

Spatial resolution measurements of the Timepix4 hybrid pixel detector were performed by evaluating the Modulation Transfer Function (MTF), using the knife-edge method. Data was taken in an electron microscope and at an X-ray beam, with two distinct Timepix4 assemblies. The MTF curves obtained from the raw data were shown to be consistent with previous measurements on detectors with the same sensor type and pixel pitch. Charge calibration and timewalk correction were performed per-pixel for each of the detectors, and clustering of the raw and corrected data was performed. It was shown that the MTF at Nyquist frequency for the devices improved by a factor of 2.94 to 3.78 for the electron data, and by a factor of 1.29 to 2.41 for the X-ray data. Test images demonstrate the improvement in contrast and clarity achievable. Further development of the clustering algorithm is expected to enable the Timepix4 to be used as a superior imaging detector for various imaging applications.



## MERLIN T4 Readout for Timepix4

- Timepix4 bump-bonded to a 300 μm planar Si sensor
- 100 V reverse-bias, 1 keV threshold
  - 'Data-driven' readout
  - 16 fast readout links
- 5.12 Gbps FireFly optical fibre

## Electron microscope data

### Detector A

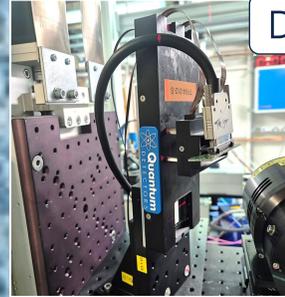
- Rosalind Franklin Institute
- JEOL cryoARM Transmission Electron Microscope
- 100 keV and 200 keV electrons
- Calibration data taken with an X-ray tube
  - Using fluorescing metal targets



### Detector B

## X-ray fluorescence data

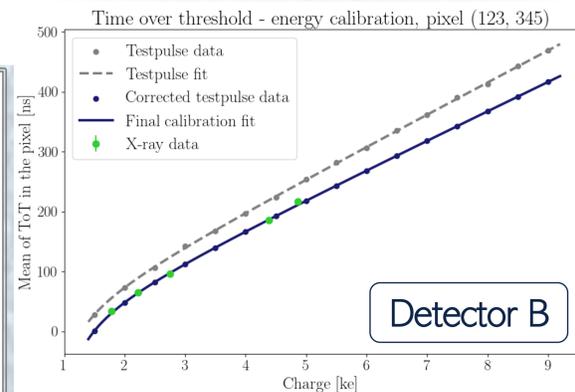
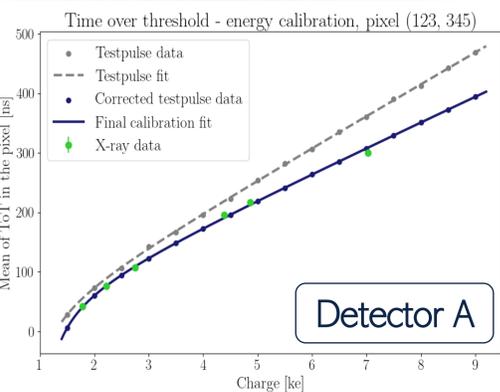
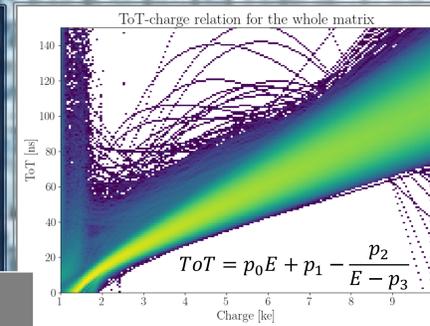
- Diamond Light Source
  - B16 beamline
- 6keV — 18keV monochromatic photons
  - Using fluorescing metal targets
- First data collected at 81.92 Gbps



## CORRECT TOT PER PIXEL

### ToT - Charge Calibration

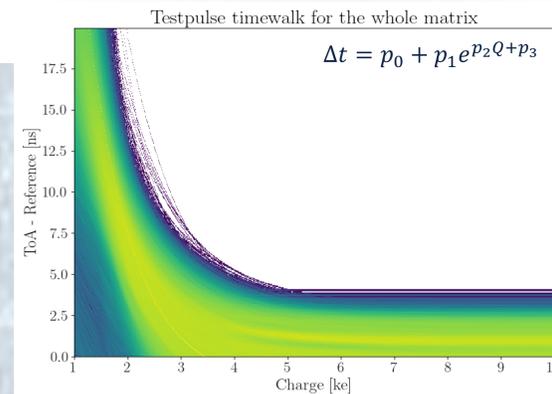
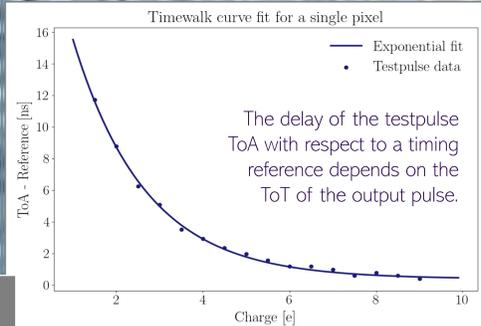
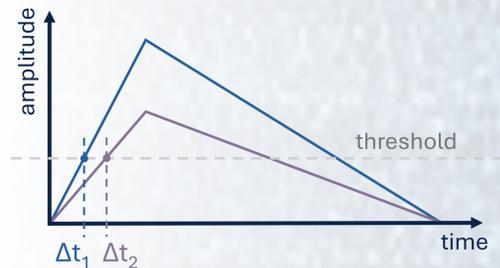
- Amplifier gain variations pixel-to-pixel
- Initial calibration using testpulses
  - Charge injected into the pre-amplifier, bypassing the sensor
- Correct testpulse data for sensor effects in each detector, using X-ray data
  - Selecting single-pixel events with known energy



## CORRECT TOA PER PIXEL, ACCORDING TO TOT

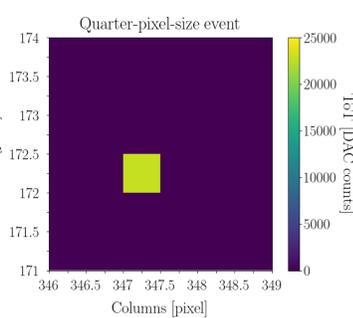
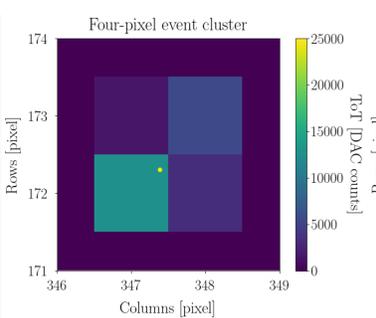
### Timewalk Correction

- ToA measurement is dependant on the ToT response
- Rise time, pulse shaping, clock distribution vary pixel-to-pixel
- Measure Δt for testpulses with varied injection charge
- Timing reference: start of testpulse generation timestamp



## CORRECT FOR CHARGE SHARING, ACCORDING TO TOA AND TOT

In red: the ROI taken for MTF calculation.

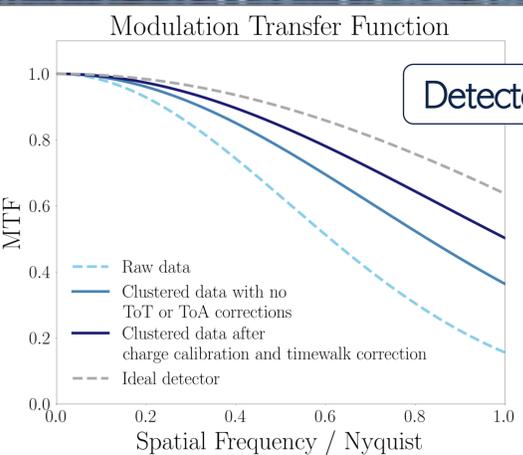
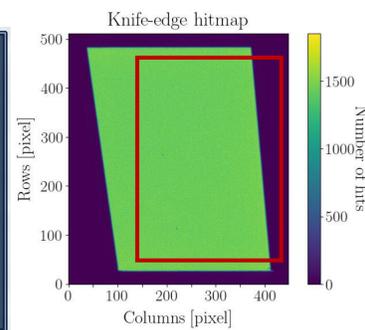


### Clustering

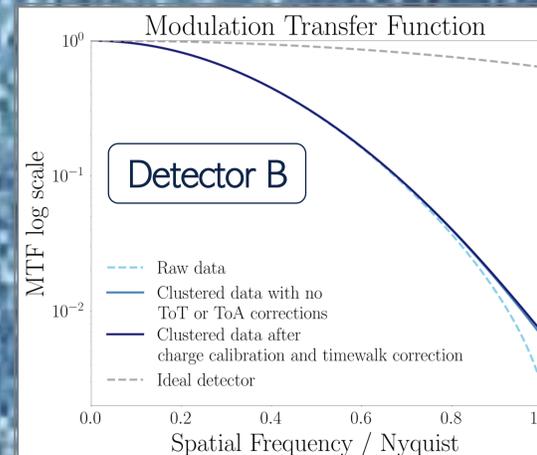
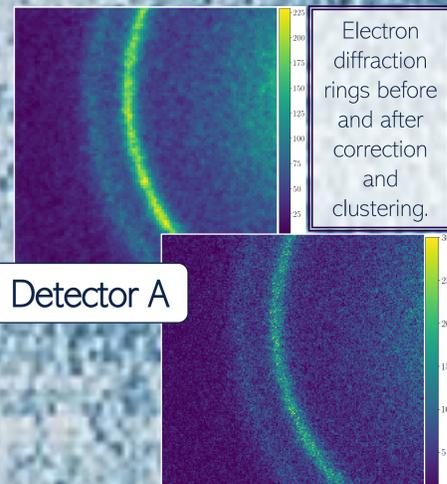
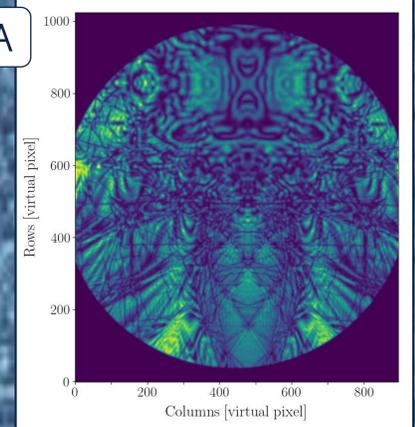
- Corrected ToT, ToA
- 100 ns time window
- ToT-based centroid
- Sub-pixel event assignment to a 'virtual pixel'

### Modulation Transfer Function

- Describes the ability of an imaging system to transfer contrast as a function of incident spatial frequency
- Simple parameter widely used in characterising imaging detectors: the MTF at Nyquist frequency
- Slanted knife-edge method
- MTF obtained from an Edge Spread Function
- Aliasing compensated for by oversampling the edge



Large angle convergent beam electron diffraction image of a thick silicon sample.



Timepix4 offers high dynamic range and a fast readout rate (1.79 Mhits/mm<sup>2</sup>/s). This makes it ideal for phase-sensitive techniques like ptychography and 4D-STEM, supporting accurate phase reconstruction and low-dose imaging.

MTF@Nyquist	Electron data, detector A			X-ray data, detector B			
	100 keV	200 keV	6.4 KeV (Fe)	8.0 keV (Cu)	9.9 keV (Ge)	15.8 keV (Zr)	17.5 keV (Mo)
Raw	0.17	0.0045	0.0082	0.0079	0.0075	0.0046	0.0027
Clustered	0.36	0.011	0.012	0.011	0.0096	0.0072	0.0065
Corrected and Clustered	0.5	0.017	0.012	0.011	0.0097	0.0074	0.007
Improvement Factor	2.94	3.78	1.46	1.39	1.29	1.61	2.59

The 1 keV threshold leads to a more significant proportion of 'lost energy' for X-rays (~36% for 10 keV) than for electrons (~3.6% for 100 keV).

Background: the ToT response of pixels to 9 keV injected into the pre-amplifier as testpulses.

[1] Timepix4 (DOI: 10.1088/1748-0221/17/01/C01044)

[2] Timepix4 imaging resolution for TEM (DOI: 10.1016/j.nima.2025.170335)