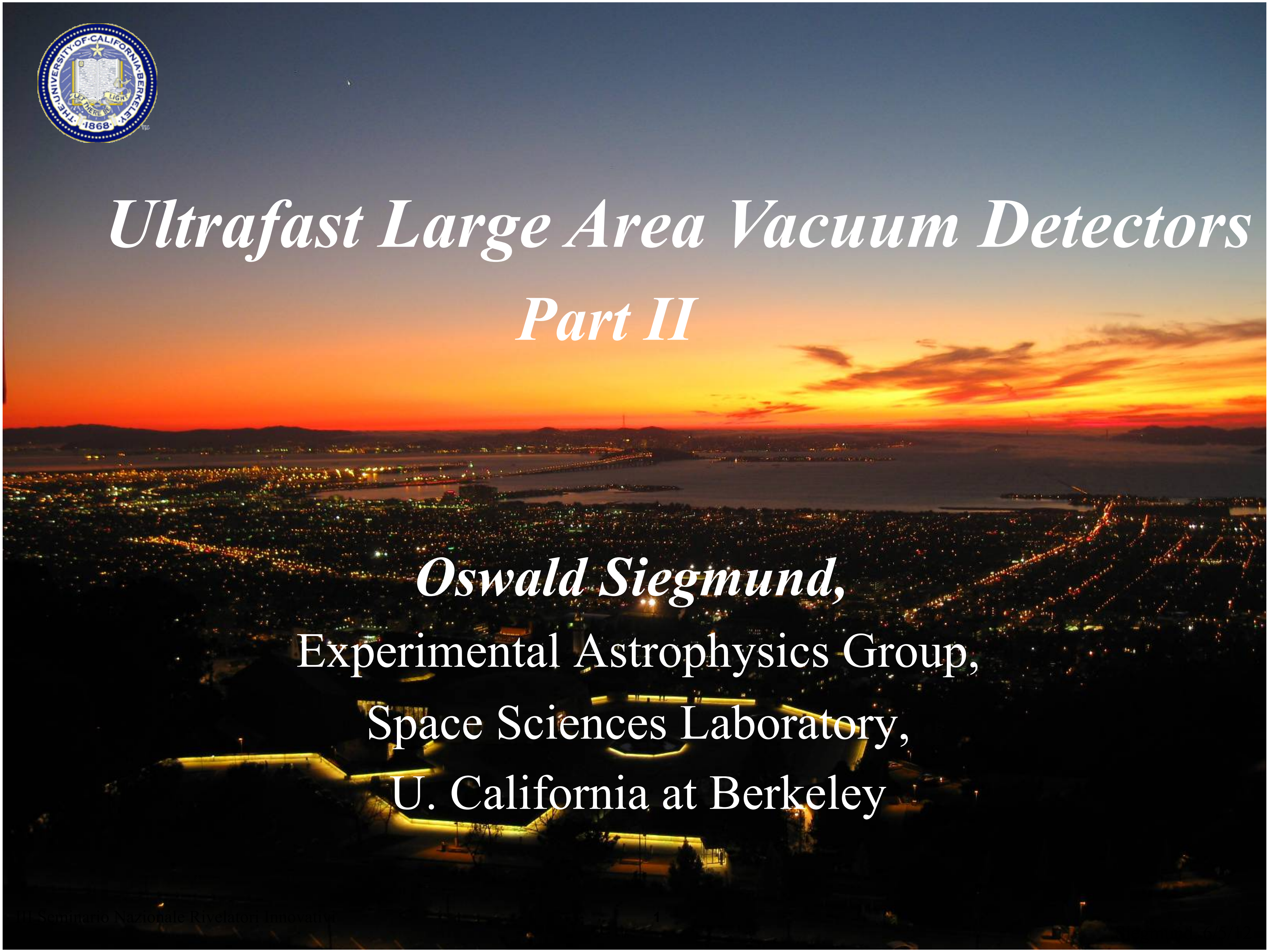


Ultrafast Large Area Vacuum Detectors

Part II

Oswald Siegmund,

Experimental Astrophysics Group,

Space Sciences Laboratory,

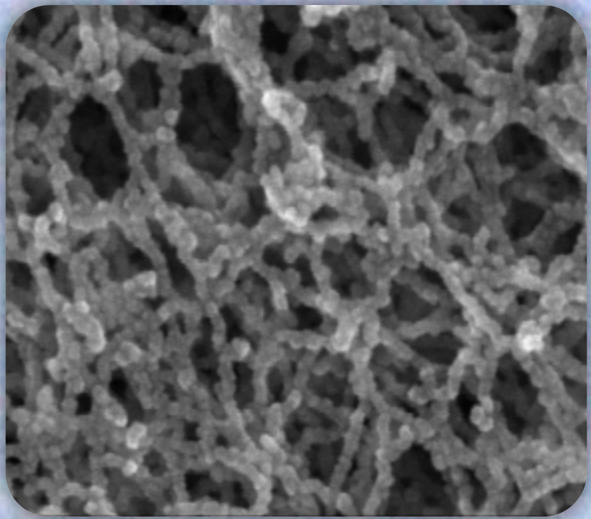
U. California at Berkeley

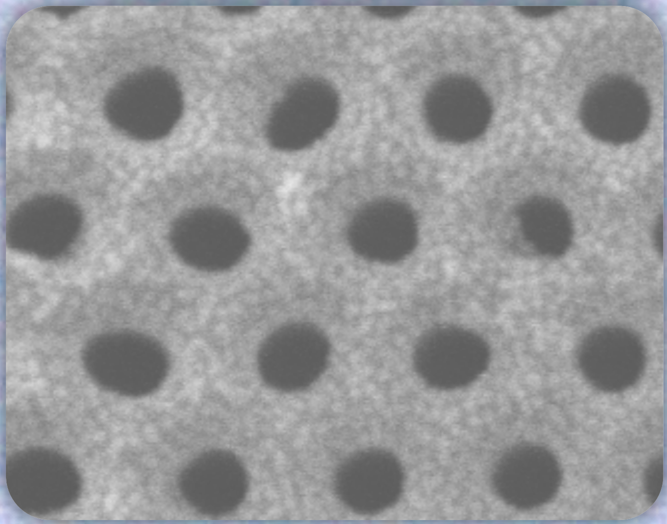
Atomic Layer Deposition Applied to Microchannel Plates

- **New effort to make MCPs more affordable and expand the capabilities of MCPs**

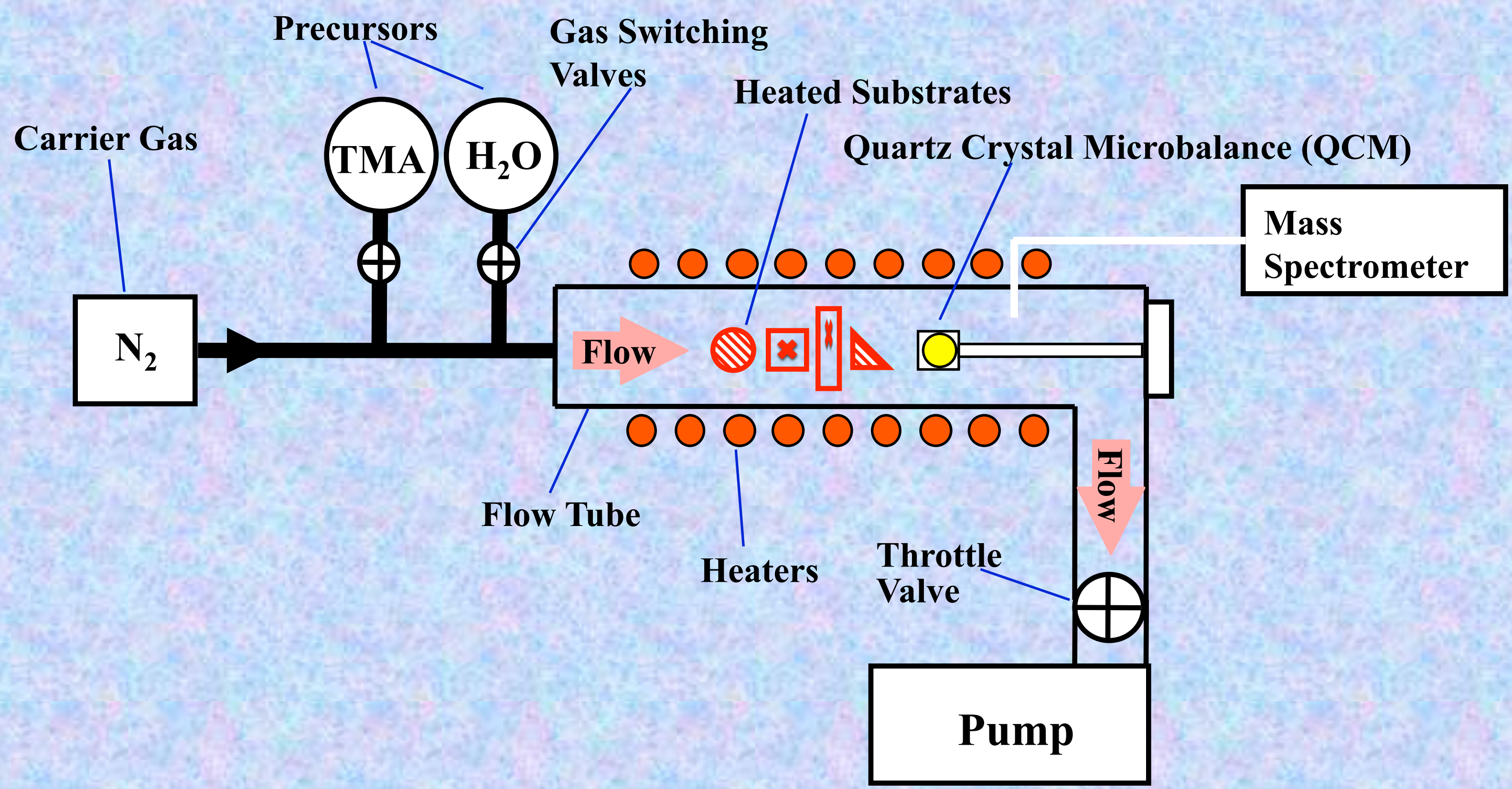
- **Atomic layer deposition (ALD)**
  - ***Layer-by-layer thin film coating method***
  - ***Atomic level control over thickness and composition***
  - ***Precise coatings on 3-D objects***

- **MCPs from AAO – Why ALD?**
  - ***Conformal (uniform thickness)***
  - ***Smooth***
  - ***Continuous***
  - ***Any material***

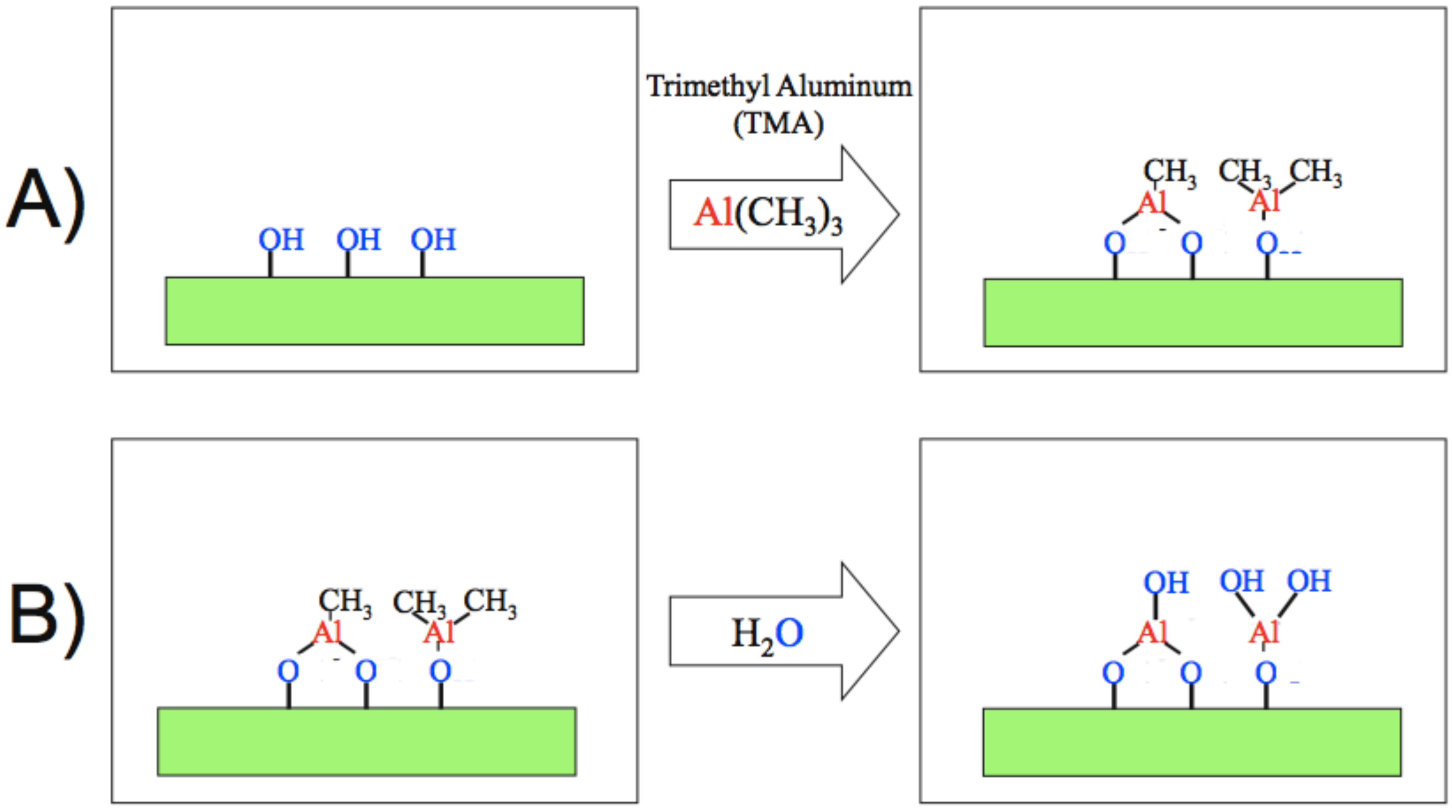




Viscous Flow Reactor for Atomic Layer Deposition

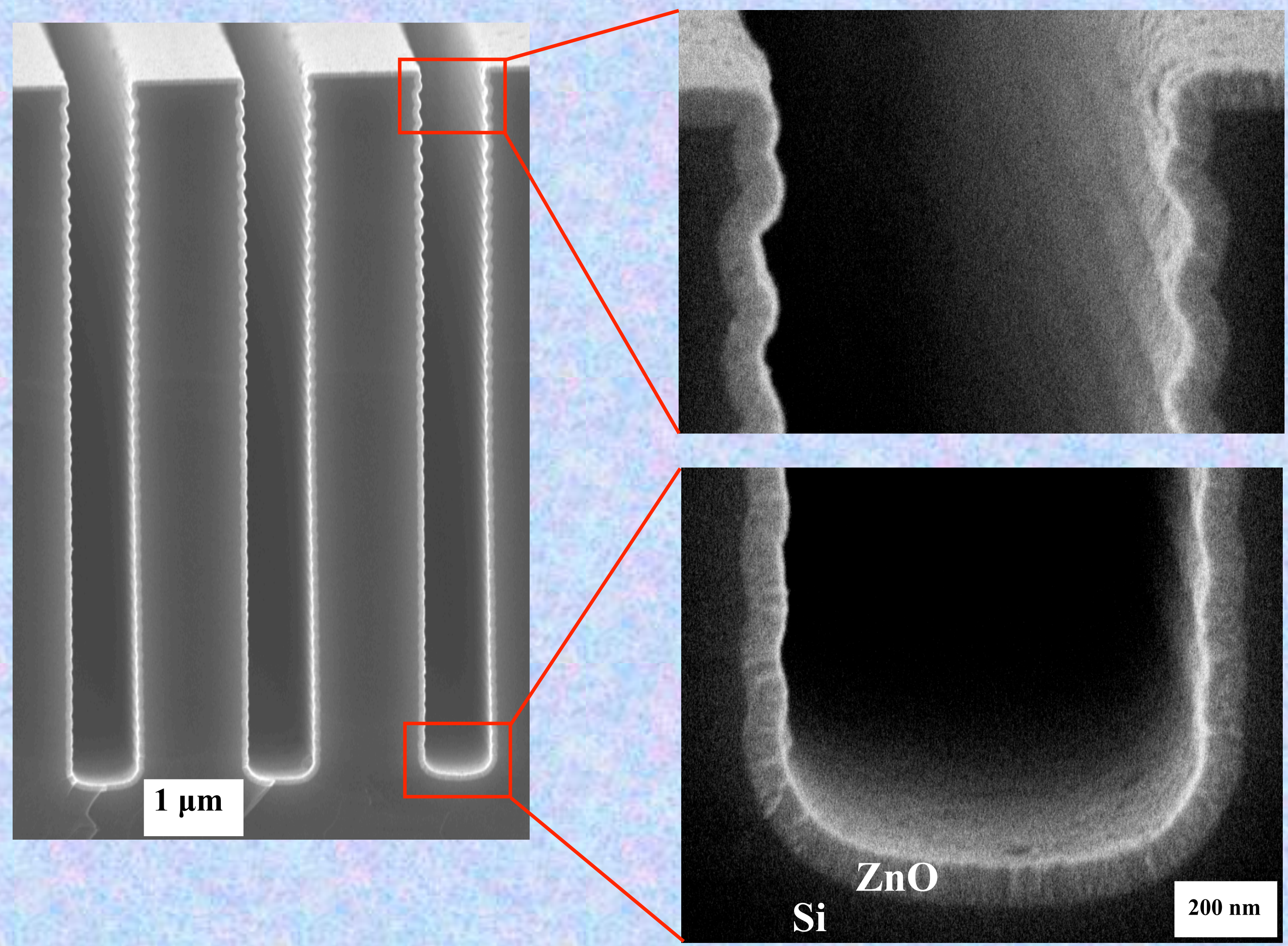


Binary Reaction Sequence for Al_2O_3 ALD



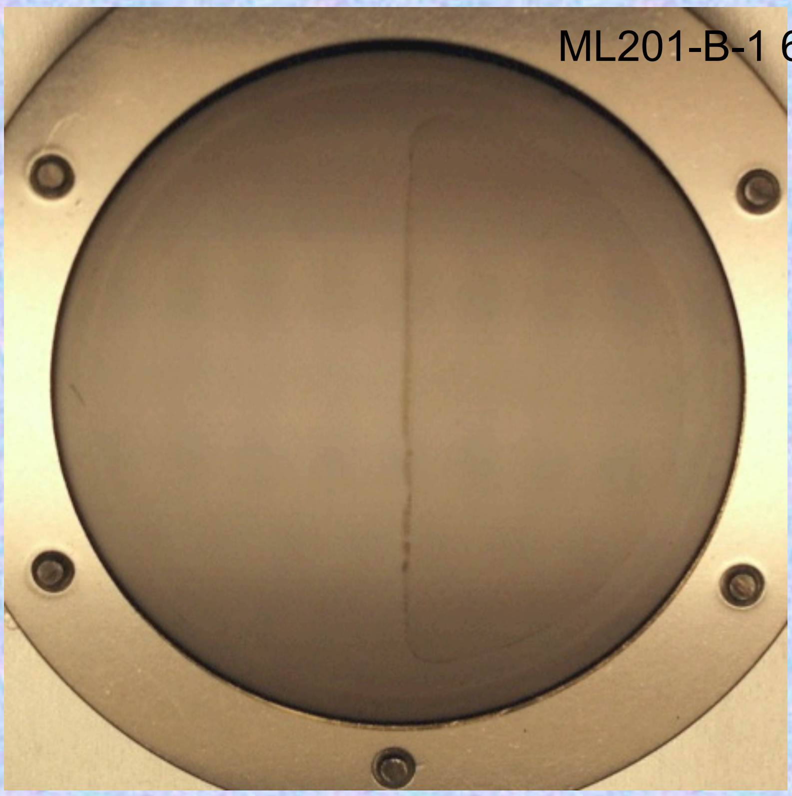
- 1 ALD Cycle of TMA/H_2O Deposits 1 Al_2O_3 "Monolayer"

ALD ZnO in Silicon High Aspect Ratio Trench



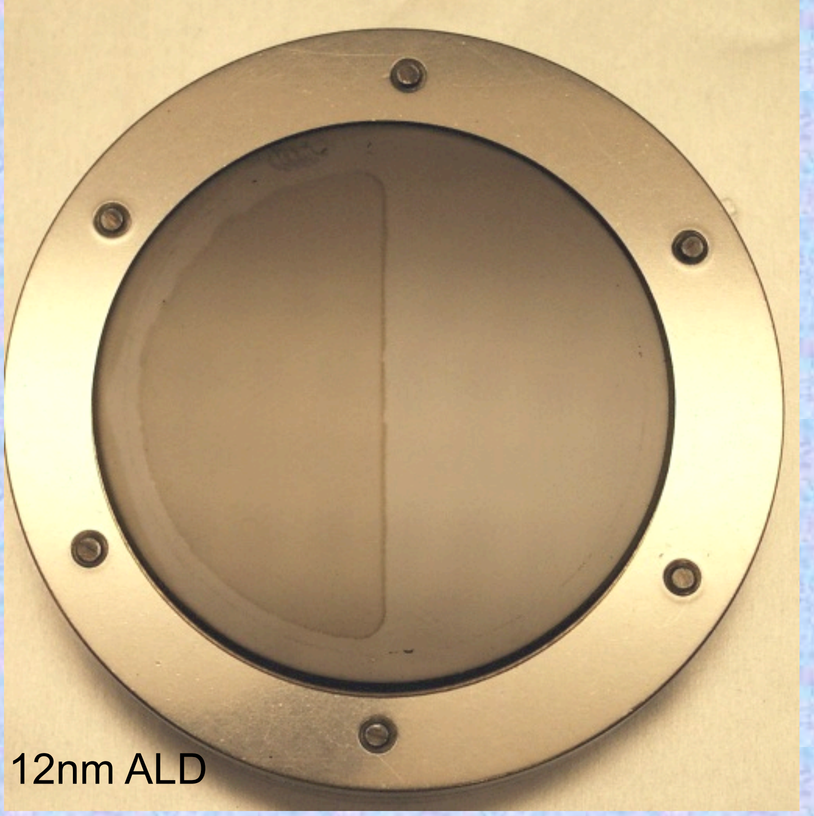
- ALD is *very* good at coating non-planar surfaces

ALD (Al_2O_3) Coated Conventional MCP



ML201-B-1 6nm ALD

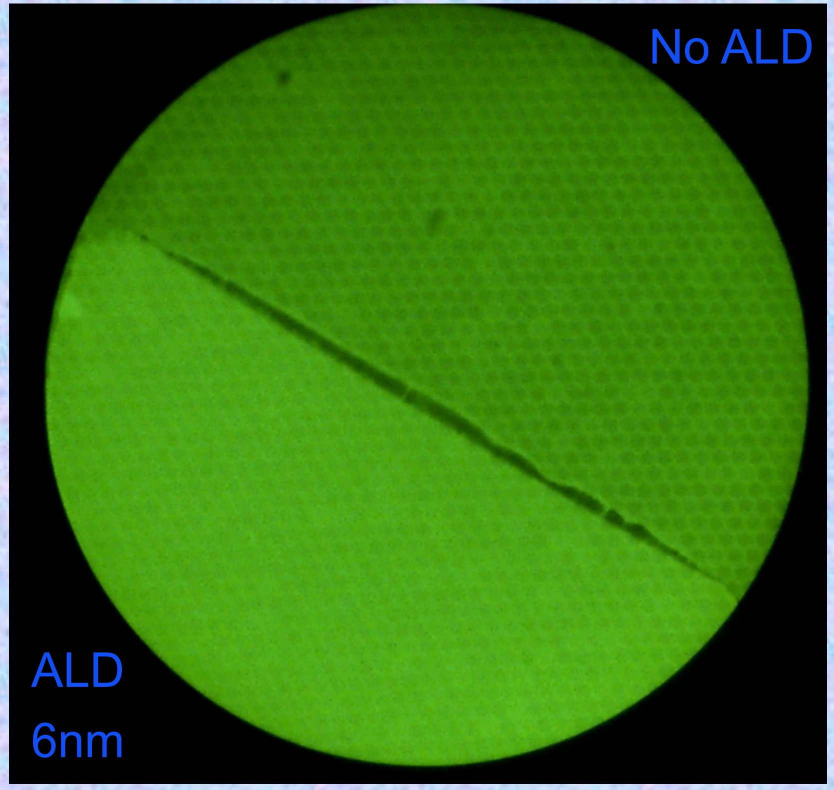
Areas were masked to provide zones with/without ALD



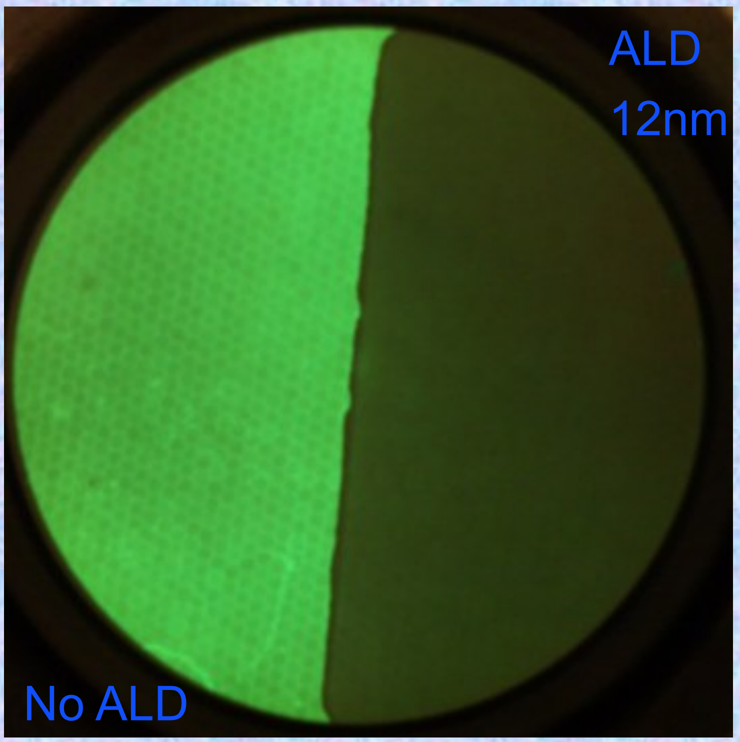
ML201-B-2 12nm ALD

Initial Imaging Results on Standard MCPs with 6nm/12nm ALD coating, single MCP, phosphor

6nm Shows definite enhancement of brightness in ALD area, due to GAIN increase!
12nm Shows definite suppression of brightness in ALD area, UV QE reduction!
No degradation of image quality, except at the boundary zone for coating



1150v MCP, 2800v Screen, UV flood
Photonis ML201-B-1 MCP, 86MΩ



1100v MCP, 2700v Screen, UV flood
Photonis ML201-B-2 MCP, 90MΩ

Early Incom MCP Substrates, 20μm

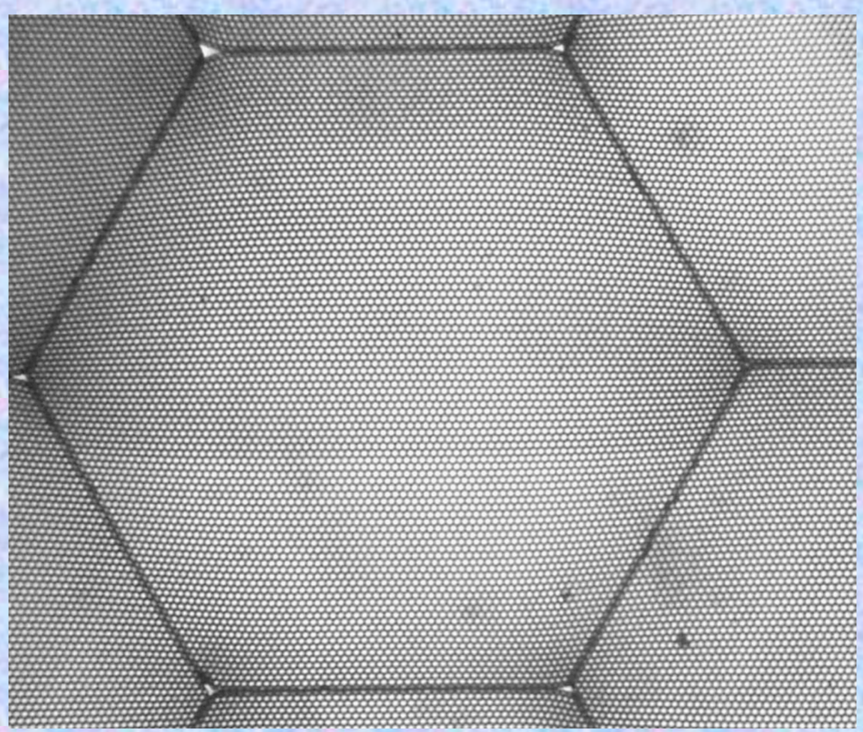
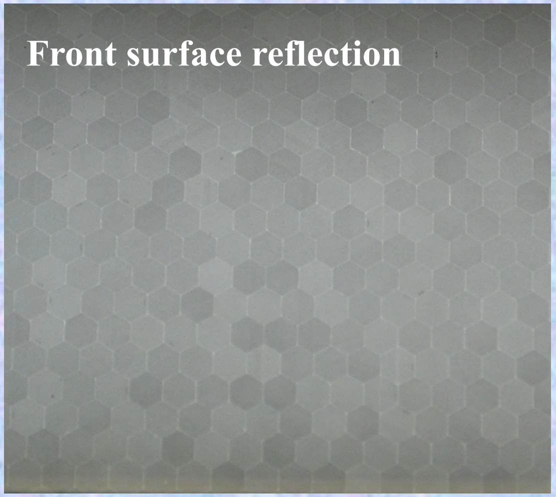


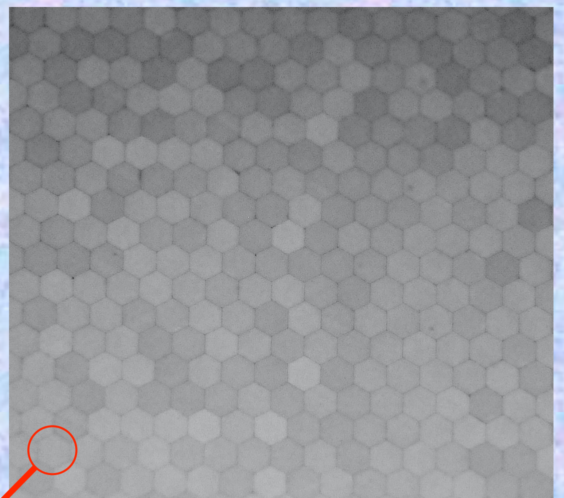
Photo of a 20μm 65% OAR, 8° bias, 60:1 L/D, finished substrate, prior to ALD coating.

Photo of a 20μm 65% OAR, 8° bias, 60:1 L/D, finished substrate, with ALD coating.

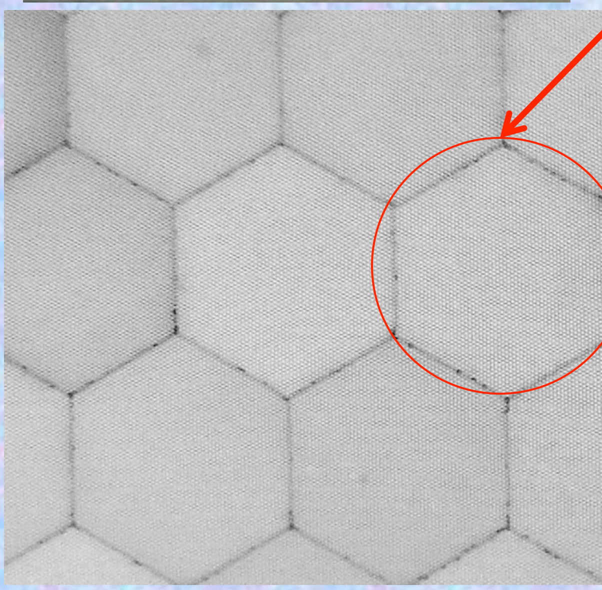
Note that there are triple point voids, some distorted channels at the multifiber boundaries, some blocked channels, and general distortions around the triple points

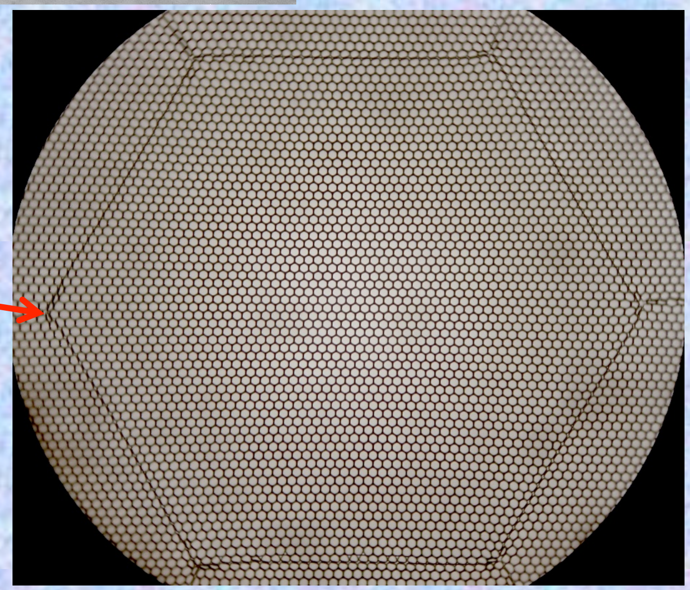
Borosilicate Substrate Atomic Layer Deposited Microchannel Plates





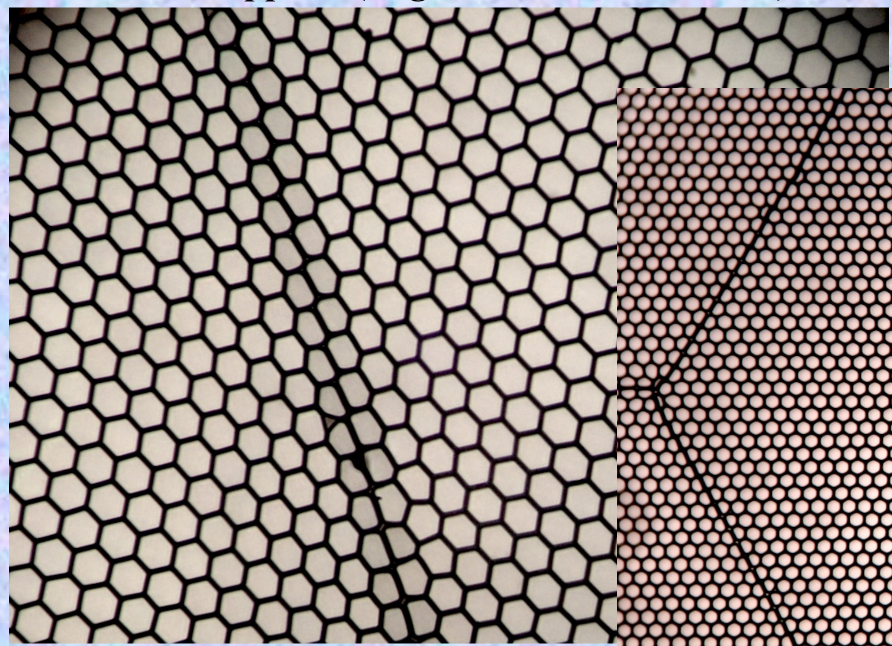
Visible light transmission for a 20 μm pore 65% open area borosilicate micro-capillary ALD 200 mm MCP. Pore distortions at multifiber boundaries, otherwise very uniform.





Borosilicate Substrate Atomic Layer Deposited Microchannel Plates

Micro-capillary arrays (Incom) with 10µm, 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. Resistive and secondary emissive layers are applied (Argonne Lab, Arradiance) to allow these to function as MCP electron multipliers.



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

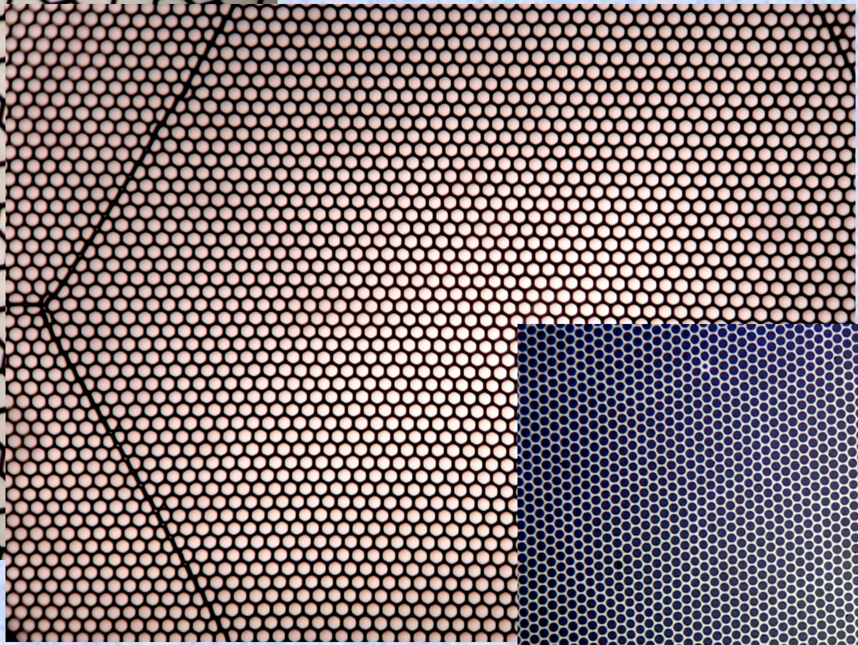


Photo of a 20 µm pore, 65% open area borosilicate micro-capillary ALD MCP (20cm).

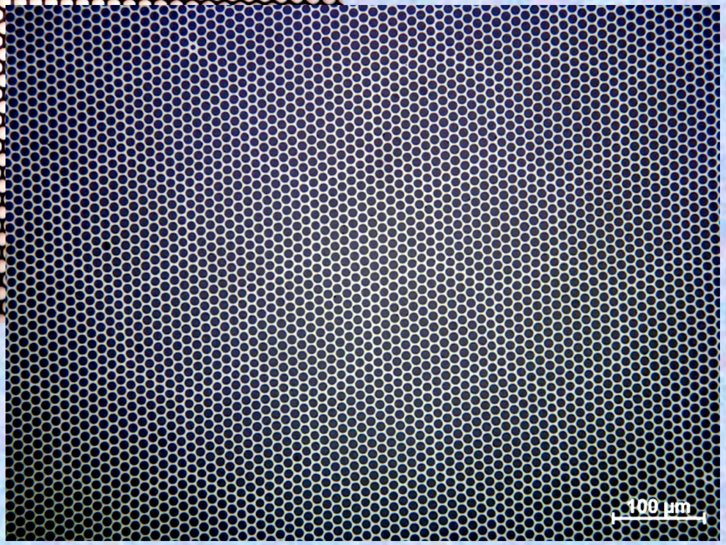
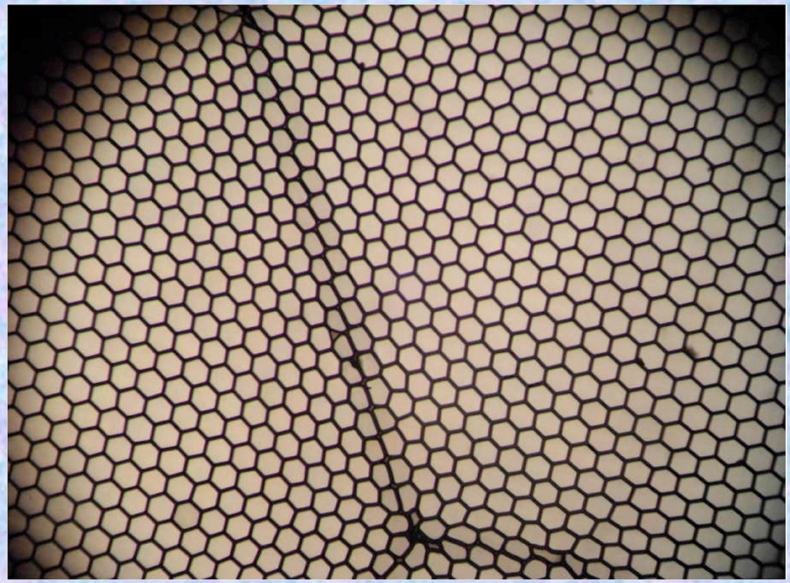


Photo of a 10 µm pore, 65% open area borosilicate micro-capillary ALD MCP.

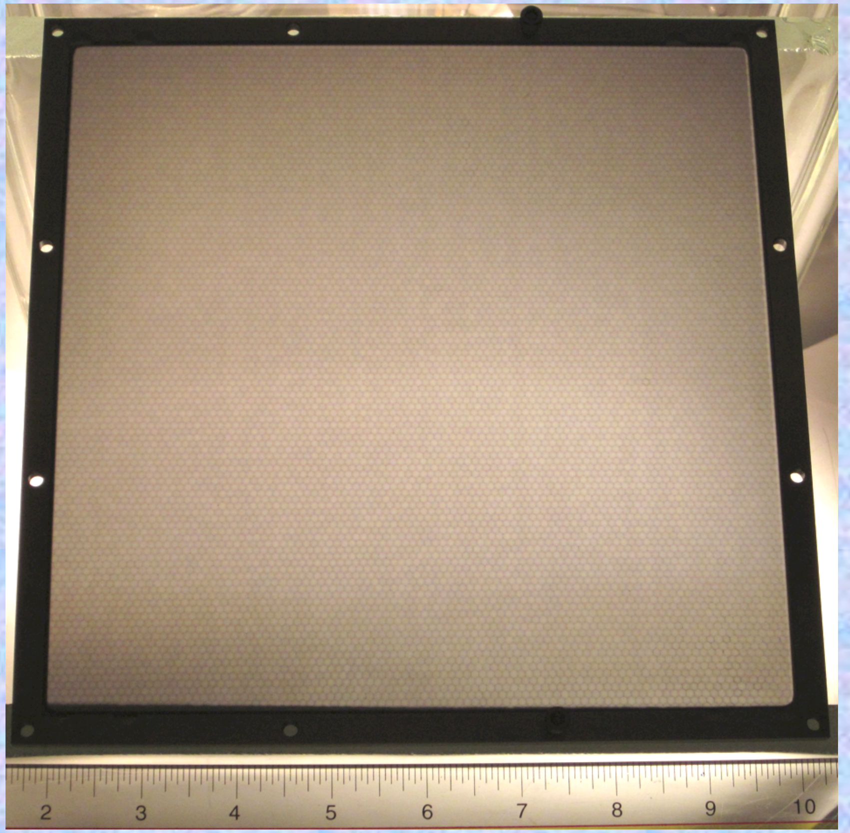
Pore distortions at multifiber boundaries, otherwise very uniform.

Progress with 20cm MCP Development

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. Resistive and secondary emissive layers are applied by atomic layer deposition to allow these to function as MCP electron multipliers.



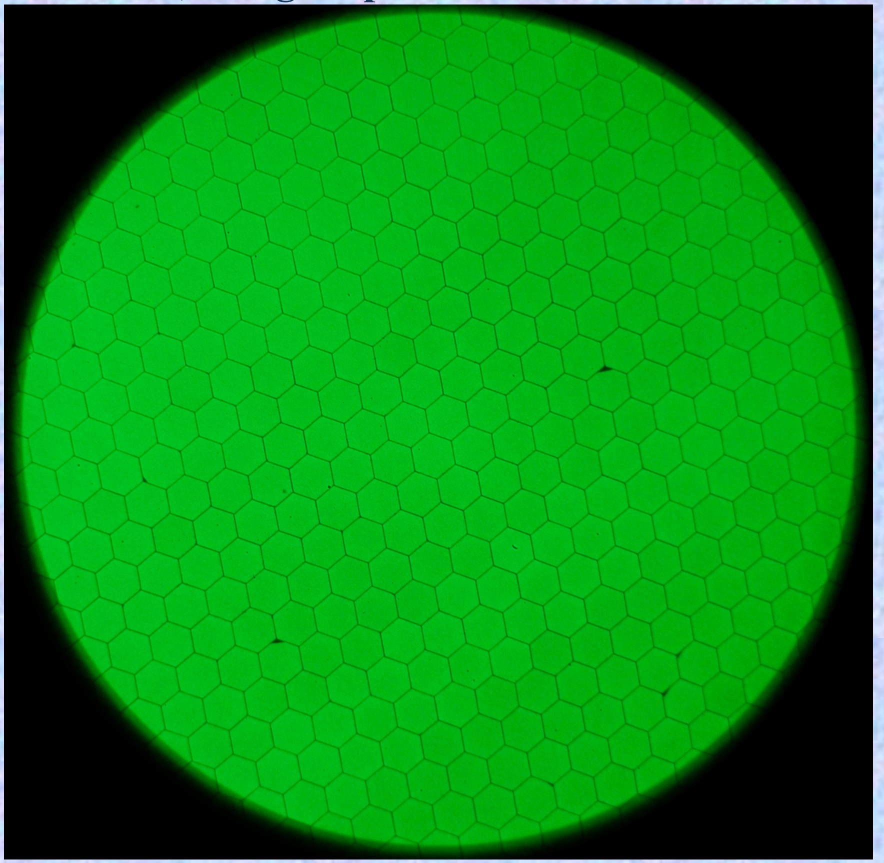
Incom substrate, 40µm pores, 8 deg bias, 40:1 L/D, 83% OAR

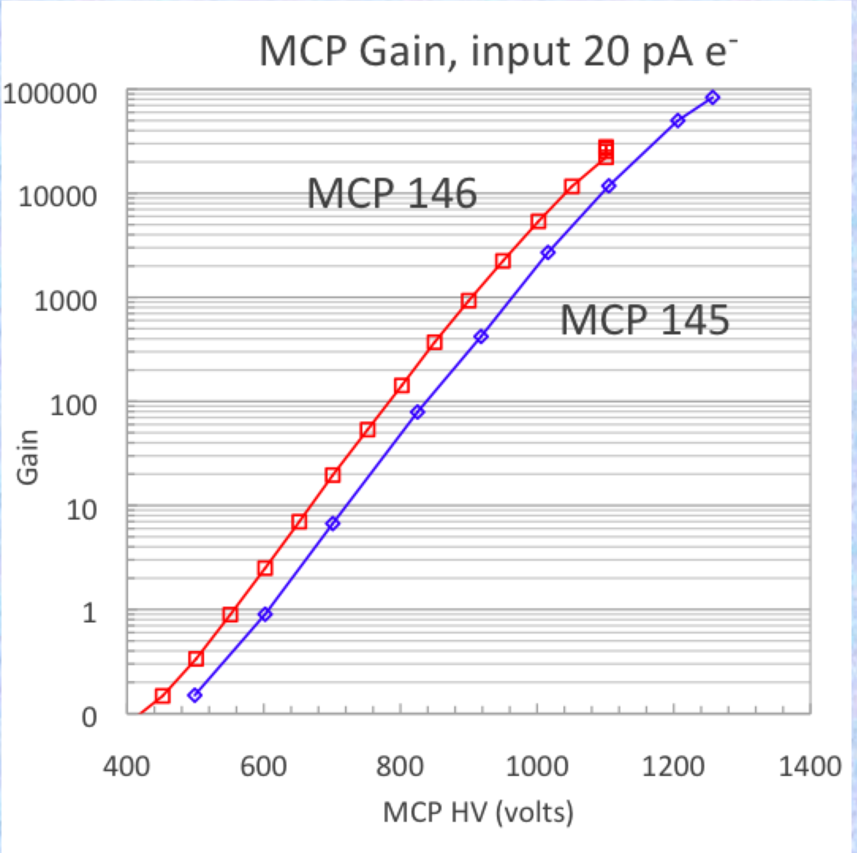


20cm MCP showing the multifiber stacking arrangement, 40µm pore, 8° bias.

ALD MCP – Phosphor Screen Tests

33mm, 20µm pore borosilicate MCP substrate, 60:1 L/d, 8 degree pore bias. 1100v MCP.

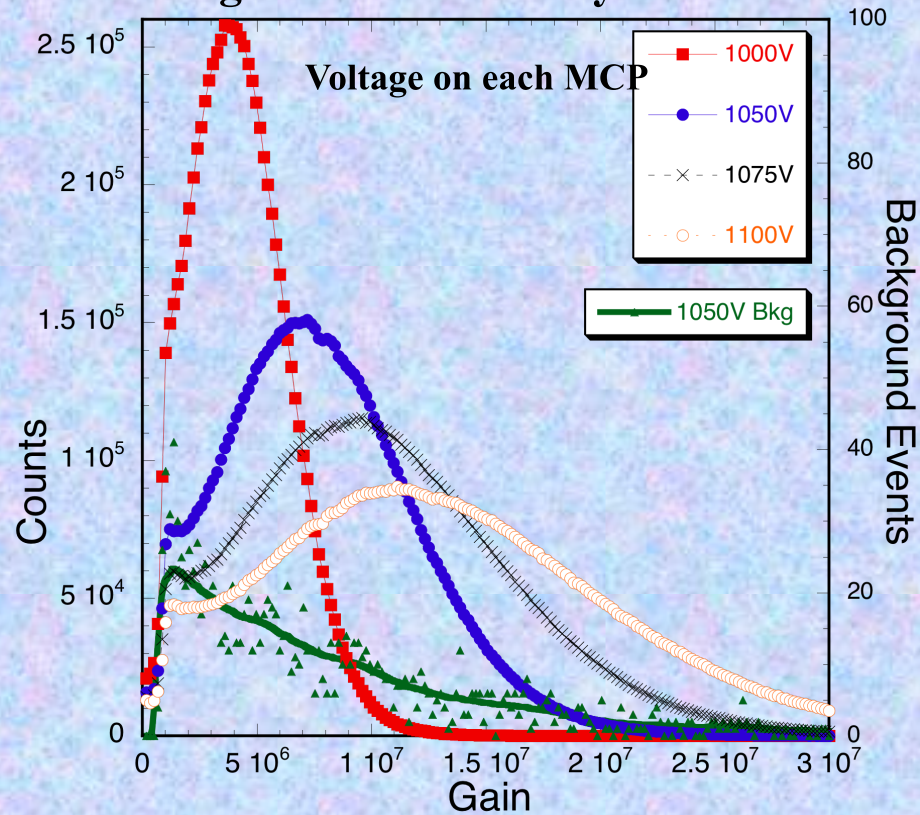




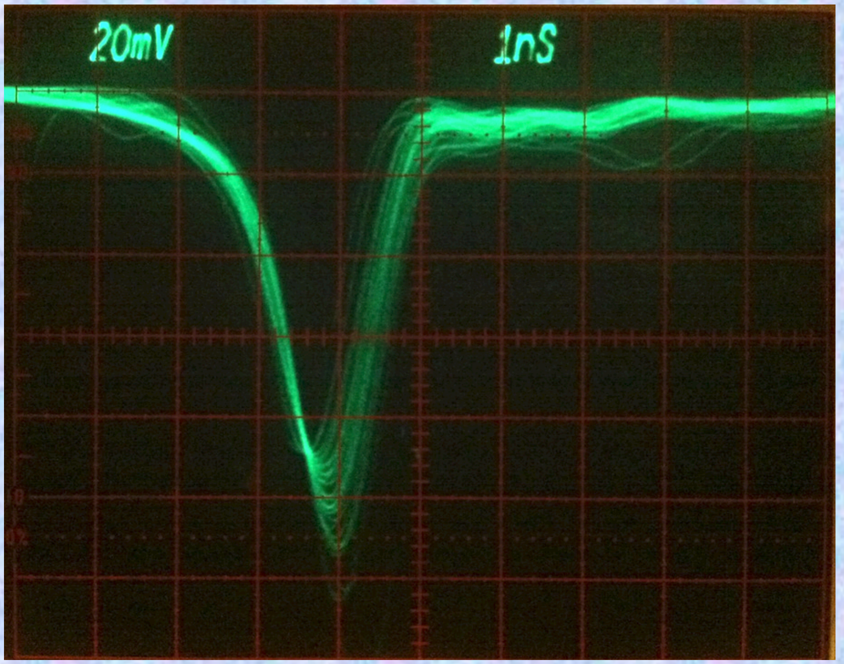
Single MCP tests in DC amplification mode show imaging and gain very similar to conventional MCPs. Sample imaging performance has improved dramatically with substrate and ALD coating process improvements.

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. MCP pair, 20µm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias. 3000 sec background.



ALD borosilicate MCP pair, 20µm pore, 60:1 L/d, 8° bias, 0.7mm/1000v MCP gap. Single event pulses are ~1ns wide. ~Typical response for 20µm pore MCPs.

Photon Counting Imaging with MCP Pairs

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

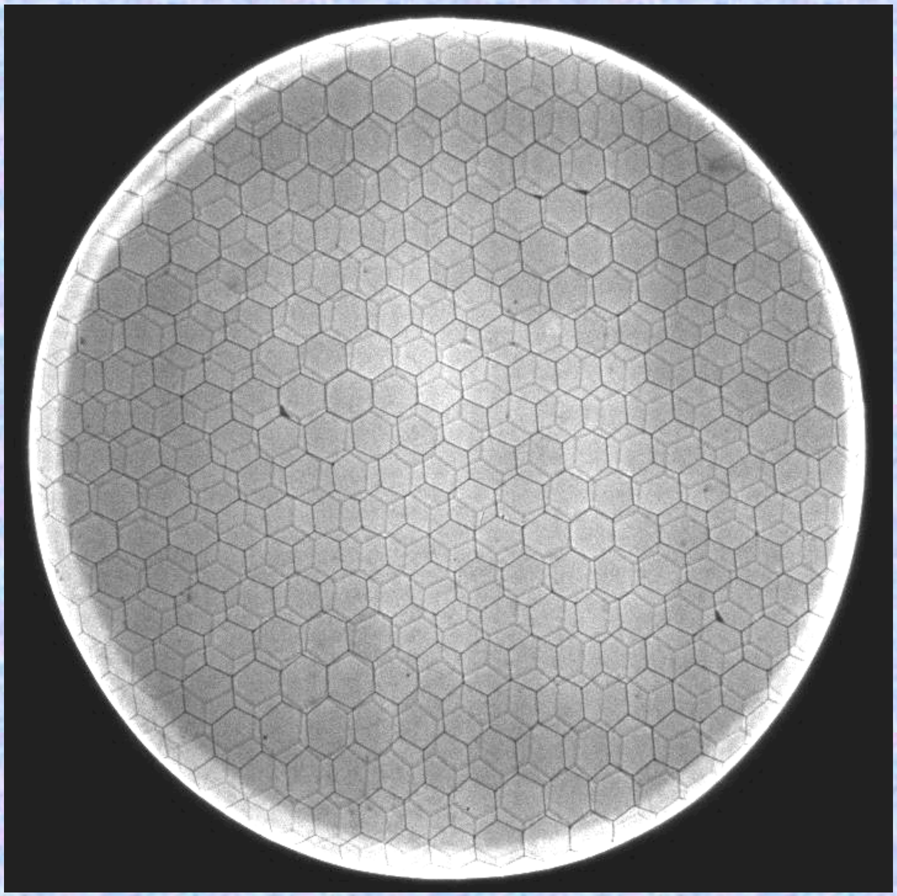
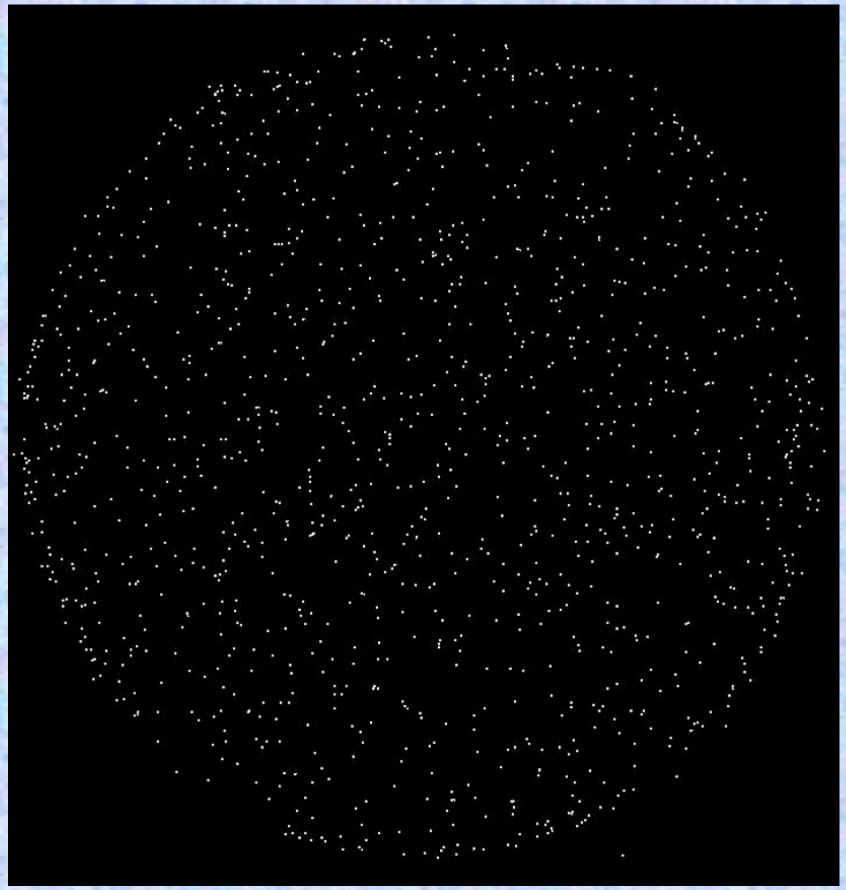


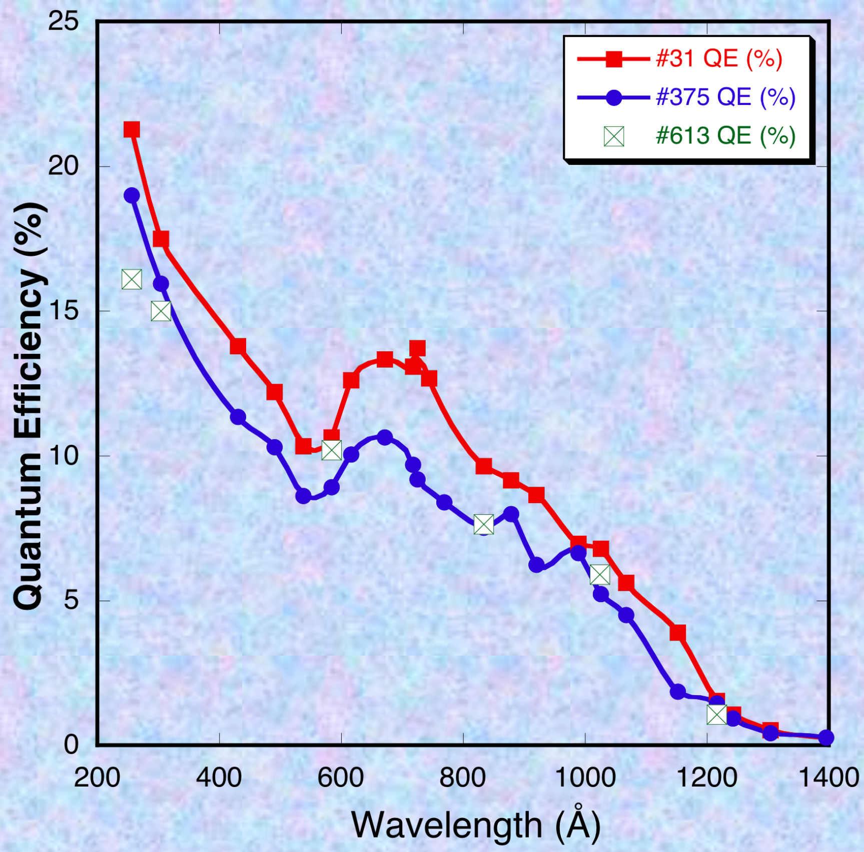
Image of 185nm UV light, shows top MCP hex modulation (sharp) and faint MCP hexagonal modulation from bottom MCP. A few defects, but generally very good. Edge effects are field fringing due to the MCP support flange.



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 most of the current 20µm MCPs.

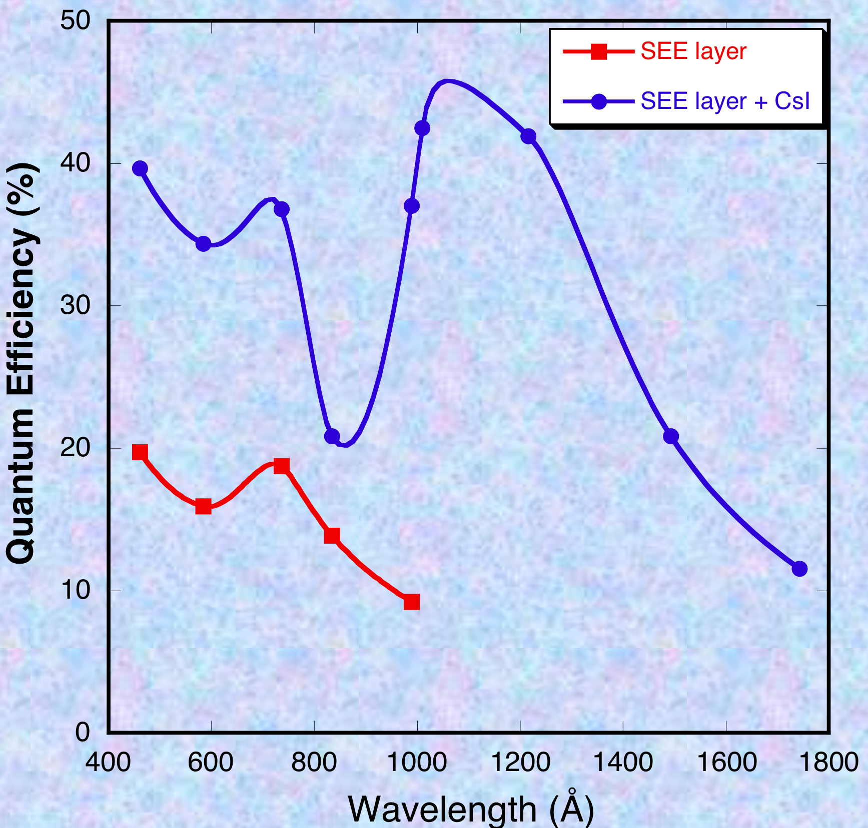
ALD-MCP Quantum Efficiency

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.

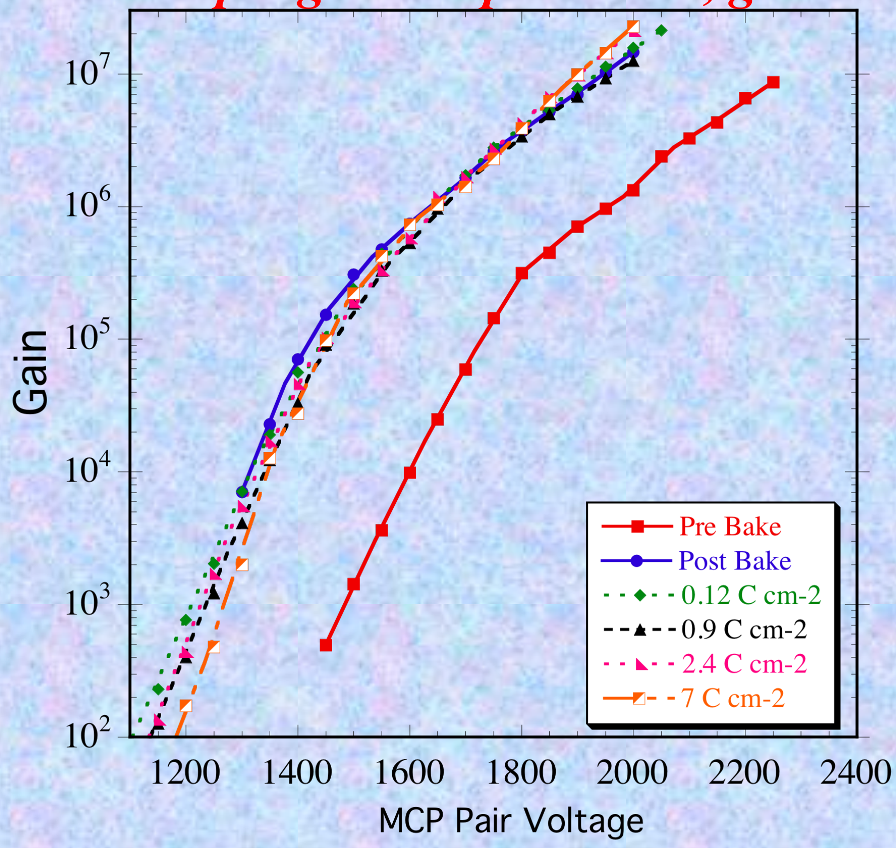
ALD – secondary emissive layer on normal MCP gives good "bare" QDE. CsI deposited on this gives a good "standard" CsI QDE.



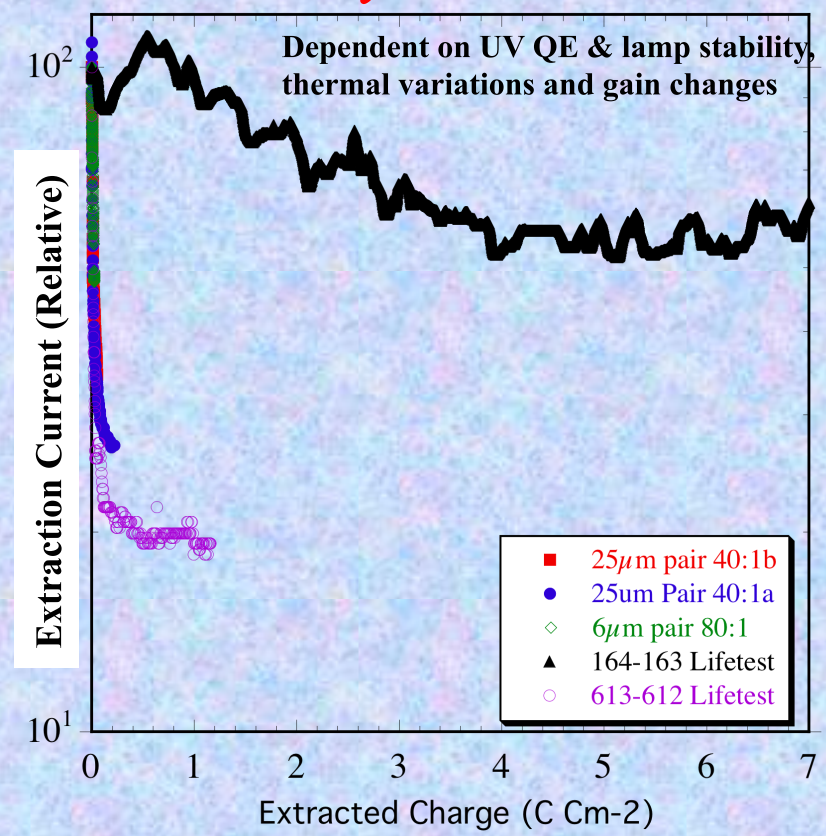
QDE for bare MCP with ALD secondary emissive layer, and with CsI deposited on top of this.

33mm ALD-MCP Preconditioning Tests

Vacuum 350°C bakeout with RGA monitoring first, then UV flood low gain, high current extraction "burn in" (1 – 3µA). ***Gain increases by x10 during bake, No rapid gain drop in scrub, gain-V curves remain very stable.***



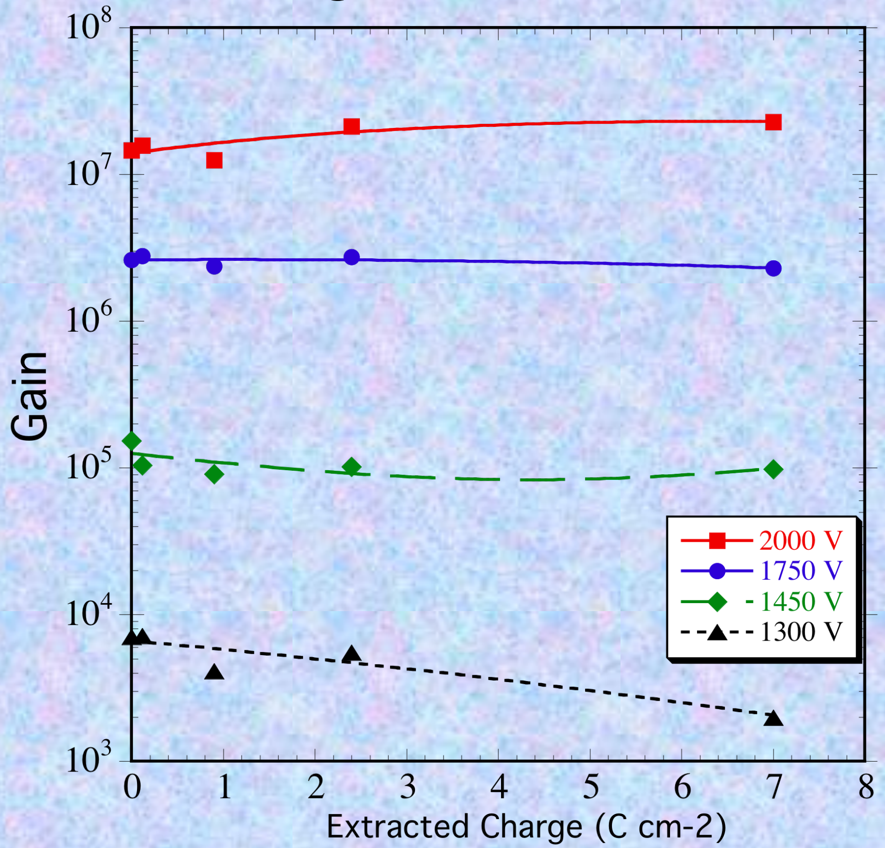
Gain curves of 164-163 MCP pair (20µm pore, 60:1 L/d, 8° bias) at stages during conditioning.



UV scrub of ALD MCP pair 164-163 (20µm pore, 60:1 L/d, 8° bias) compared with conventional MCPs. Outgas during burn-in < 4 x 10^{-10} torr H_2.

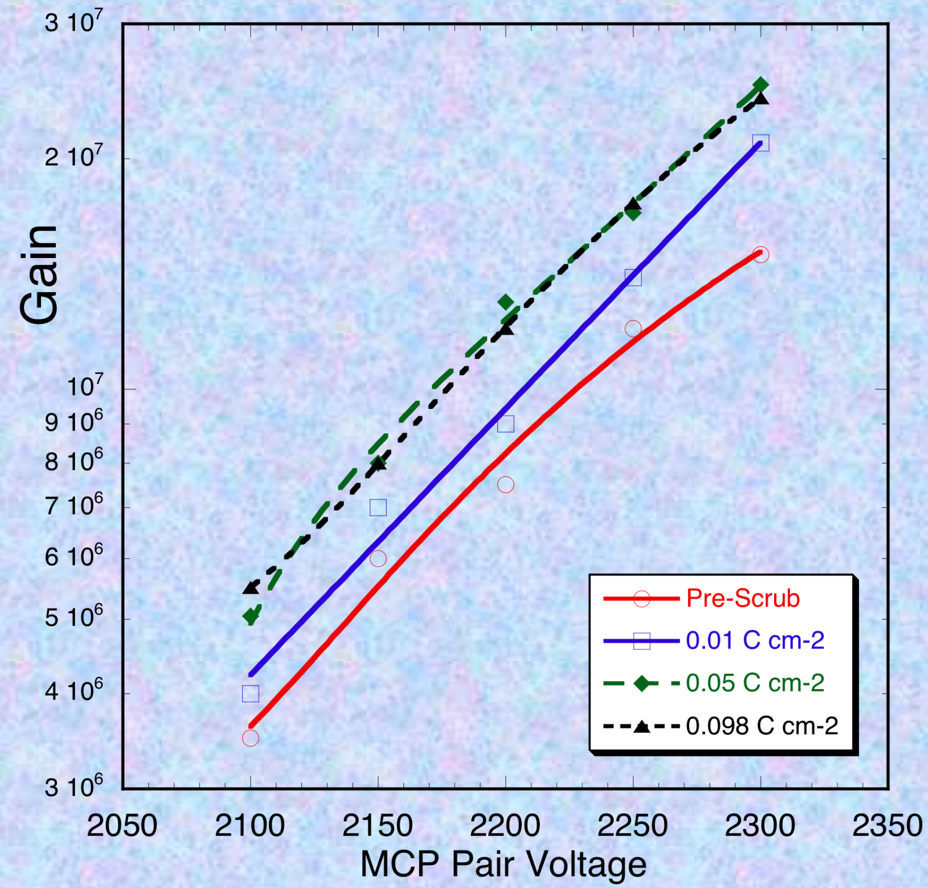
33mm ALD-MCP Preconditioning Tests

Vacuum 350°C bakeout and "burn in". Absolute measured gain is very stable at most voltages



Gain stability of #164-163 MCP pair during conditioning, for various MCP voltage settings.

Absolute gain curves for MCP pair with NO vacuum bake. Gain rises with use!

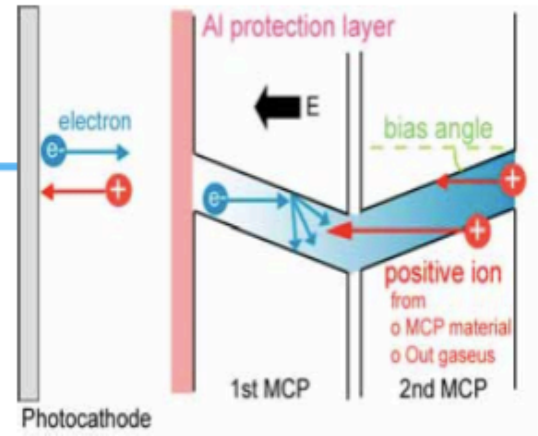


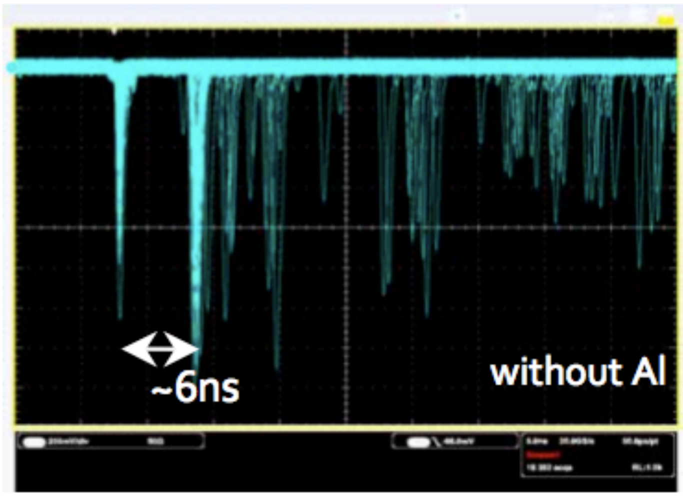
UV scrub gain curves for ALD MCP pair 180-141 (20µm pore, 60:1 L/d, 8° bias).

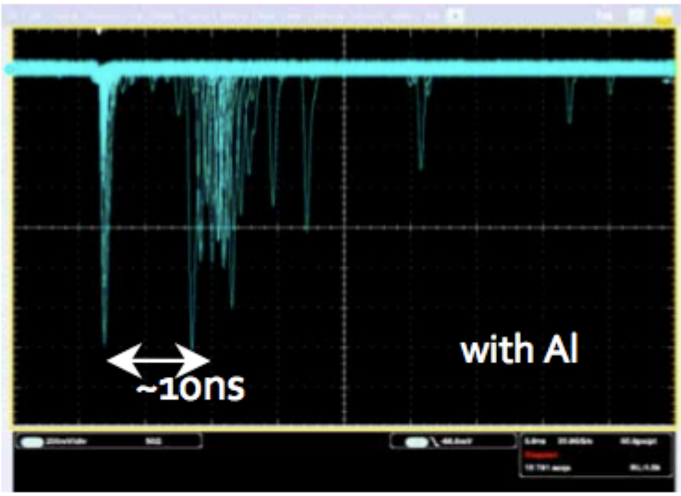
MCP Ion Feedback = Photocathode Degradation

Source of ion

- Measure timing of after pulse
  - Dark pulse (←single photon level)
  - By oscilloscope (2.5GHz)
  - → H^+ from MCP surface



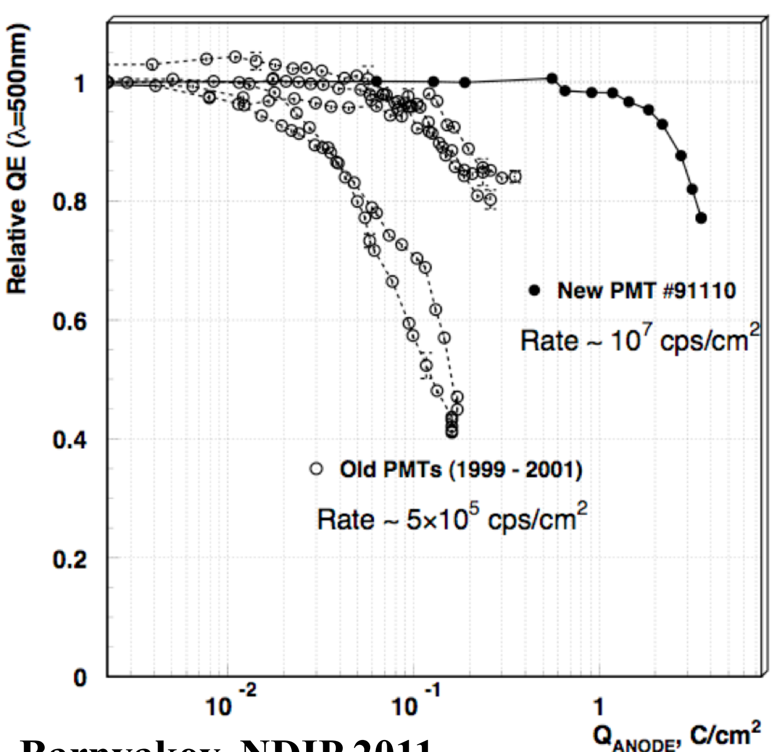




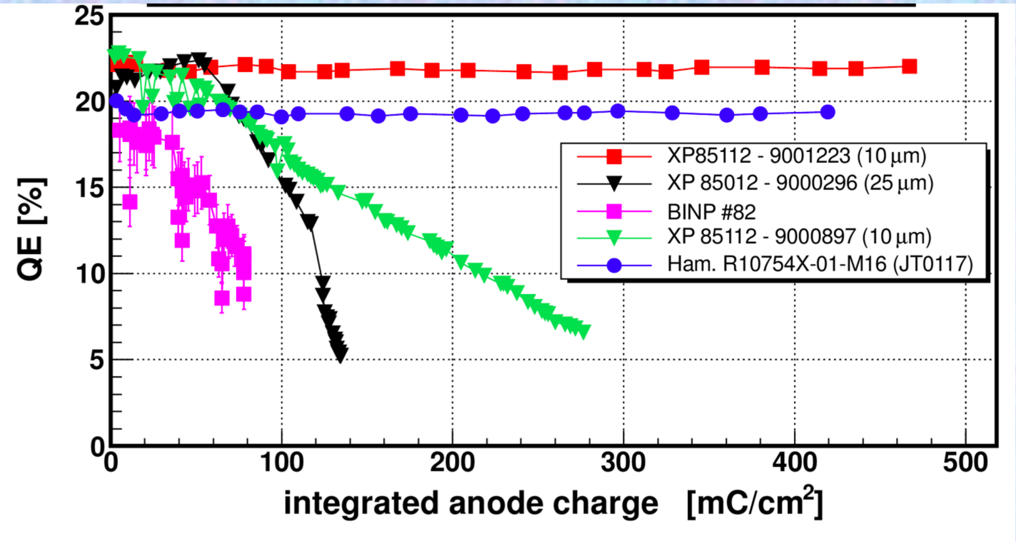
		HPK without Al	HPK with Al
ΔT(calc.)	H^+	5.4ns	10.7ns
	H_2^+, He^{2+}	7.2ns	15ns
ΔT(data)		∼6ns	∼10ns

Lifetime Studies of Improved Tube Designs/Processes

Data indicates that a primary mechanism for sealed tube degradation is outgassing of the MCPs. Adding thin film barriers between the MCPs, or increasing the scrubbing of MCPs, or putting ALD layers onto the MCP surfaces increase lifetimes substantially.



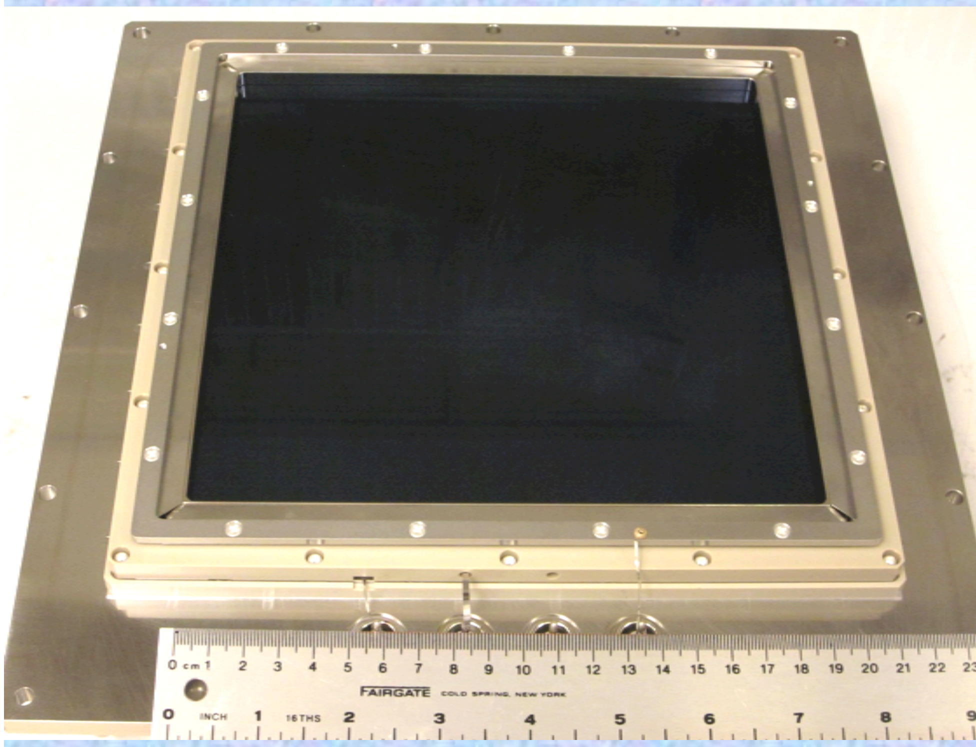
Barnyakov, NDIP 2011



Lehmann et al. IEEE 2011

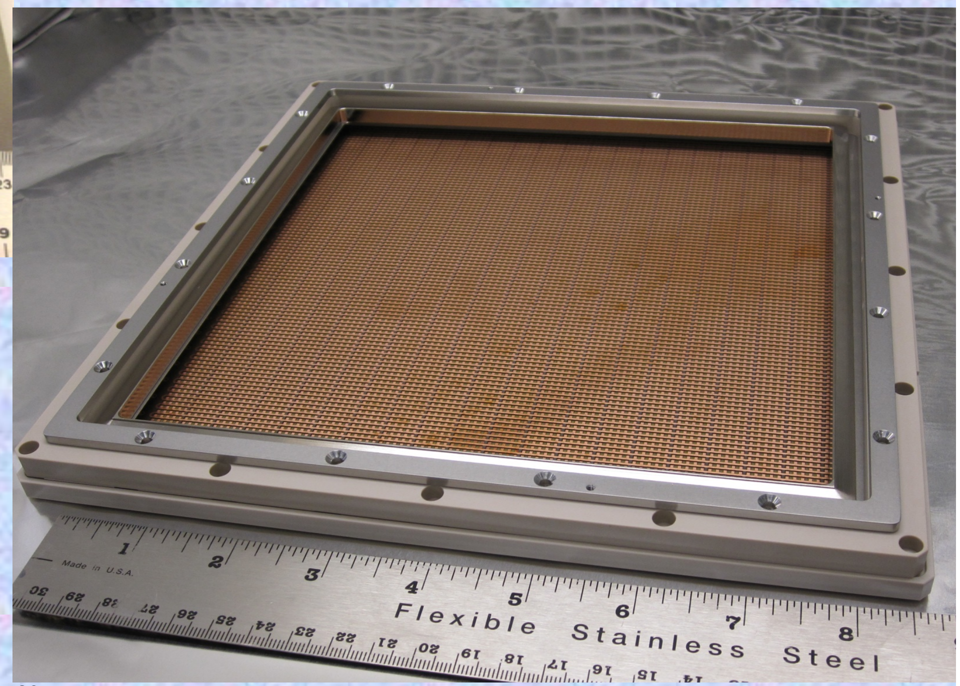
The low outgassing of borosilicate – ALD MCPs is ideal for sealed tubes

20cm MCP Detector



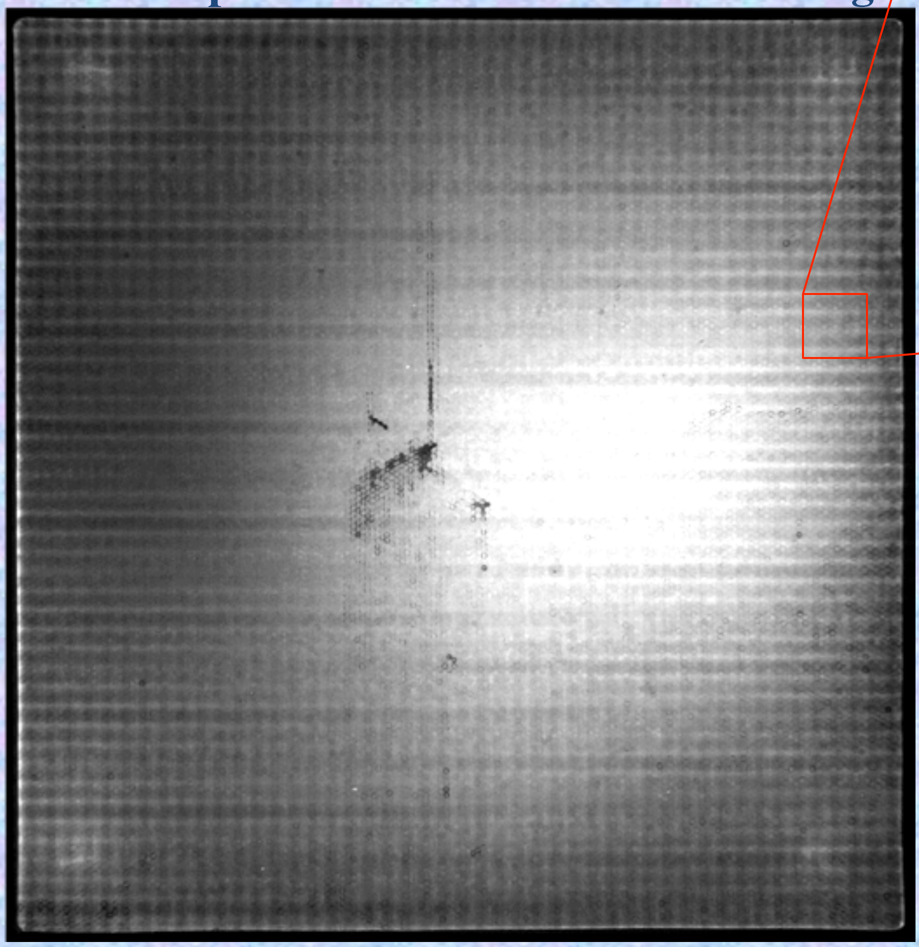
20cm ALD 20µm pore MCP pair in detector assembly with a cross delay line imaging readout.

20cm MCP detector showing the cross delay line anode readout. Gives < 100µm spatial resolution, ~100ps timing



Photon Imaging 20cm, 20µm pore ALD-MCP Pair

20µm pore, 60:1 L/d ALD-MCP pair, 0.7mm gap/200v, 1100 v per MCP. Striping is due to the anode period modulation. 4k x 4k image.



20cm MCP pair image with 185nm UV illumination
The central defect is unique to one MCP batch.

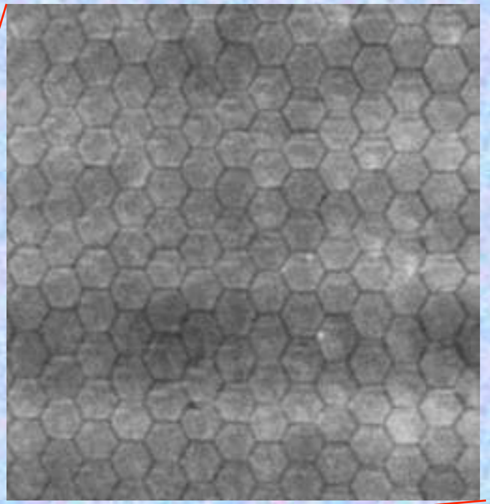


Image section showing the MCP multifibers
Spatial resolution ~100µm FWHM.

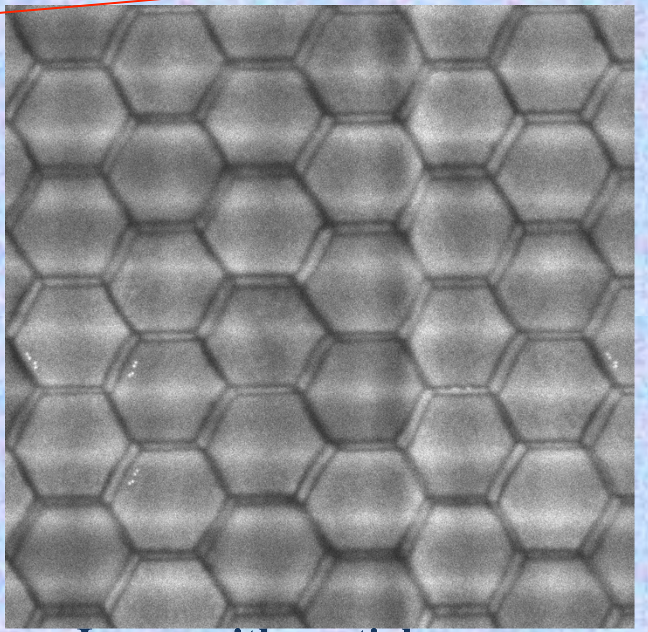
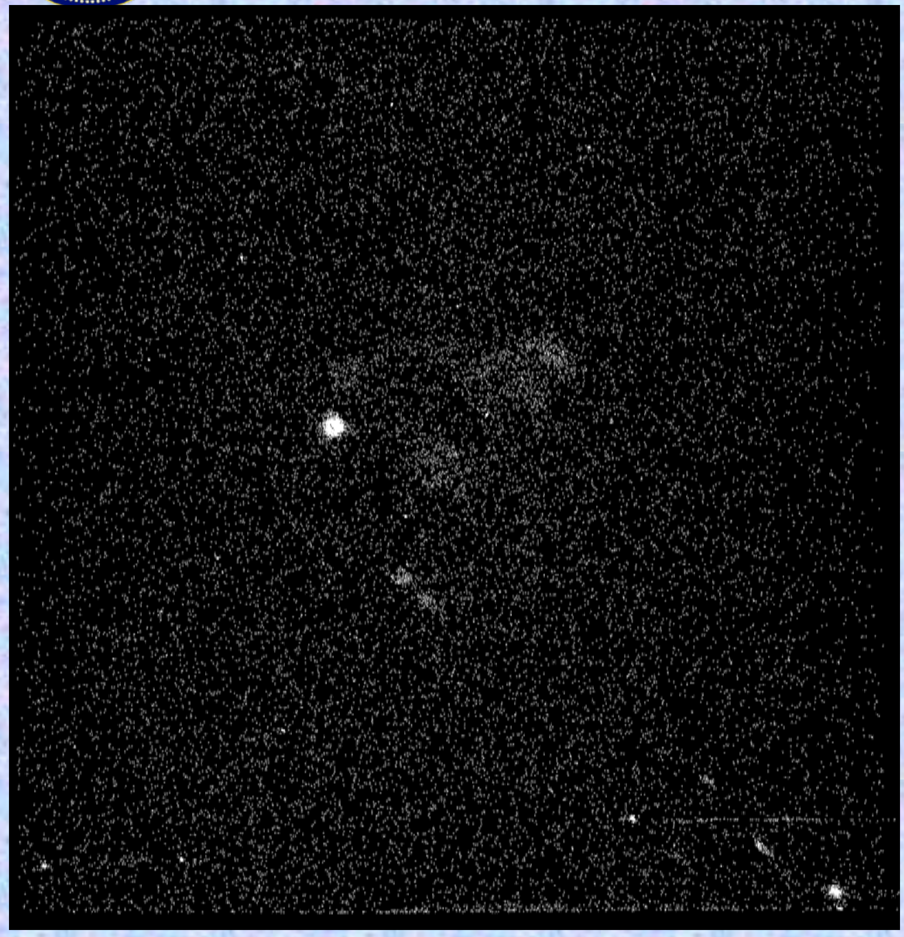


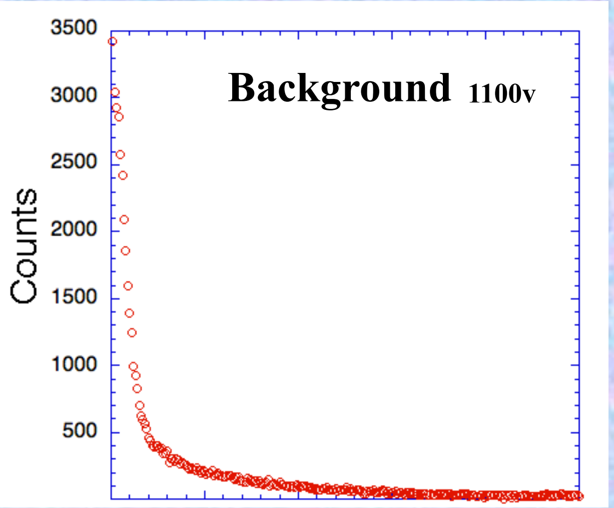
Image with spatial resolution ~25µm FWHM.

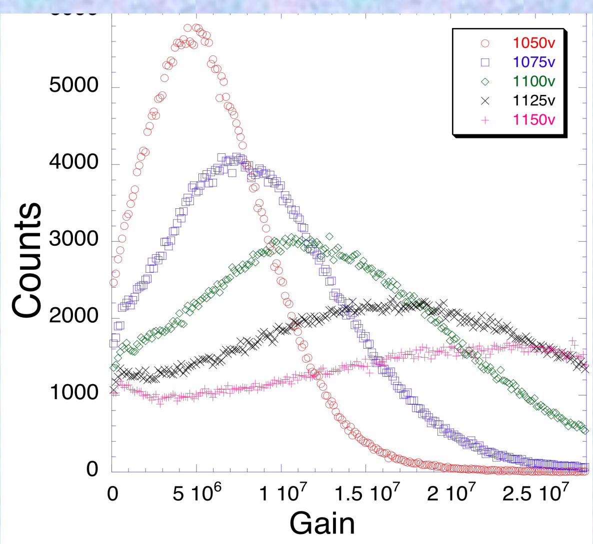
Background, 20cm, 20µm pore ALD-MCP Pair



20cm MCP pair background, 1000 sec, 0.08 cnts sec^{-1} cm^{-2}

20µm pore, 60:1 L/d ALD-MCP pair, 0.7mm gap/200v. A few hotspots. **BUT – background is 0.08 sec^{-1} cm^{-2}.** 60 sec^{-1} over 400 cm^{-2}



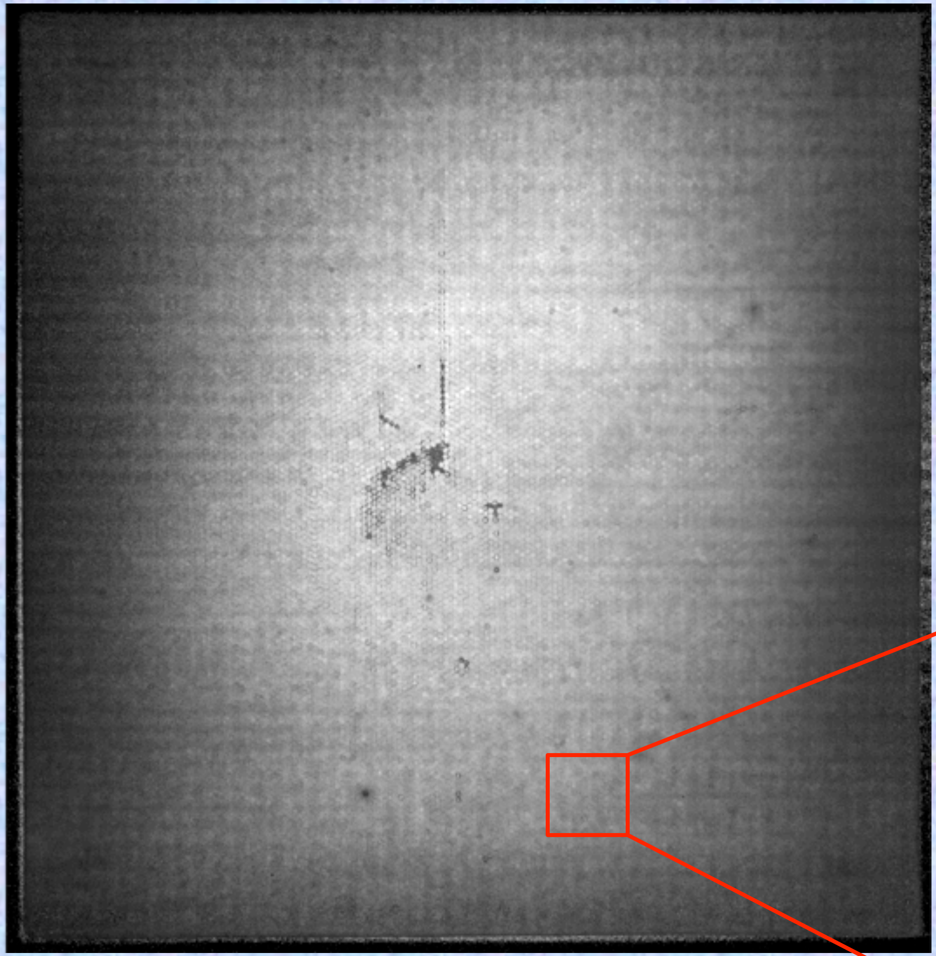


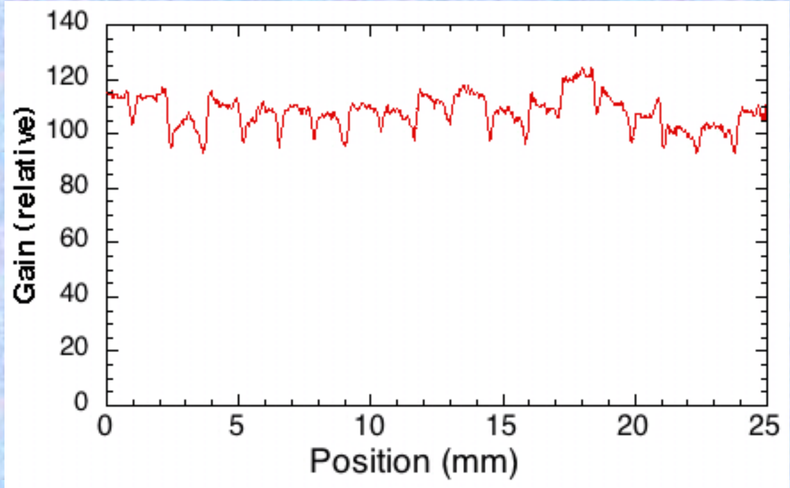
UV

UV (185nm) and background event pulse height distributions. Background events originate throughout the MCP.

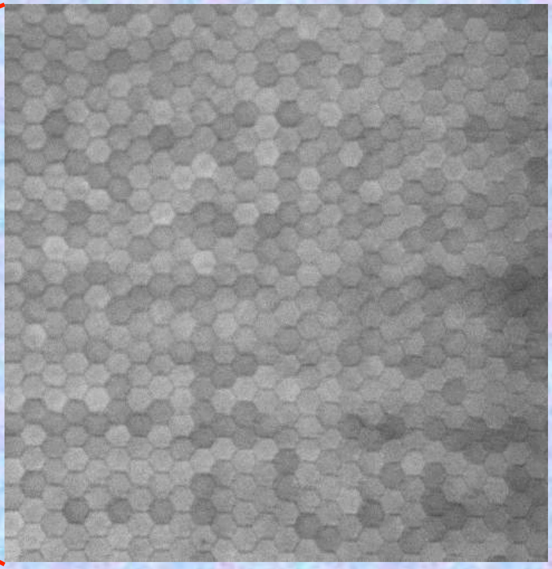
Testing of 20cm, 20μm pore ALD-MCP Gain

Mean gain ~1 x 10^7





Y slice histogram, shows multifiber gain variation of ~15% due to open area variations.



Close up shows gain variation

20cm MCP pair average gain map image

20µm pore, 60:1 L/d ALD-MCP pair, 0.7mm gap/200v, 1100 V per MCP. 4k x 4k image bins.

Siegmund, 6/5/12

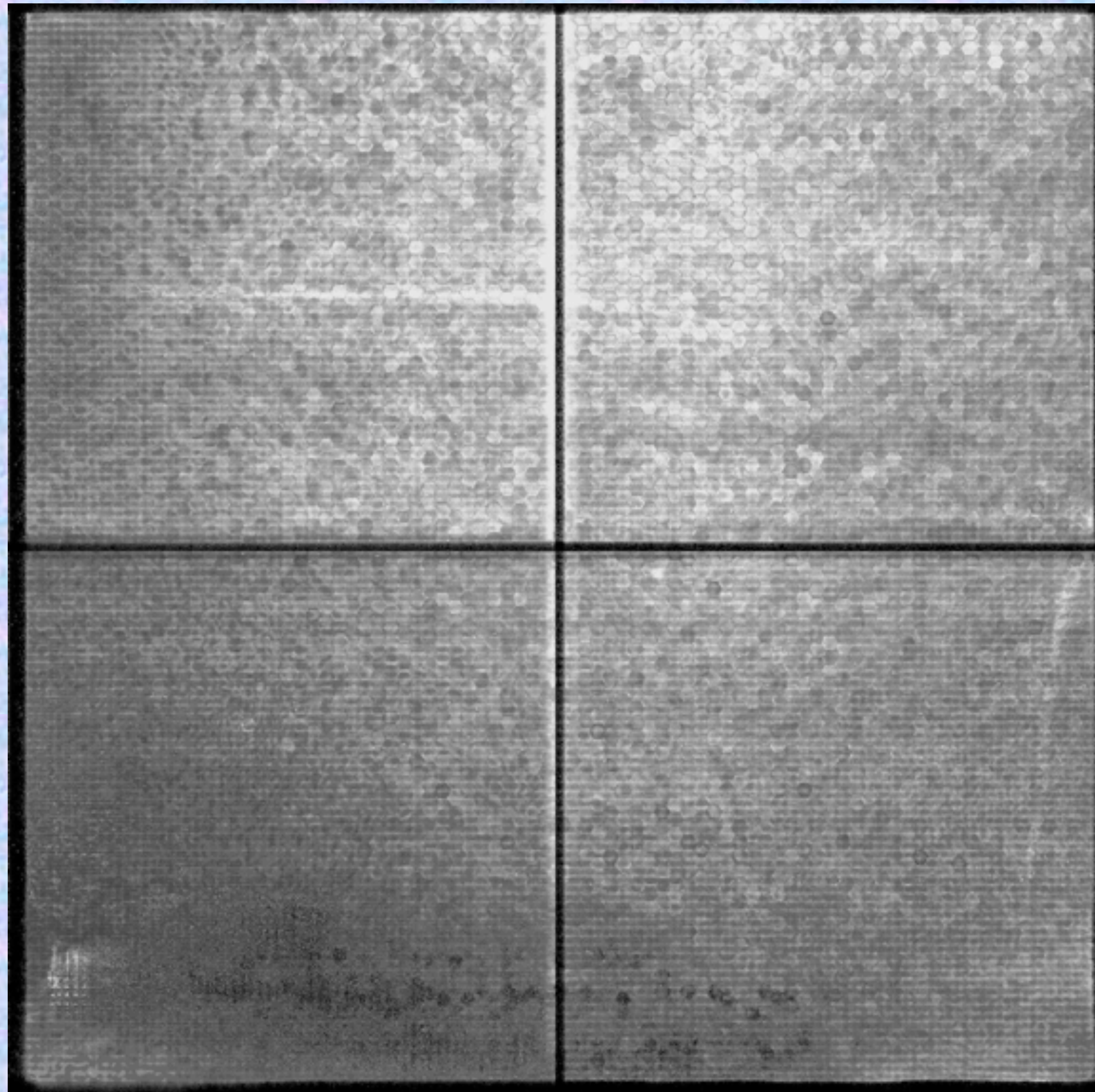
10cm x 10cm ALD MCP Pair (from 20 cm)

10 cm x 10cm cross strip readout

UV 185nm light

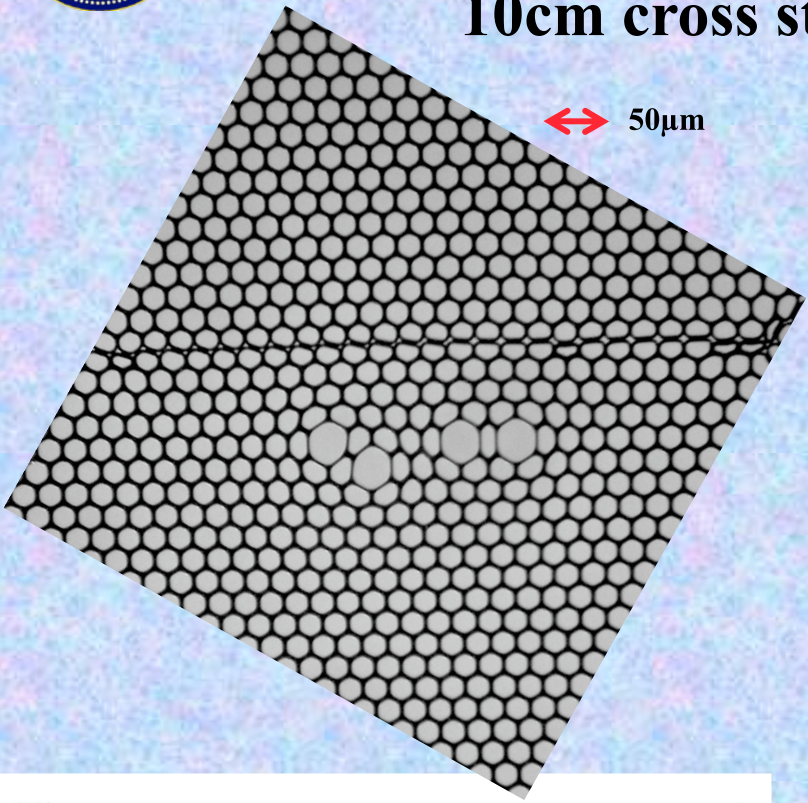
20µm pore ALD MCP

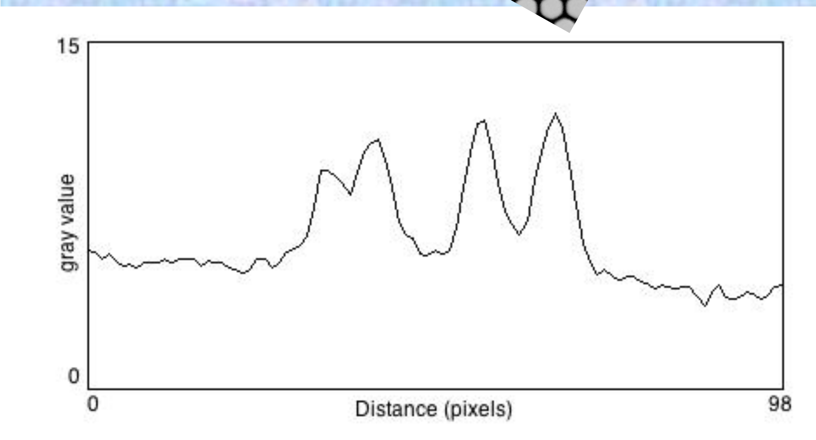
**Have to take 4 images for 10 cm area can only process anode data with 2 amplifier units, Don't have FPGA to cope with 4 amplifer units (128 +128) simultaneously yet.
Each quadrant binned to 8192 x 8192.**

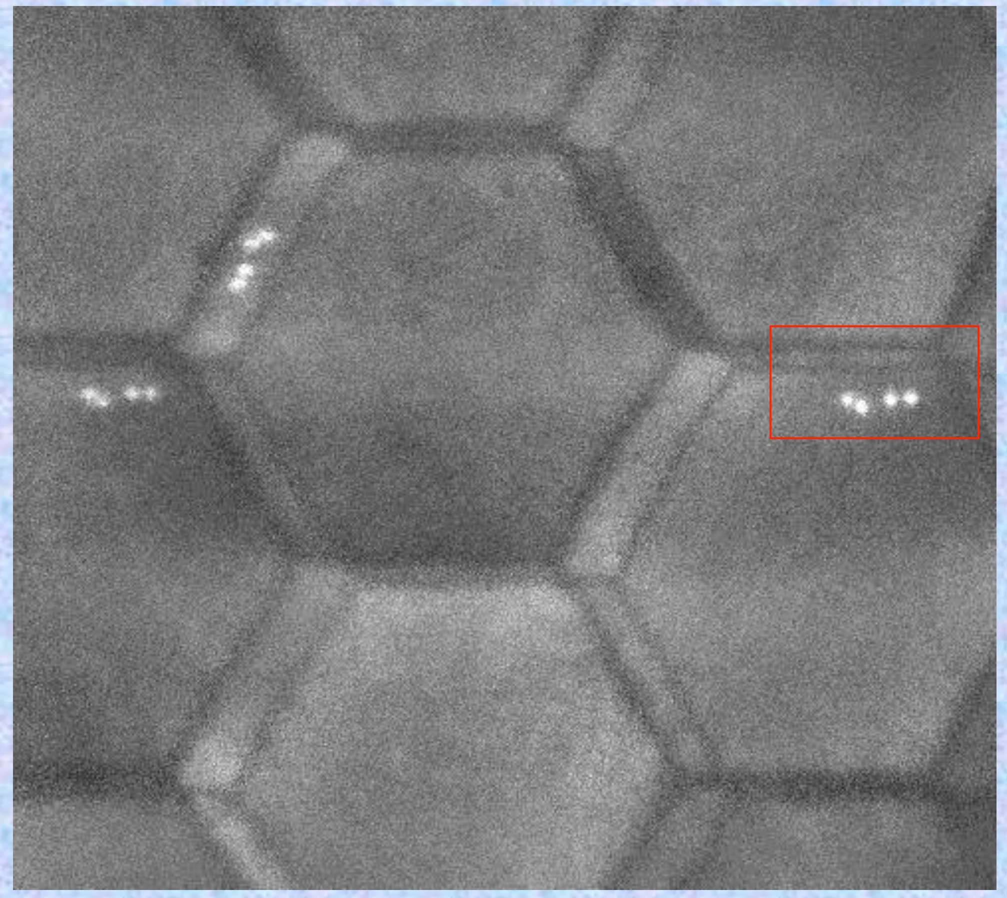


20µm MCP Pair High Resolution Imaging

10cm cross strip anode readout







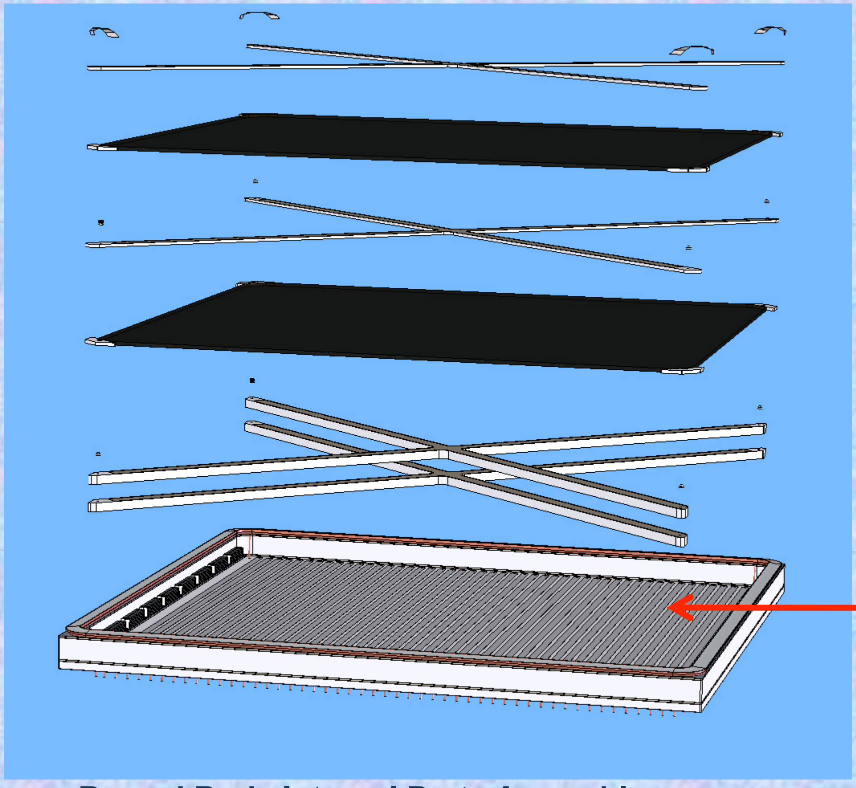
Can resolve the big pores using 6µm pixel binning (16k x 16k)

Large Area Picosecond Photodetector Design

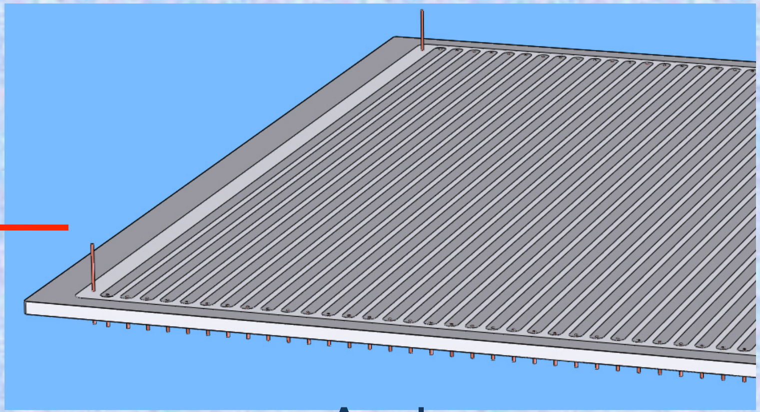
Input Window (not shown)
Borofloat 33, 5mm thick input window, using Indium seal, and semitransparent bialkali photocathode

Brazed Body Assembly
Alumina/Kovar parts brazed to form the hermetic package

Ceramic body with Cu Indium well and strip anode.

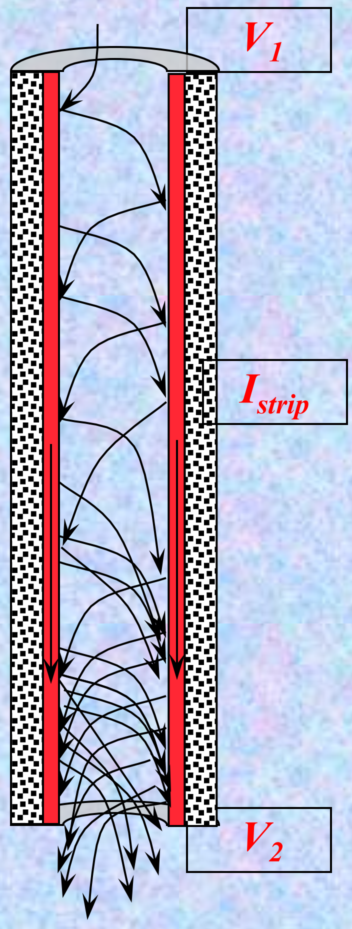


Brazed Body Internal Parts Assembly
Into the brazed body, we stack up getters, X-grid spacers and MCPs. X-grids register on HV pins and space out the MCPs.



Anode
Alumina substrate with signal and HV pin contacts.
48 signal strips inside, complete Gnd plane outside.
Signal & HV pins brazed in.

Event Counting, Fast Timing Response



- *Resistance of the pore*
  - Limited number of counts per pore per second next event with the same gain can only occur after the wall charge is replenished

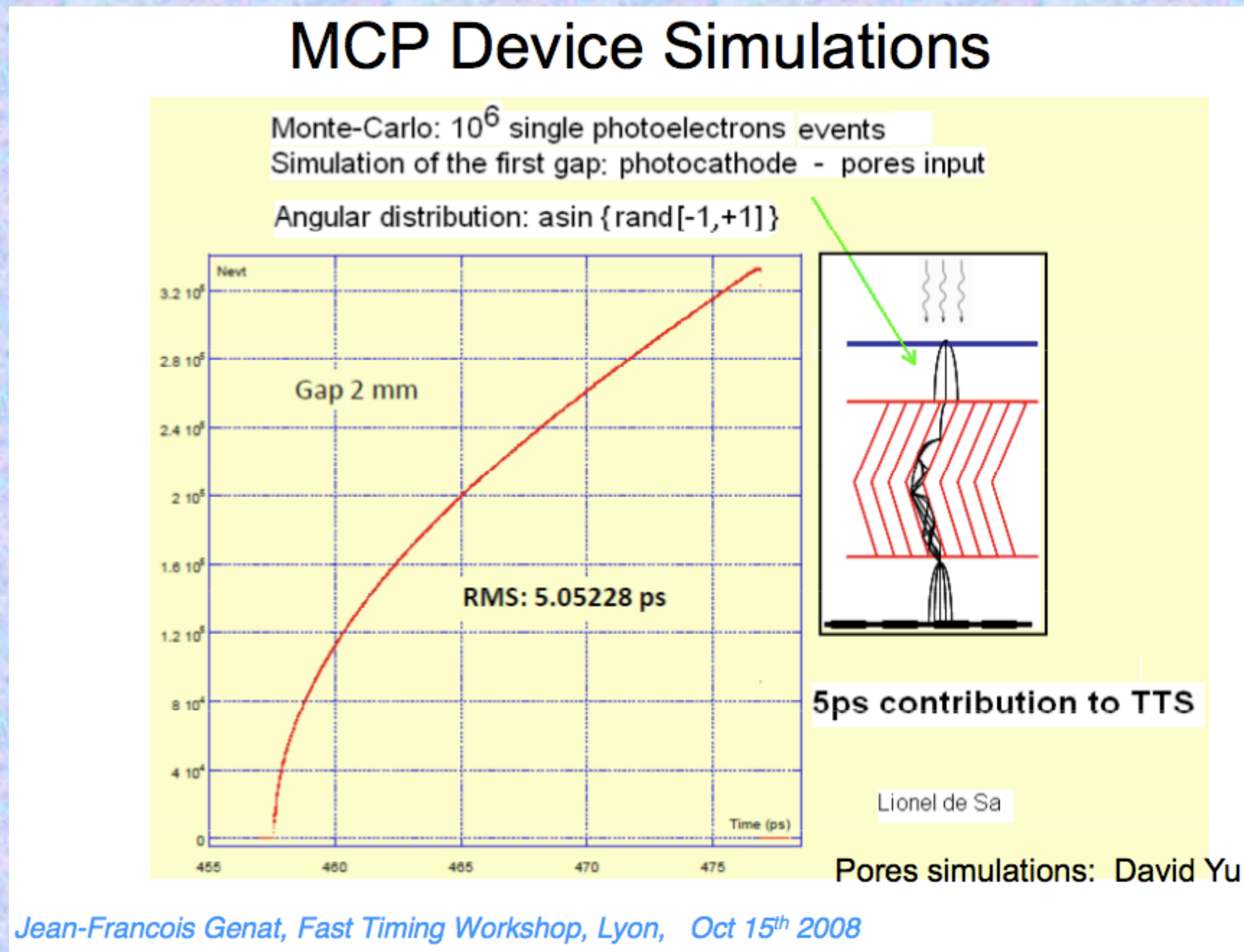
Typical event transit time ~100 ps, transit time spread 10's ps
Typical pore resistance ~10^{15} Ω
Pore current I_{strip} ~1pA

Positive wall charge builds up on the pore walls, mostly at the bottom where the amplification is the highest.

Typical pore capacitance 10^{-18} F
Recharge time ~ RC = 1 ms

Only portion of that charge replenishes the wall positive charge through tunneling

Contributors to Transit Time Spread Performance



Primary Factors

Proximity gap

MCP stack

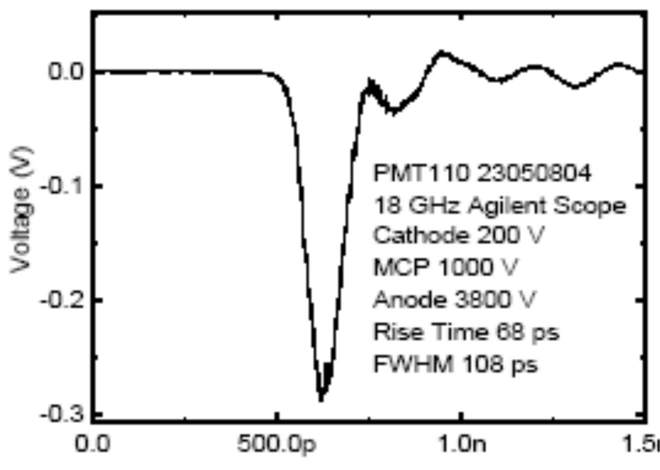
Electronics

All in the region of 10's of ps for single photoelectrons

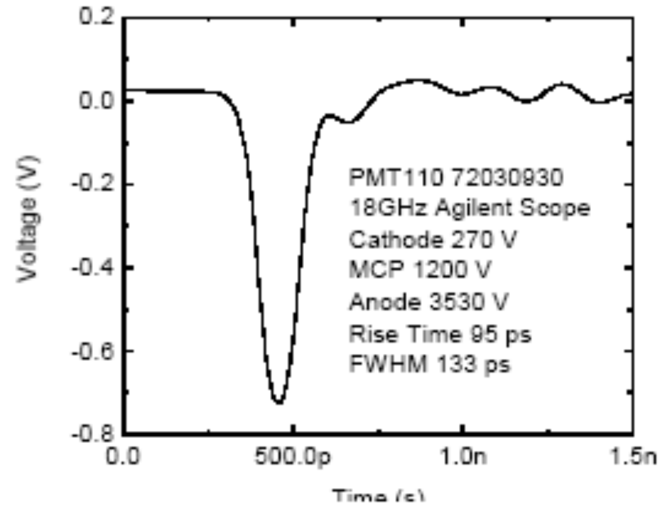
Pulse widths from the MCP vs. pore diameter

Photek

Response vs. Pore Size



3.2 µm pore MCP PMT

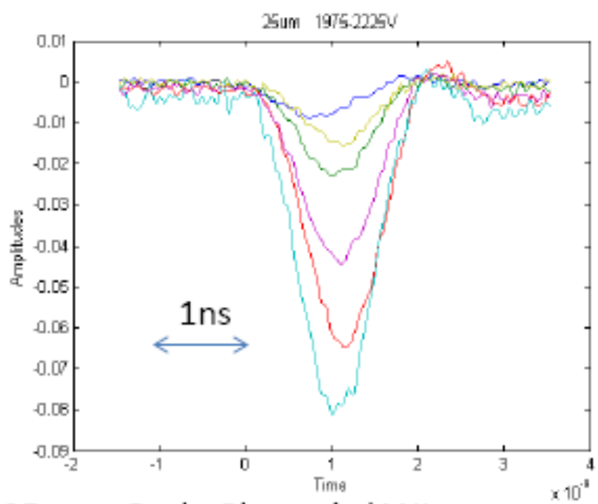


6 µm pore MCP PMT

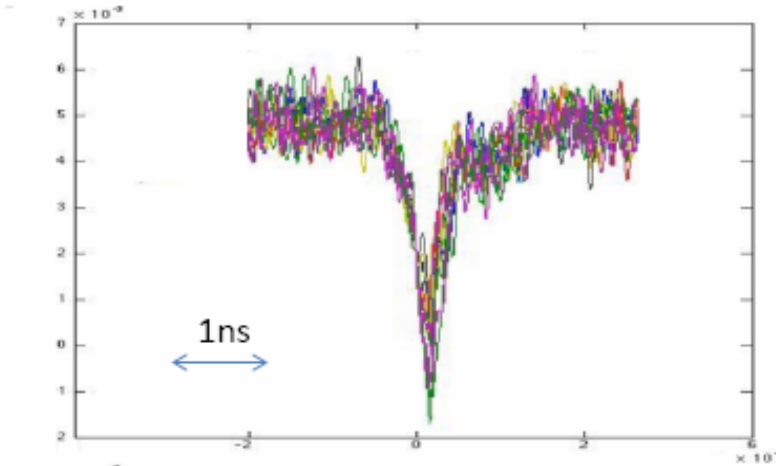
www.photek.co.uk page 5

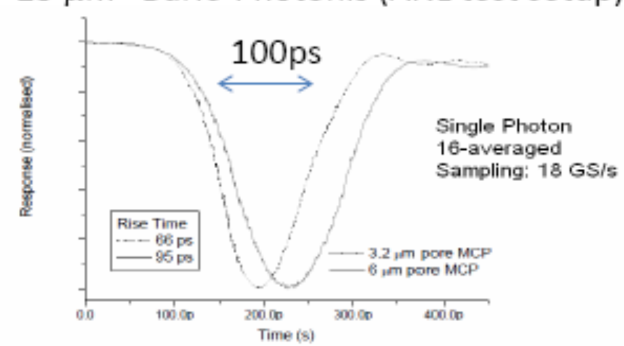
Pulse widths from the MCP vs. pore diameter

Typical MCP signals



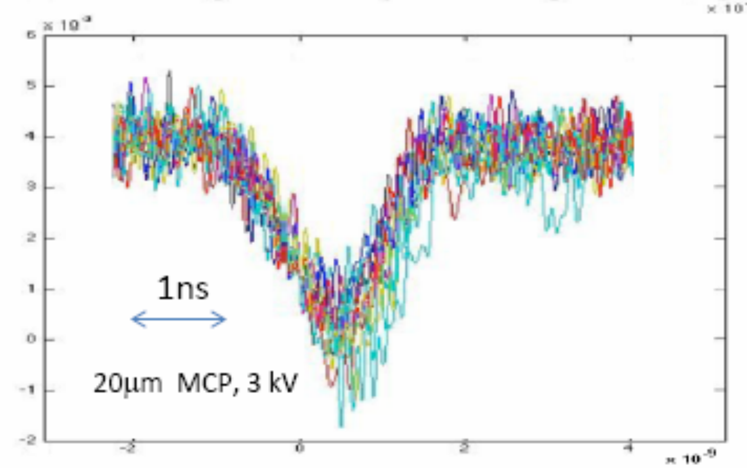
25 μm Burle-Photonis (ANL test setup)





Time response curves for two models of PMT110 with different MCP pore diameters.

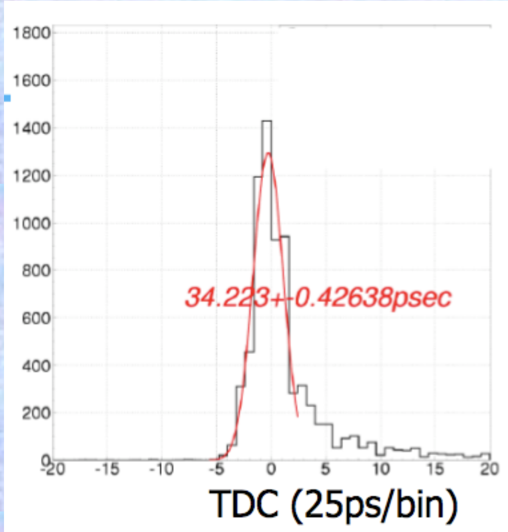
3.2 and 6 μm MCP (from J Milnes, J. Howorth, Photek)



Glass + ALD MCPs (from Matt Wetstein, ANL)

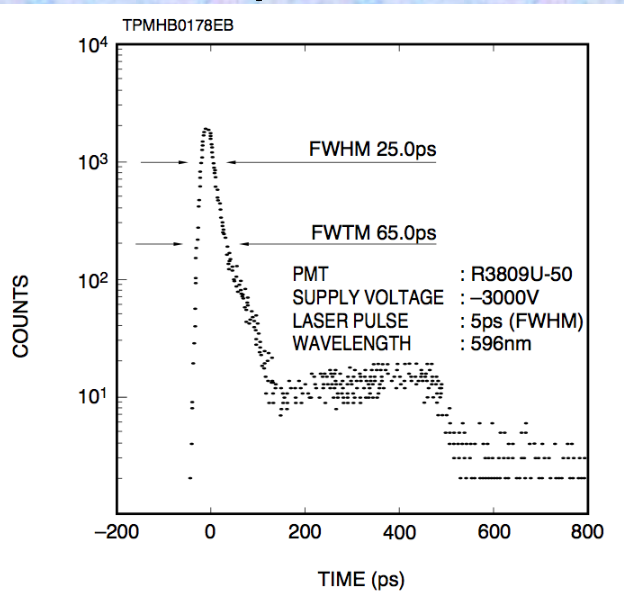
Jean-Francois Genat, Large Area Picosecond Photo-Detectors Electronics, Clermont-Ferrand, January 28th 2010

Microchannel Plate TTS

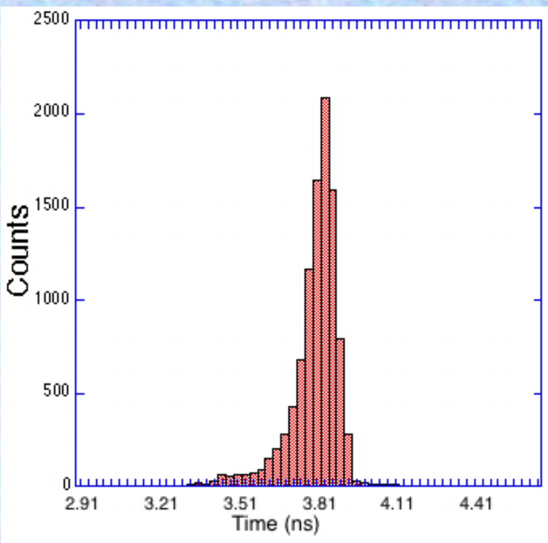


Inami - Lyon

The transit time spread for single photo-electrons is ~30ps, this gets better with multiple photoelectrons (<5ps)



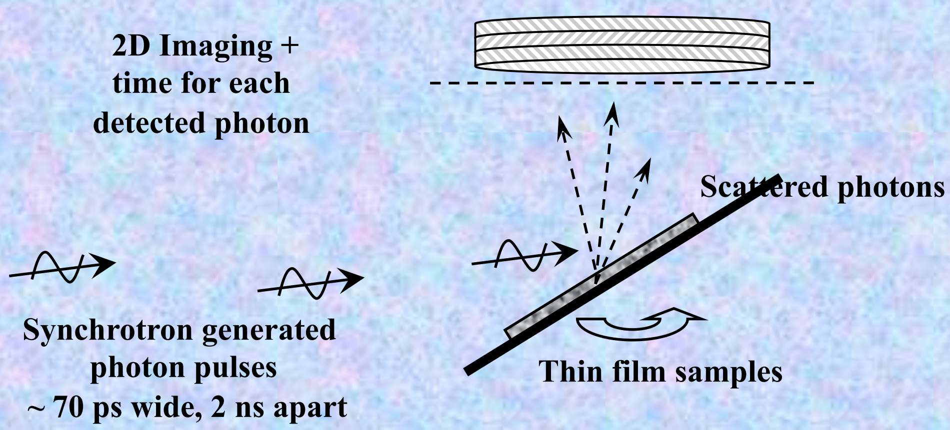
Hamamatsu TTS for MCP pair



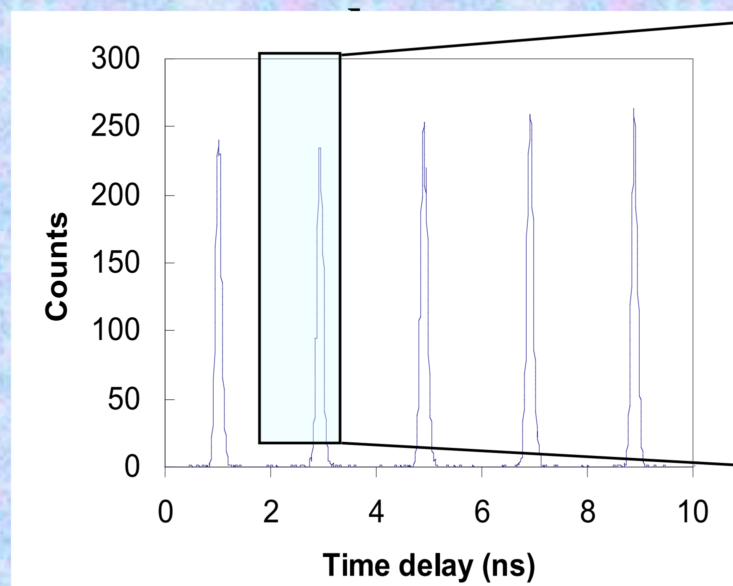
Laser (~80 ps) measurements of timing jitter show 100ps time spread, 25mm cross delay line readout, 10μm MCP Z stack, S20 photocathode

MCP timing jitter ~100 ps FWHM

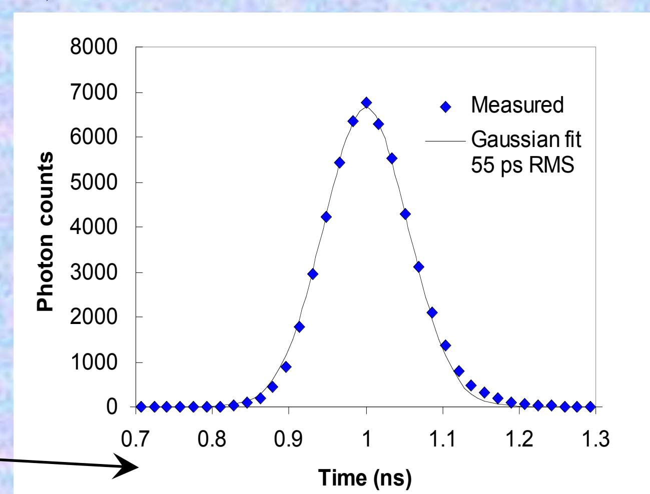
Synchrotron Timing Resolution Test



Elastically scattered



Timing accuracy 55 ps RMS (130 FWHM)



Planacon is one of the Few Comparable Standards

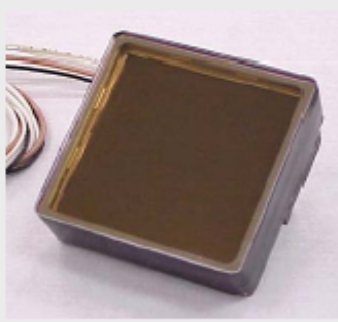
PHOTONIS — What is there Today?

PLANACON & <u>25 µm</u> MCPs

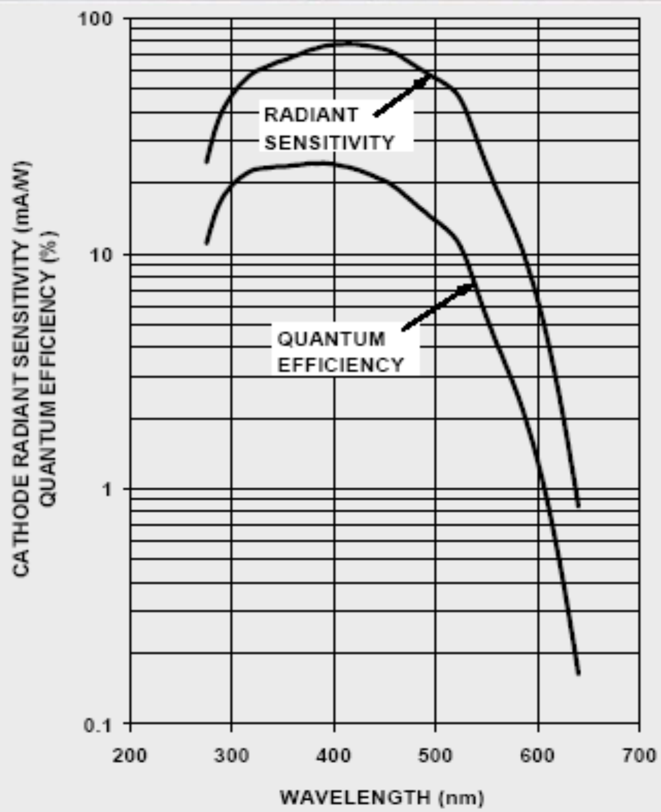
=> Typical
  Pulse Rise time 600 psec
  Pulse Width 1.8 nsec

=> Bialkali Photo-cathode

=> QE ~ 25-28% @ 400nm



=> Immune to B-fields



5

E. Schyns, Clermont-Ferrand, January 2010

Burle/Photonis MCP-PMT TTS measurement

J.Va'vra, MCP log book #3, pages 27-40

MCP-PMT 85012-501:

- **10 μm MCP hole diameter**
- **High gain: 2.8 kV, B = 0 kG, to get the best σ_{TTS}**
- **PiLas red laser diode operating in the single photoelectron mode (635 nm):**

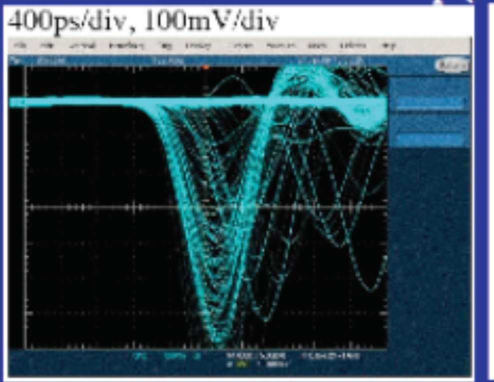
$$\sigma_{TTS} < \sqrt{(32^2 - 13^2 - 11^2)} = 27 \text{ ps}$$

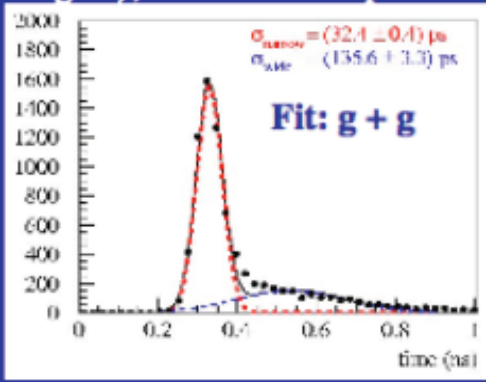
PiLas laser diode — Electronics

a) Fast amplifier + CFD/TAC:

Hamamatsu C5594-44 amplifier

1.5 GHz BW amp (63x gain), 1GHz BW scope

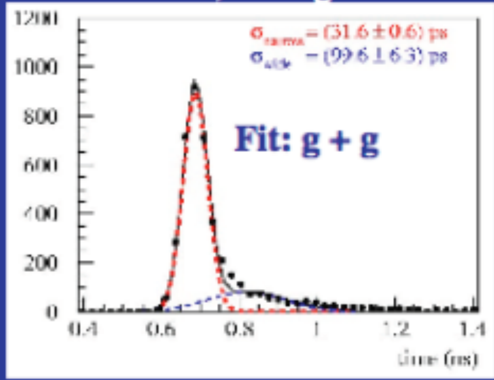




b) Slow amplifier + CFD/TAC:

Ortec VT120A amplifier

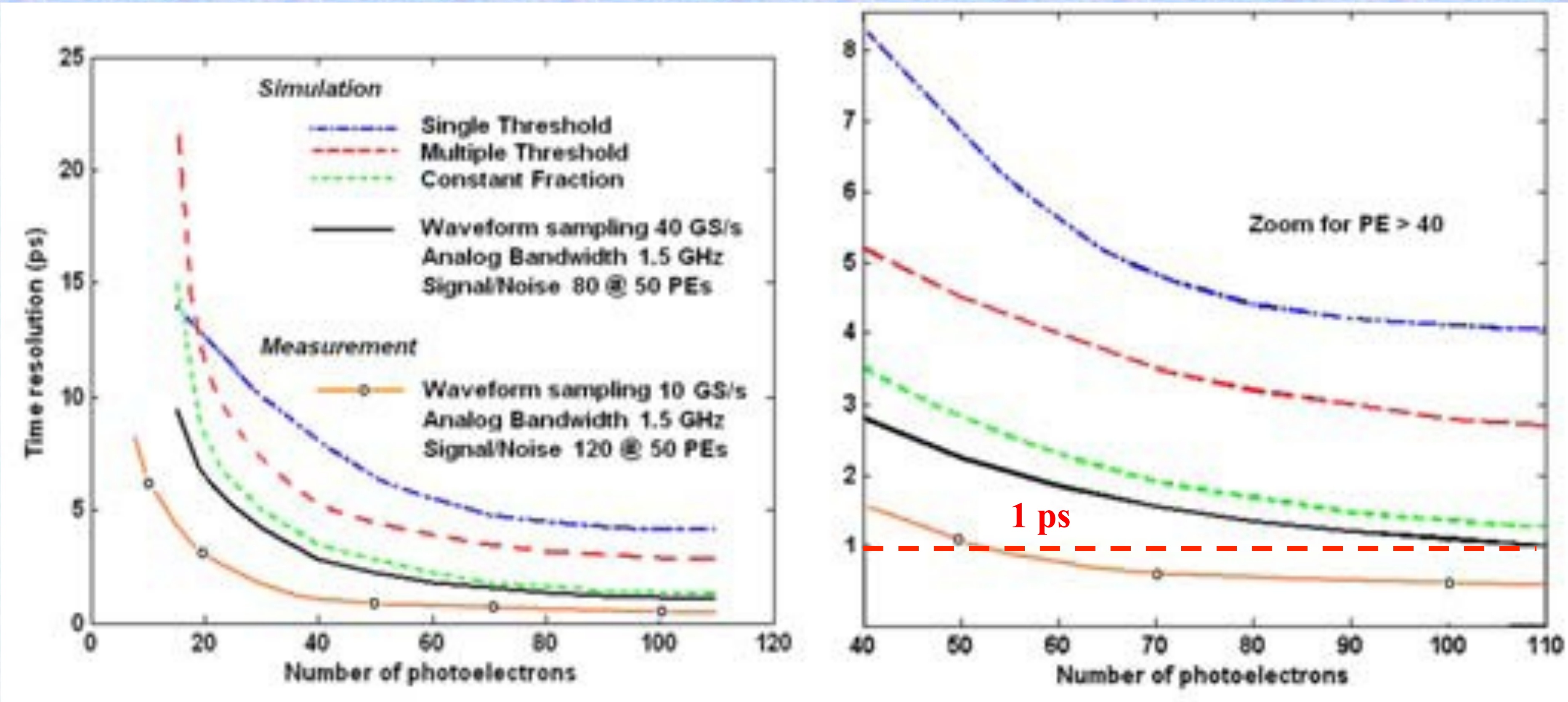
~0.4 GHz BW, 200x gain + 6dB



12/3/09 J. Va'vra, Frascatti detector lectures II 24

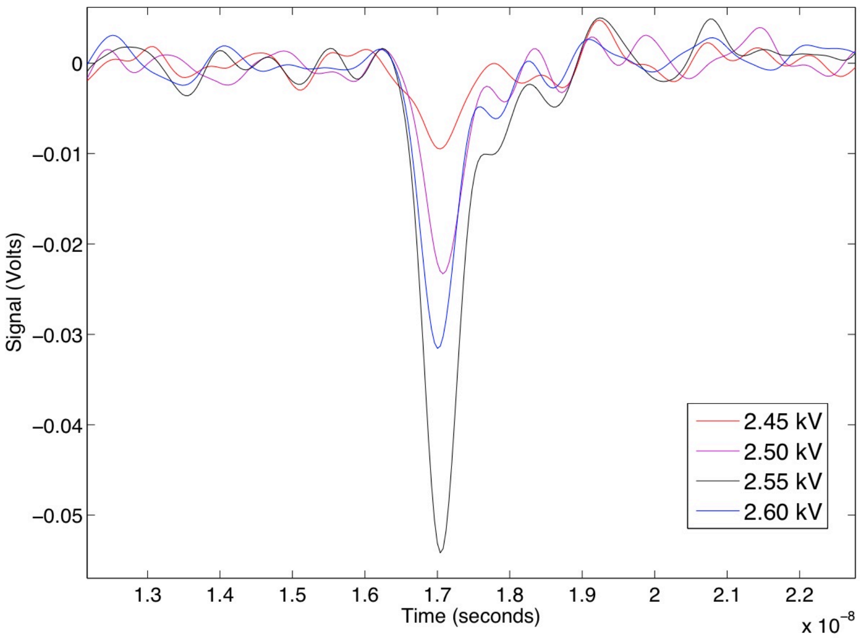
Timing Simulation of Resolution vs Analog Band Width

Jean-Francois Genat (NIM)



Brown line: 10 Gs/sec (we've done >15);
1.5 GHz abw (we've done 1.6); S/N 120 (N=0.75mv, S is app specific)

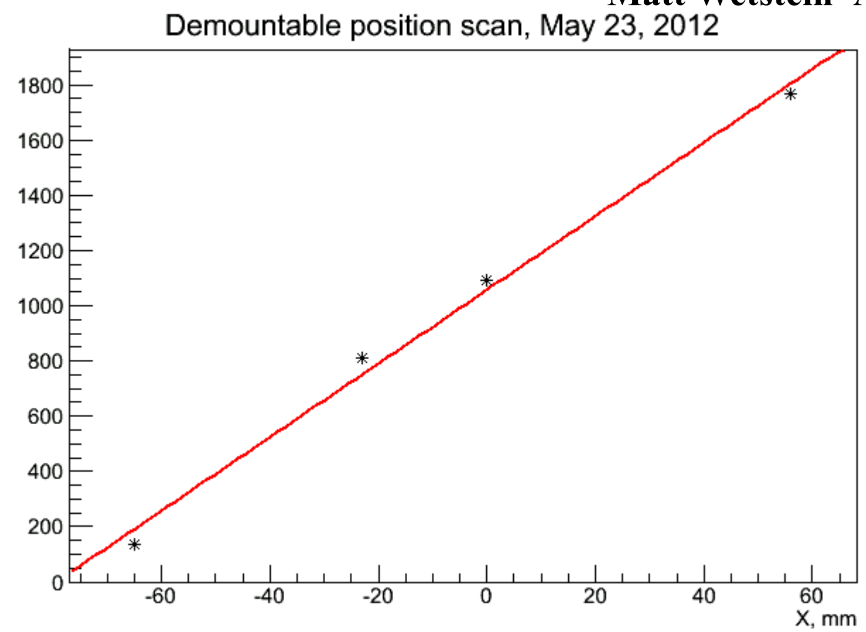
Initial Tests with 20cm ALD MCP and Stripline Anode



ALD MCP + stripline pulse shapes

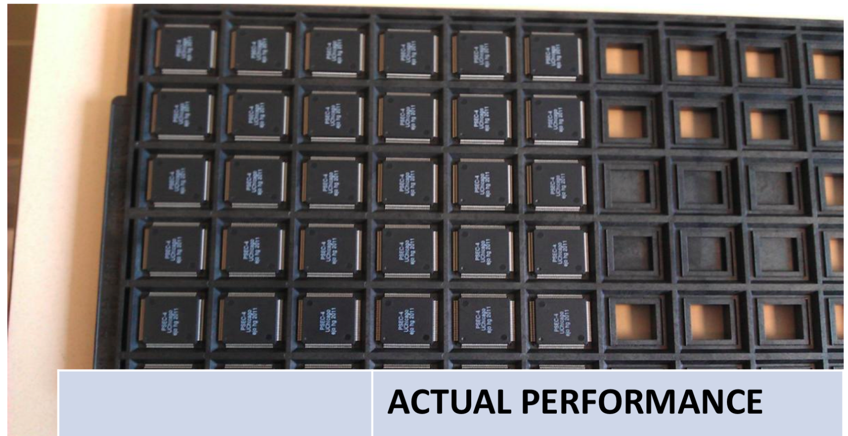
Timing vs position on 20cm ALD MCP stripline test-bed detector

Matt Wetstein- ANL



ASIC Input Chip for Timing of Strip Lines

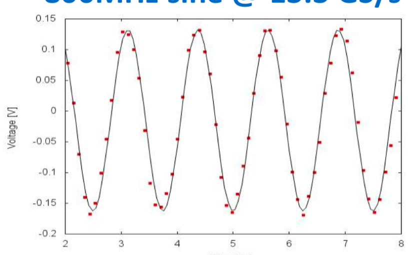
PSEC-4



- Waveform digitizing ASIC
- Sampling rate capability > 10GSa/s
- Analog bandwidth > 1 GHz
- Medium event-rate capability (up to ~100 KHz)

	ACTUAL PERFORMANCE
Sampling Rate	2.5-15 GSa/s
# Channels	6
Sampling Depth	256 points (17-100 ns)
Input Noise	<1 mV RMS
Analog Bandwidth	1.6 GHz
ADC conversion	Up to 12 bit @ 1.5 GHz
Dynamic Range	0.1-1.1 V
Latency	2 µs (min) – 16 µs (max)
Internal Trigger	yes

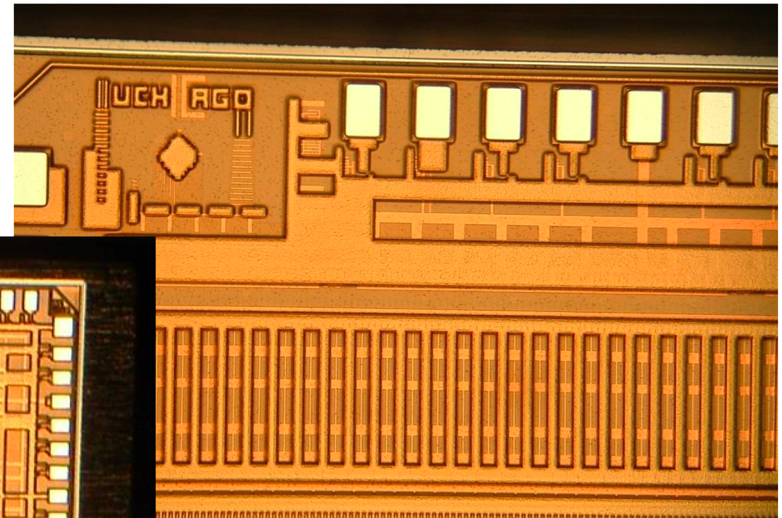
800MHz sine @ 13.3 GS/s

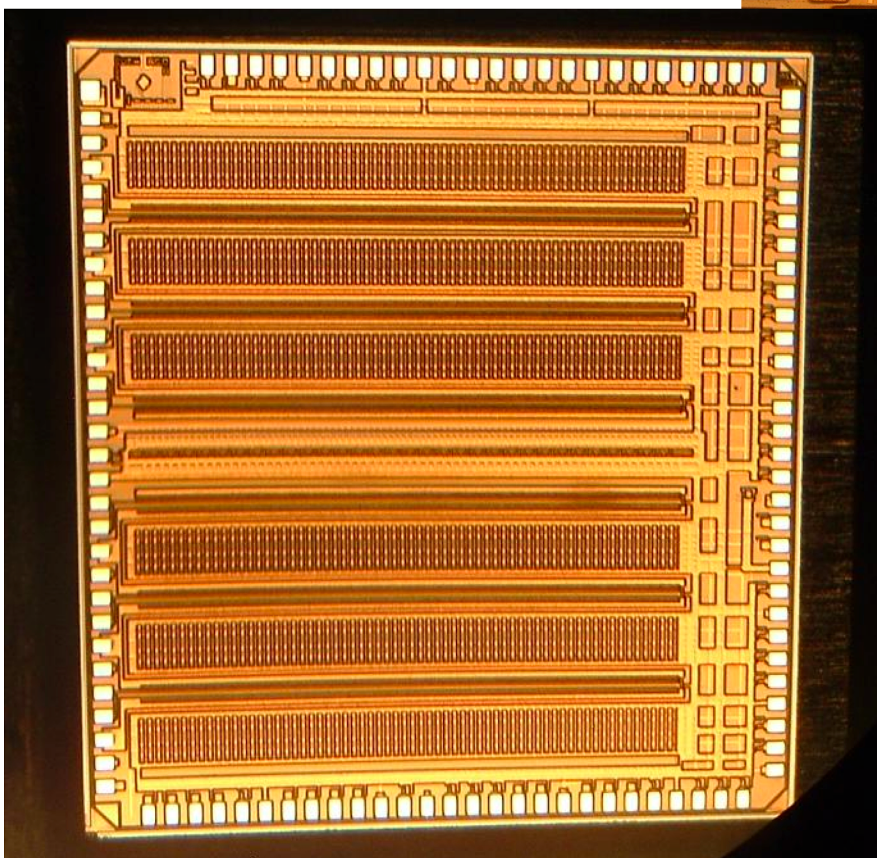


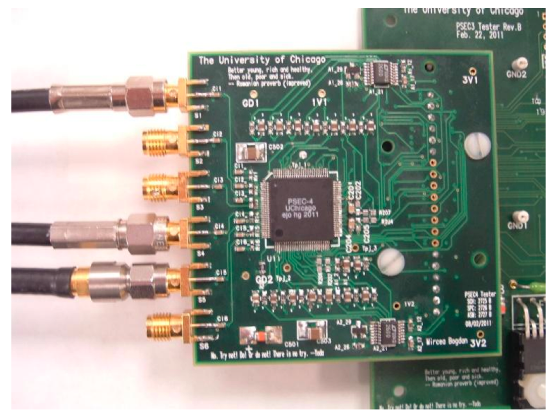
12/9/2011 LAPPD collab meeting: PSEC-4 2

Front End ASIC Layout and Board Implementation

PSEC-4



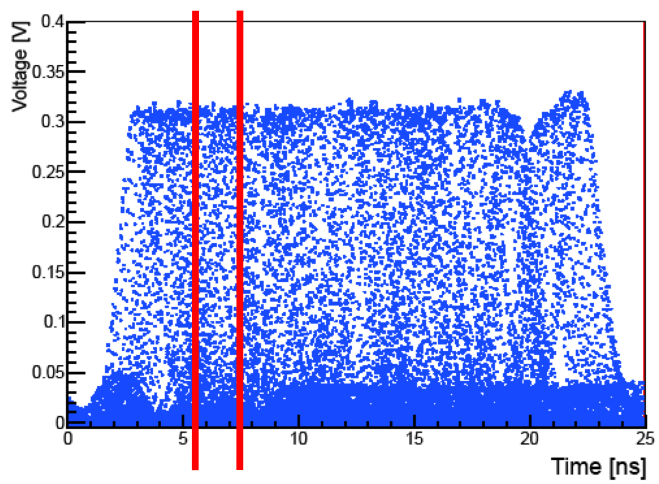




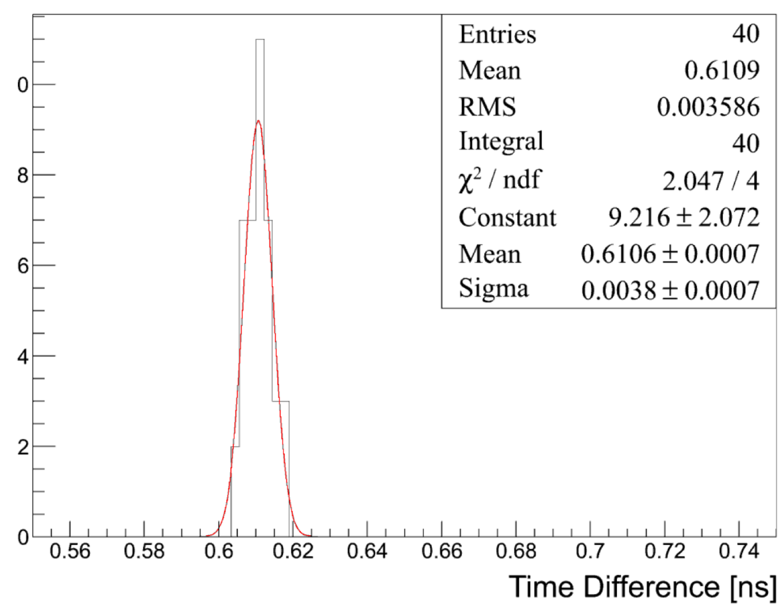
3

PSEC-4 Timing Tests

- Without time base calibration (assuming nominal 100 ps per sample interval)
- Sample several hundred Gaussian waveforms on 2 channels:



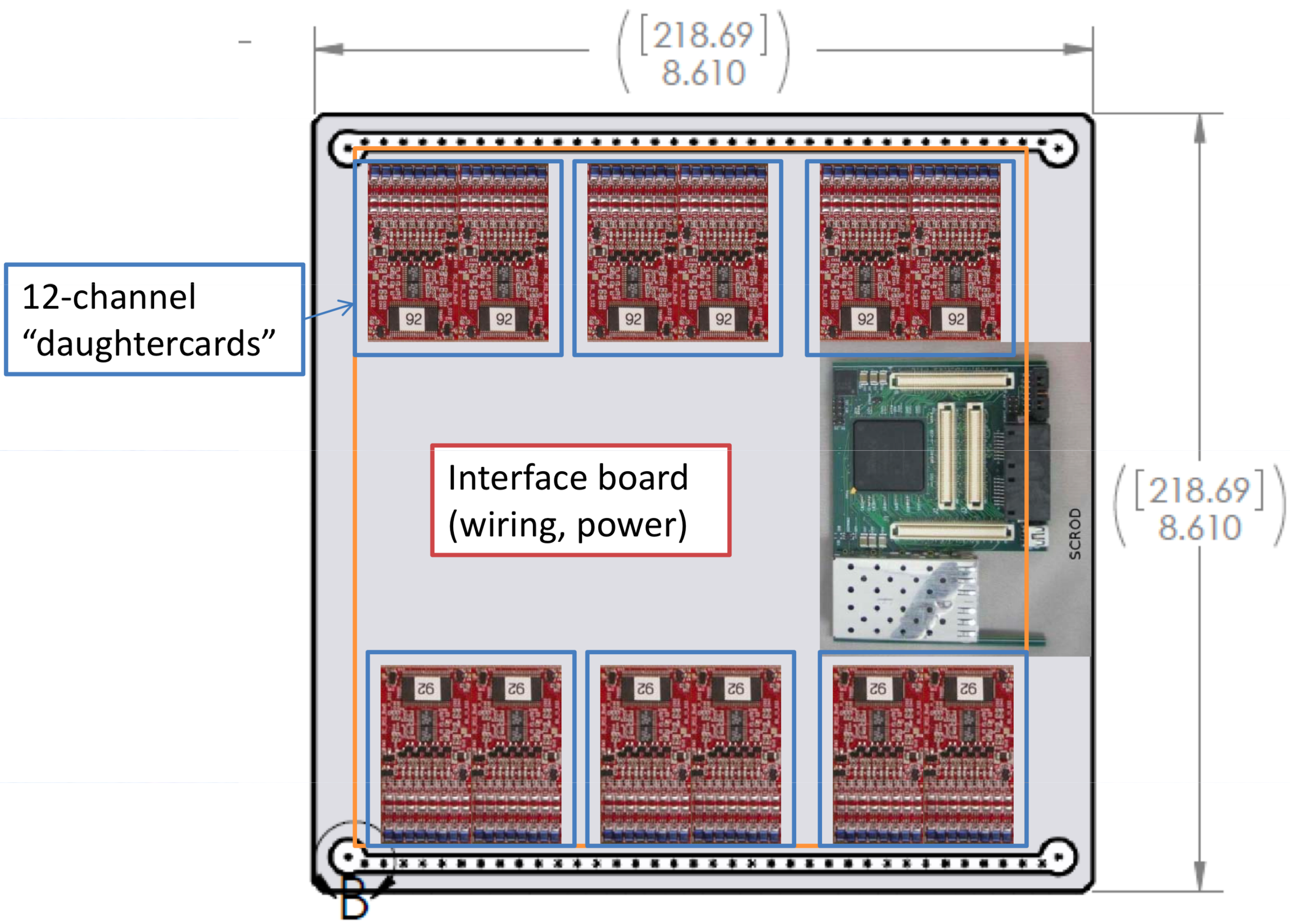
2 channel timing (window subset - 3.8ps sigma)



Working out various time-base calibration methods with Kurtis Nishimura (UH) -- should be implemented soon!

Configuration for Input ASIC Boards and IO Board Behind the 20cm Sealed Tube Detector

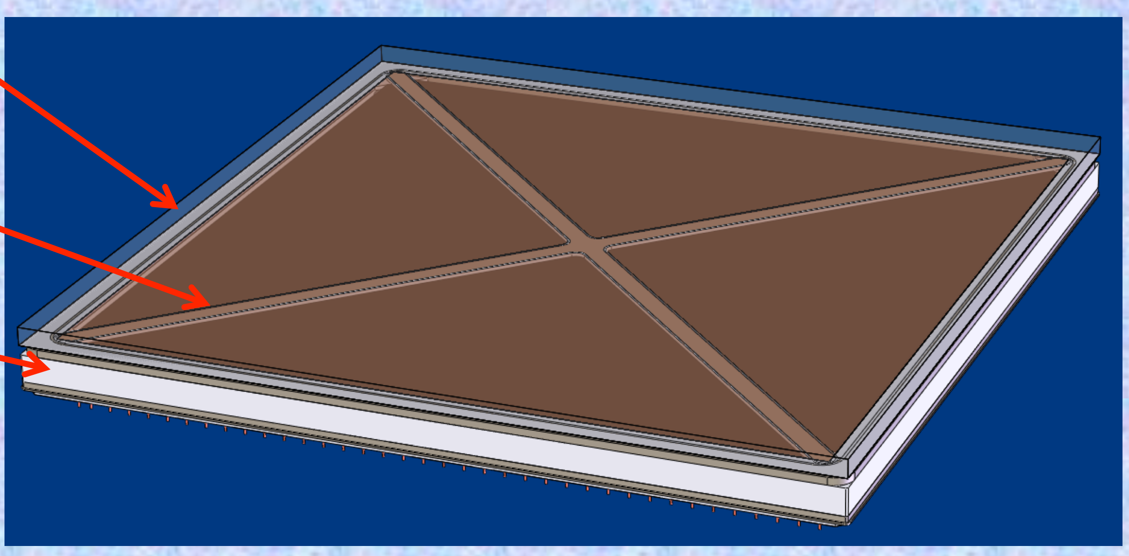
2x PSEC4, 2x IRS3, 1x TARGET per DC

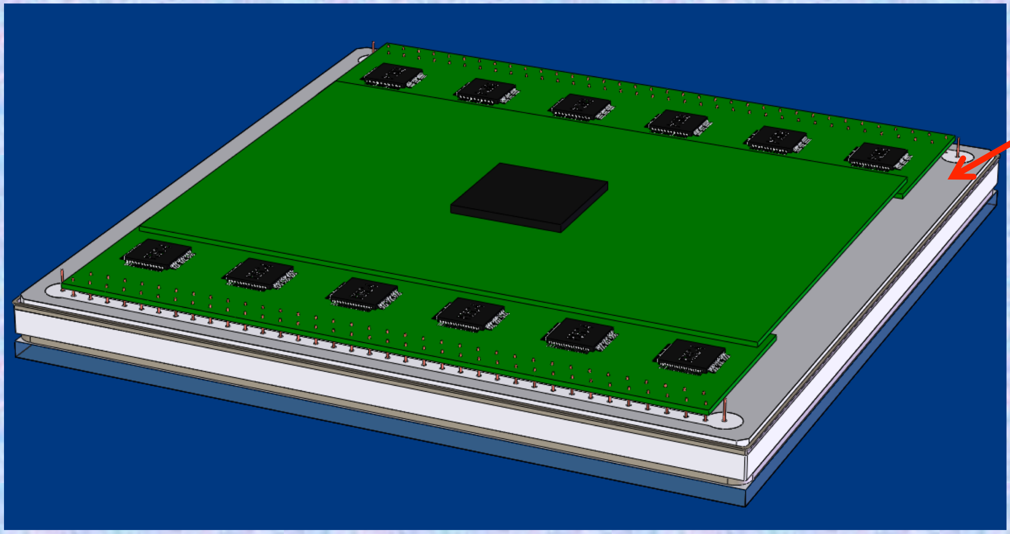


Large Area Picosecond Photodetector Structure

Window
Borofloat 33, 5mm thick input window & semitransparent bialkali photocathode
MCPs and "X" Spacers
Alumina parts brazed to form the hermetic package

Brazed Body Assembly
Alumina parts brazed to form the hermetic package

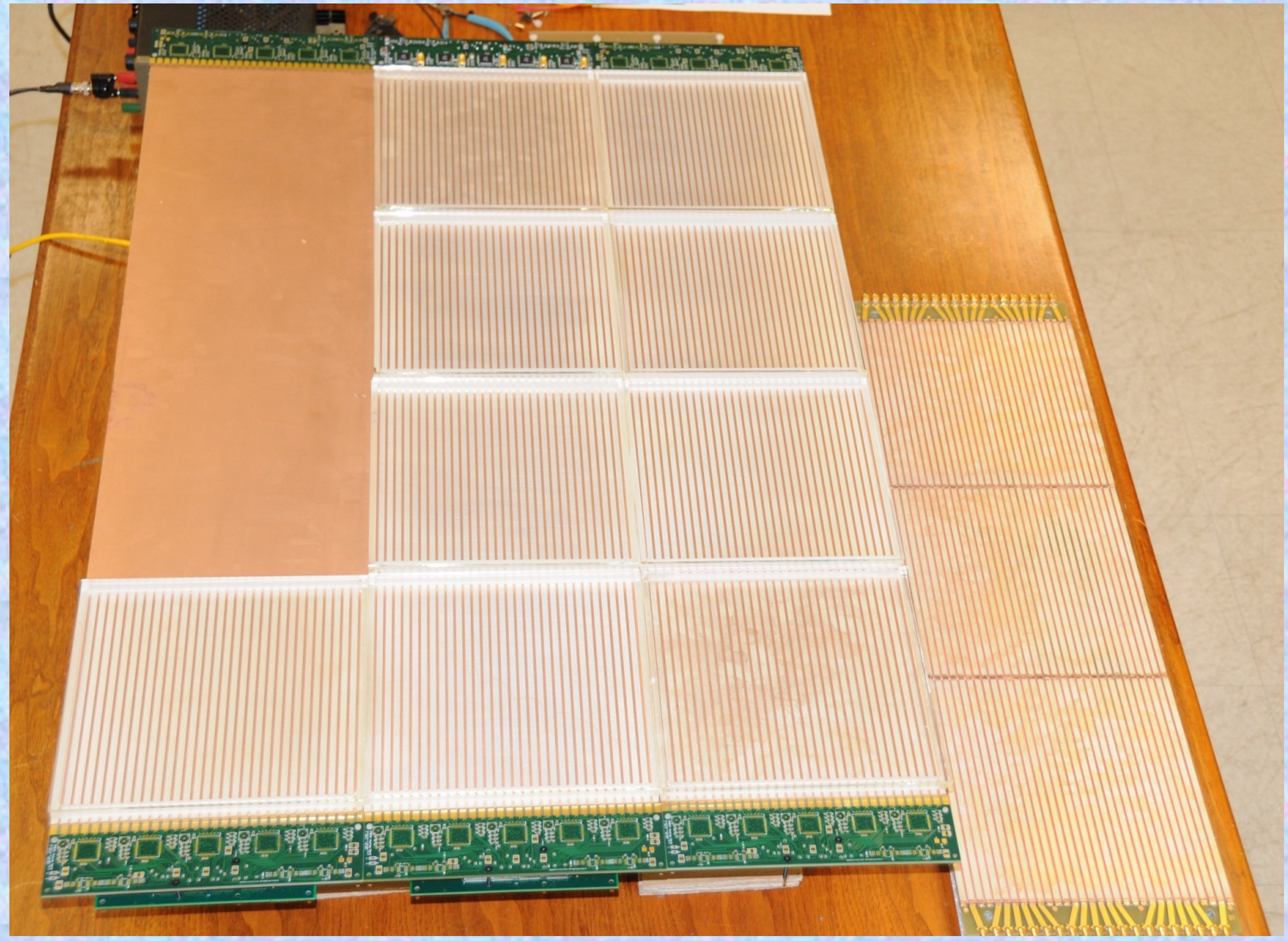




Anode
Alumina substrate with signal and HV pin contacts. 48 signal strips inside, complete Gnd plane outside. Signal & HV pins brazed in.

Electronics (See SORMA 14B-4)
Multichannel ASIC amplifier/disc/ADC on PCB attached to signal pins, and coupled to a digital processor board.

Super-Module Mockup



Argonne 20cm glass tile package parts- anode, side-wall, windows
Shows the stripline anodes (no MCPs)

Ultrafast Large Area Vacuum Detectors

Summary of New Prospects

- **ALD functionalized MCPs using borosilicate glass microcapillary arrays have been successfully made in 33mm and 20cm formats with 20µm and 40µm pores and 8° bias.**
- **Most of the performance characteristics are similar to standard commercial MCPs both in analog and photon counting modes.**
- **MCP preconditioning shows very good gain, outgas and stability.**
- **Initial 20cm, 40/20µm pore MCPs show normal gain behavior.**
- **Intrinsic background rates are low, <0.1 events cm^{-2} sec^{-1}.**
- **Design and fabrication of 20cm sealed tube is well advanced.**
- **We have made semitransparent Bialkali (25%) cathodes on borosilicate.**

This work was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences and Office of High Energy Physics under contract DE-AC02-06CH11357, and NASA grant #NNX11AD54G .