Recent Advances in Large Area Micro-channel Plates and LAPPD™

Incom, Inc. Christopher Craven, Bernhard Adams, Melvin Aviles, Justin Bond, Till Cremer, Michael Foley, Alexey Lyashenko, Michael Minot, Mark Popecki, Michael Stochaj, William Worstell

Argonne National Laboratory Jeffrey Elam, Anil Mane

University of Chicago Henry Frisch, Andrey Elagin

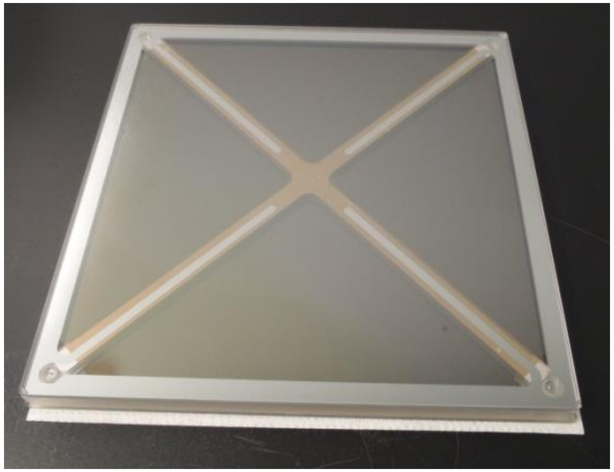
U.C. Berkeley, Space Sciences Laboratory Oswald Siegmund, Camden Ertley

Iowa State Matthew Wetstein

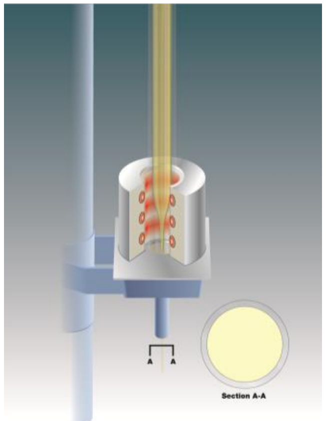
Incom, Inc.
294 Southbridge Road
Charlton, MA 01507 USA
508-909-2200
www.incomusa.com
mjm@incomusa.com

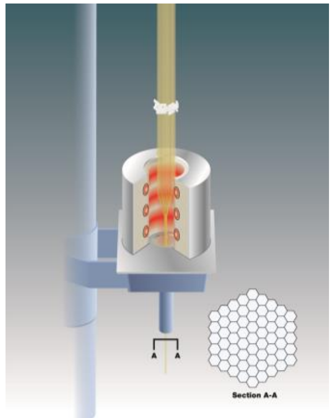
Outline

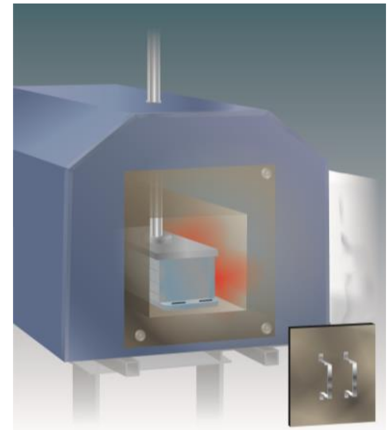
- Incom MCPs
  - How they are made
  - Advantages
  - Performance
- The Large Area Picosecond Photodetector (LAPPD™)
  - Applications
  - Design
  - Performance of sealed tiles



How Incom MCPs are Made



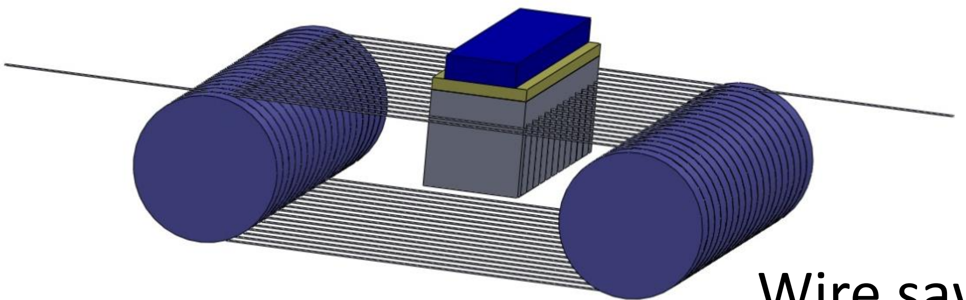




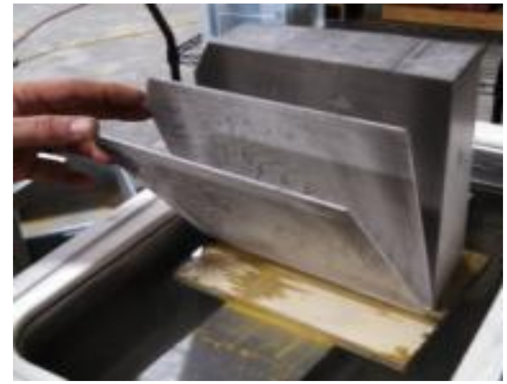
Draw glass tubes, bundle, redraw

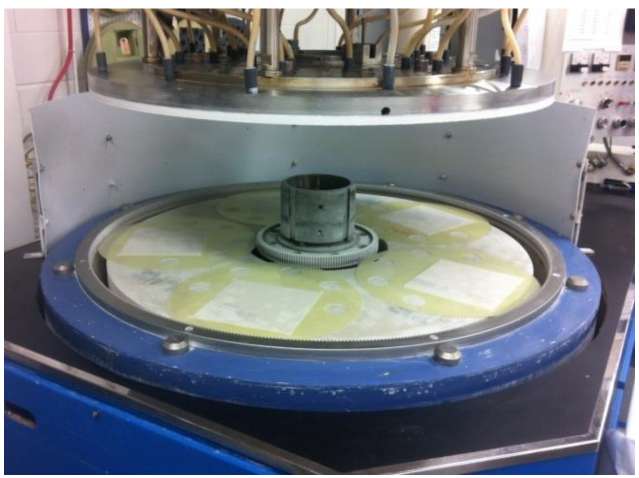
Fuse into glass capillary array blocks

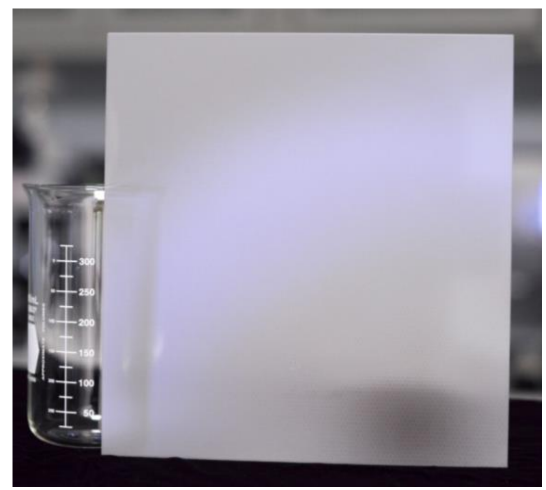
Process into Polished Glass Capillary Arrays



Wire saw







Machine to size, grind, polish, clean

Atomic Layer Deposition (ALD) Coating Converts Glass Capillary Arrays into MCPs

- Resistance can be tuned to desired value
- Al_2O_3 or MgO secondary electron emissive layer (SEE) for high gain

(Mane, et al., 2012)

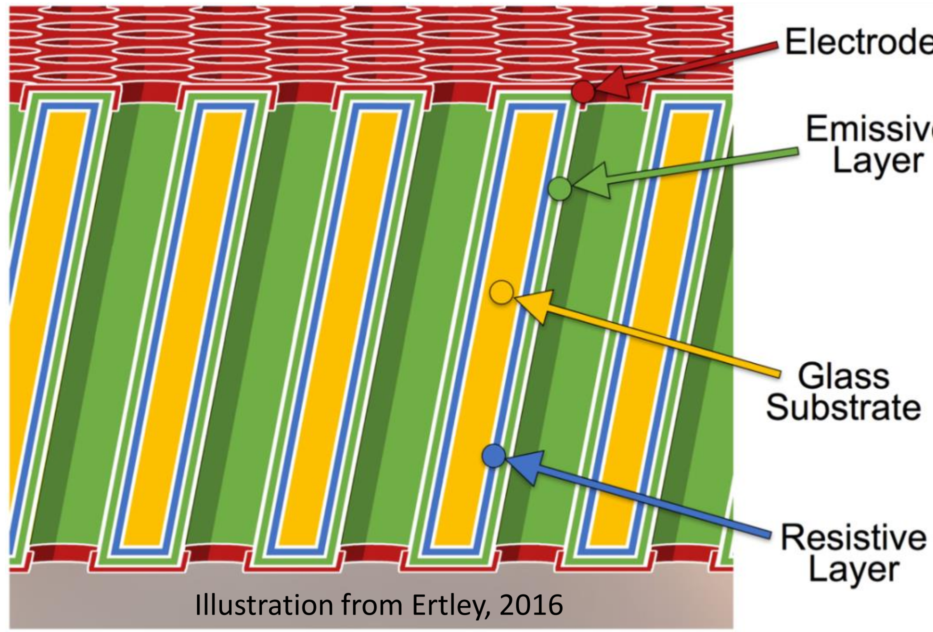
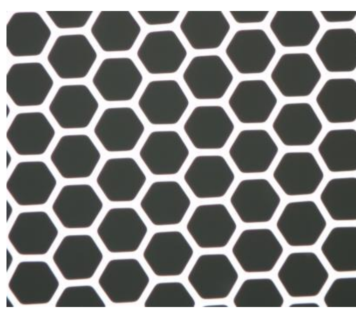


Illustration from Ertley, 2016



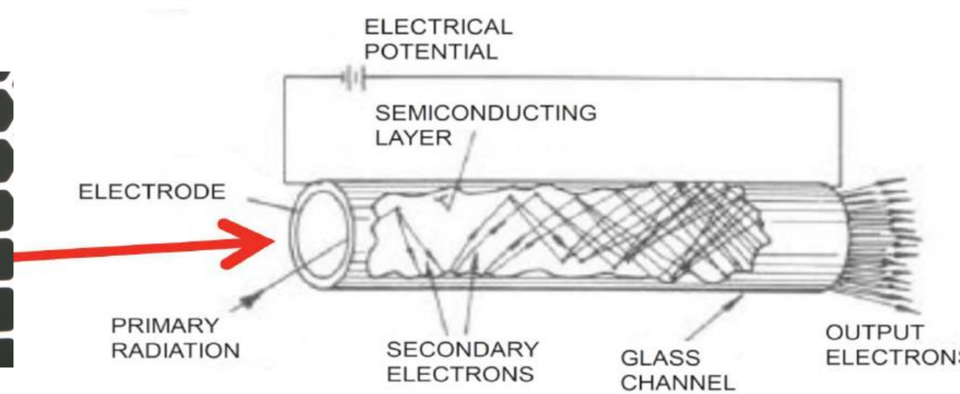
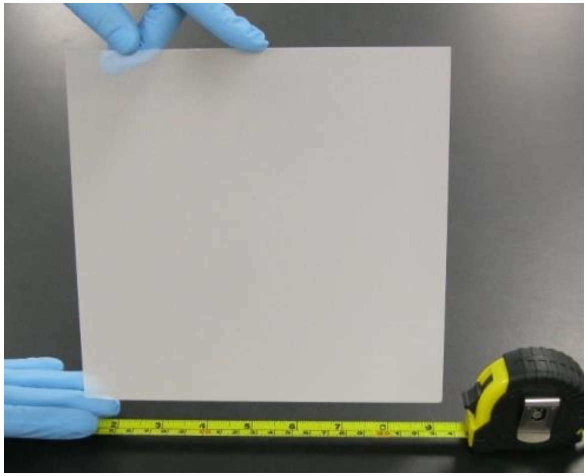


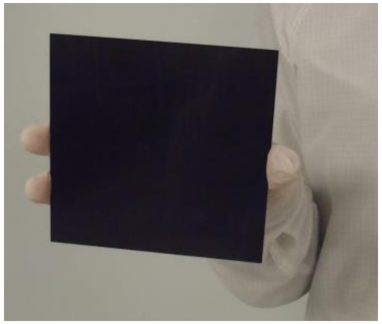
Illustration from Wiza, 1979

Advantages of the GCA/ALD Approach

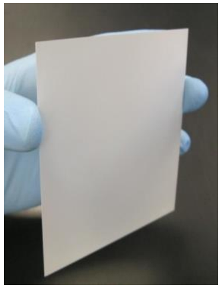
- Glass and coating can be independently optimized
- Stronger glass = larger size for a given pore size & thickness
- Flat (not specified, but typically <100 µm over 20 cm x 20 cm area)
- Alkali-free = low intrinsic noise, <0.045 cts/sec/cm^2 (Ertley, 2016)



20 cm sq., 1.2 mm thick



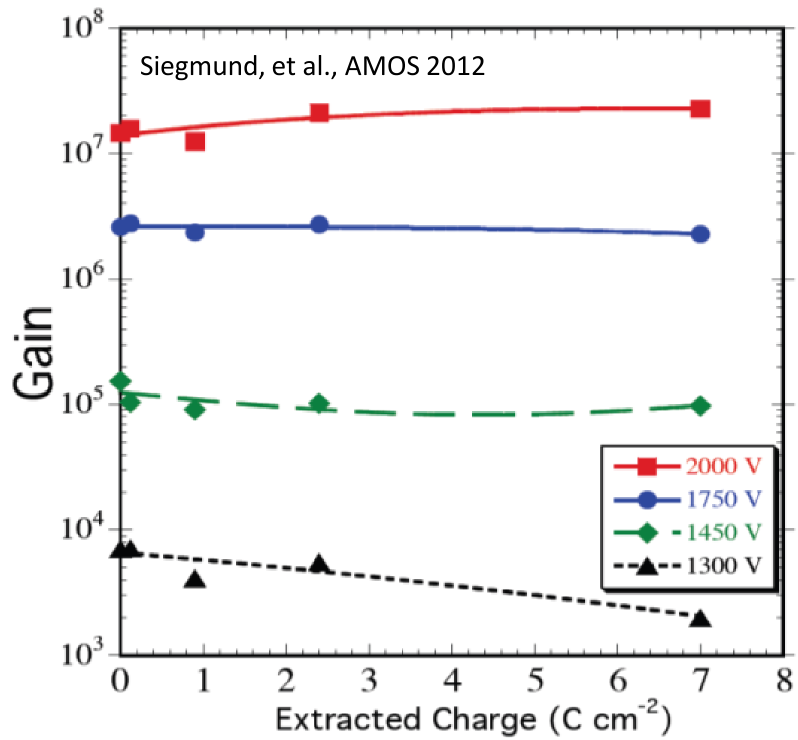
12.7 cm sq., 0.6 mm thick



9.5 cm sq., 0.25 mm thick

Stability of MgO Emissive Layer

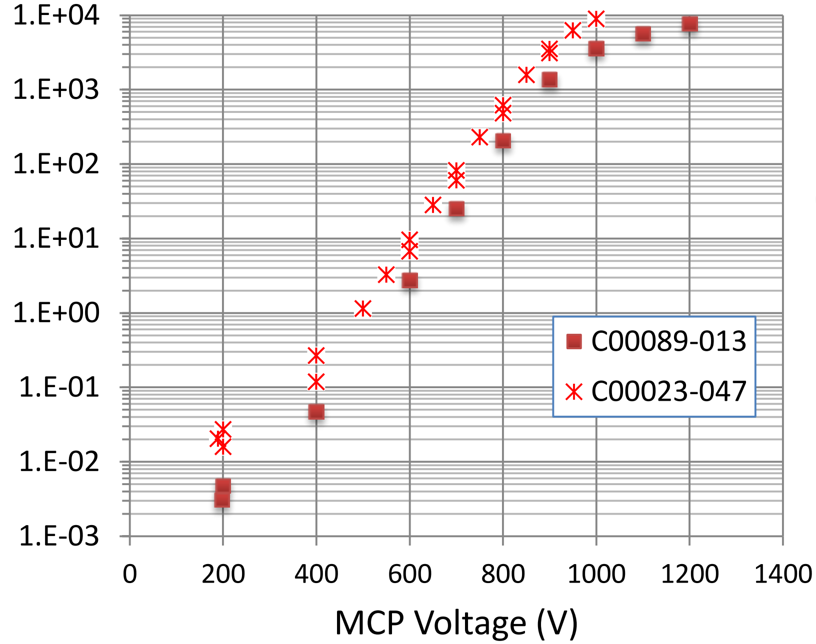
(Data from 33 mm dia. 20 µm pore MCPs)



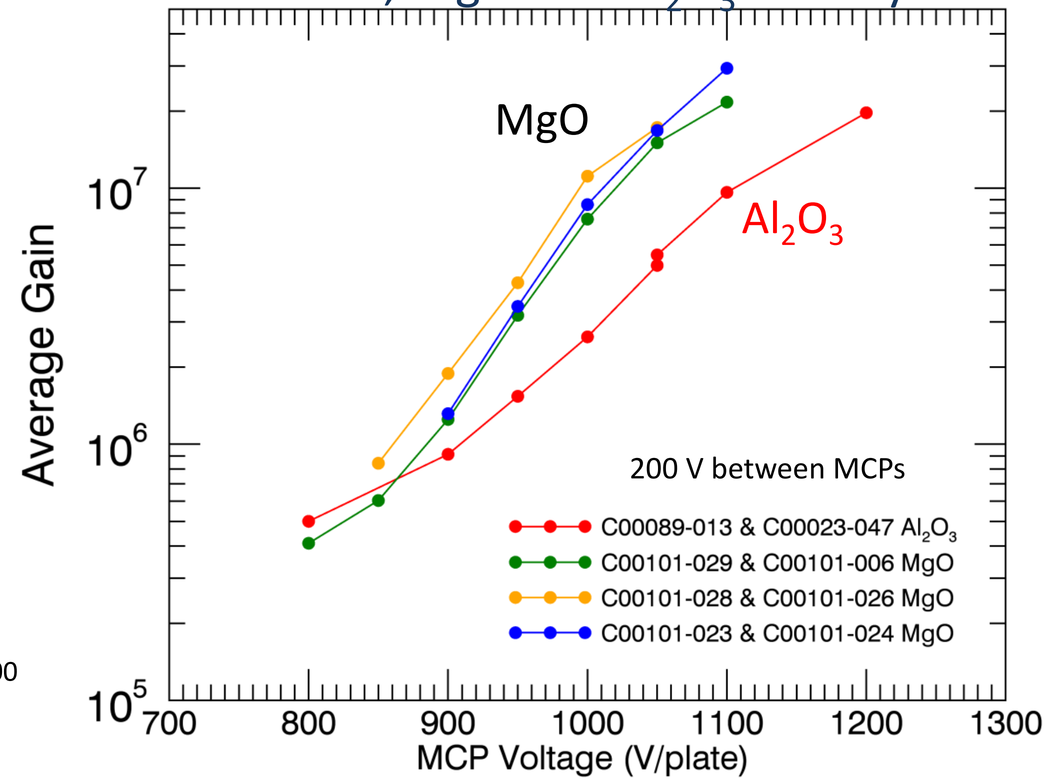
- Al_2O_3 has historically be used for 20 cm MCPs
- Now we are also developing MgO coating methods for the large area MCPs, important for sealed detectors

Gain vs. Voltage for 20 cm x 20 cm MCPs, 20 µm Pores

Two individual MCPs with Al_2O_3 SEE layer

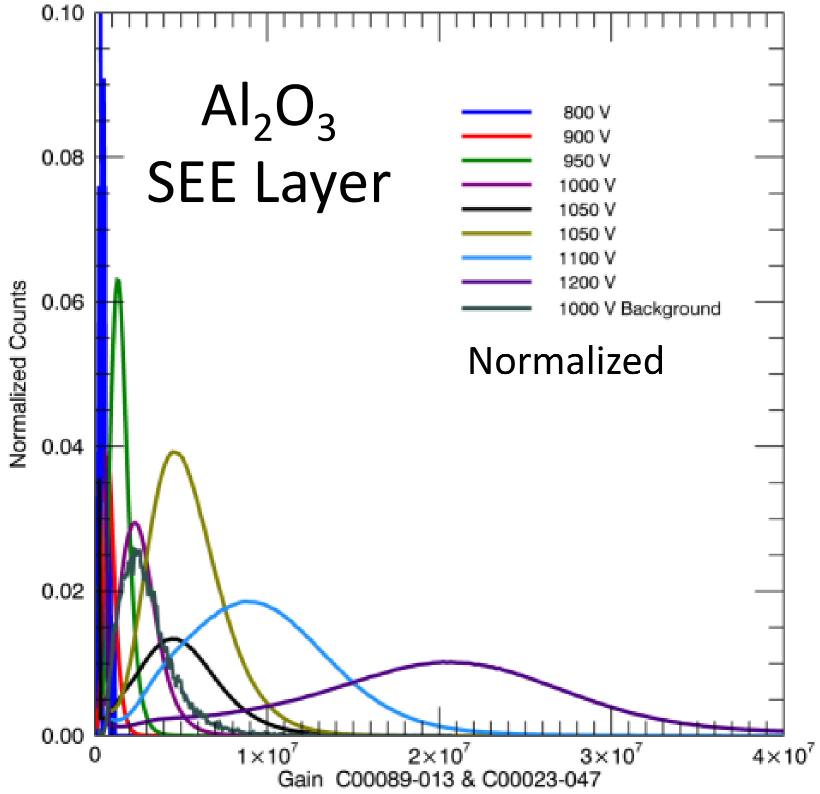


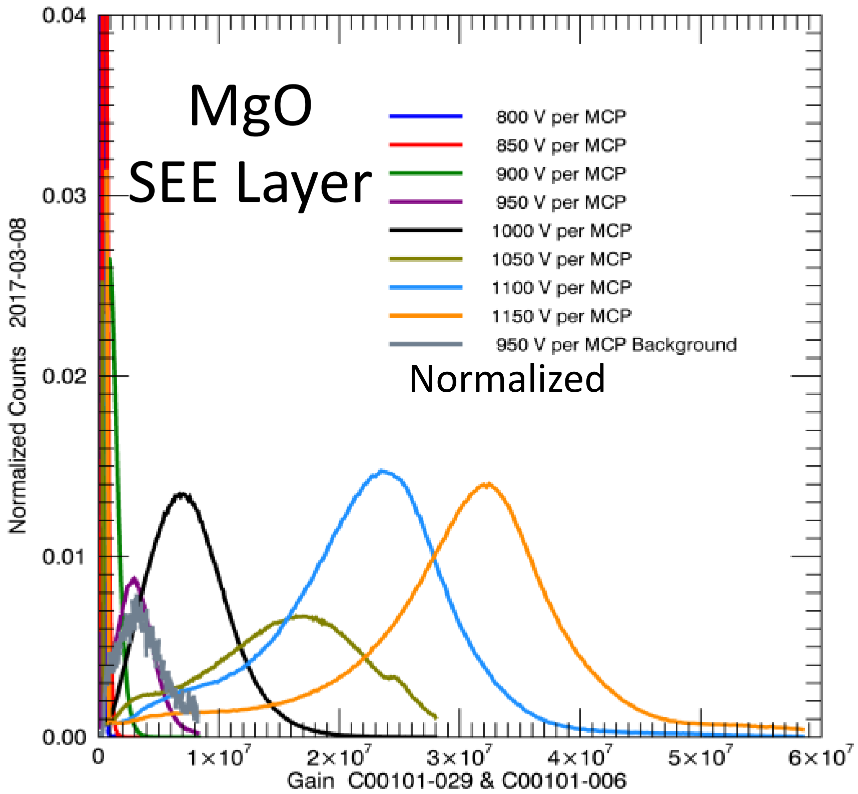
MCP Pairs, MgO and Al_2O_3 SEE Layers



- MgO gain 1×10^7 @ 1000 V/MCP
- Al_2O_3 gain 3×10^6 @ 1000 V/MCP, 1×10^7 @ 1100 V/MCP

Pulse Height Distribution (PHD) in 20 cm MCPs

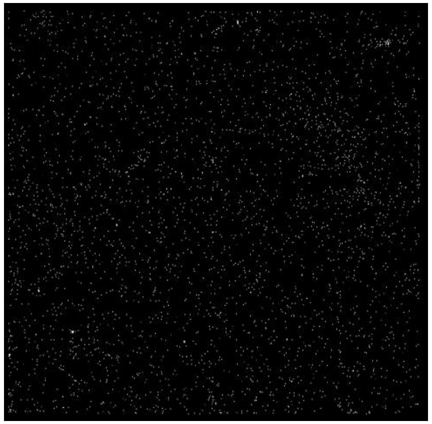




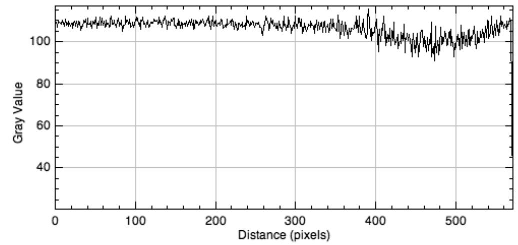
- Well peaked, especially MgO-coated MCPs
- Less sensitivity to threshold variations

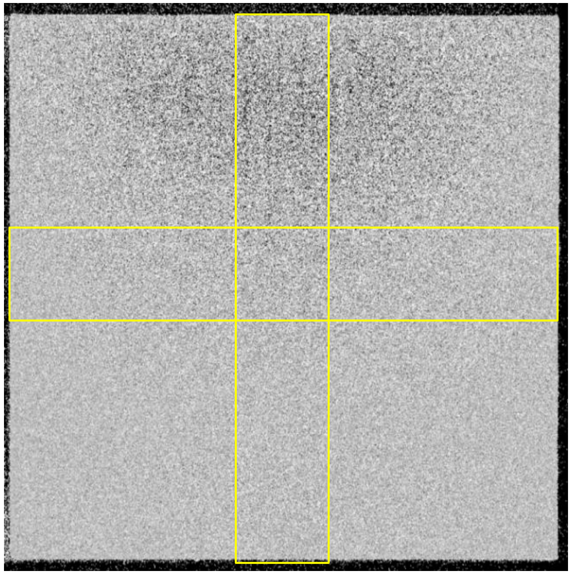
Al_2O_3 Gain Uniformity, Background Rate

(data @ 1000V/MCP)



Background after scrubbing
(file 1920160328)





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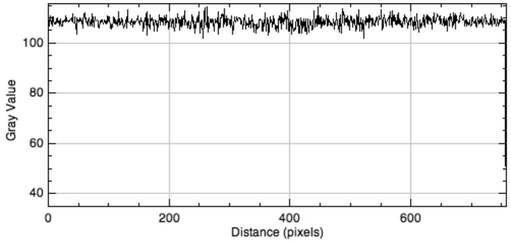
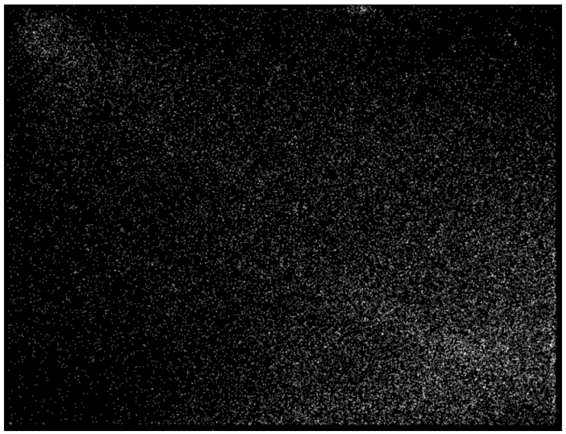
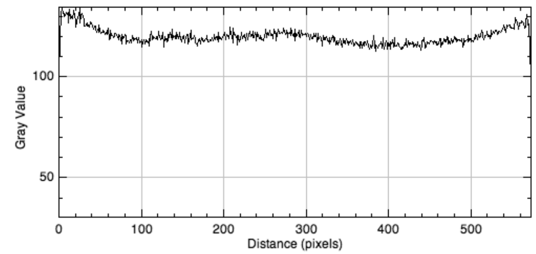


- **< 10% variation** over 400 cm^2 area
- Background rate:
  - Best = **0.05 cts/sec/cm^2** (Ertley, et al. 2016)
  - Typical = **1 ct/sec/cm^2,** including “hot spots”

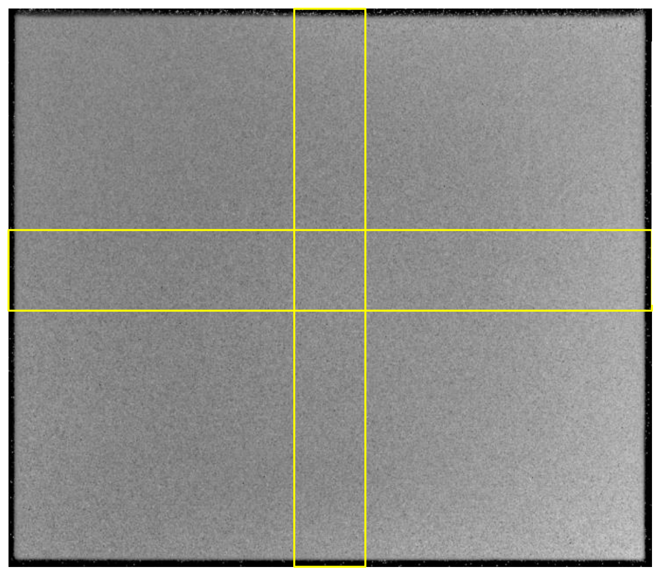
MgO Gain Uniformity, Background Rate

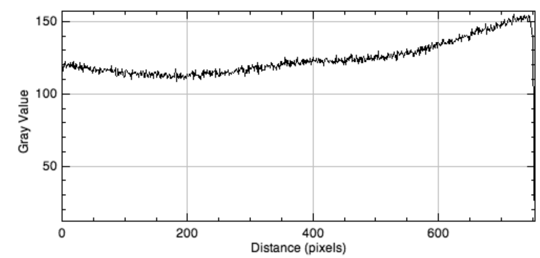
(data @ 1150V/MCP)





- **< 37% variation** over full area
- Background rate: **0.76 cts/sec/cm²**





2017-03-08 1838…fits.map C00101-029 & C00101-006

Summary of Results, 20cm x 20cm MCPs

- Al_2O_3 SEE layer
  - Gain **1 x 10^7 @ 1100 V/MCP**
  - Gain variation **< 10%** over full 400 cm^2 area
  - Background rates typically < 1 ct/sec/cm^2
- MgO emissive layer
  - Gain – **1 x 10^7 @ 1000 V/MCP**
  - Gain variation **< 37%** over full area
  - Background rates typically < 1 ct/sec/cm^2

MgO on 20 cm MCPs is being optimized, will be incorporated into LAPPDs

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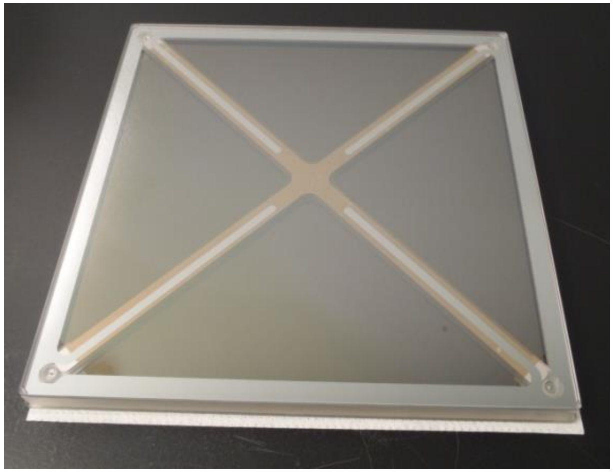


Applications

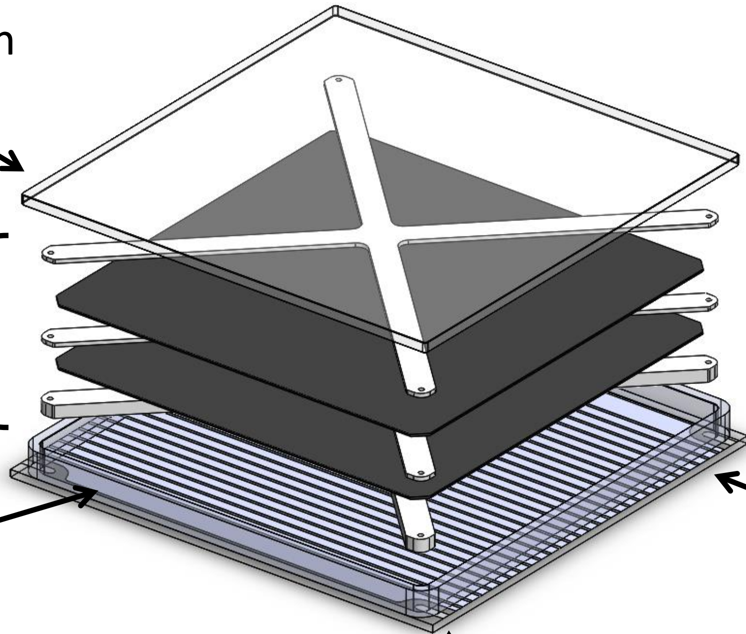
- Cherenkov/scintillation light separation for particle ID
- TOF measurements
- Optical Time Projection Chambers
- Plenoptic imaging
- Positron emission tomography (PET)
- ANNIE – Accelerator Neutrino Neutron Interactions Experiment

MCP-PMT for high spatial and temporal (ps-scale) resolution over large areas, at lower cost

LAPPD Design

Borofloat or fused silica window with photocathode on inside surface

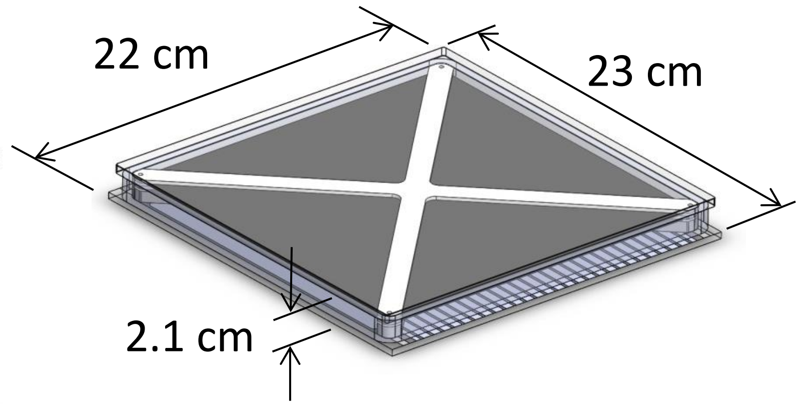
20 cm x 20 cm MCPs, spacers



Strip line anode and sidewall

Signal readout, both ends of strip lines

Voltage tab at each corner to independently power MCPs



Results using "demountable" test station (Wetstein, et al. 2012)	Single PE	Multiple PEs
Time resolution	50 ps	17 ps/2 ps?
Differential timing resolution		5 ps
Spatial resolution	1.5 mm	0.7 mm

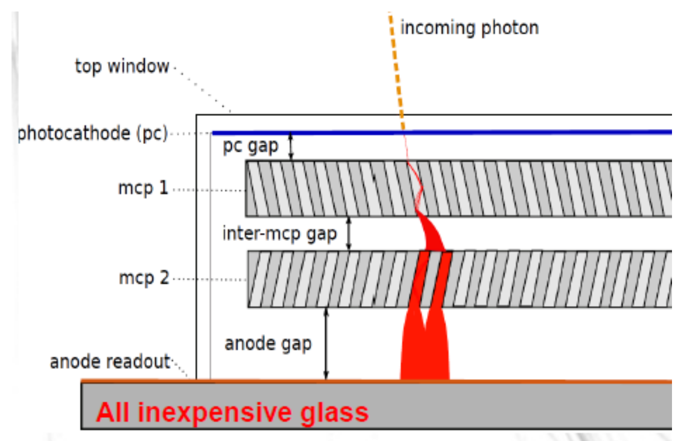
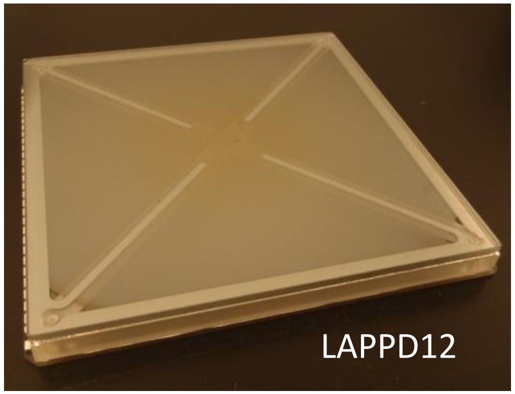
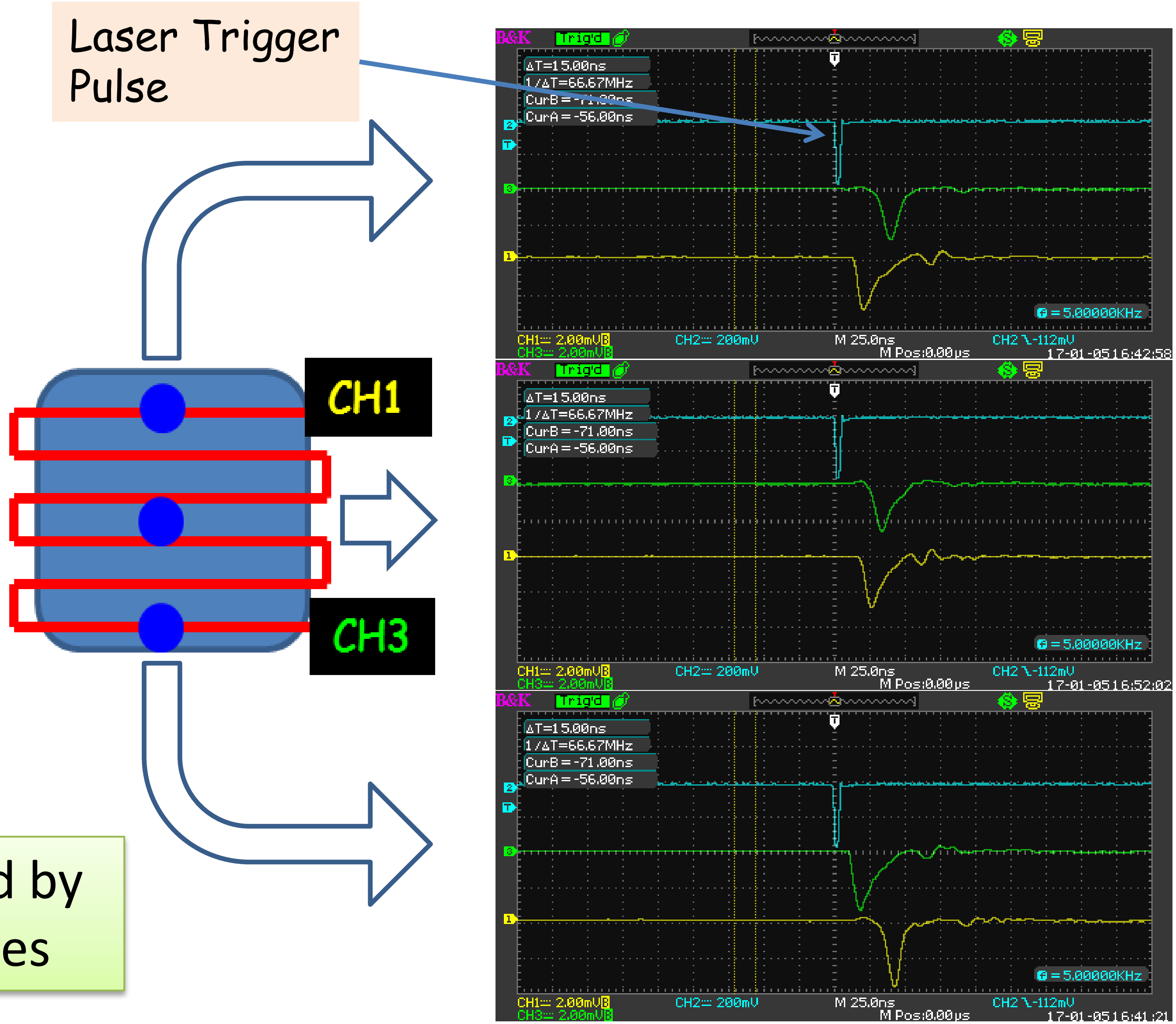


Illustration provided by Univ. of Chicago

Spatial Resolution (LAPPD12)

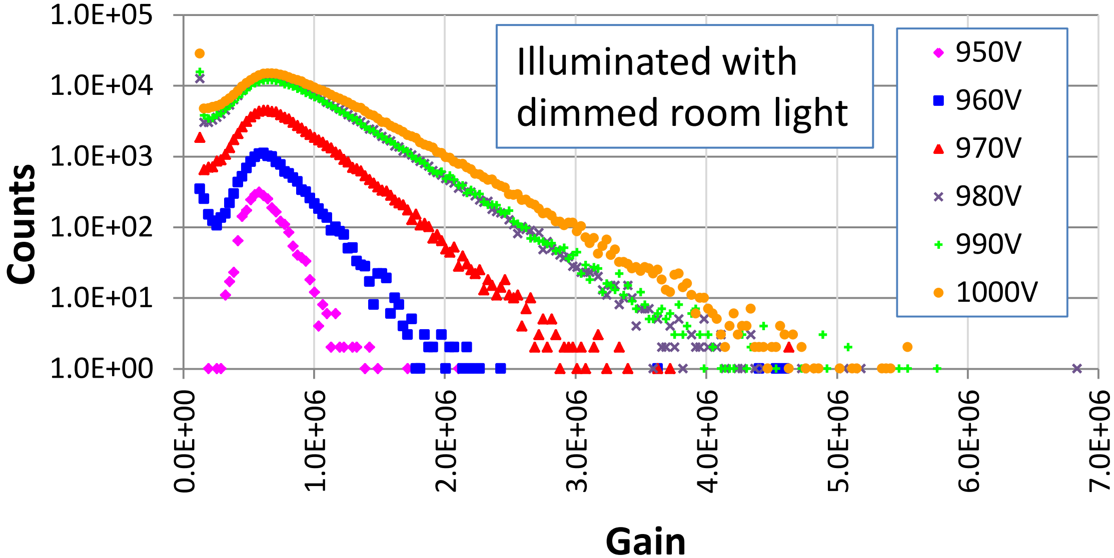


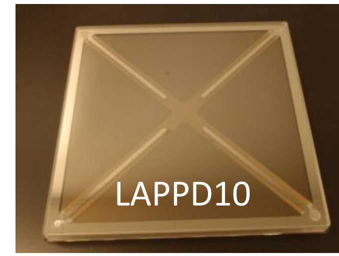
Strip lines connected into serpentine path (simplifies electronics)

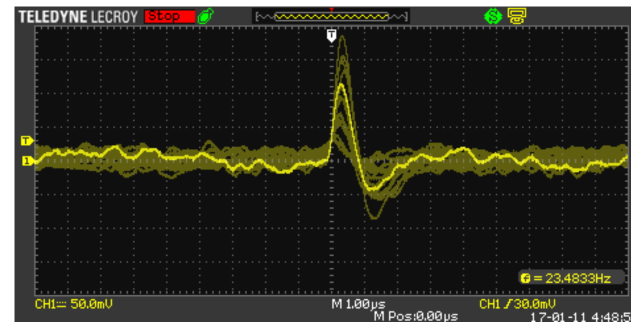


Position determined by relative arrival times

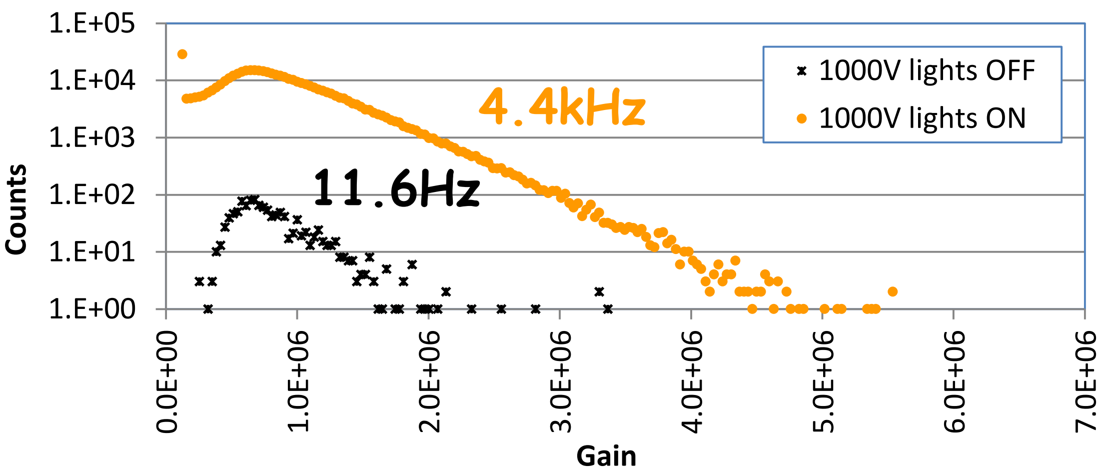
PHD for Single Photons (LAPPD10)







With room lights on/off, 200 V bias on PC, MCA threshold 50 mV



Dark counts are over <u>full area</u>, and include both MCP and PC dark rates

Photocathode: High, Stable Quantum Efficiency (QE) (LAPPD 15)

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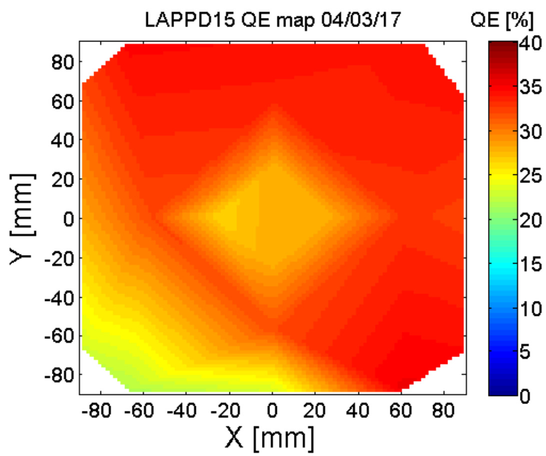
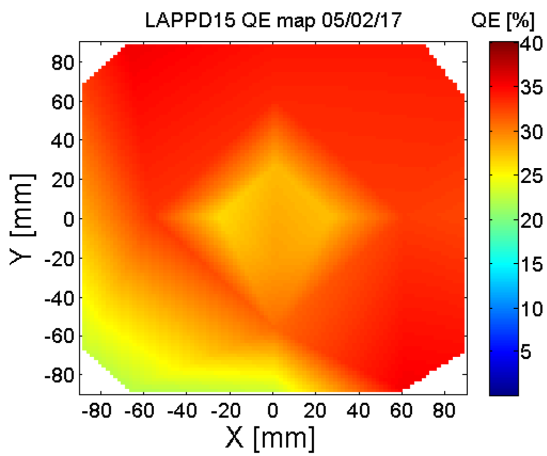
3 Days After Sealing

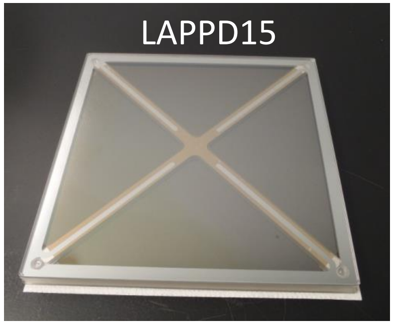


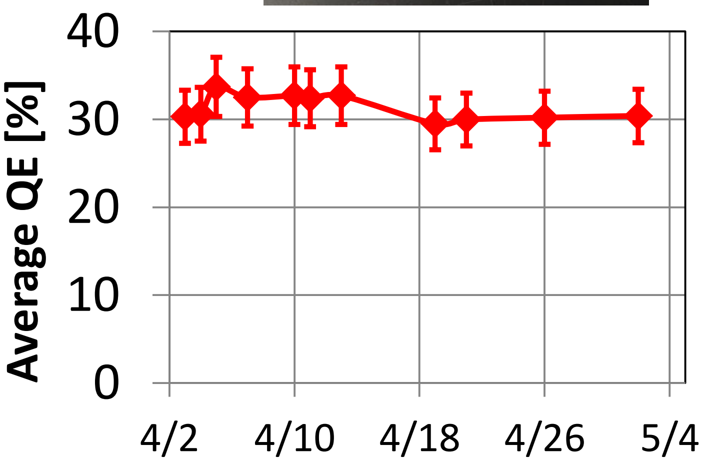
Average QE=30.3%
QE_{max}: 35.3%
QE_{min}: 21.7%
Uniformity (QE_{min}/QE_{max}): 61%

32 Days After Sealing



Average QE=30.4%
QE_{max}: 35.5%
QE_{min}: 22%
Uniformity (QE_{min}/QE_{max}): 62%

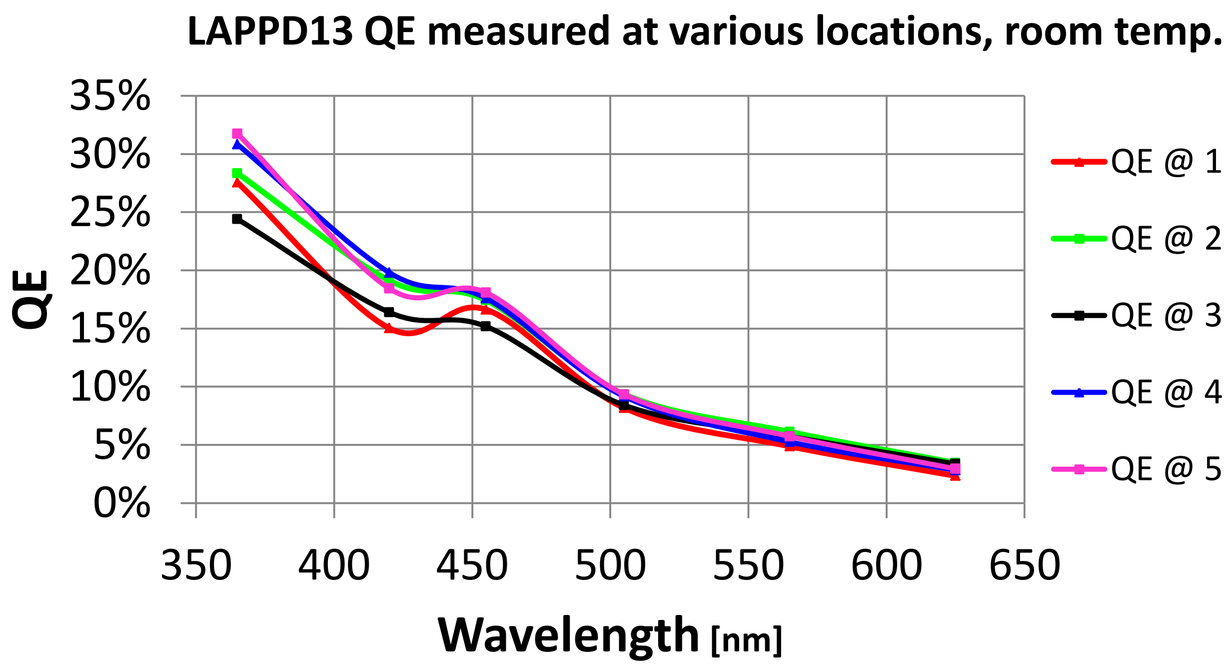


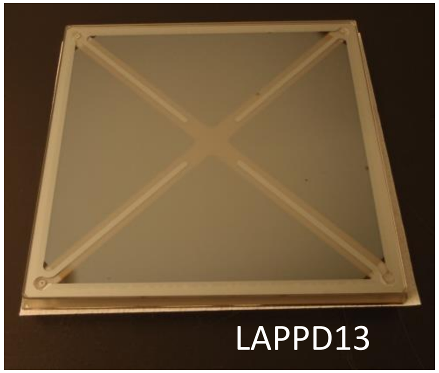


- **30%** average QE
- No degradation after a month

Cause for lower QE in corner is known (shadowing of PC sources)

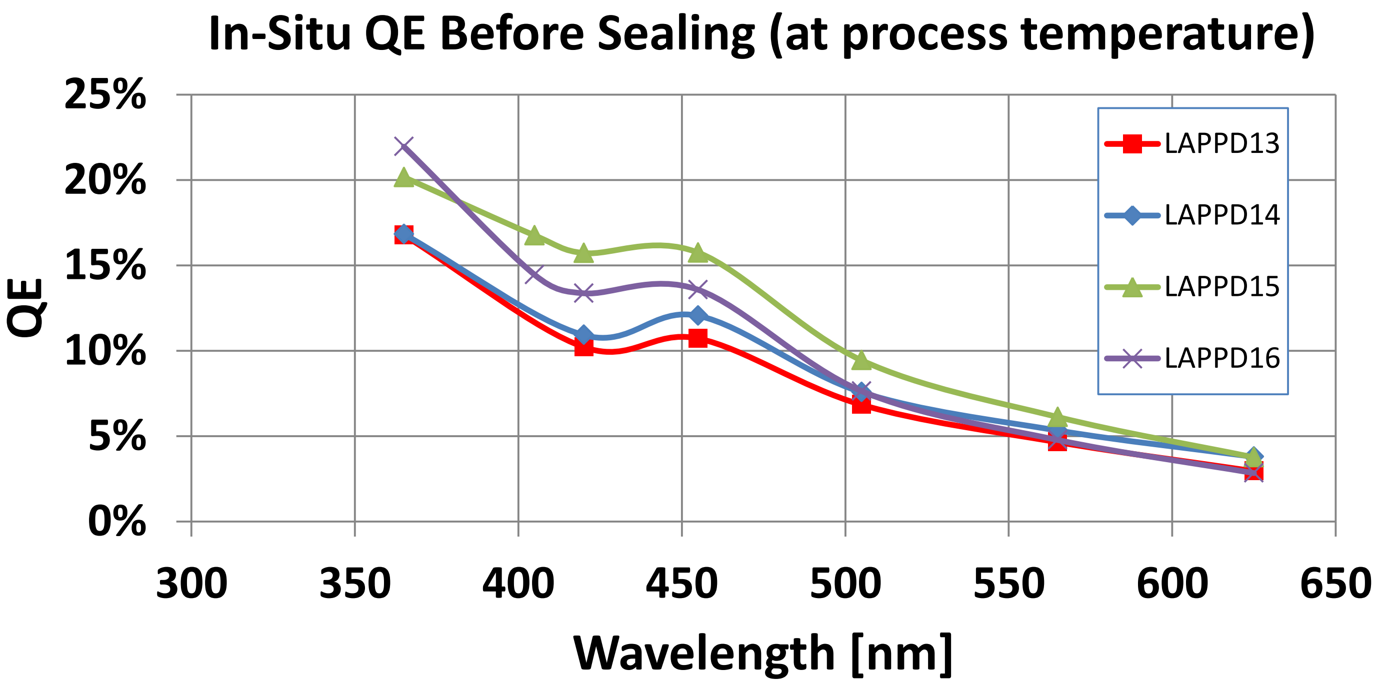
Photocathode QE Uniformity (LAPPD 13)





Average QE=28.6%
QE_{max}: 31.2%
QE_{min}: 24.4%
Uniformity (QE_{min}/QE_{max}): 78%

Photocathode Repeatability (LAPPDs 13-16)



- In-situ measurements are uncalibrated, used only for reference
- LAPPDs 14 & 16 did not seal, but performance of PC was similar

LAPPD Summary

- ✓ Multiple tiles have been sealed
- ✓ Clear pulses
- ✓ Positional information obtained from differential timing
- ✓ Photocathode QE >30% (@365 nm), uniformity >75% over 400 cm^2 area of tile
- ✓ Dark count rates (combined MCPs and PC) < 1 $ct/sec/cm^2$
- ✓ Seal integrity: 8 months and counting
- ✓ Photocathode stability: 1 month and counting

- Now that we have functional tiles, other design aspects are being optimized
- LAPPDs are currently being tested by collaborators

INCOM
Bright Ideas in Fiberoptics

Acknowledgements

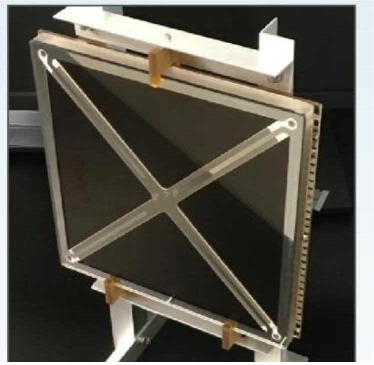
United States Department of Energy

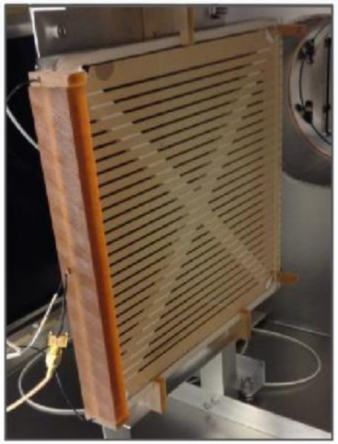
- Grant # DE-SC0009717, TTO Ph I, II, IIA “Fully Integrated Sealed Detector Devices,” 2013-2018
- Grant # DE-SC0011262, SBIR Ph I, Ph II “Further Development of Large-Area Micro-channel Plates for a Broad Range of Commercial Applications,” 2014 – 2017

LAPPD Collaboration

- Argonne National Laboratory; Fermilab; University of California, Berkeley, Space Sciences Laboratory; University of Chicago; University of Hawaii

Thanks!





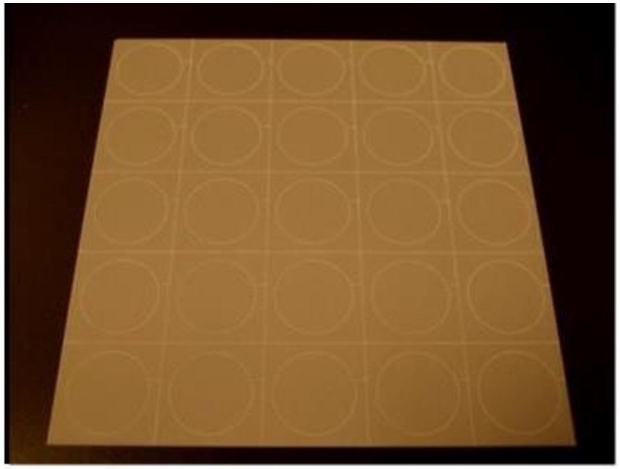
LAPPD, Package/Housing Characteristics	
Housing Size	230 mm x 220 mm x 22 mm thick
Housing Material	Borosilicate Glass
Window Material	Borosilicate or Fused Silica
Photocathode Material	Multi-Alkali (K_2NaSb)
Anode Configuration	28 silver strips, nominally 50 Ω
Voltage Distribution	5 taps for independent control of voltage to the photocathode and entry and exit MCPs
Wavelength Sensitivity	<350 nm to >625 nm

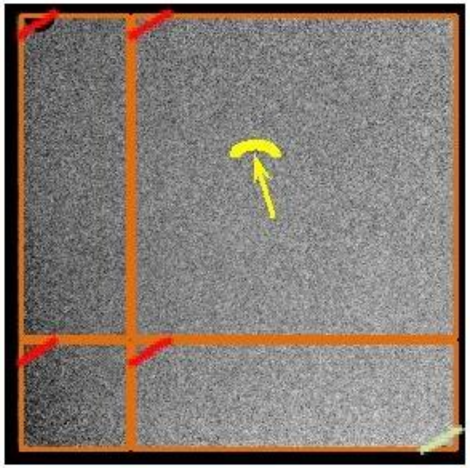
Microchannel Plate (MCP) Characteristics	
Arrangement	Two Positioned in a Chevron Pair
Dimensions	203 mm x 203 mm x 1.2 mm thick
MCP substrate	Borosilicate Glass
Capillary Pore Size	20 µm
Capillary Open Area Ratio	60-65%
Typical Gain	1×10^7
Resistive and Emissive Coatings	Applied via Atomic Layer Deposition
Emissive Layer Material	Al_2O_3

Contacts:
Chris Craven
cac@incomusa.com
Dr. Michael Minot
mjm@incomusa.com

Supporting Slides

Dicing



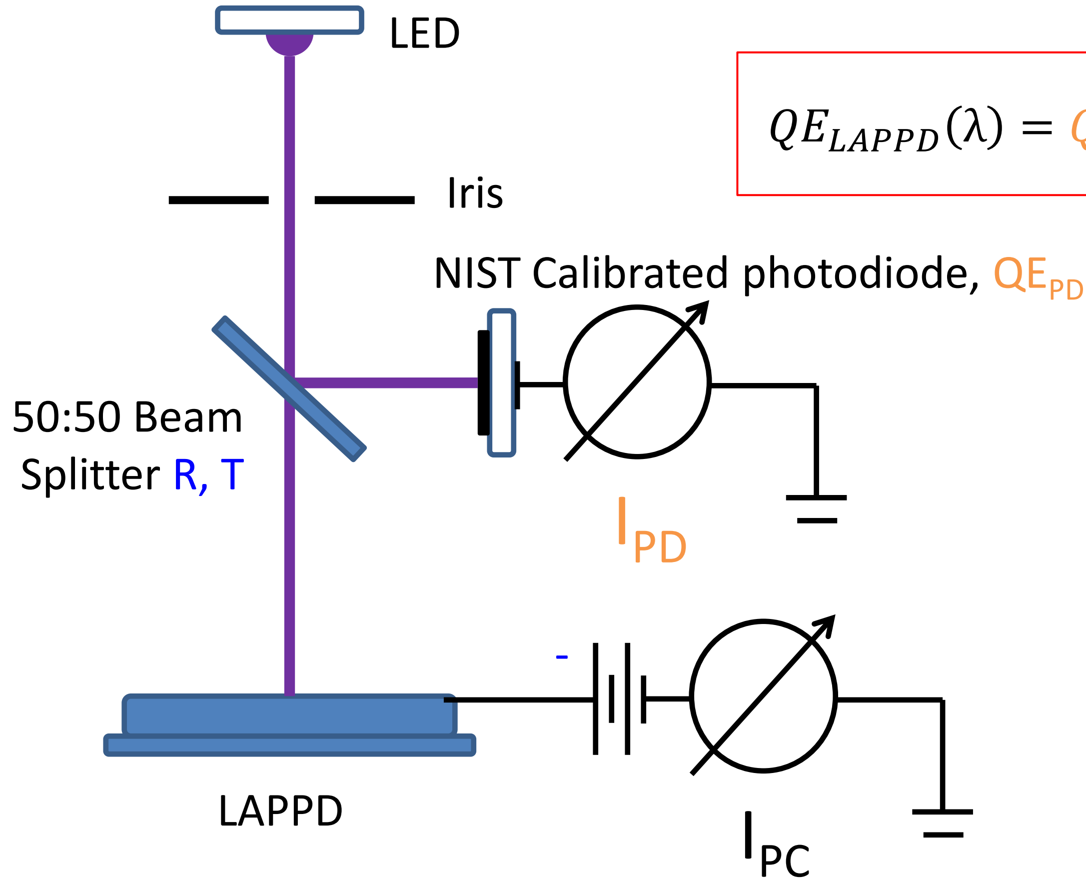


- Automatic scribing capability, ± 0.08 mm precision
- For GCAs and MCPs

20 cm MCPs can be mapped and diced to produce smaller MCPs with matched resistance

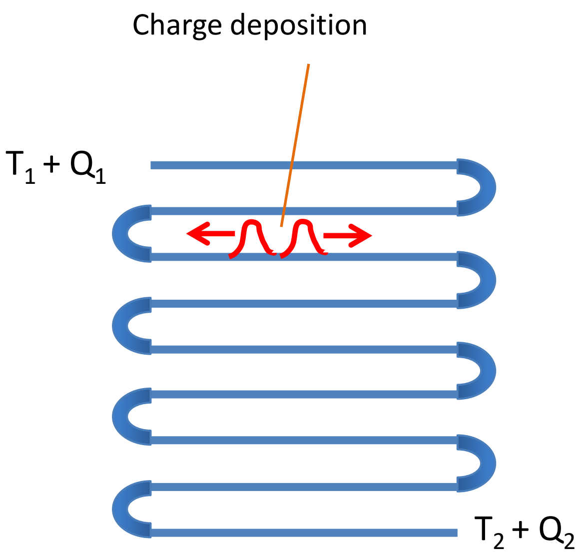
QE Measurement

$$QE_{LAPPD}(\lambda) = QE_{PD}(\lambda) \cdot \frac{[I_{PC}(\lambda) - I_{PCdark}(\lambda)] \cdot R(\lambda)}{[I_{PD}(\lambda) - I_{PDdark}(\lambda)] \cdot T(\lambda)}$$

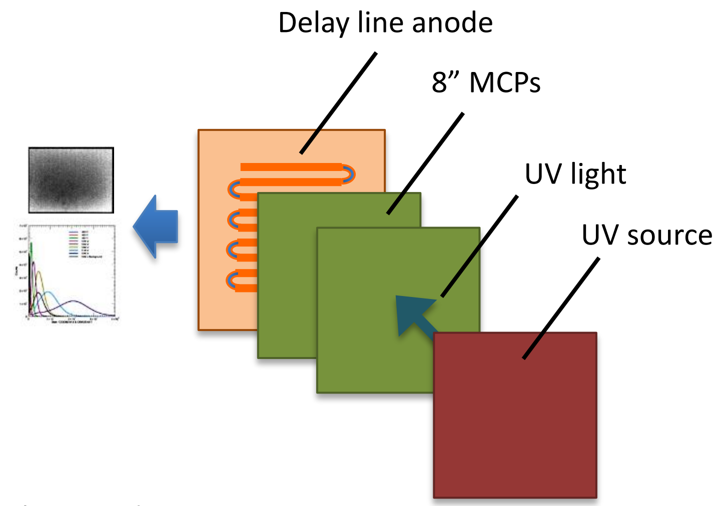


QE is measured in-situ during deposition and after tile is sealed

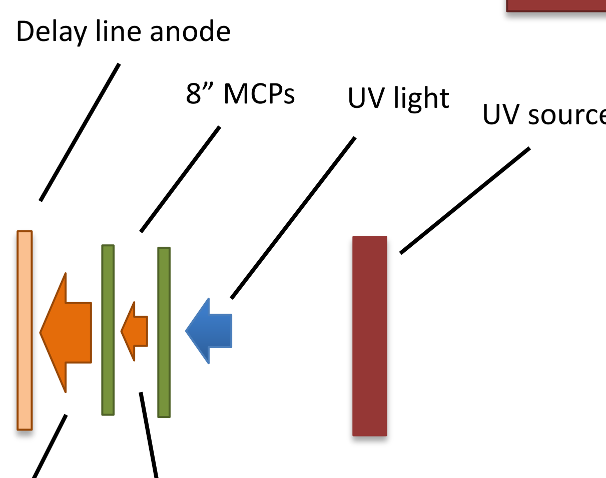
MCP Measurement



- Spatial gain image
- Charge pulse histogram



Gain = Output current/
Input current



Output current from Exit MCP –
increases with Exit MCP voltage

Input current to Exit MCP –
held constant

From Concept to Commercialization

Argonne NATIONAL LABORATORY

Fermilab

THE UNIVERSITY OF CHICAGO

UNIVERSITY of HAWAI'I

U.S. DEPARTMENT OF ENERGY | Office of Science

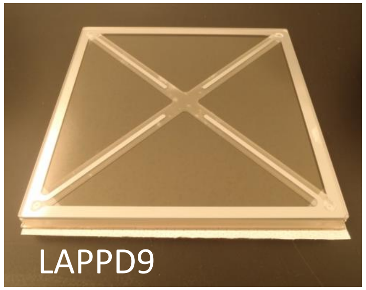
SSL UC Berkeley

INCOM Bright Ideas in Fiberoptics

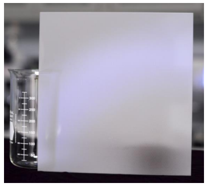
LAPPD Collaboration

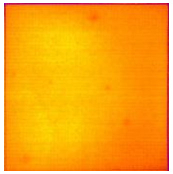
Incom funded by DOE

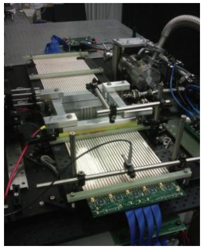
1st LAPPD tile sealed 2016

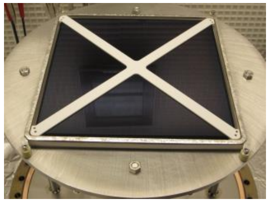


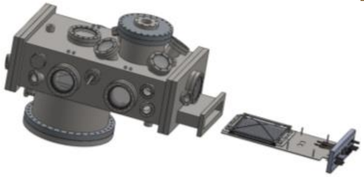
2009 · 2010 · 2011 · 2012 · 2013 · 2014 · 2015 · 2016 · 2017











Results using "demountable" test station (Wetstein, et al. 2012)	Single PE	Multiple PE
Time resolution	50 ps	17 ps/2 ps?
Differential timing resolution		5 ps
Spatial resolution	1.5 mm	0.7 mm

- Design validated using "demountable" test station (Wetstein, et al. 2013, Elagin 2013)
- Prototype sealed tiles now being made by Incom