Large high-Z pixel detectors with LAMBDA readout

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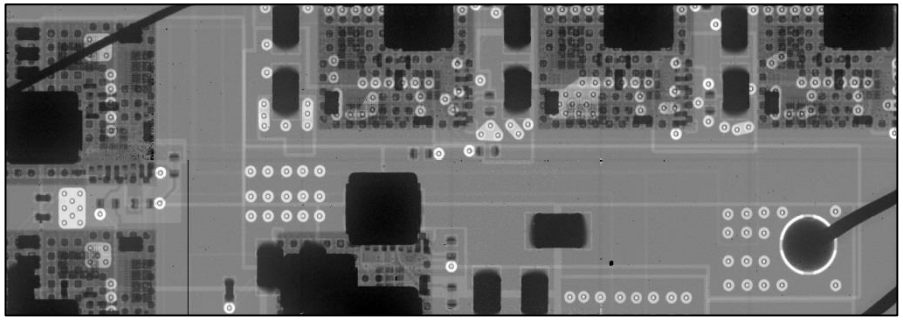
Georgy Shelkov, Alexey Zhemchugov, Sergey Kotov - Joint Institute for Nuclear Research (RU)
Anton Tyazhev - Tomsk State University, Michael Fiederle - University of Freiburg



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Introduction

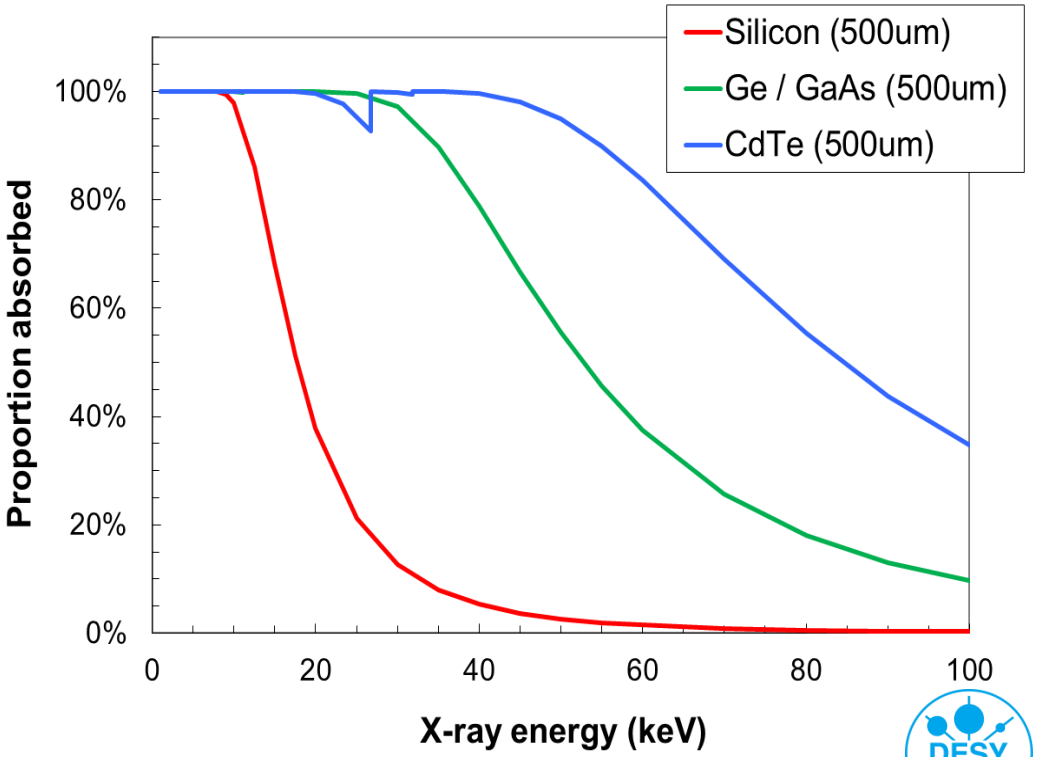
- Hard X-ray experiments and LAMBDA
- GaAs
- CdTe
- Building and applying large systems

Hard X-ray detection at synchrotrons

- Study structure of matter down to atomic scale
- Hard X-ray experiments: large samples, sample environments etc.
  - High-Z hybrid pixels offer high sensitivity and speed

PETRA-III synchrotron

Photoelectric absorption of X-rays

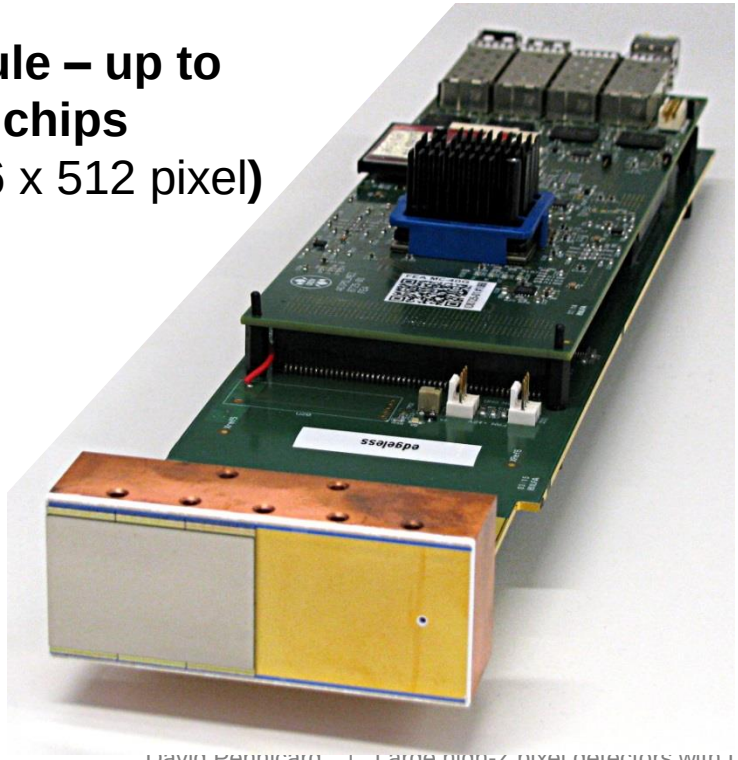


LAMBDA detector

- Hybrid pixel with Medipix3 chip (CERN)
- Photon-counting operation
- 55 µm pixel size
- 2000 fps readout

1536 x 1536 pixel
3-module – 2M

Module – up to
6 x 2 chips
(1536 x 512 pixel**)**



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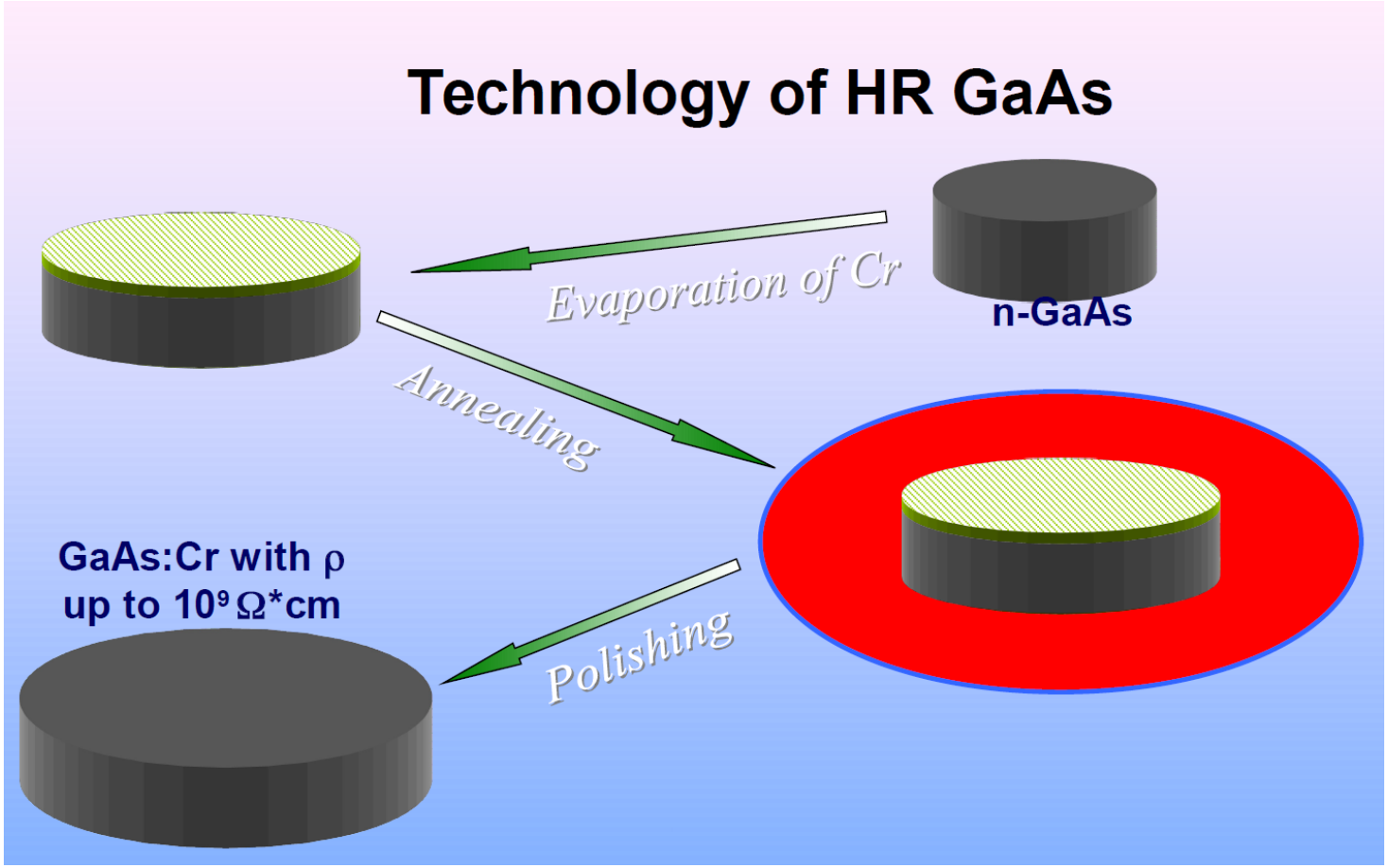
Cr-compensated GaAs

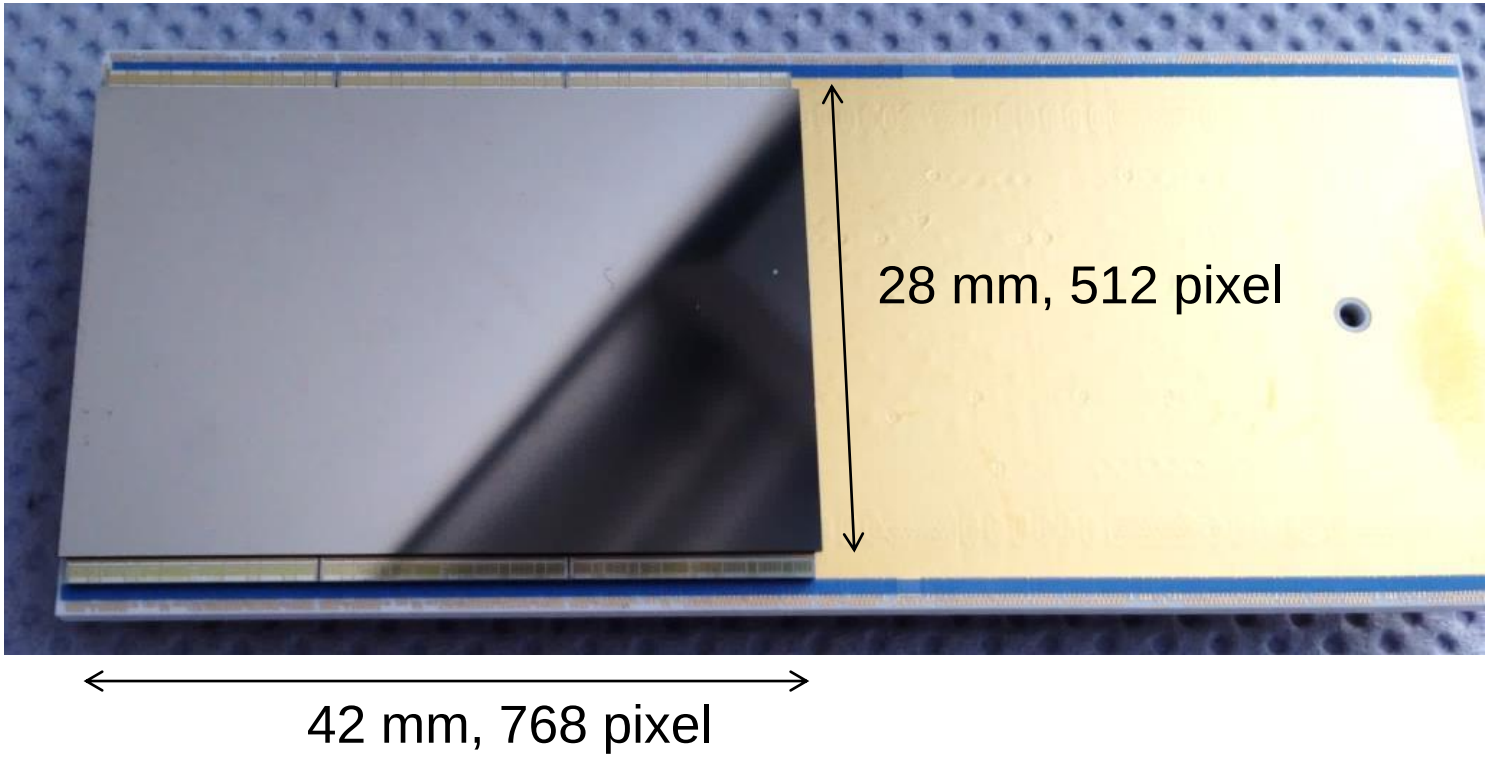
Tomsk State University
Thanks to Anton Tyazhev et al.



Gallium Arsenide sensors

- 500 µm-thick GaAs(Cr) from Tomsk State University / RID Ltd.
- Ohmic contacts, 55µm pixel size
- Bump bonding at Uni Freiburg, Fraunhofer IZM, Advacam

3 x 2-chip layout from 3” GaAs wafer



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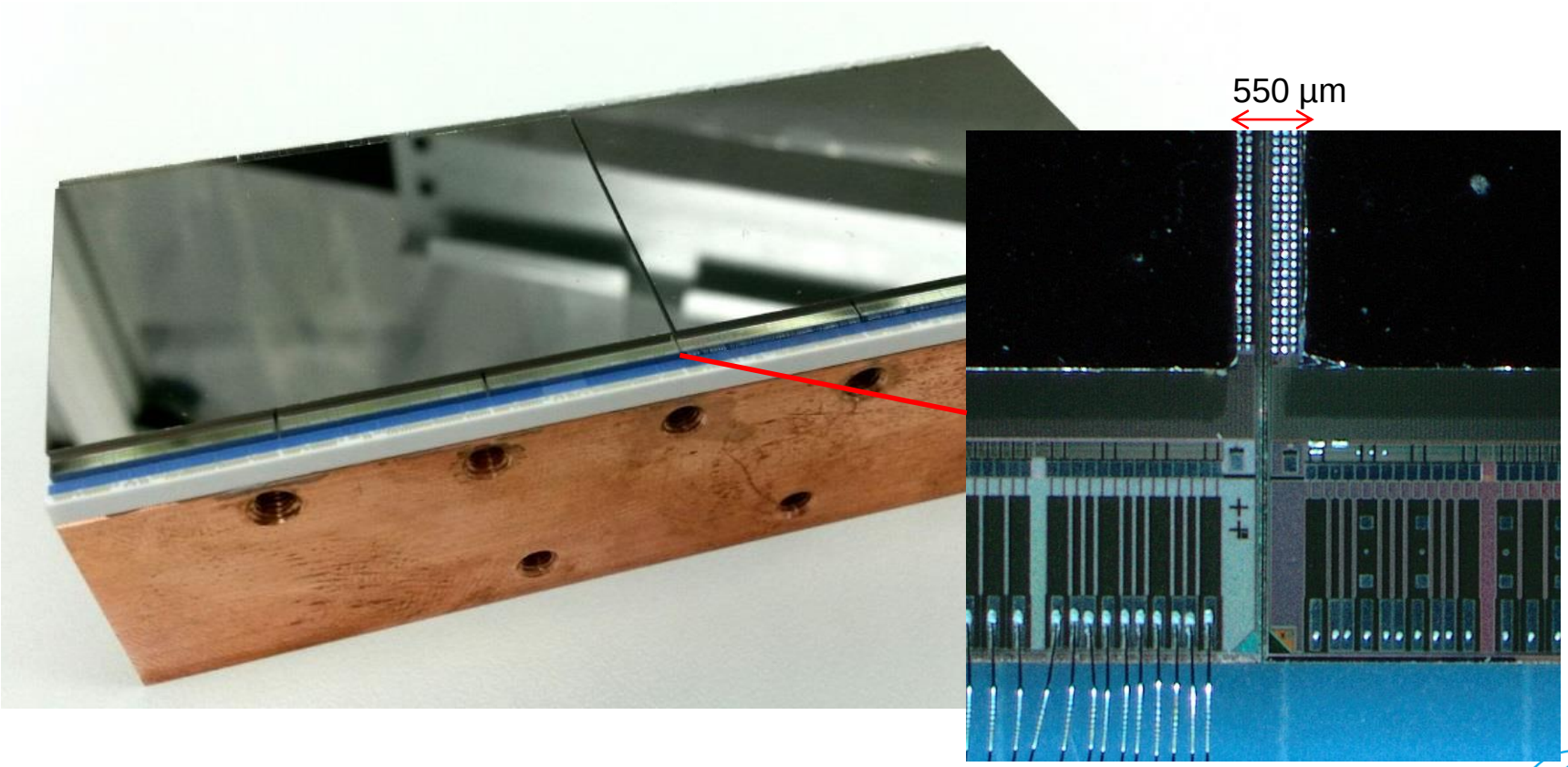

Gallium Arsenide sensors

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- Bump bonding at Advacam

6 x 2-chip layout from 4” GaAs wafer

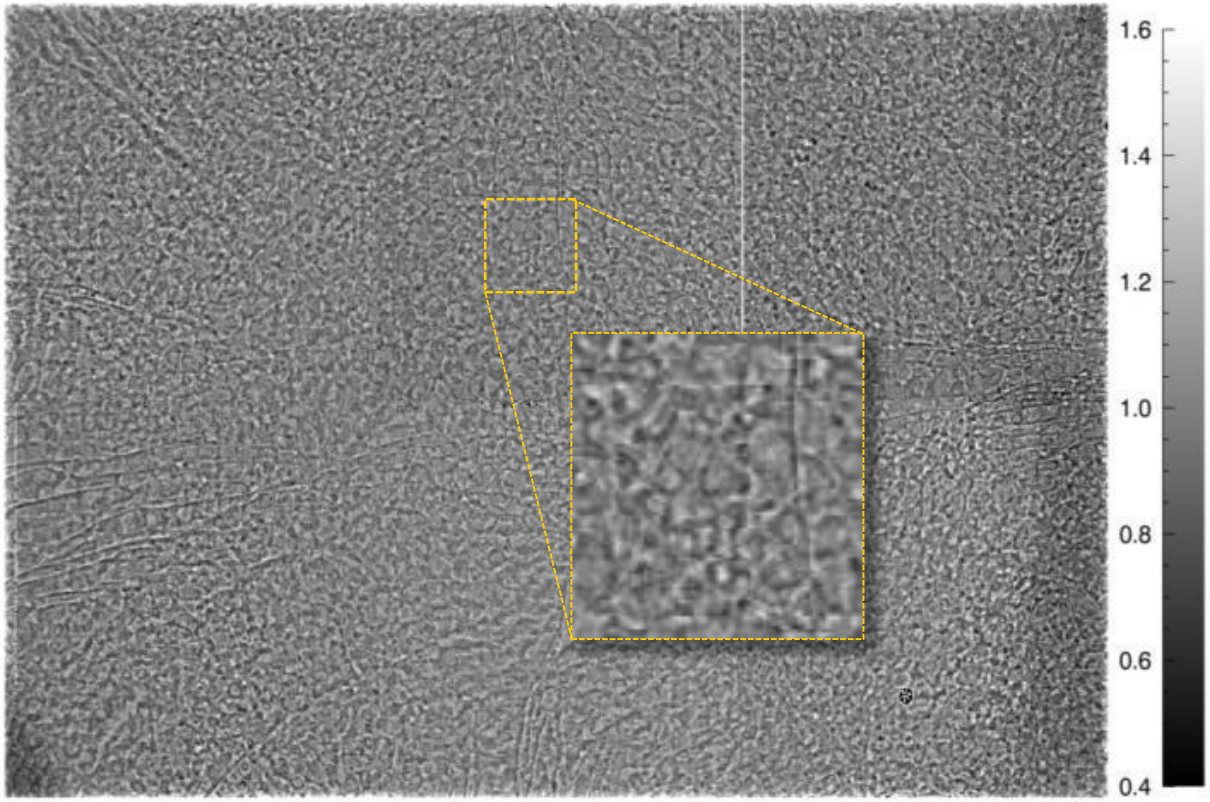
28 mm, 512 pixel

84 mm, 1536 pixel

Gallium Arsenide – 3” wafer performance

- Variation 21% RMS in raw image, 0.15% after flat-field correction
- 0.24% bad pixels

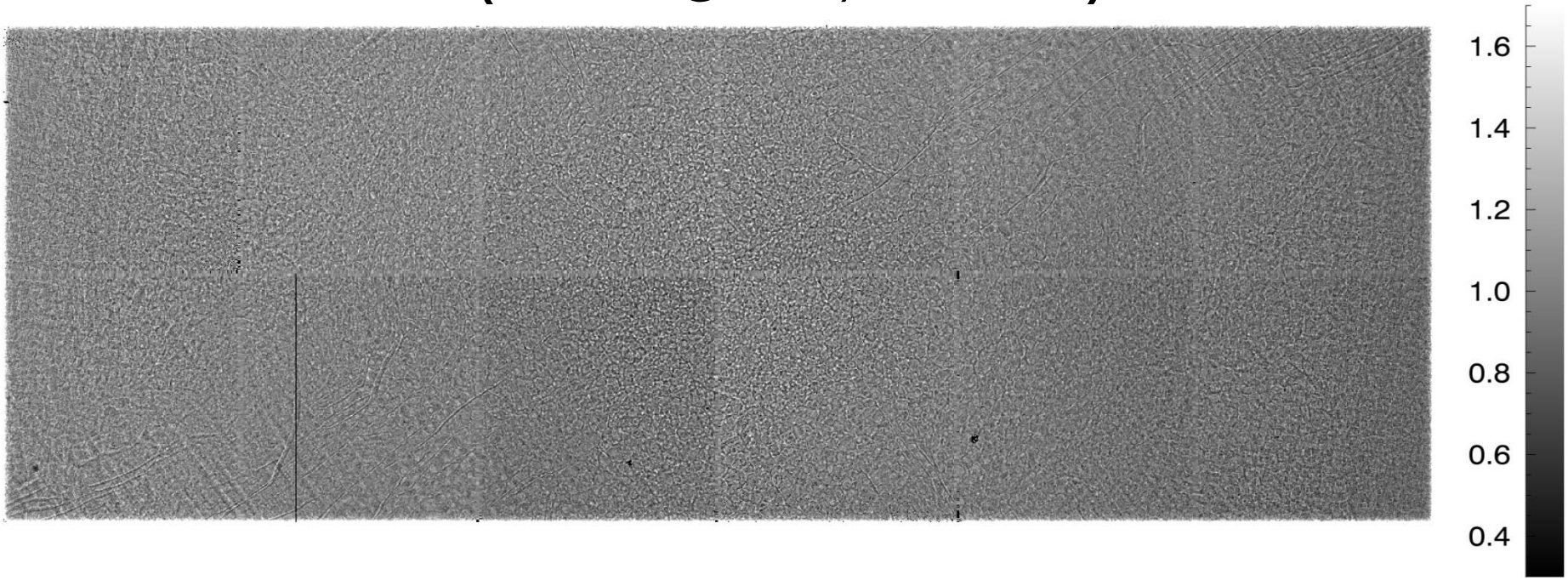
Flat field (Mo tube @ 40kV, -300V bias)



New GaAs sensor from 4” wafers

- Sensor very similar to previous 3” wafer sensors (21% RMS variation)
- PbSn bonds – good yield (0.12% bad), but wafer bending (400 µm)

Flat field (Mo tube @ 40kV, -300V bias)



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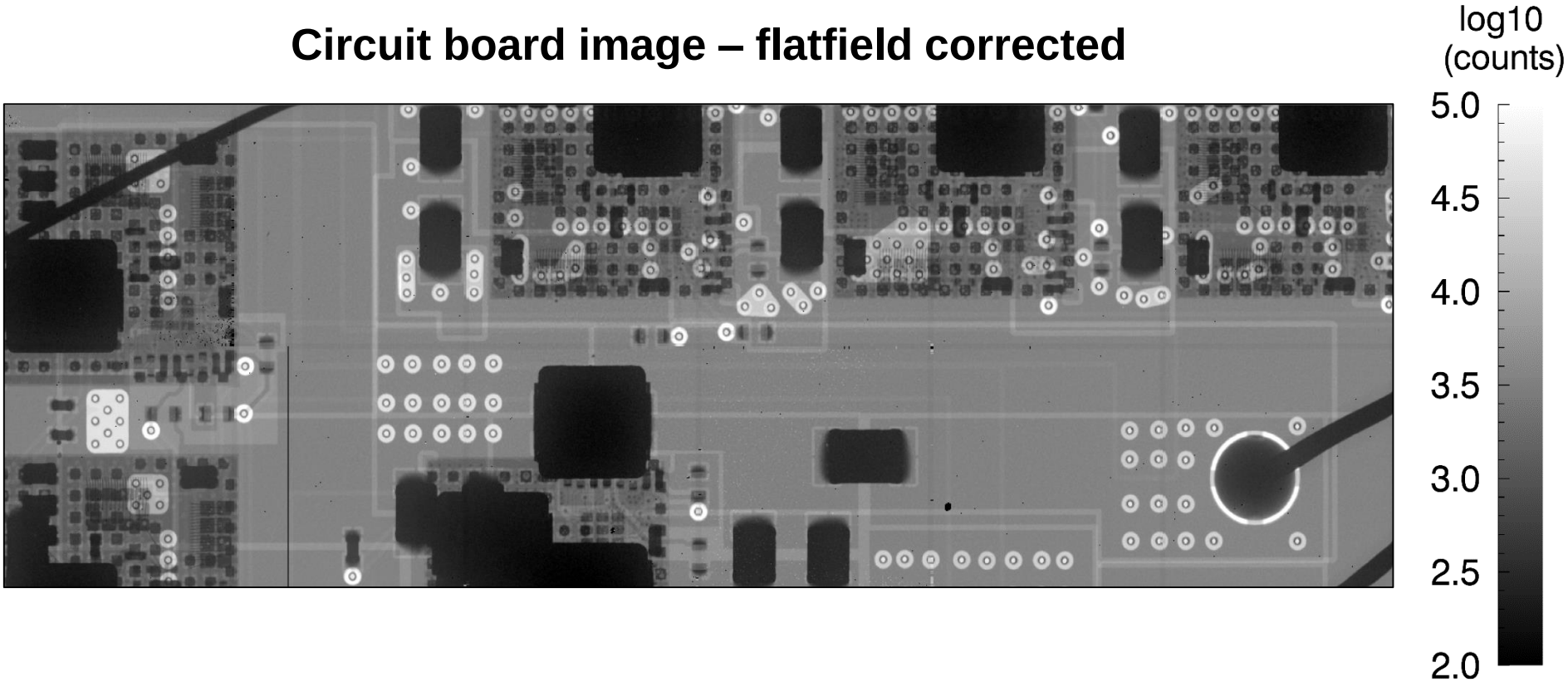
Circuit board image – flatfield corrected



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Cadmium Telluride

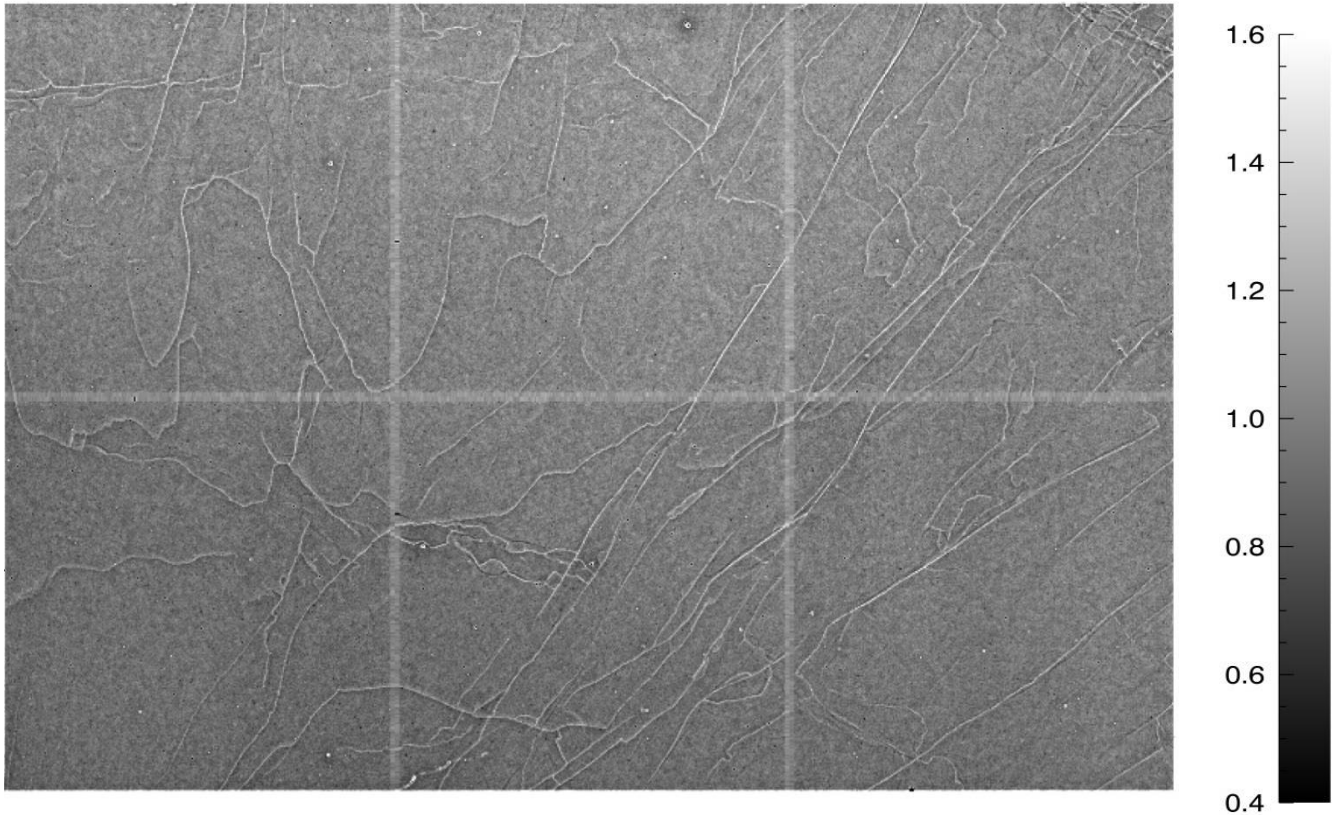
- 1 mm-thick CdTe sensors produced by Acrorad
- Ohmic contacts, 55µm pixel size
  - Higher leakage current than Schottky, but typically less polarisation
- Bump bonding by Advacam

3 x 2-chip layout from 3” CdTe wafer

CdTe performance

- Variation 8.0% RMS in raw image
- 0.06% bad pixels

Flat field (Mo tube @ 40kV, -300V bias)



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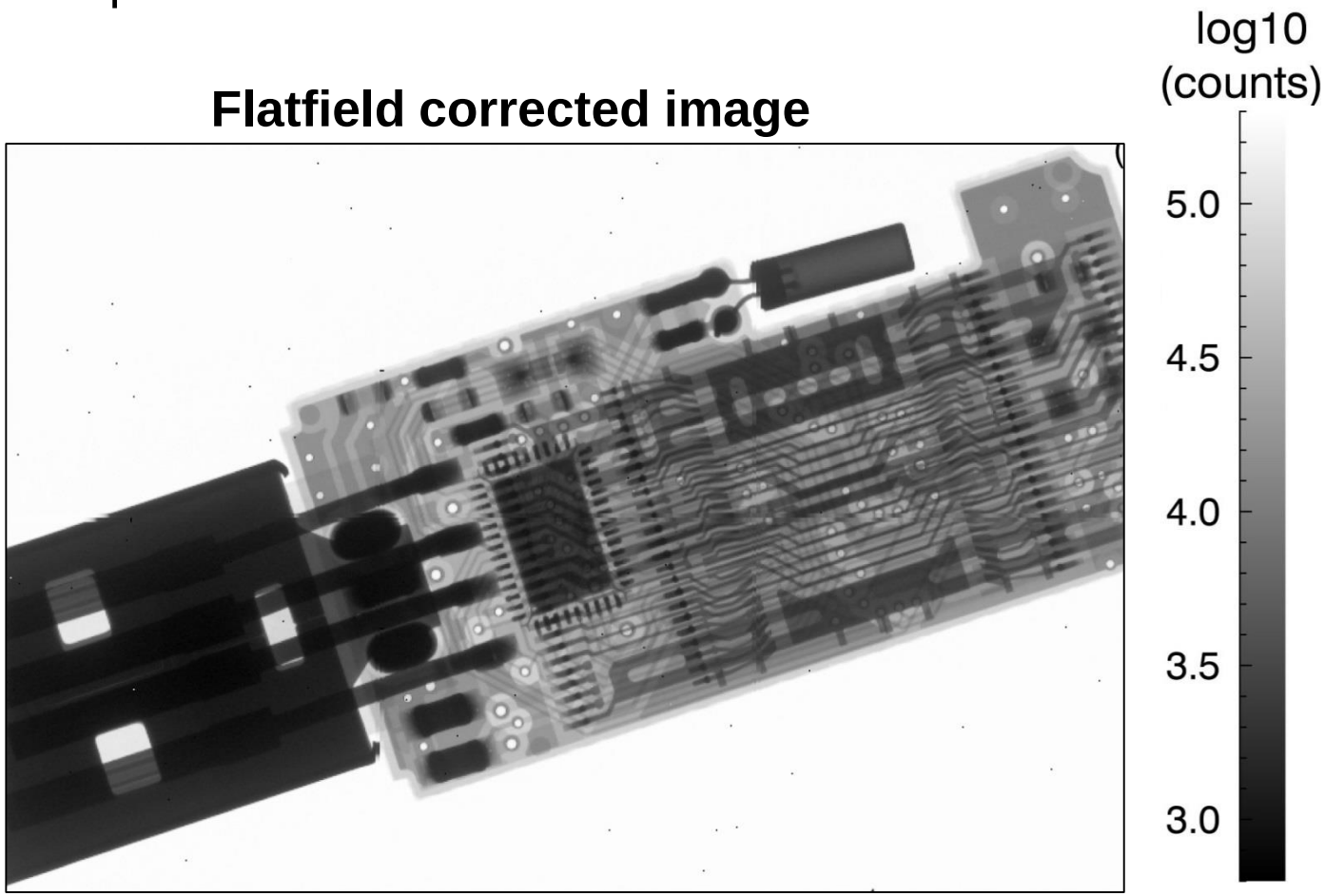
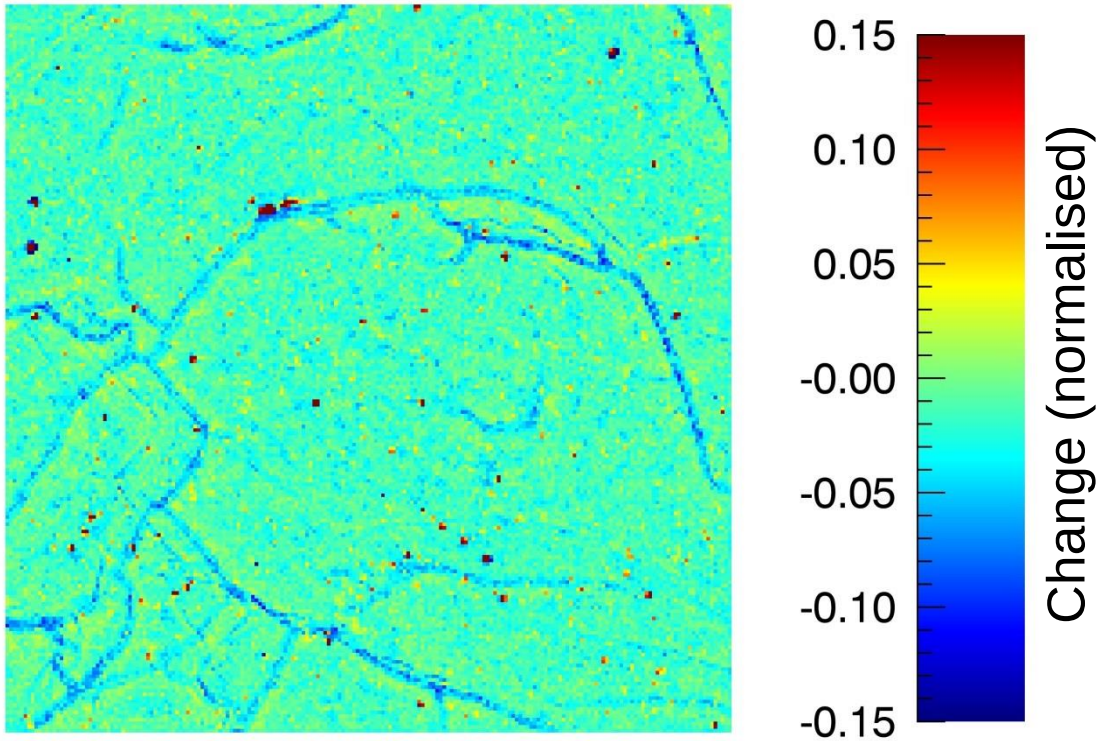
Flatfield corrected image



Change in response over time

- Comparison after 16 hours with low X-ray flux (18 keV energy)
- Intensity of lines falls, appearance of brighter patches

Change in CdTe response over 16 hours



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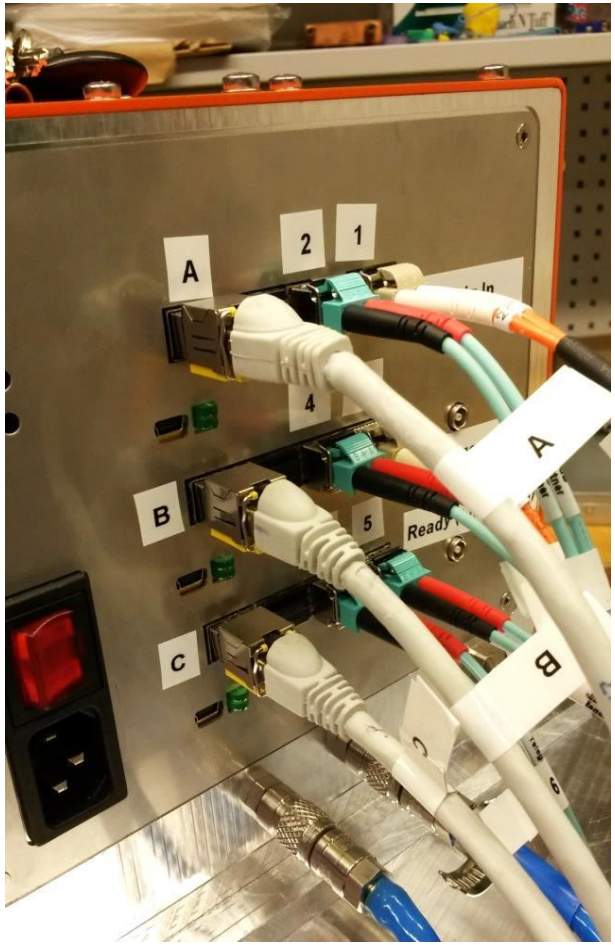
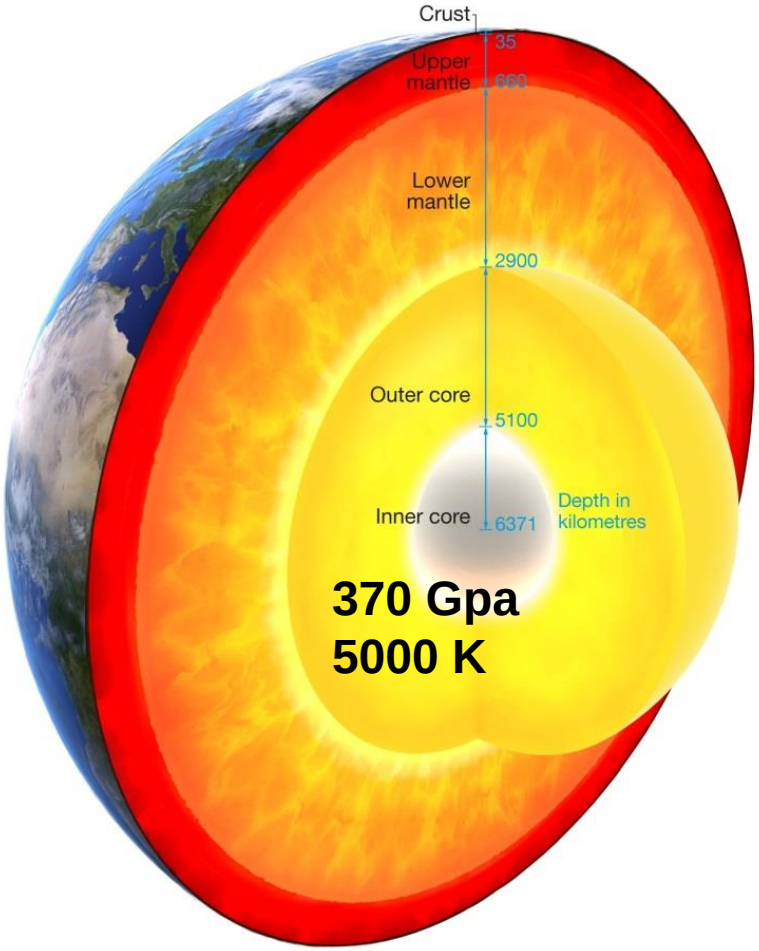
LAMBDA GaAs 2M system

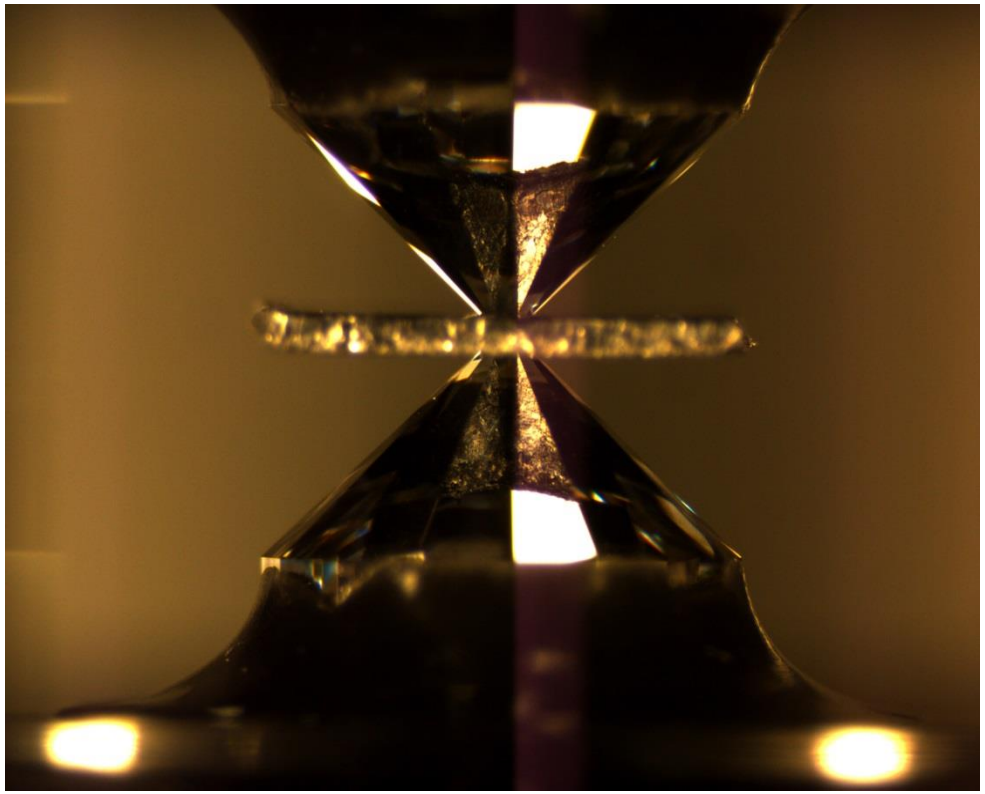


Thanks to X-Spectrum GmbH

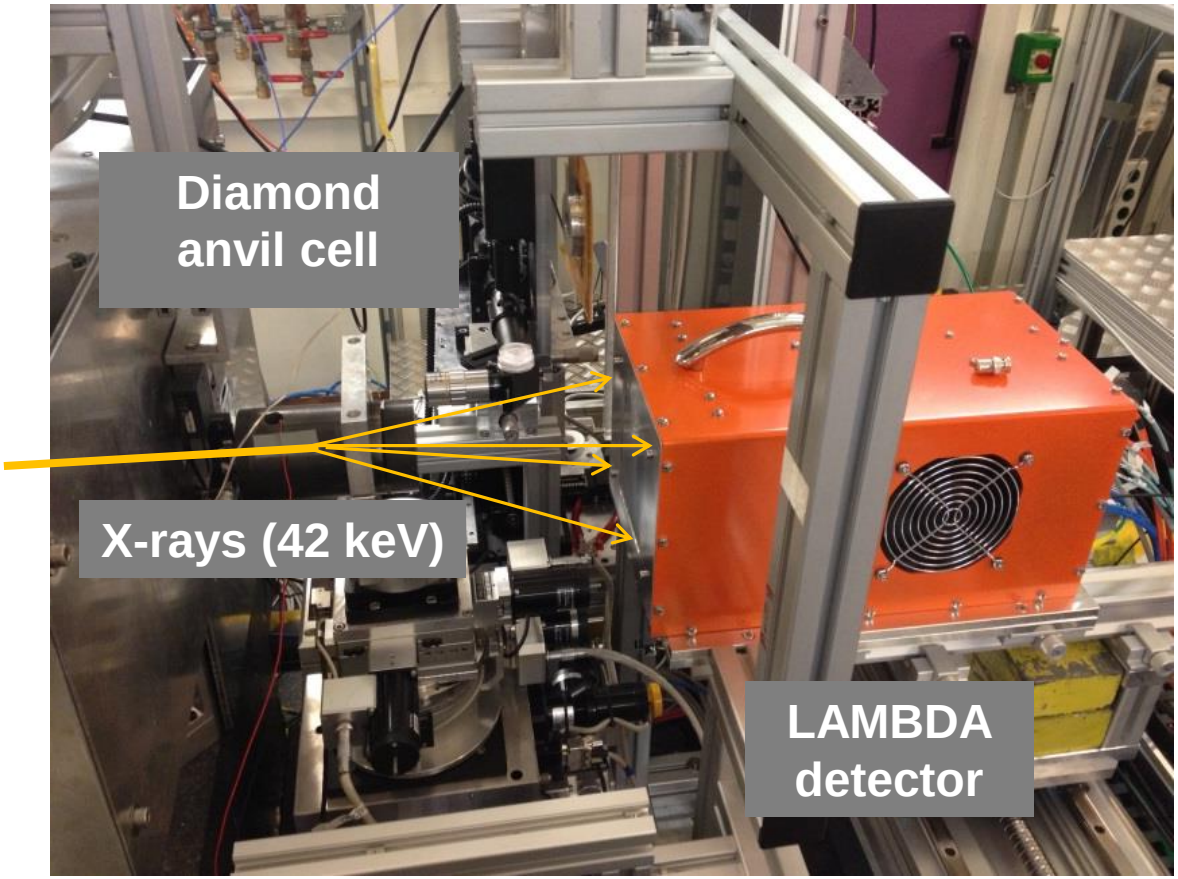
Extreme conditions experiments

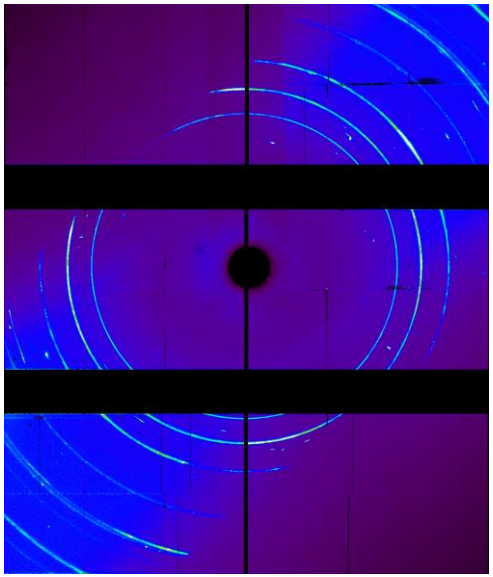


Diamond Anvil Cell (DAC)



Experiments at PETRA P02.2





- *Thanks to HP Liermann, Z. Konopkova, W. Morgenroth (DESY)*

  Z. Jenei, W. J. Evans, Y. Kono (LLNL)

Experiments at PETRA P02.2

Bi sample
Rapid compression
- 30 GPa in 5 ms

Bi-I (As-type, orthorhombic)

⬇ 2.55 GPa

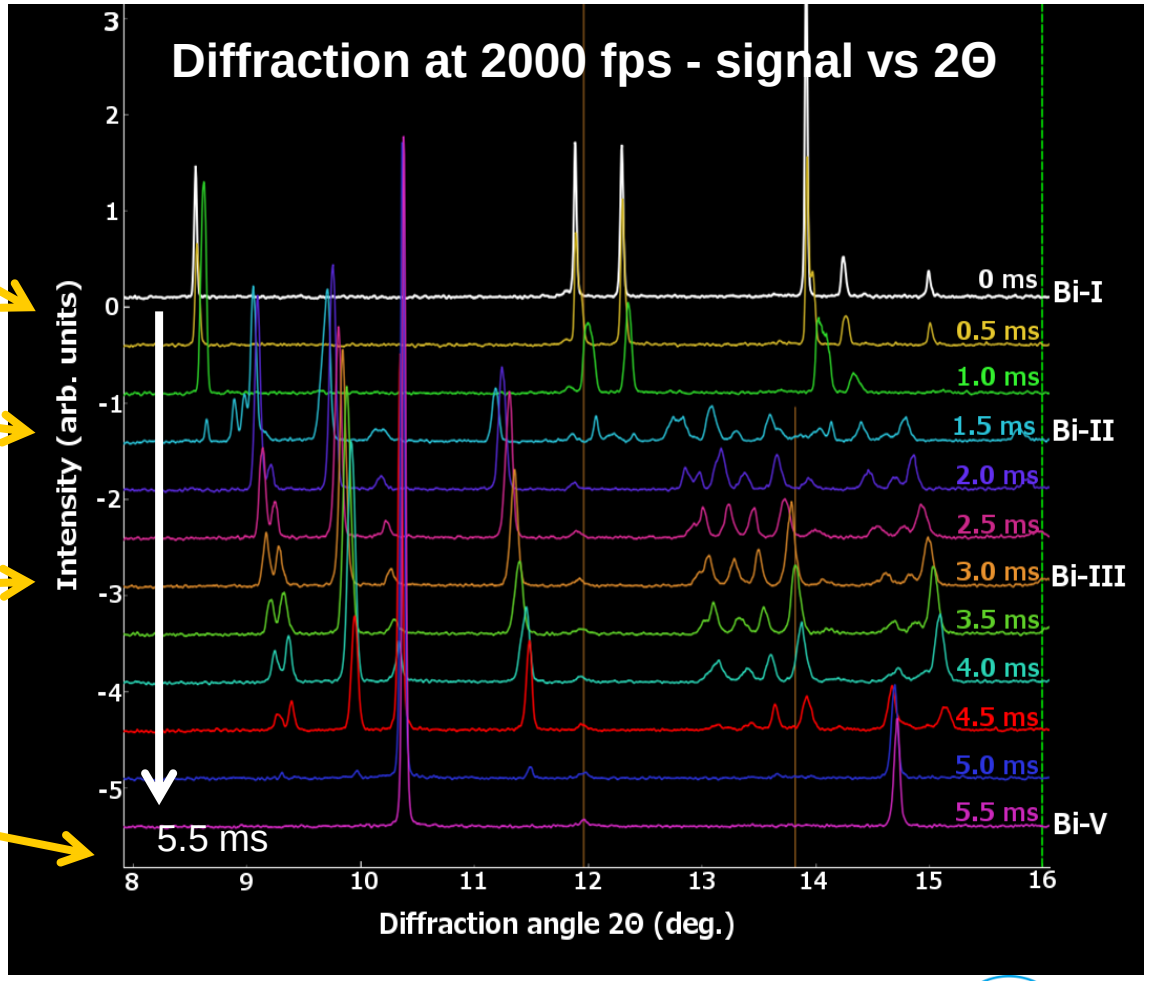
Bi-II (mC4, monoclinic)

⬇ 2.7 GPa

Bi-III (incommens. host-guest)

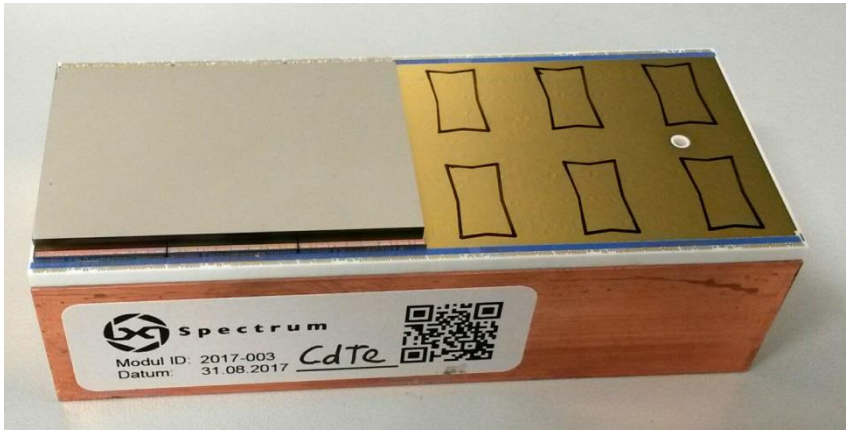
⬇ 7.7 GPa

Bi-V (bcc, cI2)



Conclusions

- GaAs sensors produced from 4” wafers - similar results to 3”
- CdTe sensors show good pixel yield, but some long-term instability
- Multi-megapixel systems used in synchrotron experiments

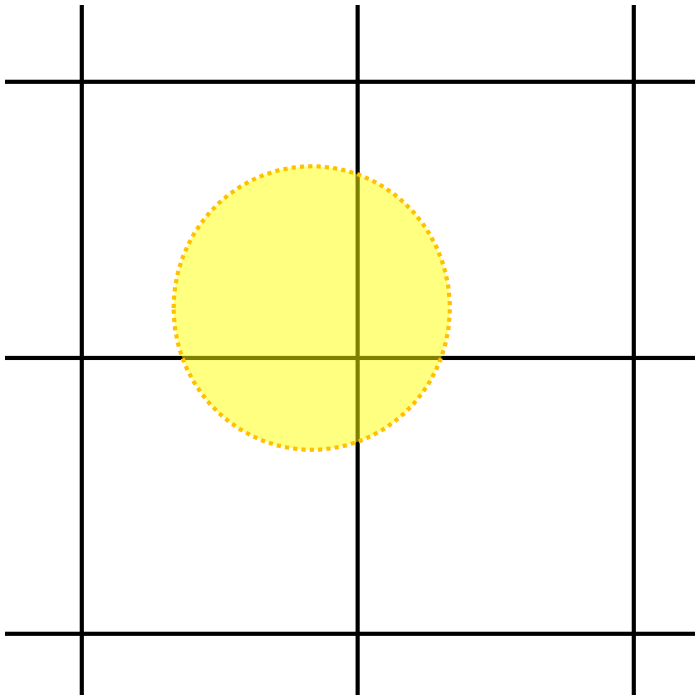


> Thanks for listening

Medipix3 charge sharing compensation

- High charge sharing leads to double counting or lost hits
- Medipix3 chip incorporates charge sharing compensation

Charge cloud shared between pixels



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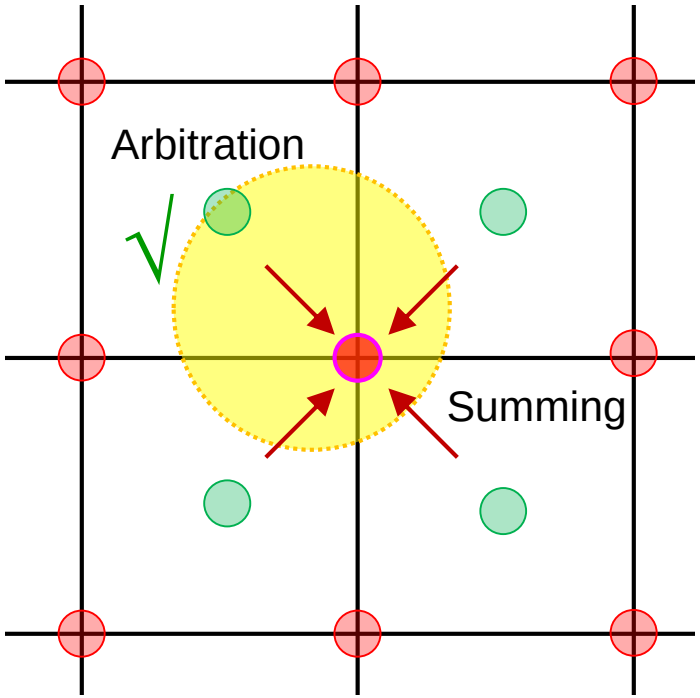
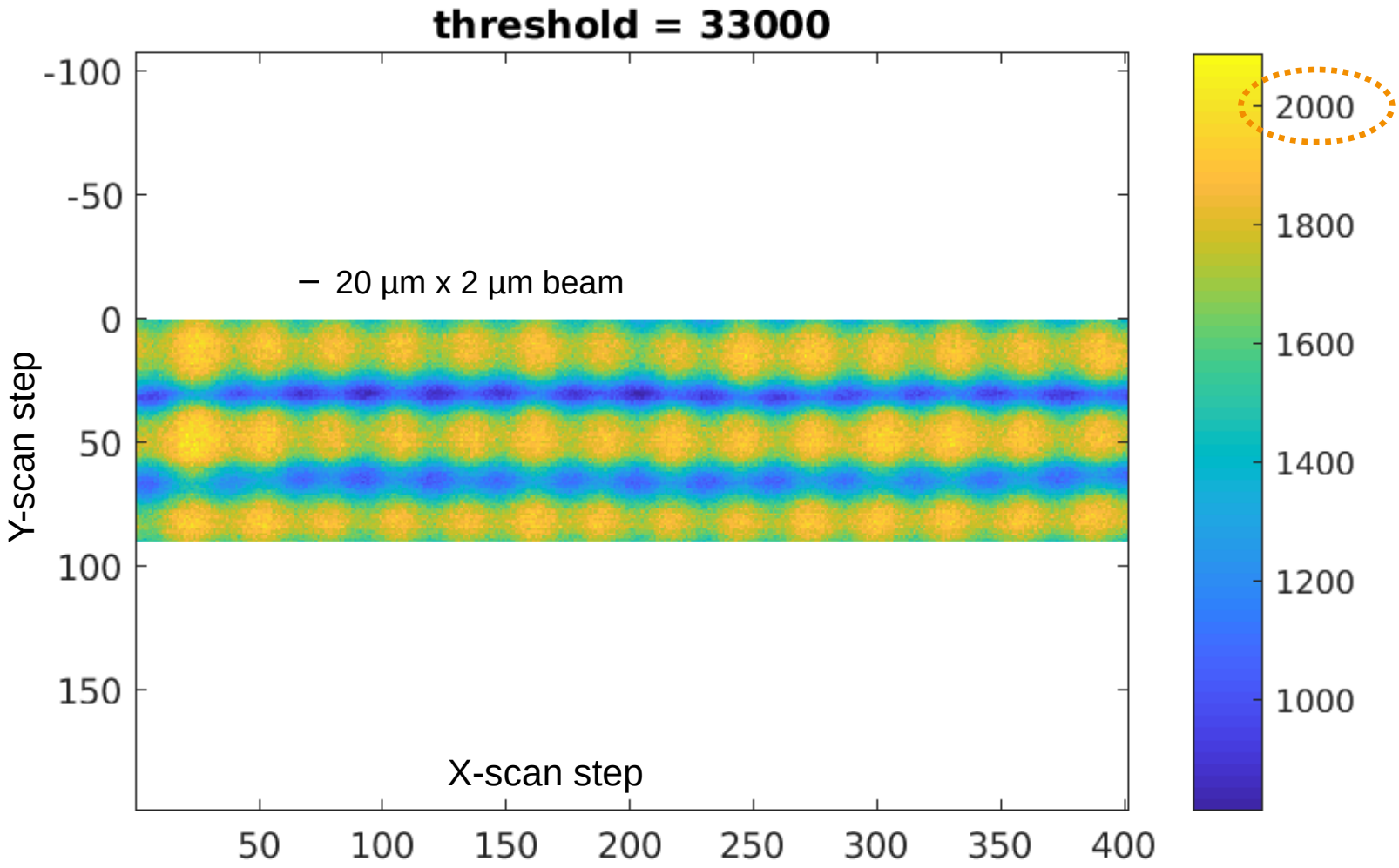
Medipix3 RX charge summing



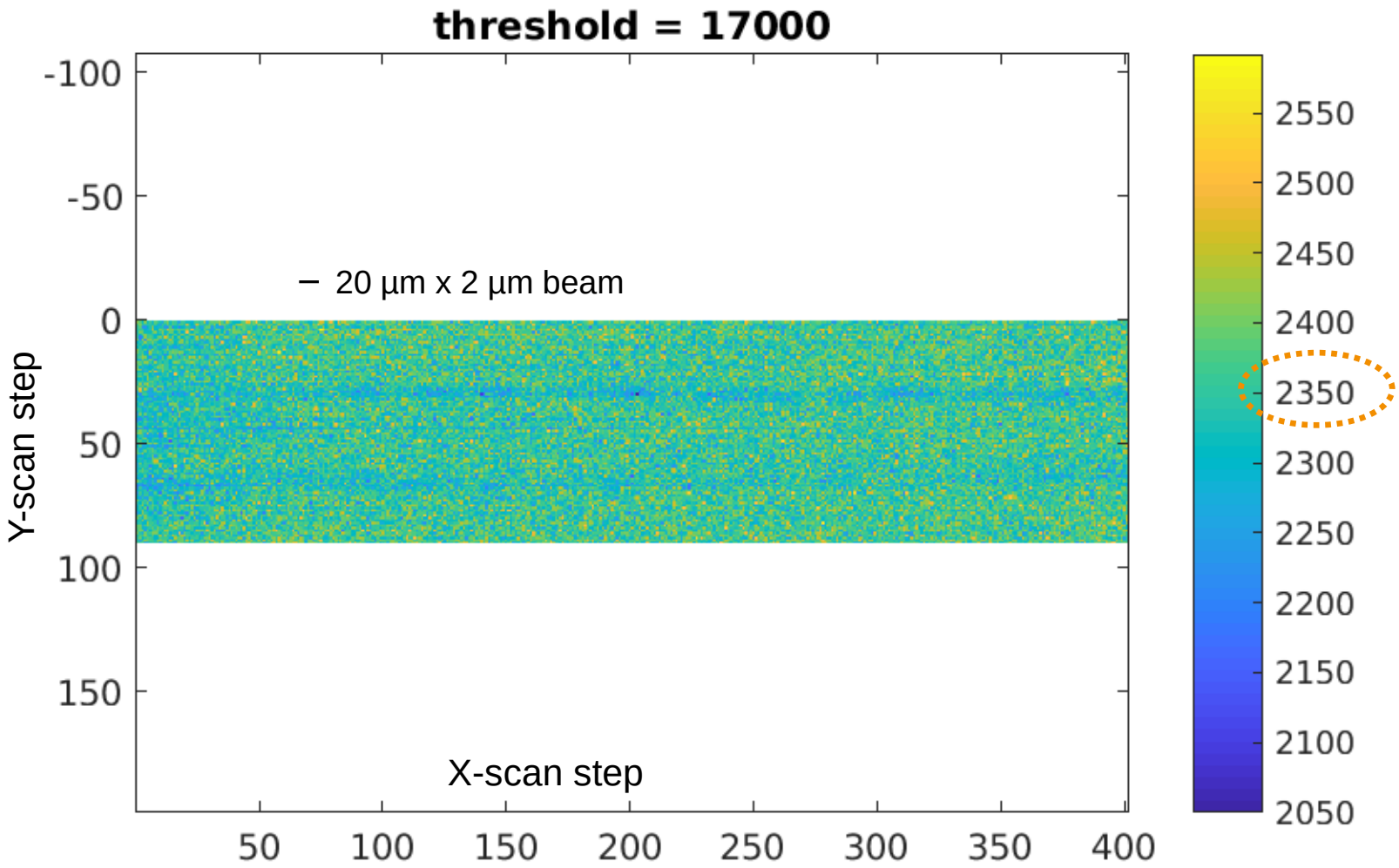
Beam scan test (CdTe) – charge summing off

- Mapped total detector response with 71 keV pencil beam - PETRA P08



Beam scan test (CdTe) – charge summing activated

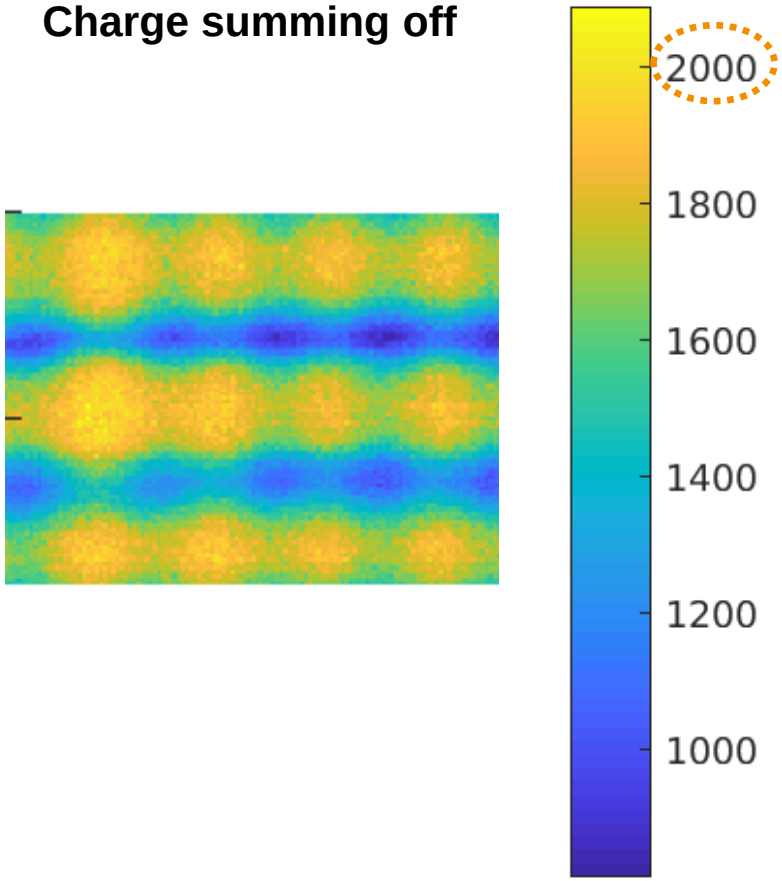
- Results with **charge summing activated**



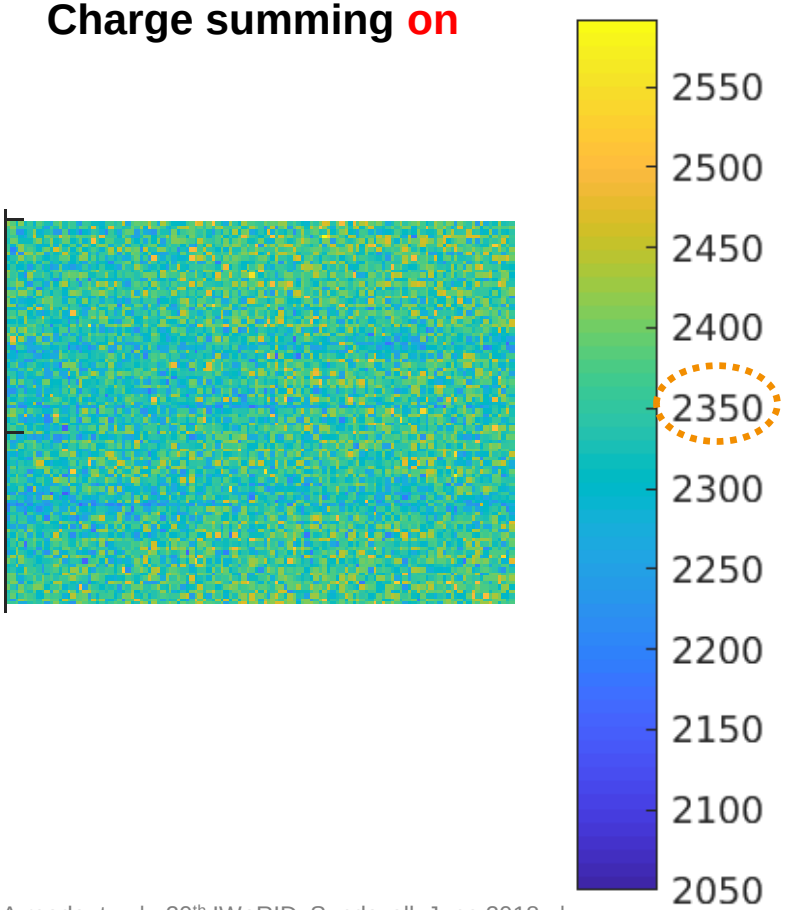
Medipix3 charge summing functionality

- Charge sharing correction in Medipix3 ASIC
- Pencil beam scan shows hits consistently counted once and only once

Charge summing off



Charge summing on



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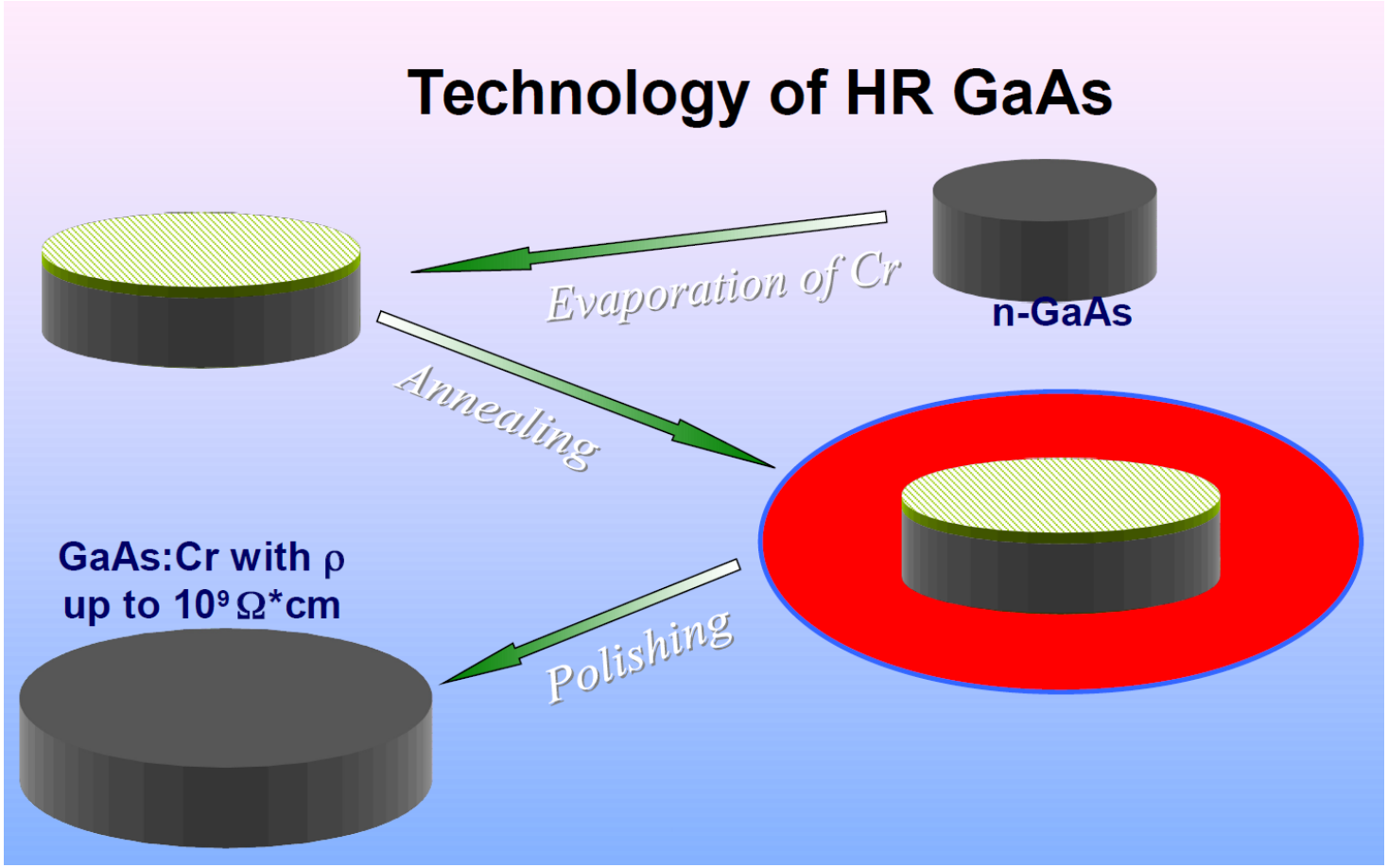

Gallium Arsenide – 3” wafer performance

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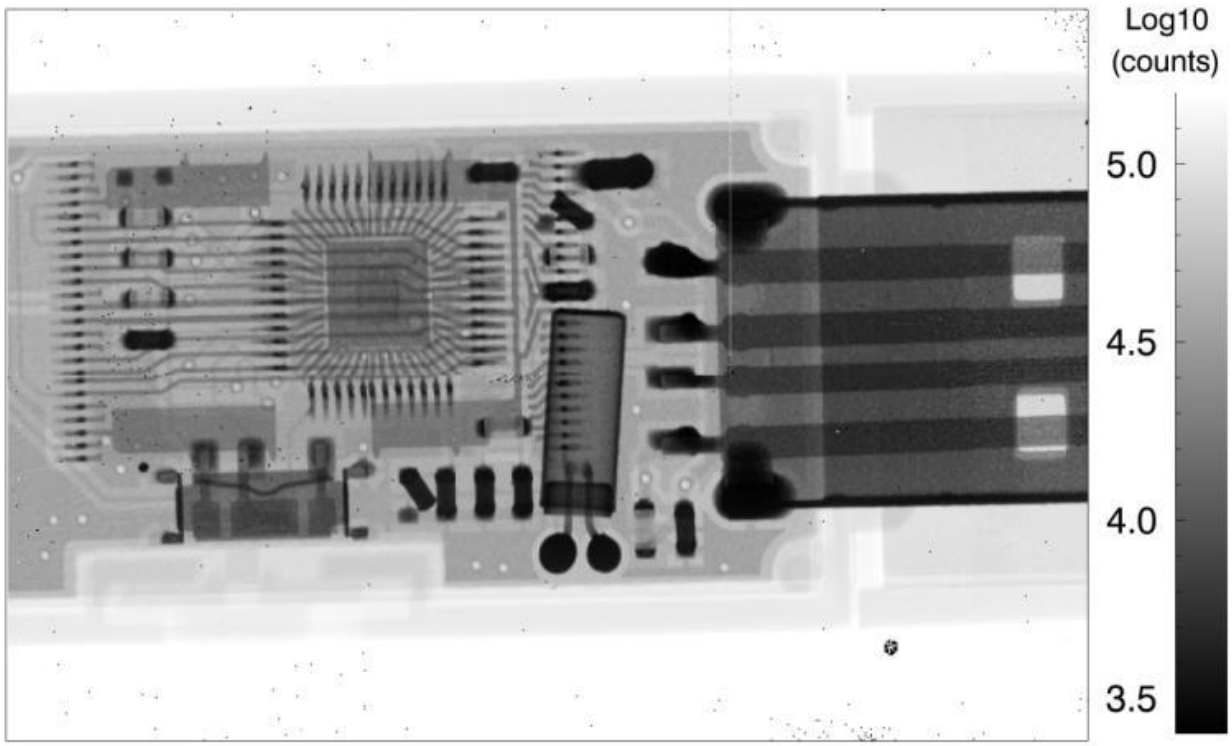
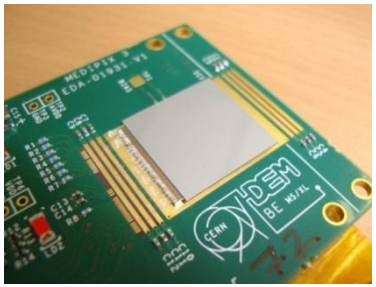
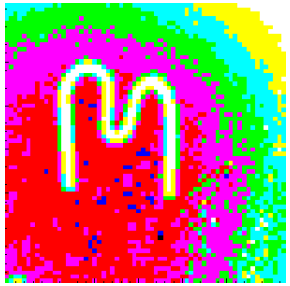
USB stick, FF corrected



Medipix3 readout chip

- Photon counting readout chip developed by collaboration of 20 groups
  - Chip design at CERN
- 2 counters and thresholds per 55 µm pixel
  - Additional interpixel communication circuitry
- Main synchrotron configurations:
  - “Continuous read write” at 2000 fps (12-bit counter depth)
  - Single 24-bit counter (1 ms readout)
- Other interesting possibilities
  - 110um pixel sensor, 4-8 energy bins for “colour” imaging
  - 6- or 1-bit depth with 4000 or 24,000 fps

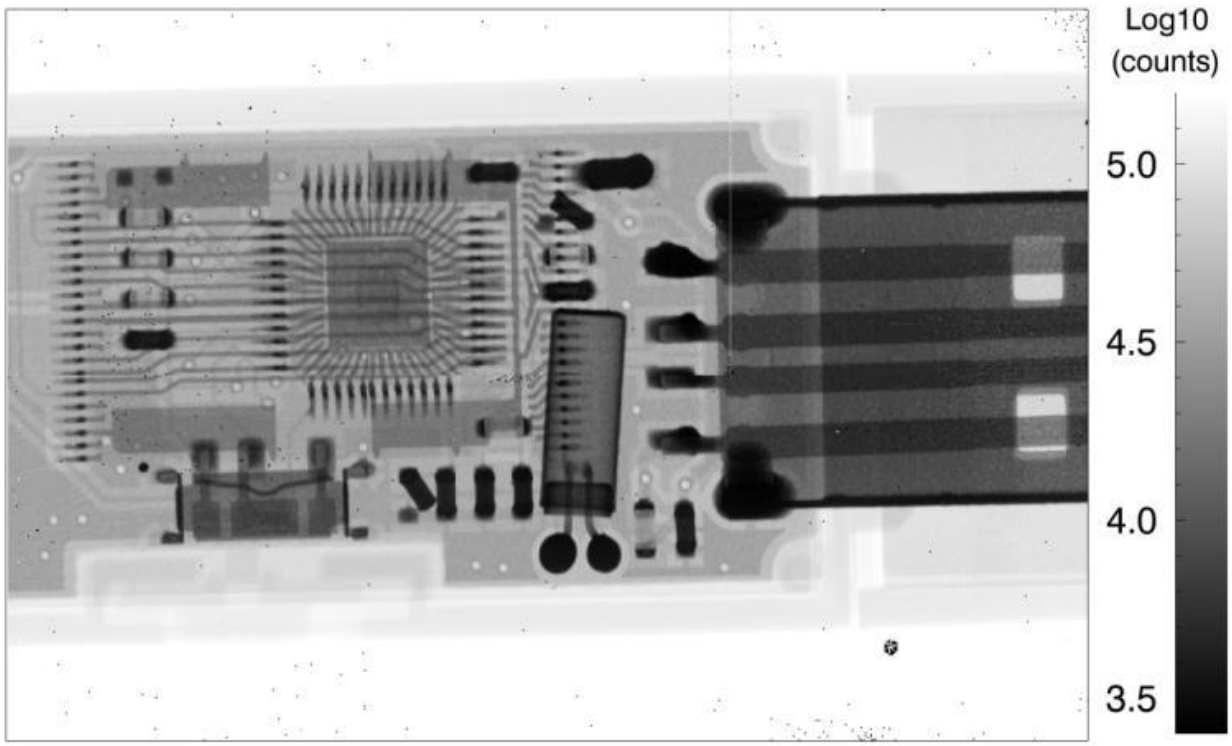




Gallium Arsenide – typical imaging performance

- Good stability, including under high flux (within limits of chip)
  - See e.g. E. Hamann PhD thesis (Uni Freiburg, 2013), M Veale et al (2017 JINST 12 P02015)

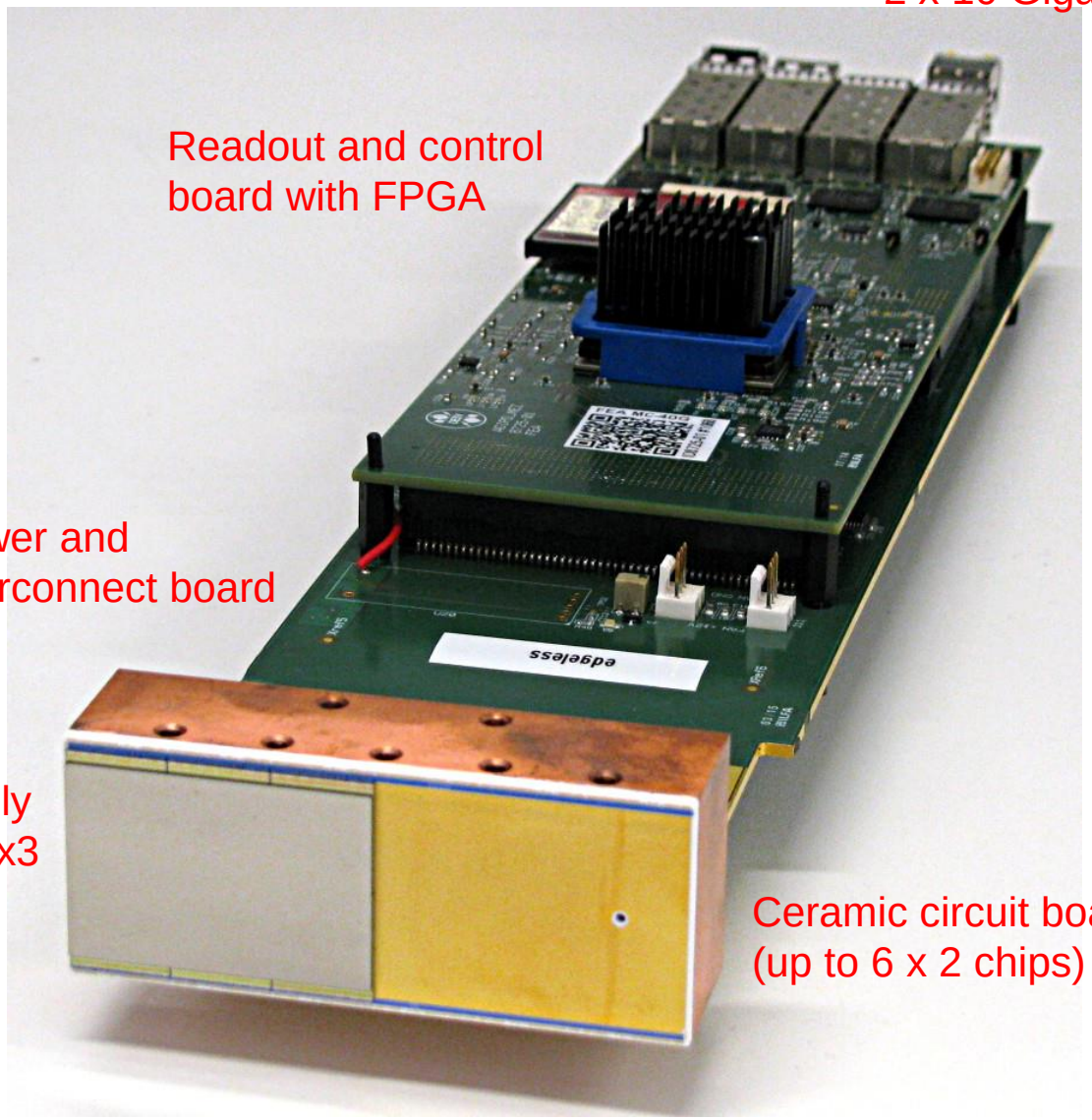
USB stick, FF corrected



Pros and cons of GaAs for diffraction at synchrotrons

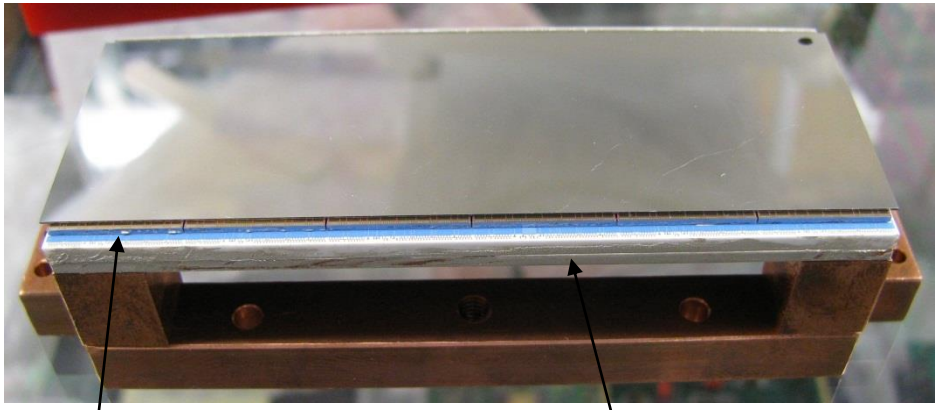
- Relative stability and high-flux capability
- Relative robustness of material for large production
- Significantly less efficient than CdTe above 50 keV
  - Many synchrotron experiments in 20-50 keV range
  - CdTe suffers more from fluorescence effects at 25+ keV
- Greater nonuniformity
  - This is more correctable in monochromatic beam experiments

LAMBDA module design



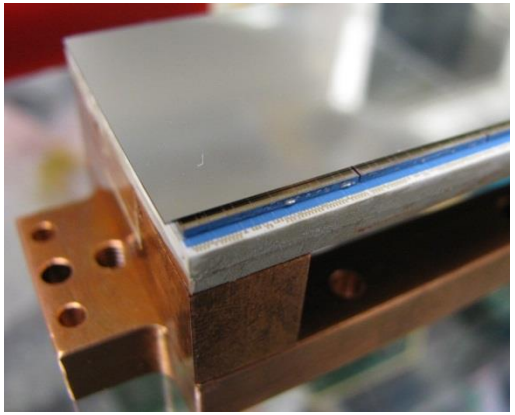
Detector head

- 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)
  - Good match to semiconductor CTE
  - Cooling through thermal vias
- 500-pin connector on board
  - Full parallel readout (8 LVDS data outputs per chip)



6 x 2 Medipix3 chips

LTCC board



High-speed electronics

- DESY high-speed readout card (also used for AGIPD and PERCIVAL)
  - Virtex-5 FPGA with PowerPC
  - Up to 4 * 10 Gigabit Ethernet links
  - DDR2 RAM (8GB)
- "Signal distribution" board connects to det. head
  - Space for vacuum barrier with germanium detector

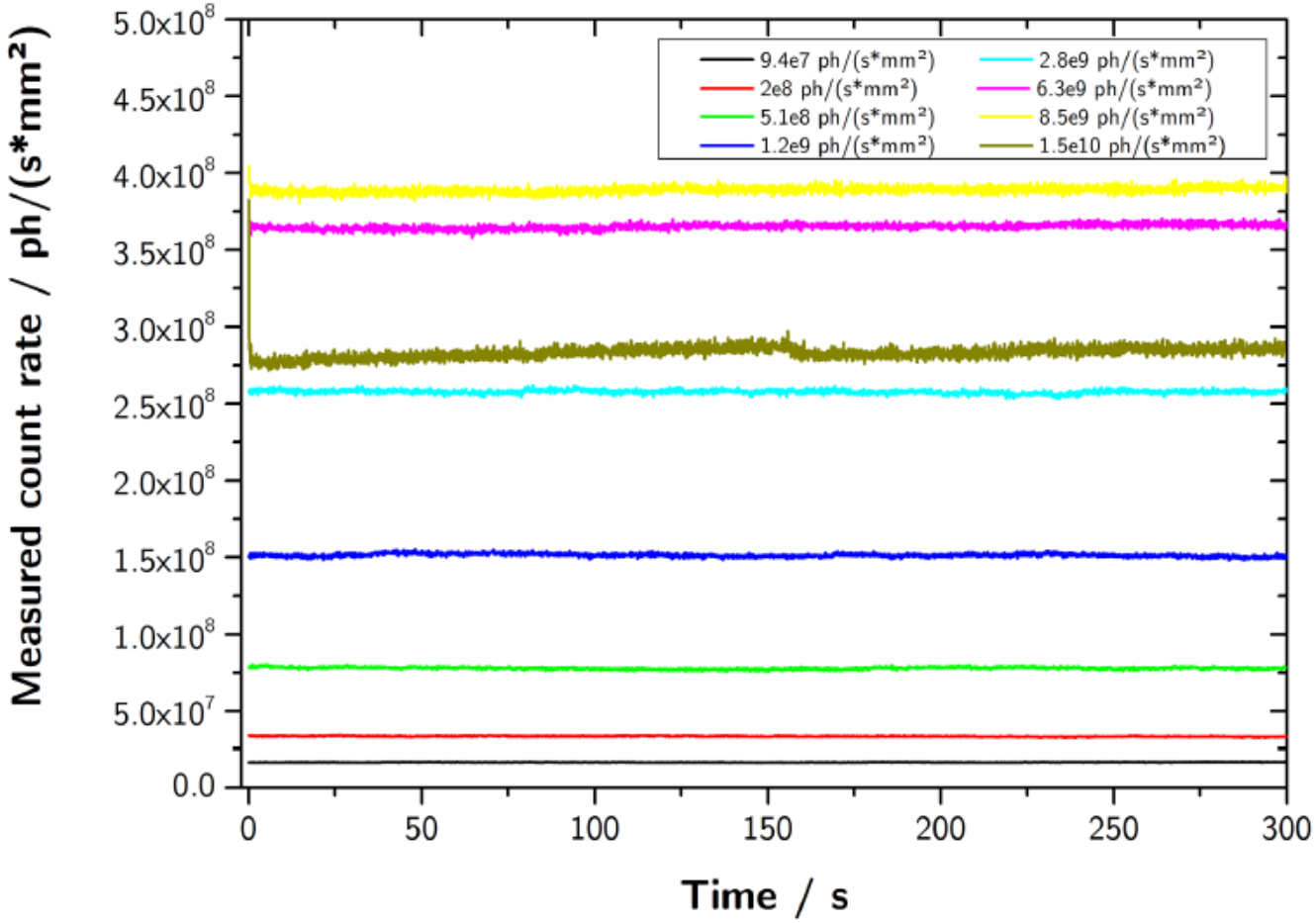
10GE links

Connector to det. head

Power / trigger in

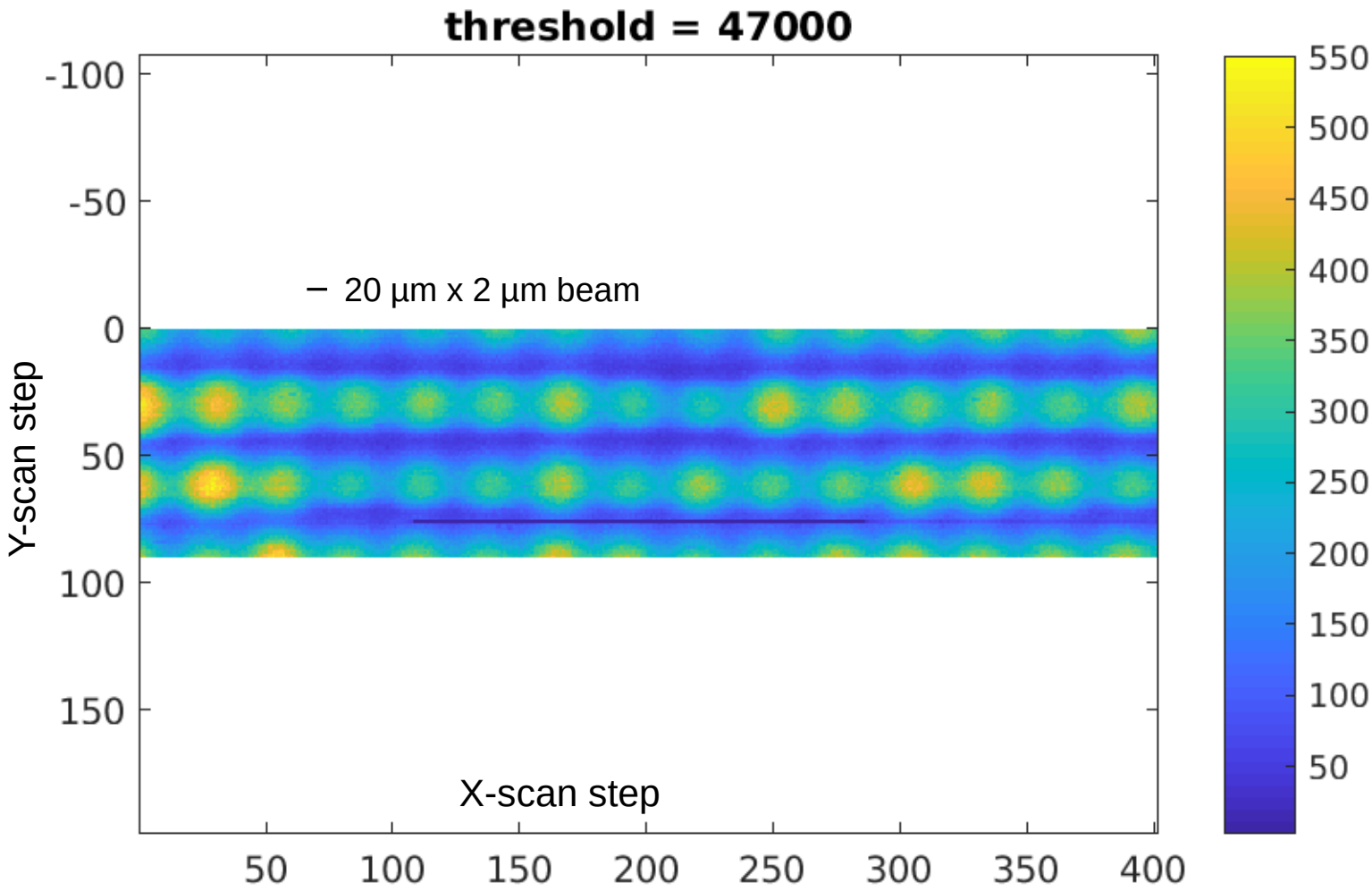
Gallium Arsenide – typical imaging performance

- Good stability (within limits of chip)
  - See e.g. Elias Hamann PhD thesis (Uni Freiburg, 2013)



Beam scan test (CdTe) – charge summing off

- Mapped total detector response with 71 keV pencil beam - PETRA P08



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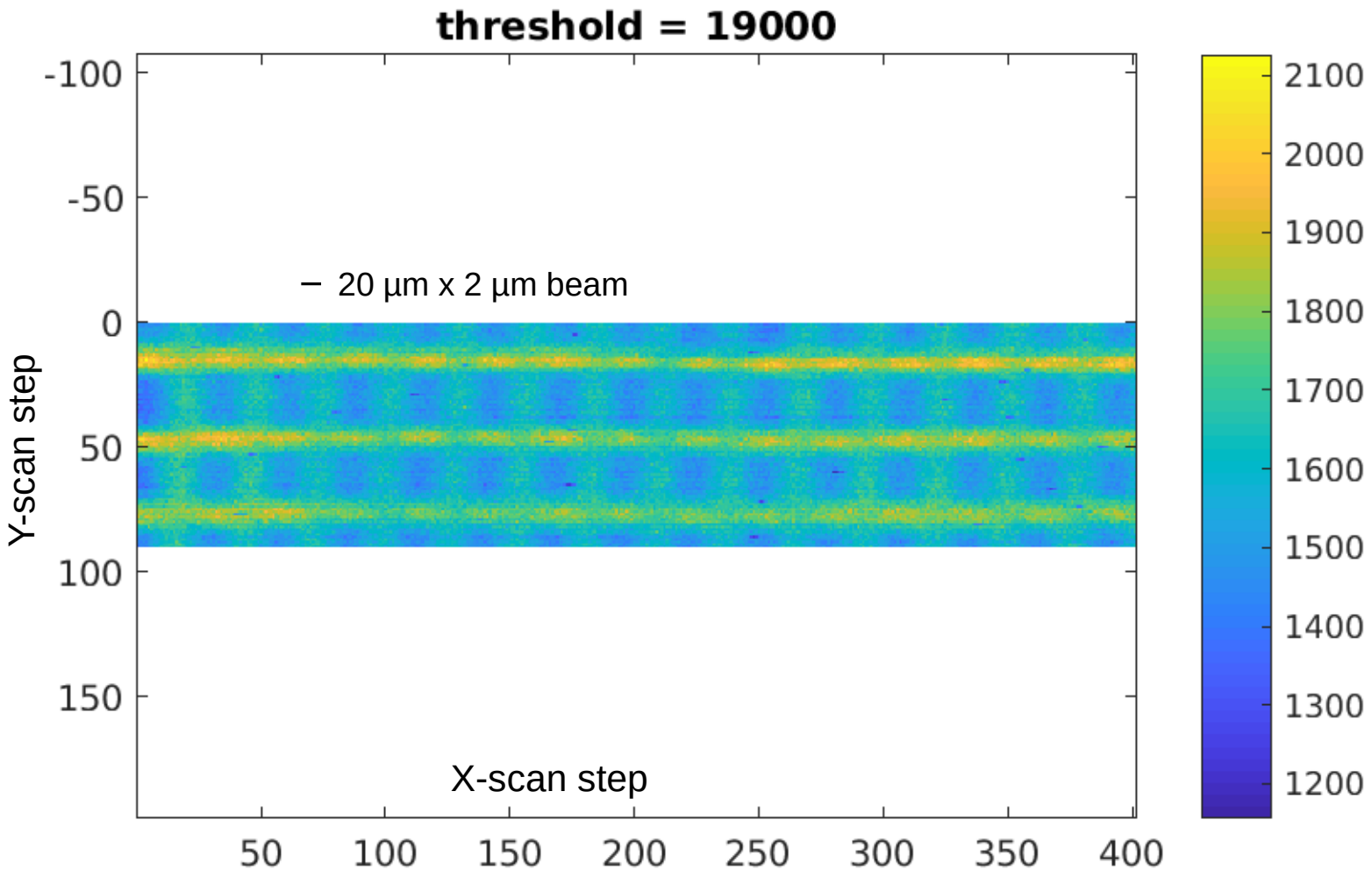
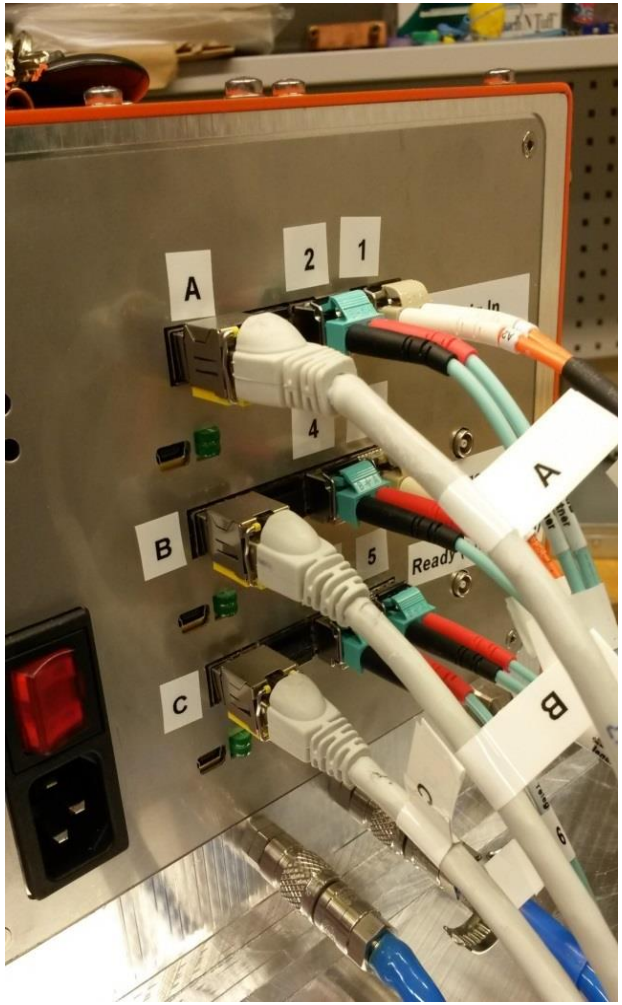


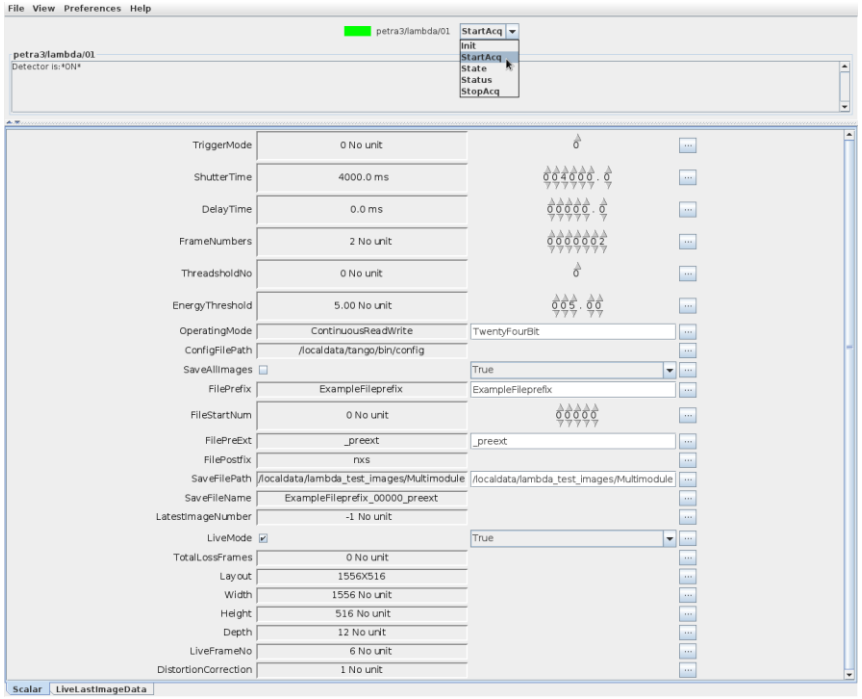
3-module DAQ

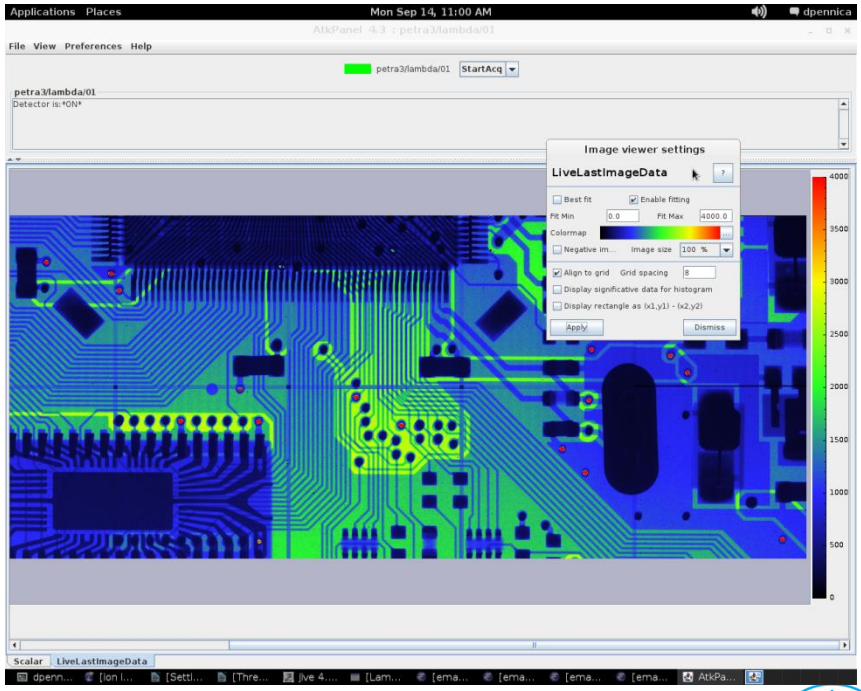
- 3 modules x 2 optical links x 10 Gigabit
  - 60 Gbit/s total readout speed
- 2 high-end server PCs used to control detector
  - First PC – 1 module data reception, “master” control and visualisation
  - Second PC – 2 modules data reception
  - Co-ordinated and controlled using “Tango” beamline control system



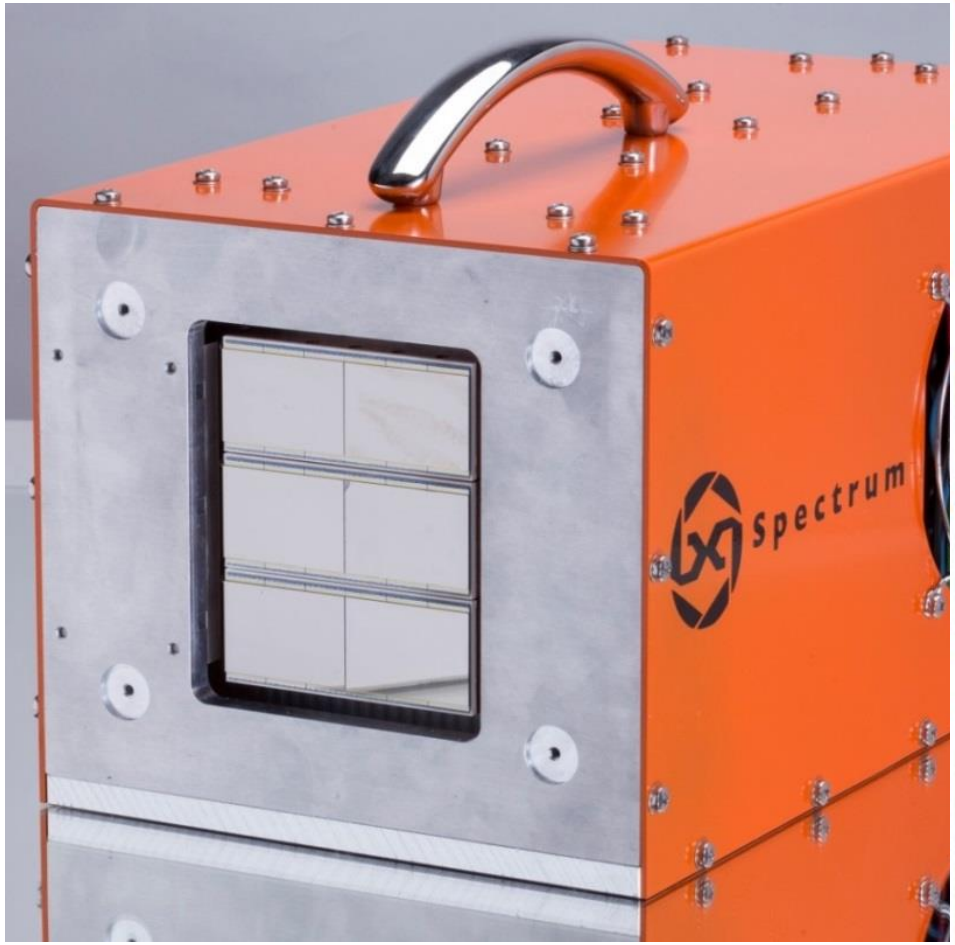
Multi-module software

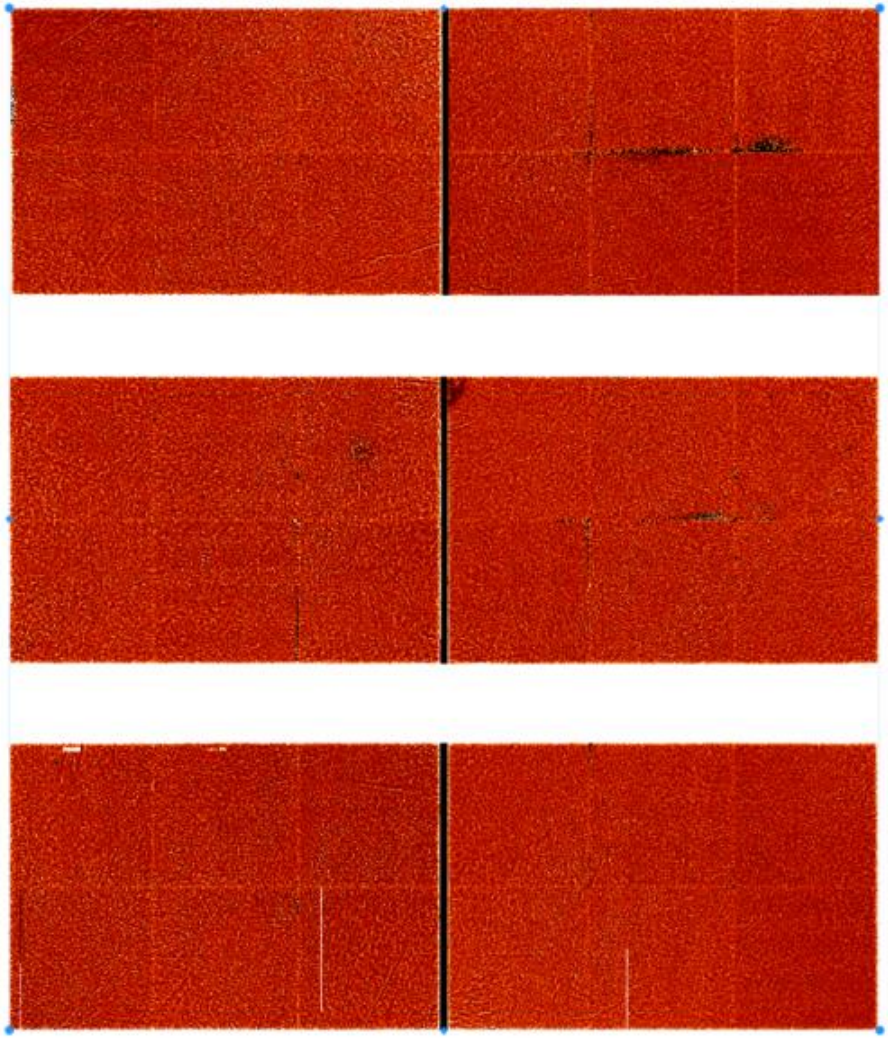
- Runs within “Tango” beamline control system
  - Tango controls many devices spread across many computers
- Each module can be read out by a different PC
- “Master” software then controls modules in parallel



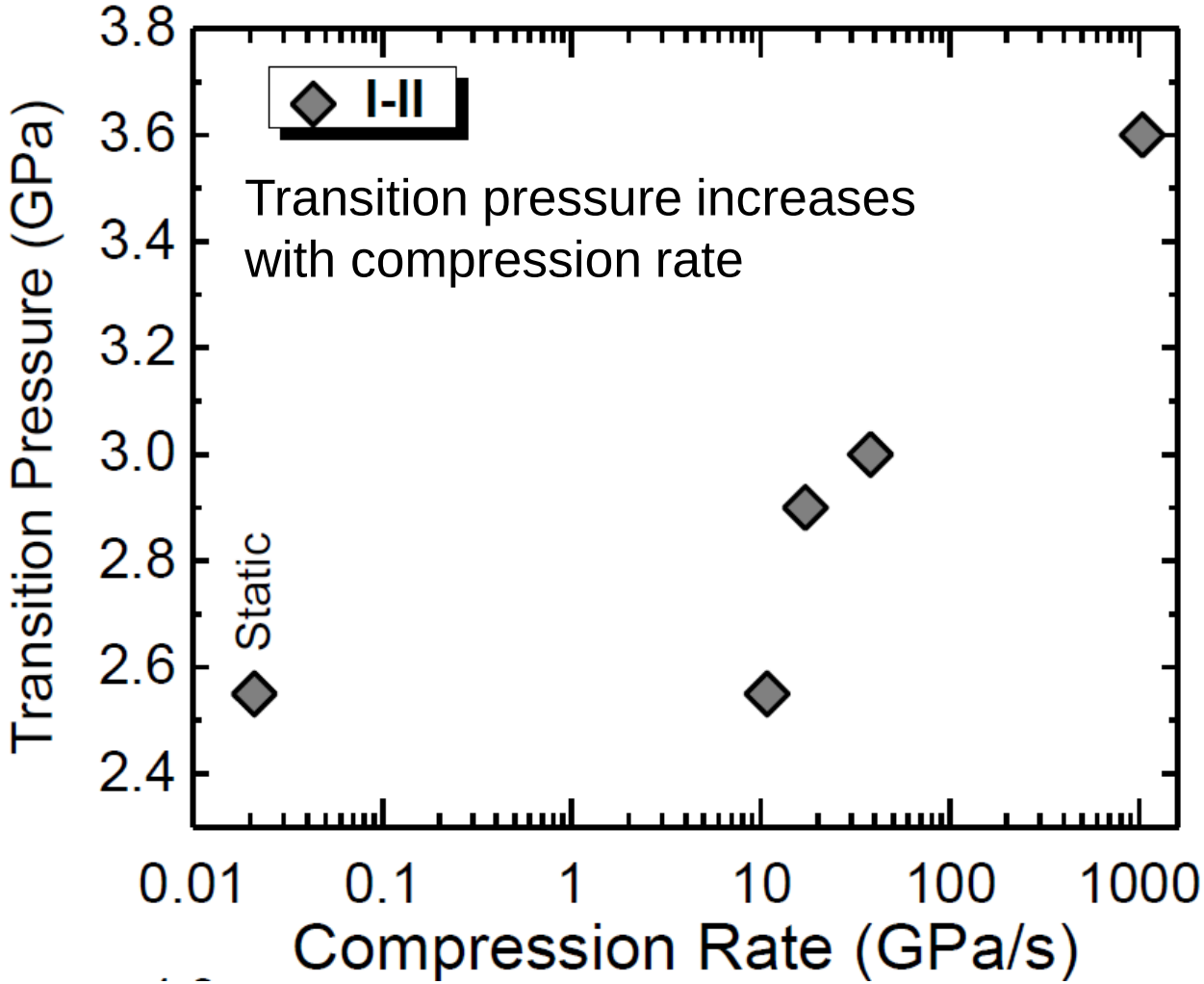


LAMBDA GaAs 2M system





Experiments at PETRA P02.2



Z. Jenei et al., 5th Workshop on High Pressure Planetary and Plasma Physics