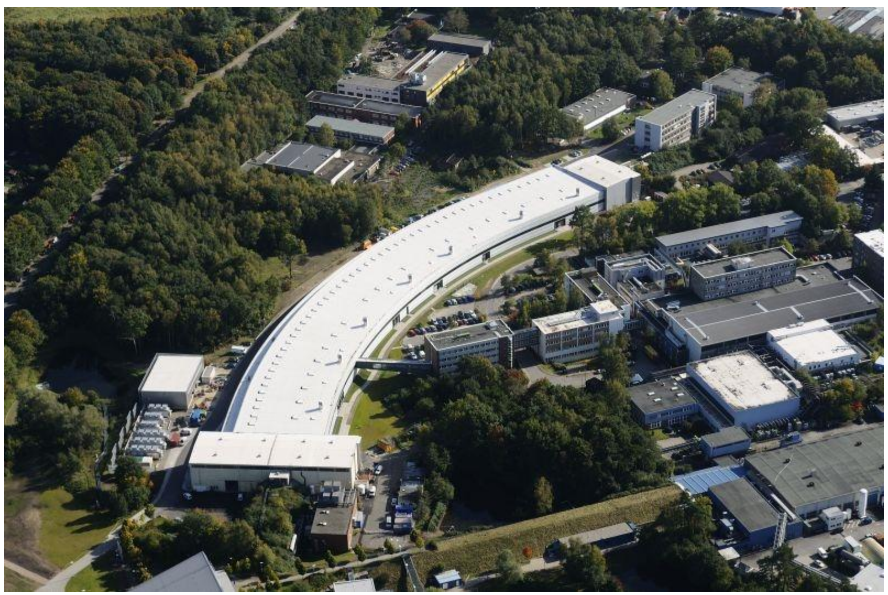
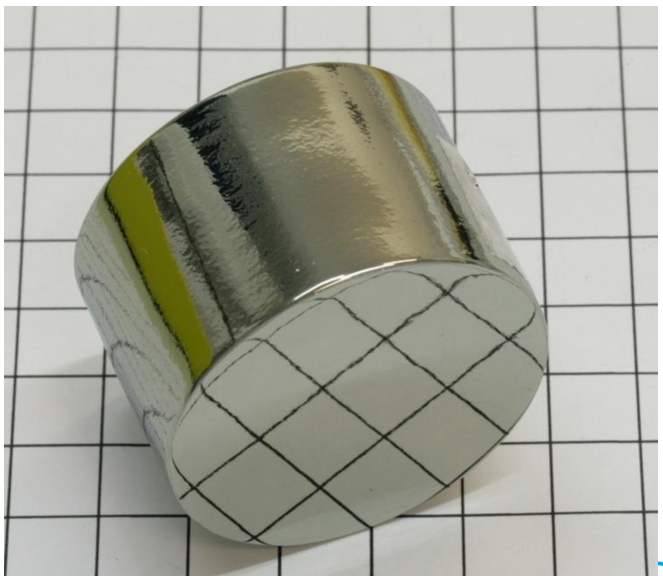
Development of high-Z sensors for pixel array detectors

David Pennicard, DESY

Heinz Graafsma, Sabine Sengelmann, Sergej Smoljanin, Helmut Hirsemann, Peter Goettlicher

Vertex 2010, Loch Lomond, 6-11 June 2010





HELMHOLTZ | ASSOCIATION

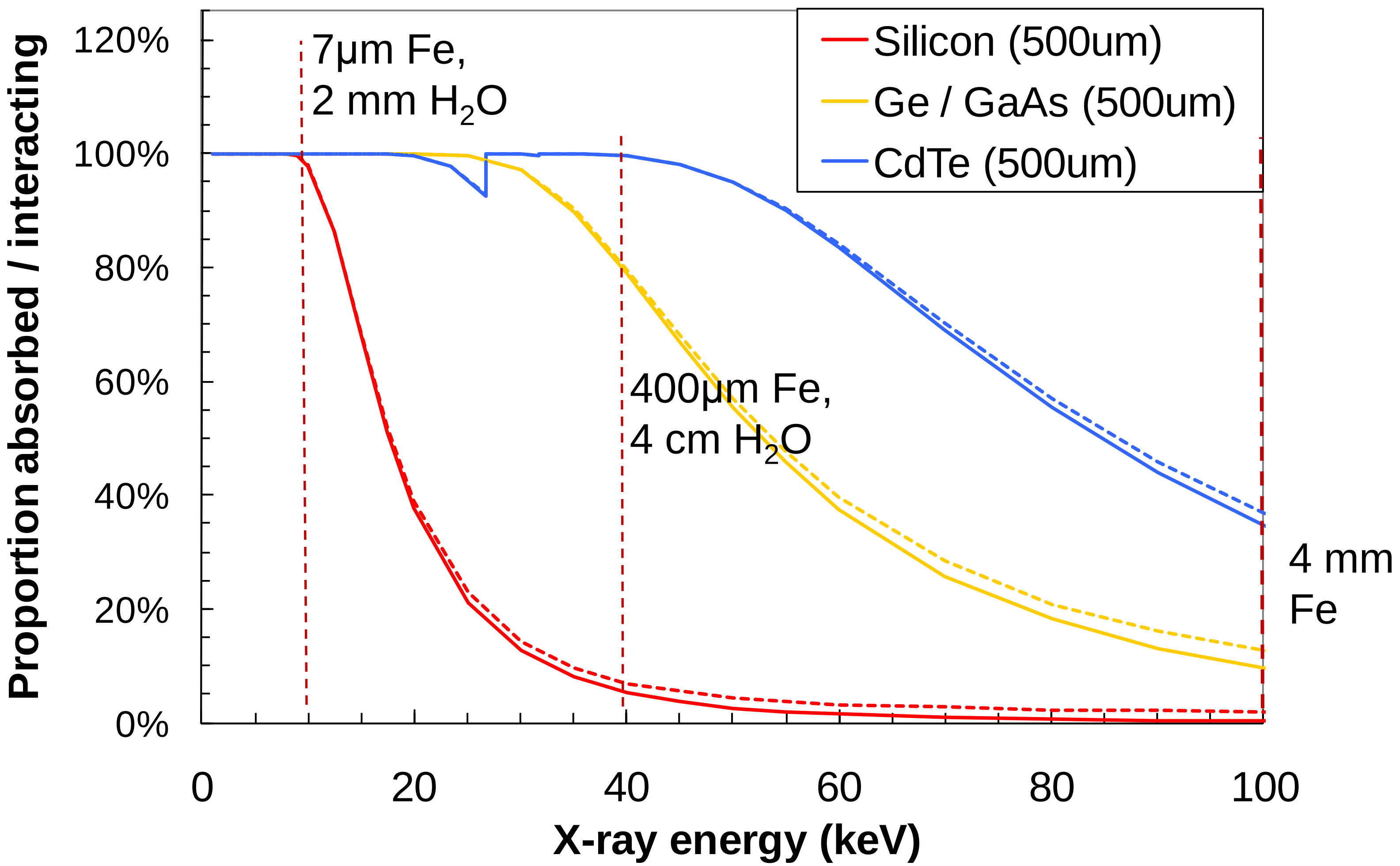
DESY

Development of high-Z sensors for pixel array detectors

- Applications of high-Z pixel arrays
- Overview of high-Z sensors
  - CdTe / CZT
  - GaAs
- Work on pixellated Ge sensors at DESY
- Summary

High-Z materials for X-ray absorption

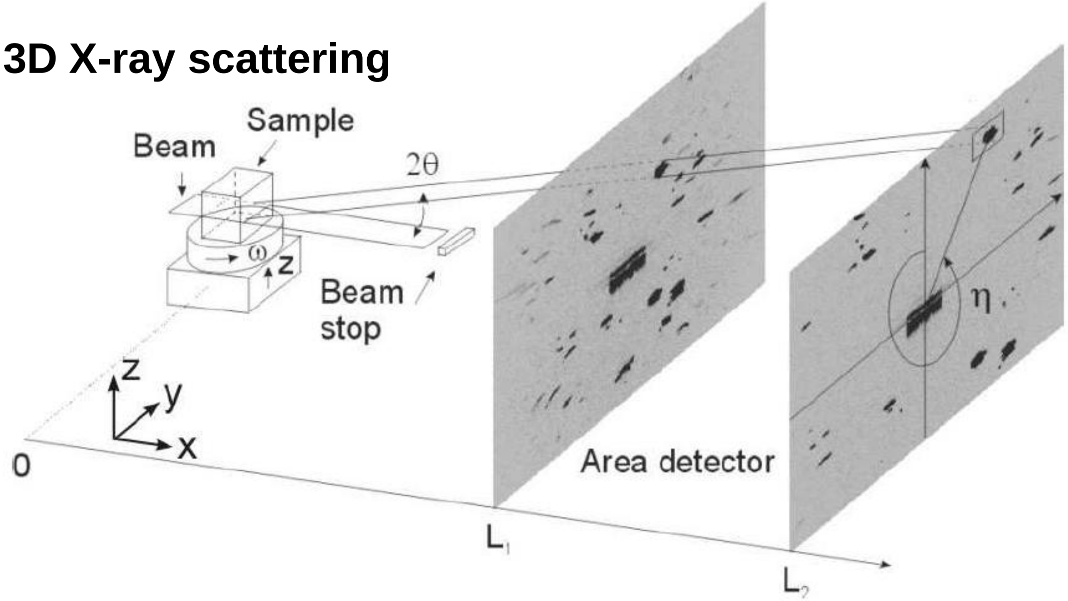
X-ray absorption / interaction



Synchrotron applications

> PETRA-III at DESY
  - Beamline energies to 150keV (mostly 50keV)
  - Materials science apps

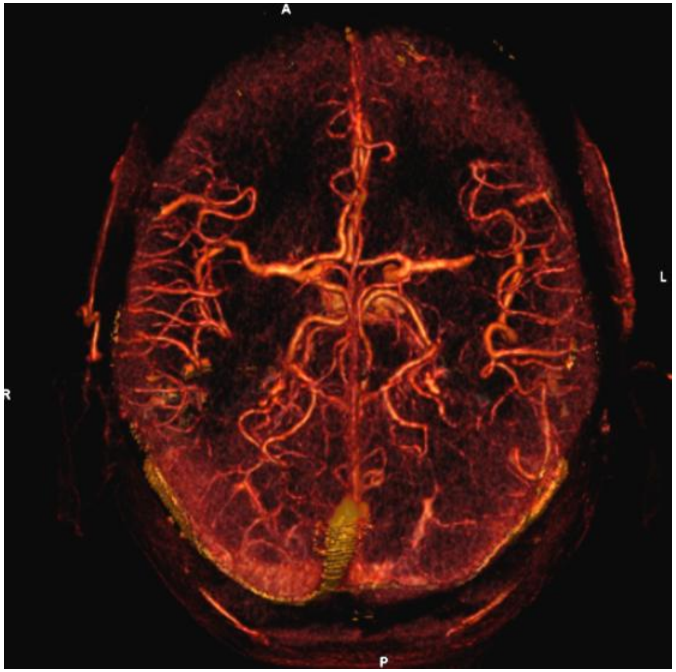
3D X-ray scattering



> High-E scattering and tomography
  - Structure at buried interfaces, grain mapping...

Other applications

- **Energy resolution!**
- Medical & small animal imaging / CT
  - Distinguish bone, tissue, contrast agents..
- Astronomy
  - Hard X-ray telescopes
- Gamma ray
  - E.g. Compton camera...



Johnson 2007 - Material differentiation by dual energy CT: initial experience

Collaborations

- **HiZPAD (Hi-Z sensors for Pixel Array Detectors)**
  - ESRF (coordinator), CNRS/D2AM, DESY, DLS, ELETTRA, PSI/SLS, SOLEIL
  - CPPM, RAL, University of Freiburg FMF, University of Surrey, DECTRIS
- **Medipix3**
  - See Richard Plackett's talk
  - *Inter-pixel communication* allows thick high-Z sensors

Development of high-Z sensors for pixel array detectors

- Applications of high-Z pixel arrays
- **Overview of high-Z sensors**
  - **CdTe / CZT**
  - **GaAs**
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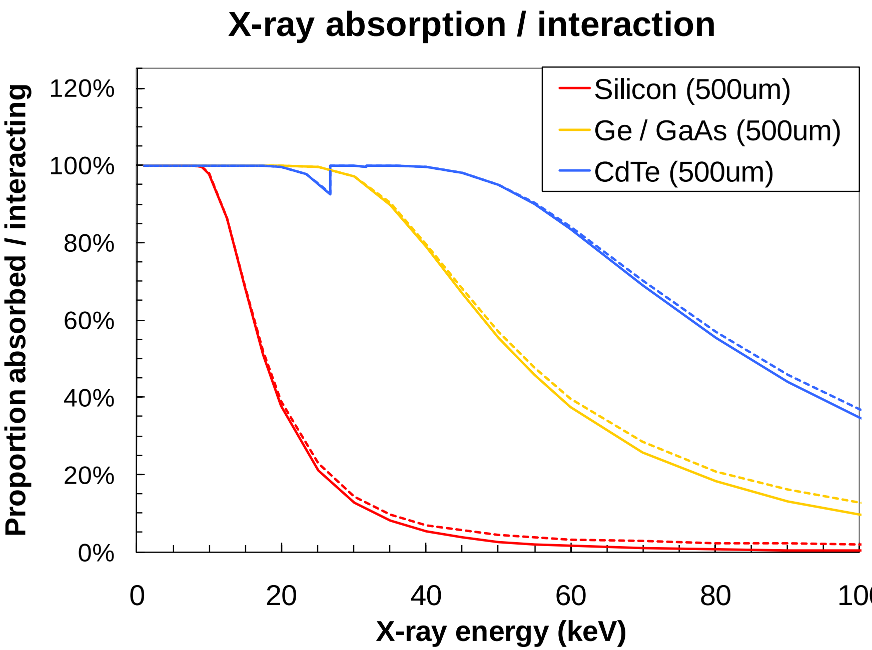
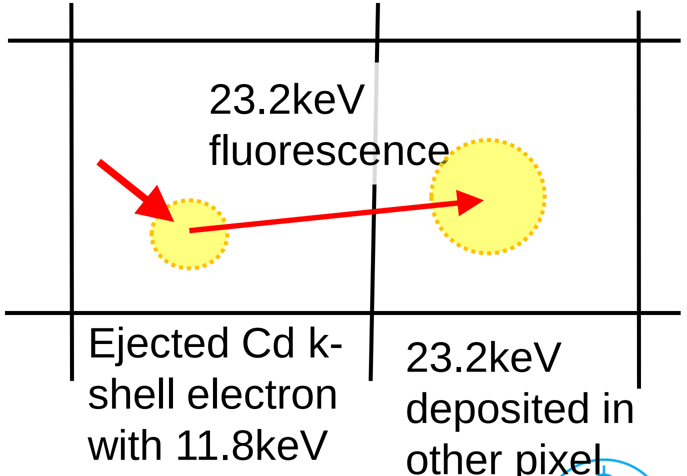
General issues with high-Z sensors

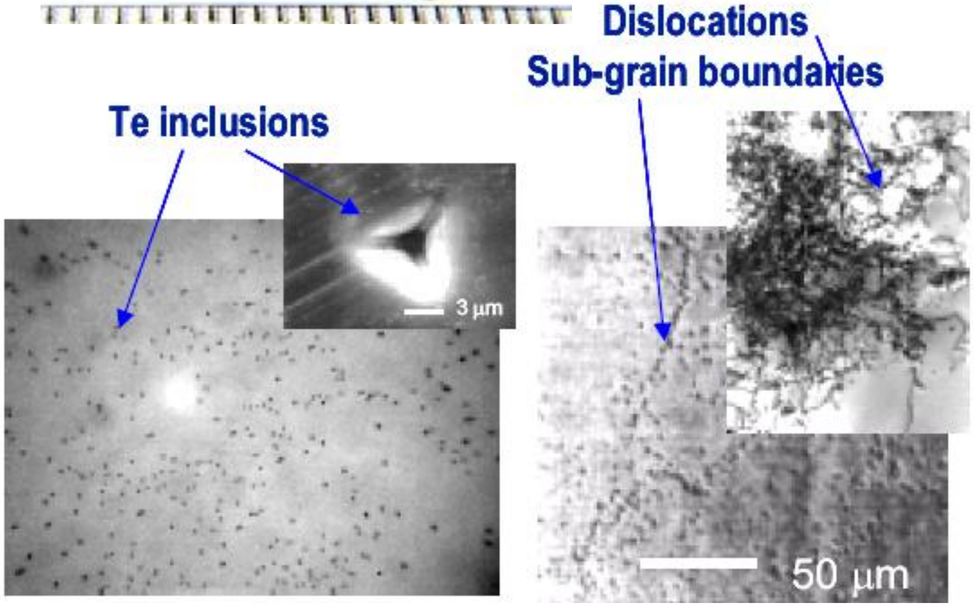
- **>** Fluorescence
  - Degrades spatial and energy resolution above k-edge
- **>** Bulk properties
  - Leakage current, resistivity, trapping
- **>** Material homogeneity and area
  - Grain boundaries – want single crystal
- **>** Pixellation
- **>** Bump bonding





Cadmium Telluride

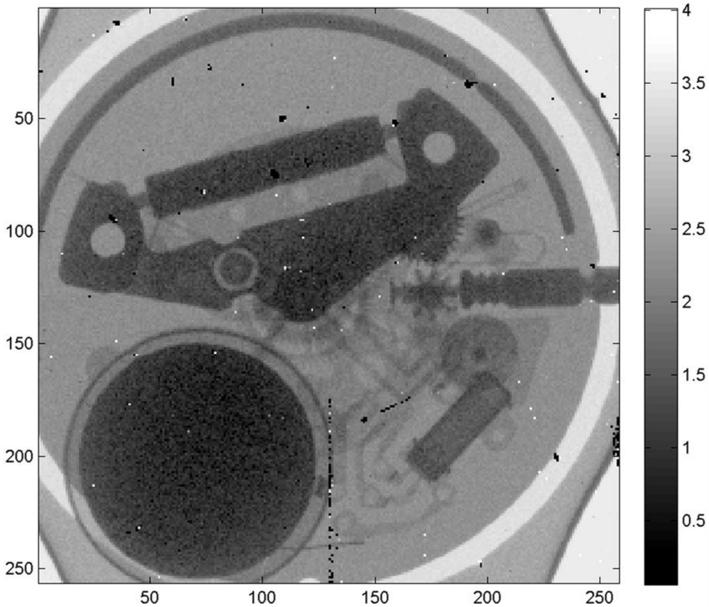
- Used for γ-ray spectroscopy
- Commercially-grown wafers:
  - Single-crystal now 3”
  - Defects affect uniformity
- Properties
  - 1.44eV bandgap (room T)
  - High resistivity
  - Schottky or ohmic metal contacts
- Trapping & drift distances:
  - Electrons - cm
  - Holes - mm
  - Use electron readout!



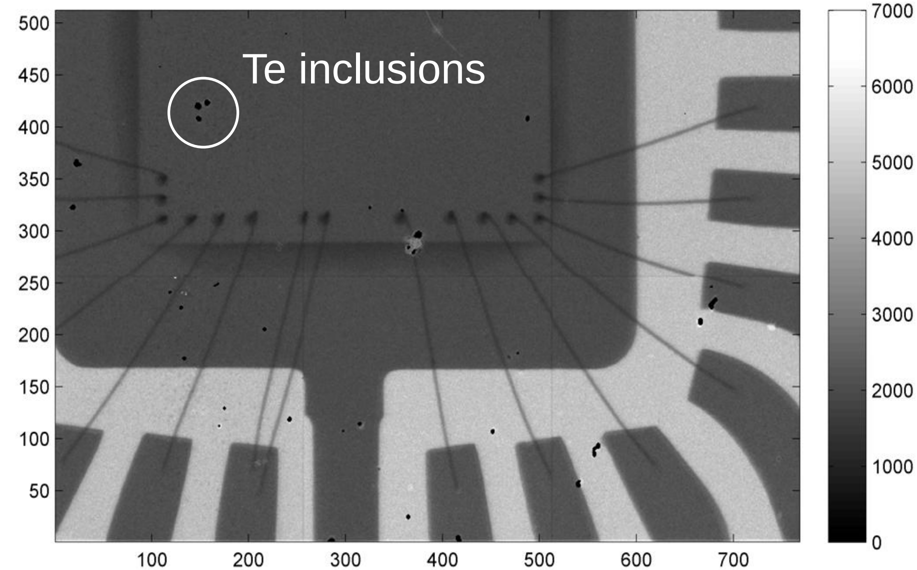
Szeles 2003, CdZnTe and CdTe materials for X-ray and gamma ray radiation detector applications

CdTe Medipix2 Assemblies

- 1mm CdTe (Acrorad, 3”)
  - Ohmic pixel contacts



>QUAD (2x2) 110 µm pixel pitch
28x28 mm^2 active area
Flat field corrected

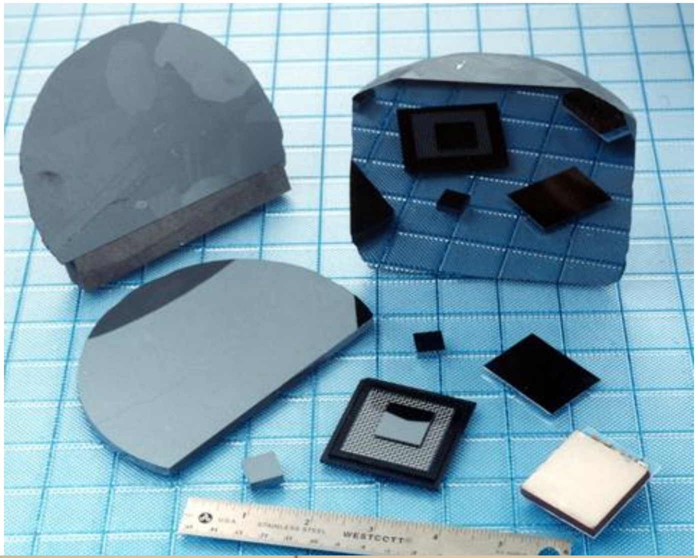


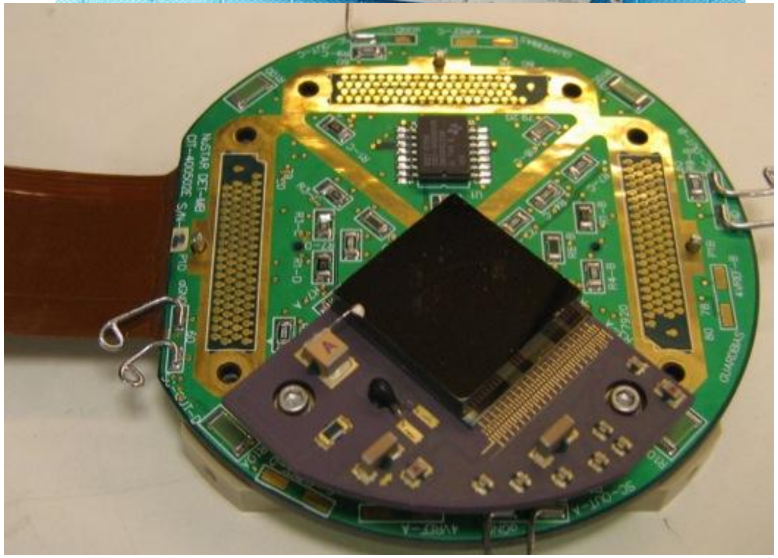
>Hexa (2x3) 55 µm pixel pitch
28x43 mm^2 active area,390,000 pixels
Flat field & filter

Produced by
A. Fauler, A. Zwerger, M. Fiederle
Freiburger Materialforschungszentrum FMF
Albert-Ludwigs-Universität Freiburg

CdZnTe

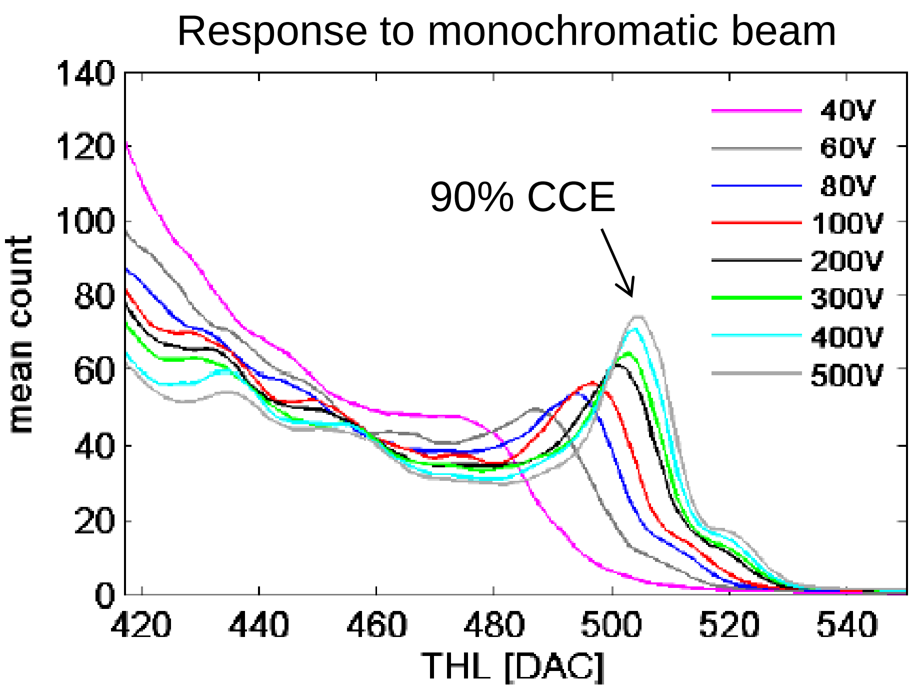
- Typically $Cd_{0.9}Zn_{0.1}Te$
  - Increased bandgap (1.57eV) – lower current
- Produced in large *polycrystalline* ingots
  - Good single-crystal segments up to 20*20mm^2
- Small pixel arrays possible
  - NuSTAR (Nuclear Spectroscopic Telescope Array)
  - 20*20mm^2, 600µm pixel size

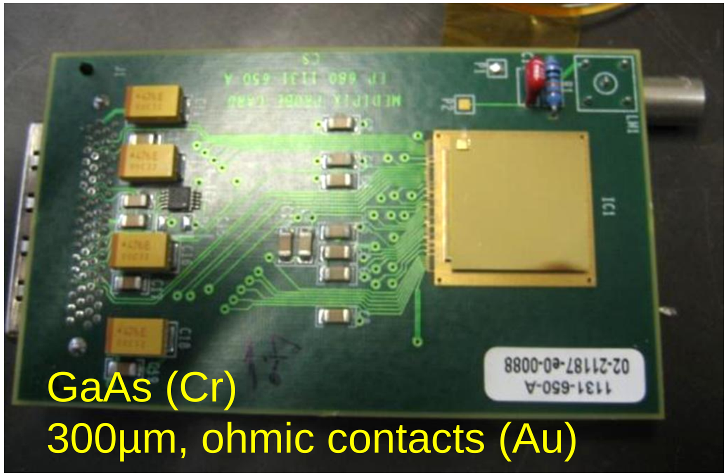




Gallium Arsenide

- Better single-crystal production (6”)
- 1.43eV bandgap (room T operation)
- Problem – defects!
  - Shallow defects prevent depletion
  - Carrier lifetimes
- Epitaxial growth or compensation





L. Tlustos (CERN), Georgy Shekov (JINR Dubna), Oleg P. Tolbanov (Tomsk State University) “Characterisation of a GaAs(Cr) Medipix2 hybrid pixel detector”, IWorid 2009

Development of high-Z sensors for pixel array detectors

- Applications of high-Z pixel arrays
- Overview of high-Z sensors
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- **Work on pixellated Ge sensors at DESY**
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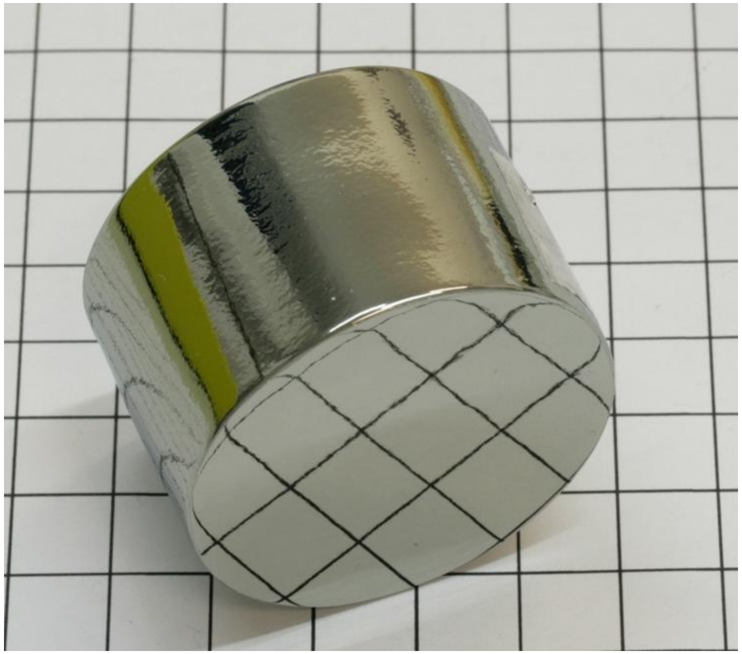
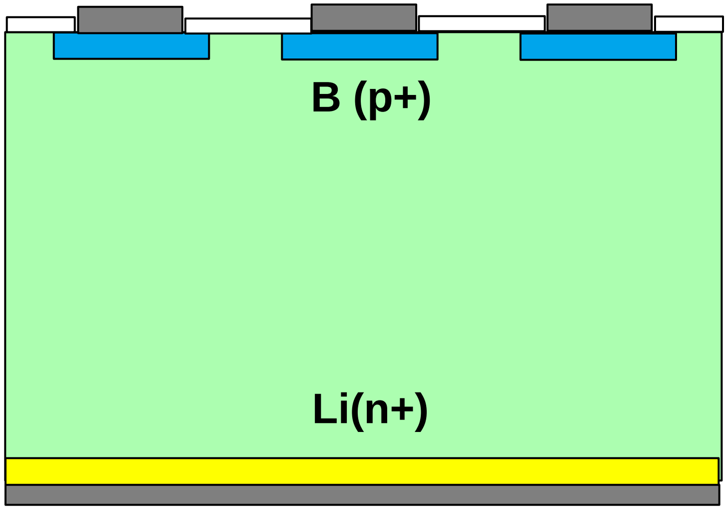
Germanium pixels

- High-purity, high uniformity 95mm Ge wafers available
  - Transport & depletion fine
- Narrow bandgap (0.66eV) means cooled operation needed
  - *Per pixel* current must be within ROC limits (order of nA)
  - Est. -50°C operation with Medipix3 (55µm)
  - Need to consider thermal contraction, etc.
  - “Engineering problems”
- Fine pixellation and bump-bonding must be developed



Pixel detector production at Canberra (Lingolsheim)

- Diodes produced by lithography (p-on-n)
  - Thinned germanium wafer (0.5mm+)
  - Li diffused ohmic back contact
  - Boron implanted pixels
  - Passivation, Al metallisation
- 2 runs planned:
- Medipix3 singles
  - 55µm, 110µm and 165µm pixel, 500µm
- Second run 2*3 assemblies (42*28mm)
  - Option of thicker Ge

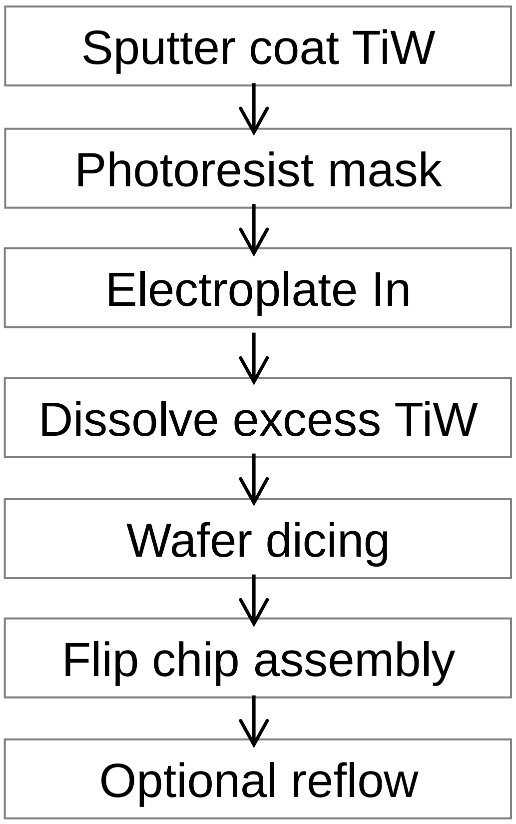


CANBERRA

M Lampert, M Zuvic, J Beau

Bump bonding at Fraunhofer IZM (Berlin)

- Low temp bonding required
- Bonds must tolerate thermal contraction
  - 3.5µm max displacement for ΔT=100K
- Indium bump bonding
  - Bumps on ASIC and sensor
  - Thermosonic compression at low T
  - *Possible* reflow above 156 C
- Currently performing tests on Ge diodes

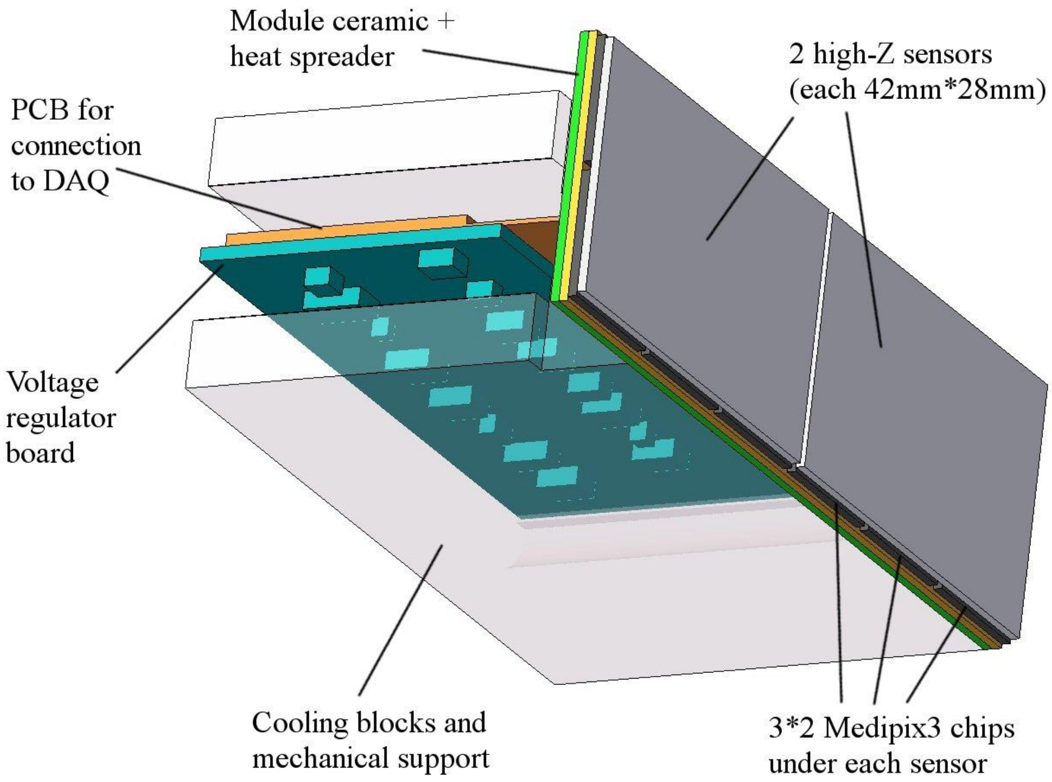


Fraunhofer IZM

T Fritzsch, H Oppermann, O Ehrmann, R Jordan

Medipix3 module readout

- 2*6 chip module (28*85mm)
  - Tilable
- Cooling through thermal vias
  - Ceramic and heat spreader match Ge CTE
- Readout FPGA board
  - 10 GBE for high-speed readout
  - Improved infrastructure needed



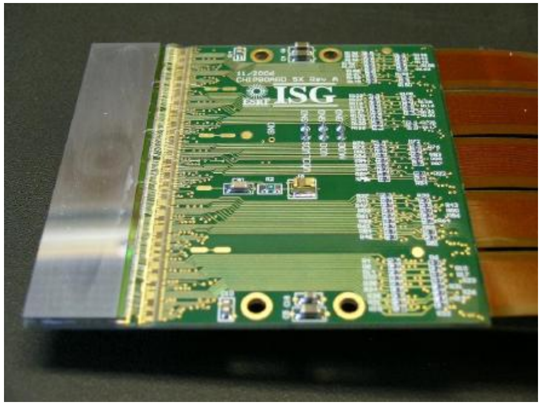
Conclusions

- Demand for high-Z hybrid pixels
  - Material science, biology / medicine, astronomy...
- Promising results from CdTe / CZT, GaAs
  - Commercial CdTe / CZT wafers improving
  - Improved GaAs compensation
- Ge pixels could provide high-uniformity sensors (albeit without room-temp operation)

Thanks for listening

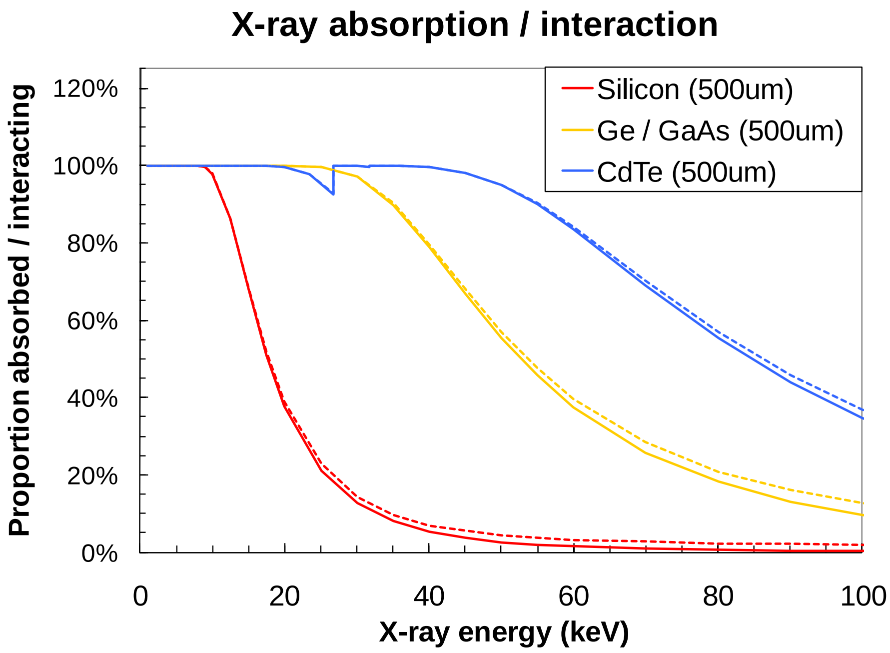
What do hybrid pixels offer?

- Current generation (Pilatus, Medipix2, XPAD2/3)
  - Noise rejection (photon counting)
  - High speed
  - Direct detection for small PSF
- Future detectors (Eiger, Medipix3, XPAD3+)
  - Deadtime-free readout
  - Inter-pixel communication (Medipix3)
    - Correct for charge sharing
    - *Allows use of thick sensors*
  - Energy measurement
    - Medipix3 provides 2 or 8 bins (55µm or 110µm)

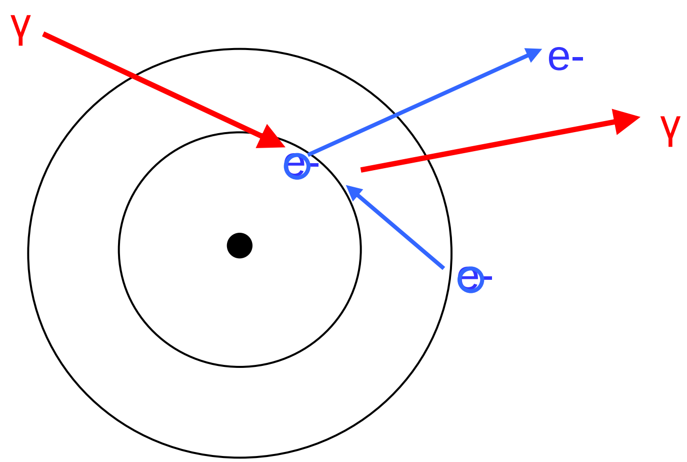


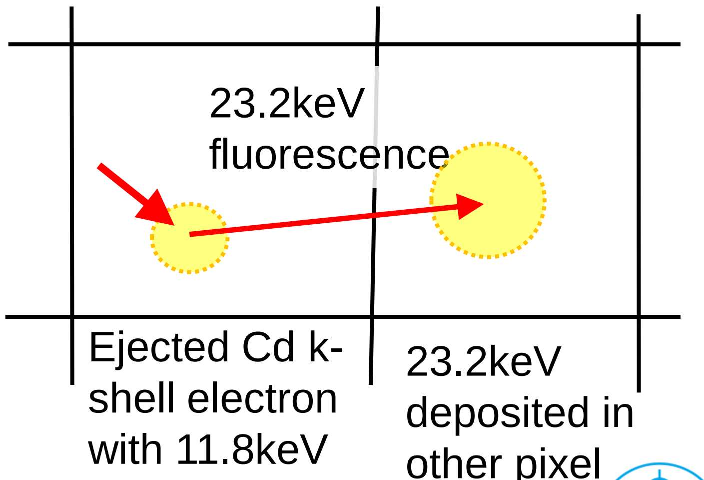
Choice of material and fluorescence effects

- Fluorescence harms performance immediately above k-shell
  - ~26.7keV for CdTe
  - ~11.1keV for Ge
- Motivation to use different materials



35keV photon in CdTe





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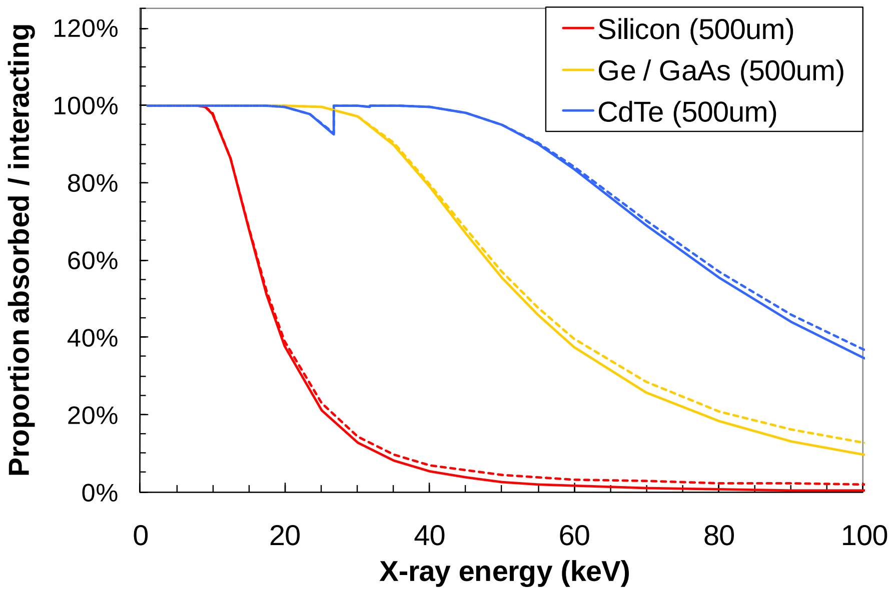
X-ray absorption / interaction



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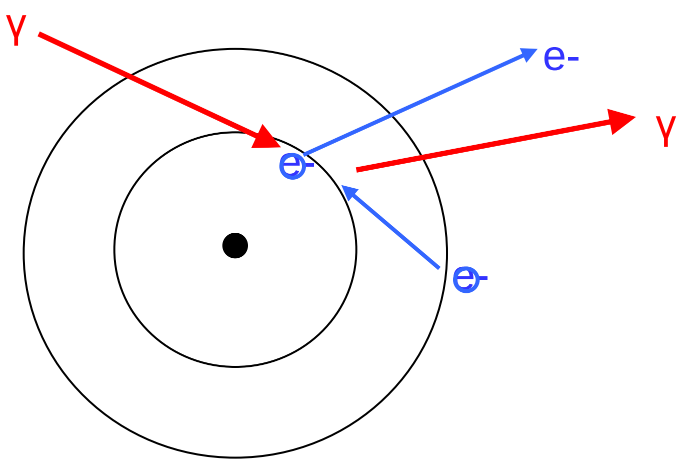
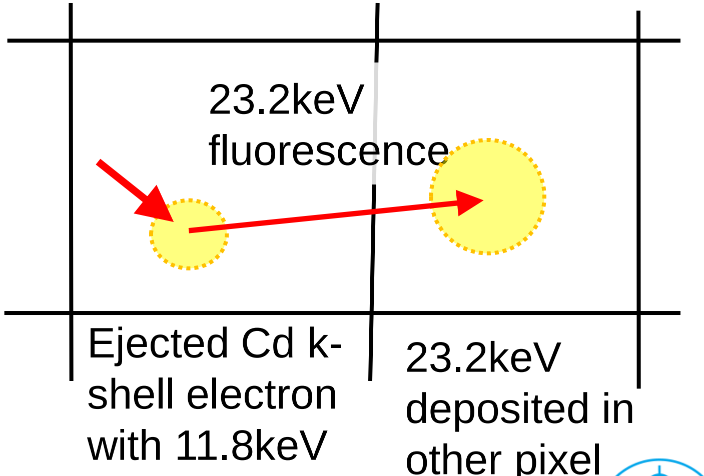
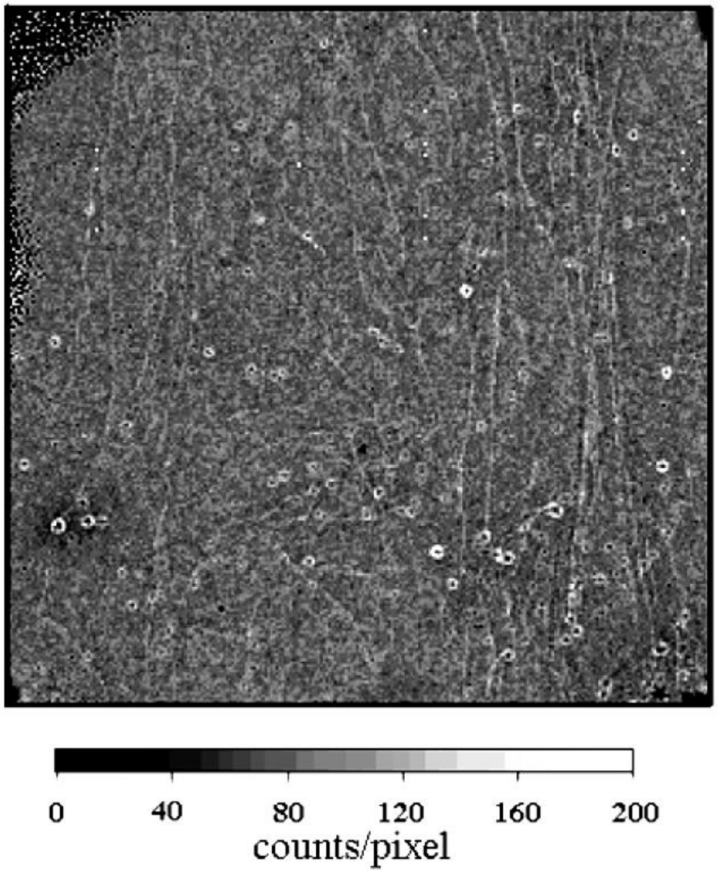




Cadmium Telluride

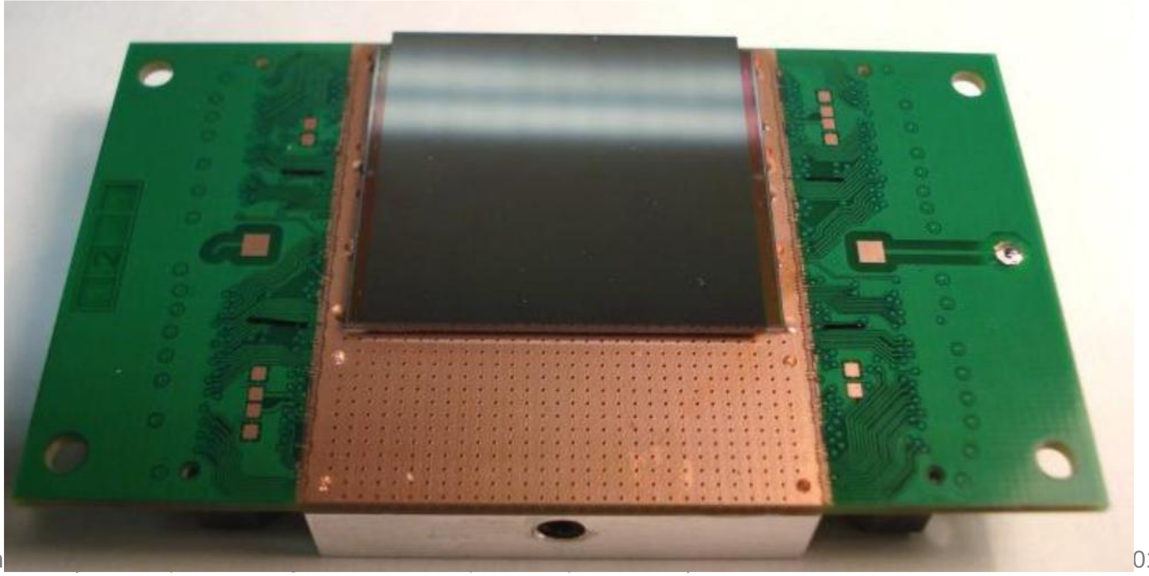
- Used for γ-ray spectroscopy
- Commercially-grown wafers:
  - Single-crystal now 3”, 1mm-thick
  - Defects affect uniformity
- Properties
  - 1.44eV bandgap (room T)
  - High resistivity
  - Schottky or ohmic metal contacts
- Trapping & drift distances:
  - Electrons - cm
  - Holes - mm
  - Use electron readout!



M. Chmeissani et al. 2004, “First Experimental Tests With a CdTe Photon Counting Pixel Detector Hybridized With a Medipix2 Readout Chip”

Cadmium Telluride

- Typically use Schottky or ohmic contacts (Pt, Au, In)
- Temperatures above 200°C degrade transport properties
  - Low temp sputtering / electroless deposition of contacts
- Low-temp bump bonding (Pb/Sn, In)
  - CdTe relatively fragile
- Demonstrated with Medipix2, XPAD3



Medipix2 quad (FMF)

Gallium Arsenide

- Better single-crystal production (6”)
- 1.43eV bandgap (room T operation)
- Problem – defects!
  - Shallow defects prevent depletion
  - Carrier lifetimes
- Semi-insulating GaAs
  - Compensation of shallow defects
  - Operated as photoconductor / Schottky
- Epitaxial GaAs
  - Growth with fewer shallow defects
  - Operated as diode

GaAs (Cr) on Medipix2

JINR Dubna &Tomsk State University

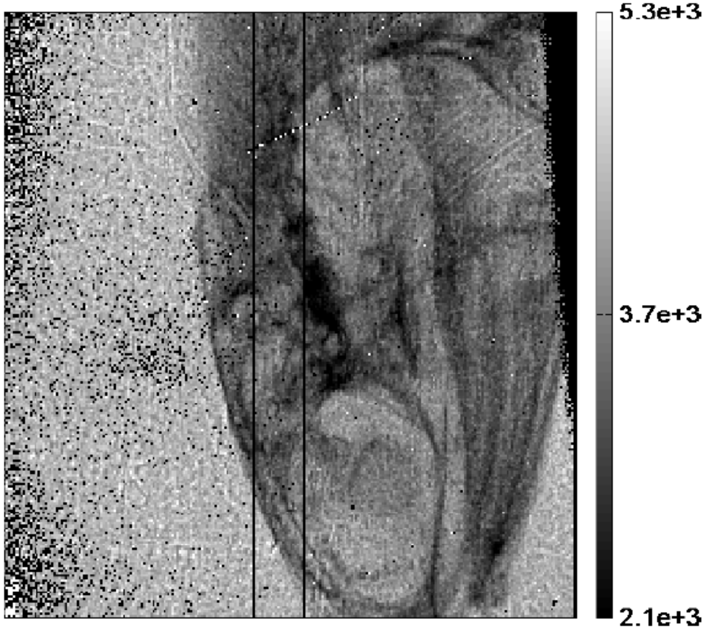
Gallium Arsenide – Semi insulating

- As-rich growth produces deep defects (EL2)
  - Compensate shallow traps
  - But increase electron trapping (~100μm)
- **Cr** compensation promising
  - Dope n-type during growth, then overcompensate p-type with Cr diffusion
- Metallised contacts
  - Au for photoconductor (right)
  - Pt-Ti-Au for Schottky
- Moderate temp tolerance, physically fragile
  - Bonding at low temp
  - Indium / low T solder

JINR Dubna, Tomsk State University

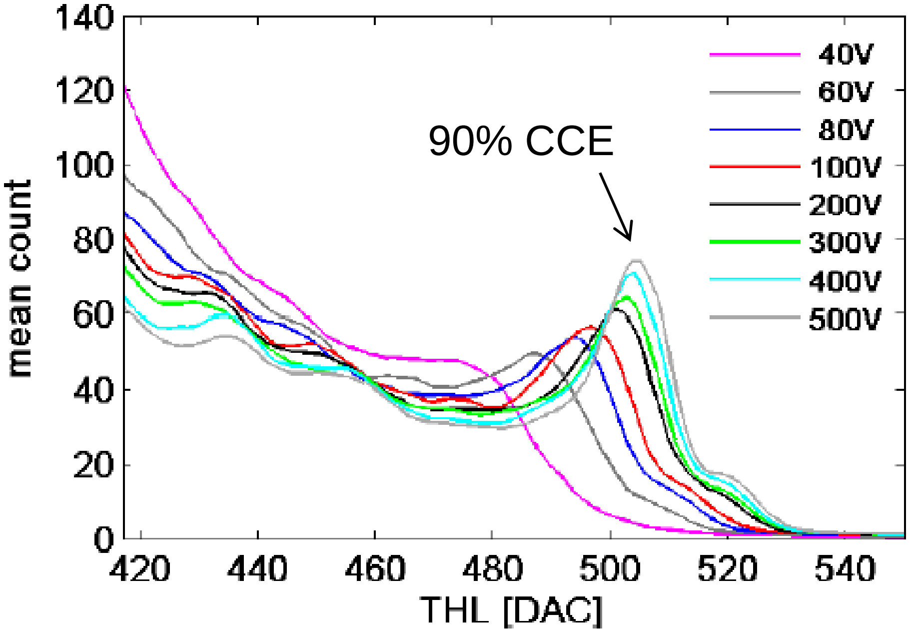
Chromium-compensated GaAs

- Medipix2
- 300µm thick (1mm possible)
  - Photoconductive sensor



Anchovy head (flat field corrected)

Response to monochromatic beam



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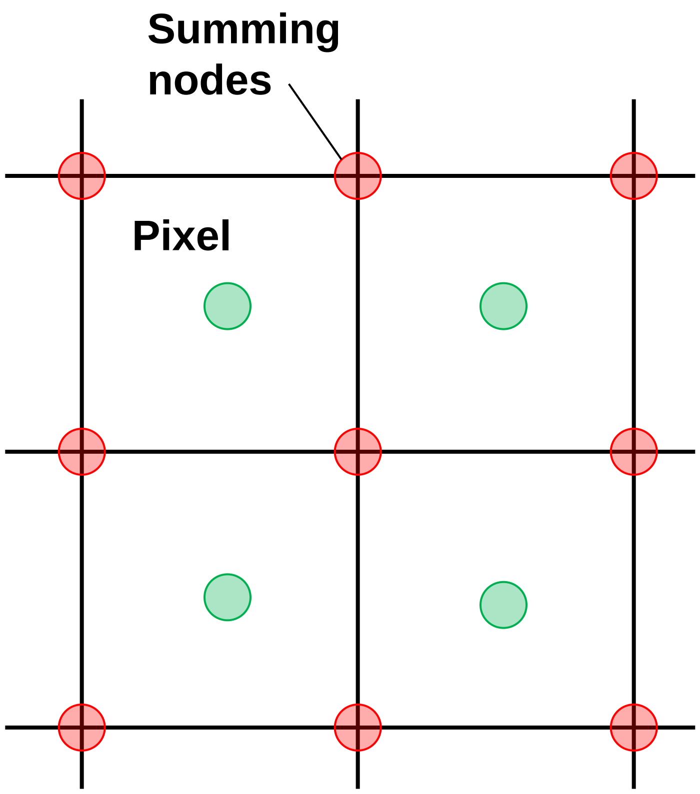
Medipix3

- 256 * 256 pixels, 55µm pitch
  - 14.1 * 14.1 mm^2 area
- Photon counting
- 2 counters / pixel (12bit)
  - Continuous R/W
  - or 2 energy bins
- Charge summing mode
- Optional 110µm pixels
  - 8 energy bins
- 2000fps
  - More with reduced counter depth



Signal summing at nodes:
Node with highest signal "wins"

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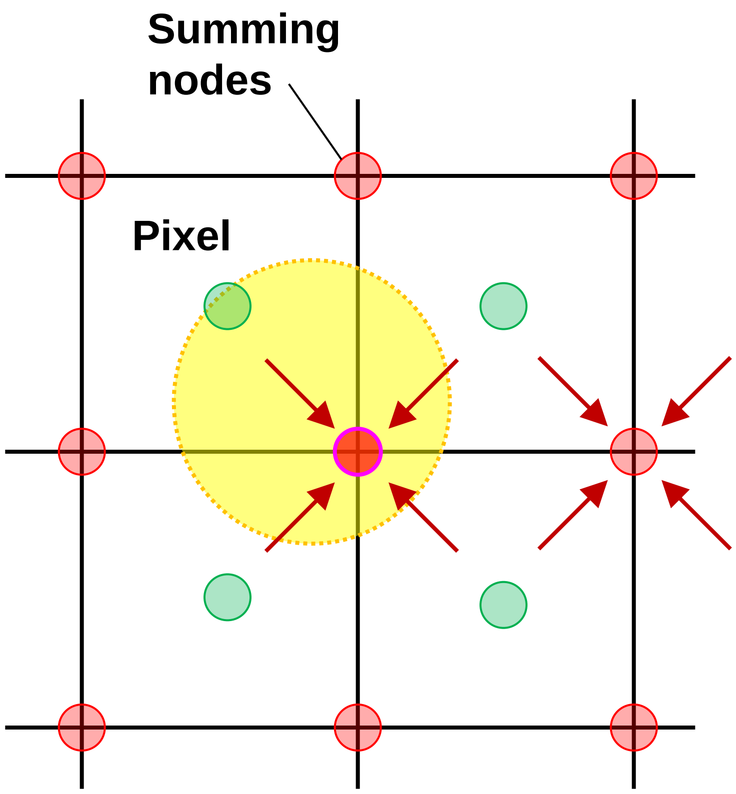

Signal summing at nodes:
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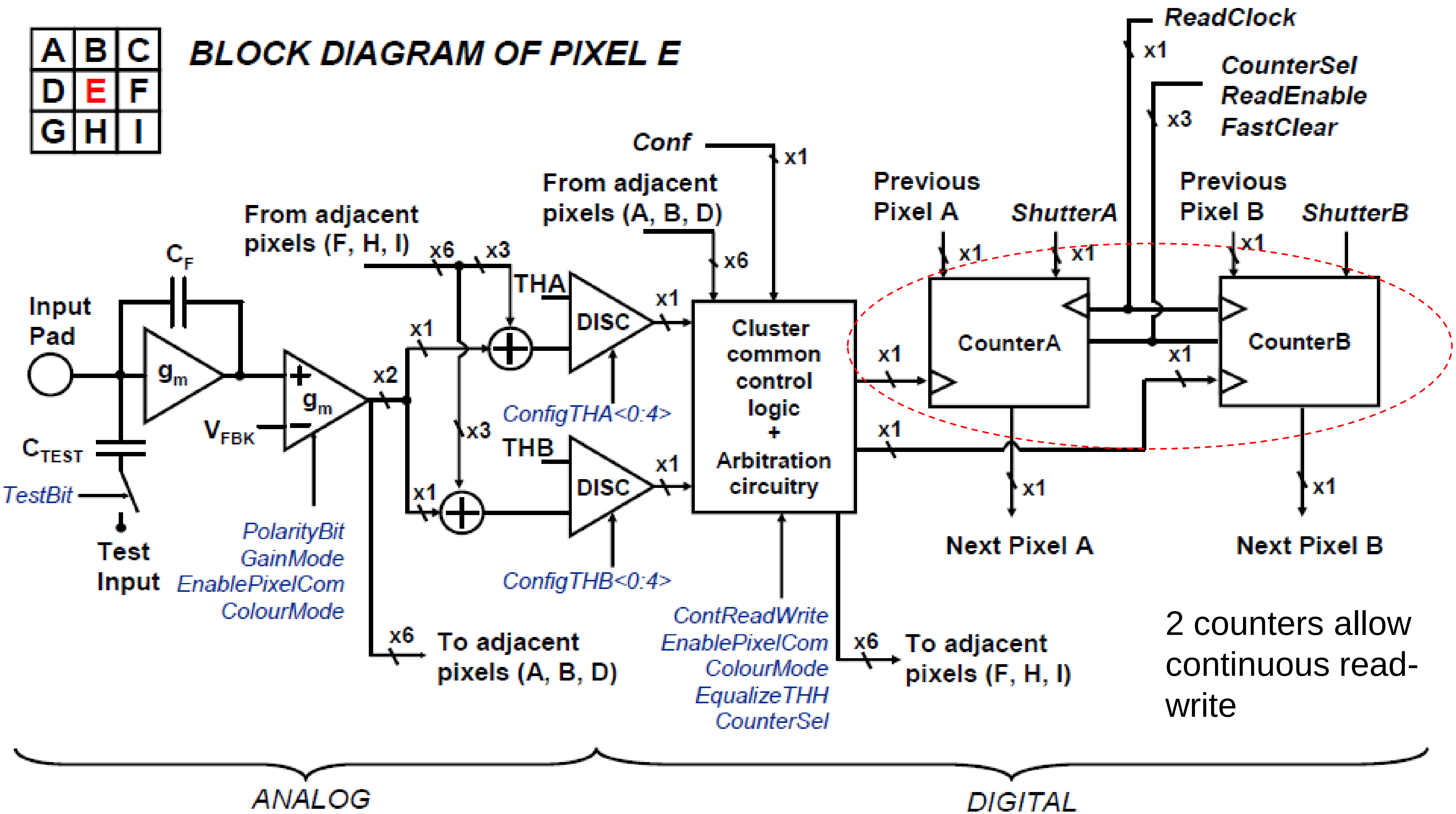
Medipix3 circuitry

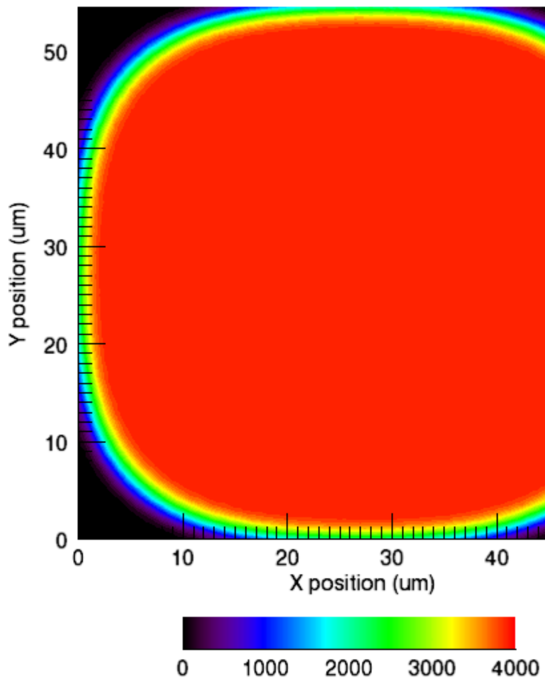


2 counters allow continuous read-write

Effects of charge sharing

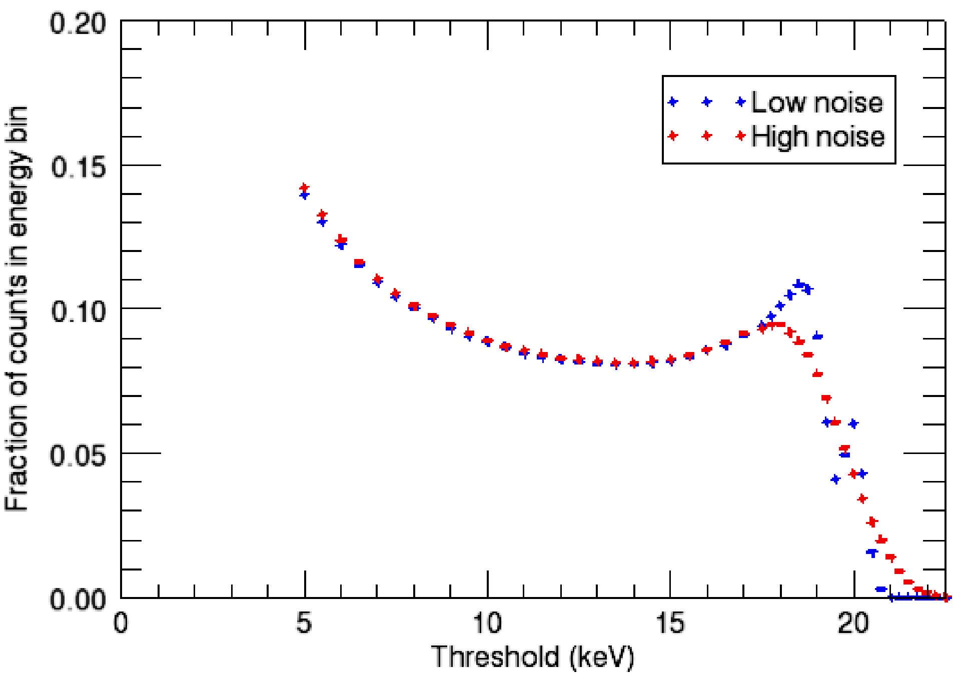
- Loss of efficiency at pixel corners
  - Typically, set threshold to E/2 with mono beam
- Loss of energy resolution

Simulated pixel scan (500µm Ge)



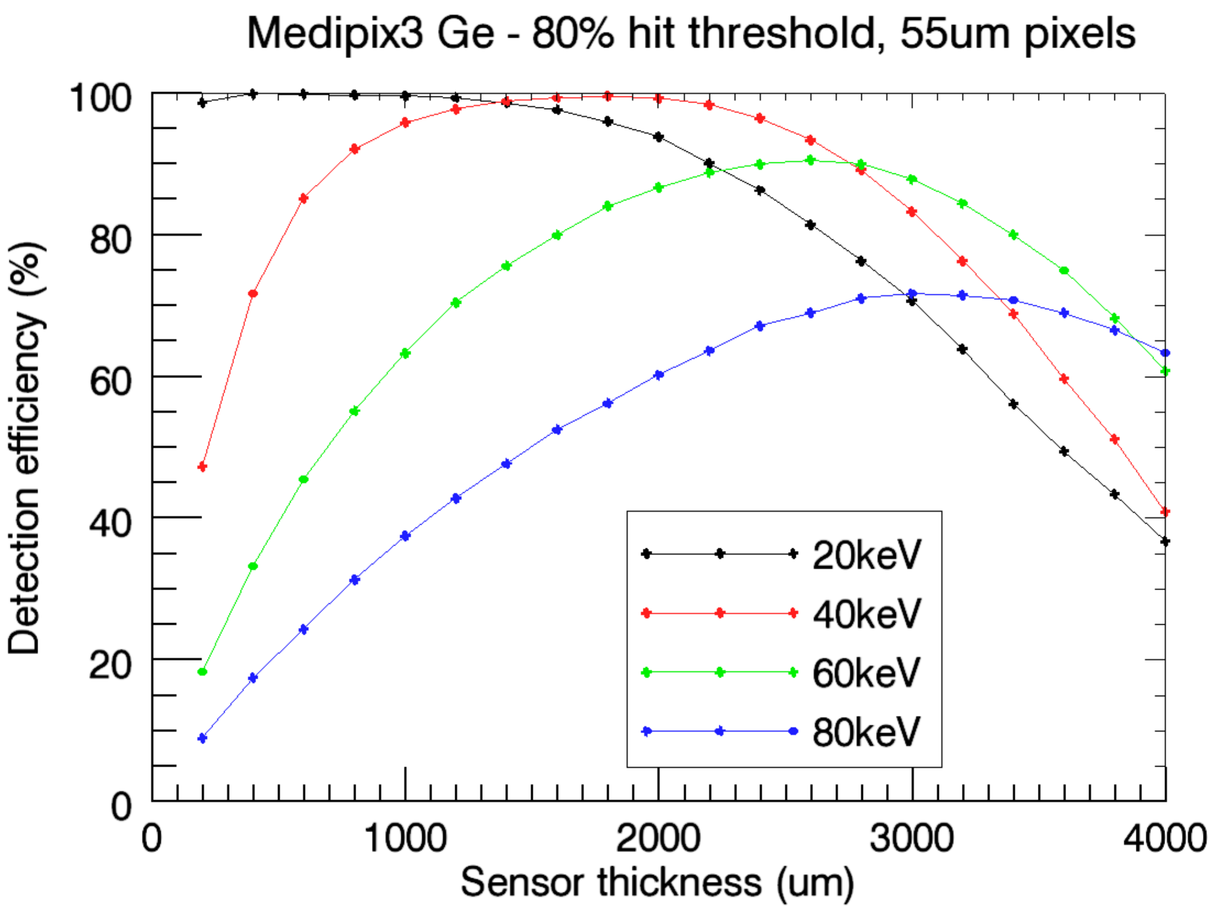
Counts lost in corner

Simulated spectrum (500µm Ge)



Medipix3 charge summing mode

- Allows large sensor thickness while maintaining energy resolution
  - No efficiency loss unless charge cloud > pixel size



Alternative methods of processing Ge

- Mechanical segmentation of contacts
  - Frequently used for large sensors
  - Limits on pitch
- Amorphous Ge contacts (e.g. LBNL, LLNL)
  - Similar to Schottky
  - Higher leakage current
  - *but* allows double-sided strips