

# High resolution UV, Alpha and Neutron Imaging with the Timepix CMOS readout

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# Desire for better detector spatial resolution

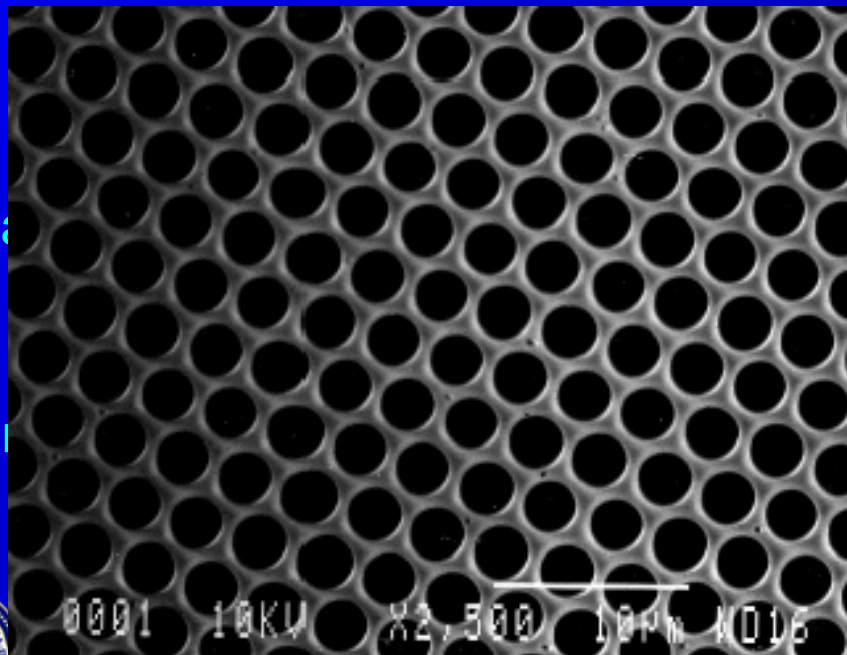
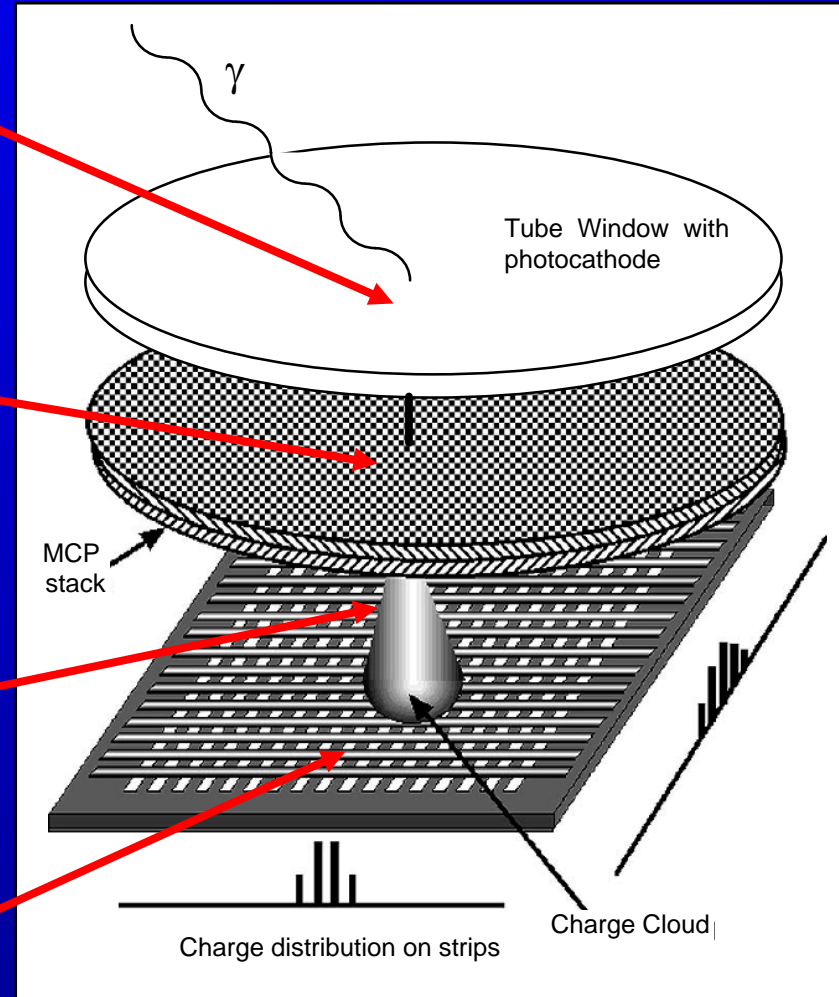
- Optics cannot always solve problem
  - Limits on physical size of detector is often fixed  
e.g. Space-based imaging (mass, optical focal length)
  - Projection length where optics don't work
- Make pixels smaller rather than detector bigger
- Ultimate limit is size of interaction region of radiation of interest



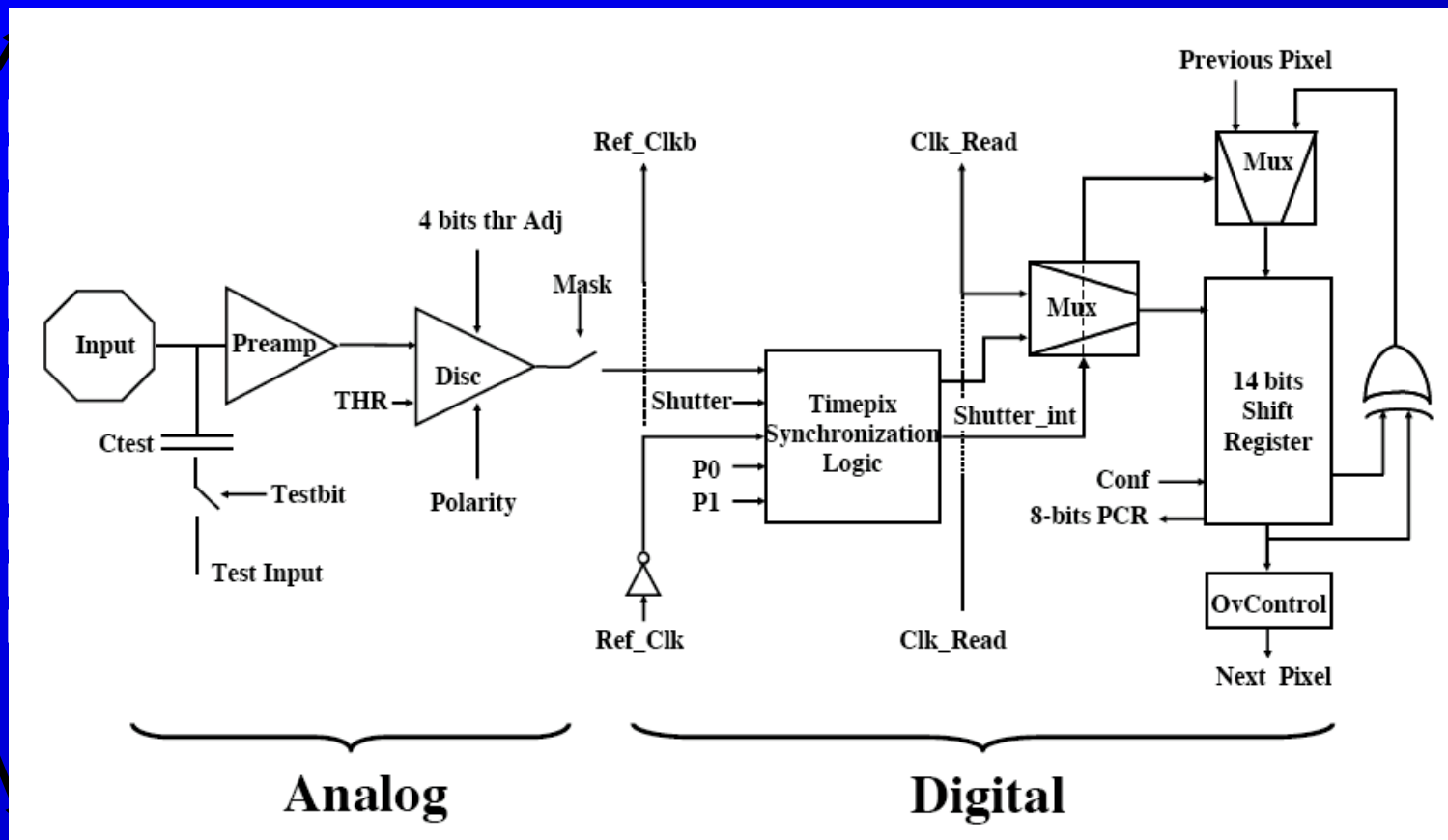
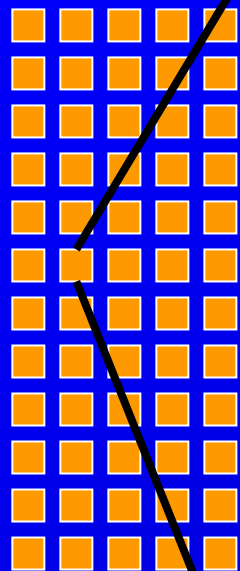
# Imaging, Microchannel Plate Detectors

~~Photocathode converts photon to electron~~  
~~MCP~~ ~~neutron~~ ~~electron~~ ~~alpha~~

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



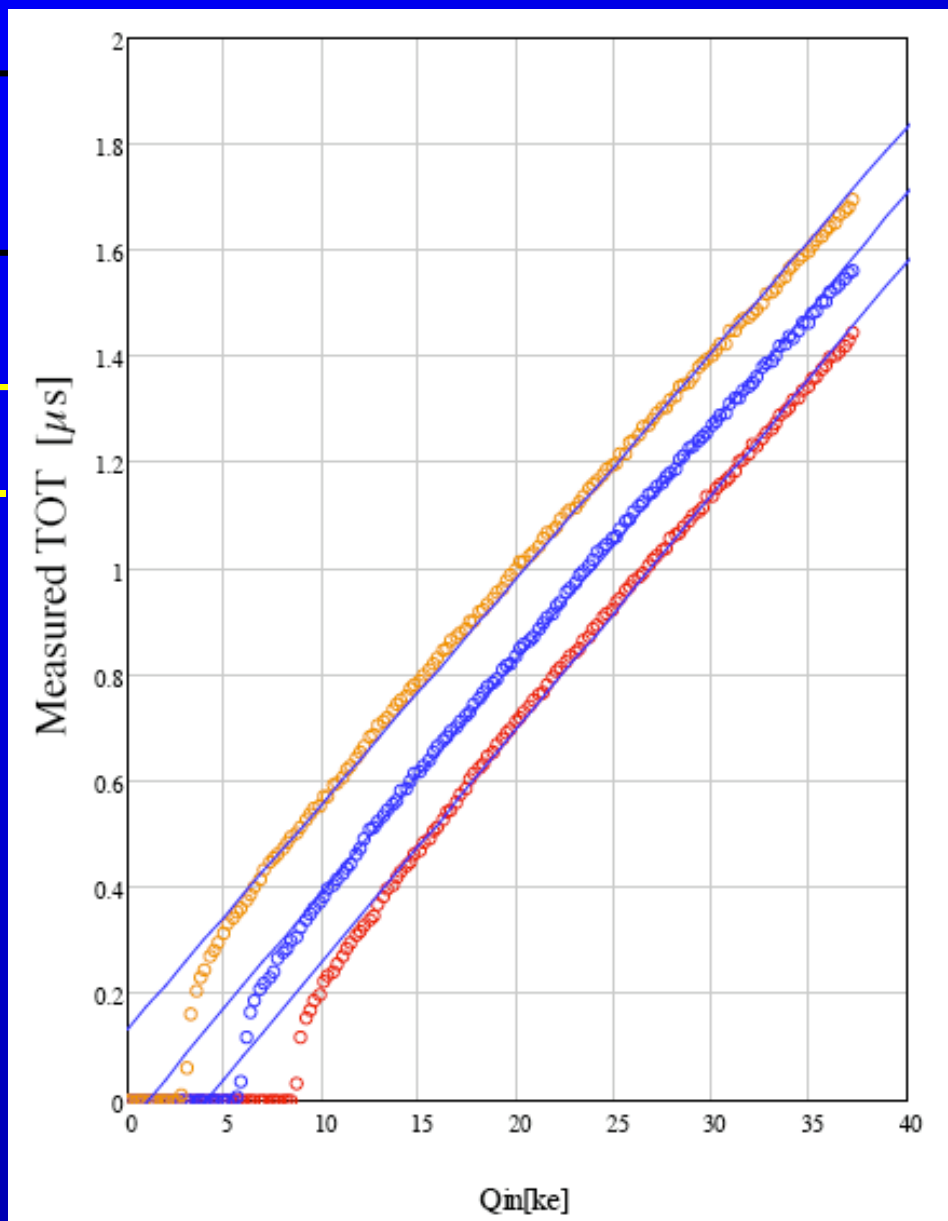
# Medipix/Timepix ASIC readout



# “Time over Threshold” = ADC

Clock

Thresh.



# Timepix version of Medipix



Amplitude rather than counts  
using “time over threshold”  
technique

If charge clouds are large, can  
determine centroid to sub-  
pixel accuracy

Tradeoff is count *rate* as event  
collisions in frame can  
destroy centroid information

Single UV photon events



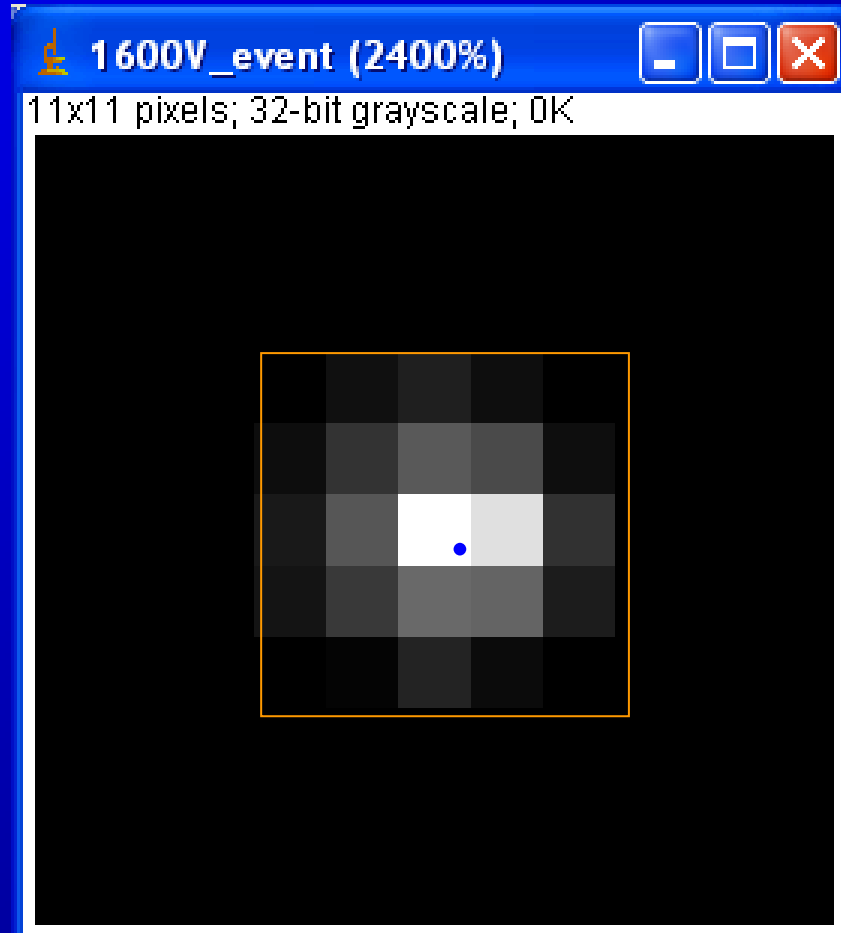
# Centroiding Algorithm

For each Frame

- Find local event peaks in 3x3 “boxcar” smoothed image

For each event

- Calculate simple 5x5 “center of gravity”
- Threshold on event sum and size
- Apply distortion correction
- Histogram *centroids* into high resolution 2D image



# Original Medipix mode readout

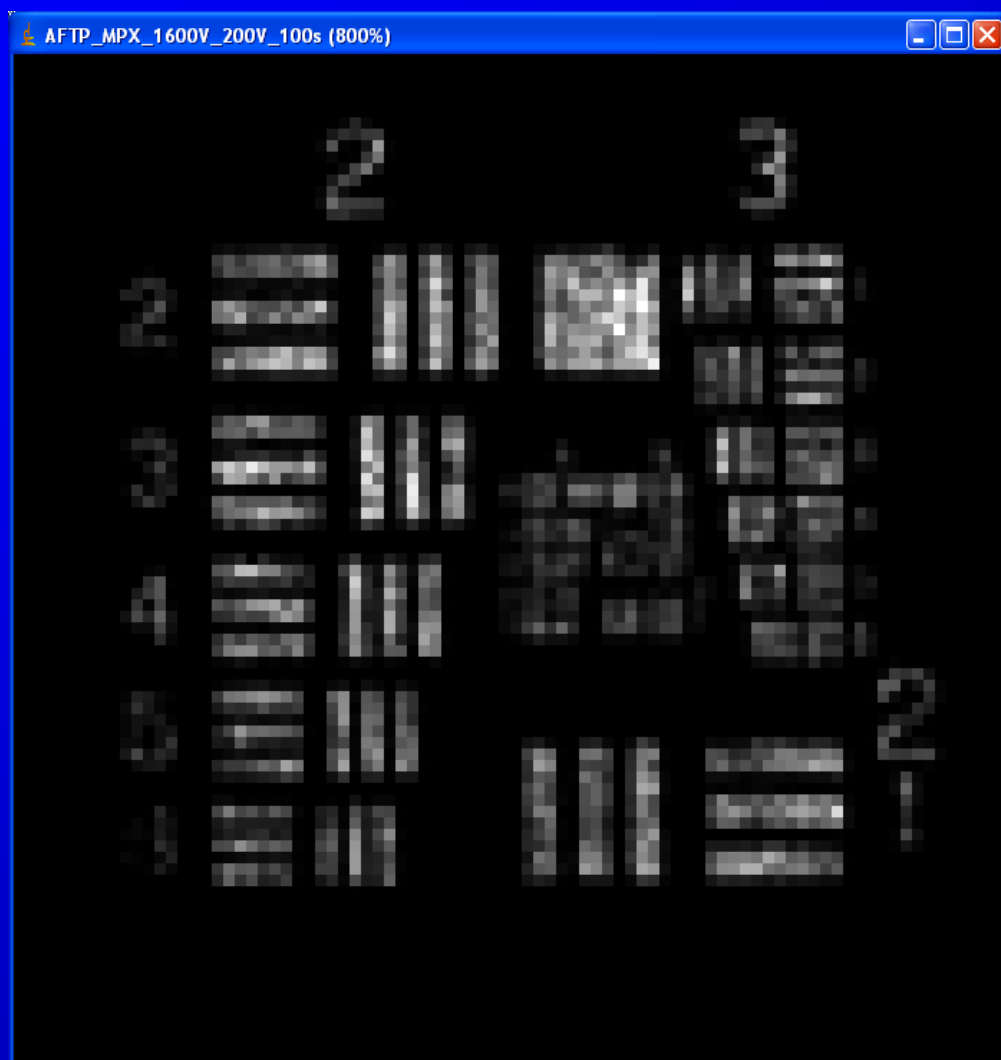


256 x 256  
(14 mm)

UV image limited by  $55 \mu\text{m}$  pixel



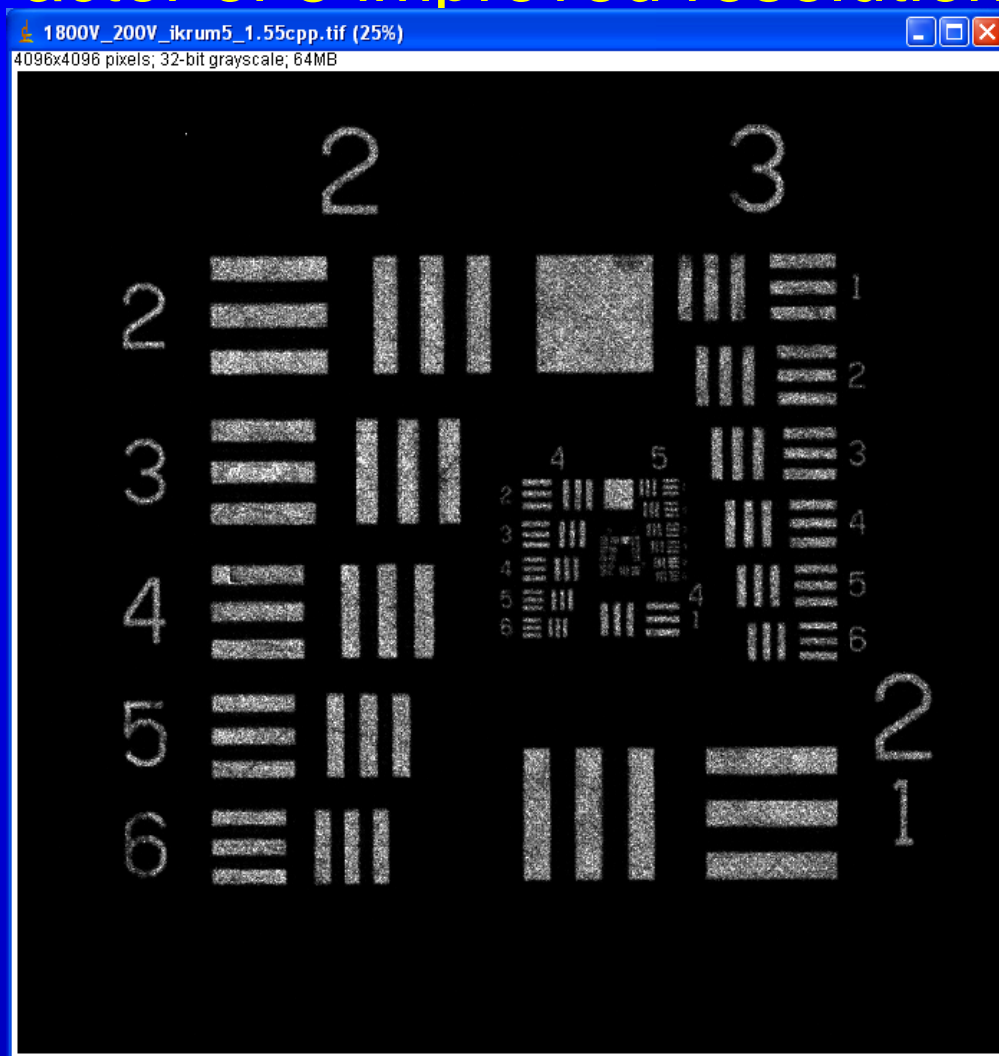
# Zoomed UV image of pattern in Medipix mode



Pattern 3-2 (= 9 lp/mm) barely resolved

# Timepix centroided mode

## Factor of 8 improved resolution!



256 x 256 converted to 8192x8192 pixels (1.7 $\mu$ m pixels)

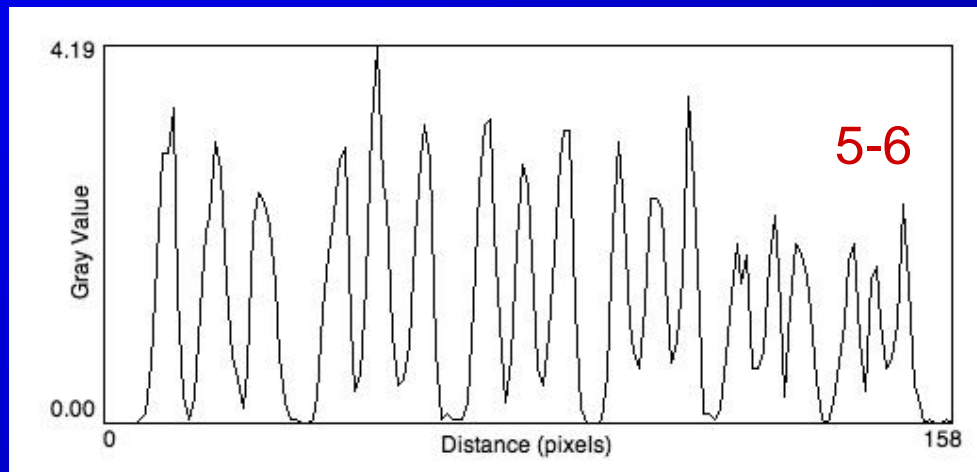
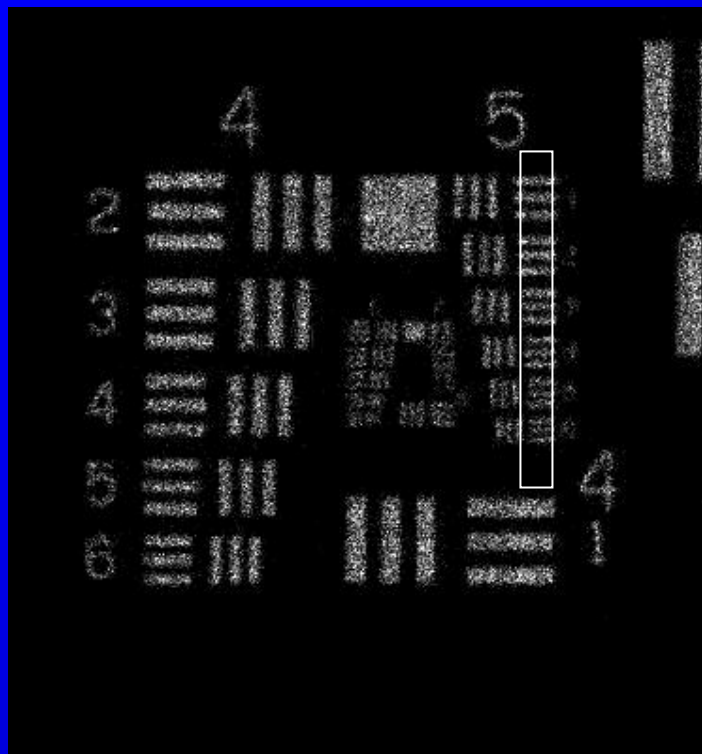


# Current Implementation

- Installed as a plugin in Pixelman software
- Designed to be computationally fast for later use in FPGA at kHz frame rates
- 30-60 events per frame
- Muros board at ~20 frames/sec
- 50k to 200k frames into 1 image (4096x4096, 1.7 $\mu$ m pixels)



# Zoomed

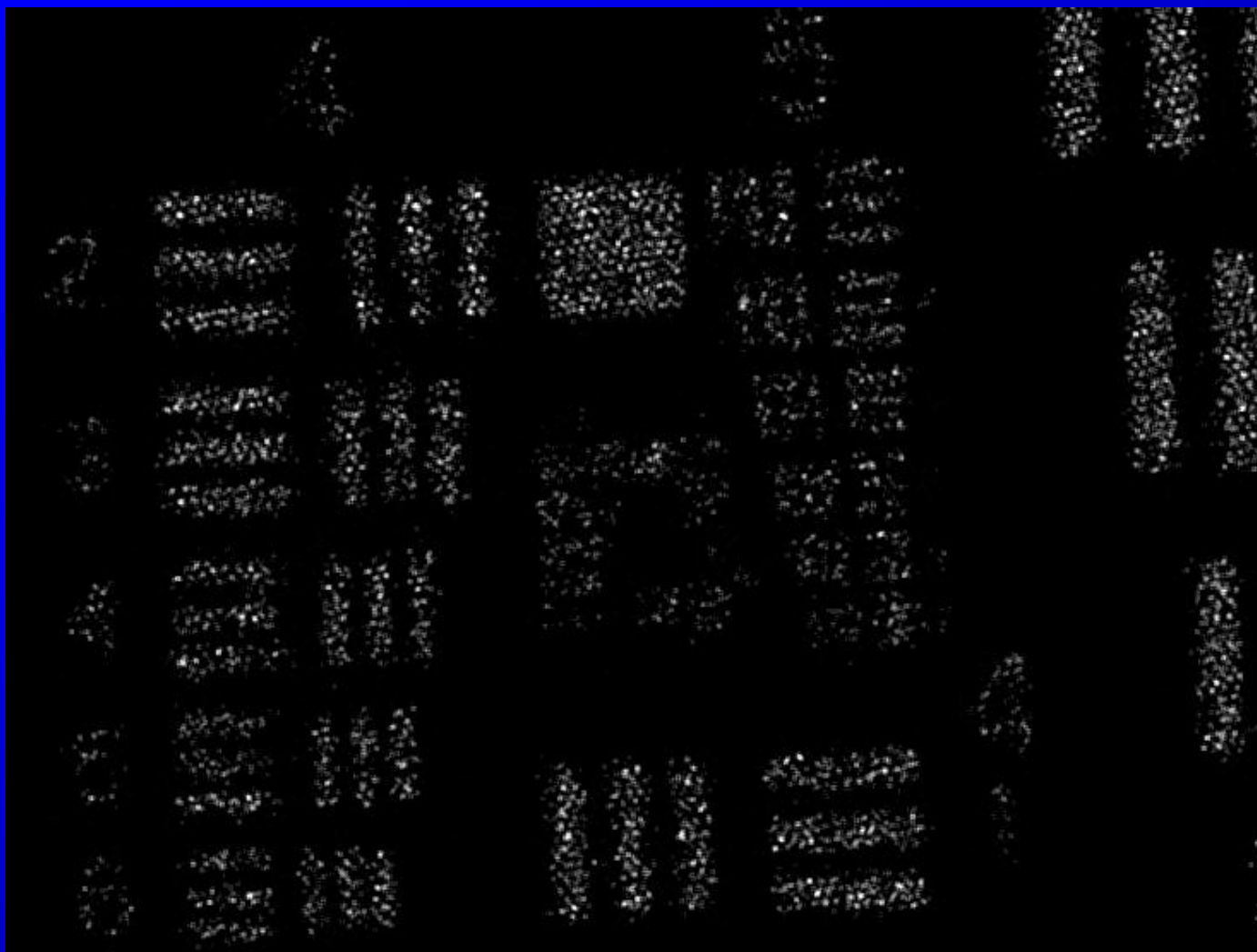


5-6 pattern resolved = 57 lp/mm  
Linewidth = 8.8  $\mu\text{m}$

The MCP pore spacing of 8 $\mu\text{m}$  limits further improvement



# MCP pores (10 on 12 micron)



For better resolution see R. Bellazzini's poster 11.16

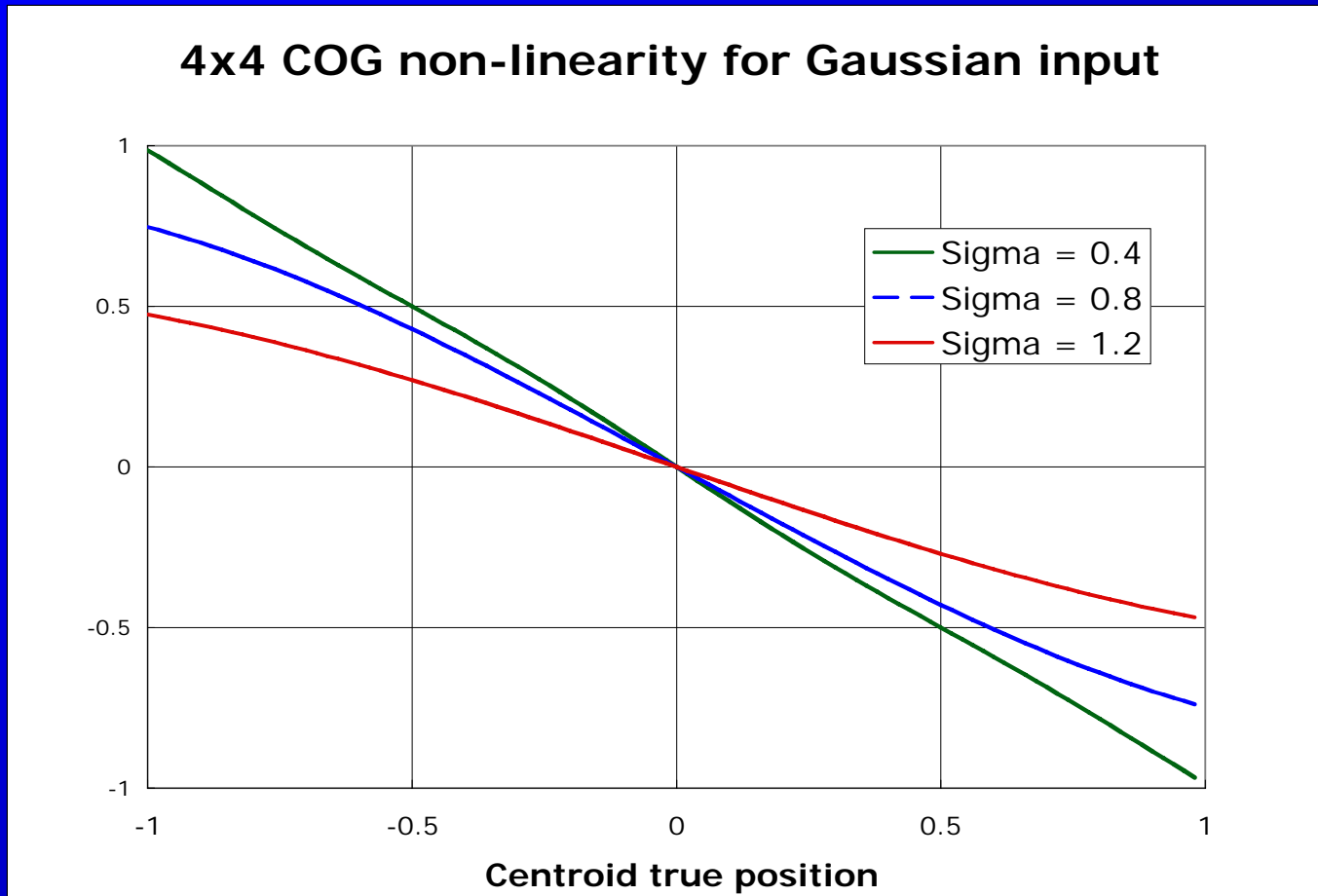


# Sub-pixel distortion

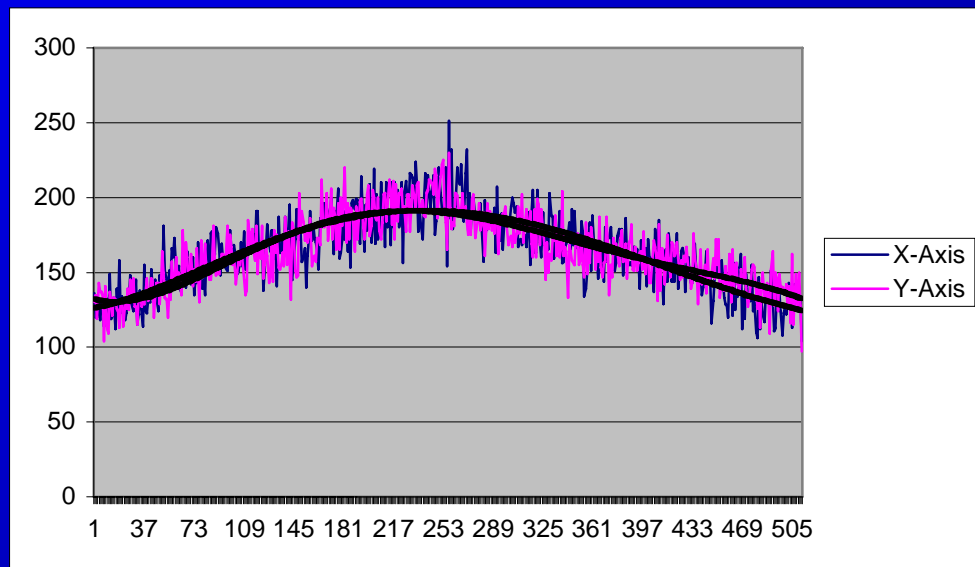
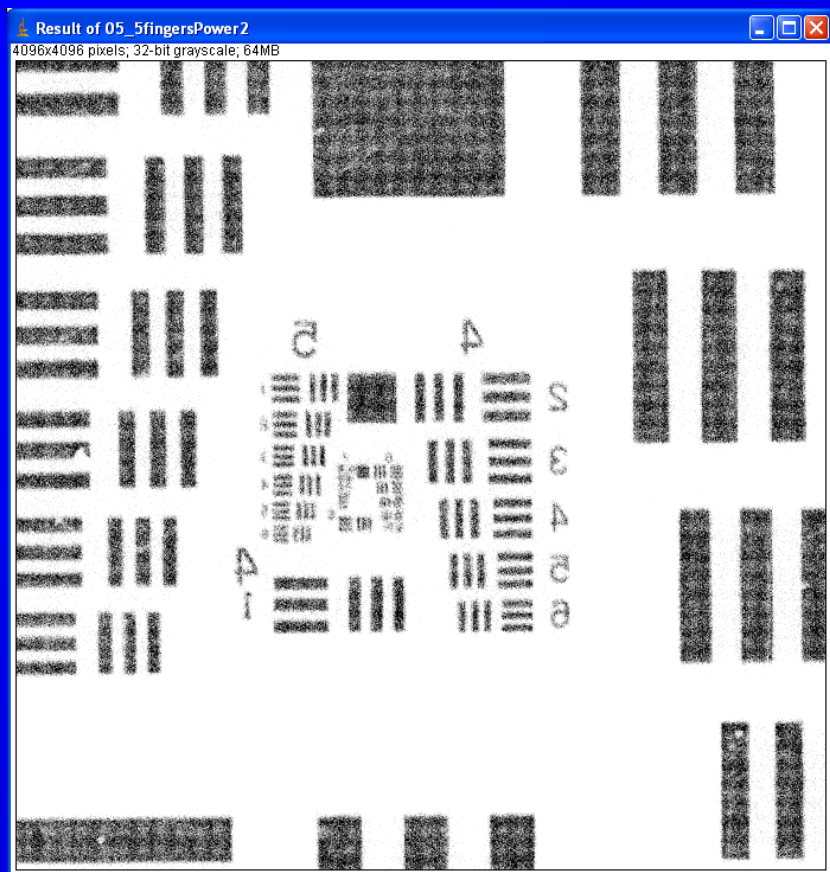
- There is a well understood distortion in the calculated centroid vs. the true centroid due to windowed sampling
  - Function of distribution size and sampling parameters
  - “Pulls” events towards center of 55  $\mu\text{m}$  pixel
  - Distortion repeats for every pixel
- If event sizes are uniform, it can be corrected by a histogram equalization technique and applied as a simple look-up table



# Modeled distortion for Gaussian



# Distortion (cont.)

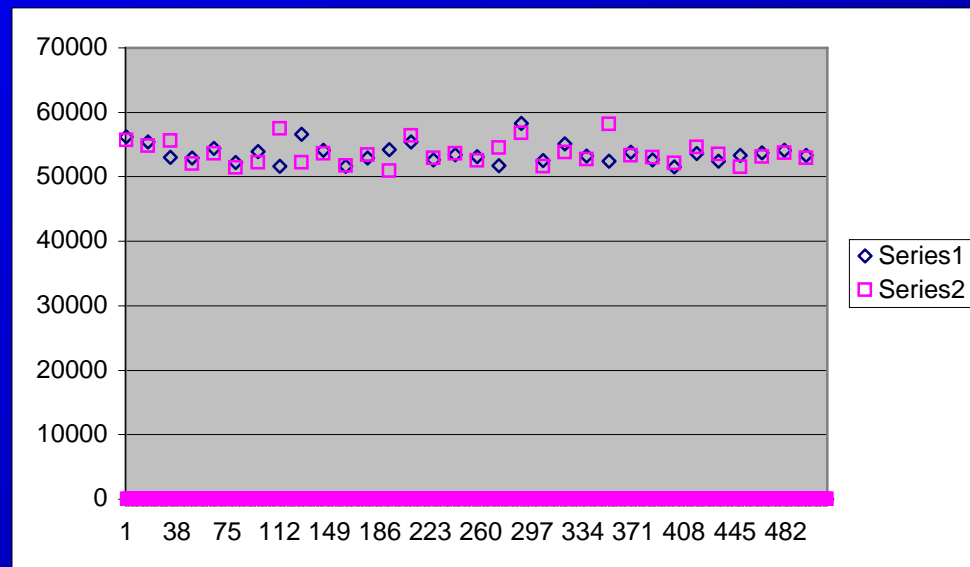
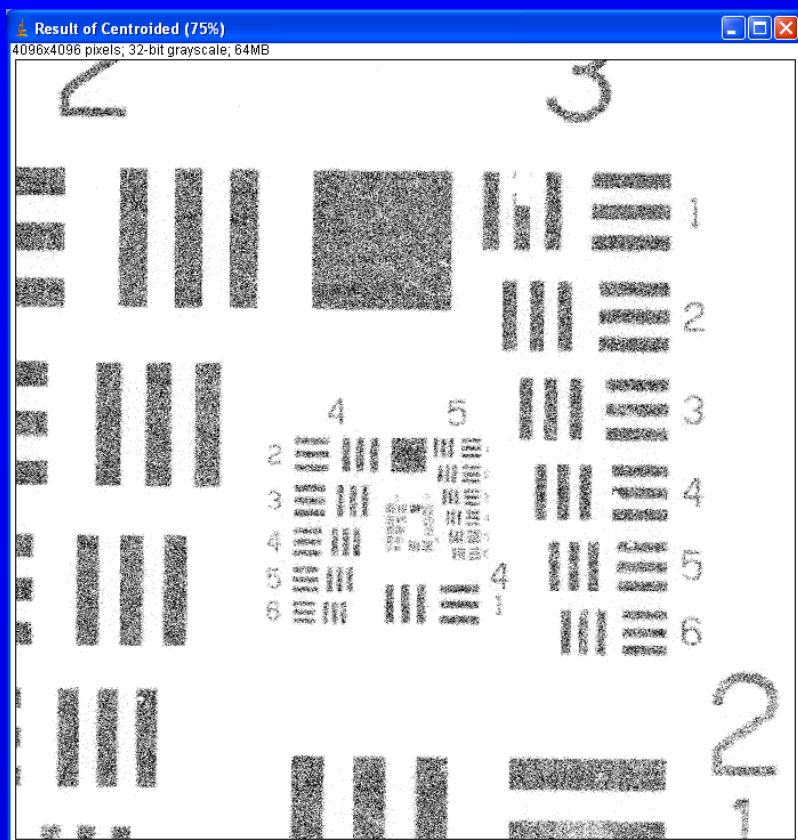


Distribution of sub-pixel locations  
across a single pixel

Use a histogram equalization  
technique to redistribute events  
uniformly across pixel



# Distortion corrected



Distribution of corrected sub-pixel locations across a single pixel

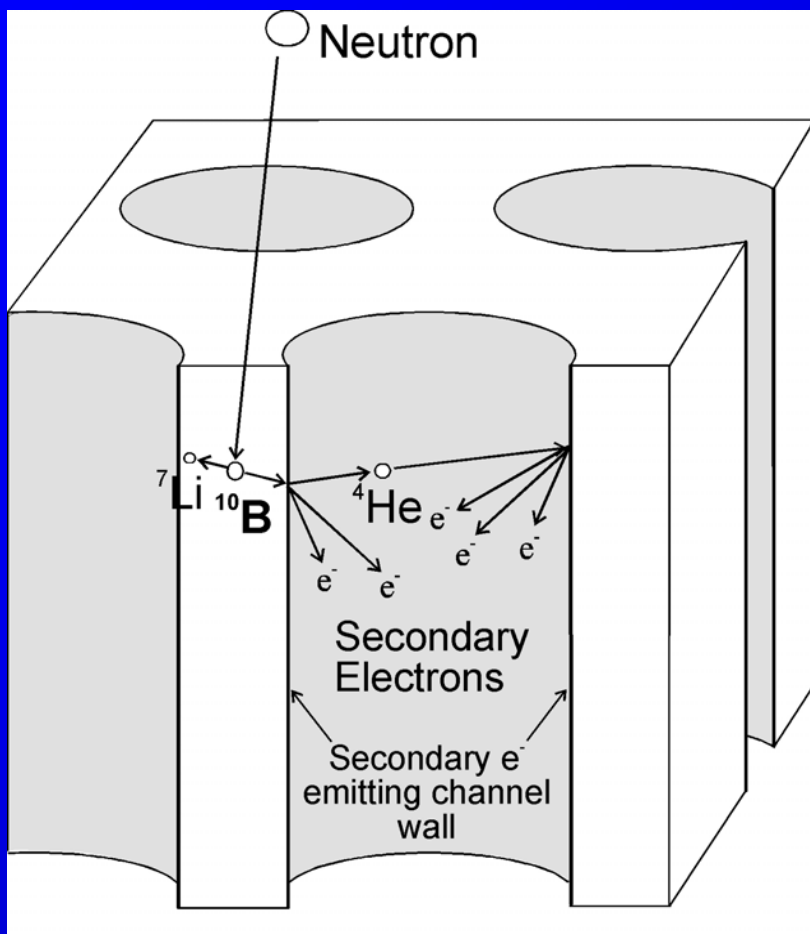


# High resolution particle imaging

- This technique can improve particle imaging as long as the initial interaction length is smaller than a pixel and there is a mechanism to spread the collected charge to many pixels
  - Neutrons in  $^{10}\text{B}$  or Gd MCPs
  - Alphas in Si or MCPs
  - Electrons ( $< 50$  keV?) in MCPs
  - Soft x-rays in MCPs ( $< 10$  keV?)



# Neutron MCPs ( $^{10}\text{B}$ or Gd doped)



Absorption of Neutron

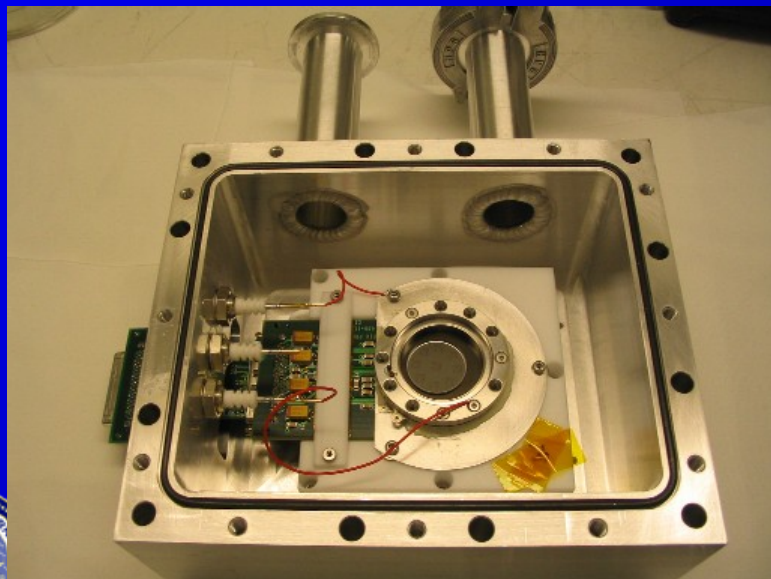
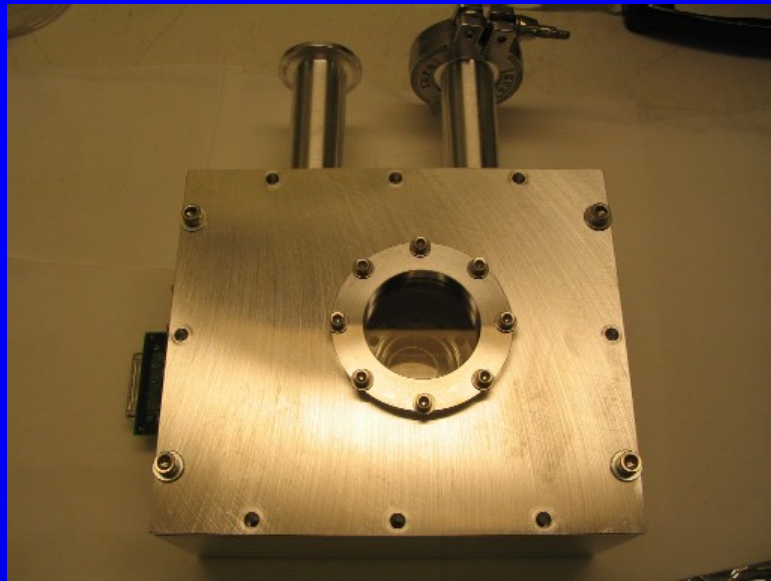
Secondary(s) reach surface of pore

Emission of photoelectron

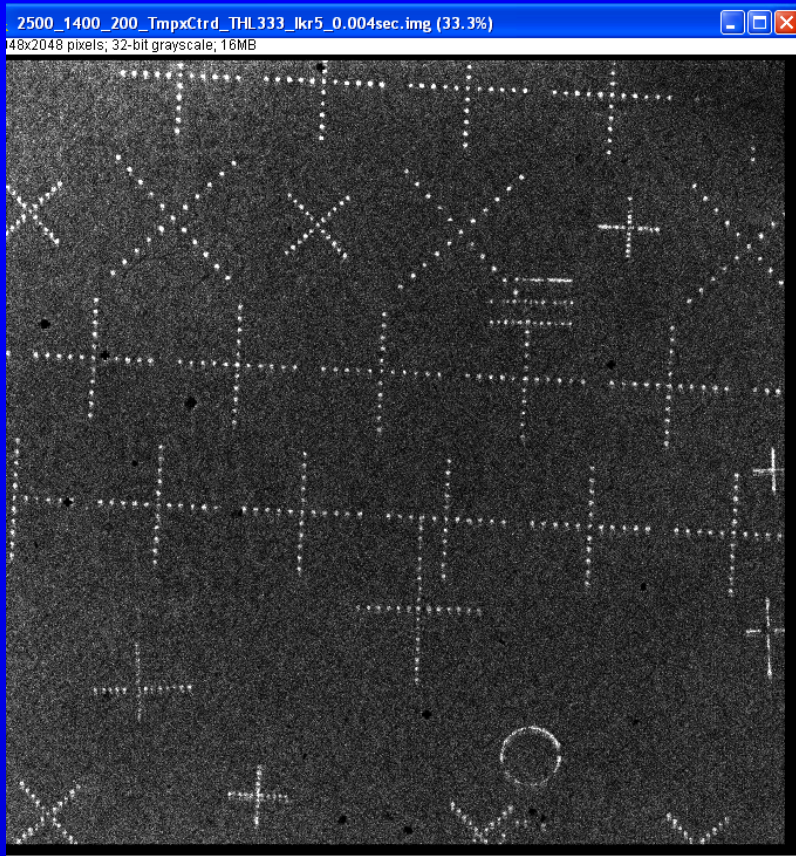
Electron gain above electronic threshold

Similar to UV resolution

# Portable MCP vacuum housing



# Neutron detected with $^{10}\text{B}$ doped MCP



McClellan nuclear rad. facility

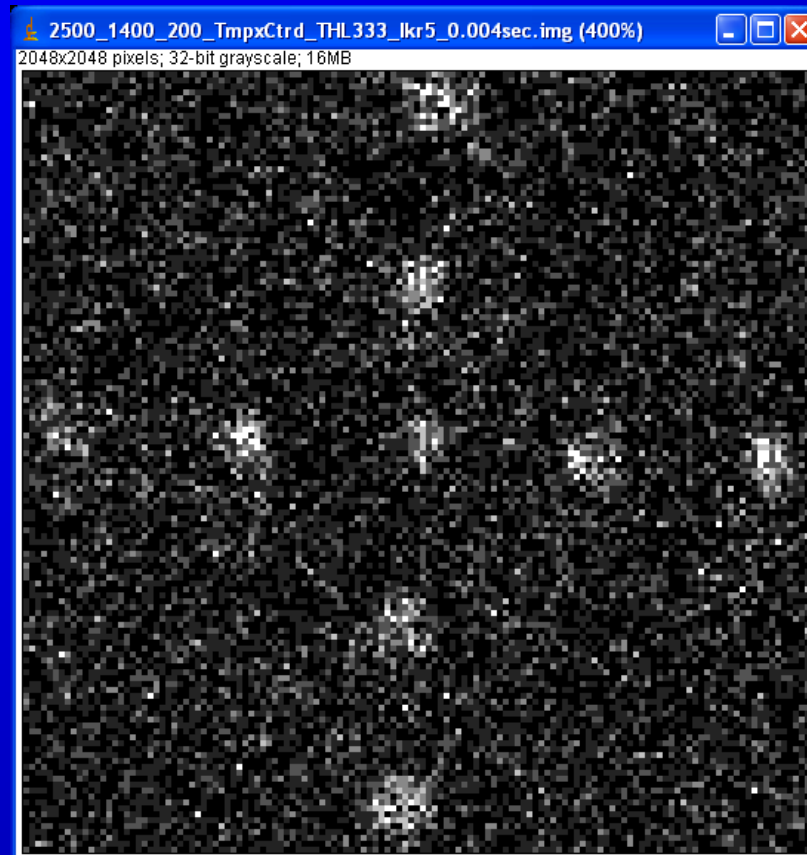
Thermal neutrons

Very high gamma bkgd.

Laser drilled Gd. mask



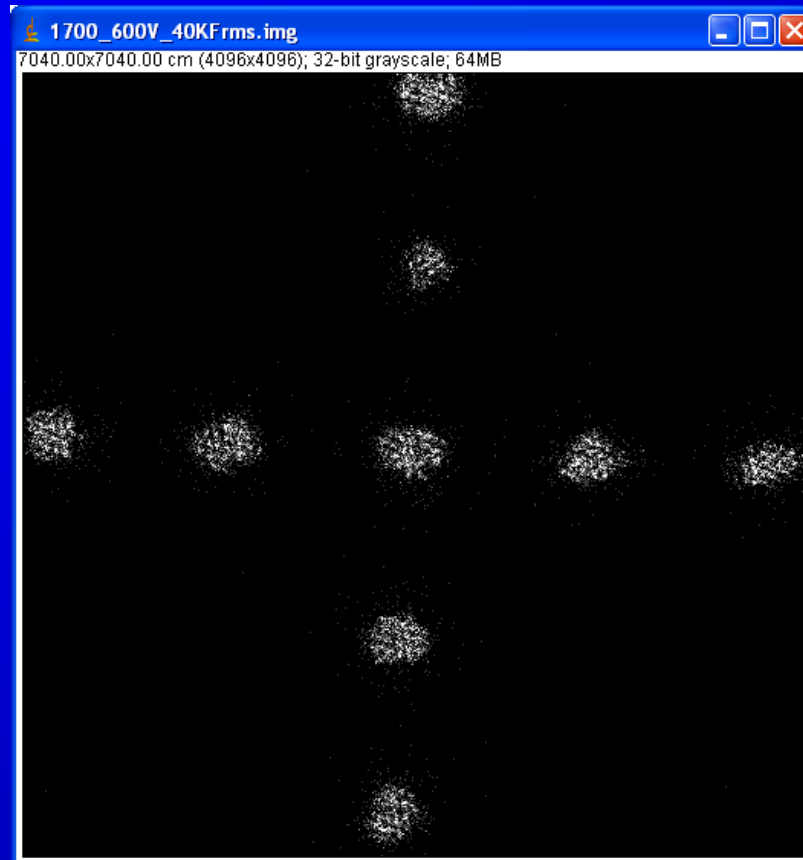
# Zoom - Neutron events



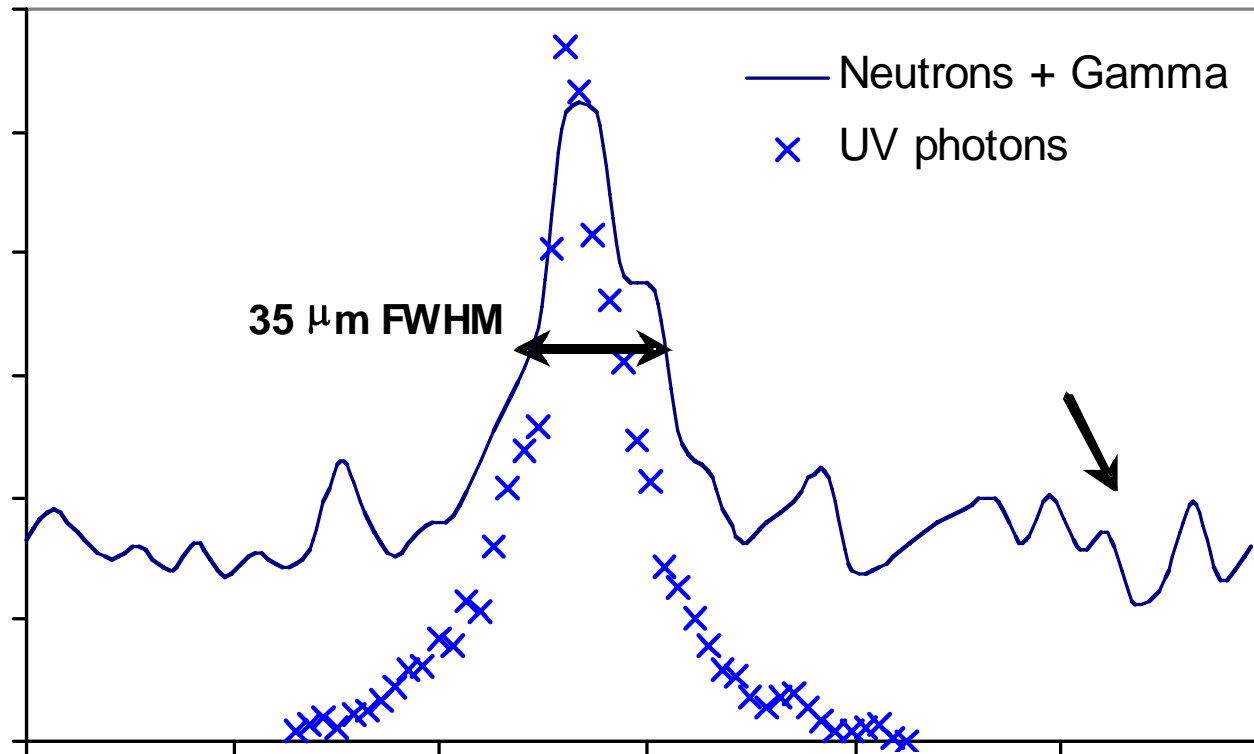
Holes approx. 60 microns



# Zoom - UV through same mask



# Best resolution of neutrons



# Alpha imaging using Timepix/Si

Diffuse  $^{241}\text{Am}$

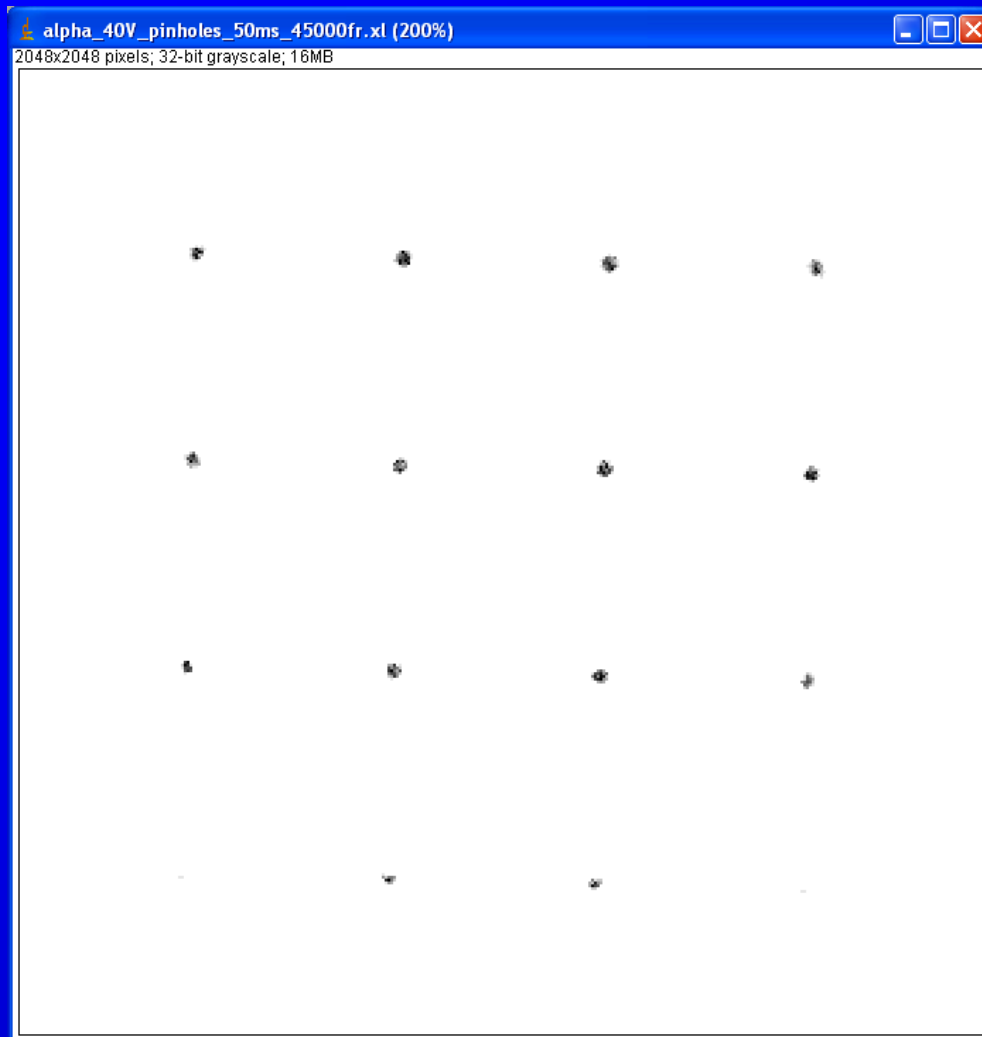
A schematic diagram of an alpha imaging setup. At the top, a red horizontal bar represents a source of diffuse  $^{241}\text{Am}$ . Four white arrows originate from this source and fan out downwards. Below the source is a thick orange horizontal layer labeled "Ni mask". The arrows pass through a narrow slit in the Ni mask. Below the mask is a large green area labeled "Si", representing a silicon detector. The arrows strike the top surface of a blue, semi-circular detector element within the Si region. At the bottom of the diagram, a purple horizontal layer contains several orange rectangular blocks, likely representing a substrate or support structure.

Ni mask

Si

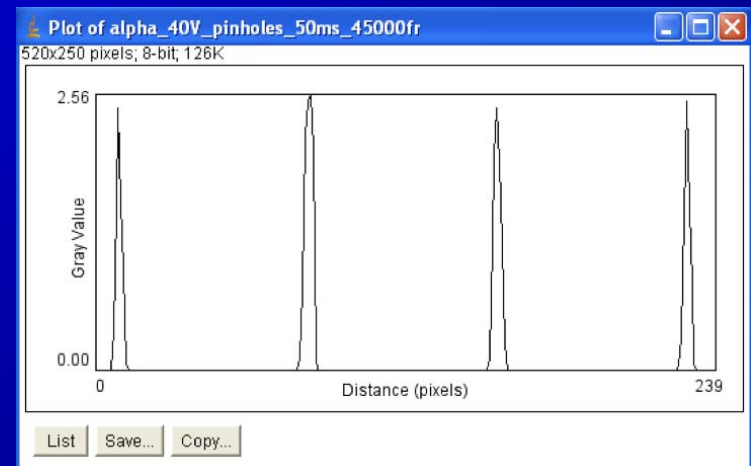


# Centroiding large events with Silicon/Timepix



$^{241}\text{Am}$  Alphas (5MeV)  
through  $10\mu\text{m}$  holes on  
 $500\mu\text{m}$  centers

< 18 micron FWHM



# Future work

- Integrate centroiding into PRIAM board (ESRF Grenoble) to get kHz framerates - factor of 50!
- Collision detection algorithm to reject miss-analyzed events
- Correct for pixel to pixel gain variations in TOT mode (necessary?)
- Optimize charge cloud size for resolution vs. rate



# Summary

- Timepix TOT mode allows us to improve spatial resolution of MCP readout by order of magnitude
- Very robust to variations of Timepix settings, nonlinearities, and non-uniformities
- Global ct. rate limited by event collision avoidance.
  - Counts/frame x Frames/sec  $\sim$  200 kHz
  - Local rate  $<$  10% of frame rate.  $\sim$  100 Hz
- Excellent for photon-starved astronomical applications (UV to x-ray)
- Biological Imaging? Neutron imaging? Electron imaging?



# Acknowledgements

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We would also like to thank the Medipix2 Collaboration

