MCP/Timepix soft X-ray event counting detectors

A.S. Tremsin

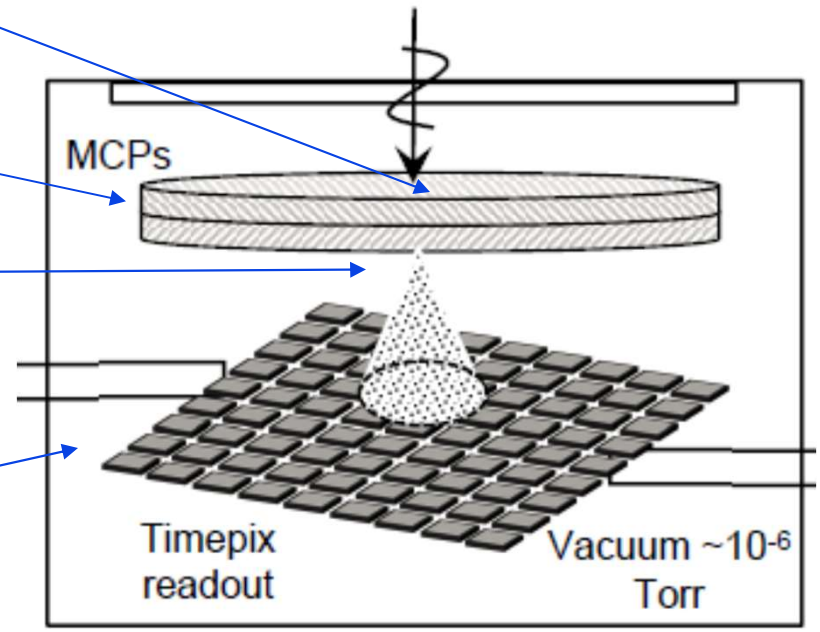
Space Sciences Laboratory,
University of California at Berkeley

Berkeley, CA 94720, USA

MCP detector configuration for soft X-ray applications

- Photocathode converts photon to electron
- MCP(s) amplify electron by 10^3 to 10^7
- Rear field accelerates electrons to readout
- Different readouts can be used, optimized for particular application

Photocathode is used for **photon** detection



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

MCP detectors vs conventional imaging devices

MCP detectors

- **No readout noise**
- **High detection efficiency (neutrons, soft X-rays)**
- **Time and position for every detected particle** (~10-30 µm and ~10-100 ps, photons, electrons, ions, alphas; <0.5 µs thermal, ~10 ns epithermas neutrons)
- **Event counting**
- **TOF applications**
- **High counting rates** possible with latest readouts (~1 GHz no timing resolution, >20 MHz with timing resolution)

- **No intrinsic energy resolution**
- **Small area**
- Require **vacuum**
- Require **high voltage**
- **Image distortions**

Frame-based devices (CCD, image intensifiers)

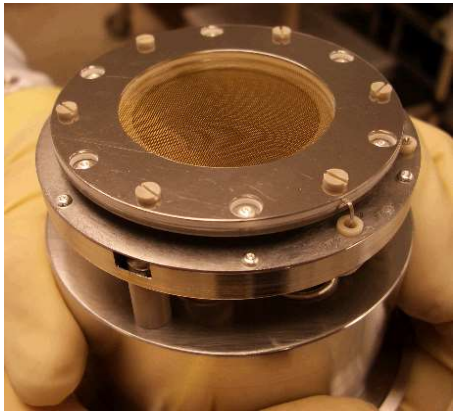
- **Reconfigurable active area**
- **No high voltage**
- **No vacuum**
- **Commercially available sensors**, well established technology
- **Easy to operate**
- **Very uniform response in active area**

- **Readout/dark noise**
- **Stroboscopic mode in TOF experiments**
- Limited **time resolution**
- **Cooling required**

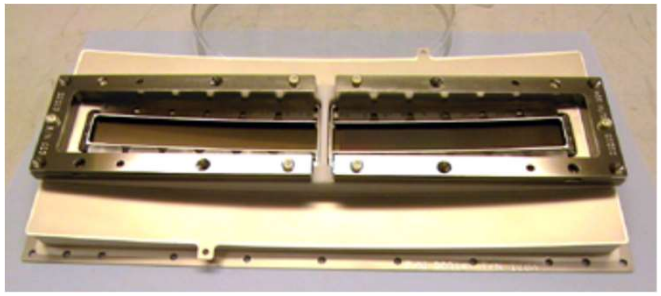
Highly generalized

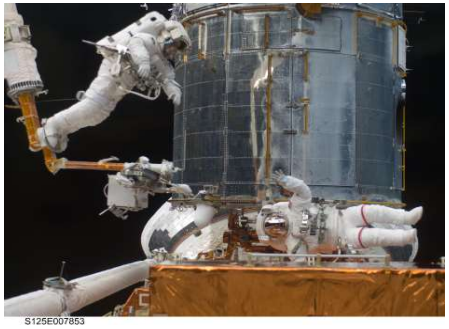
Detector hardware implementations by Space Sciences Laboratory (UCB)

Synchrotron beamline detectors:
ARPES – angular resolved photoelectron emission spectroscopy

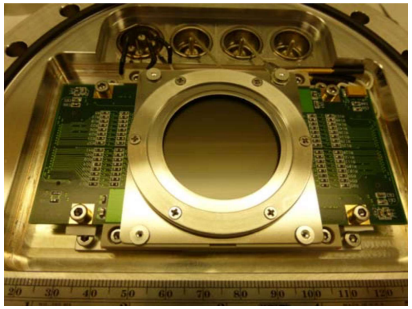


COS detector
Installed on Hubble telescope

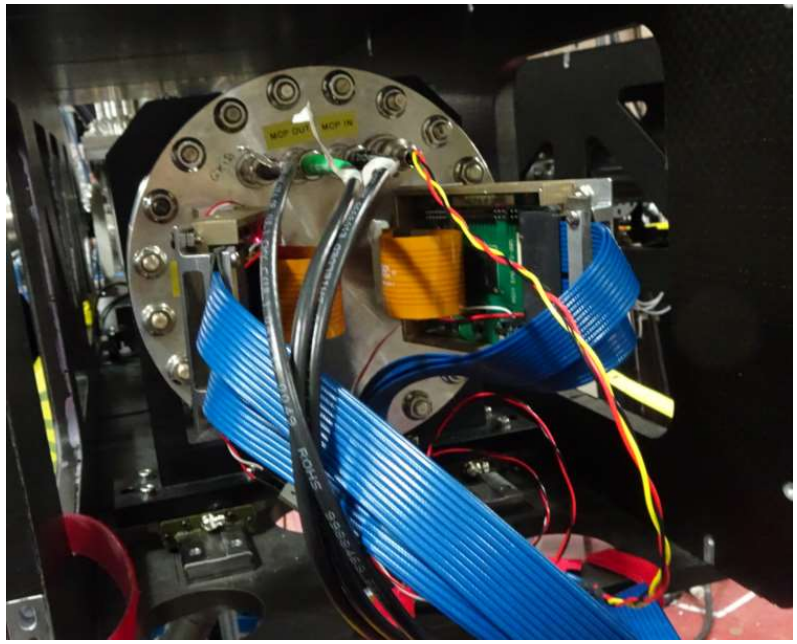




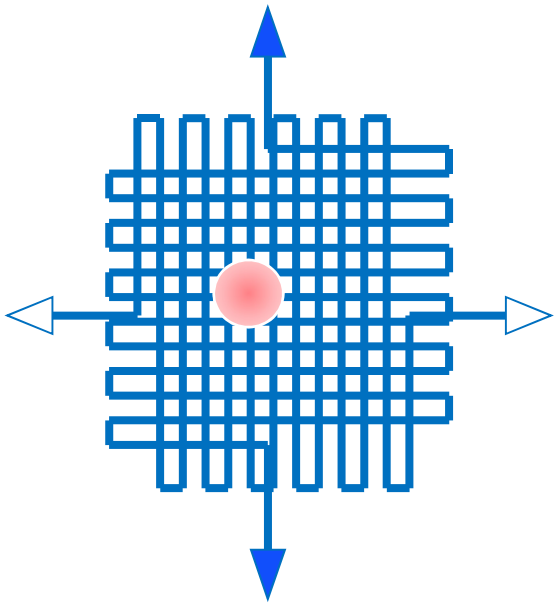
NASA Shuttle STS-125 Mission



BL8 RIXS detector, 2018

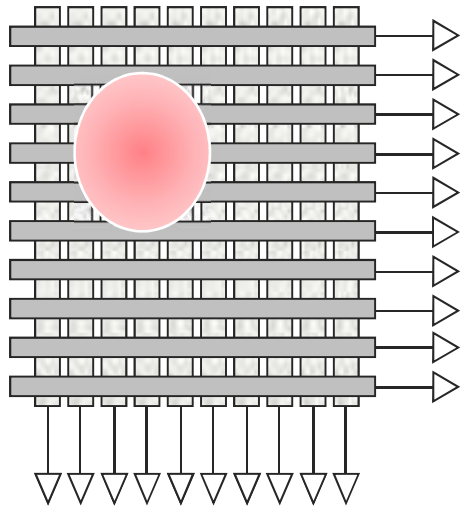


Readout types



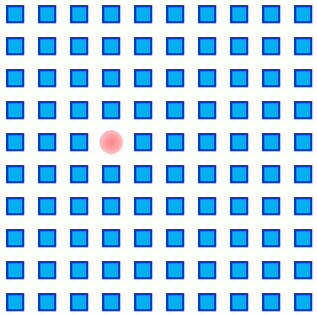
Cross Delayline (XDL)

4 amps
Gain ~ 10^7
Rate < 1MHz
Δt ~ 50 ps rms



Cross Strip (XS)

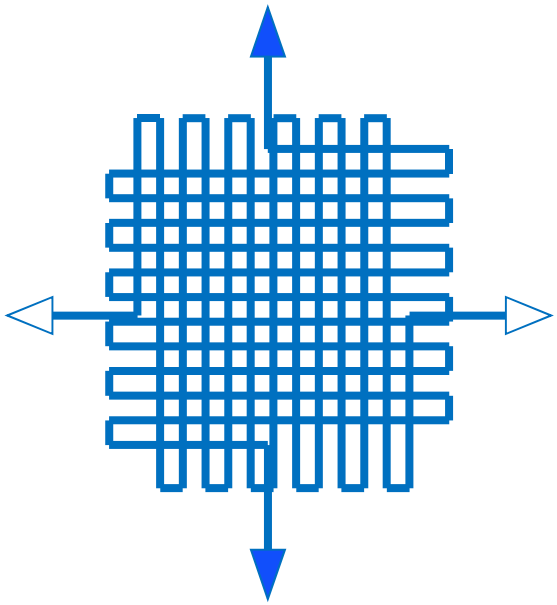
2 x N amps
Gain ~ 10^6
Rate < 5MHz
Δt ~ 100 ps rms



Medipix/Timepix ASIC

N x N amps
Gain ~ 10^4-10^5
Rate > 500MHz
Δt ~ 10 ns - 1 ms

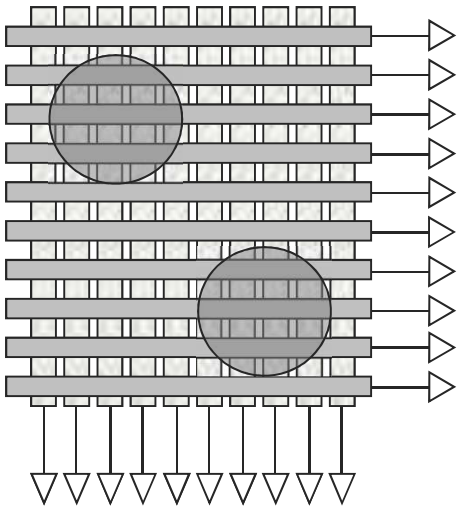
Readout types



Cross Delayline
(XDL)

Single particle processed

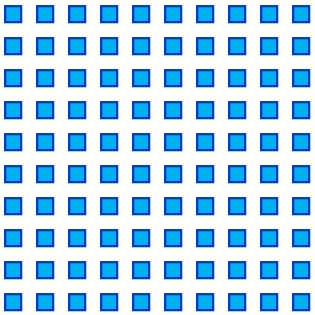
Dead time 200-300 ns



Cross Strip
(XS)

Single particle processed

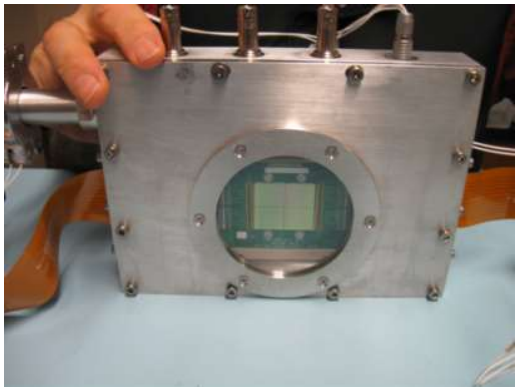
Dead time ~300ns
only for active fingers

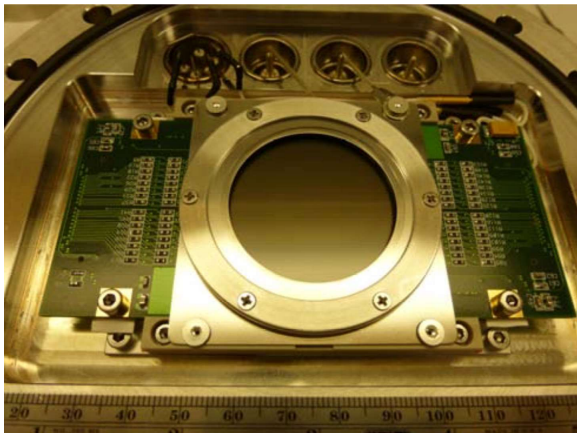


Medipix/Timepix
ASIC

Multiple events detected
(up to 25000)
1200 frames/s
Timepix3 –
80 MHits per chip

MCP/Timepix detector configuration: Gen. 2





MCPs

64 data lines @100 MHz

FPGA

~1.8 Mb/frame, up to 1200 frames/s

Timepix readout

Vacuum ~10^{-6} Torr

64 data lines @100 MHz

FPGA

~1.8 Mb/frame, up to 1200 frames/s

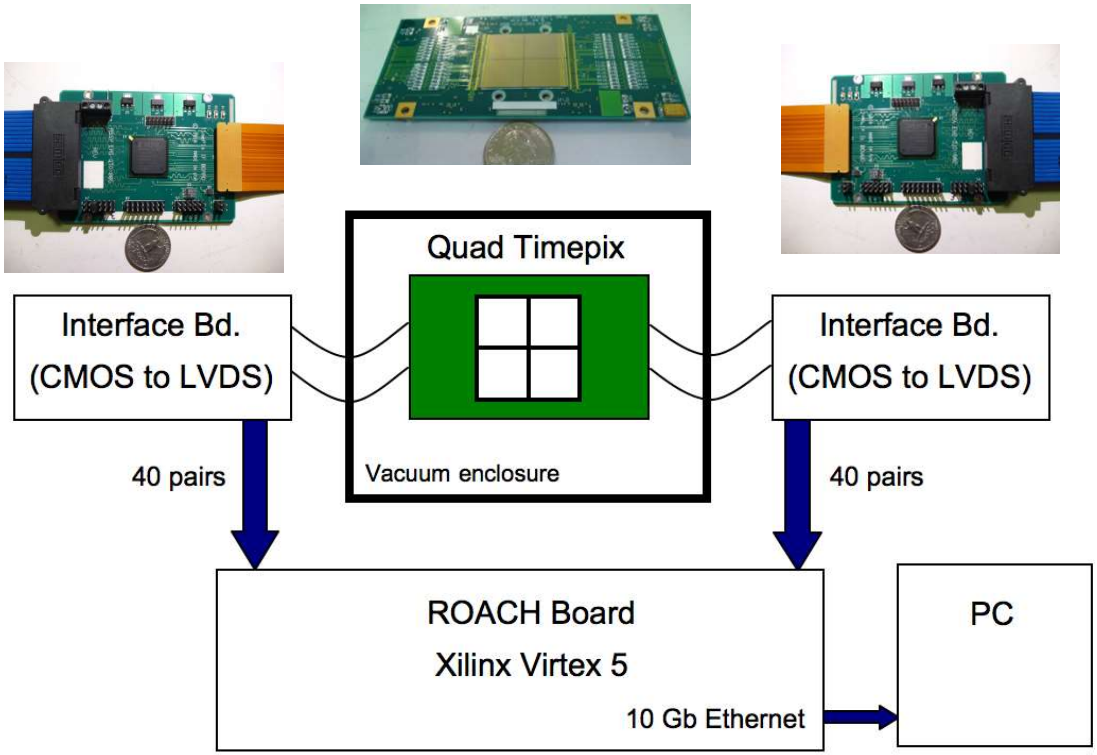
10 Gb interface

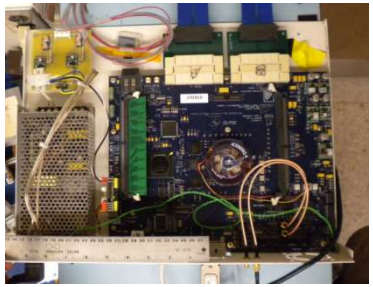
Up to ~5 Mb/s

PC

A.S. Tremsin, et al., *Nucl Instr Meth* A 787 (2015) 20

MCP detector with Medipix/Timepix readout: Gen 2



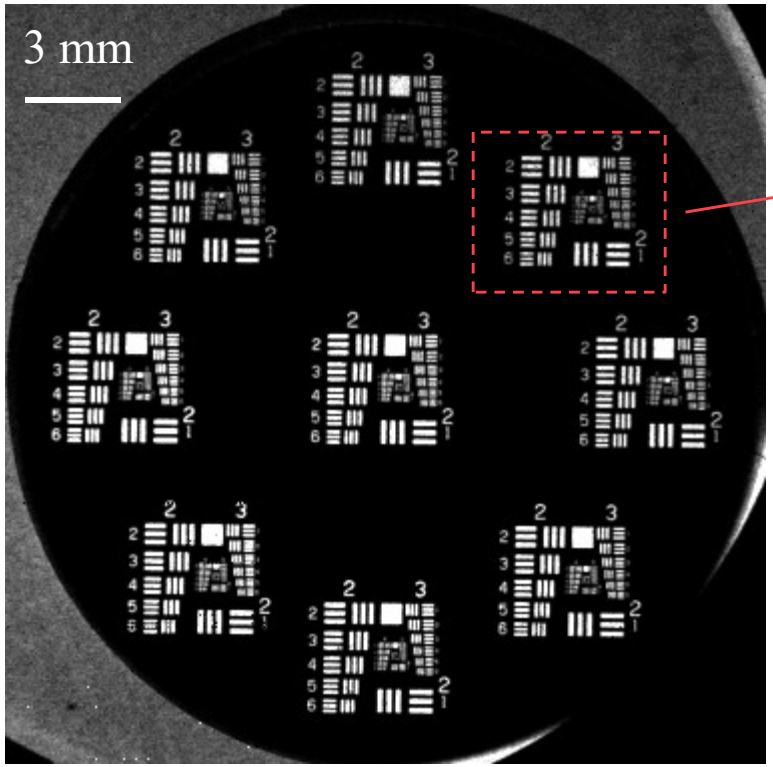


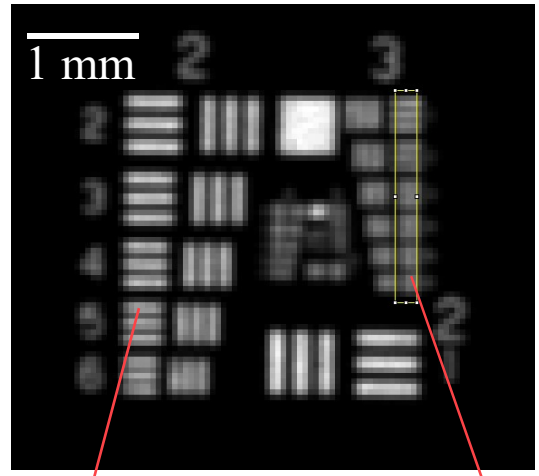
- Up to 1200 frames/sec
- Readout time ~310 μs (0 us for new generation)
- 3 acquisition modes. Each pixel provides either:
  - Event counts (image integrated on the chip)
  - Time of event (up to 10 ns accuracy)
  - Charge accumulated in a pixel (ToT mode)

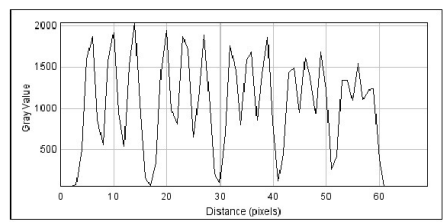
Timepix readout for MCP detectors: Gen 2, Gen 3, Gen. 4

- **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 (Gen. 2), >30 MHz (Gen. 3, 4) per 2x2 Timepix readout with resolution of <10 μm .**
- **Analog amplification in pixels, only digital signals read out.**
- **No readout noise.**

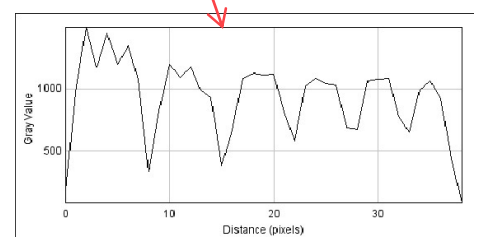
Mode 1: High input rates - frame-based event counting mode







Group 2

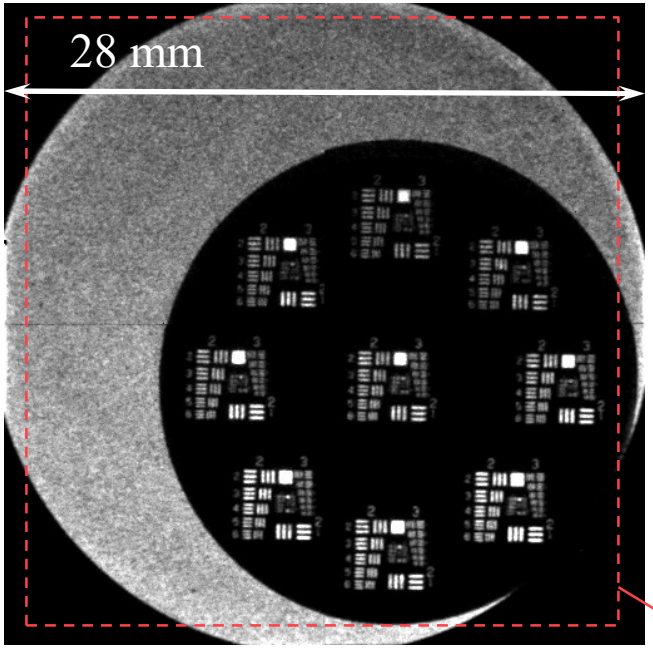


Group 3

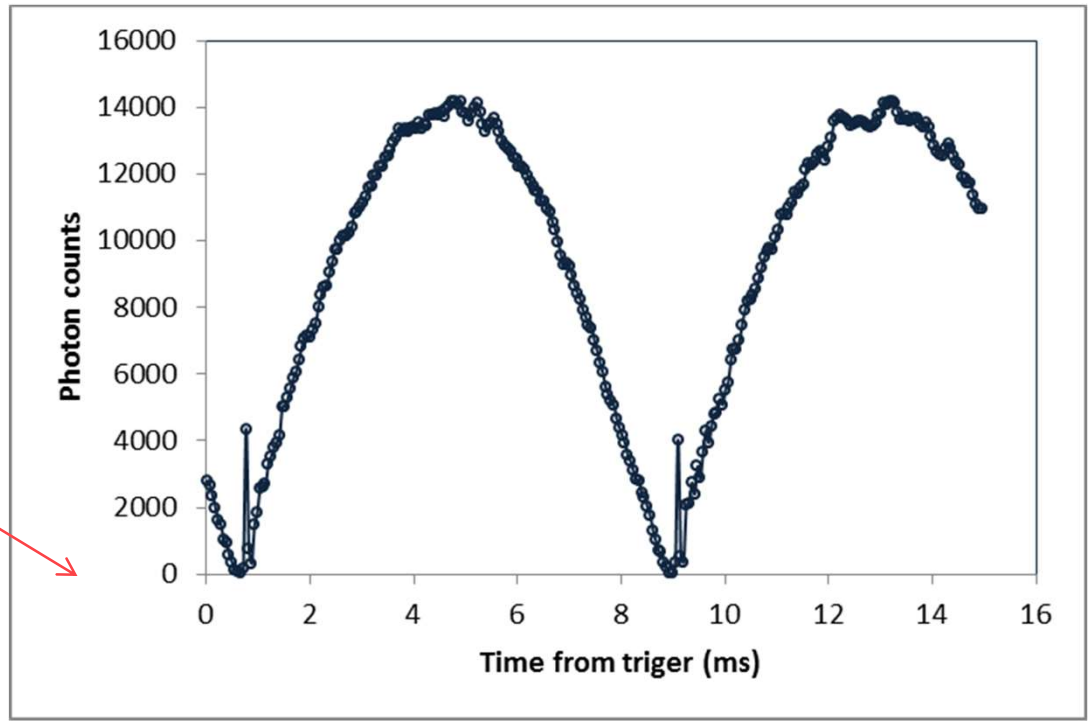
High count rates are possible.
Up to 11800 counts per pixel before readout out.

Resolution limited by ~55 μm pixels

Mode 2: Time of each event



UV penray lamp intensity fluctuations (60 Hz AC)

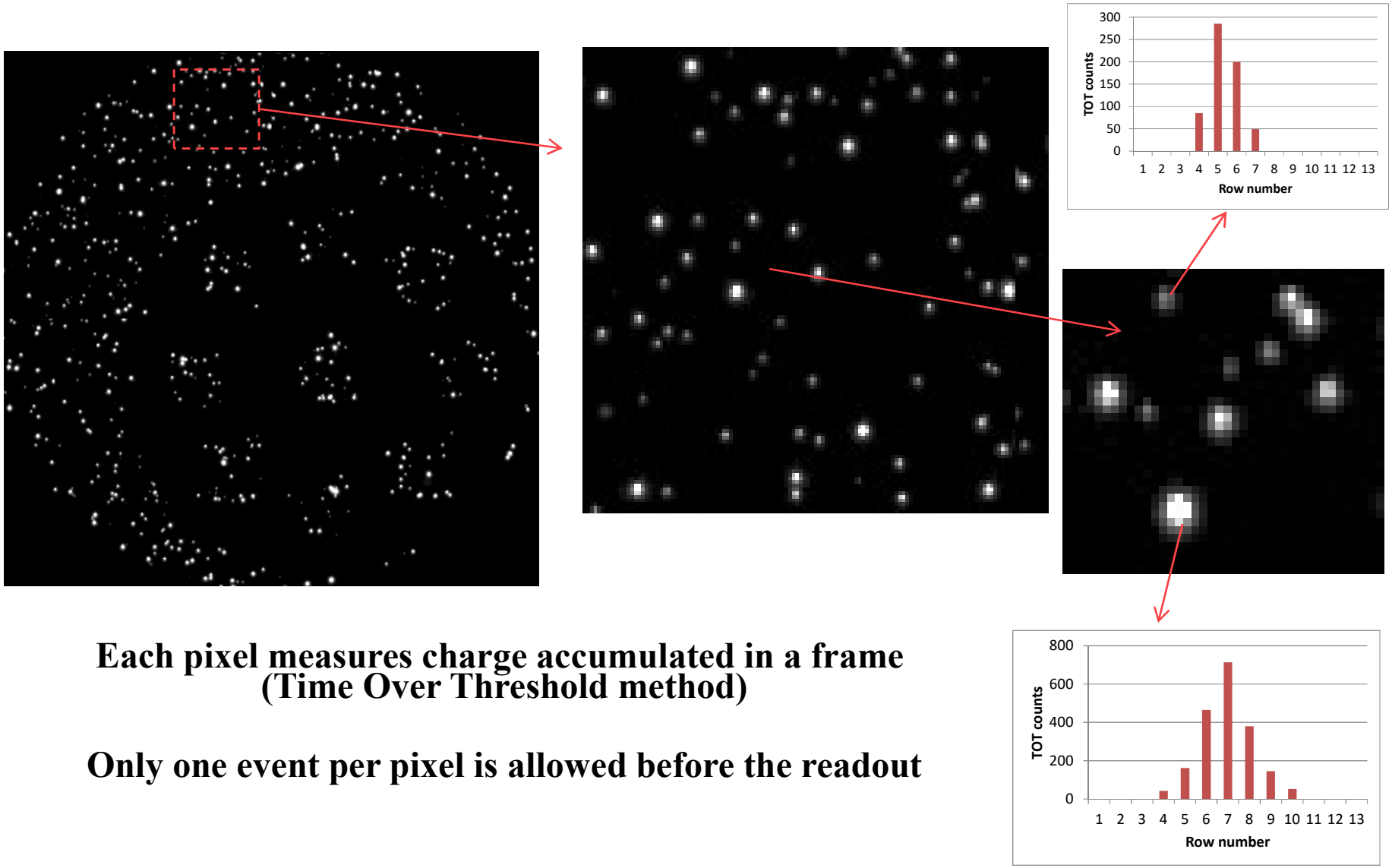


Timing of each event (currently with 10 ns resolution, Gen 2, 1.6 ns Gen.3 and <200ps Gen. 4) relative to external trigger is measured.

Time histogram is accumulated in each pixel.

Spatial resolution limited by ~55 μm pixels (Gen. 2), ~7 μm (Gen. 3, 4)

Event centroiding

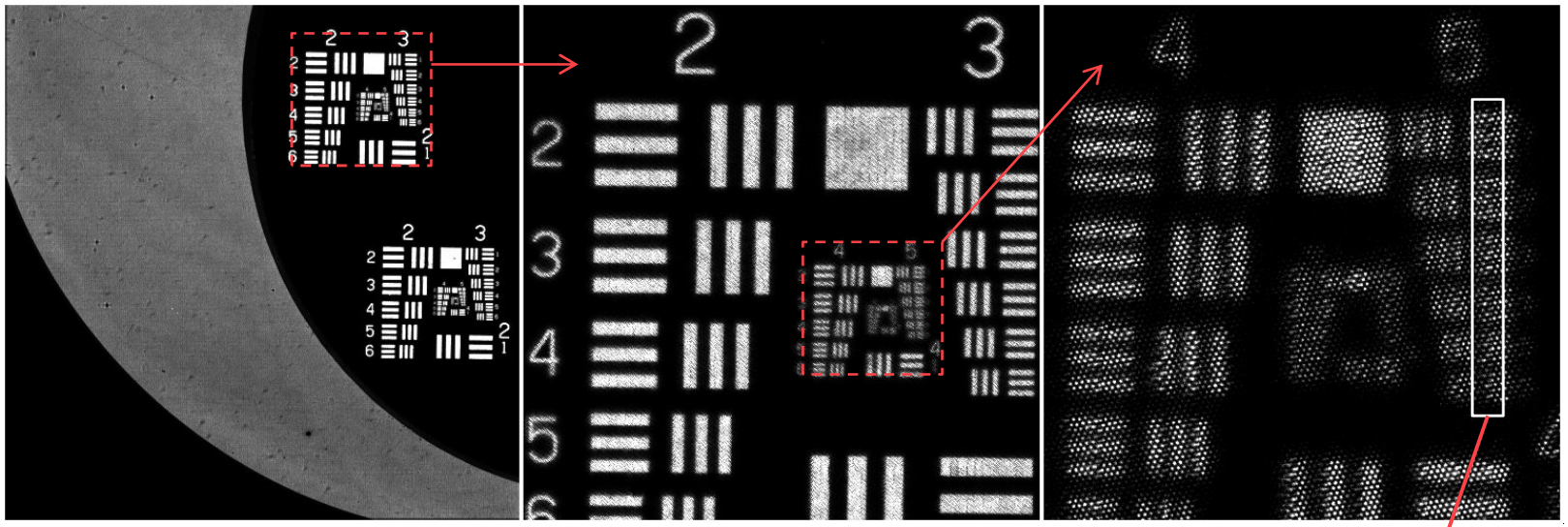


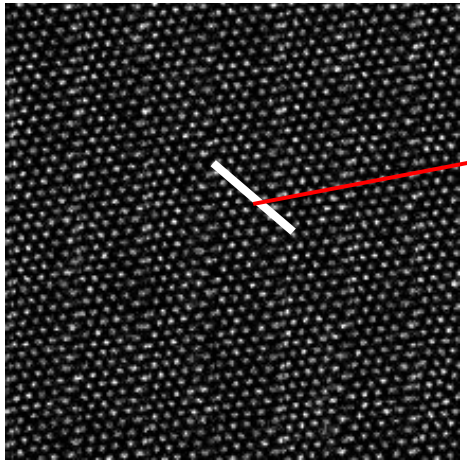
Each pixel measures charge accumulated in a frame (Time Over Threshold method)

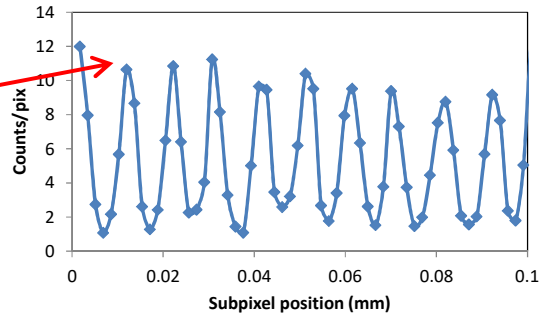
Only one event per pixel is allowed before the readout

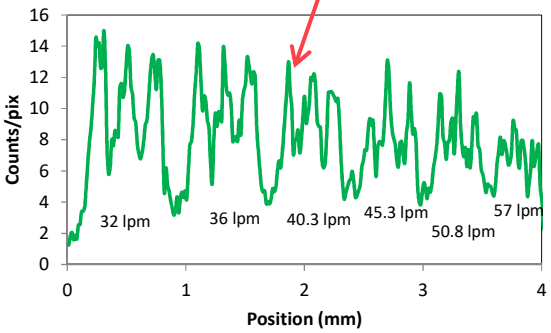
High resolution mode: Event centroiding

High resolution imaging with resolution ~ MCP pore is possible







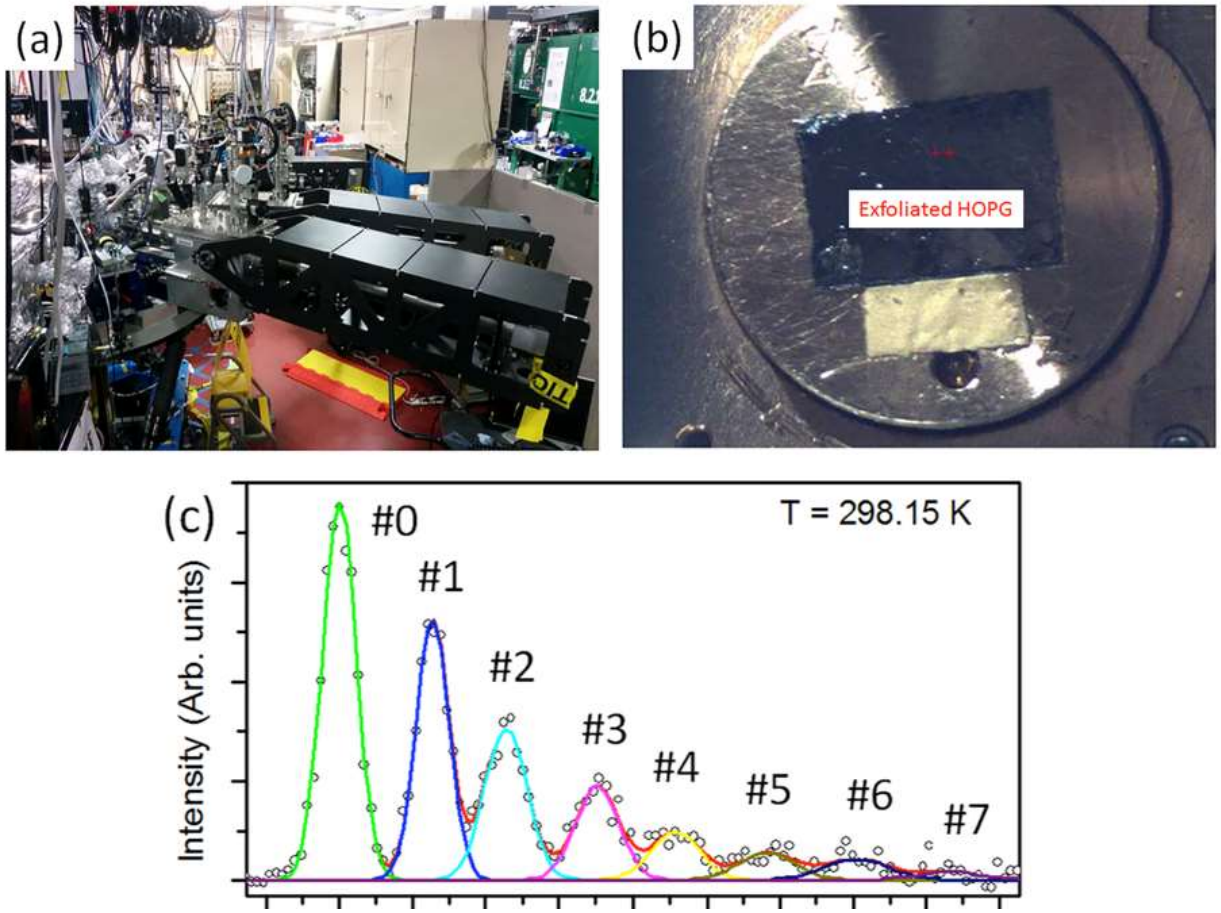


Readout resolution ~4 μm FWHM

Nucl, Instr. Meth. A 787 (2015) pp. 20-25.

Latest tests at ALS beamine 8

HOPG elastic peak vibronic coupling



Courtesy of Xuefei Feng (ALS), Yi-De Chuang (ALS), Shawn Sallis (ALS), Wanli Yang (ALS), Jinghua Guo (ALS)

MCP/Timepix soft X-ray detectors roadmap

Gen. 2

- **Spatial resolution** 55 μm with 10 ns timing resolution
- **Either** high spatial resolution (~7 μm), **or** high timing resolution
- **Count rate** in high spatial resolution (~7 μm), is **limited to ~3 MHz**
- **Count rate** with 10 ns and 55 μm is ~ **30 MHz**
- **320 μs** readout time (**dead time)** per frame
- **Power dissipation** ~1W/chip

Gen. 3

- **Timing resolution improved to ~1.6 ns**
- **Spatial resolution 7.2** μm with 1.6 ns timing resolution
- **Both high spatial (~7.2** μm) **and timing resolution (1.6 ns) is possible**
- **No readout time: event driven readout**
- **More heat generated in vacuum (power dissipation ~2 W/chip)**
- **Longer cable out of vacuum (LVDS signal output)**

Gen. 4

- **Timing resolution to be improved to <200 ps**

Summary

- MCP detectors provide unique opportunities in applications where event counting with high spatial and time resolution is required.
- Specific photocathode, type of MCP readout, detector area have to be selected for a particular application.
- Latest developments of MCP manufacturing technology and fast electronics substantially improve the performance of MCP detectors: longer lifetime, high counting rate capabilities, larger sensitive area, many simultaneous particles.
- Various new applications of MCP detectors have been demonstrated recently in very diverse fields.
- These devices are still relatively complicated and not as easy to operate as scientific CCD/CMOS detectors.

This work was supported in part by NASA, DOE, NSF, NIH and NNSA.

The work on MCP/Timepix detector was done within the Medipix collaboration.

- **Experimental Astrophysics group, Space Sciences Laboratory, UC Berkeley, USA:** O. H. W. Siegmund, J. V. Vallerga, J. B. McPhate, J. Hull, J. Tedesco, S. Jelinsky, C. Ertley, B. Welsh, P. Jelinsky, S. Jelinsky
- **Techne Instruments, Oakland, CA, USA:** R. Raffanti

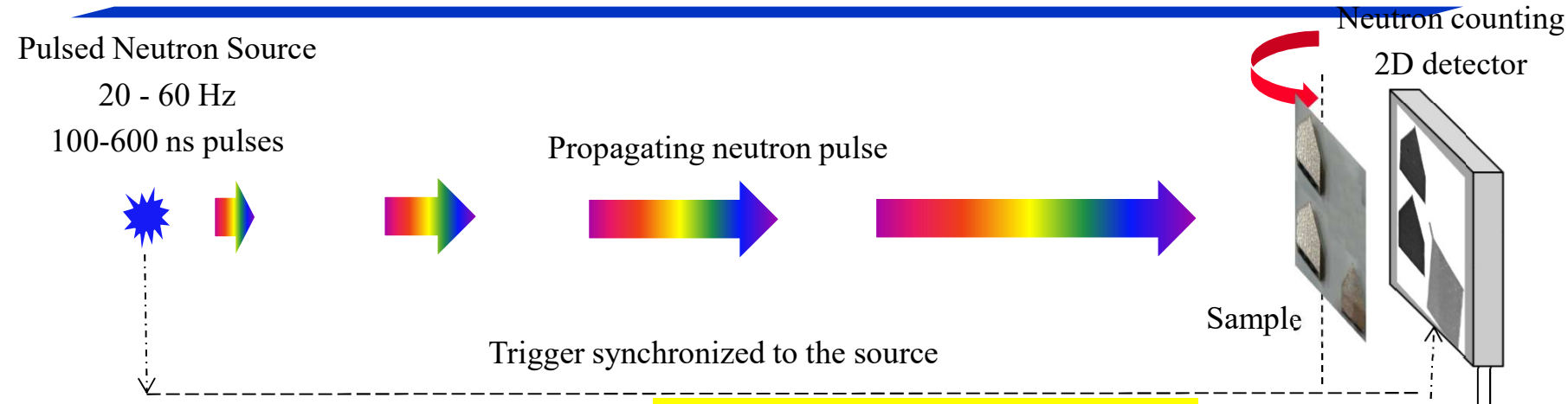
3 modes of event counting/imaging

1. **Event counting in each pixel**
   - up to 11800 events per pixel/frame
   - ~10 kHz rate/pix
   - detector global rate >100 MHz with no resolution degradation
   - local counting rate ~100 kHz
   - spatial resolution = 55 μm pixel
   - time resolution = shutter length (1μs-seconds)
   - can be synchronized to external trigger (stroboscopic imaging)

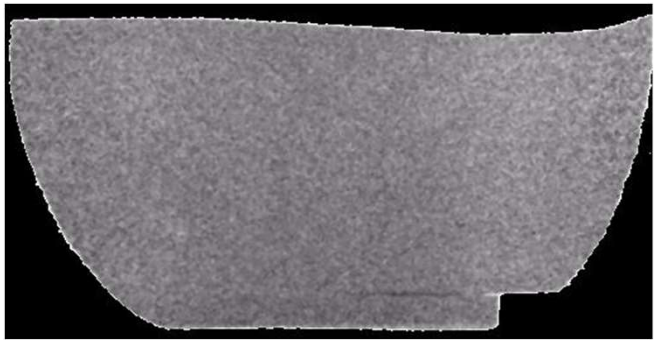
2. **Time of event : internal clock or relative to external trigger**
   - 1 event per pixel/frame (~25K events/frame)
   - time bin from 10 ns (1.2 ns)
   - time range = 11800 x time bin
   - spatial resolution = 55 μm pixel
   - multiple shutters per trigger

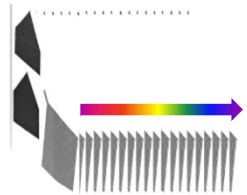
3. **Charge in pixel**
   - 1 event per pixel/frame (~25K events/frame)
   - spatial resolution = 55 μm pixel
   - time resolution = shutter length (1 μs to secondss)
   - can be synchronized to external trigger
   - multiple shutters per external trigger

Experimental setup

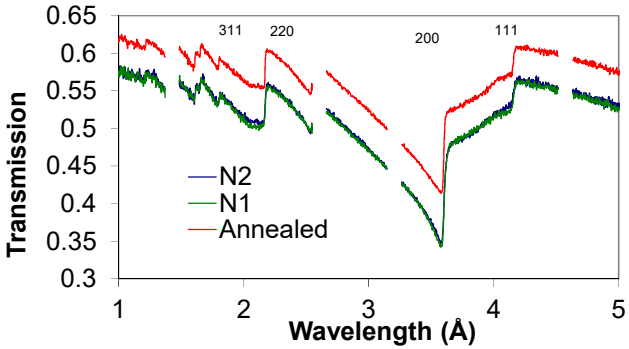


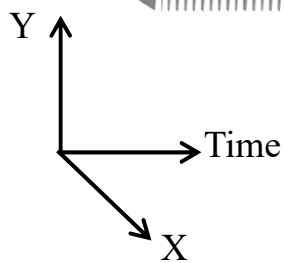
All energies are imaged at the same time!





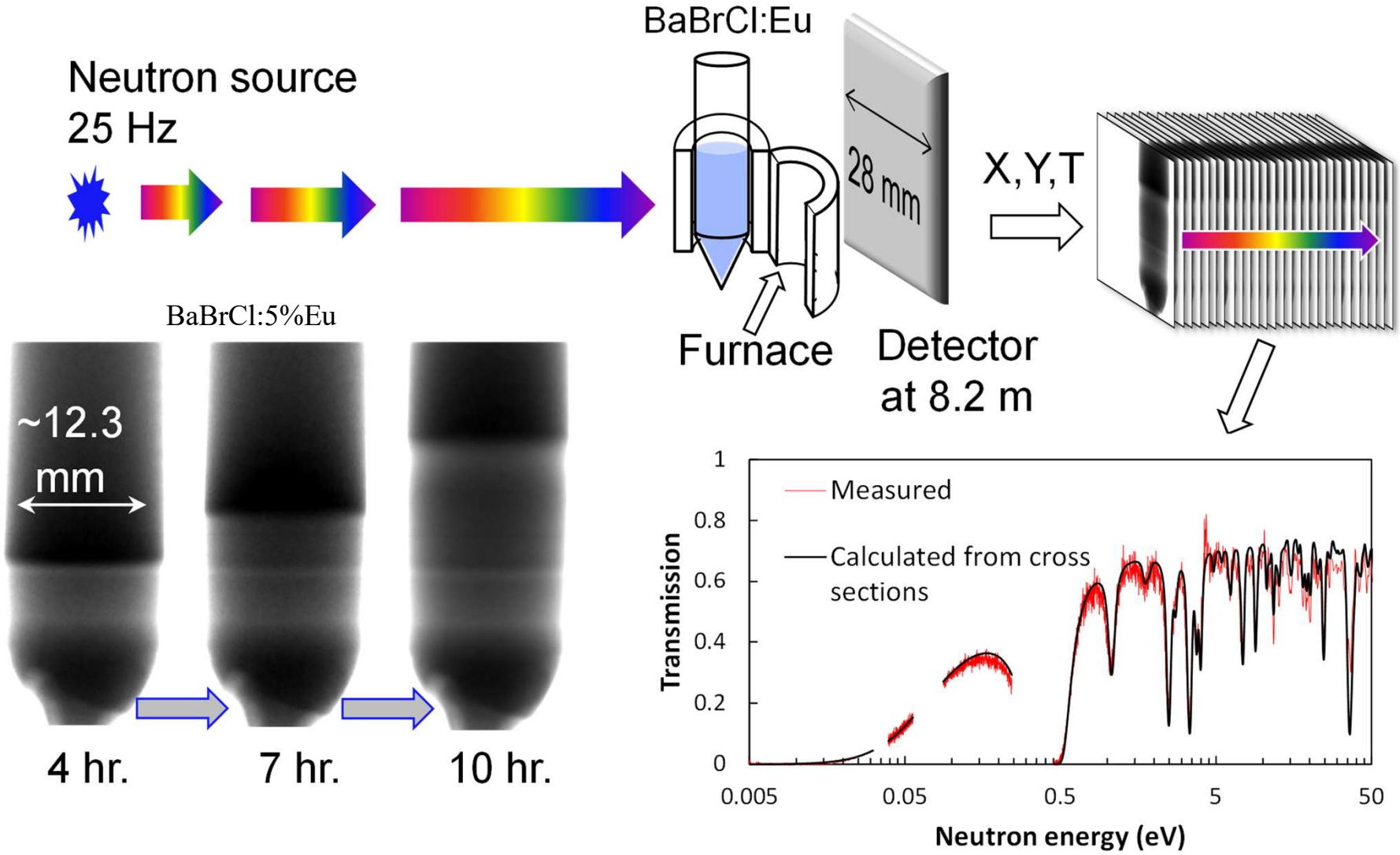
X,Y,T for every detected neutron



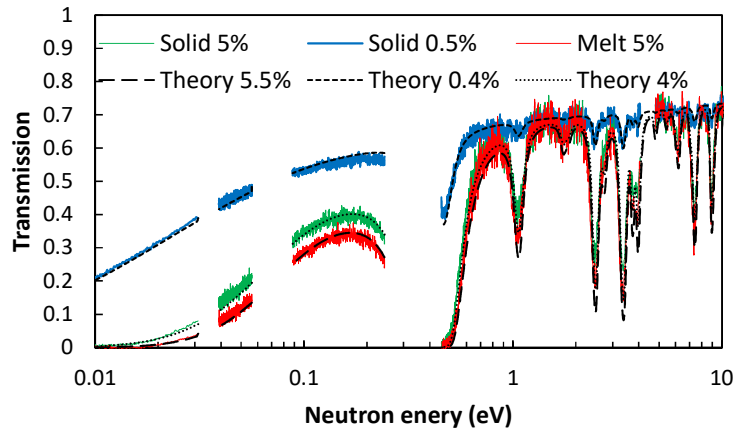


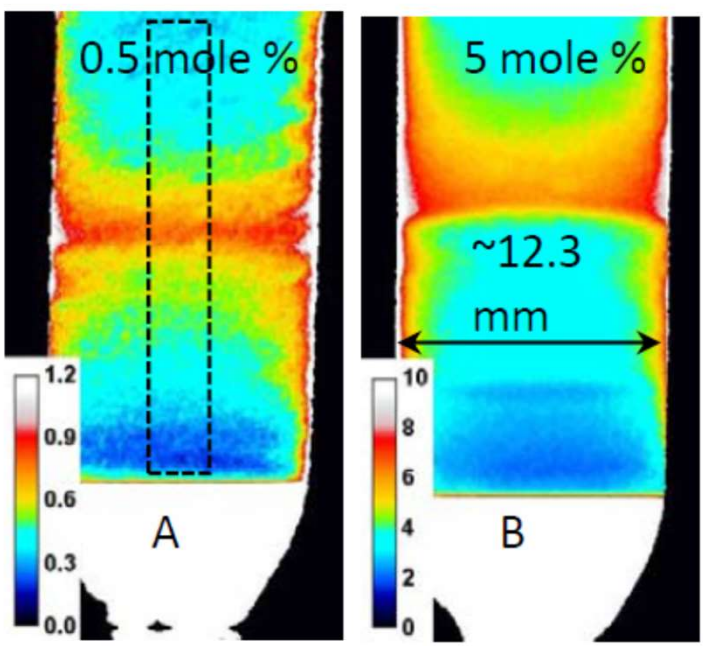
~250,000 spectra is measured simultaneously!

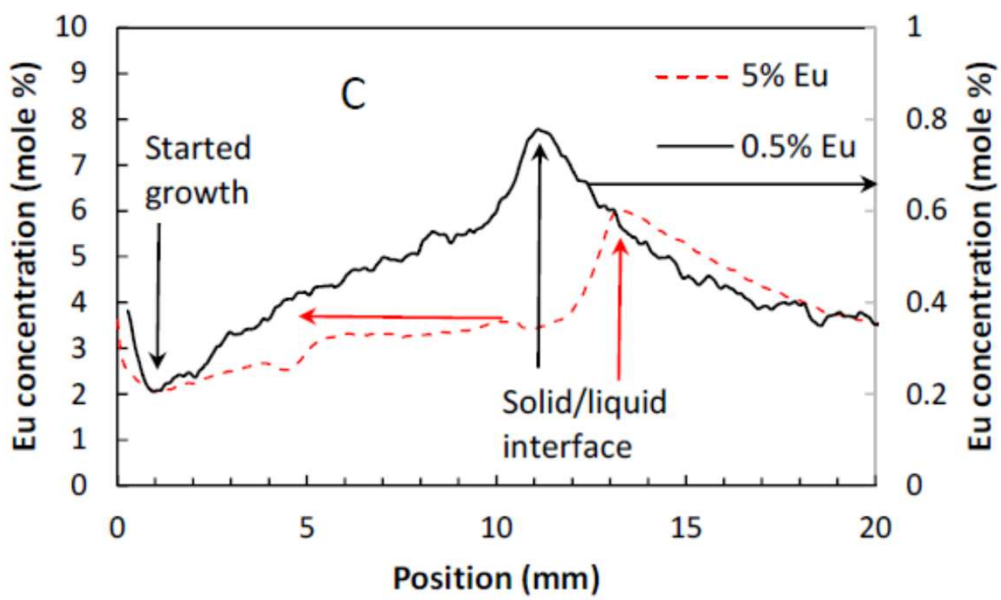
Experimental setup pulsed beam; energy resoled imaging



Eu distribution quantification







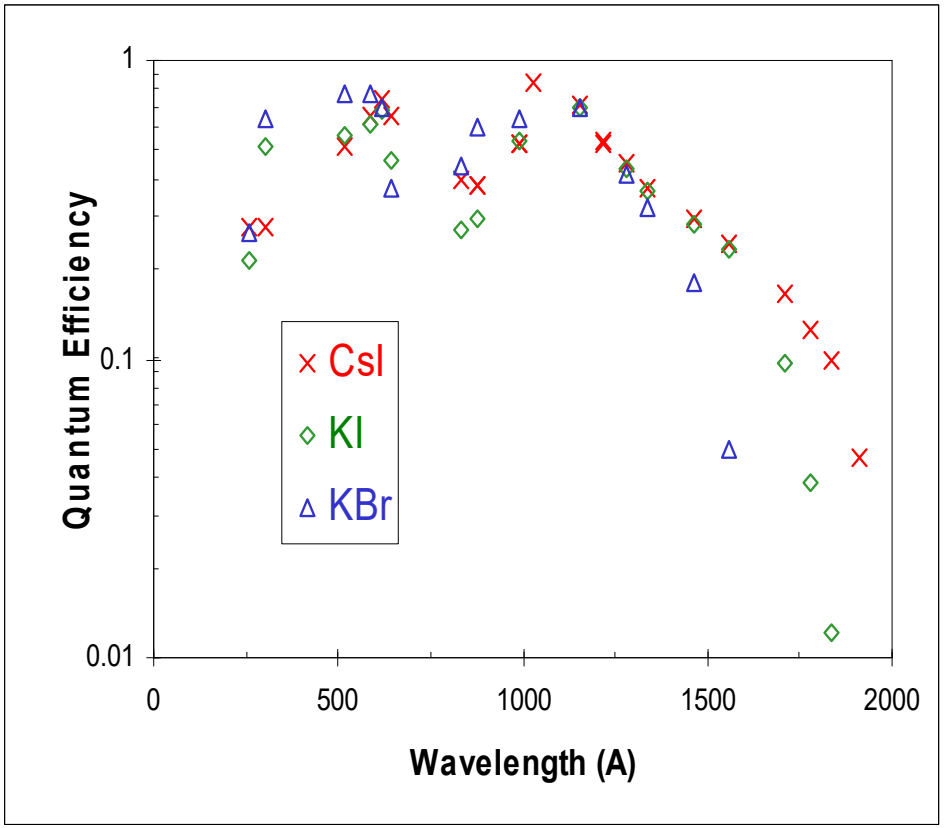
An ideal photocathode

- High quantum efficiency
- Stable in time, stable under air exposure
- Radiation hard
- Fast
- Solar blind
- No thermionic electron emission
- Easy to manufacture
- Do not require operation in high vacuum
- Can be deposited on different substrates
- …

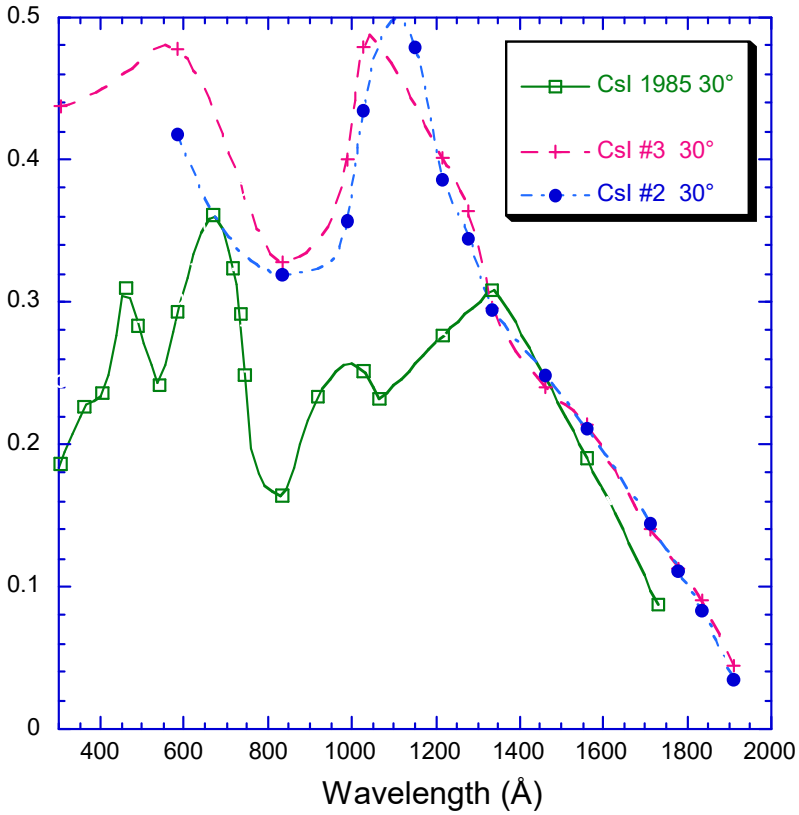
Does not exist ⇒ To be optimized for a particular application

UV and soft X-ray photocathodes

Quantum Efficiency of alkali halide photocathodes



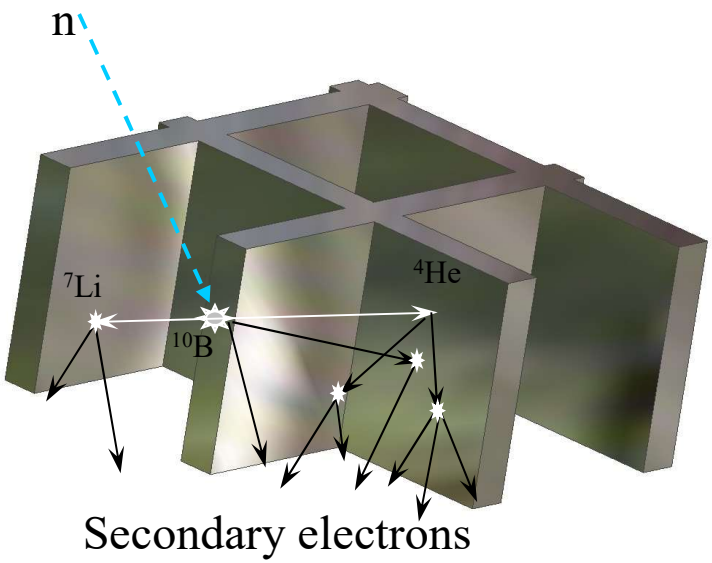
Reflective

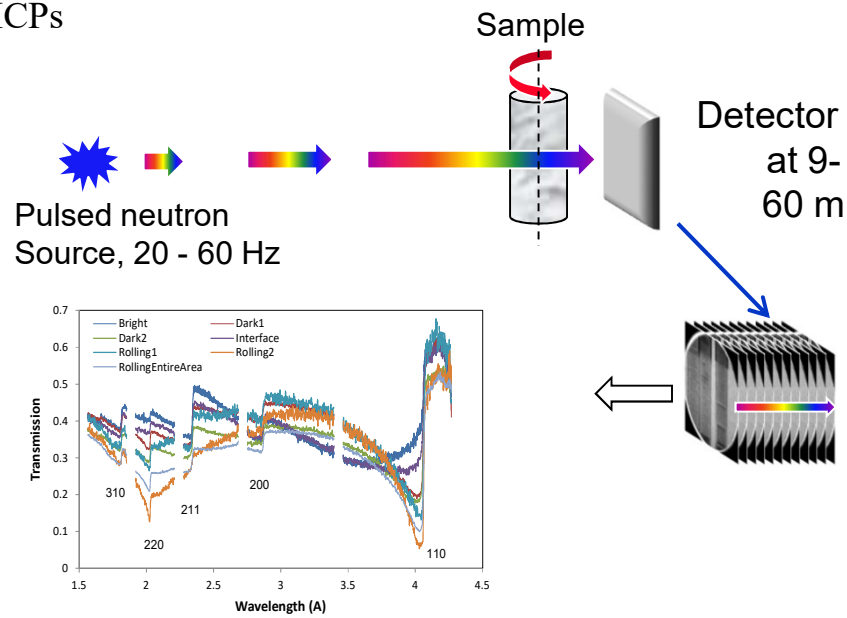


Opaque on MCP

Neutron sensitive MCPs: ^{10}B doped glass

Nova Scientific, Inc, MA, USA produces ^{10}-B doped glass MCPs
Novel non-destructive testing applications become possible





TOF = neutron energy
>250000 spectra measured at the same time

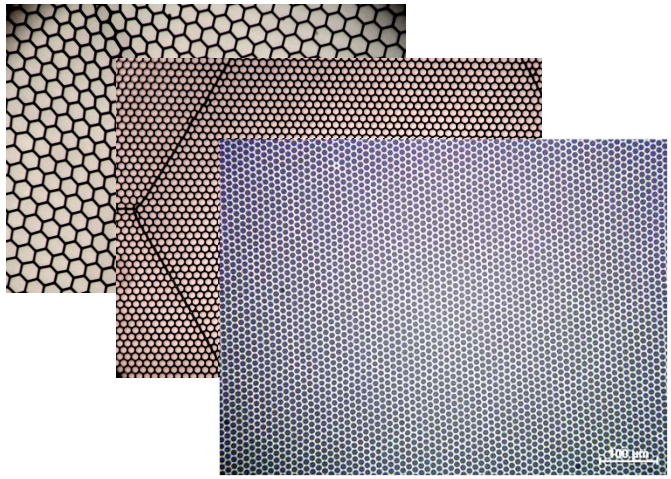
~8 µm pores on 11 µm centers, L/D ~100:1
Detection efficiency > 50 % for thermal neutrons

A.S. Tremsin et al., Nucl. Instr. Meth. Phys. Res. A 539 (2005) 278-311

Novel MCPs manufacturing technology enabling novel applications

Nano-engineered MCPs: borosilicate glass and plastic

Micro-capillary arrays (Incom) made with borosilicate glass.
L/D typically 60:1 but can be much larger.
Open area ratios from 60% to 83%.
No etching is needed.
Resistive and secondary emissive layers are applied (Arradiance, Argonne Lab) to allow these to function as MCP electron multipliers.

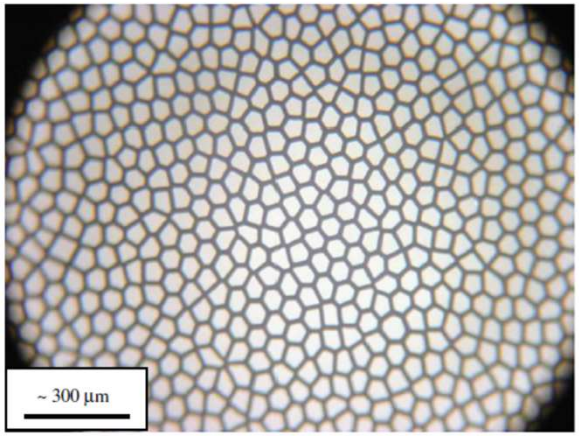


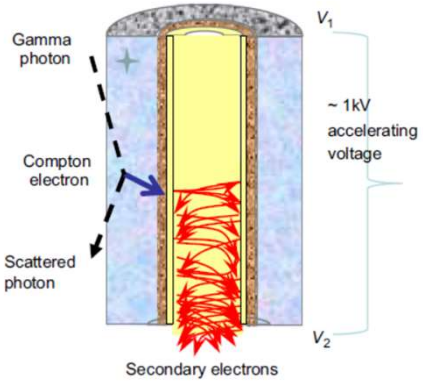
40µm pore borosilicate micro-capillary MCP with 83% open area.

O.H.W. Siegmund, et al.,
Proc. of SPIE Vol. 8859, 88590Y (2013);

Many publications at LAPPD collaboration reference list

Plastic MCPs (Arradiance) made from PMMA.
L/D typically 100:1, 50 µm pores.
Resistive and secondary emissive layers are applied by Atomic Layer Deposition (Arradiance)





D.R. Beaulieu et al., Nucl. Instr. Meth. Phys. Res. A 659 (2011) 394–398

ALD / Borosilicate Glass MCPs

Fabricated using hollow tube draw and stack technique

Glass is inexpensive, low Z (no lead), higher softening temperature (>700° C)

- *Lower gamma background, low high energy particle cross section*
- *Deposition of high Temp opaque photocathodes like GaN*
- *Very large formats (>20cm) are possible*

Functionalized using Atomic Layer Deposition (ALD)

- *Semiconductor Resistive layer, tunable over wide range*
- *Amplifying layer (e.g. Al_2O_3 or MgO) with high secondary electron coeff.*
- *Better lattice match to GaN, also good for conventional cathodes*
- *Can be used on conventional MCPs and MCP substrates*

Separates MCP functional properties from substrate optimization!

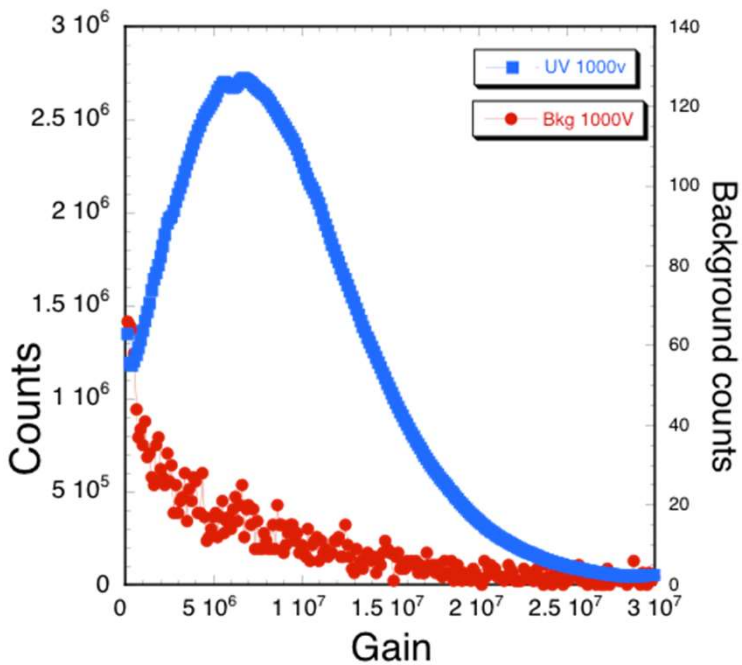
O.H.W. Siegmund, et al., Proc. of SPIE Vol. 8859, 88590Y (2013)

Imaging 20cm, 20µm pore ALD-MCP Pairs

A number of 20cm MCP substrates have been functionalized by ALD at ANL, and put through detailed tests at UCB-SSL .

Expanded area view showing the mutifiber edge effects.

Pulse height distributions for UV and background.



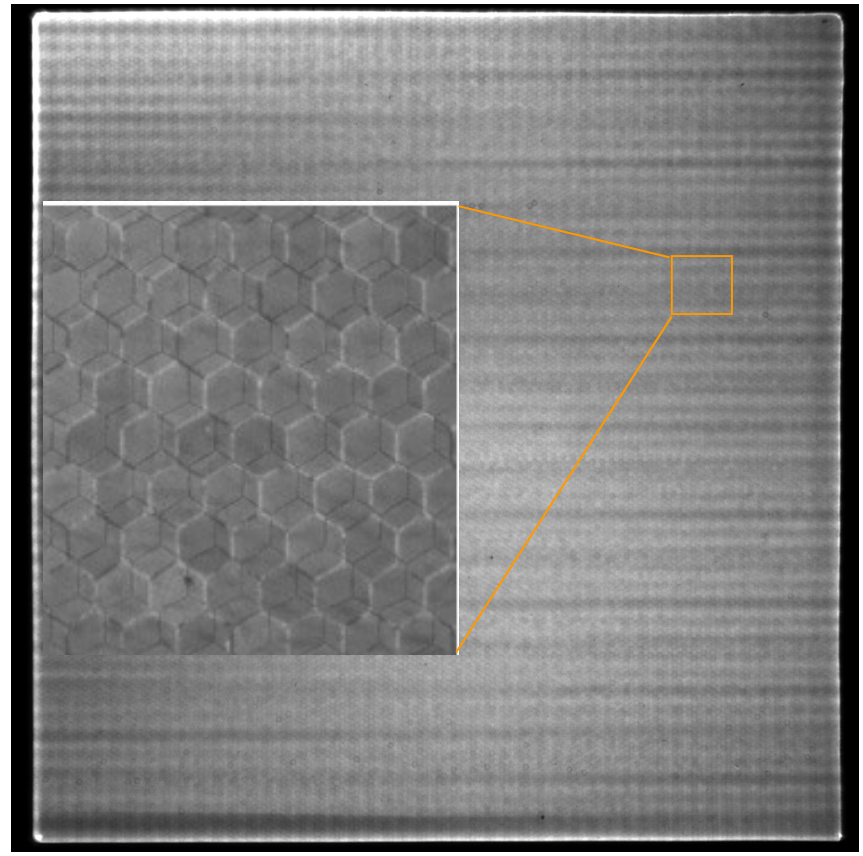
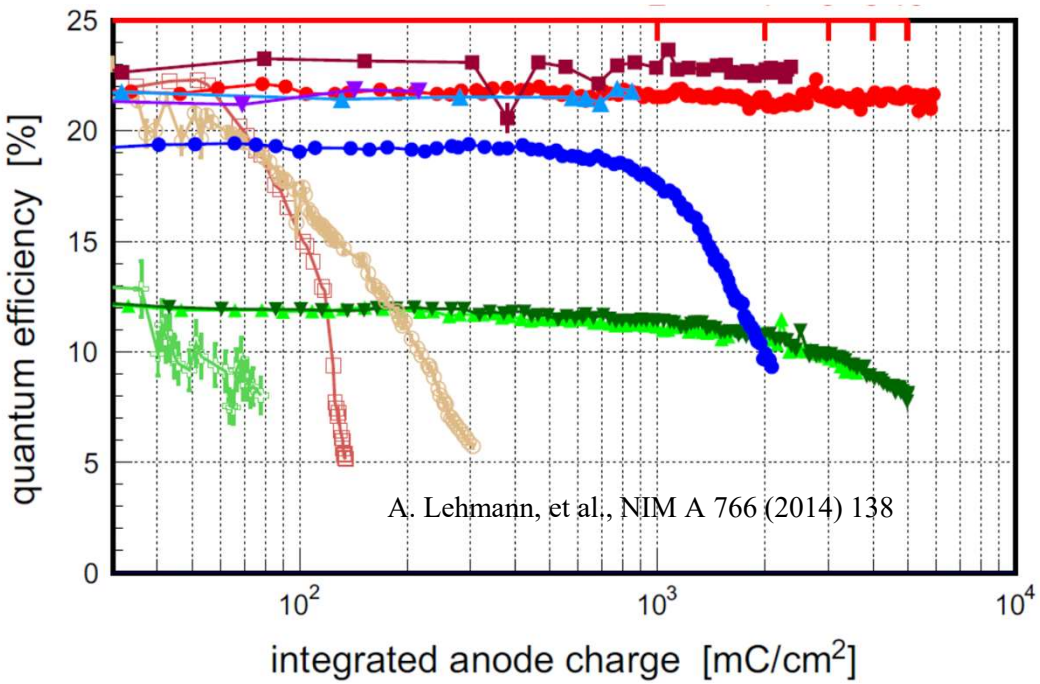


Image striping is due to the anode period modulation as the charge cloud sizes are too small for the anode. 20cm, 20µm pore, Al_2O_3 SEY, MCP pair image with 185nm non uniform UV illumination.

Stability of MCP: new technology of MCP manufacturing

- MCP scrubbing/preconditioning is a well known problem with photon detectors, used in very high count rate applications.
- Novel technology of MCP manufacturing has solution for it (not done for neutron-sensitive MCPs yet).
- **Improved lifetime of microchannel-plates**



D.R. Beaulieu et al., NIM A 607(2009) 81
O.H.W. Siegmund, et al, NIM A 787 (2015) 110