Application of Atomic Layer Deposited Microchannel Plates to Imaging Photodetectors with High Time Resolution

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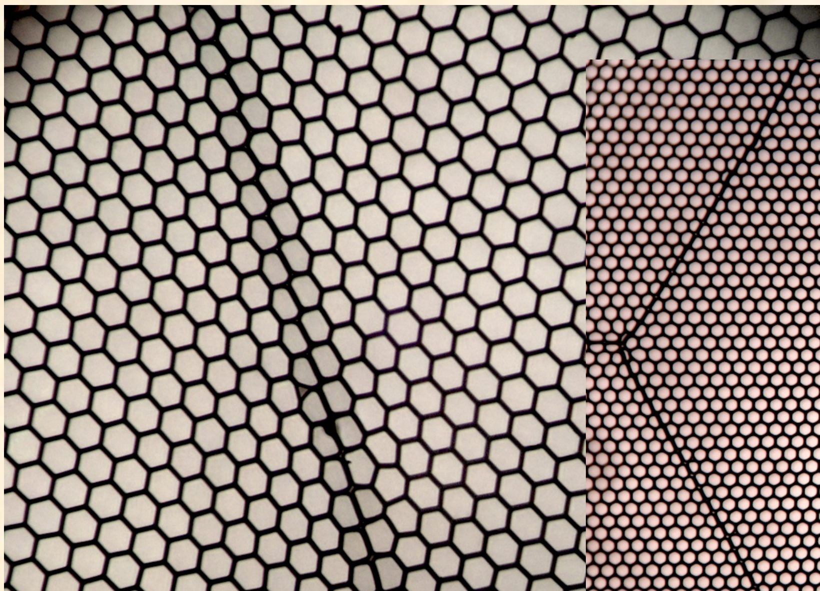
Borosilicate Substrate Atomic Layer Deposited Microchannel Plates

Micro-capillary arrays (Incom) with 10µm, 20 µm or 40µm pores (8° bias) – borosilicate glass. l/d typically 60:1, but can be much larger. Open area ratios from 60% to 83%. Fabricated with using hollow tubes (no etching). Separate resistive and secondary emissive layers are applied (ANL, Arradiance) using atomic layer deposition to allow these to function as MCPs. ALD secondary emissive layers can also be applied to "standard" MCPs to improve yield.



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

Pore distortions at multifiber boundaries, otherwise very uniform.

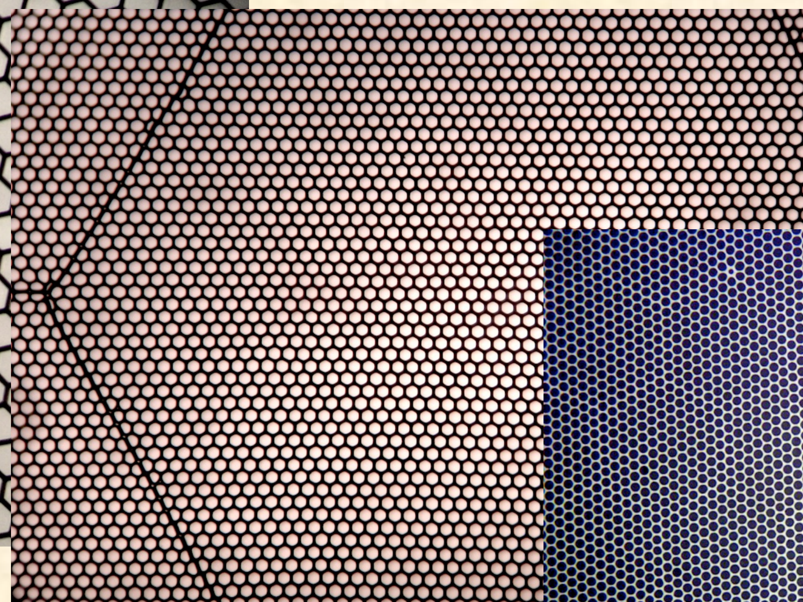


Photo of a 20 µm pore, 65% open area borosilicate micro-capillary ALD MCP (20cm).

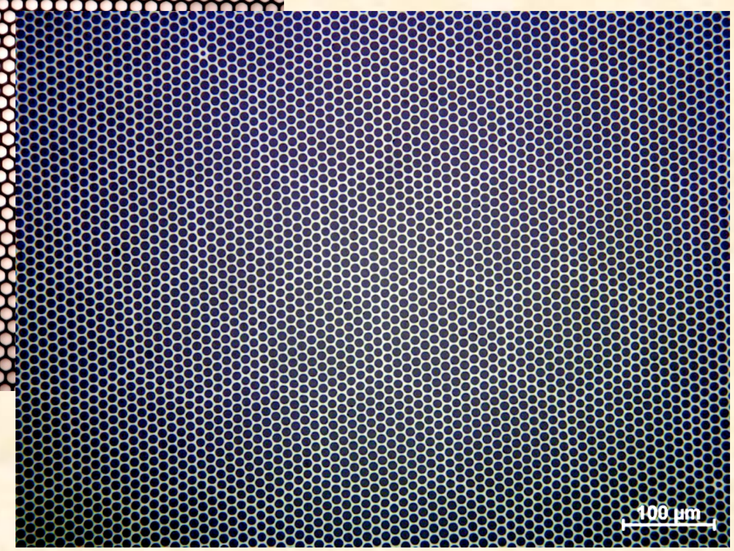


Photo of a 10 µm pore, 60% open area borosilicate micro-capillary ALD MCP.

Key Issues for ALD Borosilicate MCPs

Current MCP devices have specific limitations due to the nature of the structure and processing of conventional MCPs. Atomic layer deposited (ALD) MCPs made on borosilicate substrates provide a unique way to improve on current devices or make new device types.

<u>Borosilicate substrate</u>:- Strong & clean compared with standard MCP glass

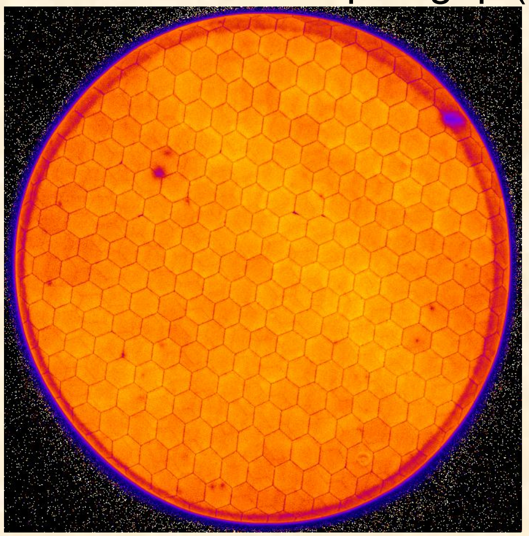
Large areas can be made	– large detectors for security applications
Larger open area ratios	– higher photon /electron/ion detection efficiency
Low/no radioactive content	– lower background for security applications
Low outgassing	– longer device lifetimes, shorter process/fab times
High temperatures	– deposit materials & cathodes not otherwise possible

<u>Atomic layer deposition</u>:- Decoupled from substrate, many materials possible

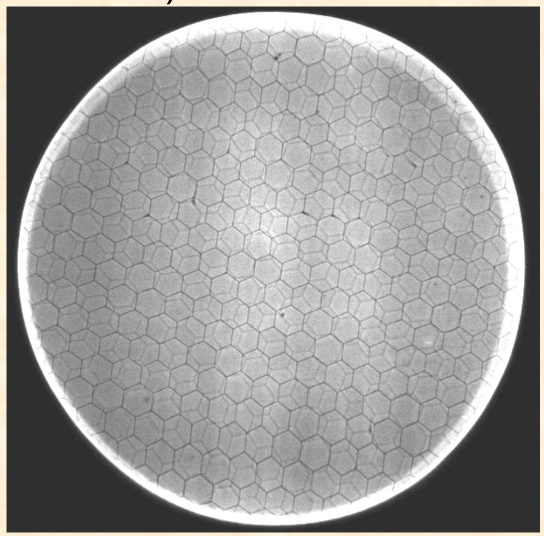
Resistance tailored to suit	– can make a wider range than standard MCPs allowing high local counting rates
High secondary emissive layer	– better pulse height at low gain, better gain
Stable secondary emissive layer	– faster gain burn-in, or none needed – very long lifetime & durability – compatibility with alkali cathodes

33mm ALD Borosilicate MCP Performance

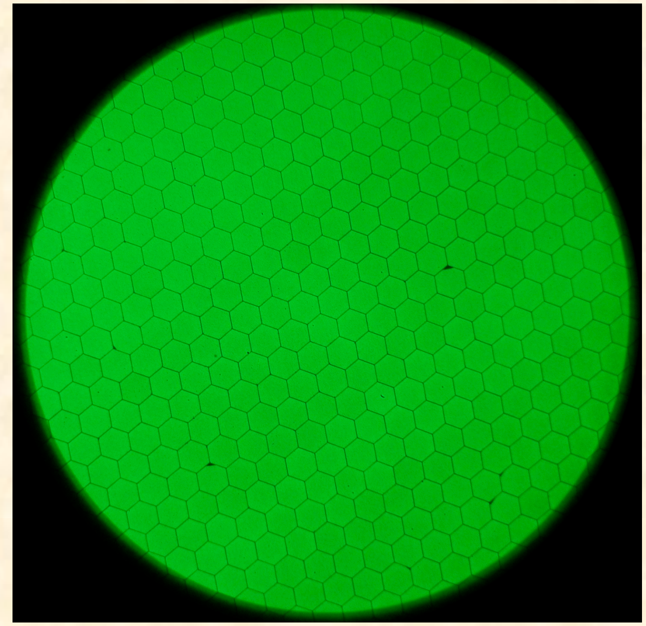
MCP pair, 20µm pores, 8° bias, 60:1 L/d, 0.7mm pair gap (300V bias). Gain ~6 x 10^6.



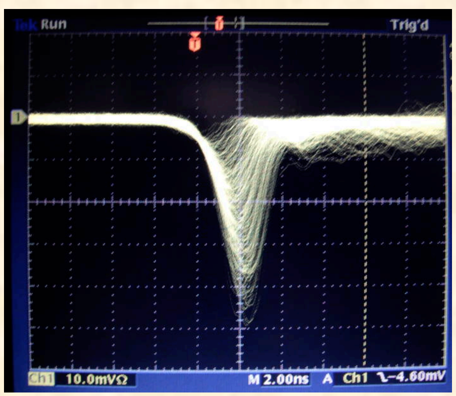
Gain "map" images show ~15% variations & "hex"



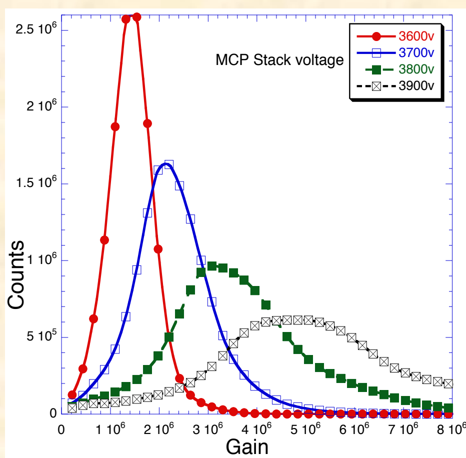
Images with 185nm UV show MCP multifibers



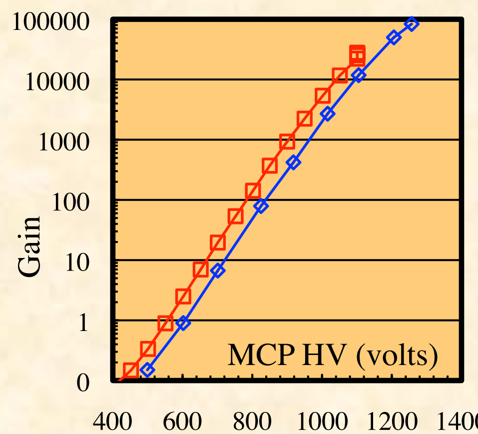
Phosphor screen image of 20µm pores, 8° bias, 60:1 L/d, ALD borosilicate MCP



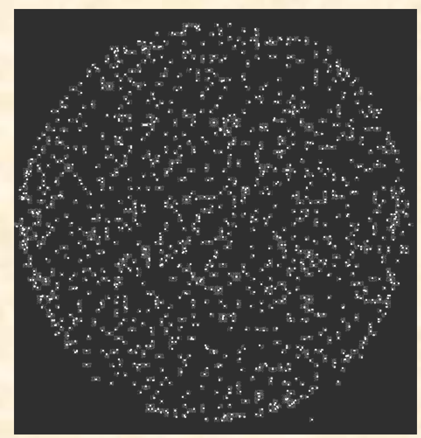
MCP fast pulse shapes ~2ns wide like "normal" MCPs



Pulse amplitude distributions



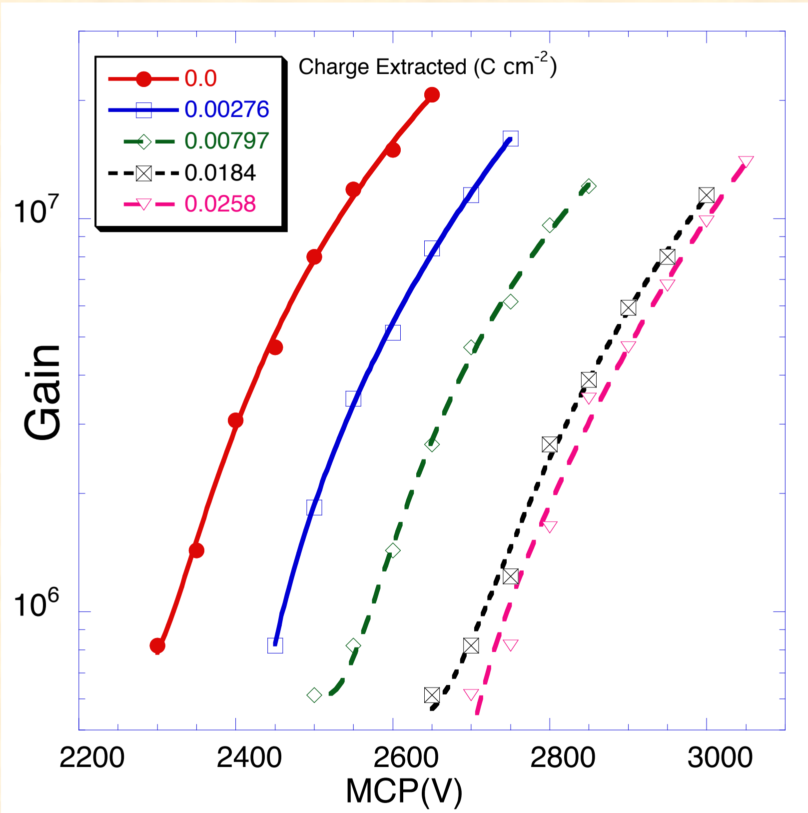
Gain/V curves for MCPs



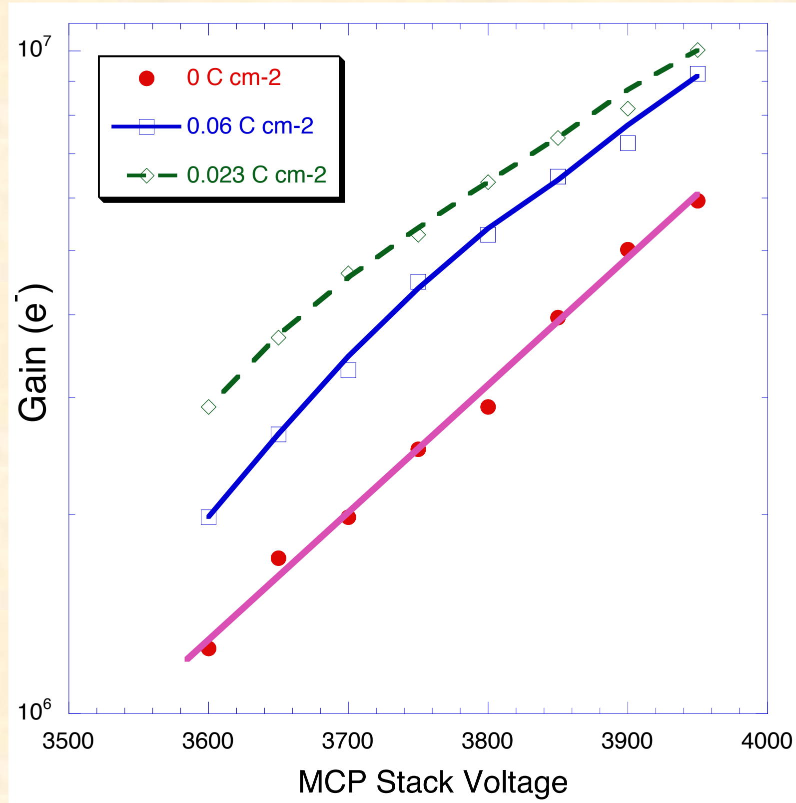
Background event rate 0.07 cts cm^{-2} sec^{-1}

MCPs “Burn-In” – Standard/MgO ALD Coated

Conventional MCP “Z” stack with 10μm pores, 60:1 L/D, **NO** coating



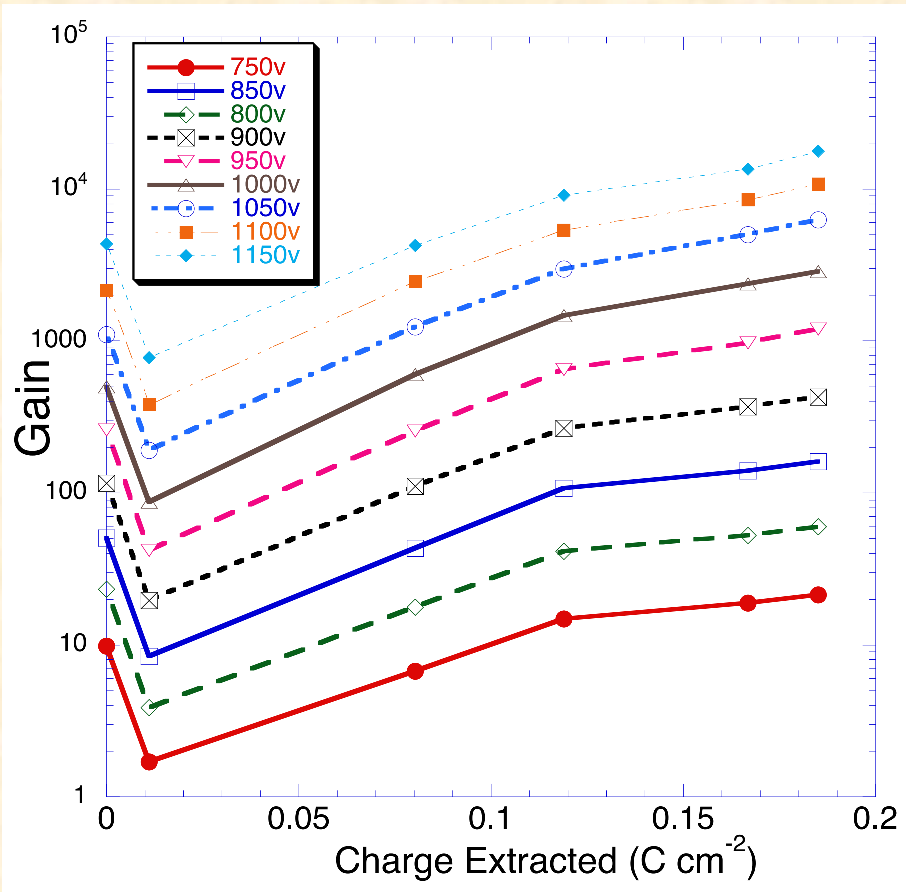
Conventional MCP with 6μm pores, 80:1 L/D, MgO ALD coating



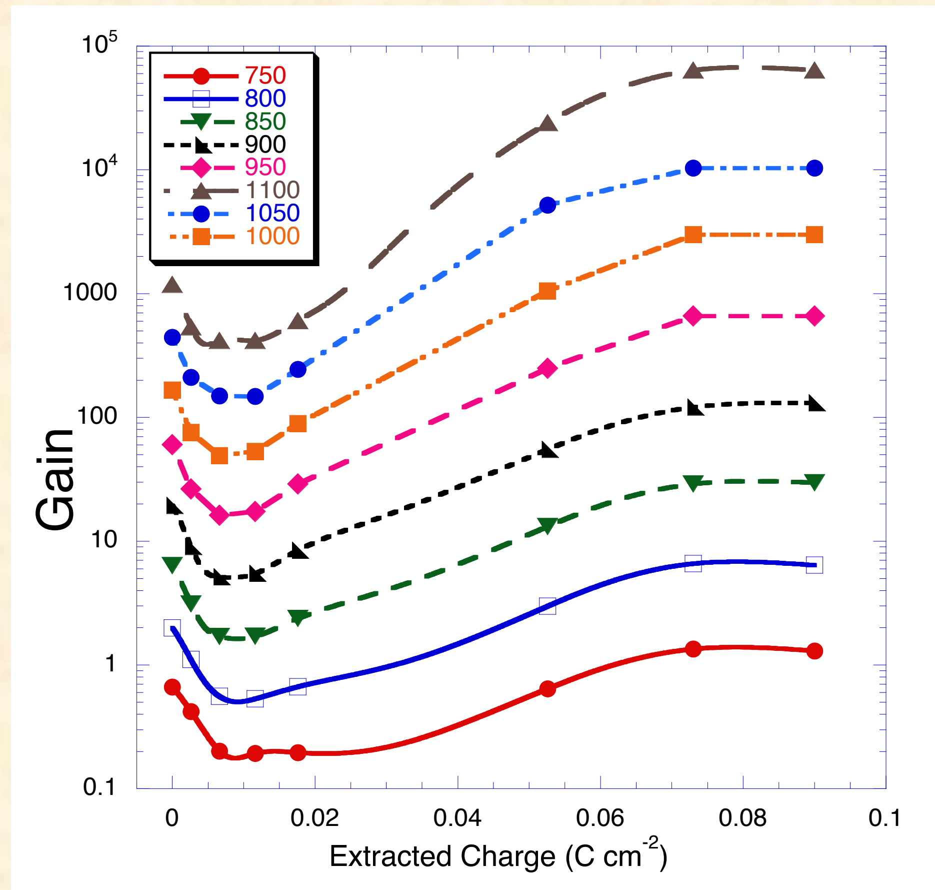
Conventional lead glass MCPs drop in gain considerably during “burn-in”, however with MgO secondary emissive layer the gain trend is upward to stabilization.

MCPs "Burn-In" – MgO ALD Coated

Borosilicate MCP with 10μm pores, 80:1 L/D, MgO ALD coating



Conventional MCP with 6μm pores, 80:1 L/D, MgO ALD coating

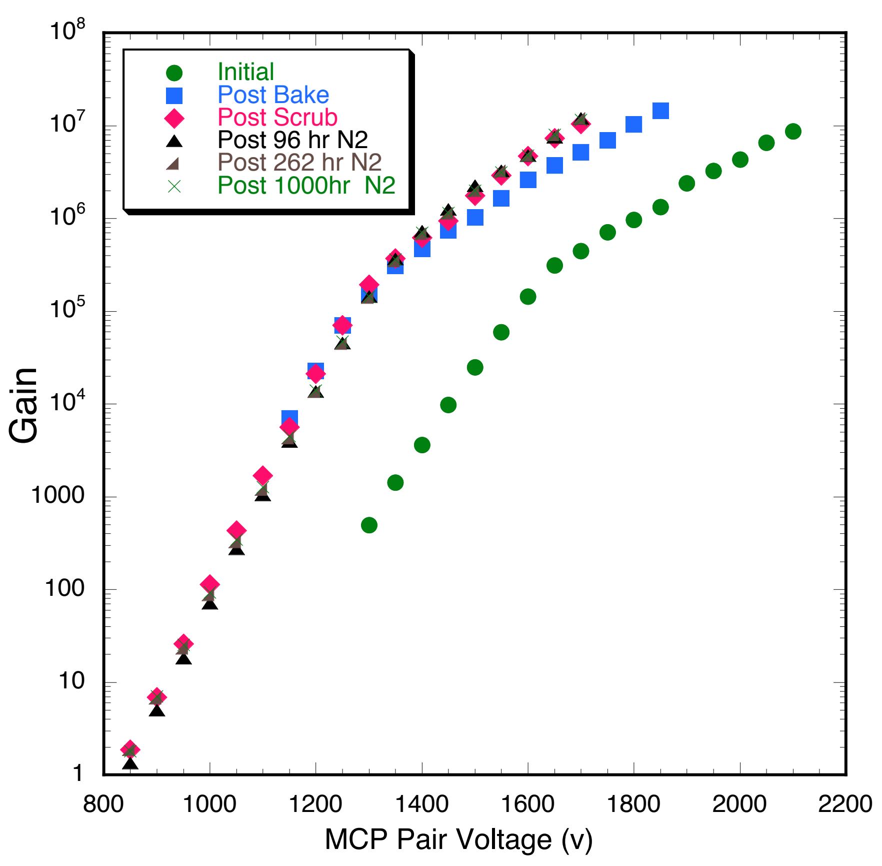


Gain drop at beginning of burn in with significant gain increase thereafter.

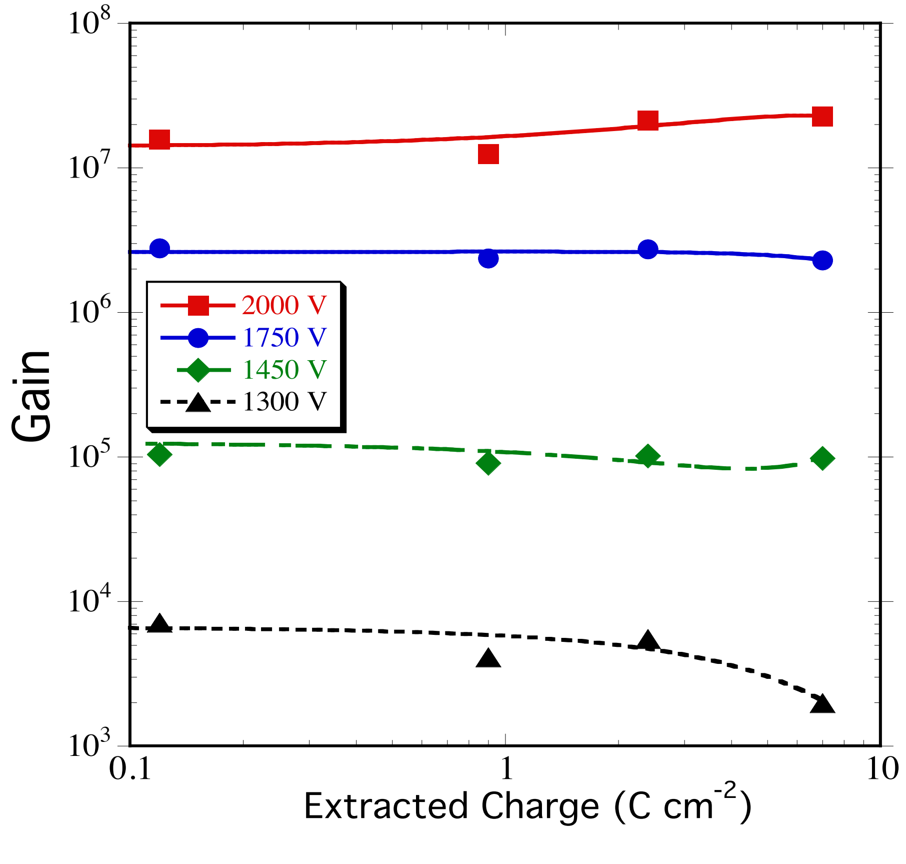
Stabilizes after ~0.07 to 0.2C cm^{-2} extracted – or – immediate if baked (pg-7)

33mm ALD-MCP Preconditioning Tests

Vacuum 350°C bakeout with RGA monitoring first, then UV flood low gain, high current extraction "burn in" (1 – 3µA). Very low outgassing, and gain increases by x10 during bake. No rapid gain drop in burn-in, gain-V curves remain very stable even after 1000 hours of N_2 exposure.



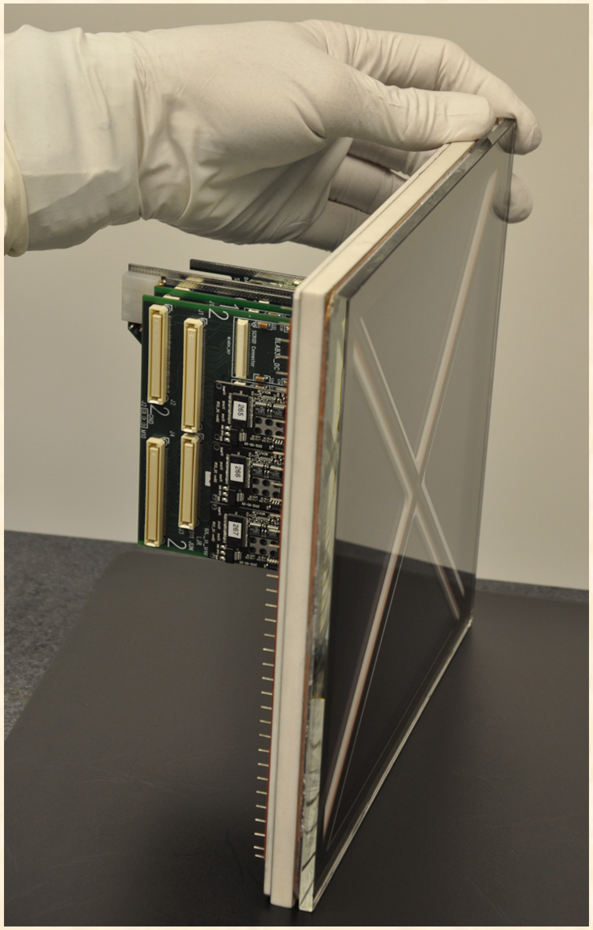
Gain curves of MCP pair (20µm pore, 60:1 L/d, 8° bias) at stages during preconditioning and nitrogen exposure (now up to 1000hr N_2 exposure).



UV scrub of ALD MCP pair 164-163, (20µm pore, 60:1 L/d, 8° bias, borosilicate substrate with MgO).

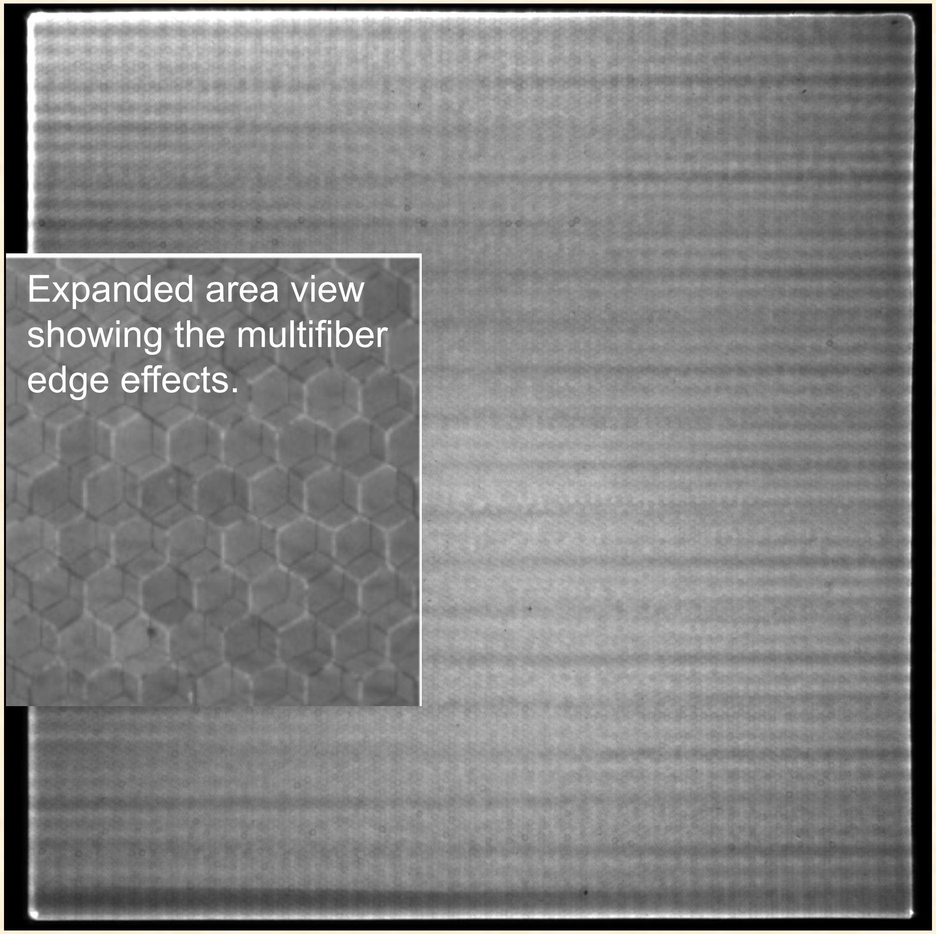
20cm ALD-MCP & Sealed Tube Development

LAPPD collaboration development of 20cm ALD MCPs and sealed tube with bialkali cathode and stripline anode for 2D imaging and <10ps timing.



Also see Incom poster.

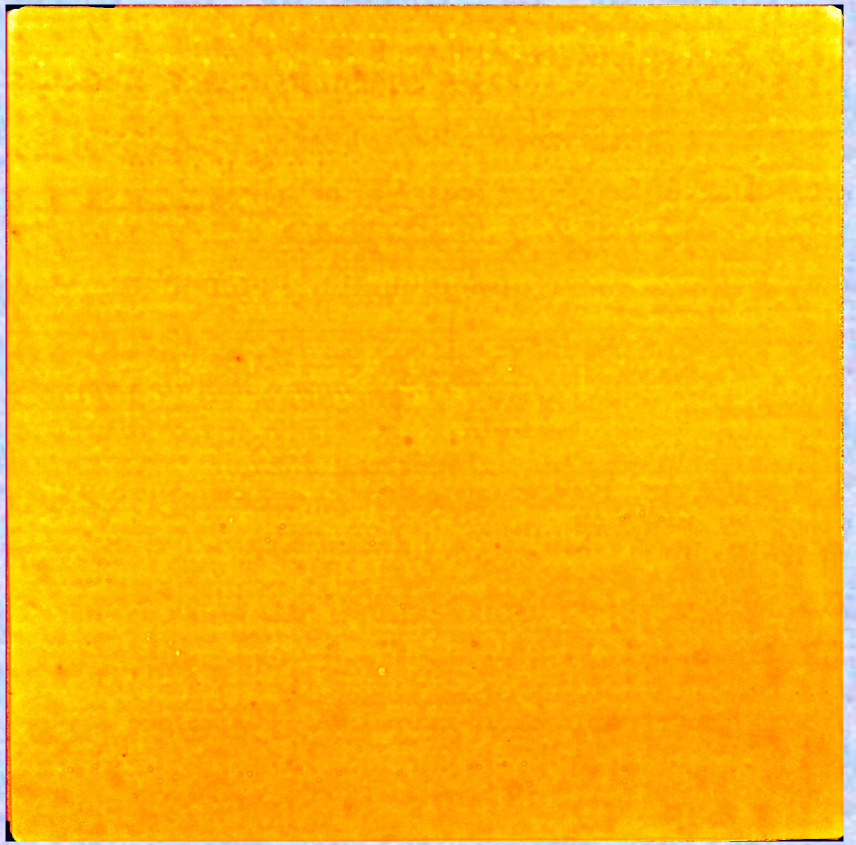
First tube did not seal, making new tubes this summer



20cm, 20μm pore, Al_2O_3 SEY, MCP pair image with 185nm non-uniform UV illumination. Cross delay line photon counting anode. Image striping is due to the anode period/charge cloud size modulation.

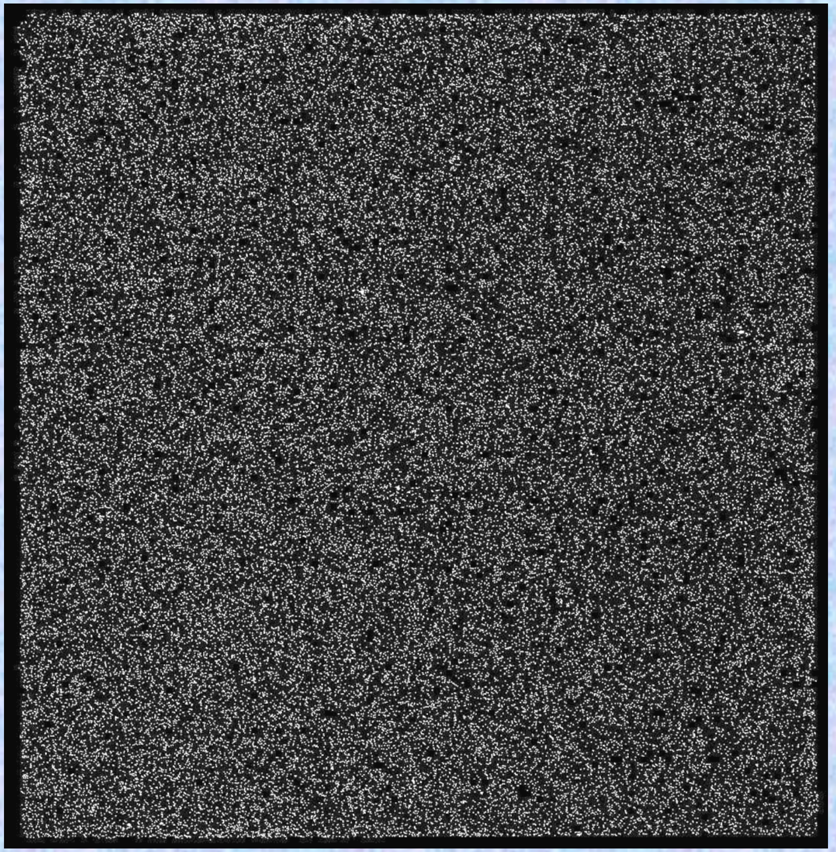
Testing of 20cm, 20μm pore ALD-MCPs

Average gain image "map" has <15% overall variation



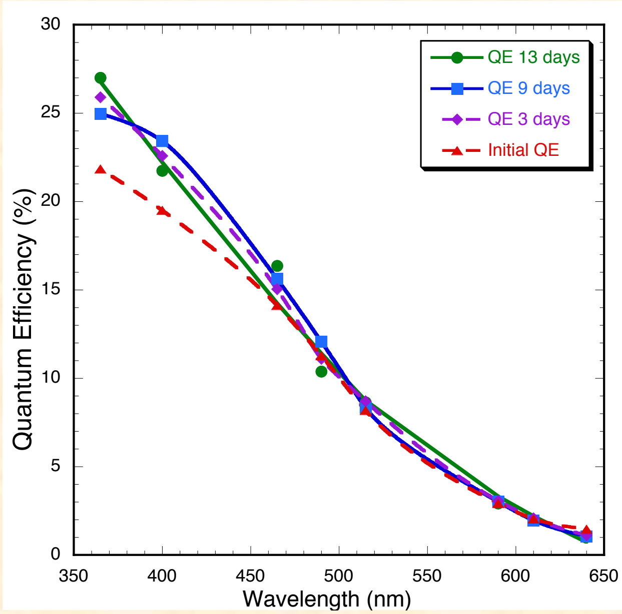
8" MCP pair average gain map image 20µm pore, 60:1 L/d ALD-MCP pair. ~7 x 10^6 gain, 0.7mm gap/200v.

Overall background ~5x better than standard glass MCPs (<K^{40})

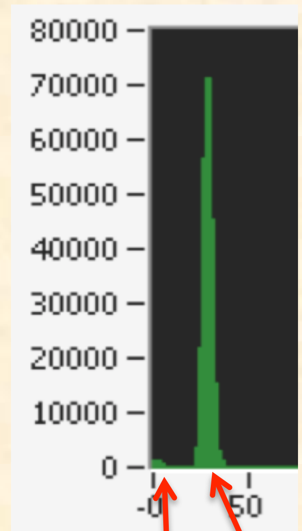


20cm MCP pair background, 2000 sec, 0.055 cnts sec^{-1} cm^{-2}. 2k x 2k imaging.

20cm Tube Cathode, Imaging, Pulse Height

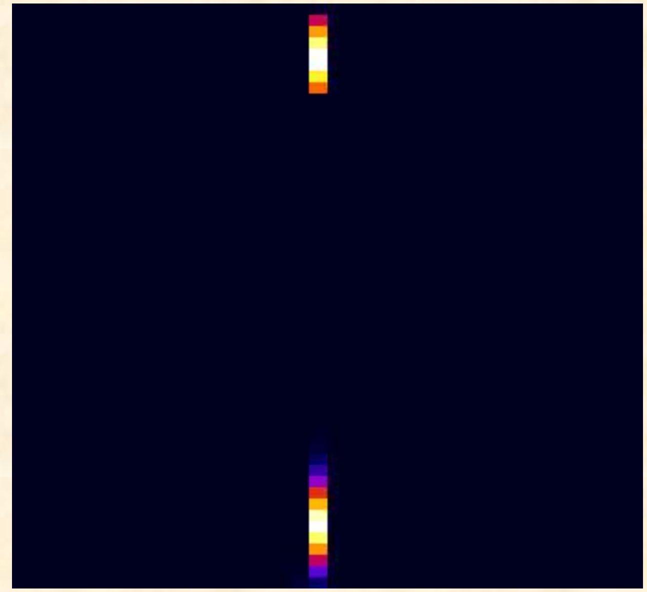


Have repeated the 20cm Na_2KSb photocathode process in 4 different process runs in 2 different tanks with ~25% peak QE, good uniformity and shown stability up to several months.



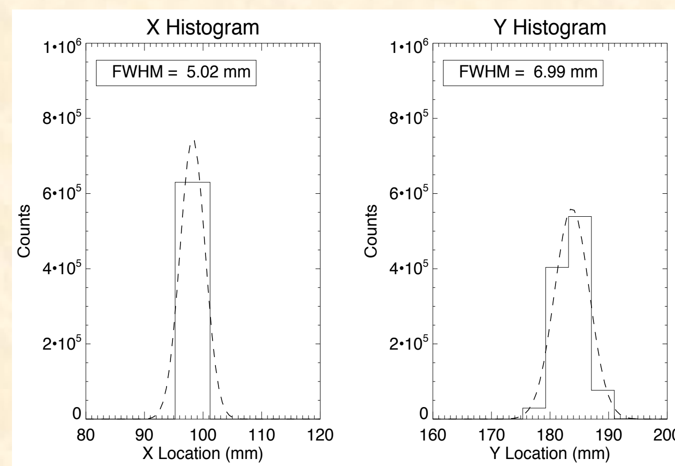
Pulse amplitude ~10 photoelectron pulses (80ps laser). See single electron noise in PHD!

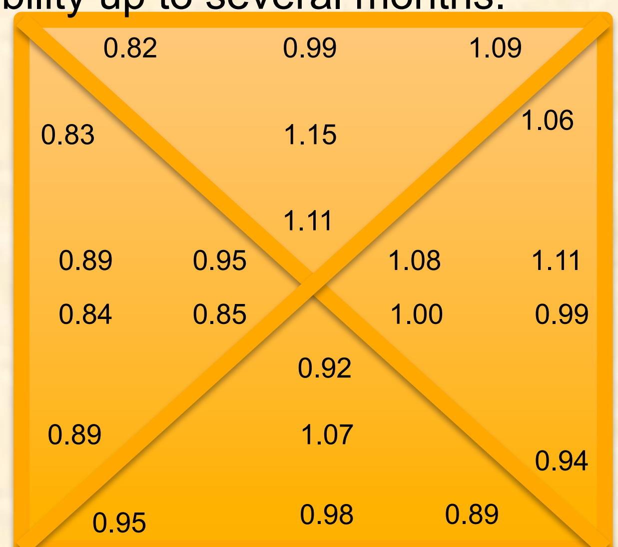
Laser spot Image



Stripline anode used as delayline

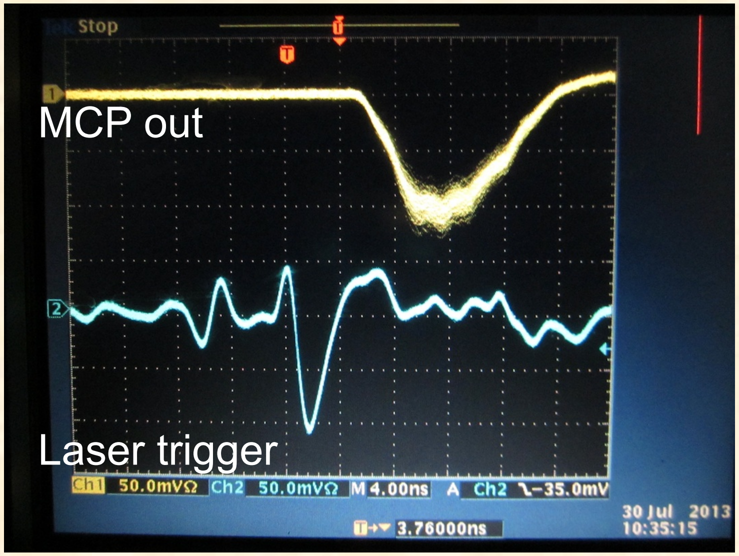
Laser spot images are 4-5mm FWHM

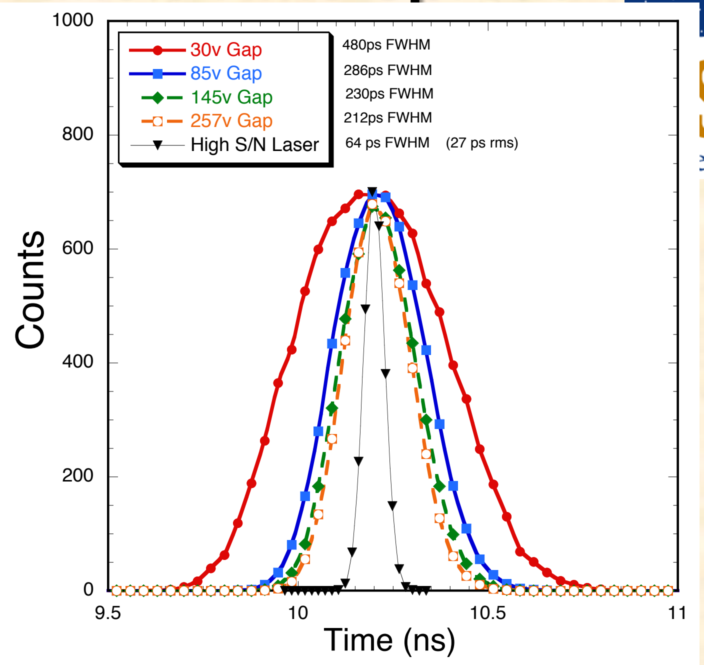


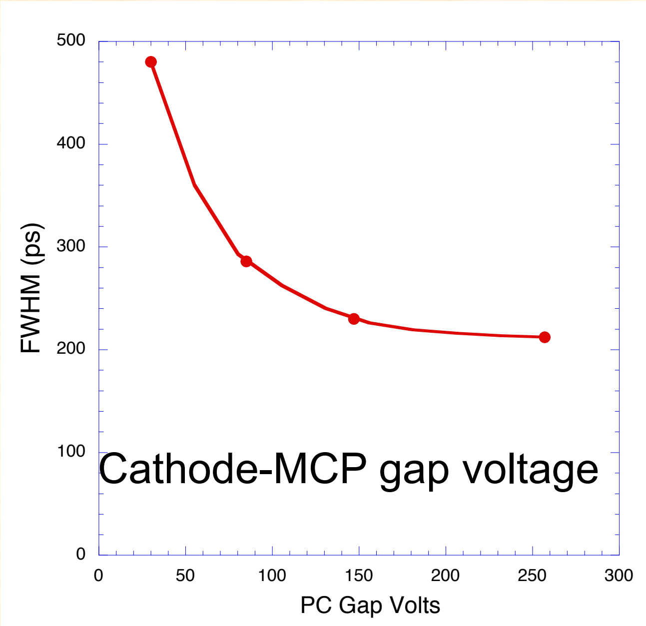


Cathode uniformity

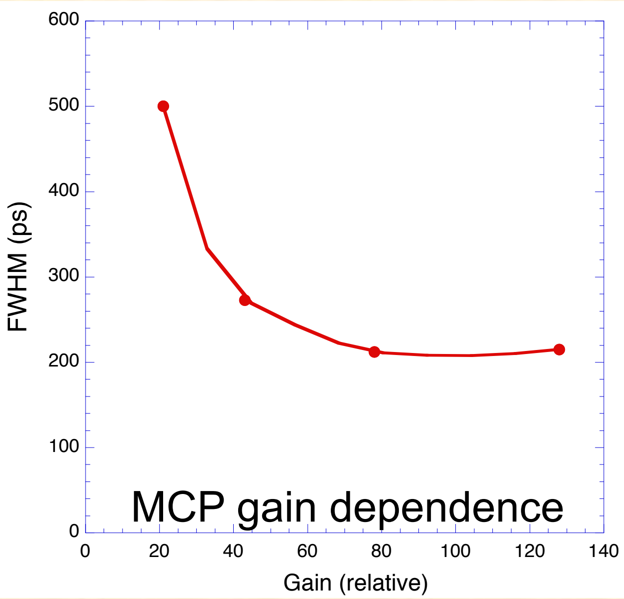
20cm Detector, Laser Pulse Transit Time Spread







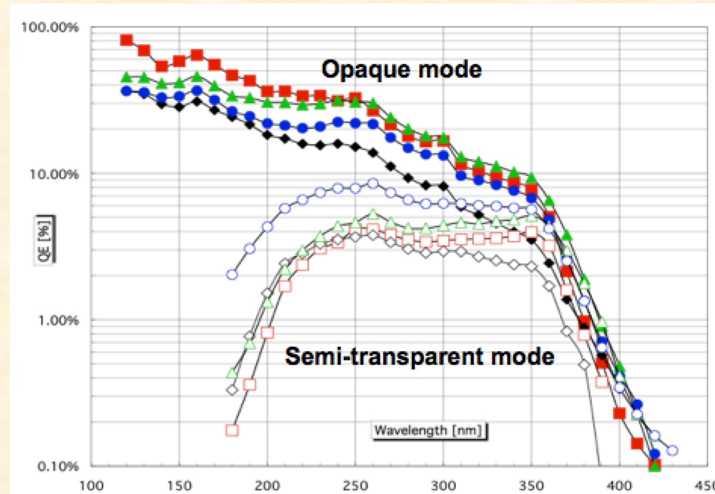
Transit time spread asymptote at ~200ps is due to poor matching and connections of the signals for the configuration inside the vacuum processing tank (confirmed with high S/N tests)



Opaque GaN ALD MCP 25mm Tube

We have constructed a cross delay line readout sealed tube with an opaque GaN photocathode deposited onto the top MCP of a borosilicate ALD MCP pair.

GaN deposited by MBE (SVT assc inc.) on front ALD MCP (borosilicate + Al_2O_3) 20µm pore, 60:1 l/d, installed into 25mm tube.

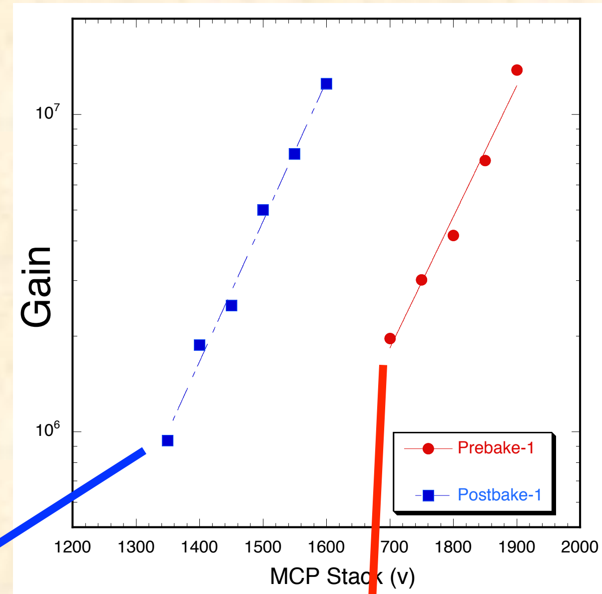


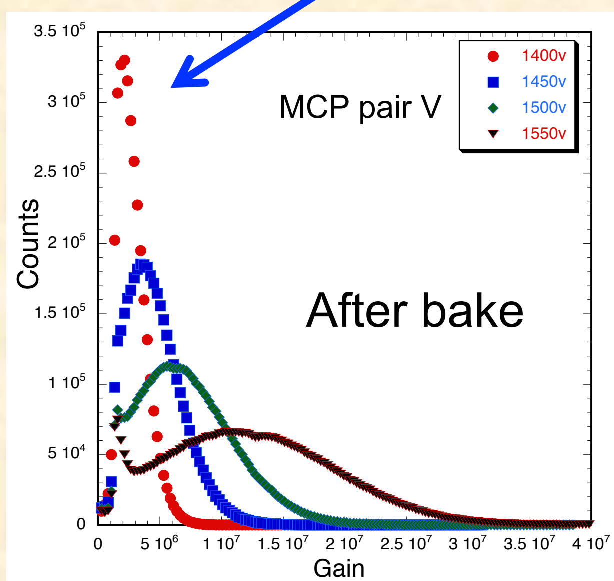
GaN photocathode response (Siegmund et al SPIE, 2010) for Al_2O_3 substrates. After cleaning and vacuum baking, cesiation of GaN is performed to maximize the quantum efficiency.

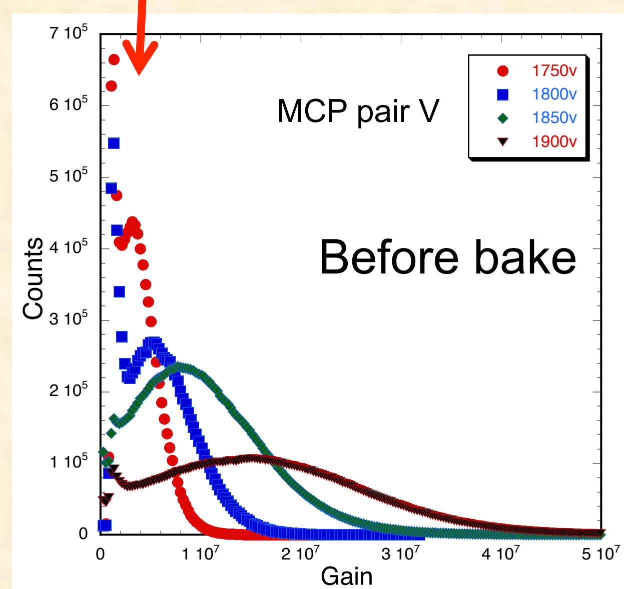
GaN ALD MCP 25mm Tube Processing

PHDs before and after vacuum bake. The gain of the MCPs increased by about 1 order of magnitude following the vacuum bake. Gains of ~10^7 achieved with low bias (780v) per MCP.

Subsequent “burn-in” showed almost no gain decrease.

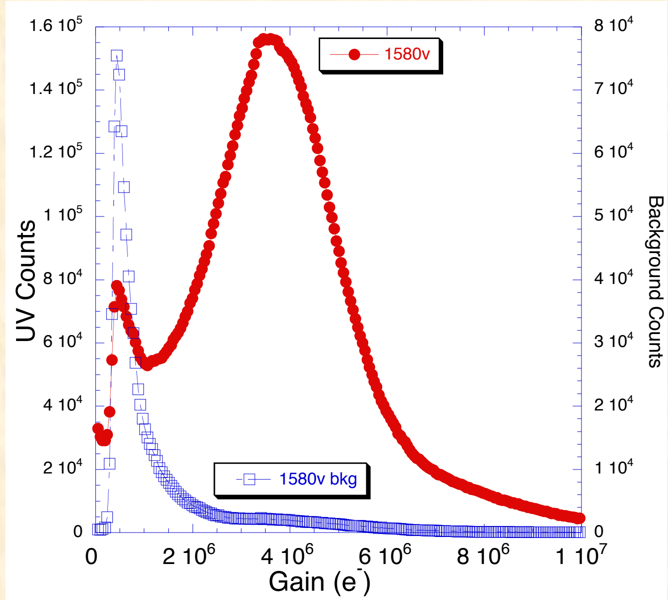


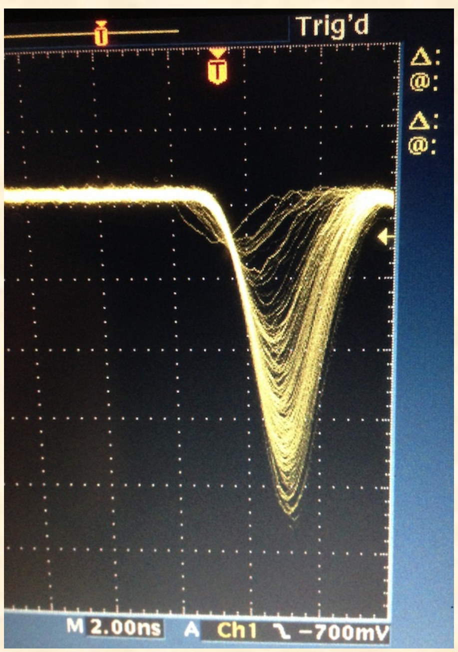




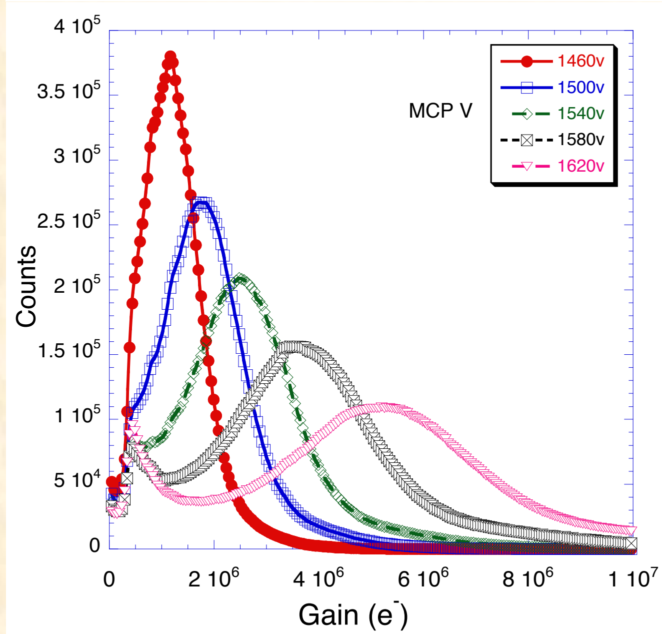
GaN ALD MCP 25mm Tube Tests

PHDs after burn-in, GaN cesiation and tube sealing. PHD's are quite narrow even for low gains, with low bias on the MCPs. Good for low gain – high rate applications. The general distributed background rate increased to ~15 cts cm^{-2} sec^{-1} after cesiation, which is similar to bialkali rates.



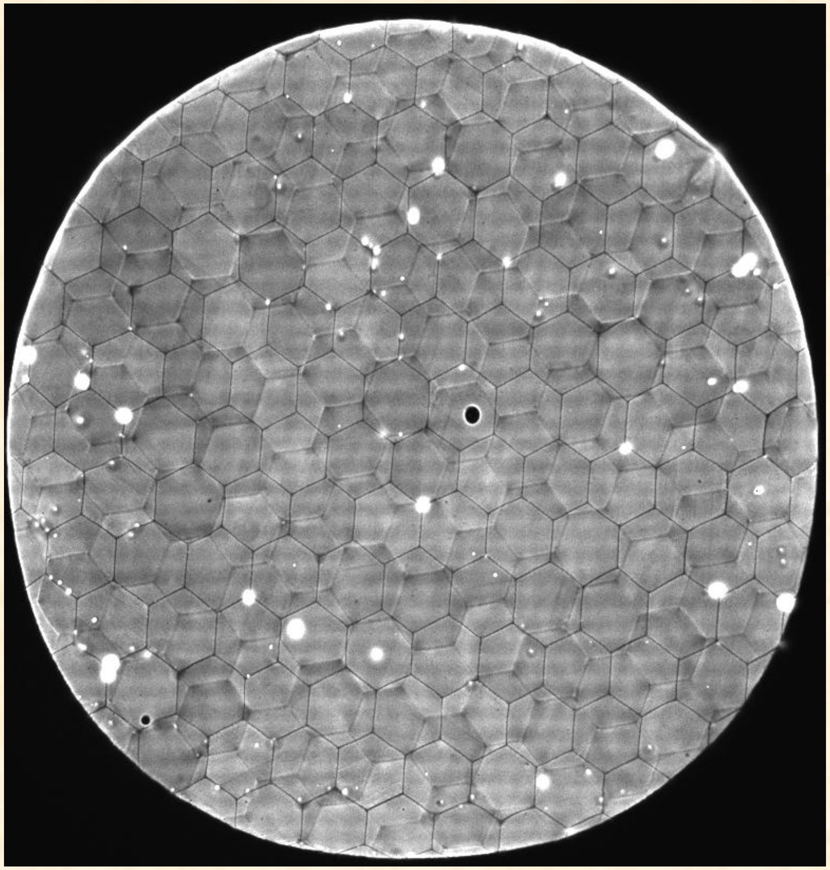


185nm UV photon signals at ~6 x 10^6 gain. VT120 preamp show the expected fast pulse shapes with ~1ns risetimes.

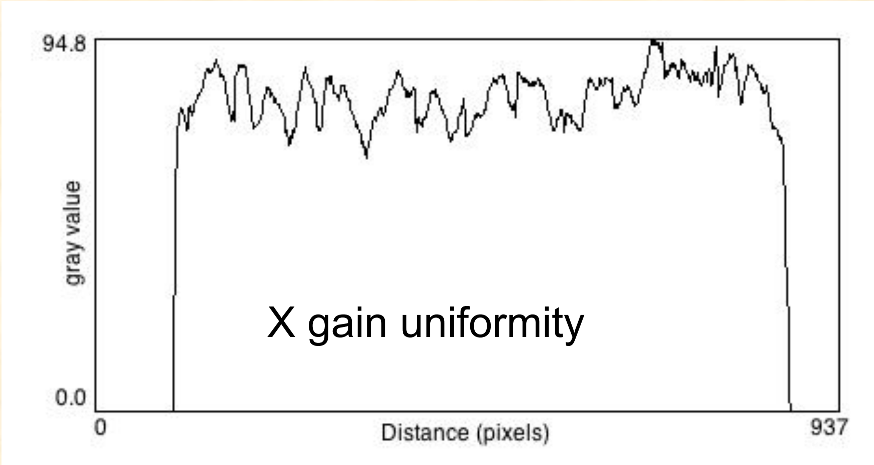


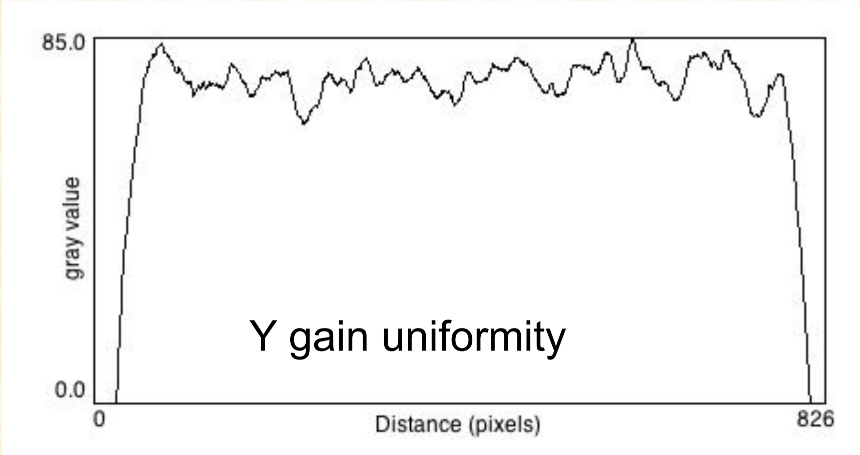
GaN ALD MCP 25mm Tube Tests

Imaging and gain map data shows very flat gain modulated by MCP multifibers, hotspots and darkspots due to debris from excessive handling during processing steps.



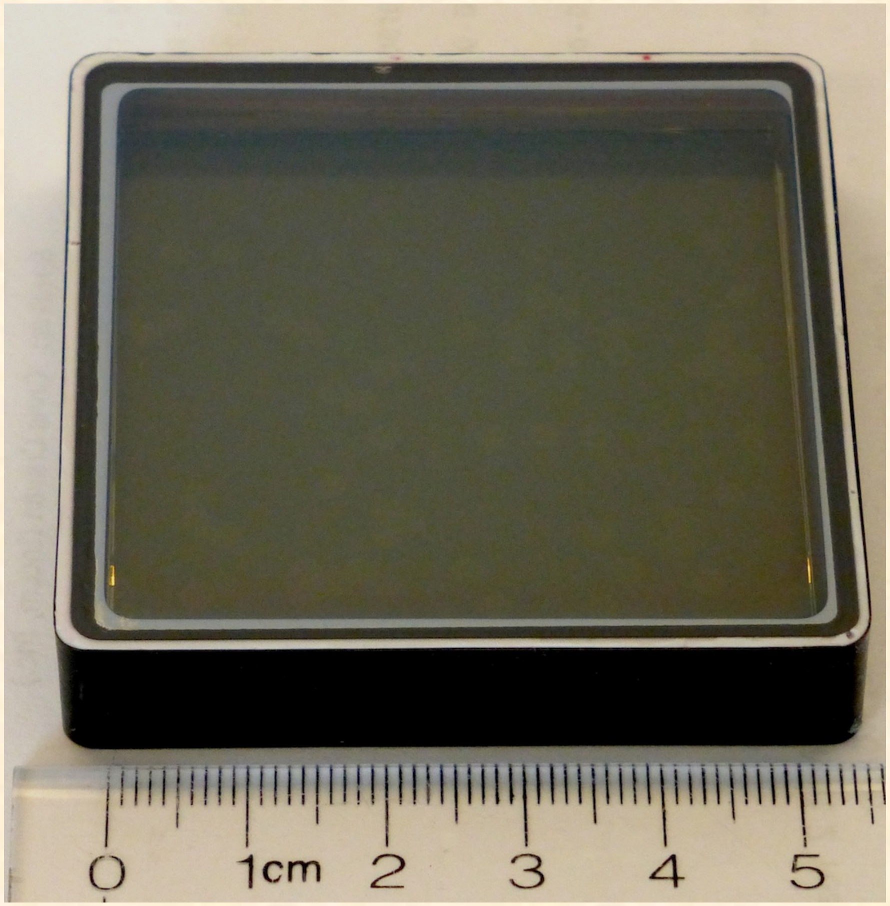
184nm UV response image shows MCP multifiber from these older-early development stage MCP substrates, hotspots/darkspots but overall uniformity is quite flat.





Fast timing, & lifetests about to commence

Planacon with ALD 10μm MCP Pair



1st Planacon with a pair of borosilicate ALD functionalized MCPs, 10μm pore, 60:1 L/d.

We have initiated evaluation of ALD MCPs on borosilicate substrates in the PHOTONIS Planacon detector scheme.

This is a ~50mm format with a pair of MCPs and several possible formats of pad (8x8, 32x32) readouts with multialkali photocathodes.

ALD 10μm MCP Pair Tests for Planacon

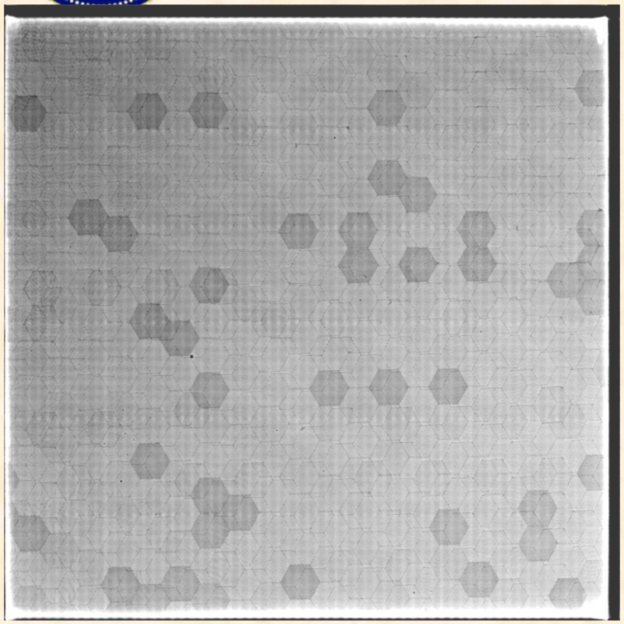


Image of 185nm UV for an ALD MCP pair at ~10^6 gain. MCP multifibers and anode readout modulation visible.

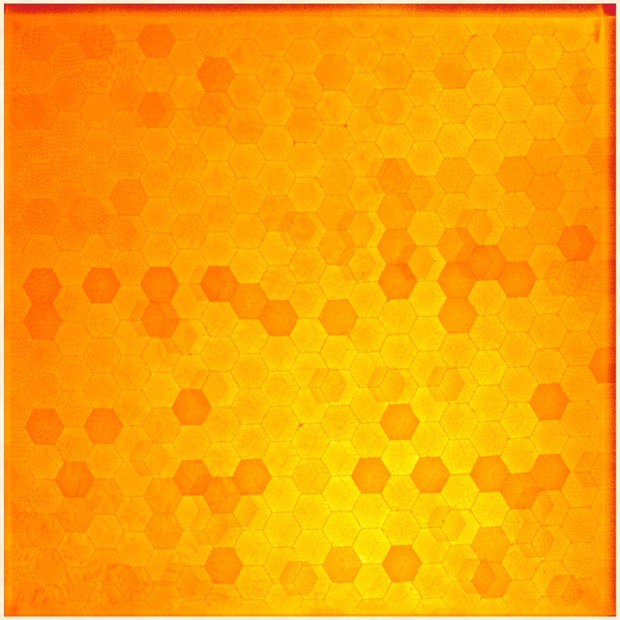
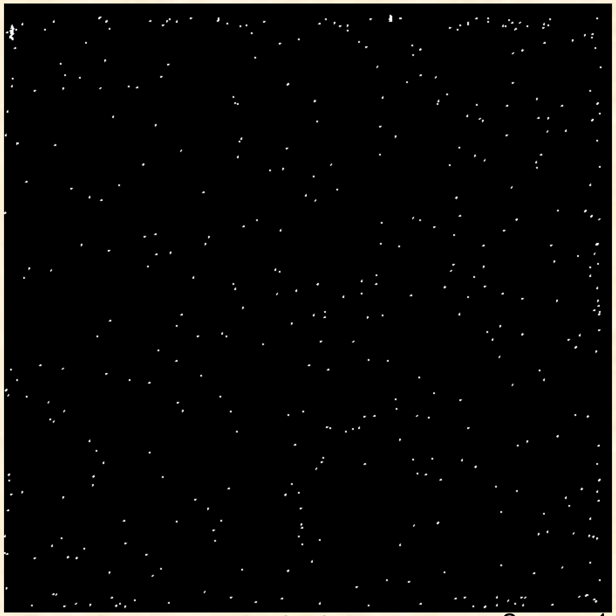
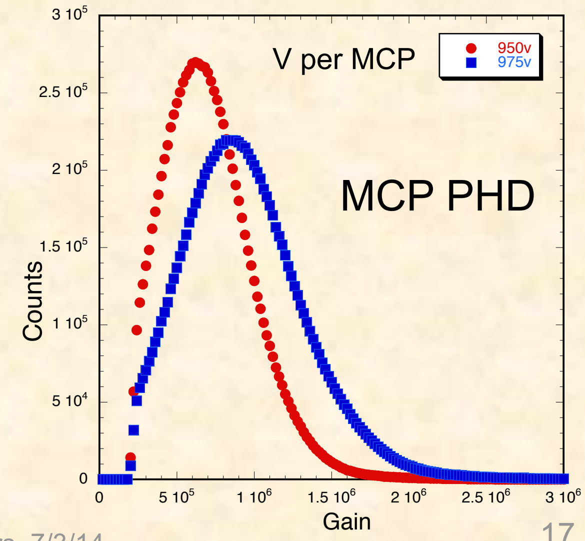


Image gain map of an ALD MCP pair. A few multi-fibers have slightly smaller open area and show lower gain. ~0.7 x 10^9 events.

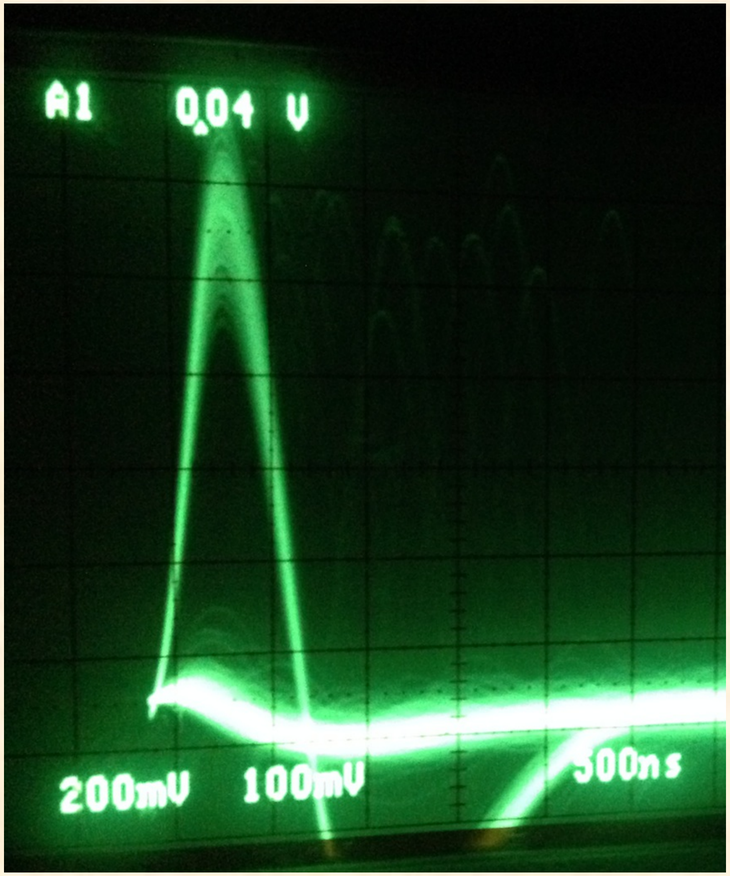


Background, 0.14 cts $cm^{-2}sec^{-1}$



Pair of borosilicate ALD functionalized MCPs, 53mm square 10µm pore, 60:1 L/d, 8° bias. Tested prior to Planacon integration in a high resolution cross strip readout detector system.

ALD 10μm MCP Planacon Tests



Scope trace at with 80ps 610nm laser.
Laser pulse ~20 photoelectrons/pulse
Showing the single photoelectron baseline.
~100mV, 1 Photo e^- is about 5 x 10^5 e^-

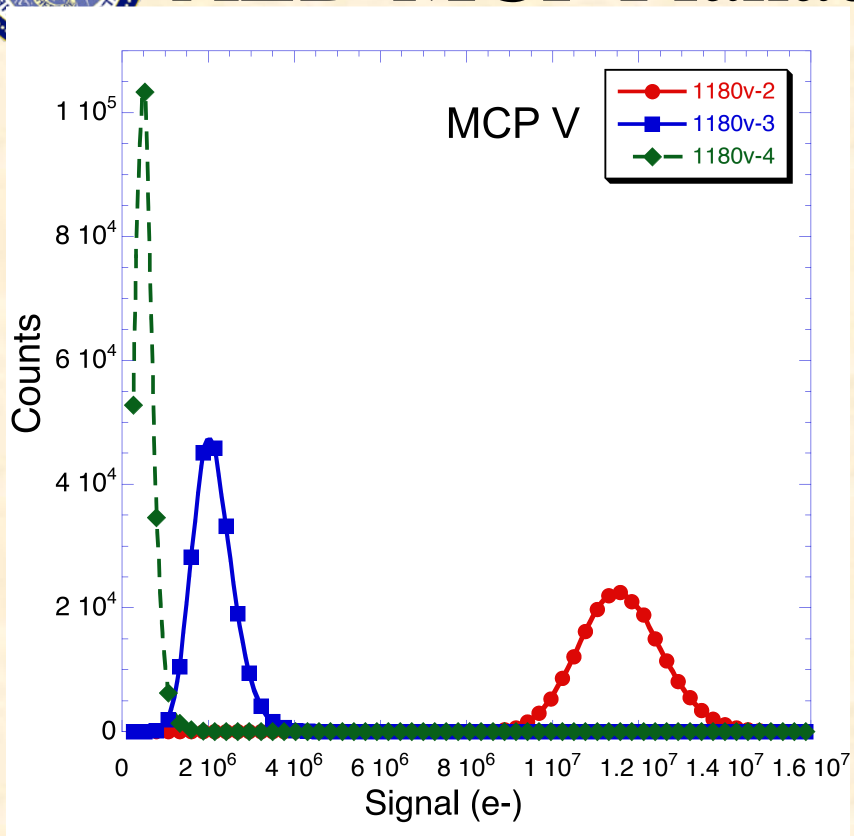
Relative signal v.s. position

0.59	0.62	0.60
0.73	1.0	0.80
0.77	0.82	0.67

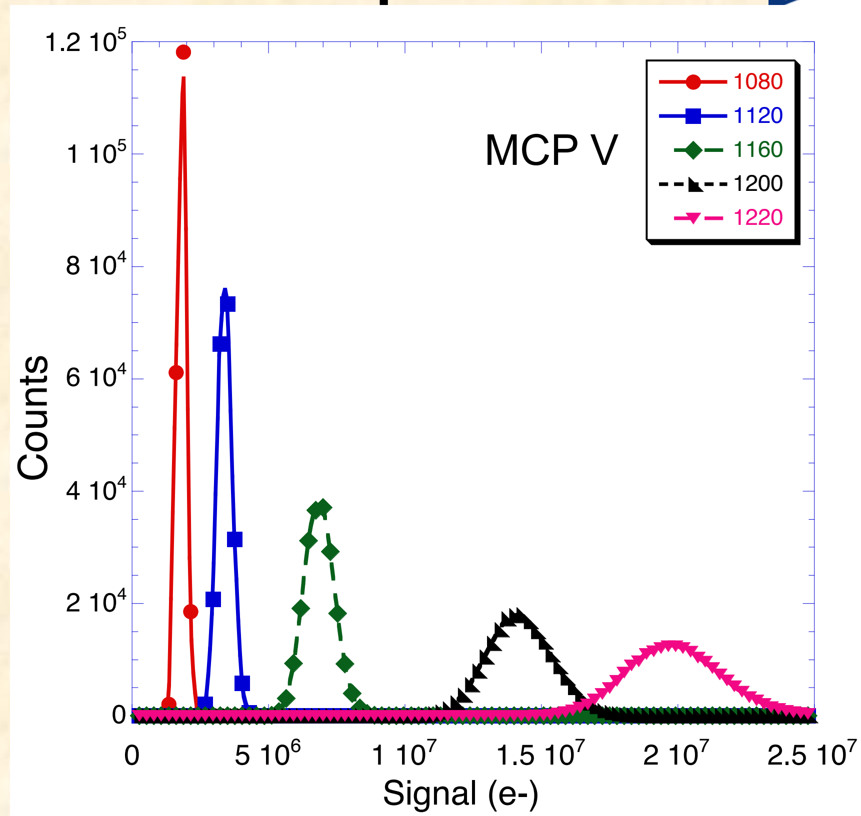
Relative efficiency v.s. position

0.98	1.0	0.93
0.87	0.72	0.77
0.87	0.86	0.90

ALD MCP Planacon with 80ps Laser



Pulse heights at ~1180 per MCP for ND 2/3/4 filters, laser spot ~1mm.



Pulse heights vs applied MCP voltage for 80ps laser + ND 2 filter (~20 photo e^-)

Fast timing tests and imaging with 8 x 8 electronics will be done shortly,

Currently testing new borosilicate ALD MCPs for more planacon builds to test overall tube lifetime improvements.

Atomic Layer Deposited-MCP Summary

- Borosilicate Micro-capillary arrays offer a robust substrate for atomic layer deposited MCPs, and distortion/defect quality is still improving.
- Gain, imaging, and detection efficiency ~same as standard MCPs
- Background rates are low, <0.06 events cm^{-2} sec^{-1}
- High temp vac bake for tube processing has very positive effects
  - Factor of >5x gain increase optimizes MgO ALD layer SEY
  - Establishes very low MCP outgassing (borosilicate, ALD, MgO)
- Excellent MCP pair lifetest characteristics – “burn-in”
  - Essentially no gain drop at the nominal gain over 7 C cm^{-2}
  - Very stable to dry N_2 exposure thereafter
- ALD MgO/Al_2O_3 applied to help normal MCPs lifetime and gain
- ALD functionalized MCPs provide potential improvements in detector/ sealed tube/cathode lifetime and in reduction of the tube fabrication/processing turn around time.