Development of Large Area Fast Microchannel Plate Photodetectors

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for the **L**arge **A**rea **P**icosecond **P**hoto**D**etector (LAPPD) Collaboration
Argonne National Laboratory

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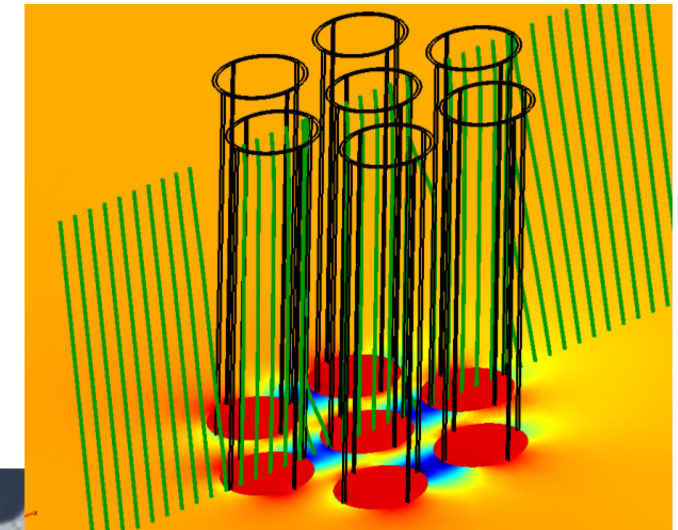
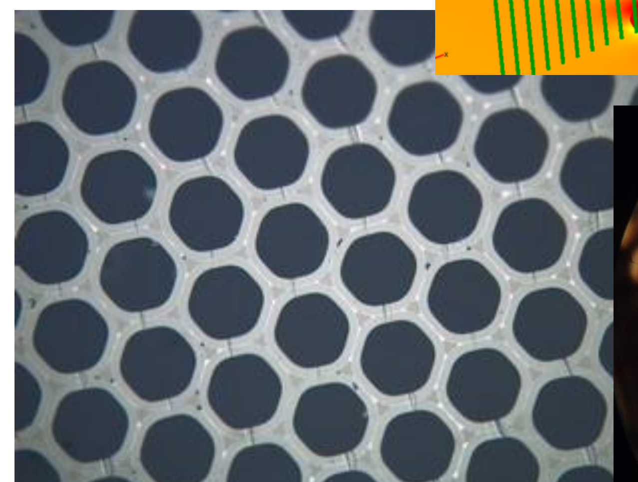
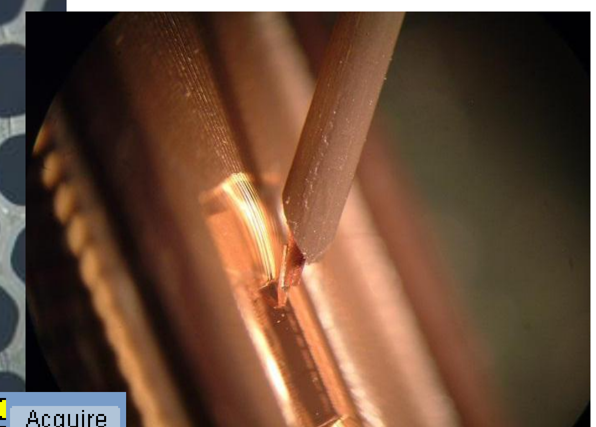
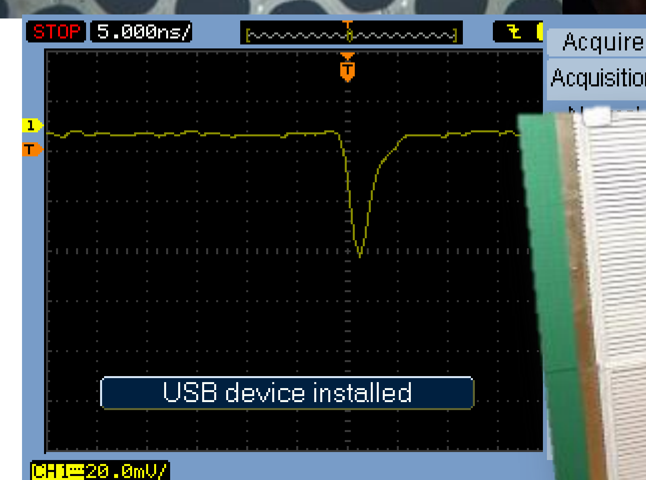
Talk Outline

- Introduction and Overview
- MCP Development
- Photocathodes
- Anode and signal readout
- Mechanical Design
- Simulations and Testing
- Conclusion









Introduction: The LAPPD Collaboration

Large Area Picsecond Photodetector Collaboration

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Oswald Siegmund, Anton Tremsin

Space Sciences Laboratory, University of California, Berkeley, CA

Dimitri Routkevitch

Synkera Technologies Inc., Longmont, CO

David Forbush, Tianchi Zhao

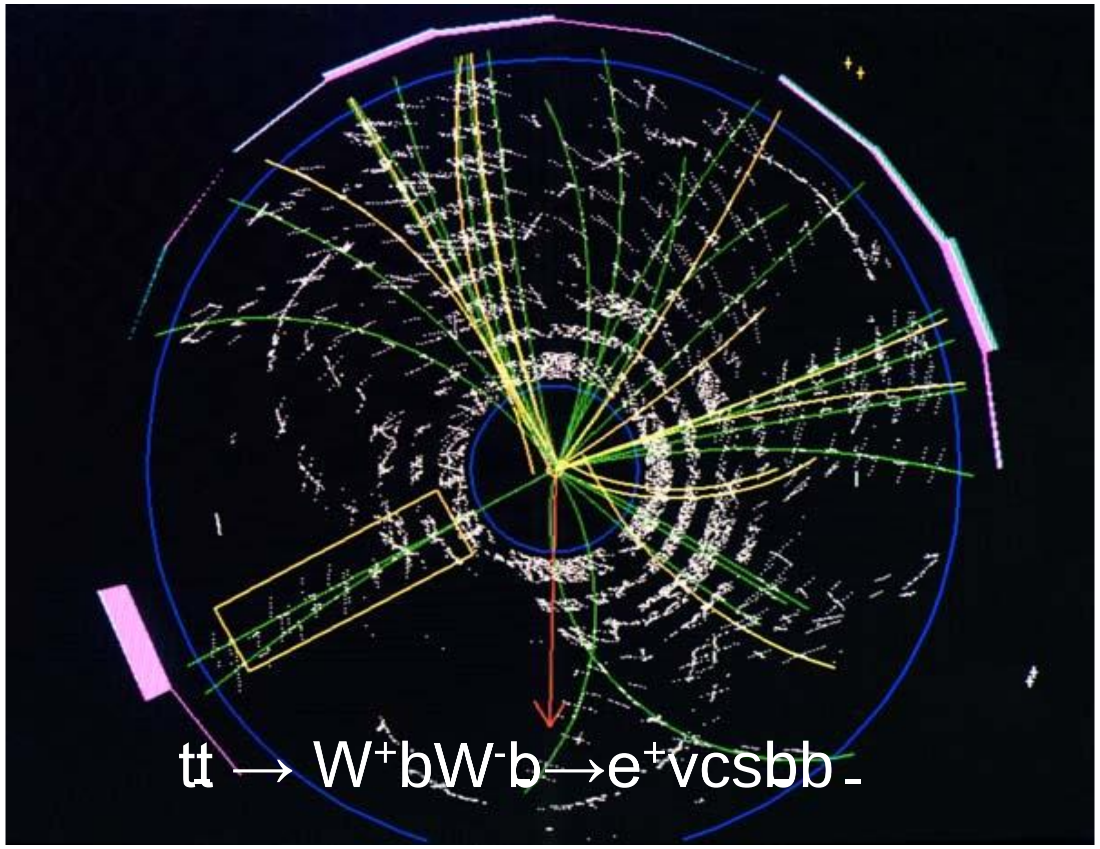
Department of Physics, University of Washington, Seattle，WA

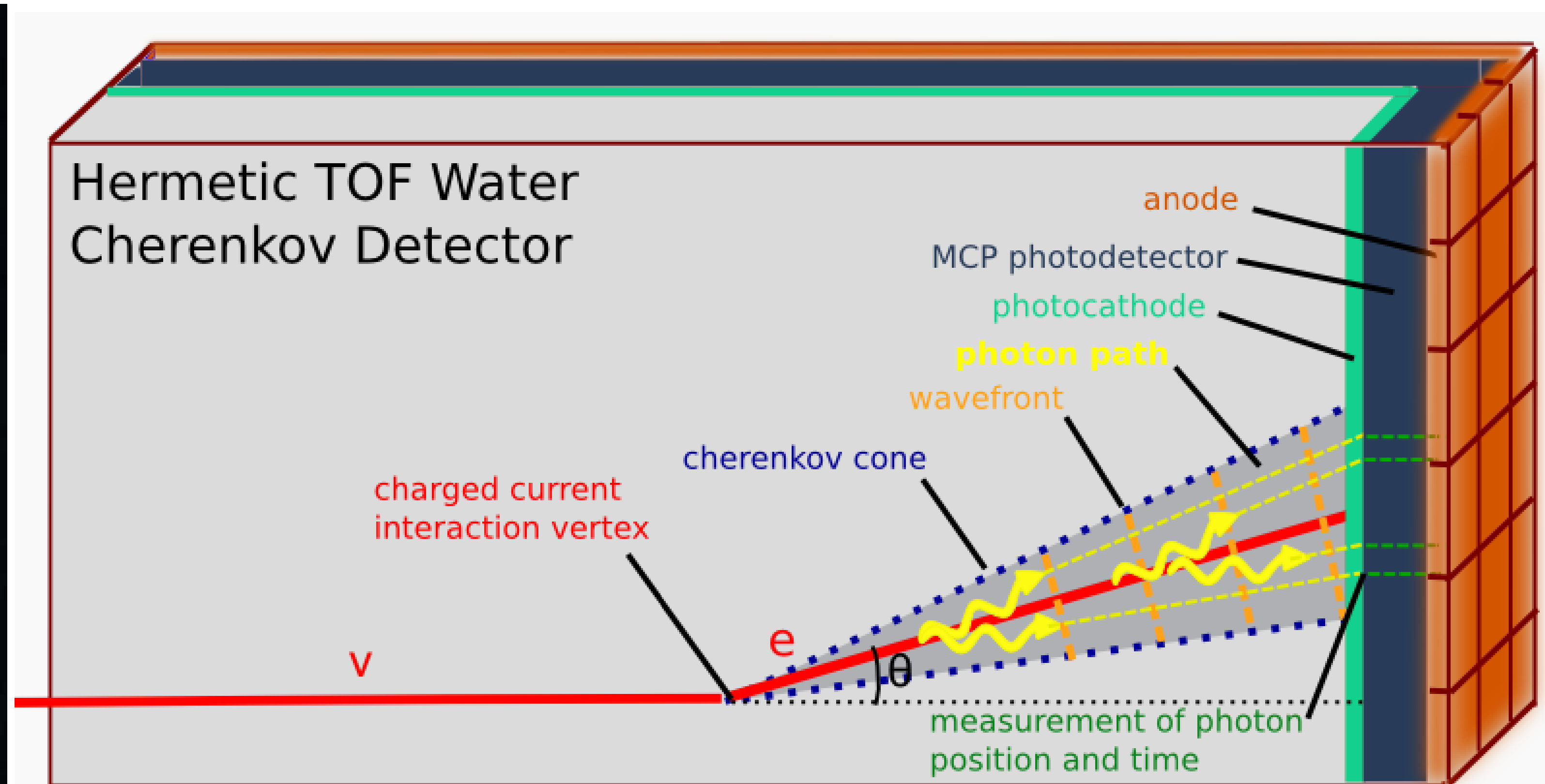
- Newly funded (end of August 2009) by DOE and NSF
- 4 National Labs
- 5 Divisions at Argonne
- 3 US small companies;
- Electronics expertise at Universities of Chicago and Hawaii
- Photocathode expertise at Washington University, St. Louis and Univ. of Illinois, Chicago

Goals:

- **Exploit advances in material science and nanotechnology to develop new, batch methods for producing cheap, large area MCPs.**
- **Develop path to a commercializable product on a three year time scale (approaching the end of .year 2 – this summer)**

Overview: Motivation

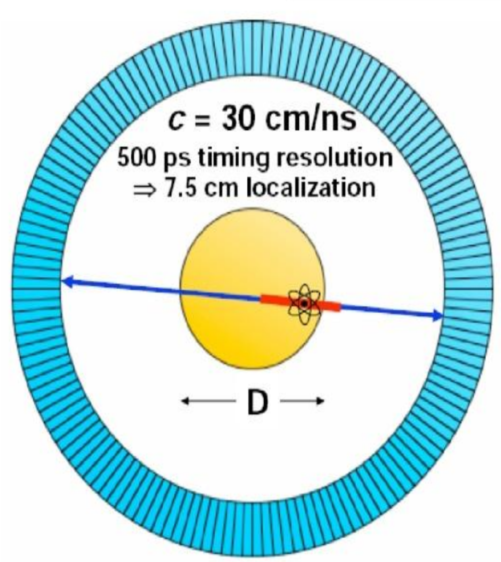




Complete particle measurement: E, p + m(PID)
1ps time & 1mm space resolution, $100k/m^2

Water Cherenkov neutrino detector (DUSEL) ~80-90% coverage and 3-d photon vertex reconstruction
100ps time & 10mm space resolution, $10k/m^2

Time-of-Flight in PET



- Can localize source along line of flight.
- Time of flight information reduces noise in images.
- Variance reduction given by 2D/cΔt.
- 500 ps timing resolution ⇒ 5x reduction in variance!

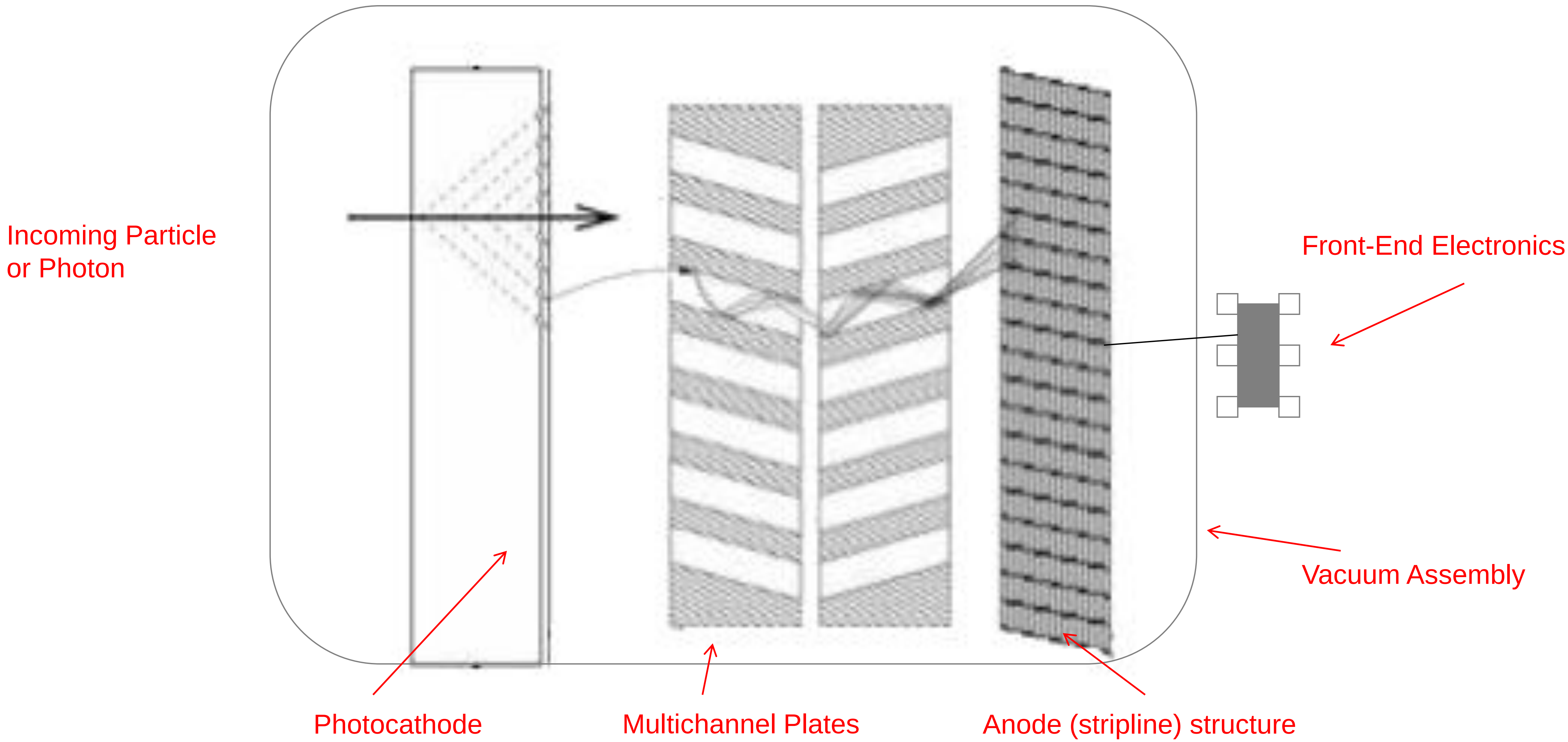
- Time of Flight Provides a *Huge* Performance Increase!

TOF (Effective Efficiency) Gain for Whole-Body PET (35 cm)

Hardware	Δt (ps)	TOF Gain
BGO Block Detector	3000	0.8
LSO Block (non-TOF)	1400	1.7
LSO Block (TOF)	550	4.2
$LaBr_3$ Block	350	6.7
LSO Side Coupled	250	9.3
LSO Small Crystal	210	11.1
LuI_3 Small Crystal	125	18.7
$LaBr_3$ Small Crystal	70	33.3

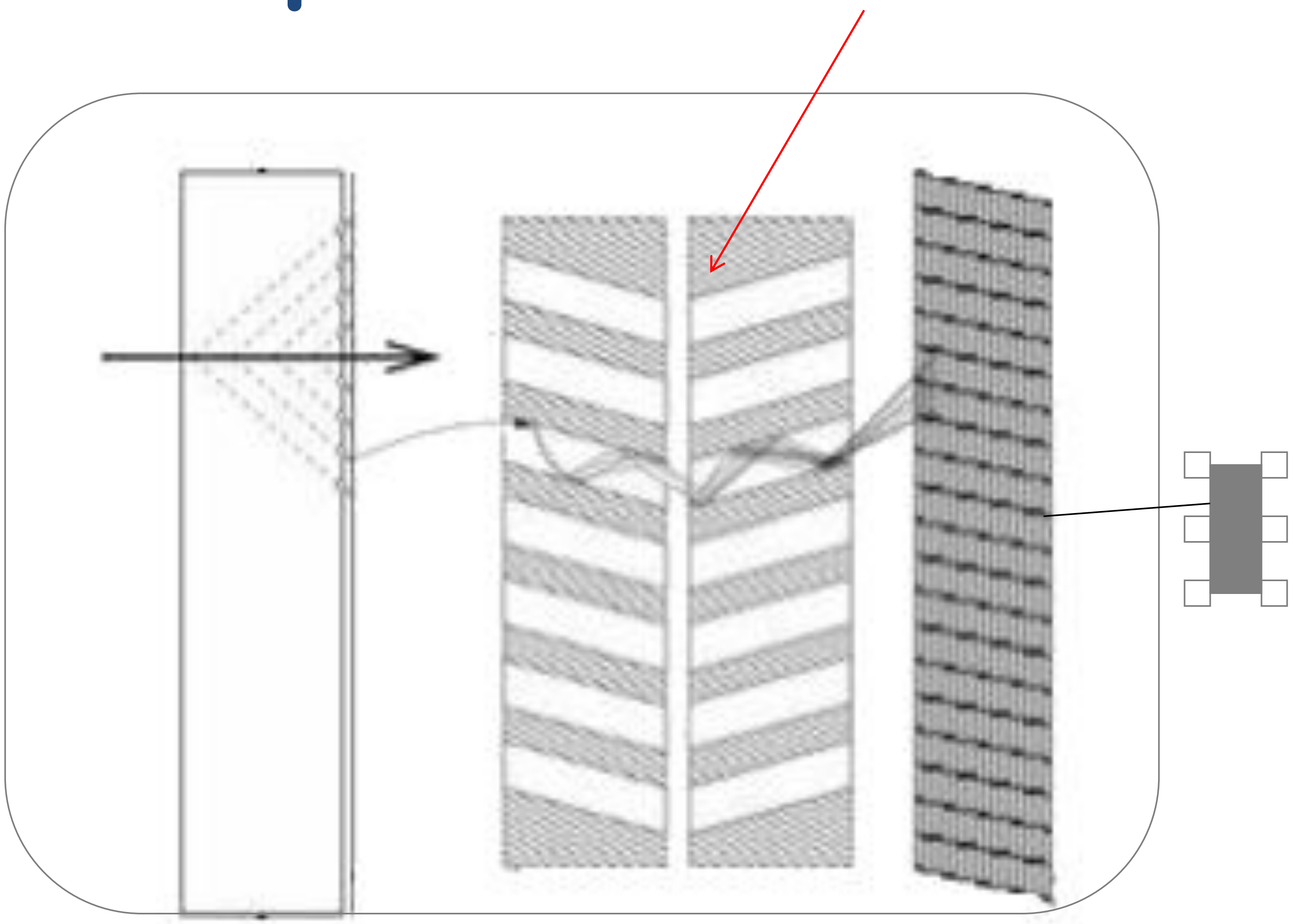
- *Incredible* Gains Predicted
- *Nothing* Else Can Give Us Gains of This Size!

Overview: Micro Channel Plates PMTs

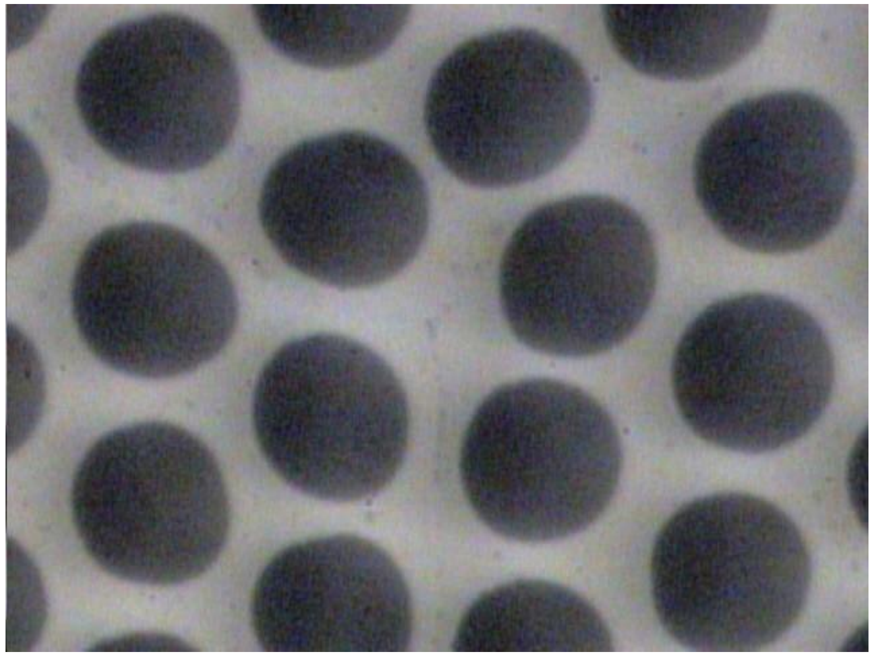


Photon and electron paths are short – few mm to microns which results in fast, uniform Planar geometry, scalable to large areas

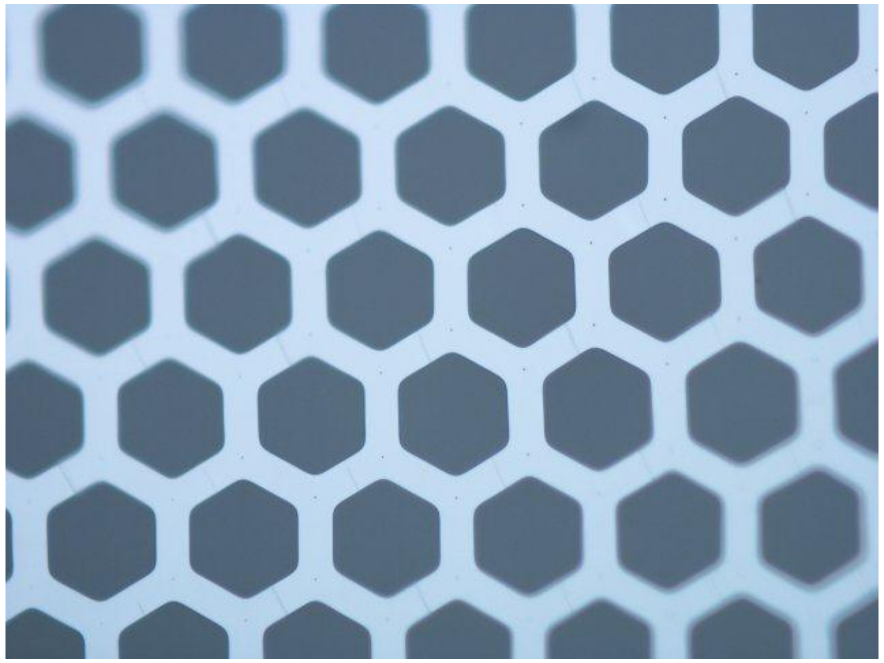
MCP Development



MCP Development: Simplifying MCP Construction



Conventional Pb-glass MCP



Incom Glass Substrate

Chemically produced and treated

- Pb-glass provides 3 functions:
  - Provides pores
  - Resistive layer supplies electric field in the pore
  - Pb-oxide layer provides secondary electron emission

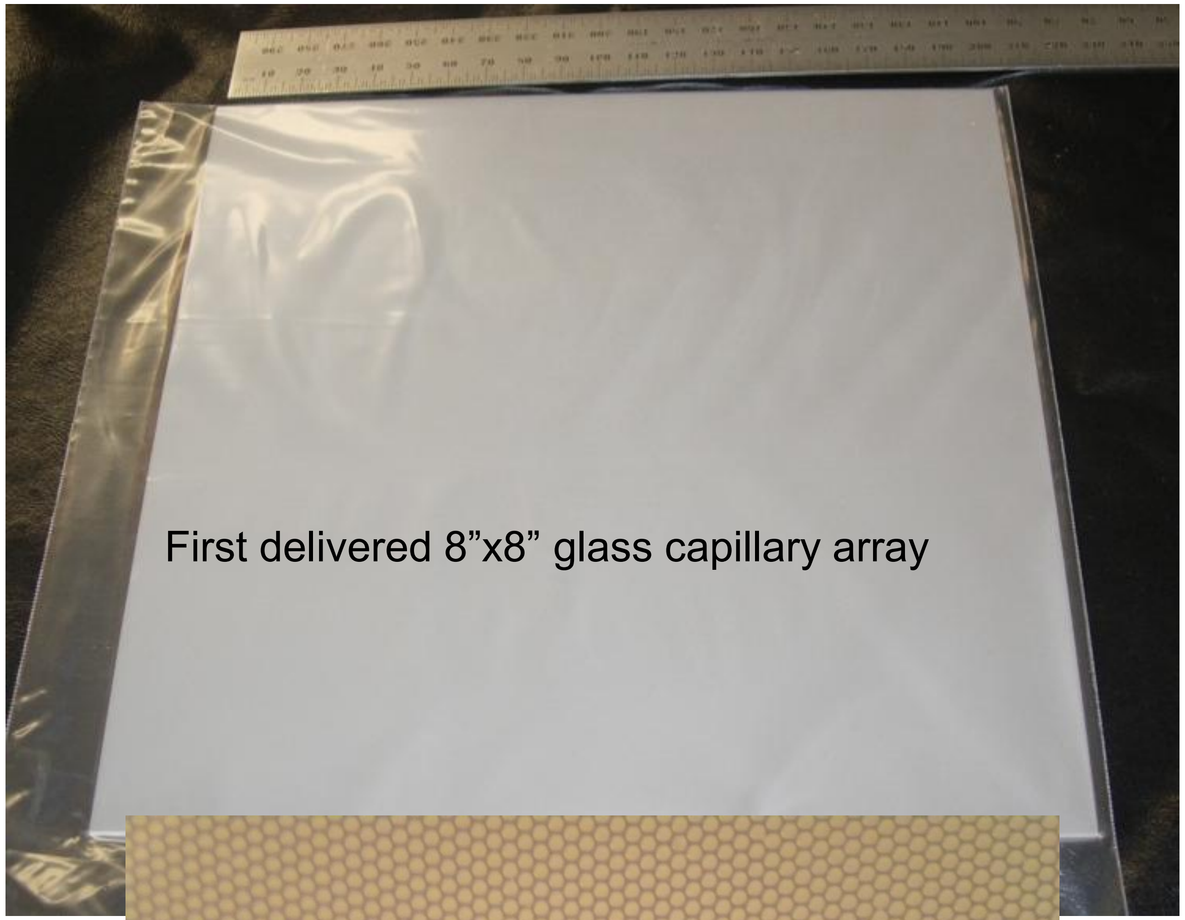
Separate the three functions:

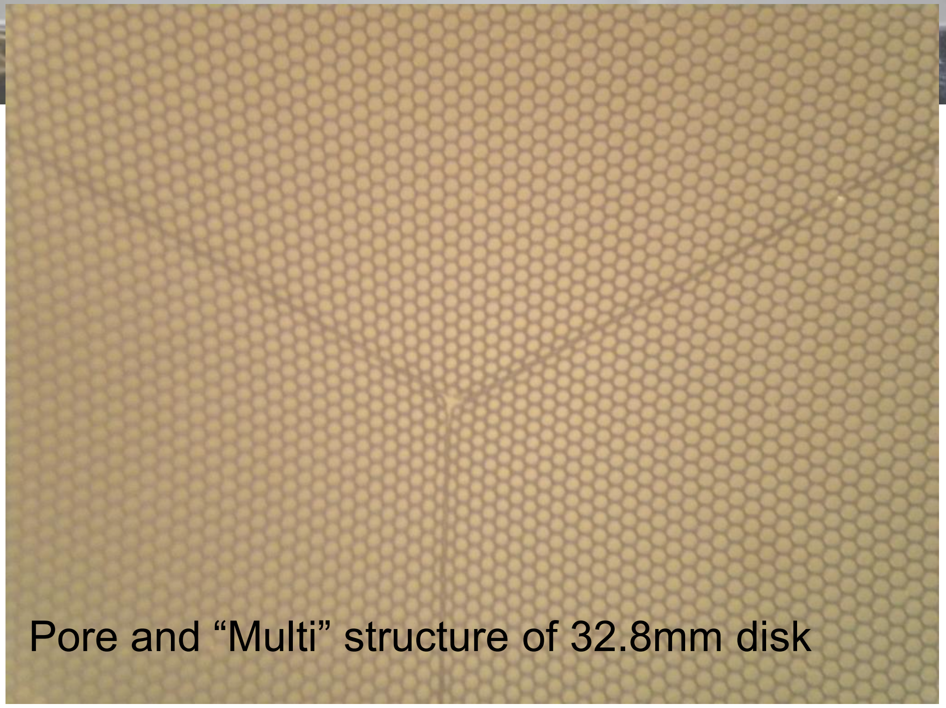
- Hard glass substrate provides pores
- Separate Resistive and Emissive layer functions
- Produce Tuned Resistive Layer (Atomic Layer Deposition, ALD) provides current for electric field;
- Specific Emitting layer provides secondary electron emission

MCP Development: Glass Capillary Substrate Development

Incom

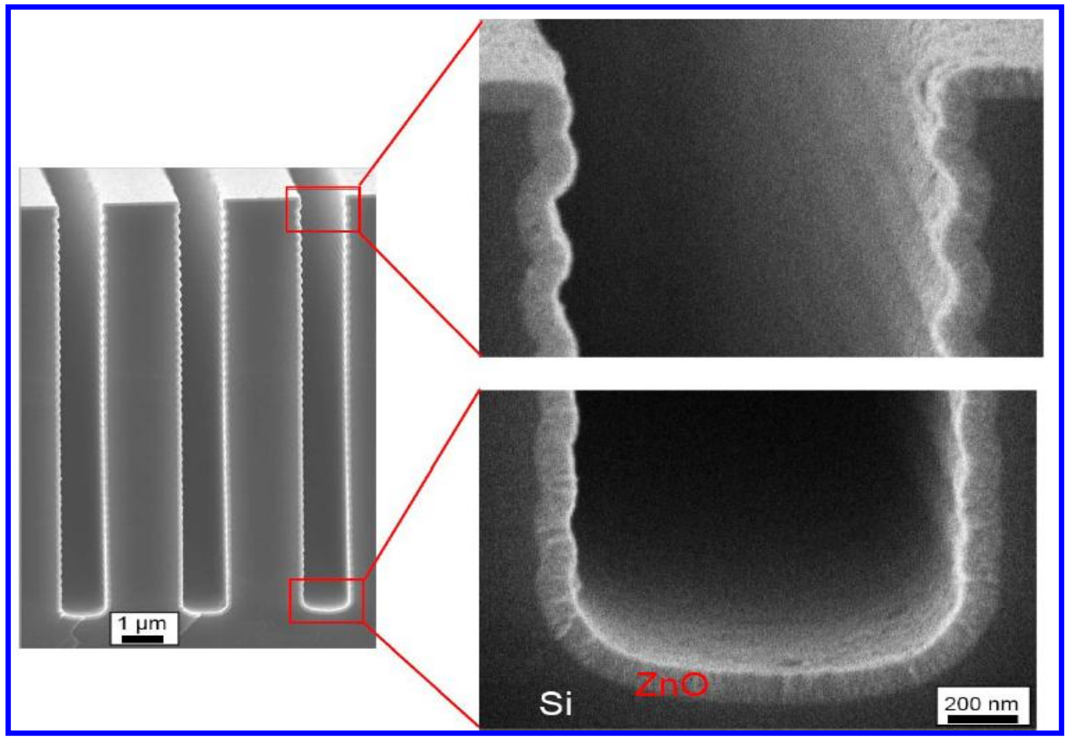
- Glass substrate development, fabrication, finishing by Incom, Inc. (Charlton, MA, USA)
  - Borosilicate glass capillary
- Disk development substrates produced in quantity (for R&D)
  - 32.8mm diameter
  - 20µm pore L/D=60
- All substrate pores have 8˚ bias w.r.t axis ⊥ to substrate
  - Used in pair chevron configuration to reduce positive ion feedback damage to photocathode
- **First four 8”×8” 20µm pore substrates delivered Aug 2010**

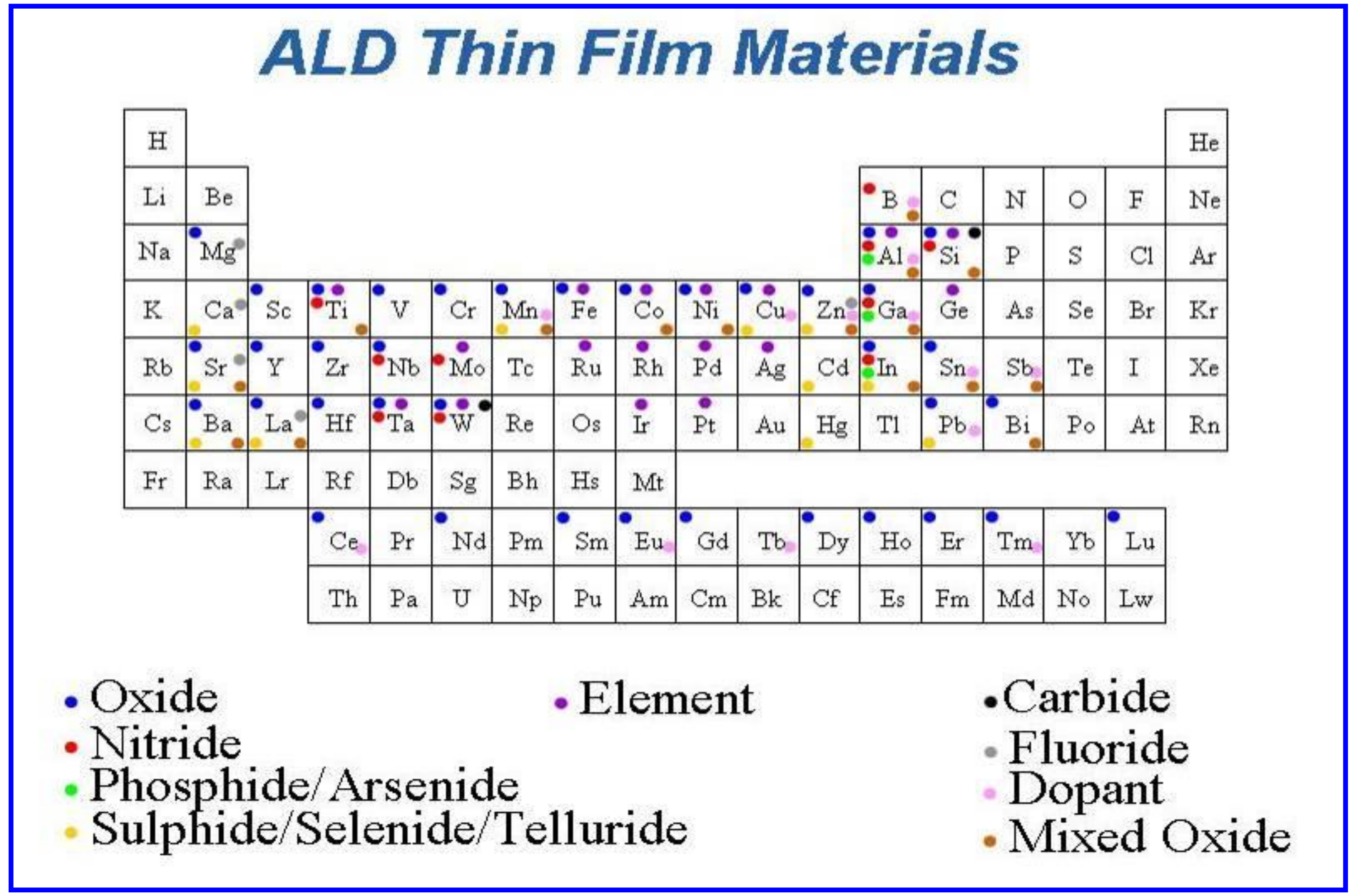

First delivered 8”x8” glass capillary array


Pore and “Multi” structure of 32.8mm disk

MCP Development: Atomic Layer Deposition

Argonne, Arradiance





J. Elam, A. Mane, Q. Peng, T. Prolier (ANL:ESD/HEP), N. Sullivan (Arradiance), A. Tremsin (Arradiance, SSL)

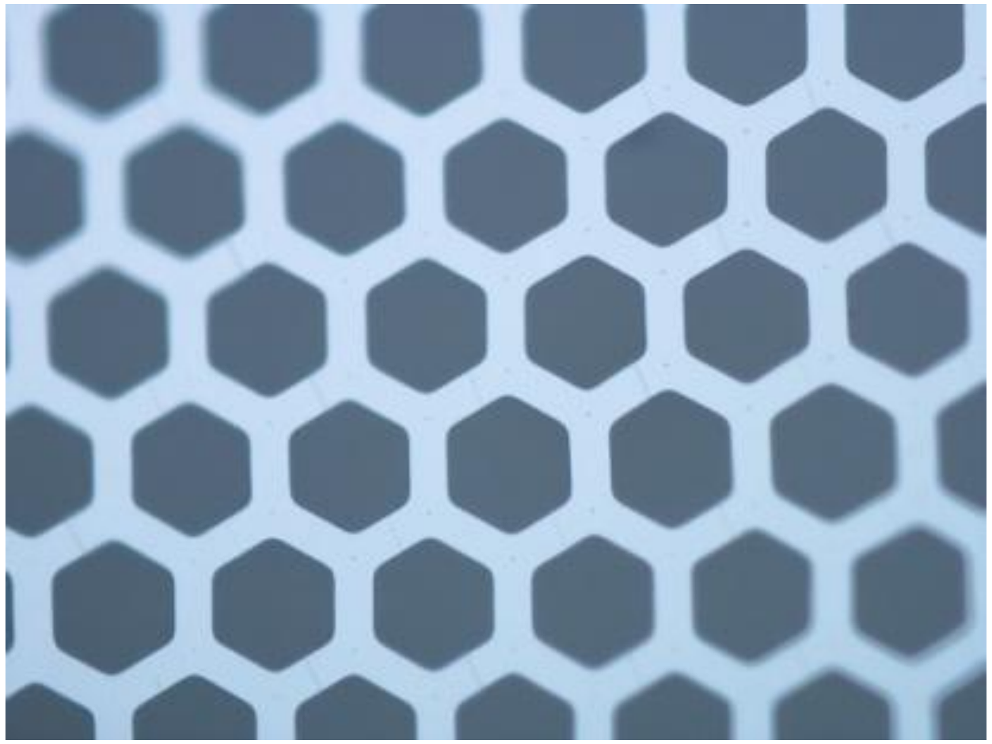
- A conformal, self-limiting process.
- Allows atomic level thickness control.
- Applicable for a large variety of materials.

Poster by Anil Mane on ALD and LAPPD project: Thur Conf. 8031

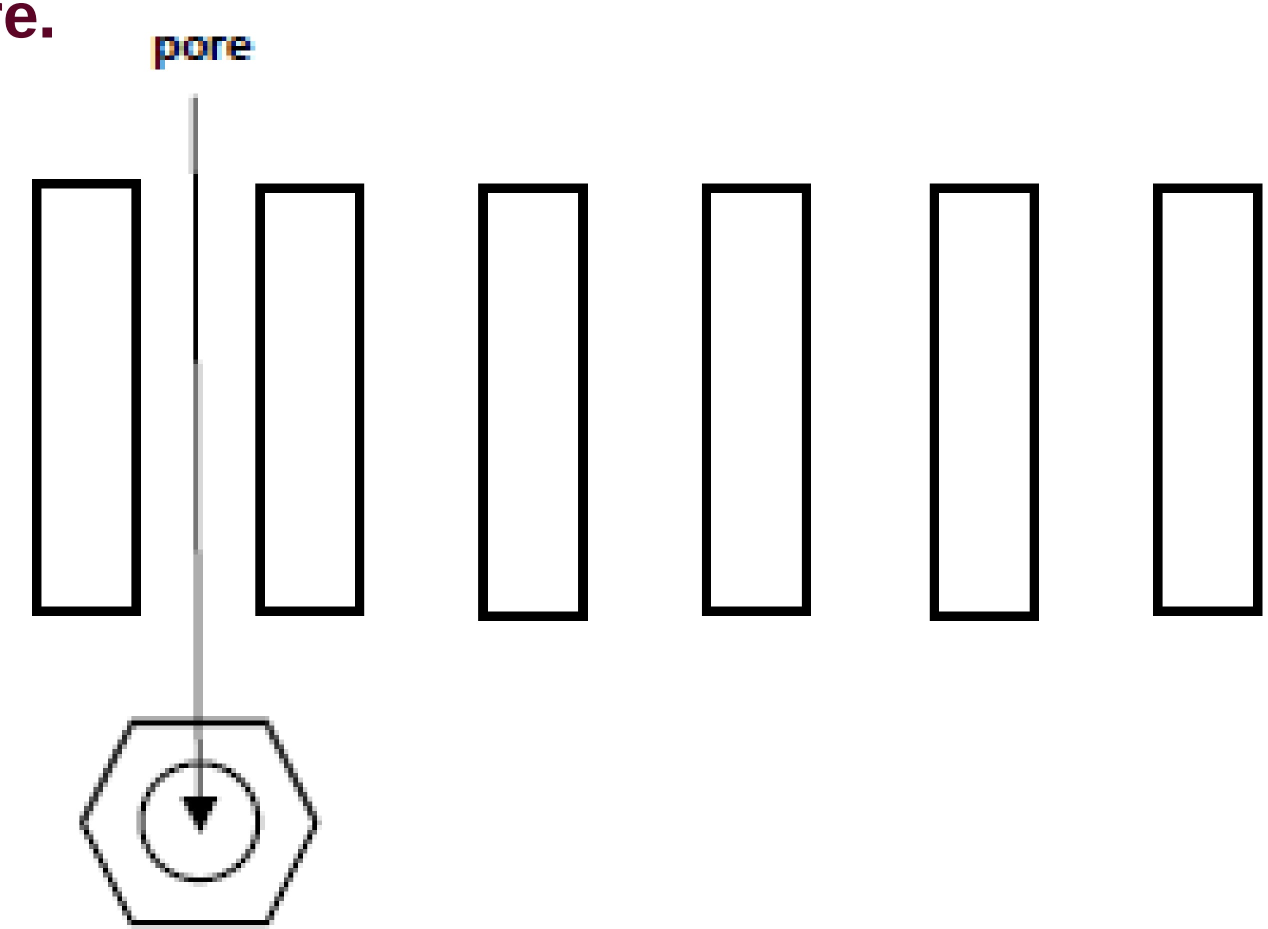
MCP R&D : Channel Plate Fabrication w/ ALD

1. **Start with a porous, insulating substrate that has appropriate channel structure.**

Incom



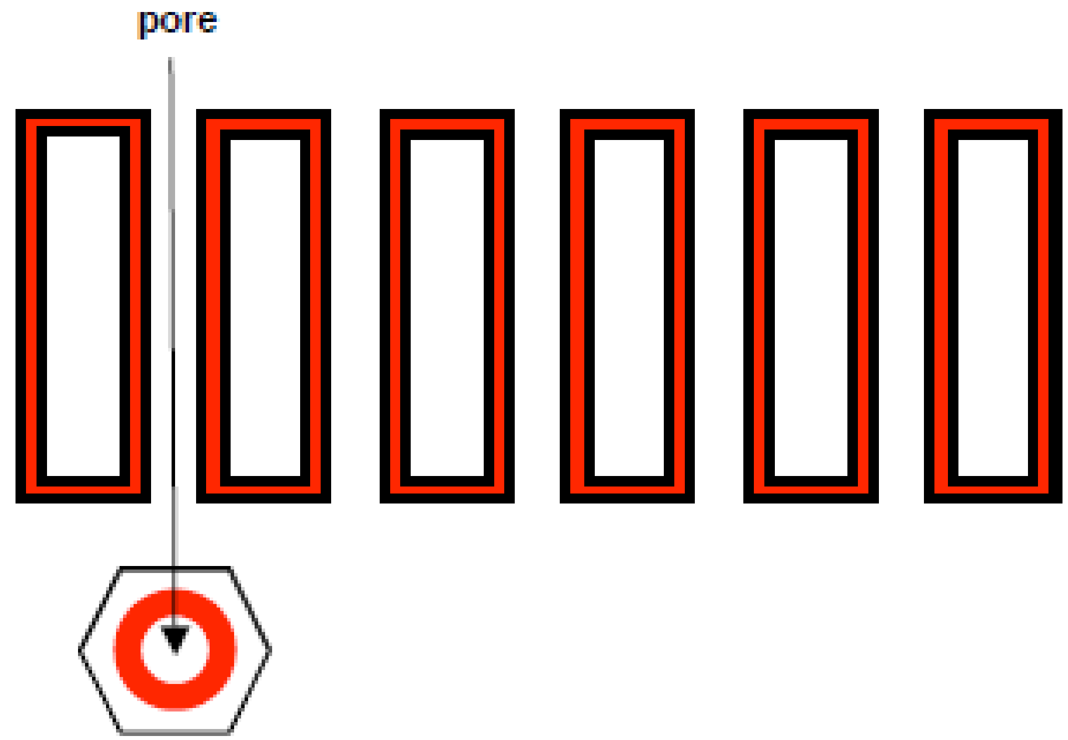
borosilicate glass filters



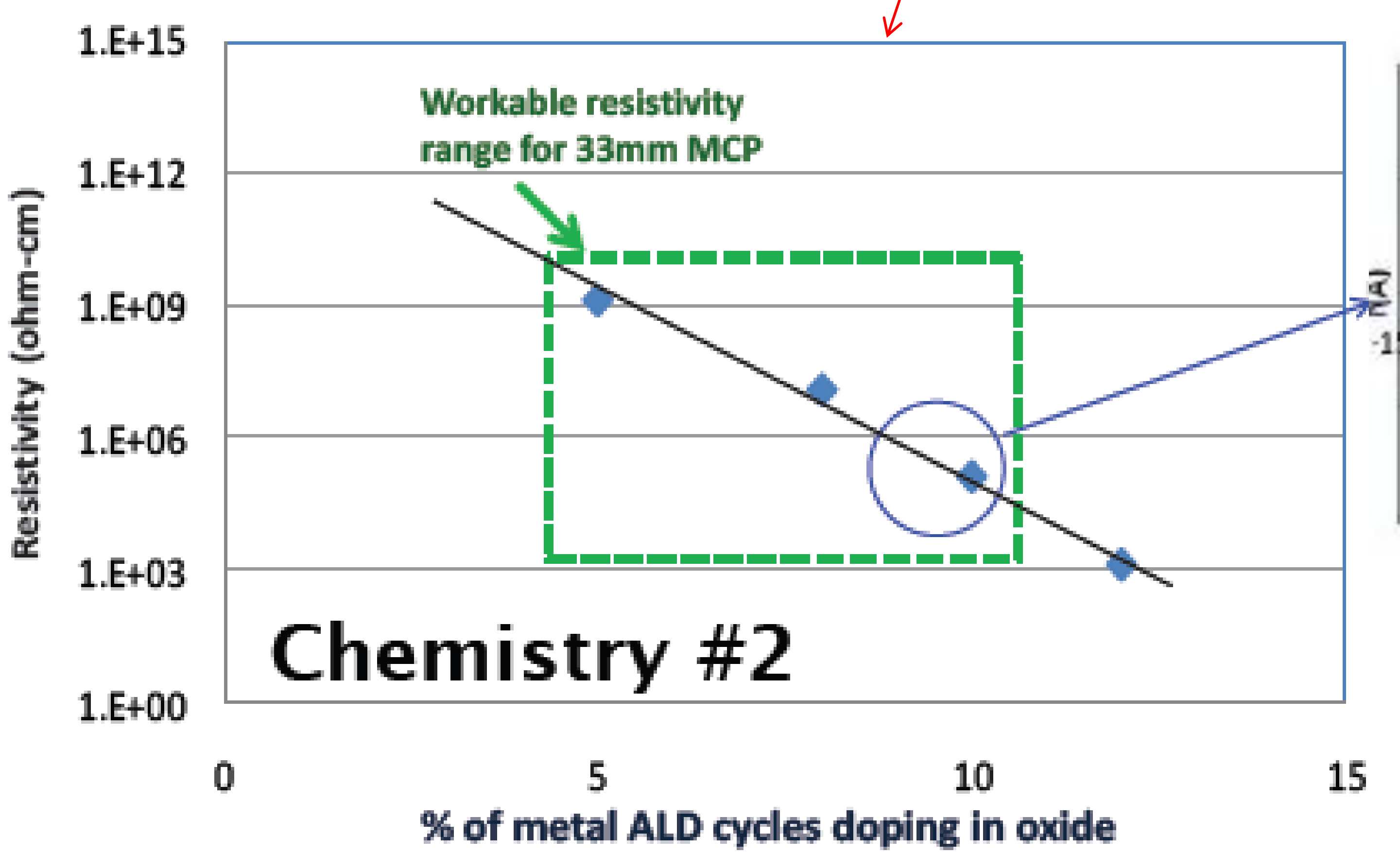
U.S. DEPARTMENT OF ENERGY

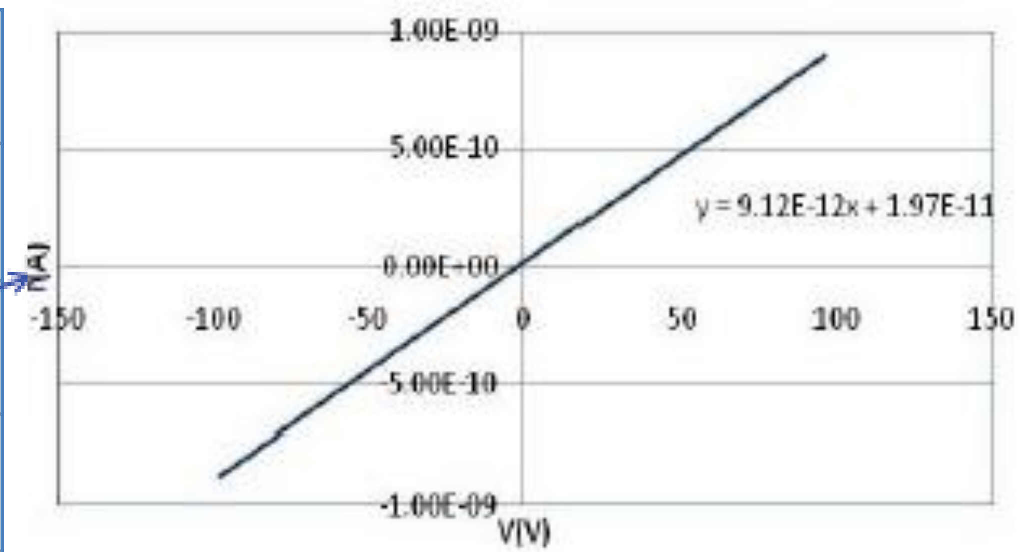
MCP R&D : Channel Plate Fabrication w/ ALD

2. Apply a resistive coating (ALD)



- *Good control of resistivity*
- *Uniform, smooth coating w/no etching*
- *Functionalized pair exhibited high gain*
- *Scalable to large surface*

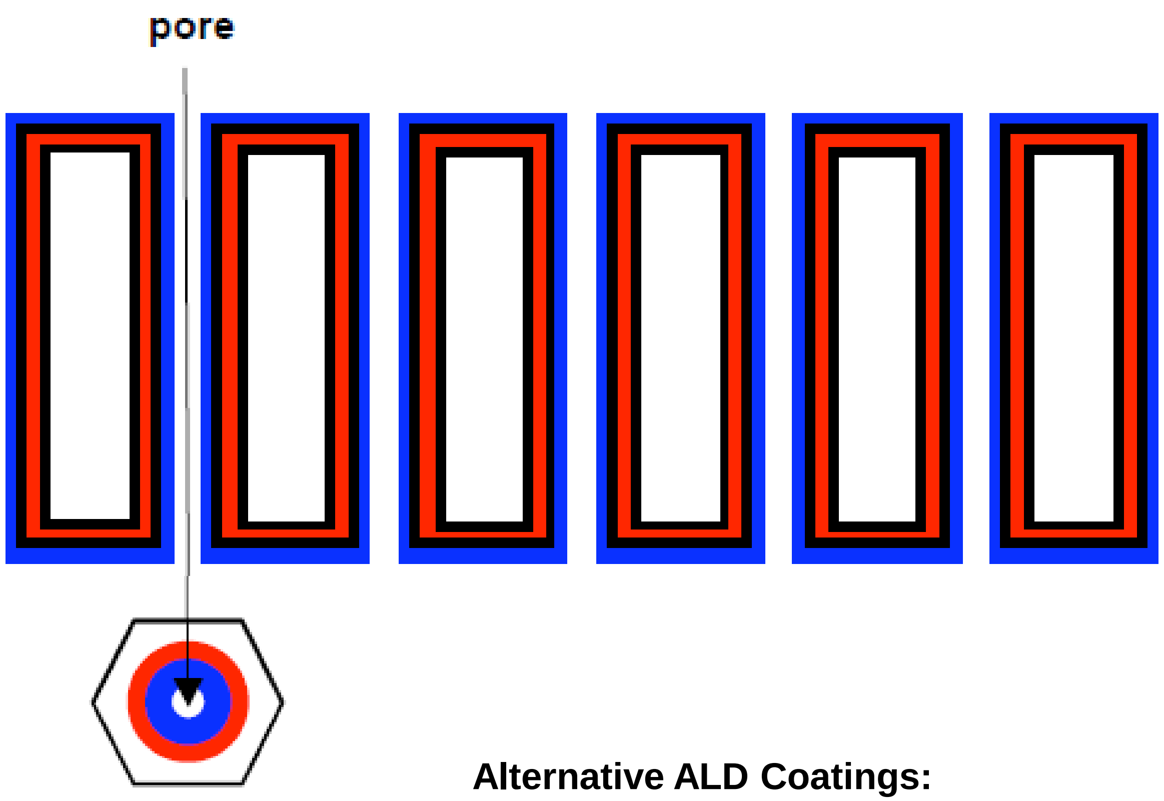




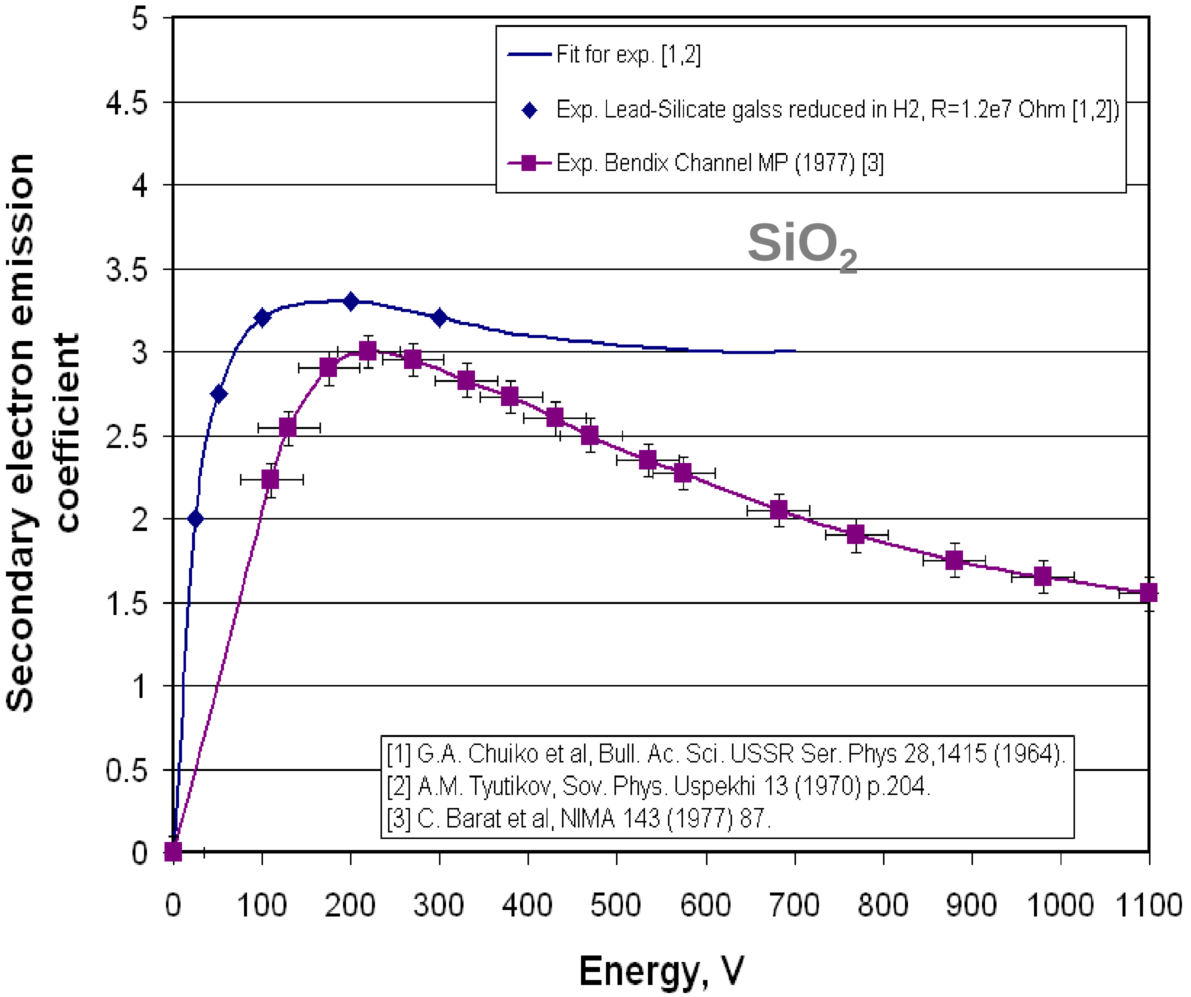
•Linear I-V on Glass

MCP R&D : Channel Plate Fabrication w/ ALD

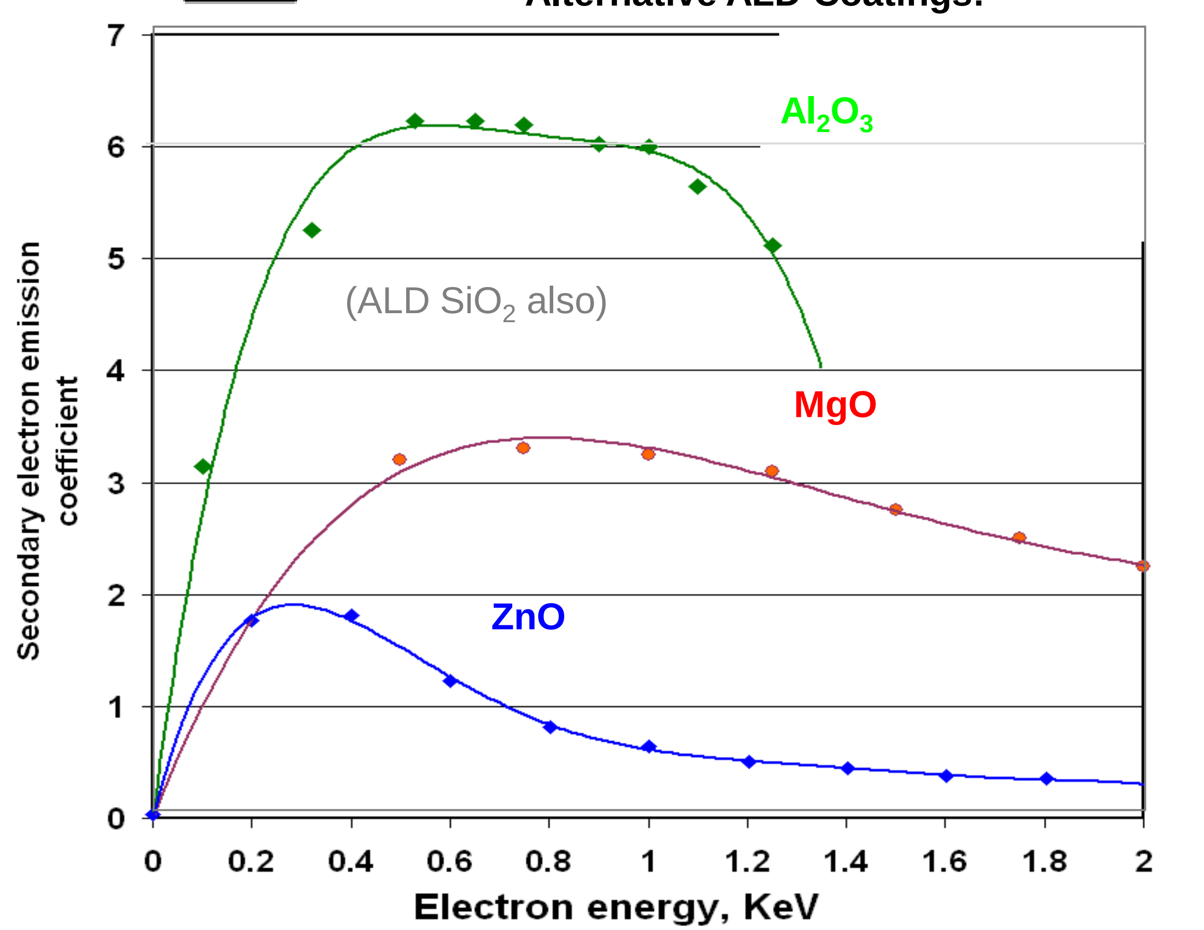
3. **Apply an emissive coating (ALD)**



Conventional MCP's:

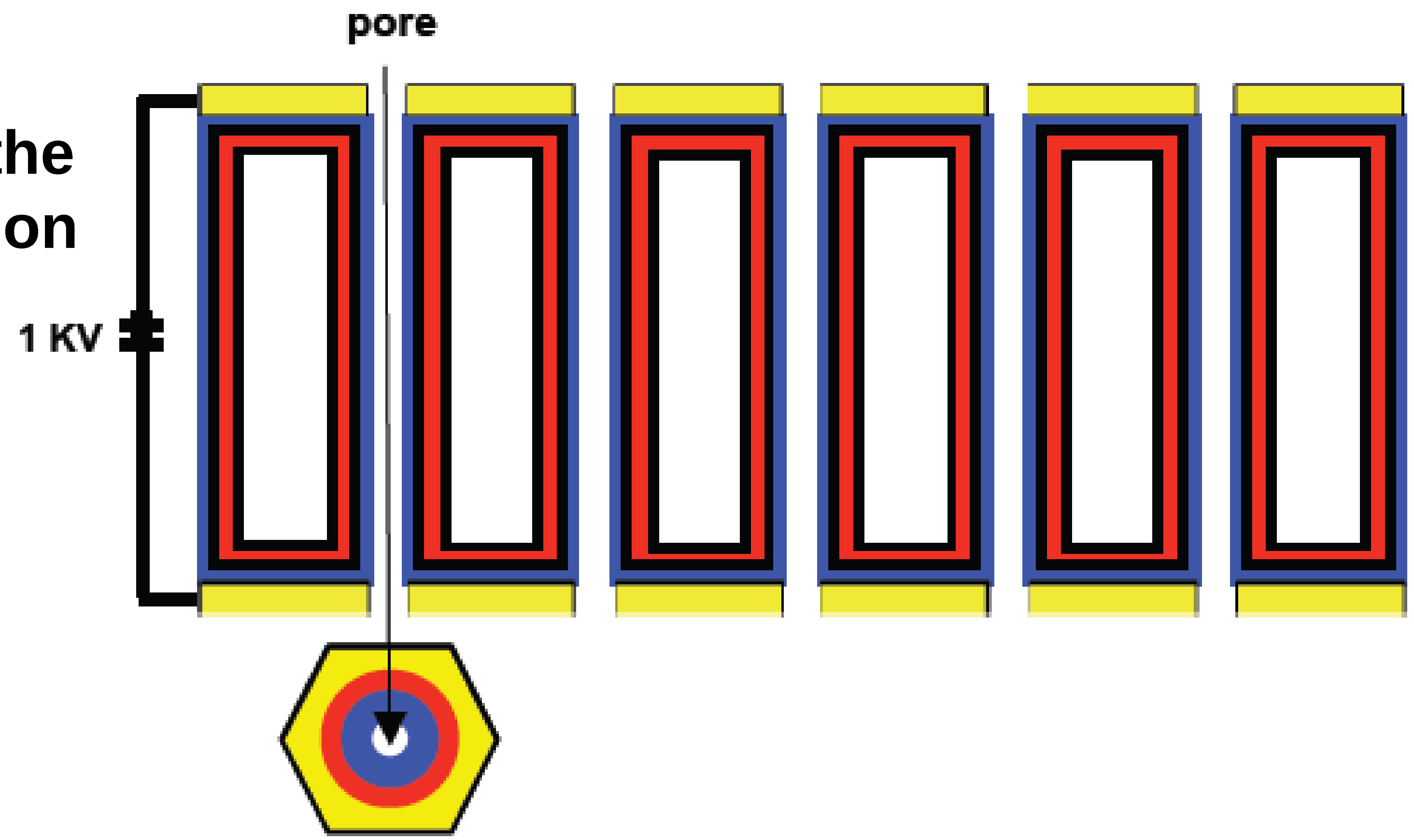


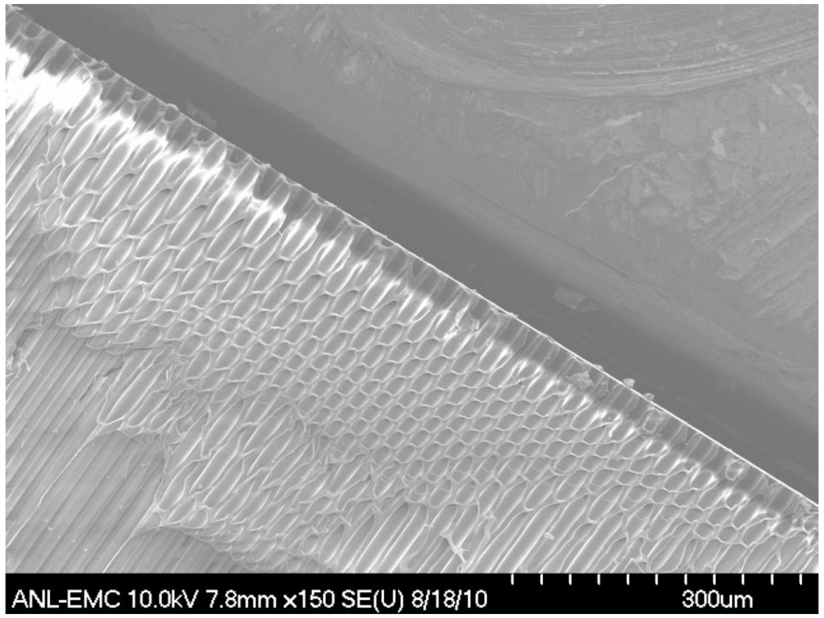
Alternative ALD Coatings:

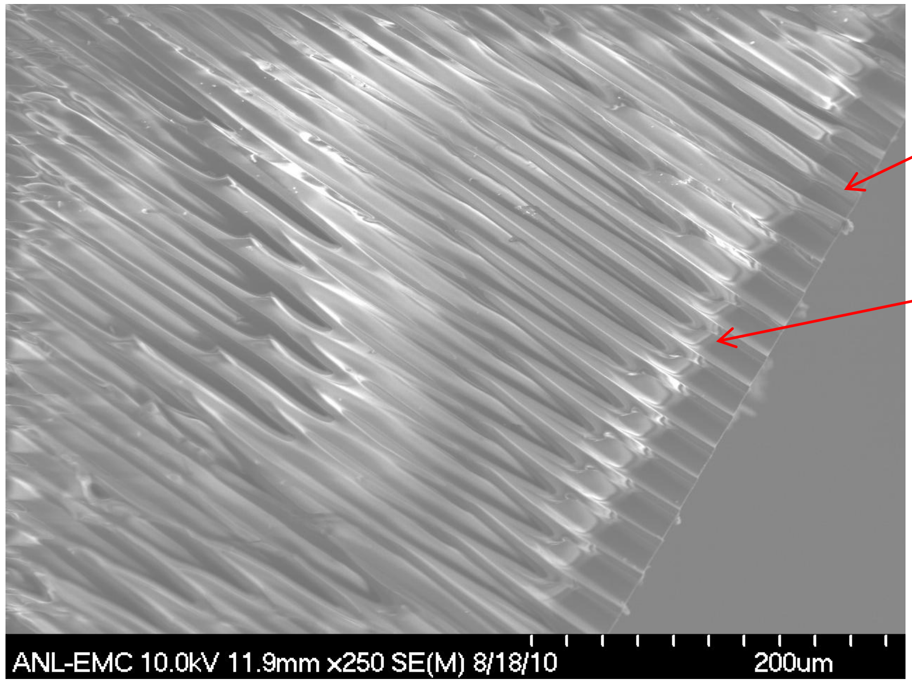


MCP R&D : Channel Plate Fabrication w/ ALD

4. **Apply a conductive coating to the top and bottom (thermal evaporation or sputtering)**

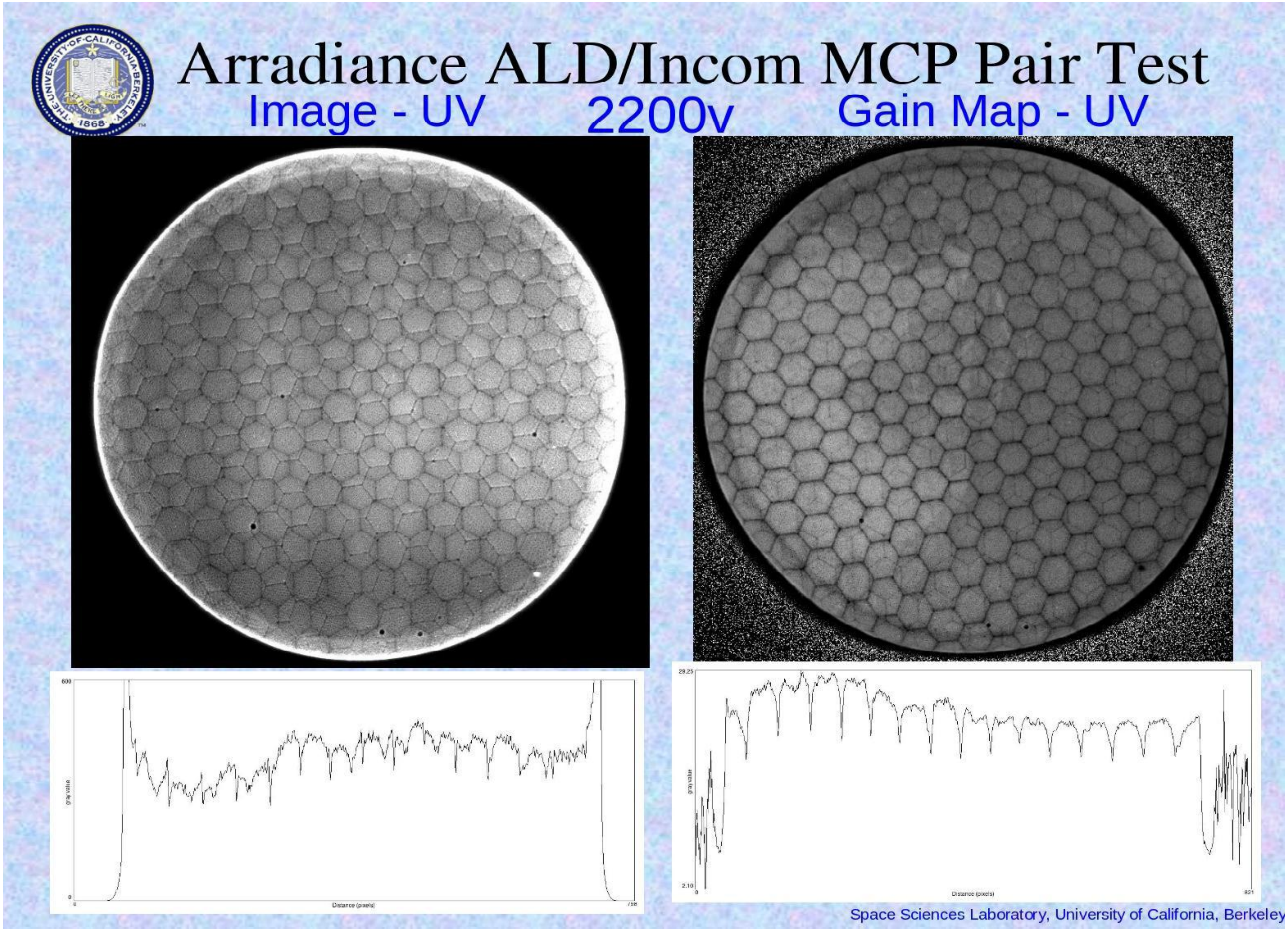




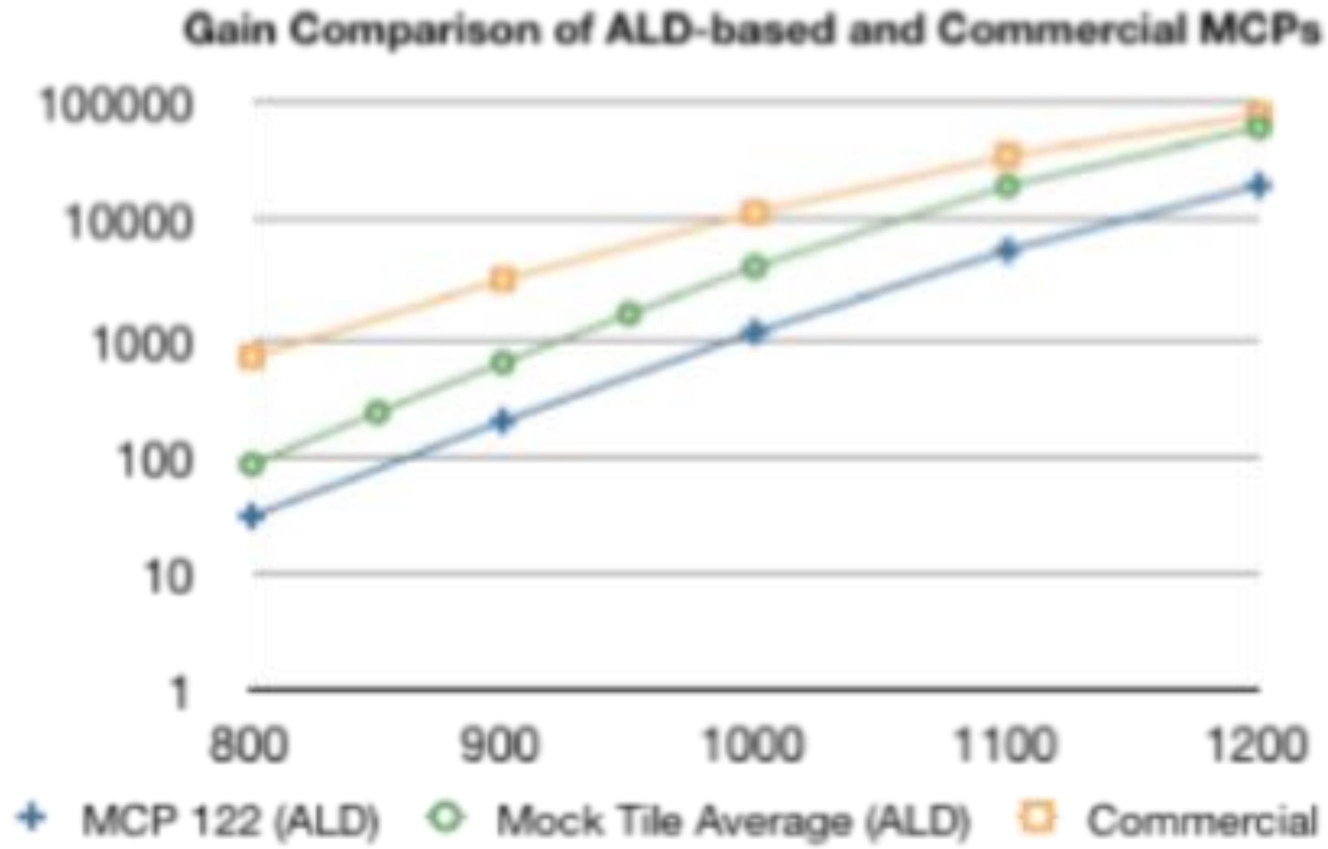


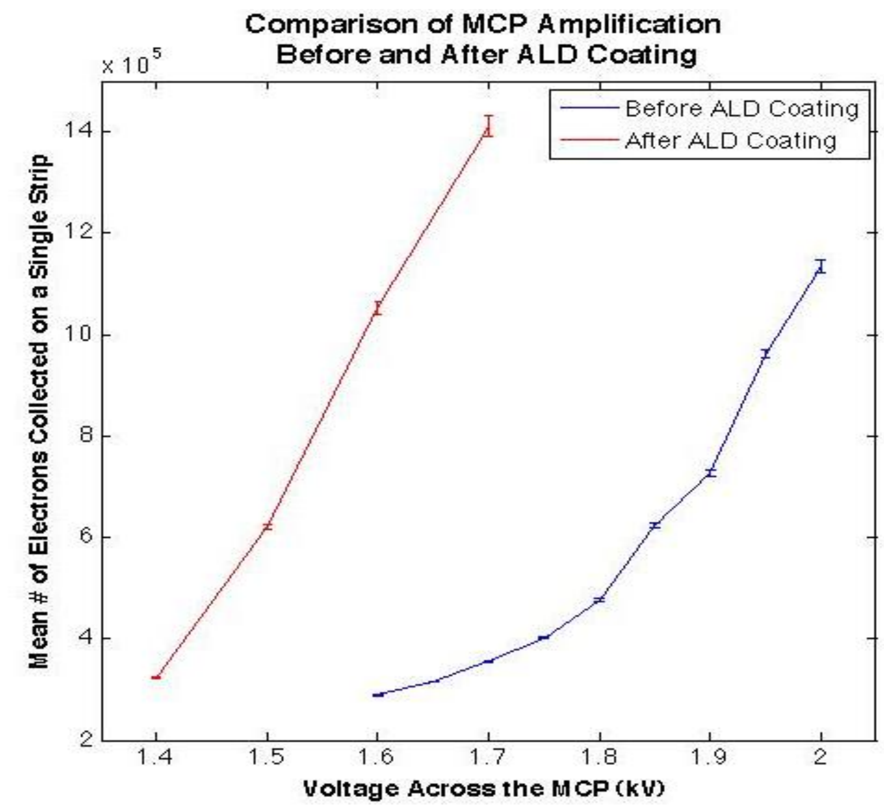
- **SEM photos of endspoiling from first use of fixture**
- **Penetration of electrode into capillary pores is ~30µm**

MCP Development: Testing at SSL

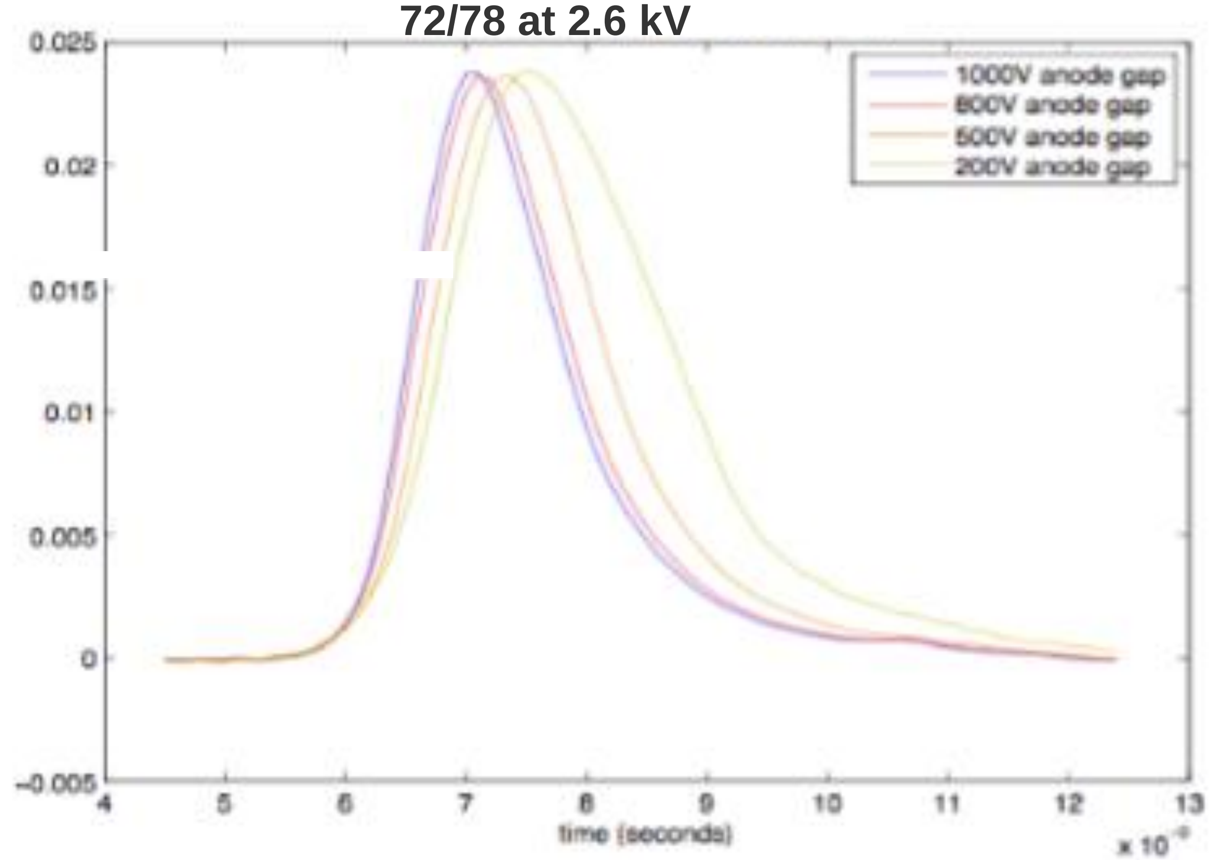


MCP Development: Testing at ANL



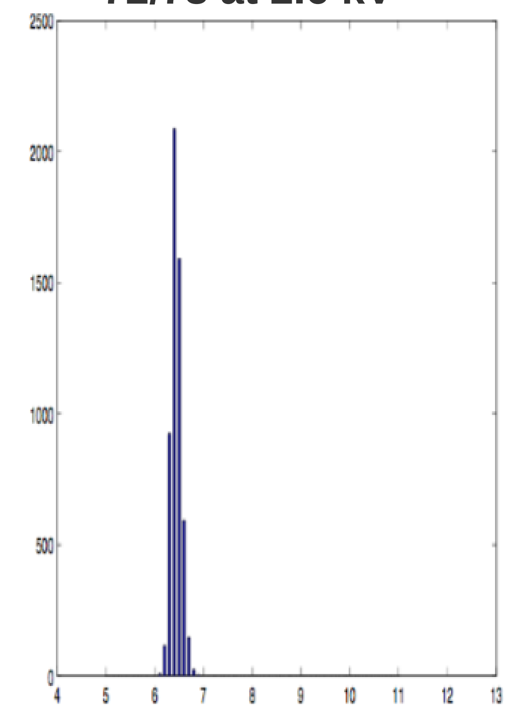


Mean Pulse Shape for MCP 72/78 at 2.6 kV



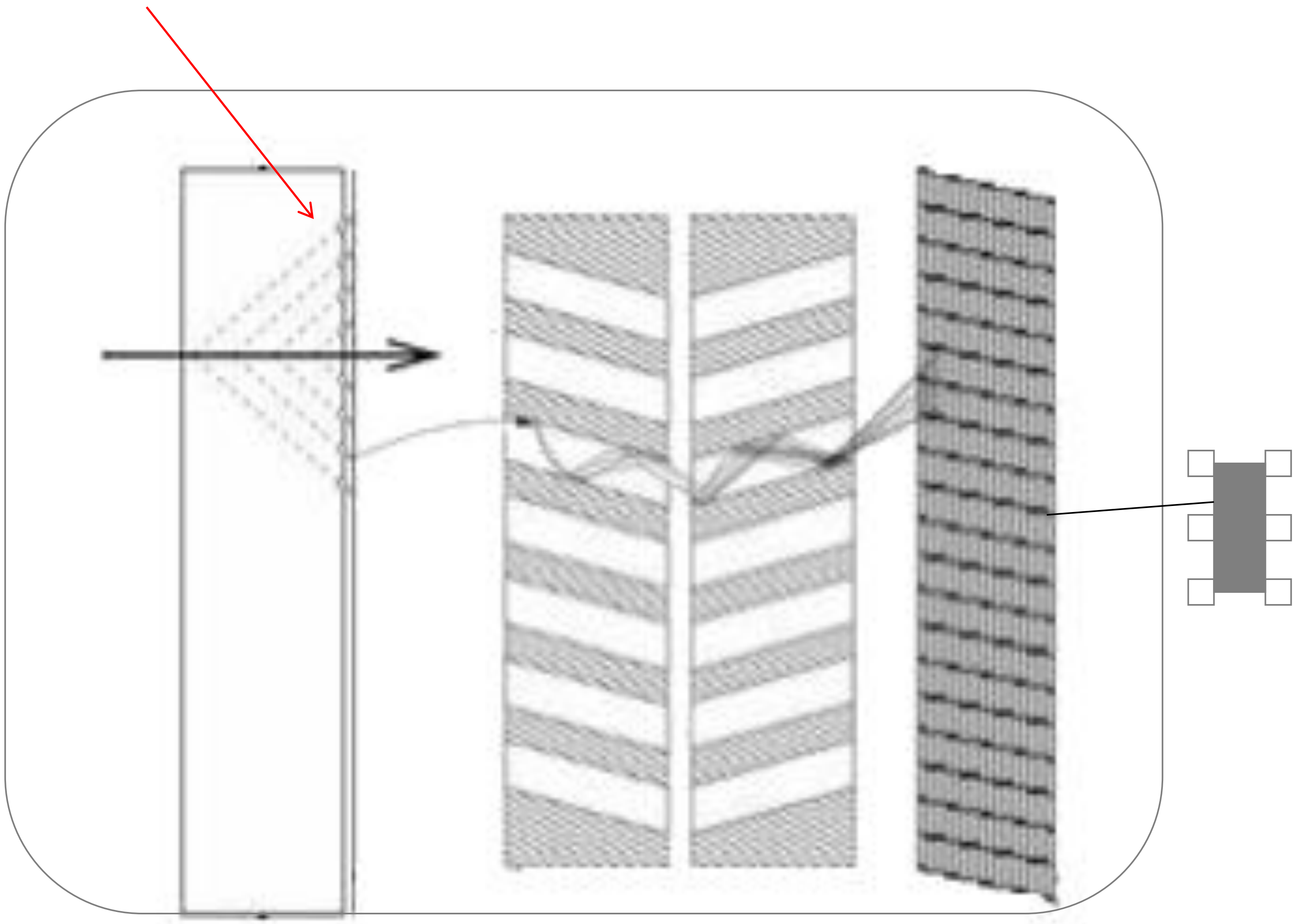
arrival time (nanoseconds)

Transit Time Spread for MCP 72/78 at 2.6 kV



arrival time (nanoseconds)

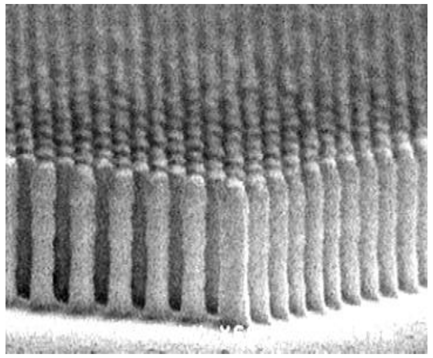
Photocathodes



Photocathodes: Three thrusts

Argonne, Space Sciences Lab, UC-Berkeley, Washington Univ., St. Louis, Univ. of Illinois, Chicago

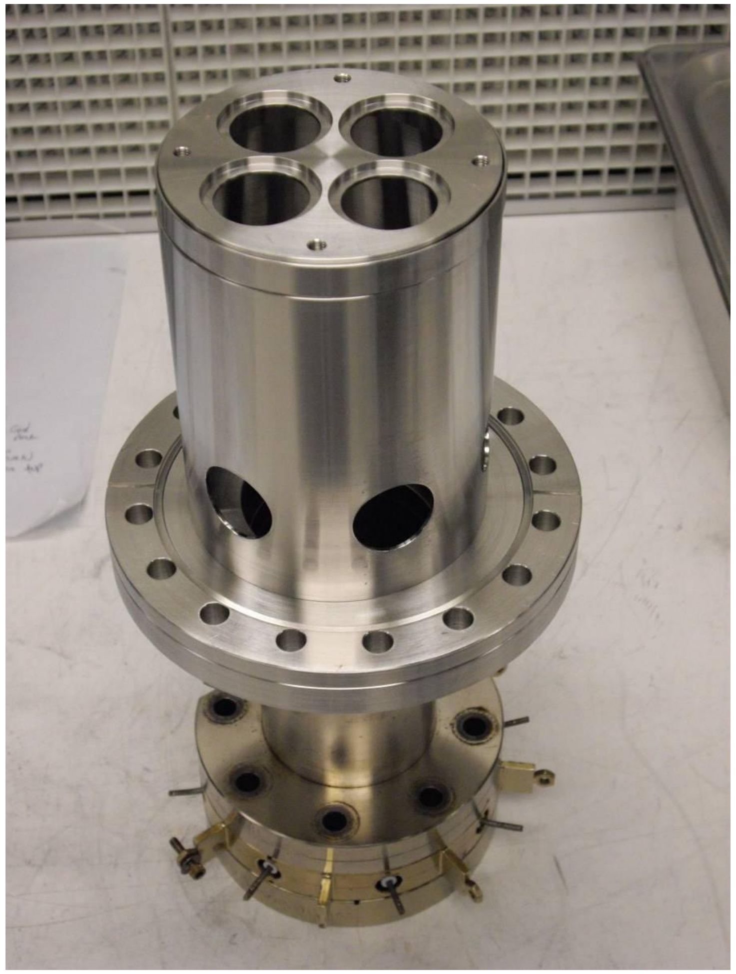
- SSL: R&D focus on scaling up of traditional bi-alkalai to large area
  - Proven history with planacon
- ANL/WashU/UICU: R&D focus on theory inspired design
  - New novel photocathode technologies like nano-structured photocathodes
  - III-V have the potential for high QE, shifting toward the blue and robustness (ie. they age well, high temp)
  - Simulations, testing & characterization
- ANL: R&D focus on design for industrial production of large area photocathodes for a tile factory
  - what does this mean for industry



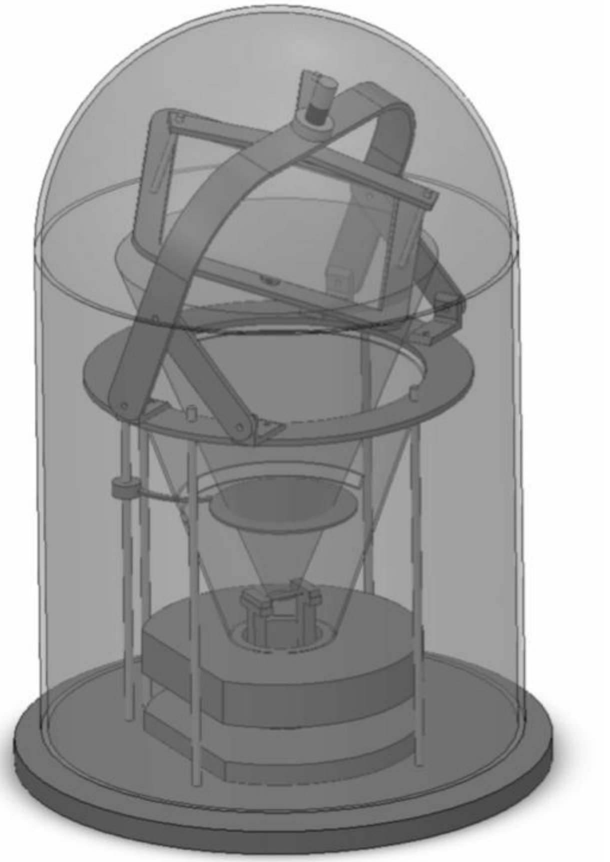
- Nano-structured photocathodes:
  - Reduction of reflection losses (light trap)
  - Heterogeneous structure permits multi-functionality (electrically, optically, electron-emission, "ion-etching resistant")
  - Increased band-gap engineering capabilities

Photocathode Deposition Development

Work performed by Space Sciences Lab, UC-Berkeley



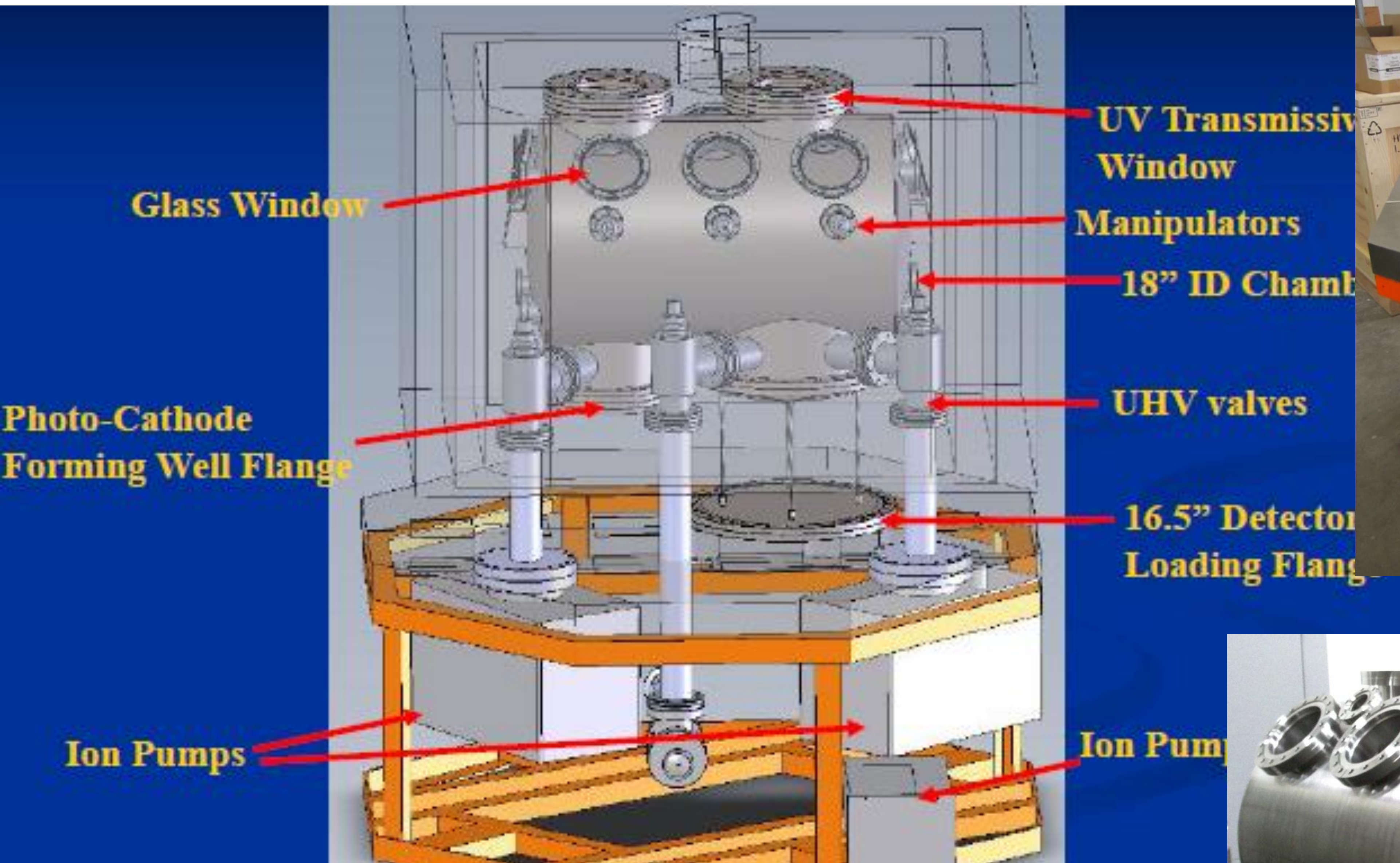
Evaporation tooling
for 8.7” windows



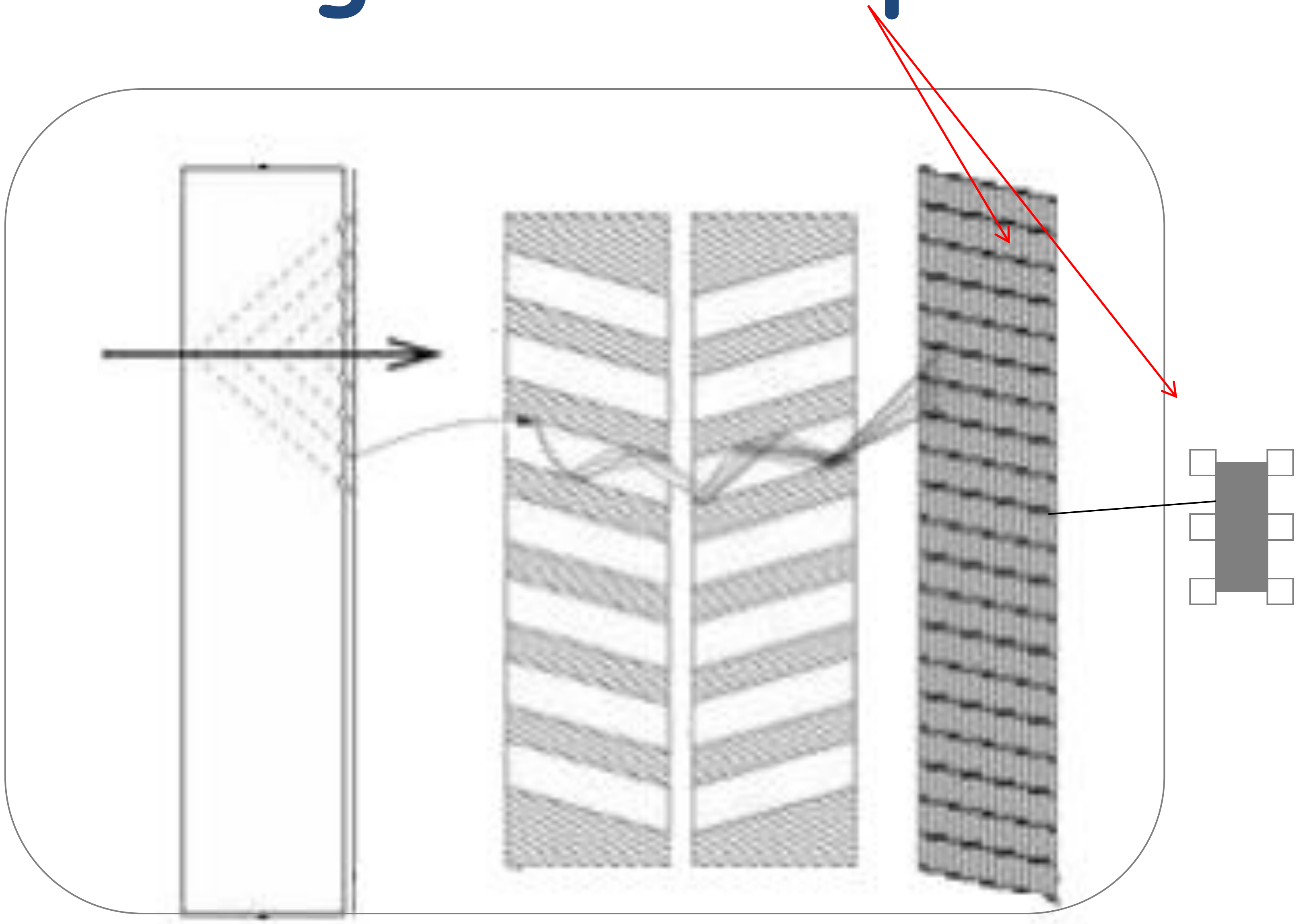
16” tank for full-sized 8.7” windows

Small tank for 1.22” test run samples
Test runs with Fused Silica, Borofloat glass
ITO & MgO coated ALD layers on glass; scrubbing

SSL Large Process Chamber



Anode and Signal Development



Anode and Signal Readout

Univ. of Chicago, Univ. of Hawaii

- Resolution depends on & photoelectrons, analog bandwidth, and signal-to-noise.

Simulations showed "pulse sampling" to give the best results

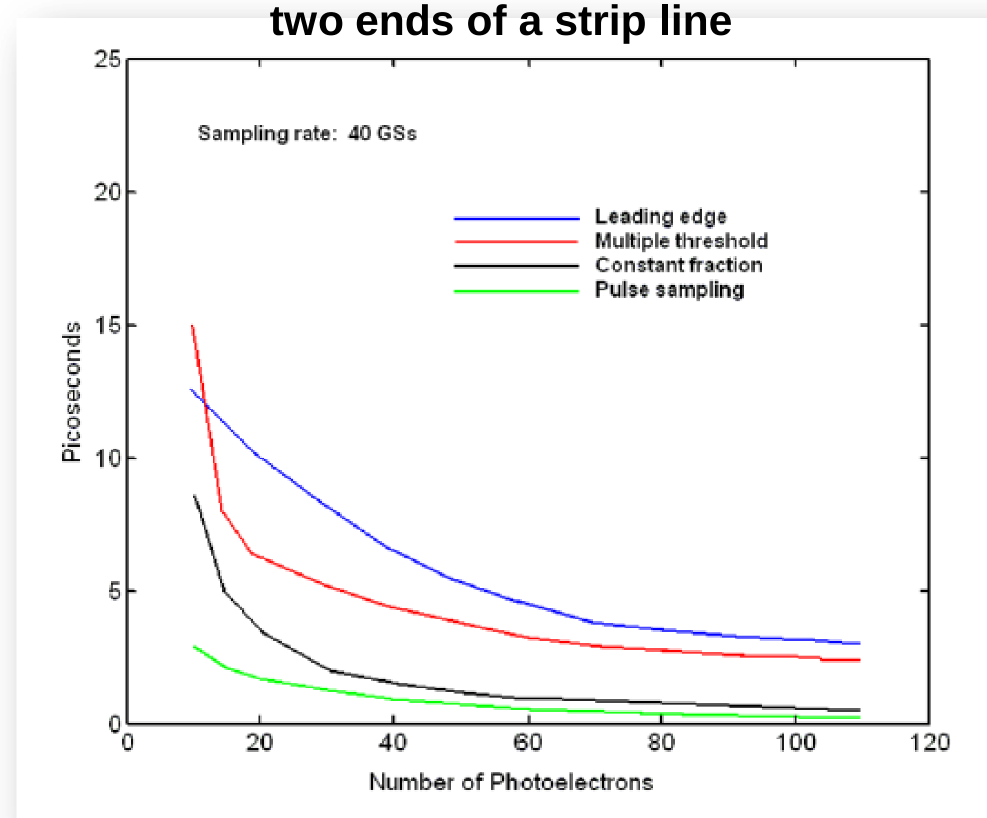
- Transmission Line:

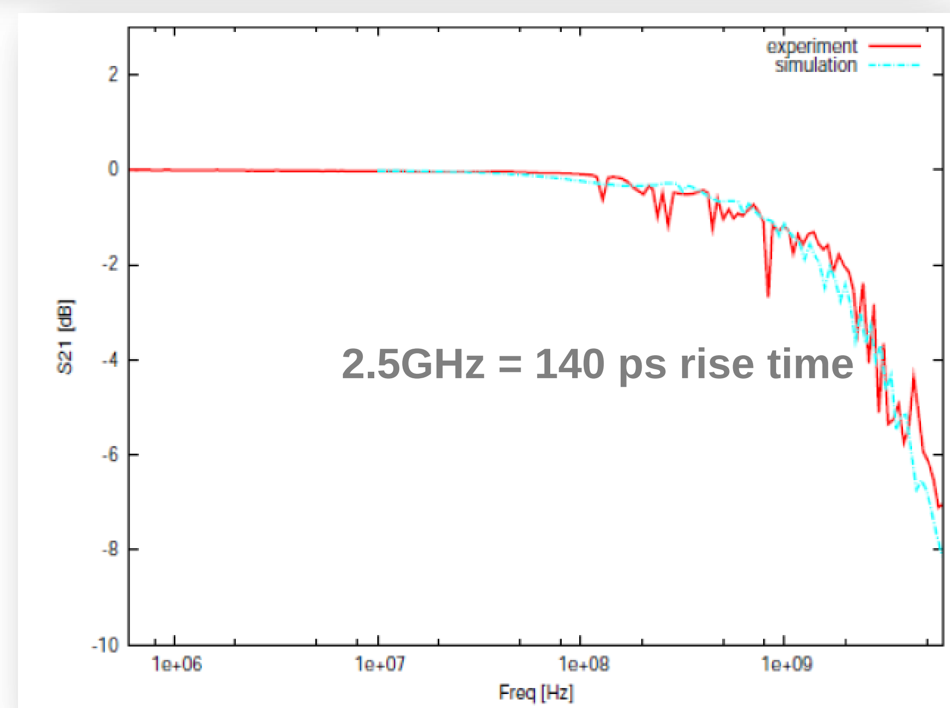
readout both ends → get position and time

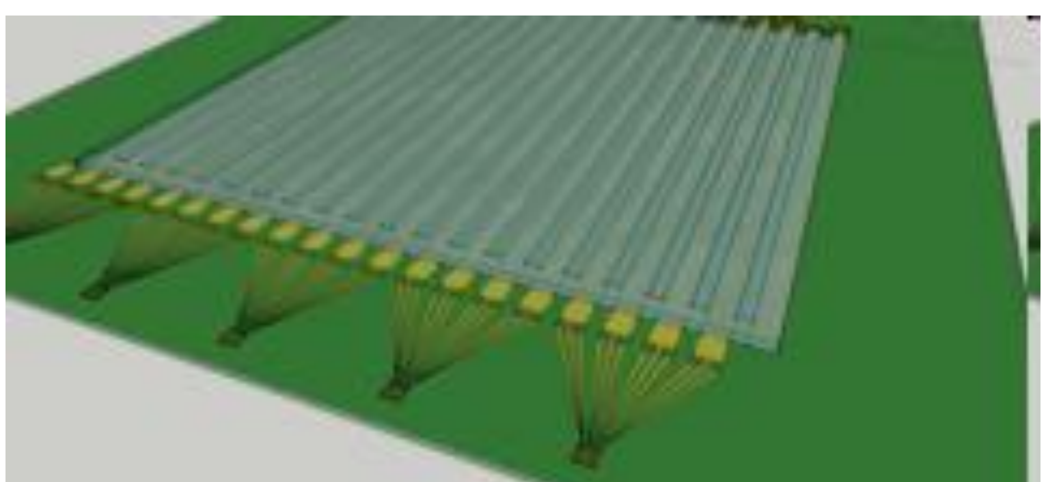
- Cover large areas with much reduced channel count.

- Simulations indicate that these transmission lines could be scalable to large detectors without severe degradation of resolution.

Differential time resolution between two ends of a strip line

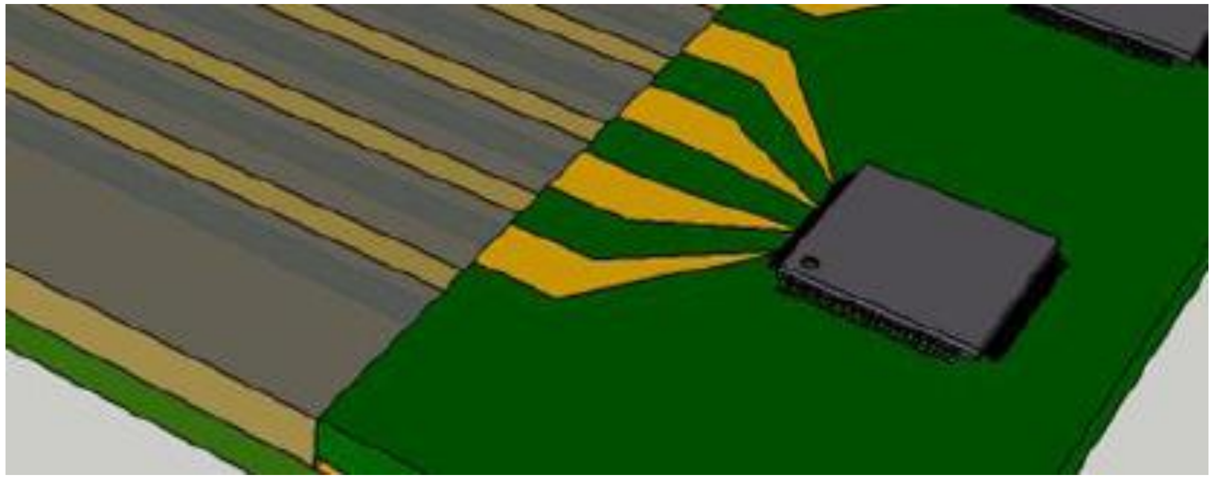




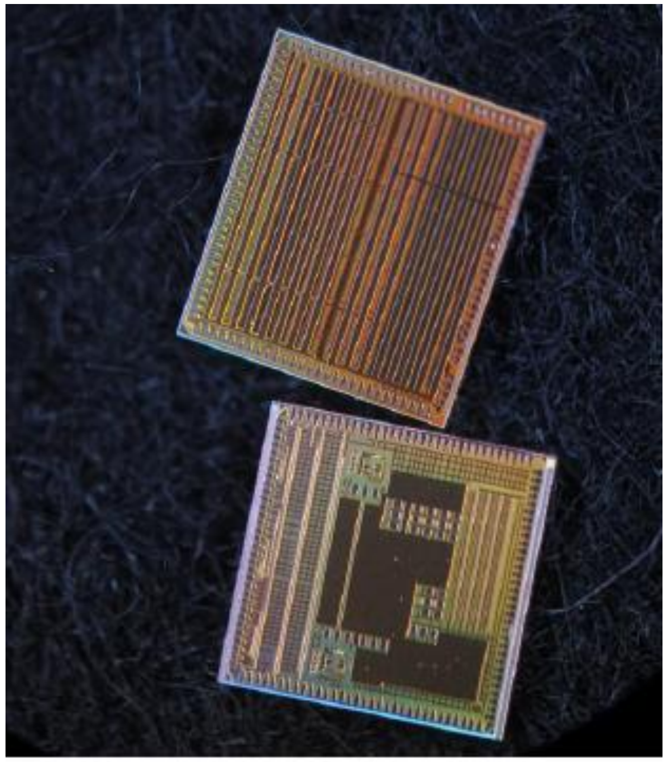


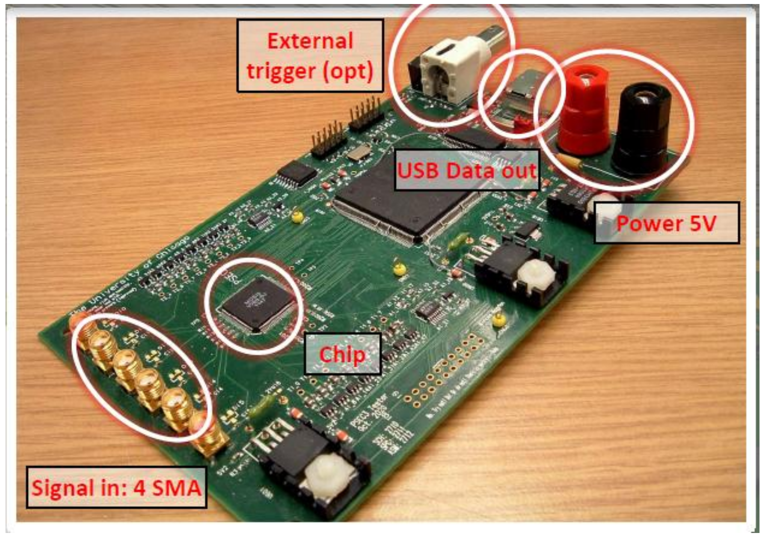
Anode and Signal Readout: ASIC Sampling Chip

- New 10Gs/s high input bandwidth, 130nm CMOS sampling chip is being developed, "PSEC3"
- Proposed schematic of custom transmission line anode & fast sampling ASIC



Chip characteristics	Value
Technology	IBM CMOS 0.13µm
Sampling frequency	>10Gs/s
Number of channel	4
Number of sampling cells	256
Input bandwidth	>2GHz
Dead time	2µs
Number of bits	8
Power consumption	To be measured

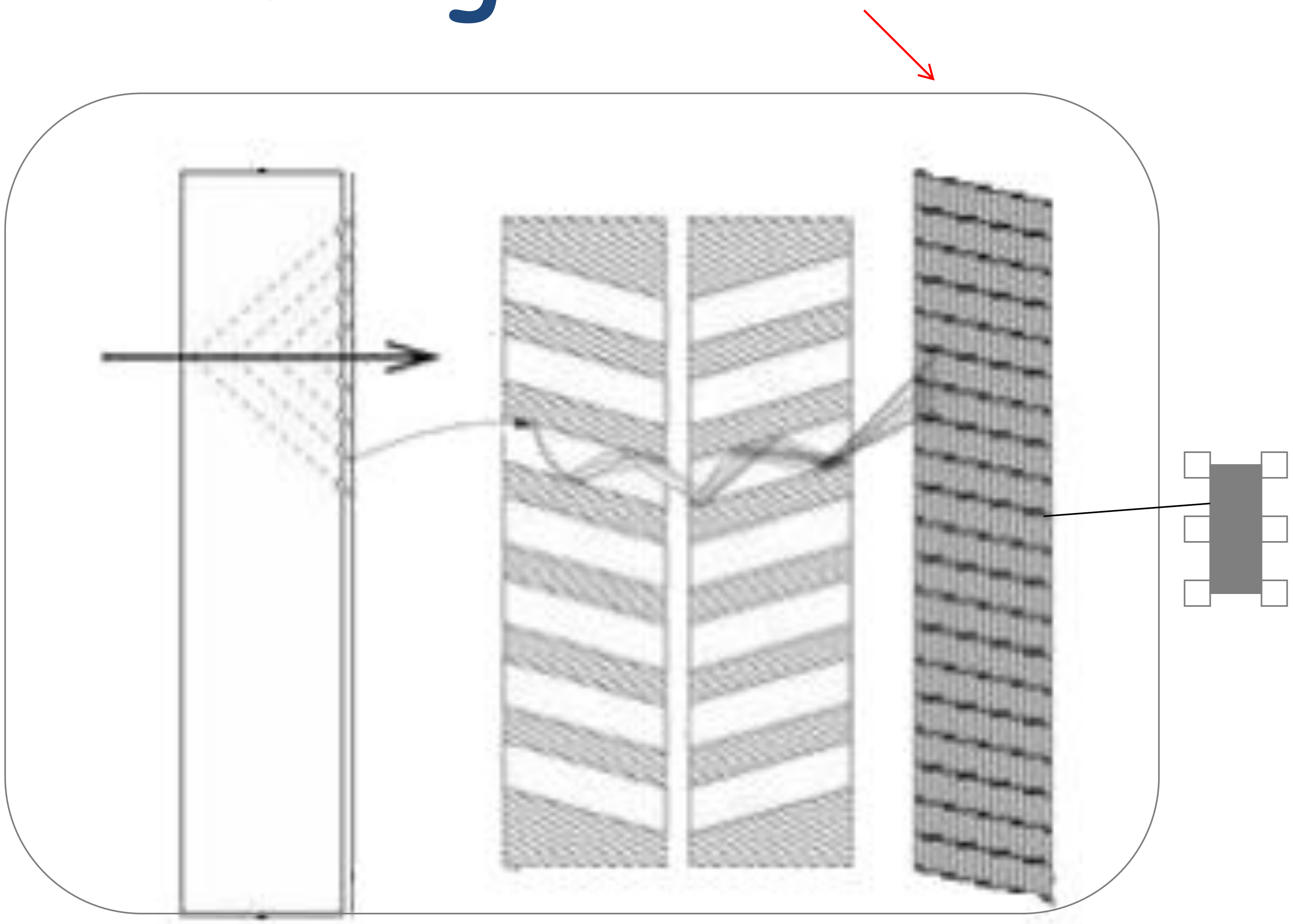




Test board for studying PSEC3

Mechanical Design

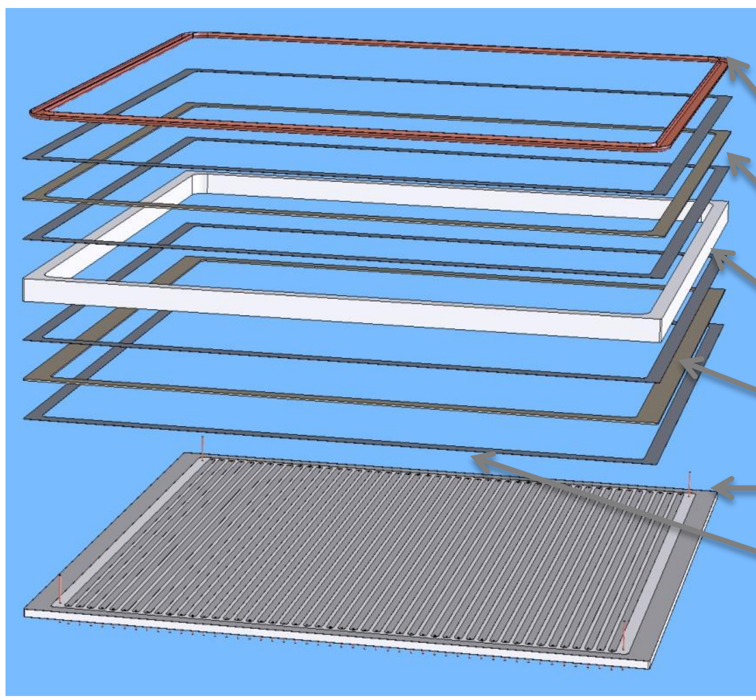
Hermetic Packaging



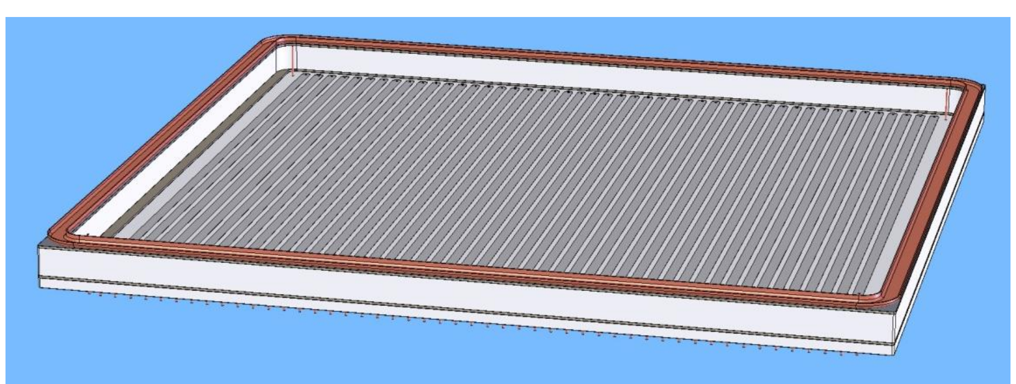
Mechanical Design: Ceramic

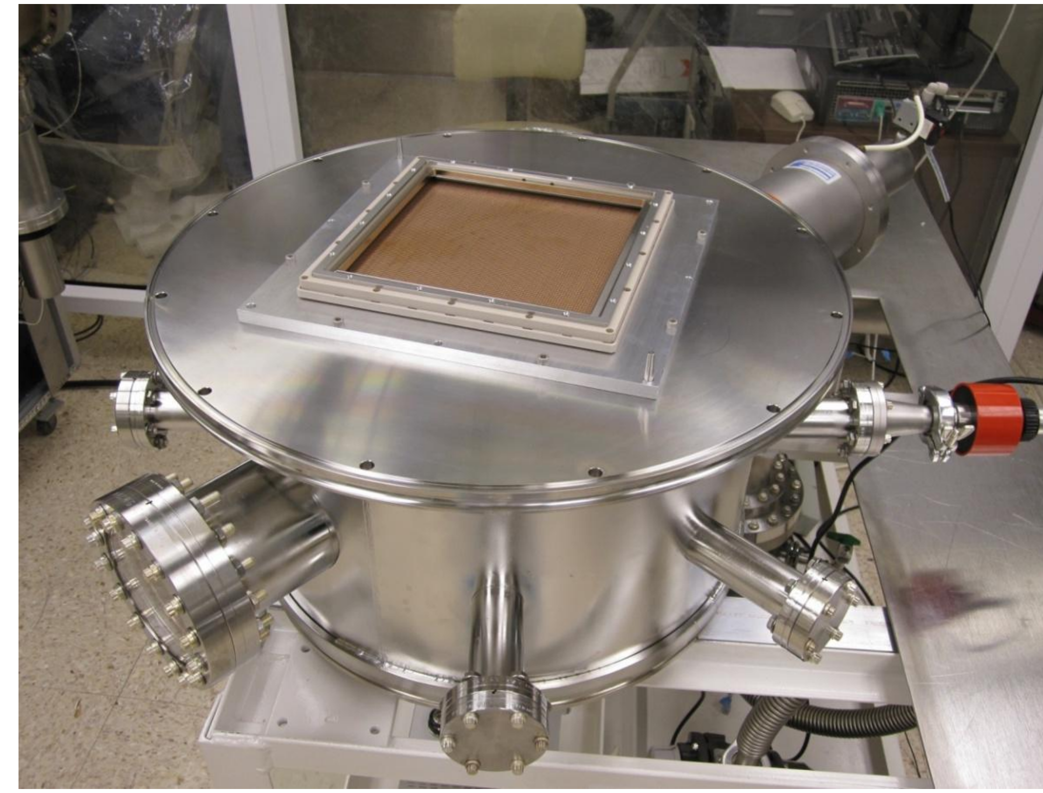
Space Sciences Lab, UC Berkeley

- Use ceramic assemblies, similar to those used by conventional MCPs.
- Well developed technology, know-how available at SSL.

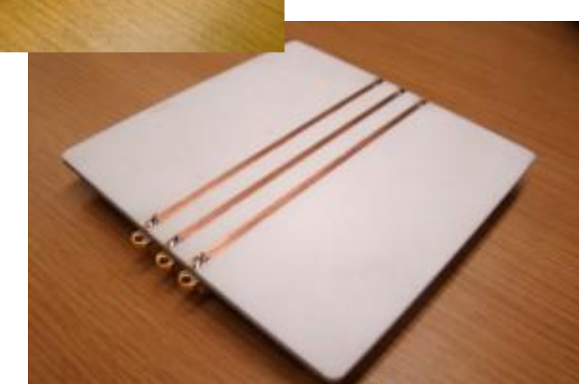


- Single step braze
  - Stamped OFHC Cu or Kovar indium well
  - Kovar intermediary flange
  - Alumina wall
  - Kovar getter flange
  - HiTemp, CuSil brazed anode
- InCuSil braze alloy (750°C braze)
  - Avoids remelt of anode CuSil
- Four braze joints in final assembly





SSL Vacuum test chamber system for testing 8” MCPs



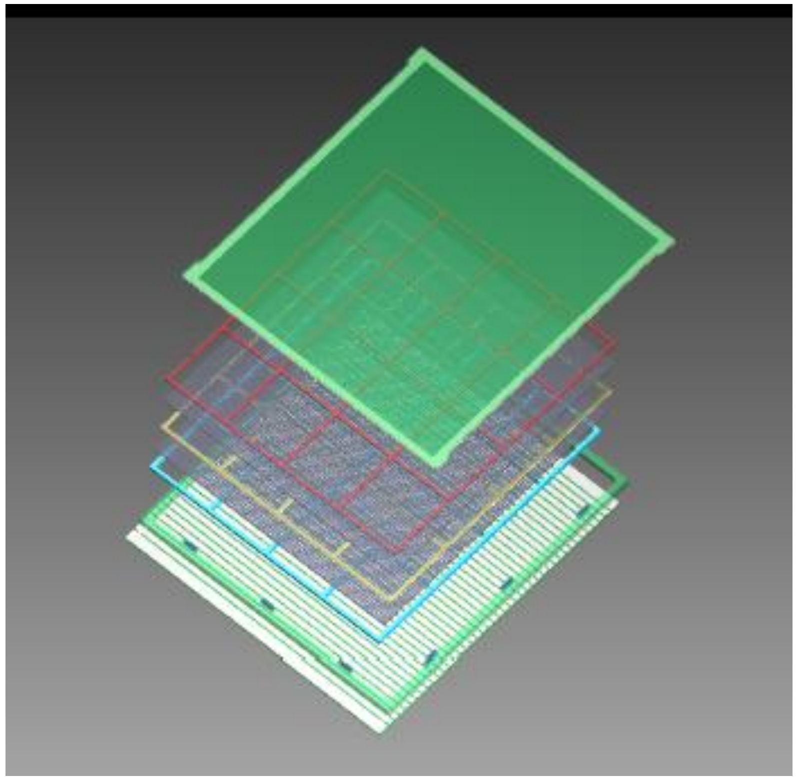
SSL Anode Plates

Mechanical Design: All Glass

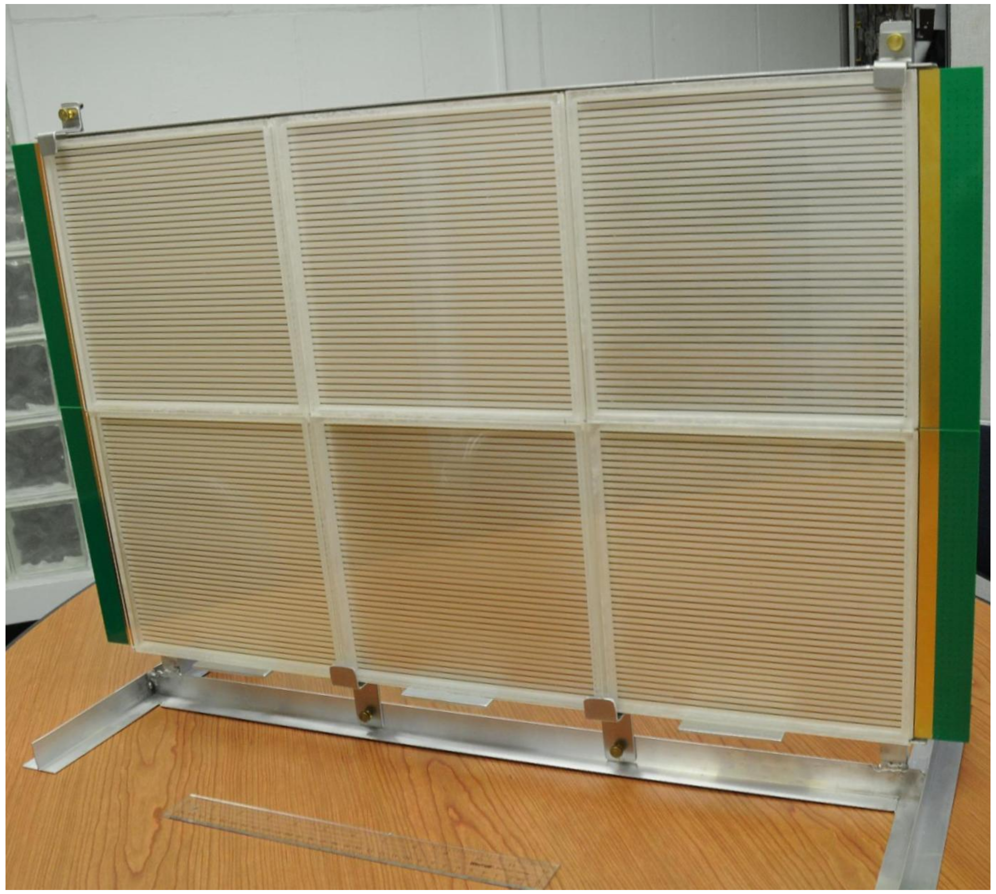
Argonne, Univ. of Chicago

Goals:
- **Use inexpensive borosilicate glass for containment vessel**
- **Avoid use of pins penetrating glass for HV and signal**
- **Cheap, reliable, reproducible containment vessel fab.**
- **Demonstrate feasibility with partially active mock-up**

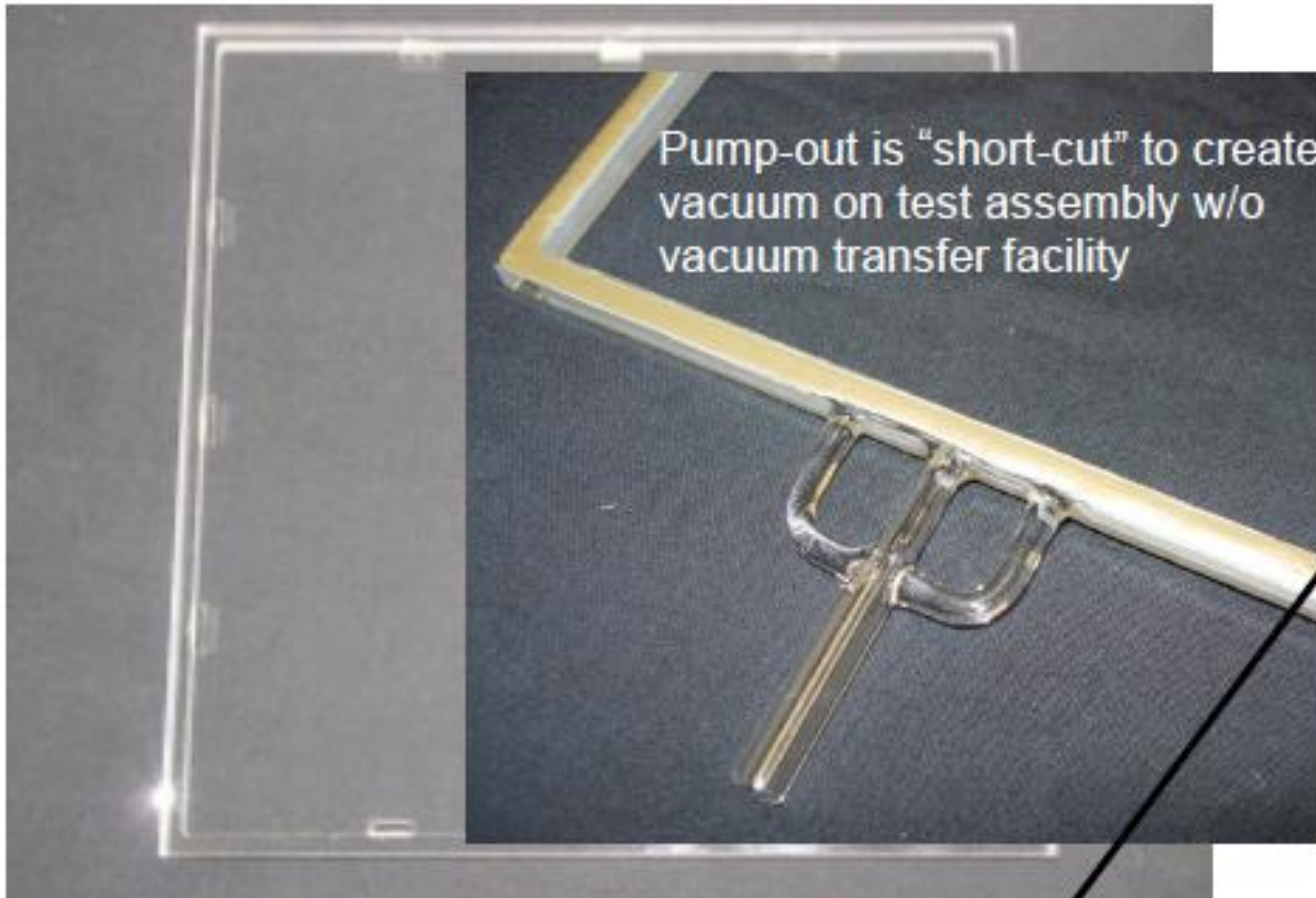
Constraints:
- **Support vessel against implosive atmospheric pressure**
- **Top photocathode window seal at low temp. (<120 º C)**
- **~10 yr stability for seal with small leak rate**
- **Min. handling steps in fabrication**
- **Avoid particulates in vacuum space**
- **Materials chemicall compatible with alkali metal photocathode**



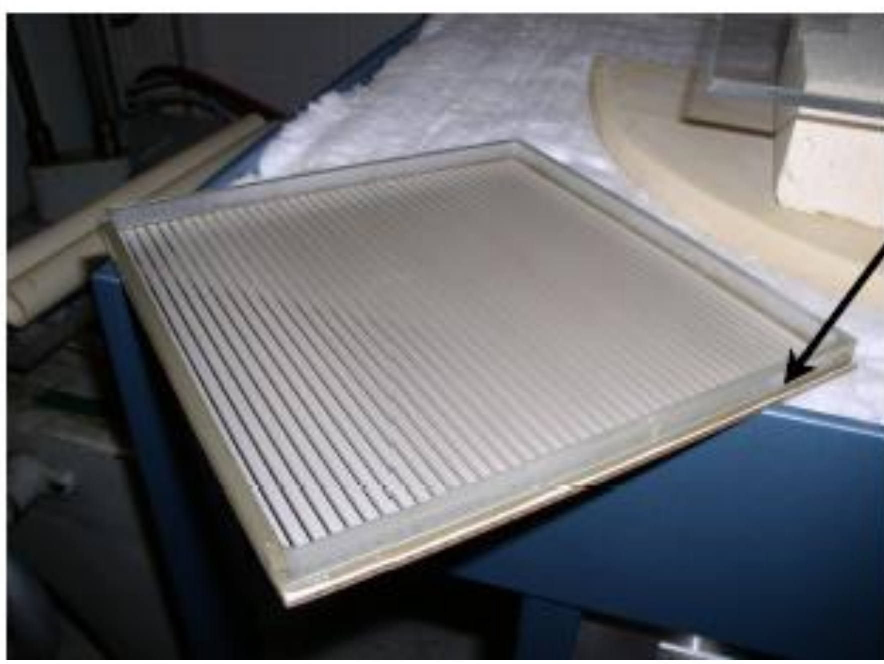
Our first sealed box under pressure.
It is a 8” square sealed box



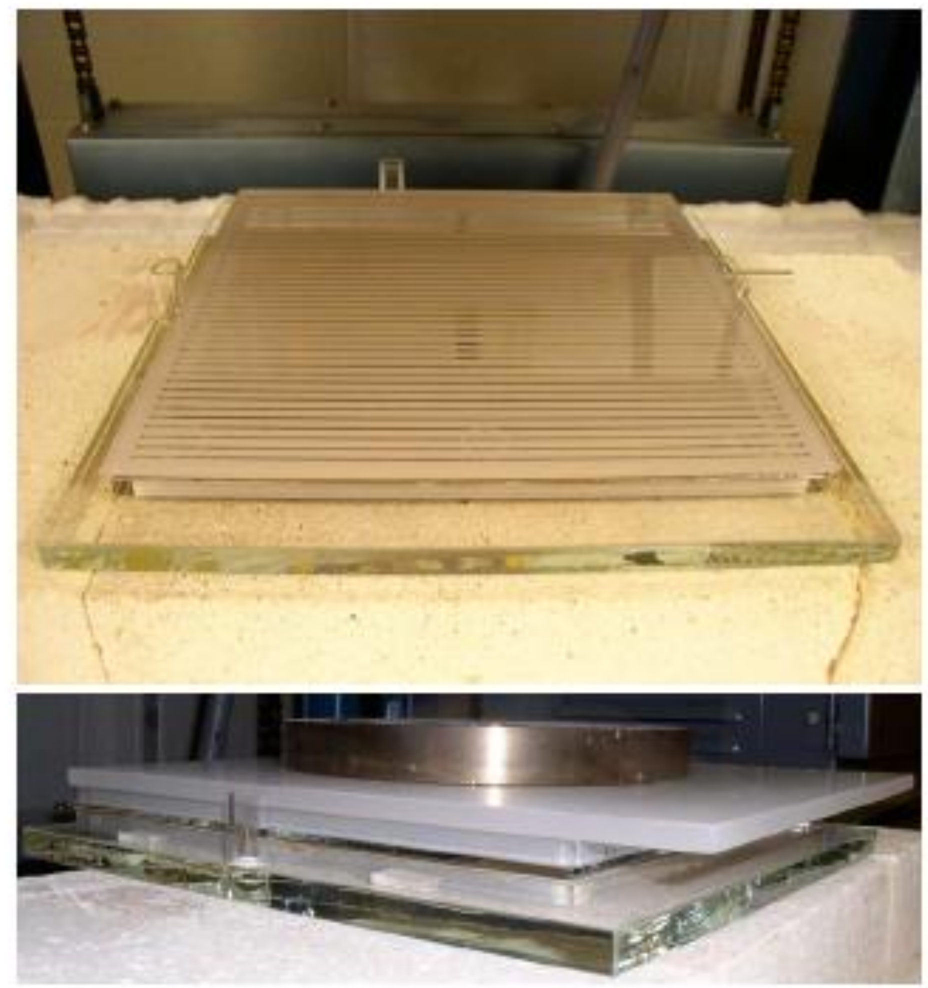
Tile Base Assembly -- Anode Bottom Plate & Sidewall



- **Develop technique to reproducibly bond sidewall to bottom anode plate**
  - Center sidewall frame w.r.t. bottom plate; 2 sides flush, equal overhang on anode ground strips
  - Attach getter holder tubes

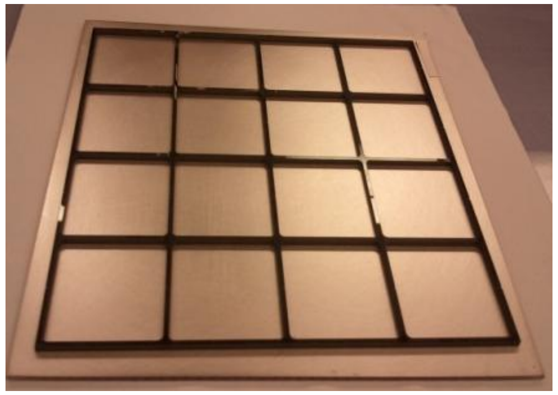


Sidewall bonds on alternating silver strips and bare glass gaps. Extension of strip past sidewall for bridging between tiles & readout connection.

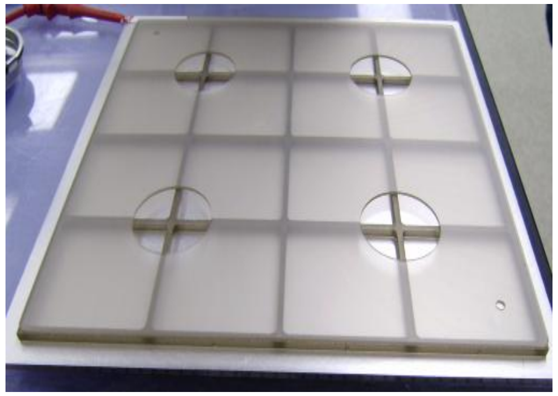


Original steel fritting fixture replaced with much simpler all glass devised by Joe Gregar

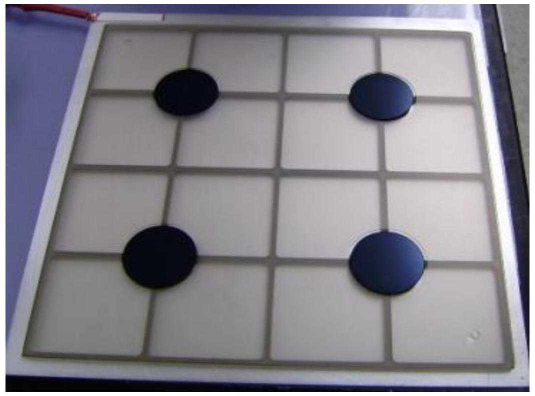
Construction of first all glass mock tile:



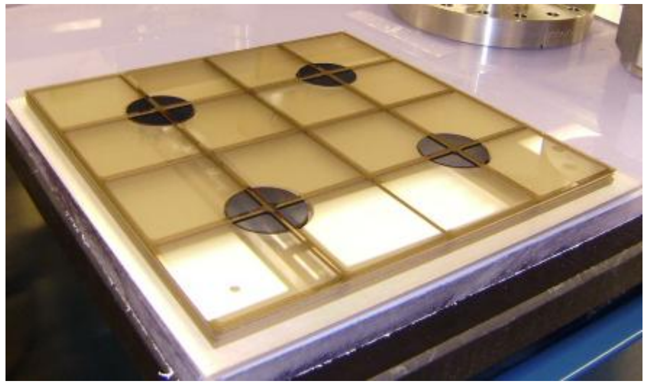
a) 2.97mm bottom Grid Spacer



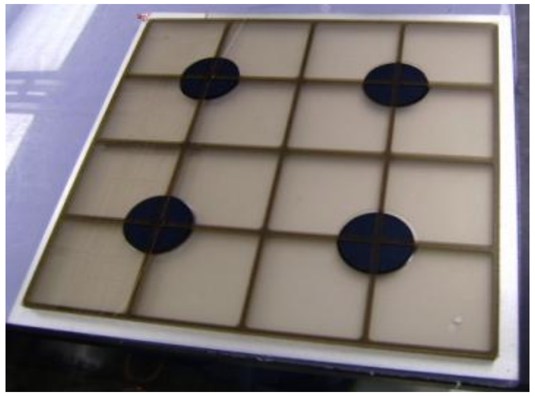
b) add Mock MCP



c) add functionalized MCPs

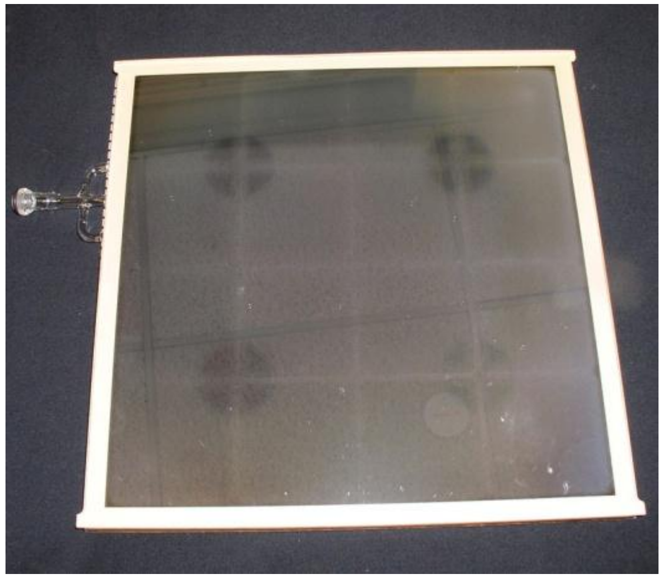


d) add 1.1mm Grid spacer

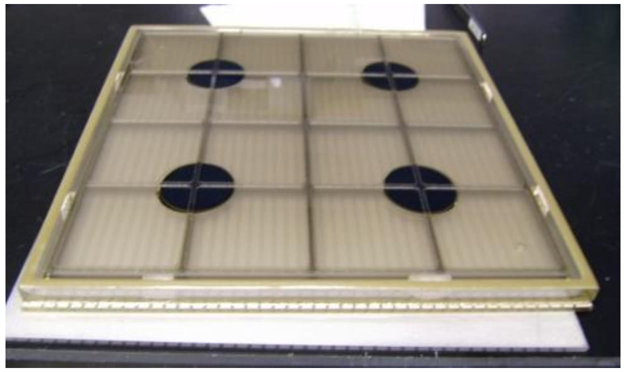


e) Add mock MCPs, 33mm functionalized MCPs & top 1.1mm Grid spacer

g) Anil & Bob Holding mock tile



h) Mock tile after sealing & evacuation



f) full stack in mock tile

Simulations and Testing

Microscopic/Materials-Level

Material Science Division, ANL

Constructing dedicated setup for low-energy SEE and PE measurements of ALD materials/photocathodes.

parts-per-trillion capability for characterizing material composition.

Berkeley SSL

Decades of experience.

Wide array of equipment for testing individual and pairs of channel plates.

Infrastructure to produce and characterize a variety of conventional photocathodes.

Macroscopic/Device-Level

HEP Laser Test Stand, ANL

Fast, low-power laser, with fast scope.

Built to characterize sealed tube detectors, and front-end electronics.

Highly Automated

Advanced Photon Source, ANL

Fast femto-second laser, variety of optical resources, and fast-electronics expertise.

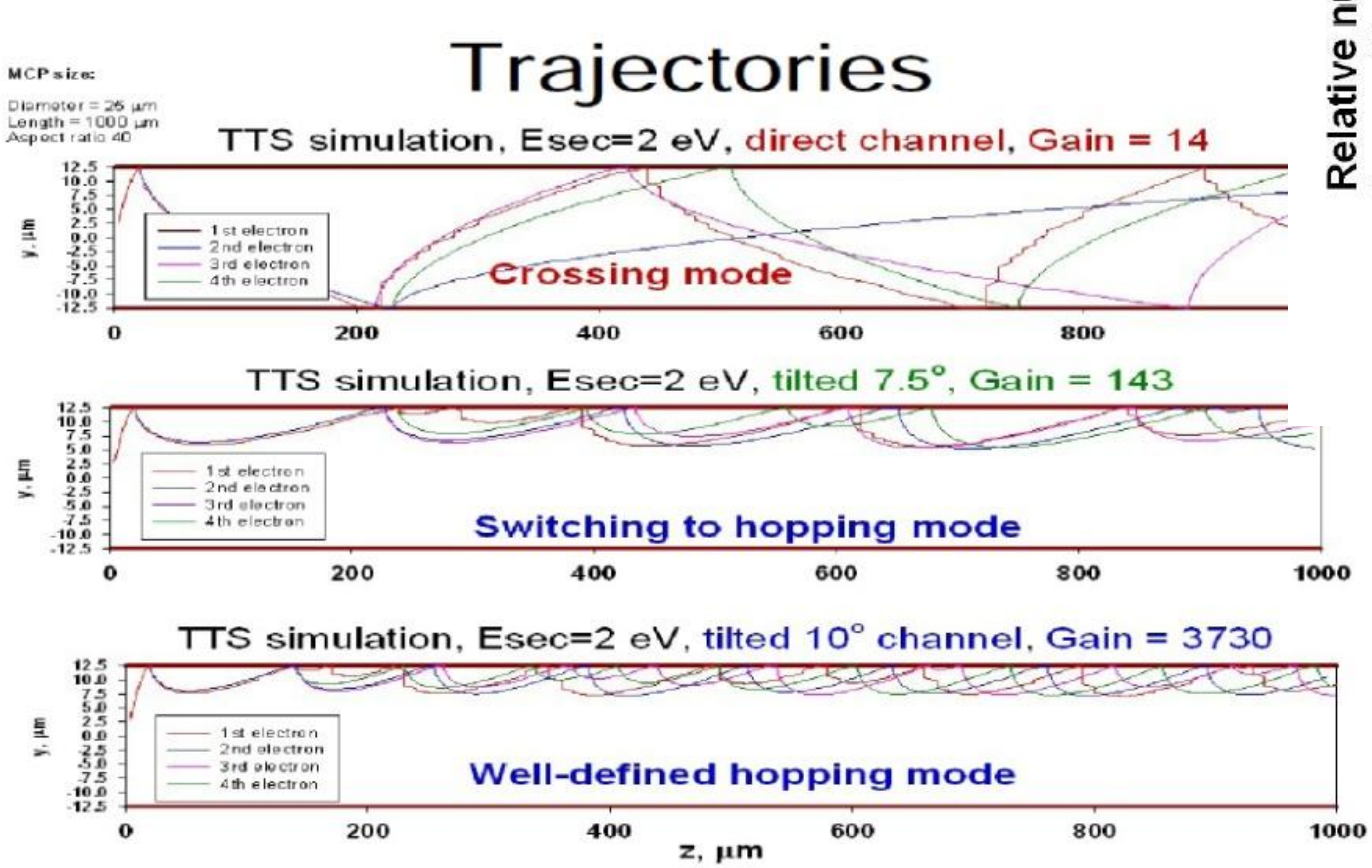
Study MCP-photocathode-stripline systems close to device-level. Timing characteristics amplification etc.

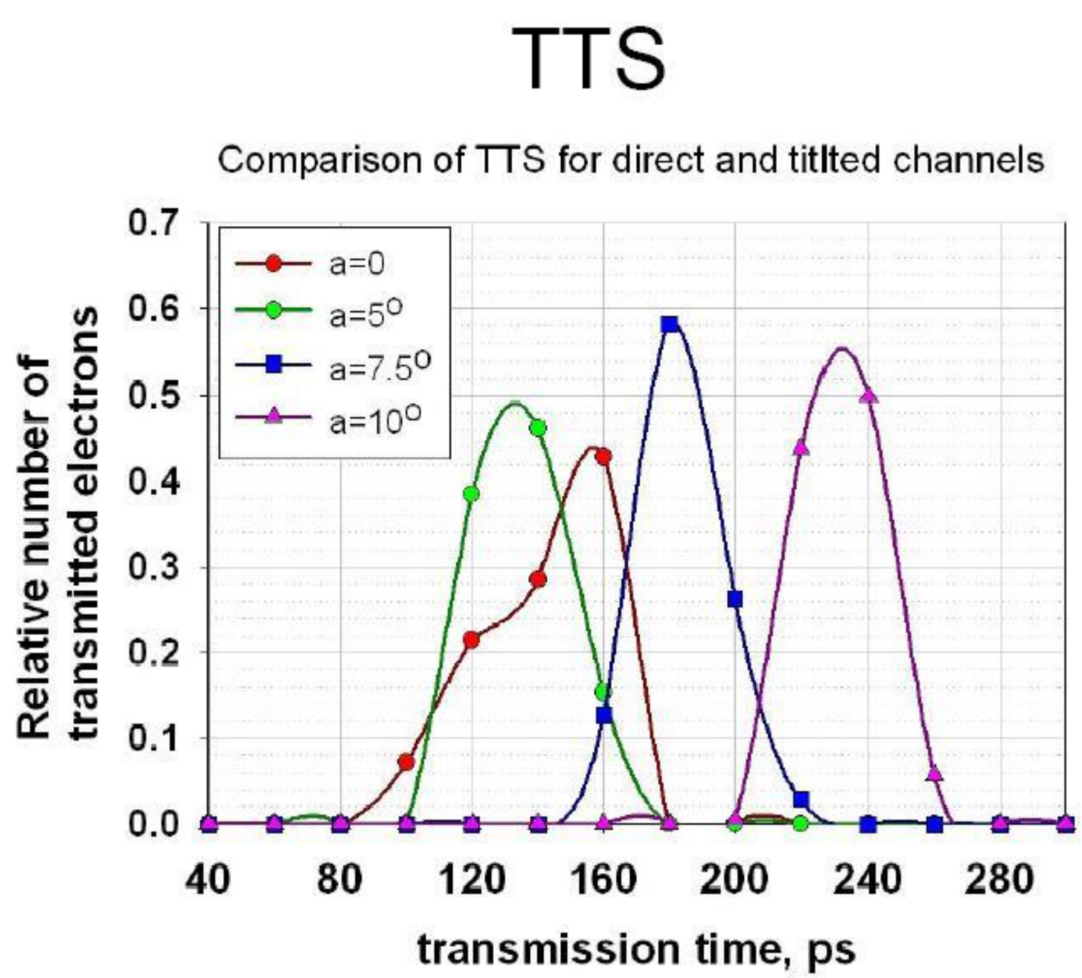
Simulations

Argonne, Muons,Inc, Arradiance

Transit Time Spread (TTS)

- **Working to develop a first-principles model to predict MCP behavior, at device-level, based on microscopic parameters.**
- **Will use these models to understand and optimize our MCP designs.**



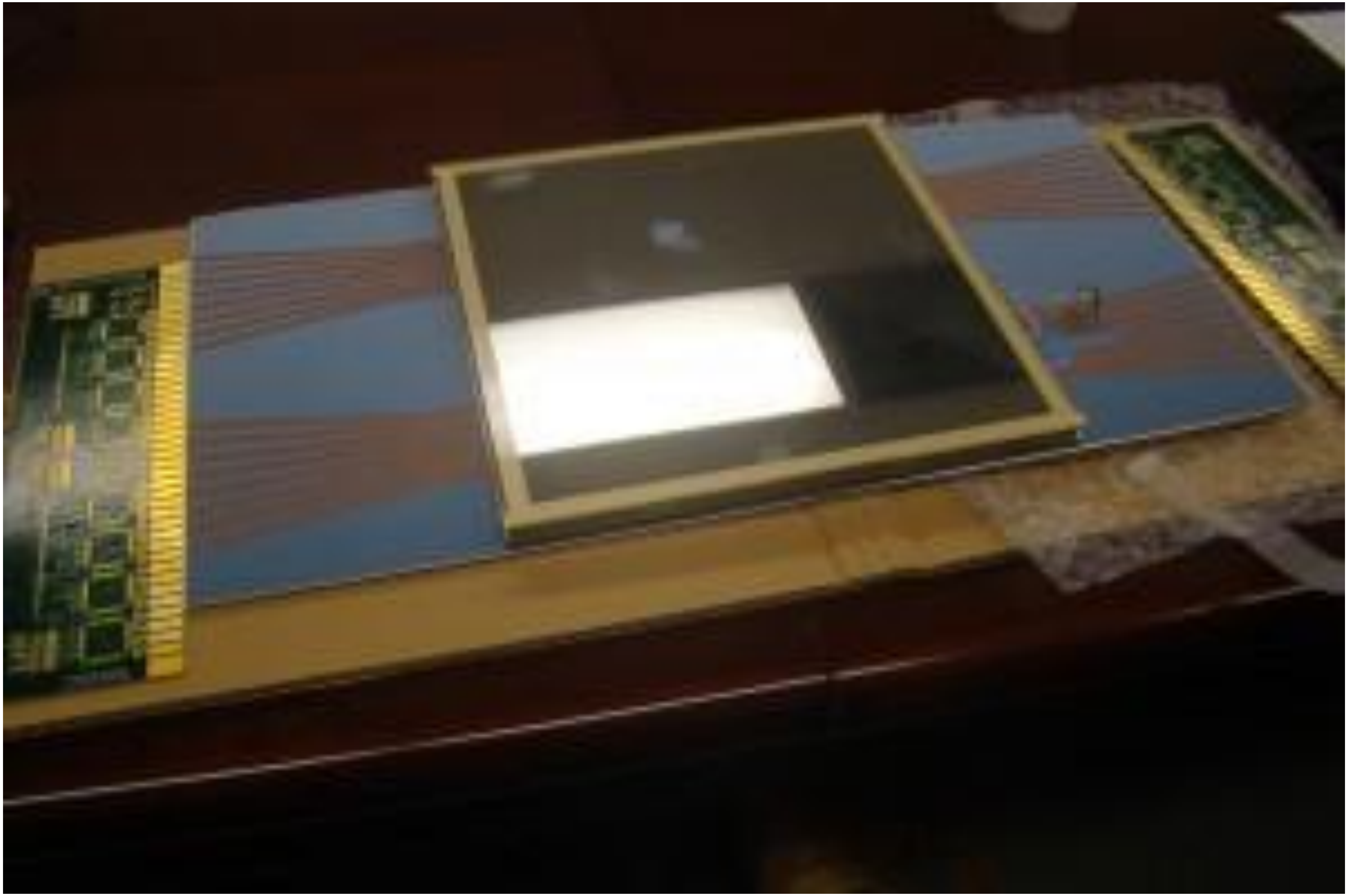


U.S. DEPARTMENT OF ENERGY

Conclusion

- Large Area Picosecond Photodetector Development collaboration is on track to deliver a working prototype by the end of year 3 (summer 2012)
- Atomic Layer Deposition coatings of 33mm glass capillary disks are producing gain $>10^6$ for MCP pair; Are in the process of scaling up to 8" ALD
- Have developed 3 ALD resistive + 2 ALD emissive chemistries
- Mature mechanical designs for hermetically sealed tube
  - Proven design in ceramic by SSL
  - Well-advanced inexpensive glass design -- first hermetic box completed
- Moving to reliable and reproducible fabrication of sealed tubes in quantity
- Designing a tile production facility at Argonne
  - Lab space for tile facility is being developed
  - Layout design of labs for wet chemistry and vacuum handling underway

Anode and Signal Readout: First Mock Tile

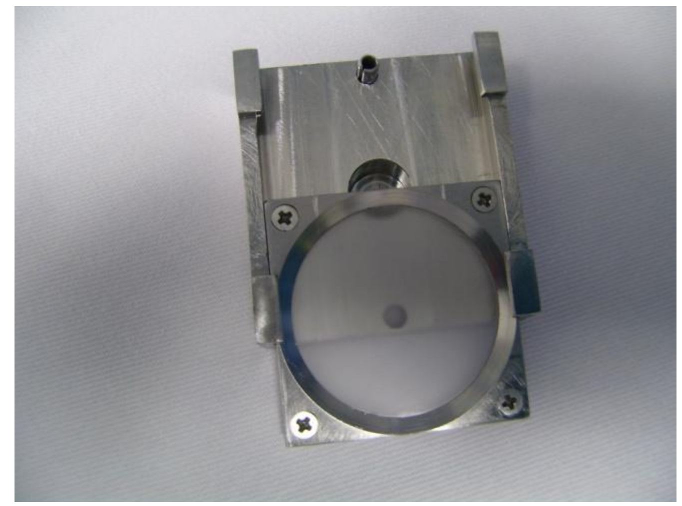


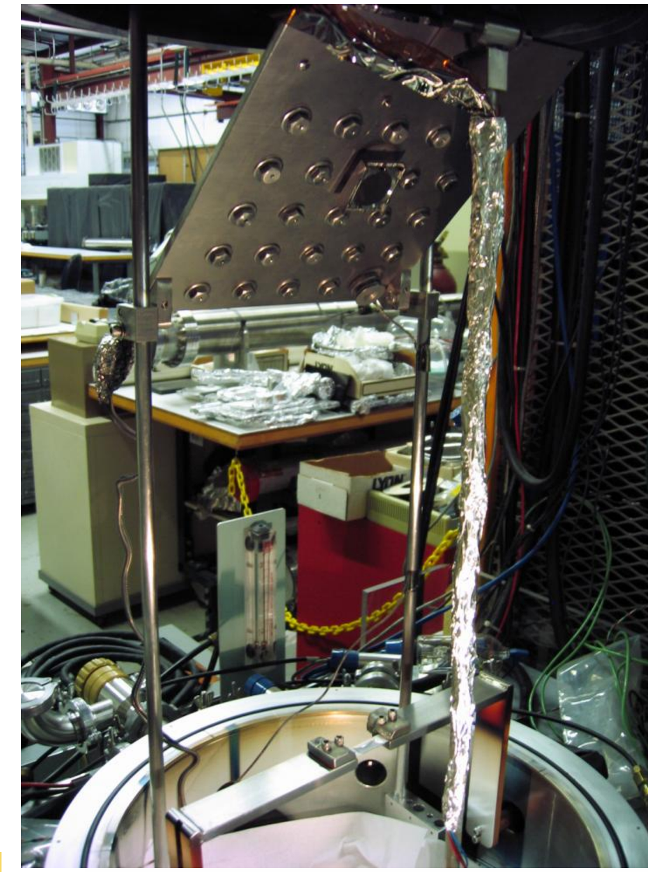
- Backup

MCP Development: Electrode Evaporation onto MCPs - Endspoiling

Fermilab and Space Sciences Laboratory, Berkeley, UC

FNAL

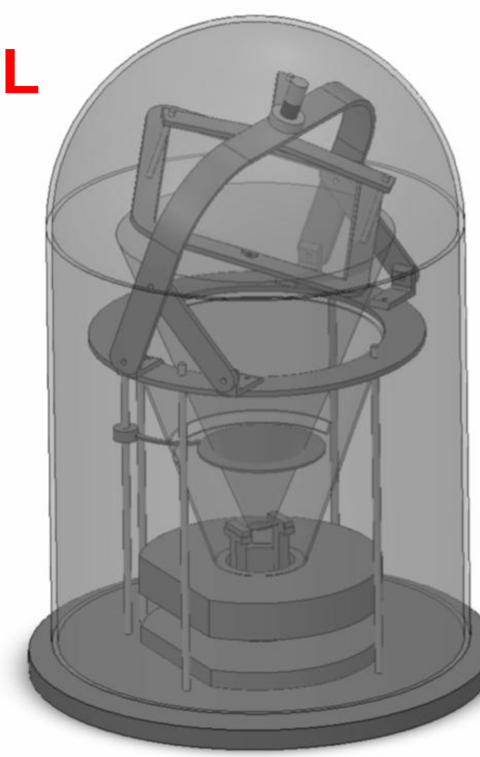




- **Metallization for electrical contact applied to bare glass capillary before ALD**
- **Nichrome evaporation performed at Fermilab Thin Film Facility and as SSL**
- **FNAL Fixture must rotate MCP about 8˚ bias of pores**
- **Penetration of electrode into pores is 1 diameter, i.e. 20µm (endspoiling)**

SSL current Bell jar setup for fixturing 33mm sample evaporations and cartoon of modifications to accommodate 8” tiles

SSL

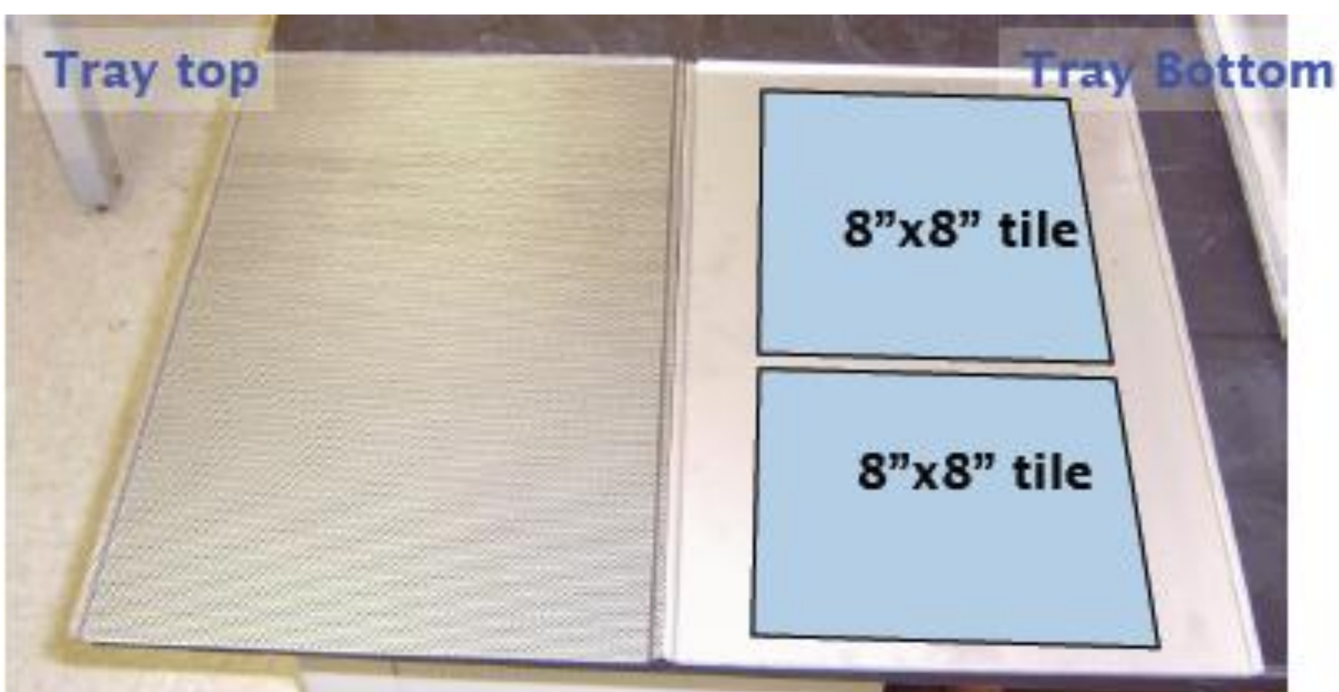


MCP Development: Scale-up of ALD Processing

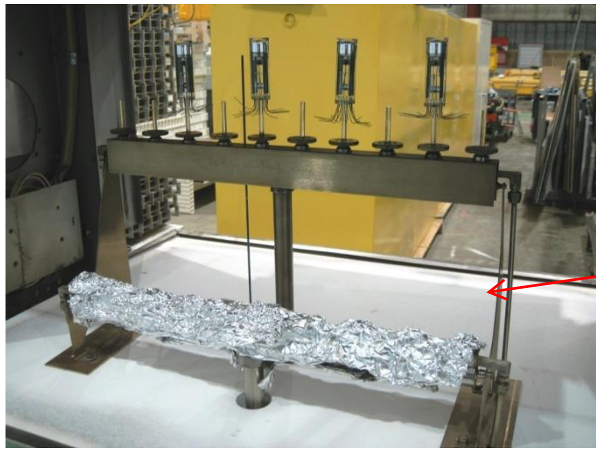
Studying ALD on Large Surface Areas

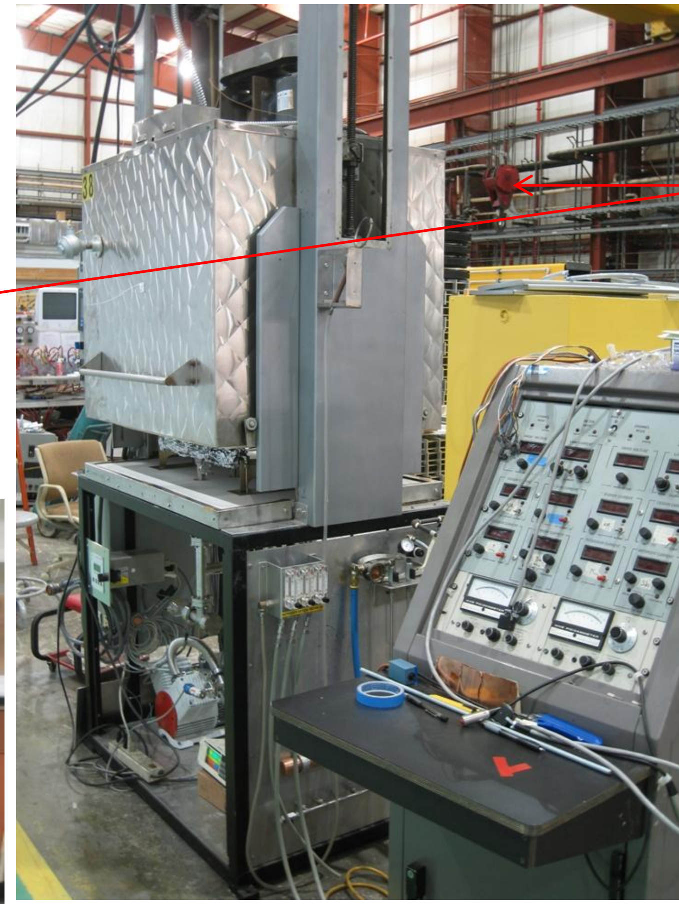
- 33mm disk surface area is $0.13m^2$
- 8" x 8" surface area is $6.4m^2$
- 20 MCPs area is $129m^2$

New Beneq Reactor



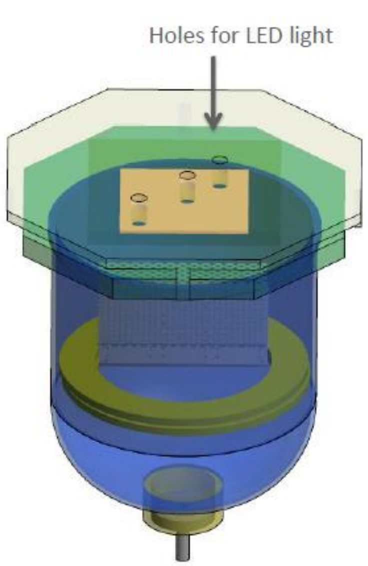
New Photocathode Lab at Argonne w/Burle Equipment





New Burle Equip.

- Just sitting up equipment
- First photocathodes w/QE>15%
- Plan to use this eqpt for mock tile assembly scaleup



Photocathode Lab Plan View