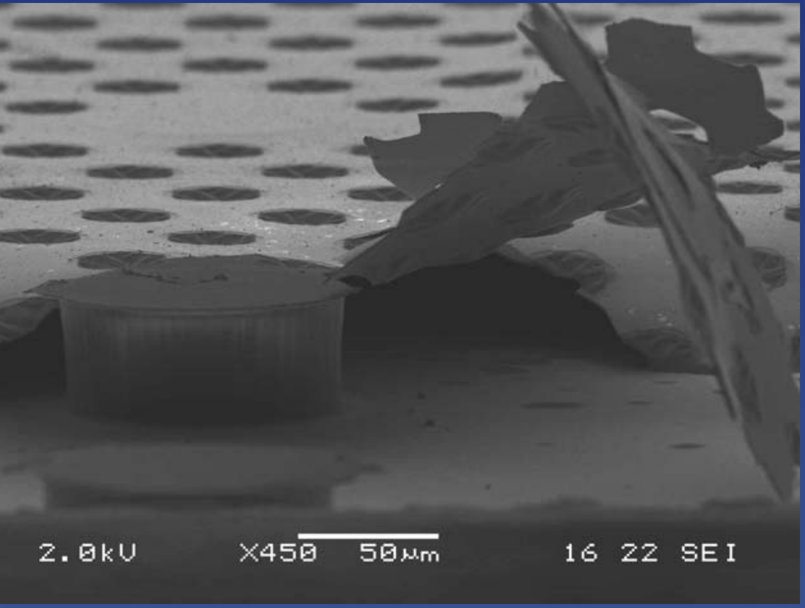


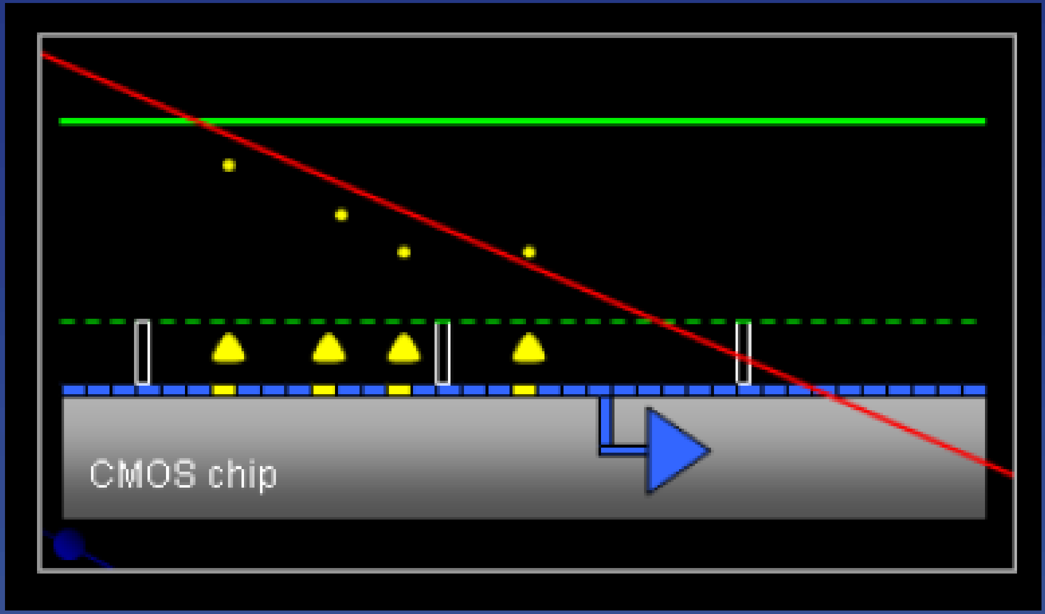
- Change discriminator to clock
- Use same config register
- Can measure ToT
- Can measure time to start/stop
- Can photon count
- Uses same ~ 500 transistors



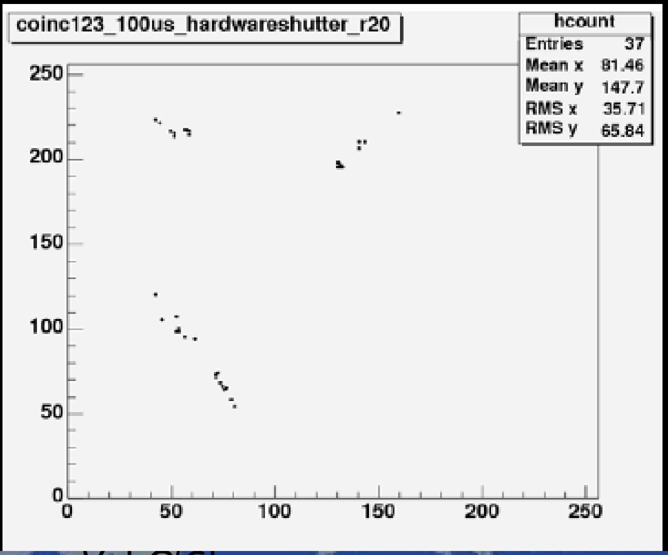


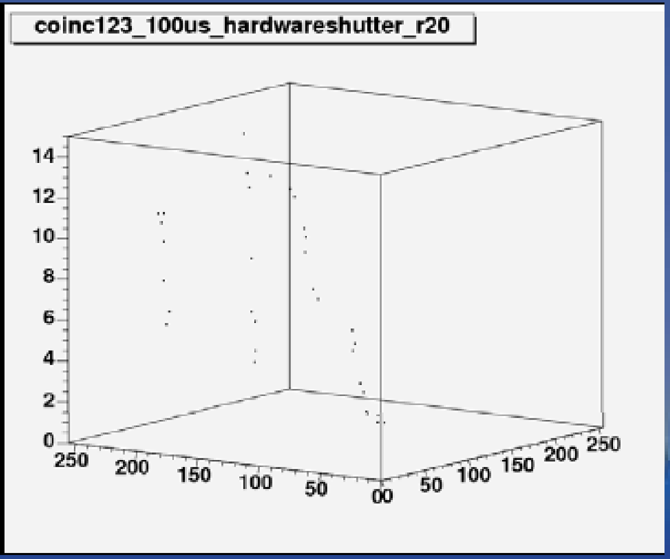
Gossip - Timepix





Integrate gas gain mechanism directly on CMOS





What can be done with 500 transistors or less

Applications

Neutron Imaging

Autoradiography

X-ray Tomography

Electron Beam Microscopy

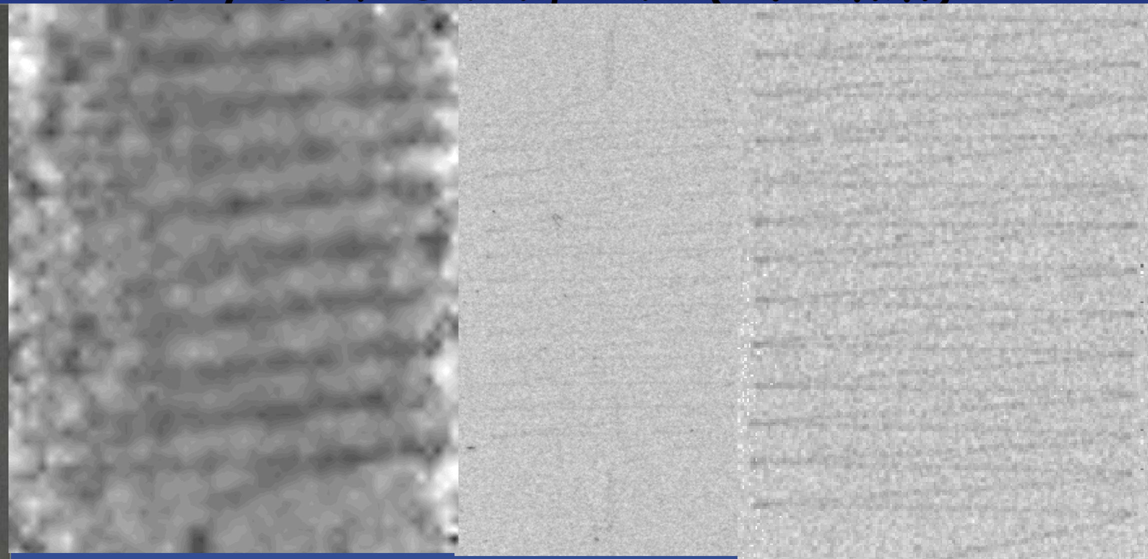
Adaptive Optics

Synchrotron Applications

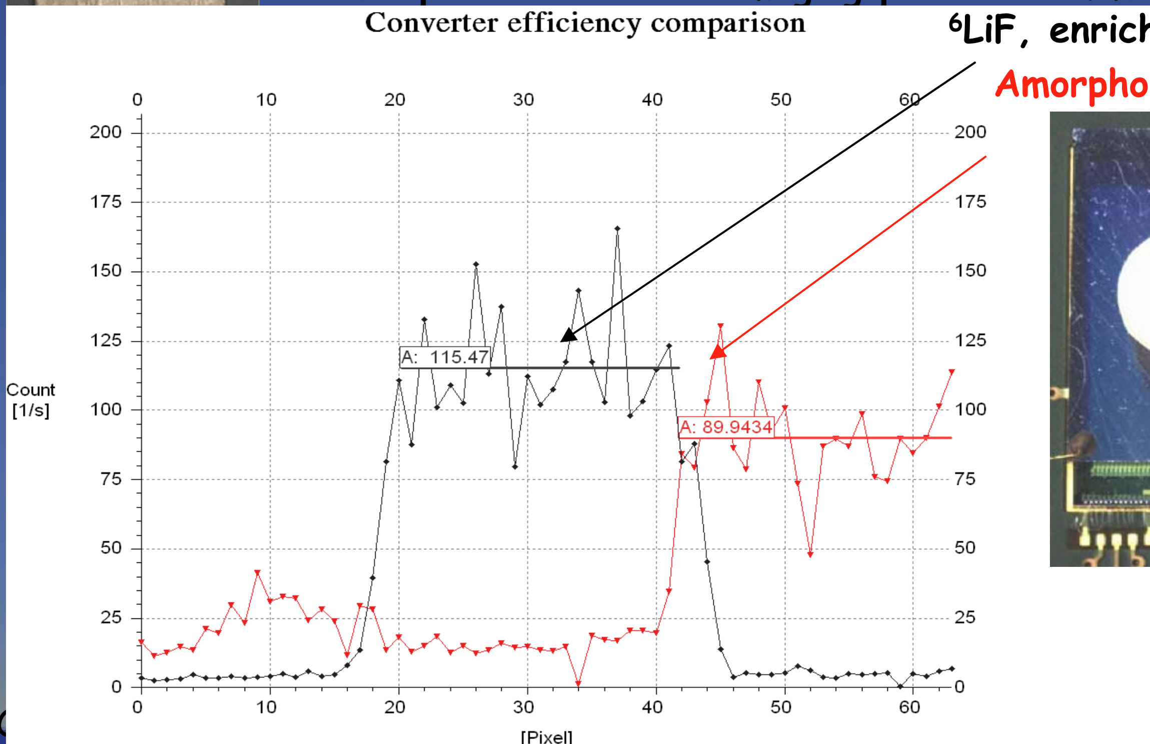
HEP Applications

Dosimetry

Nylon Fishing line (0.1 mm)

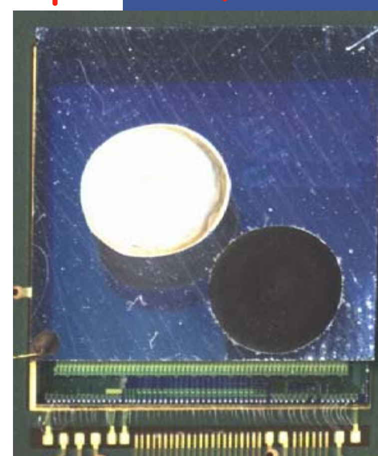


Medipix-1 **Imaging plate** **Medipix-2**



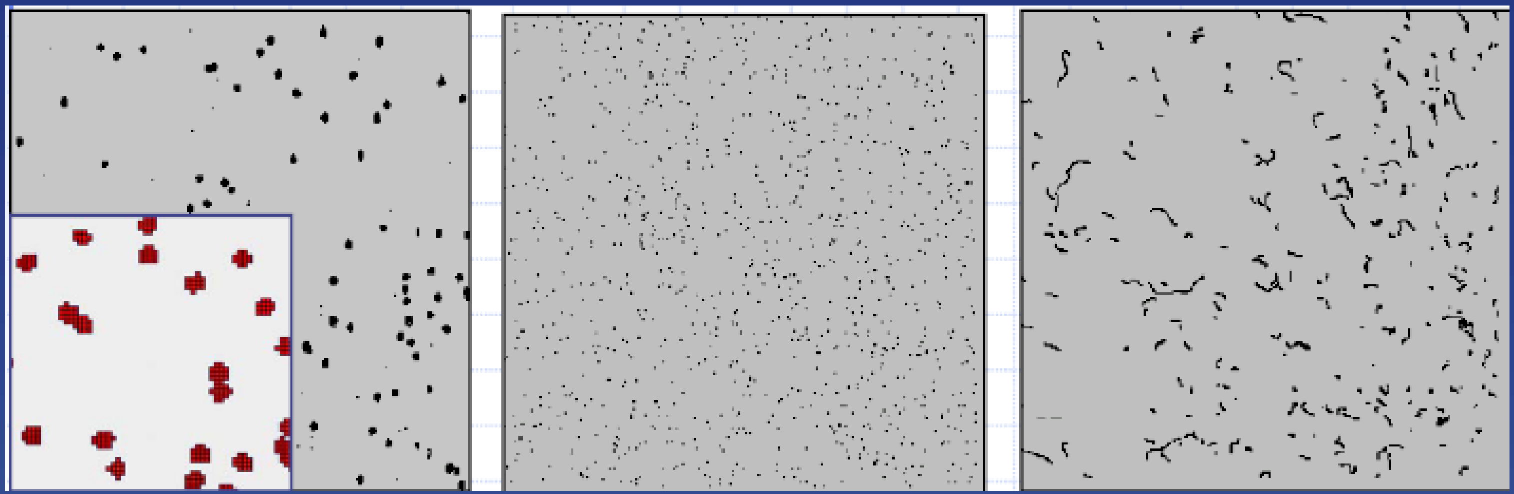
^{6}LiF, enrichment 90%

Amorphous ^{10}B, enrichment 80%



Ratio between ^{6}LiF efficiency and ^{10}B is 1.28

Quantum Dosimetry



Identify each hit by radiation type and energy from track/cluster shape

Method, Apparatus and Computer Program for Measuring the Dose, Dose Rate and Composition of Radiation

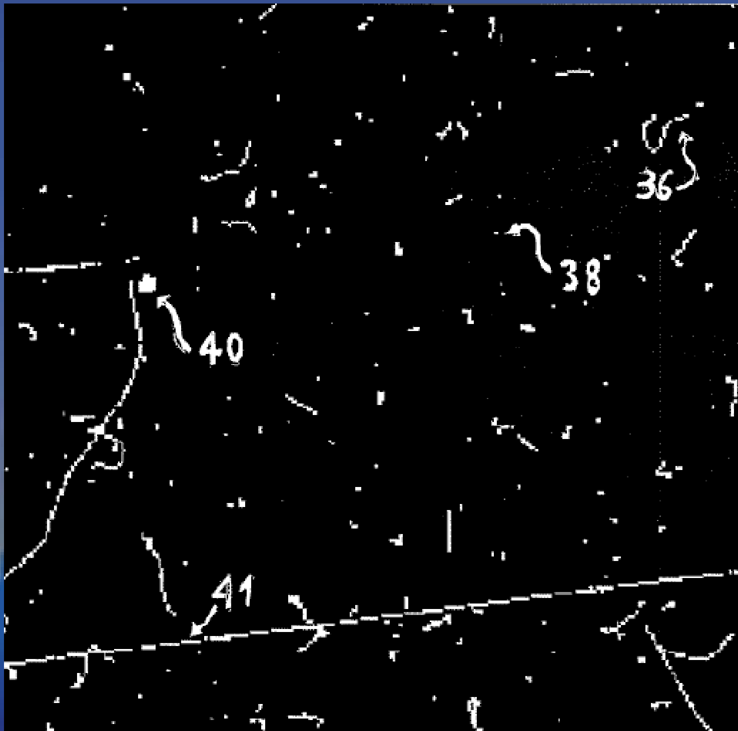
Patent submitted 09/03/'07

36 Electron

38 Photon

40 Neutron

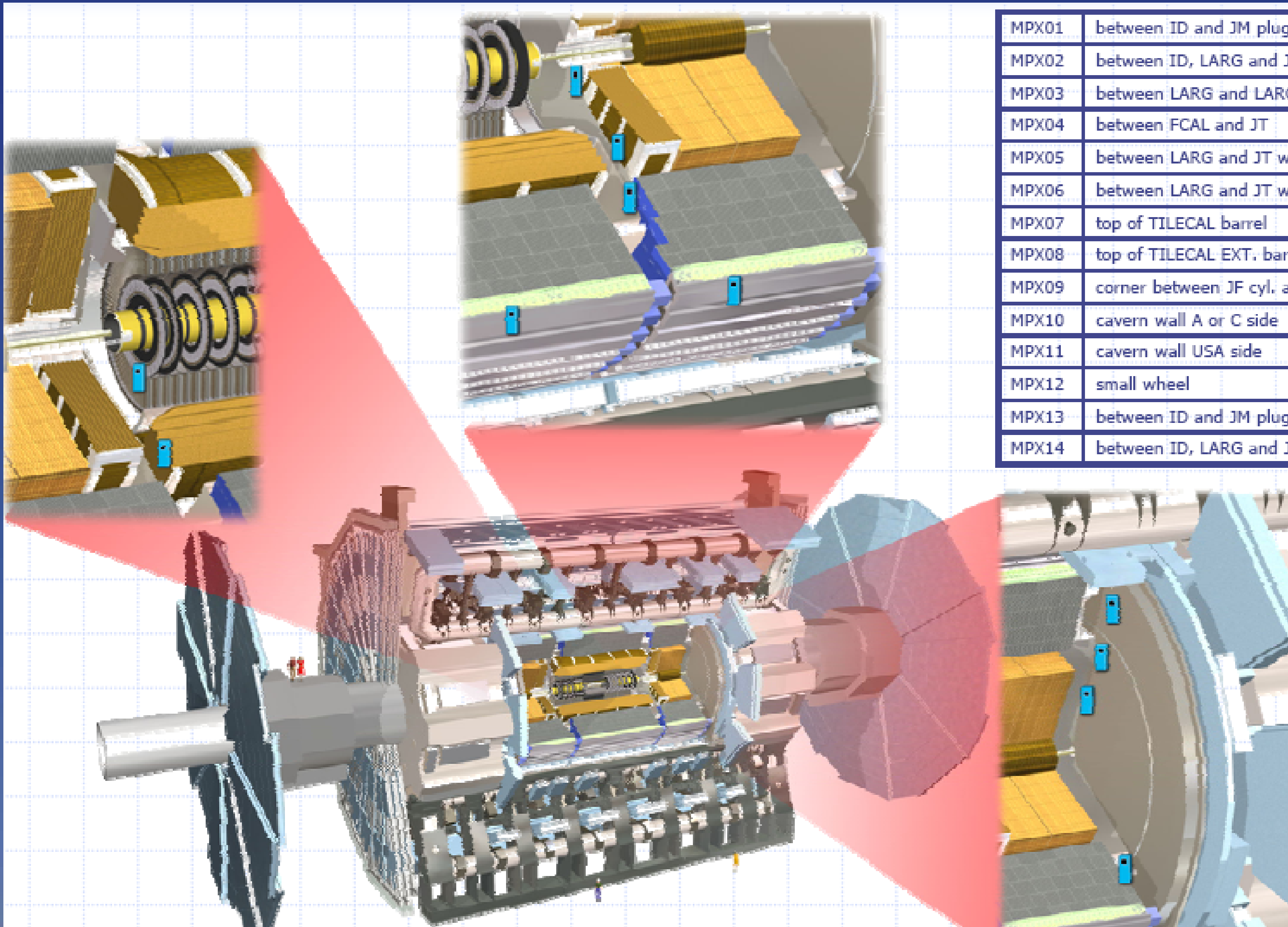
41 Muon



Val O'Shea

Dosimetry in ATLAS

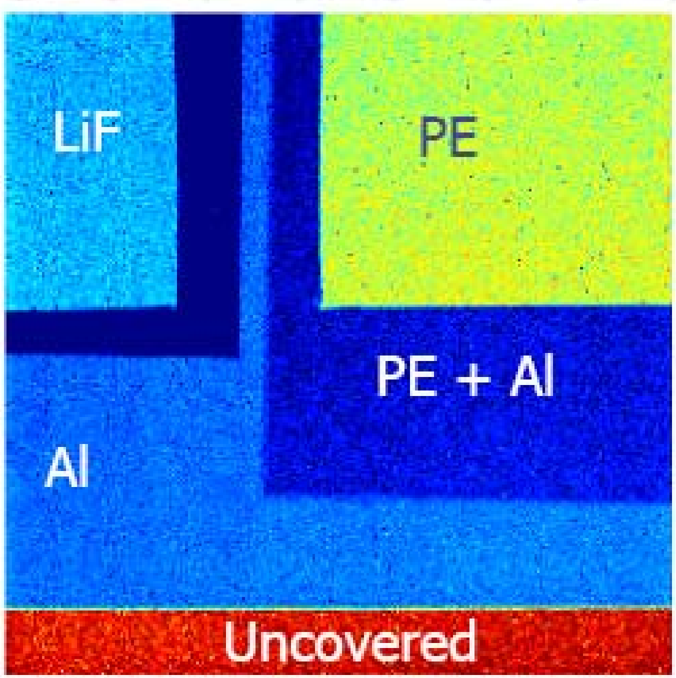
MPX01	between ID and JM plug
MPX02	between ID, LARG and JM
MPX03	between LARG and LARG EC
MPX04	between FCAL and JT
MPX05	between LARG and JT wheel
MPX06	between LARG and JT wheel
MPX07	top of TILECAL barrel
MPX08	top of TILECAL EXT. barrel
MPX09	corner between JF cyl. and hexagon
MPX10	cavern wall A or C side
MPX11	cavern wall USA side
MPX12	small wheel
MPX13	between ID and JM plug
MPX14	between ID, LARG and JM

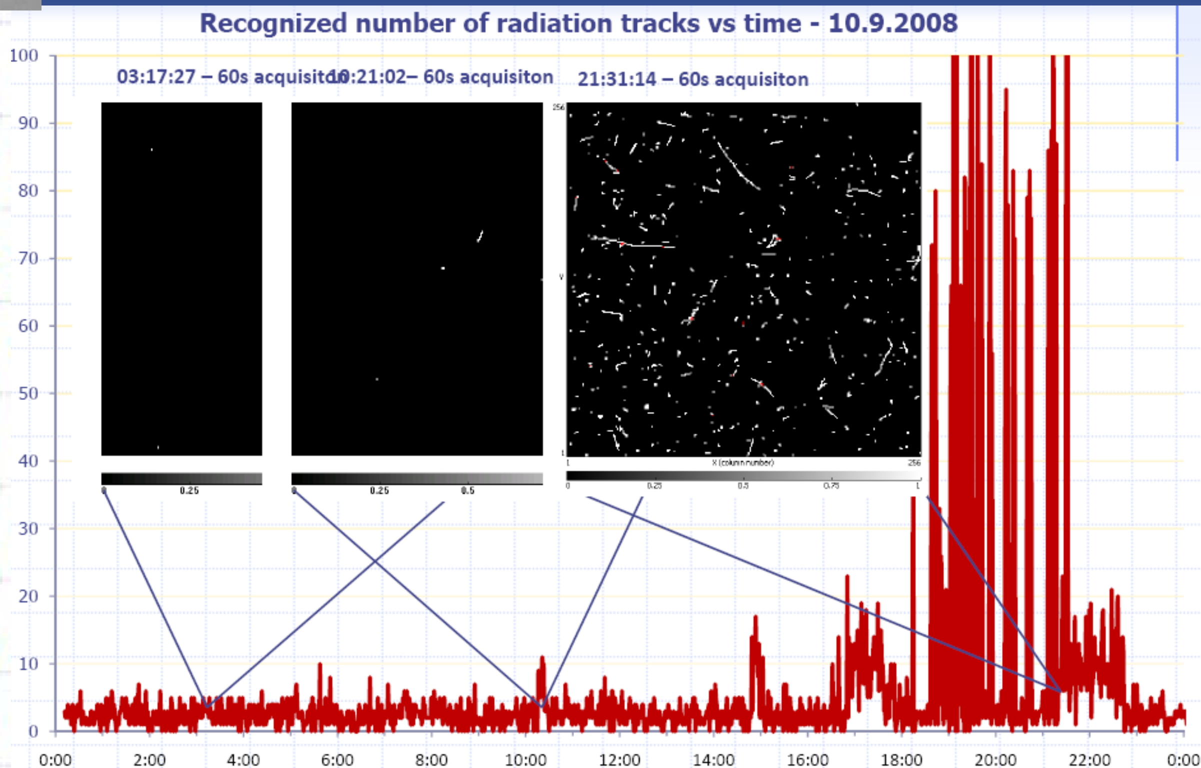


Dosimetry in ATLAS – 1st Results

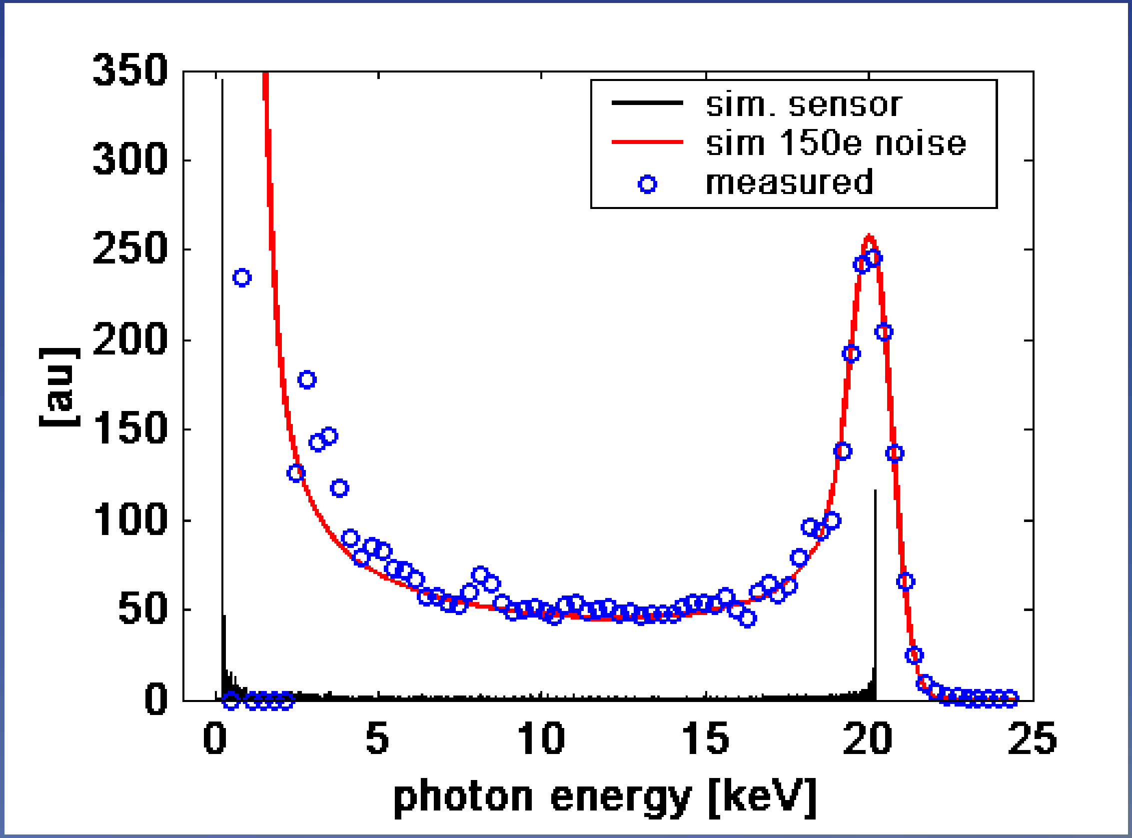
- 14 monitors throughout ATLAS
- Encouraging initial results
- Plans to deploy on the LHC machine

X-ray image of conversion layers





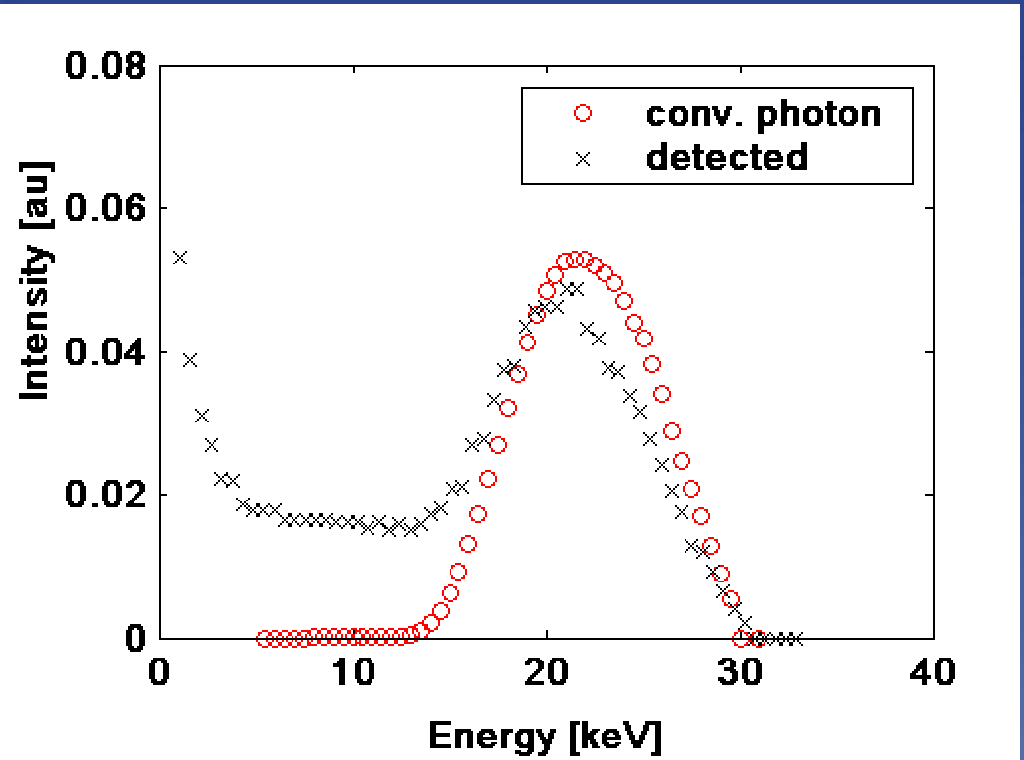
Energy resolution



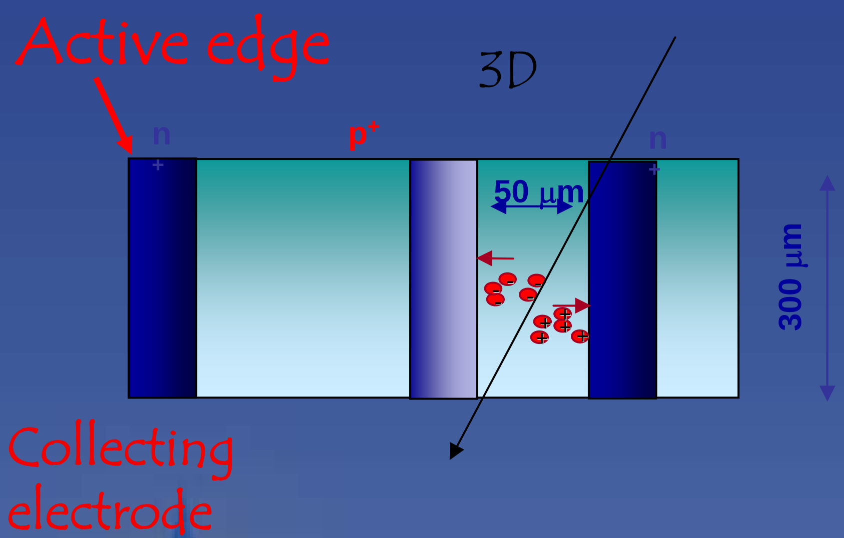
- 20 keV photons collimator 1 mm^2
- Experimental curve: mean response of 330 pixels
- Apparent energy resolution of a single pixel ~190 e$^-$ / 0.7 keV

Detected energy spectrum
Spectral source

- Deformation of the detected spectrum depends on pixel geometry
- Simulation W-tube 30 keV, 2.5 mm Al, 300 μm Si sensor

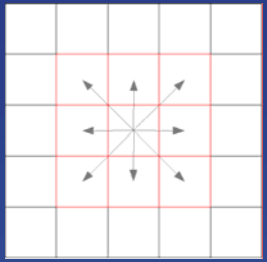


100 μm pixel



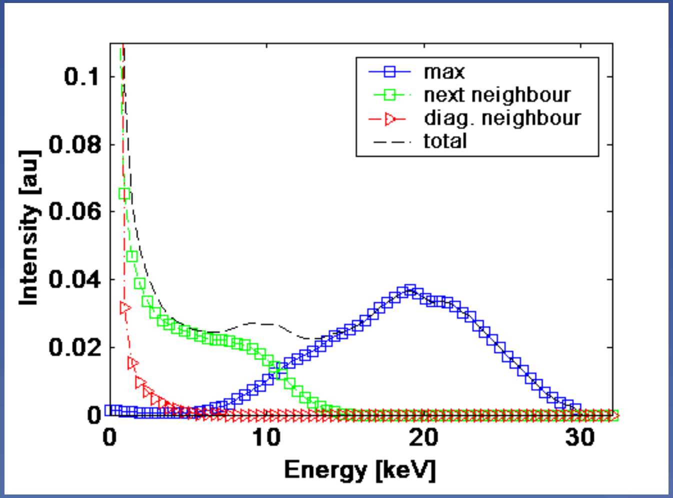
Charge sharing correction

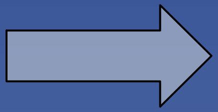
Simulation of charge sharing correction



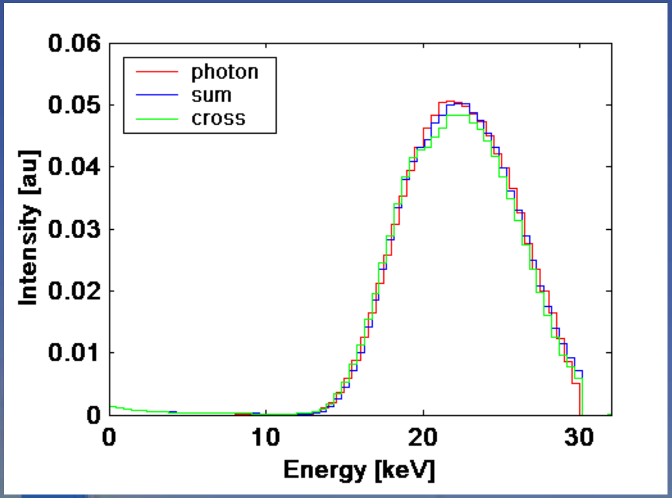
Summing of signals seen in a cluster of 3x3 pixels

Charge shared spectrum (simulation)





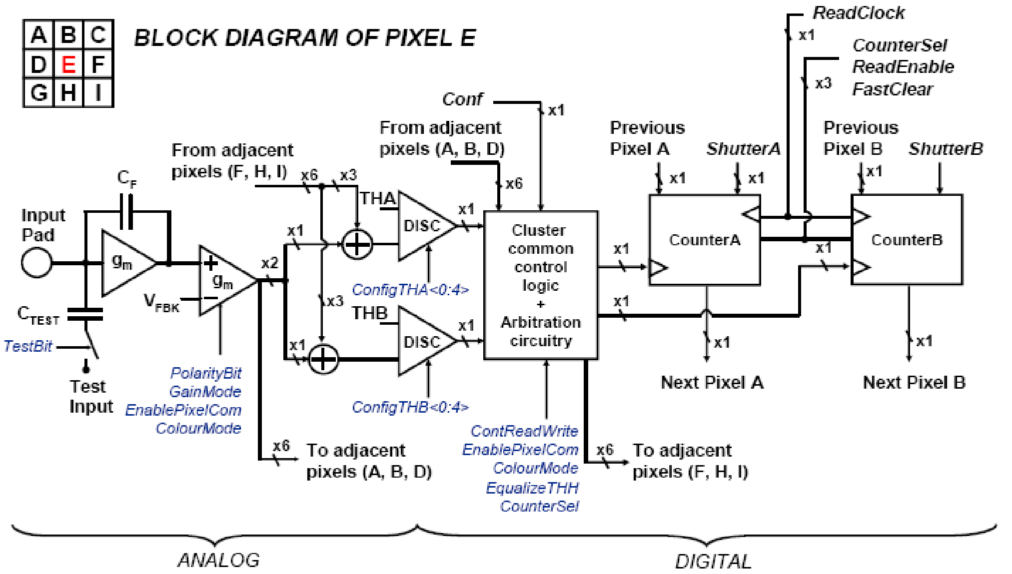
Corrected spectrum (simulation)

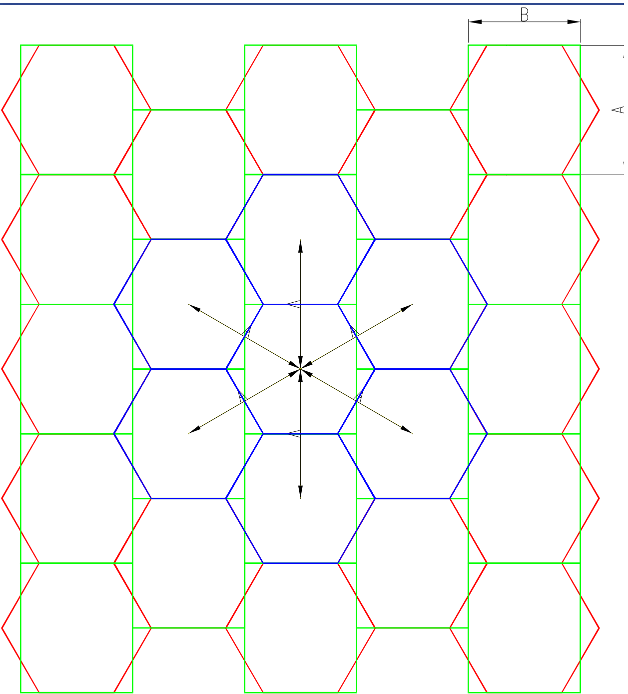


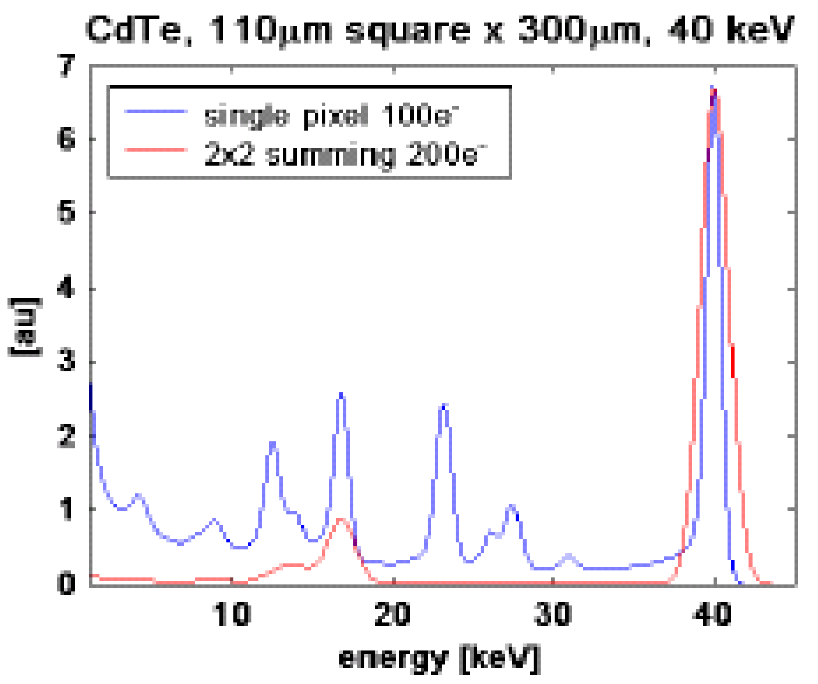
Medipix3

15 Institutes 2006

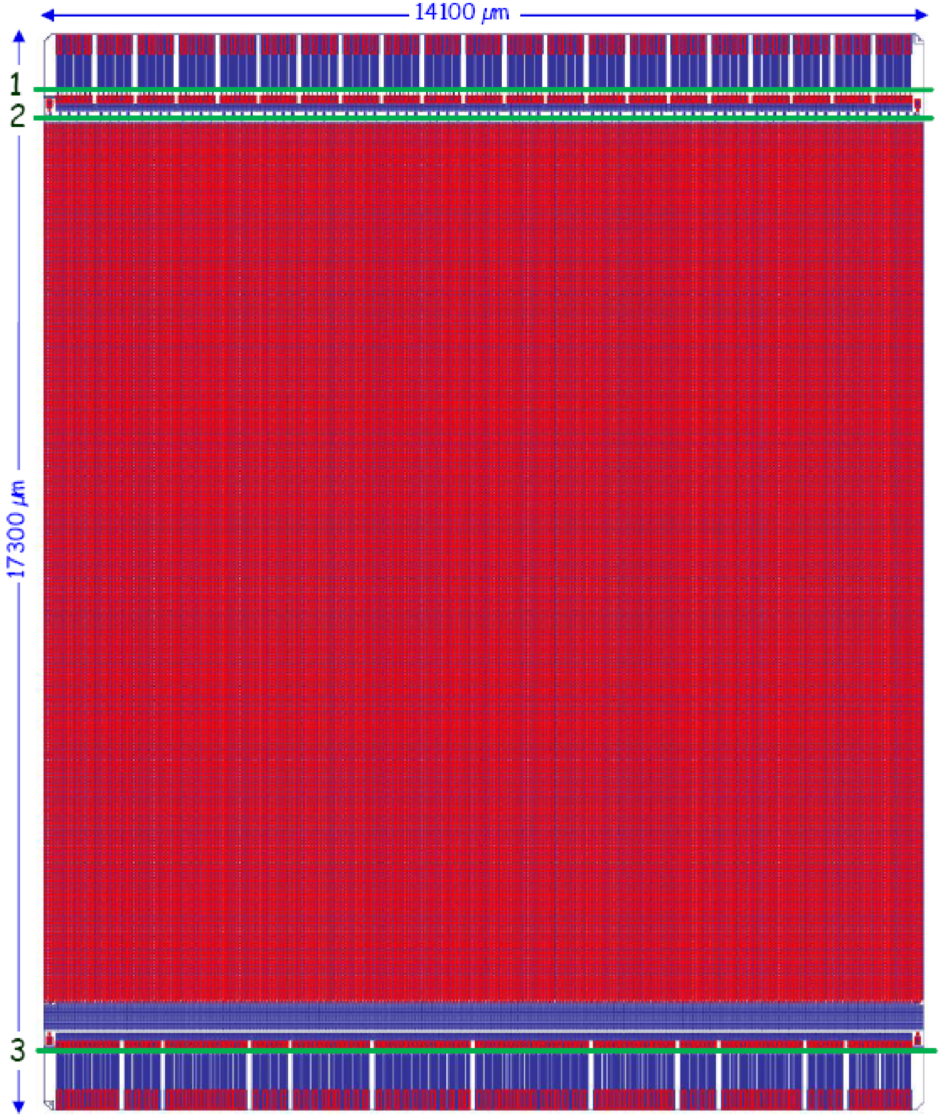
- 1086 transistors per pixel
- Simultaneous read/write
- Charge summing mode
- Colour mode







Medipix3



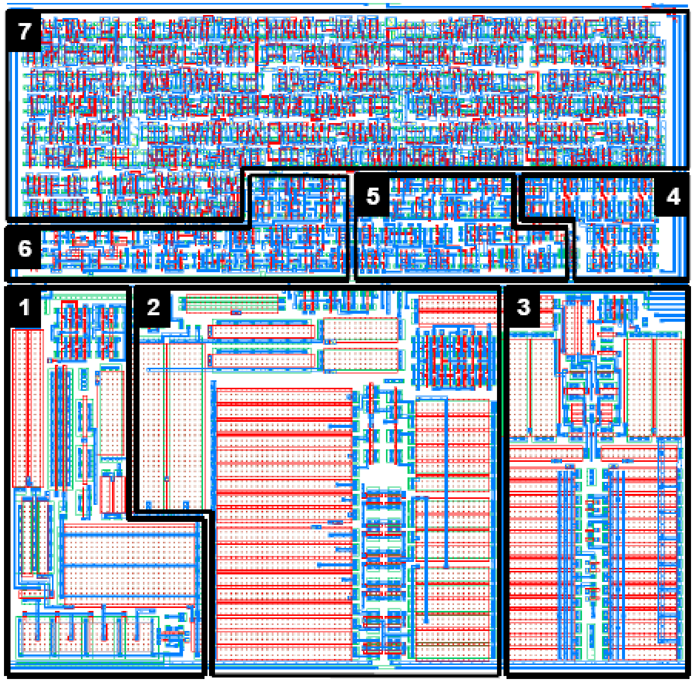


Figure 6. Medipix3 chip pixel cell layout. 1. Preamplifier. 2. Shaper. 3. Two discriminators containing a 4-bit DAC each for threshold adjustment. 4. Configuration bits. 5. Arbitration logic for charge allocation. 6. Control logic. 7. Configurable counter.

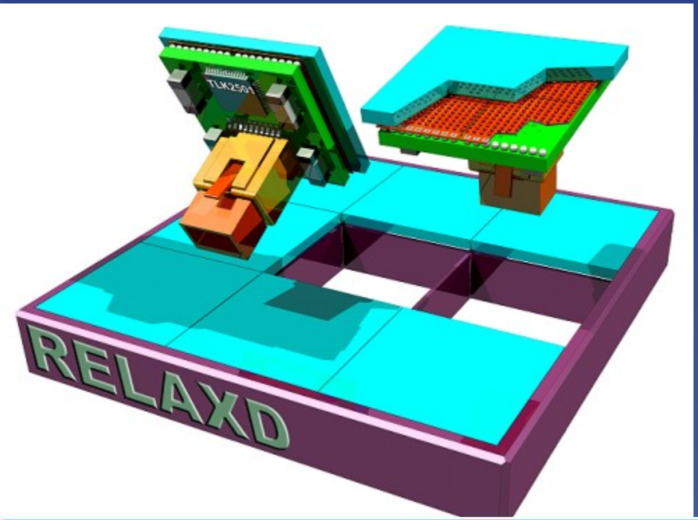
Table 1. Active area depending on dicing cuts

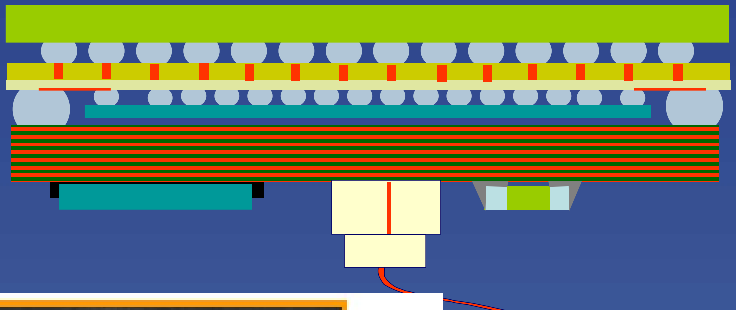
	In-chip Dicing	X [µm]	Y [µm]	Active Area
Medipix2 and Timepix	None	14111	16120	87.1%
Medipix3 top and bottom WB	None	14100	17300	81.2%
Medipix3 bottom WB	2	14100	~15900	88.4%
Medipix3 top and bottom TVS	1 and 3	14100	~15300	91.9%
Medipix3 bottom TVS	2 and 3	14100	~14900	94.3%

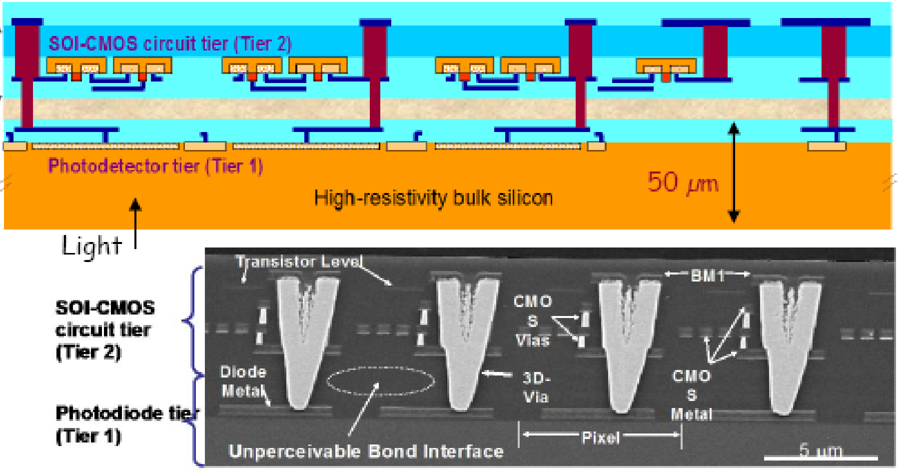
Future Work
Tiling of 3D-image stacks

Tiling on frame :
- flexible design,
- high accuracy alignment

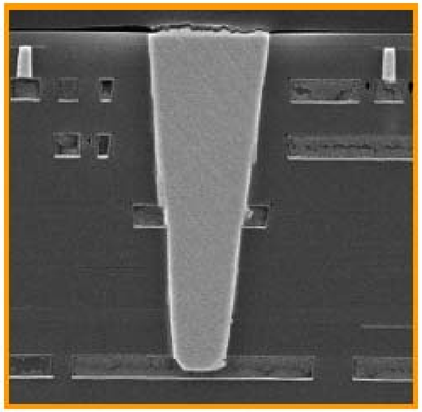
Basic image cell : vertical hybridisation of detector, read-out electronics & Interface circuitry & connector
New RELAXD project – NIKHEF, IMEC and Panalytical





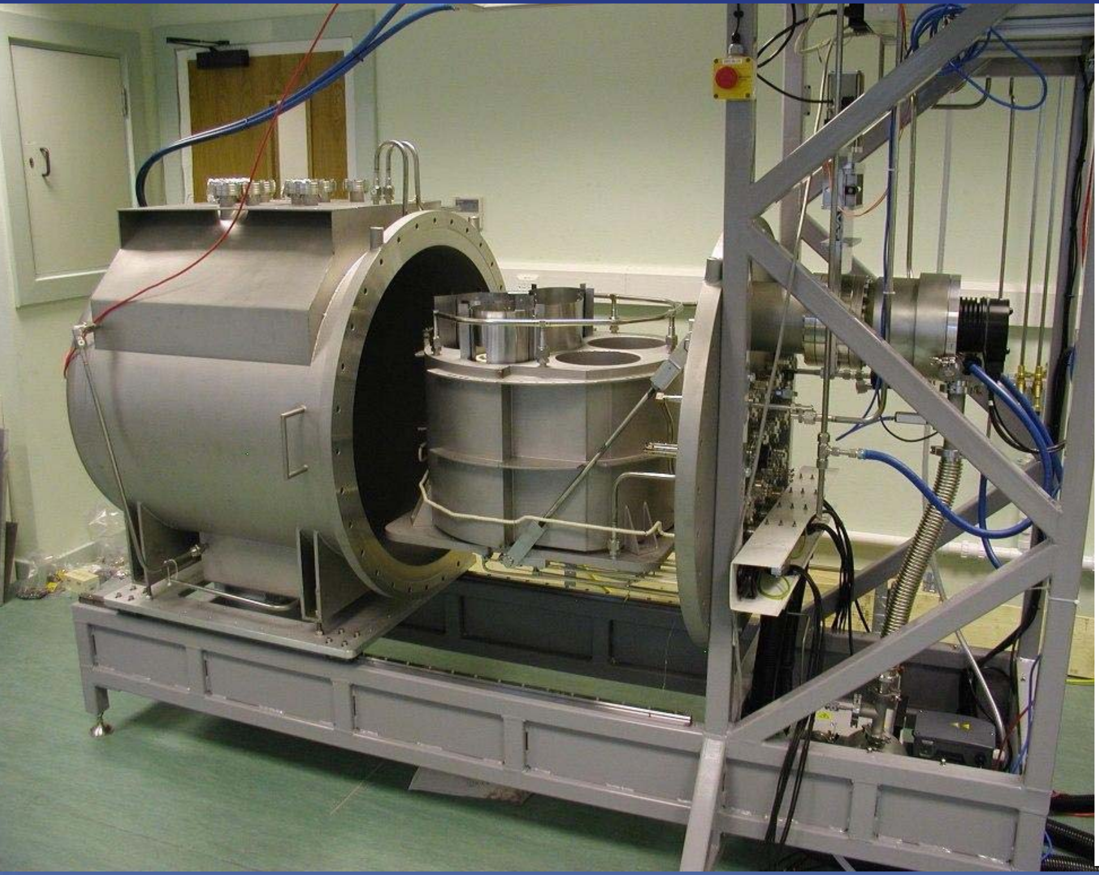


Drawing and SEM Cross section



Tapered wall using high density plasma oxide etch (MIT Lincoln Labs)

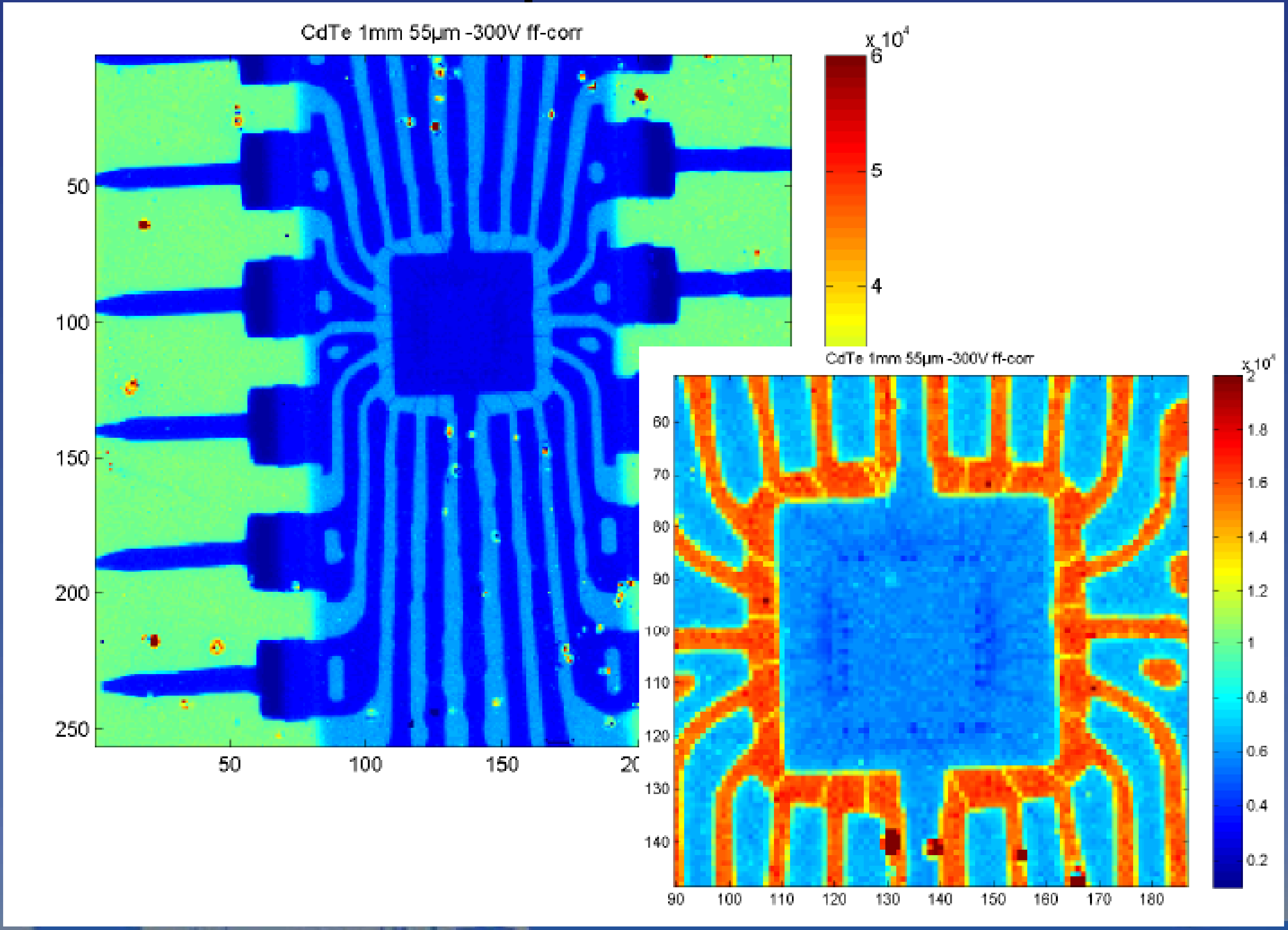
Materials – Cd(Zn)Te



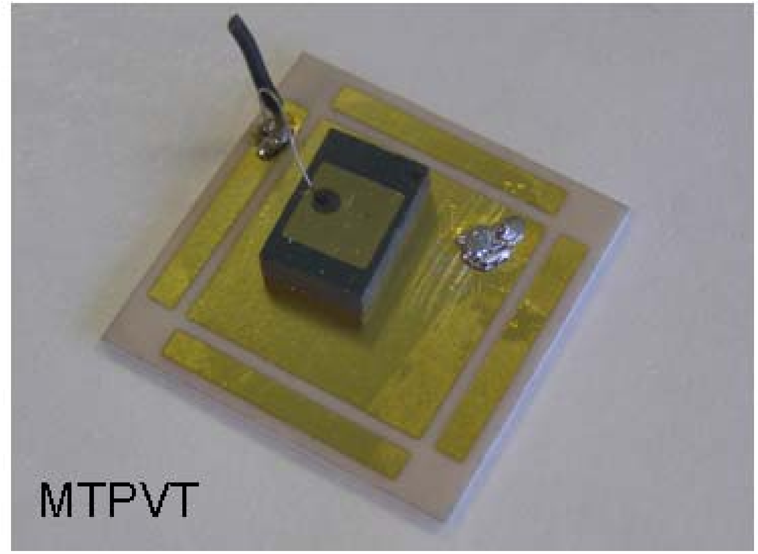
M4_019, 50 mm diameter CZT boule grown in new MTPVT system

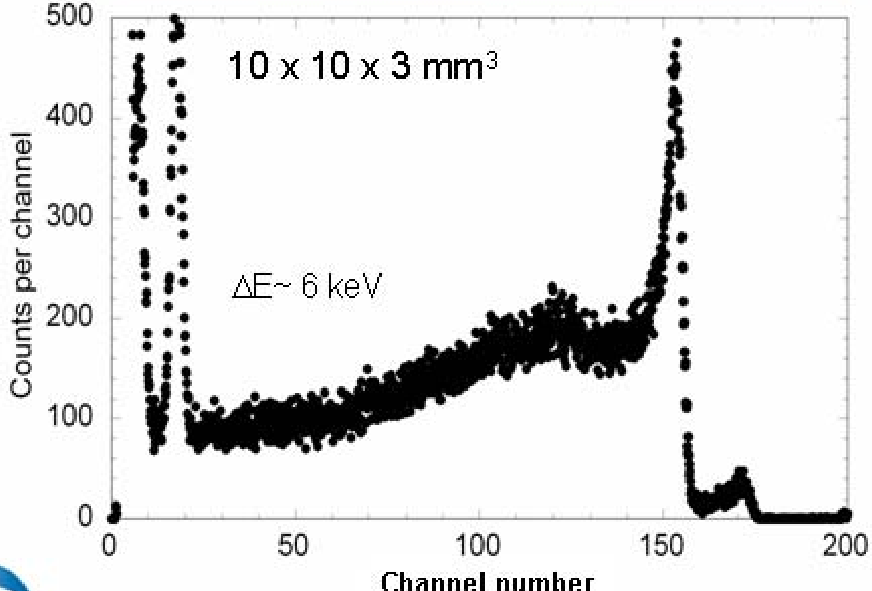
- Permits growth of multiple crystals at same time
- Currently completed growth trials
- 2" crystals chosen as research vehicle. Process immediately scaleable to 3"

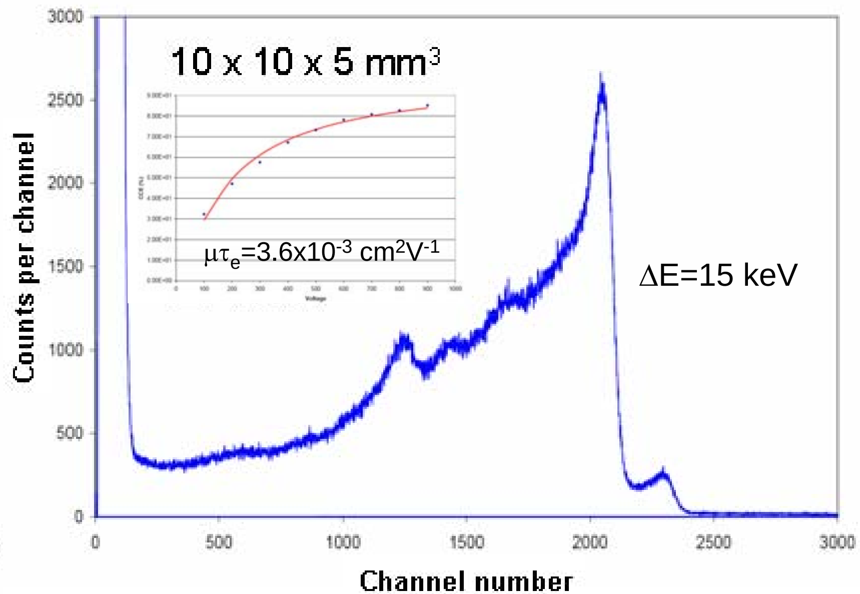
Timepix – 1mm CZT



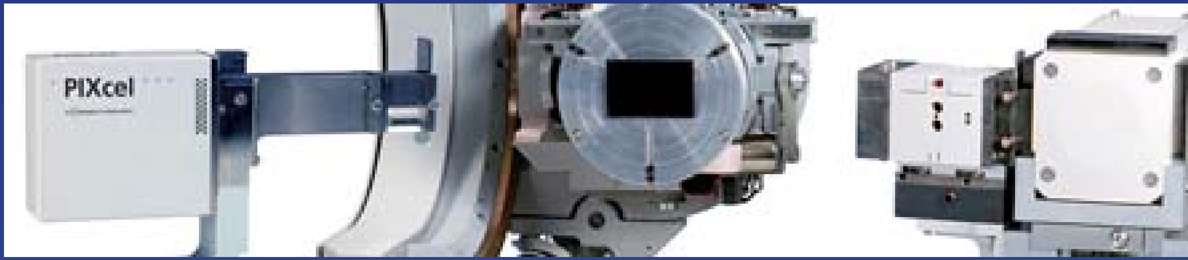
Comparison of ^{57}Co spectral performance







Medipix



- MPX3 back from foundry Feb 09
  First results encouraging
- MPX2 licensed to Panalytical
  (200 units sold in 2008)
- Philips Healthcare discussing cooperation with Medipix
- MPX2 licensed to Canterbury
- MPX2 dosimeter deployed in ATLAS
- Timepix variant proposed for LHCb VeLo Upgrade

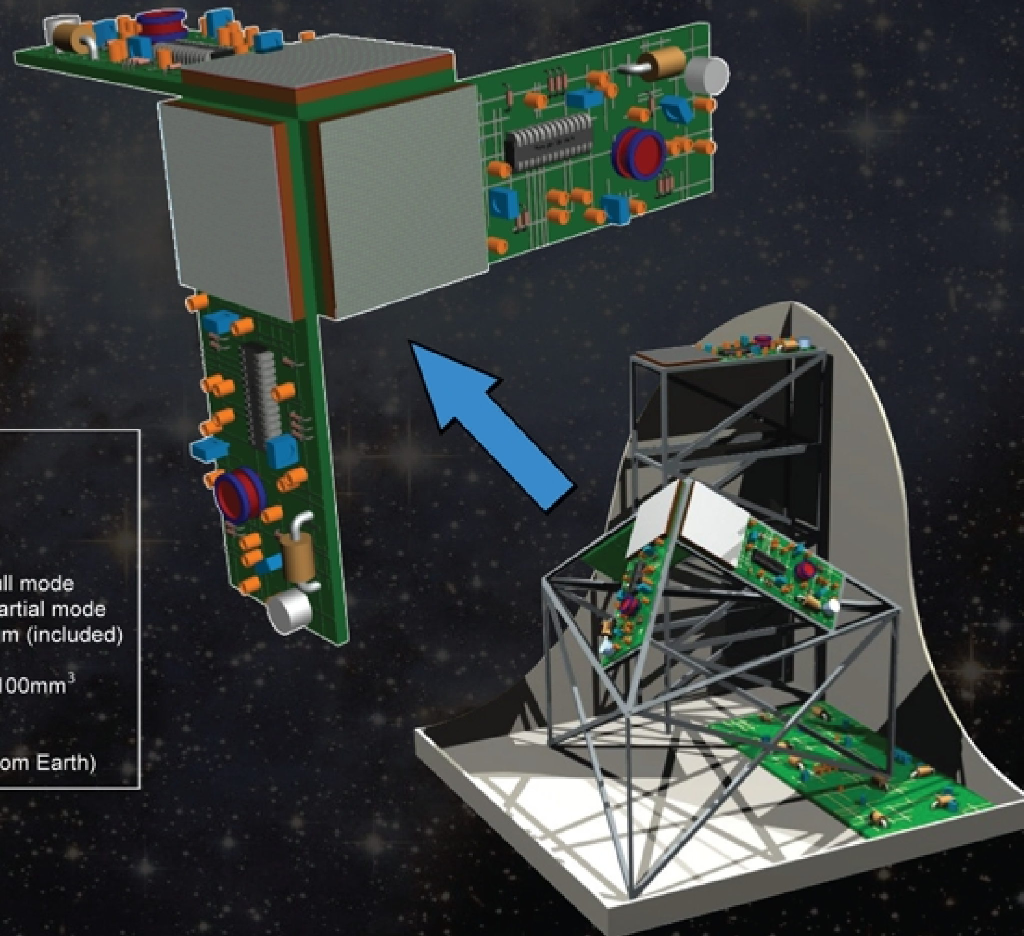
One detector for all applications
PIXcel can be utilized in a wide range of static and scanning 1-D and 0-D applications, including:
Thin film diffraction: rocking curves, reciprocal space maps, reflectivity
Powder diffraction: rapid scanning, high resolution powder diffraction, kinetic and non-ambient experiments

Medipix in Space

The Design

The basic componants of LUCID are:

3 Timepix chips
1 neutron-ready Timepix chip
Housekeeping electronics
Data storage unit
Optical Surface Reflector



Budgets and Specifications

Mass	-	0.7kg
Power	-	3.52W peak
	-	1W average
Data Capture Rates	-	4.8 gigabytes/day full mode
	-	1.1 gigabytes/day partial mode
Data Storage Requirements	-	4 gigabytes maximum (included)
Cost	-	£35,000
Volume	-	Within 100 x 100 x 100mm^3
Duty Cycle	-	Variable
Mission Length	-	5 years minimum
Location on Satellite	-	Space side (away from Earth)

LUCID

Langton • Ultimate • Cosmic Ray • Intensity • Detector

http://www.thelangtonstarcentre.org/satellite/design.html