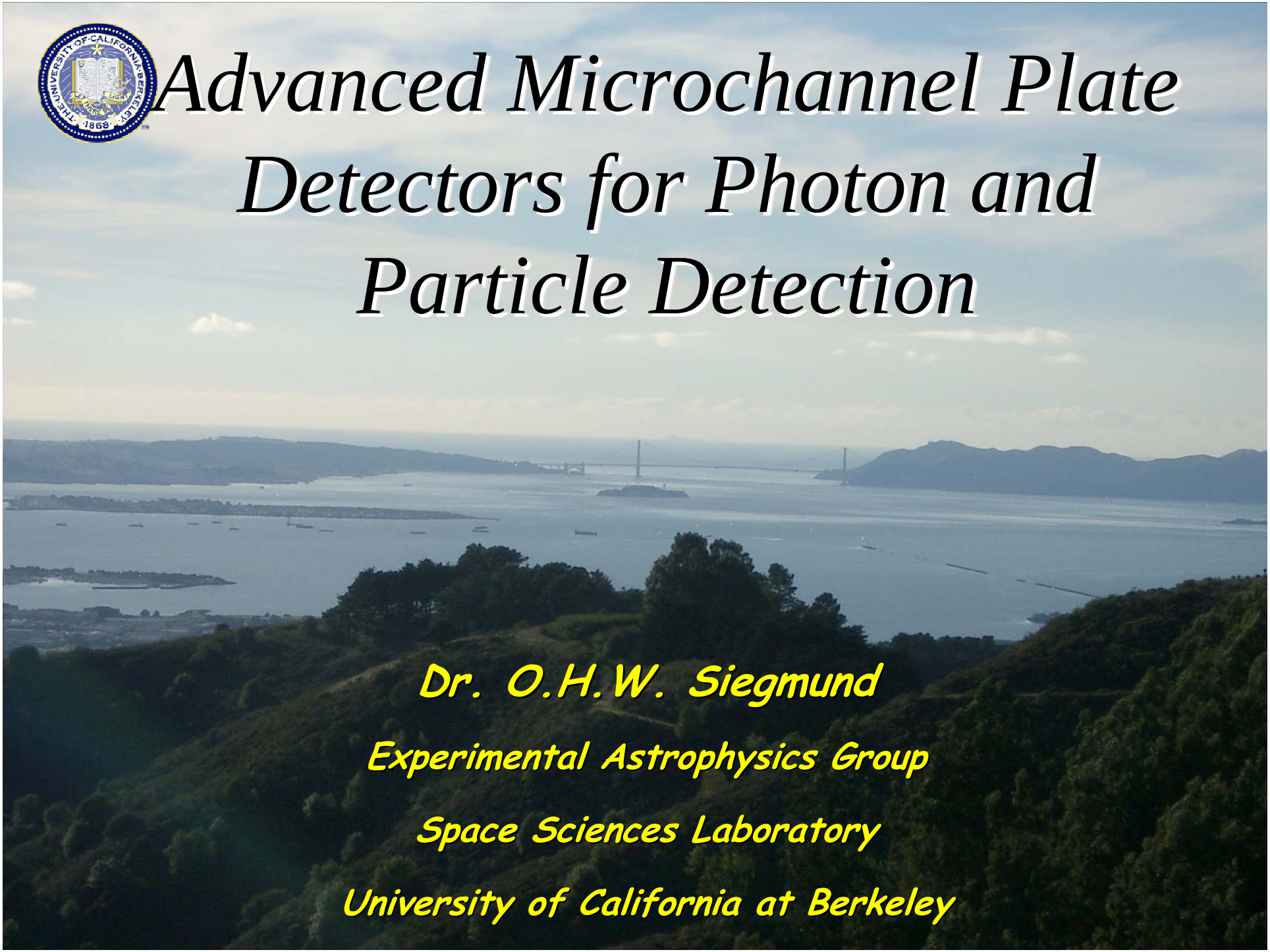


Advanced Microchannel Plate Detectors for Photon and Particle Detection

Dr. O.H.W. Siegmund

Experimental Astrophysics Group

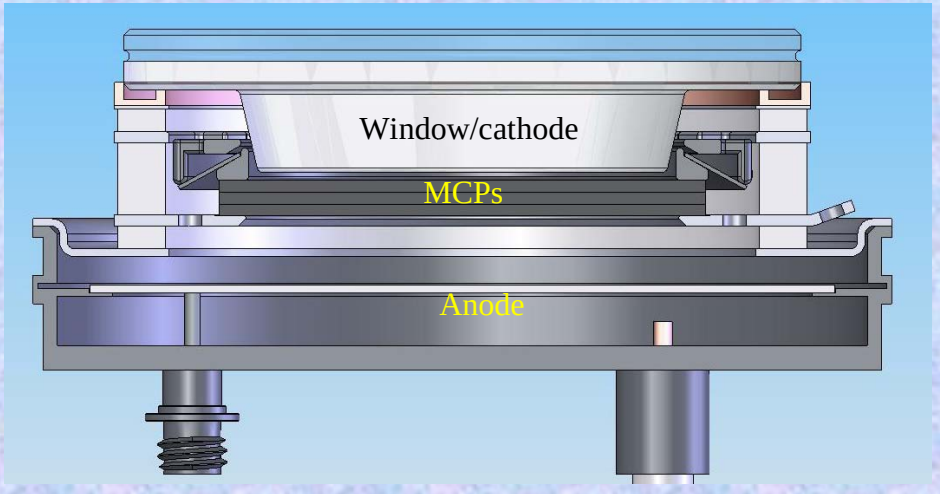
Space Sciences Laboratory

University of California at Berkeley

Microchannel Plate Detectors

There are many MCP detector schemes each with specific advantages/problems.

General scheme is photon conversion (photocathode) or direct detection (ions/e^-), 1,2 or 3 MCPs to provide gain, and then some type of readout.



Photocathodes

Alkali halides

Multi-alkalis

GaAs (P/In)

GaN

Diamond

Microchannel plates

Glass

- low noise
- curved

Si - lithiographic

Ceramic - lithographic

Readouts

Resistive anode

Wedge and strip

Phosphor/CCD

Codacon/Mama

Delay line

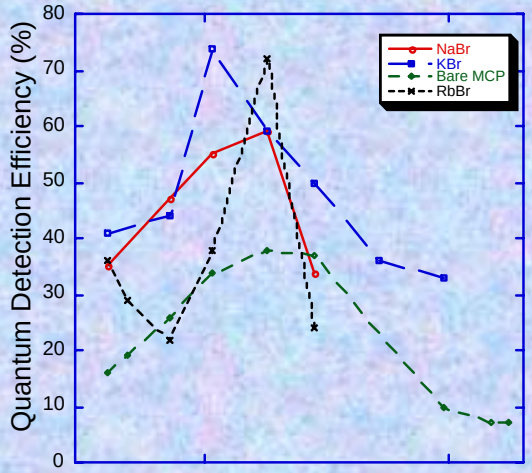
Cross strip

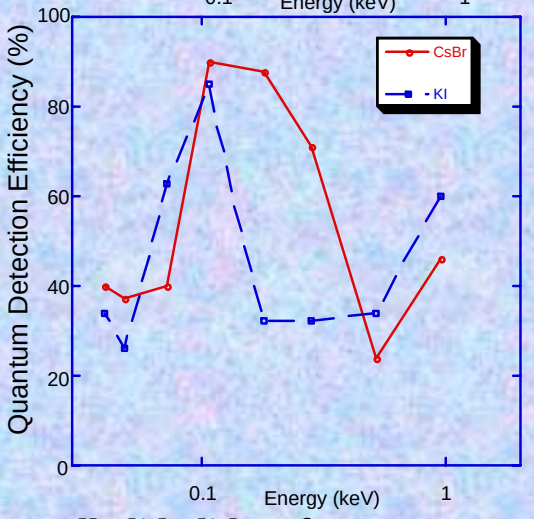
ASIC/APS

Photocathodes and Microchannel Plates

Cathodes

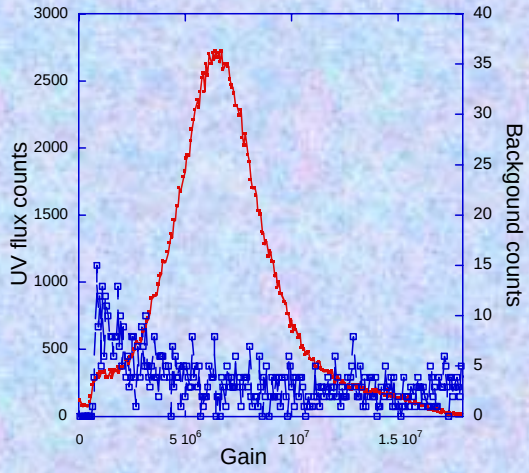
Alkali halides have high QE.
Susceptable to radiation damage and atmospheric exposure



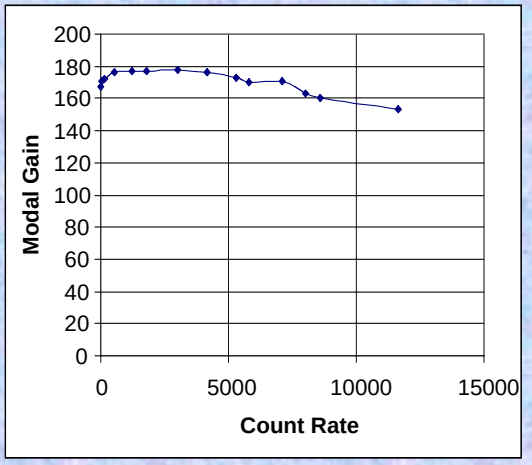


Alkali halide soft X-ray QE

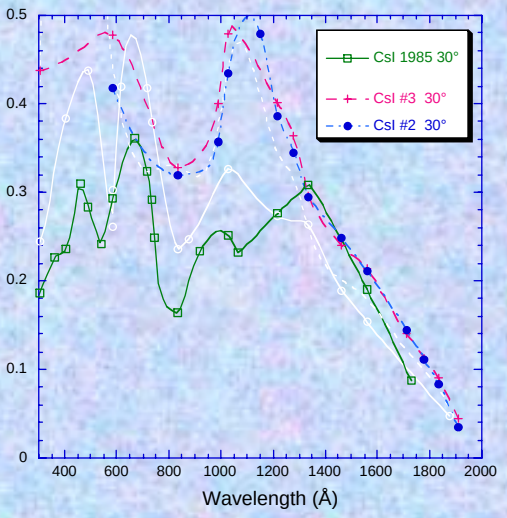
Glass Microchannel Plates



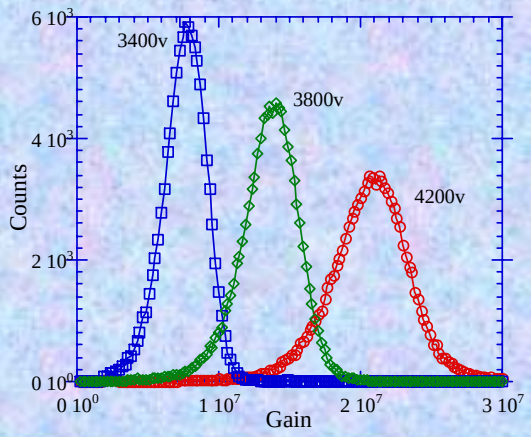
MCP background 0.25 cm^{-2} sec^{-1}



MCP local rate vs gain (100µm spot)



CsI on MCP with collection bias



MCP event pulse height distributions

Microchannel Plate Detectors (current)

Our current workhorse is the cross delay line readout MCP detector

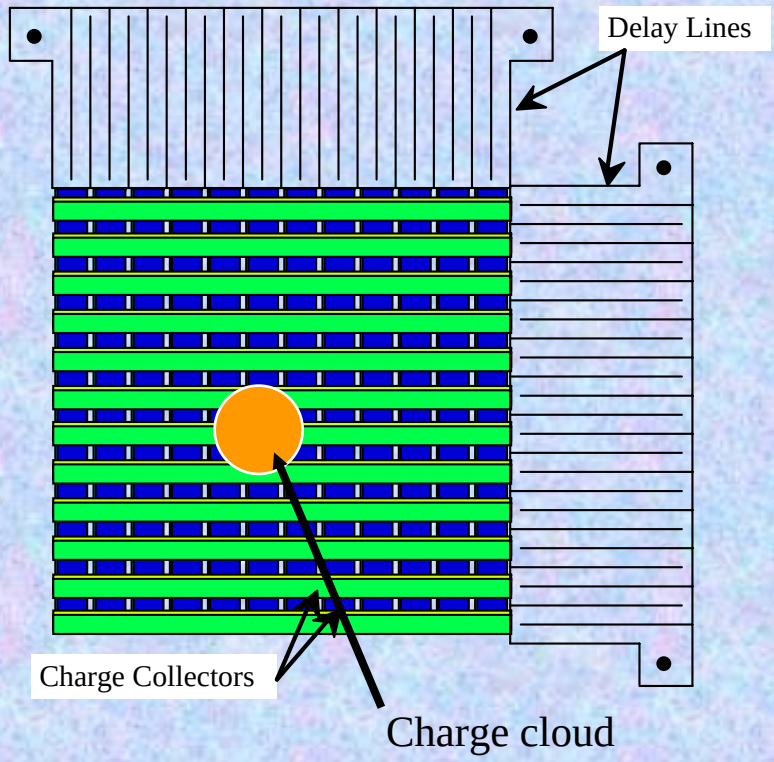
Typical characteristics

Use alkali halides for XUV QE (~50%),
Glass MCPs. Gain ~10^7
Photon, ion, electron, neutron sensing
Size formats to 100mm, Resolution ~30μm
Event rates to >1 MHz, (kHz/pixel rates)
Timing <100ps (~20ps limit)

Issues,

High gain/lifetime/local-global rate limits
Single event sequential processing

Cross delay line anode is a multi-layer crossed conductor layout. Period is ~0.5mm on ceramic. MCP charge divides between upper and lower charge collectors, Event centroids are linearly proportional to signal arrival time difference at ends of delay lines. Fast event propagation (50 ns). Compact and robust (900°C).

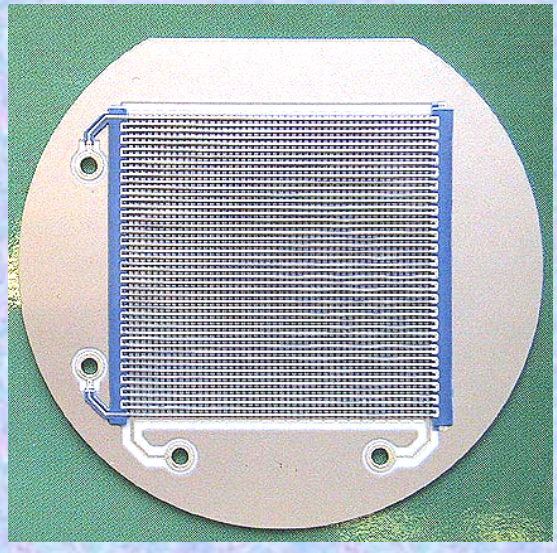


Cross delay line readout scheme

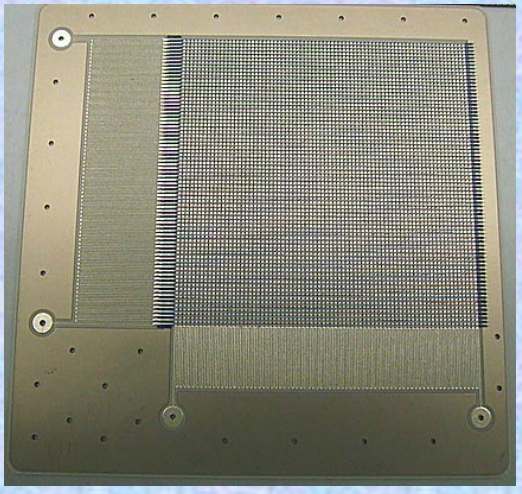
Cross Delay Line Readout

40mm 4 quadrant multi-hit cross delay line anode

Many different cross delay lines have been made, some large area (100mm), some small to get fast end-end delay (<10ns), some subdivided to get multi-hit data (ion/electron TOF).



30mm Cross delay line ceramic anode

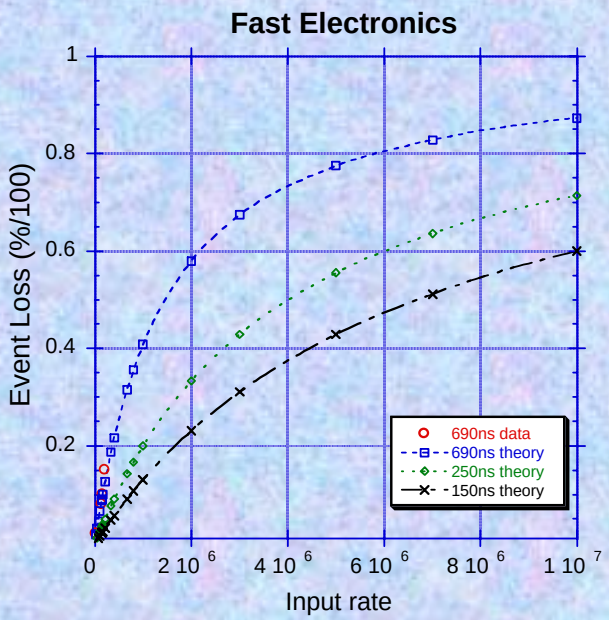


45mm Cross delay line ceramic anode

105mm cross delay line ceramic anode

Cross Delay Line Electronics Implementation

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.



Counting rates of a few MHz are attainable

13 bit, <15ps FWHM resolution, <400ns conversion, X, Y, charge and T (25ns/bin) with internal constant fraction timing discriminator. Second unit may be daisy chained to give 2 channels of "fine" timing for high resolution timing (external trigger - ALS, etc). More units can be daisy chained to latch events for short inter-event times (~10ns). Interfaces directly to National PCI card.

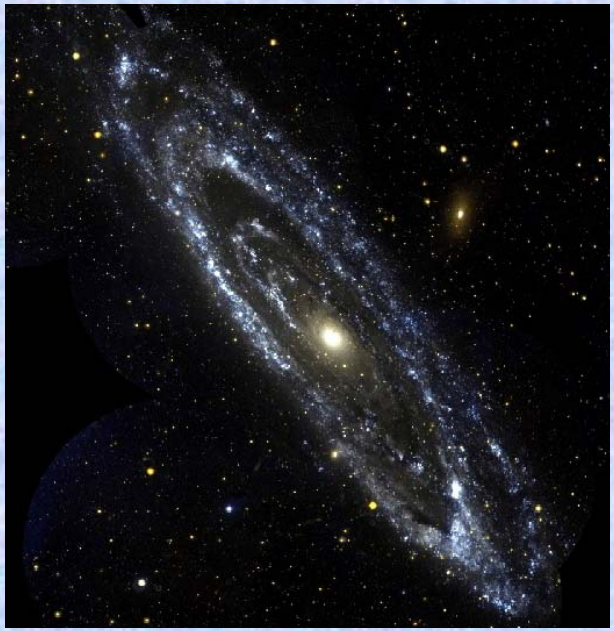
X,Y:- 13 + 13 bit (15ps jitter)
T_{course}:- 32 bit (25ns/bin)
T_{fine} :- 2ea, 13bit (15ps jitter)
Deadtime:- <400ns (200ns underway)
Inter-event deadtime:- ~10ns (multi-unit)

Amplifier - 4 fast timing channels and two slow charge channels.

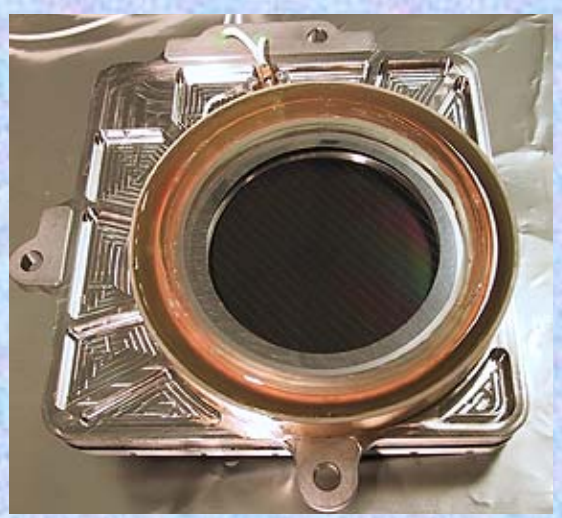
Astronomical MCP Photon Counting Sensors

Imaging

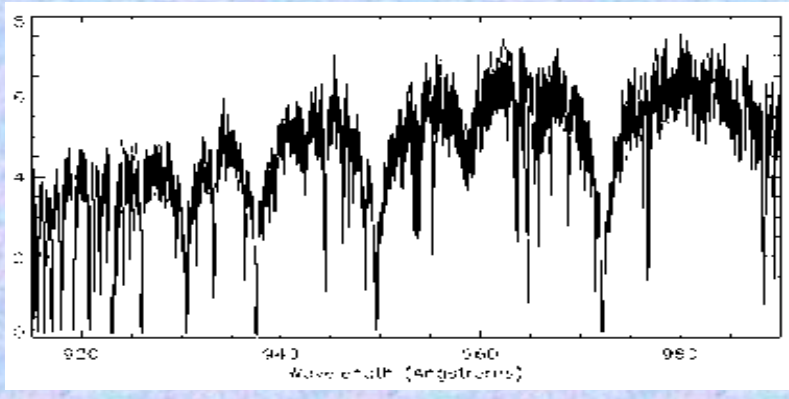
M31/32



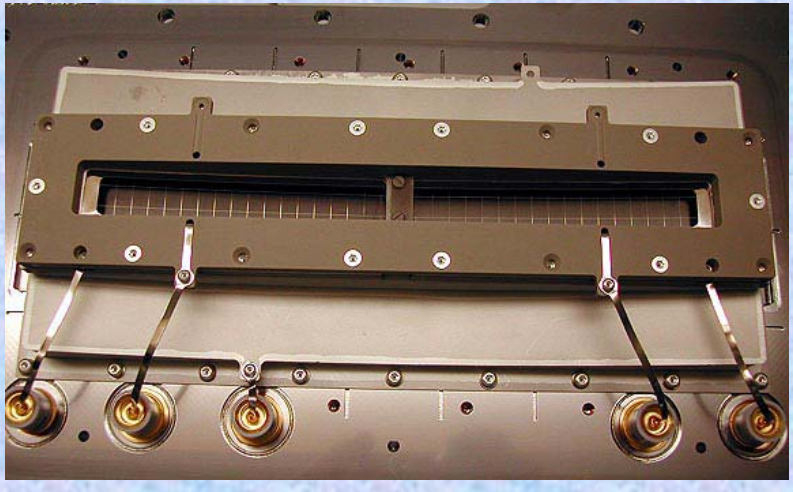
GALEX 65mm MCP sealed detectors, 2k x 2k format 130nm - 300nm



Spectroscopy



FUSE/COS rowland circle 200 x 10mm curved MCP detector, 10k x 300 format, (<20µm FWHM spatial resolution)



Microchannel Plate Photon Counting Detector for Fluorescence Lifetime Imaging and Timing

Image tube inside housing, showing the entrance window and photocathode

The course/fine time tagging of each photon event allows the image to be selectively edited after the data acquisition, to extract any arbitrary time/position characteristics so that the data collection can be done in one run.

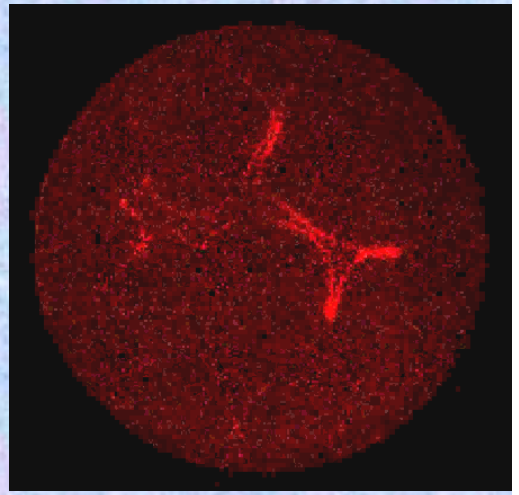
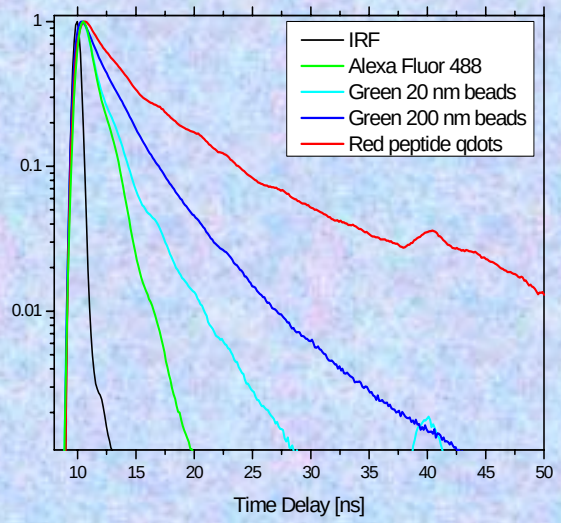
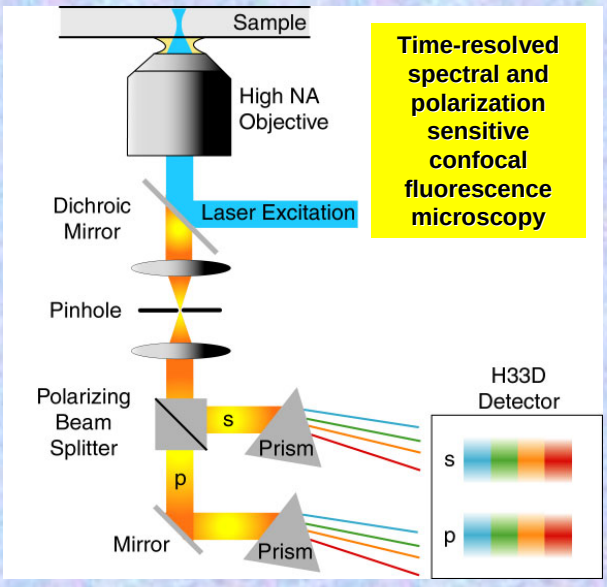


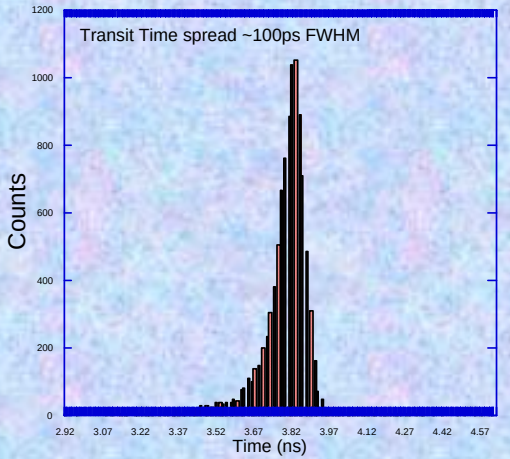
Image results for laser excited nanocrystals showing time dependent emission characteristics



Measured time decay curves for several common fluorophores



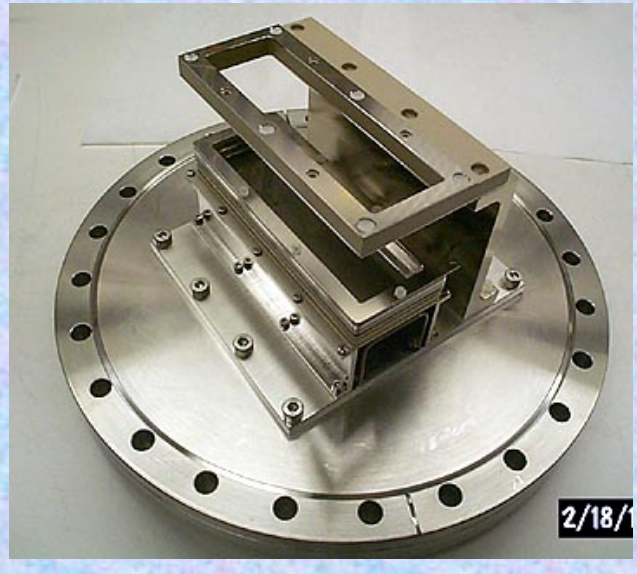
Time-resolved spectral and polarization sensitive confocal fluorescence microscopy



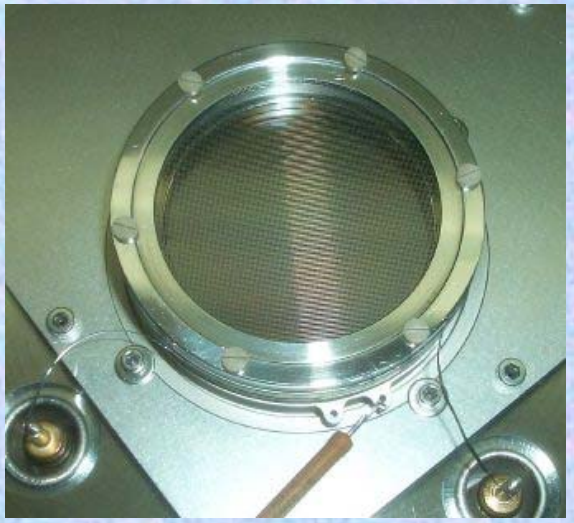
System has very small timing errors

Cross Delay Line MCP Readout

25mm Cross delay line TOF detector for electrons (UVA)



100 x 30mm delay line TOF detector for mass spectroscopy (NRL)



40mm Cross delay line TOF detector for electrons/ions (Sandia, NRC, U. Oklahoma, IMS, SDL, ++).

45 x 15mm cross delay line TOF detector for ion magnetic Spectrometer (Sandia/ALS)

Cross Delay Line MCP Sample Results

kHz Chopped Neutron Beam Test

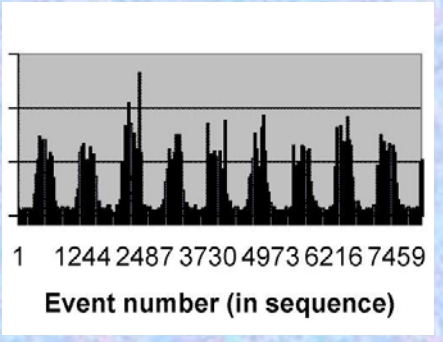
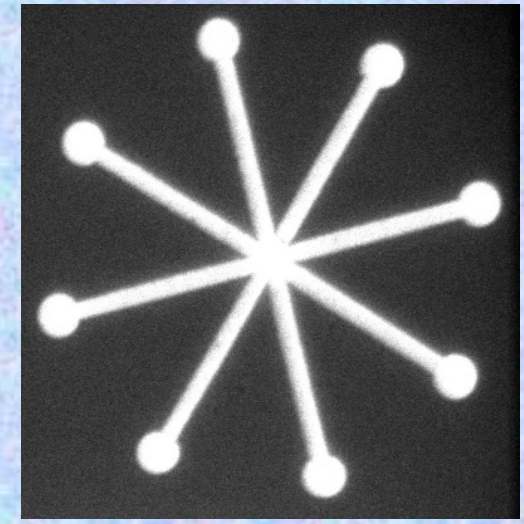
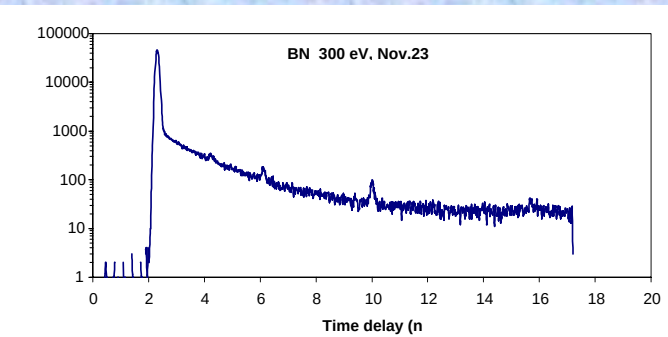
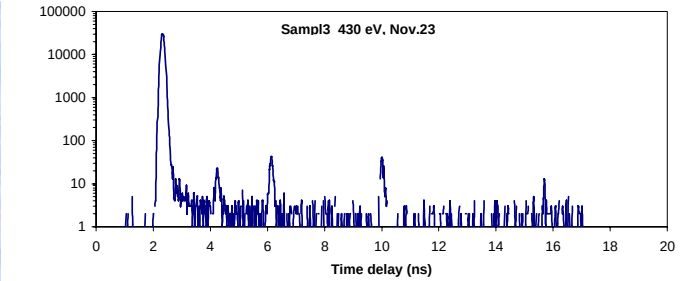


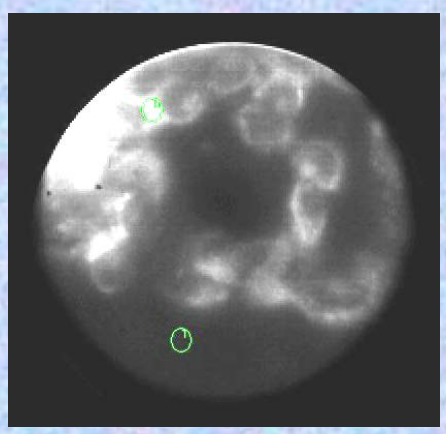
Image of Cd test target with Neutrons (>1 MHz) at NIST using XDL and neutron sensitive MCP, 25µm resolution





ALS timing measurements for sample fluorescence, with 2D imaging





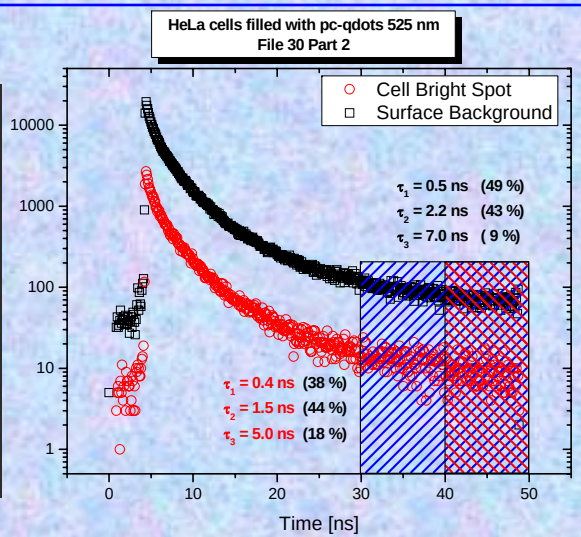


Image of pc-quantum dots (525nm) in HeLa cells

Event Counting MCP Sensor Prospects

•Cathodes

• GaN, Diamond, QE >50% over 10nm - 900nm range, in selectable bandpasses, with solar blind options.

•Microchannel Plates

•Ceramic MCP's with <5um pores, low fixed pattern noise, low background <0.02 cm^{-2} sec^{-1}, lifetimes/local rates100x better. Compatible with CVD/MBE cathodes.

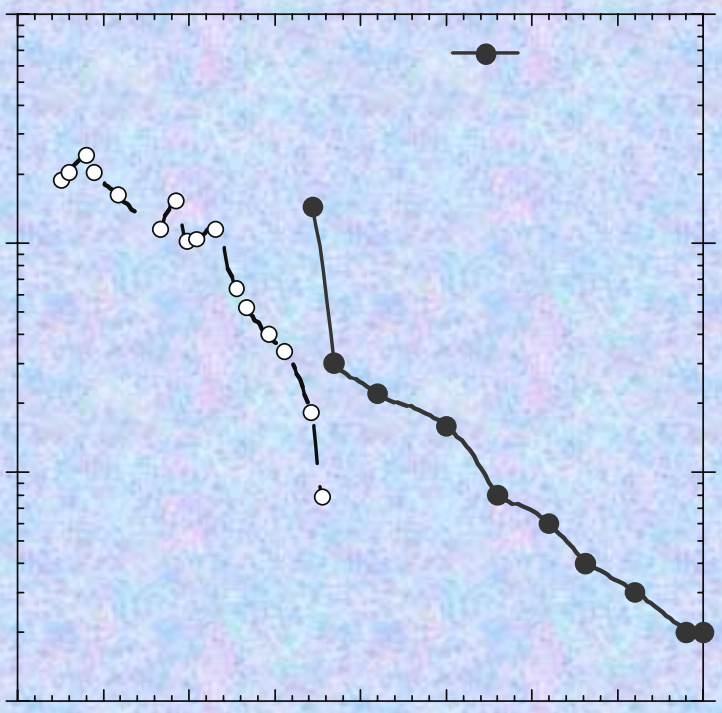
•Readouts

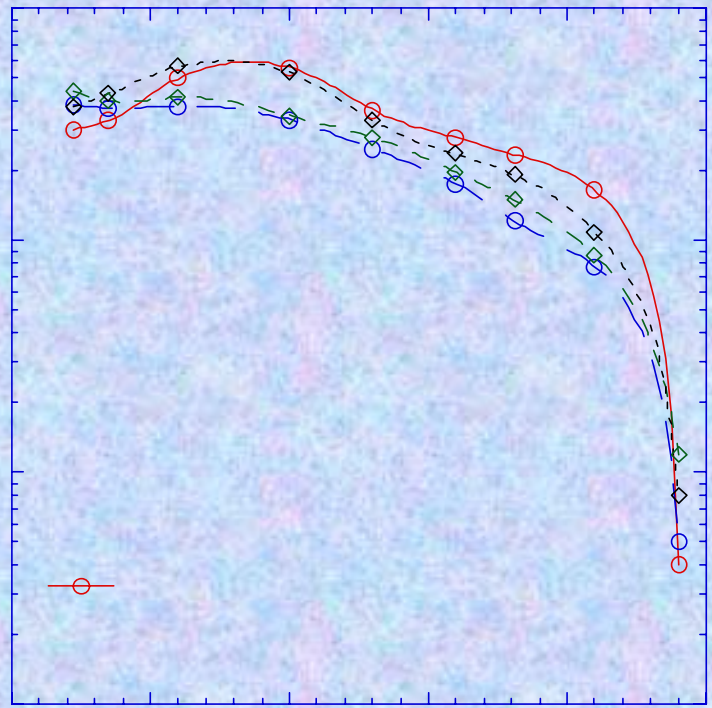
•Cross strip readouts with >10k x 10k resolution, selectable format sizes up to >100 x 100mm, & counting rates >10 MHz, with 100x improved local rates and simultaneous event detection.

•CMOS, MEDIPIX, readouts with GHz rates, 256 x 256 abuttable to 1k x 1k with <55um pixels.

UV Photocathodes, 10- 4000Å

Diamond and GaN are robust materials which when properly treated provide negative electron affinity. Diamond is air stable, but GaN(Cs) requires UHV environment.

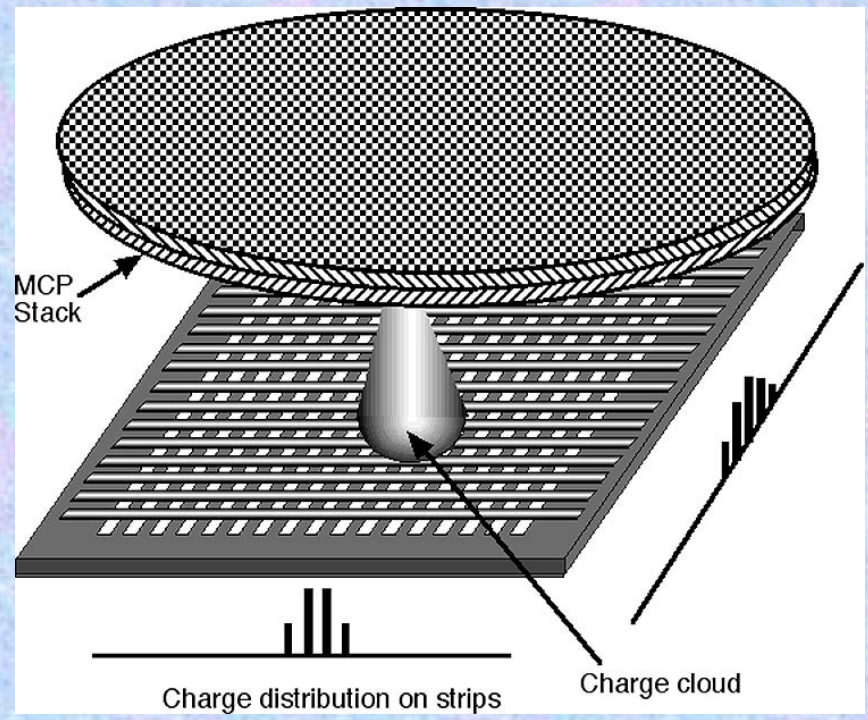


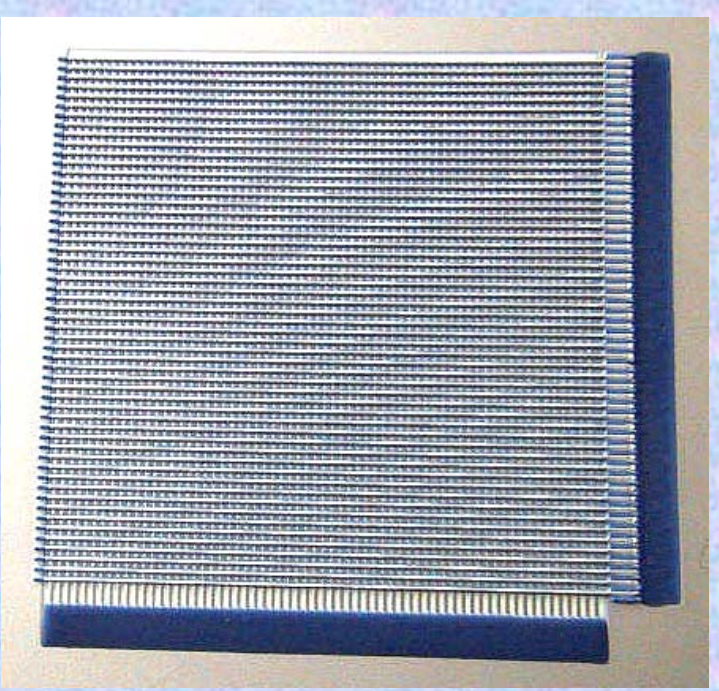


Development of opaque Diamond photocathodes on Si MCP substrates, with H_2 & Cs activation is underway

Recent opaque GaN photocathodes on sapphire substrates, with Cs activation have better overall QE and much better red response.

Cross strip anode readout





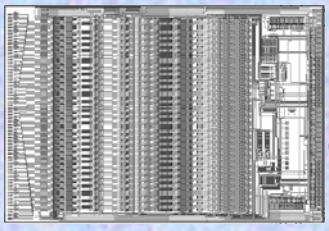
32mm x 32mm XS anode, 0.5mm period

Cross strip is a multi-layer cross finger layout.
Fingers have ~0.5mm period on ceramic.
Charge spread over 3-5 strips per axis,
Event position is derived from charge centroid.
Can encode multiple simultaneous events.
Fast event propagation (few ns).

Anodes up to 45 x 45mm have been made.
Signals brought to backside by hermetic vias
Electronic packaging can be compact
Processing speed should support >> MHz rates
Compact and robust (700°C).

Current Cross Strip Encoding Electronics

128ch



IDEAS VaTagP3

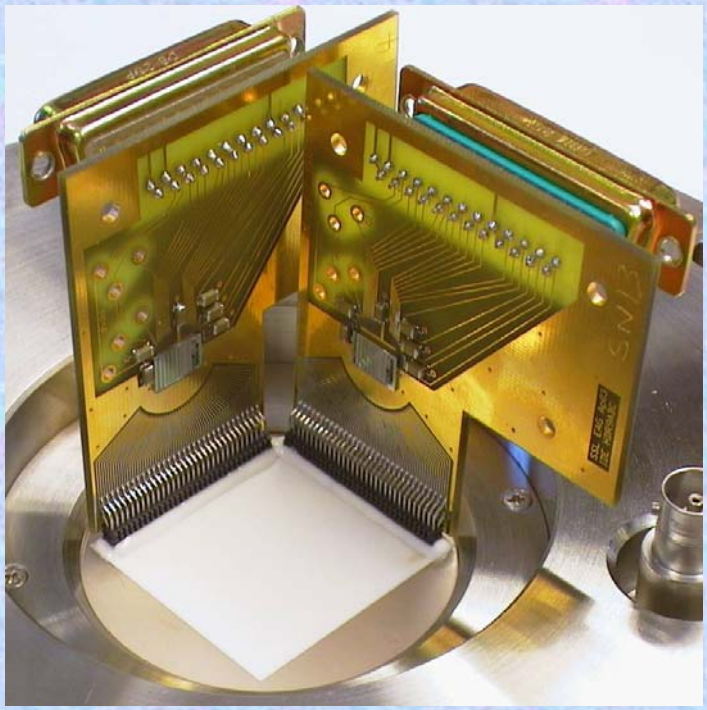
Serial, (sparse or full)

ADC

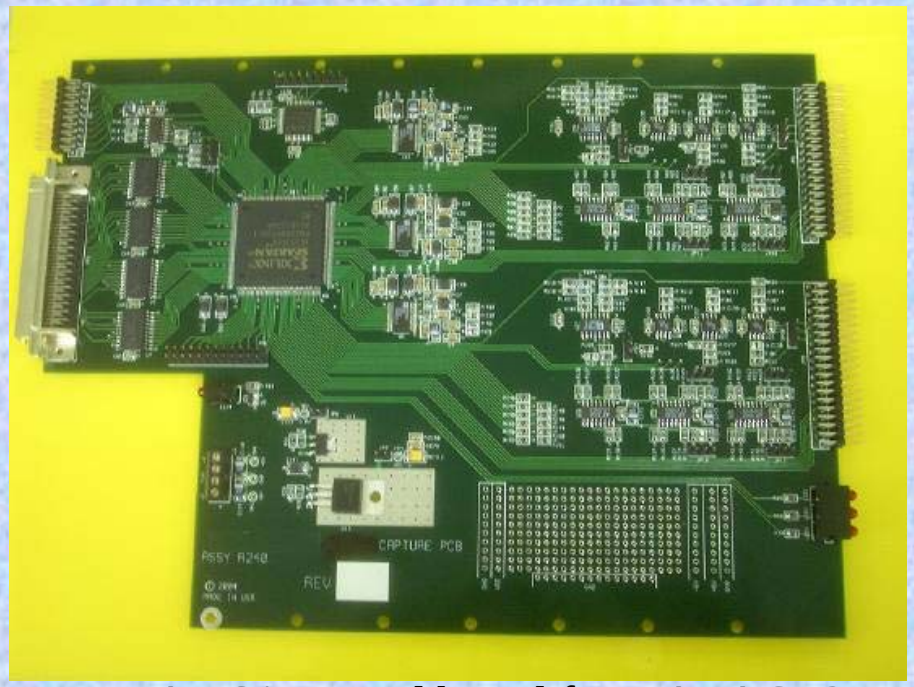
FPGA

Corrections & centroids

X or Y centroid positions

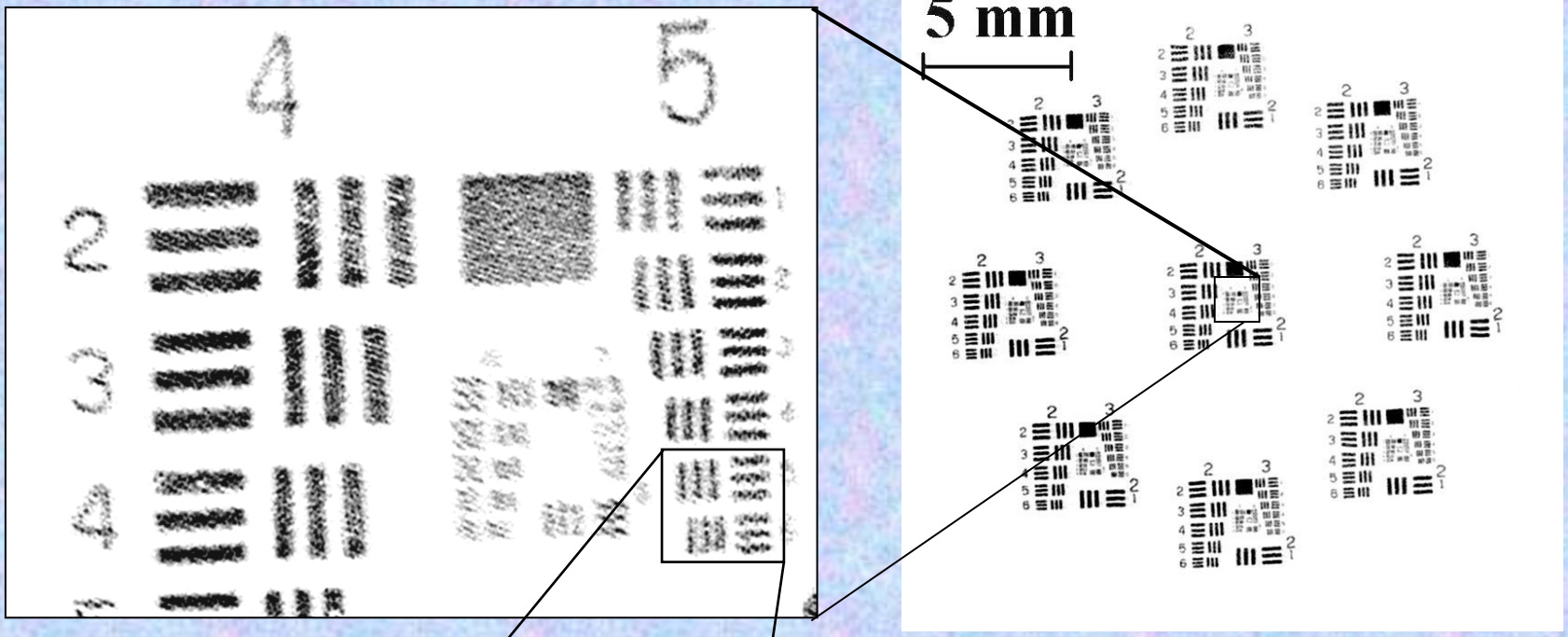


XS anode with VA64HDR amplifiers



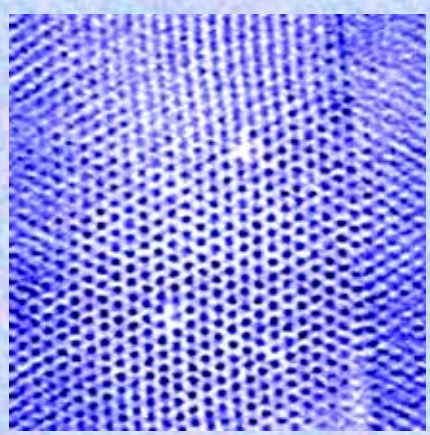
X,Y ADC/centroid board for VATAGP3

Cross Strip MCP Detector Imaging



Air force mask on
6μm pore MCP pair
with cross strip readout

Image of 7μm pore MCP pair at 10^6 gain .



Spatial resolution <5μm for gain $5x10^5$ for

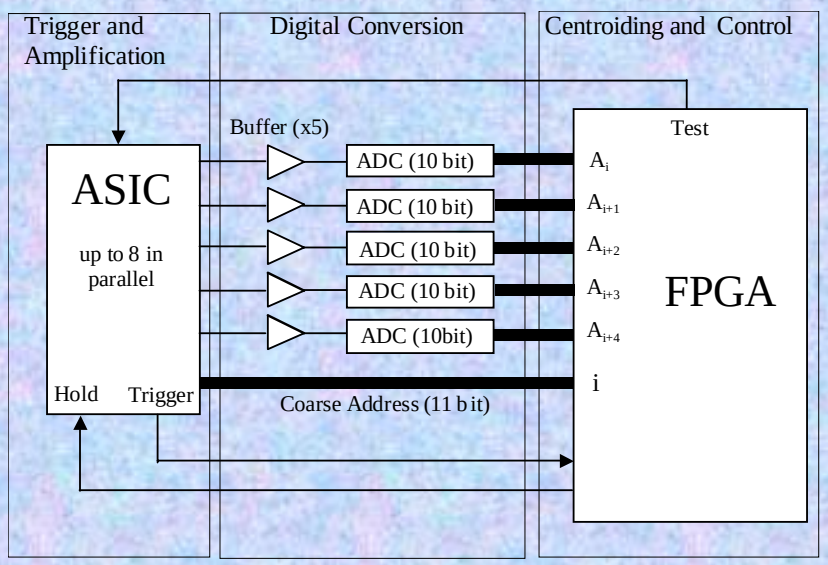
~500e^- noise, 10 bit charge/strip digitization

Cross Strip Development Issues

Event rate is currently limited by ASIC amps (serial)
Move to fast (40ns) parallel ASIC amp & ADCs.
Use FPGA to do charge measurement, corrections and produce position centroids.

Timing produced by MCP output, remains <100ps

Non overlapping events could also be processed simultaneously!!



High speed readout development scheme

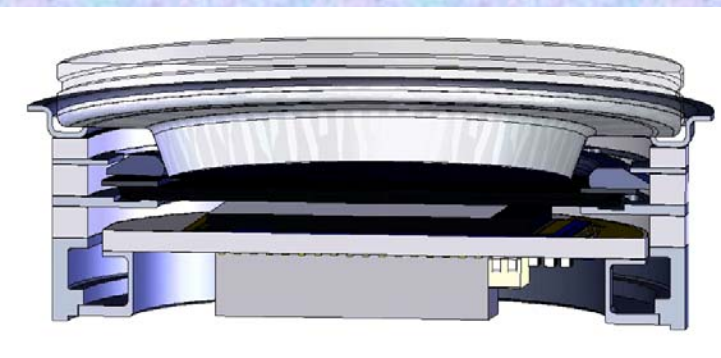
Enhanced performance MCP detectors:-
MBE/CVD cathodes, ceramic MCPs, cross strip readouts

- **Develop diamond/GaN for UV QE (>50%), use GaAs sealed tubes for visible/NIR**
- **Ceramic MCPs. Gain 4 x10^5, no fixed pattern noise, 100x better lifetime and local event rate**
- **Size formats to 100mm, resolution <10µm FWHM, (10k x 10k) [already have 5k x 5k]**
- **Event rates of several MHz (ASIC limited), timing <30ps (MCP limited)**
- **Multiple simultaneous event sensing algorithms could push event rates much higher.**

Medipix II applications for Adaptive Optics

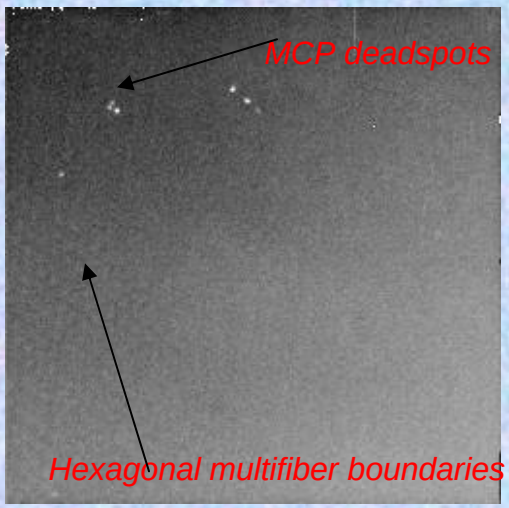
•John Vallerga, PI at UCB

Objective: to build MCP/Medipix tube for real time adaptive optics (Shack-Hartman) astronomical image stabilization

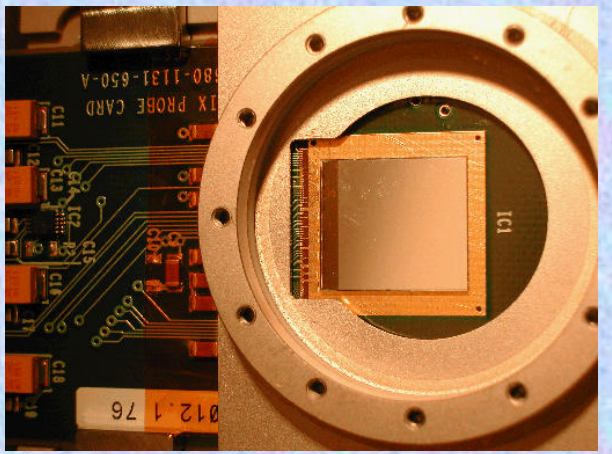


MEDIPIX tube concept using GaAs photocathode. Initial tubes ready to be constructed

MEDIPIX on ceramic tube header

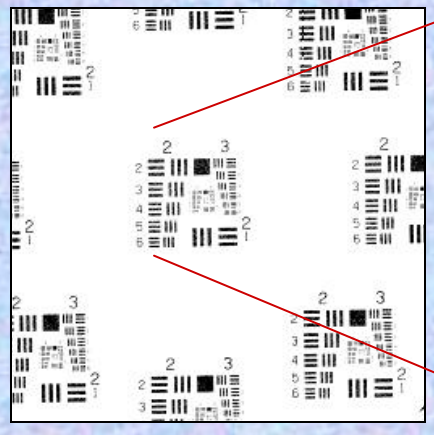


Flat field 1200 cts/bin - 500Mcps

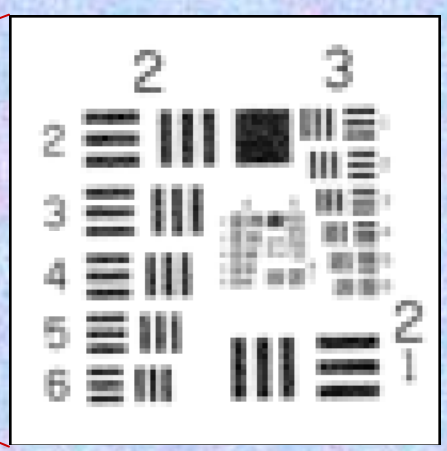


MEDIPIX used as readout for MCP

1 s



Resolution test mask image



Group 3-2 visible 9 lp/mm = 55µm (Nyquist limit)