DECTRIS 20 YEARS ENABLING SCIENTIFIC BREAKTHROUGHS

New sensors R&D at DECTRIS with the ERMINE ASIC for laboratory X-ray applications

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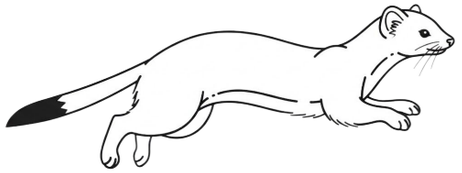
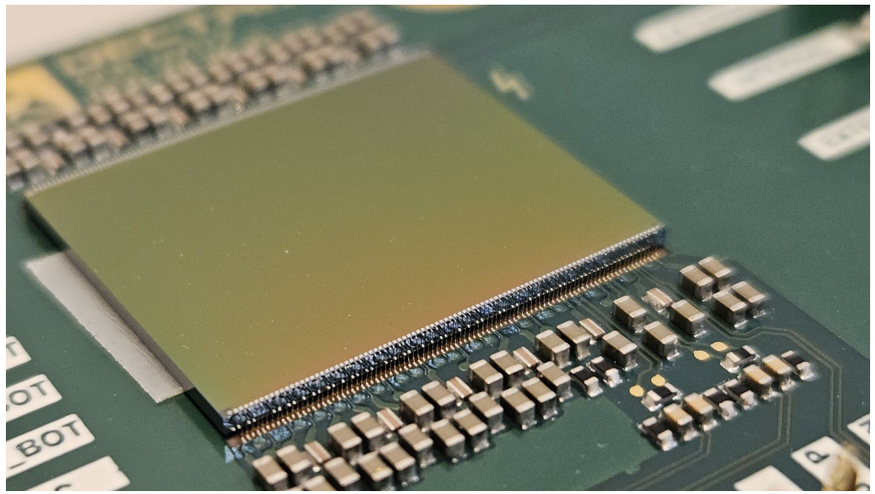
ERMINE ASIC



A photon counting chip for laboratory X-ray applications

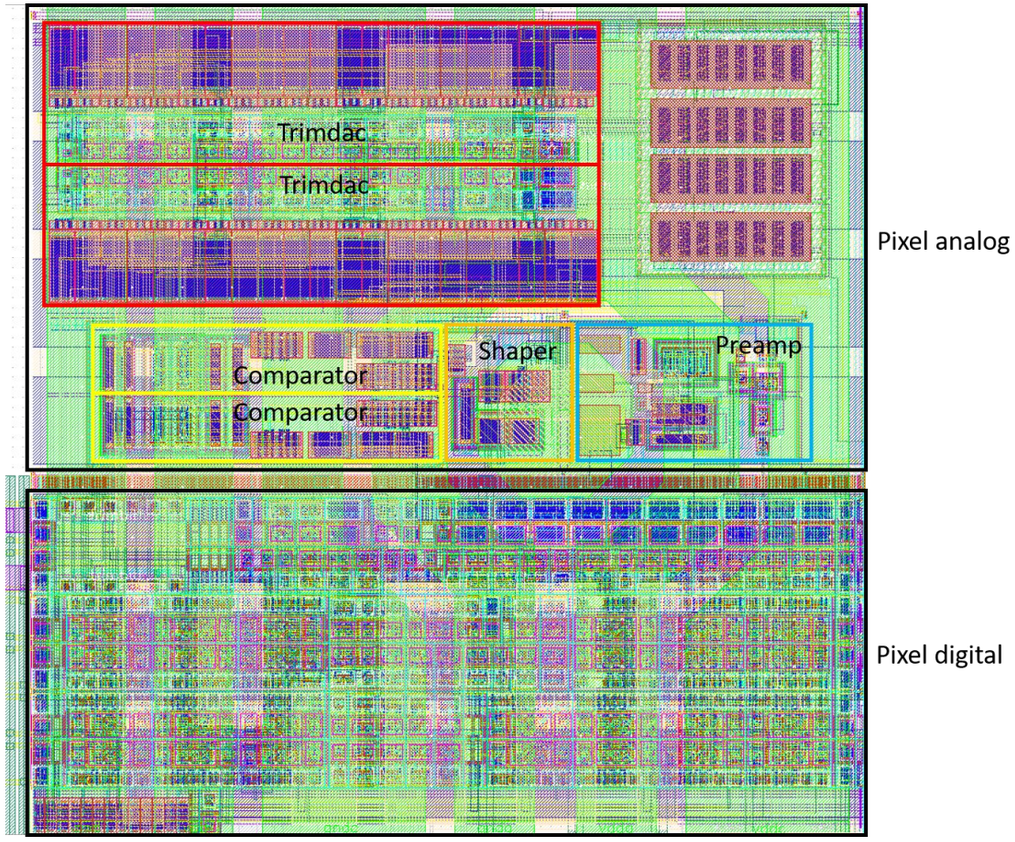
- Optimized toward low noise
  - high energy resolution to suppress fluorescence and high energy background
  - still 1 Mcount / pixel / s achievable
- 2-side buttable, when wide angular coverage is needed
- Temperature stability



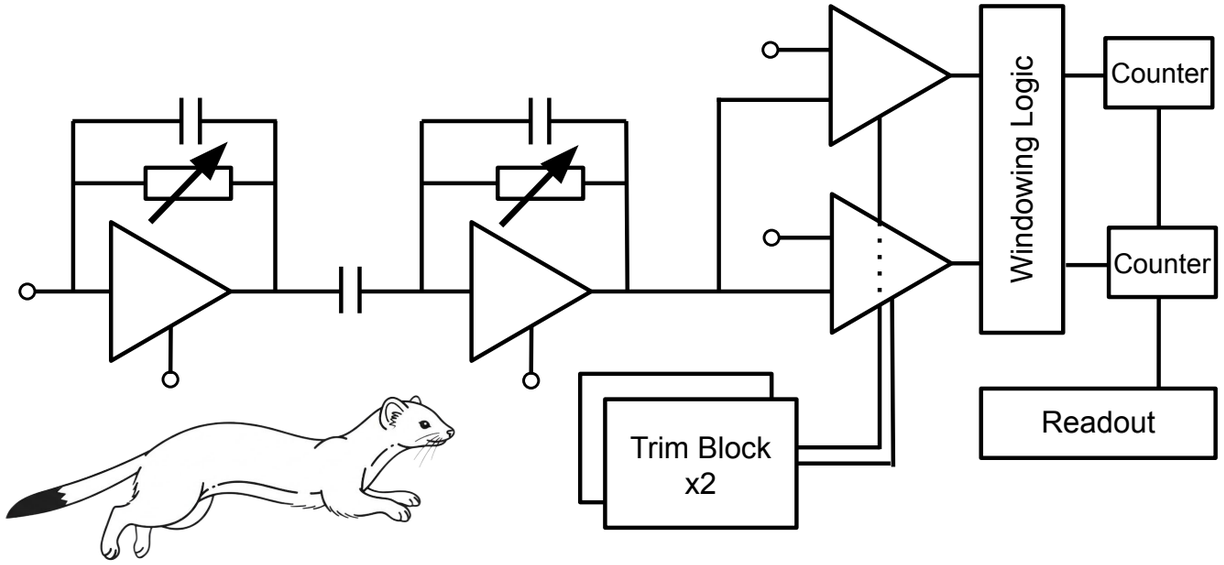
Specifications

Pixel size	75 μm
Array size	192 x 256 pixels (14.4 mm x 19.2 mm)
Geometry	2-side buttable
Input polarity	Pos / Neg
Thresholds	Single threshold or windowing
Counters	2 counters 12 bit, ~0 dead time
Frame rate	400 fps
Count rate	> 1 Mcount / px / s with Cu radiation
Threshold range	Si: 4 - 11 keV, High-Z: 8.7 - 25 keV
Energy resolution	< 600 eV @ 8keV, < 900 eV @ 17 keV
Power consumption	< 1.2 W

ERMINE ASIC - The pixel



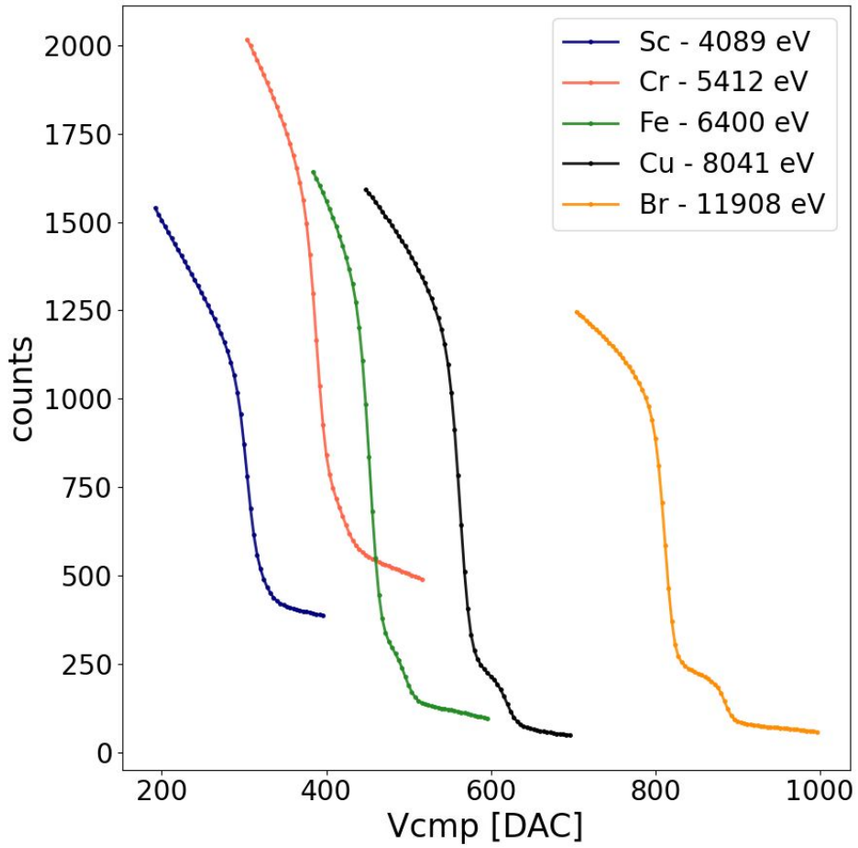
- Signal readout: typical design in terms of photon counting detectors
  - analog signal chain: preamplifier + shaper, comparators
  - digital: counters, windowing logic for simultaneous fluorescence and high energy background suppression
  - trimming block
- More than 50% area is dedicated to the analog part



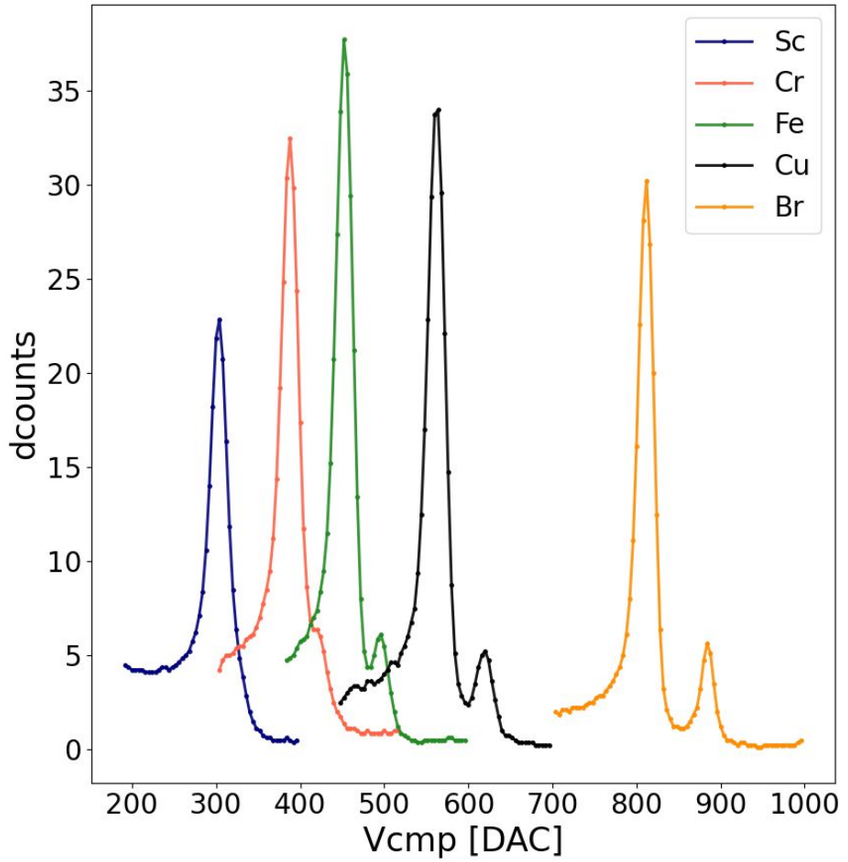
ERMINE ASIC - Energy calibration

Characterization with p-on-n silicon

- Threshold scans with fluorescence samples



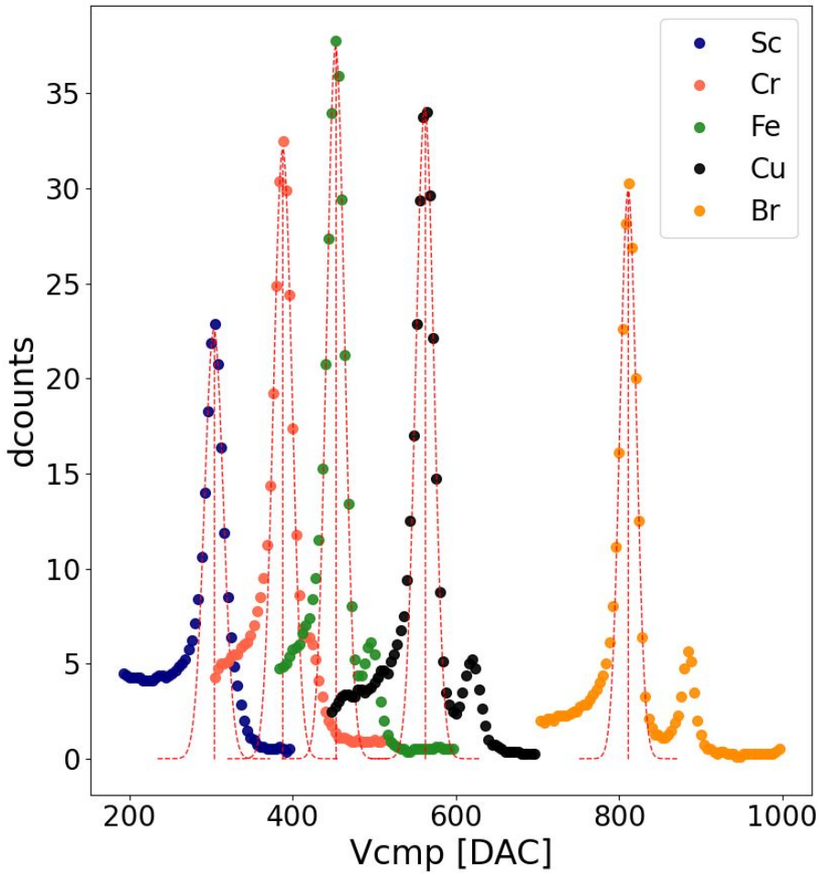
- Derivative spectra

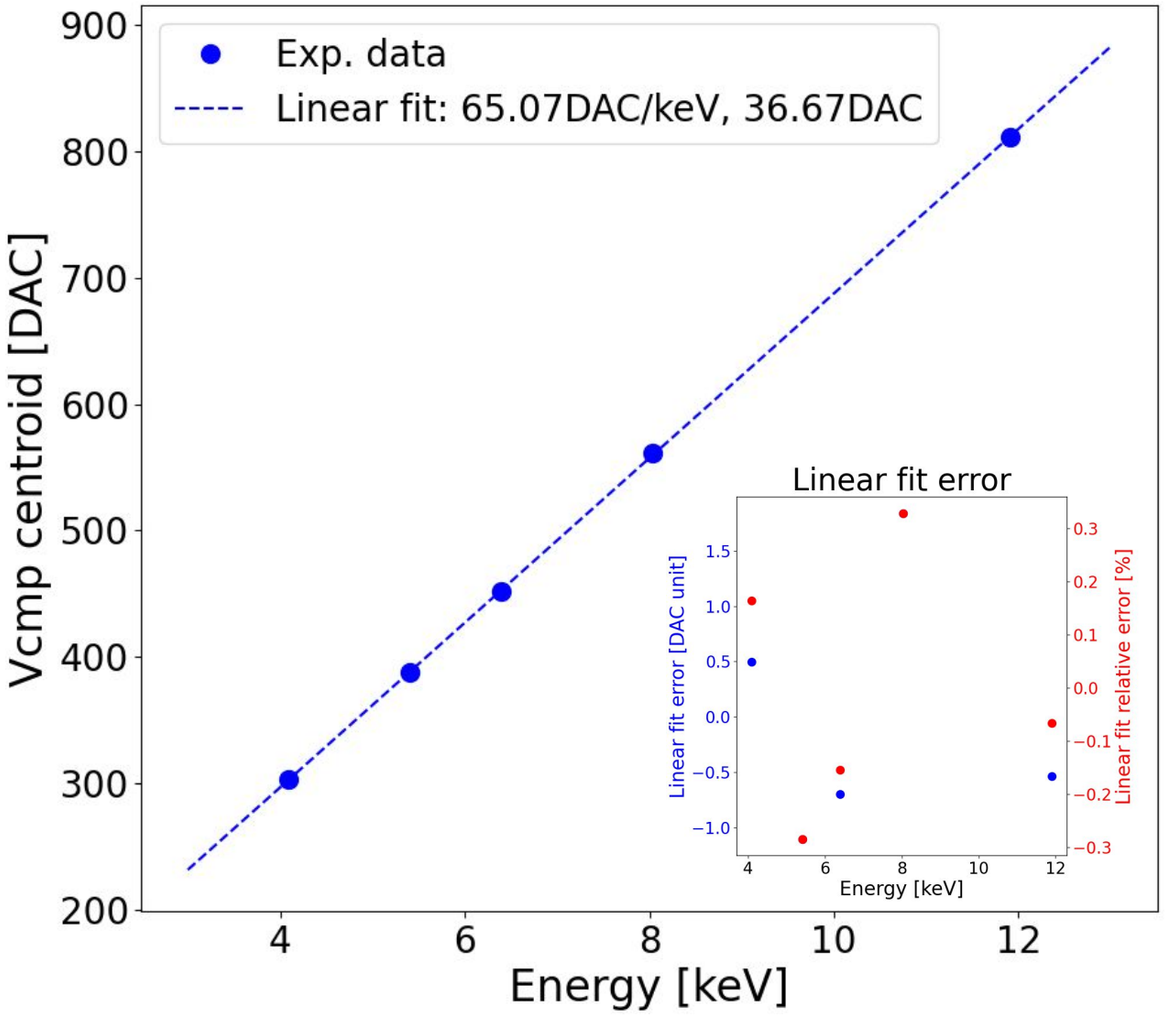


ERMINE ASIC - Linearity

Characterization with p-on-n silicon

- Gaussian fit of derivative spectra

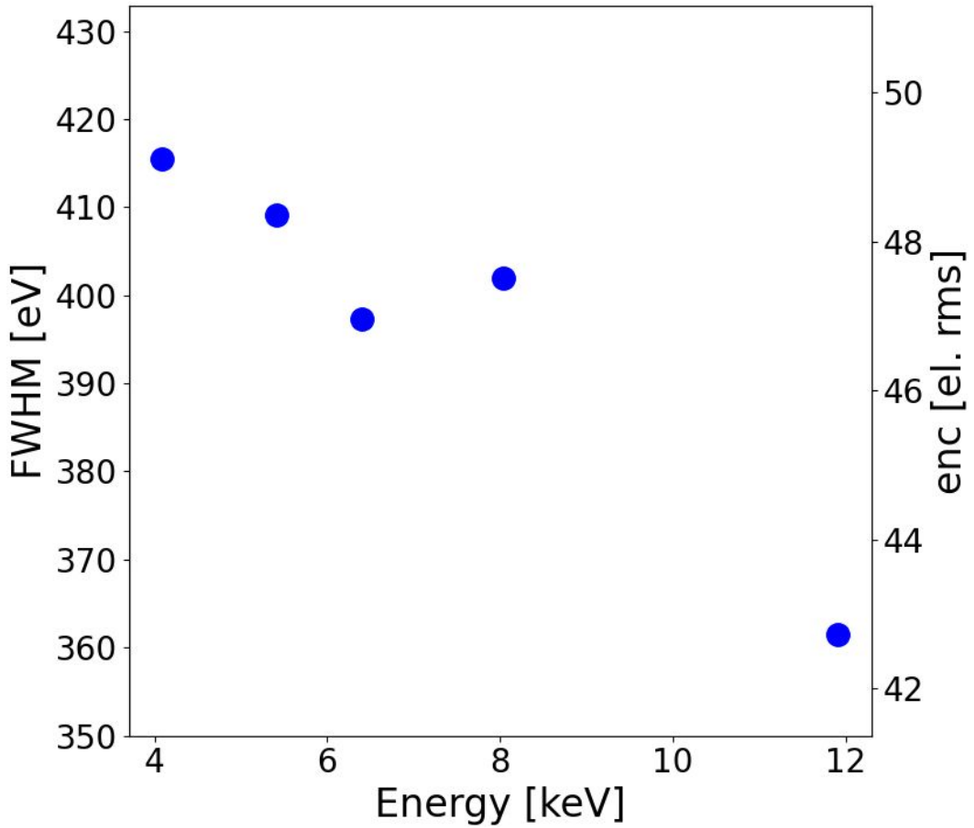




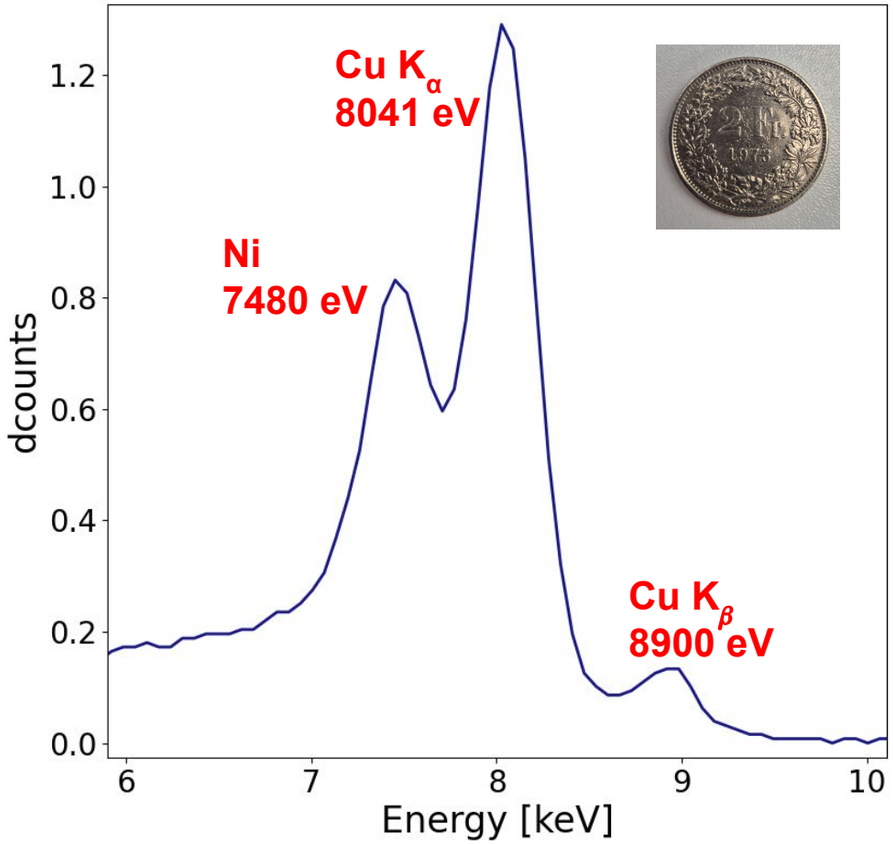
ERMINE ASIC - Energy resolution

Characterization with p-on-n silicon

- Energy resolution, FWHM from gaussian fit



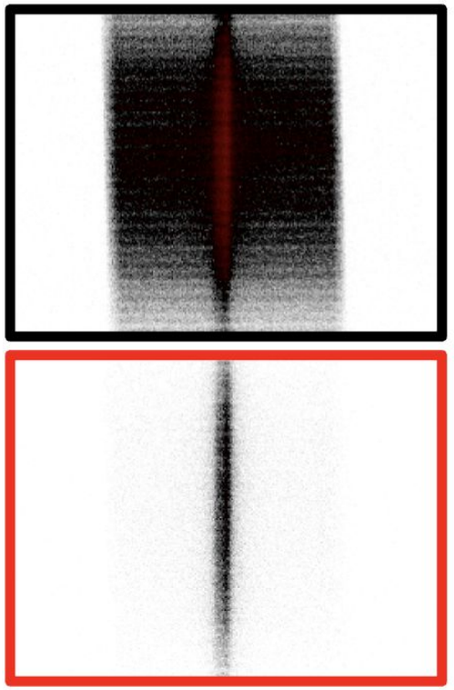
- Fluorescence spectrum of a Swiss coin

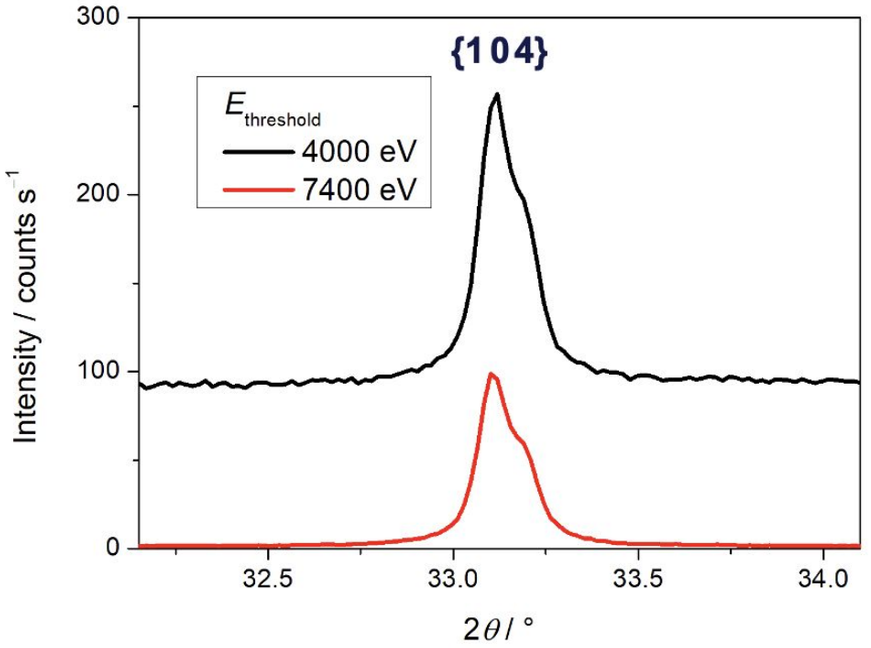


ERMINE ASIC - X-ray Fluorescence suppression

Results from a user test in a real application: Bragg-Brentano Powder diffraction of Hematite (Fe_2O_3) with Cu-K_α radiation (8041 eV)

- Threshold at 7.4 keV to suppress Fe fluorescence
  - 40x more peak to background
  - 4.7x more signal to noise ratio

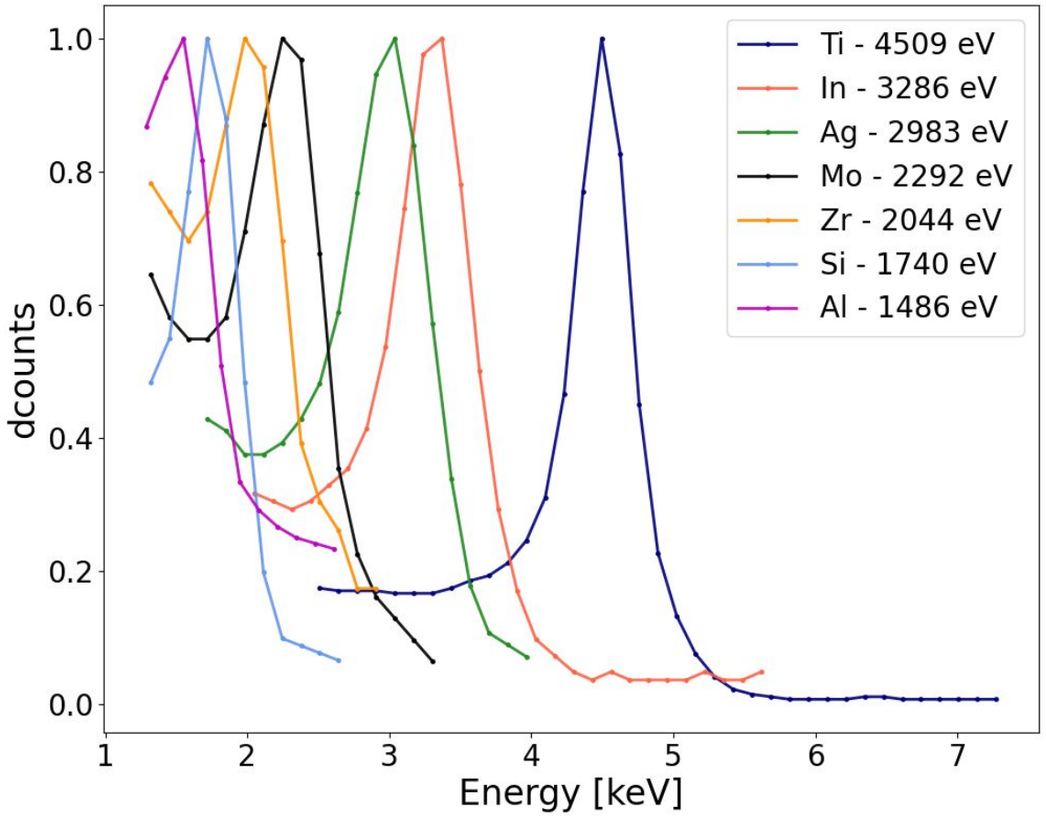




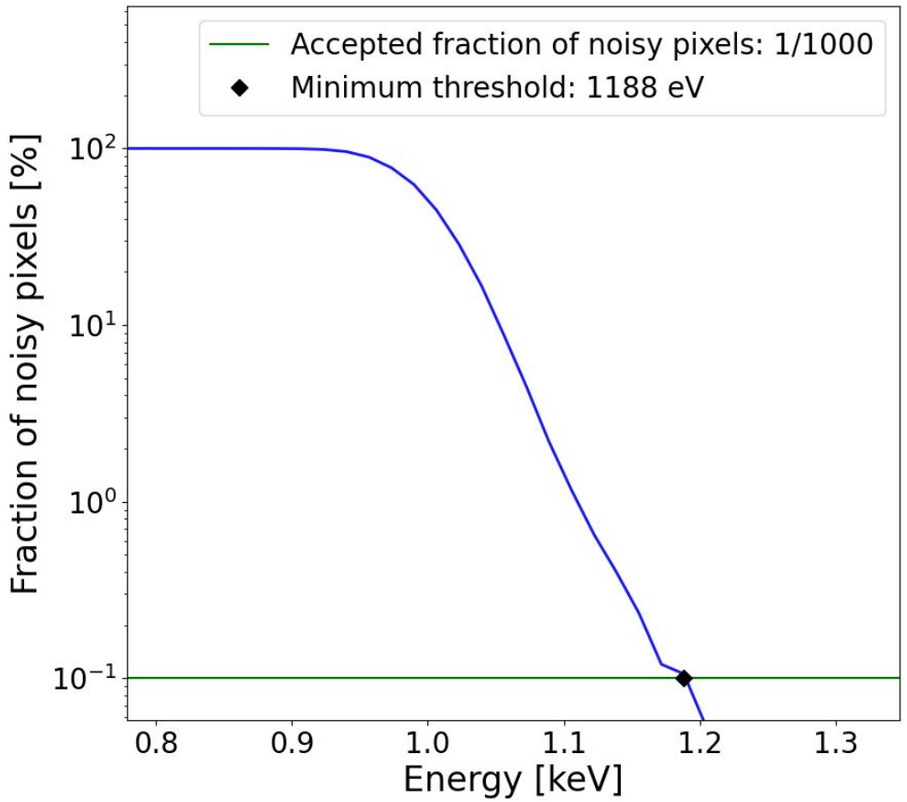
ERMINE ASIC - Toward soft x-rays

Characterization with p-on-n silicon

- In vacuum tests with liquid cooling
- Chiller temperature 23C, just to prevent overheating



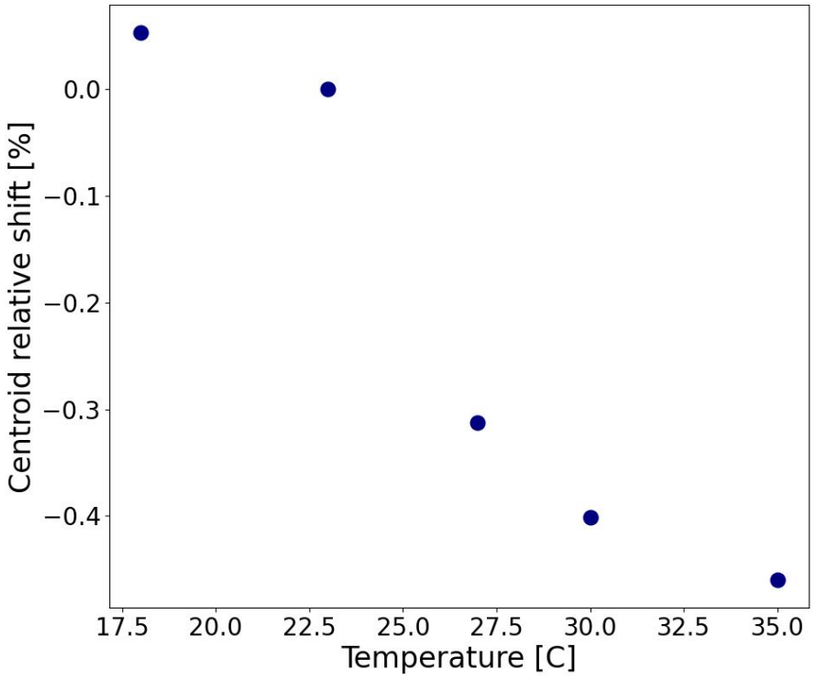
- Minimum threshold ~1.2keV

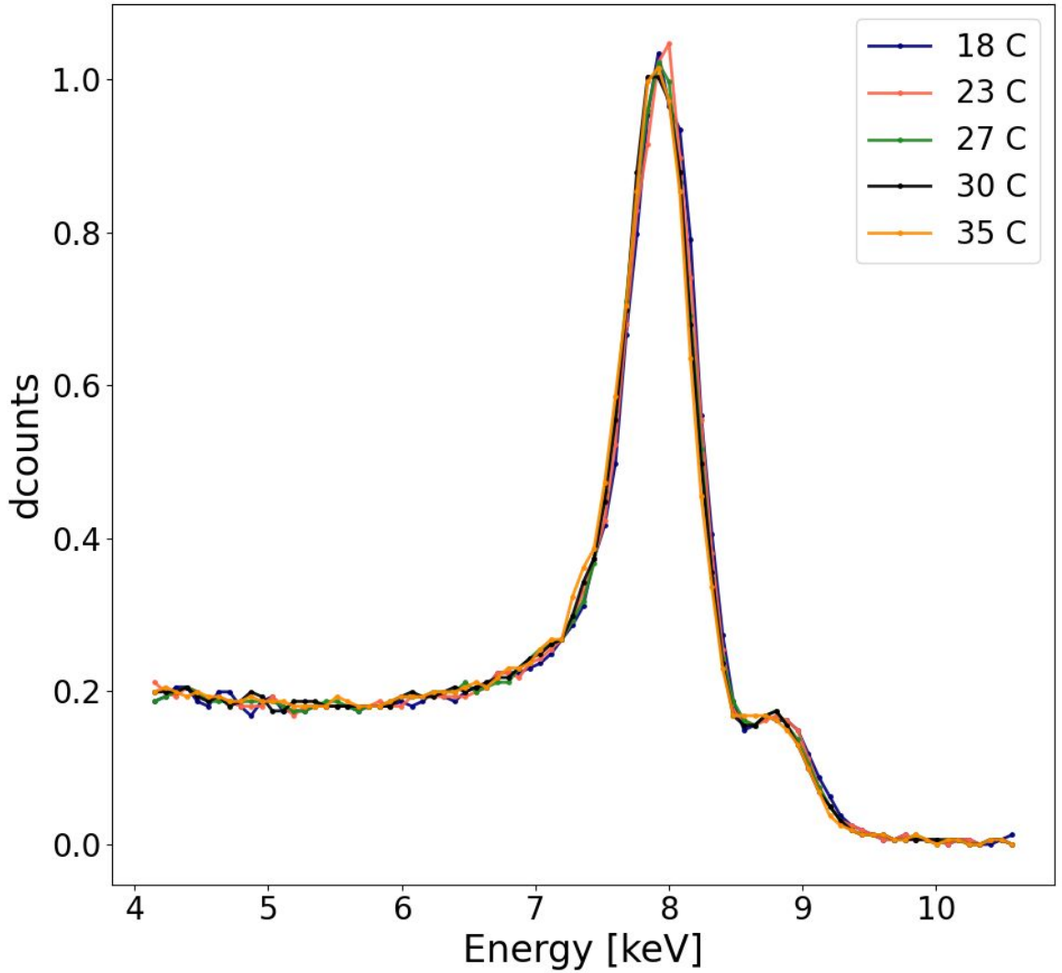


ERMINE ASIC - Temperature stability

Characterization with p-on-n silicon

- Temperature stability
  - setup liquid cooled, temperature range of 17C
  - calibrated at 23C
  - Peak position very stable, total variation is ~0.5%





Sensors development

- p-on-n silicon
  - different anode size -> effect on the readout
  - rectangular pixels -> enhanced spatial resolution
- GaAs -> higher quantum efficiency
  - sensor thickness
  - square and rectangular
- n-on-p silicon -> single polarity ASIC
  - square and rectangular pixels with re-routing
- part of this sensor development is done in collaboration with Hamamatsu

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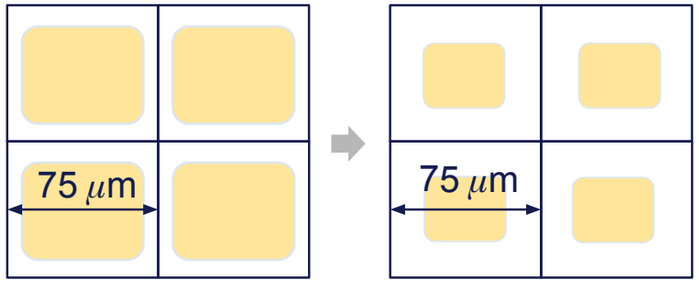
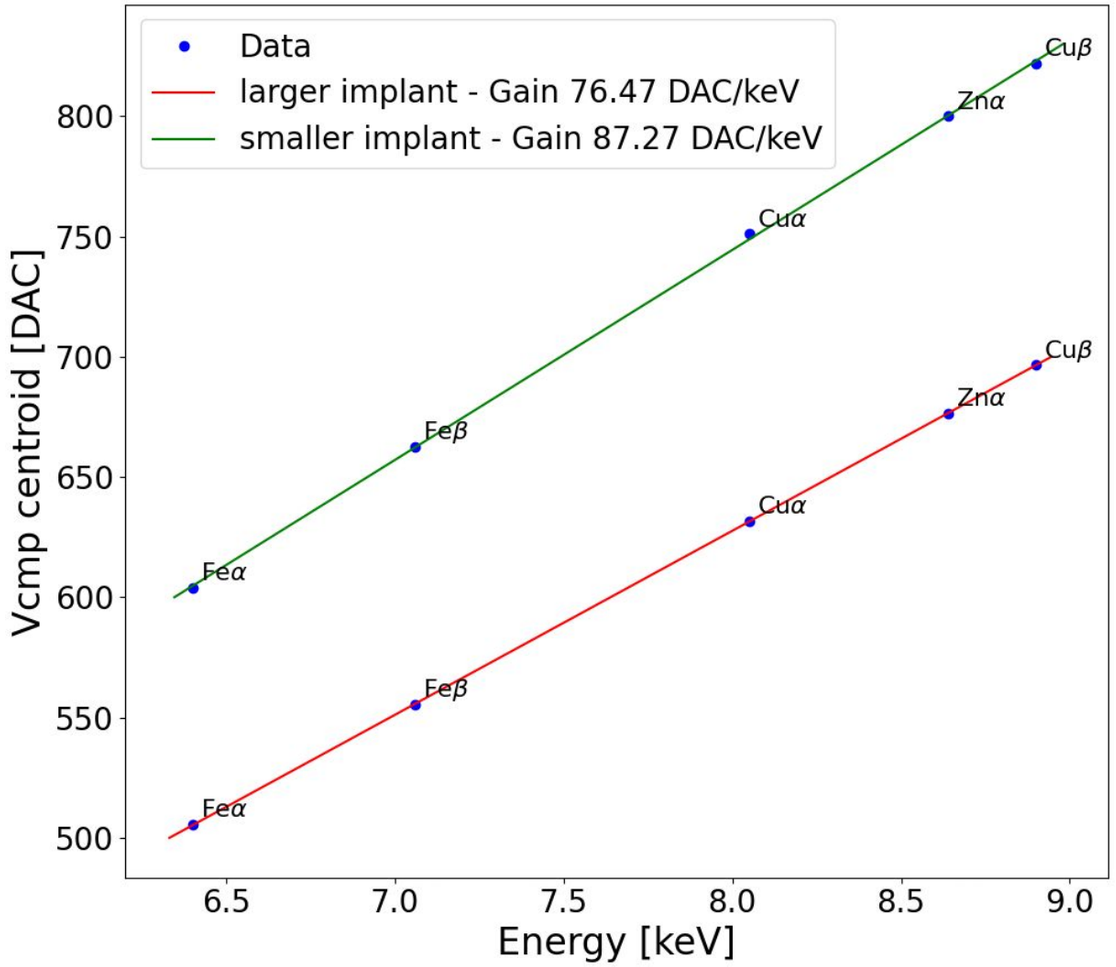
p-on-n - Anode implant size

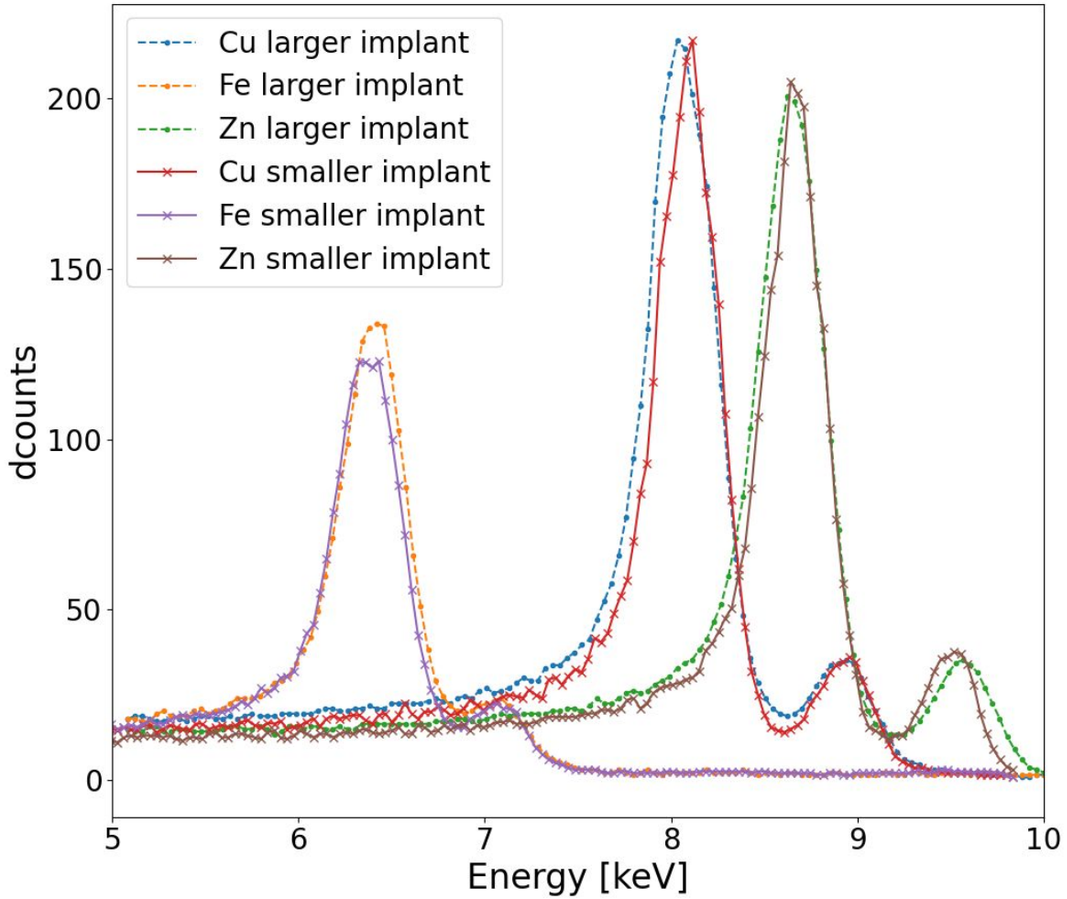
- Investigate the influence of the anode implant size on the readout
  - Gain is higher with the smaller implant

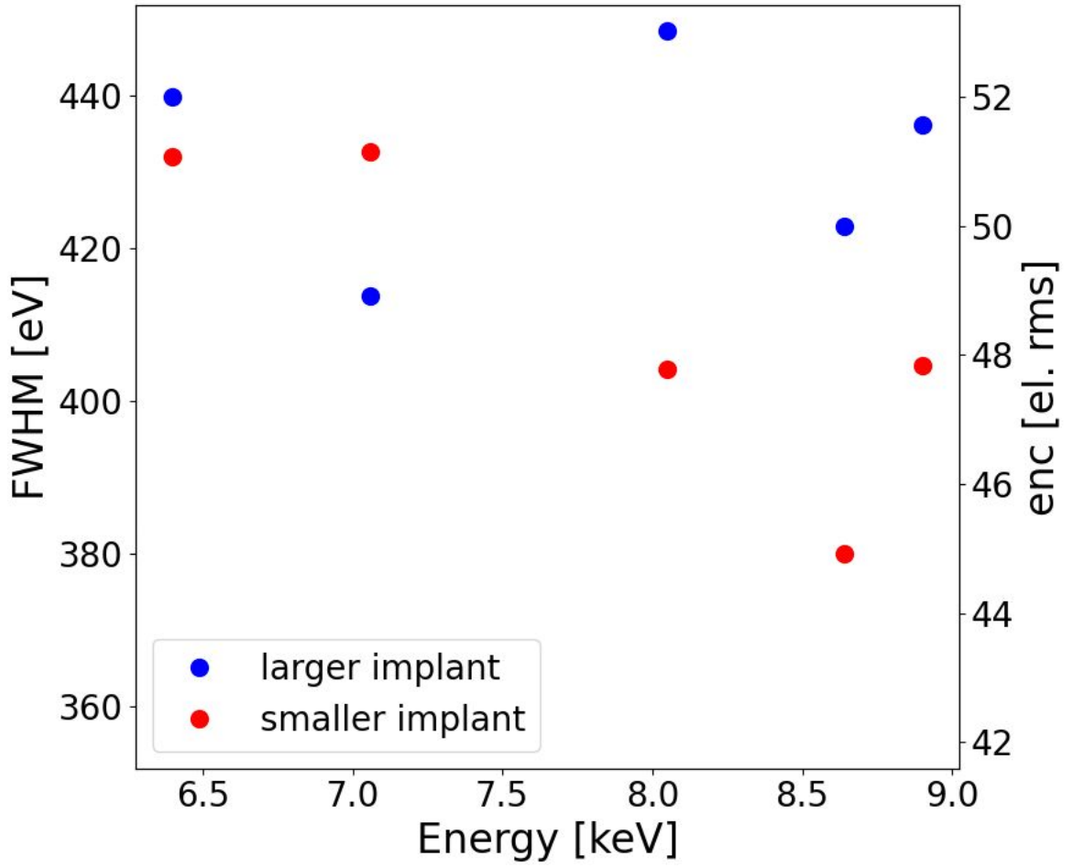




p-on-n - anode implant size

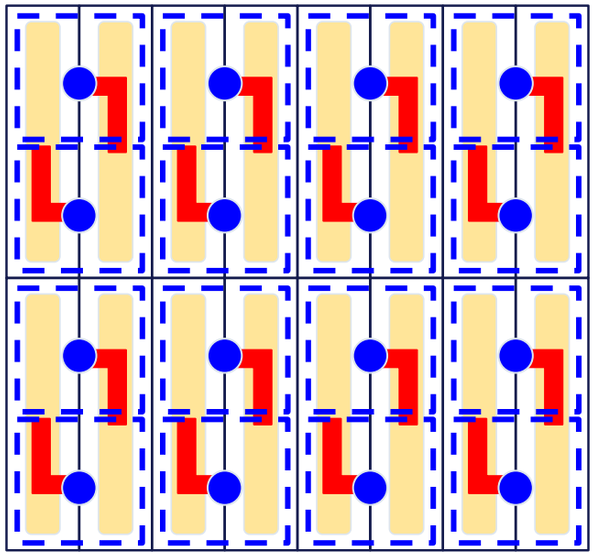
- Energy resolution improves

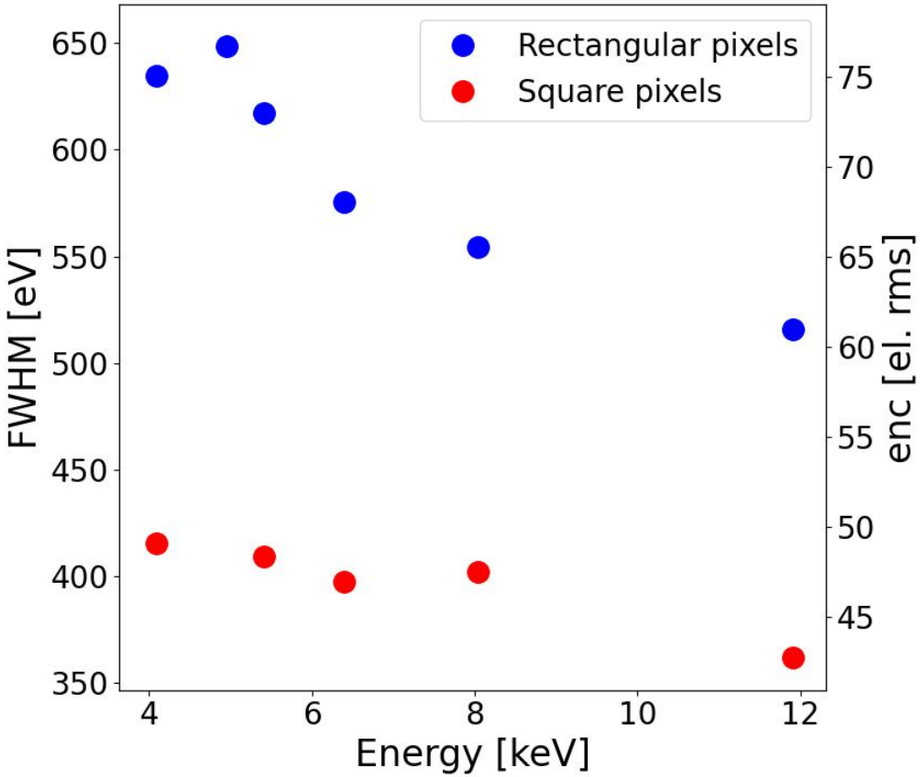




p-on-n - Rectangular pixels

- Improve the spatial resolution in one direction -> fine pitch like a microstrip detector but still with 2D information
- Pixel area is preserved, pitch is doubled in one direction and halved in the other
  75 μm x 75 μm -> 150 μm x 37.5 μm
- Rerouting layer for sensor - ASIC bump bonding

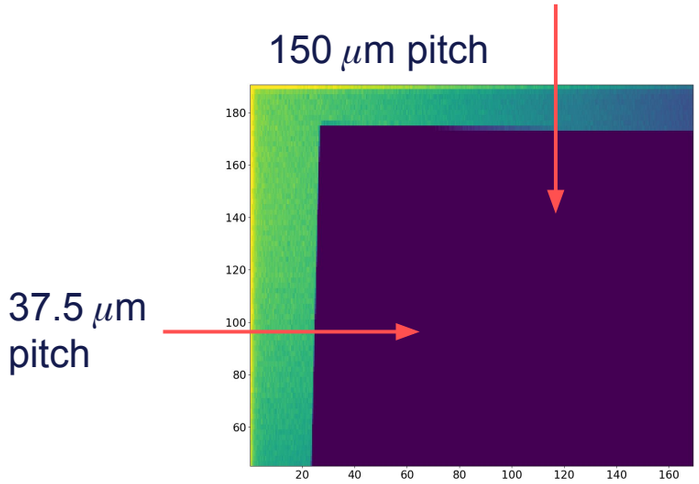


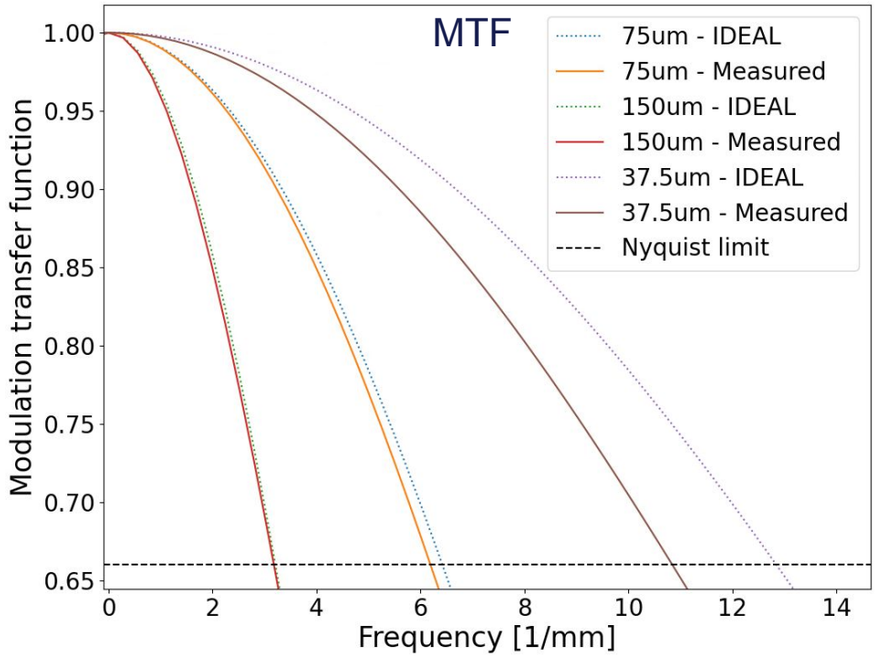


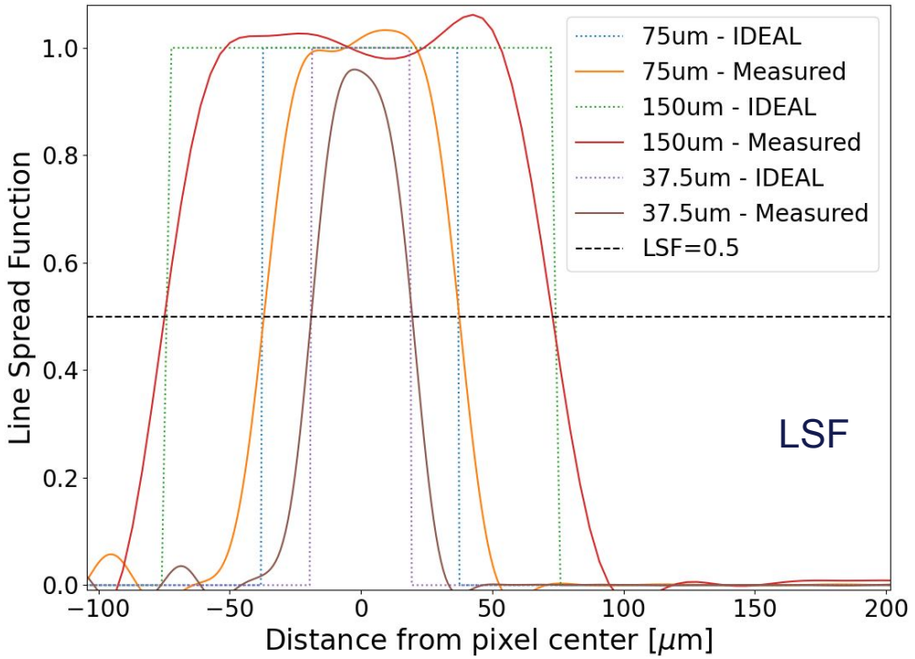
- Higher spatial resolution comes with a tradeoff in the energy resolution:
  - increased charge sharing
  - more stray capacitance in the pixel

p-on-n rectangular - Spatial resolution

- Slanted edge measurement
  - W edge 4 mm thick
  - Cu fluorescence, 50% threshold
  - Cu sample - W edge distance 85 cm
  - W edge very close to the sensor, <1mm
  - Grid to filter out photons coming from wide angles

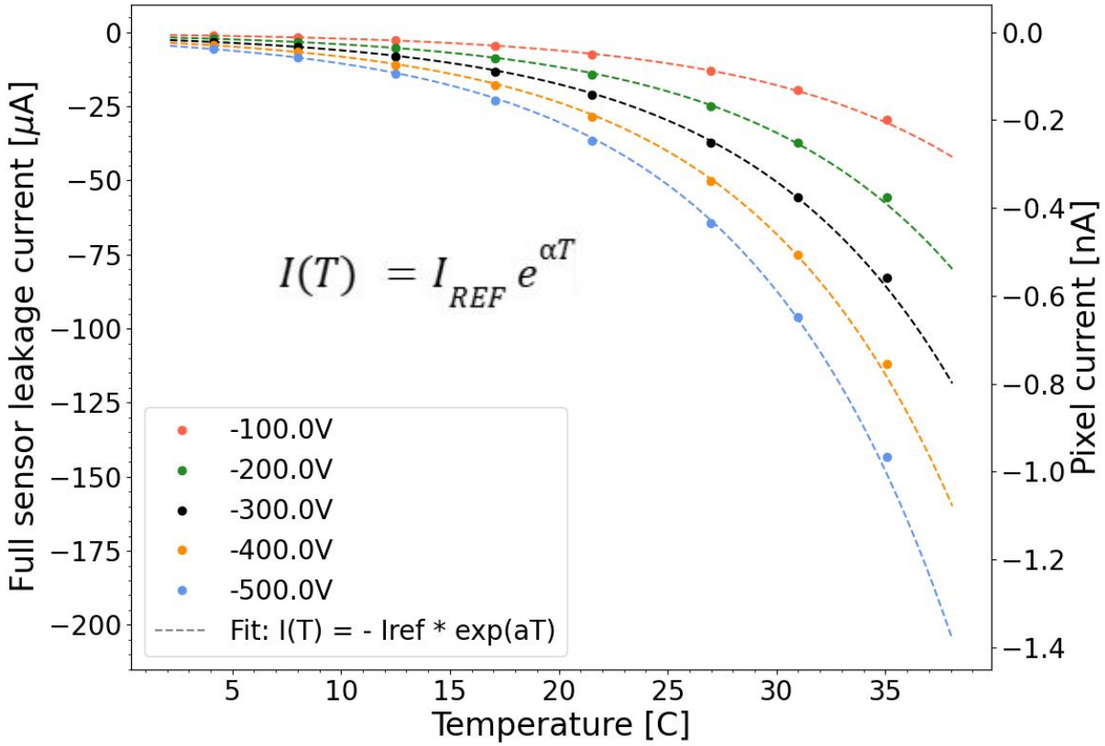




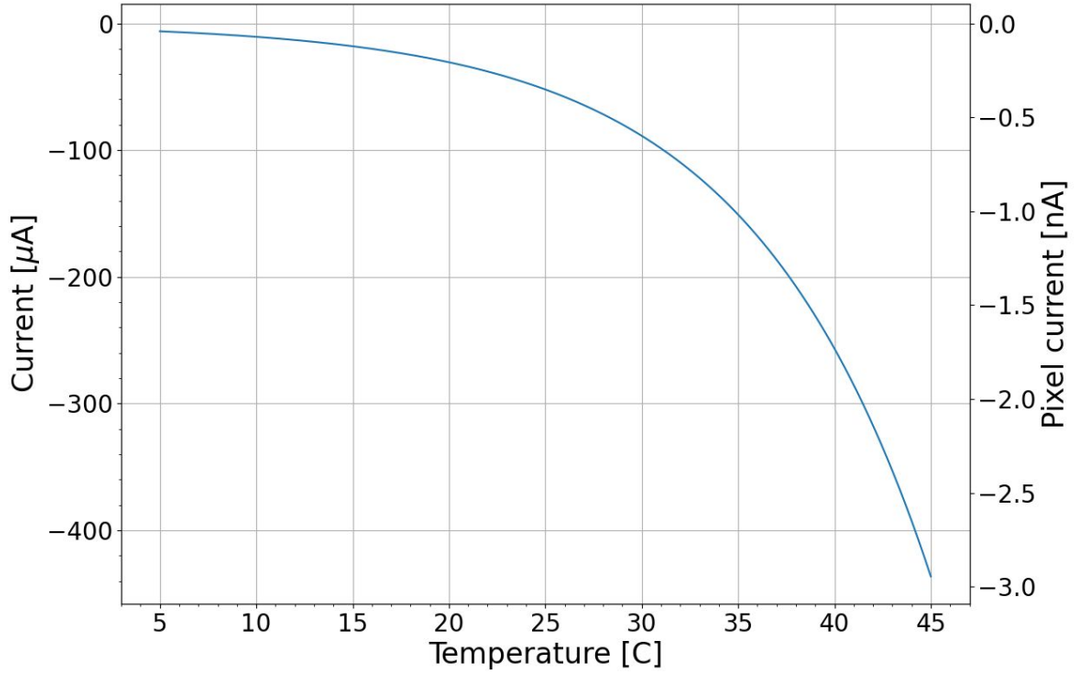


GaAs - Leakage current

- Sensor thickness 500 μm
- Setup liquid cooled to control the temperature



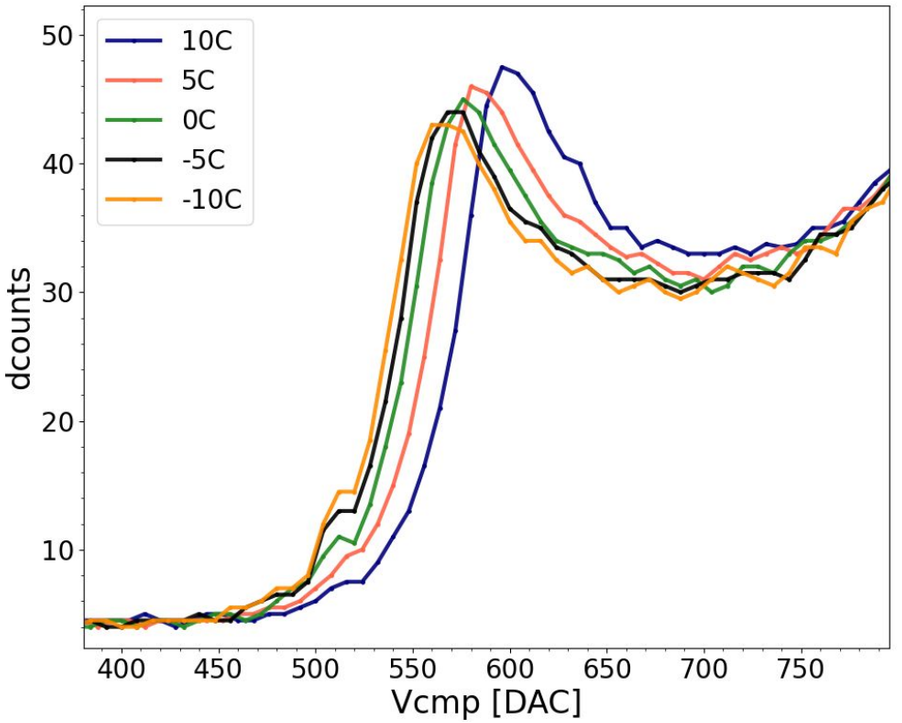
- Leakage current at -500V (fitting model)



- At the expected temperature of operation in the field the current per pixel is ~nA -> too high for the pixel readout electronics

GaAs - Readout behavior

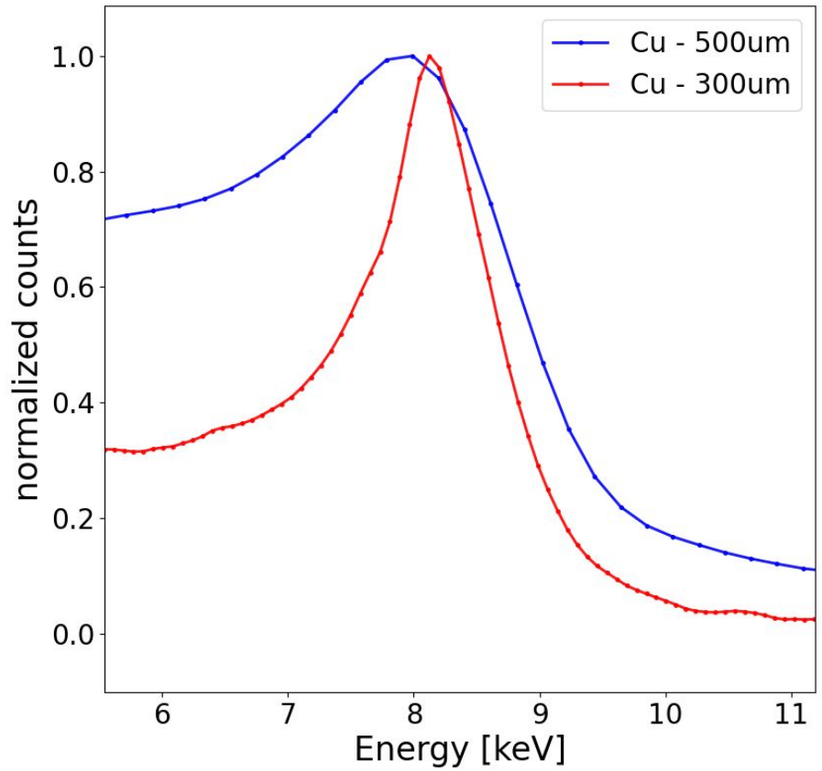
- The pixel readout electronics is affected by the leakage current -> strong temperature dependence

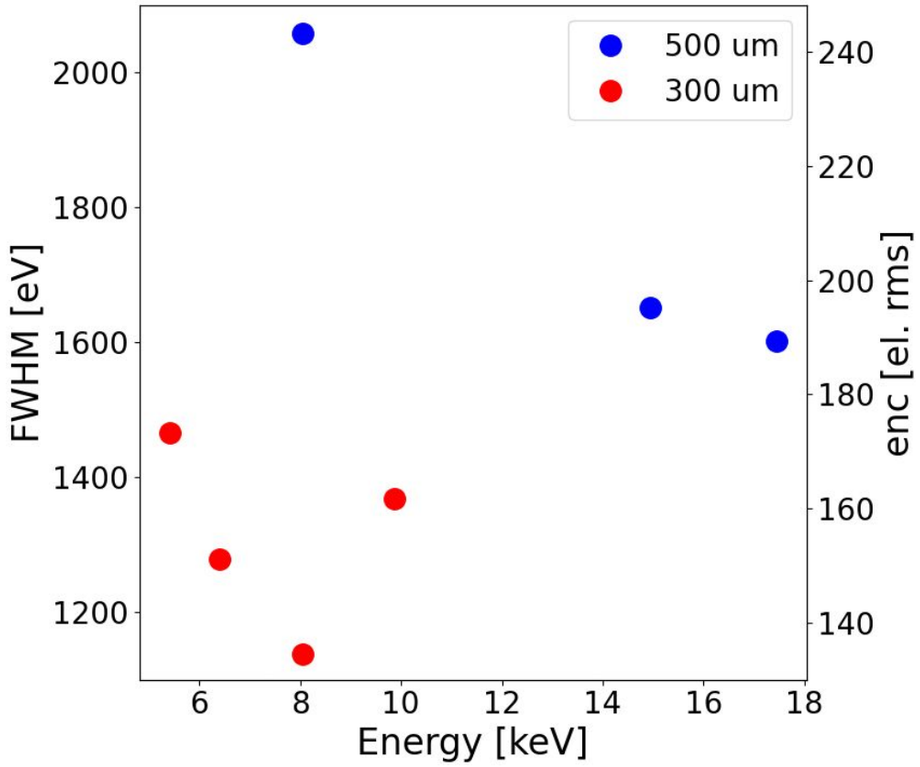


The design of a new chip revision to handle more leakage current is ongoing

GaAs - Sensor thickness

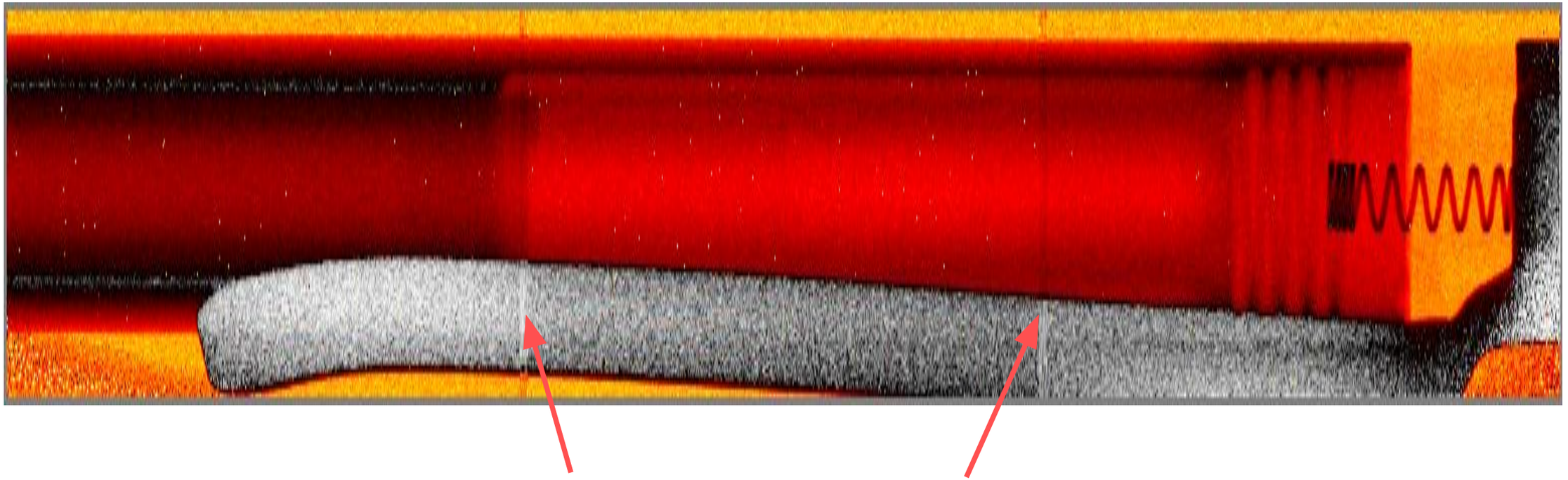
- Compared 500 μm with 300 μm thickness GaAs (same electric field)
- Less charge sharing with 300 μm and better energy resolution
- Still not as good as expected from the chip





GaAs - Rectangular pixels

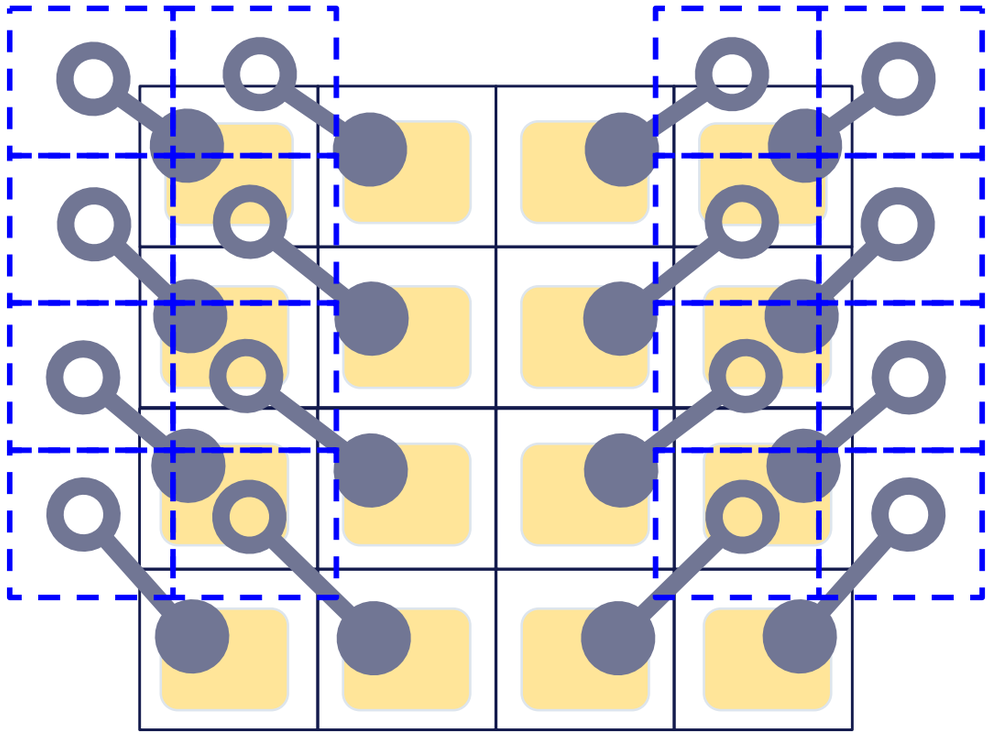
- GaAs development on going
- Also produced sensors with rectangular pixels: 150 μm x 37.5 μm
  - X-ray image of a pen with a module with 3 ASICs



Can we get rid of these gaps?

n-on-p rerouting - Concept

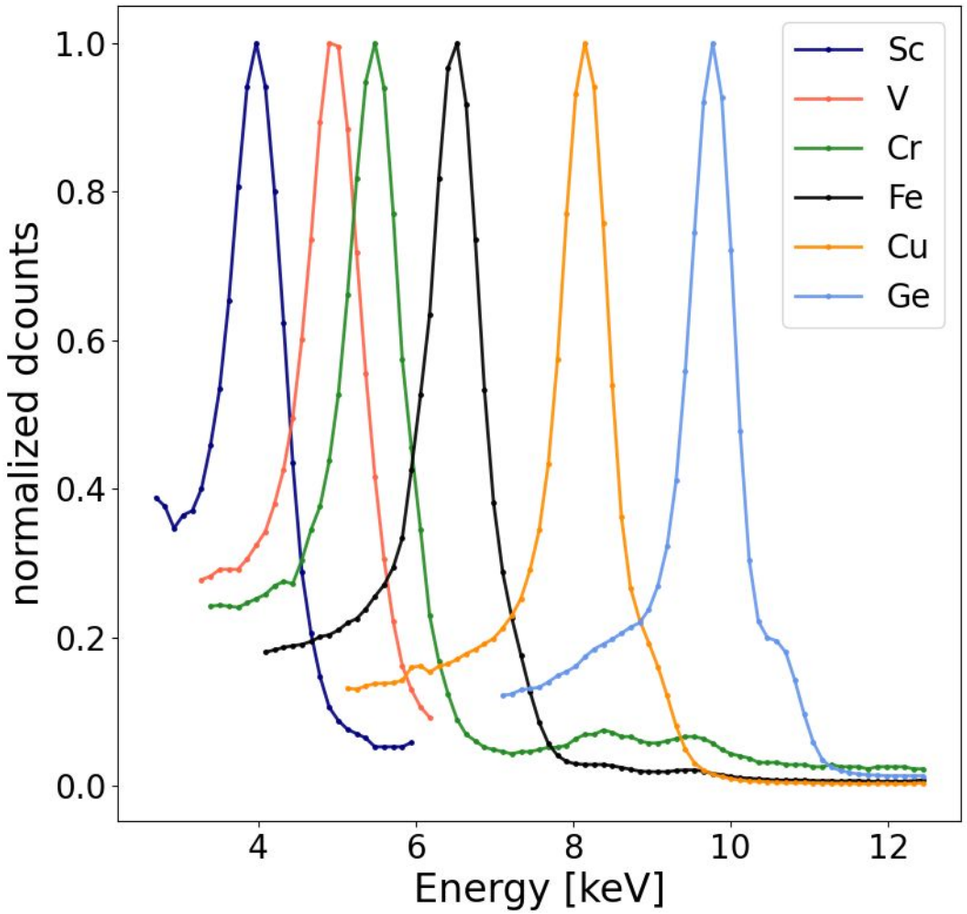
- Slightly increase the pixel pitch to fill the sensor with uniform pixel size, then reroute every pixel to the bump bonding pad using extra metal layers to match the ASIC pitch

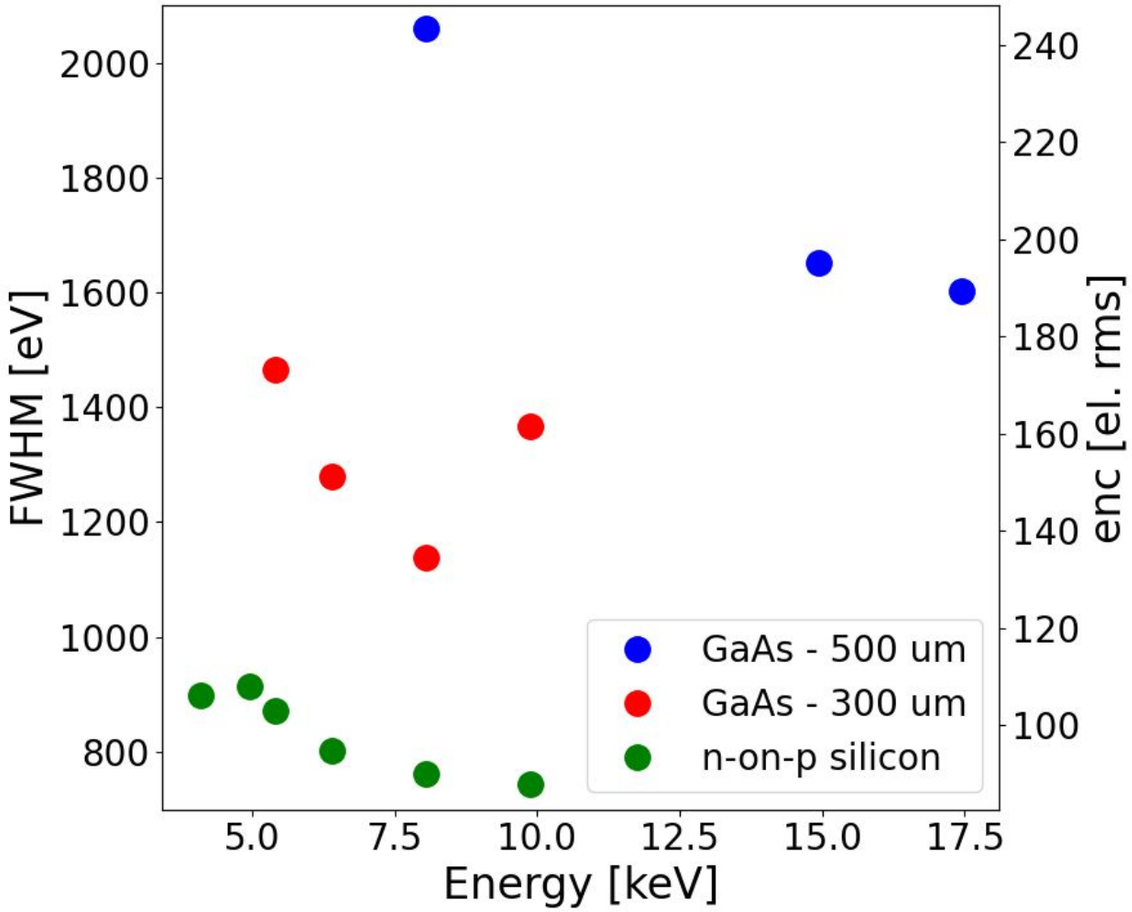


n-on-p rerouting - Concept

n-on-p rerouting - Square pixels

- Energy resolution better than GaAs, more aligned to the expectations from the chip

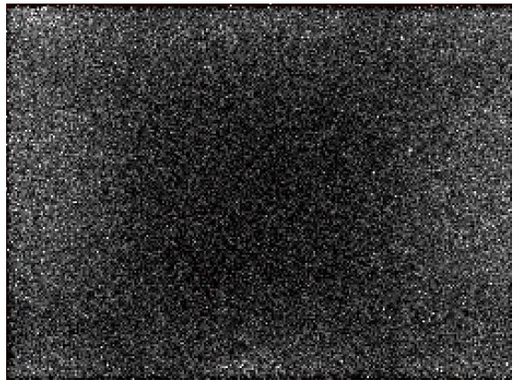




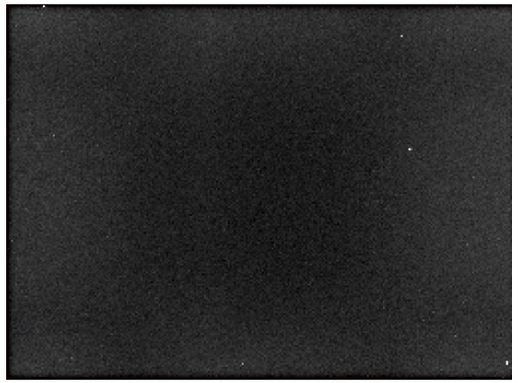
n-on-p rerouting - Gain variation

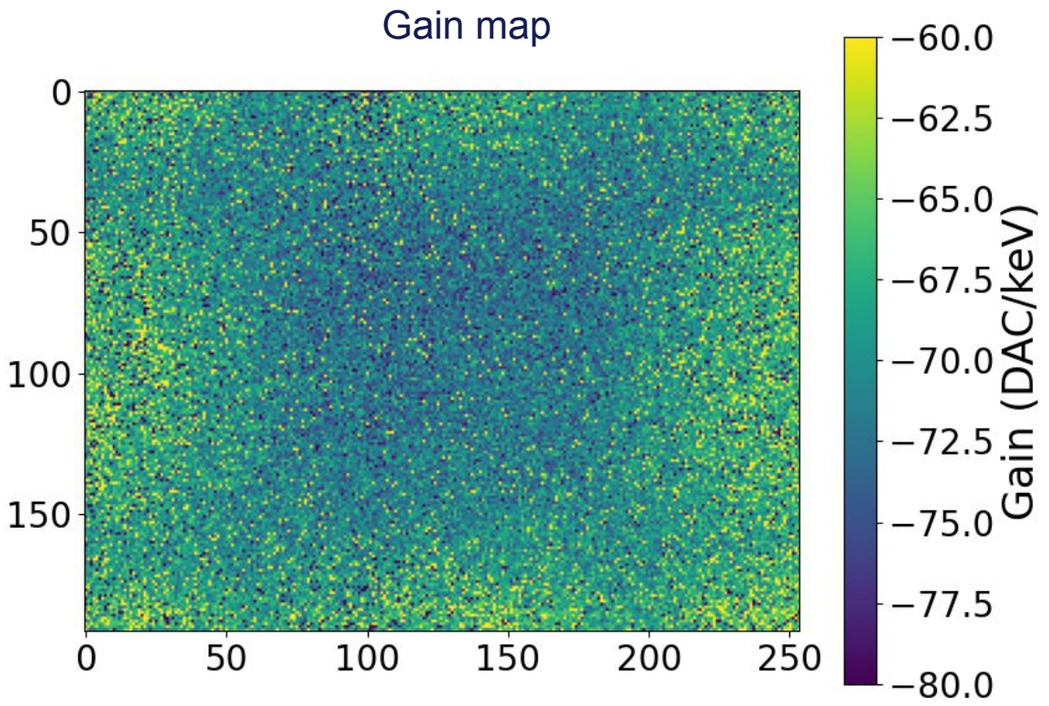
- Pattern related to rerouting
  - can be mitigated with trimming but not eliminated, it's a gain variation
  - rerouting can be smarter to avoid pixel-to-pixel variation

Not trimmed



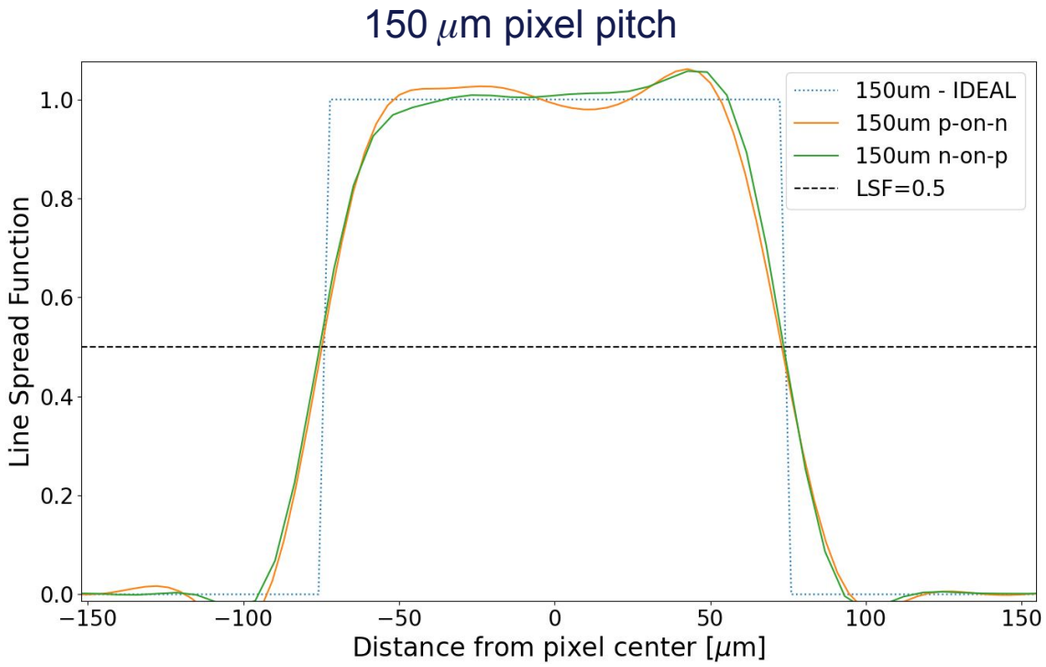
Trimmed

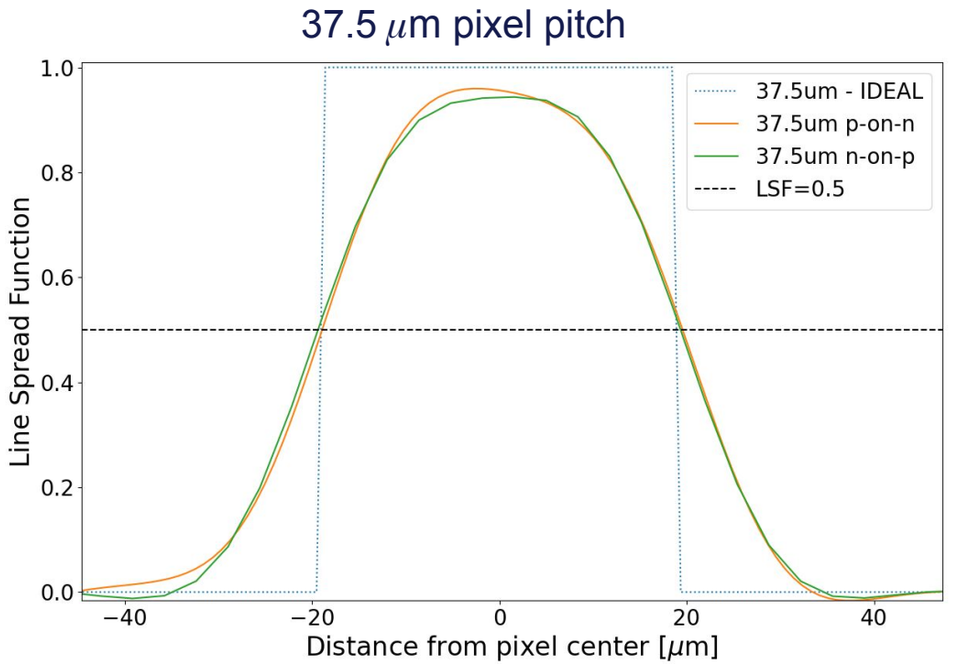




n-on-p rerouting - Rectangular pixels

- Comparison of spatial resolution of rerouted sensor with p-on-n silicon





Conclusion and next steps

- The ERMINE ASIC shows excellent performance with silicon sensor for the laboratory applications
- Ideal platform for testing many sensors, being low noise is sensible to sensor related effects
- GaAs
  - high leakage current -> design of new chip revision ongoing
  - energy resolution not aligned to expectations, likely because the material
- p-on-n silicon
  - rectangular pixels show excellent spatial resolution
  - engineering the anode size can help to optimize even more the energy resolution
- n-on-p silicon
  - designed square and rectangular pixel versions
  - useful to evaluate the energy resolution of the chip in negative polarity
  - rerouting can be optimized to improve the gain uniformity and chip trimming

Thank you for your attention