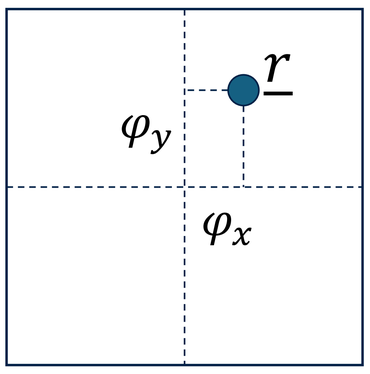
Centroiding Strategies for Timepix4 in Electron Imaging Resolution Studies

Nina Dimova | Nina.Dimova@physics.ox.ac.uk

Improved localisation does not guarantee super-resolution.
Subpixel reconstruction bias in centroided data prevents faithful virtual-pixel imaging.

Timepix4 offers high-rate, large-dynamic-range electron imaging for TEM applications. Centroiding can improve spatial resolution beyond the native 55 µm pixel pitch by estimating the electron entry point from cluster information.

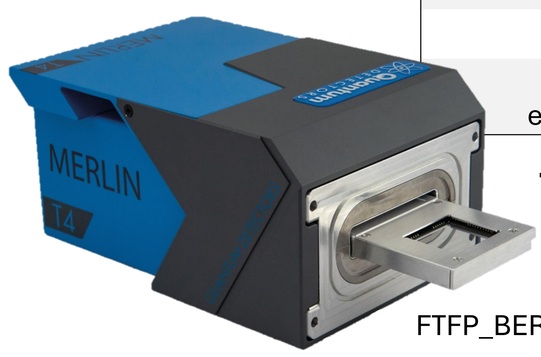


The true incidence coordinate is $\underline{r} = (x_0 + \varphi_x,\ y_0 + \varphi_y)$
The detector output is the cluster $Z = \{x,\ y,\ ToA,\ ToT\}$, given the detector response $p(Z \mid \underline{r})$.

We work to calculate a centroid $\underline{r_c} = (\hat{x}_0 + \hat{\varphi}_x,\ \hat{y}_0 + \hat{\varphi}_y)$ by constructing an inverse mapping $\hat{p}(\underline{r_c} \mid Z)$.

Ideally, $\hat{\boldsymbol{p}} \equiv \boldsymbol{p^{-1}}$

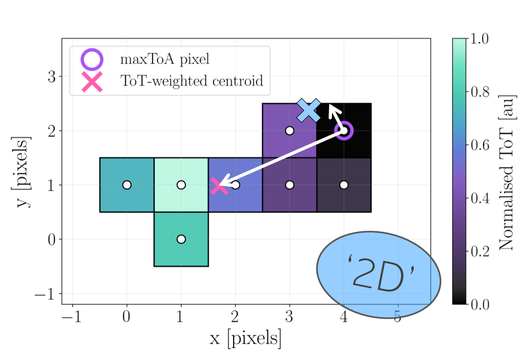
The Timepix4 Detector
300 µm planar Si sensor
55 µm pixel pitch
100 V reverse-bias, 1 ke⁻ (3.6 keV) threshold
Merlin T4 readout event-driven up to 1.28x10⁹ hits/s (81.92 Gbps)

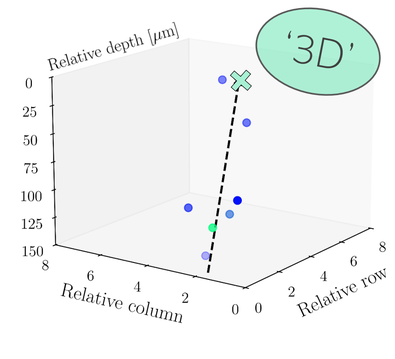


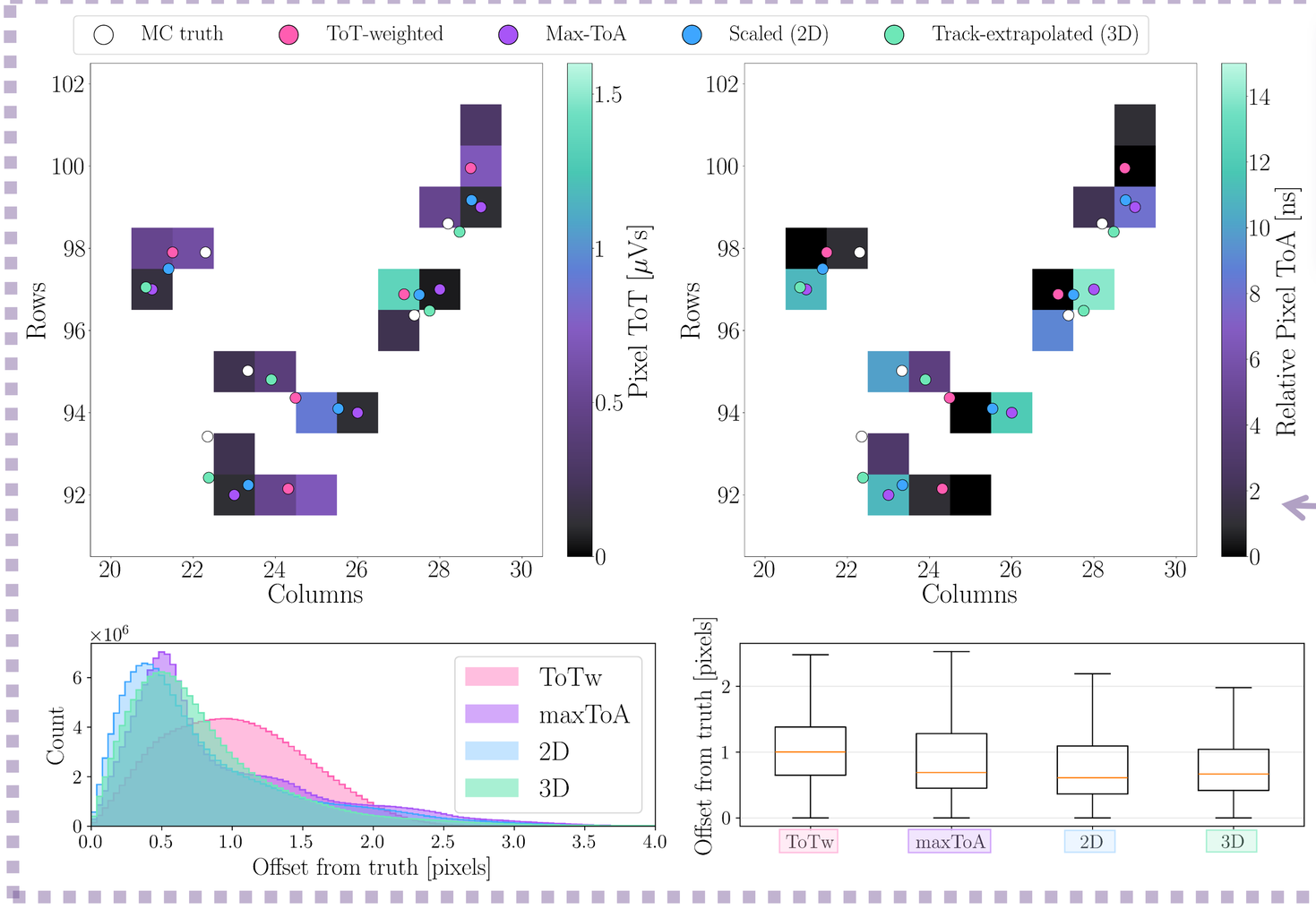
Transmission Electron Microscope Data
JEOL cryoARM TEM at the Rosalind Franklin Institute

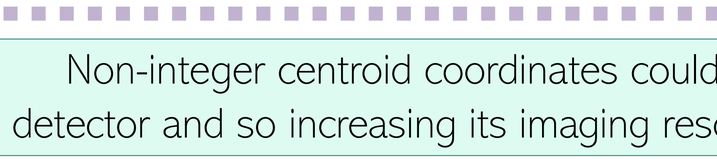
Allpix² Simulated Data
FTFP_BERT_LIV, linear E field, GenericPropagation, CSADigitiser

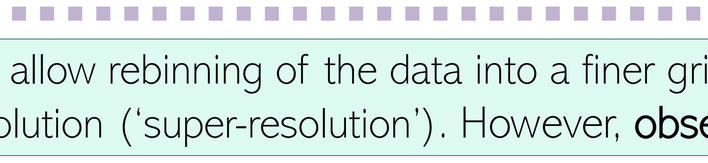
Centroid Method	Principle	Best Suited For
ToT-Weighted	Charge-weighted centre of gravity	Photons, low-energy electrons
Max ToA	Assign to centre of pixel in cluster with max ToA	High-energy electrons, creating a 'track' in the sensor
'2D'	Morphology-dependent interpolation	
'3D'	Deposition depth reconstruction and track fitting	





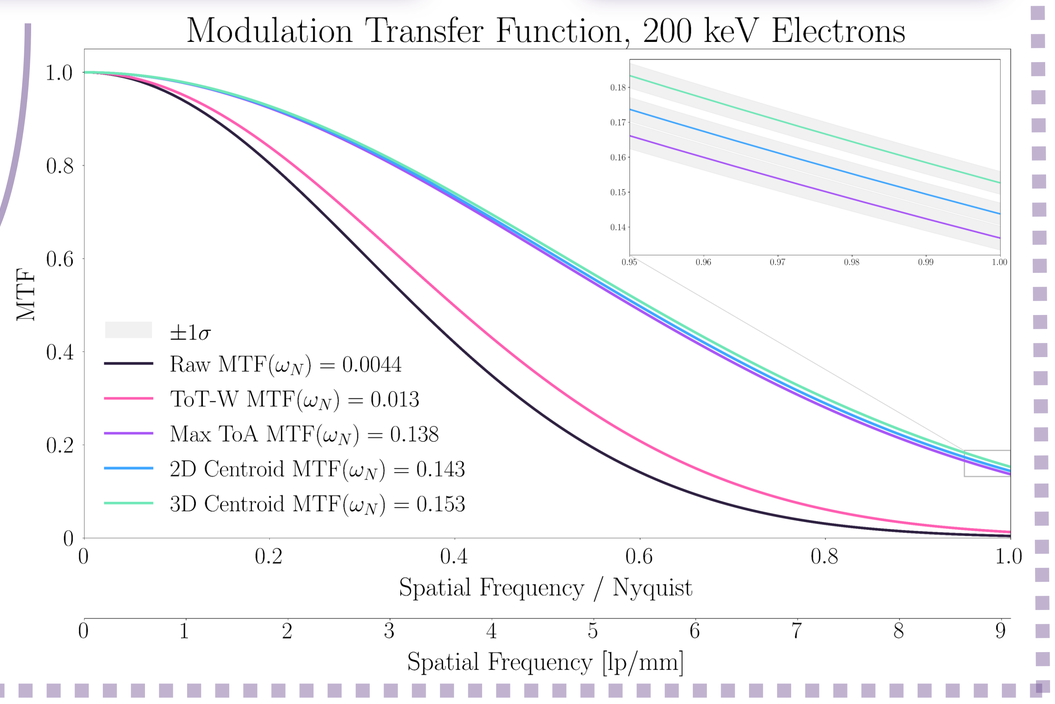




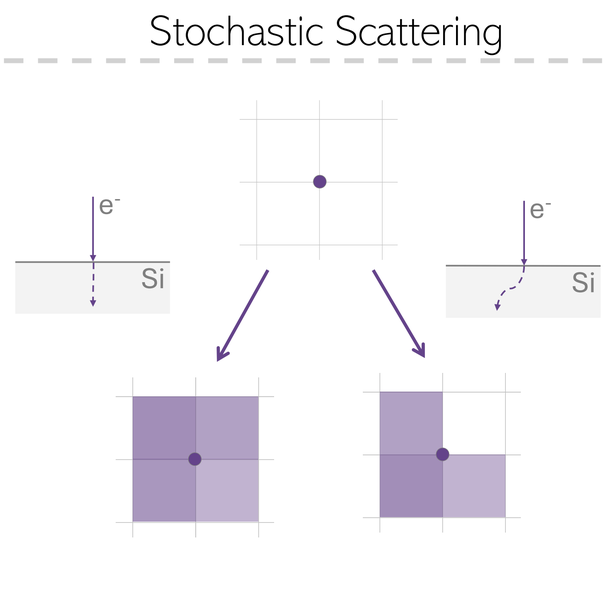


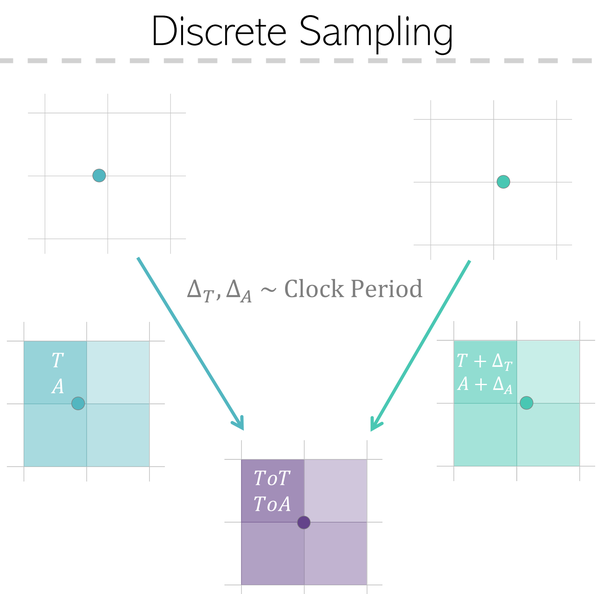
Simulated 200 keV electron data were used to compare centroid estimates with the true incidence position.

Real 200 keV electron data demonstrate the improvement in contrast preservation during imaging.

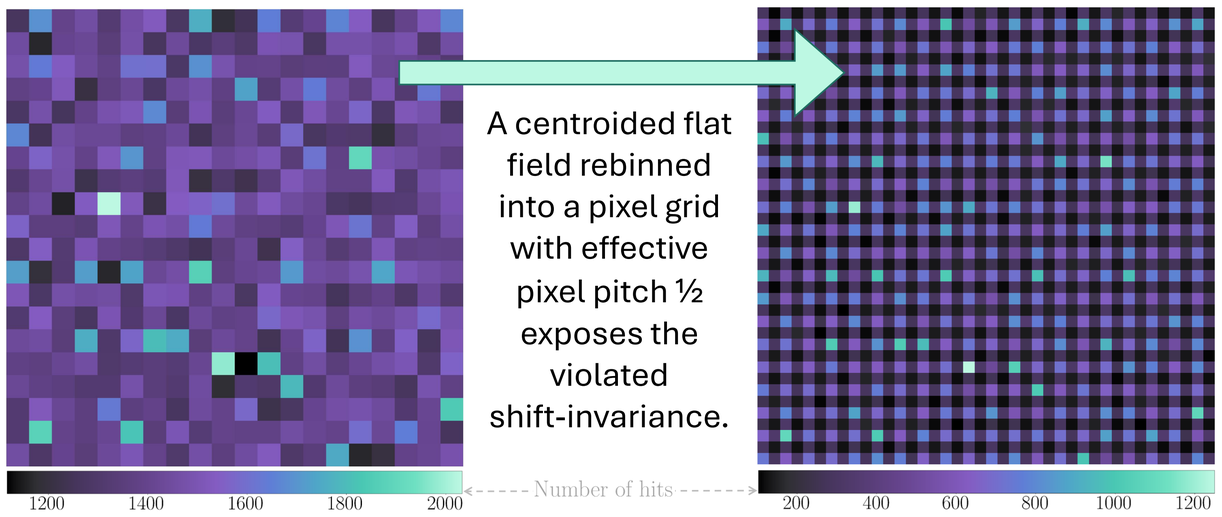


Non-integer centroid coordinates could allow rebinning of the data into a finer grid of virtual pixels, decreasing the effective pixel pitch of the detector and so increasing its imaging resolution ('super-resolution'). However, **observable-based** centroiding violates intra-pixel shift invariance.





T, A: true time over threshold and time of arrival
ToT, ToA: as discretised by the detector



Centroid reconstruction relying on discrete observables introduces true-incidence bias.
The rebinned image is no longer shift-invariant.

True incidence coordinates — Cluster observables

$\{\underline{r}\}$ is continuous, while $\{Z\}$ is discrete:
The inverse mapping is fundamentally underdetermined and $\hat{\boldsymbol{p}} \neq \boldsymbol{p^{-1}}$ always.
The reconstructed centroids $\{\underline{r_c}\}$ are a discrete set of possible coordinates.

This applies to purely observable-based analytic or heuristic methods, and ML optimised exclusively for event localisation [1, 2].

van Schayck et al. *'Sub-pixel electron detection using a convolutional neural network'* [1]
Khalil et al. *'Subpixel resolution in CdTe Timepix3 pixel detectors'* [2]