eRD14 EIC-PID review meeting

PHOTOSENSORS

JUNQI XIE

Medium Energy Physics Group
Argonne National Laboratory
9700 S Cass Ave., Lemont, IL 60439
jxie@anl.gov

Sep 19, 2019

PHOTOSENSOR WORKGROUP

Argonne 6cm MCP-PMT development:

Argonne National Laboratory
Junqi Xie, Edward May, Lei Xia, Robert Wagner
(Soon: Zein-Eddine Meziani)
Brookhaven National Laboratory
Mickey Chiu
Florida A&M University
Stacyann Nelson, Carol Scarlett

Commercial MCP-PMT testing:

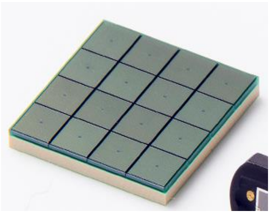
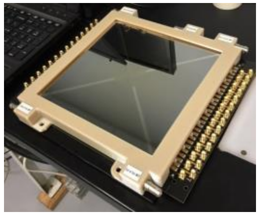
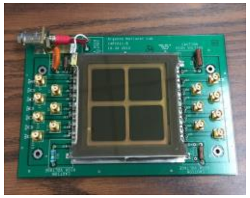
University of South Carolina
Yordanka Ilieva, Brandon Tumeo
Jefferson Lab
Carl Zorn, *Jack McKisson*
Catholic University of America
Greg Kalicy
University of New Hampshire
Tongtong Cao
University of Indiana
Colin Gleason

SiPM testing:

INFN groups

PHOTOSENSOR OPTIONS

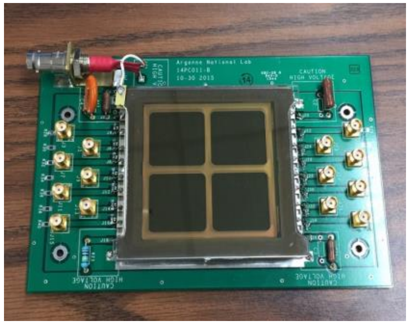
Commercial products | R&D only

	Planacon	SiPM	LAPPD	Argonne MCP-PMT
Area	6cm x 6cm		20cm x 20cm	6cm x 6cm
Pixel	3x3 mm available	3x3 mm available	25x25 mm available 3x3 mm needs test	3x3 mm demonstrated, needs full device validation
Magnetic field	Yes	Yes	0.7 T, needs 10um MCPs for > 1.5 T	> 1.5 T
Radiation	Yes	Need test	Expect good	Expect good
Availability	In-stock	In-stock	In-stock for 20 um, in 2 years for 10 um	Mar 2020
Price	$15-20 k/each, Significant cheaper in large unit	$1 /mm^2 ?	$50 k/ each now $25 k/ each 4 years later based on Incom	-
Unit price	$12.5k /25cm^2 Cheaper in large	$2.5k /25cm^2	$3.125k /25cm^2 now or $1.56k /25cm^2 future Gen-III unknown	-
Concerns	No, except expensive for R&D	Radiation hardness	Cross talk, integration availability	-
Risk	No risk	No risk if radiation is OK	Achievable with risk, Gen-II, III LAPPD design	R&D only

*Photek MCP-PMT is also a potential option for commercial small-pixel MCP-PMTs although not listed in details here.

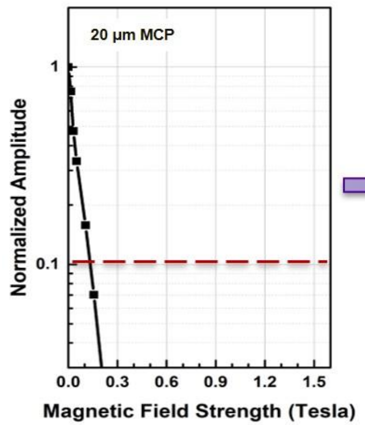
ARGONNE MCP-PMT R&D STATUS



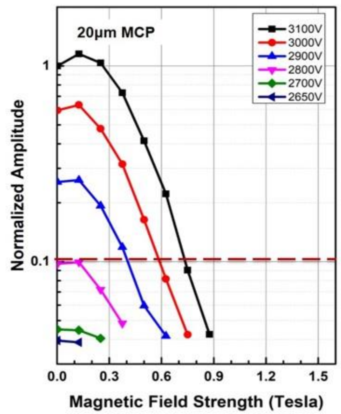
Optimize LAPPD design on Argonne whole glass/fused silica MCP-PMT design specifically for EIC-PID:
Mature and low-cost fabrication technique, high yield, Incom integrated in Gen I LAPPD

Magnetic field tolerance and timing improvement

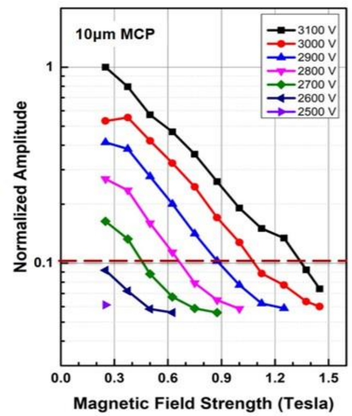
ANL version 1
Internal resistor chain



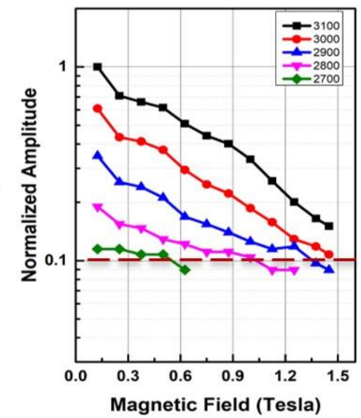
ANL version 2
IBD design 20 µm MCP



ANL version 3
IBD design 10 µm MCP



ANL version 4
IBD design 10 µm MCP
reduced spacing



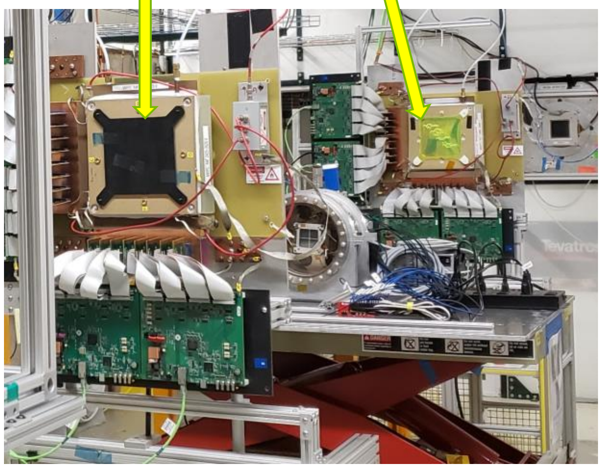
		ANL Version 2 Standard 20 µm MCP-PMT	ANL Version 3 10 µm MCP-PMT without reduced spacing	ANL Version 4 10 µm MCP-PMT with reduced spacing
Gain Characteristic	Gain	1.35×10^7	3.05×10^6	2.0×10^7
Time Characteristic	Rise time	536 ps	439 ps	390 ps
	Timing distribution RMS	**204 ps**	**106 ps**	**109 ps**
	System resolution	70.0 ps	37.2 ps	41 ps
	Time resolution	**63 ps**	**20 ps**	**28.5 ps**
	Differential time spread	11 ps	7 ps	5 ps
	Spatial resolution	0.83 mm	0.53 mm	0.38 mm
Magnetic Field	Magnetic field tolerance	**0.7 Tesla**	**1.3 Tesla**	**> 1.5 Tesla**

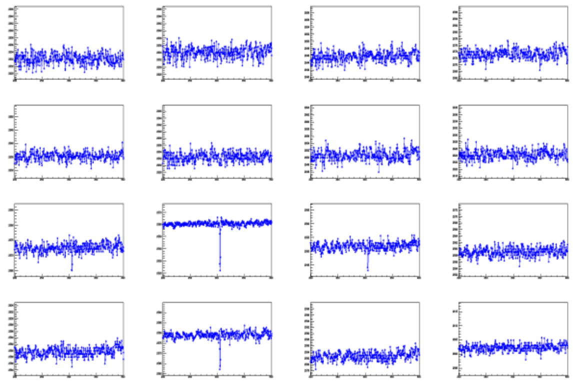
ARGONNE MCP-PMT R&D STATUS

Fine pixel size development

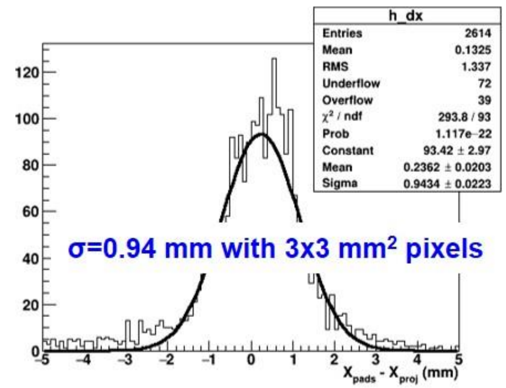
3mm x 3mm pixel size with <1 mm position resolution demonstrated with MCP stack in dynamic vacuum chamber

MWPC tracking used

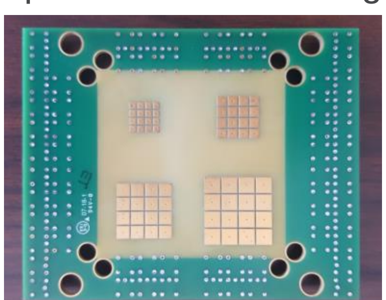




Confined signal spread in 4x4 mm^2 pads



4 different pixel sizes (2x2,3x3,4x4 and 5x5 mm^2) implemented for testing



Fine pixel size (2~5x mm^2)

Pixel size	X res (mm)	Y res (mm)
2x2 mm^2	1.4	1.7
3x3 mm^2	0.94	0.95
4x4 mm^2	0.81	0.76
5x5 mm^2	1.1	0.97

Capacitively coupled through glass anode, confined charge sharing helps position resolution

ARGONNE MCP-PMT R&D PLANS

FY2020

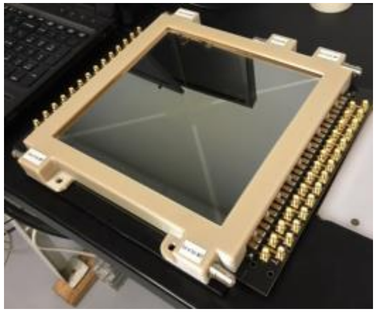
6cm MCP-PMT:
The most critical issues of magnetic field (>1.5 T), fine pixel size (3x3 mm^2) and timing resolution RMS (100 ps) were all demonstrated at current R&D stage. The next step is to demonstrate integrated 6cm MCP-PMT device with above performance.

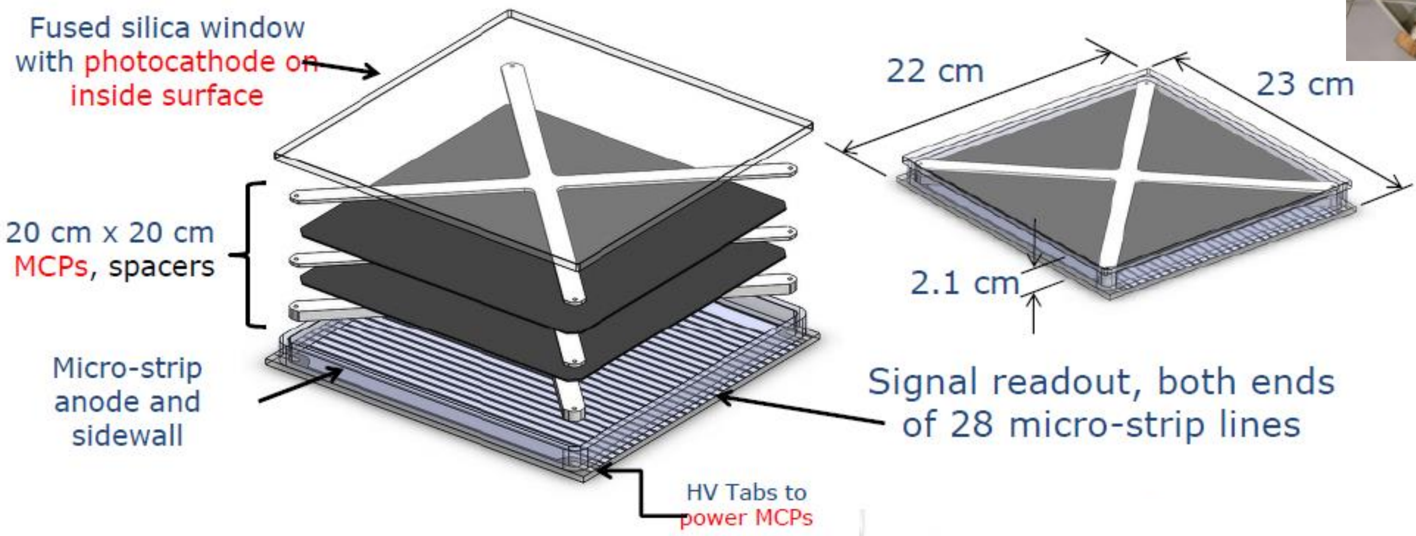
Two 6cm pixelated MCP-PMTs with integrated design will be fabricated and placed in Fermilab beamline for testing together with pixel readout and BNL zigzag readout.

FY2021 - 23
Identify MCP-PMTs with different ALD coated MCPs (MgO, Al_2O_3 etc), performance comparison in magnetic fields to study why ALD affects the gain dependence on the magnetic field as committee recommended.

Current status of LAPPD: Gen I

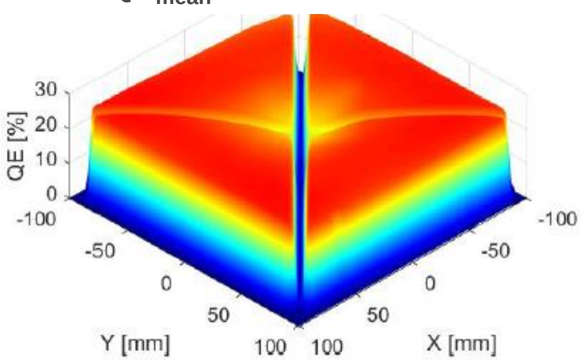
Gen I LAPPD: Glass body, mature sealing process, high yield from Incom.

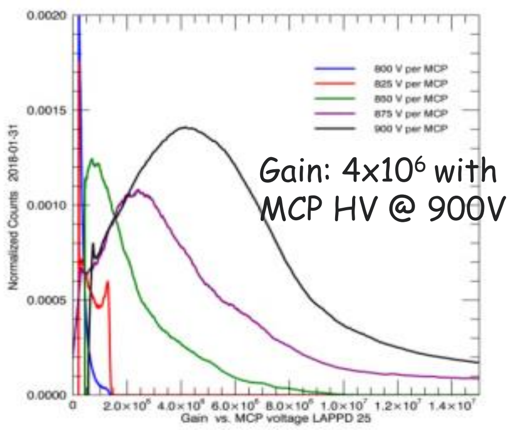


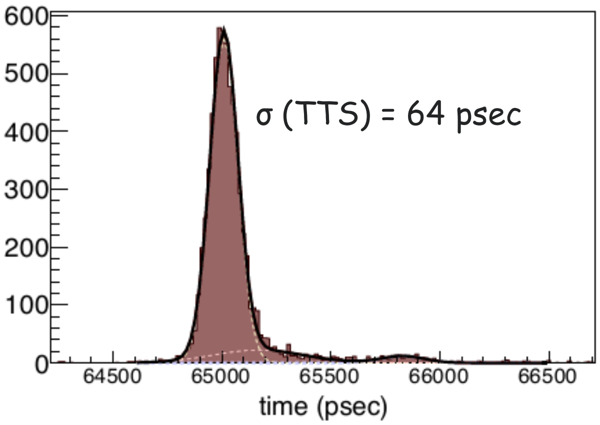


- Signal & HV pass under frit bonded side walls. **Stripline, not pixelated**

QE_{max} = 26.1%
QE_{mean} = 24.3% ± 2.5%





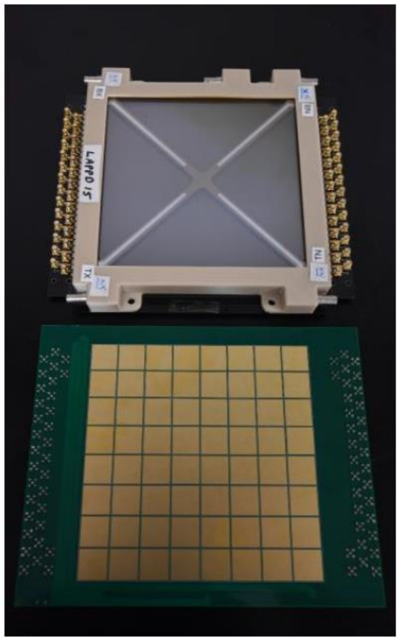


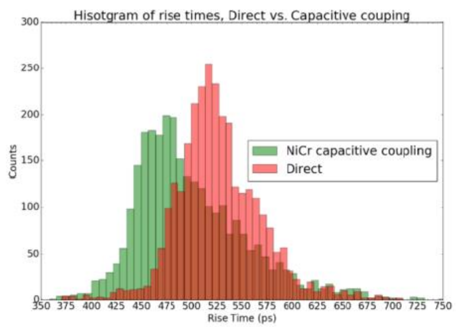
Current status of LAPPD: Gen II

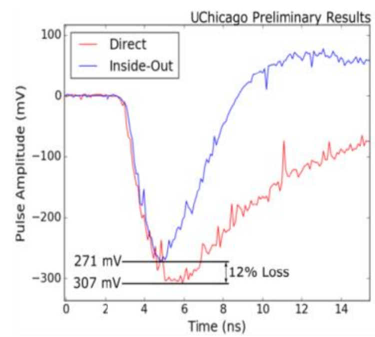
NP-SBIR supporting through Phase I, II and IIA:
Development of Gen-II LAPPD^{TM} Systems For Nuclear Physics Experiments

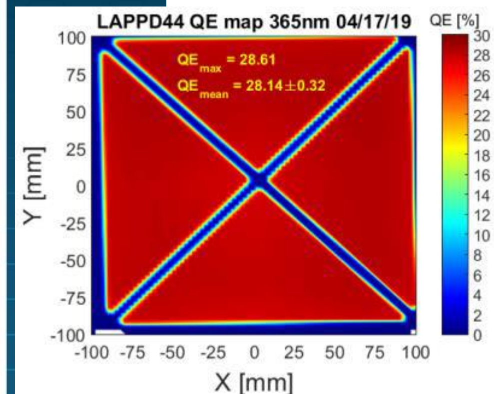
Gen-II LAPPD™ Concept

- A robust ceramic body
- UV-grade fused silica window
- Capacitive signal coupling: to an external PCB anode









The capacitive readout scheme preserves rise-time of pulses (rise time is a key factor in timing resolution)

For pad pattern: 80% of the directly coupled amplitude

E. Angelico et al., Nuclear Instruments and Methods in Physics Research A 846 (2017) 75–80

Pixelated Gen II LAPPD is available at Incom with 25 mm × 25 mm pixel size.

How does the ceramic capacitive coupling work with fine pixel (3~6 mm) sizes?
What is its smallest pixel size with acceptable signal spread and cross talk?

LAPPD DELIVERY PLANS FROM INCOM

Michael Minot, Incom LAPPD R&D director

INCOM GEN-II LAPPD PLANS

Incom is under NP-SBIR Phase IIA contract to develop ceramic Gen-II LAPPD.

Development of Gen-II LAPPD^{TM} Systems For Nuclear Physics Experiments

Email exchange with Michael Minot, Incom LAPPD R&D director

The Incom development plan, as currently understood, will proceed in two steps as follows:

1. Full characterization of the current baseline GEN II capabilities to meet the needs of EIC. Our GEN II LAPPD relies on capacitive coupling of the signal and the key issues to be resolve near term are

   a. whether signal intensity drops off to a level that would require amplification for small 3mm pixels, and

   b. whether signal quality is compromised by unwanted capacitive pulse coupling across multiple distant anode pads.

   To address both of these issues we are committed to characterize GEN II LAPPD using 25mm. 12 mm, 6mm and 3mm square pixels deployed onto printed circuit boards and capacitively coupled for signal read-out to the LAPPD. The 25mm and 12mm printed circuit boards are in hand and are being used as GEN II LAPPD are available for test. Printed circuit boards with 6mm and 3mm pixelated anodes are being designed by the ANL electronics group in a joint effort between Incom and Bob Wagner and Junqi Xie at ANL. Testing of these boards will commence as soon as they are available.

Signal spread and cross talk is a big concern on ceramic Gen II LAPPD, needs immediate validation for its performance with 3~6 mm pixel sizes.
Argonne electronic engineers are modifying Incom 25mm x 25mm adaptor board for 3~6 mm pixel sizes, expecting test results in Jan 2020.

INCOM GEN-II LAPPD PLANS

Summary of the Three Phase Approach

Incom is adopting a 3-phase approach to address the needs of the nuclear physics community.

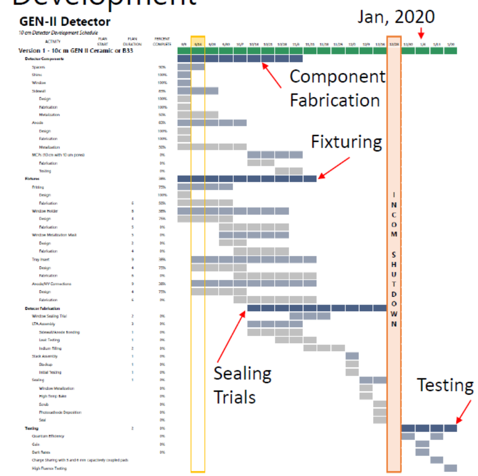
1. Through the current Phase IIA SBIR program, fully characterize and optimize the Gen-II LAPPD readout.
   - Maximize coupling to the external readout board my minimizing the anode thickness while maintain mechanical stability
   - Optimize the internal resistive anode by exploring materials, patterns, and resistivity
   - Design and test the limits of a pixelated readout board
2. Use a 10 cm × 10 cm version of the Gen-II LAPPD to further optimize detector design,
   - Taking advantage of the 10 μm pore MCPs
   - Reduced gap spacing for improved timing resolution and B-Field tolerance
   - An unobstructed FOV (no window support)
3. Development of a novel anode to advance the LAPPD performance beyond what is capable in the current designs
   - Decouple the electrical and mechanical properties of the anode so each can independently optimized.
   - Preparing phase I DOE SBIR proposal (funding period Feb-Nov 2020)

9/16/2019 Future LAPPD and HRPPD Development Meeting

Incom direct meeting with Pawel and Yordanka

Current Gen-II 10 cm Detector Development

- Detector design phase complete
- Kit components in house
  - Sidewalls out for metalization
  - Anodes out for metalization
- Actively designing fixturing
  - Some early processing step fixtures complete and expected in house soon.
- Next steps
  - Sealing tank fixture fabrication
  - Window – Sidewall sealing trials
  - Sidewall – Anode bonding
- Sealed 10 cm detector expected Jan 2020



9/16/2019 Future LAPPD and HRPPD Development Meeting 13

With proven R&D results and emphasis on NP request, Incom starts integration of Argonne's input:

A 10x10 cm^2 Gen II LAPPD with 10um MCP-PMTs and reduced spacing, delivery in Jan 2020.

Argonne NATIONAL LABORATORY

INCOM GEN-III LAPPD PLANS

Email exchange with Michael Minot, Incom LAPPD R&D director

2. Large Area Multi-Anode MCP-PMT for High Rate Applications - The ultimate goal of this program is to demonstrate over the next two years, the readiness of LAPPD, equipped with a 2-3 mm pixelated anode, to perform with high spatial ($\leq$1 mm^2) and timing (<10 ps) resolution at rates $\geq$200 kHz/cm^2 in a high radiation (10 Mrad with 10^{15} n/cm^2) and large magnetic field (2-3 T) environment for time-of-flight and Cherenkov detectors with broad particle identification capabilities.

   This program will proceed in steps:

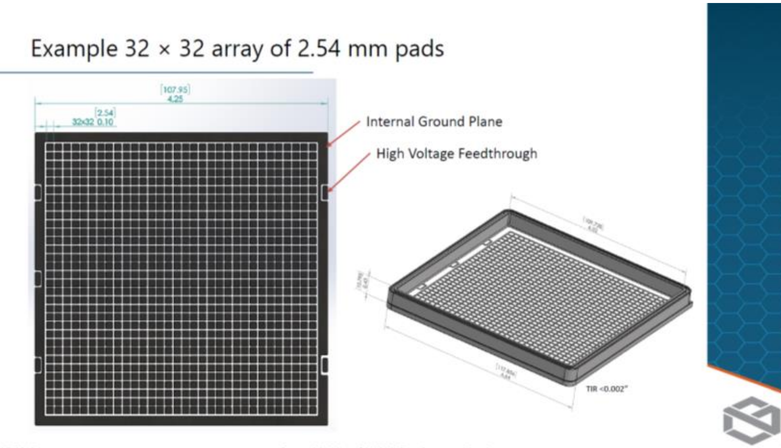
   a. Fabrication of a 10cm X 10cm analogue to the full size 20cm X 20cm LAPPD - this represents an important early stage milestone, which is already underway, since it we will likely be able to incorporate MCPs with 10-micro pores in this smaller device well ahead of the full size 20cm X 20cm LAPPD. In addition to the smaller pore size MCP, the gaps between components will be optimized; both of these variables are critical for timing and B-field. First prototypes will be our standard GEN II, but now with the advantage of the smaller pore MCPs, and in a tile format without X-spacers that obscure the open area.

   b. While the full limits of current baseline GEN II have not yet been fully explore innovative anode designs will ultimately be needed to go beyond the perform commercially available detectors such as Planacon. A development plan was NP SBIR support (Letter of Intent just submitted to our DOE Program Manager build upon recent advances in the development of a second generation (GEN Picosecond Photodetector (LAPPD™) to develop an advanced co-fired ceramic need for a large area microchannel plate (MCP) photodetector with high rate the detector requirements of next generation nuclear physics (NP) experimen SoLID. Phase I of the program will focus on the development of the co-fired a devices made in Phase II.

DOE SBIR Phase I

Proposal Due Oct 15, 2019

9 Month funding period starts Feb 18, 2020



A new SBIR with high temperature co-fire ceramic (HTCC) anode Gen-III LAPPD (10x10 cm^2) is initiated by Incom for FY2020, with all required EIC performance integrated.

Gen-III LAPPD delivery expected in FY2021 if DOE-NP approves the 2nd SBIR.

ARGONNE LAPPD TESTING PLANS

FY2020

LAPPD:
Validation of Incom's current Gen II ceramic LAPPD for fine pixel size (3~6 mm) and other performance. If it works at 3~6 mm pixel size with acceptable charge sharing and cross talk, it can be directly applicable to sub-system beamline test.

If Gen II ceramic pass fine pixel test, validation of Incom's Gen-II LAPPD with 10 µm pore size MCPs and reduced spacing upon delivery.

FY2021 - 23
Future Argonne effort within EIC-PID will focus on LAPPD full validation upon Incom's delivery, support electronics integration to MCP-PMT/LAPPD and their testing in sub-system beamline experiments.

To be conservative

Argonne commits on 6cm MCP-PMTs for EIC-PID related R&D, Incom LAPPD full characterization upon delivery.

Argonne is not under contract with Incom to develop LAPPD for NP, has no commitment on Incom Gen II, Gen III LAPPD's delivery.

ACTIVITY

Work task	FY2020	FY2021	FY2022	FY2023	Funding request	Priority	FY20	FY21	FY22	FY23
6cm MCP-PMT					10k materials		x.x			
Fabrication of two integrated 6cm MCP-PMTs					50k effort	High, at	x.x			
Full characterization of integrated 6cm MCP-PMTs					20k effort	least one	x.x			
Fermilab beamline test with two MCP-PMTs					5k effort	MCP-PMT	x			
						fabrication				
Investigation of ALD coating on gain					50k effort			xx		
dependence in magnetic field										
LAPPD										
Gen II LAPPD minimal pixel size validation					10k effort	High	x			
Gen III LAPPD pixel performance validation					5k effort	High		x		
If LAPPD successfully delivered and acceptable										
Accepted Gen II or Gen III LAPPD full test					20k effort		xx	x	x	x
Electronics integration					10k effort			x		
LAPPD delivery to sub-system Fermilab beamtest					10k effort			x	x	x
More LAPPD test and delivery					LAPPD prices			x	x	x
ANL/BNL/FAMU Travel					10k total		x	x	x	x
						Total request	**115k**	**105k**	**40k**	**40k**
							Not include LAPPD price			

Validation of Gen II and Gen III LAPPDs for fine pixel performance is the first priority upon Incom delivery, fabrication of Argonne design pixelated MCP-PMT for device validation is also a priority, needs two Argonne pixelated MCP-PMTs for FY2020 Spring beamline test.

Argonne NATIONAL LABORATORY

Argonne’s internal plans for MCP-PMT/LAPPD

Argonne (PHY/MEP) is in the process of discussing with DOE NP and SBIR office to facilitate the path for Incom to deliver the successful LAPPD with required needs for EIC.

To this end, Argonne will continue to invest in low-cost whole glass/fused silica MCP-PMT R&D, we plan to upgrade the outdated 6x6 cm^2 MCP-PMT facility to a practical 10x10 cm^2 MCP-PMT facility. The effort from PHY-MEP at Argonne will be aligned with EIC-PID Cerenkov type photosensor requirement as well as Argonne TOPSiDE gas only-RICH prototype. Furthermore, it will also serve as R&D platform for future MCP-PMT development for radio-pure environment (NLDBD), solar blind detection (Mu2e), isotope detection (TRACER) and cryogenic applications (Dark matter) for particle physics community.

COMMERCIAL MCP-PMT EVALUATION IN HIGH MAGNETIC FIELDS

Objective

Evaluation of commercial photosensors for EIC PID detectors in order to

- assess the limitations of current MCP-PMTs for high-B operations at EIC
- identify most favorable sensor orientations, i.e. tilt angle with respect to the local B-field
- investigate suitable parameters for High-B operations, i.e. most optimal voltage distribution

MCP-PMT Characterization

Gain, efficiency, timing resolution, ion feedback

Operational variables:

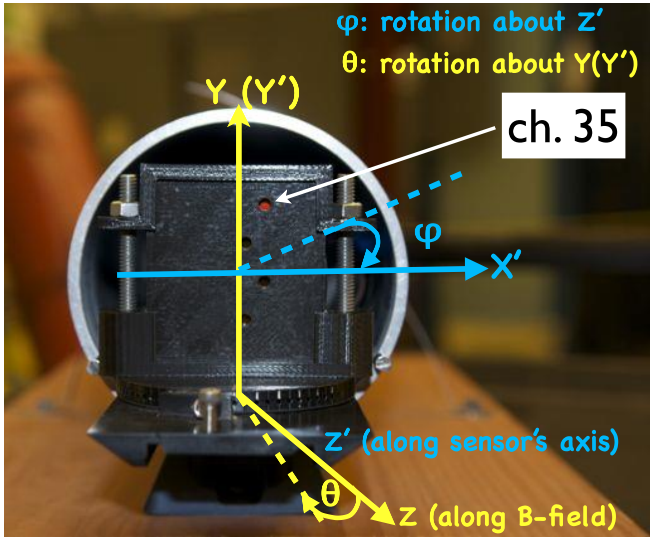
B, θ, φ, HV, $HV_{photocathode\text{-}MCP1}$, $HV_{MCP1\text{-}MCP2}$, $HV_{MCP2\text{-}anode}$

Past Activities

Large-pixel-size Planacons B-field evaluation

Multi-anode Hamamatsu B-field evaluation

Single-anode sensors (various small pore sizes) B-field evaluation



COMMERCIAL MCP-PMT EVALUATION IN HIGH MAGNETIC FIELDS

Timelines and Activities for TDR Readiness

Activity	FY20	FY21	FY22	FY23	Notes
Procure one unit of XP85122-S	$6.5k				Partial cost requested in FY20. Rest of cost covered from $10k carry-over
Cryogens and small components	$9.7k	$9.7k	$9.7k	$9.7k	
Travel	$12.3k	$12.3k	$12.3k	$12.3k	USC personnel to JLab
Student Summer Salary	$10.8k	$10.8k	$10.8k	$10.8k	Sensor measurements
Procure one unit of multi-anode Photek 6-μm sensor			$15k		
XP85122-S Characterization					
Photek multi-anode 10-μm characterization					
Gain, timing, and uniformity characterization of MCP PMTs for DIRC prototype with HI electronics					
Characterization of potentially available multi-anode 6-μm Photek PMT					
Total cost	$39.3k	$32.8k	$47.8k	$32.8k	