Characterisation of thick pixelated CZT sensors using MAXIPIX

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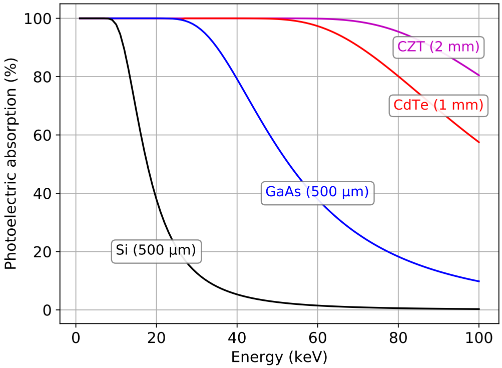
Motivation for CZT

- ESRF in shutdown phase for its upgrade (P. Fajardo's talk this morning)
- Need for efficient detectors at moderate and high x-ray energies (30-100 keV)
- Research programme for high-Z sensors
- CZT could be a promising alternative
- Limitations? Leakage current? etc.

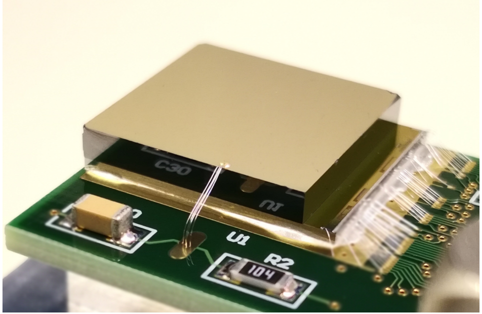
Property	Si	GaAs.	CdTe	CZT
Z (average)	14	32	50	49.1
Density ($g\,cm^{-3}$)	2.33	5.32	5.85	5.81
Energy gap (eV)	1.12	1.42	1.44	$\geqslant$1.6
Intr. carrier conc. (cm^{-3})	$\sim 10^{10}$	$2 \cdot 10^{6}$	$\sim 10^{7}$	$\sim 10^{7}$
W-value (eV)	3.62	4.3	4.43	4.64



Ref: Data obtained from XCOM NIST database

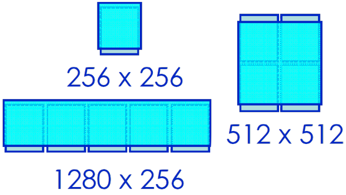
CZT module developement at ESRF

- Collaboration with IMEM (Parma)
- Redlen "high-flux" CZT
- Maxipix system (Timepix)
- Bump bonding by ADVACAM
- Wire bonding by HCM.SYSTREL



Sensor	Samples	Thickness (mm)	Pixel (µm)	Module id.
CZT	2	2	110	D140844 / tpxatl164
		2	110	D140845 / tpxatl165
CZT	2	2	55	D140531 / tpxatl166
		2	55	D140540 / tpxatl167

Maxipix readout system

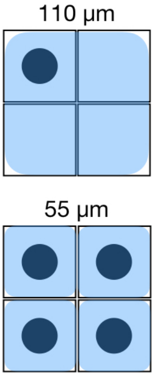


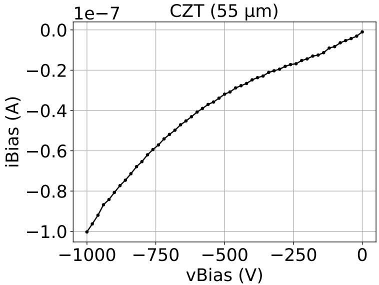
- Developed by ESRF (Medipix2/Timepix)
- 1.4 kHz maximum frame rate
- $2 \cdot 10^5$ counts/pixel maximum count rate
- 0.29 ms dead time at 100 MHz clock
- Minimum threshold $\sim$ 4 keV
- 11810 pixel counter depth

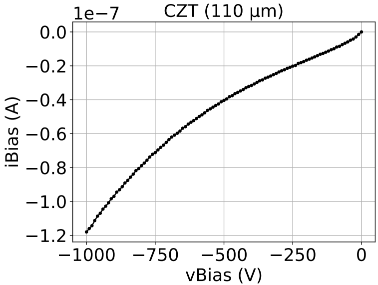
Ref: C. Ponchut et al. 2011 JINST 6 C01069

Leakage current vs bias voltage

- No X-rays
- Current we see at the power supply



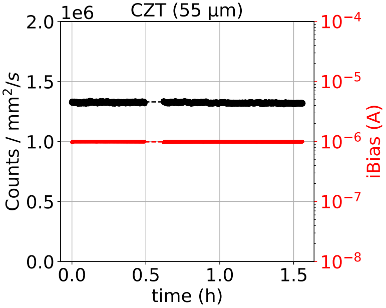


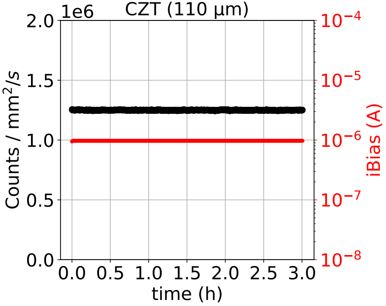


	55 µm	110 µm
Sensor bias voltage (V)	-1000	-1000
Bias leakage current (µA)	0.10	0.12
Equivalent pixel leakage current (pA)	1.52	7.32

Stability test

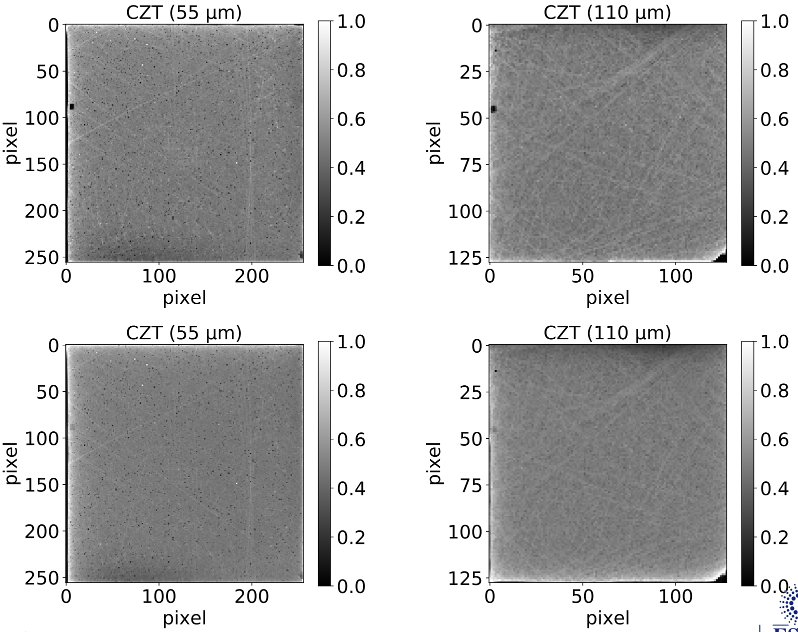
- COMET X-ray tube (up to 160 keV)
- W Anode/250 µm W filter ($\sim$ 60 keV)
- Tube settings (80 kV/8.0 mA)
- Detector 1.07 m away from source
- Ramp up voltage and X-rays on
  $E_{thl} = E_{beam}/2$





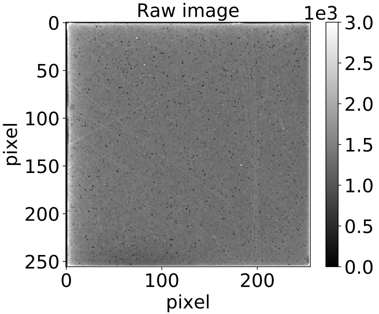
Flood images

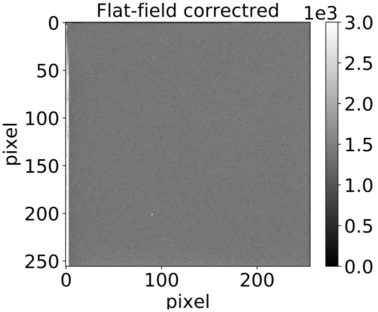
- Top: $E_{beam} = 22$ keV
- Bot: $E_{beam} = 60$ keV
- $E_{thl} = E_{beam}/2$
- No significant difference
- Bias contact on the left



Relative signal-to-noise ratio (rSNR)

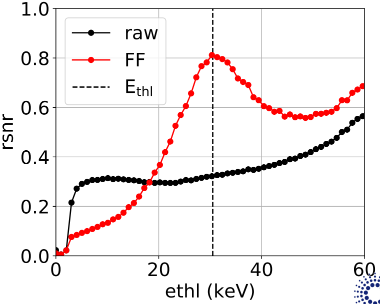
- Flat field correction needed due to spatial inhomogeneity
- Valid only for images taken at the same conditions
- Make use of rSNR to quantify its effectiveness



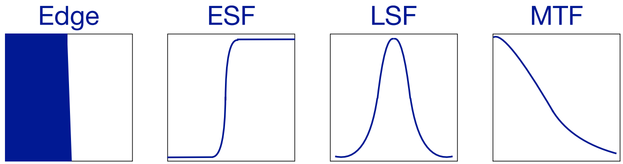


- Calculate rSNR with varying energy threshold

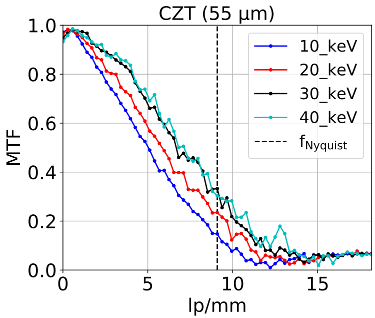
$$\mathrm{rSNR} = \frac{\mathrm{SNR}_{\mathrm{image}}(\mathrm{ROI})}{\mathrm{SNR}_{\mathrm{poisson}}(\mathrm{ROI})} = \frac{\frac{\mathrm{mean}(\mathrm{ROI})}{\sigma(\mathrm{ROI})}}{\sqrt{\mathrm{mean}(\mathrm{ROI})}} = \frac{\sqrt{\mathrm{mean}(\mathrm{ROI})}}{\sigma(\mathrm{ROI})}$$

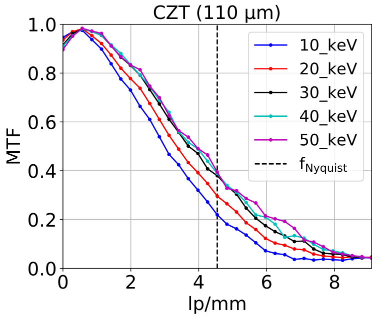


Modulation tranfer function (MTF) - presampling



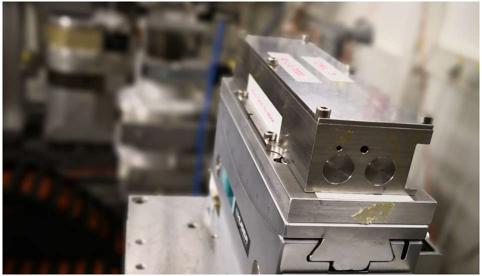
- $E_{beam} = 60$ keV
- Make use of slanted edge method
- Edge/line spread functions (ESF/LSF)
- $LSF(x) = \frac{d}{dx}\{ESF(x)\}$
- $MTF(u) = |\mathcal{F}\{LSF(x)\}|$

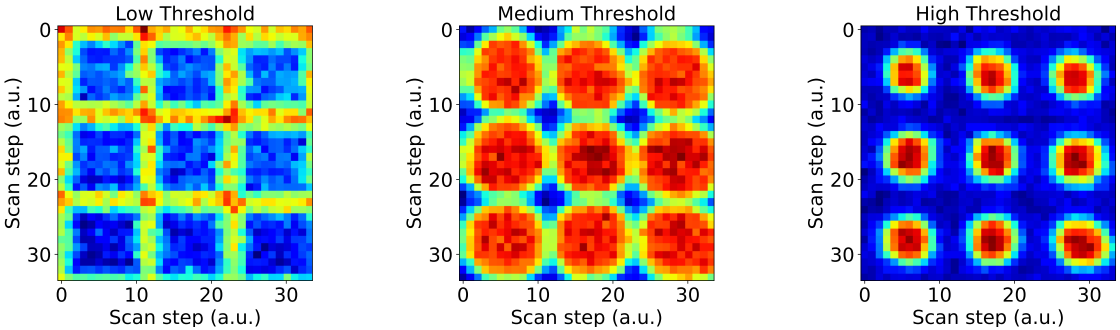




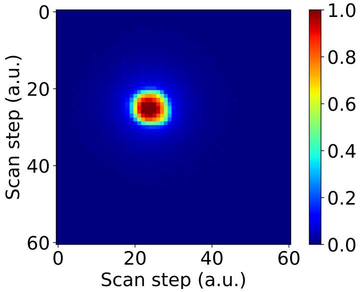
Mesh scans with micro-focused beam

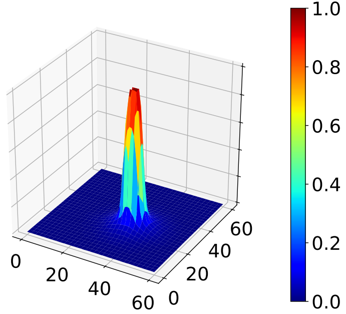
- 30 keV monochromatic beam
- ($_4$Be) compound refractive lenses
- Beam spot << pixel size
- Precise mapping of a sensor area
- Effective pixel shape





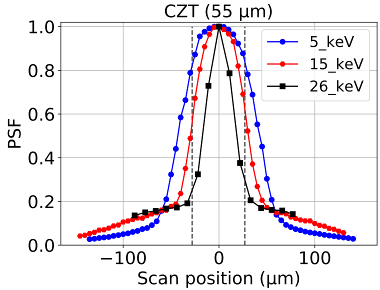
Point spread function (PSF)

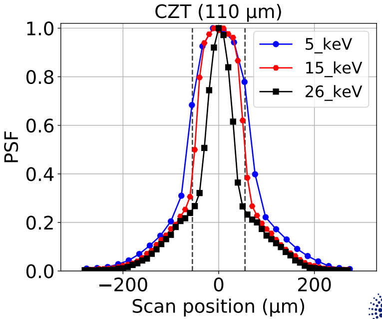




- Choose a single pixel within the scan area
- Extract the 1D PSF for various thresholds

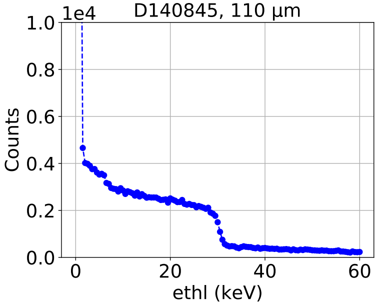
Pitch (µm)	E_{thl} (keV)	FWHM (µm)
55	5	85.63
	15	60.37
	26	35.86
110	5	137.44
	15	105.82
	26	65.01

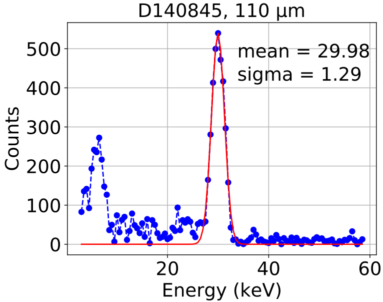




Threshold scans and single pixel spectra

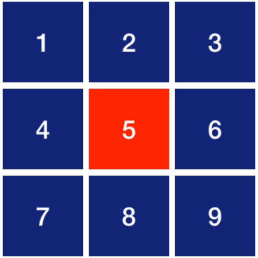
- Align beam at the center of a pixel
- Vary the discriminator threshold
- Measure the number of counts for each threshold step
- The derivative of the threshold scan gives the single pixel energy spectrum
- The peak should correspond with the beam energy

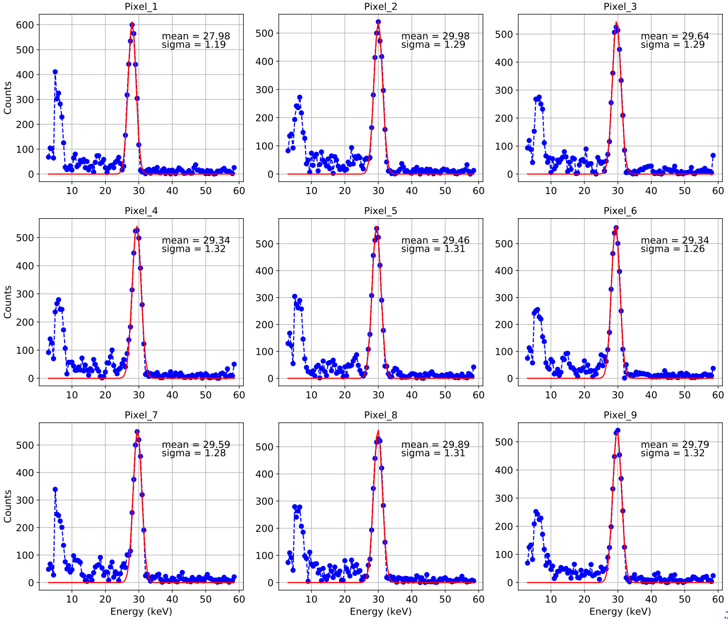




Single pixel spectra of a 3×3 area

- CZT (2 mm, 110 μm)
- Crosscheck for calibration





Outlook

- Characterisation of "high-flux" CZT (Redlen) with X-rays up to 60 keV
- Stable performance over time, high spatial resolution despite the thickness
- Work in progress (DQE, CCE, $\mu\tau$, simulations, etc.)
- More tests with standard CZT (IMEM) and thick GaAs:Cr

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Thank you!