ADVANCES IN MICROCHANNEL PLATE DETECTORS FOR HIGH SPATIAL AND TIMING RESOLUTION EVENT SENSING

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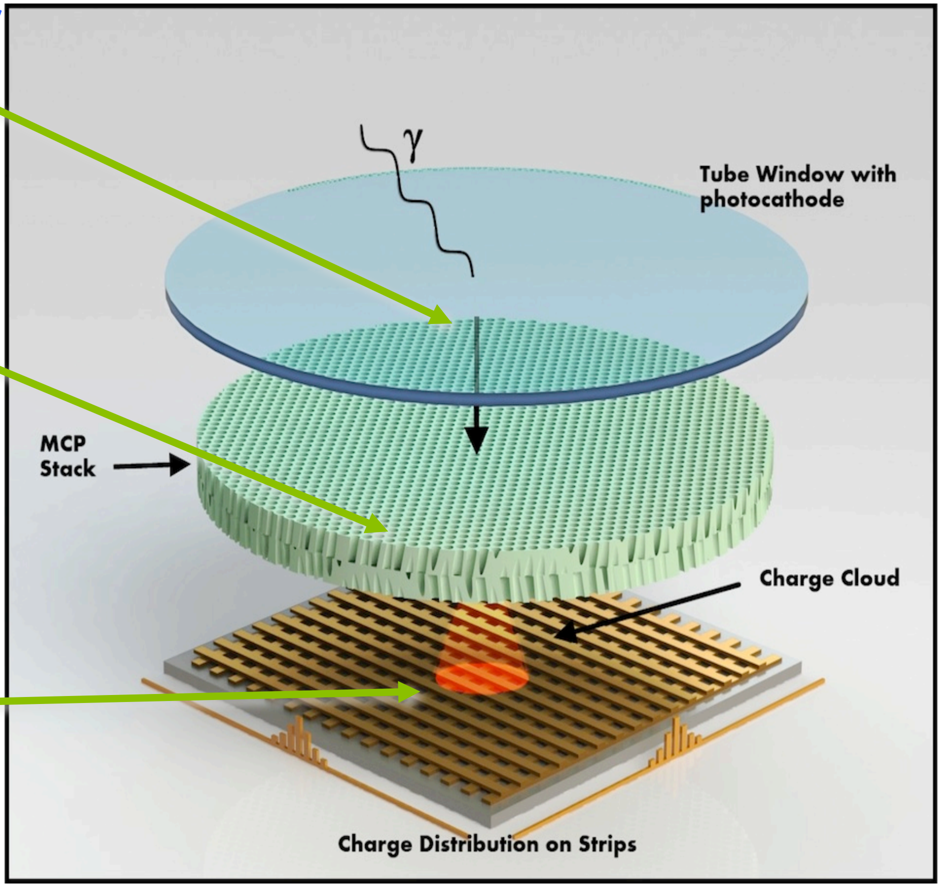
Workshop on Novel Trends in Photoemission, LBNL October 4, 2011

Microchannel Plate Detector Scheme

Photocathode on window or MCP converts photon to electron –**or**- direct electron/ion detection by MCP

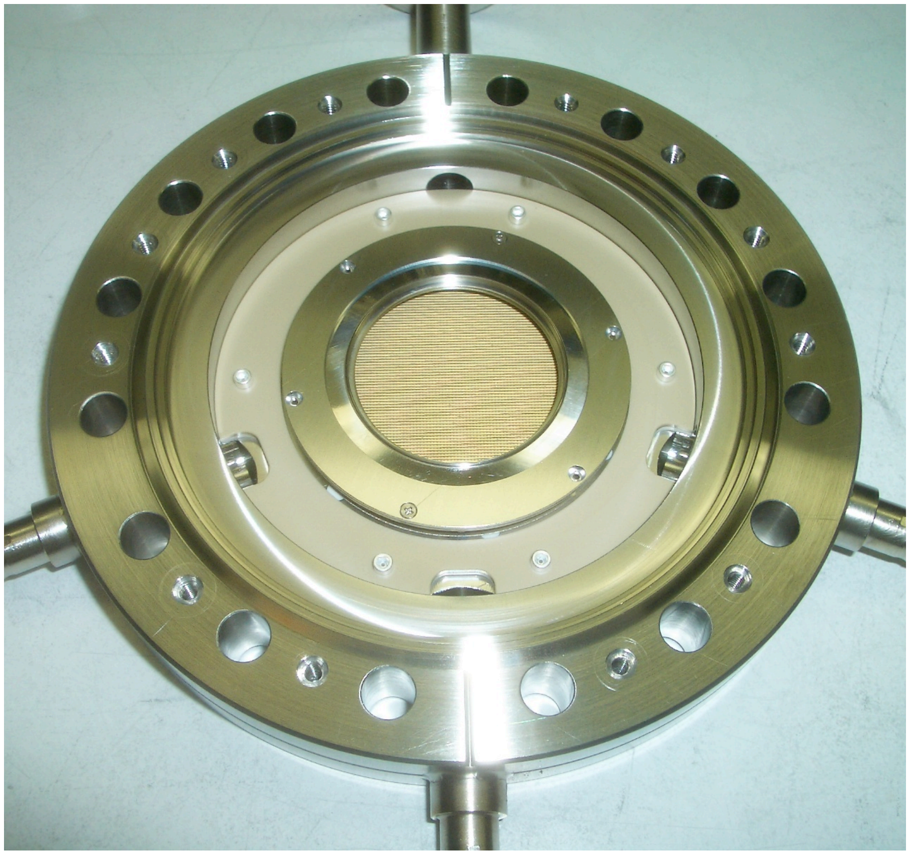
MCP(s) amplify electron by 10^4 to 10^7

Patterned anode measures charge centroid

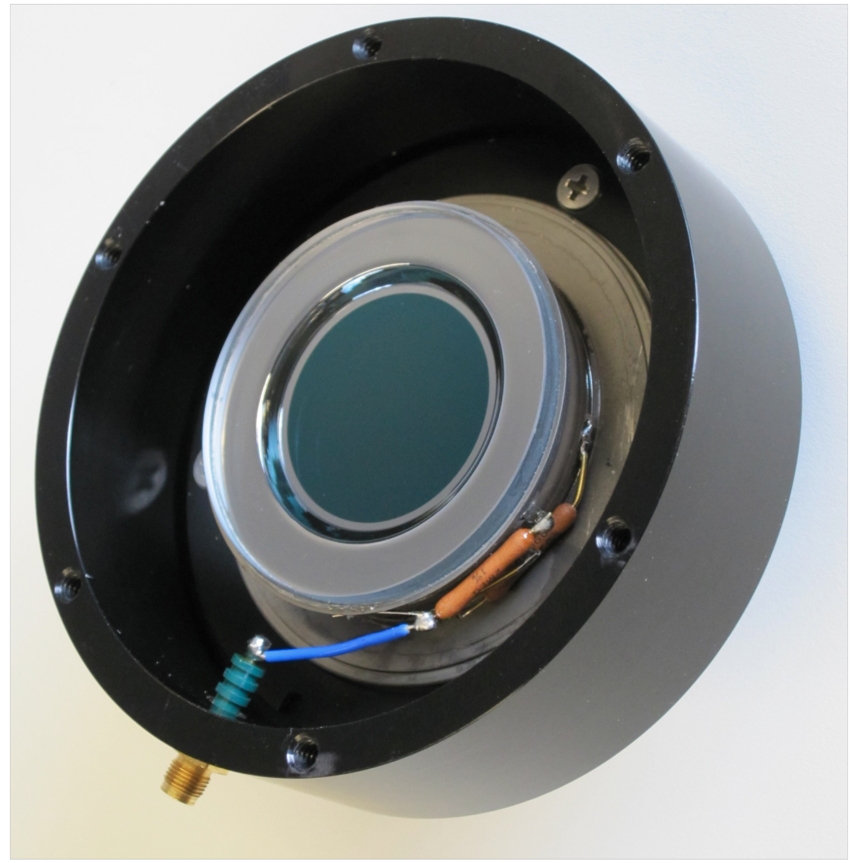


Microchannel Plate Detectors

Open face for ion/particle/electron/photon detector, sealed tube for photons

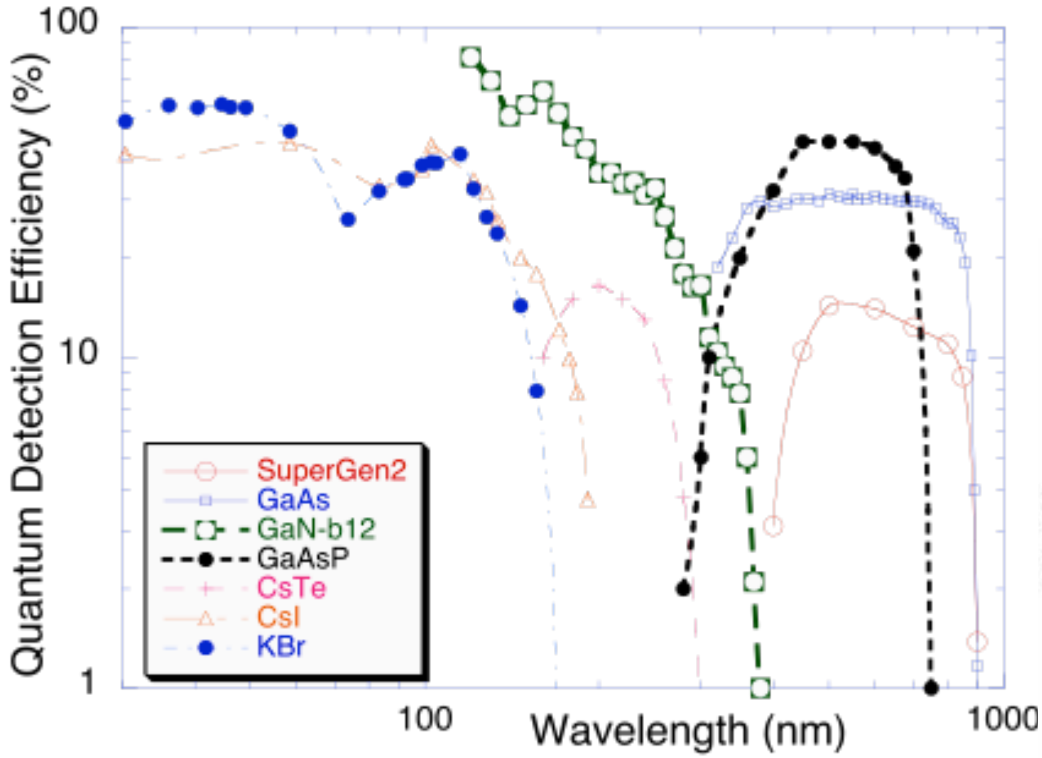


50 mm Cross Strip anode detector

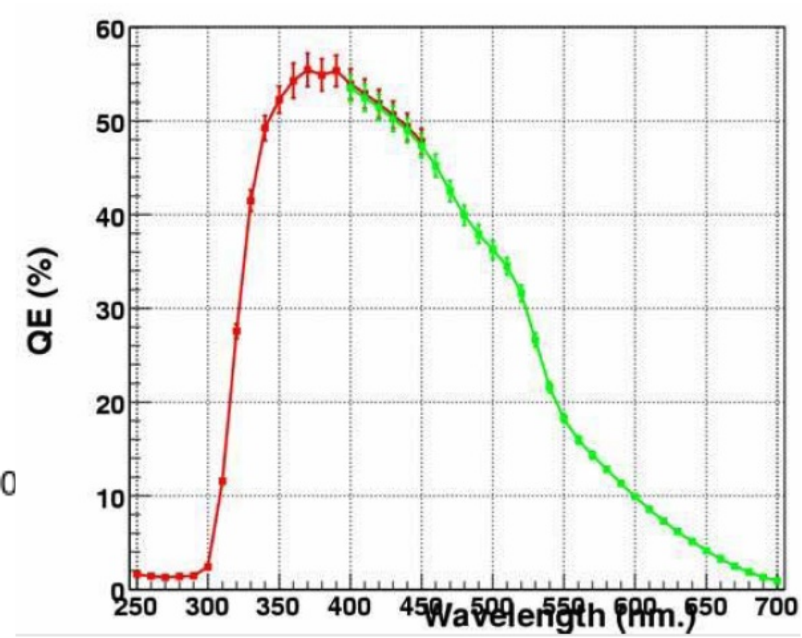


25 mm cross delay line anode sealed tube, Trialkali photocathode

Photocathodes 10nm - 1000nm



General comparison of conventional and GaN photocathodes.

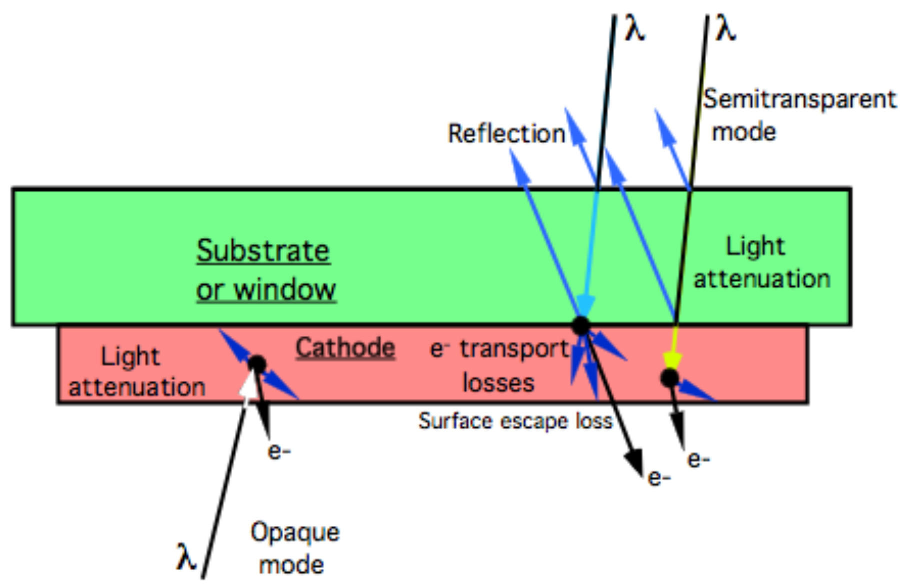


Recent improvements in bialkali cathodes, fills the gap between GaN and GaAsP.
PHOTONIS – Clermont-Ferrand workshop 2010

GaN Photocathodes

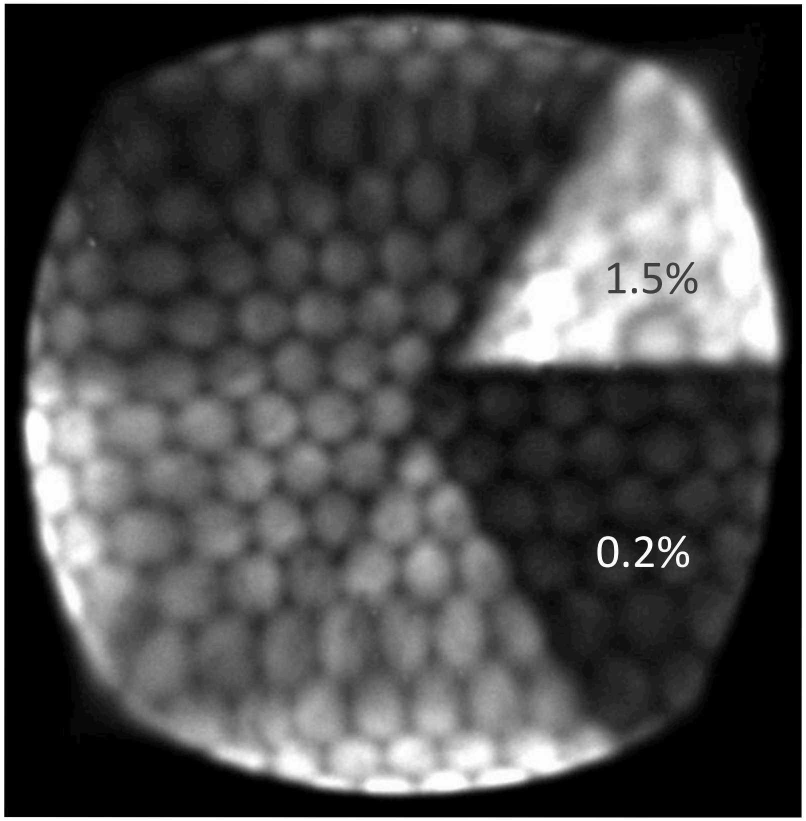
- "Solar blind" efficient cathode for 100nm-400nm
- Band gap energy 3.5 eV, (~355nm)
- Alloys ($Al_xGa_{1-x}N$, $In_xGa_{1-x}N$) can change the bandgap
- Robust, compatible with sapphire substrates/coatings
- p (Mg) doped to promote bulk electron transport
- NEA is established by surface cesiation
- >100nm GaN layers typical
- semitransparent or opaque

- Numerous processes affect the QE



Opaque GaN Deposited on ALD MCPs

Borosilicate/ALD MCP coated by MBE with P-doped GaN/AlN of various thicknesses (amorphous/polycrystalline) and tested in a photon counting imaging detector



Integrated photon counting image using 185 nm UV shows unprocessed GaN layer response vs bare MCP, with approximate QE values, no Cs.

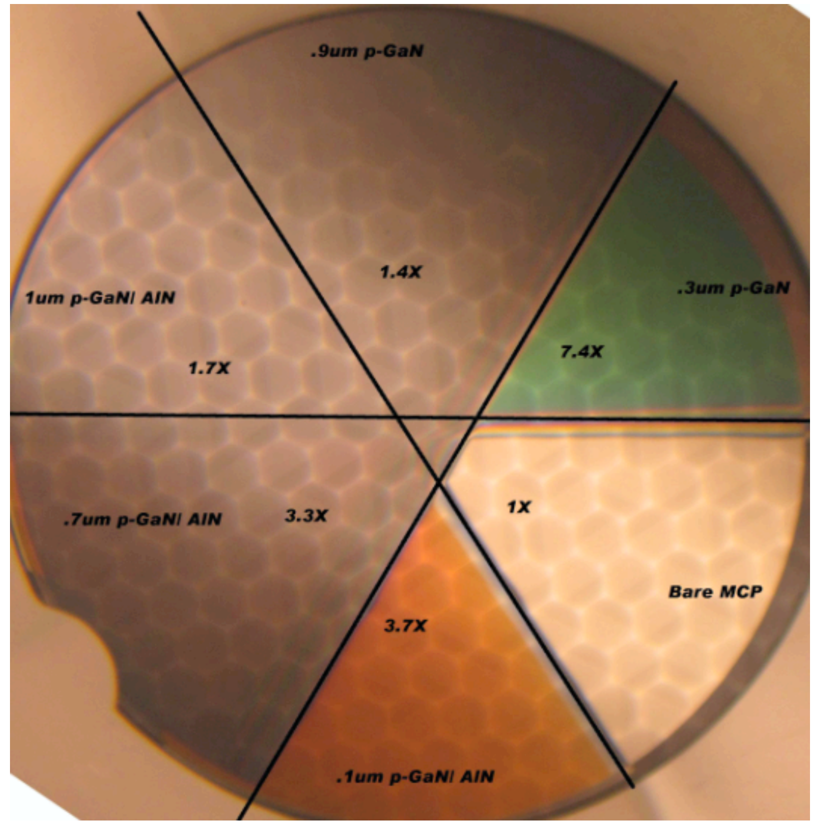
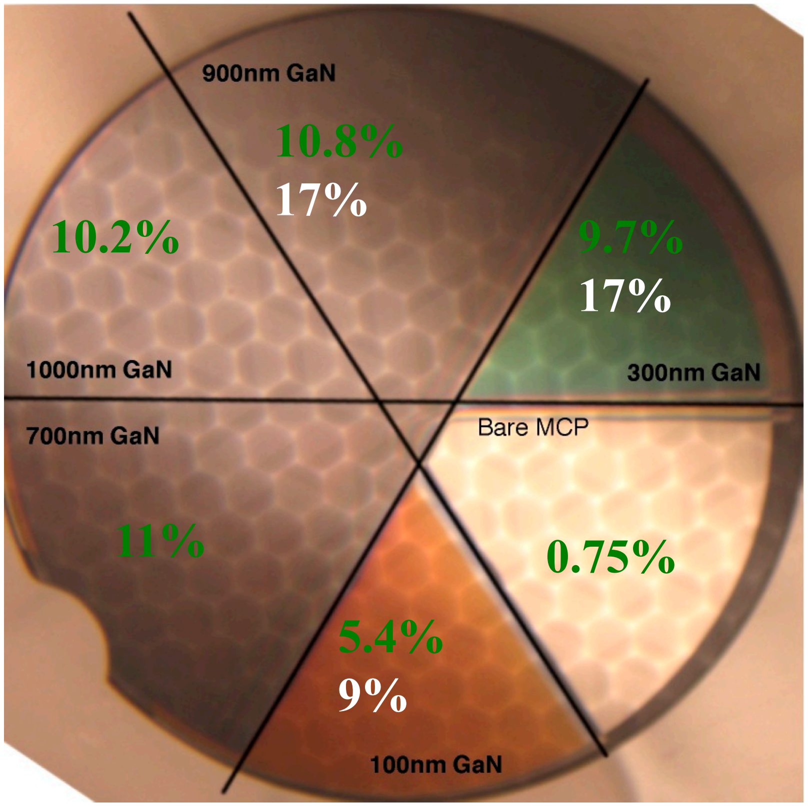
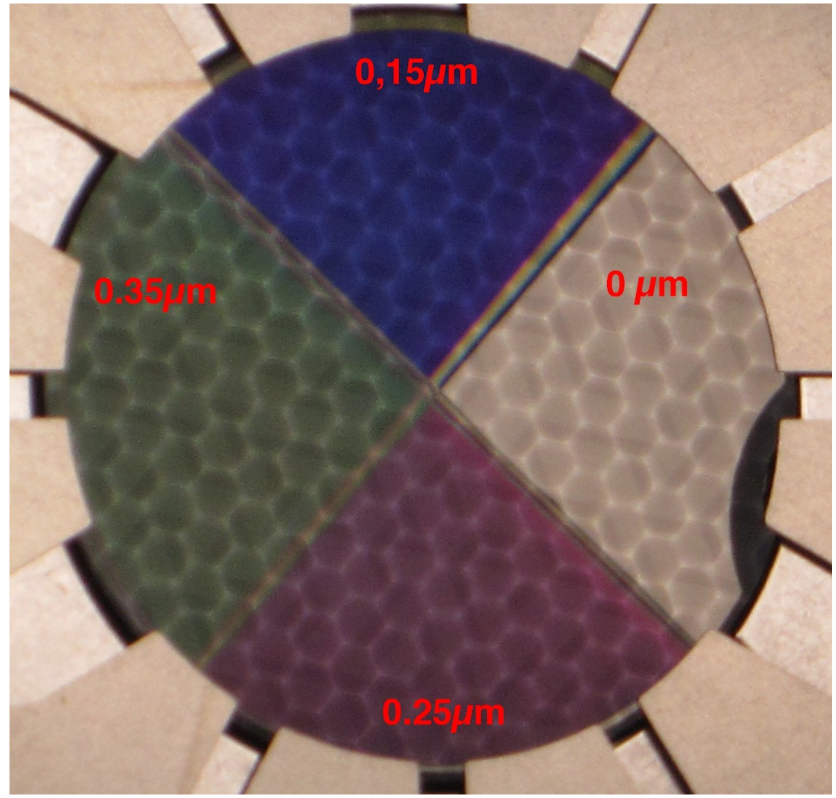


Photo of 20µm pore MCP with zones of different GaN thickness and structure, Deposited by SVT associates (A. Dabiran).

GaN Cathode on ALD Borosilicate MCP
(NiCr electrode)





- QEs measured after Cs (214nm, web)
- 10º (green) or 45º (white) graze angle
- Shows typical QE-thickness asymptote for opaque cathode

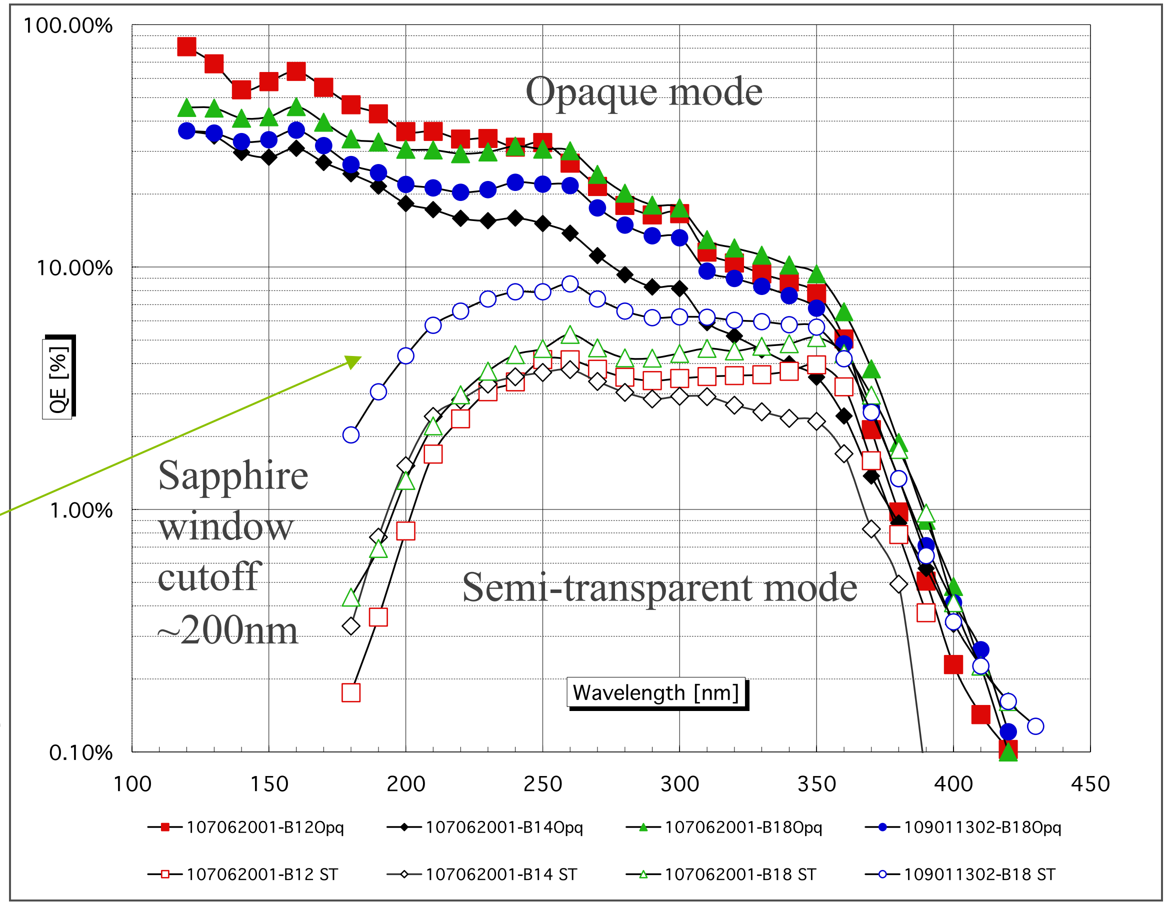
- Next sample to be tested
- More samples in fab with ALD sapphire on top of MCP as base layer for GaN(Mg) deposition.

GaN Cathode QE
(opaque and semi-transparent)

Response a function of thickness and process techniques (cleaning, heat treatment, cesiation)

Semi-transparent optimization not the same as opaque

Achievable Semi-Trans cathode QE is actually a factor of two higher than the average measured value here since the high QE is only on 50% of the patterned substrate.



Various process runs and samples of GaN photocathodes on sapphire, measured in both opaque and semitransparent mode.

Atomic Layer Deposition – Borosilicate Glass Microchannel plate Development Efforts

Concept

Use borosilicate microcapillary array as a substrate and coat with an atomic layer deposited resistive layer and secondary electron emissive to functionalize the microchannel plate.

Large Area Picosecond Photodetector Program

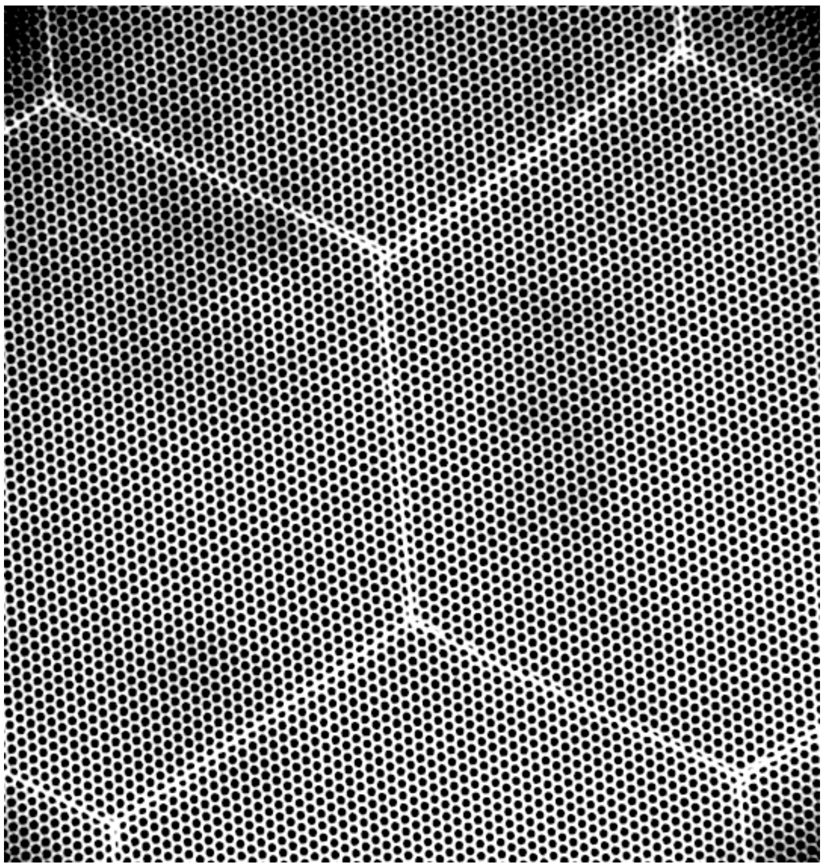
Major effort at Argonne National Lab., U. Chicago, UC Berkeley and several other National Labs, Universities and Industry to develop large area (8”) microchannel plates and employ them in sealed tube sensors with optical photocathodes for high speed timing/imaging applications in High Energy Physics, Astronomy, etc.

NASA APRA – Nanoengineered MCPs for Astrophysics

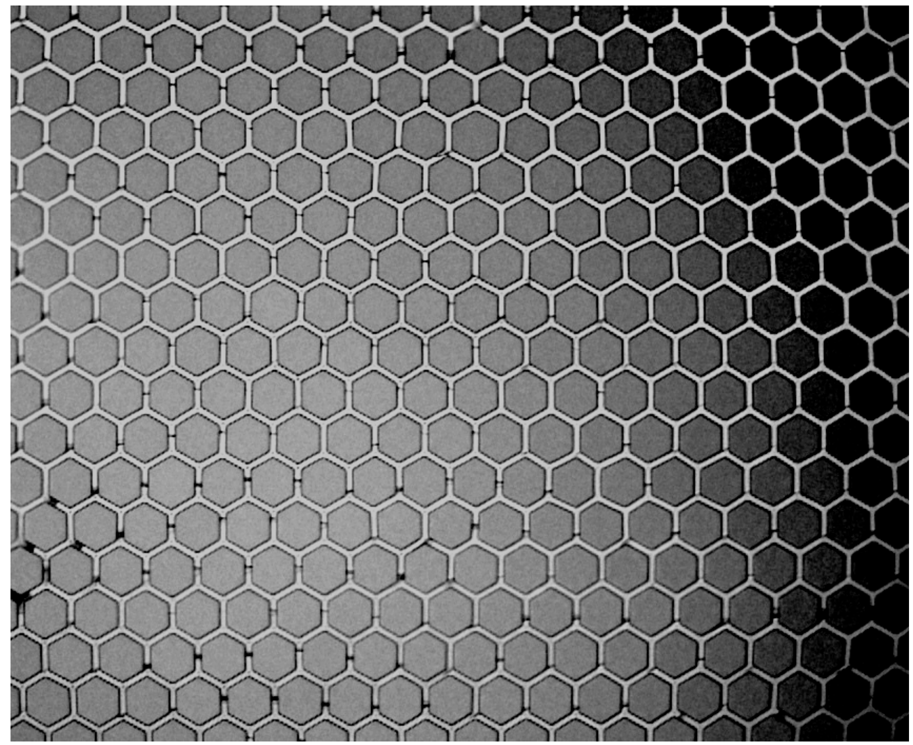
Development study to produce small pore, large area MCPs with borosilicate glass substrates and ALD, with high quality imaging, high spatial resolution, low background and high QDE (compatibility with high temperature photocathode depositions).

Borosilicate Microchannel Plate Substrates

Micro-capillary arrays (Incom) with 20 µm or 40µm pores (8° bias) made with borosilicate glass. L/d typically 60:1 but can be much larger. Open area ratios from 60% to 83%. These are made with hollow tubes, no etching is needed.



20 µm pore borosilicate micro-capillary substrate. Pore distortions at multifiber boundaries, otherwise very uniform.



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

Borosilicate Substrate Atomic Layer Deposited Microchannel Plates

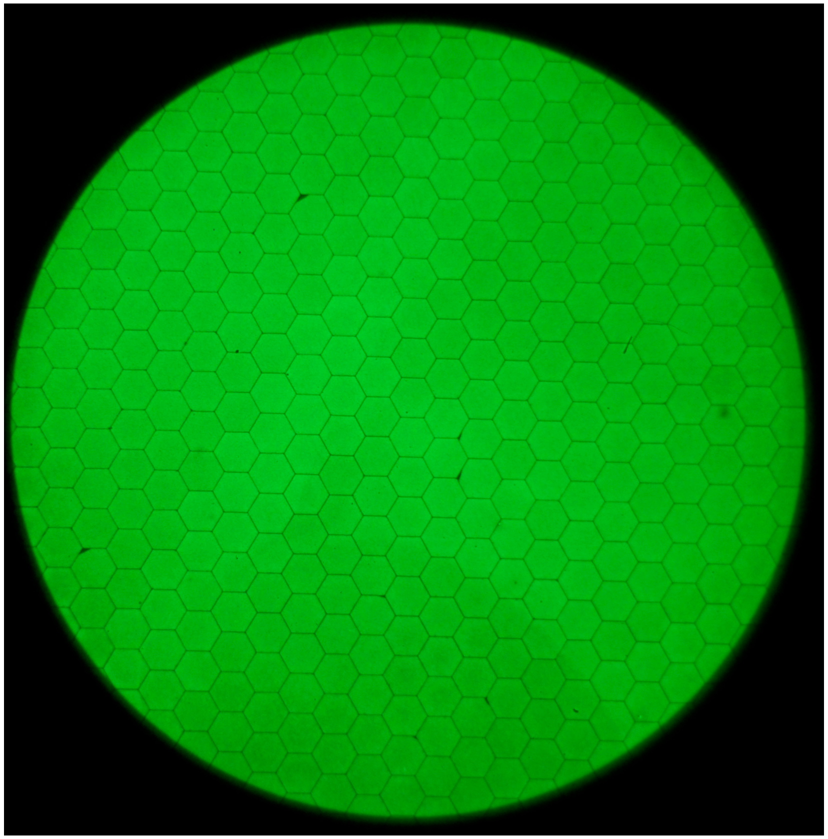
Micro-capillary arrays (Incom) with 20 μm or 40μm pores (8° bias) made with borosilicate glass. Resistive and secondary emissive layers are applied (Argonne Lab, Arradiance) to allow these to function as MCP electron multipliers. Each step is separately engineered/optimized.

Visible light transmission for a 20 μm pore borosilicate micro-capillary ALD MCP .

Surface photo for a 20 μm pore borosilicate micro-capillary ALD MCP with NiCr electrode .

Robustness of ALD MCPs, 33mm

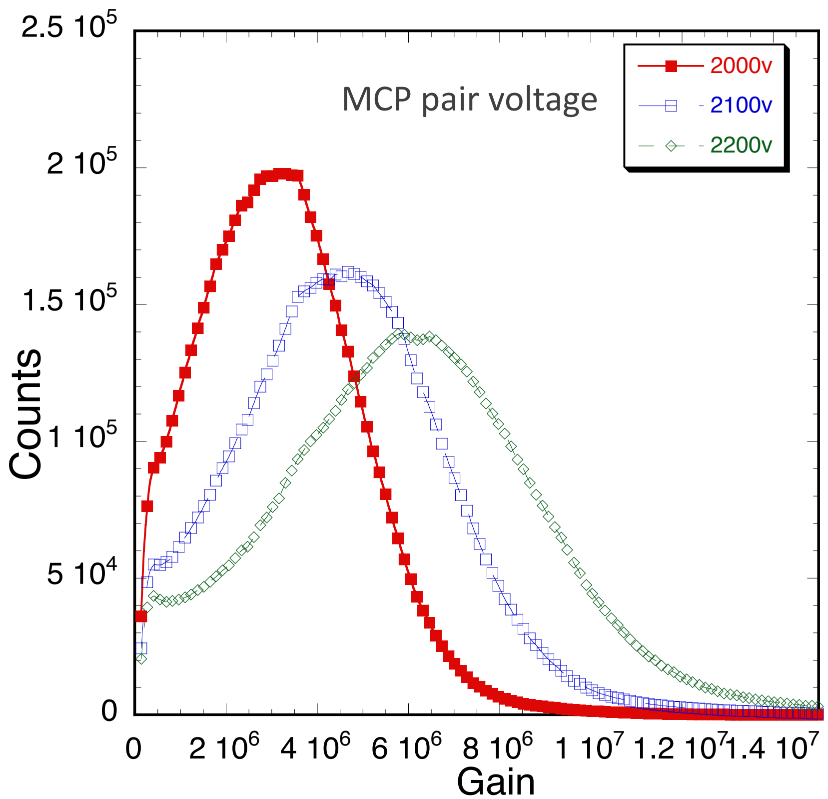
Conventional MCPs are highly likely to be physically damaged by high voltage breakdown events. We had a phosphor screen failure that damaged an ALD functionalized borosilicate glass MCP. Inspection showed no melting of the pores!



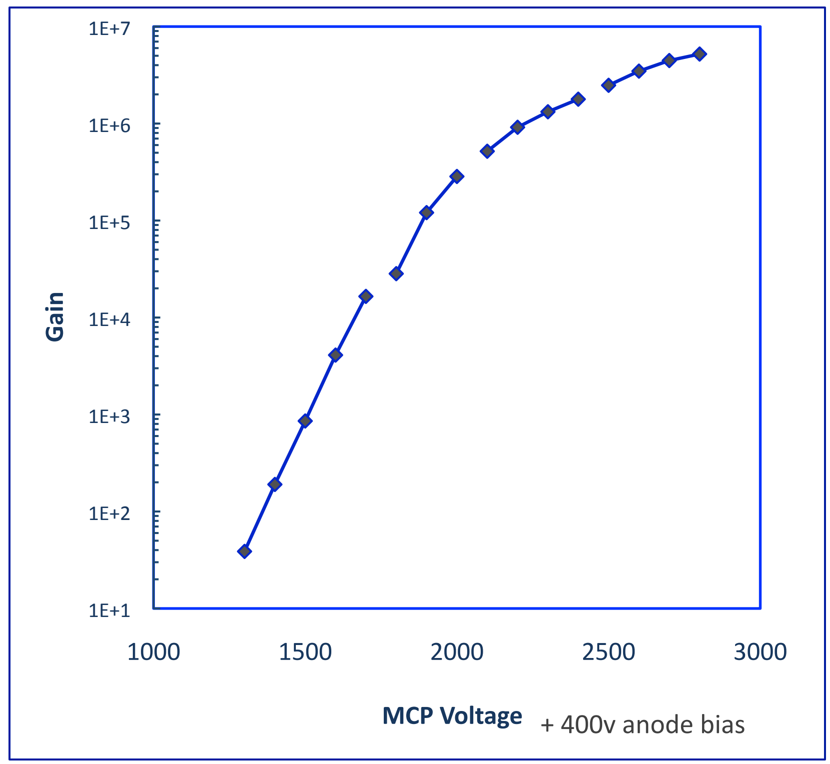
An additional electrode layer was applied on top of the damaged face and then tested in our phosphor detector – no sign of any damage in the image!!!

ALD-MCP Performance Tests, 33mm pairs

UV illuminated test results show similar gains to conventional MCPs, exponential gain dependence for low applied voltages, then saturation effects appear above gains of 10^6. Pulse heights are reasonably normal for 60:1 L/d pairs.



Pulse height amplitude distributions for a 33mm ALD MCP pair, 40µm pore, 60;1 L/d, 8 degree bias.



Gain for a pair of 20µm pore 33mm ALD MCP's, 60:1 L/d, 8 degree bias.

Photon Counting Imaging with MCP Pairs

MCP pair, 20μm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias.

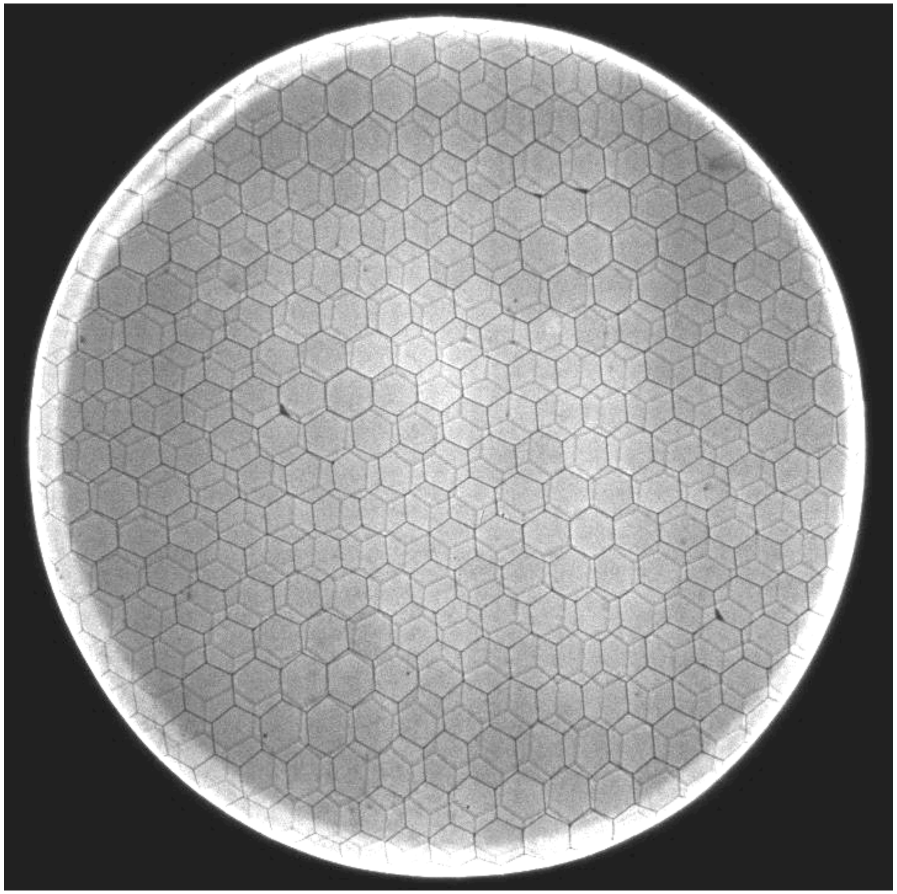
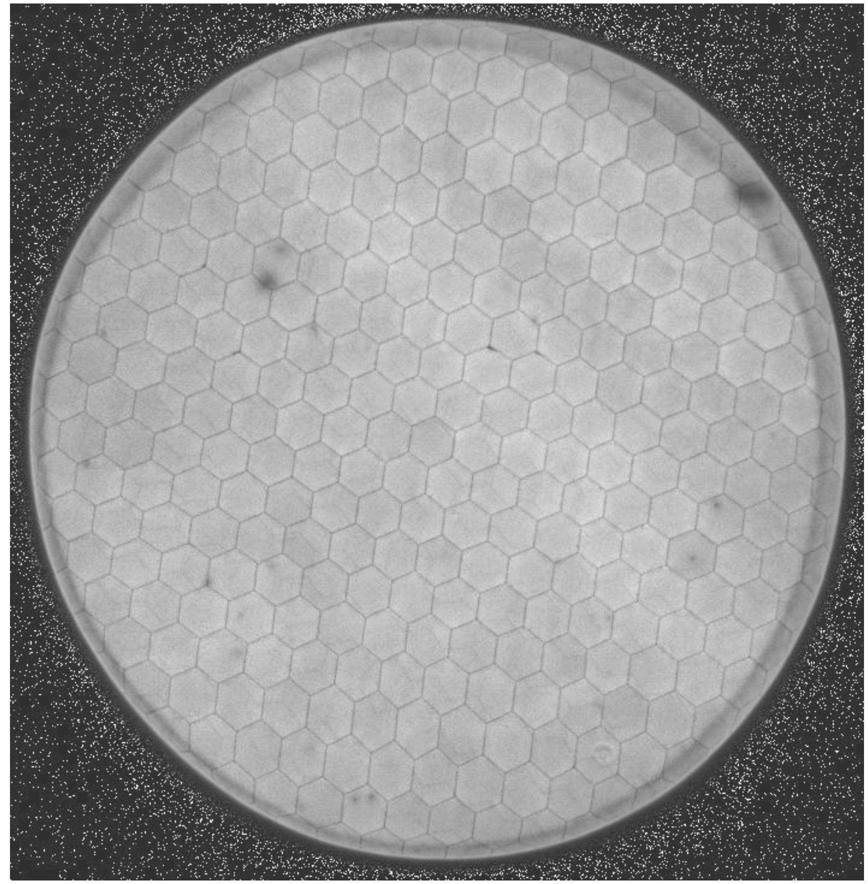


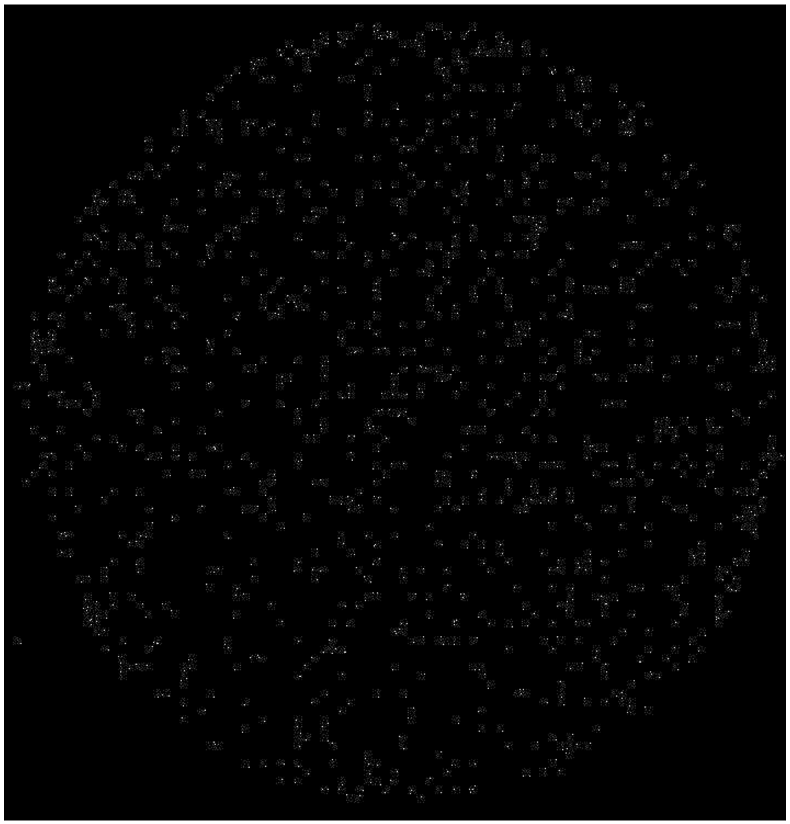
Image of 185nm UV light, shows top MCP hex modulation (sharp) and faint MCP hexagonal modulation from bottom MCP. A few defects, but generally very good. Edge effects are field fringing due to the MCP support flange.

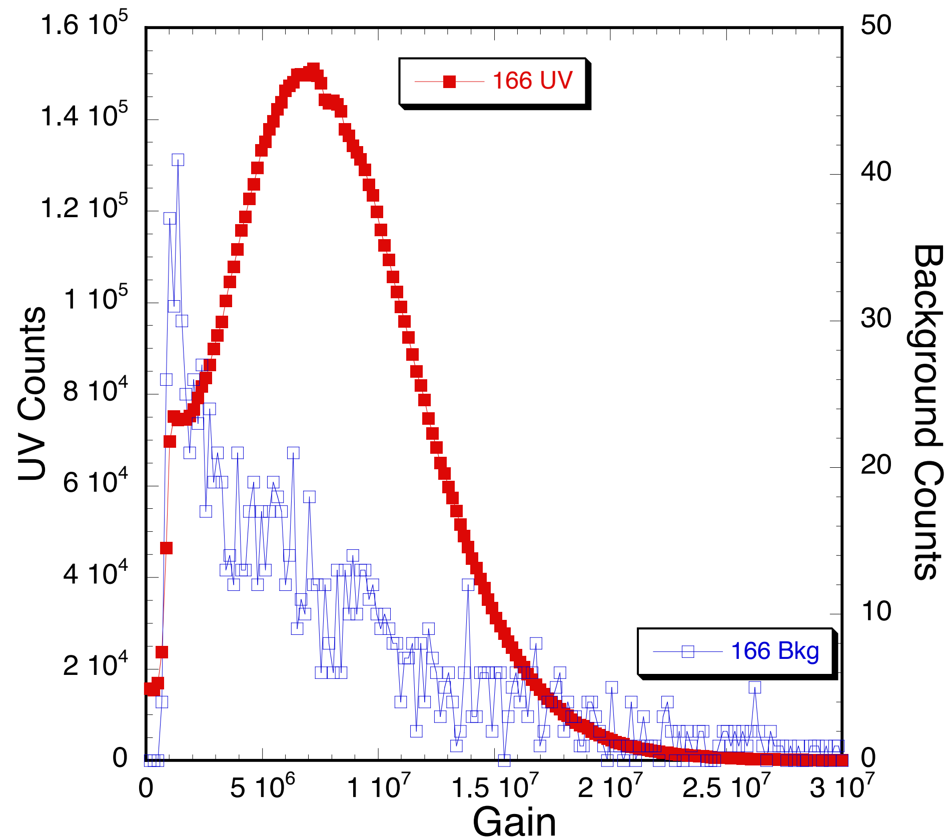


Gain map (average gain), shows top MCP hex modulation (sharp) and a few spots where the gain is low.

ALD-MCP Background Rate

MCP pair, 20µm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias.



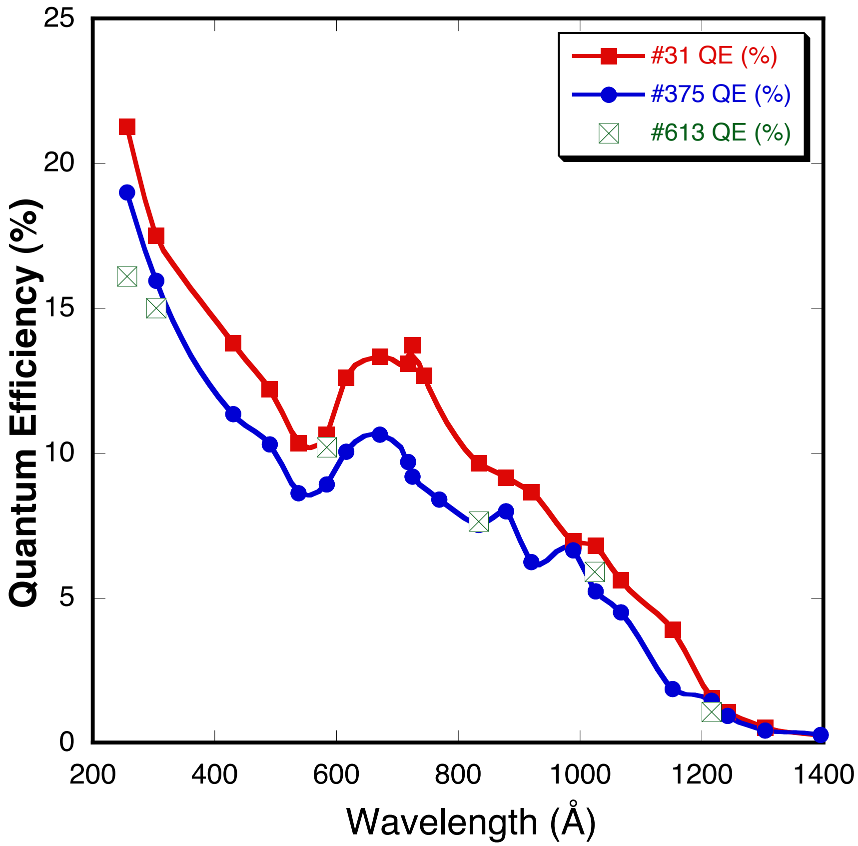


3000 sec background, 0.0845 events cm^{-2} sec^{-1}.
at 7 x 10^{6} gain, 1050v bias on each MCP. Get same behavior for all of the current 20µm MCPs

Pulse amplitude distributions for UV 185nm, and for background events.

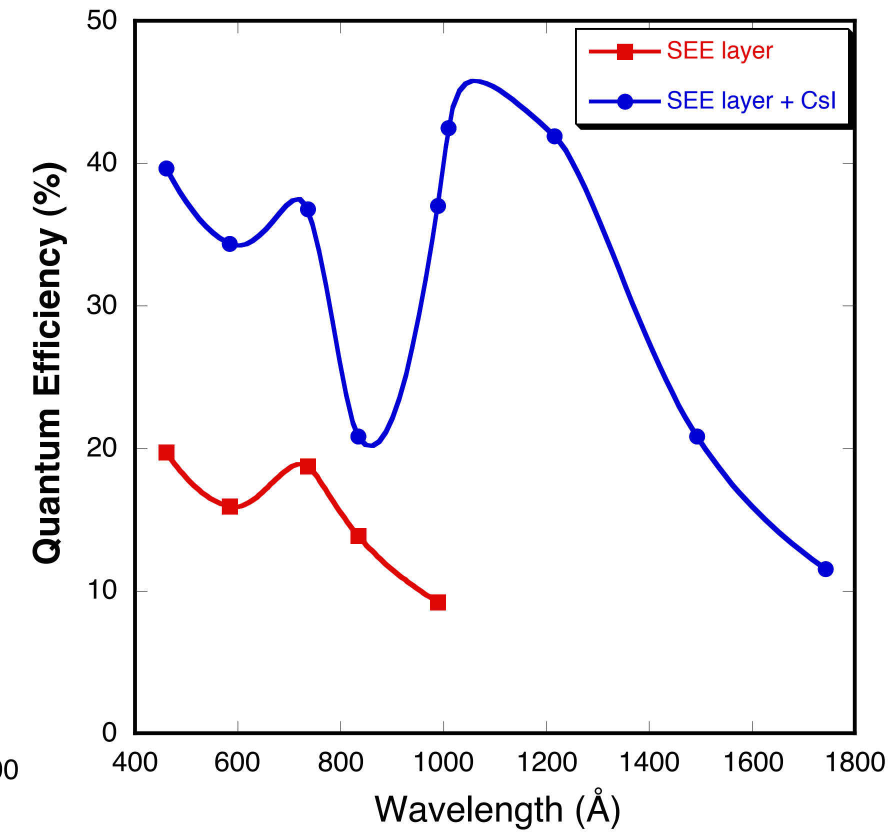
ALD-MCP Quantum Efficiency

ALD – borosilicate MCP photon counting quantum detection efficiency, normal NiCr electrode coating gives normal bare MCP QE.



#375 & #613 MCP pairs, 20µm pores, 8° bias, 60:1 L/d, 60% OAR. #31 MCP pair, 40µm pores 8° bias, 60:1 L/d, 83% OAR, shows higher QDE.

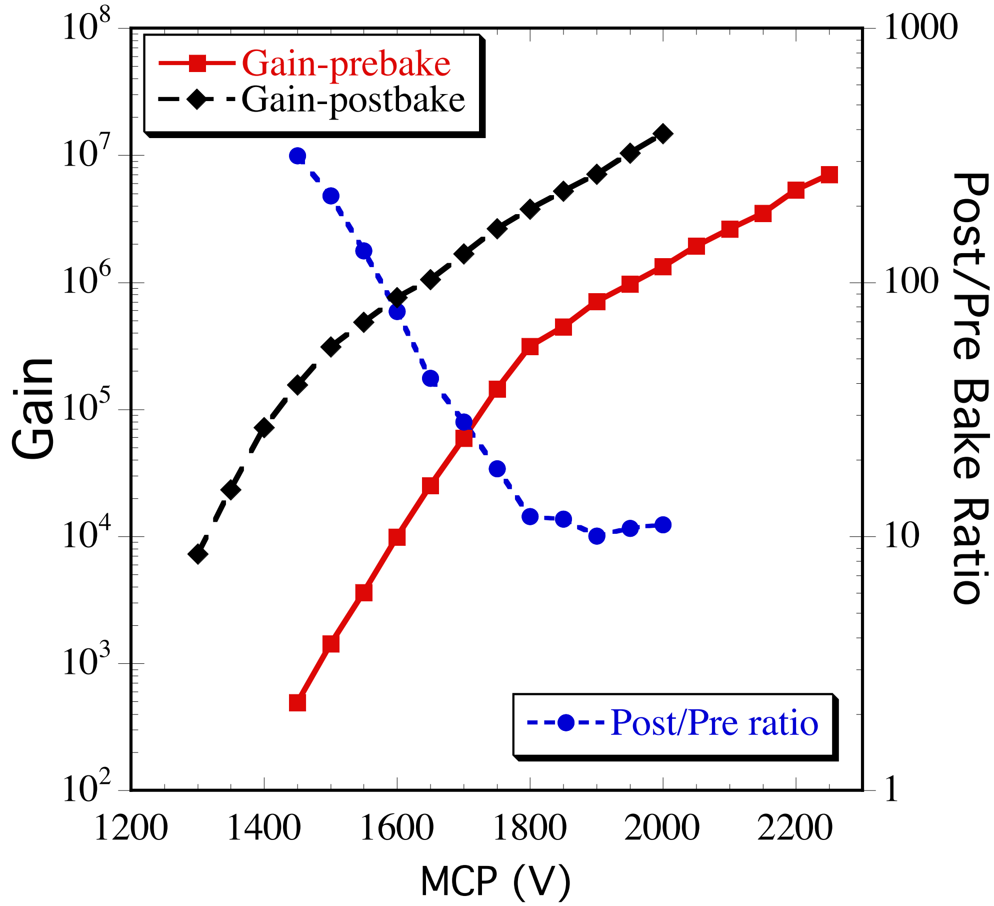
ALD – secondary emissive layer on normal MCP gives good "bare" QDE. CsI deposited on this gives a good "standard" CsI QDE.



QDE for bare MCP with ALD secondary emissive layer, and with CsI deposited on top of this.

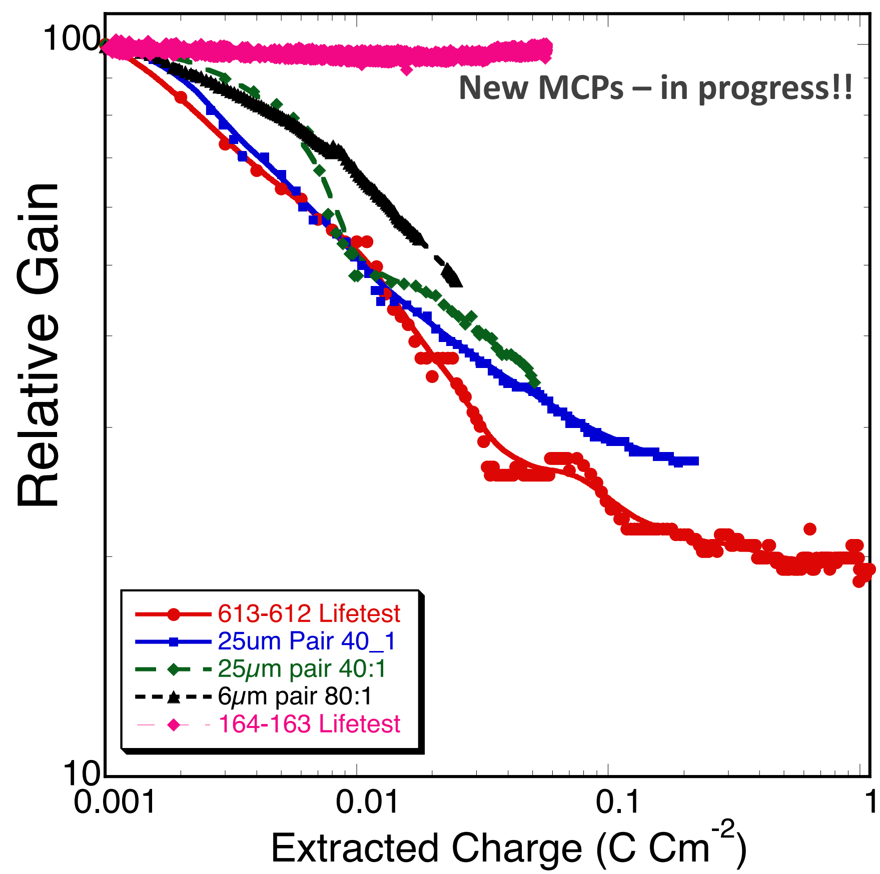
33mm ALD-MCP Preconditioning Tests

Gain curves before and after 350°C vacuum bake



Very large gain increase after the bake. Probably due to secondary electron coefficient change.

Burn-in test, new MCPs very stable!

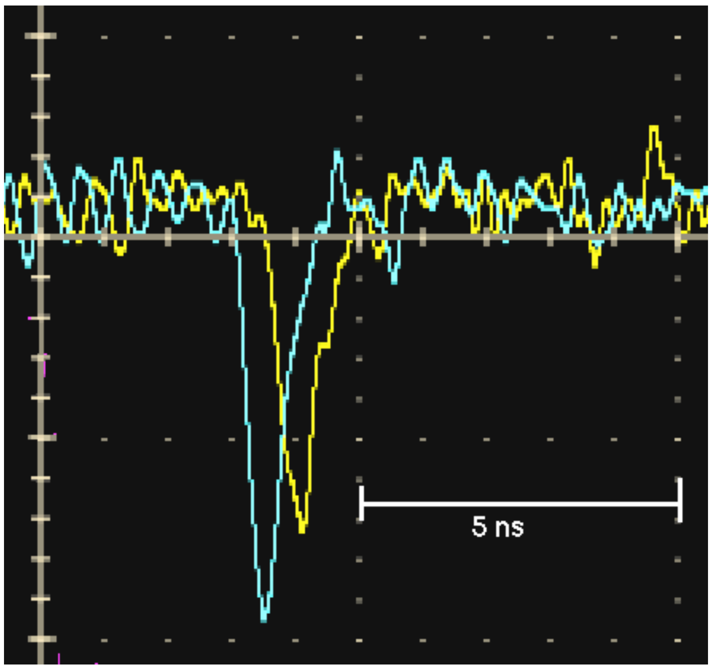


1μA scrub @ 3 x 10^5 gain, 700v per MCP

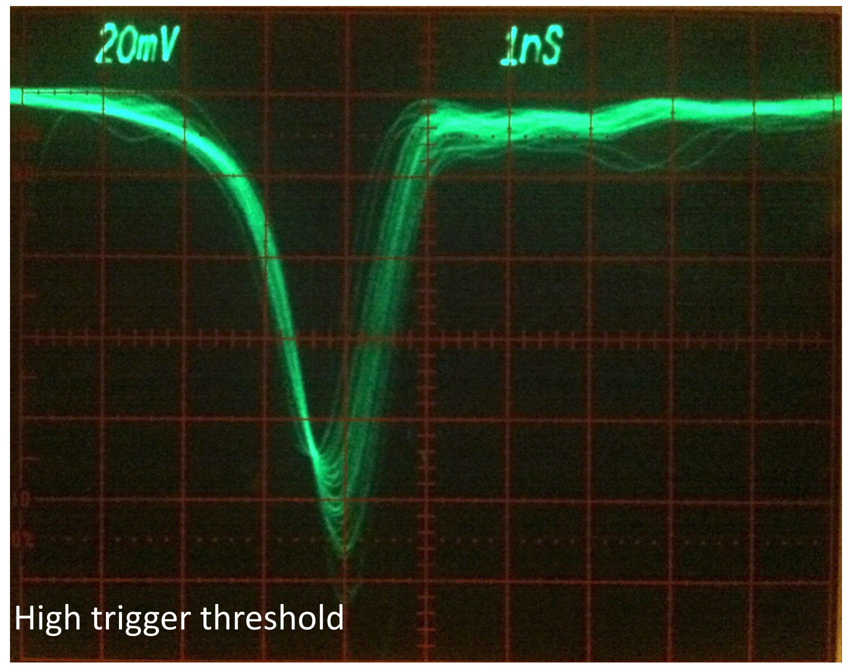
Gain drop <5% over 16 hours and 0.01 C cm^{-2}, quite stable since then.

ALD-MCP Pulse Timing Tests

ALD MCPs have pulse characteristics similar to normal MCPs



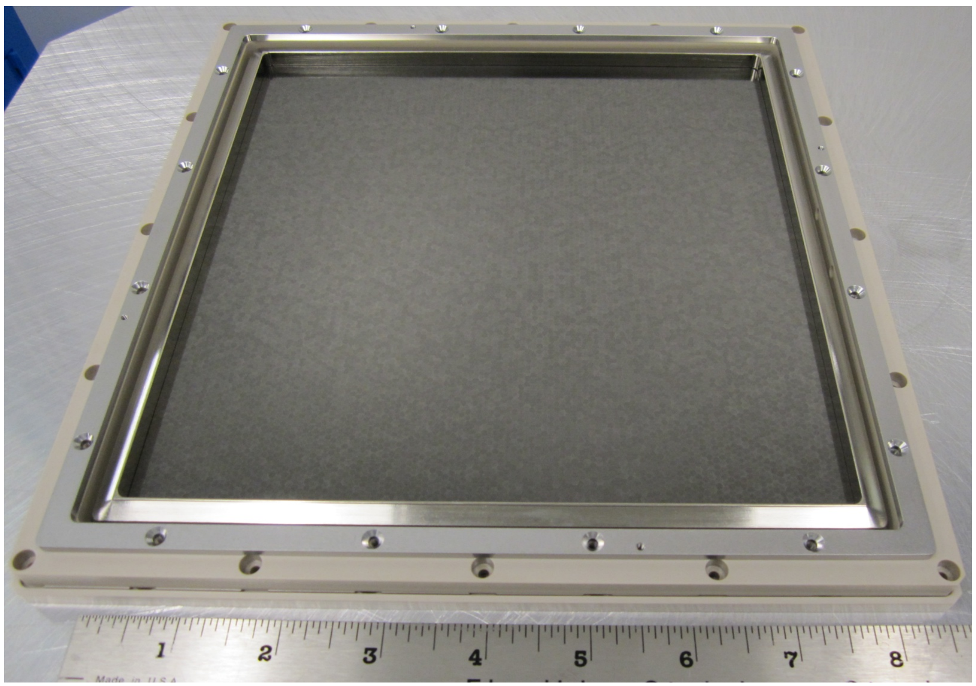
ALD borosilicate MCP pair, 20/40µm pore, 60:1 L/d, 8° bias. Fast laser pulse, multi-photon response (2 events shown) <1ns pulse width. Courtesy M. Wetstein, Argonne National Lab.



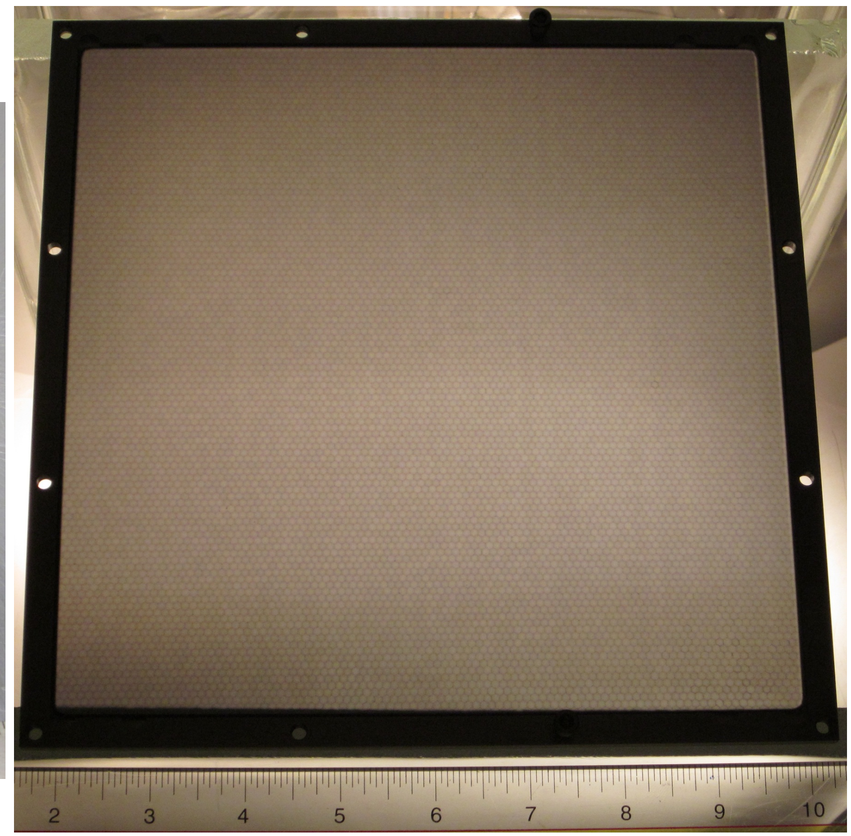
ALD borosilicate MCP pair, 20µm pore, 60:1 L/d, 8° bias, 0.7mm/1000v MCP gap. Single photon pulses are ~1ns wide, limited by scope bandwidth (1GHz).

Progress with 20cm MCP Development

A small number of 20cm MCP substrates (20µm pore) have been functionalized by ALD at ANL and electroded at UCB-SSL. One has been tested successfully showing gain in a detector specifically built to allow single MCPs, or pairs, to be evaluated.

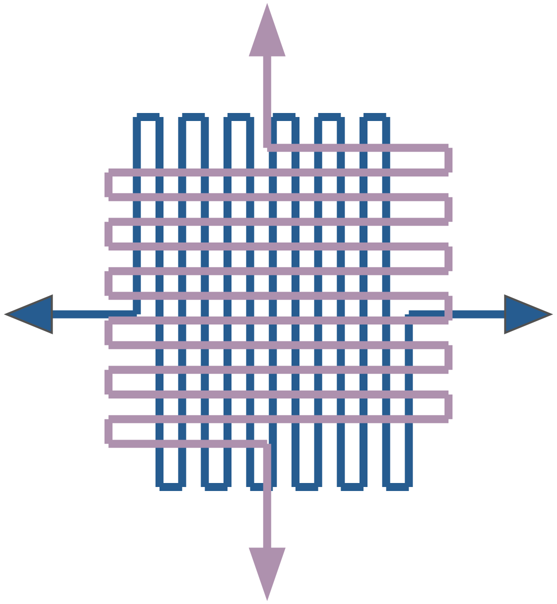


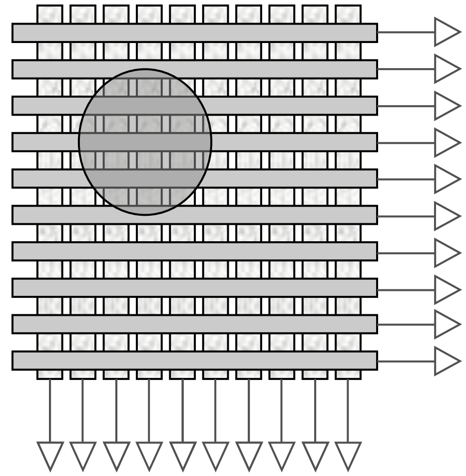
20cm electroded ALD 20µm pore MCP in detector assembly with a cross delay line imaging readout

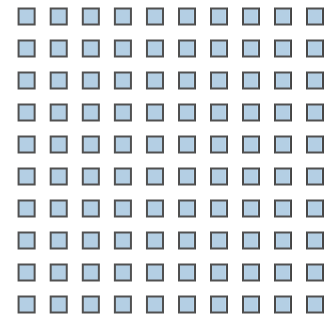


20cm MCP showing the multifiber stacking arrangement, 40µm pore, 8° bias.

Microchannel Plate Readout Anode Types







Cross Delayline (XDL)

4 amps
Gain ~ 10^7
Rate ~ 2 MHz +
Δt ~ 100ps
Multi-event? – a few depends on electronics and design

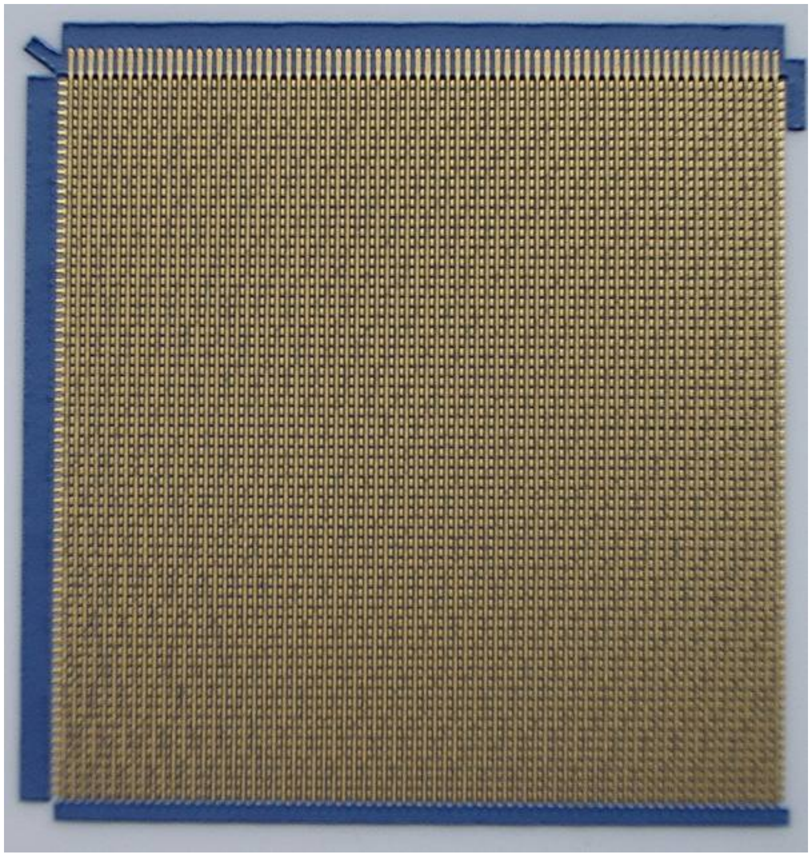
Cross Strip (XS)

2 x N amps
Gain ~ 3x 10^5 - 10^6
Rate ~ 5 MHz +
Δt ~ 100ps
Multi-event? – a few more. Non spatially overlapping events!

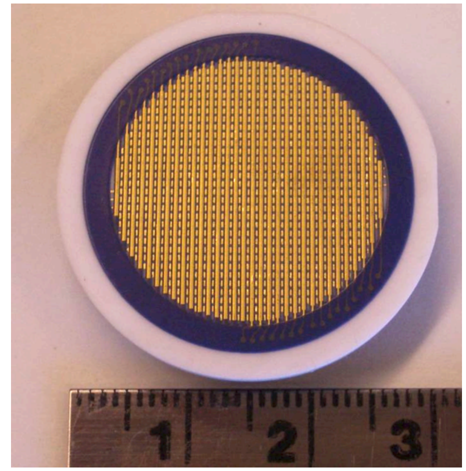
Medipix/Timepix ASIC-ROIC

N x N amps
Gain ~ 10^4-10^5
Rate ~ 200MHz
Δt ~ 1 ms.
Multi-event? – many! Non spatially overlapping events!

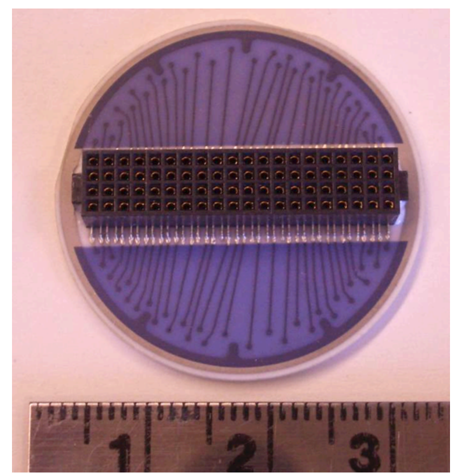
Cross Strip Anode Designs



50 mm square Cross Strip Anode with 0.64 mm finger period. All metal and ceramic. Recently duplicated in polyimide using photolithography and laser etching.



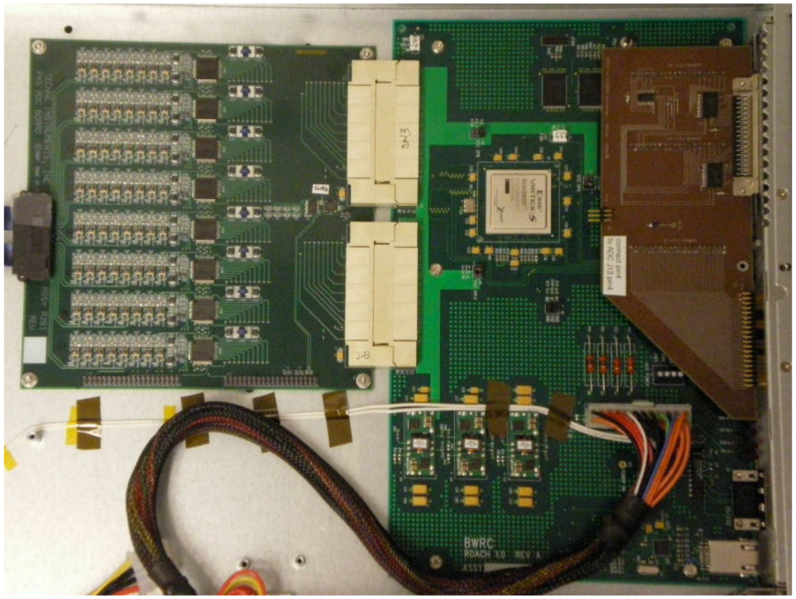
22mm round cross strip



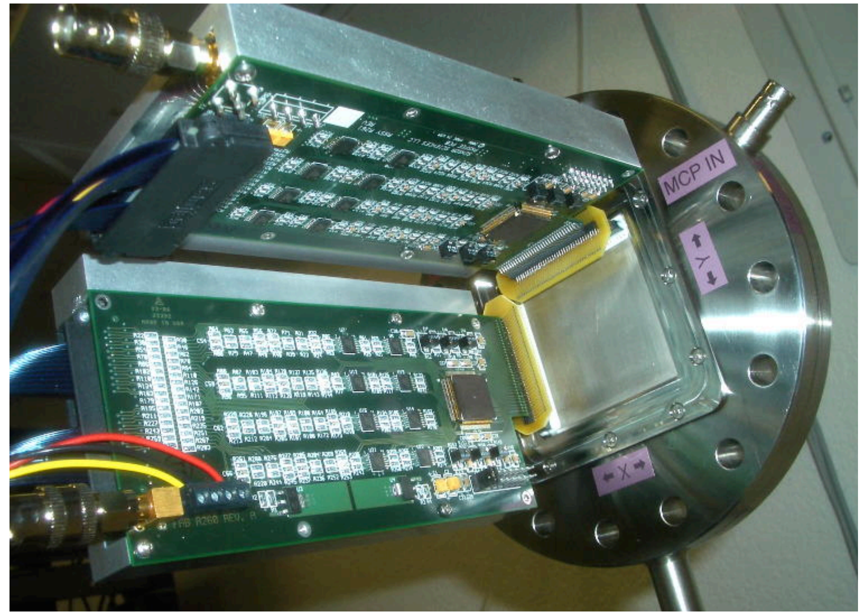
22mm round cross strip showing vias and connector

50mm Cross Strip Readout Electronics

64 chan
50MHz
8 octal
ADC
board



64 channel 50MHz ADC module coupled to the Xilinx Virtex 5 FPGA board for amplifier signal digitization and signal conditioning and centroid calculation.



ASIC amps on 40mm cross strip

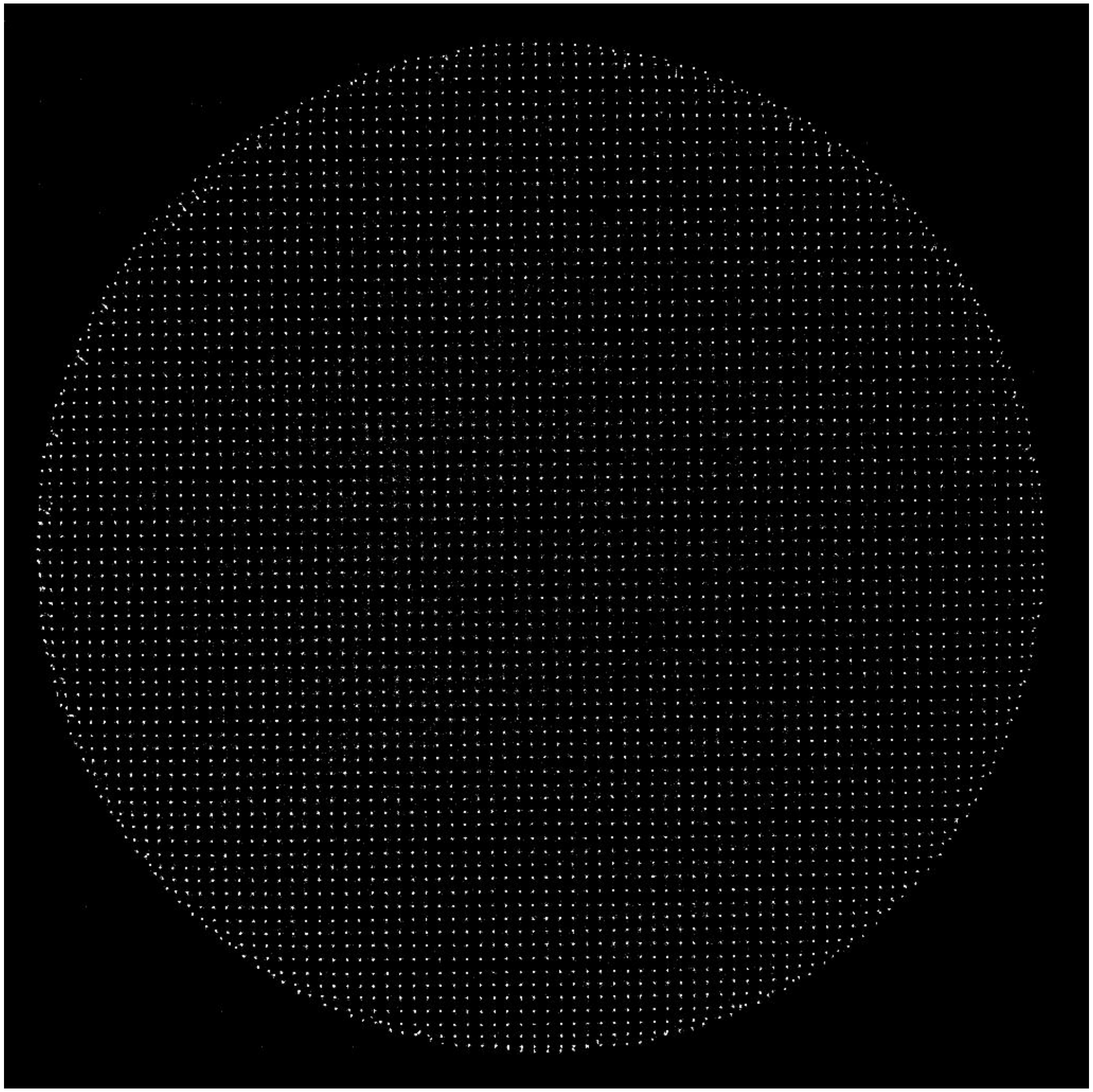
32 Amplifier RD20 chip

Spatial resolution of <15µm on 50mm format, >3k x 3k

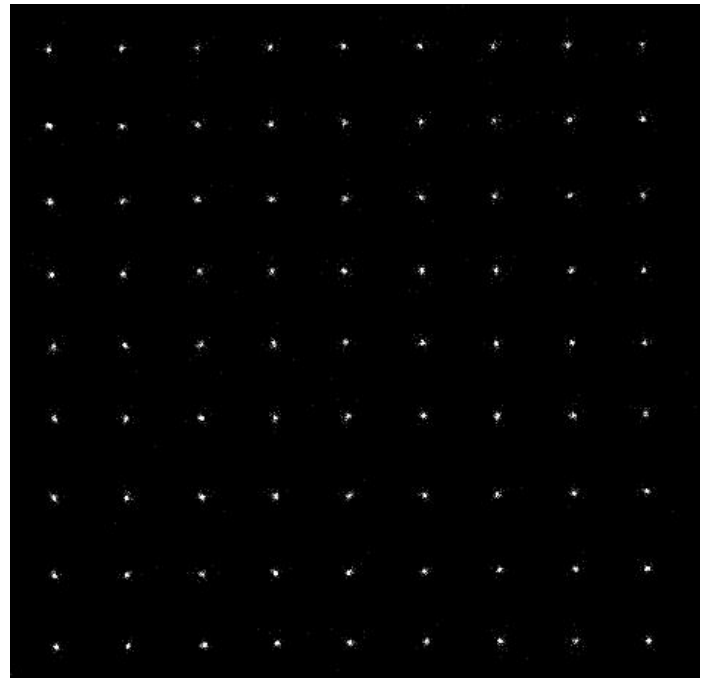
Lower gain (5×10^5), longer lifetimes, than existing devices

Can be extended to large sizes, but needs modern ASIC electronics to fully implement performance capabilities with >10MHz rates and large formats. (in progress).

50 mm XS anode spatial-resolution



40 mm active area - 0.5 x 0.5 mm pinhole grid



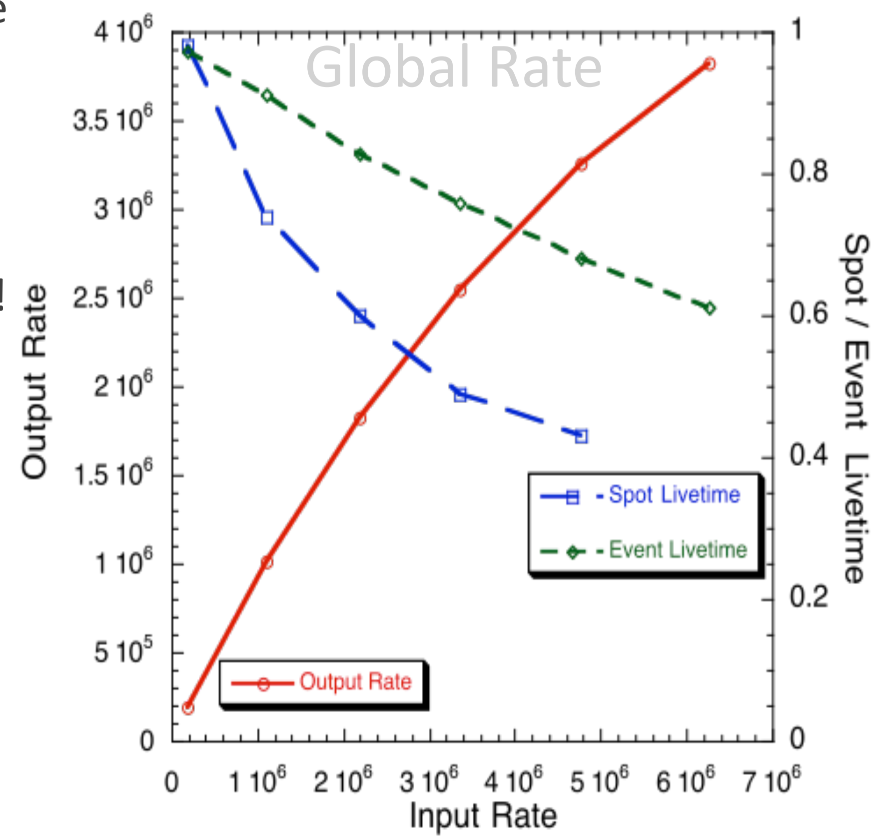
Zoomed - 20 µm FWHM avg.

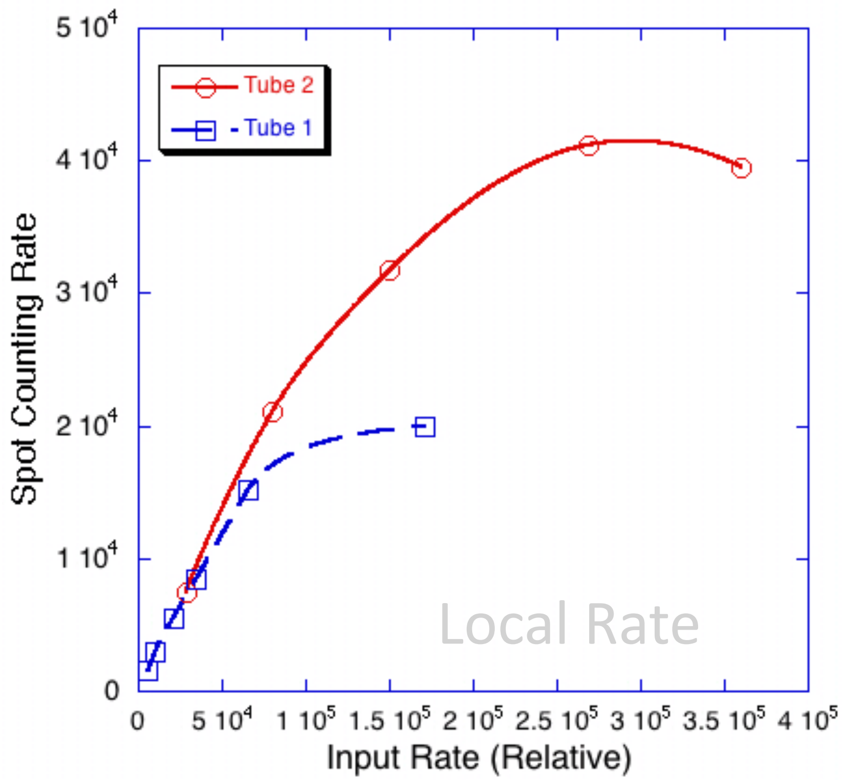
Dynamic Range - Global and Local

Projected spots onto visible XS tube

Increased rate by leaking in background

Rate limited by ASIC amp, -being replaced with new design 10 faster!



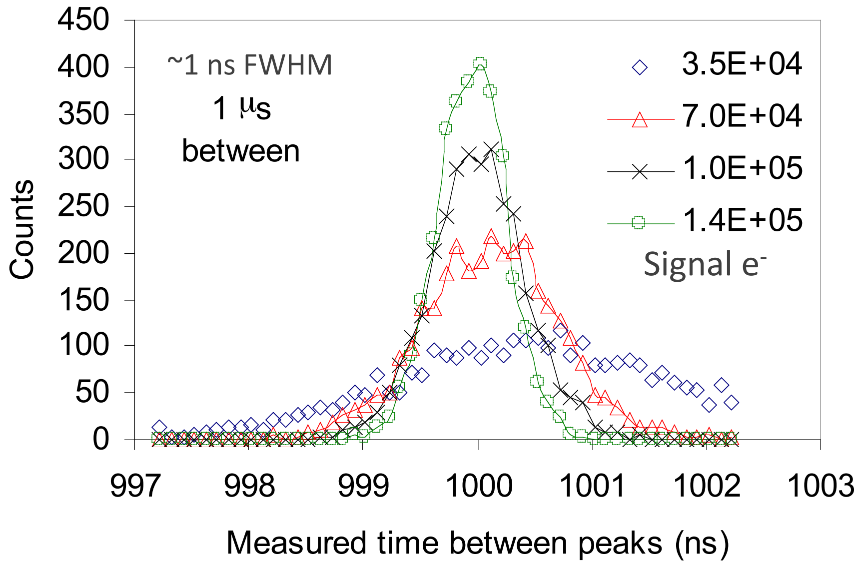


100µm spot for two chevron sets of different resistance: 170MΩ (Tube1) and 105MΩ (Tube 2)

Event Timing Resolution

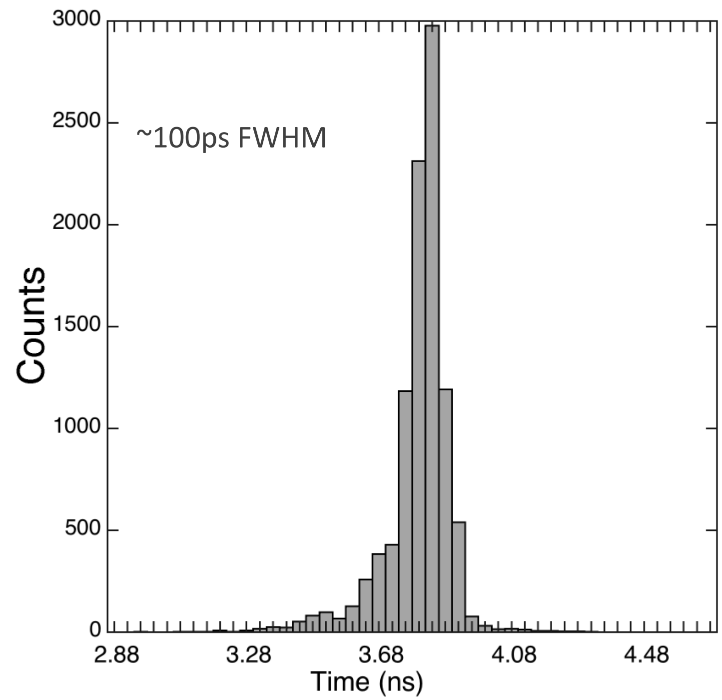
The time of each event can be registered several ways:

- Time to digital interval times from the back of the MCP
- digitization and digital filtering of the RD20 signals directly



)

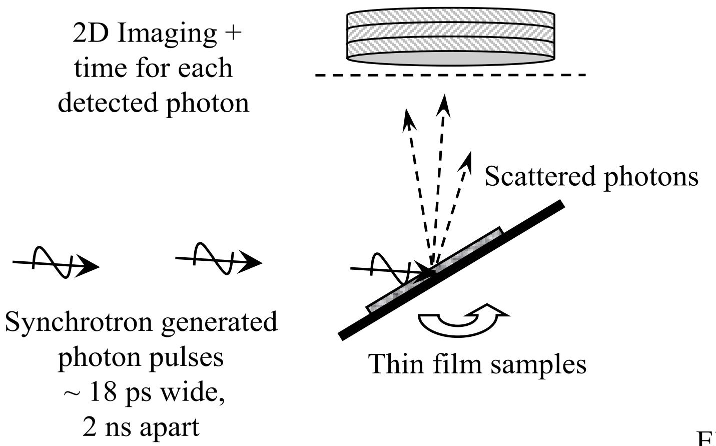
board for XS anode, digitized and peak times determined with FIR filter algorithm.



Time jitter measurement for a 25mm MCP detector with XDL anode using a fast amp and TDC on the MCP output, 80ps laser input.

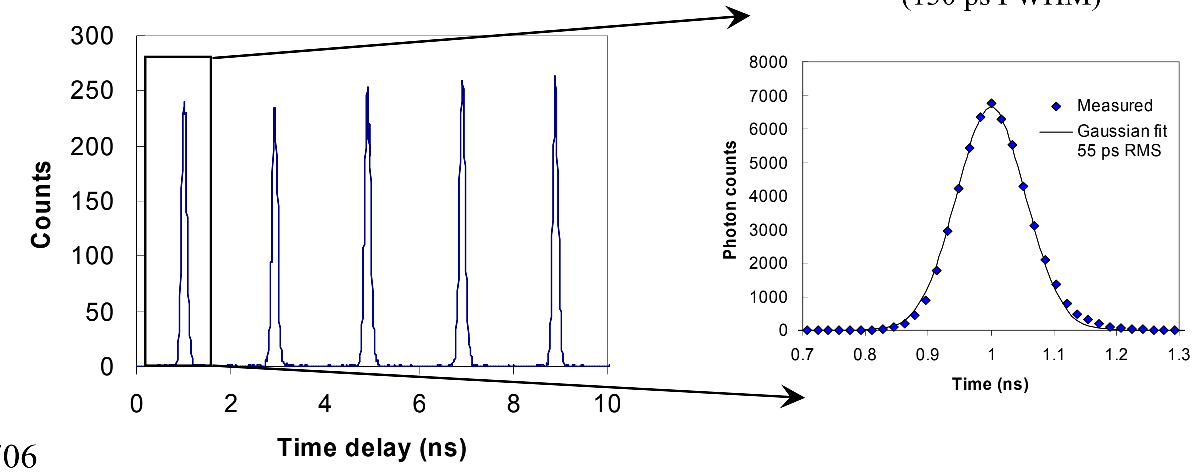
Timing resolution of XDL detectors

ALS Soft X-ray photon scattering



Elastically scattered photons

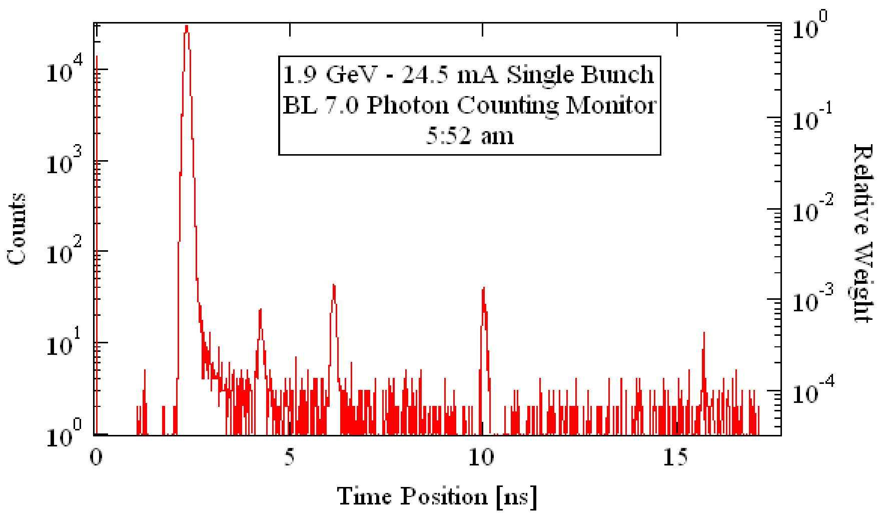
Timing accuracy 55 ps RMS
(130 ps FWHM)



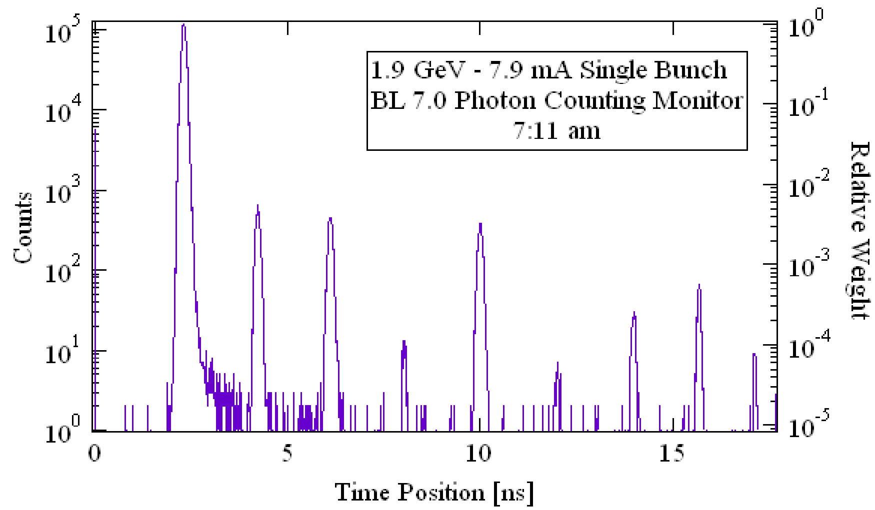
A. S. Tremsin, et al.,
IEEE Trans. Nucl .Sci. 54 (2007) 706

Synchrotron bunch diffusion

Bunch population after injection



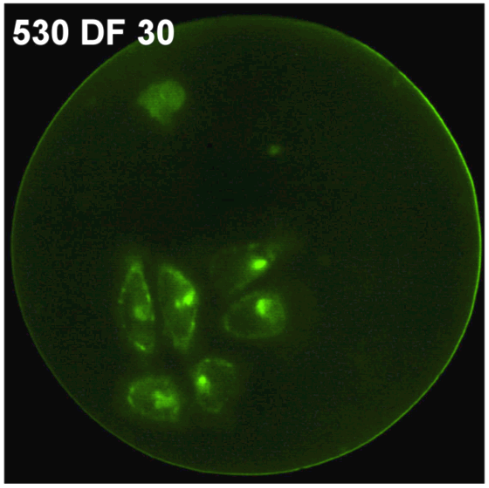
Bunch population ~76 min later

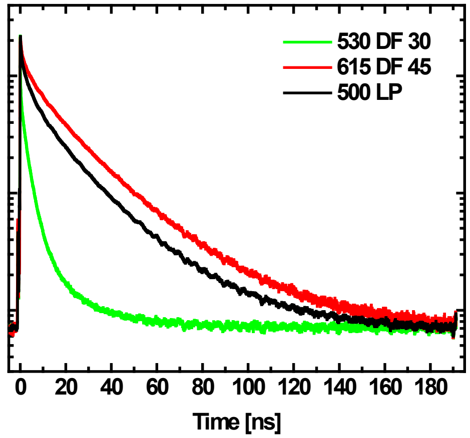


Diffusion of electrons between the adjacent bunches was optimized with our detection system

W. E. Byrne, C.-W. Chiu, J. Guo, F. Sannibale, J.S. Hull, O.H.W. Siegmund, A. S. Tremsin , J.V. Vallerga
Proceedings EPAC'06, Edinburgh, June 2006

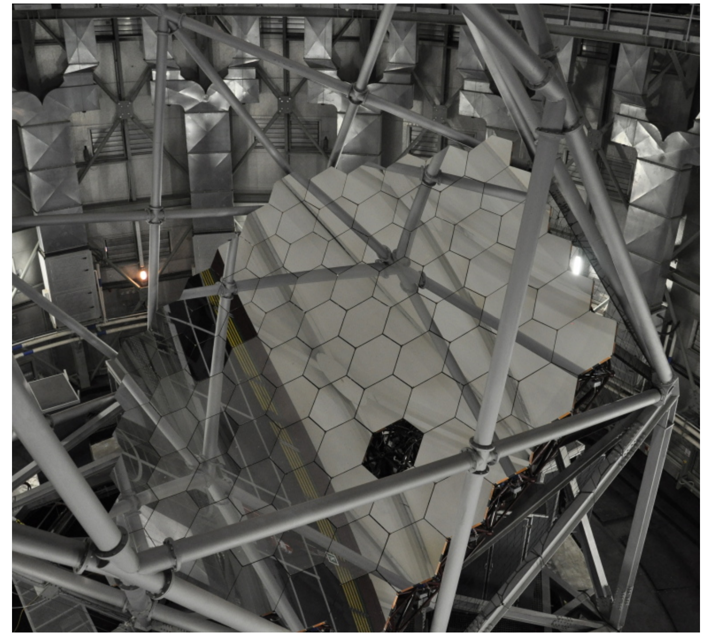
Microchannel Plate Sensor Applications

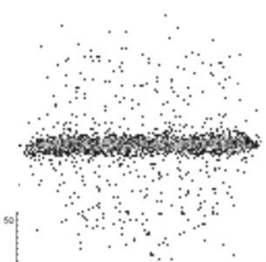




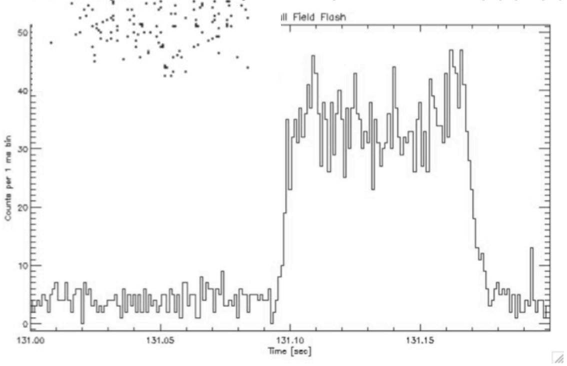
Fluorescent dye decay time

Biological fluorescence lifetime imaging

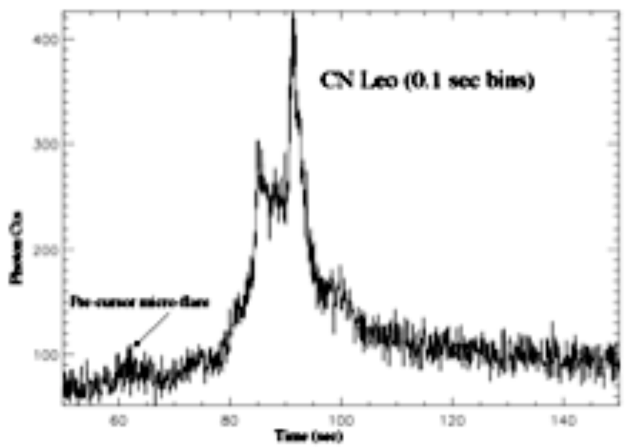




Satellite ~8.5 km/sec in low earth orbit, 70 ms to track Across 100” field of view. Lick 1m telescope 25mm XDL sealed tube.

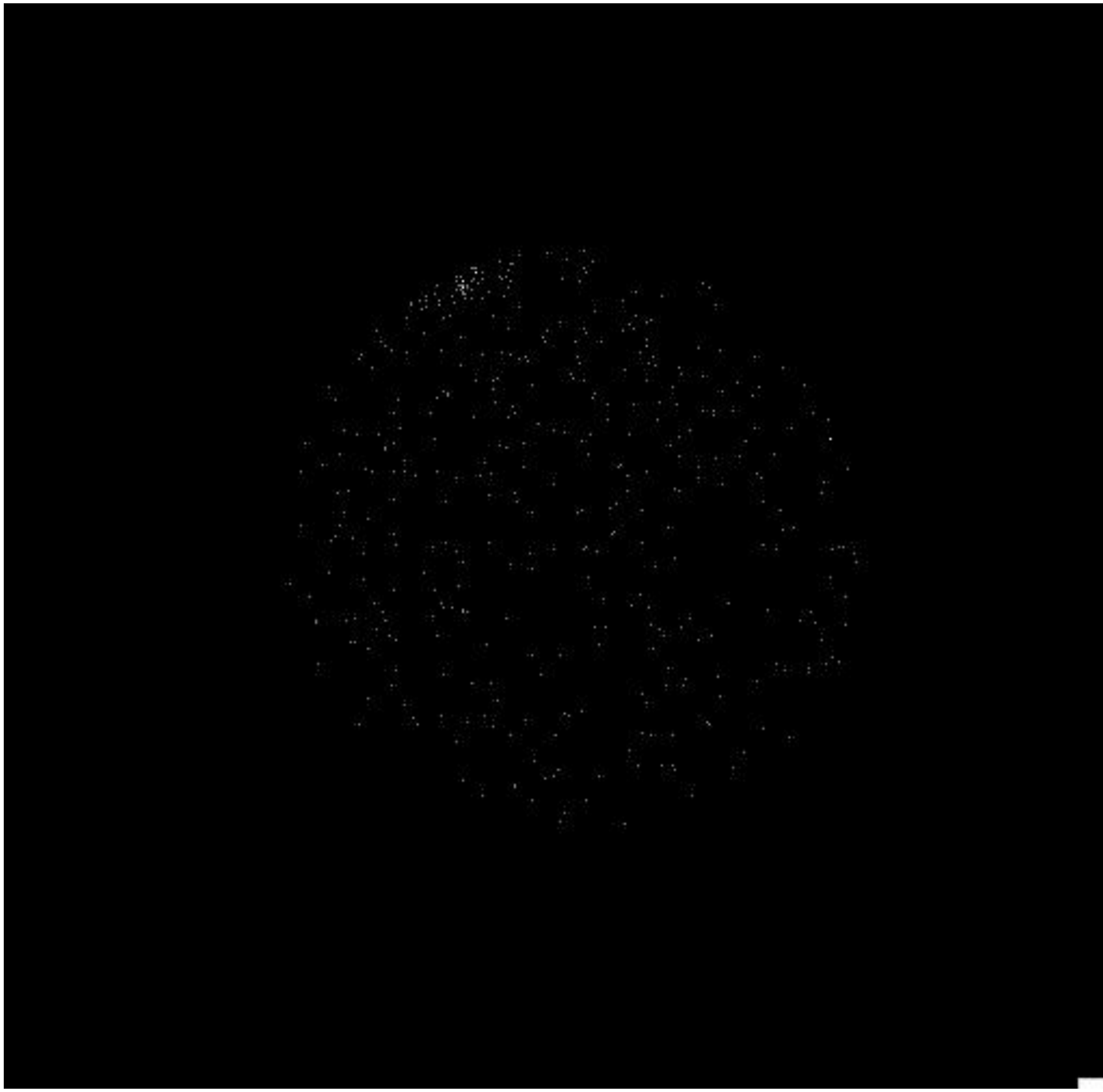


- 10m SAAO SALT telescope



High time resolution Astronomy

Meteor Observation at SALT



Meteor crossing the SALT field of view (2') showing the ablated head and tail (5 ms movie). Equivalent magnitude of ~9 M_v. (Meteor photons seen in 1ms integration = M_v16 star in one sec. [velocity ~10 km sec^{-1} at ~100 km altitude].