High resolution photon and neutron imaging options with MCP/Timepix event counting detectors

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MCP particle counting detector configuration

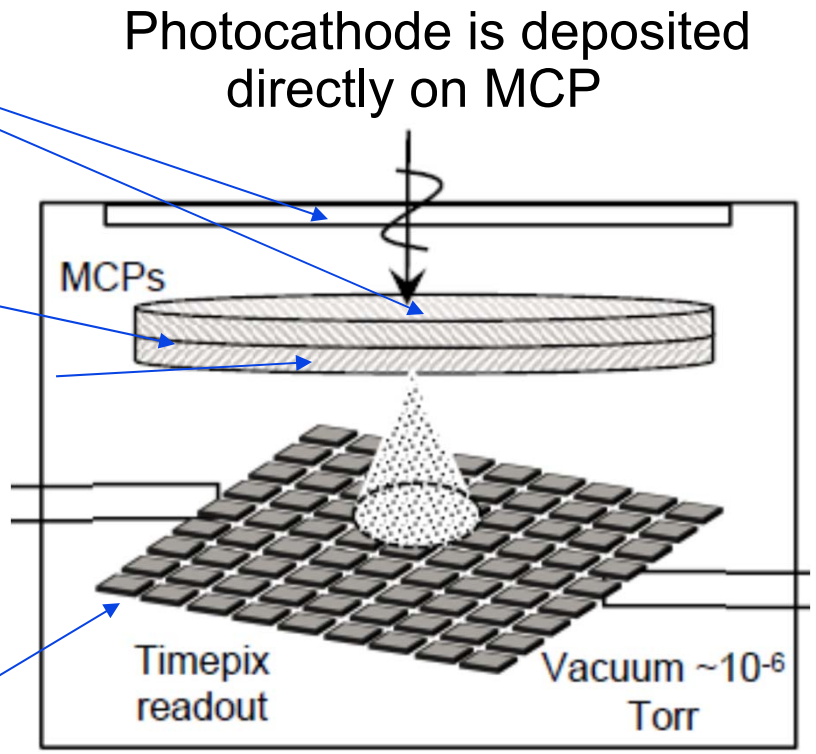
Photocathode converts photon to electron

Neutrons are absorbed in the MCP glass (B10 capture reaction)

MCP(s) amplification: 10^3 to 10^7

Rear field accelerates electrons to readout

Different readouts can be used, optimized for particular application



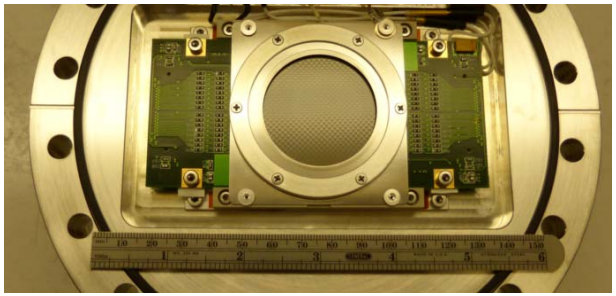
No ideal detector fitting all applications.
Compromises are always to be found.

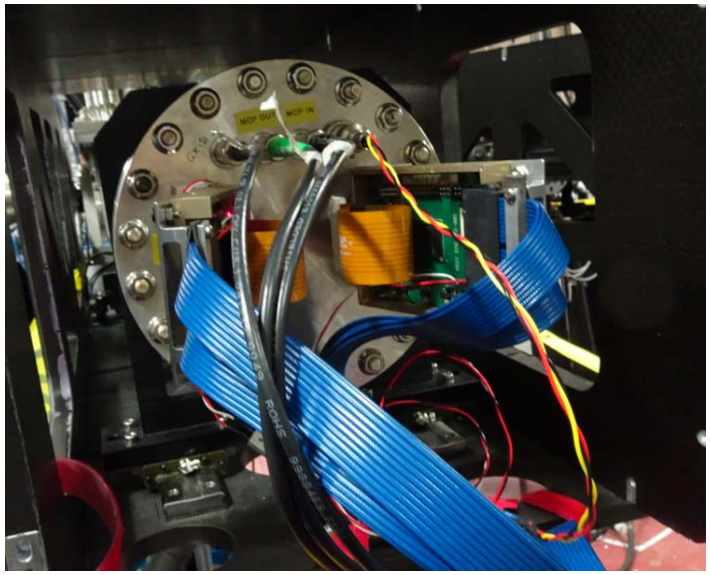
Pixelated readout for MCP detectors

- **Simultaneous events can be detected (up to ~25000).**
- **The same detector: event counting or frame-based imaging.**
- **Operate at low gains (10^4-10^5).**
- **Can operate at very high counting rates exceeding 100 MHz/cm^2 (55 μm resolution) or at rates of ~2-3 MHz per 2x2 Timepix readout with resolution of <10 μm.**
- **Analog amplification in pixels, only digital signals read out.**
- **No readout noise**
- **Very uniform readout (lithographic processing) – no image distortions.**

Detector hardware implementations

Soft X-ray detector for synchrotron applications
Mounted on 8” Conflat flange





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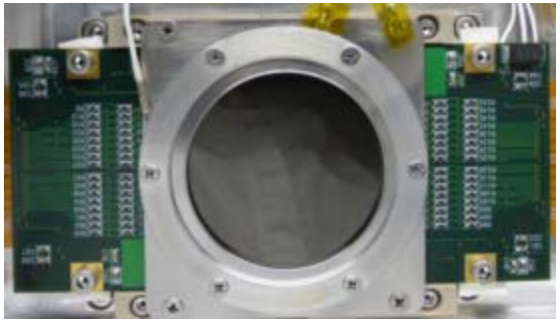
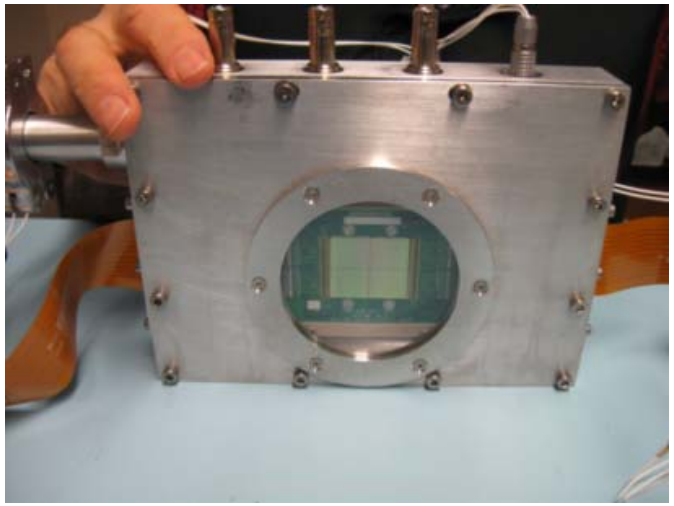
Neutron detector
Aluminium vacuum enclosure





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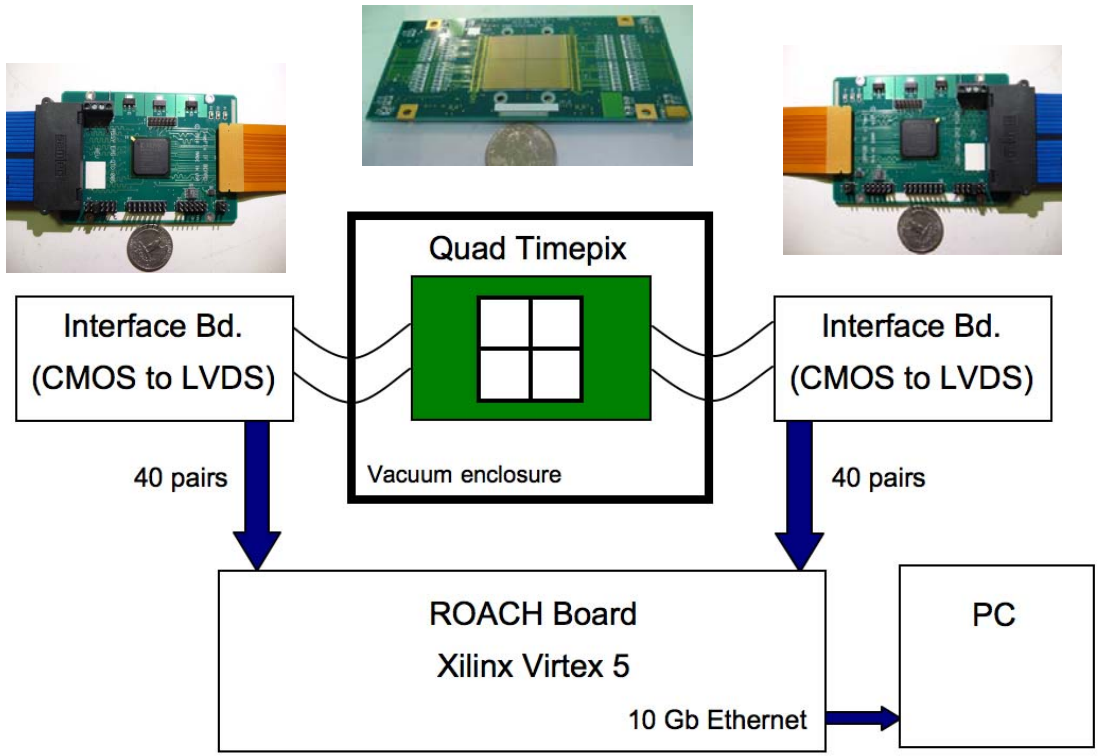
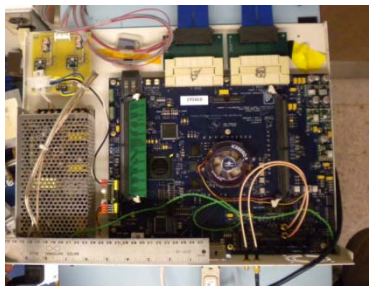
MCP detector with 2x2 Timepix readout

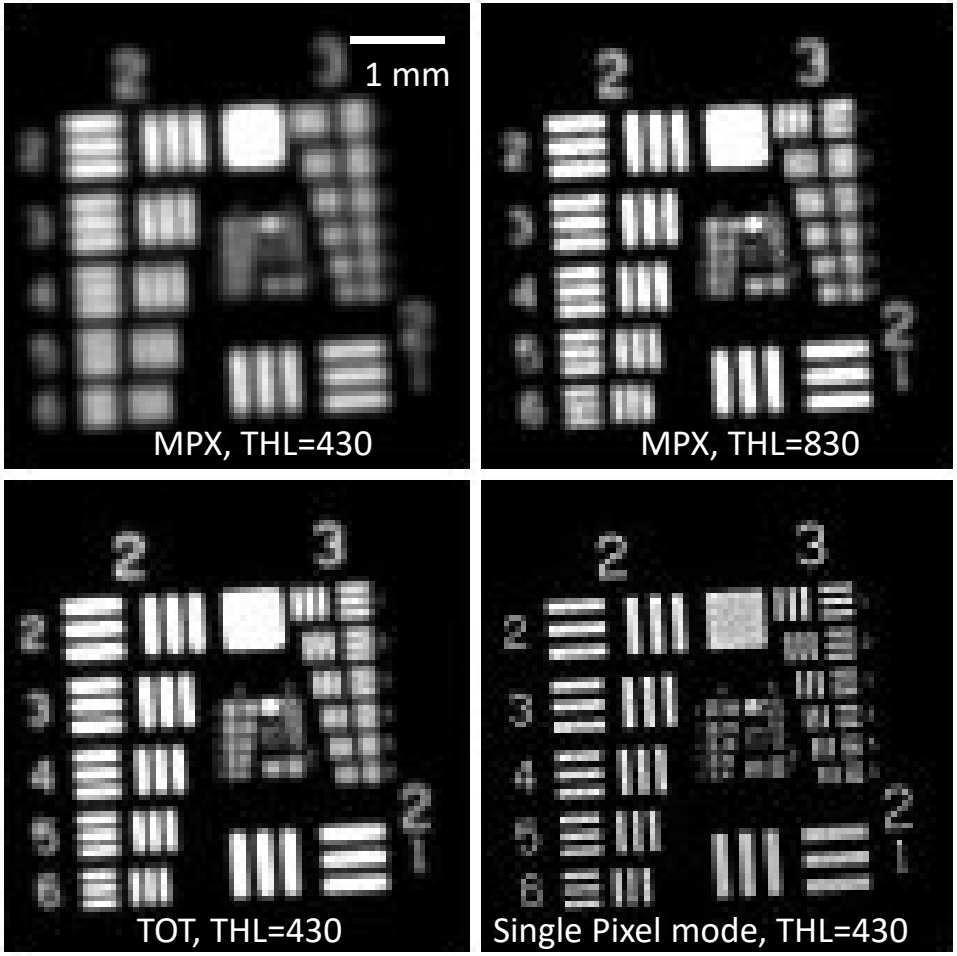




- Up to 1200 frames/sec
- Readout time ~310 μs
- 3 acquisition modes.
  Each pixel provides either:
  - Event counts
    (image integrated
    on the chip)
  - Time of event
    (up to 10 ns accuracy)
  - Charge accumulated
    in a pixel (ToT mode)

Events counted with 55 μm resolution

MPX image Low THL



MPX image High THL

TOT image

Single pixel Image.

Event counting with 55 μm resolution

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High spatial resolution through event centroiding

Spatial resolution in native mode is limited to readout pixel size of 55 μm

Event centroiding can be implemented as in many other MCP readouts (e.g. cross strip).

Sub-pixel resolution, as high as ~1-2 μm can be achieved by the Timepix readout.

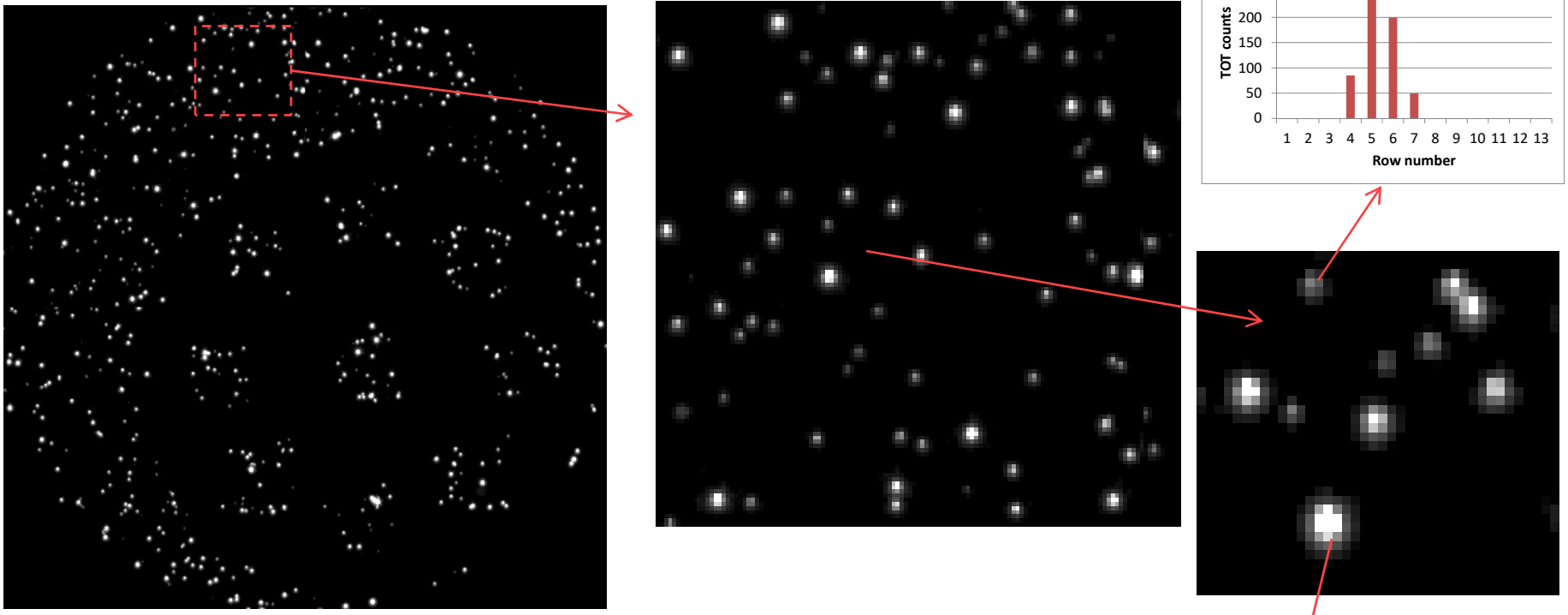
Detector resolution is limited by the size of the MCP pore.

Commercial MCPs with 5 μm pores on 6 μm centers readily available (photon detection). Neutron MCPs with 8 μm pores on 11 μm centers .

No need to change anything in the detector hardware.

Count rate is limited as single events need to be separated from the neighbors.

High spatial resolution through event centroiding



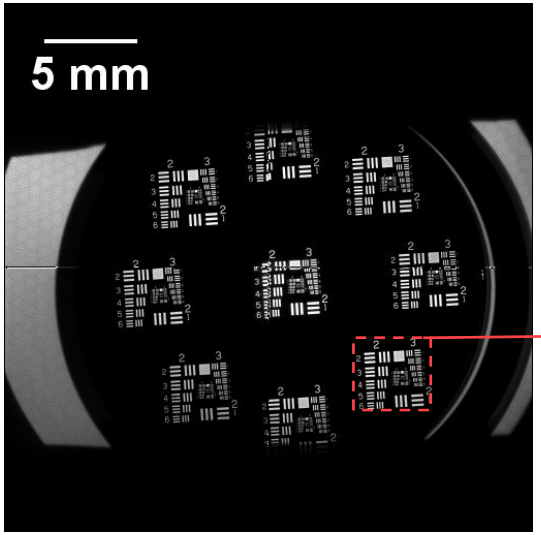
Each pixel measures charge accumulated in a frame (Time Over Threshold method)

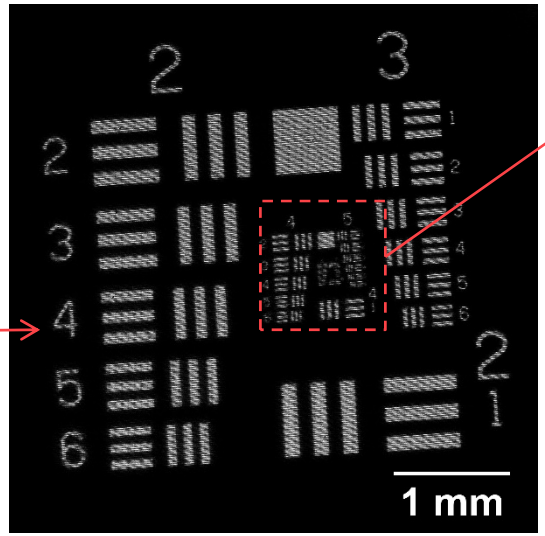
Only one event per pixel is allowed in a frame

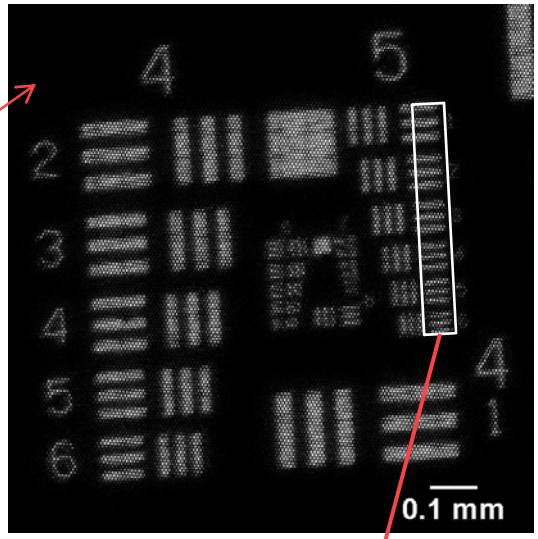
Event-driven mode for Timepix3/Timepix4 detectors

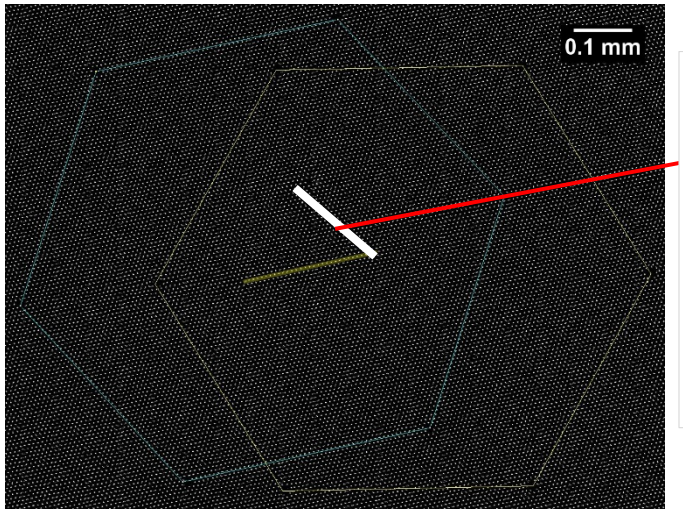
High spatial resolution through event centroiding

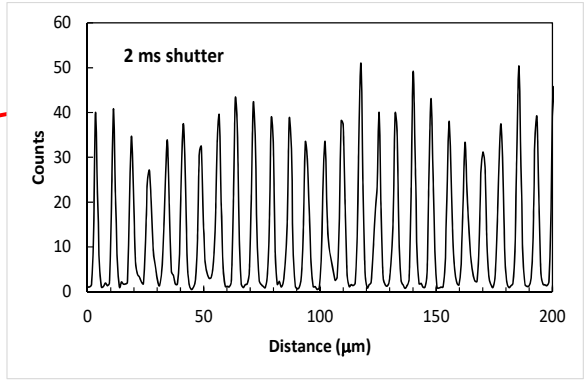
High resolution imaging with resolution ~ 6 um MCP pores

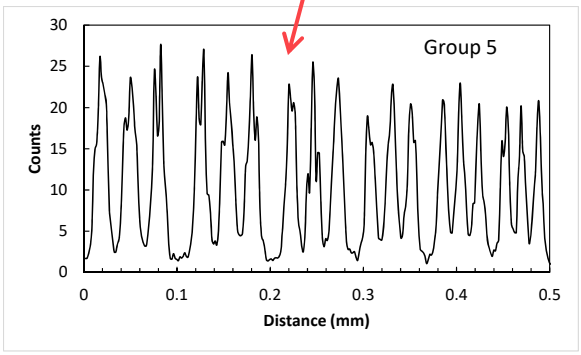








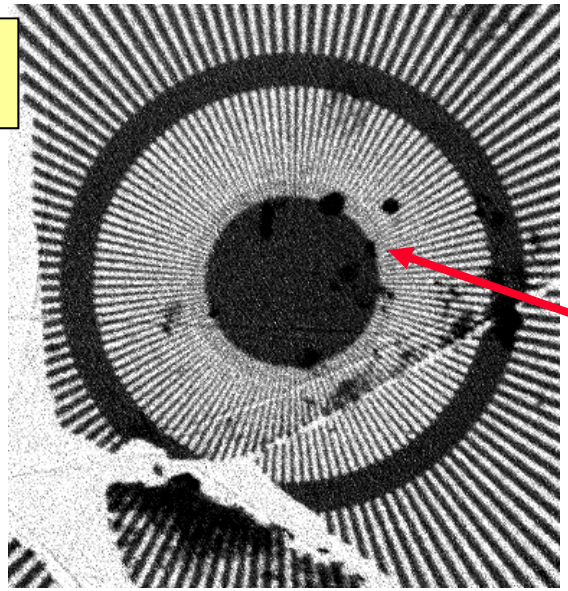




Readout resolution ~2 µm FWHM

Neutron radiography with high spatial resolution

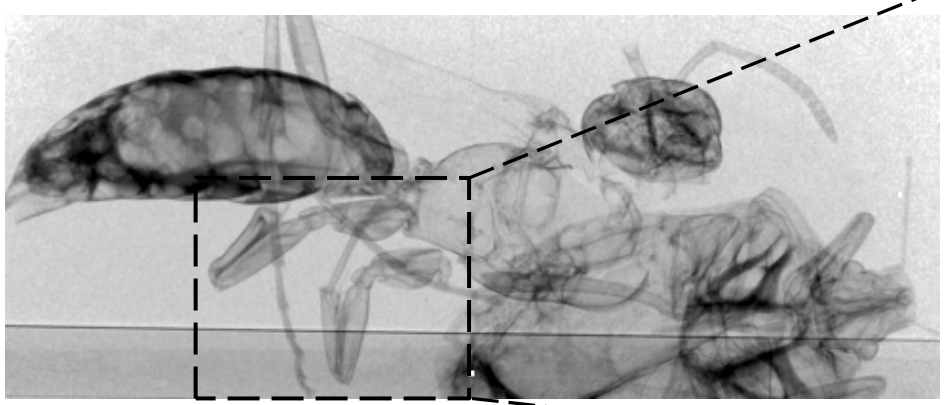
Broken Siemens star resolution mask



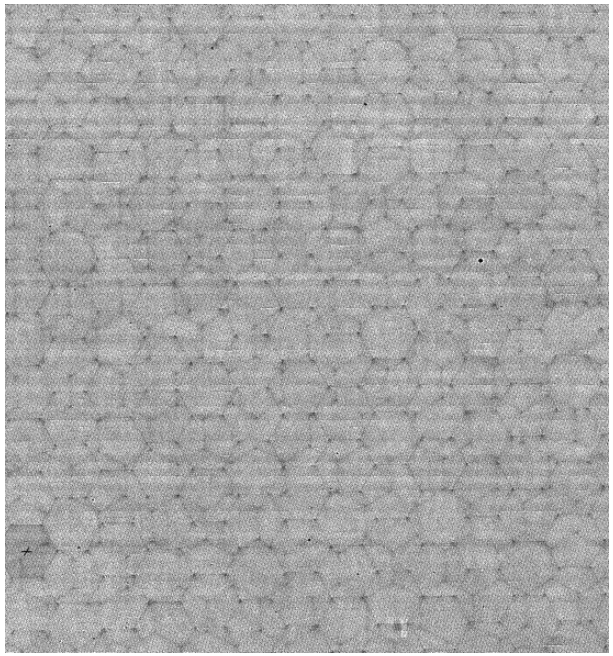
Measured at ORNL CG1D neutron imaging beamline

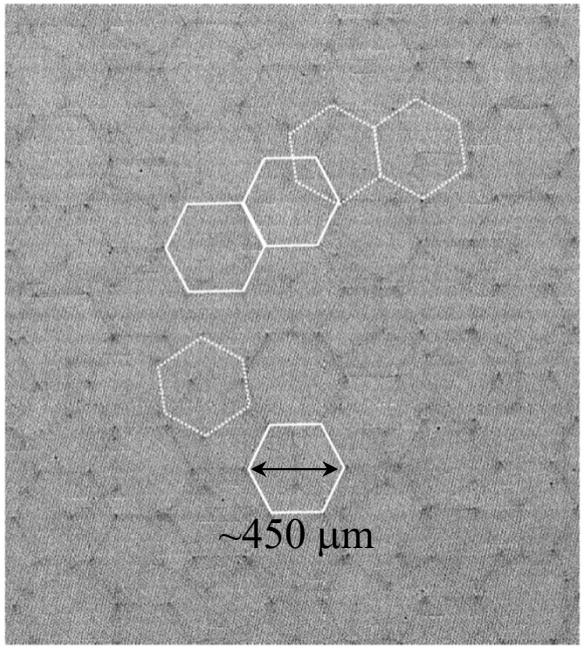
Resolving ~12 μm features (25 μm per line pair here)

Event centroiding is done in real time, no raw data storage!

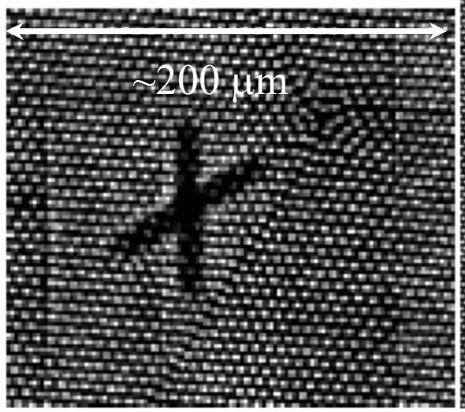


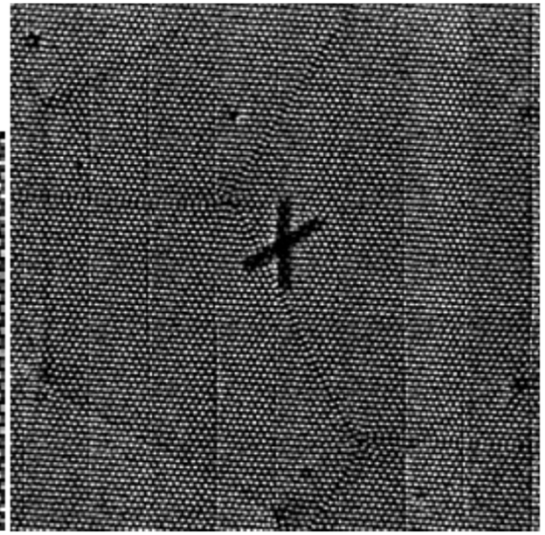
High resolution through event centroiding





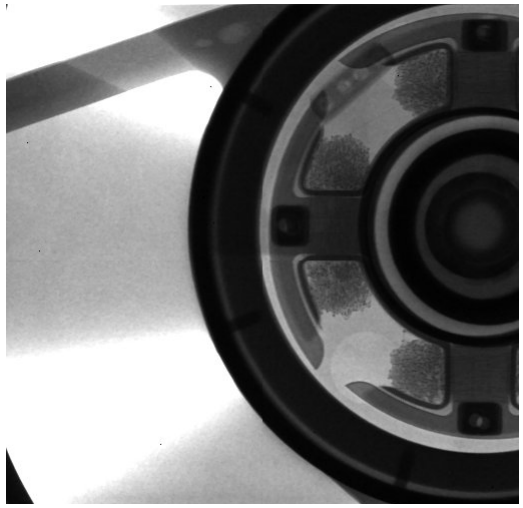
Multifibers from both MCPs are visible



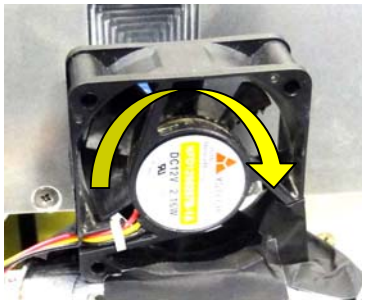


Dots in the image are single pores (5 μm diameter, ~6 μm hex spacing)

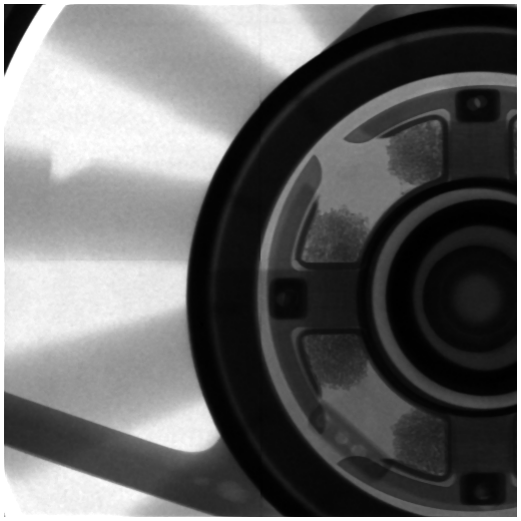
Imaging of dynamic processes: dynamic neutron radiography



Stationary PC cooling fan

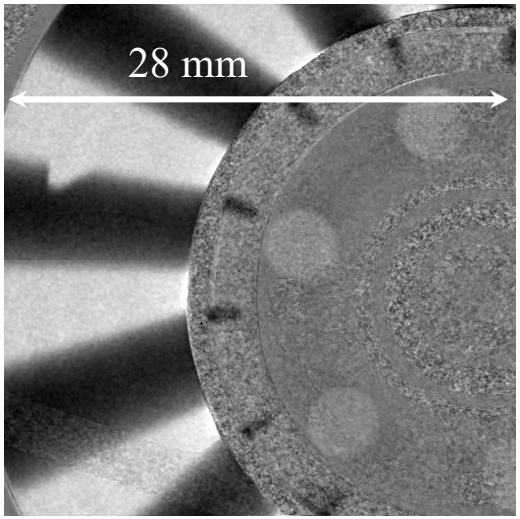


The spinning components are enhanced by normalization of a stationary image by the image of a spinning fan



A time slice of 38.4 μs width.

A "frozen" image of a spinning fan.



A time slice of 38.4 μs width.

Only spinning components are visible here.

This time time slice is normalized by the long integration image of a spinning fan.

All phases of a periodic process are images at the same time!

Summary

- MCP detectors provide unique opportunities in applications where event counting with high spatial and time resolution is required.
- Specific type of MCP detector configuration has to be selected for a particular application.
- High spatial resolution is achieved by event centroiding. Currently the MCP geometry determines the detector resolution (5 μm pores on 6 μm centers).
- Event-driven Timepix3 and Timepix4 readout (as opposite to frame-based Timepix) should allow higher event counting rates.
- Dynamic processes can be studied: time-tagging of each detected particle enables measurement of dynamical phenomena and to image numerous phases of a repetitive process.

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