DynamiX

A prototype high-framerate, high-dynamic-range hard X-ray detector for 4th generation synchrotrons

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On behalf of the XIDyn Collaboration

iWoRiD 2025

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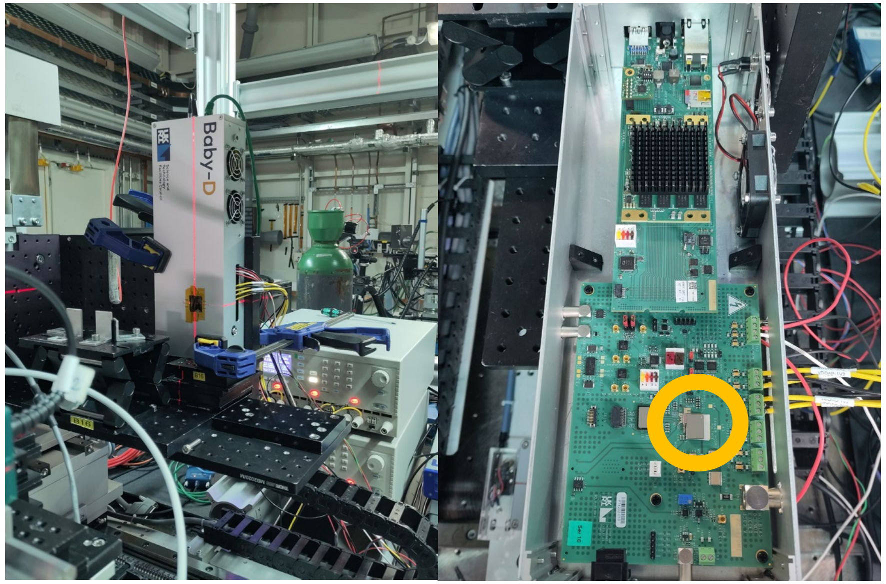
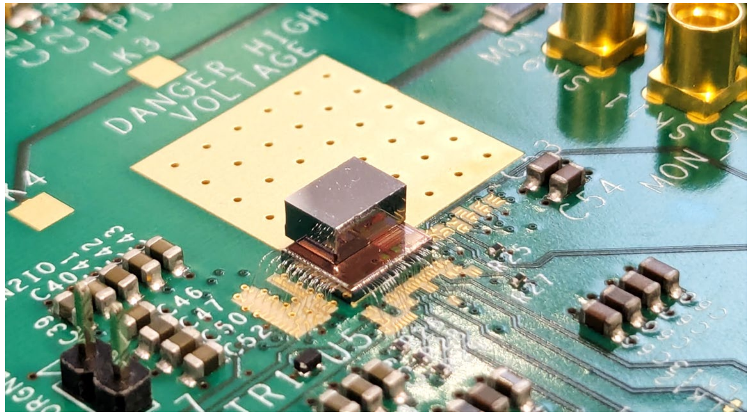
DynamiX Overview

- Charge-integrating hybrid pixellated detector system prototype
- Aims to meet challenges of synchrotron upgrades
  - Higher fluxes → new ASIC architecture
  - Higher energies → CZT sensor material
- 16 x 16 pixels on 110µm pitch
- 534kHz (adjustable) framerate to match Diamond orbit
- Readout at 14Gbps



Aligning DynamiX at Diamond Light Source (DLS)

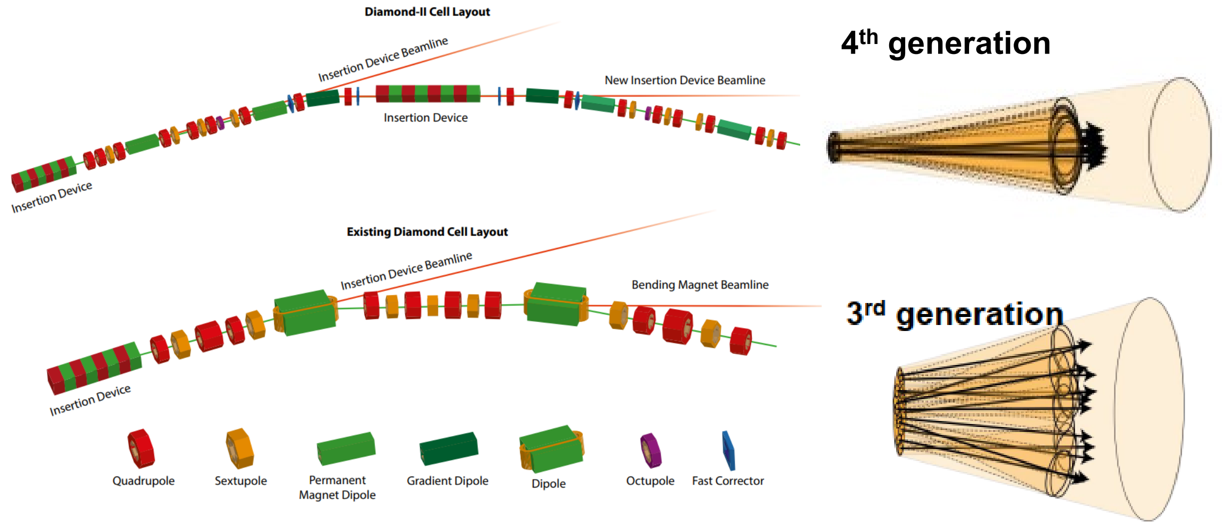


DynamiX bonded to 2mm Redlen HF-CdZnTe

Content

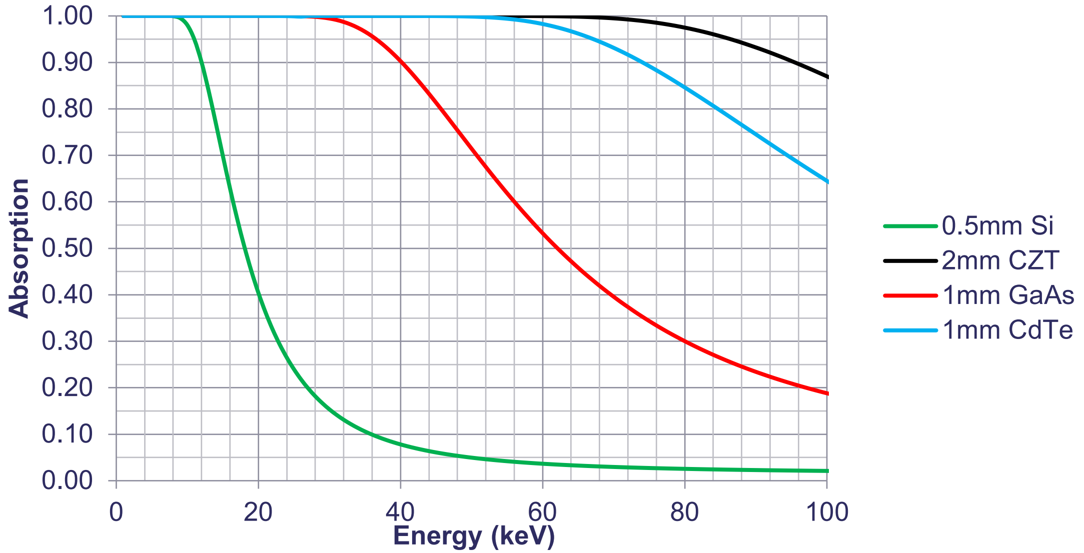
- Motivations
- Chip architecture
- Results from testing at DLS B16
- Summary

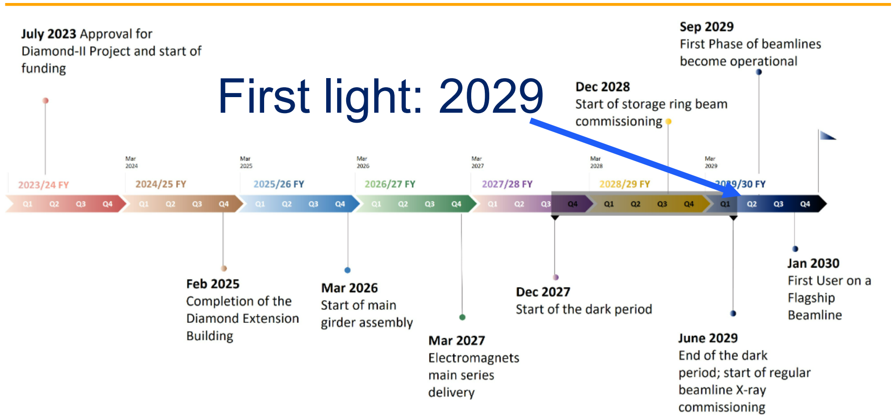
Credit: https://www.diamond.ac.uk/Diamond-II.html



Motivation

- Diamond II upgrade
- Up to $10^{11\text{-}12}$ ph/mm^2/s
- Many beamlines >20keV
- Mpixels for 2029

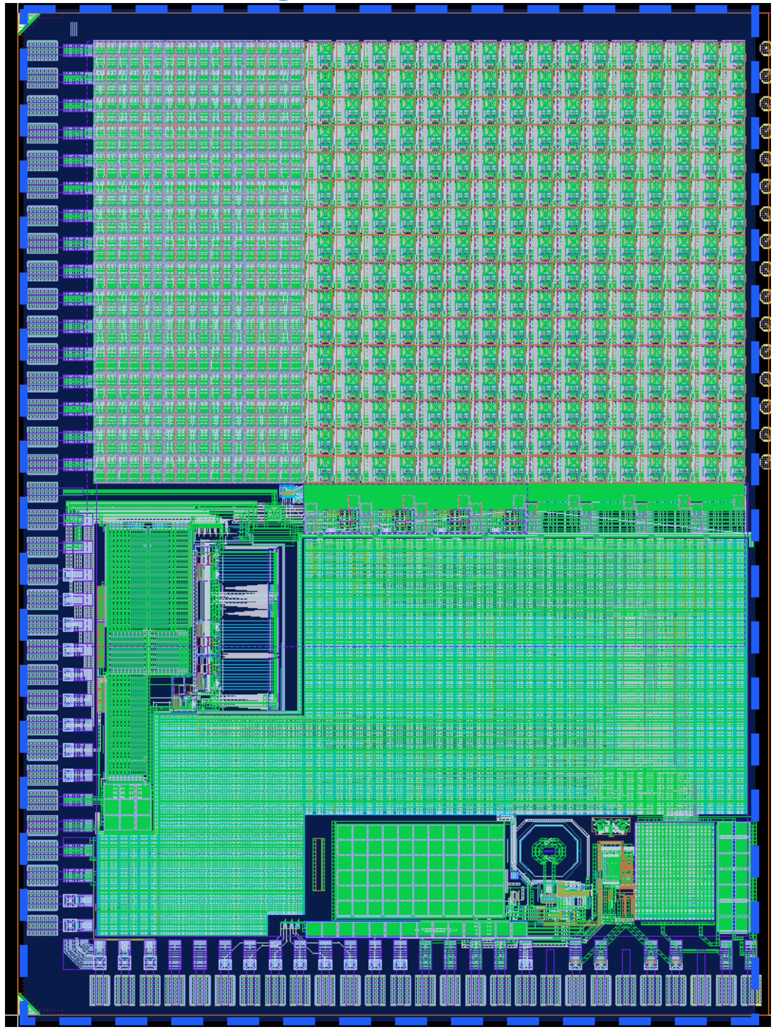




DynamiX Spec

Parameter	DynamiX
Flux	>10^9 ph/s/pixel
Pixel Size	110 µm
Frame Rate	534 kHz (Synchrotron determined)
Dynamic Range	>10^{11} ph/mm^2/s
Energy	25keV typical
Noise Level	<single photon

The DynamiX Chip



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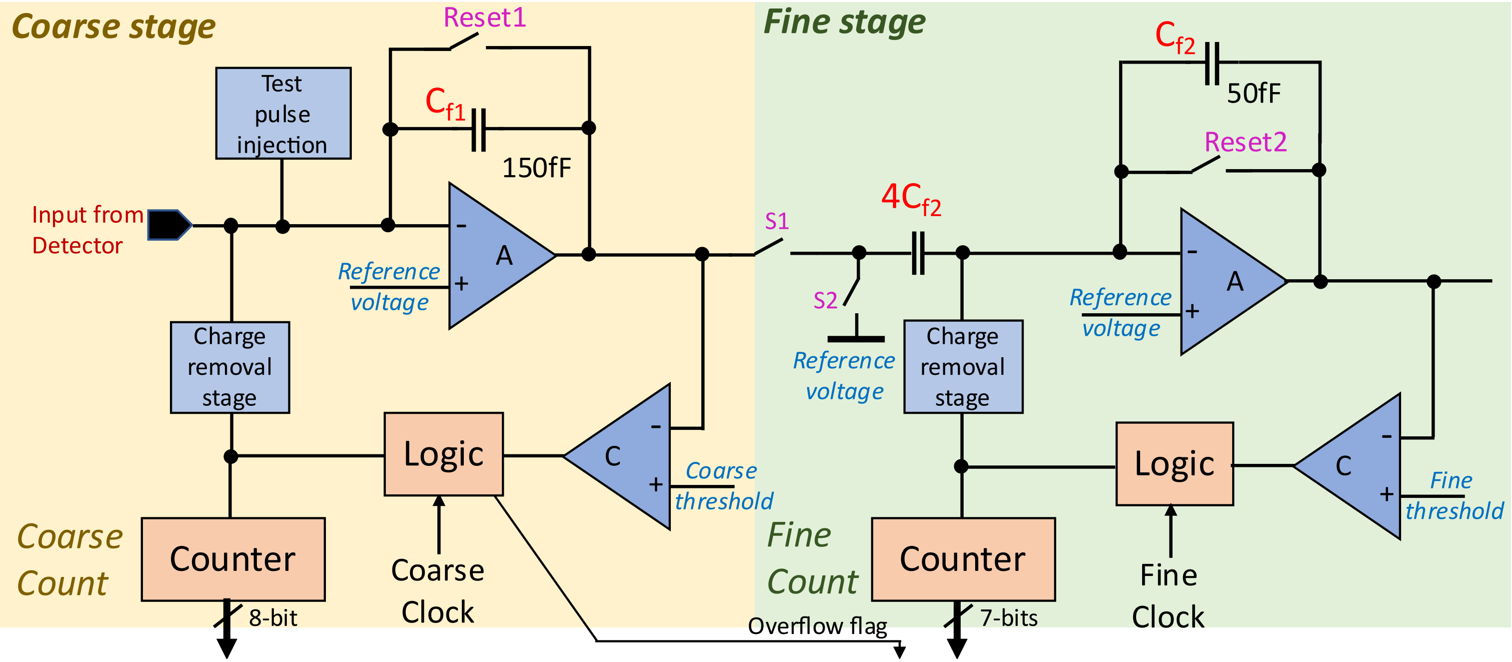
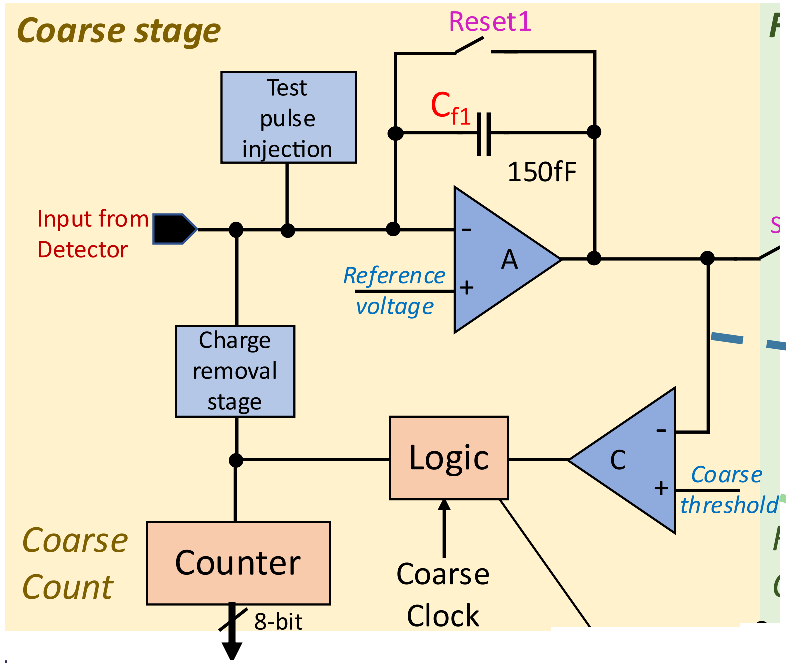
Chip Architecture

Incremental digital integration (per pixel):

- 2 stage charge cancellation circuit
- Signal integrated in coarse stage cancelled and remainder passed to fine stage
- Coarse and Fine counters output



Coarse Stage (<6400 ph/pix/frame @ 30keV)



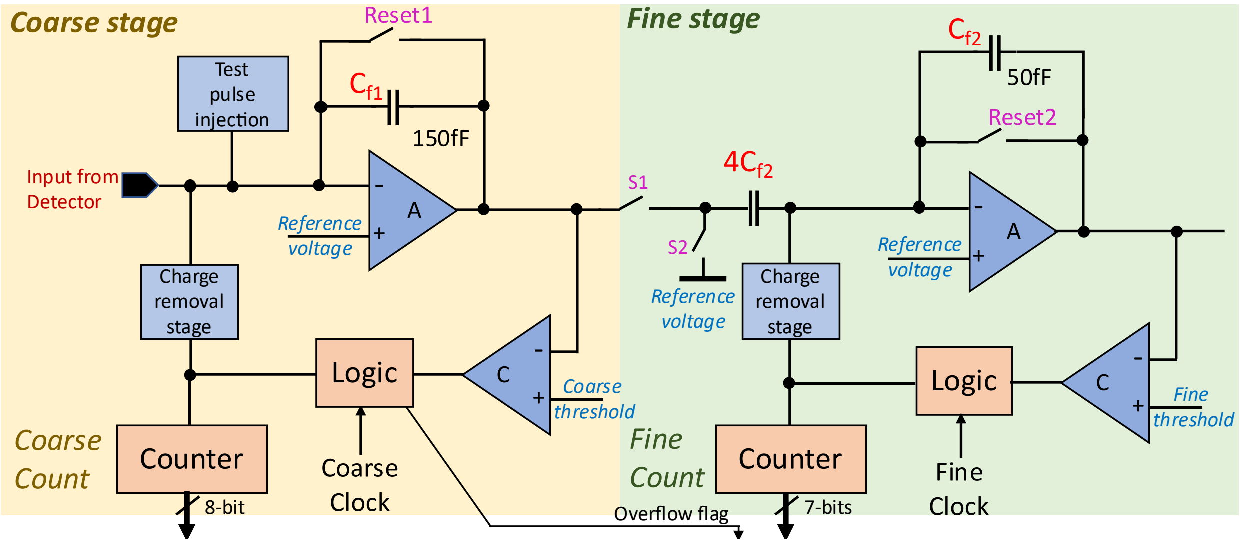
Signal

Coarse threshold

Coarse counts

Transfer and Fine Stage (<25 ph/pix/frame @ 30keV)

NEW NEW



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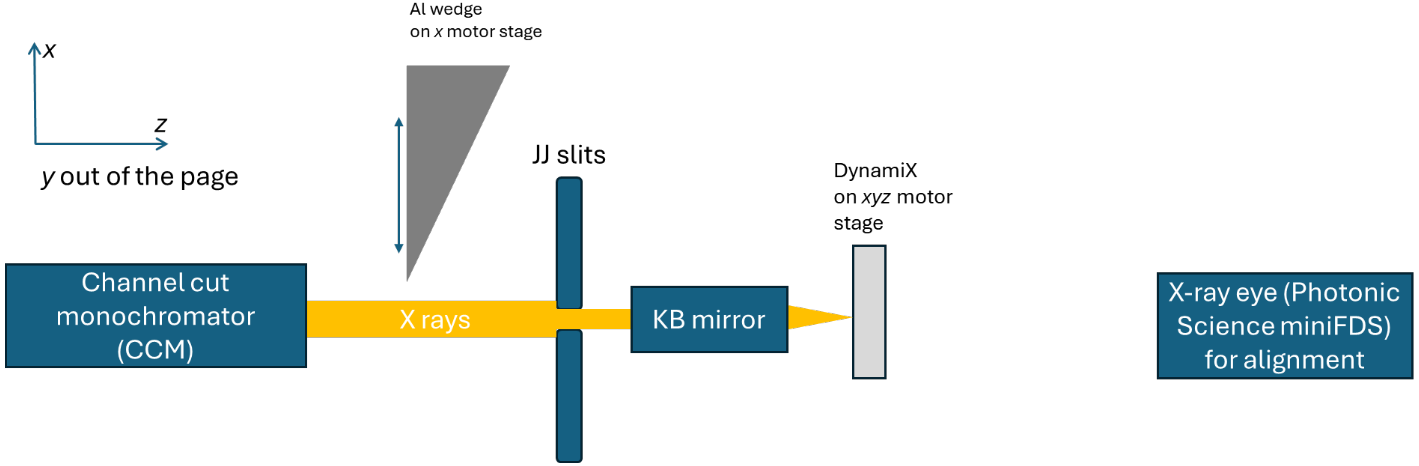
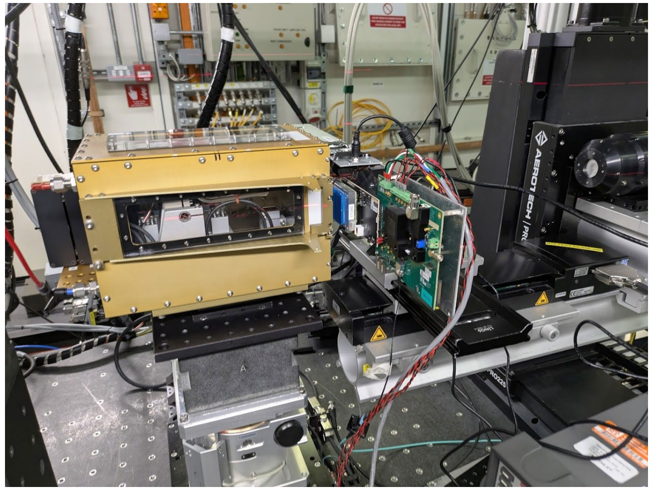
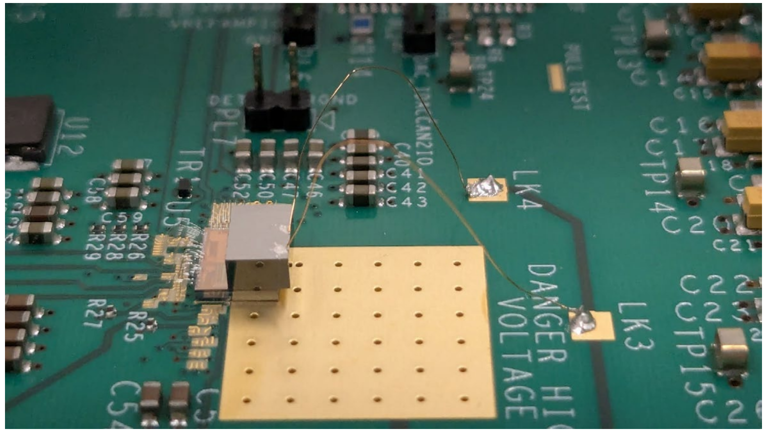
Results from beam tests at DLS B16

Setup at DLS B16 Test Beamline

- Focusing used to access sub-pixel-sized beam
- Beam energies of 20,30,40 and 50keV
- Sensor biased to -1000V
- Later switched to DCM to access higher fluxes at 20keV







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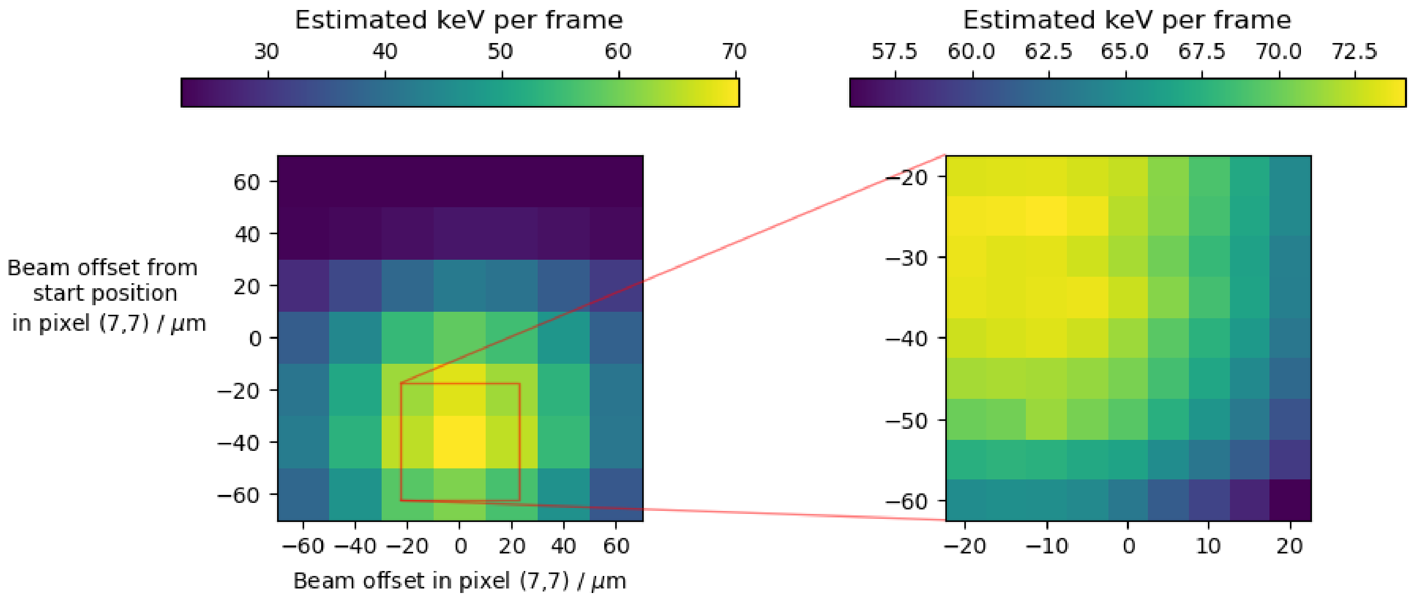
Charge sharing – raster scanning beam within pixel (20keV, ~20µm beam)

- Measured signal in pixel strongly depends on beam alignment to centre of pixel
- Evidence of charge sharing to neighbouring pixels in CZT
- Destroys ability to resolve single photon peaks → challenging to calibrate without pencil beam centred in-pixel



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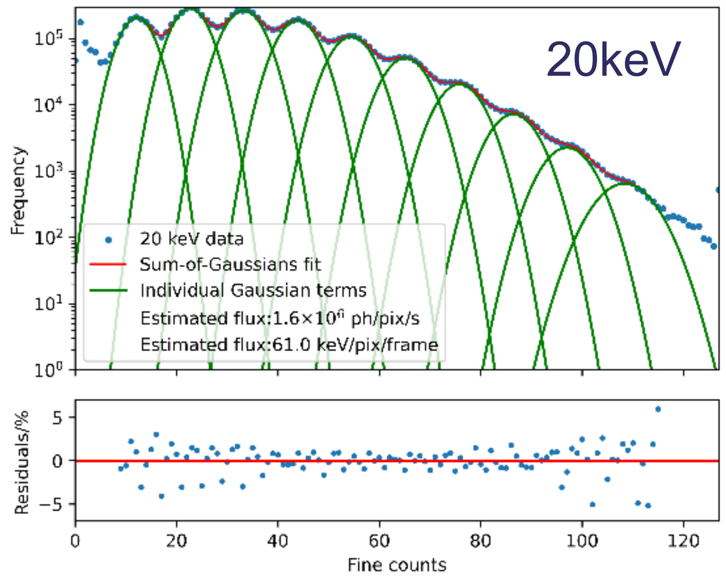
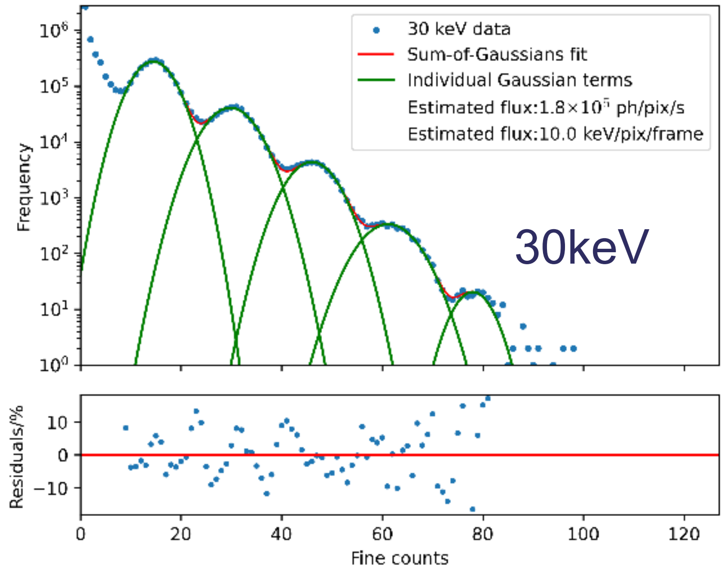
Single photon peaks

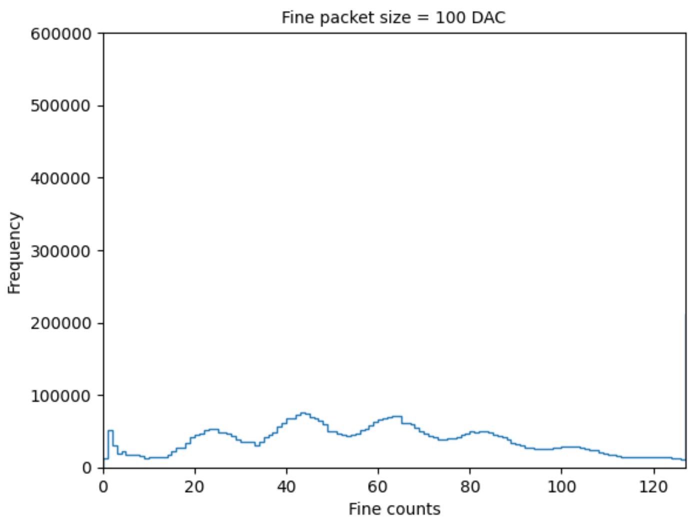
- Able to resolve single-photon peaks (up to 10 single-photon peaks for 20keV beam)
- Width σ ≈ 5.7keV (≈1200 e^- RMS)
- Photodiode-measured fluxes:
  - 20keV: 1.58 x10^6 ph/pix/s
  - 30keV: 2.80 x10^5 ph/pix/s

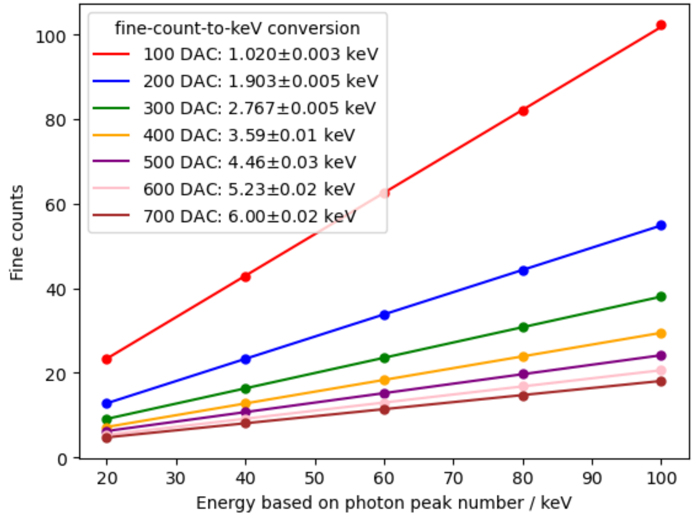




Single photon peaks – changing fine packet size

- Measurements taken at 20keV, flux ≈$1.6x10^6$ ph/s/pix
- Can change digitisation resolution at expense of dynamic range
- Smaller packets → more packets to remove same charge
- Better quality fit with smaller packets → easier to estimate noise
- Settled on packet size 100 DAC as this looks like 1 fine count ≈ 1 keV





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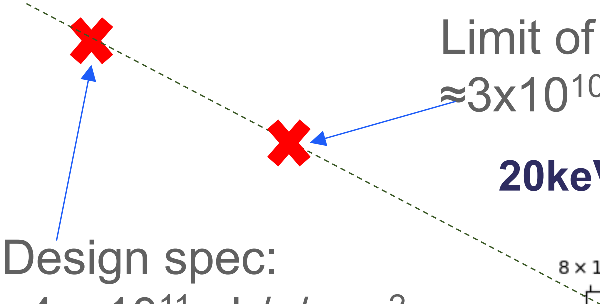
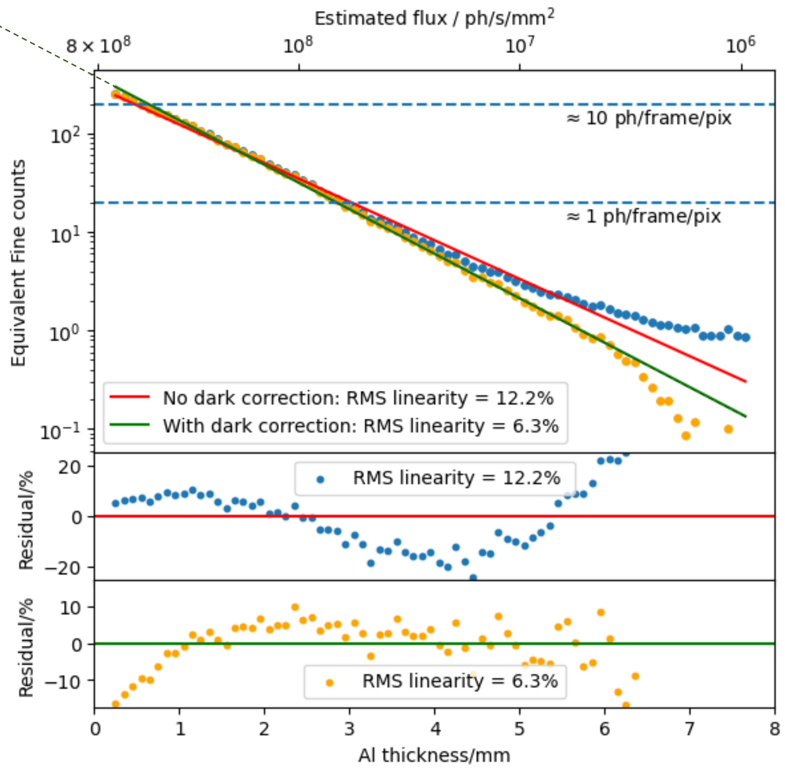
Linearity with increasing flux



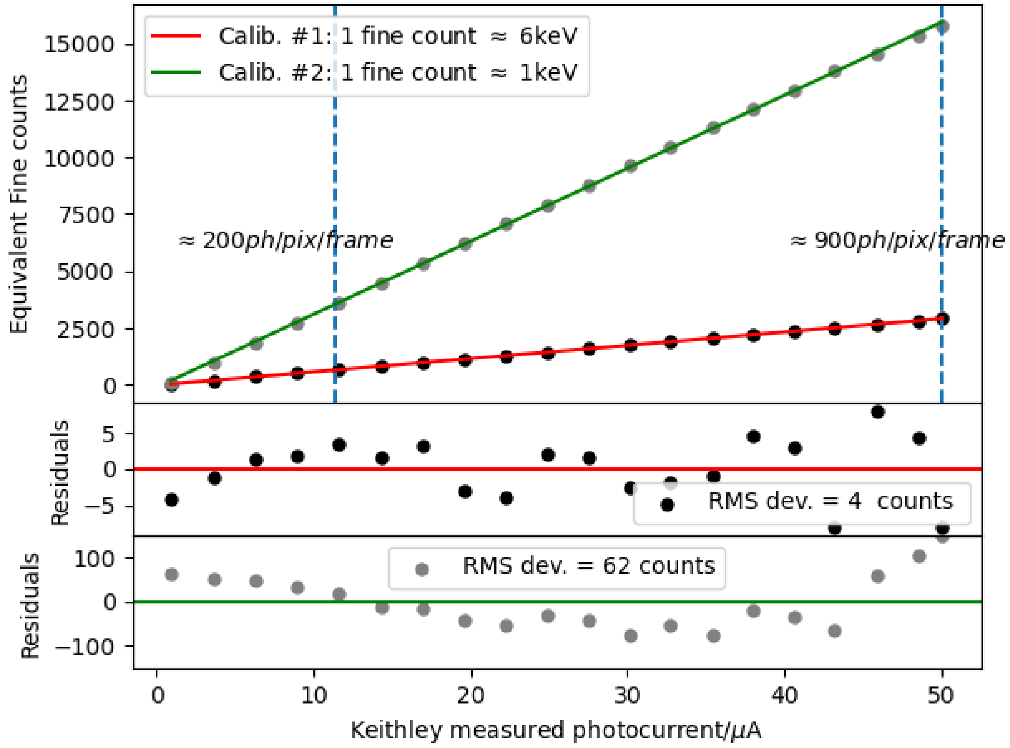
Limit of flux from X ray set:
≈3×10^{10} ph/s/mm^2 equiv. @ 20keV

Design spec:
≈4×10^{11} ph/s/mm^2
@20keV

20keV beam, moving Al wedge into beam



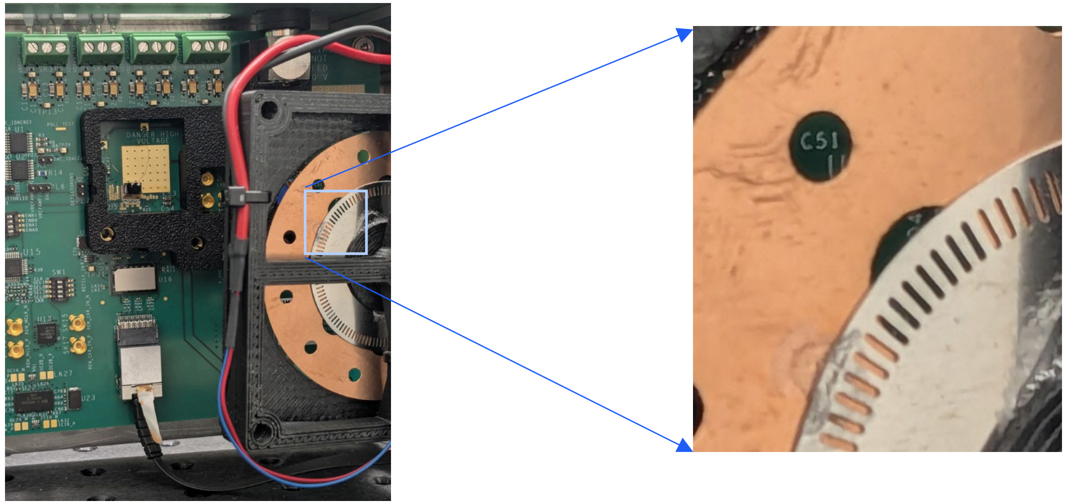
160kV W X-ray set (polychromatic)

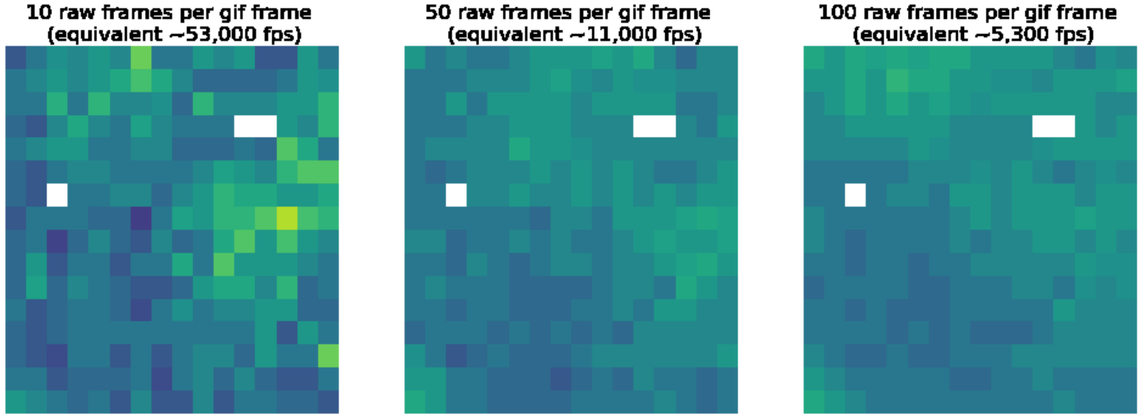


Limited by flux available at the beamline, not the DynamiX detector

Whole array measurements

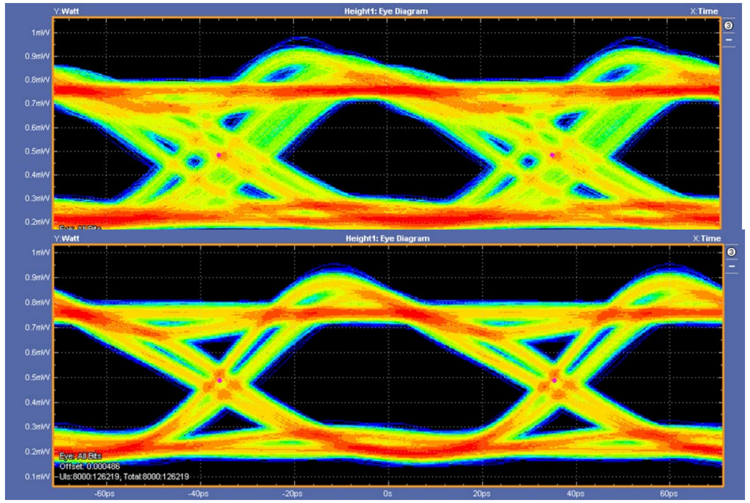
- Imaged a spinning slitted disc (copper and steel) at 533kHz
- 100kV tube voltage, 30mA tube current
- Frames flat-field corrected
- Averaged over windows of 10,50 and 100 frames



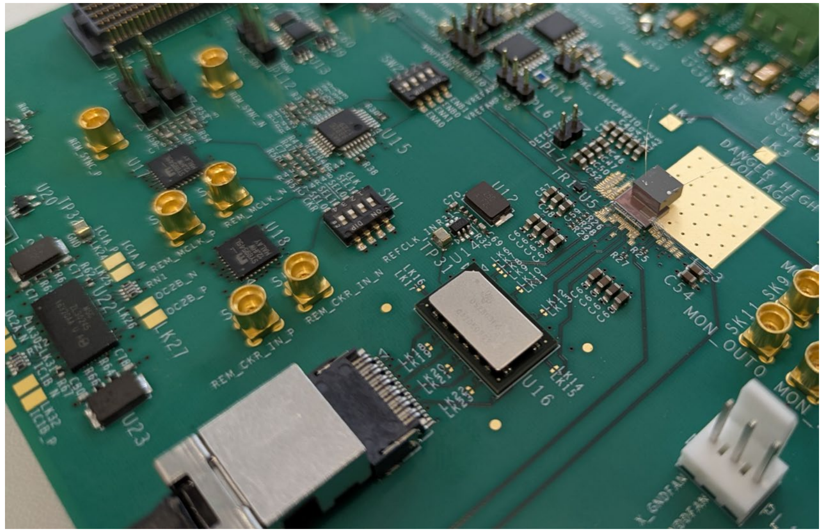


14 Gbps Serialiser Results

- Aurora encoded 66b64b CML
- 14 Gbps working and continuously writing to disc at 534 kfps
- Data passes through retimer IC → allows inspection of eye quality
- Conversion to optical via Samtec FireFly close to ASIC
- Receiver and frame built in FPGA with 100G UDP out



Eye diagrams without and with retiming



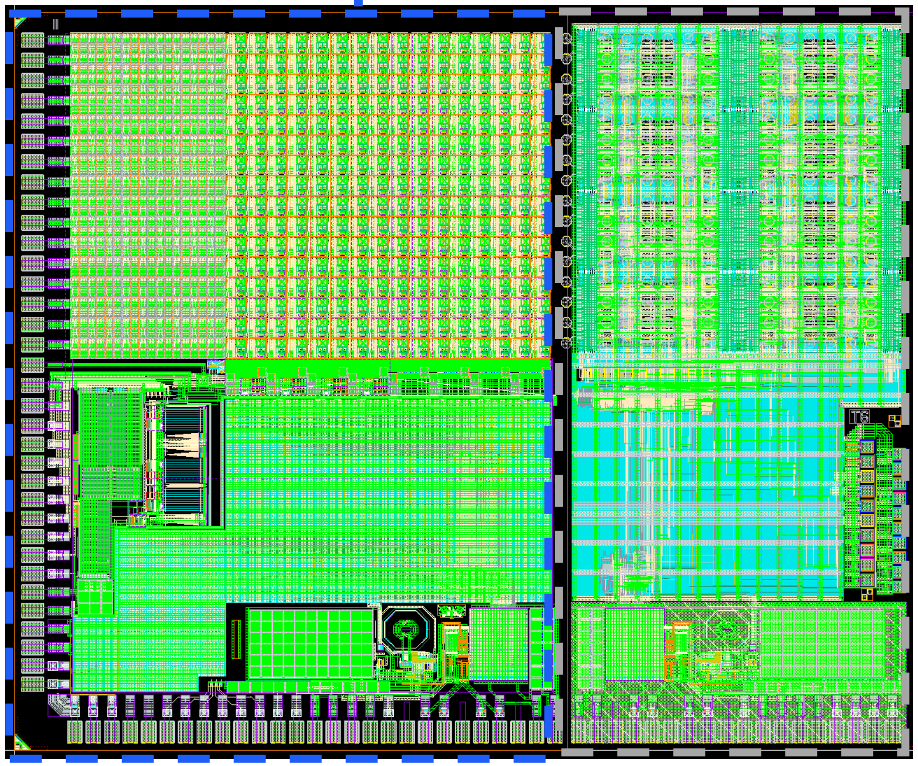
Samtec FireFly and retimer IC next to DynamiX ASIC

Towards the full-scale ASIC, XIDyn

- 192 x 144 pixel ASIC, combining XIDER and DynamiX designs
- Improvements to pixel design, including:
  - Increased trim range for calibration of thresholds & packet sizes
  - Switch to disconnect front end from pixel during transfer to prevent saturation
- Submission planned for autumn this year, with wafers expected back in spring

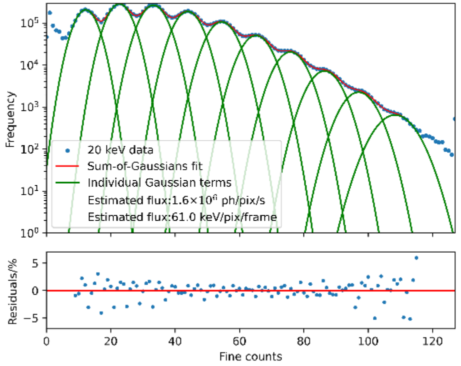
DynamiX Chip

XIDER Chip

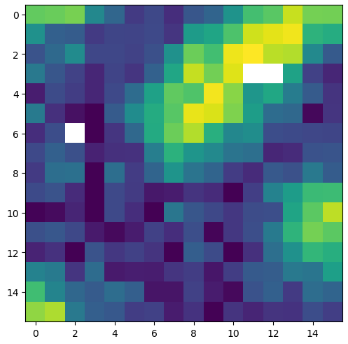


Summary

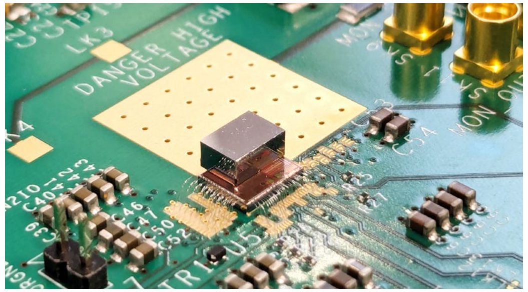
- Continuous full-frame readout at 534 kHz
- Able to resolve single photons with width σ ≈ 5.7keV
- Measurements taken in range <1ph/pix/frame → ≈900 ph/pix/frame
- Submission of full ASIC in autumn, tileable on 3 sides
- Upcoming beamtimes at Diamond & ESRF to go to higher fluxes



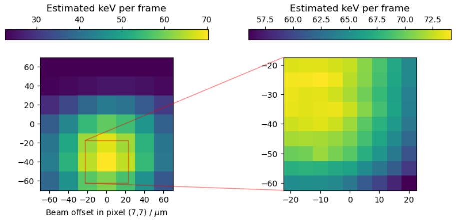
Single-photon peaks @ 20 keV



Still from imaging spinning slitted disc at 534kfps



The DynamiX ASIC with Redlen HF-CZT



Rasting scanning beam within pixel

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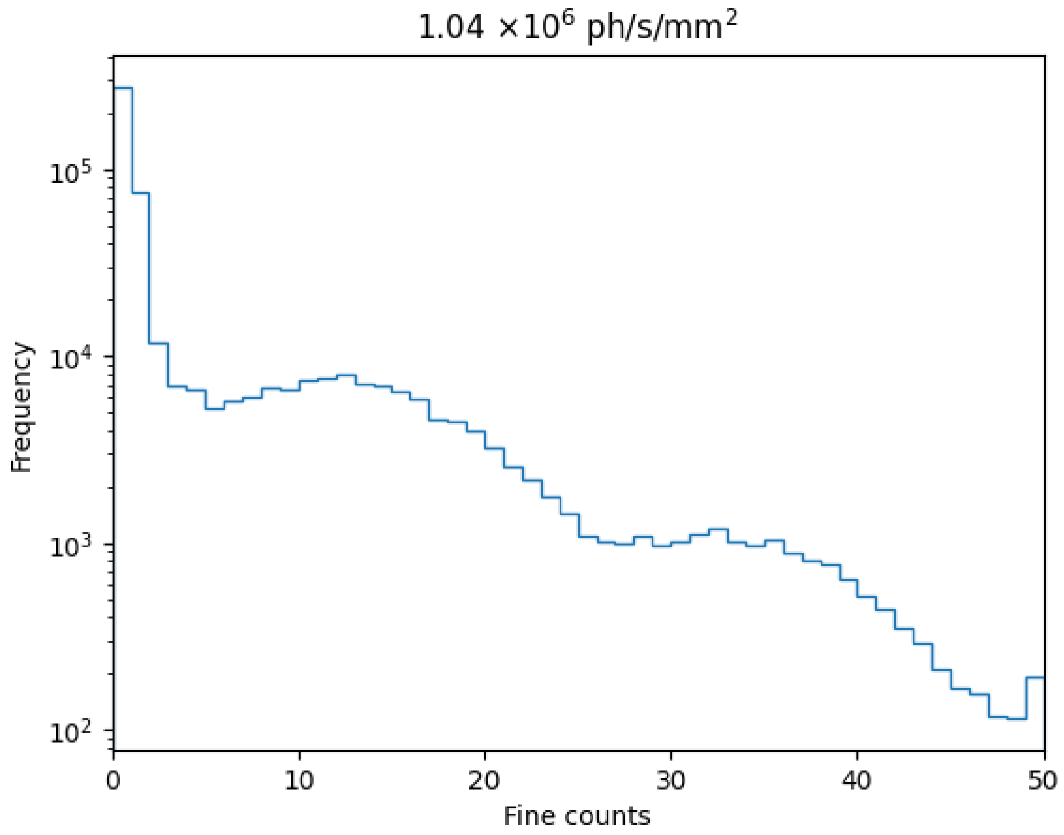
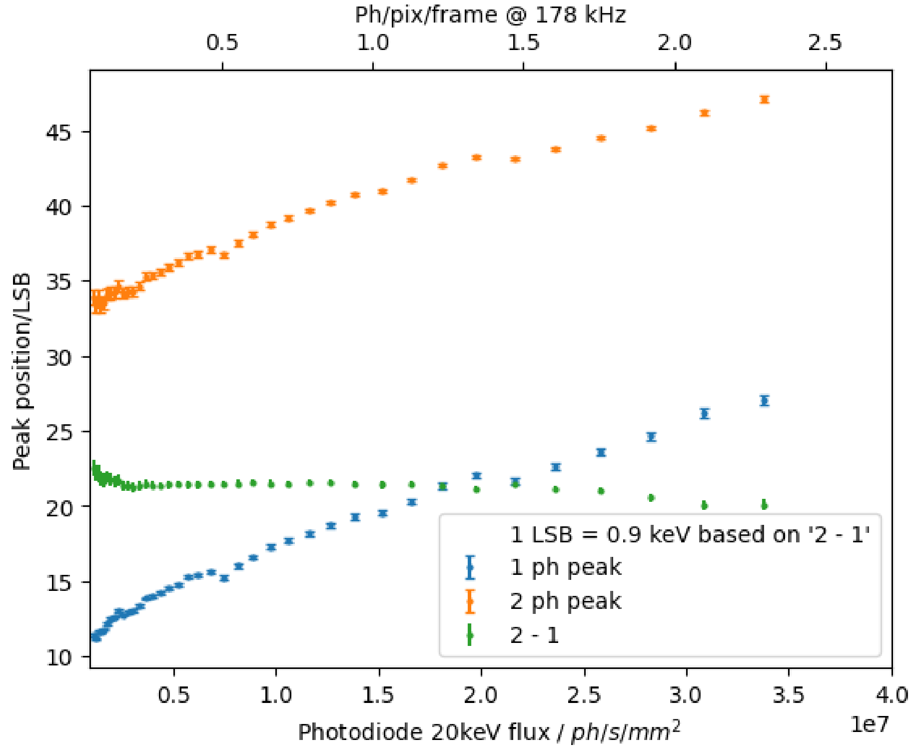
Additional Slides

Leakage current shift

(FL = 3 Diamond turns)

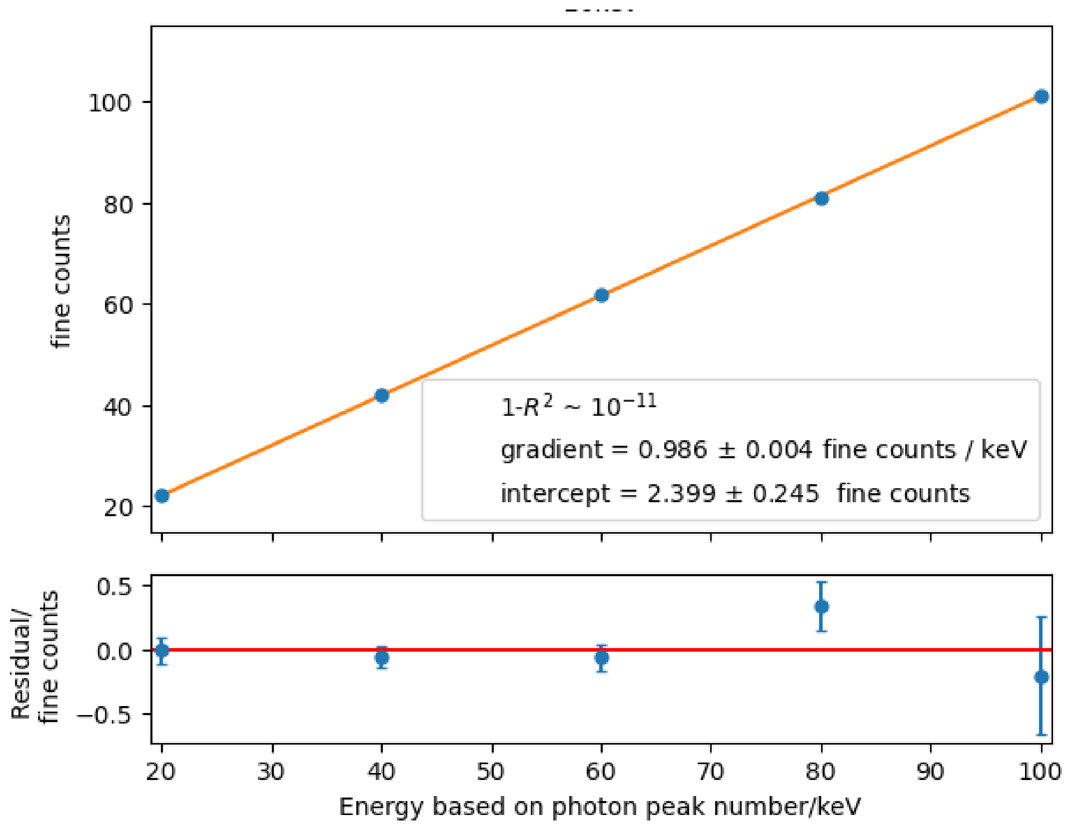


- 1 and 2 photon peaks move to higher channel numbers with increasing flux
- With FL = 1 turn, beam 50 μm x 50 μm, excess leakage current density in this flux range ≈ 41 nA/mm^2
- This effect has been seen in Redlen HF CZT before, e.g. Cline and XIDER



Calibrating from single photon peaks
(aim: 1 coarse = 64 fine)

1. Determine ADU → keV conversion from photon peak spacing



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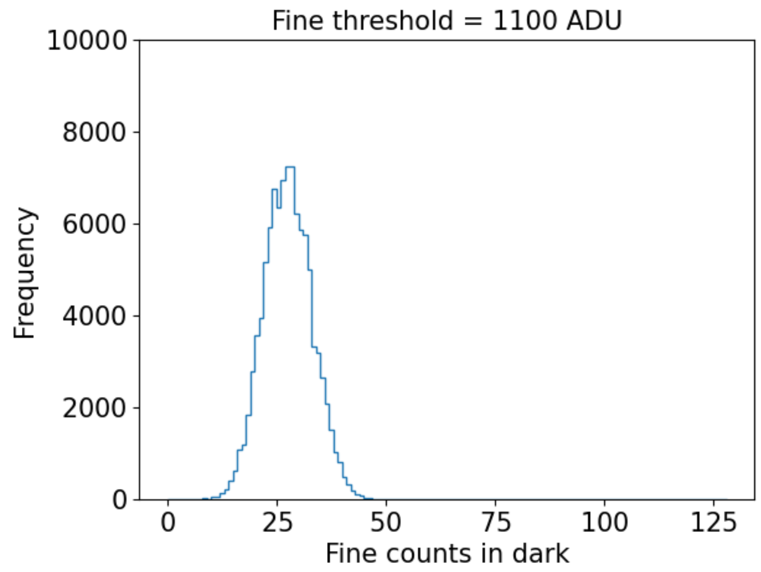
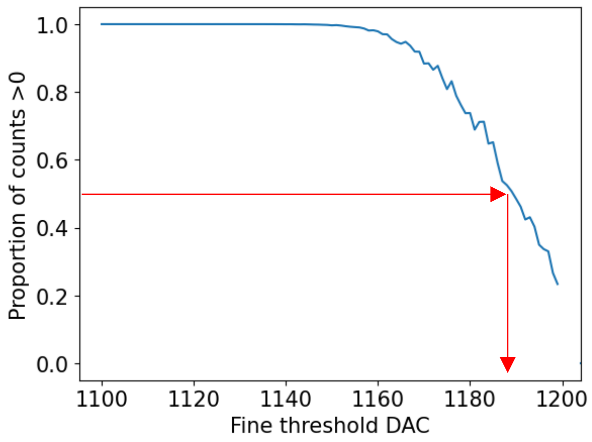
Calibrating from single photon peaks
(aim: 1 coarse = 64 fine)

1. Determine ADU → keV conversion from photon peak spacing

2. Change fine threshold to move noise peak to 0
    - Find threshold such that 50% counts are >0





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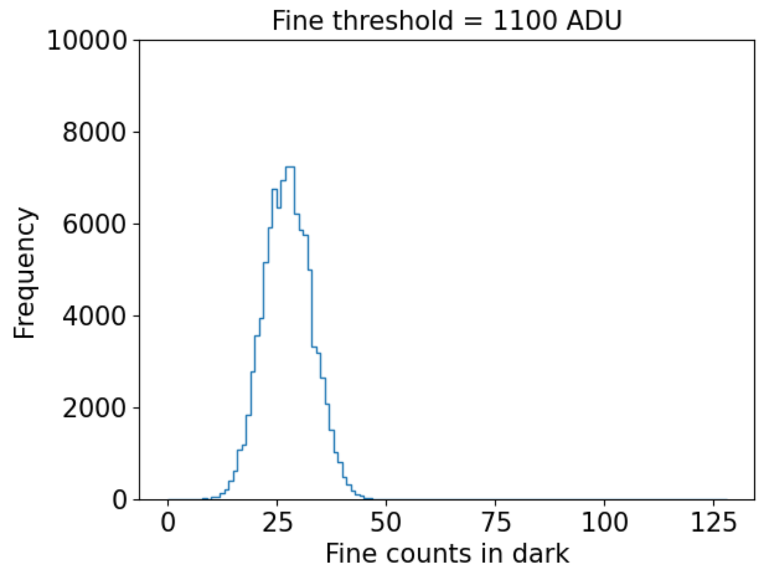
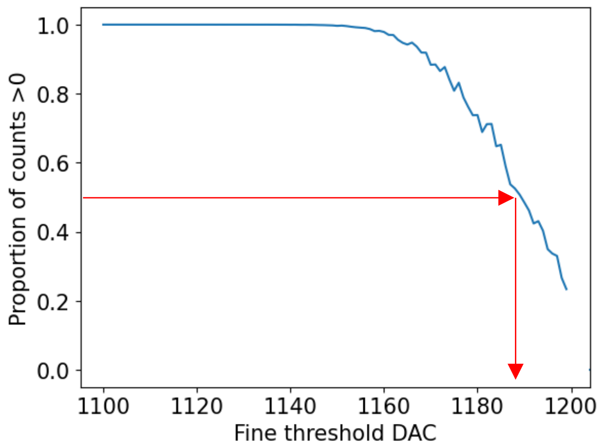
Can also estimate noise:

- Look at σ of dark counts where distribution is well away from 0
- σ ≈ 5.50 LSB ≈ 5.57 keV ≈ 1210 e^-
- 150fF fine stage feedback, includes leakage + sensor capacitance





Calibrating from single photon peaks
(aim: 1 coarse = 64 fine)

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3. Find test pulse setting to give 64 fine counts (≈65 keV)

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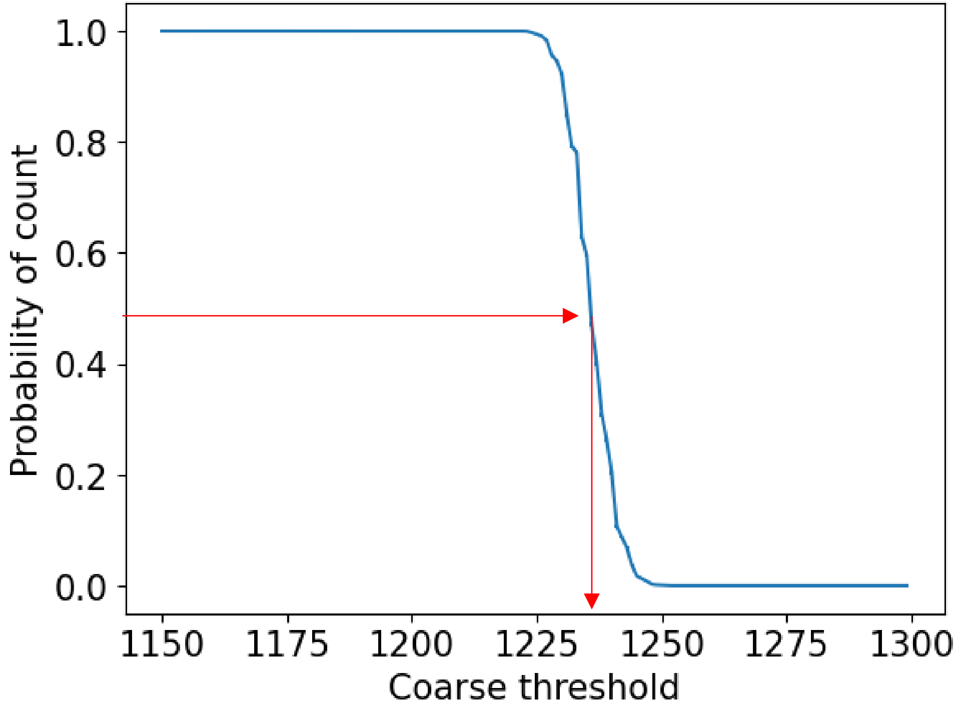
(aim: 1 coarse = 64 fine)

1. Determine ADU → keV conversion from photon peak spacing

2. Change fine threshold to move noise peak to 0
   - Find threshold such that 50% counts are >0

3. Find test pulse setting to give 64 fine counts (≈65 keV)

4. Sweep coarse threshold while injecting 64 fine counts
   - Find threshold such that 50% chance of triggering
   - Set threshold slightly higher to avoid cancelling below baseline



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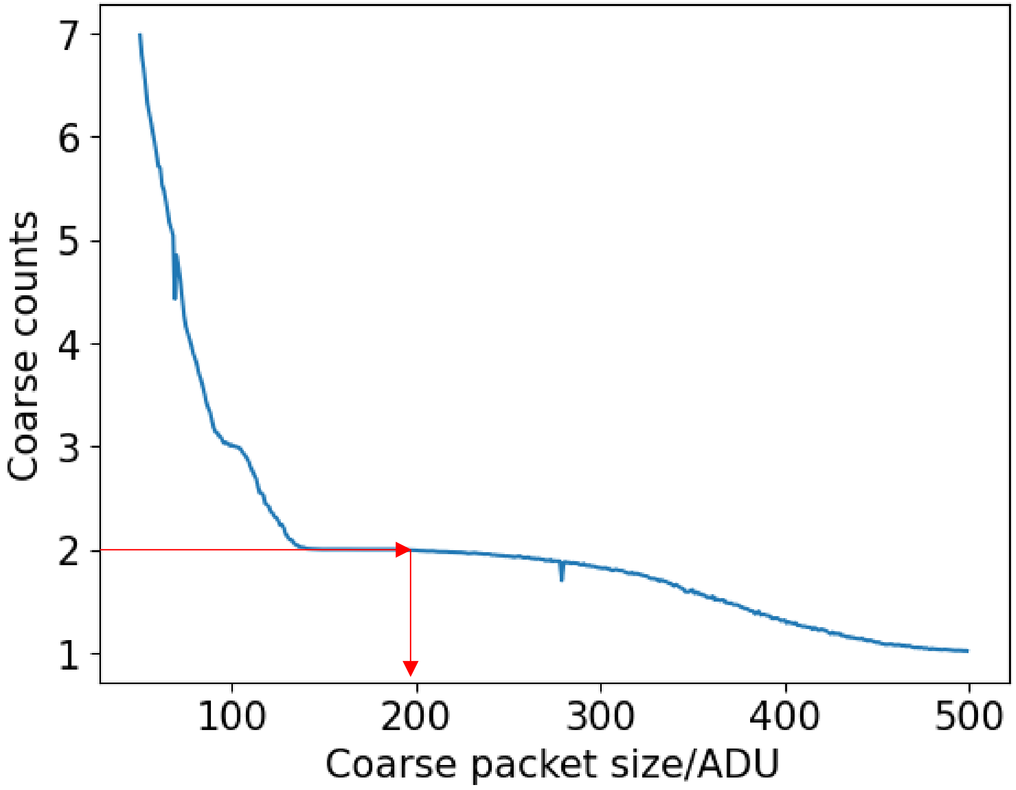
5. Inject 3 coarse counts (=3 x 64 fine counts) and sweep coarse packet size
   - Find maximum packet corresponding to 2 coarse counts



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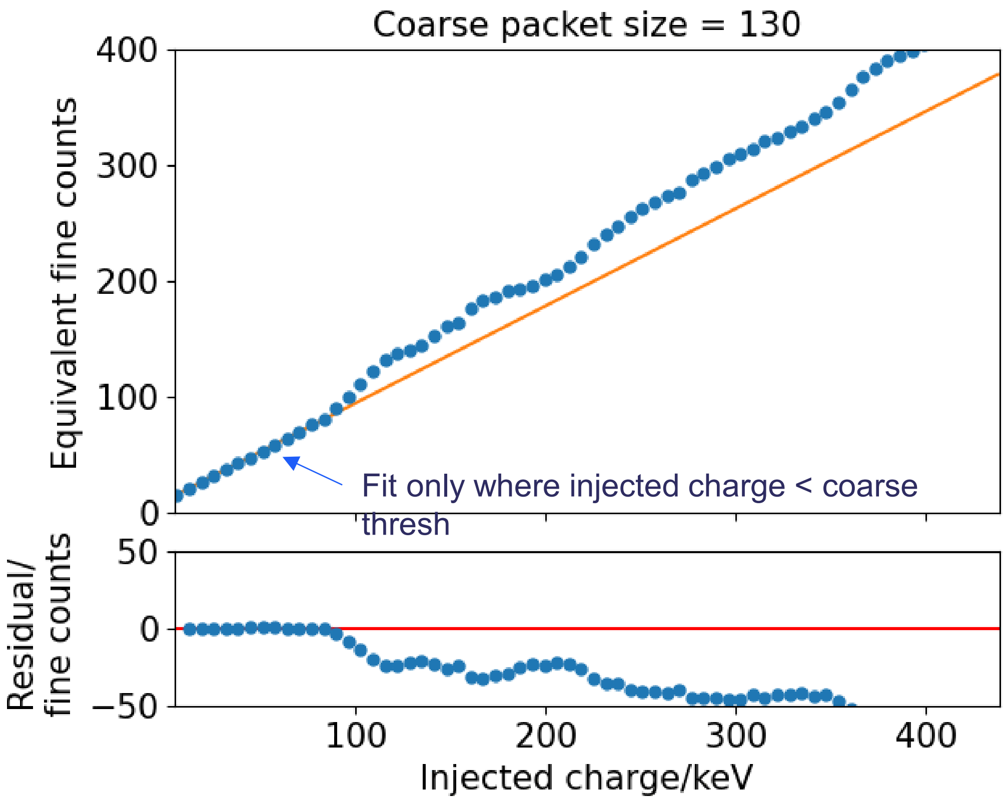
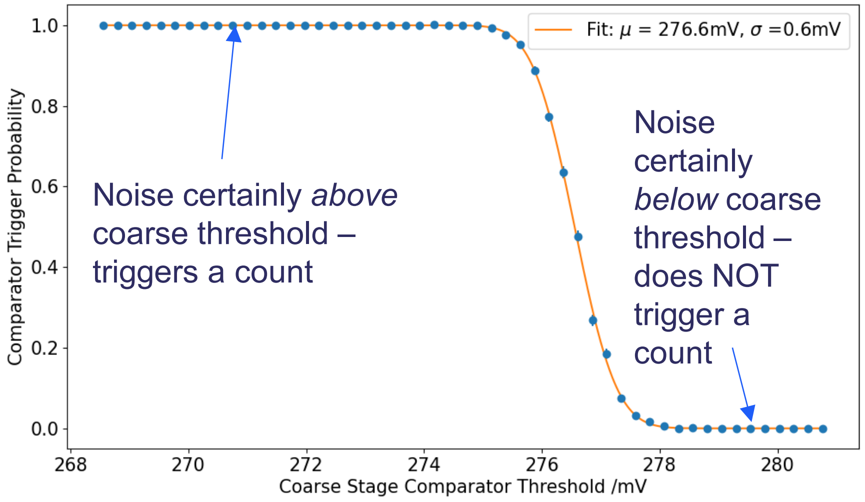
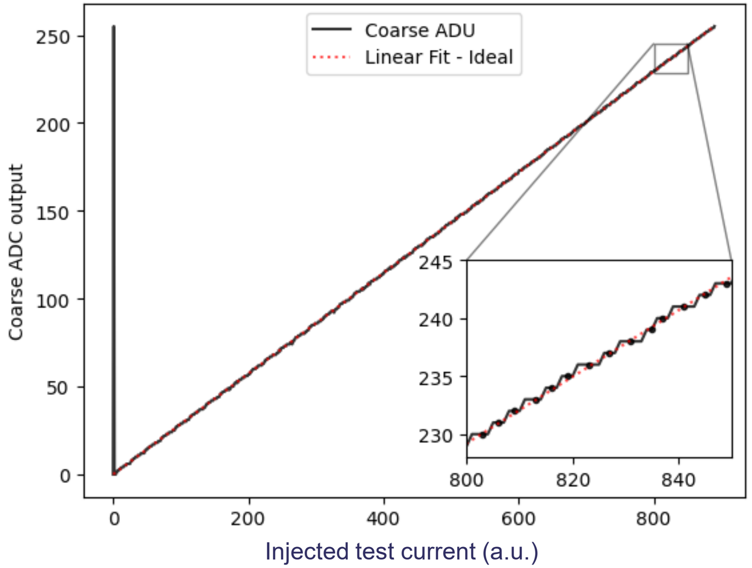
6. Fine-tune coarse packet size by verifying goodness of fit while injecting increasing charge per frame



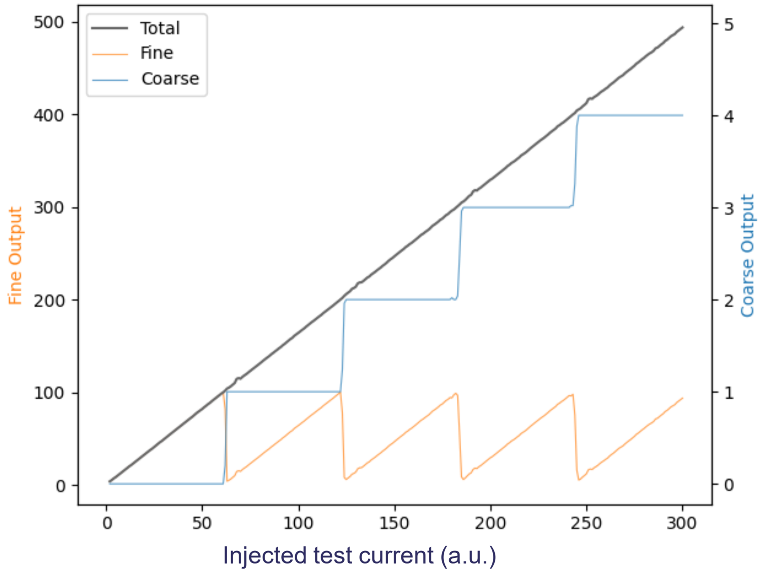
Pixel Test Results – Coarse Stage (inbuilt test pulse)



Sweep coarse stage threshold → measure coarse output → repeat to obtain probability of triggering → determine dark noise



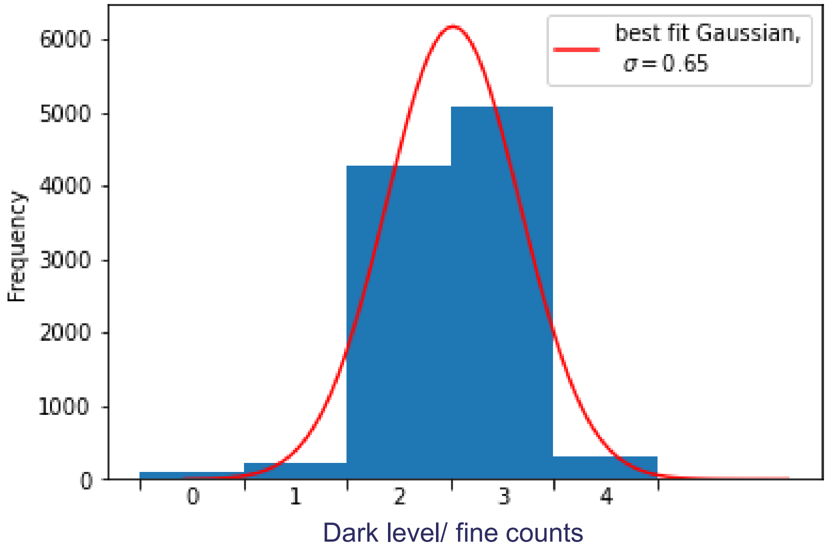
Vary input test current → measure coarse ADC output



Vary input test current → measure coarse and fine counts

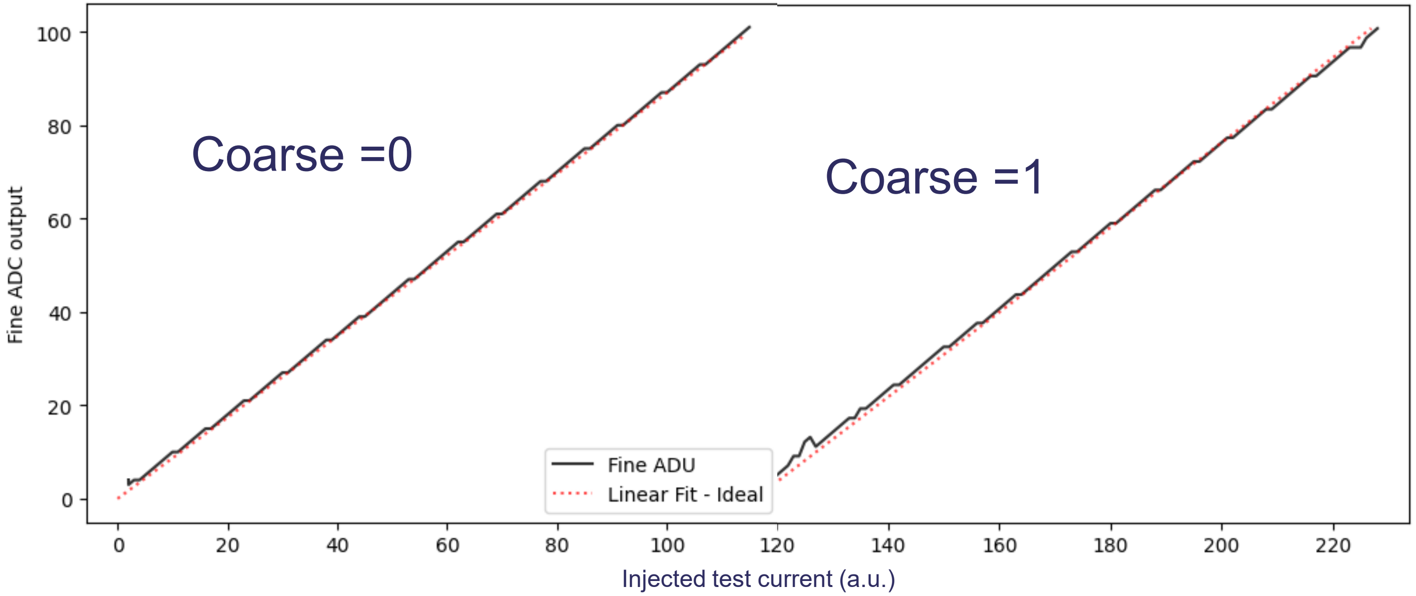
Pixel Test Results – Fine Stage (inbuilt test pulse)

1 fine count = 0.25 of 30keV Photon



No current injected → measure counts due to noise

Fine stage ADC linearity



Increase injected current → measure fine ADC output

Single photon peaks

- Monochromatic beam focused to sub-pixel level ≈50 µm x 50 µm and centred in pixel
- Can resolve single photon peaks with a width σ ≈ 5.7keV (~1200 e- RMS)
- Misalignment between peaks of same energy:

  $\mu_{2x20\ keV} \neq \mu_{40\ keV}$

  $\mu_{3x20\ keV} \neq \mu_{2x30\ keV}$

  …
- Thought to be due to flux-dependent excess leakage current in HF-CZT