Large Area Picosecond Microchannel Plate Photodetectors

Current
From Photo Sensors Like This

TO

Future
Something Like This

Karen Byrum
Argonne HEP Division
7 March 2013
for the LAPPD Collaboration

Outline

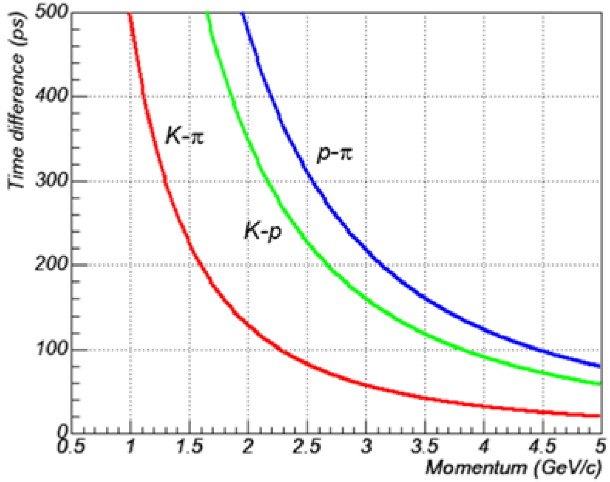
- Motivation(s) and Possible Applications
- LAPPD Introduction
- Micro Channel Plates
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Conclusions

Acknowledgements- Henry Frisch, Bob Wagner, Ossy Siegmund, Jeff Elam, Matt Wetstein & LAPPD collaborators, Howard Nicholson and the DOE HEP, ANL Management, and the NSF.

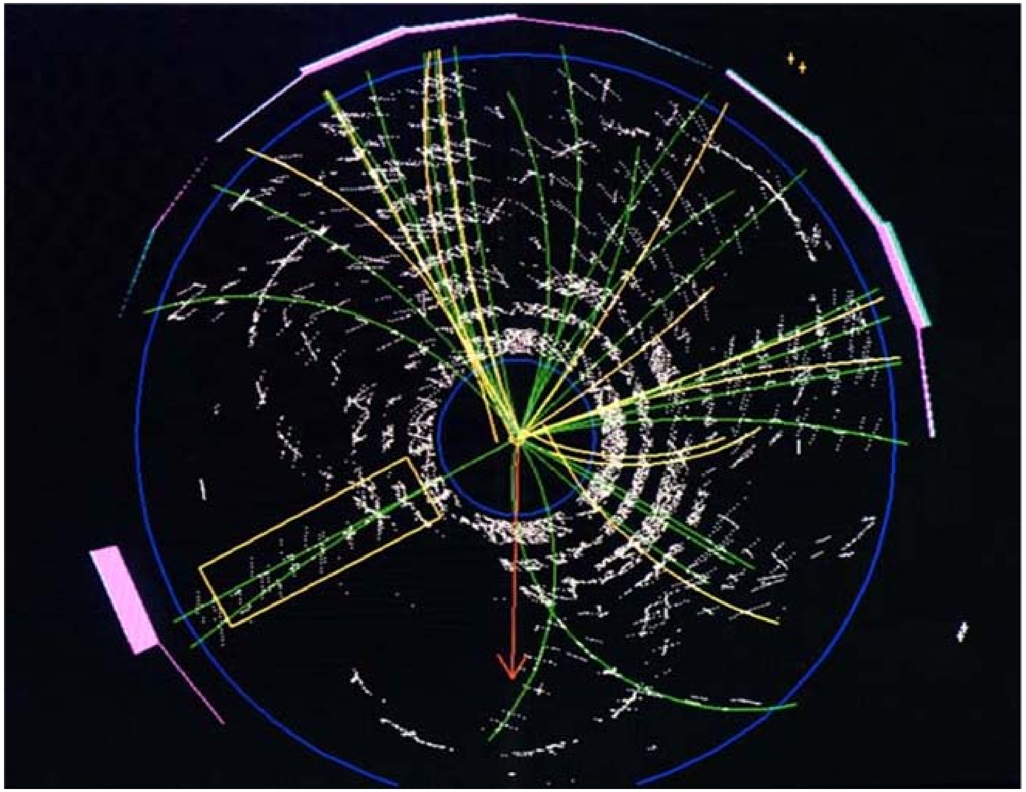
Energy Frontier – Precision TOF and Photon Vertexing

Need: 1) identify the quark content of charged particles
Photons arrive 1st, followed by pions, kaons, etc

Extract *all* the information in each event (4-vectors) – only spins remain…

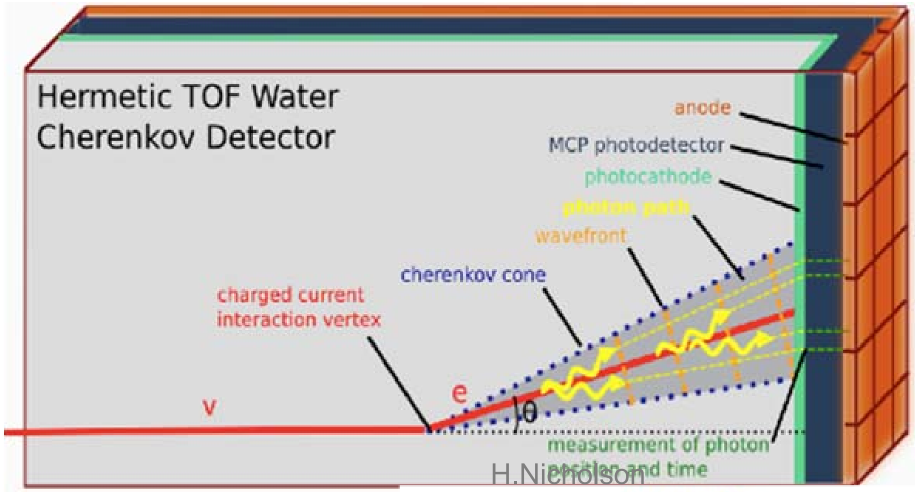


Complete particle measurement: E, p + m(PID) 1ps time & 1mm space resolution



(Note: conventional TOF resolution is 100 psec -factor of 100 worse than our goal= 1" is 100 psec, so need a small scale-length).

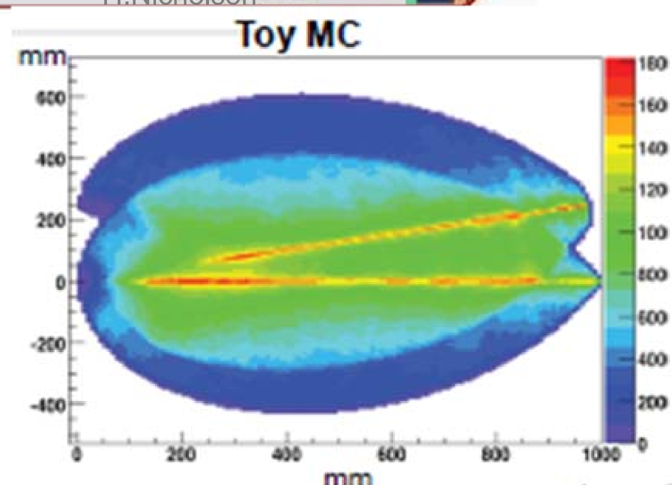
Intensity Frontier — Tracking Neutrino Water Cherenkov Detector



H.Nicholson

Technique: measure arrival time and position of photons and reconstruct tracks in water

Tesselation of detector with Large Area MCP-PMTs

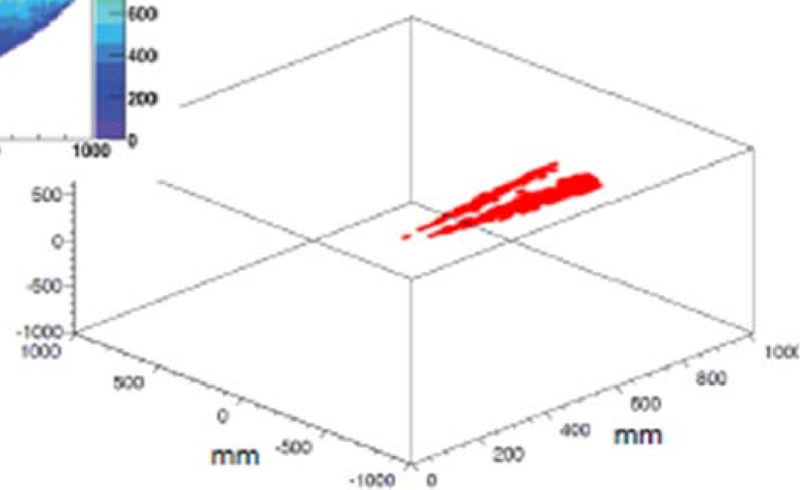


Need: ~100ps

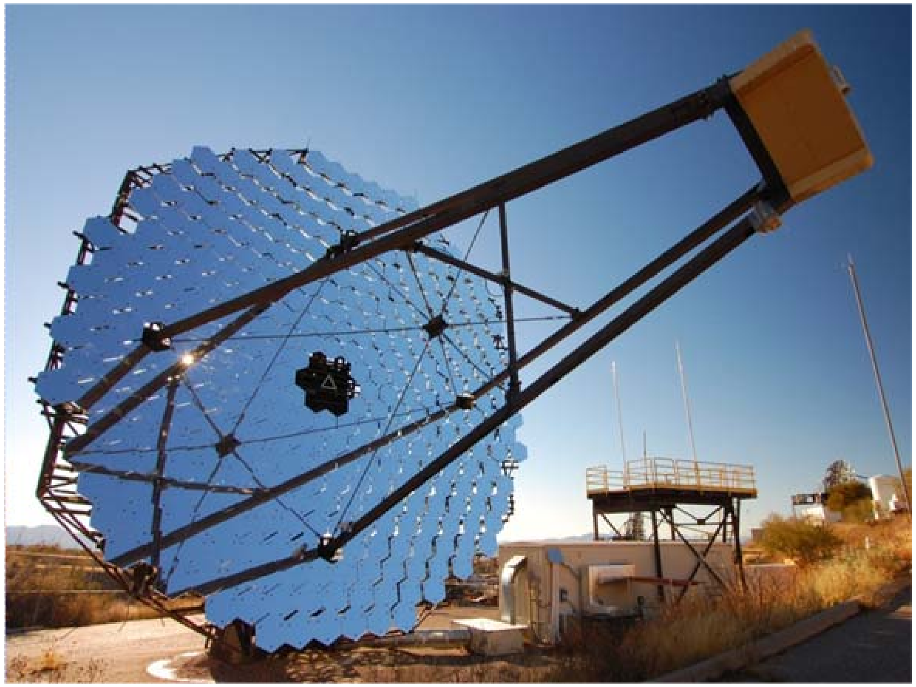
M. Wetstein

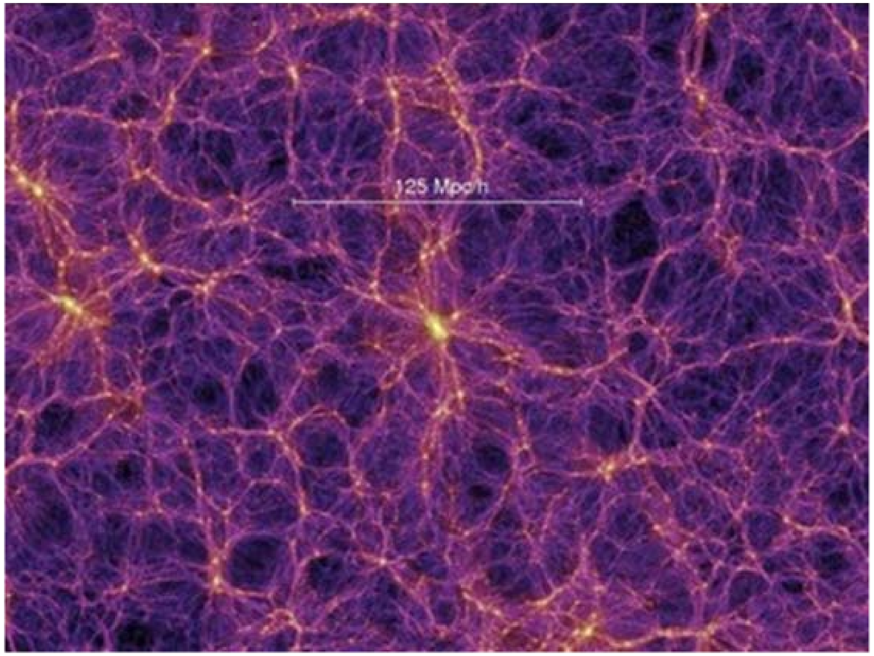
$\pi^0 \rightarrow \gamma\gamma$

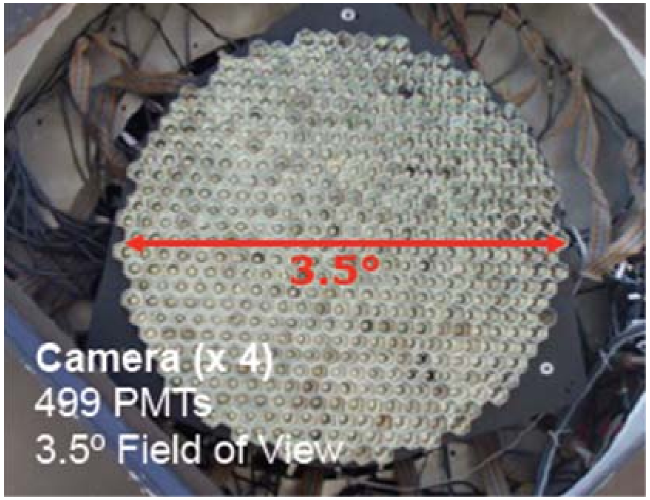
Reconstructed 1.5 GeV Pi0 (geant)

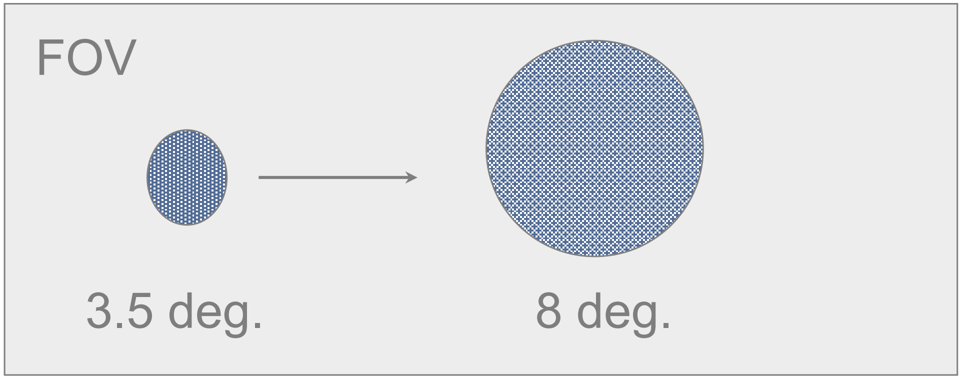


Cosmic Frontier – Cherenkov Imaging Cameras









Outline

- Motivation(s) and Possible Applications
- LAPPD Introduction
- Micro Channel Plates
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Conclusions

The Large Area Picosecond Photodetector Collaboration (LAPPD)

National Labs

- Argonne
  - HEP Division
  - Energy Systems Division
  - Nuclear Engineering Division
  - Glass Shop
  - X-ray Sciences Division
  - Materials Science Division
  - Mathematics and Computer Science Division
- Fermilab

U.S. Companies

- Incom, Inc.
- Arradiance, Inc.
- Synkera Technologies, Inc.
- Minotech, Inc.
- Muons, Inc.

Universities

- University of Chicago
- Space Sciences Lab/UC-Berkeley
- University of Hawaii
- Washington University –St Louis
- University of Illinois — Chicago
- University of Illinois — Urbana/Champaign

LAPPD is a multi-disciplinary/multi-institutional effort that draws on the unique expertise and infrastructure at Laboratories, Universities and Industry partners

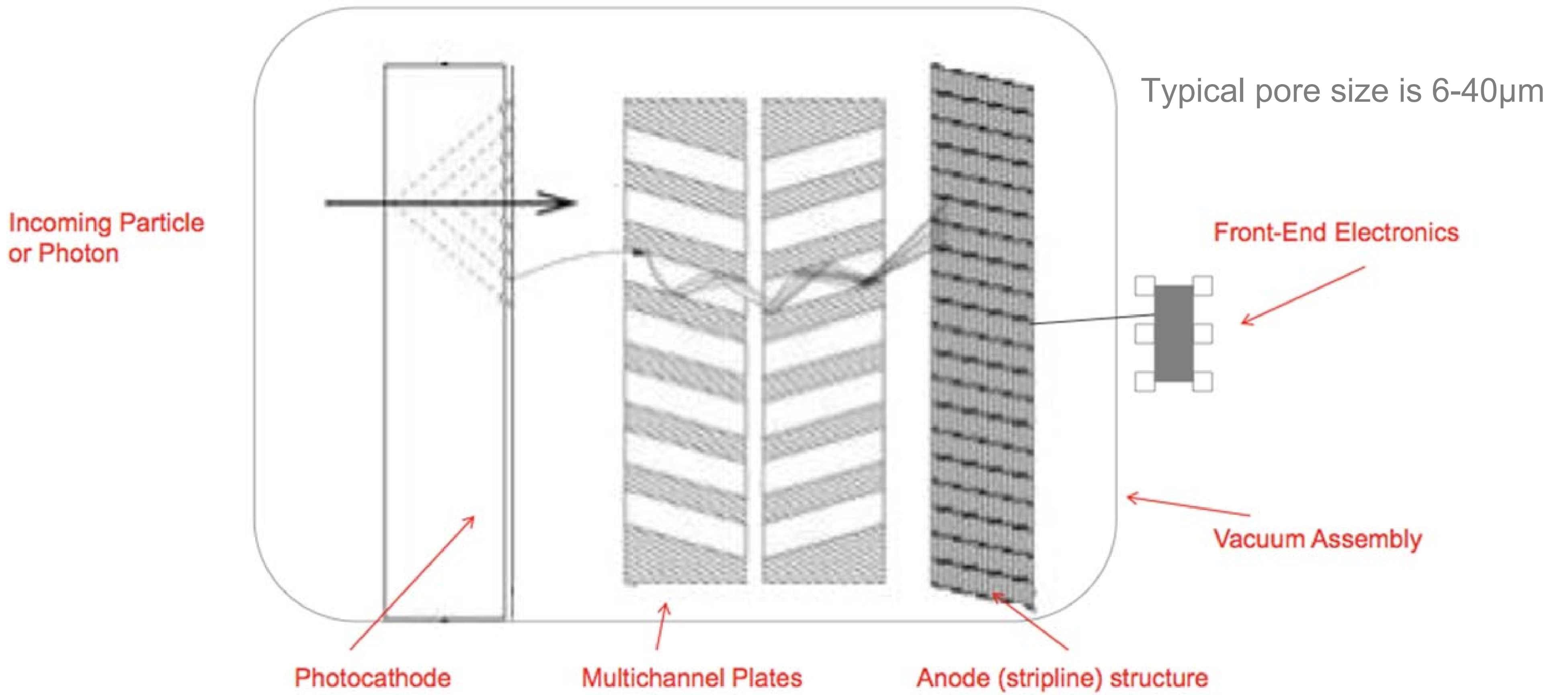
“Portfolio of Risk- Parallel Efforts

- **Two parallel but intertwined efforts at different levels of risk, reward:**
  - **SSL/Hawaii** (Siegmund)- ceramic package based on Planacon experience, NaKSb cathode, higher cost, smaller area, lower throughput, **lower risk due to fewer innovations, more experience;**
  - **ANL/UC** (Wagner, Byrum,Frisch)- glass package, KCsSb cathode, lower cost, larger area, higher throughput, **higher risk, but more innovation and use of new technologies.**
- **Reduce risk and enhance reward by diversification onto the 2 paths.** Has proved very beneficial to both efforts (much cross-fertilization, and shared MCP development)

LAPPD Introduction

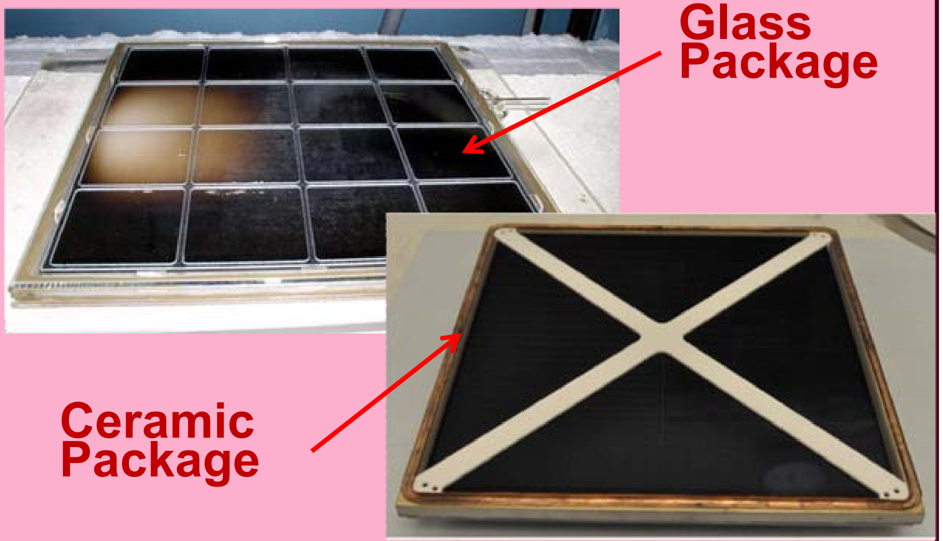
Requirements: large-area, gain > 10^7, low noise, low-power, long life, $\sigma(t)$<10 psec, $\sigma(x)$ < 1mm, and low large-area system cost

Realized that an MCP-PMT has all these but large-area, low-cost:
(since intrinsic time and space scales are set by the pore sizes- 2-20μ)

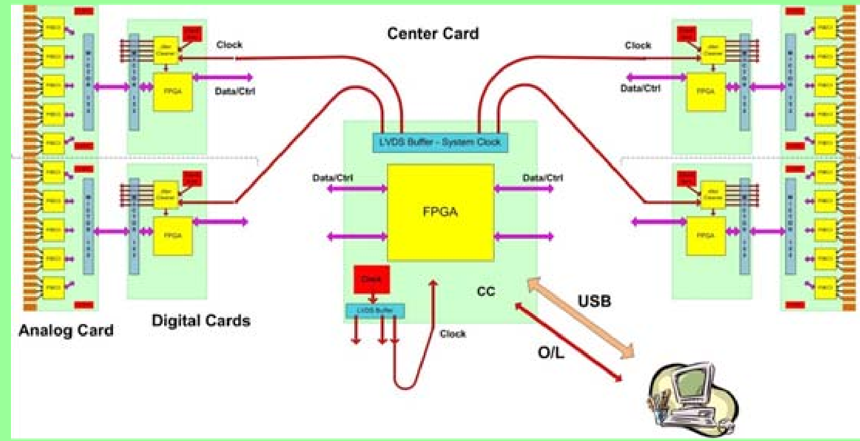


The 4 `Divisions' of LAPPD

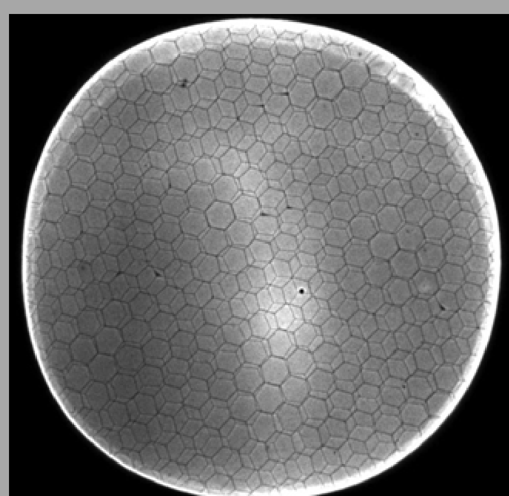
Hermetic Packaging



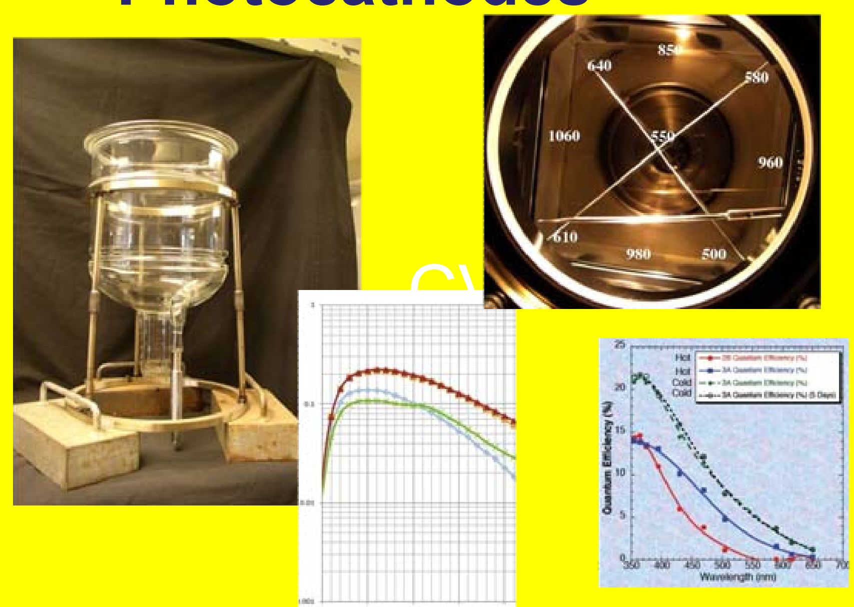
Electronics/Integration



MicroChannel Plates



Photocathodes

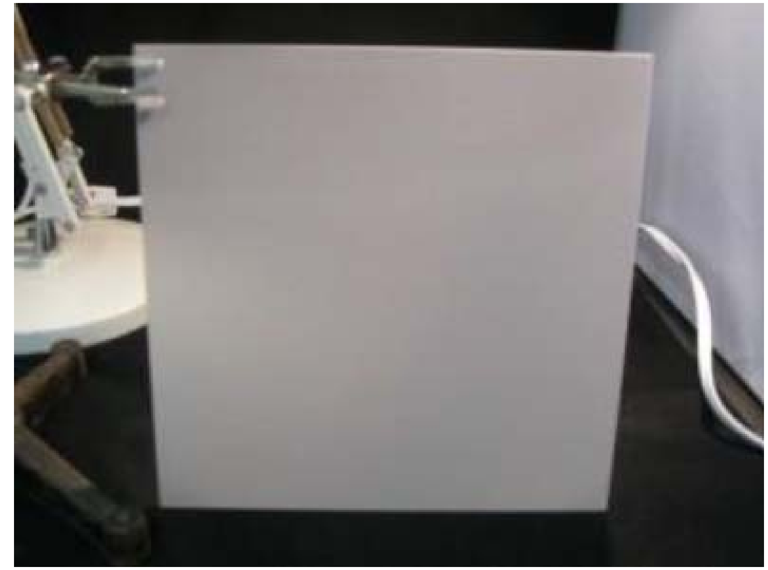


Outline

- Motivation(s) and Possible Applications
- LAPPD Introduction
- Micro Channel Plates (MCP)
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Conclusions

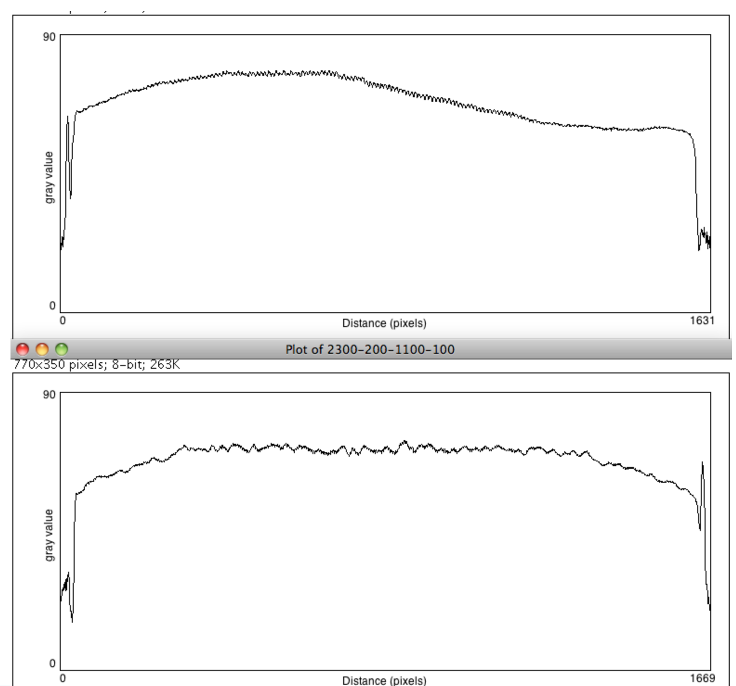
MCP Major Achievements

R&D 100 Award for cost-effective and robust route to fabricate large-area MCP detectors



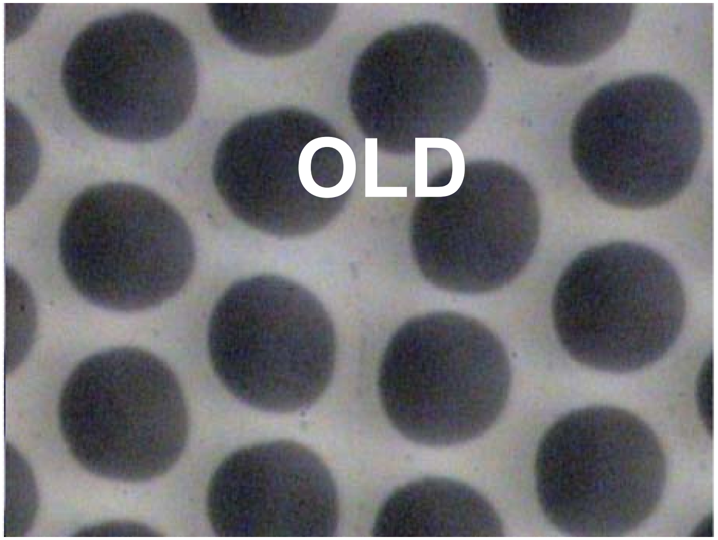
Gain Map of ALD-Functionalized 8" MCP

Development of 8" 20μ Substrates



Simplifying MCP Construction

Conventional Pb-glass MCP



Chemically produced and treated Pb-glass does 3-functions:

1. Provide pores
2. Resistive layer supplies electric field in the pore
3. Pb-oxide layer provides secondary electron emission

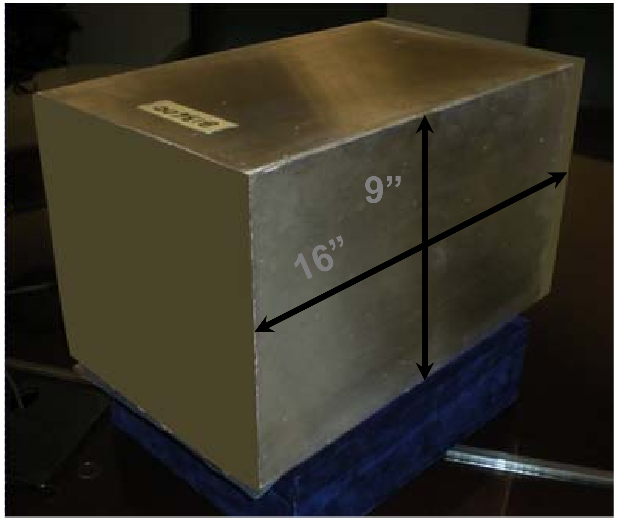
Incom Glass Substrate

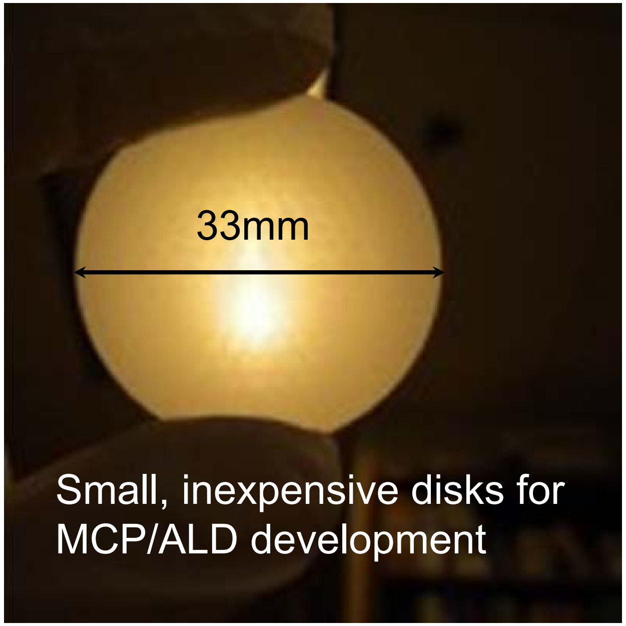
Separate the three functions:

1. Hard glass substrate provides pores;
2. Tuned Resistive Layer (ALD) provides current for electric field
3. Specific Emitting layer provides SEE

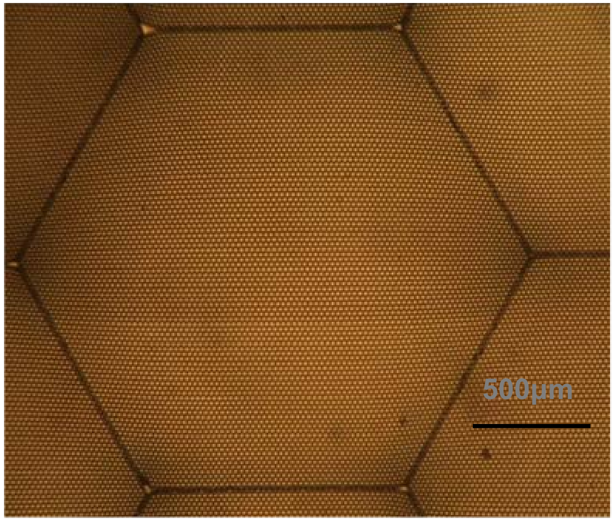
Development of Economical Borosilicate Capillary Arrays for MCPs — Industrial Partnership w/Incom, Inc

Fused block ready for slicing



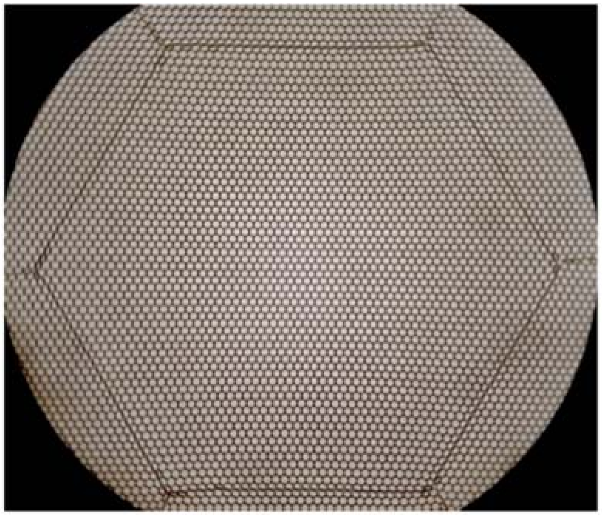


First block



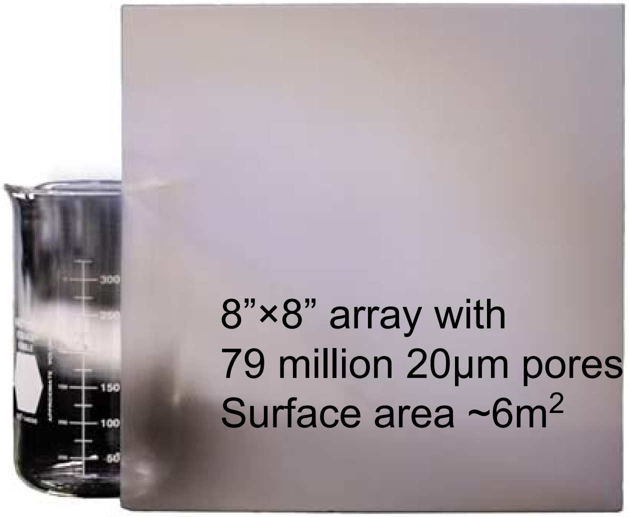
- Multifiber stacking
- Triple point gaps
- Pore crushing at multifiber boundaries

Most recent block

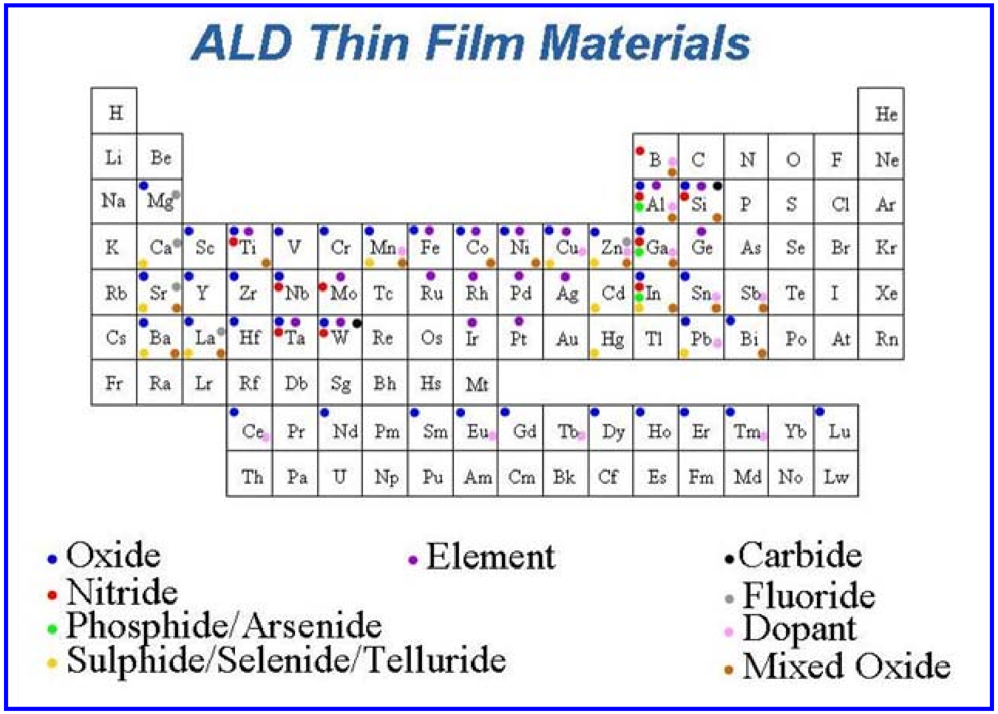


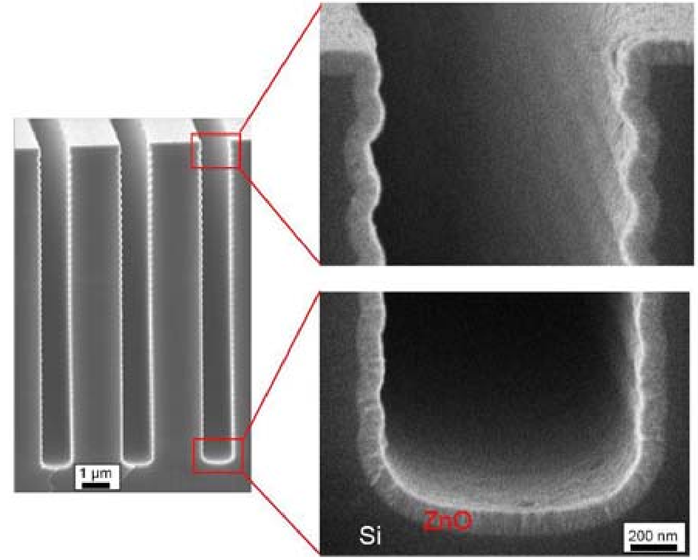
- Triple points eliminated
- Minimal boundary pore distortion

Capillary array quality dramatically improved during last 2.5 years



Atomic Layer Deposition (ALD) Thin Film Coating Technology



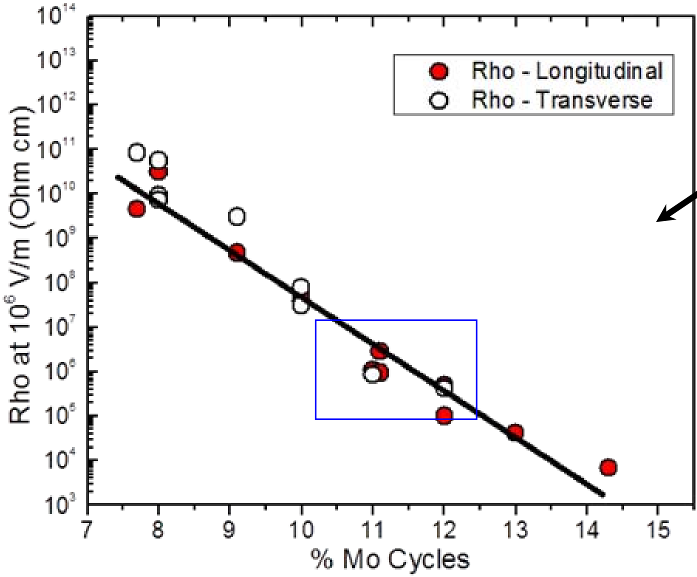


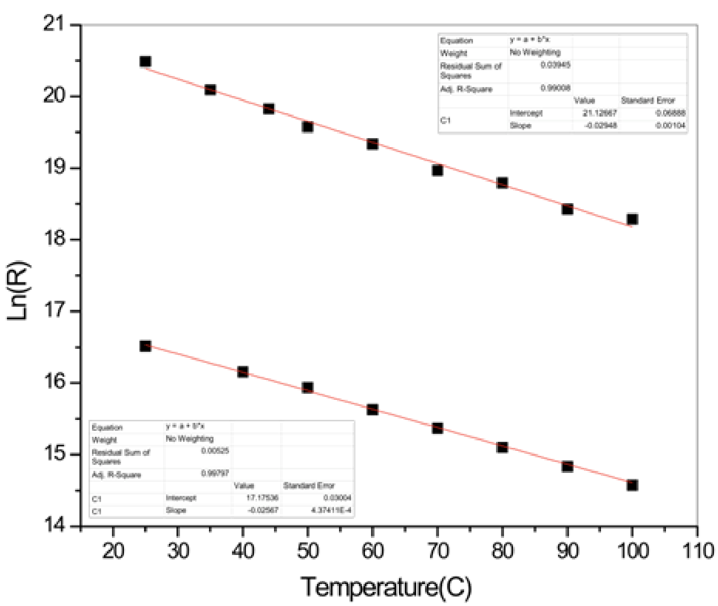
ALD is a chemical vapor synthesis process that permits deposition of a film one atomic layer at a time.

Lots of possible materials => much room for higher performance

- A conformal, self-limiting process.
- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects
- Separate Resistive & Emissive Layers

ALD Materials Development



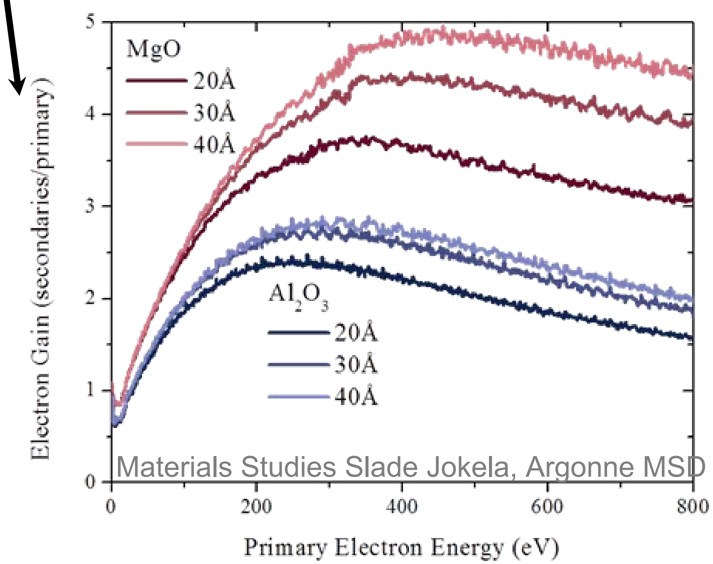


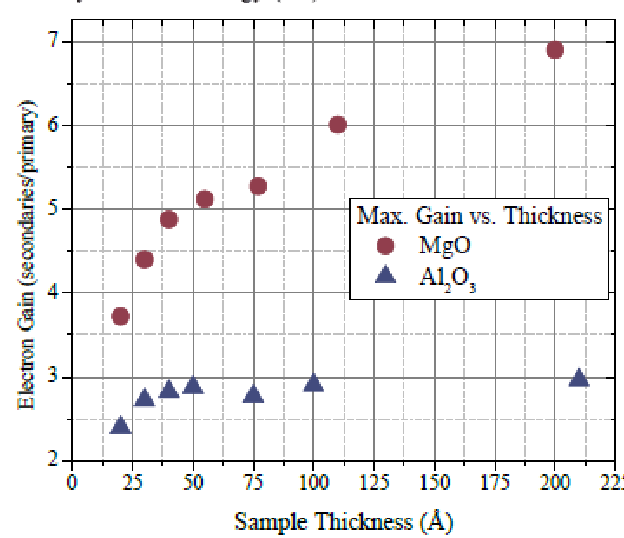
Resistive Layer

- 3 Resistive Chemistries invented by ANL ALD Group
- Tunable R over 6+ orders of mag.
- R vs. Temp. stable against thermal runaway

Emissive Layer

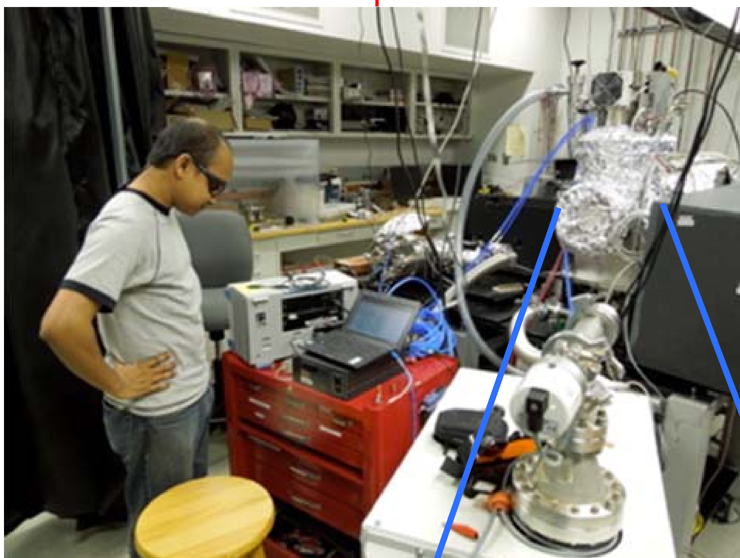
- materials and thickness dependences





MCP Testing at Argonne and SSL — Facilities

Argonne 33mm & 8" Test Chambers
with UV fs-pulse laser

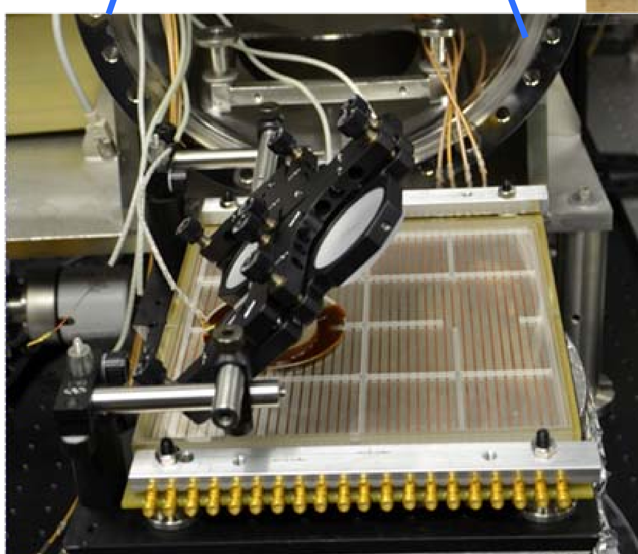


SSL 33mm Test Chambers

Phosphor detector on left imaged with camera

Cross-strip delay line on right for gain mapping

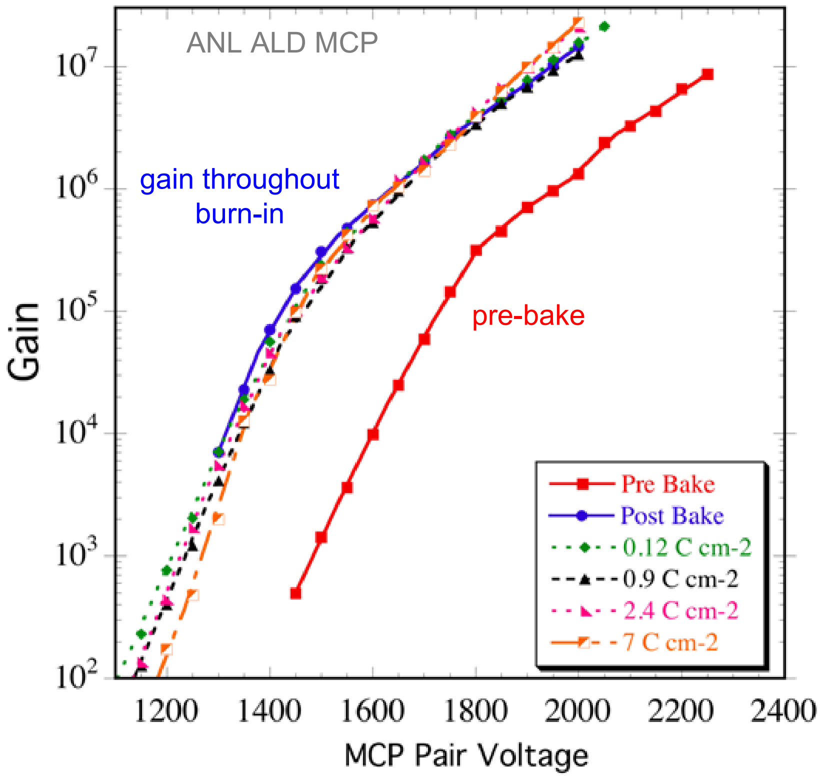
MCP on stripline anode ready for insertion into 8" chamber



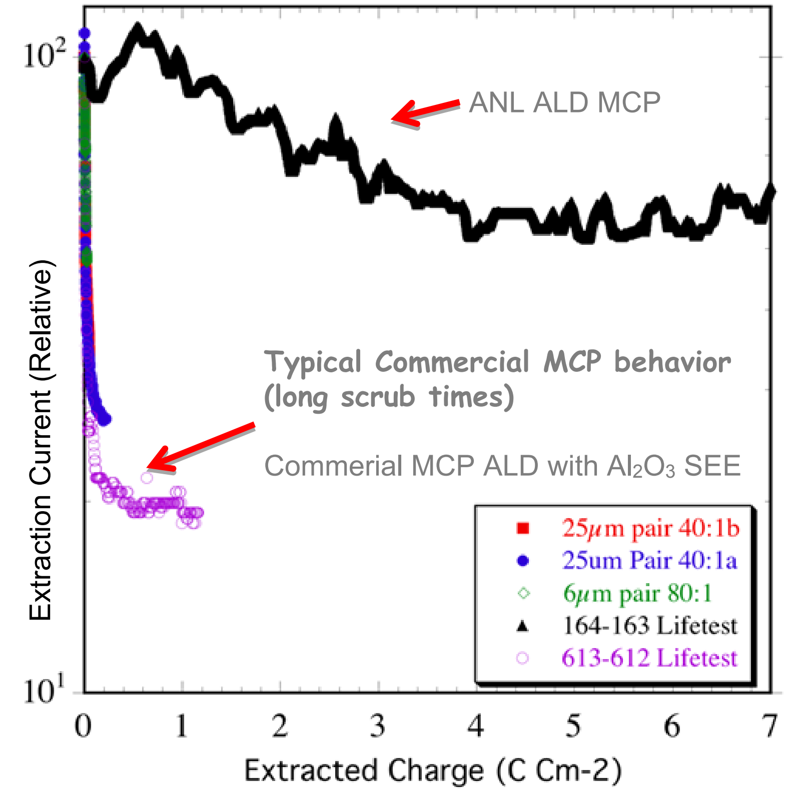
SSL 8" MCP Test Detector Vacuum System

MCP Development & Testing

MCP Tests Performed at SSL: 350˚C bakeout (aka scrub) then 1-3μA "burn-in" to 7C/cm²



Gain curves of 33mm ALD MCP pair at stages during conditioning.



UV scrub of ALD MCP pair 164-163 compared with conventional MCPs. Outgas during burn-in < 4 x 10^{-10} torr H_2.

Desirable MCP properties with MgO SEE:

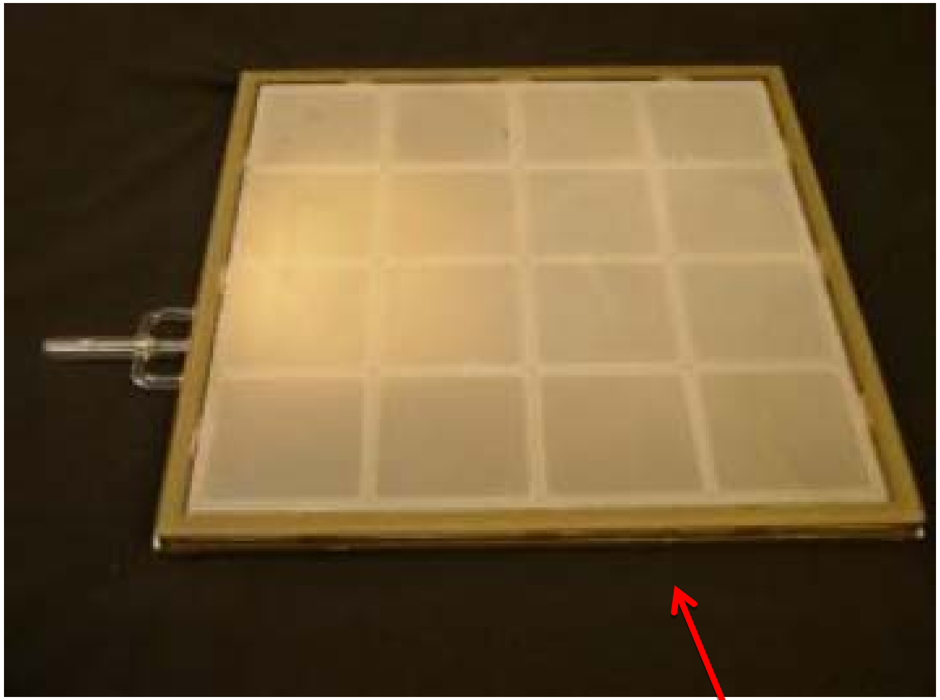
- **Precipitous initial gain decrease seen in commercial MCPs absent in ALD-functionalized sample.**
- **ALD MCPs show little or no aging up to 7C/cm².**

graphics: Ossy Siegmund & Jason McPhate, SSL

Outline

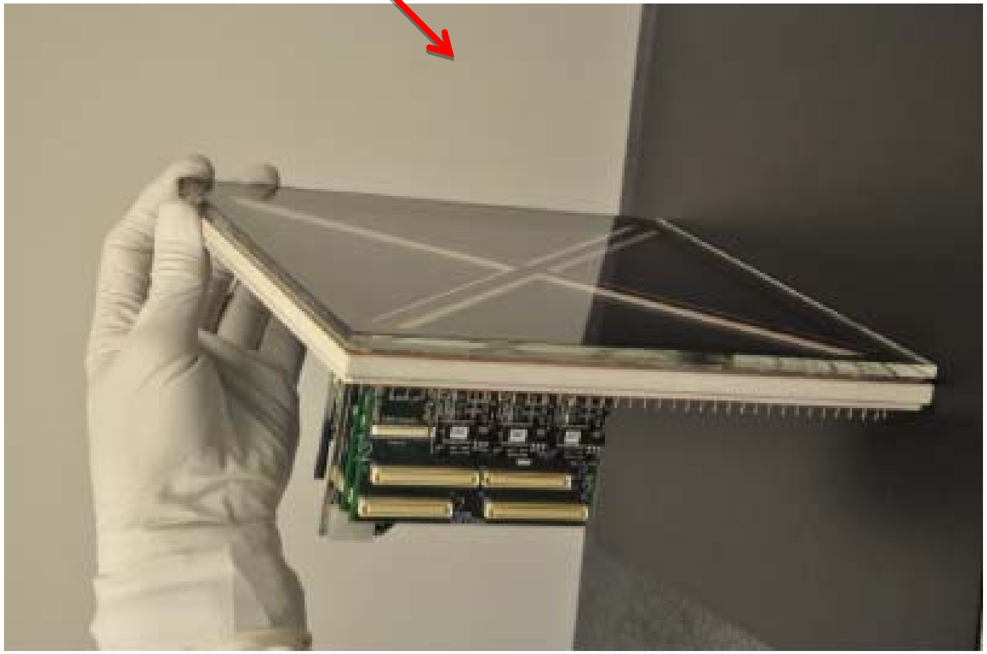
- Motivation(s) and Possible Applications
- LAPPD Introduction
- Micro Channel Plates
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Conclusions

Packaging Major Achievements



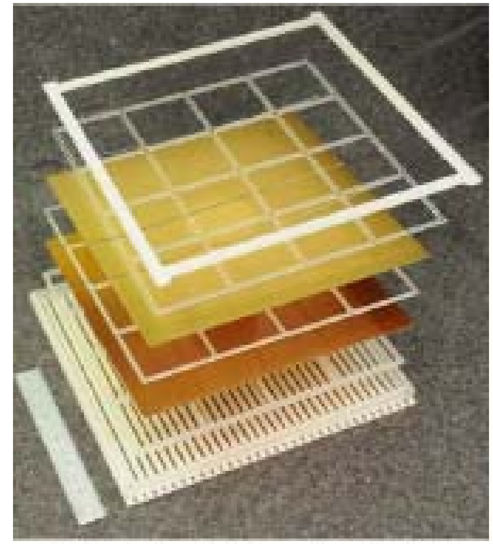
Development of a 'frugal' glass tile package with internal HV divider, capacitive GHz readout

Development of a complete ceramic package system design

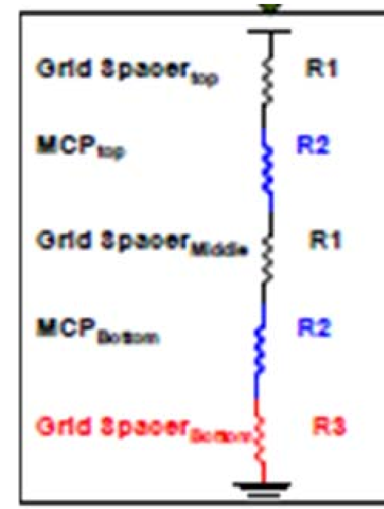


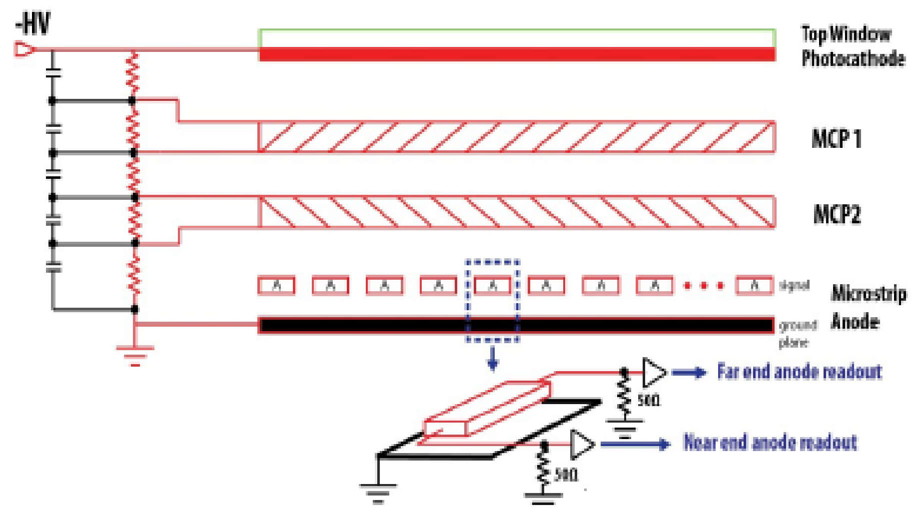
Development of Hermetic Package — All Glass Tile

- Cheap, widely available float glass
- Cheap silver silk-screened RF Stripline Anode
  - High bandwidth
  - 50 Ω impedance designed for fast timing
- Flat panel
- No pins, single HV cable
  - HV distribution is controlled by the resistance of the internal parts functionalized with ALD
- Modular design

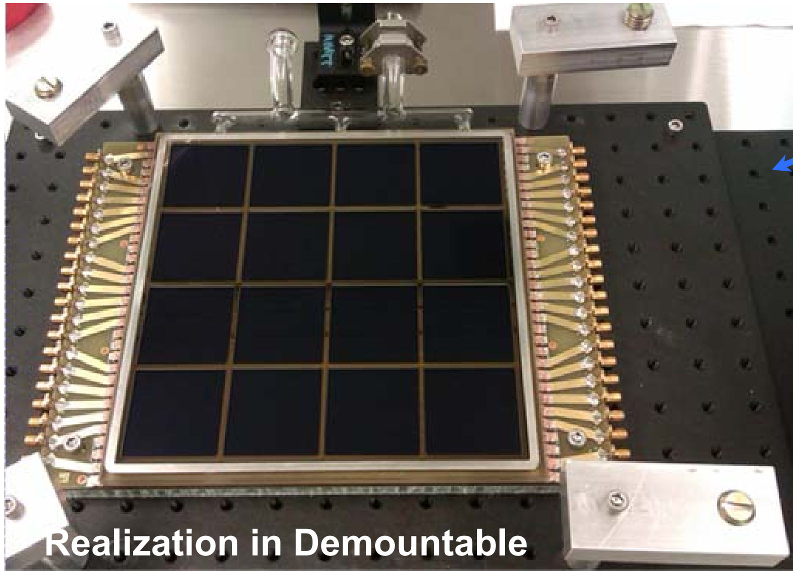


Actual Glass Parts - April 2012





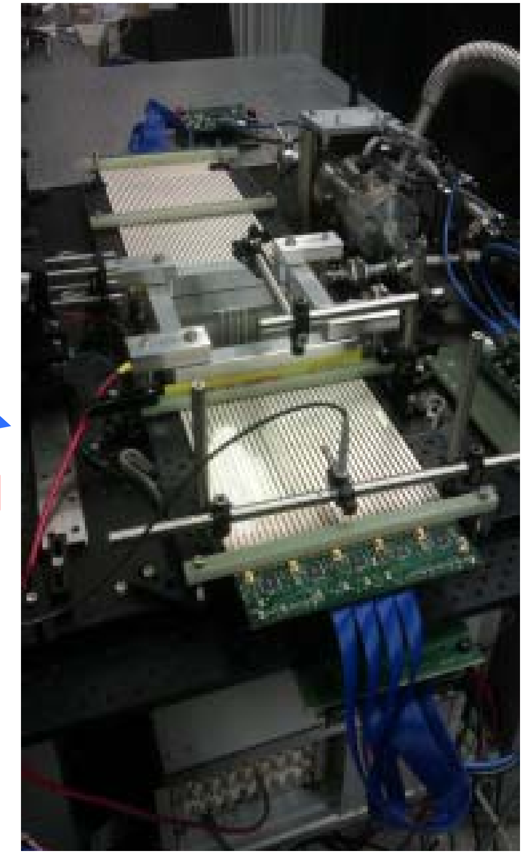
Development of Hermetic Package — All Glass Tile



Demountable

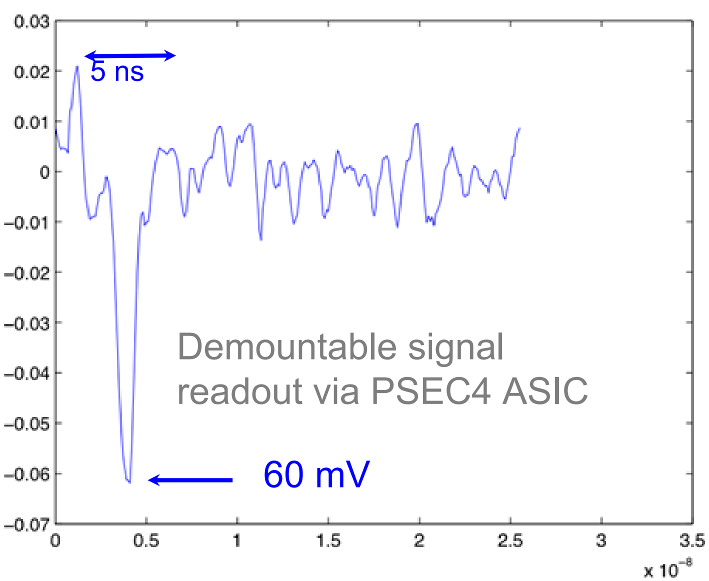
Assembled in ALD Lab Clean Room

Transported to APS UV Laser Test Setup



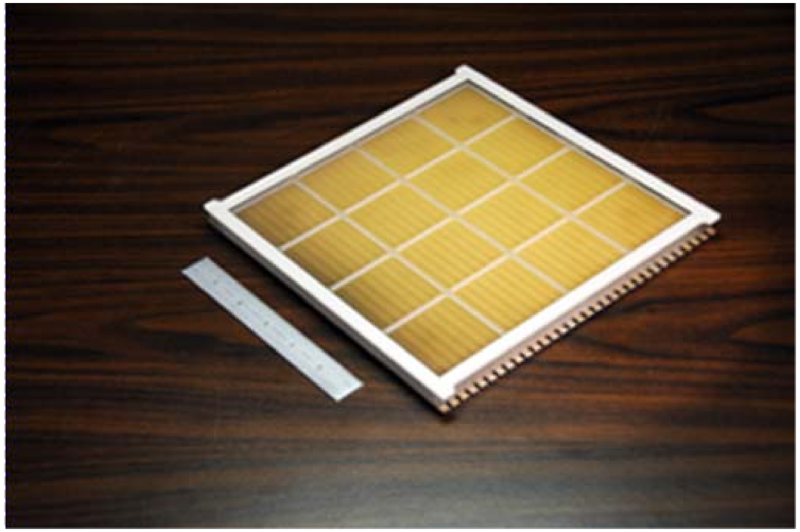
All glass package concept demonstrated with o-ring sealed tile:

- Continuously pumped
- MCP pair: Chem. 2 + MgO SEE
- Al photocathode on quartz window
- ALD grid spacer for HV distribution
- 30-strip anode to fanout board

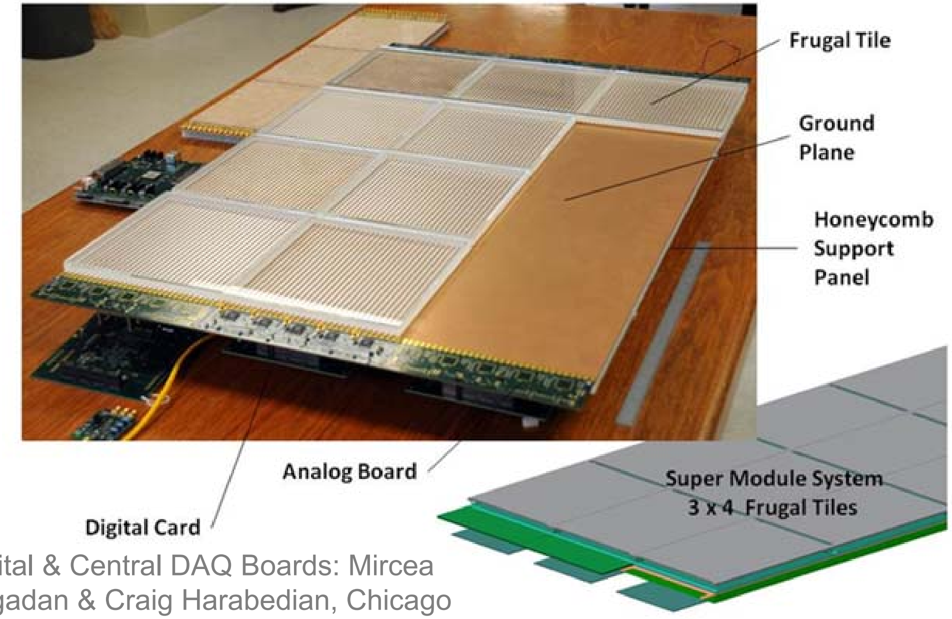


- **Future Work:**
- **Complete work presently ongoing for Indium pressure seal for top window**
- **Produce sealed tiles with bialkali PC in future Argonne Single Tile Processing System**

Glass MCP Phototube Strip Line Anode



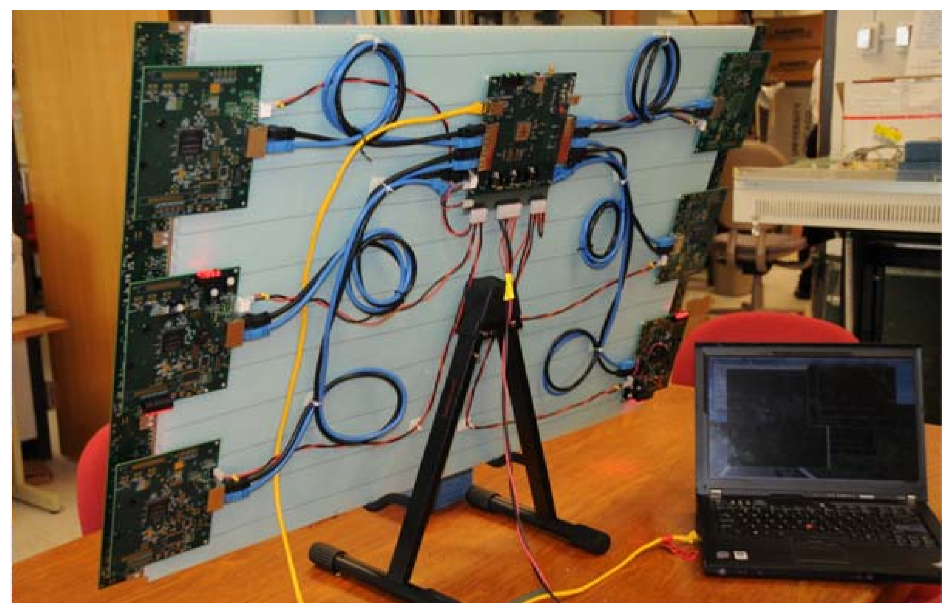
Tile base is 30 strip silk-screened anode



Digital & Central DAQ Boards: Mircea Bogadan & Craig Harabedian, Chicago

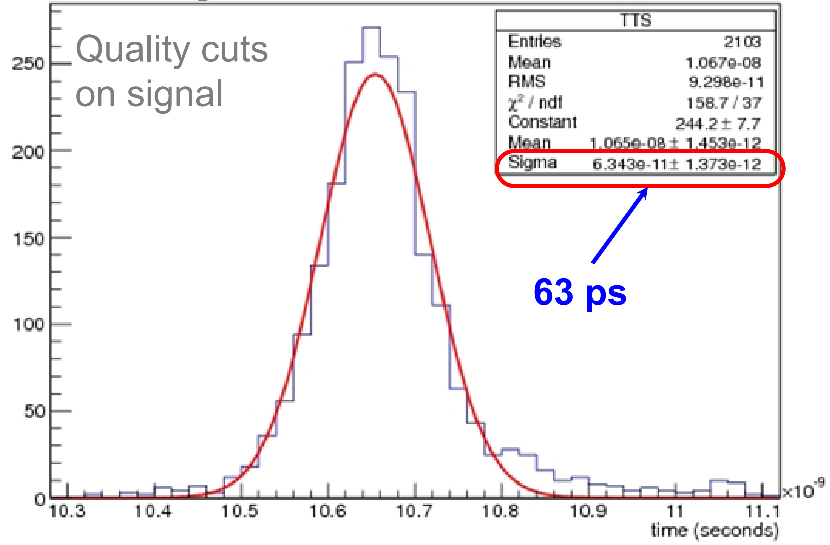
Tray and Tiles - The Super Module System

- One 8” MCP Glass PMT ≡ Tile
- Serial connection of tiles with common double-end readout minimally affects performance
- 4×3 array of tiles ≡ SuperModule Tray
- Complete readout chain from front-end waveform sampling ASIC through digital and central control cards to graphics processor PC has been integrated into SuperModule

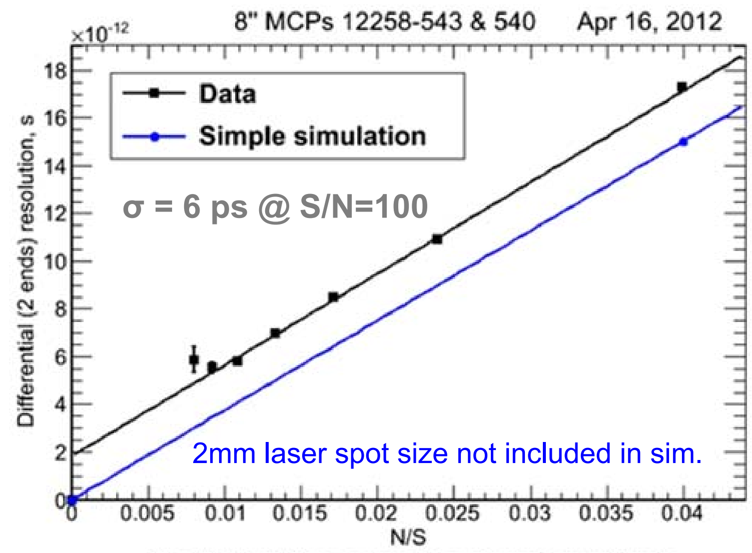


Strip Line Anode Performance with 8” MCP Pairs

Single PE Time Resolution



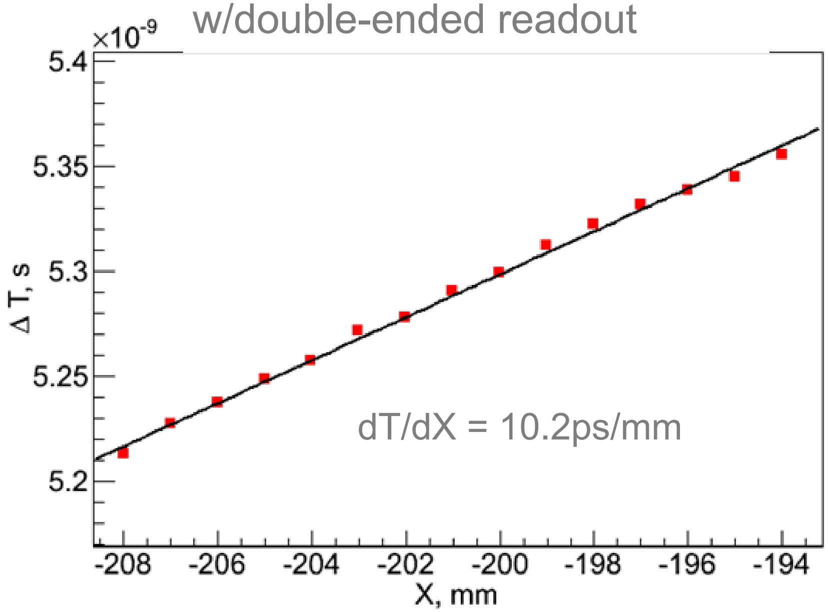
Differential Time Resolution vs. Noise



N = RMS of the noise; S = signal amplitude

Simulation has many more points than shown. All are very well consistent with the blue line.

Position scan along stripline w/double-ended readout

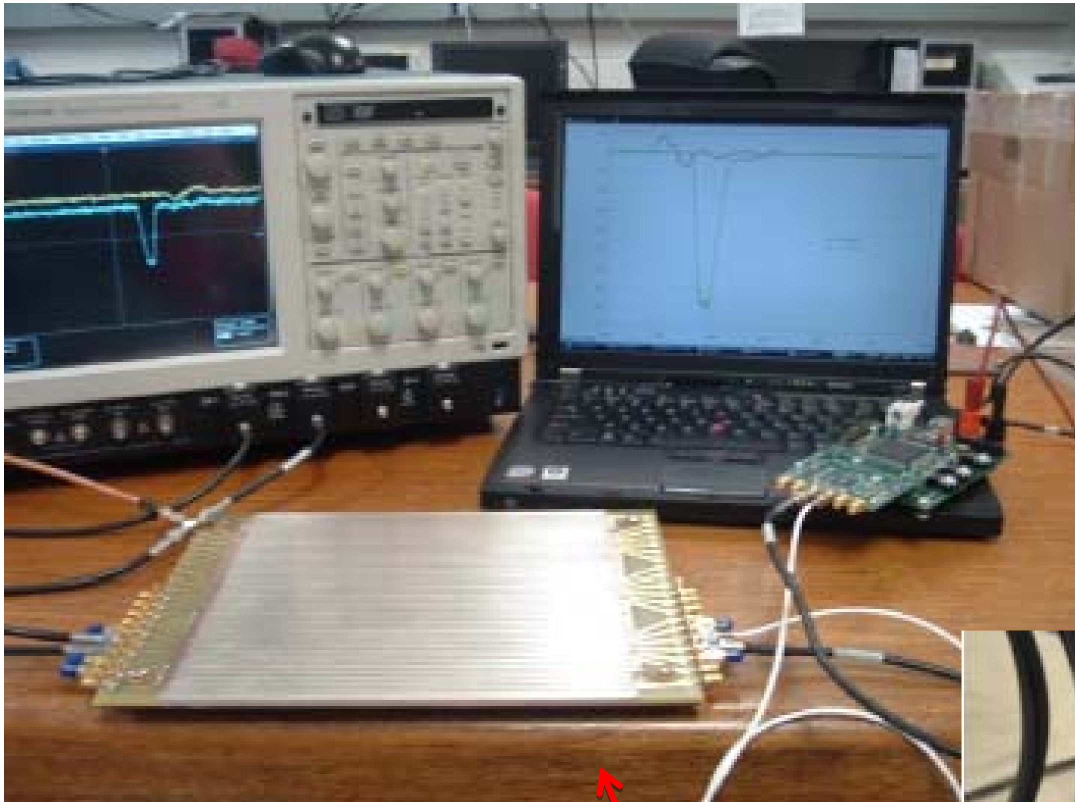


- Results from Argonne 8” Test Ch. w/UV laser excitation, fast scope readout (M.Wetstein, B. Adams, A. Elagin, R. Obaid, A. Vostrokov)
- Un-optimized Anode performance impressive and meets present needs
- Prospects for improvement to few ps resolution are good

Outline

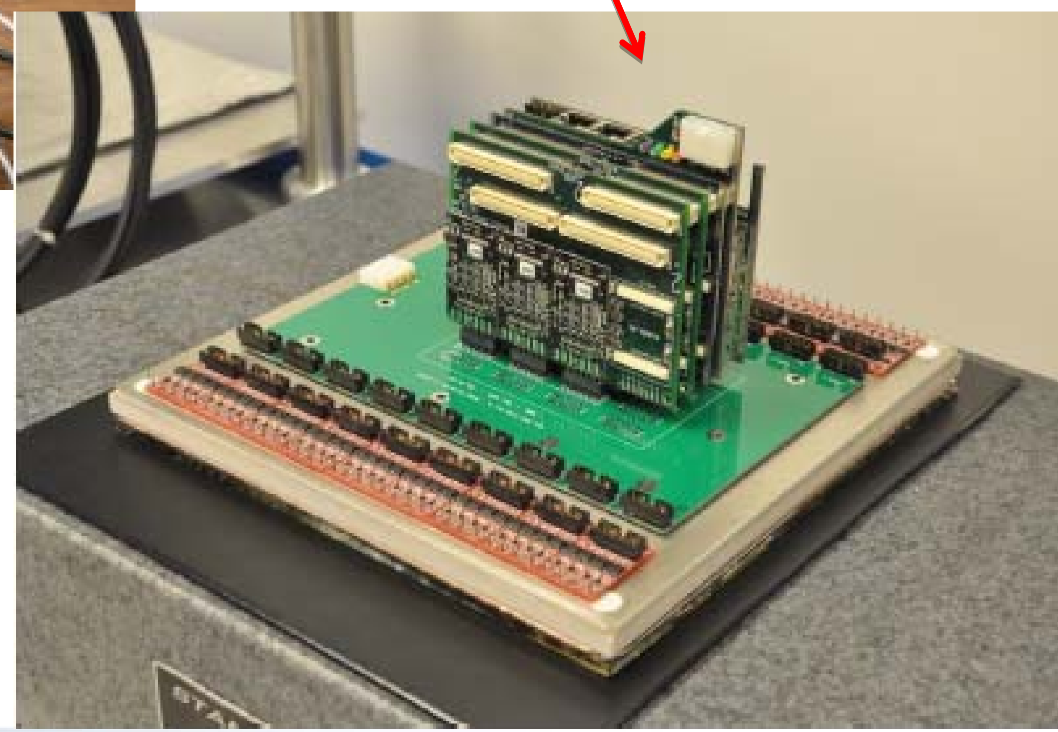
- Motivation(s) and Possible Applications
- LAPPD Introduction
- Micro Channel Plates
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Conclusions

Electronics Major Achievements

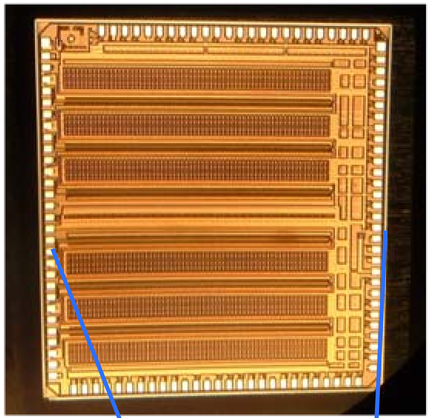


Development of a 15 GS/sec waveform sampling ASIC

Development of a complete system for the ceramic tube

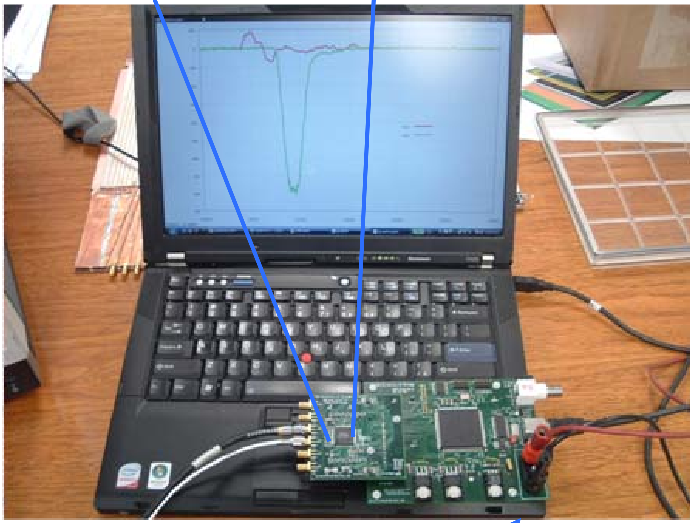


Development & Testing of Front-end Electronics



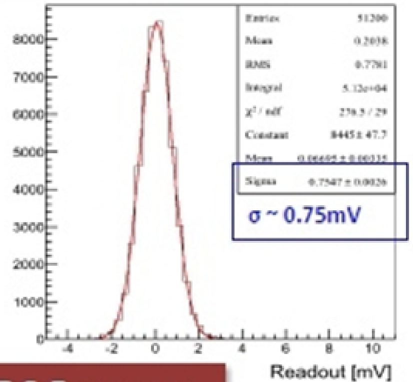
PSEC4 6-ch.
"scope-on-a-chip"
1.6 GHz BW, 10-15 GSa/s,
130nm technology

PSEC ASIC Design and Testing by
Univ. of Chicago & Univ. of Hawaii

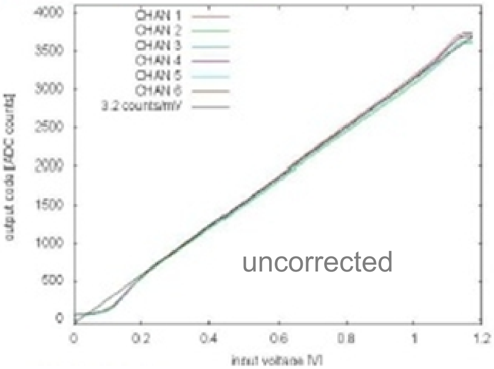


Evaluation board w/2.0 USB
interface + PC DAQ software

Noise

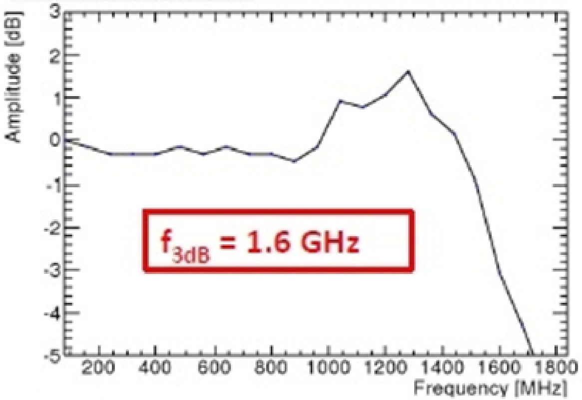


DC Response



- Low noise <1 mV
- ~1V dynamic range with excellent linearity
- Analog bandwidth of 1.6 GHz
- Sampling rates up to 15 GSa/s

Frequency Response

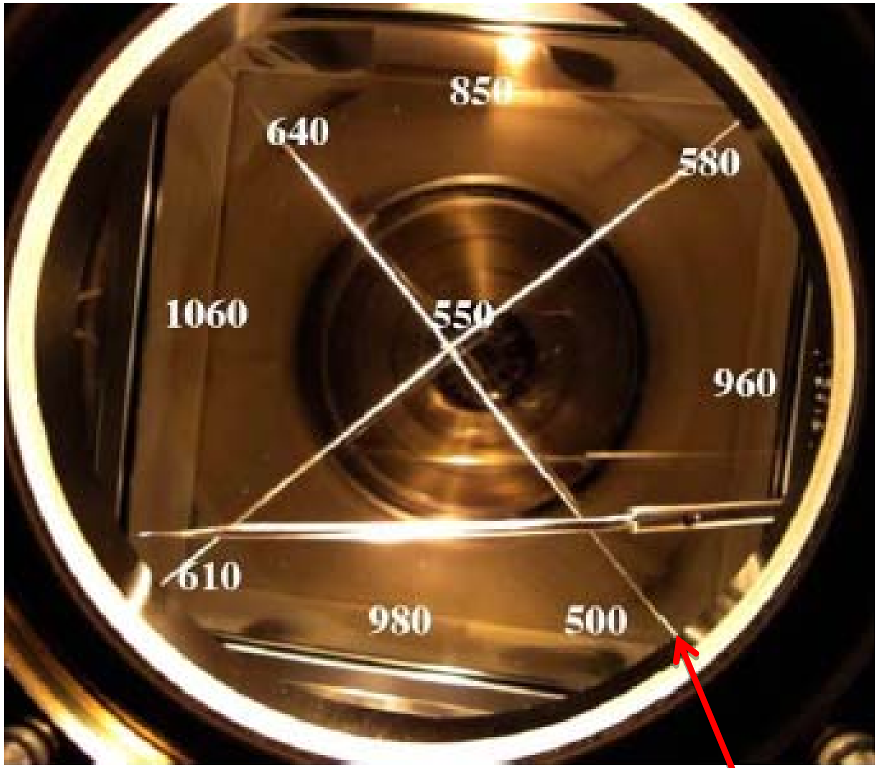


PSEC 4 design & test results: Eric Oberla &
Hervé Grabas, Chicago

Outline

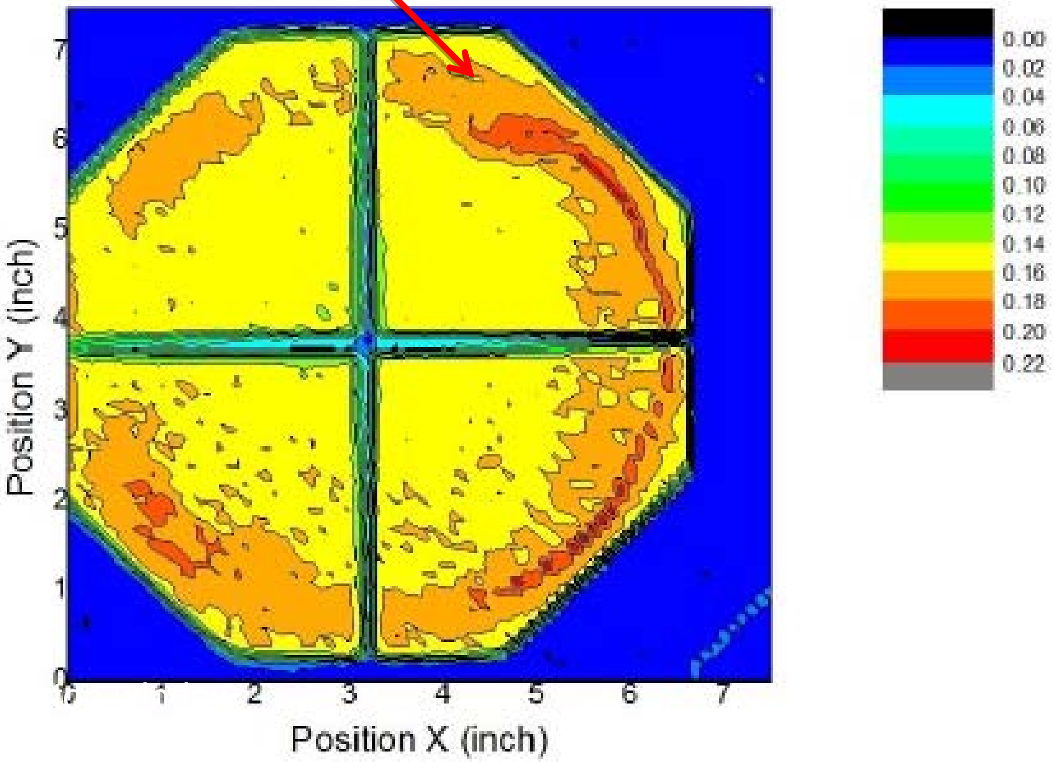
- Motivation(s) and Possible Applications
- LAPPD Introduction
- Micro Channel Plates
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Conclusions

Photocathode Major Achievements



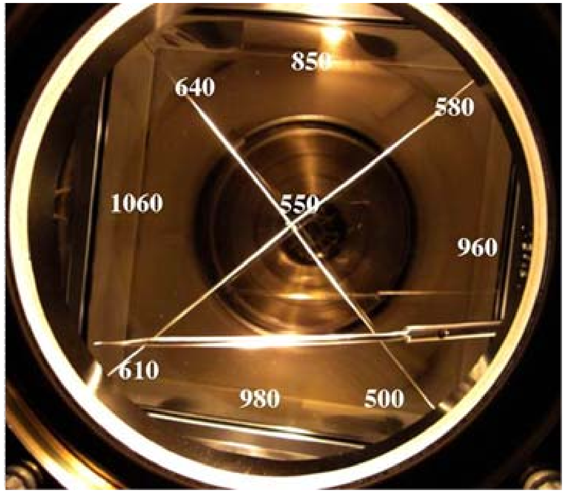
A successful 8" Bialkali Cathode made at SSL

A 7" Bialkali made in the Burle Equipment at ANL

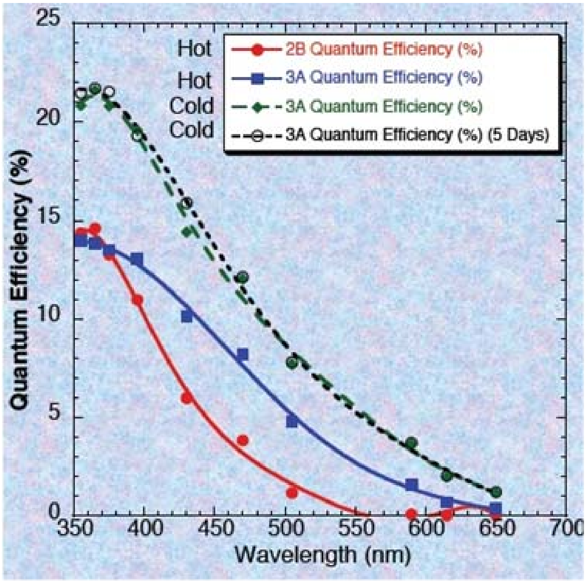


PhotoCathode Development

Have made >20% 8"PC at SSL; at ANL, 25% ½" PC's, 18% 7" PCs



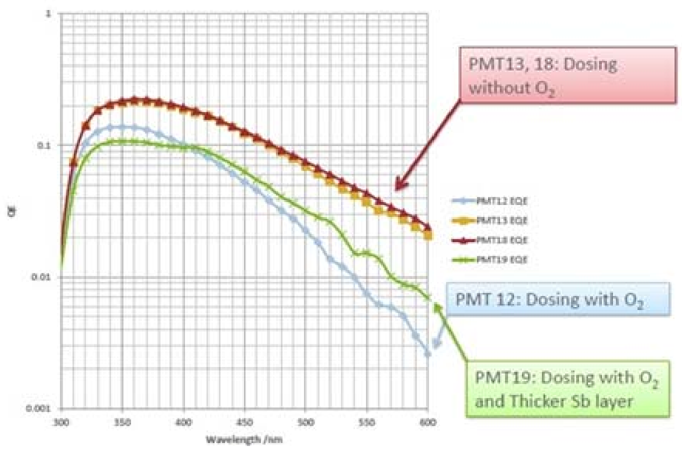
SSL 8" SbNaK cathode



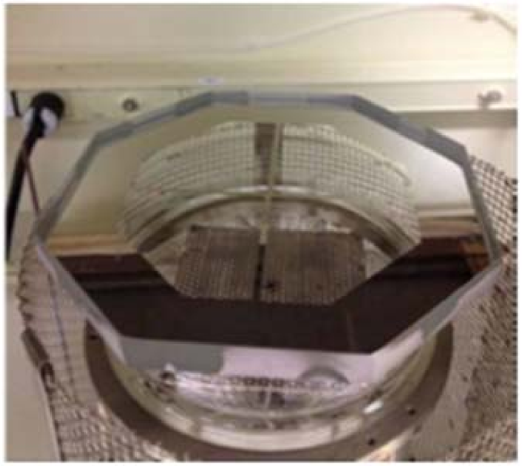
QE of SSL 8" SbNaK cathode

Summary of cathodes grown by Burle Equip

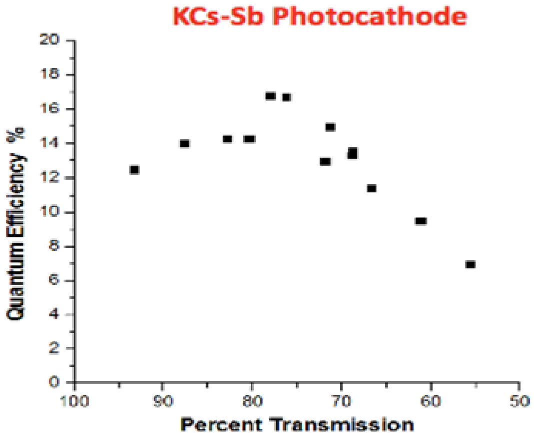
ANL



QE of ANL small SbKCs cathodes



QE Map



7" cathode: Chalice in Burle oven

Outline

- Motivation(s) and Possible Applications
- LAPPD Introduction
- Micro Channel Plates
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Conclusions

LAPPD Project Summary

- Many applications can benefit from precise timing, excellent spatial and large area coverage of photodetectors
- Picosecond timing on large area seems to be within the reach of LAPPD (working in a large parameter space of cost and performance)
- Innovative inter-disciplinary program with mix of laboratories, universities and industry: R&D 100 award
- 1 year goal to produce first sealed tube
- 3 years goal: deliver first tile systems to early adopters

More information on web:
http://psec.uchicago.edu/