Direct detector technology

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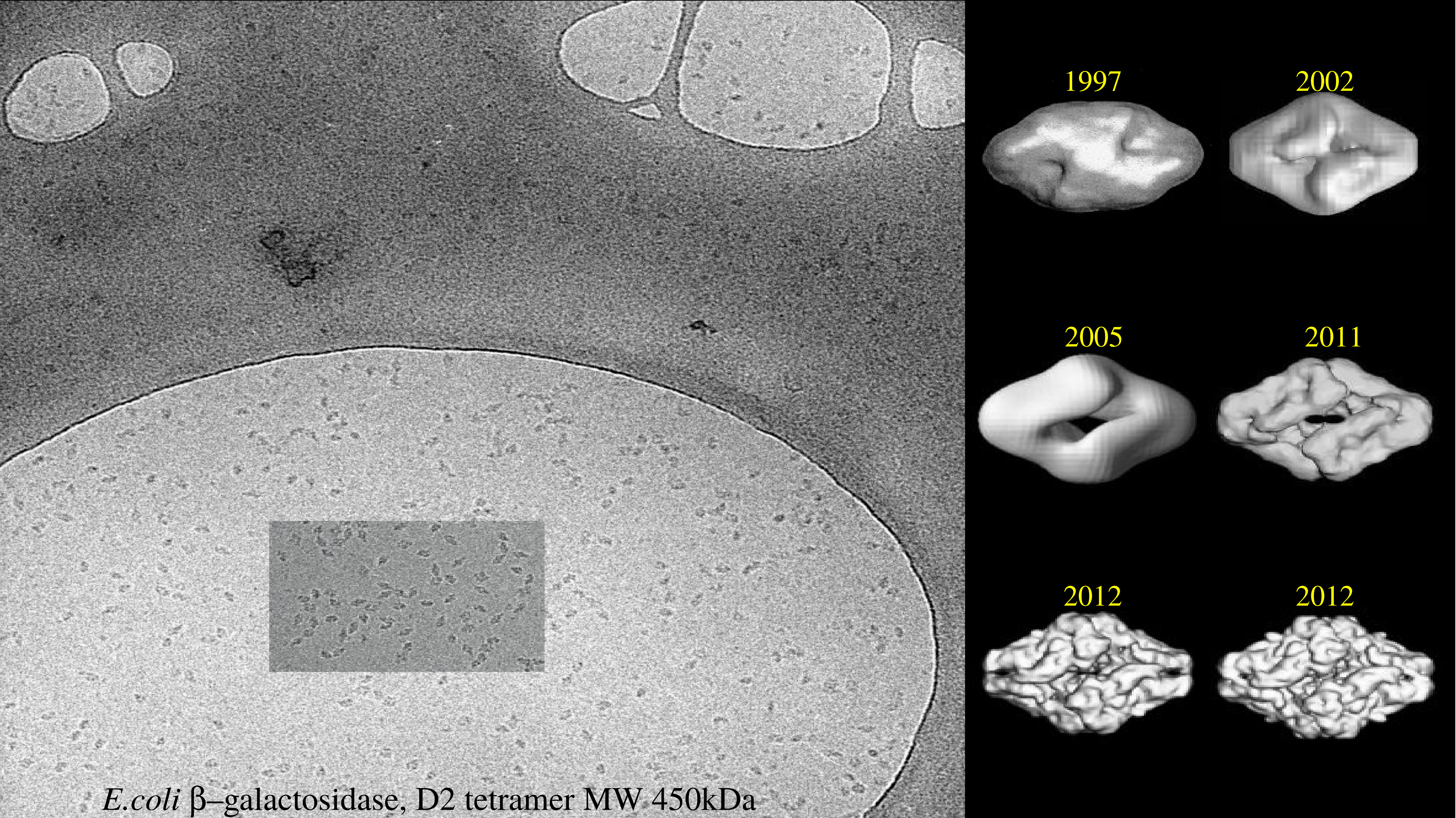

1997
2002
2005
2011
2012
2012
E.coli β–galactosidase, D2 tetramer MW 450kDa

Change is not all due to detectors

- Microscopes have improved.
- Reconstruction programs have improved.
- Improved computing allows things to be done correctly
- Lots more data
- Improved samples
- Expectations

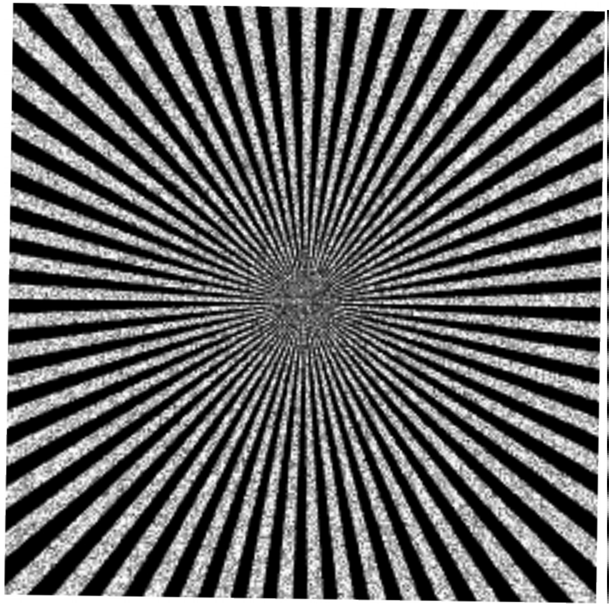
Detecting electrons

- Should be easy
  - 300 keV versus 1/40 eV room temperature
- Electrons are light and interact strongly:
  - Only lose small amount of energy each time
  - Long tracks
  - Random direction change

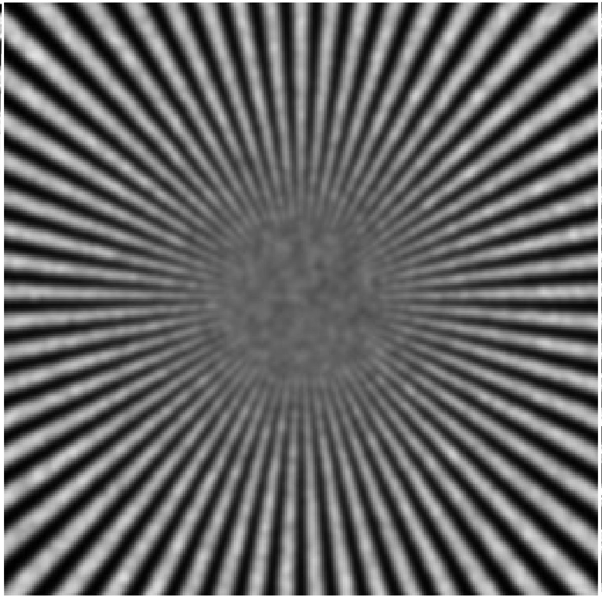
MTF/DQE

- DQE is the important property
- Unlike CCD detectors drop in MTF doesn't lose information (acts as low pass filter)

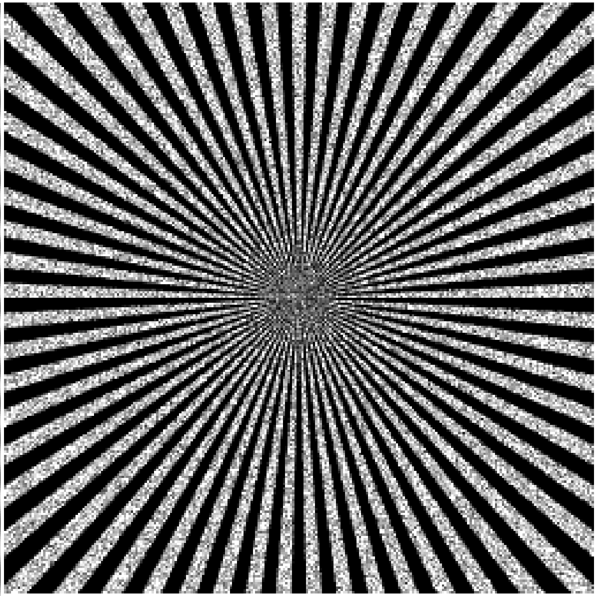
MTF: Poor MTF is not necessarily a problem



Original



MTF blur



Sharpened

Problems getting high DQE

- Variable energy deposition (Landau noise)
- Long trajectories with energy loss concentrated at the end as it slows down

Energy loss from high energy particles

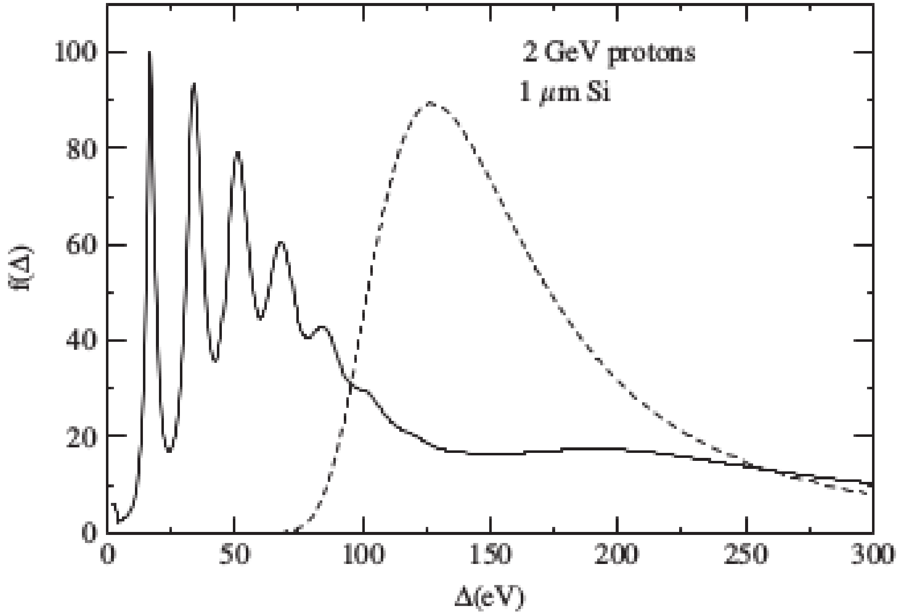
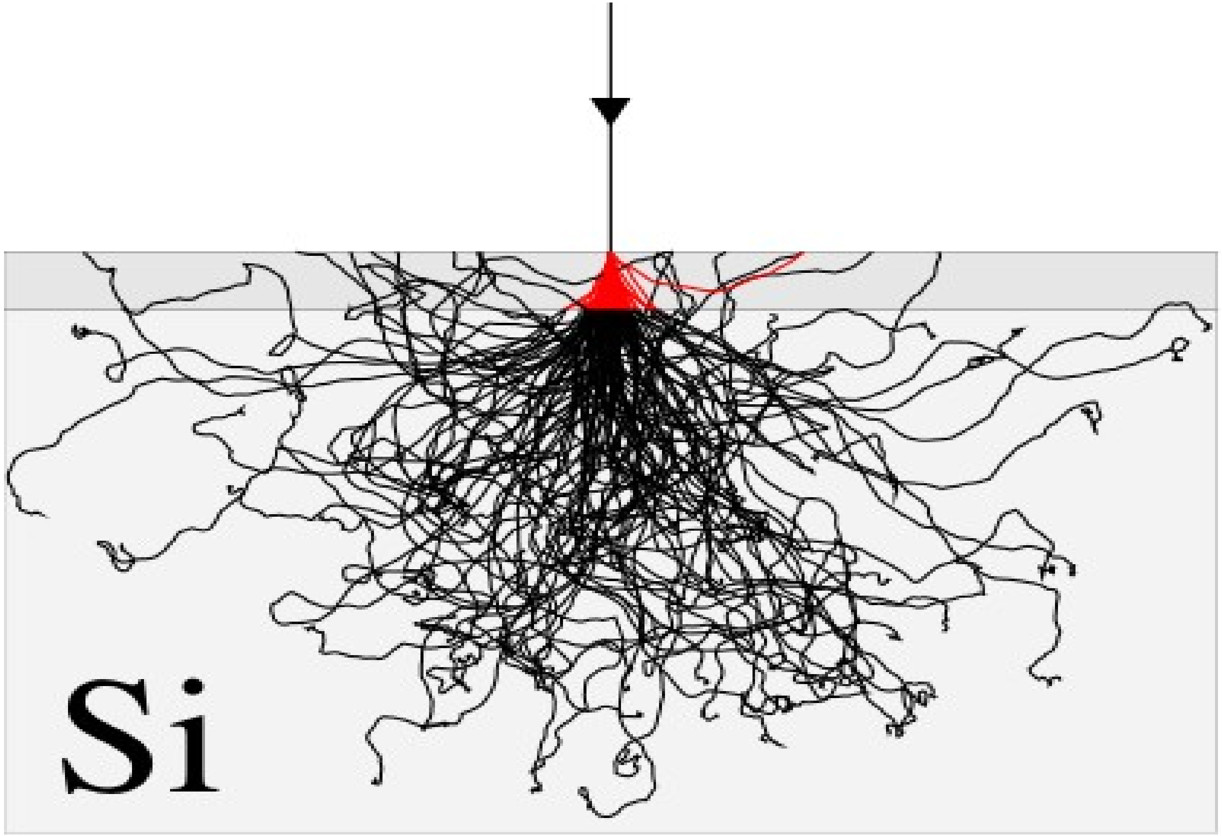


Fig. 2. Straggling in 1 μm of Si, compared to the Landau function. The Bethe–Bloch mean energy loss is $\langle \Delta \rangle = 400\,\mathrm{eV}$.

Bichsel *Nuclear Instruments and Methods A* ***562*** (2006) 154-197

300 keV electron trajectories in silicon



Monte Carlo simulation

Two problems:

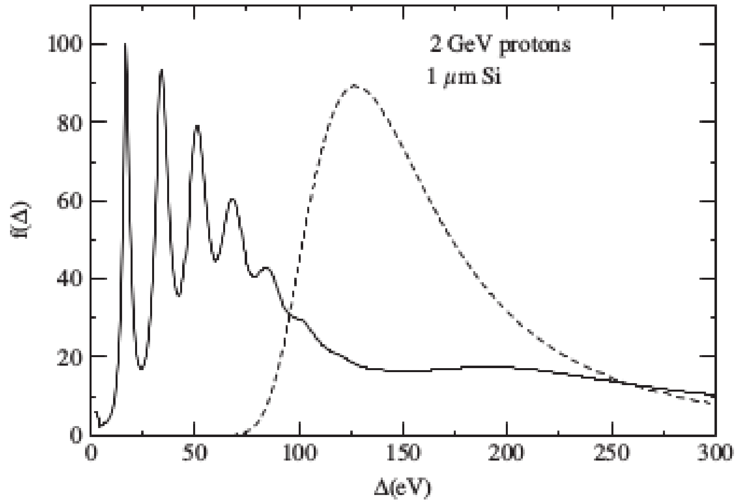
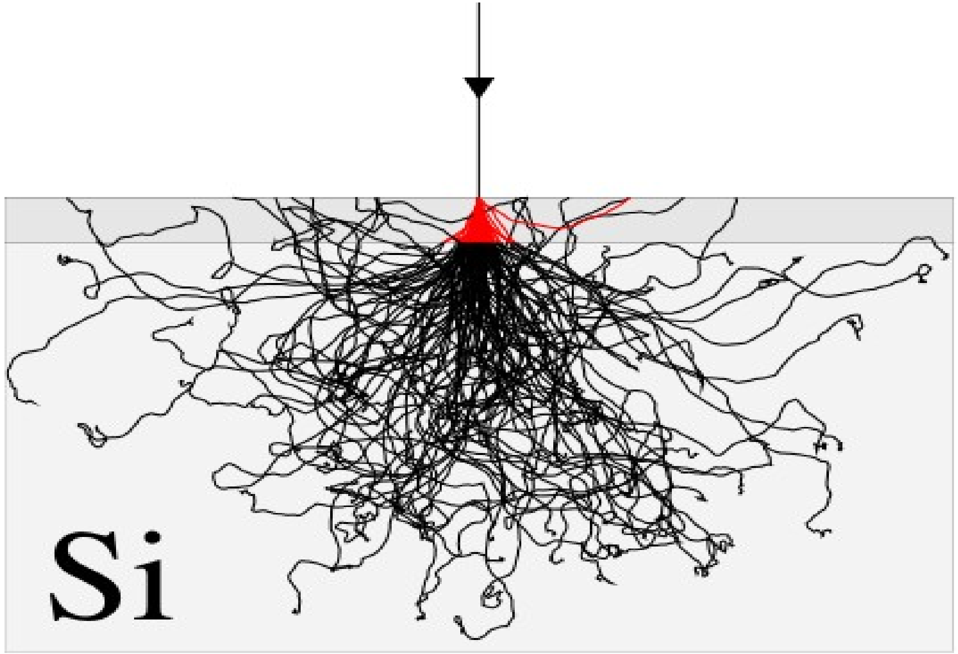


Fig. 2. Straggling in 1 μm of Si, compared to the Landau function. The Bethe–Bloch mean energy loss is $\langle \Delta \rangle = 400\,\mathrm{eV}$.



Solution 1: Hybrid pixel detectors

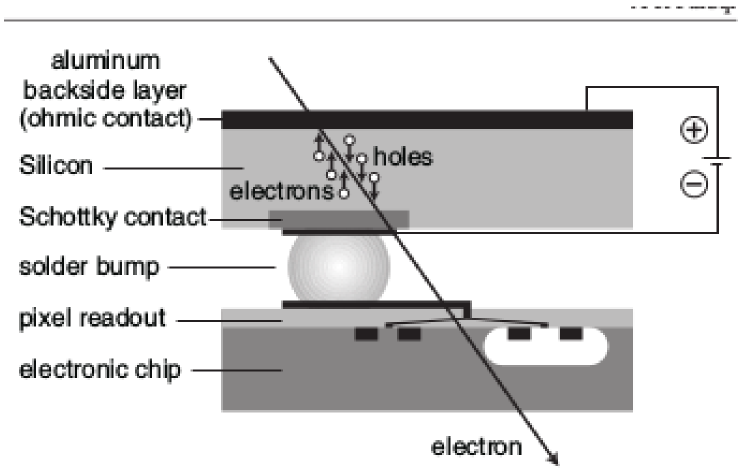
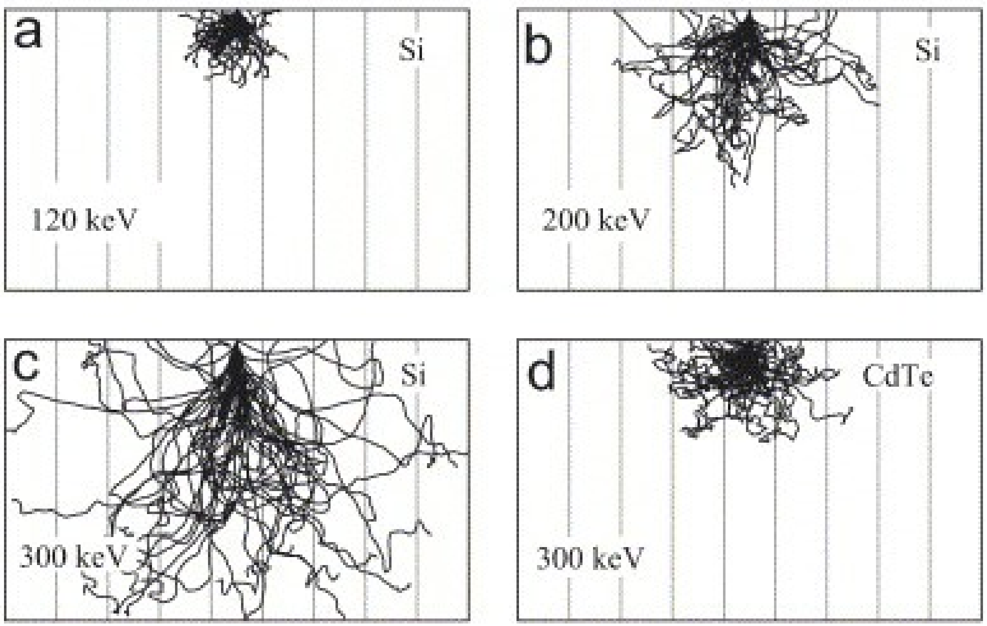


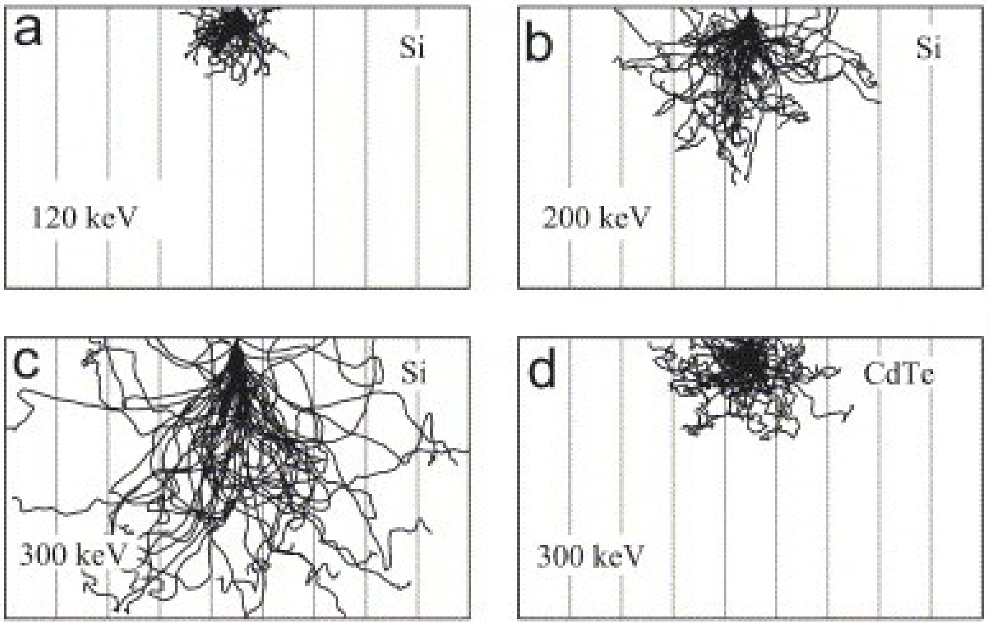
Figure 4. Schematic diagram of a single Medipix2 pixel with the sensor and readout separated by a bump bond. The aluminium layer forming the ohmic contact is only a fraction of 1 μm, making it more convenient for the detection of low energy electrons.

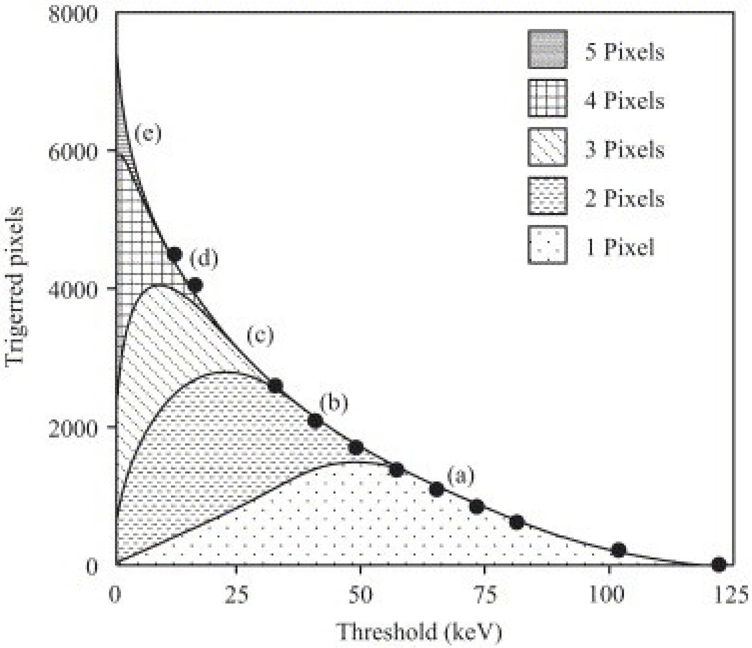


Faruqi *J.Phys.:Condens Matter* **21** (2009) 314004

Ultramicroscopy ***107*** (2007) 401-403

Problems with solution 1:



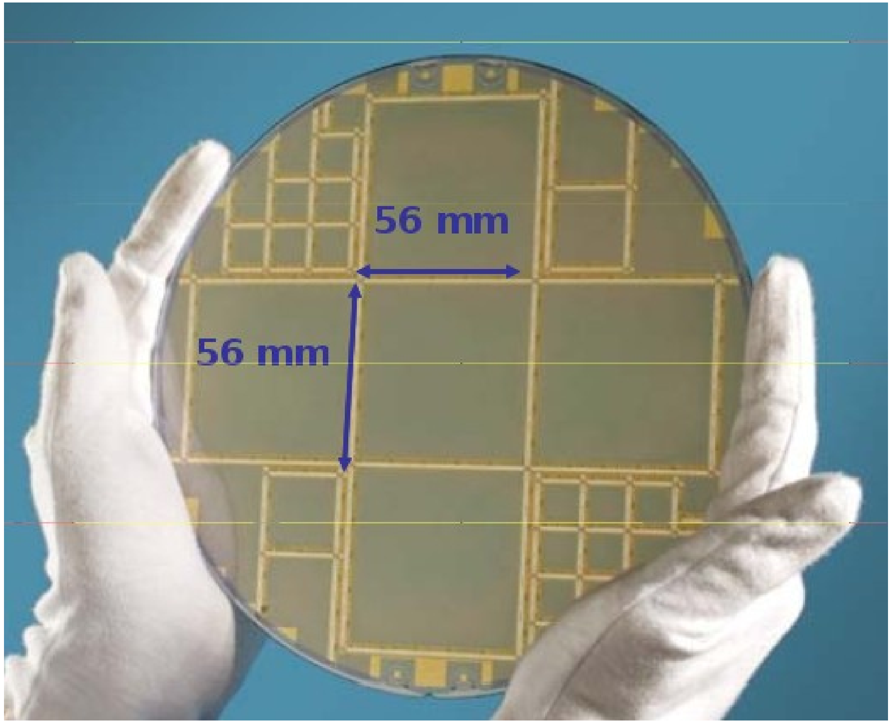


Ultramicroscopy ***107*** (2007) 401-403

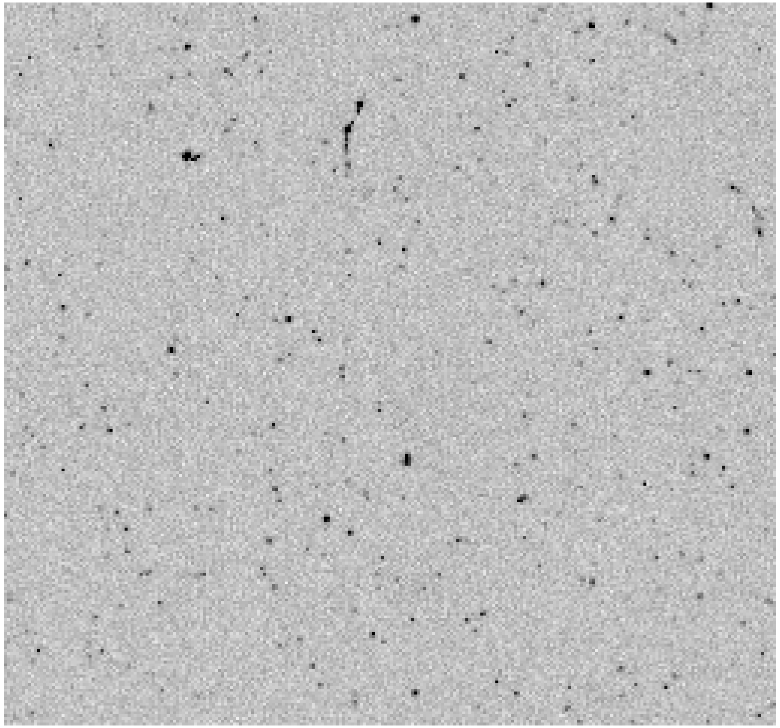
Hybrid pixel detectors

- Very fast
- Radiation hard
- Medipix III has event processing
  - Winner takes all.
- Several companies are in process of introducing them for EM.
- Best suited for low energy (< 100 keV)
- Medipix4 in the future

Solution 2: Backthinned MAPS detectors

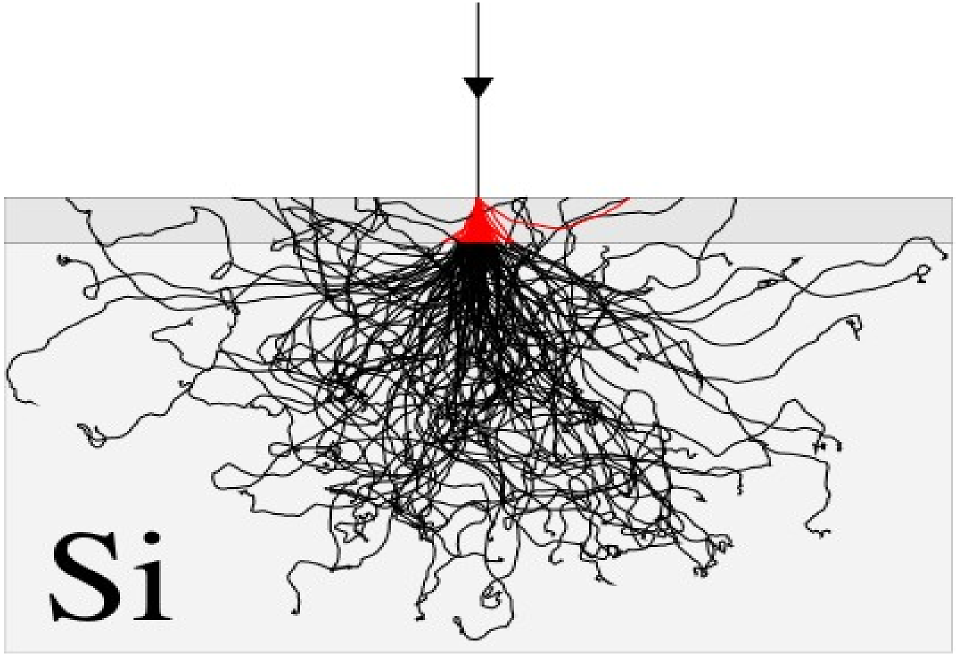


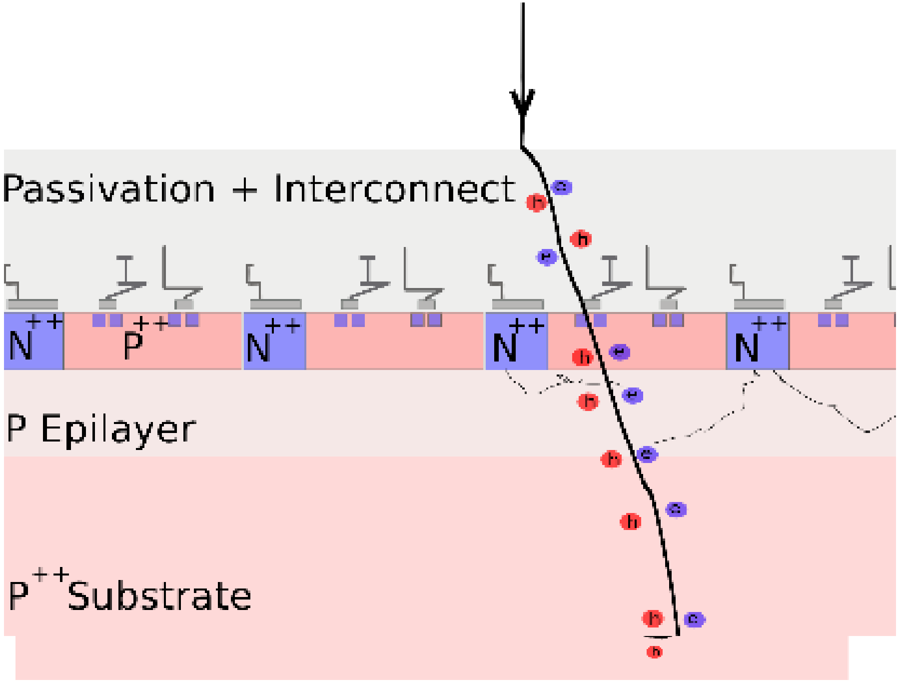
"Standard" CMOS technology



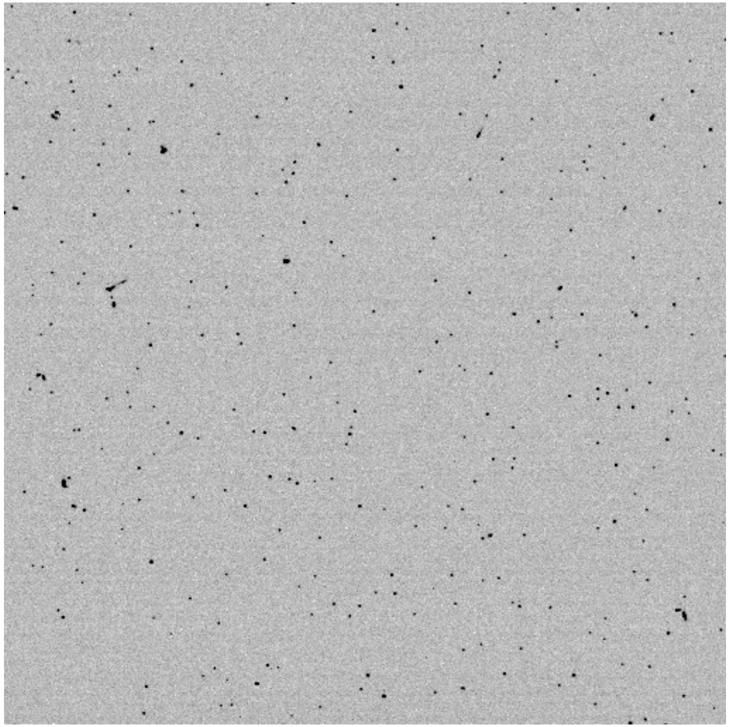
Large format with high sensitivity for electrons

Solution 2: Backthinning reduces track problem. (strong backscattered events)

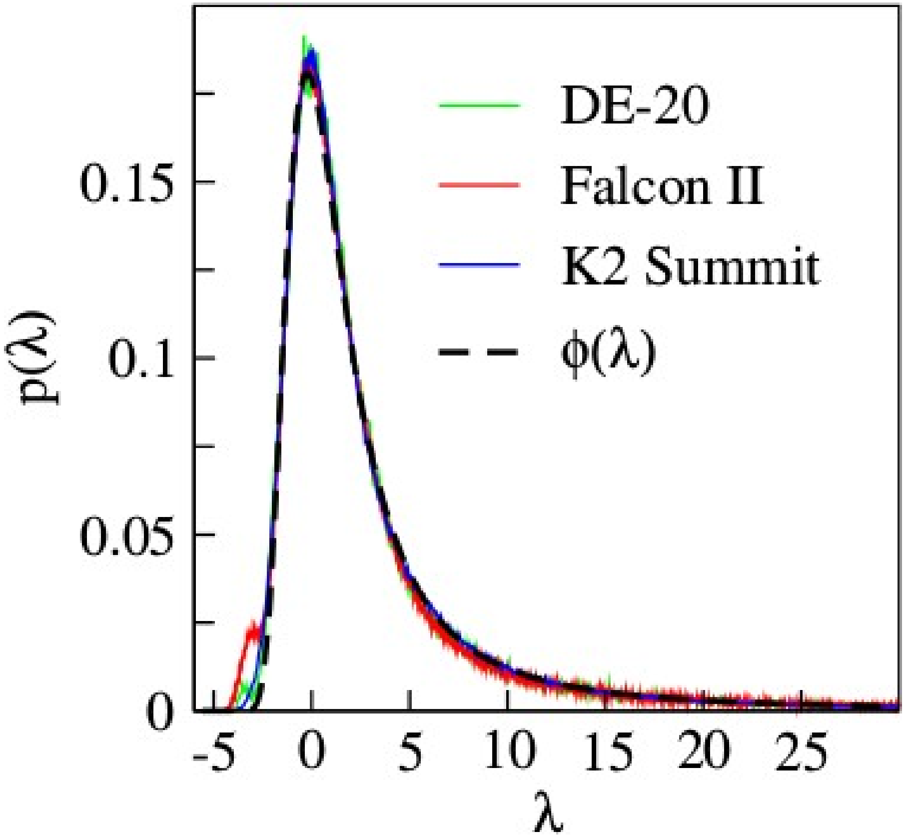




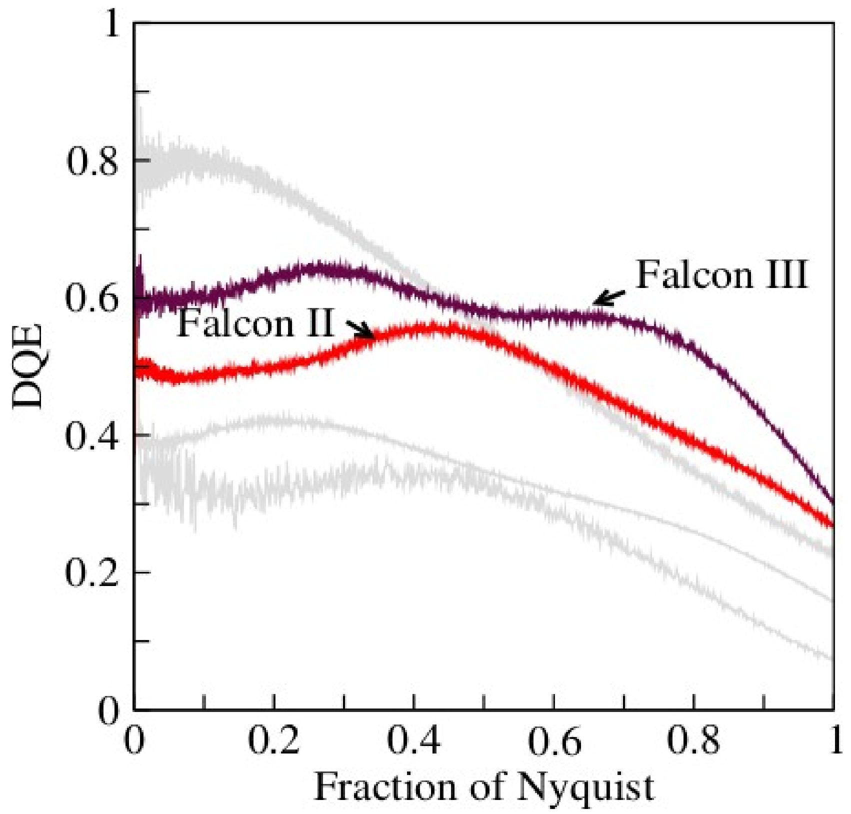
Still have Landau noise problem



Ultramicroscopy ***147*** (2014) 156-163



Landau noise limits integrating DQE



- DQE ~ 0.6 is the limit of an integrating detector
- Better performance at Nyquist than current counting detectors
- Faster data acquisition

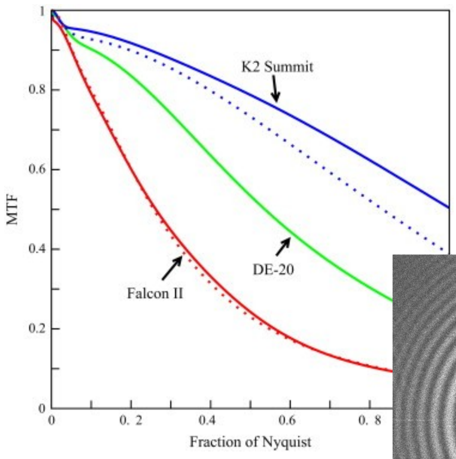
Future is counting

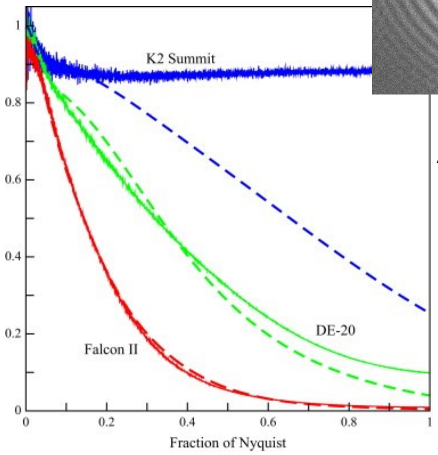
- Anything to improve images helps
- Gatan K2 currently counts
- DE and FEI are introducing products
- Two problems:
  - Even K2 is not fast enough
  - Performance at Nyquist frequency is poor

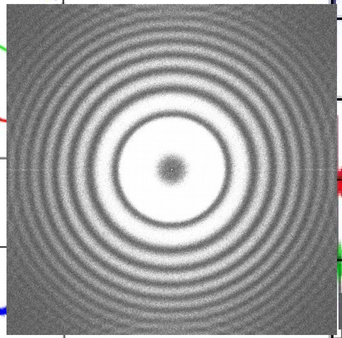
Speed is important

- Can not tell if an event is 1 or 2 electrons
- Can not tell with neighbouring pixel events if this results from 1 or 2 electrons
- Need 1 electron per 100 pixels in a frame
- Long exposures need drift correction
- Long exposures slow down data acquisition

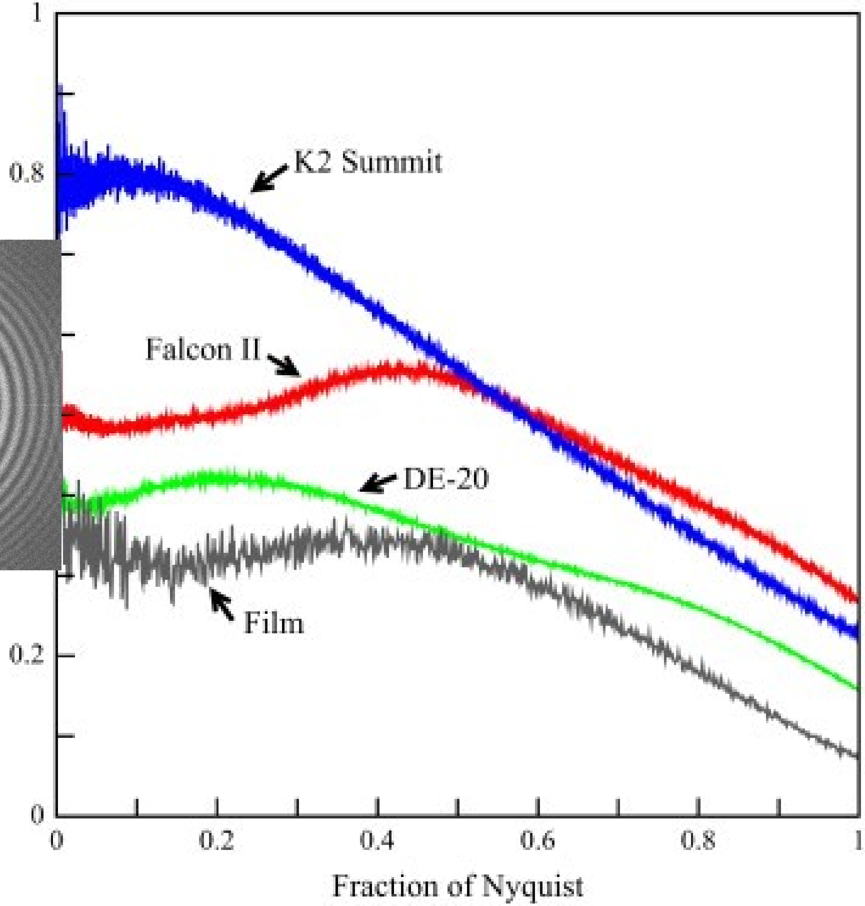
DQE ~ MTF^2/NPS



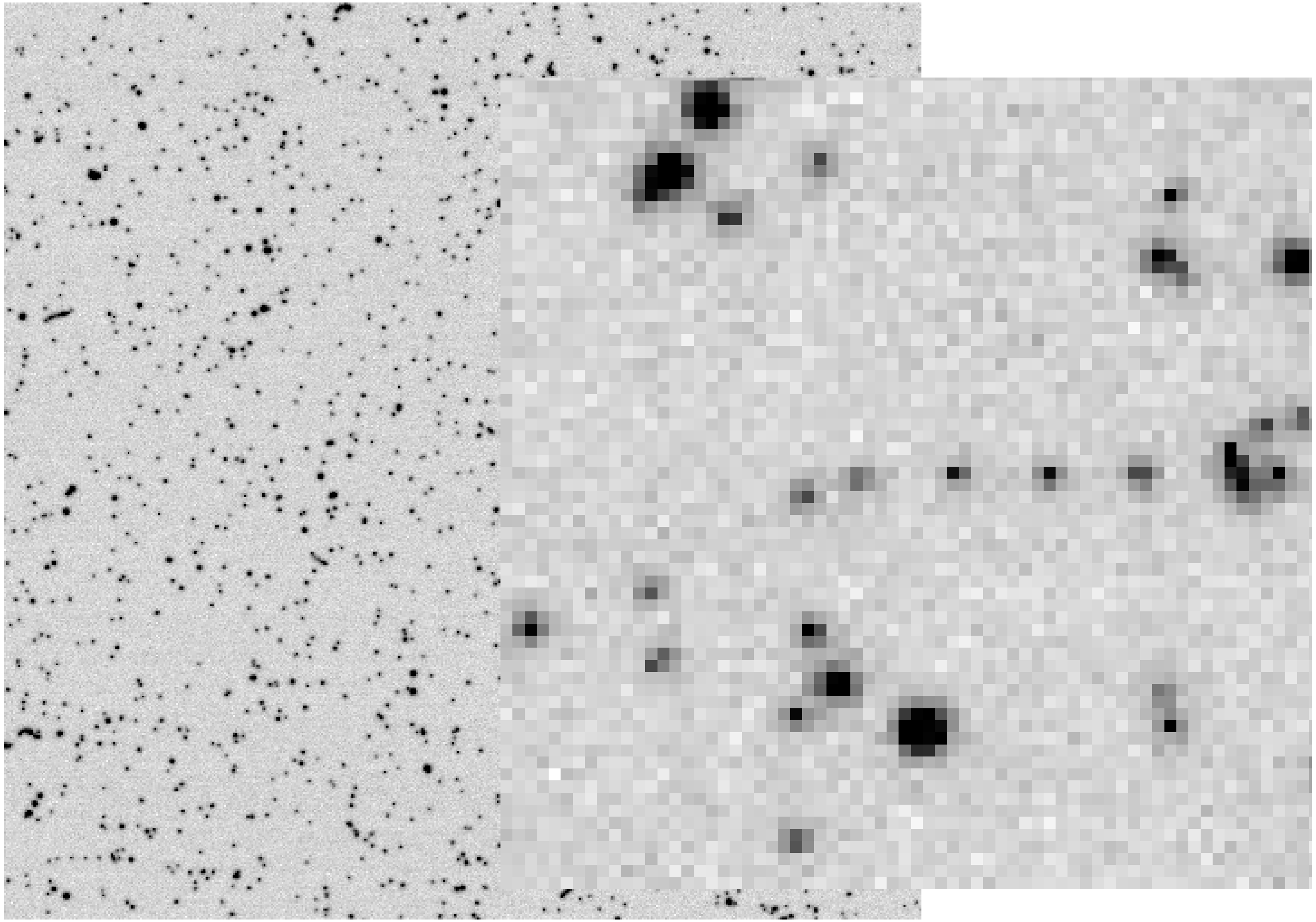


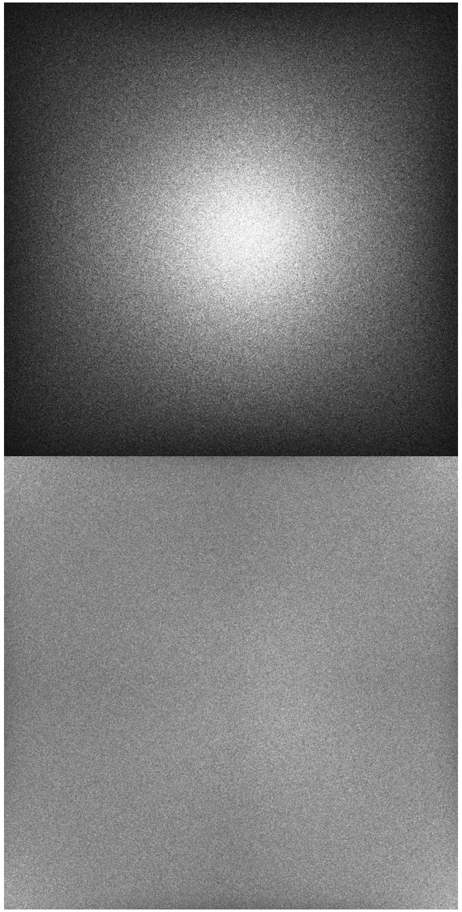


Aliasing



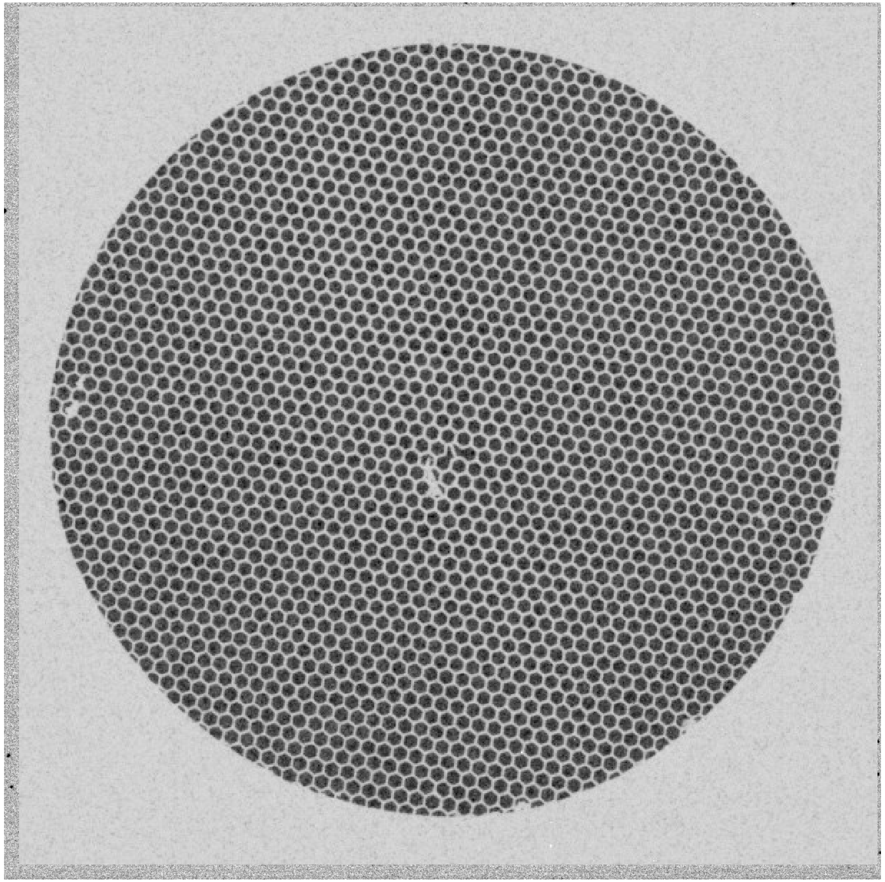
Improving Nyquist frequency performance

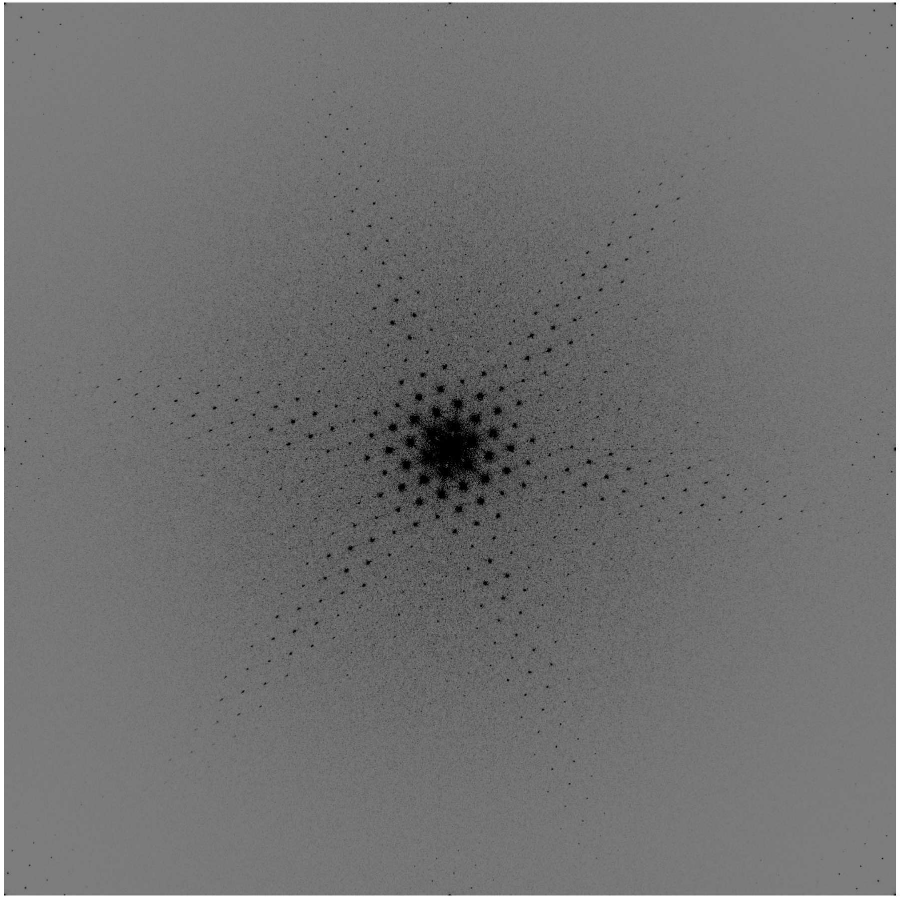




Inferred incident electron position within pixel

Showing improved performance





Direct detectors

- Better images
- More images
- Movie processing
- Optimal exposures
  - CTF determination
  - Particle picking
  - Radiation damage weighting

Future is Counting (but)

- Currently Gatan K2 summit is the only detector fast enough but still too slow.
- Nyquist frequency performance is too low. Getting the best DQE requires high magnification with small field of view
- Better performance is possible
  - when and how much will it cost

Thanks

MRC Laboratory of Molecular Biology

- Richard Henderson
- Wasi Faruqi
- Vinoth Kumar
- Jake Grimmett
- Toby Darling
- …

Help from

FEI™