Fast-timing microchannel plate photodetectors: design, fabrication and characterization

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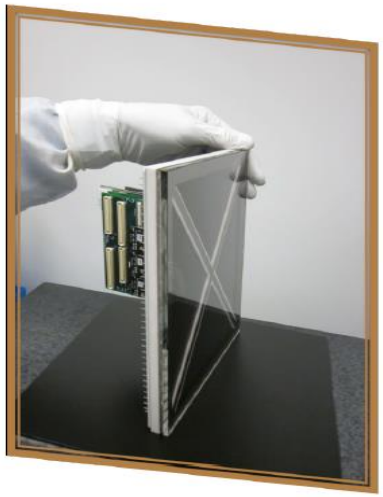
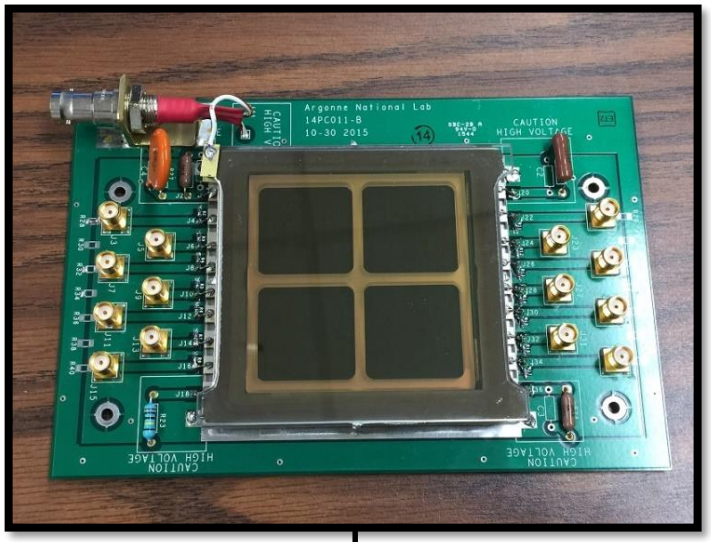
Background: Large Area Picosecond PhotoDetector (LAPPD)

- **LAPPD** is a photomultiplier based on new generation microchannel plate, reinvents photodetector using transformational technologies.
- Goals: low-cost, large-area (20 cm x 20 cm), picosecond-timing, mm-position
- Applications: picosecond timing, mm-spatial on large-area
  - ✓ Particle physics: optical TPC, TOF, RICH
  - ✓ Medical imaging: PET scanner, X-ray imaging devices
  - ✓ National security: Detection of neutron and radioactive materials
- Status: Incom, Inc. is routinely producing standard LAPPD on a pilot production basis for test and evaluation by “Early Adopters”.



Argonne MCP photodetector program within LAPPD



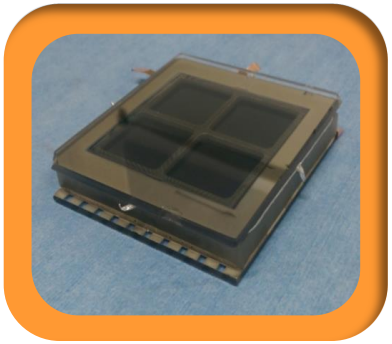
6 cm × 6 cm

- Produce the first functional devices and provide them to the community for evaluation and incorporation into experiments
- Support the industry for commercialization of large-area devices
- Provide a flexible platform for further R&D efforts (VUV-UV-Vis response, B-field application, cryogenic application…)

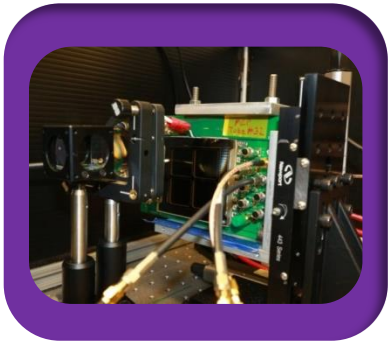
ALD-MCP

Photocathode

Packaging

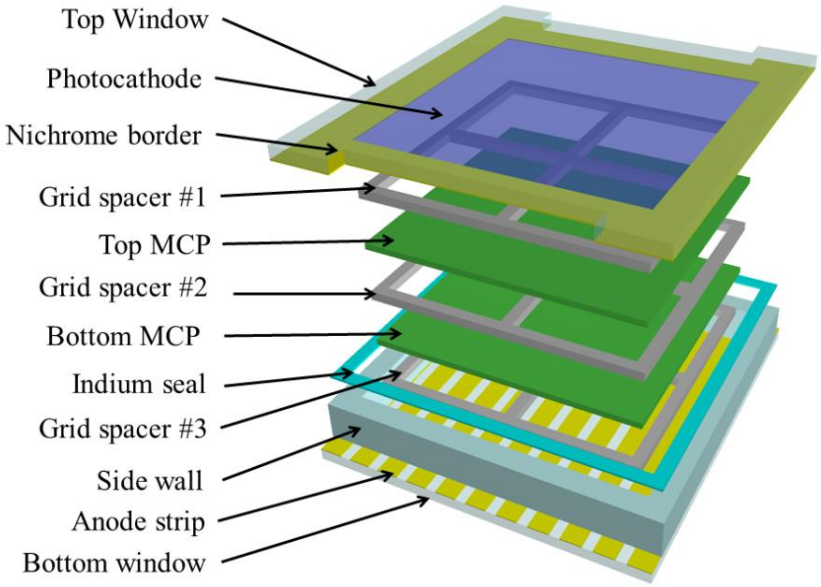


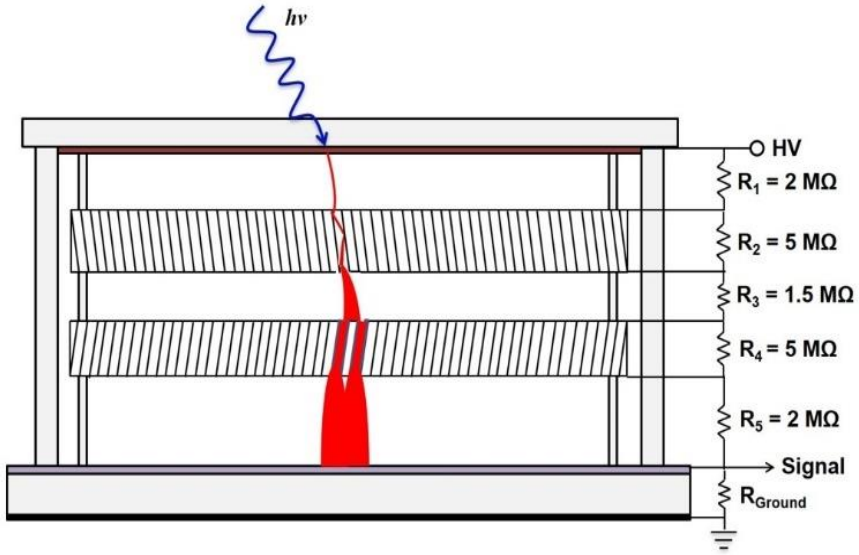
Testing



Argonne 6 cm × 6 cm MCP-PMT

- A glass bottom plate with stripline anode readout
- A glass side wall that is glass-frit bonded to the bottom plate
- A pair of MCPs (20μm pore) separated by a grid spacer.
- Three glass grid spacers.
- A glass top window with a bialkali (K, Cs) photocathode.
- An indium seal between the top window and the sidewall.





A very flexible platform for R&D efforts!

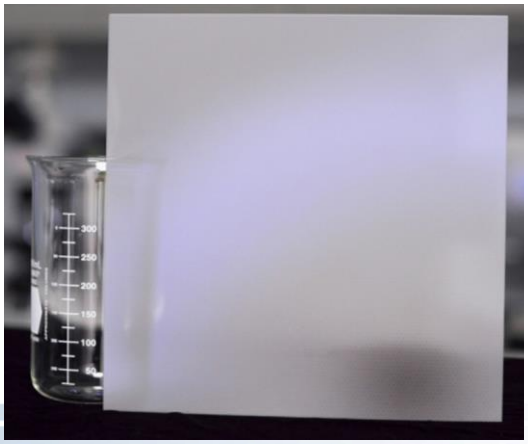
Next generation micro-channel plates – 1.GCAs

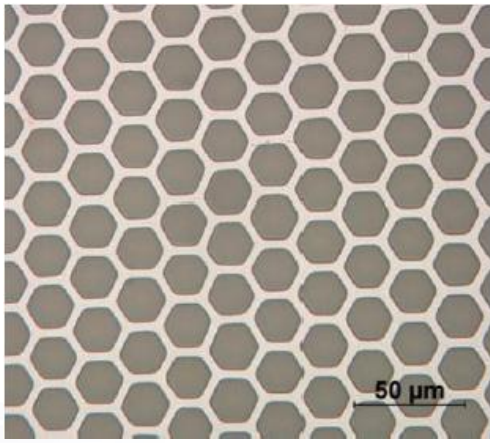
- **Conventional Pb-silicate glass MCP:** Based on optic fiber production, chemical etching and thermal processing
  - × Expensive lead-silicate glass
  - × Complex, labor consuming technology
  - × Large deviation of channel diameters within MCP
  - × Difficult to produce large area MCP, brittle after firing

❖ **"Next generation" MCPs - Break through 1: Production of large blocks of hollow, micron-sized glass capillary arrays (GCAs)** based on the use of hollow capillaries in the glass drawing process

- ✓ Use considerably less expensive borosilicate glass (Pyrexs or similar)
- ✓ Eliminate the need to later remove core material by chemical etching
- ✓ Low alkali content for reduced background noise
- ✓ World's largest MCP: 20 cm x 20 cm

*M. Minot et al., Nucl. Instr. Meth. A **787** (2015) 78-84*

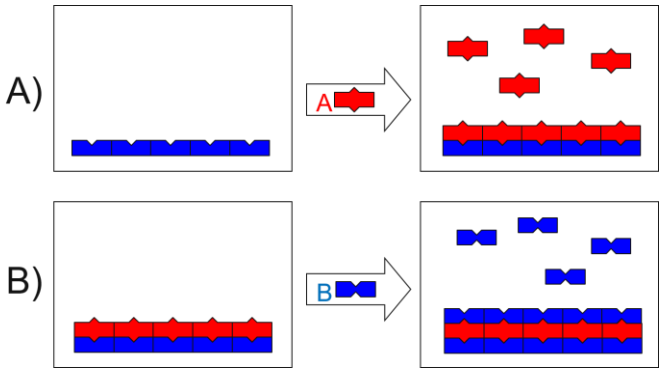




Next generation micro-channel plates – 2.ALD

- **"Next generation" MCPs - Break through 2:**
  Functionalization of the glass capillary arrays with atomic layer deposition (ALD) methods
  - ✓ Self-limiting thin film deposition technique
  - ✓ Controlled film thickness
  - ✓ Freedom to tune the capabilities:
  - ✓ Robust, good performance

Self-terminating surface reactions

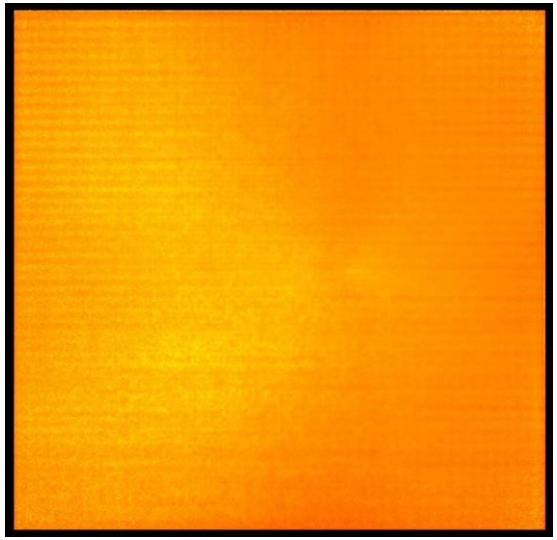


MCP after functionalization

MCP parameters

- Pore size: 20 µm
- Thickness: 1.2 mm
- L:D ratio: 60:1
- Open area ratio: 60%
- Average gain: 7×10^6
- Gain variation: <10%

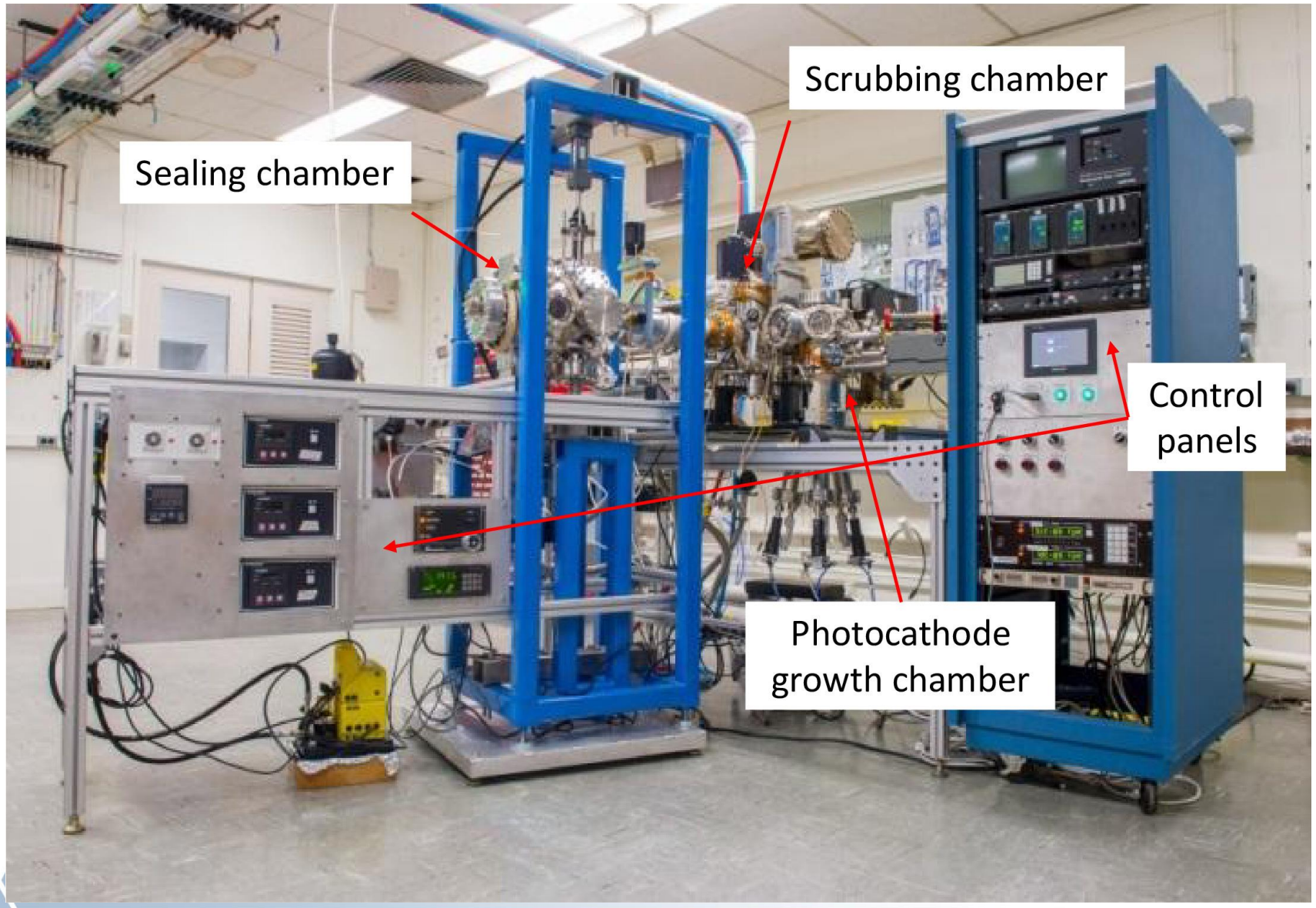
Average gain image "map"



*M. Minot et al., Nucl. Instr. Meth. A **787** (2015) 78-84*

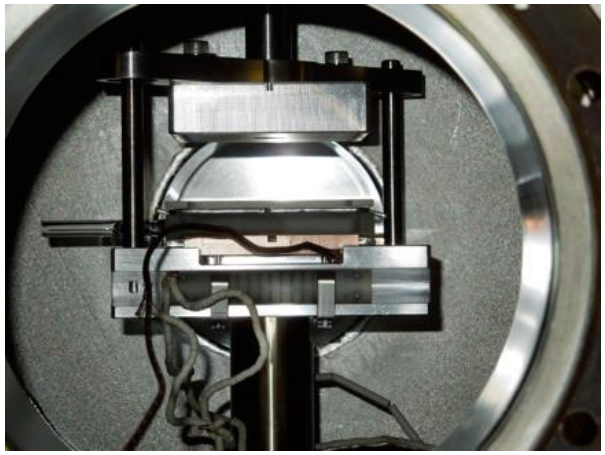
The Argonne ALD technique has been licensed to Incom, Inc. for commercialization.

Photodetector fabrication lab

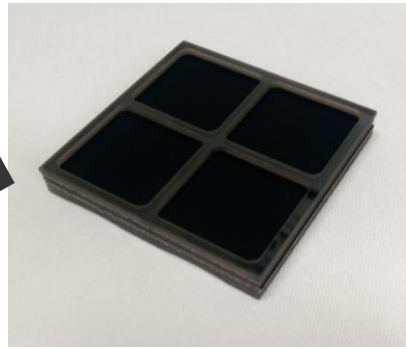


Hermetic packaging

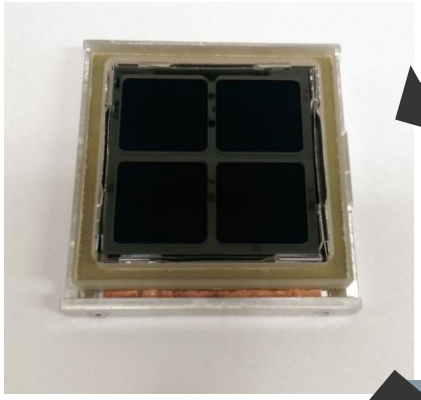
hydraulic driven platens



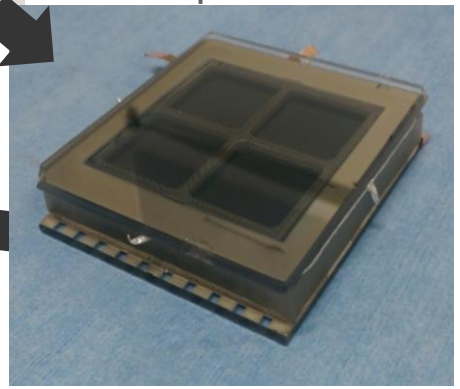
MCP & Resistive Grid Spacer Stack



Glass LTA



Completed Tube

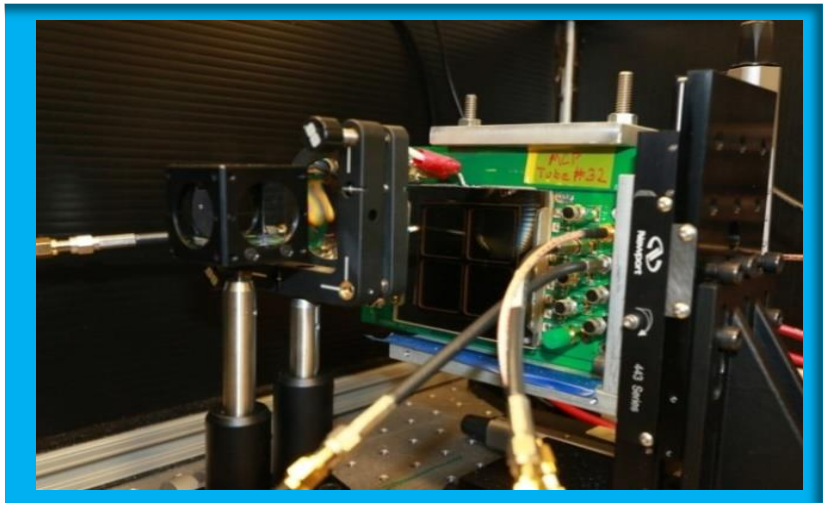


Baking, scrubbing, photocathode deposition, compression sealing

Test facilities

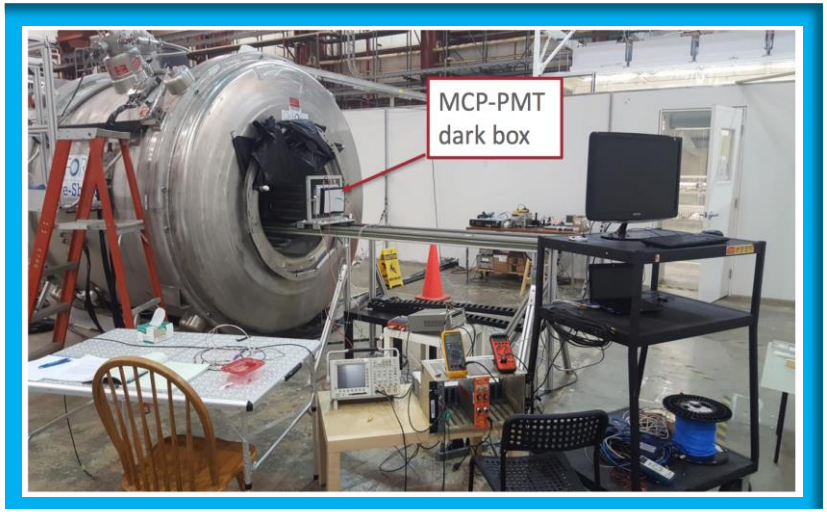
Optical Table for photocathode test

ps-Laser Facility for timing characterization



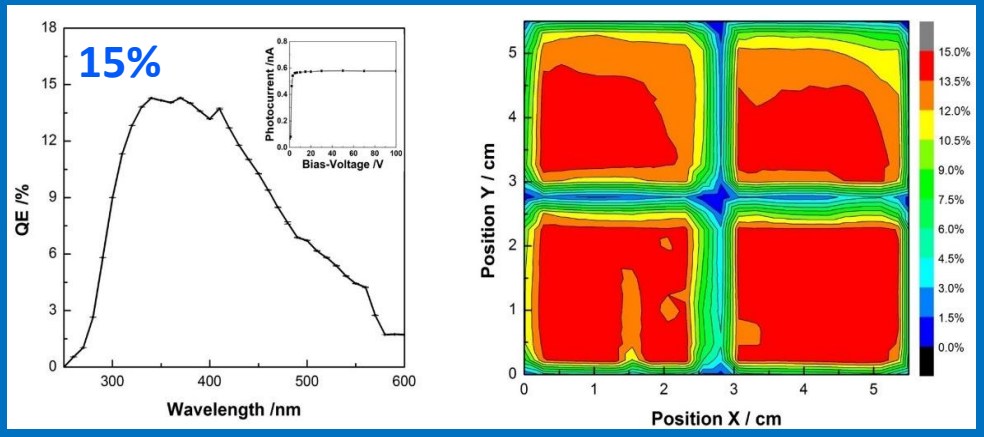
Fermilab/JLab Test Beam Facilities

ANL G-2 Magnetic Field Test Facility

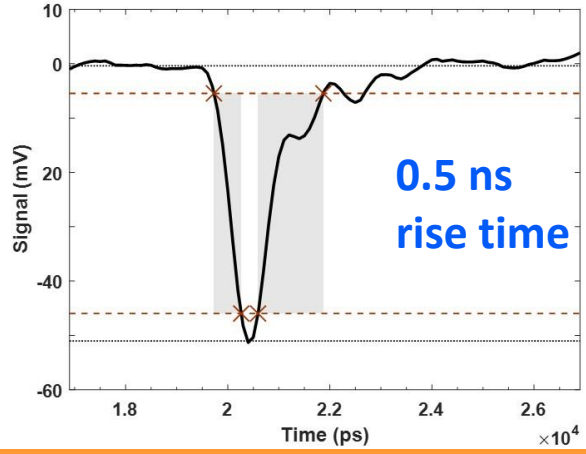


Argonne 6 cm × 6 cm MCP-PMT Key performances

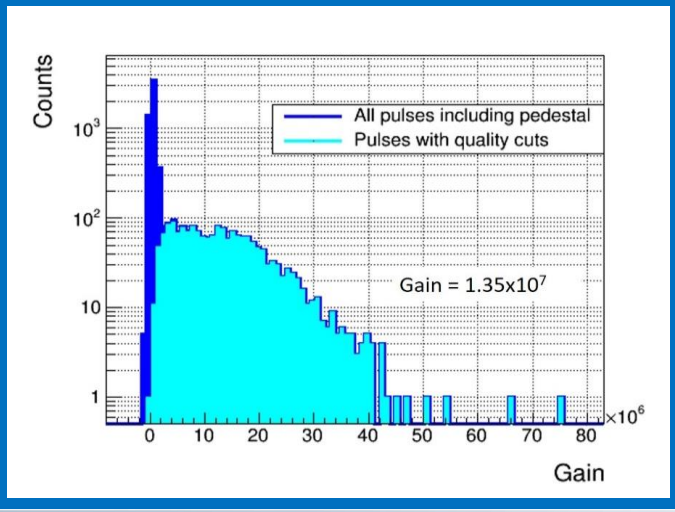
Spectra response



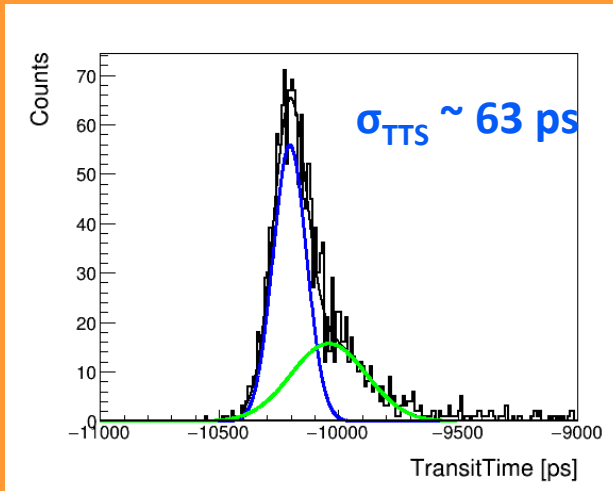
Signal component



Gain > 10^7



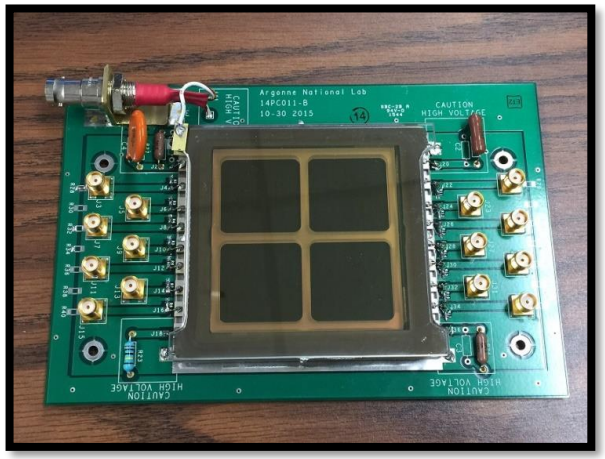
Timing resolution



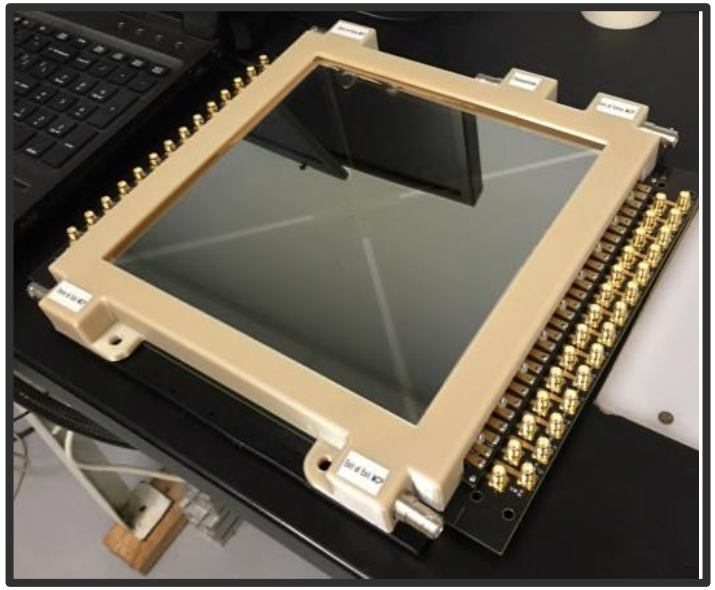
Argonne 6 cm MCP-PMT & LAPPD™

Small form factor LAPPD (6 cm MCP-PMT) was produced at Argonne for R&D.

R&D test bed: 6x6 cm²



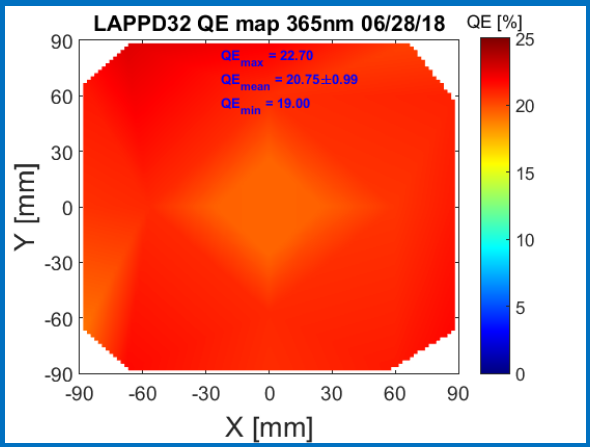
Commercialization: 20x20 cm²



- The Argonne 6 cm MCP-PMT and INCOM 20 cm LAPPD™ share the same MCPs and similar internal configuration and signal readout.
- The Argonne 6 cm MCP-PMT serves as R&D test bed for performance characterization and design optimization; INCOM 20 cm LAPPD™ is the final commercialized product.
- Close collaboration and communication (bi-weekly meeting, joint SBIR program), optimized configurations are directly transferrable to INCOM production line for mass production.

LAPPD^{TM} Key performances

Spectra response

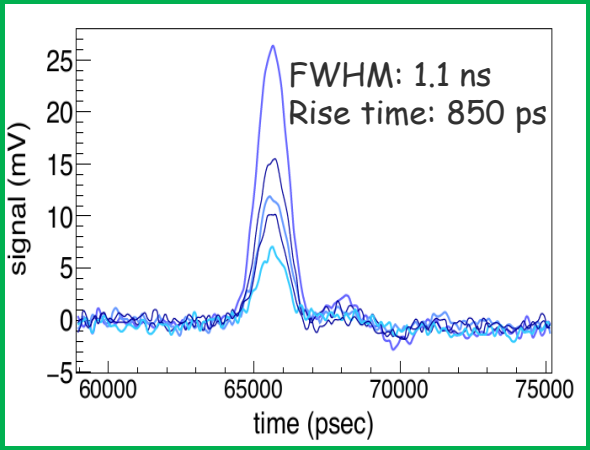


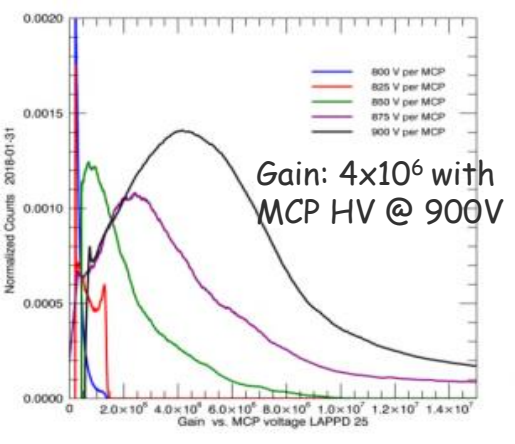
Large Area Photocathode production process is established
QE >20% demonstrated in sealed LAPPDs

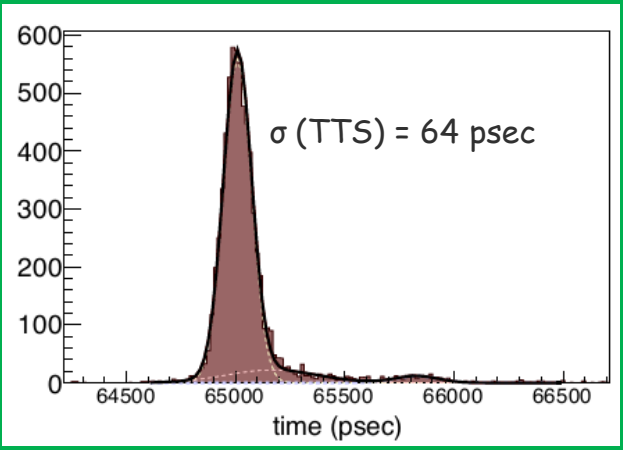
LAPPD S/N	Maximum %	Average %	Minimum %
LAPPD #13:	23.5	18.6±3.3	13.5
LAPPD #15:	25.8	22.3±3.0	15.7
LAPPD #22:	14.7	10.6	7.0
LAPPD #25:	10	7.1	5.0
LAPPD #29:	19.6	13.0±6.0	3
LAPPD #30:	22.9	17.2±2.5	13
LAPPD #31:	19.6	16.0±1.9	12.1
LAPPD #32:	22.7	20.8±1.0	19.0

Uniform QE at 20% average was achieved, but varies from run to run, addressing it now at INCOM

Gain & Timing



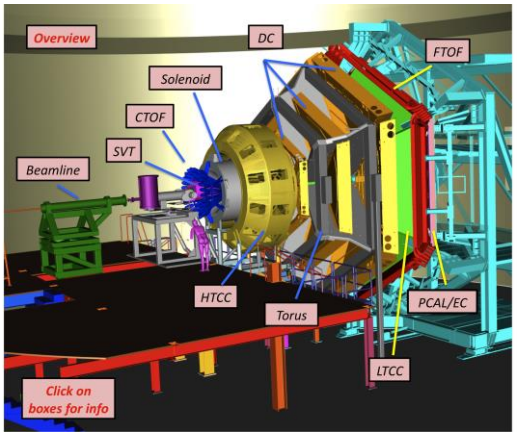




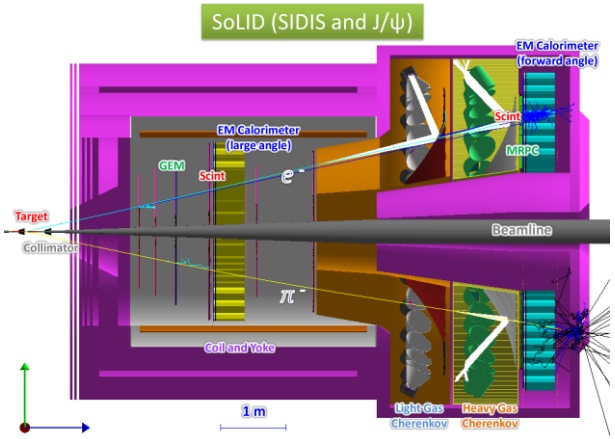
Waveform and timing measurement credit to M. Westin at Iowa State Univ.

LAPPD^{TM} towards Nuclear Physics Application

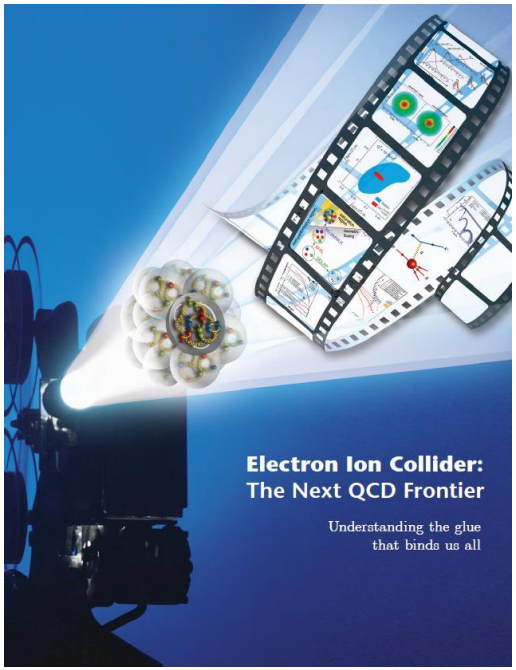
Ultimate GOAL: Achieve mass produced low-cost LAPPD^{TM} with specifications fulfill Nuclear Physics requirements



CLASS 12 collaboration



SoLID collaboration

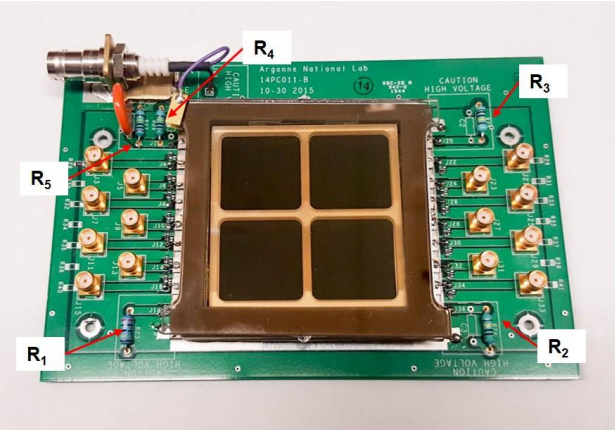


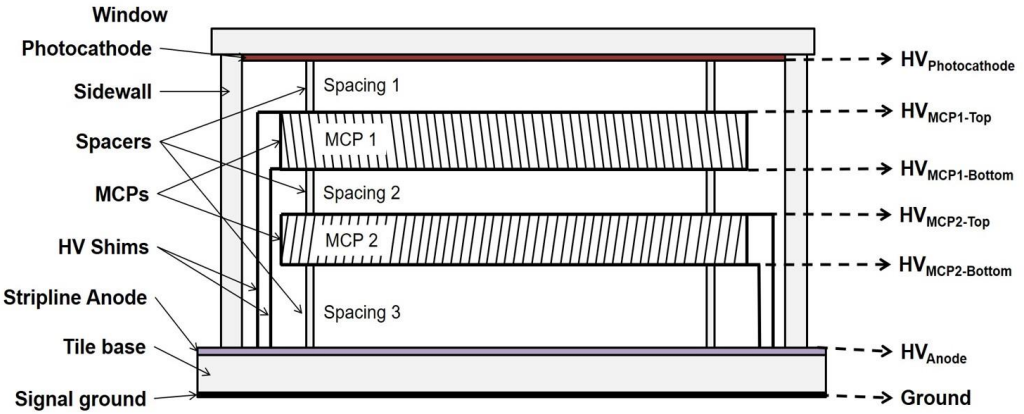
arXiv:1212.1701

- Nuclear Physics programs call for **low-cost, large-area Multi-channel Plate (MCP) type detector** with high time and spatial resolution, high rate capability, radiation tolerance and **magnetic field tolerance** for particle identification (PID) ($e/\pi/K/p$).
- Optimization of current LAPPD^{TM} design, extensive characterization to address issues, and industrial mass production are critical to the success of Nuclear Physics programs.

Geometry of two completed MCP-PMTs:

Different pore size MCPs but same stack height



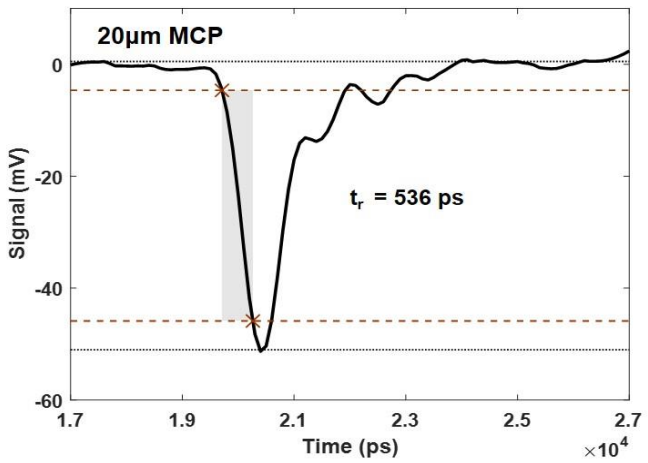


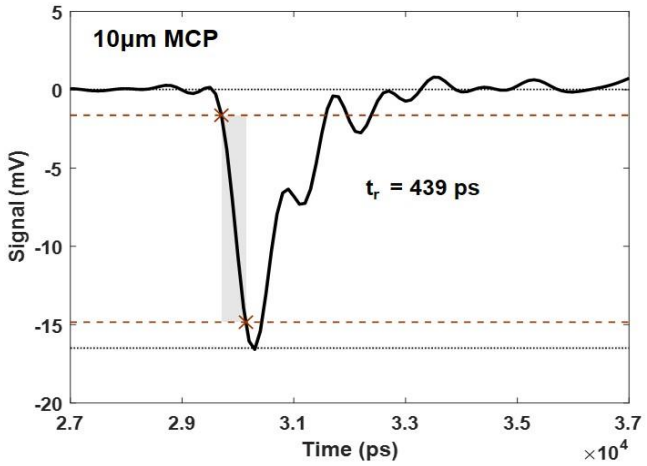
		20 µm MCP-PMT	10 µm MCP-PMT
MCP	Pore size	20 µm	10 µm
	Length to diameter ratio (L/d)	60:1	60:1
	Thickness	1.2 mm	0.6 mm
	Open area ratio	60 %	70 %
	Bias angle	8°	13°
Detector geometry	Window thickness	2.75 mm	2.75 mm
	Spacing 1	3.25 mm	2.25 mm
	Spacing 2	1.75 mm	2.0 mm
	Spacing 3	2.0 mm	4.0 mm
	Shims	0.3 mm	0.3 mm
	Tile base thickness	2.75 mm	2.75 mm
MCP-PMT stack	Internal stack height	9.70 mm	9.75 mm
	Total stack height	15.20 mm	15.25 mm

Performance of two completed MCP-PMTs:

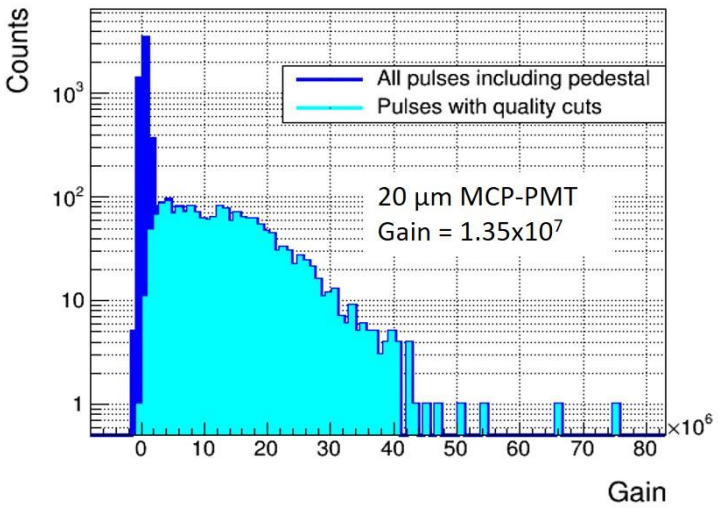
Different pore size MCPs but same stack height

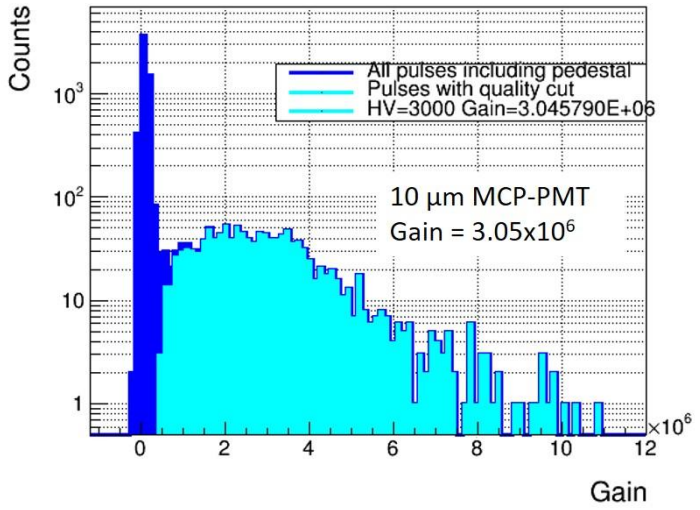
Rise time





Gain



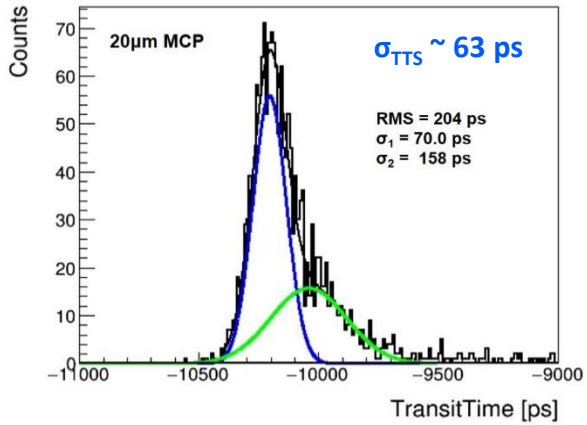


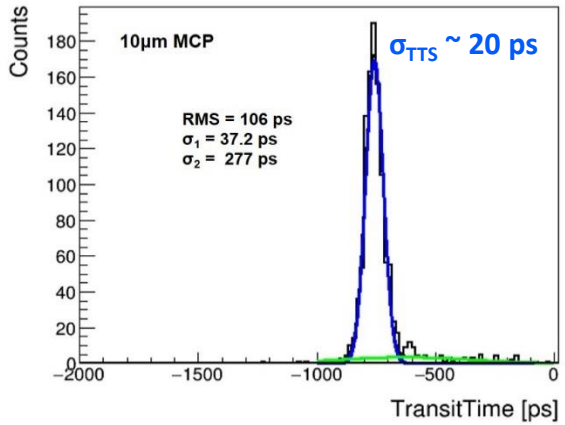
Performance of two completed MCP-PMTs:

Different pore size MCPs but same stack height

Timing resolution (SPE)

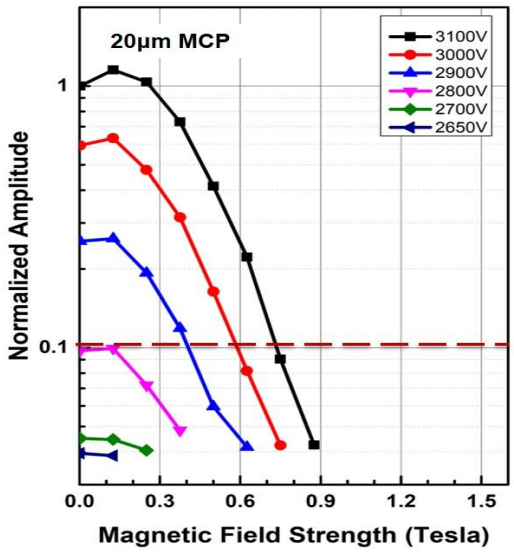
$$\sigma_{MCP-PMT} = \sqrt{\sigma_1^2 - \sigma_{Laser}^2 - \sigma_{Ele.}^2}$$

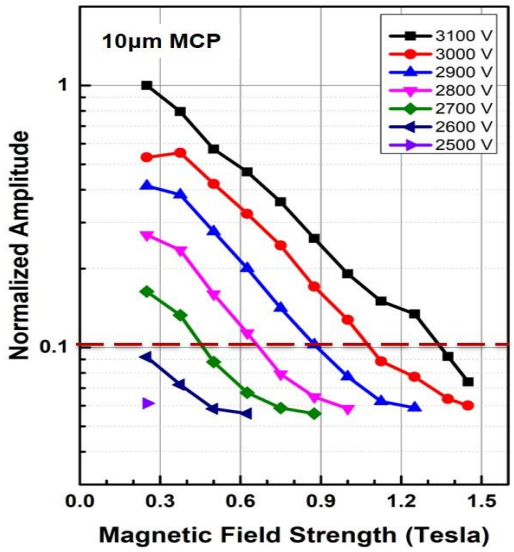




System: σ_1 = 37.2 ps
Laser jitter: σ_{Laser} = 30 ps
Electronics: $\sigma_{Ele.}$ = 7 ps
*10 μm MCP-PMT: **σ = 20 ps***

Magnetic field tolerance





20 μm MCP-PMT	10 μm MCP-PMT
0.7 Tesla	**1.3 Tesla**

Conclusion

- An MCP-PMT fabrication facility was designed and built at Argonne National Laboratory
- Multiple small form factor LAPPDs were fabricated for initial R&D.
- LAPPD collaboration successfully commercialized the LAPPD^{TM}.
- Optimization of the MCP-PMT configuration is undergoing to fulfill NP requirement
- MCP-PMT with smaller pore size exhibits improved timing and magnetic field tolerance

		20 µm MCP photodetector	**10 µm MCP photodetector**
Gain characteristic	Gain	1.35×10^7	3.05×10^6
Time characteristic	Rise time	536 ps	439 ps
	Timing distribution RMS	204 ps	106 ps
	System resolution	70.0 ps	37.2 ps
	Time resolution	63 ps	20 ps
	Differential time spread	11 ps	7 ps
	Spatial resolution	0.83 mm	0.53 mm
Magnetic field	Magnetic field tolerance	0.7 Tesla	1.3 Tesla

Acknowledgments

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And many others …

The LAPPD collaboration, The EIC PID consortium, The Argonne EIC-LDRD program

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Thank you for your attention!

Questions?