Prototype Production of Large Area Picosecond Photo Detectors -LAPPDs

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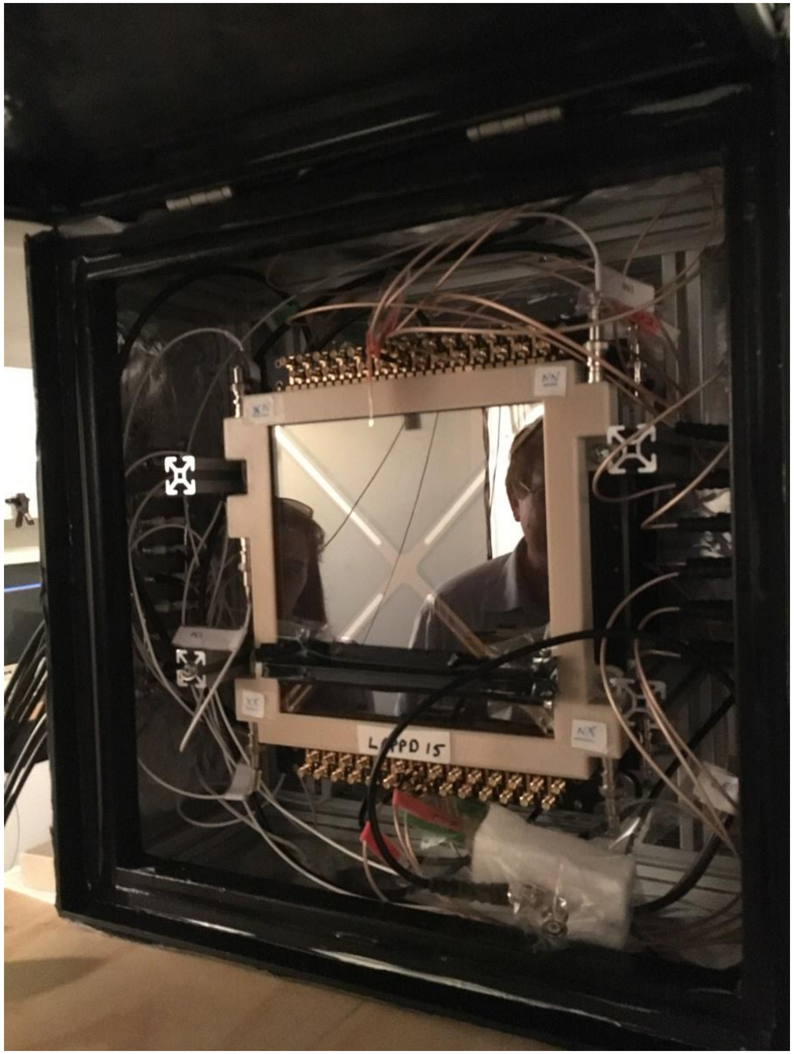
Outline

- Motivation
- LAPPD design
- MCP fabrication and gain
- Photocathode QE
- LAPPD Performance
  - Time Resolution along and across anode striplines
- Early Adopters/Programs
- Pilot Production Now
- New Innovations



Pair of LAPPDs at Massachusetts General Hospital for Proton Beam Testing

Large Area Picosecond Photo Detectors -LAPPDs

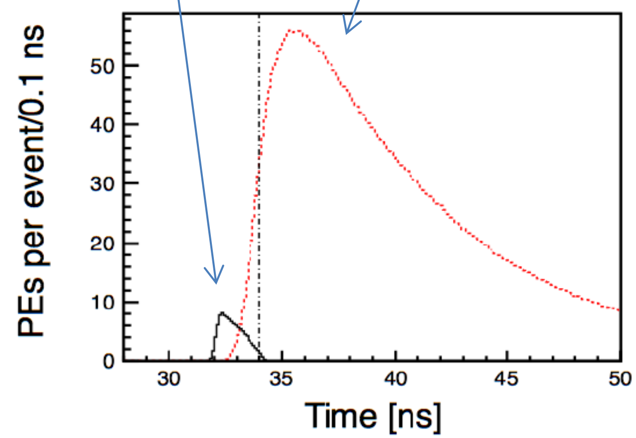
- Fast timing, high gain, single photon imaging
- Large Area: 200 x 200 mm^2
- Picosecond Timing: resolution <64pS for SPE
- QE: ~20% w/bi-alkali photocathode
- Low Cost per Unit Area
- mm spatial resolution

Applications: HEP, NP and others

- DOE-supported R&D
    - Deep Underground Neutrino Experiment (DUNE),
    - Accelerator Neutrino Neutron Interaction Experiment (ANNIE) and WATCHMAN
- Nuclear physics applications such as Electron Ion Collider (EIC), Neutrinoless double-beta decay (NuDoT)
- homeland security sensors, astronomy,
- fluorescence imaging (future)
- medical imaging: PET scanning, proton therapy beam targeting

- Prompt, brief Cherenkov light.
- Requires:
    - Fast timing
    - High gain

Long duration, bright scintillation light



References from:
ANNIE (M. Wetstein),
WATCHMAN (M. Malek),
NuDot (J. Gruszko, L. Winslow)

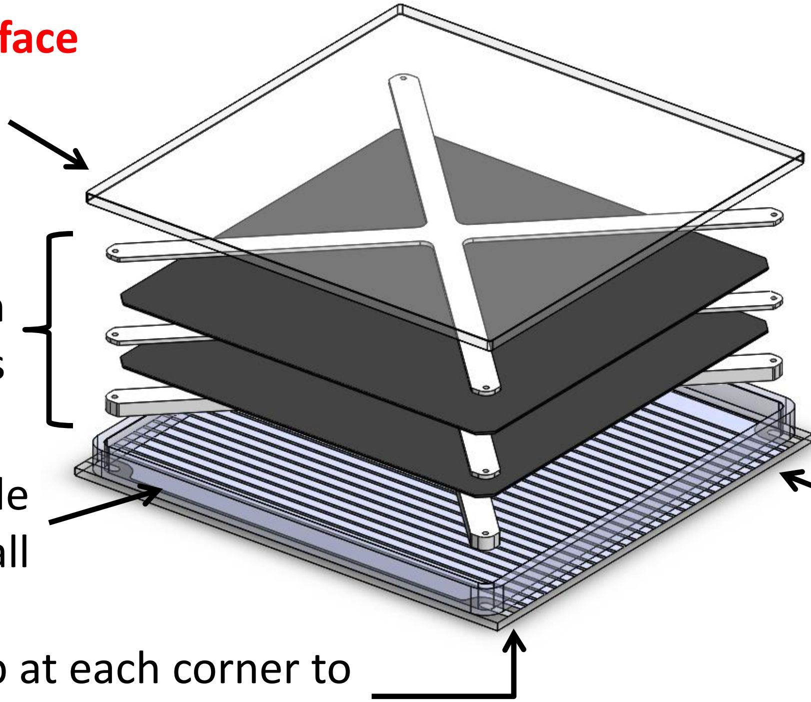
JINST 9 (2014) P06012

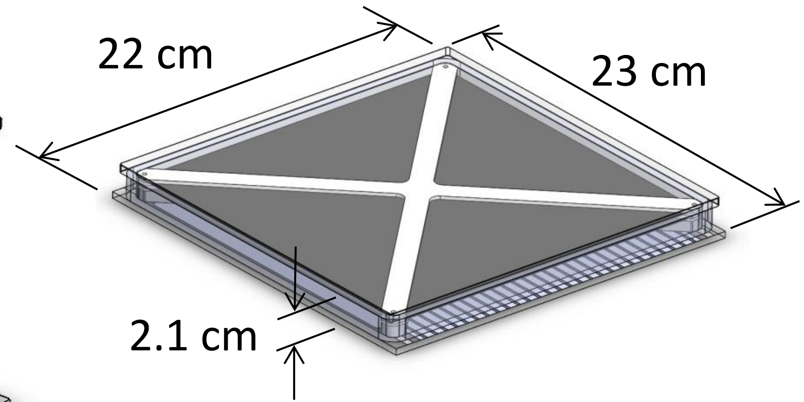
LAPPD Design

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 28 strip lines

Voltage tab at each corner to **independently power MCPs**

- Signal and high voltage delivered on strips passing under a frit bond.
- **No wall or anode penetrations**.
- **Active area: 195 x 195mm** less the x-spacers
    - 34,989 mm^2, 350 cm^2
    - 92% active area

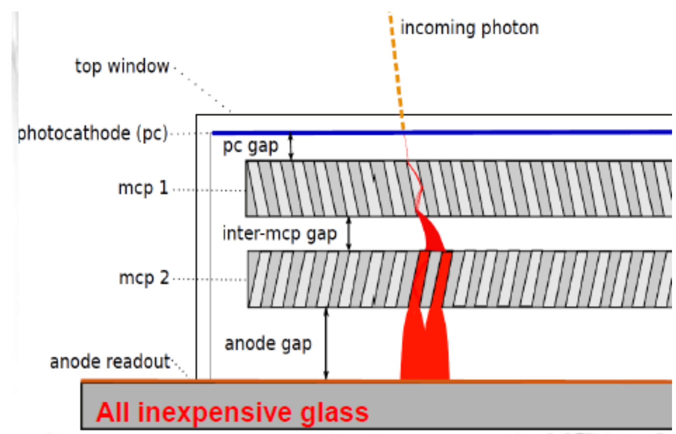
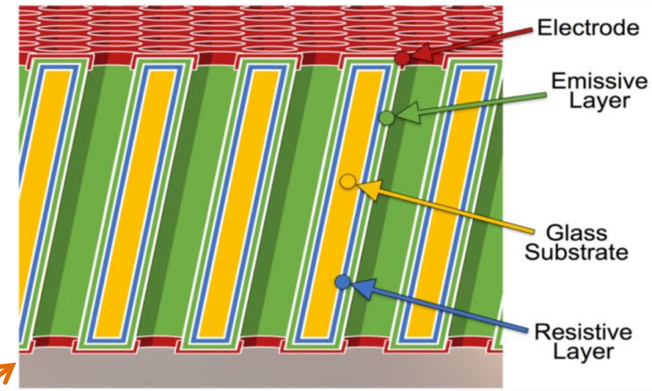


Illustration provided by Univ. of Chicago

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

- 203 mm **robust glass substrates** are made with ~20 micron diameter microchannels.
- Many choices for the glass substrate, including non-leaded or low potassium glass.
- **Resistive film** is applied with ALD
  - Resistance can be tuned to desired value .
- Al_2O_3 or MgO **S**econdary **E**lectron **E**missive film is applied over the resistive film for **high gain**.
  (Mane, et al., 2012)



ALD+ glass substrate MCP: cross section

Illustration from Ertley, 2016

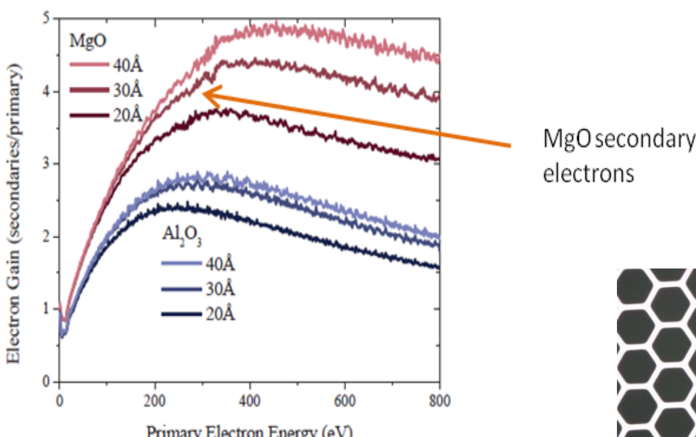
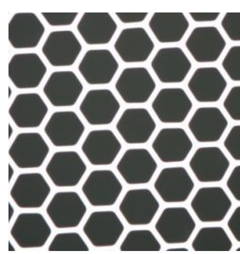


Figure 2. Secondary electron yield from select thicknesses of ALD MgO and Al_2O_3. See Figure 3 for the entire data set.



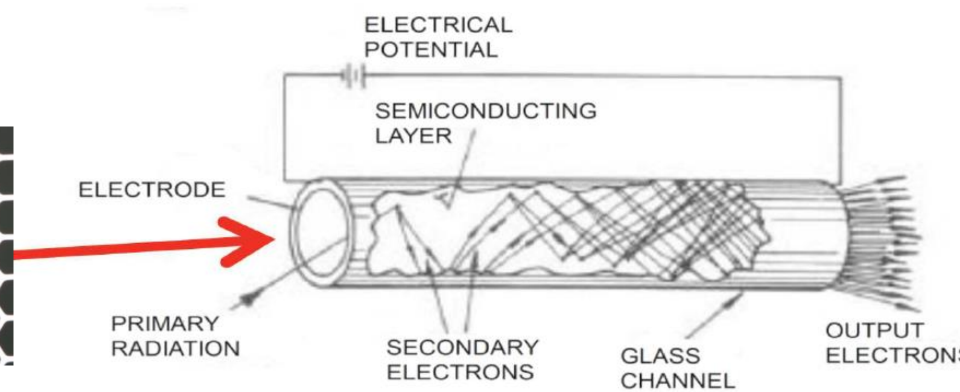
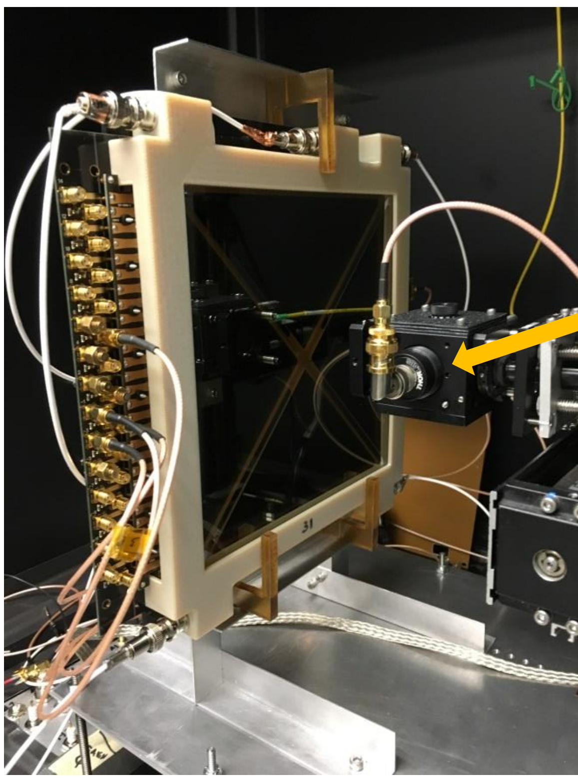


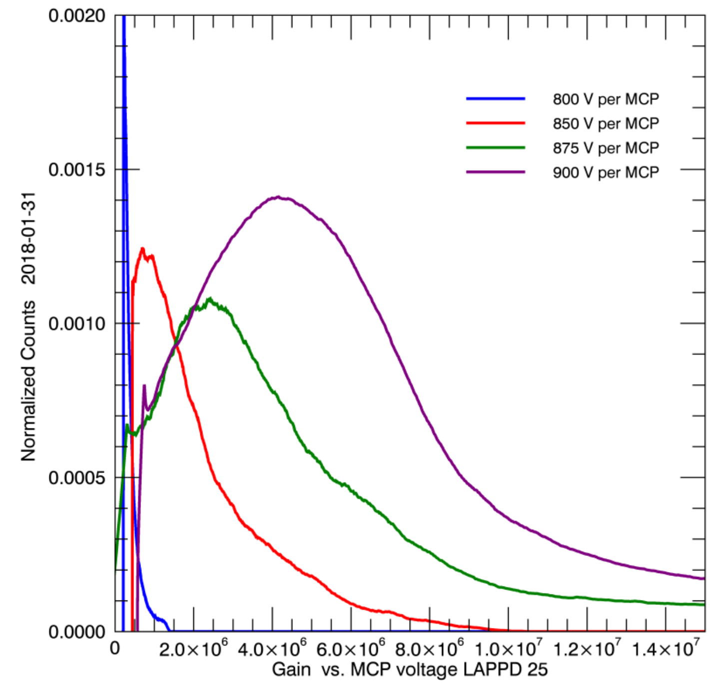
Illustration from Wiza, 1979

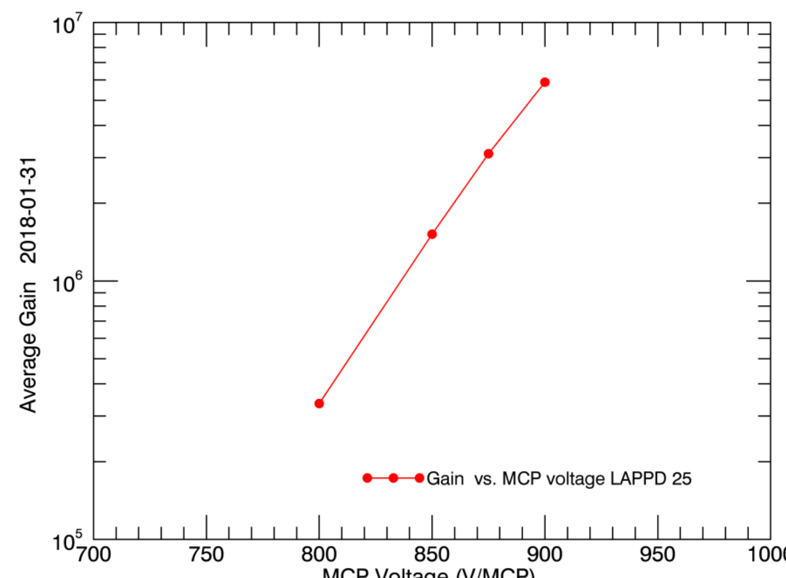
Gain: LAPPD 25

- **Pulse height distributions** and **average gain** are shown vs. **MCP voltage for single photo electrons**
- Gain is as high as 6×10^6 at 900 V/MCP.



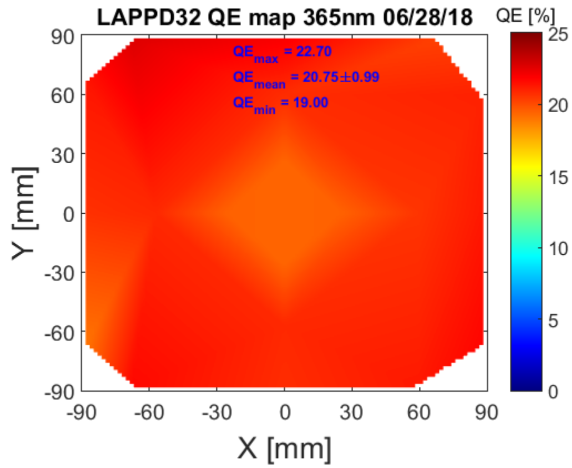
Light source: laser or LED



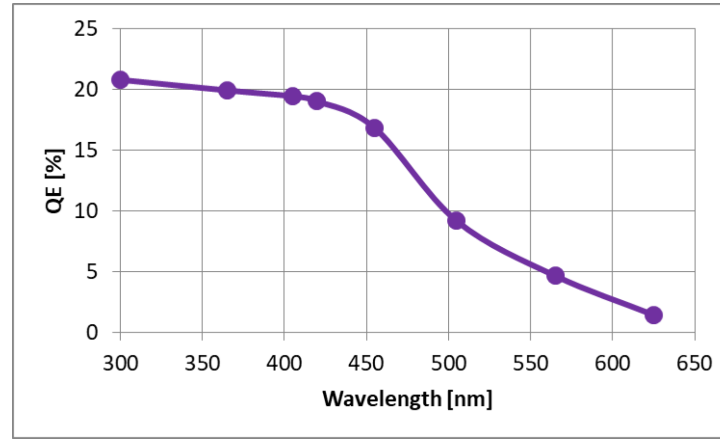


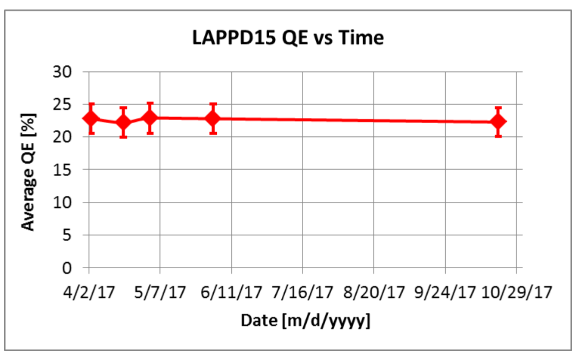
Photocathode QE

- bi-alkali Na_2KSb
- QE measured at 365 nm
- Highest avg. is 22%
- Stable for > 6+ months and counting



± standard deviation



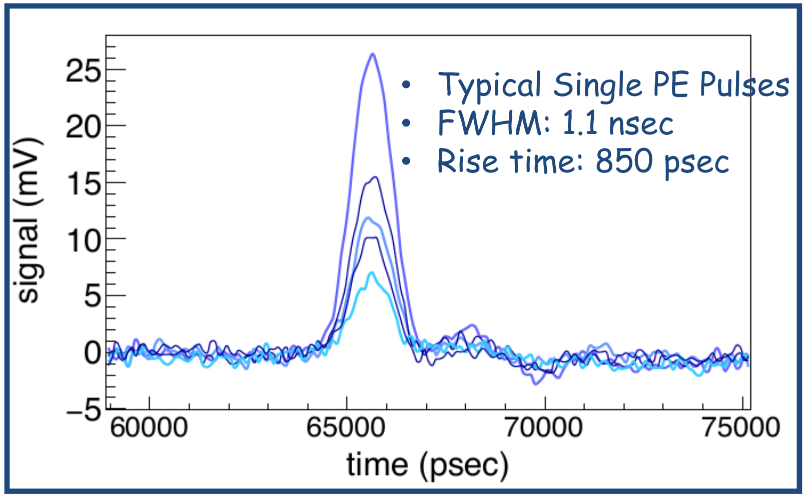


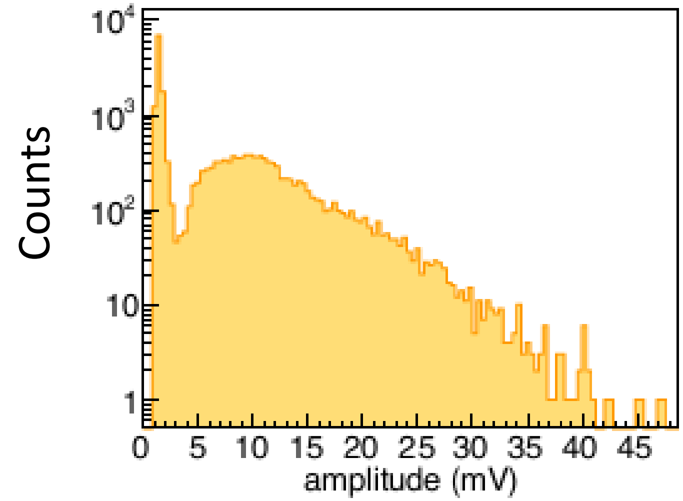
Large Area Photocathode production process is established
QE >20% demonstrated in sealed LAPPDs

LAPPD S/N	Maximum %	Average %	Minimum %
LAPPD #13:	23.5	18.6±3.3	13.5
LAPPD #15:	25.8	22.3±3.0	15.7
LAPPD #22:	14.7	10.6	7.0
LAPPD #25:	10	7.1	5.0
LAPPD #29:	19.6	13.0±6.0	3
LAPPD #30:	22.9	17.2±2.5	13
LAPPD #31:	19.6	16.0±1.9	12.1
LAPPD #32:	22.7	20.8±1.0	19.0

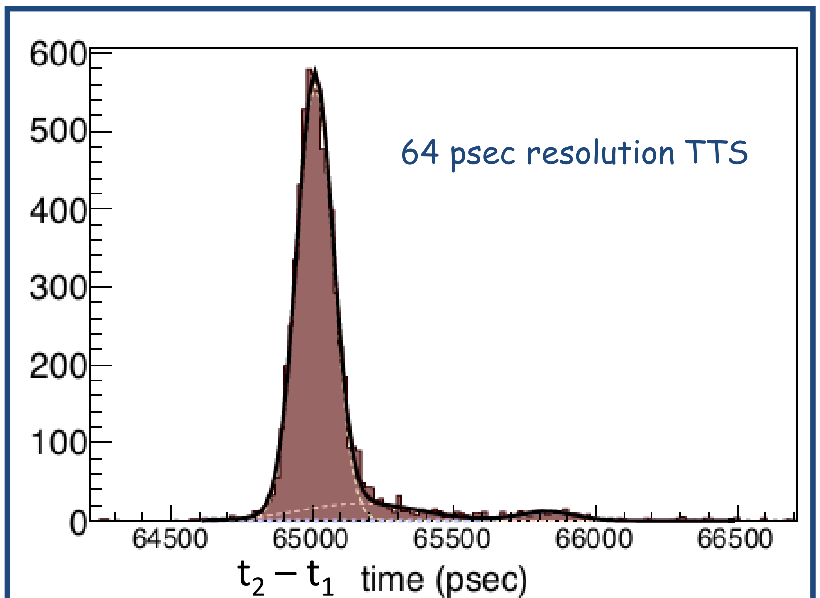
Time Resolution LAPPD #25

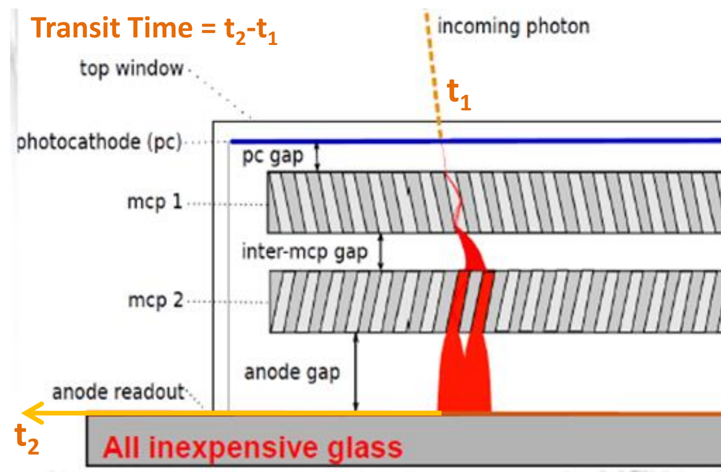
Testing at Iowa State University, Matt Wetstein, ANNIE Program





Unamplified pulse height

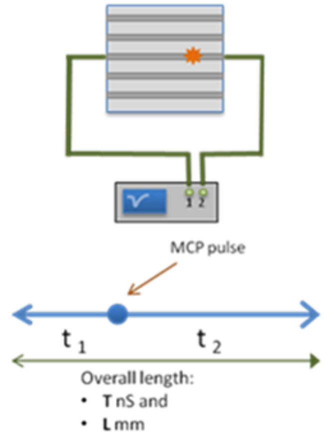


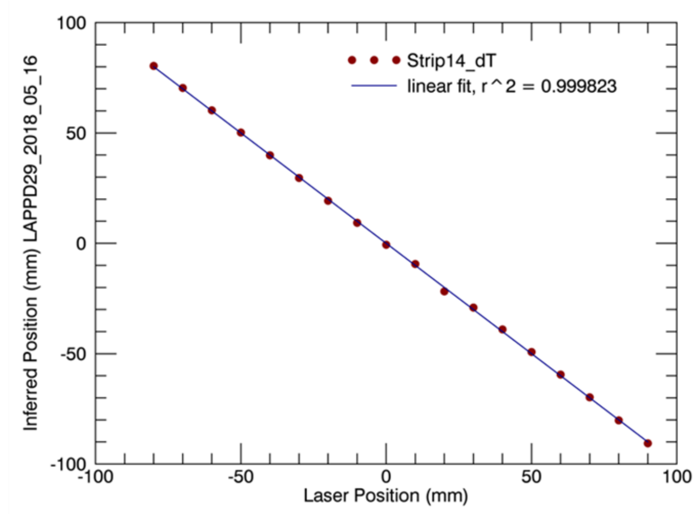


Measuring Position with the LAPPD Anode

Position measurement along an anode strip:

- Position is inferred from relative time of arrival of pulses at each end.
- Linear response; position uncertainty derived from spread in relative arrival times.
- **2.2 mm uncertainty**

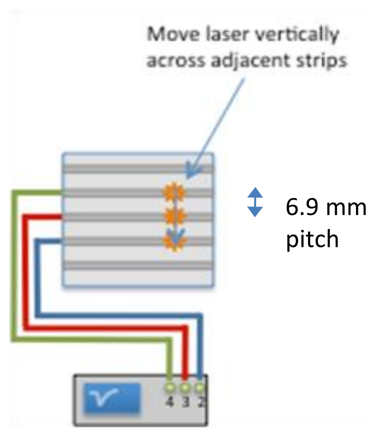


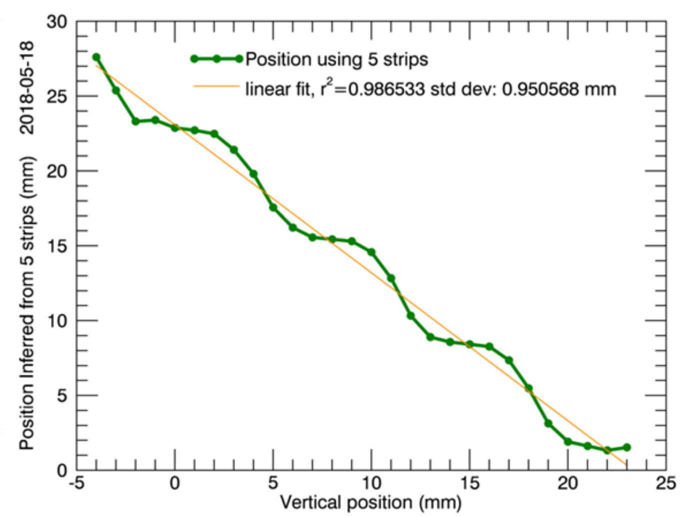


LAPPD 29

Position measurement across anode strips:

- Position calculated by centroiding five adjacent strip signals using charge.
- **0.95 mm standard deviation from linearity.**





LAPPD 29

LAPPD™ Early Adopter Programs

PRINCIPAL INVESTIGATOR & SPONSOR	PROGRAM TITLE
Bill Worstell, Incom Inc.	TOF Proton Radiography for Proton Therapy
Henry Frisch (U of Chicago)	LaRiaT (Liquid Argon Beam-line Experiment, Fermi Lab)
	Sub-psec TOF for collider vertex and particle ID
	Track reconstruction in a small water Cherenkov counter
	Double-beta decay development
Mayly Sanchez and Matthew Wetstein, Iowa State	ANNIE - Atmospheric Neutrino Neutron Interaction Experiment
Andrey Elagin (U of Chicago)	Neutrino-less Double-Beta Decay
Mickey Chiu (BNL) -	Phenix Project - "eIC Fast TOF"
Erik Brubaker, Sandia National Lab/CA	Neutron Imaging Camera
John Learned, U. of Hawaii, and Virginia Tech	Short Baseline Neutrino (NuLat)
Lindley Winslow (MIT)	Search for Neutrino-less Double-Beta Decay (NuDot) Using Fast Timing Detectors
Bill Worstell, Incom Inc, Bob Wagner & Junqi Xie. ANL, Jefferson Laboratory	Magnetic Field Tolerant Large Area Picosecond Photon Detectors for Particle Identification
Andrew Brandt, University of Texas, Arlington	Life Testing of LAPPD
Dr Matthew Malek, The University of Sheffield	~10,000 LAPPDs for Hyper-Kamiokande (10 years)

Summary

- Incom's LAPPD (Devices now commercially available)
  - World's largest high speed high gain imaging photo sensor ideal for fast timing/imaging applications
  - Large area & large open area ratio, simple planar construction, no package penetrations
  - Innovative method for fabricating LARGE area MCP with high sustained gain and well formed PHDs
- Photocathode process with spatially uniform QE, moderately high QE and time stability
- Positional accuracy
  - Linear response along strips with 2.2 mm uncertainty
  - Use centroiding to get the position of the charge deposited on adjacent strips (0.95 mm)
- Both Domestic and International Early Adopters have attended our on-going workshops.
  - Let us know your interest in attending
  - http://www.incomusa.com/mcp-and-lappd-documents/
- Next Gen LAPPD (PI = Foley) with capacitive coupling will allow user defined anode for readout

Current Funding & Personnel Acknowledgements

- DOE, DE-SC0011262 Phase IIA - "Further Development of Large-Area Micro-channel Plates for a Broad Range of Commercial Applications"
- DOE, DE-SC0015267, Development of Gen-II LAPPD™ Systems For Nuclear Physics Experiments
- DOE DE-SC0017929, Phase I – "High Gain MCP ALD Film" (Alternative SEE Materials)
- NIH 1R43CA213581-01A Phase I - Time-of-Flight Proton Radiography for Proton Therapy
- DOE, DE-SC0018445 Magnetic Field Tolerant Large Area Picosecond Photon Detectors for Particle Identification
- **DOE (HEP, NP, NNSA) Personnel**: Dr. Alan L. Stone, Dr. Helmut Marsiske, Dr. Manouchehr Farkhondeh, Dr. Michelle Shinn, Carl C. Hebron, Dr. Kenneth R. Marken Jr, Dr. Manny Oliver, Dr. Donald Hornback and many others.

New Formula : “R+D=P”

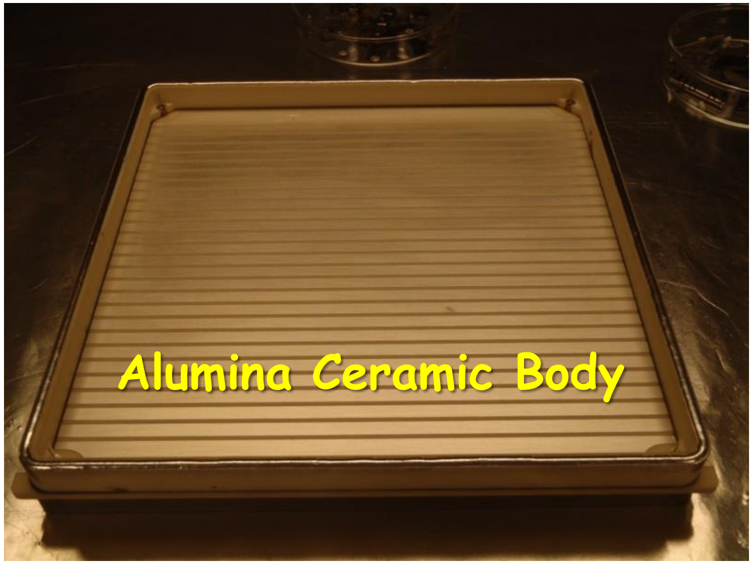
R&D must not forget “P”…Prototype, Pilot line & PRODUCTION

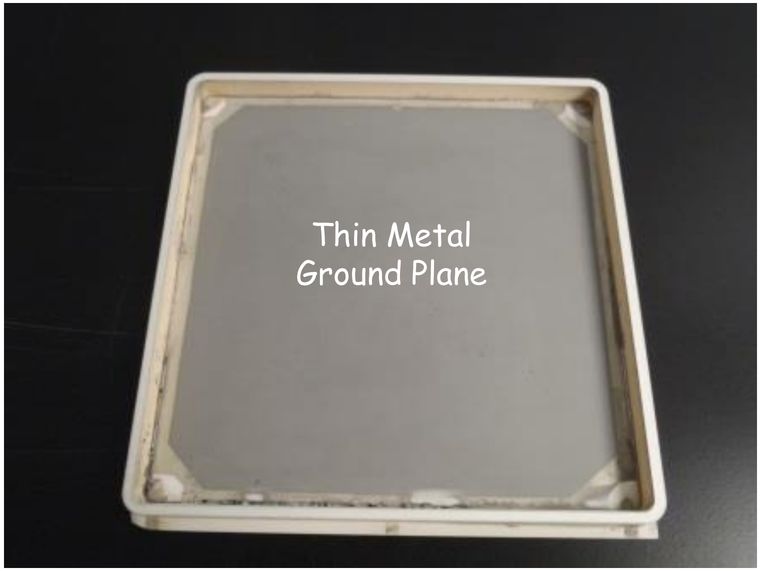
Any Questions?

Back up slides

Innovation in the LAPPD design

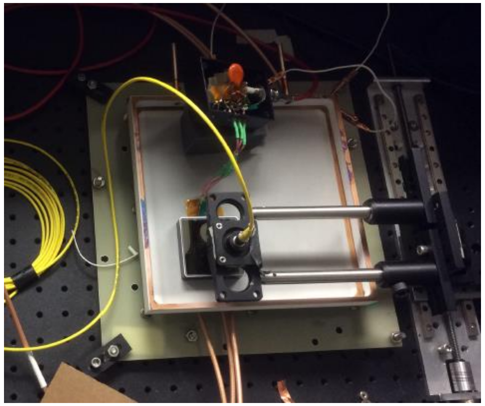
- Inside out anode
  - Capacitively coupled signals
  - Both striplines or user defined pixelated pattern
  - Outside of the package – easily changed
- Materials other than borofloat
  - Very rugged materials (toughness, strength)
    - Alumina, fused silica/quartz
    - Capacitive coupling is improved over B33
      - due to dielectric constant and low loss tangent.



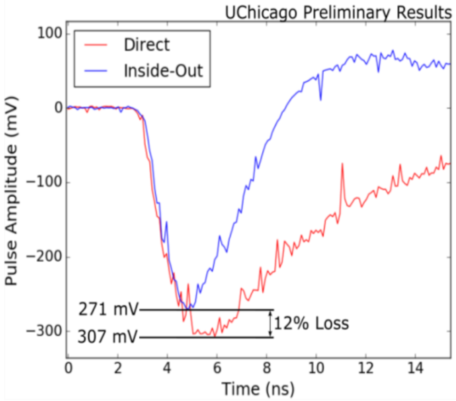


GEN II Ceramic Package LAPPD™

DOE – NP Phase I SBIR, February 2016 in collaboration with U of Chicago



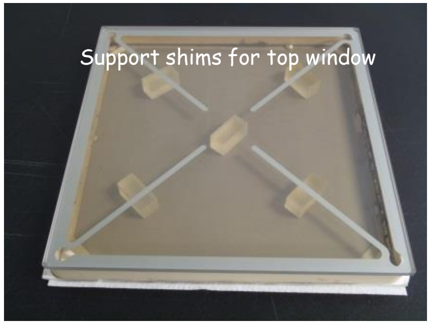
A thin metal layer anode serves as a DC ground on the inside of the detector. 88% of an MCP fast signal pulse was capacitively coupled through the ceramic, to strips or pads on the outside.

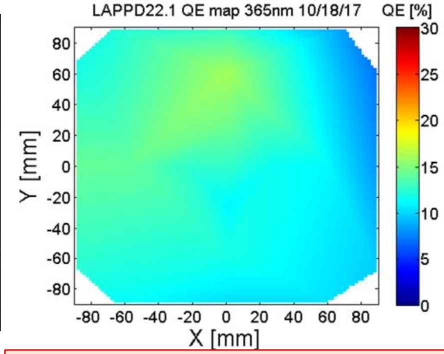


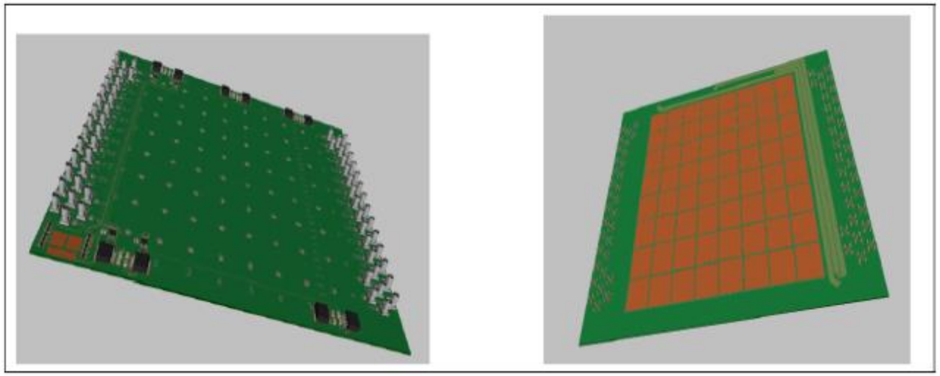
- B.W. Adams,et al, "An internal ALD-based high voltage divider and signal circuit for MCP-based photodetectors", Nucl. Instr. Meth. Phys. Res. A 780 (2015) 107-113
- Private Communication, Todd Seiss and Evan Angelico, University of Chicago. Inside-Out Tests of Incom Tiles, June 23, 2016
- Angelico, Evan et al., "Development of an affordable, sub-pico second photo-detector", University of Chicago, Poster 2016

Ceramic LTA w/ Photocathode

DOE-NP Phase II SBIR, Oct 2017

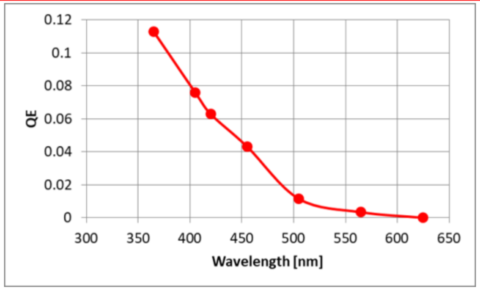






Mean QE=11.6%
QE_{max}: 16.0%
QE_{min}: 7.0%

LAPPD22.1 QE (single point) of 12/12/17



PCB placed under Gen-II tile with the signal-pickup pads facing the tile.

Prototype Production of LAPPDs

- Commenced January 2016
- Functionalize glass capillary arrays (GCAs)into micro channel plates (MCPs) w/full test reports
- Fabricate lower tile assemblies for LAPPD package
- Stack up MCPs with spacers and electrical connections
- Deposit photocathode
- Seal photocathode window to stack up package in UHV
- Attach all electronics and test in Dark Box

Incom hosts on-going workshops for hands-on operation of LAPPDs

Most recent design