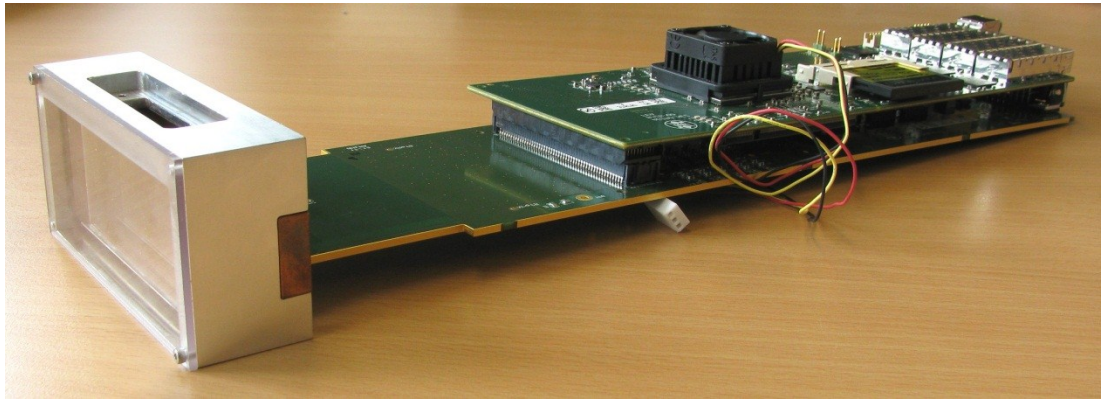
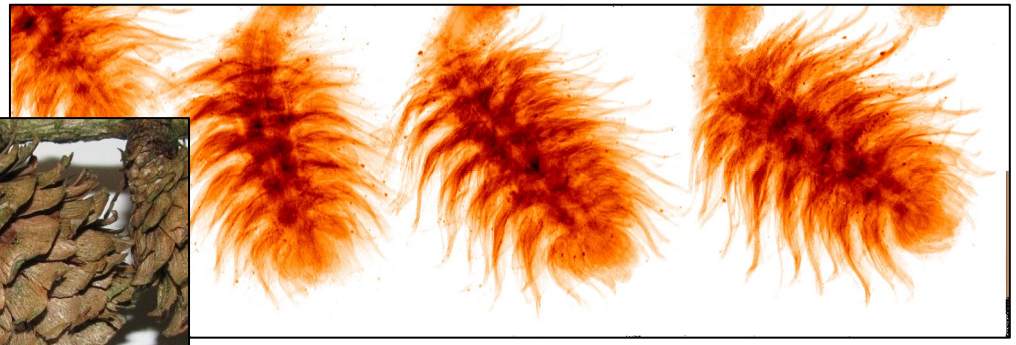
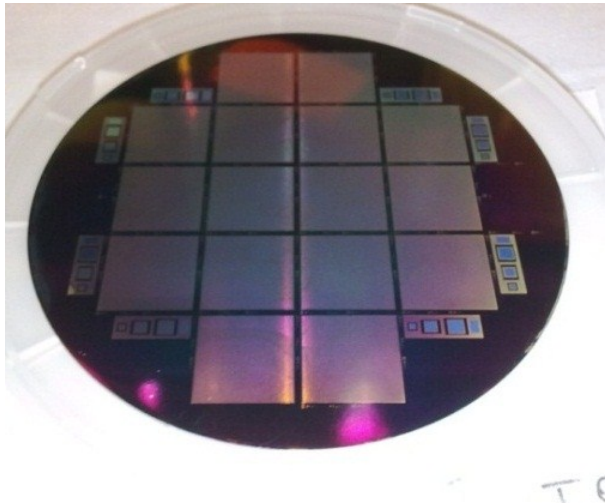
The LAMBDA photon counting pixel detector with germanium sensor

David Pennicard, Sabine Lange, Sergej Smoljanin, Helmut Hirsemann, Heinz Graafsma - *DESY*
Michael Epple - *Technical University of Munich*
Milan Zuvic, Marie-Odile Lampert - *Canberra France Speciality Detectors*
Thomas Fritzsch, Mario Rothermund – *Fraunhofer IZM*

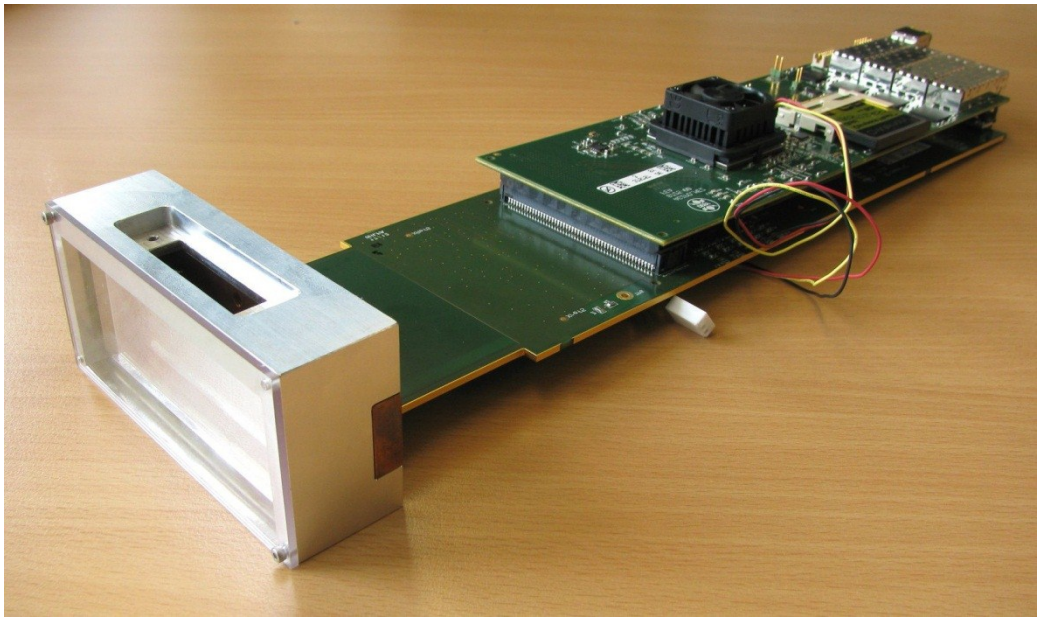






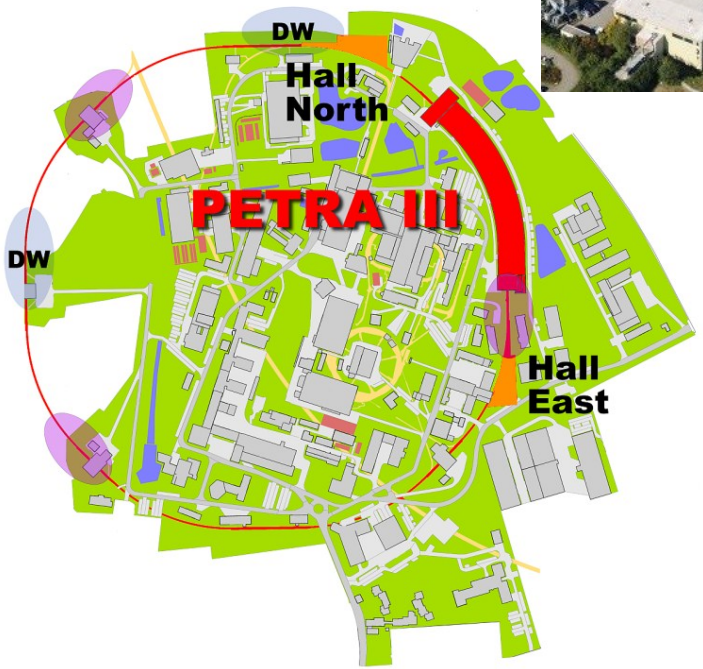
LAMBDA and germanium sensors

- Large Area Medipix-Based Detector Array
  - Photon-counting system based on Medipix3 chip
- High-Z pixel detector development
  - Germanium detector project with Canberra and Fraunhofer IZM



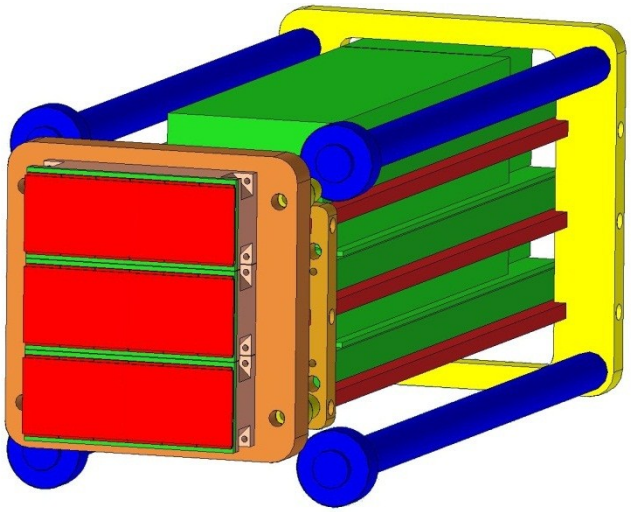
Experiments at PETRA-III

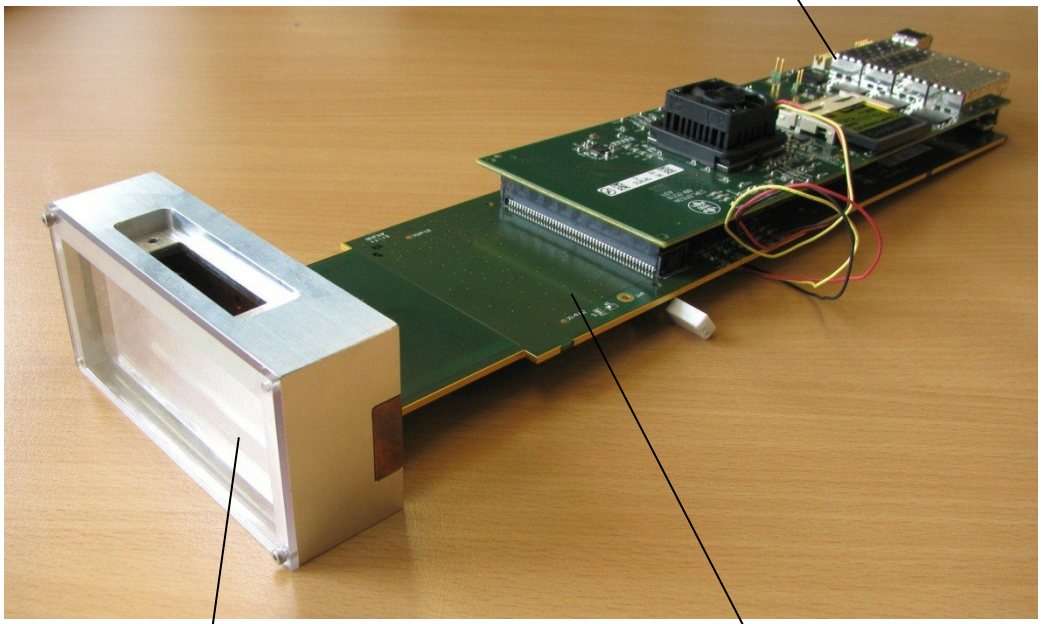
- 6 GeV source with low emittance (1 nmrad)
  - Nanofocusing, high-resolution, coherence…
  - Hard X-rays (>20 keV)
- 14 beamlines
  - 8 in user operation
- 2 extensions planned
  - Replacement for DORIS-III
  - 10 beamlines
  - Higher flux



Large Area Medipix-Based Detector Array

- Photon-counting detector
- Small pixel size (55µm)
- Large, tilable modules (1536 by 512 pixels)
- Fast readout (2 kHz+)
- High-Z compatible
  - inc. germanium cooling

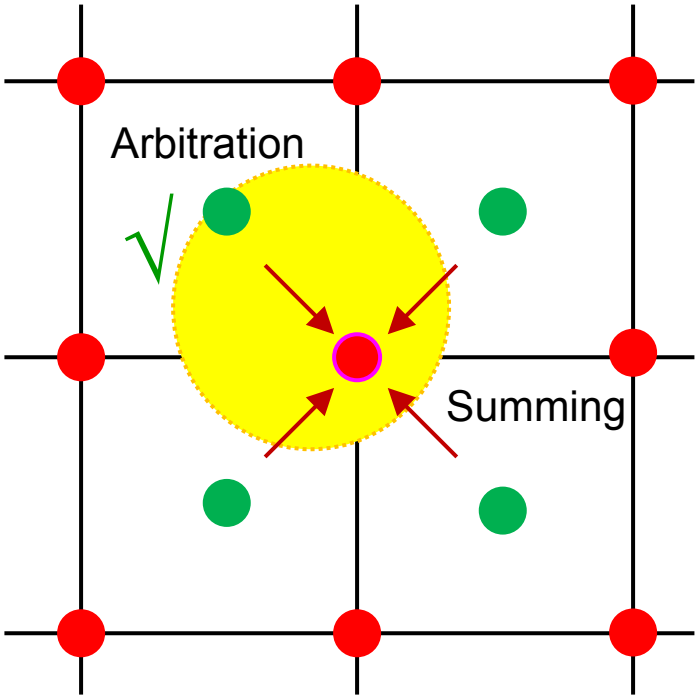




Medipix3 readout chip

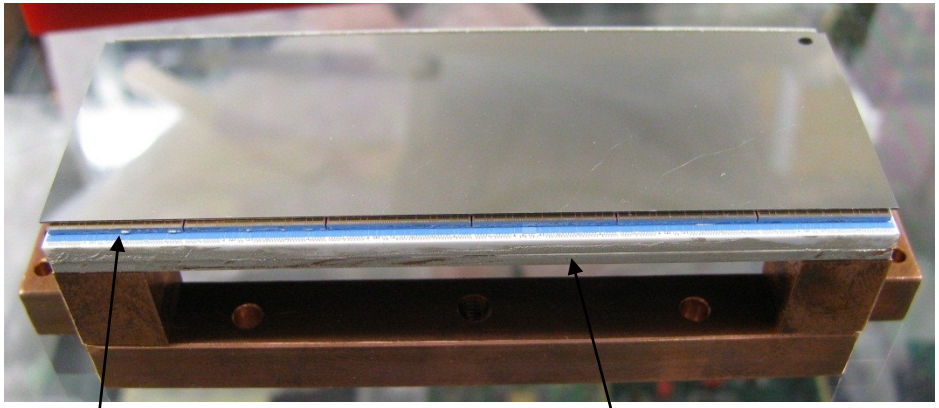
- CERN-led collaboration
- 256 by 256 array of 55µm pixels
- 2 counters / pixel for continuous read-write
  - 2000 fps at 12 bit depth
  - 6 (4) and 1 bit also possible
- Interpixel communication – avoids hit loss & double counting, better discrimination
- *Medipix3 "RX"*
  - First silicon assemblies received at CERN
  - CRW and interpixel communication fixed
  - Stability and pixel-to-pixel uniformity as designed

Medipix3 RX interpixel comm.



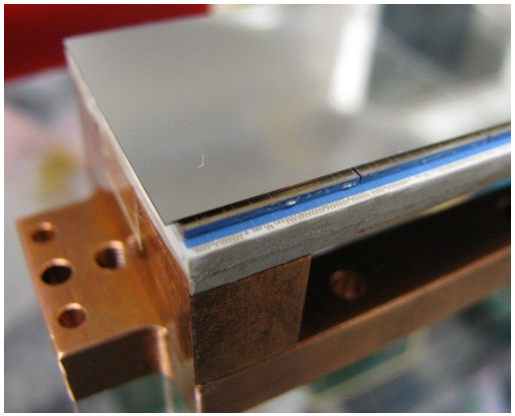
Detector head

- 6 by 2 chips (1536 by 512 pixels)
  - Large Si sensor
    - 300µm Si sensor here
  - 2 x “Hexa” high-Z sensors
- Ceramic circuit board (LTCC)
  - 14 layer board
  - Good match to germanium CTE
  - Cooling through thermal vias
- 500-pin connector on board
  - Full parallel readout (8 LVDS data outputs per chip)
  - ~150 LVDS pairs total



6 x 2 Medipix3 chips

LTCC board



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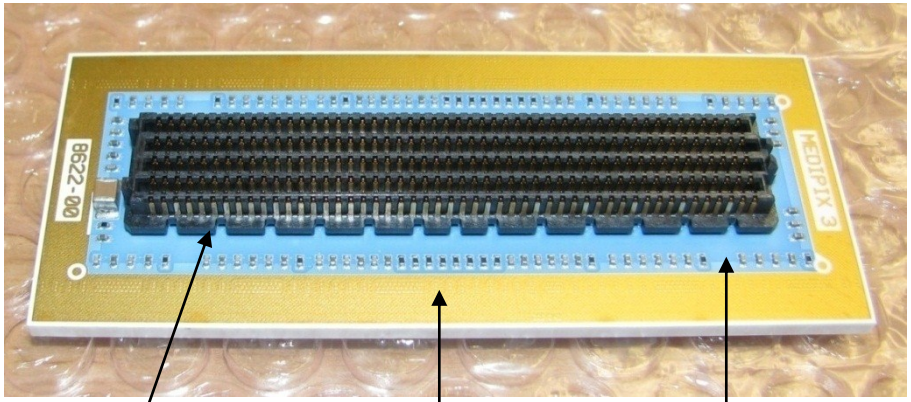
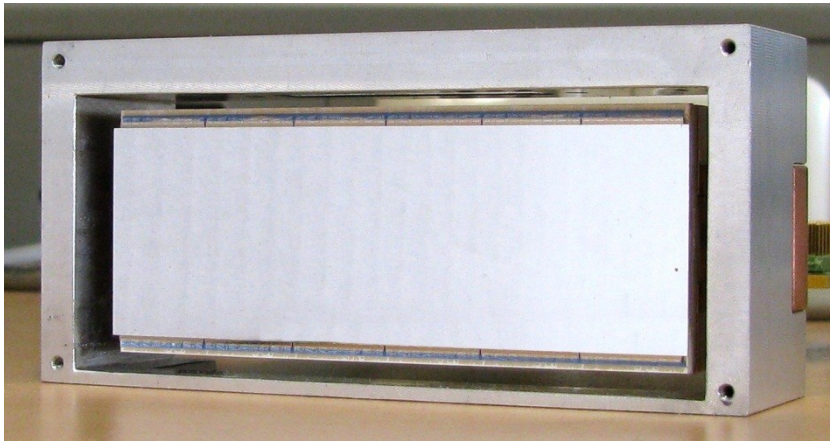


500-pin connector

RC components

Contact to cooling block



High-speed readout system

- Previously developed prototype system (USB2 readout only)
- High-speed readout with common DESY mezzanine card
  - Virtex-5 FPGA with PowerPC
  - 4 * 10 Gigabit Ethernet links
  - DDR2 RAM (8GB)
- “Signal distribution” board connects to det. head
  - Space for vacuum barrier with germanium detector
- Currently working on high-speed readout firmware

10GE links

Connector to det. head

Power / trigger in

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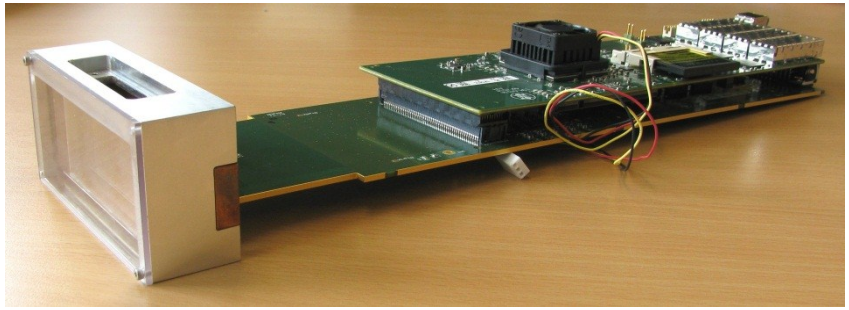
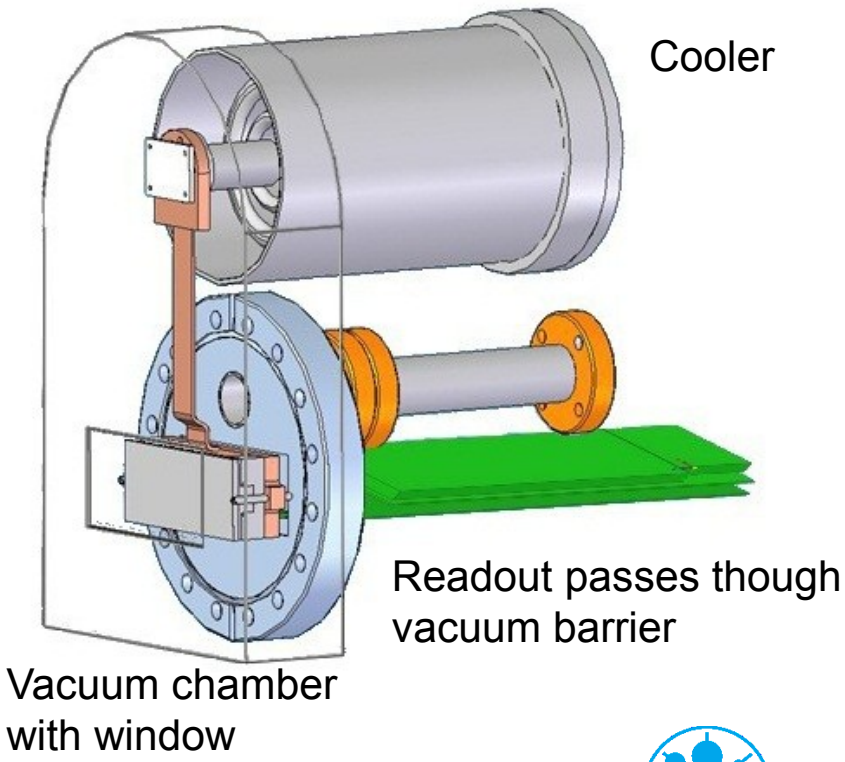
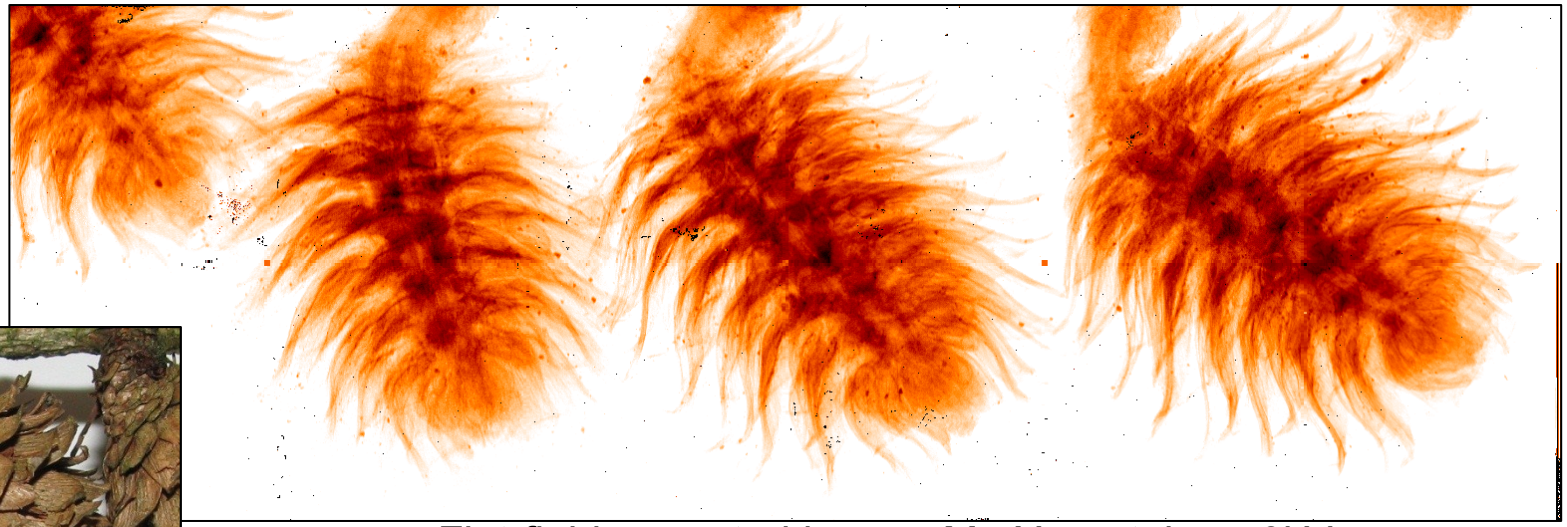




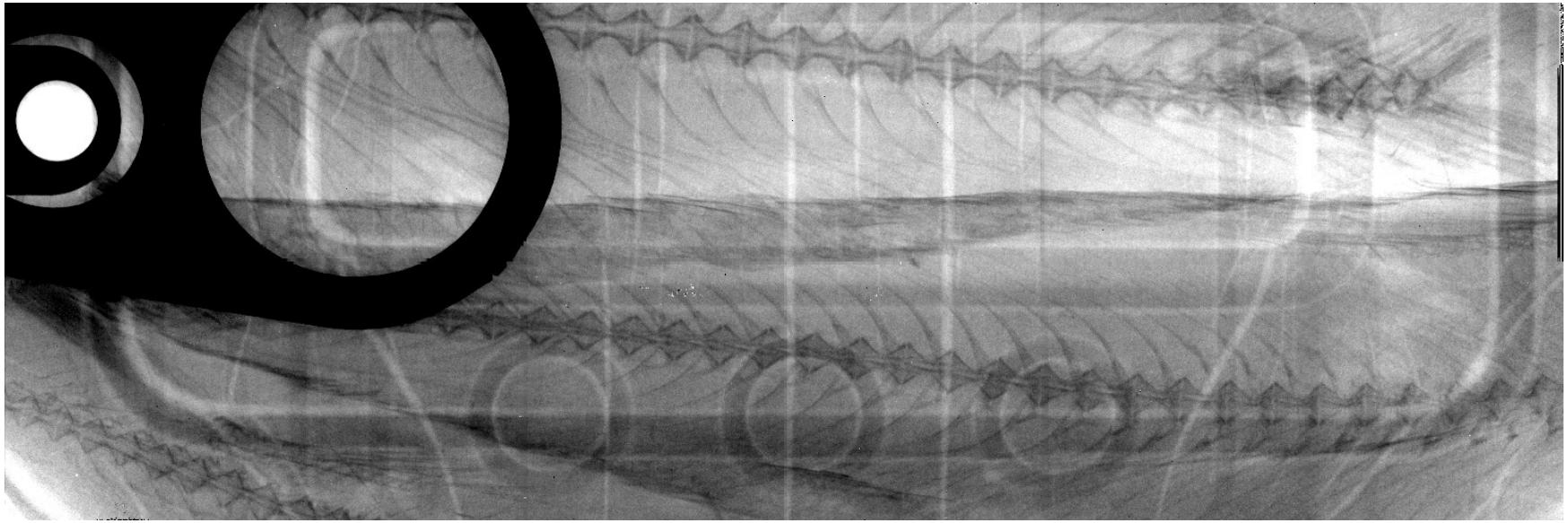
Test results with Si module

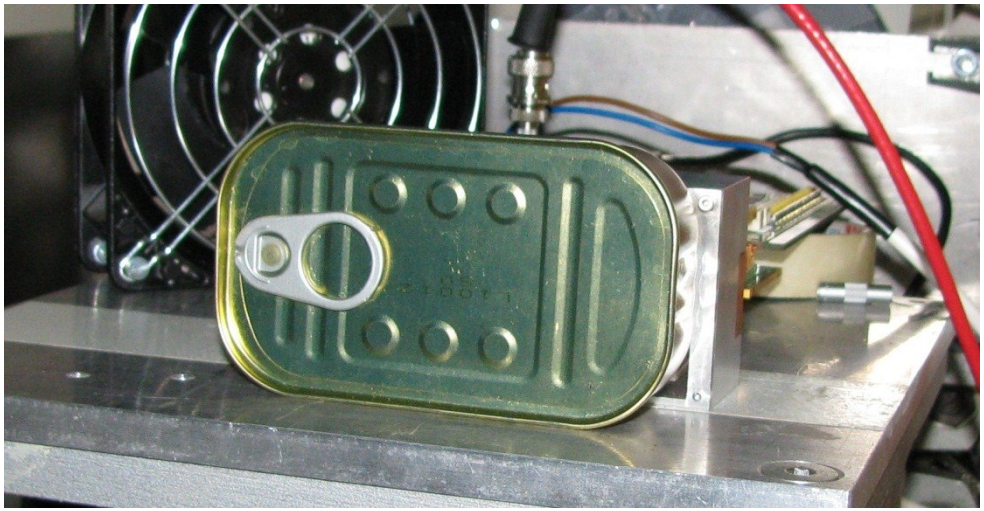
- First full Si module assembled (300µm sensor from Canberra)
  - All 12 chips successfully bonded (by IZM) and functional
  - 1280 digitally bad pixels, 15 noisy, 700 insensitive – 0.25%
    - Digitally bad pixels: 5 columns in bottom-right corner
    - This was first module bonded – IZM expect improvement of remainder



Flat-field corrected image, Mo X-ray tube, 40kV

Test results with Si module





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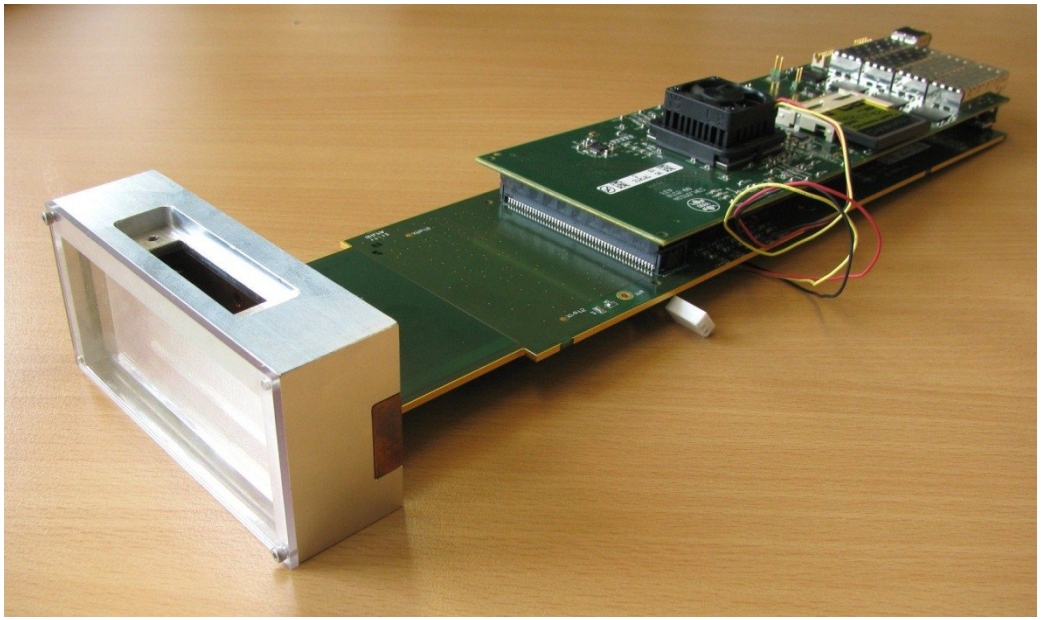
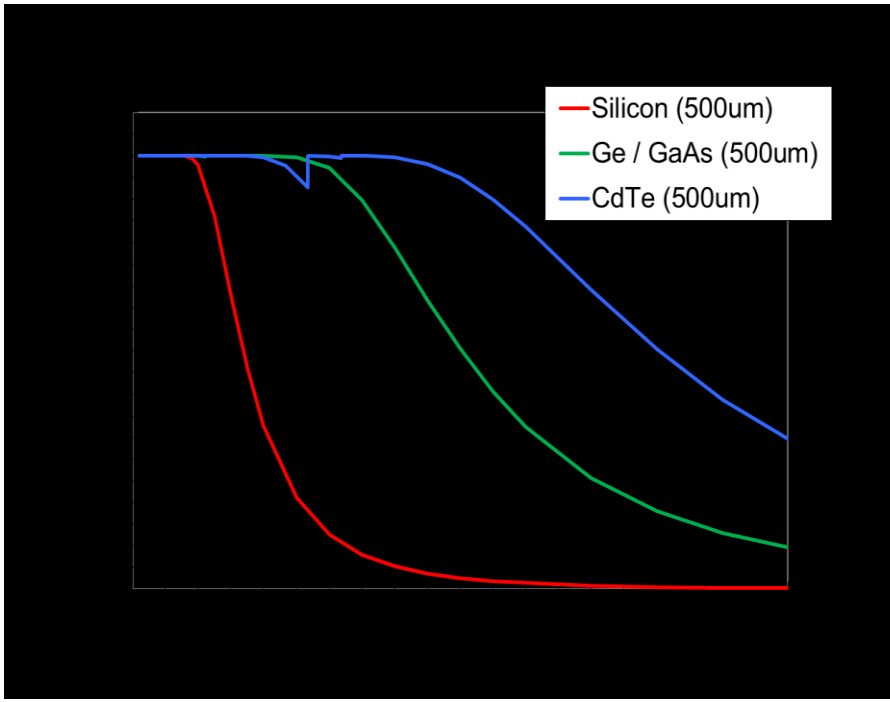


High-Z development

- Germanium – Canberra France Speciality Detectors, Fraunhofer IZM
- Gallium Arsenide – Galapad project –RID Ltd. (Tomsk), JINR (Dubna), FMF (Freiburg), KIT (Karlsruhe),
- Cadmium telluride – HiZPAD collaboration – Acrorad sensors, FMF bonding



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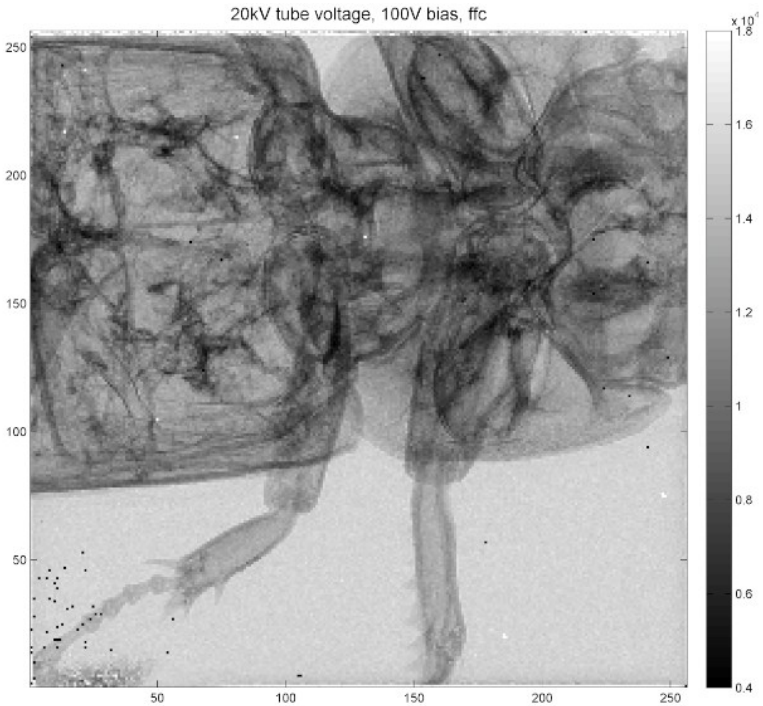
GaAs bonded to Timepix (25keV)



Flat-field corrected image

Thanks to Simon Procz, Alex Fauler and Michael Fiederle (FMF / University of Freiburg)

High-Z development

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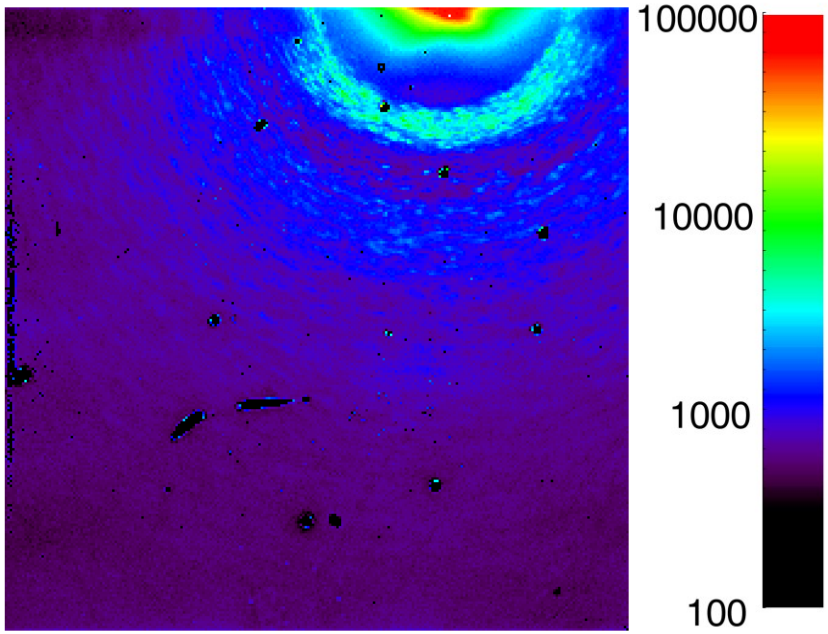
CdTe bonded to Timepix



Scattering from $LiMnPO_4$ at DORIS BW5 (100keV)

Germanium pixel detector

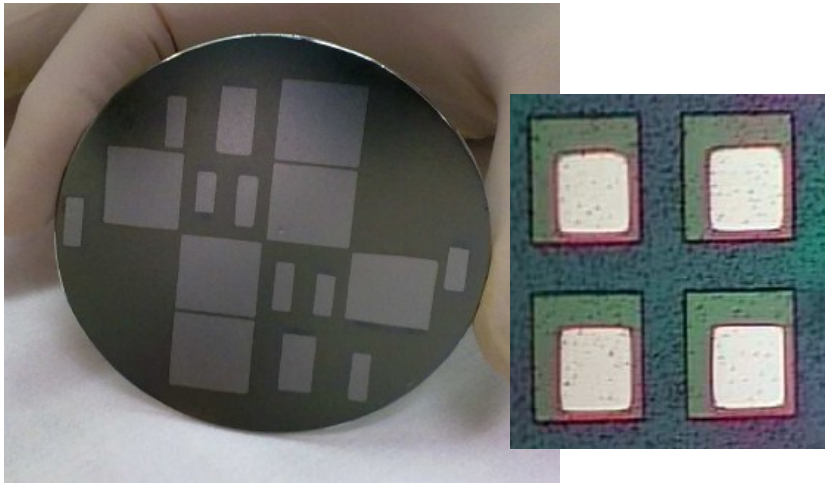
Canberra (Lingolsheim): M Lampert, M Zuvic, J Beau

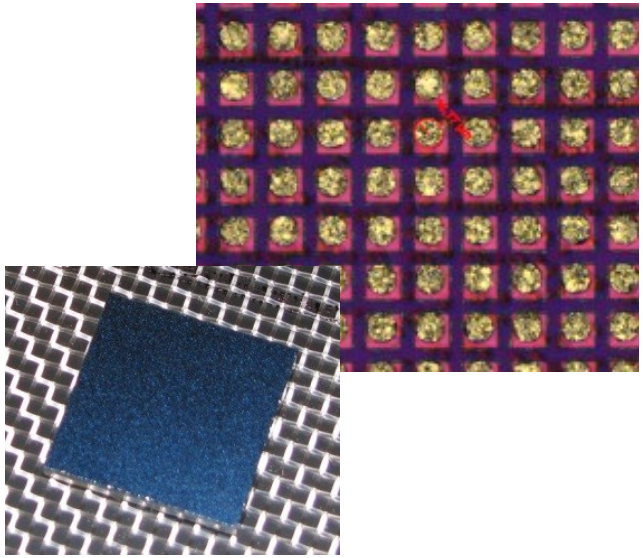
Fraunhofer IZM (Berlin): T Fritzsch, M Rothermund, H Oppermann, O Ehrmann

- High-purity, high uniformity 90 mm Ge wafers available
- Cooled operation needed to reduce leakage current
  - Must avoid saturation & excessive noise in amplifier
  - Est. **-70°C** operation with Medipix3 (small pixel, leakage tolerant design)
    - Measured transport and depletion fine at this temperature
- Lambda module designed to be cooled
- *Fine pixellation and bump-bonding must be developed*

Sensor production and bump bonding

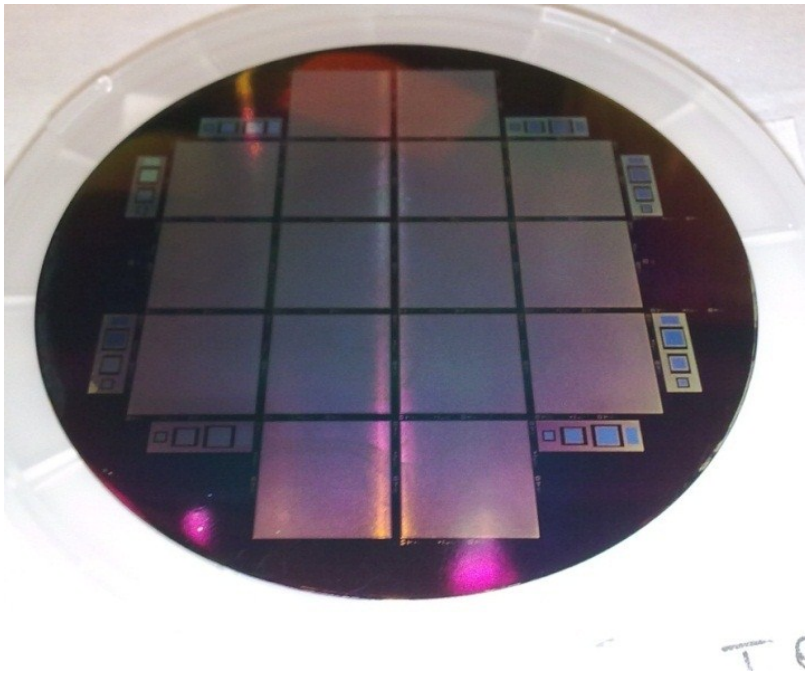
- Detector structure (Canberra)
  - Modification of existing strip detector technology
  - 55µm pixels, 600 µm thick
  - Electron readout
- Indium bump bonding (IZM)
  - Sensor and ROC bonded at < 100C temp
  - During cooling, ductility of In compensates for mismatch in contraction
  - Process and temperature optimised using Ge diodes
  - Bond height and flip-chip optimised with mechanical dummies

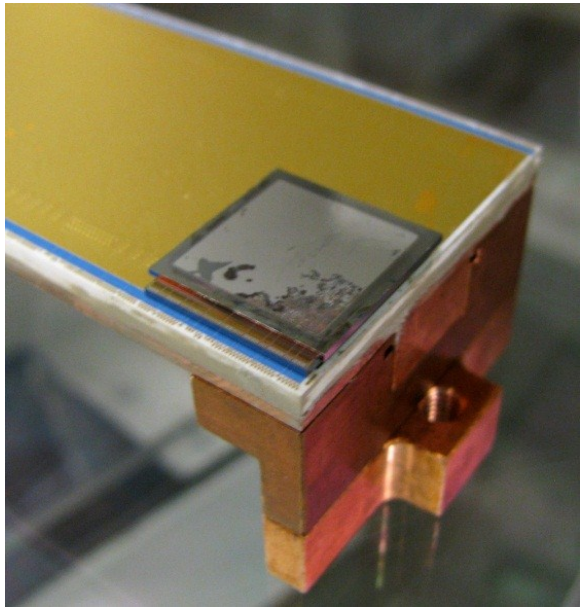




Sensors

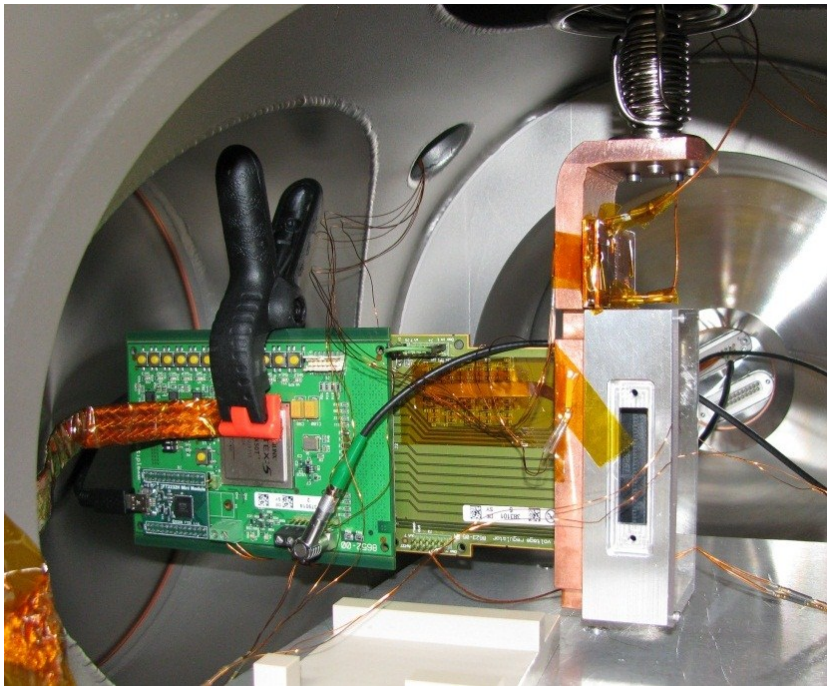
- 2 high purity Ge wafers produced by Canberra
  - 16 Medipix3 singles / wafer
- First 2 assemblies bonded last week





Preliminary test results

- Tested in vacuum chamber with Cryotiger cooler at **-70ºC**
  - Need to improve isolation – cooler should be able to go much lower!
- Guard ring current high – tested at 50V (~2.5mA current)
  - No breakdown, but reaches source limit
  - Temp dependent
- Mini Ag-target X-ray tube used (50kV)
- Not yet equalised
  - Medipix 3.0 has large dispersion!
  - Look at single pixel spectra



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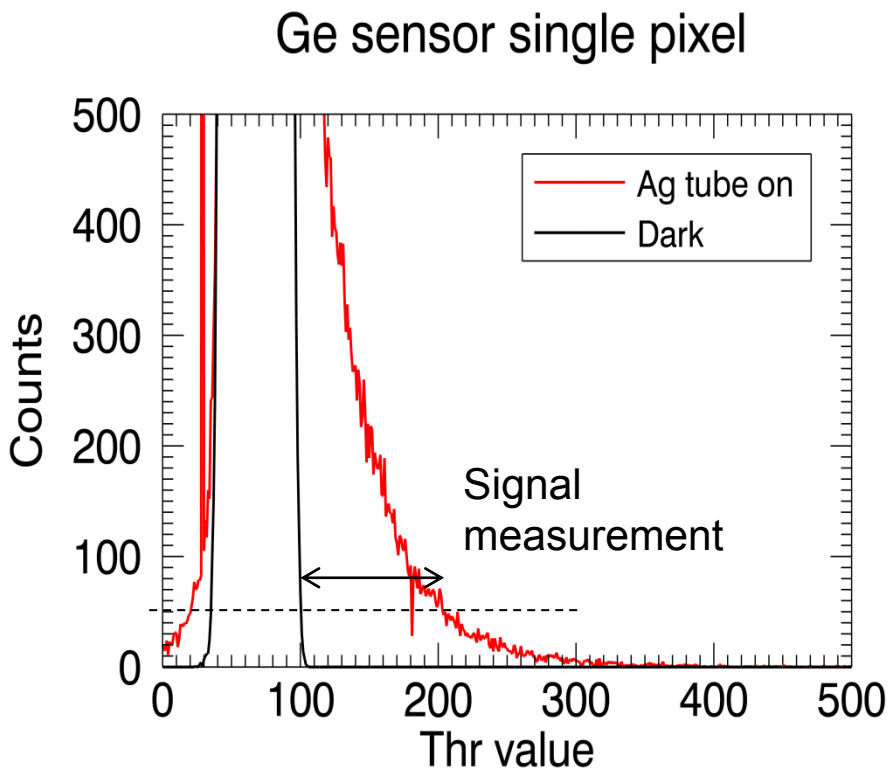
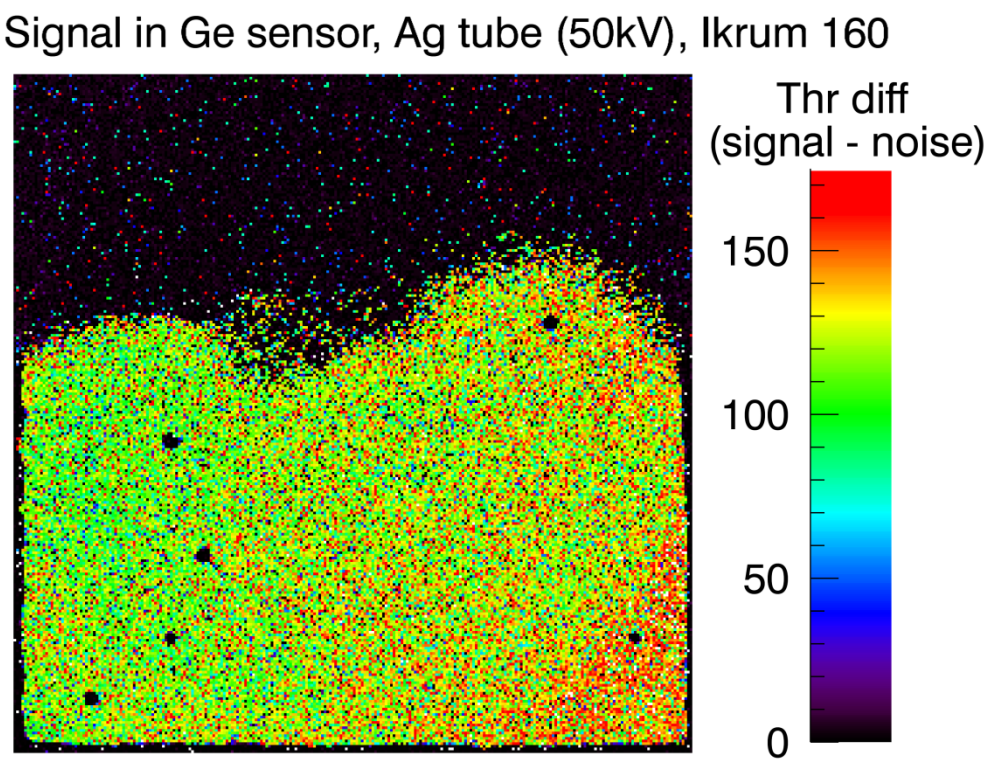
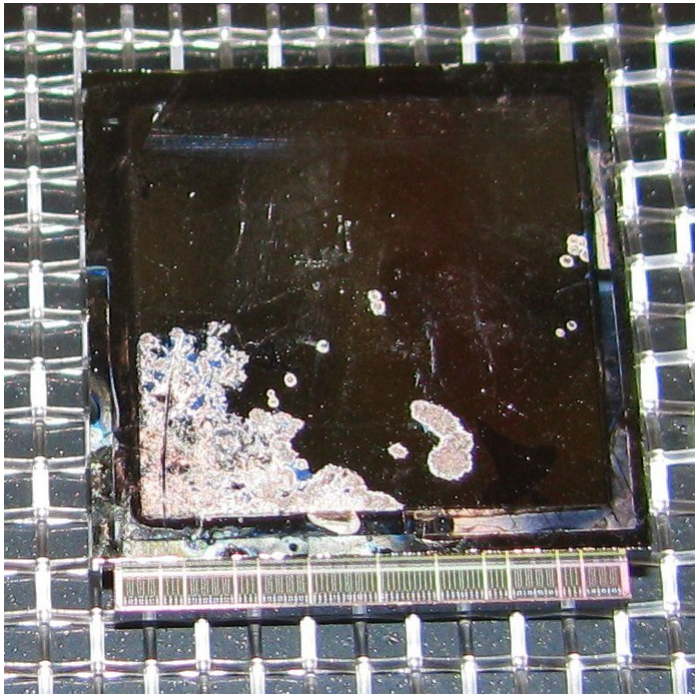


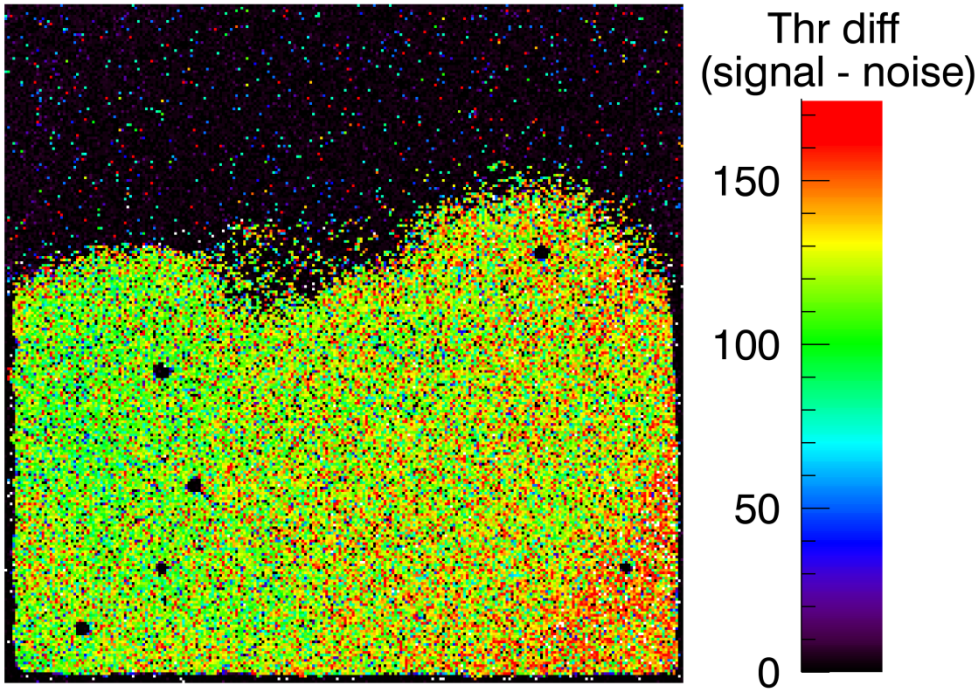


- Preliminary threshold scans made on unequalised detector
  - Signal seen in majority of pixels, but some regions are insensitive (particularly edges)
  - Spectrum shows large charge sharing, as expected (charge summing in Medipix3 not used in these tests)

Preliminary test results



Signal in Ge sensor, Ag tube (50kV), Ikrum 160

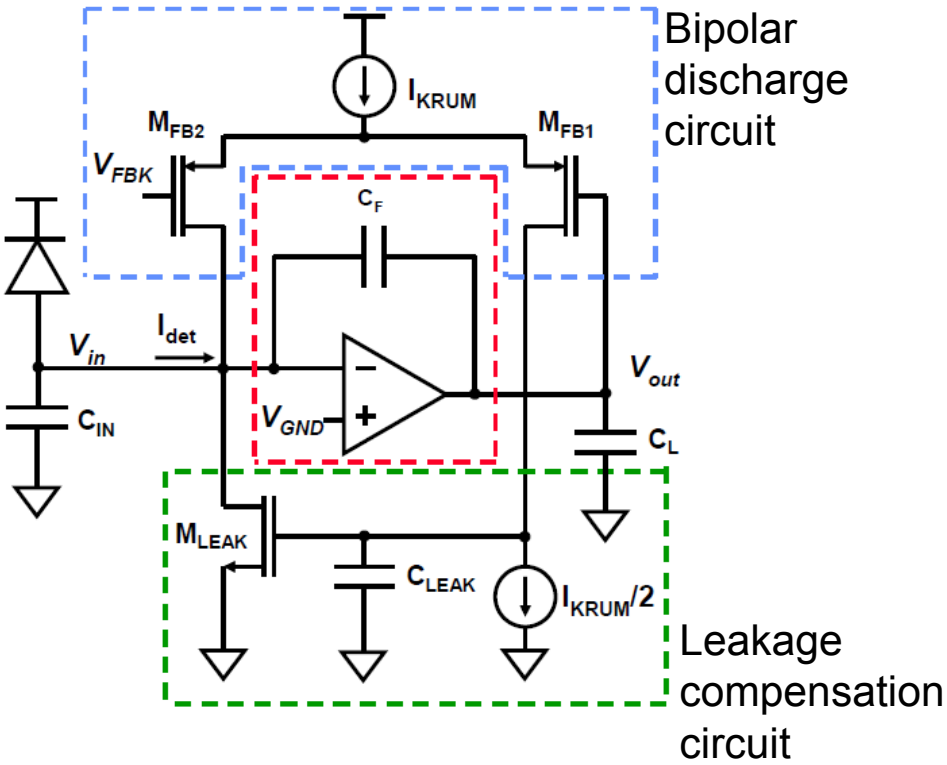


- First sensors showed some delamination of metallization after flip chip
- However, delamination doesn't appear to affect result

Effects of chip settings

- Leakage current compensation limited by Ikrum setting
  - Current setting ~10nA / pixel

Medipix3 preamplifier circuit

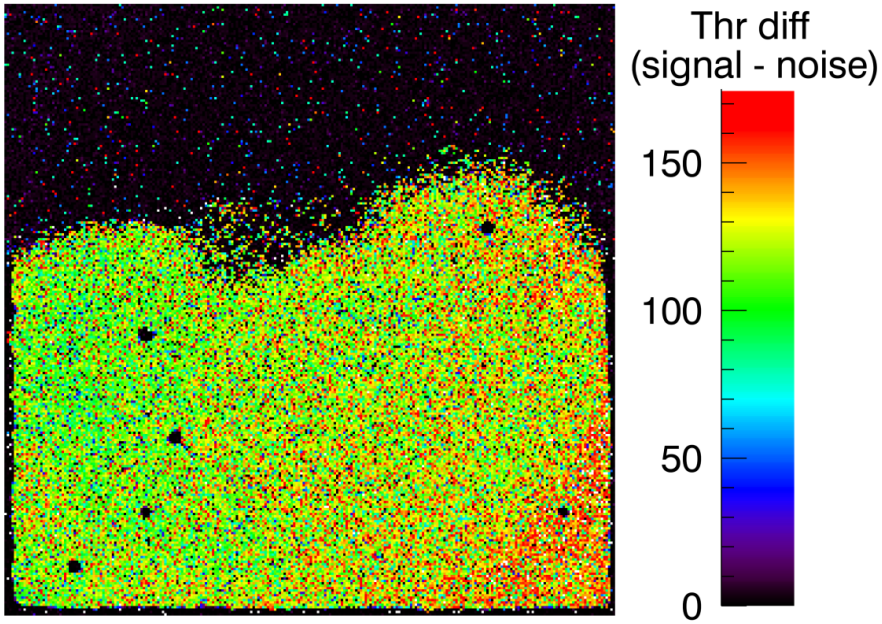


Rafael Ballabriga Suñé, CERN Thesis 2010-055

Effects of chip settings

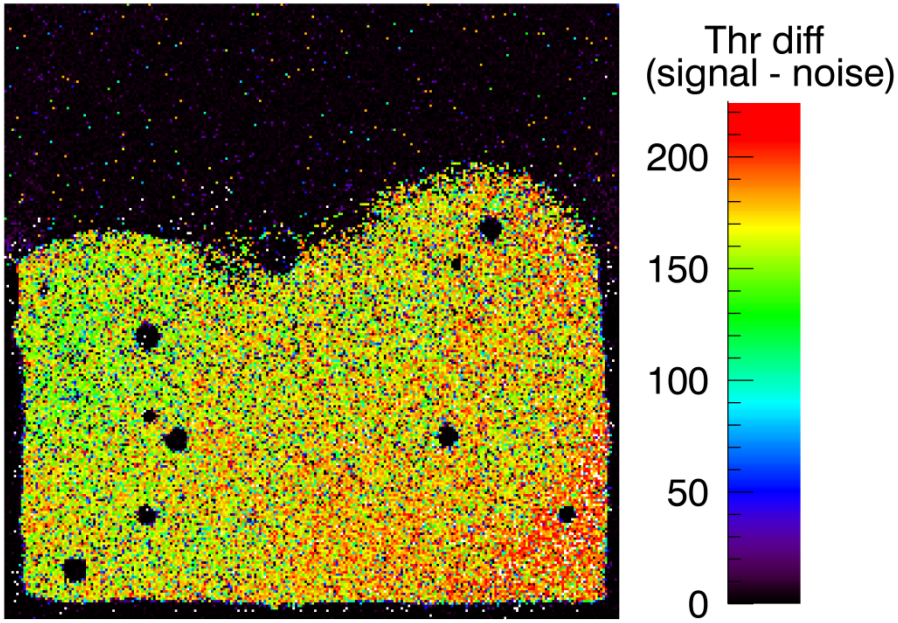
- Insensitive blobs / edges worsen with low Ikrum
  - Implies pixels are saturated with leakage current
  - Performance should improve with deeper cooling (say -100C)

Signal in Ge sensor, Ag tube (50kV), Ikrum 160



Ikrum setting 160

Signal in Ge sensor, Ag tube (50kV), Ikrum 40



Ikrum setting 40

Summary

- Goal: Flexible photon-counting detector for PETRA-III
- First silicon detector modules working
- High-speed readout in progress
- Prototype germanium sensor sees X-rays
  - Full characterisation needed (including lower T performance)
  - Also need to test other chips in batch