Neutron Imaging with High Spatial and Temporal Resolution Microchannel Plate Detectors

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Microchannel Plate Detectors

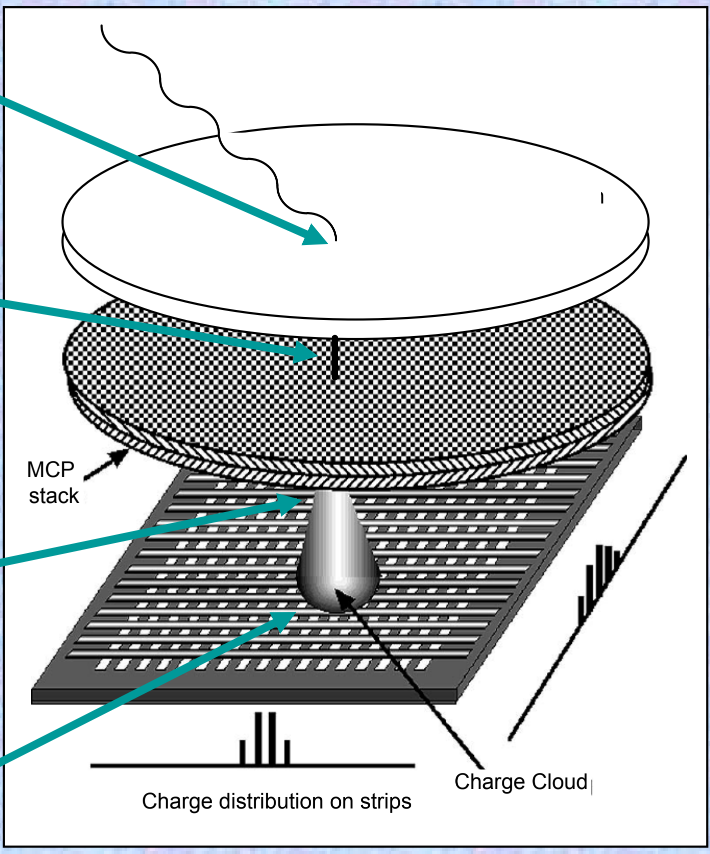
~~Photocathode~~ converts ~~photon~~ to electron(s)

MCP neutron

MCP(s) amplify electron by 10^4 to 10^8

Rear field accelerates electrons to anode

Patterned anode measures charge centroid



Microchannel Plates for Neutron Detection

By including neutron absorbers, Nova Scientific has been able to efficiently detect Neutrons with microchannel plates. The products of neutron interactions in the MCP initiate electron multiplication.

HB4 MCP types use Boron to detect neutrons

$n + {}^{10}B \rightarrow {}^{7}Li\ (1.0\ MeV) + {}^{4}He\ (1.8\ MeV)$ 7%

$n + {}^{10}B \rightarrow {}^{7}Li\ (0.83\ MeV) + {}^{4}He\ (1.47\ MeV) + \gamma\ (0.48\ MeV)$ 93%

$\sigma = 2100$ b at 1 Å

B14 MCP types use Gadolinium to detect neutrons

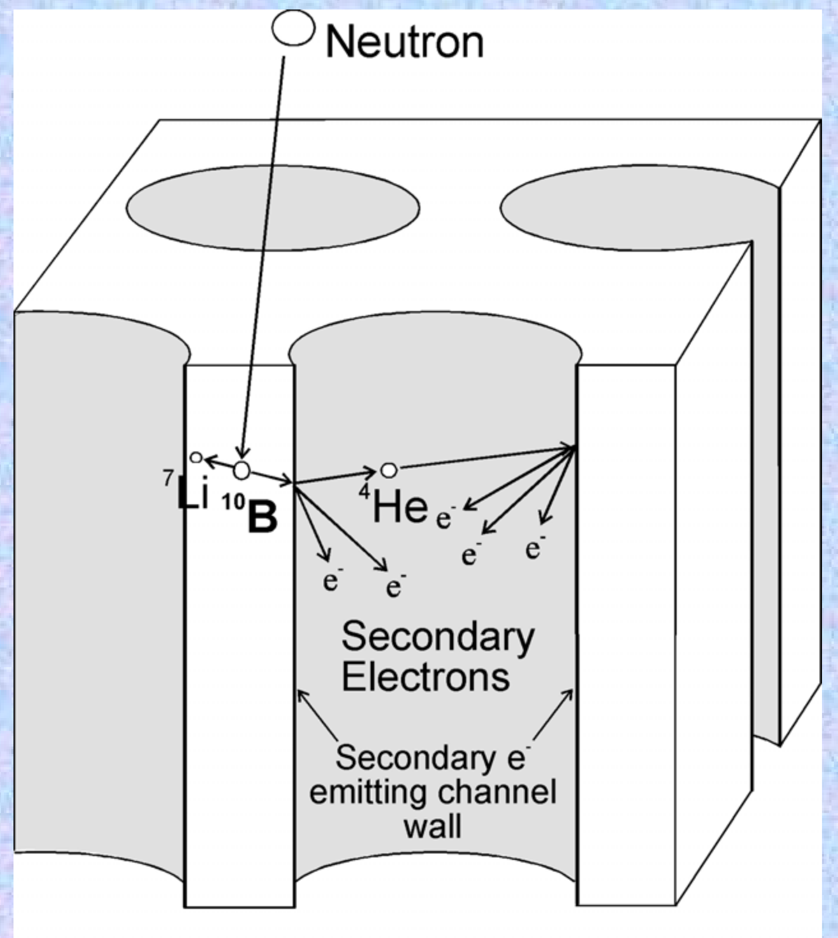
$n + {}^{157}Gd \rightarrow {}^{158}Gd + \gamma's + X\text{-rays} + e^-$

(29 keV - 182 keV, ~75%) $\sigma = 70{,}000$ b at 1 Å

$n + {}^{155}Gd \rightarrow {}^{156}Gd + \gamma's + X\text{-rays} + e^-$

(39 keV - 199 keV; ~75%) $\sigma = 17{,}000$ b at 1 Å

Quantum Efficiency to Neutrons



Absorption of Neutron

Secondary(s) reaching surface

Emission of photoelectron

Electron gain above electronic threshold

MCP Detector Anodes

Event based (*e.g. delayline*, *cross-strip*)

- X,Y,T of each event
- Timing to ~100 ps
- High spatial resolution (MCP pore)
- Coincidence/Anti-coincidence tools
- Flux up to ~ MHz

Integrating (*Intensifier-CCD*, *Medipix*)

- Histogram X,Y
- T from frame readout
- High flux capability (GHz)

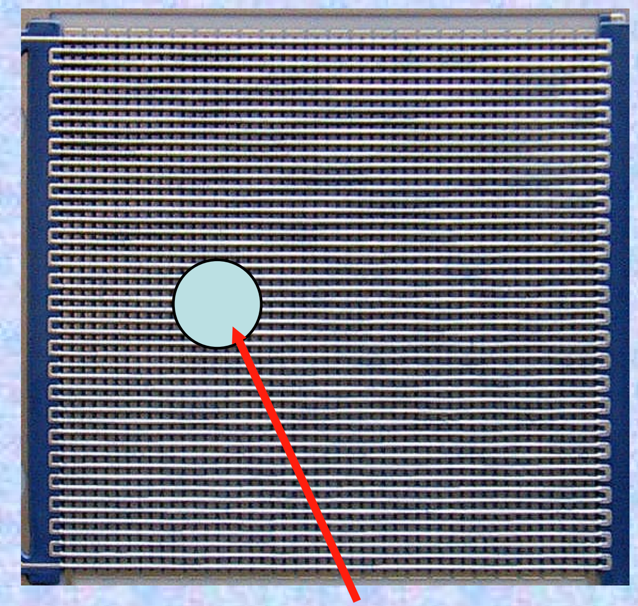
Microchannel Plate Detectors

Sealed tube

Open face (25 mm)

Cross delay line anode

Period is 0.5mm on ceramic. Event centroids are linearly proportional to signal arrival time difference at ends of delay lines. Resolution ~20µm FWHM at 10^7 gain, MHz rates supported, and <100ps event time tagging.



Charge cloud

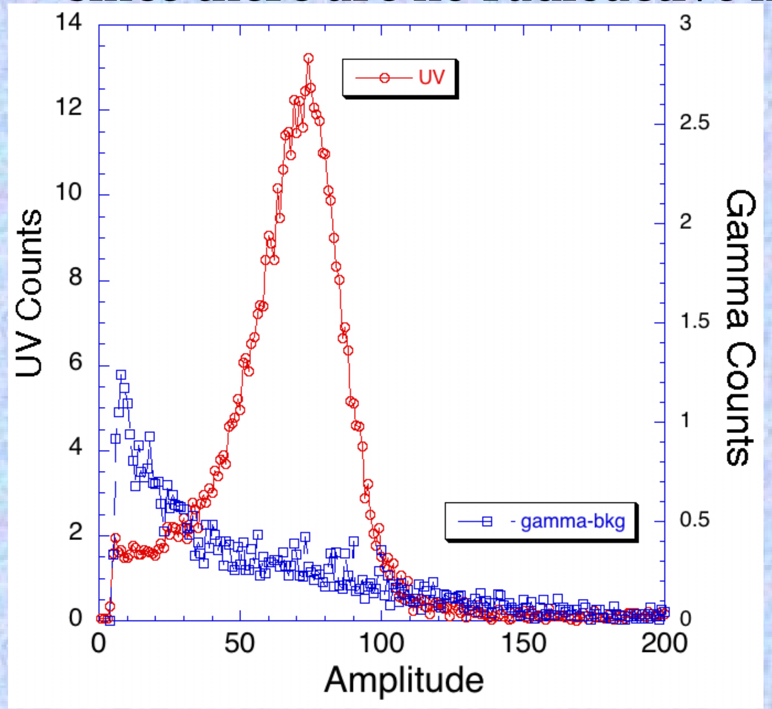
25mm cross delay line anode detector showing neutron sensitive MCPs

Amplitude Distributions for Radiation

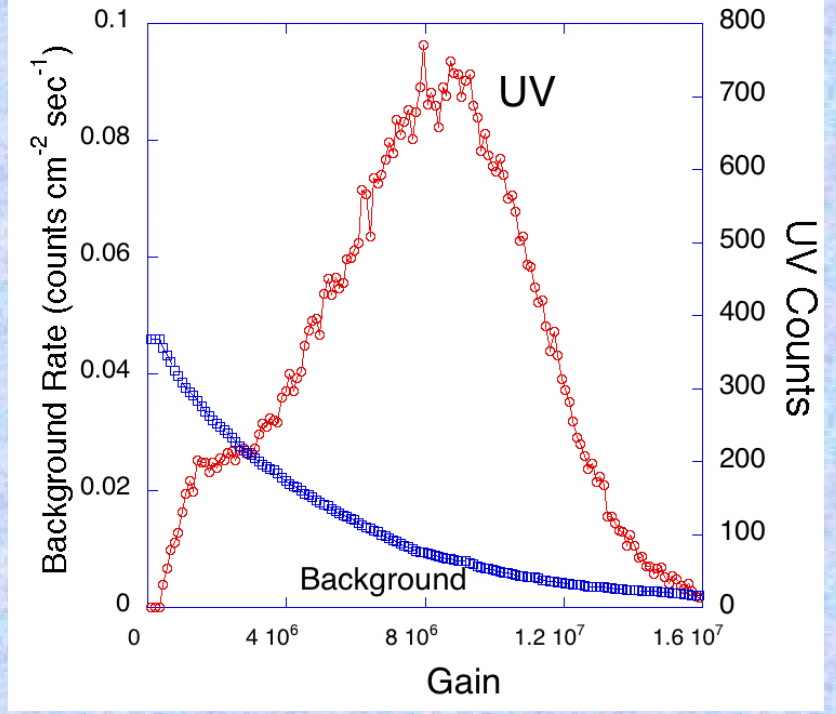
UV interacts at the top of the MCP stack, producing photoelectrons that initiate full gain electron avalanche multiplication with tight PHDs

Gamma events (^{60}Co, ^{137}Cs) interact throughout the MCP stack causing a wide range (exponential) of gain values for events

Intrinsic MCP background event rate is very low < 0.04 events cm^{-2} sec^{-1} since there are no radioactive materials in the glass.



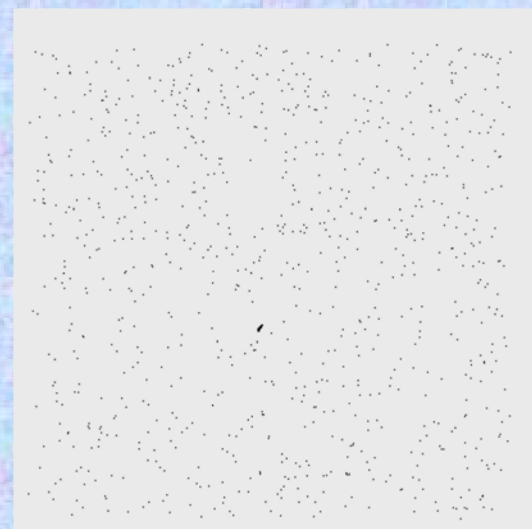
Boron MCP + 2 glass MCPs
UV and gamma ray distributions



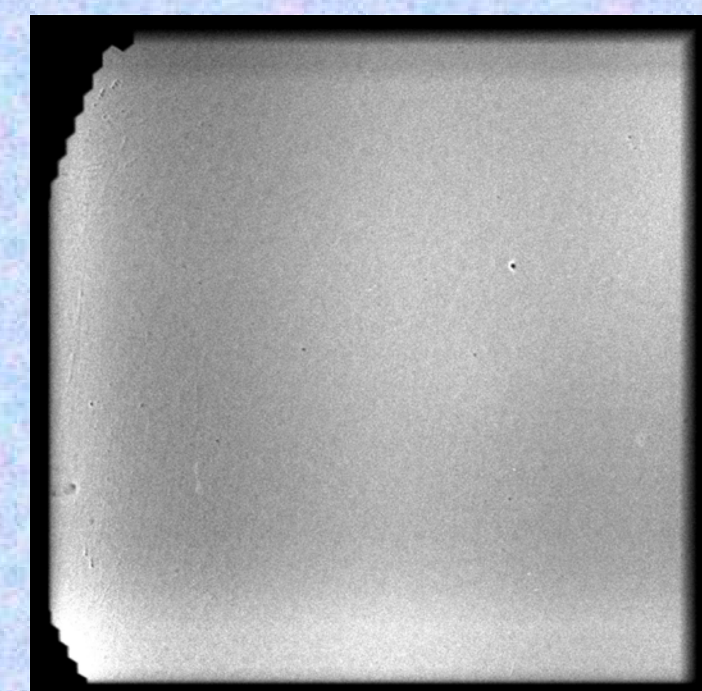
Gd MCP stack of 3 plates
UV and background event distributions

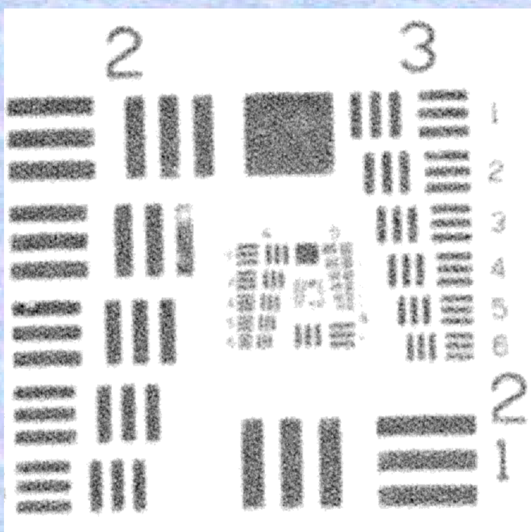
Neutron MCP - Cross Delay Line UV Imaging

Gd MCP stack of 3 plates, 1000 sec integration, one “warm” spot.



Gd MCP Z stack and 32mm XDL anode. Deep (10^8 count) image section accumulation, shows few defects and little fixed pattern noise





Gd MCP Z stack and 32mm XDL anode measurements of spatial resolution indicate ~23 µm FWHM for ~10^7 gain.

Air force test pattern image

NIST NCNR BT6 Beam Line Tests

Image of Cd test target with Neutrons (>4.8 x 10^6 cm^{-2} s^{-1}, 1.6Å) at NIST using XDL detector with neutron sensitive MCPs, <25µm rms resolution.

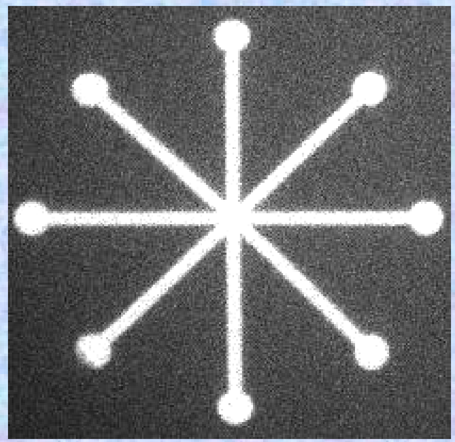
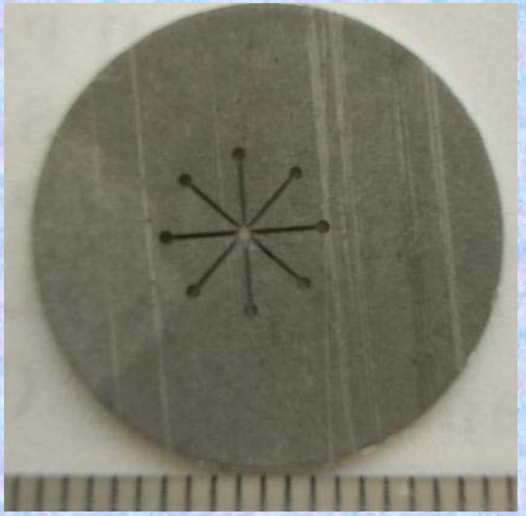


Image using Gadolinium MCPs



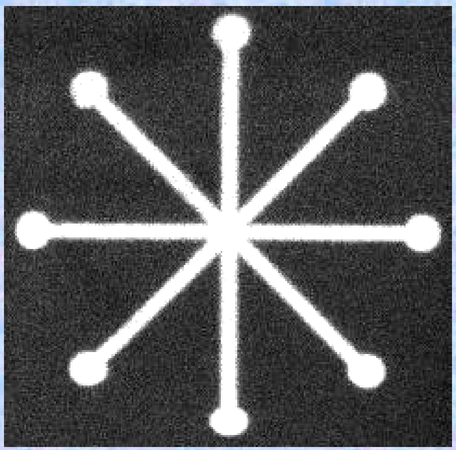
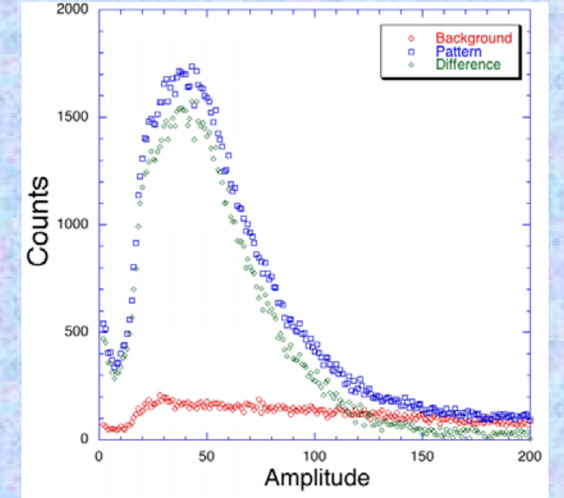
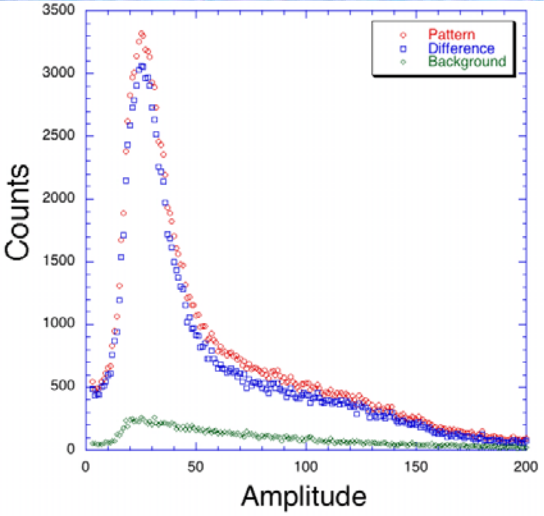


Image using Boron MCPs



PHDs for through, and under mask, gammas dominate at high amplitudes

Mask: 1mm thick Cd
6.5mm star pattern,
165µm wide bars



PHDs for through, and under mask. Neutron (alpha) events give high amplitudes.

NG6-M Beam Line Boron MCPs

• Image of Cd test target with Neutrons (~10^5 cm^{-2} s^{-1}, 5Å) at NIST using XDL detector with neutron sensitive Boron MCPs, 17μm rms resolution.

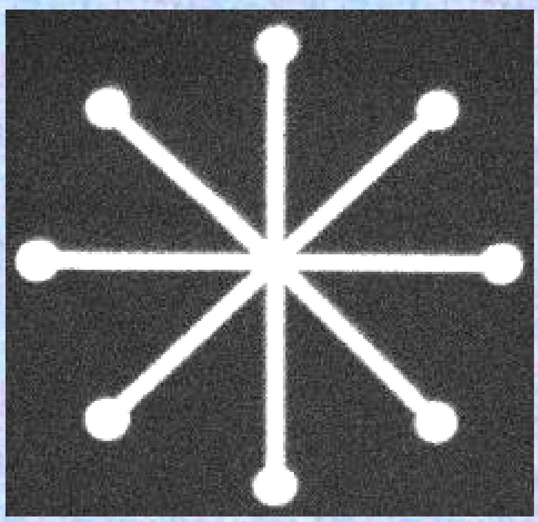
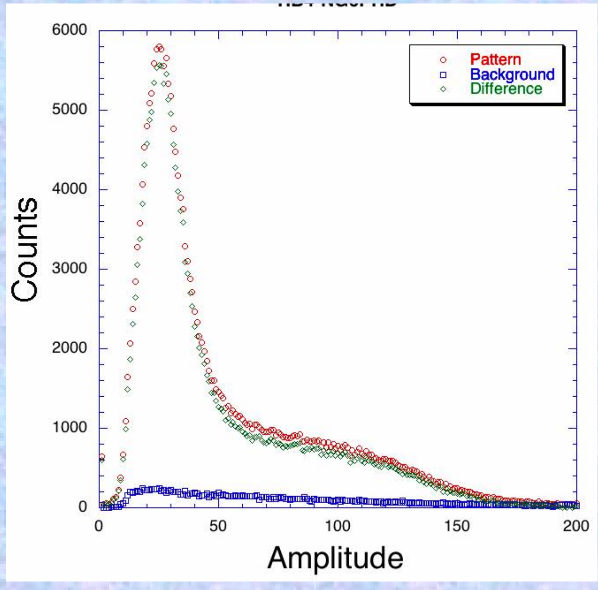


Image using Boron MCPs

PHDs for through, and under mask. Neutron (alpha) events give high amplitudes. Gamma flux is much lower at NG6 so that neutron detections dominate the distribution.



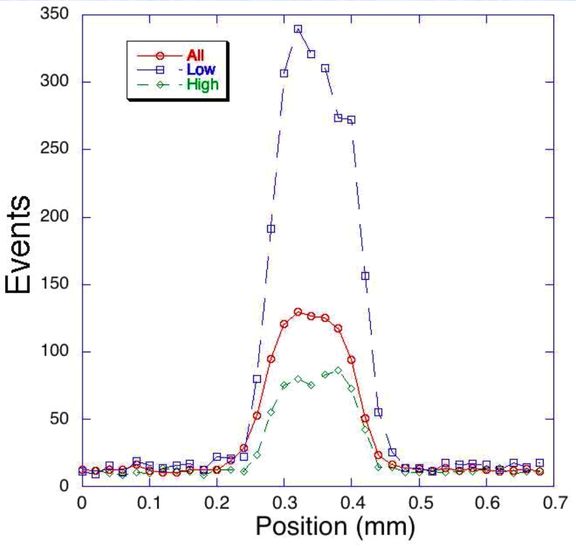
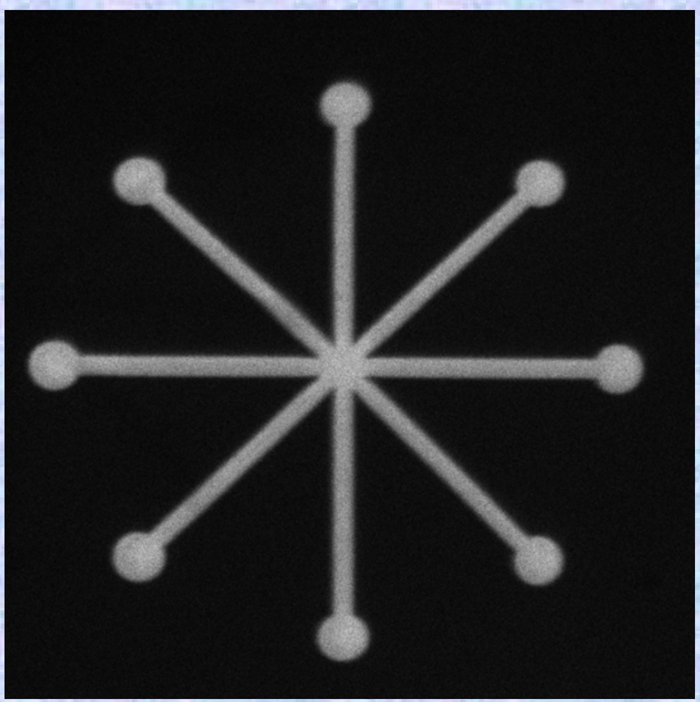


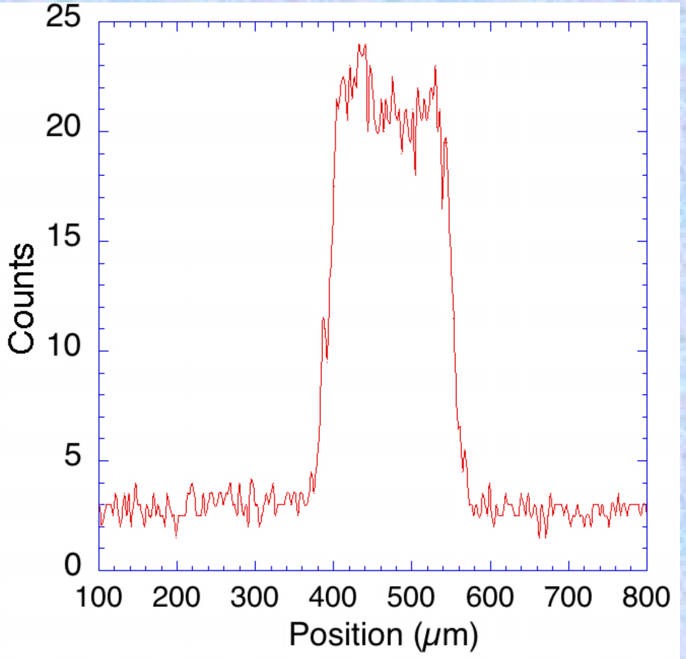
Image slice across one arm of the star pattern. Contrast is poor if all events, or only high amplitude events are used. Using only the low amplitude peak events gives a high contrast (30:1) image at the expense of some efficiency.

NG6-M Beam Line Tests - Spatial Resolution

Lower gamma flux at the NG6-M beam and better beam collimation and lower energy gives better contrast than the BT6 beam



Cd mask image for HB4 (Boron) MCP Cross delay line detector



Histogram of horizontal bar gives **~17μm rms** resolution (44 μm FWHM)

Neutron Detection Efficiency

The efficiency of both B14 and HB4 MCPs to neutrons was estimated from the BT6 beam (~1.6Å) flux:

HB4 (Boron) ~ 21%

B14 (Gadolinium) ~ 18%

Efficiencies are lower than expected given cross sections

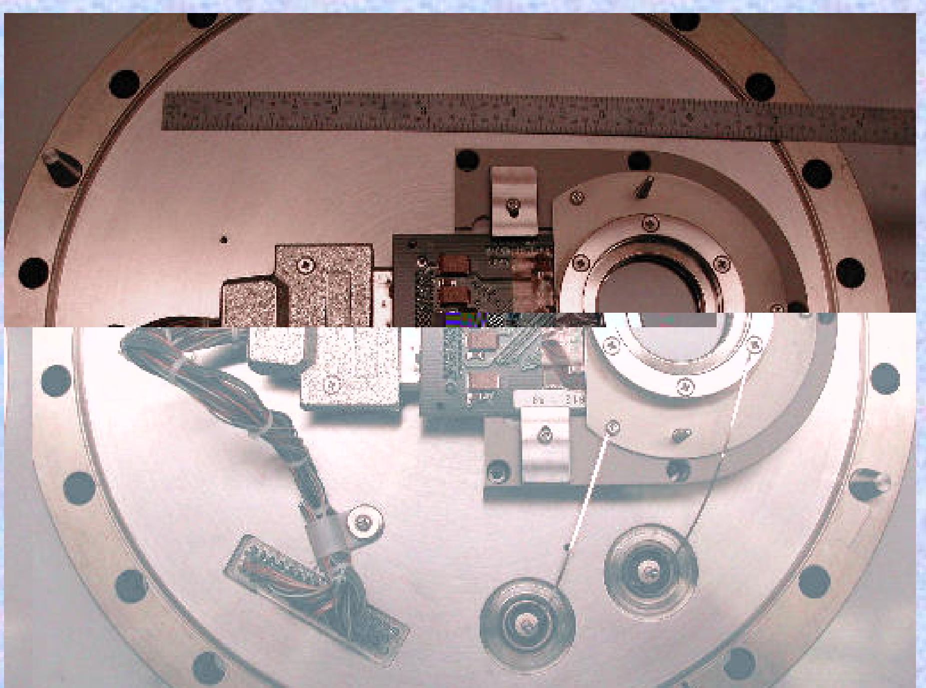
MCP configuration can be improved to enhance practical efficiency

- Pore diameter, bias and spacing
- Shape of wall, thickness of plates

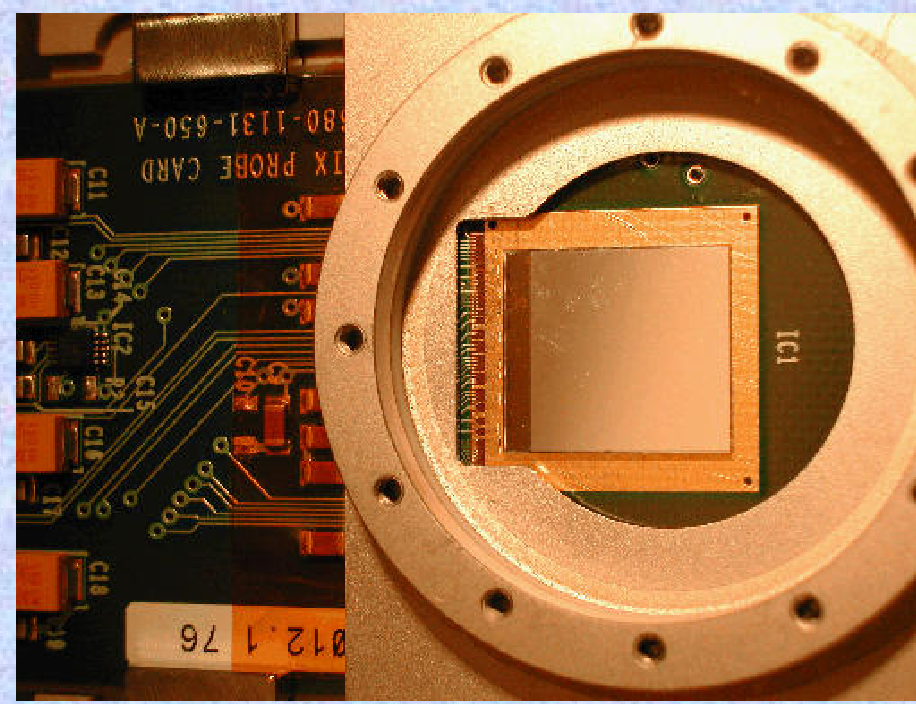
Neutron MCPs with Medipix Readout

Medipix/MCP hybrid originally developed for noiseless, fast readout optical detector for adaptive optics

Medipix readout allows high flux and frame rate

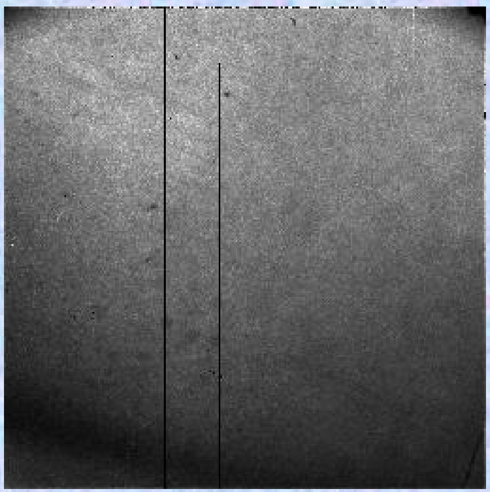


Open face “demountable” detector

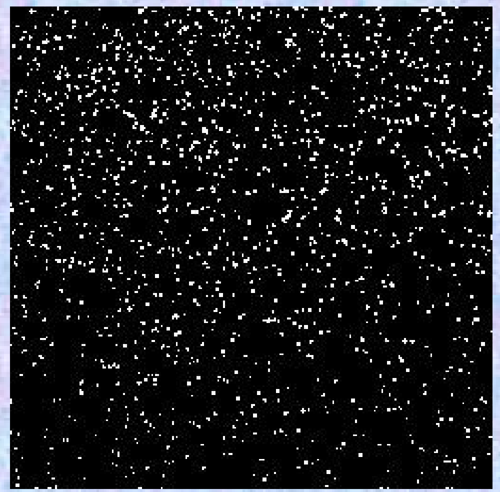


MCPs removed showing Medipix

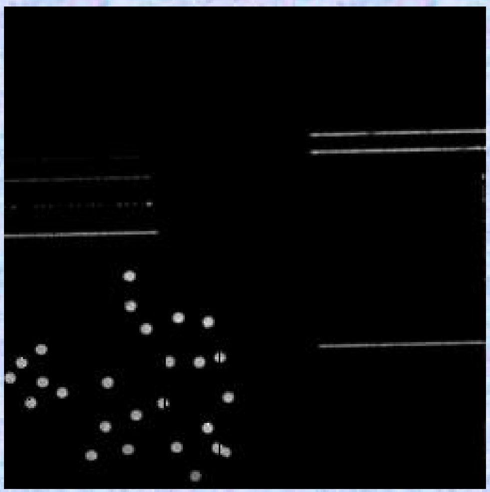
Gd plates w/ Medipix - UV illumination



50 sec flat



1 ms flat

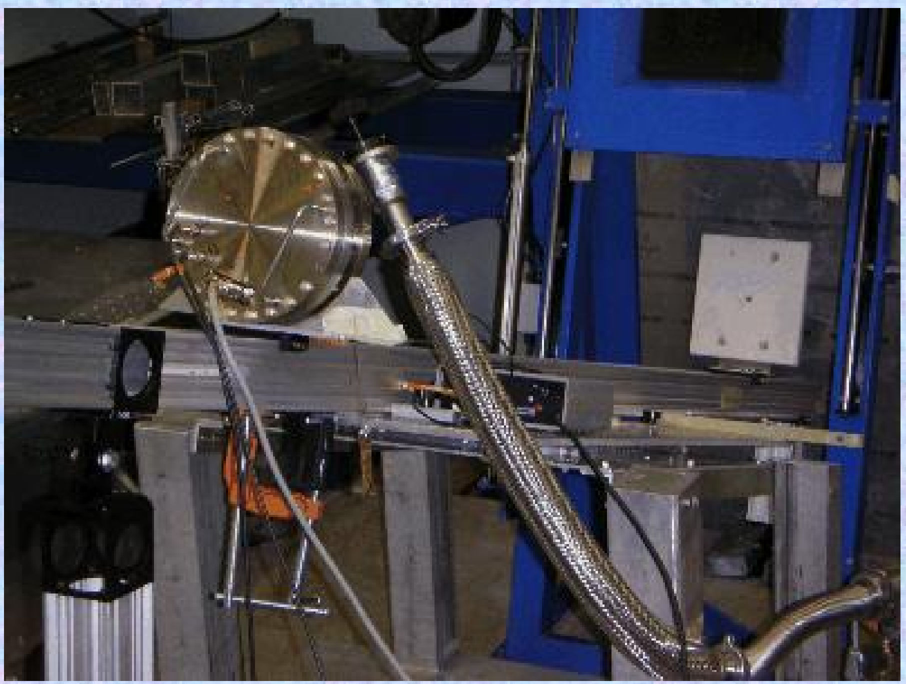


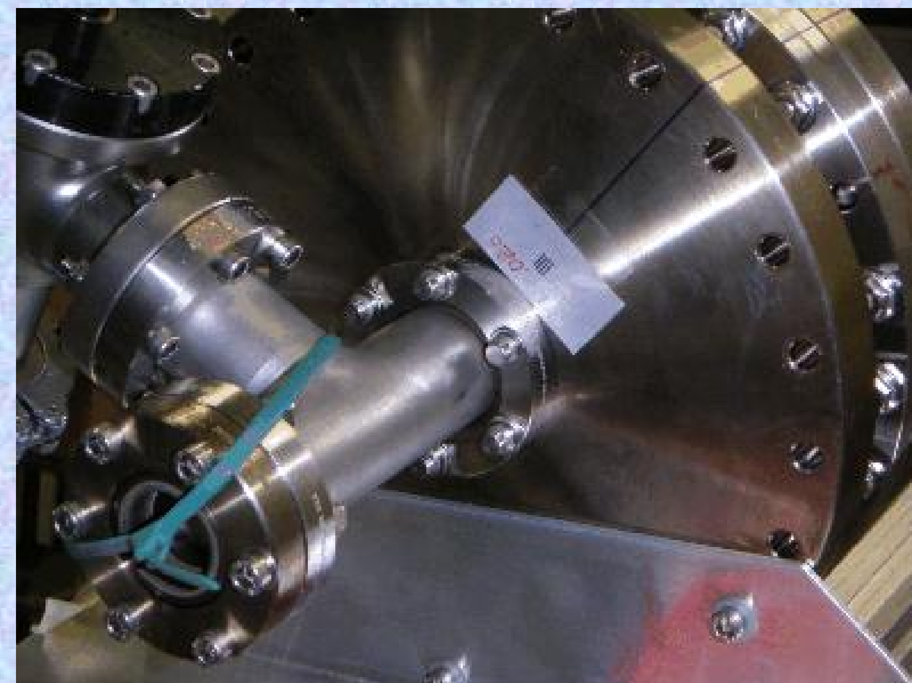
Gd mask

Resolution and count rates consistent with normal MCPs

MCP/Medipix in Neutron beam

Quick experiment using demountable detector in steel(!) vacuum tank in thermal neutron beam

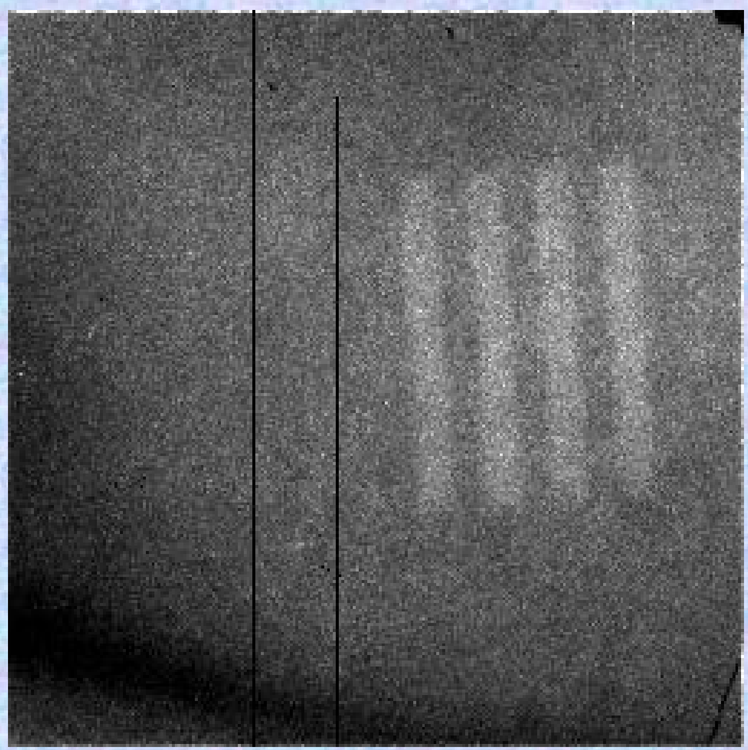




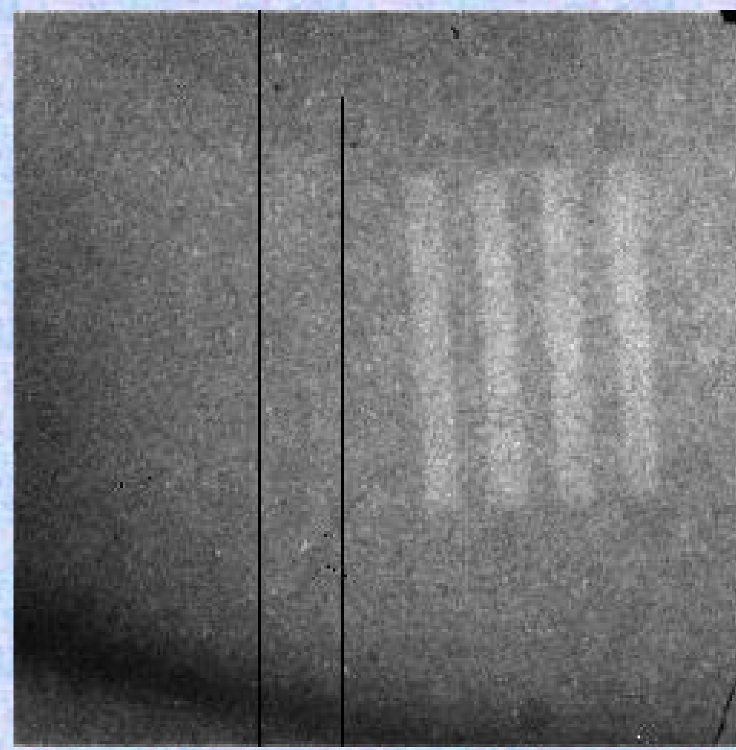
Detector vacuum housing at McClellan nuclear radiation center

Cd mask images in thermal neutron beam

250 μm slots on 500 μm centers

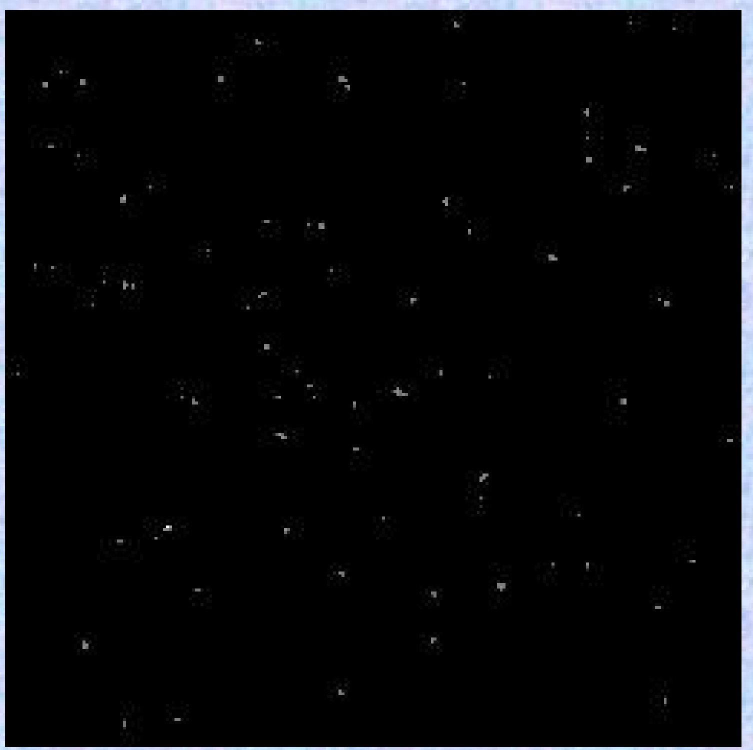


Low event threshold

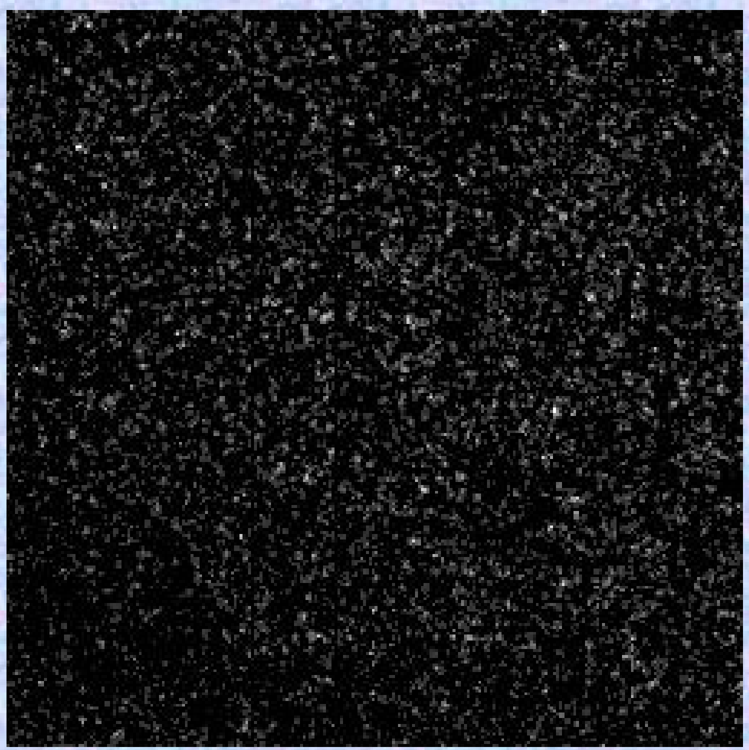


High event threshold

Cd mask images in thermal neutron beam



1 ms



100 ms

Summary

^{10}B and Gd doped MCPs are a new tool for imaging neutrons with high resolution and efficiency

Imaging MCP detector technology allows flexible and sophisticated techniques to match the sensor to the application

Optimization of the MCP physical parameters to improve sensitivity are continuing, but existing plates are already quite good and available

End