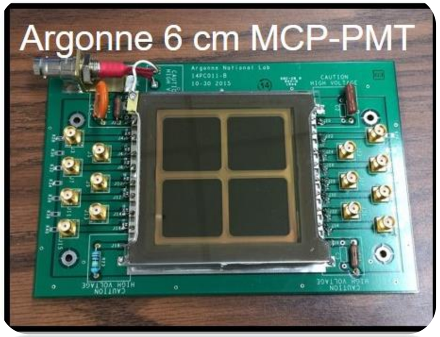
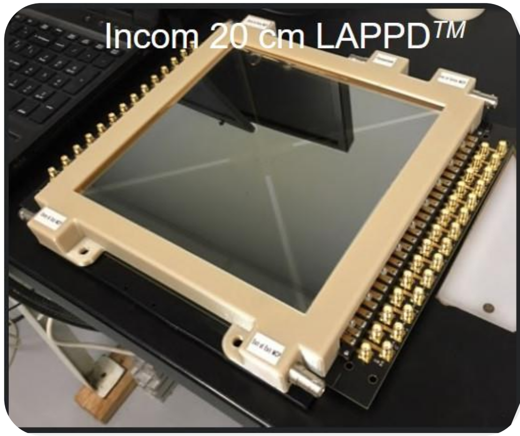
EIC PID WORKSHOP

MCP-PMT/LAPPD^{TM} DEVELOPMENT FOR PARTICLE IDENTIFICATION





Large Area Picosecond PhotoDetector (LAPPD^{TM})

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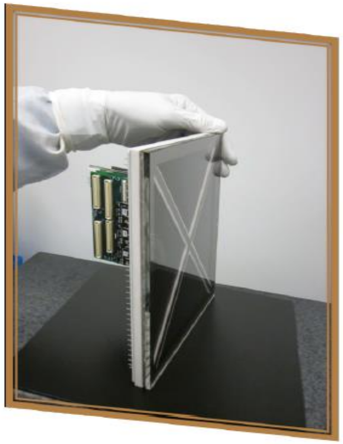
July 9, 2019
Stony Brook University, NY USA

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”.



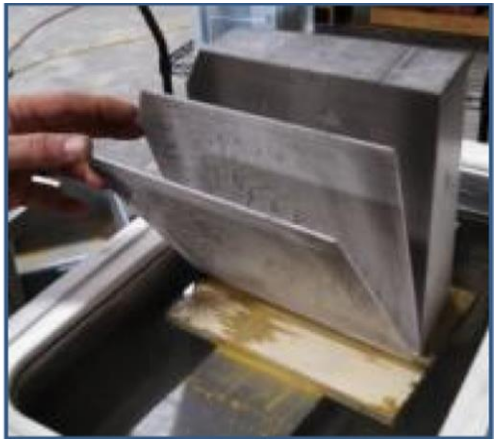
NEXT GENERATION MICRO-CHANNEL PLATES – 1.GCAS

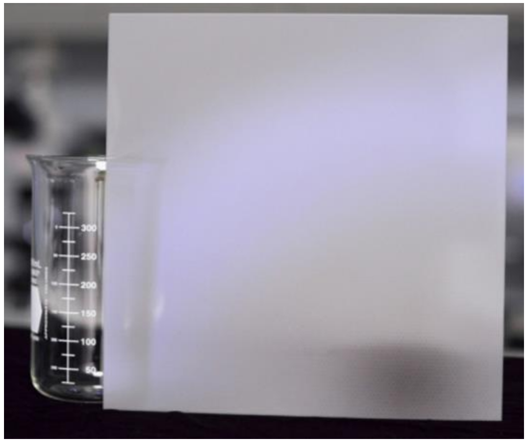
- **Conventional Pb-silicate glass MCP:** Based on optic fiber production, chemical etching and thermal processing
  - × Expensive lead-silicate glass
  - × Complex, labor consuming technology
  - × Large deviation of channel diameters within MCP
  - × Difficult to produce large area MCP, brittle after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

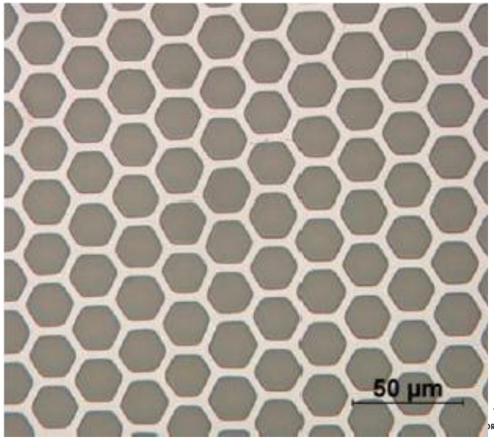
❖ **"Next generation" MCPs - Break through 1: Production of large blocks of hollow, micron-sized glass capillary arrays (GCAs)** based on the use of hollow capillaries in the glass drawing process

- ✓ 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*





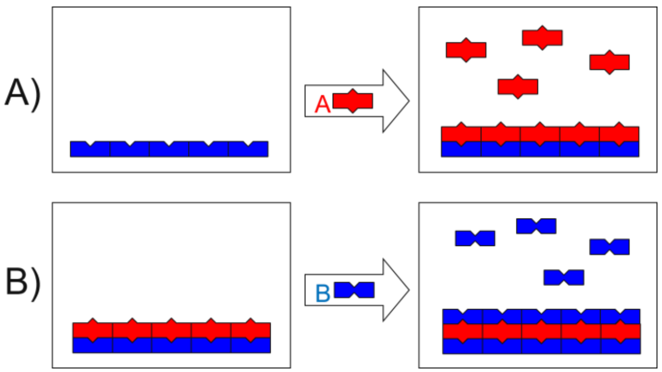


NEXT GENERATION MICRO-CHANNEL PLATES – 2.ALD

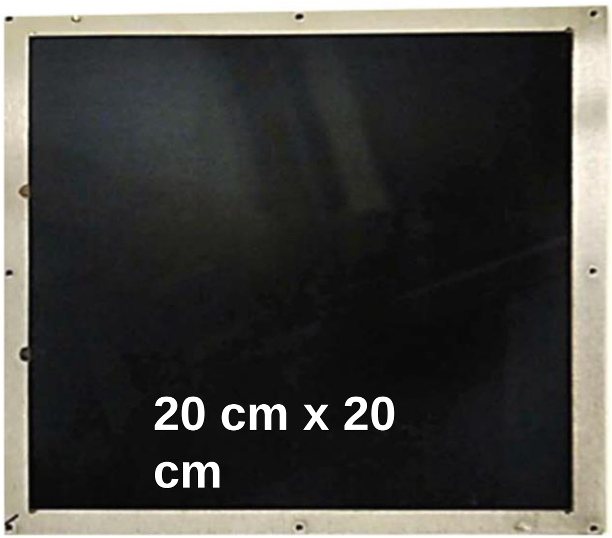
- **“Next generation” MCPs - Break through 2: Functionalization of the glass capillary arrays with atomic layer deposition (ALD) methods**

✓ Self-limiting thin film deposition technique
✓ Controlled film thickness
✓ Freedom to tune the capabilities:
✓ Robust, good performance

Self-terminating surface reactions



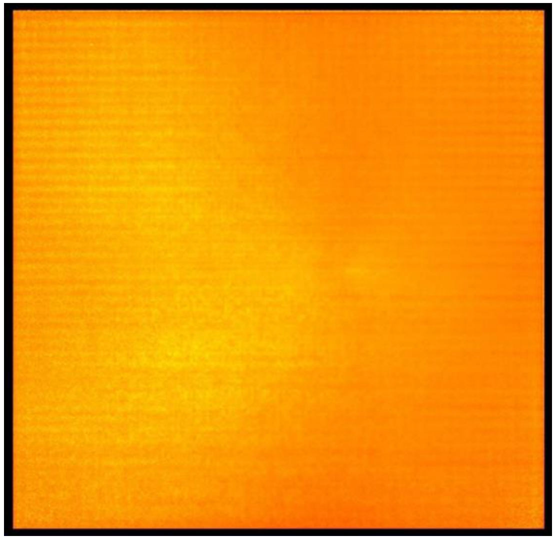
MCP after functionalization



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”



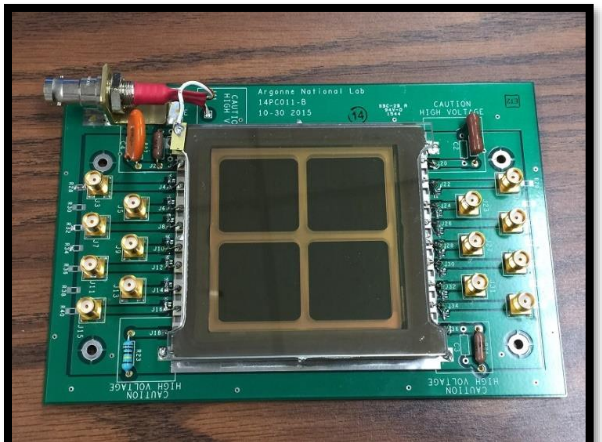
M. Minot et al., Nucl. Instr. Meth. A ***787*** *(2015) 78-84*

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

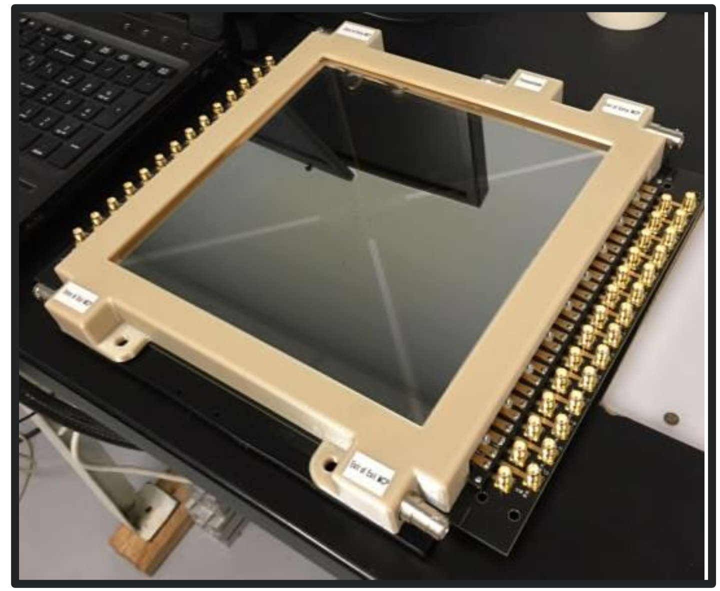
ARGONNE 6 CM MCP-PMT & LAPPD^{TM}

Small form factor LAPPD (6 cm MCP-PMT) was produced at Argonne for R&D. Knowledges, Design and Experiences were transferred to Incom to support commercialization of 20 cm LAPPD^{TM}

R&D test bed: 6x6 cm^2



Commercialization: 20x20 cm^2

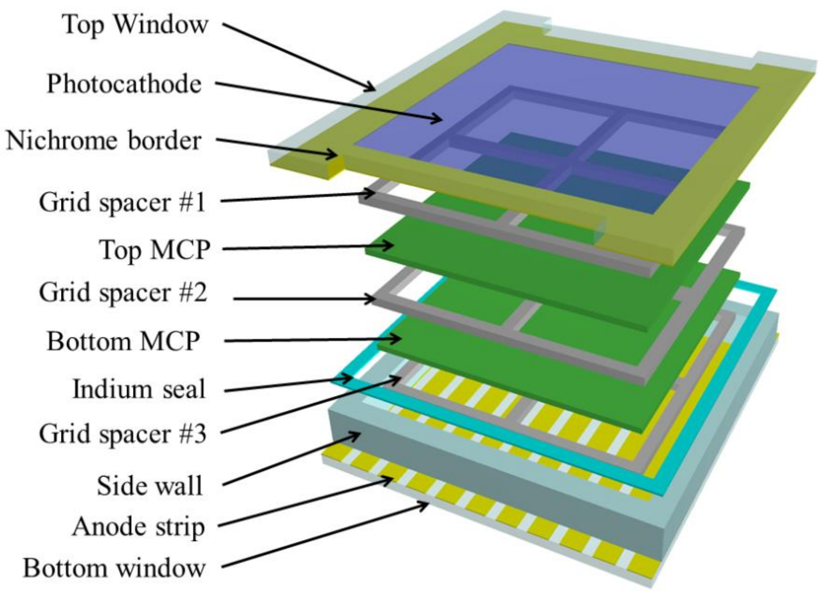


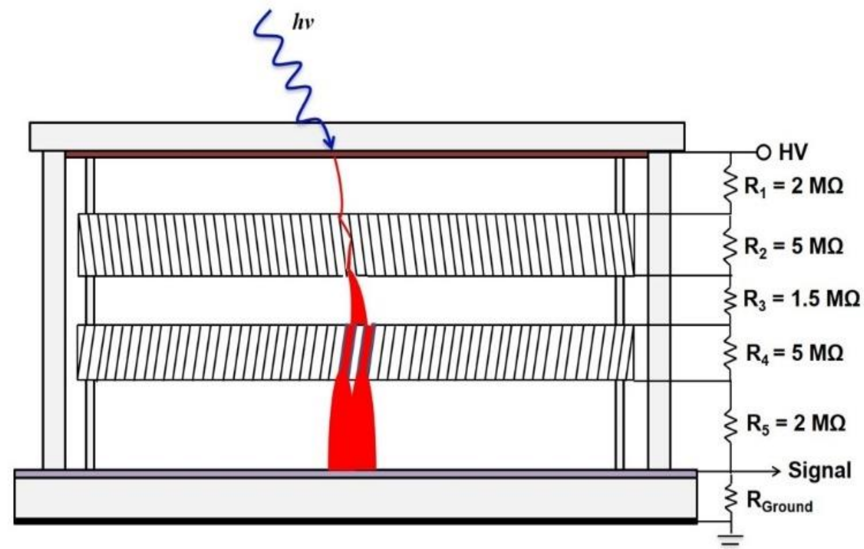
- The Argonne 6 cm MCP-PMT and Incom 20 cm LAPPD^{TM} share the same MCPs and similar internal configuration and signal readout.
- The Argonne 6 cm MCP-PMT serves as R&D test bed for performance characterization and design optimization; Incom 20 cm LAPPD^{TM} is the final commercialized product.
- Close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

ARGONNE 6 CM MCP-PMT

FLEXIBLE DESIGN FROM INITIAL LAPPD

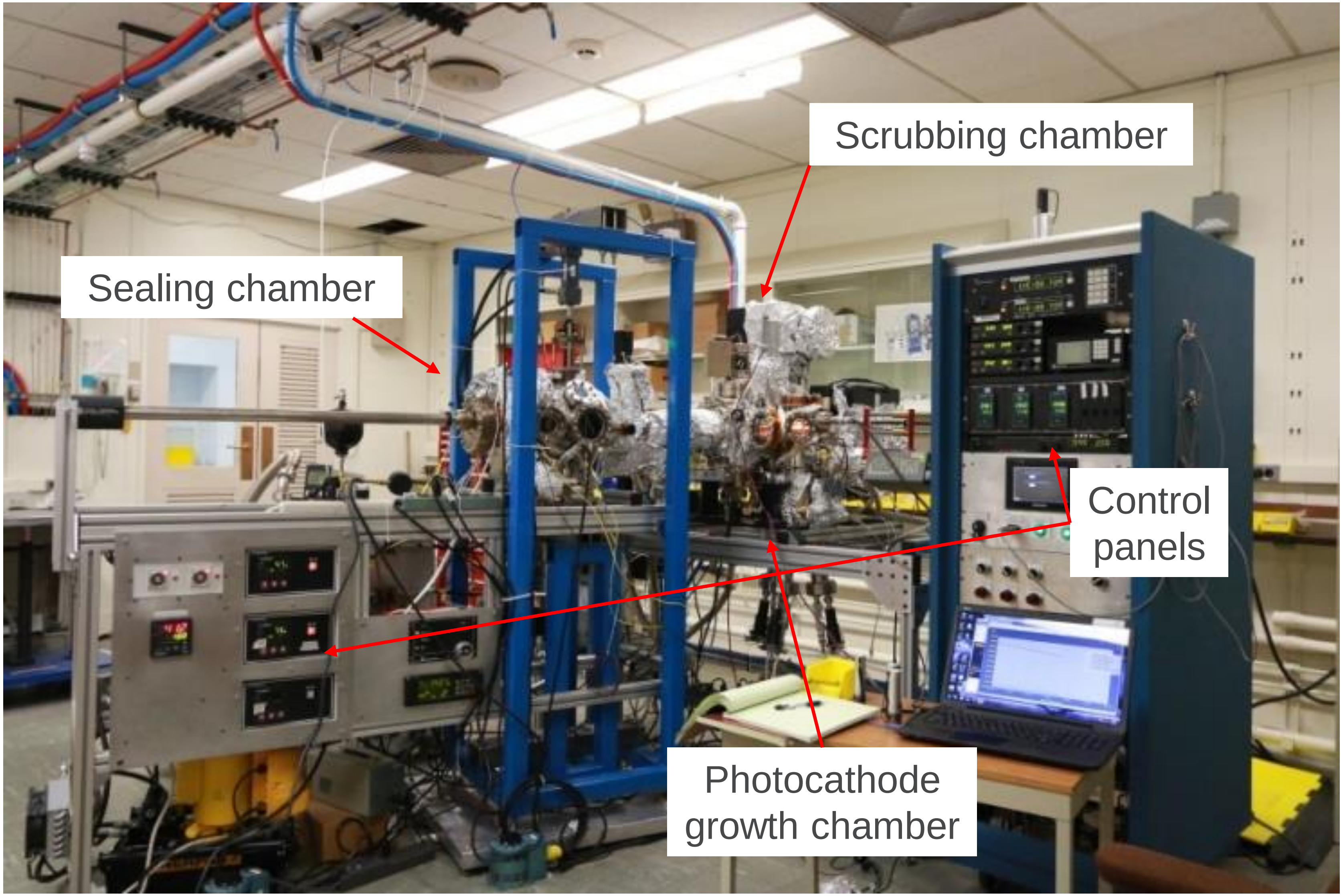
- A glass bottom plate with stripline anode readout
- A glass side wall that is glass-frit bonded to the bottom plate
- A pair of MCPs (20µm pore) separated by a grid spacer.
- Three glass grid spacers.
- A glass top window with a bialkali (K, Cs) photocathode.
- An indium seal between the top window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





A very flexible platform for R&D efforts!

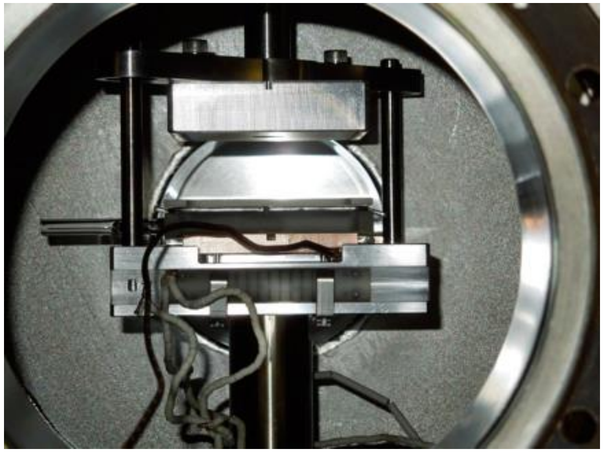
PHOTODETECTOR FABRICATION LAB



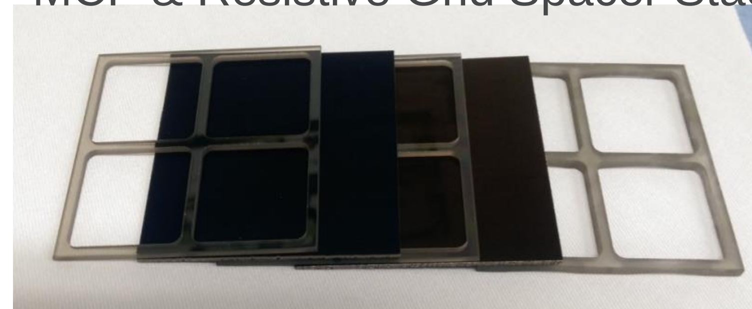
The only place in US academia that functional MCP-PMTs with low-cost Incom MCPs were fabricated.

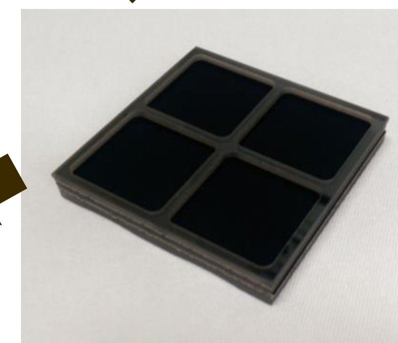
HERMETIC PACKAGING

Hydraulic driven platens

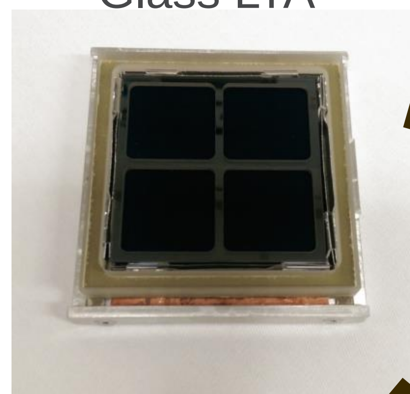


MCP & Resistive Grid Spacer Stack





Glass LTA



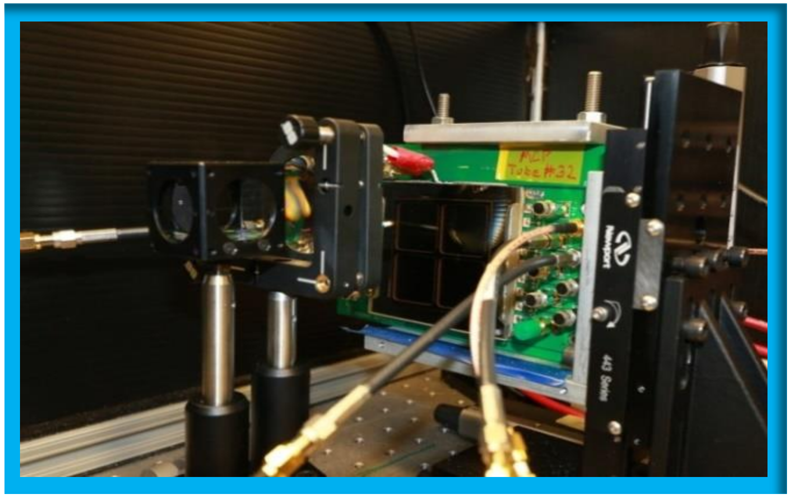
Completed Tube

- **Tube processing is very challenging**
- **Achieved 95% sealing yield**

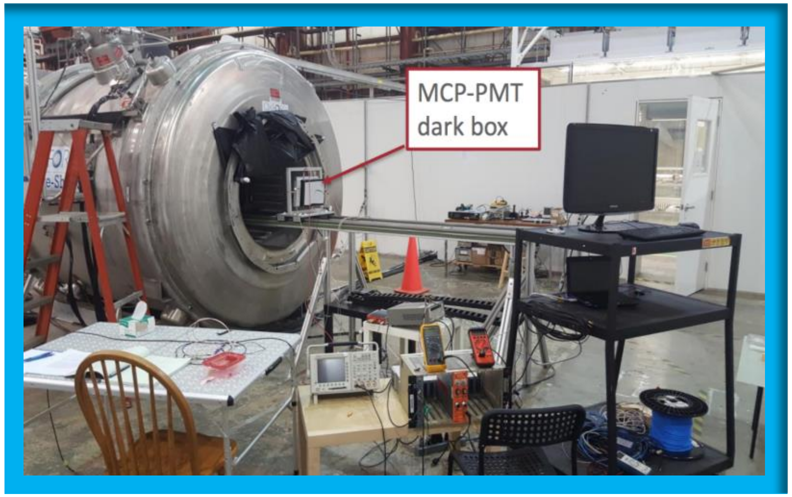
TEST FACILITIES

Optical Table for photocathode test

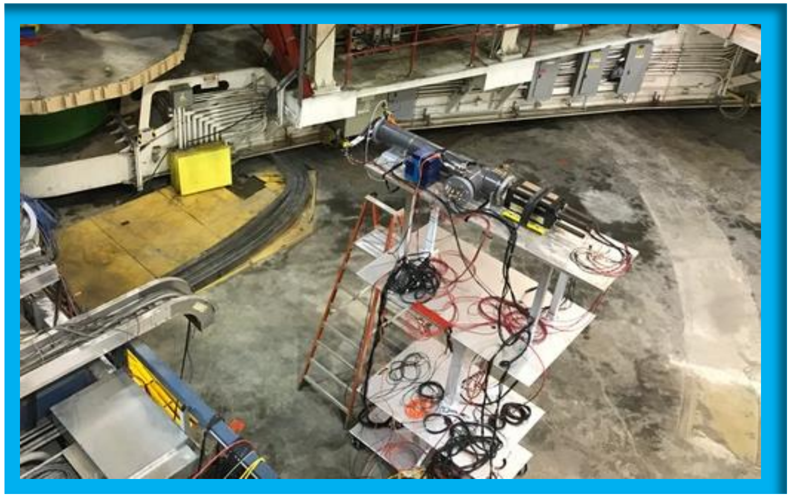
ps-Laser Facility for timing characterization



ANL g-2 Magnetic Field Test Facility



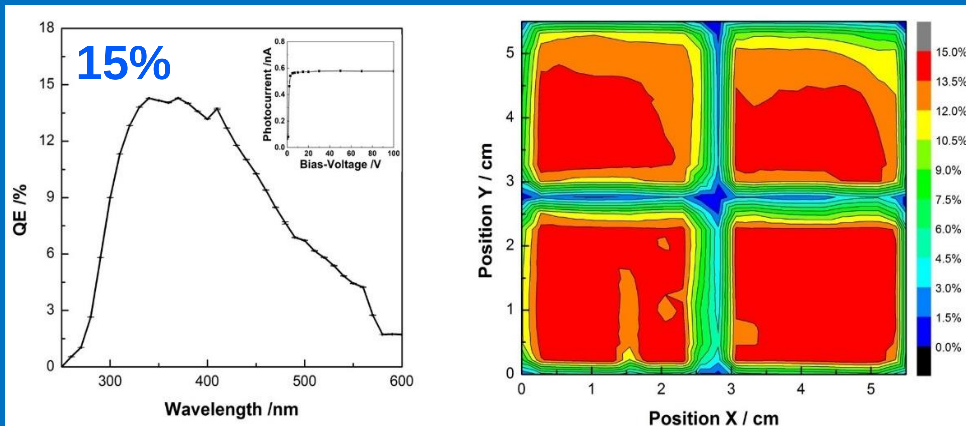
Jlab Hall C / Fermilab Test Beam Facilities



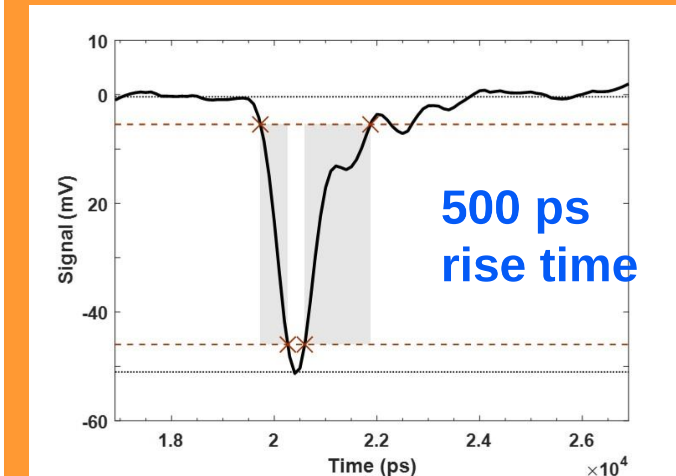
ARGONNE MCP-PMT KEY PERFORMANCE

WITH 20 MICRON MCP PORE SIZE

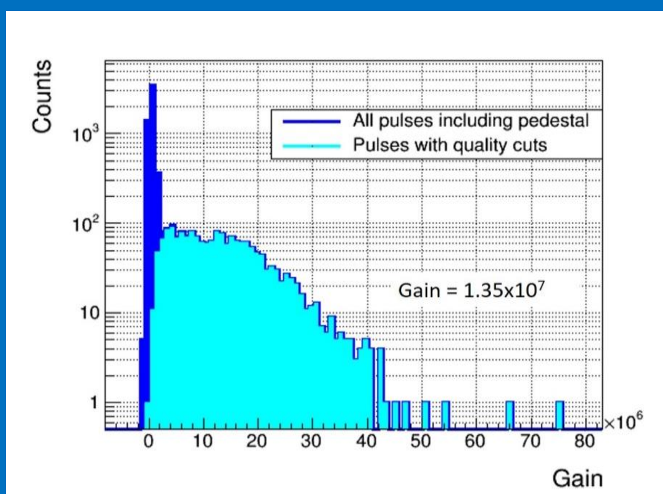
Spectra response



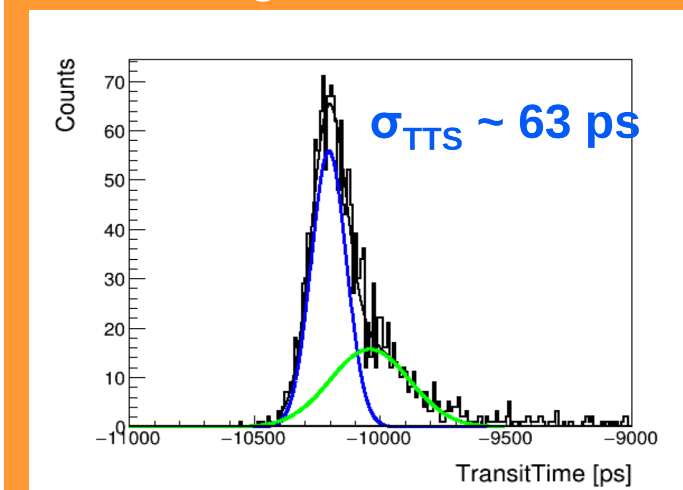
Signal component



Gain > 10^7



Timing resolution

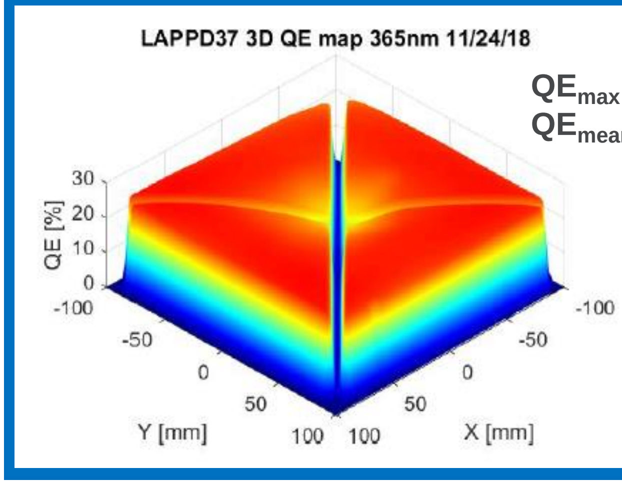


COMMERCIALIZED STANDARD LAPPD^{TM} KEY PERFORMANCE

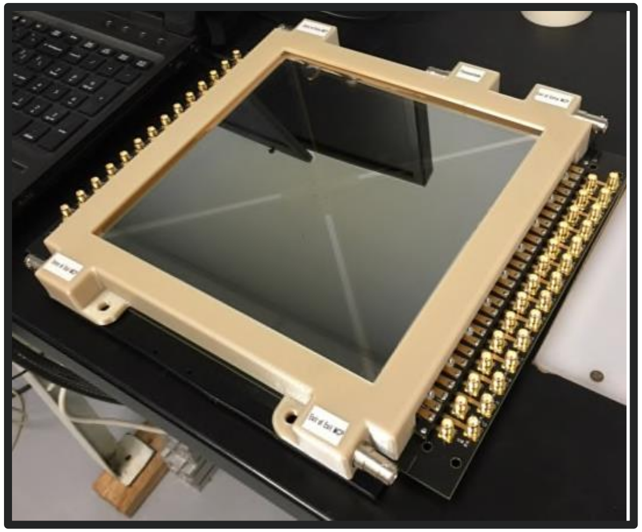
WITH 20 MICRON MCP PORE SIZE, STRIPLINE READOUT

Credit to: Incom, Inc. LAPPD R&D group

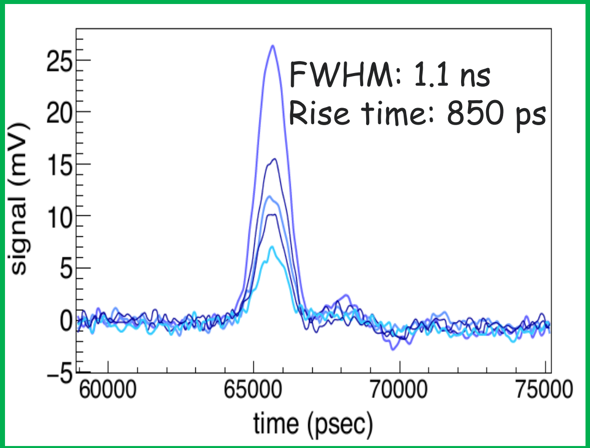
Spectra response

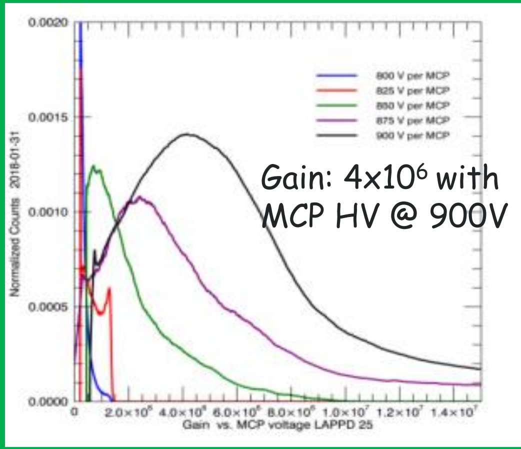


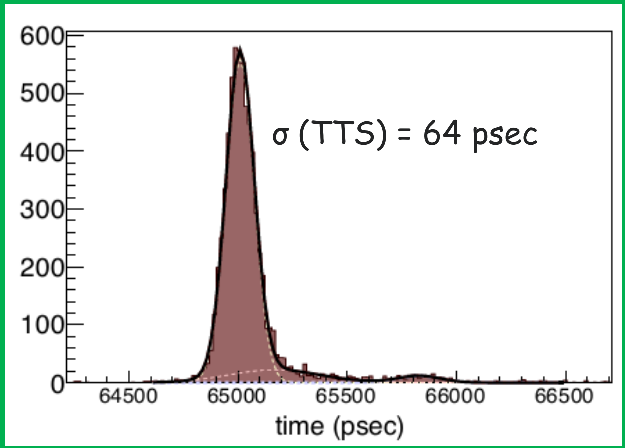
QE_{max} = 26.1%
QE_{mean} = 24.3% ± 2.5%



Gain & Timing

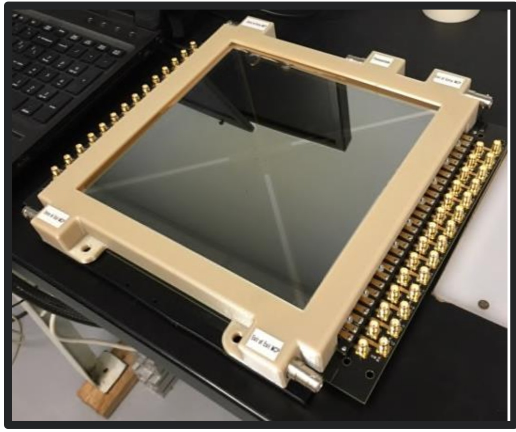




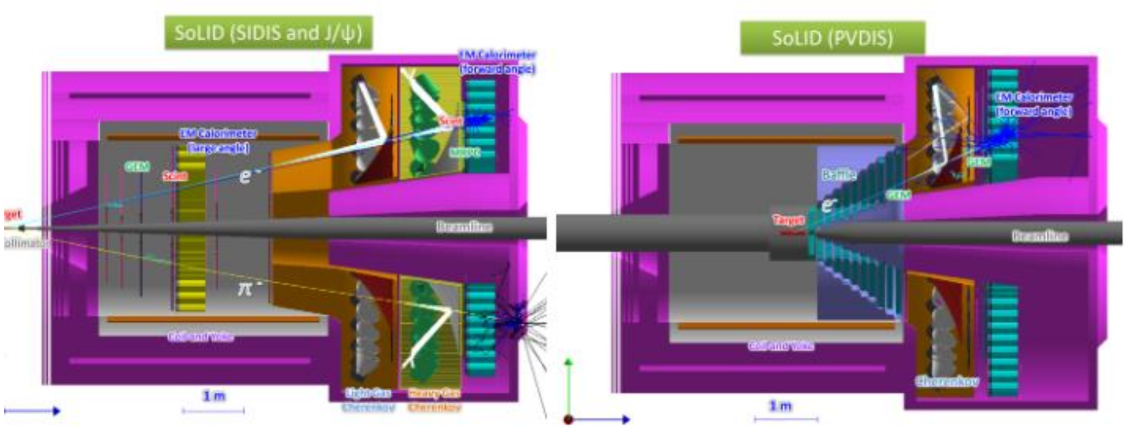


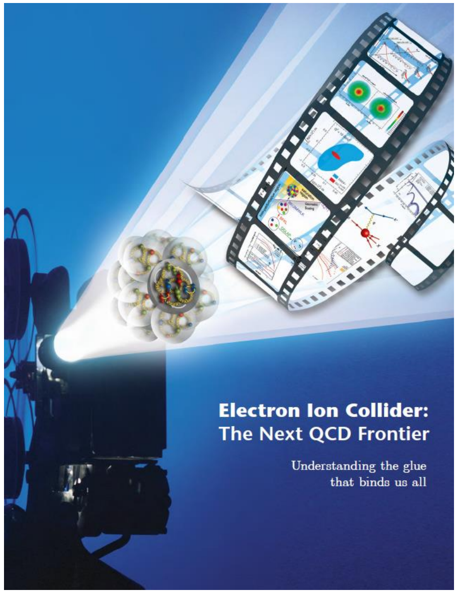
WITH THE SUCCESS OF STANDARD LAPPD^{TM} COMMERCIALIZATION

NEXT …



OPTIMIZATION OF STANDARD LAPPD^{TM} DRIVEN BY PROJECTS & APPLICATIONS





Near-term: SoLID

Long-term: EIC

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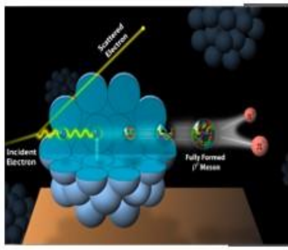
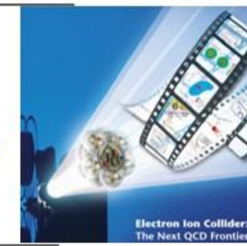
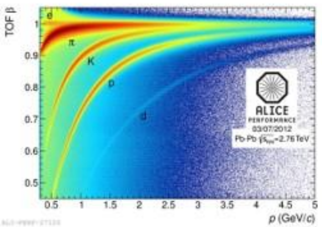


EIC science program will profoundly impact
our understanding of nucleon structure and the glue
uniquely tied to a future high energy, high luminosity,
polarized ep / eA collider
never been measured before



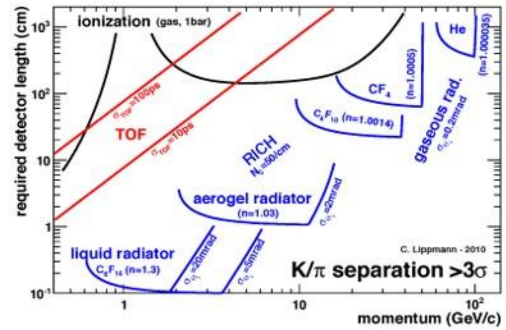
probe the "cell"
Deep Inelastic Scattering (DIS):

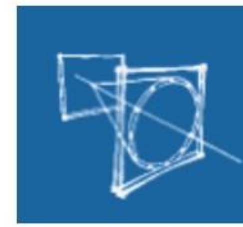
PID is critical for EIC Detector

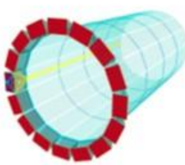


PID

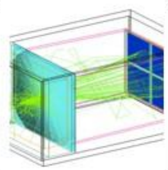
Need more than one technology to cover the entire momentum ranges at the different rapidities



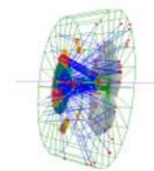




DIRC
PANDA prototype
to US



mRICH
GSU Prototype test
@ GSU

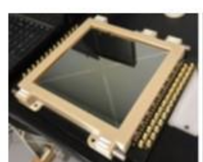


dRICH
Simulation only
@ INFN

Sensors & Electronics

Thick GEMs and Micromegas for gas RICH

INFN, Rate capability issue



Low-cost LAPPD fits for Every sub-system

Argonne & Incom

SiREAD for LAPPD electronics

Univ. of Hawaii & Incom

Key Issue: Photodetectors

- **Photo Detectors:** The most important challenge is to provide a reliable highly-pixilated photodetector working at 2-3 Tesla. This problem is not yet solved.

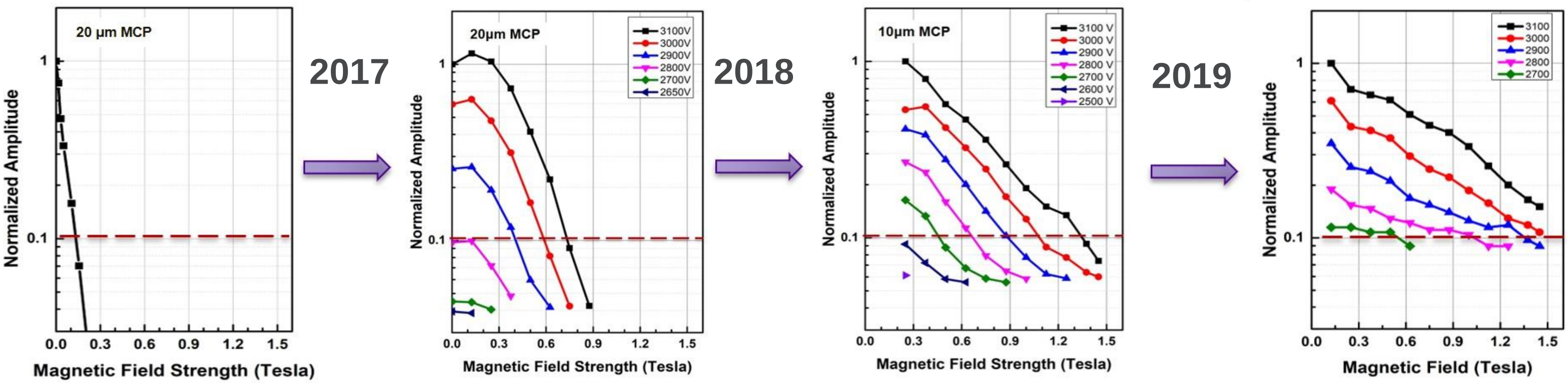
- **Large-Area Picosecond PhotoDetector (LAPPD)**
  - Promising but still not fully applicable for EIC needs.

- **Current focus at Argonne National Laboratory:**
  - Magnetic field tolerance
  - Fine pixel readout

- Other requirement:
  - QE uniformity (addressed by Incom)
  - Life time (testing at University of Texas, Arlington)
  - Rate capability, radiation hardness (SoLID)
  - After pulse
  - Stability …

IMPROVEMENT OF ARGONNE MCP-PMT PERFORMANCE IN MAGNETIC FIELD

ANL version 1	ANL version 2	ANL version 3	ANL version 4
Internal resistor chain	IBD design 20 µm MCP	IBD design 10 µm MCP	IBD design 10 µm MCP reduced spacing



0 < B < 0.15 T	0 < B < 0.7 T	0 < B < 1.3 T	0 < B < at least 1.5 T

Babar Magnet: 1.5T

- Optimization of biased voltages for both MCPs: **version 1 -> 2**
- Smaller pore size MCPs: **version 2 -> 3**
- Reduced spacing: **version 3 -> 4**
- Further improvement if needed:

Smaller pore size is planned: 6 µm, version 4 -> 5 (future)

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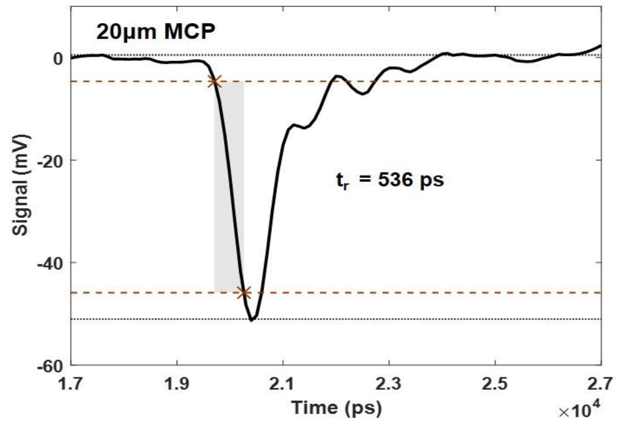
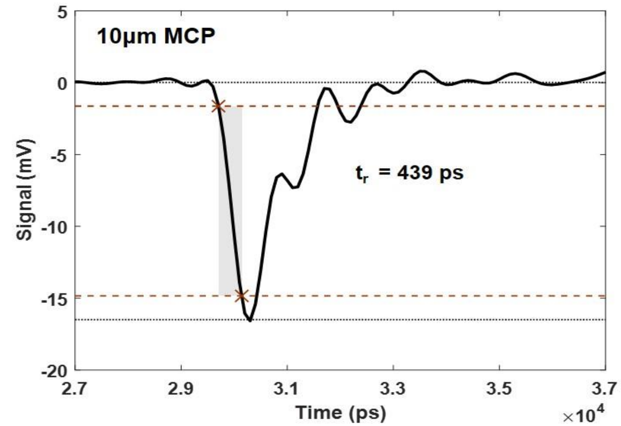
MCP-PMT TIMING RESOLUTION IMPROVEMENT

Rise time

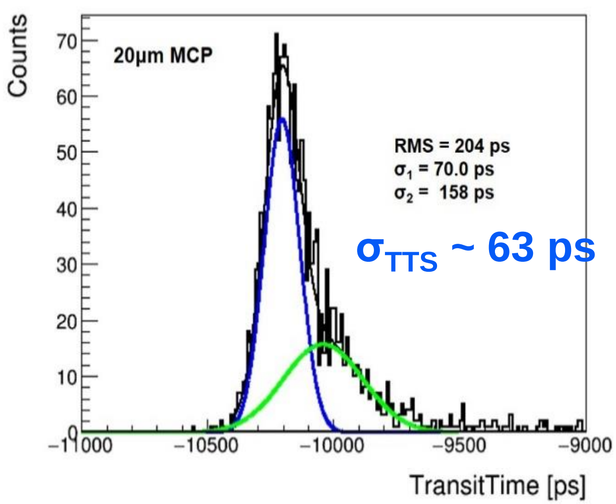
ANL version 2

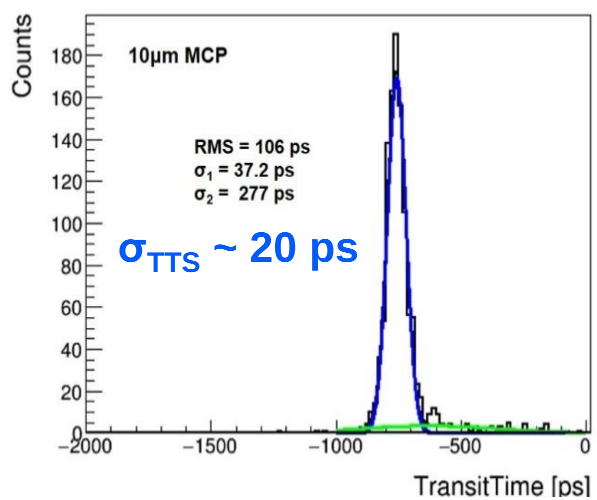


ANL version 3



Timing resolution (SPE)





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

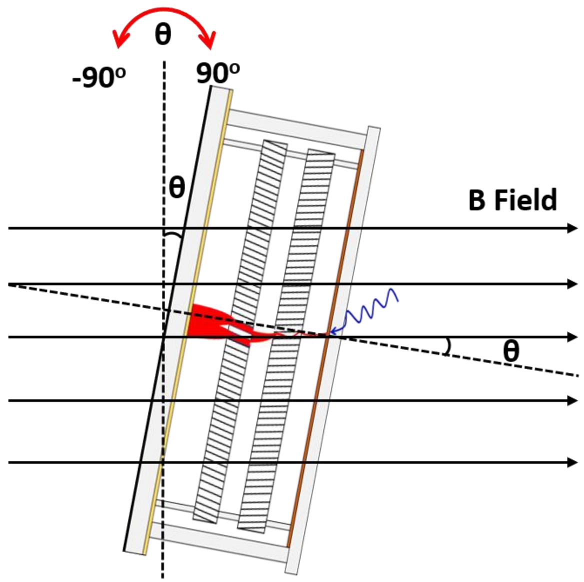
System: σ_1 = 37.2 ps
Laser jitter: σ_{Laser} = 30 ps
Electronics: $\sigma_{Ele.}$ = 7 ps
10 μm MCP-PMT: ***σ ~ 20 ps***

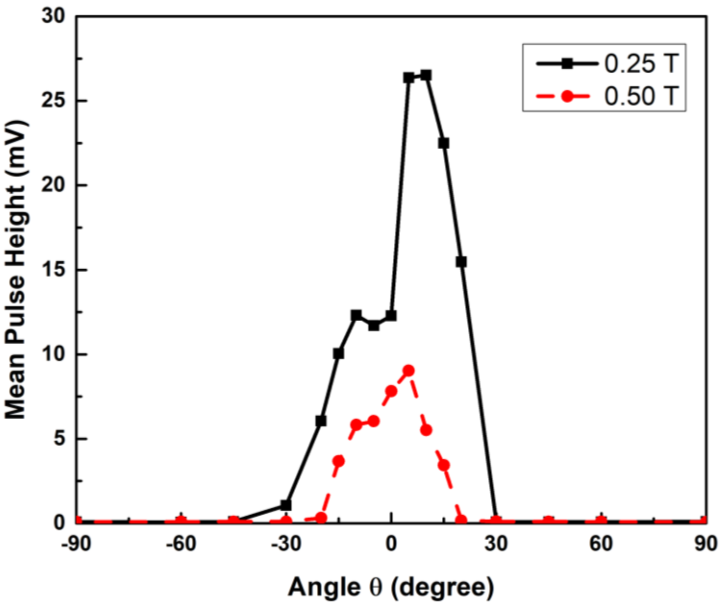
Suppressed back scattering signal

ARGONNE MCP-PMT PERFORMANCE SUMMARY

		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
MCP	Pore size	20 μm	10 μm	10 μm
	Length to diameter ratio (L/d)	60:1	60:1	60:1
	Thickness	1.2 mm	0.6 mm	0.6 mm
	Open area ratio	60 %	70 %	70 %
	Bias angle	8^o	13^o	13^o
Detector geometry	Window thickness	2.75 mm	2.75 mm	2.75 mm
	Spacing 1	3.25 mm	2.25 mm	2.25 mm
	Spacing 2	1.75 mm	2.0 mm	0.7 mm
	Spacing 3	2.0 mm	4.0 mm	1.1 mm
	Shims	0.3 mm	0.3 mm	0.3 mm
	Tile base thickness	2.75 mm	2.75 mm	2.75 mm
MCP-PMT stack	Internal stack height	**9.70 mm**	**9.75 mm**	**5.55 mm**
	Total stack height	15.20 mm	15.25 mm	11.05 mm
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	190 ps
	System resolution	70.0 ps	37.2 ps	43 ps
	Time resolution	**63 ps**	**20 ps**	**30 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**	**Over 1.5 T**

ANGLE DEPENDENCE ISSUE

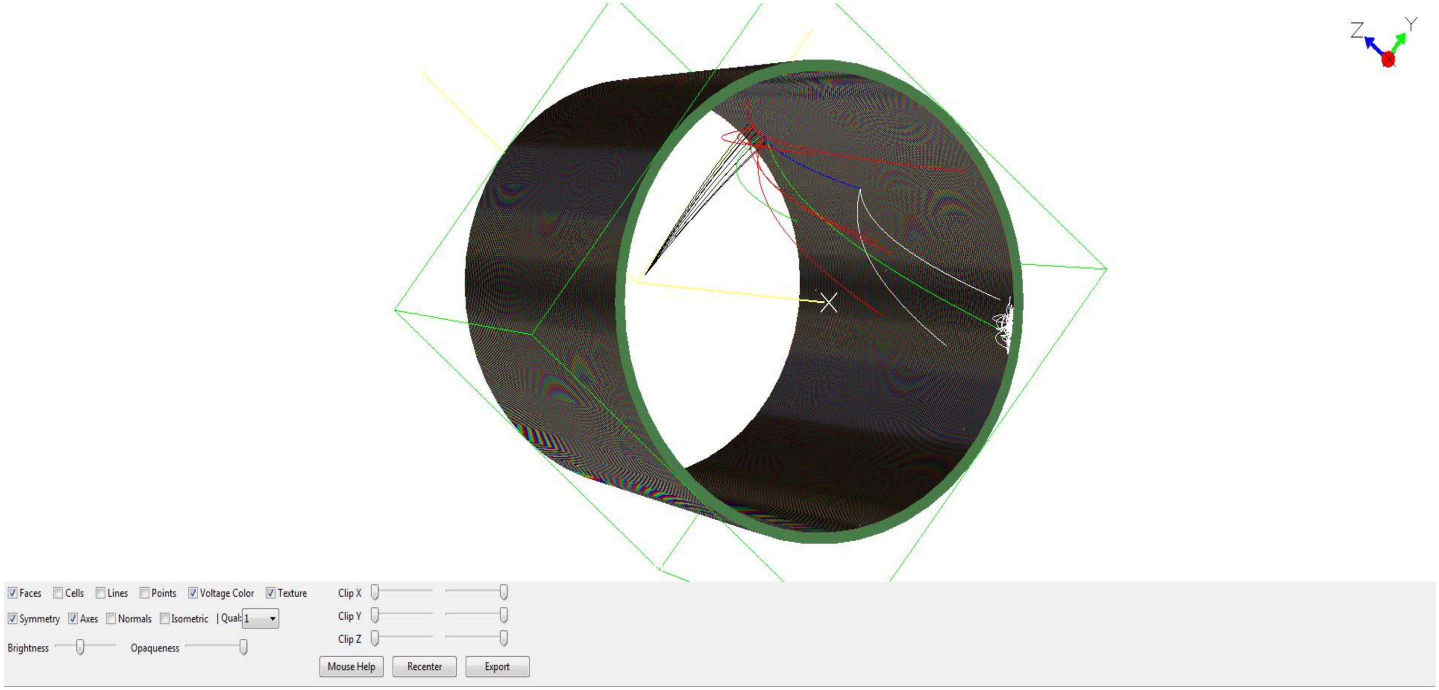




- The MCP-PMT performance in magnetic field is clearly angle related, due to the 8º MCP bias angle, the highest gain is obtained around 8º.
- Notice the two peaks around ±8º, indicating the effect from upper and lower MCP bias angles are different.

- **This is an issue, needs to be solved** for LAPPD. With large area, there is always angle difference for the center and edge regions in a magnetic field.
- Simulation is initialized to explain the different effect, seeking solution.

MCP SIMULATION WITH SIMION: PORE MODEL



- Cylinder pore model with potential gradient defined (can be scaled)
- Validation of the secondary emission model
- SIMION smooths adjacent grids in this geometry

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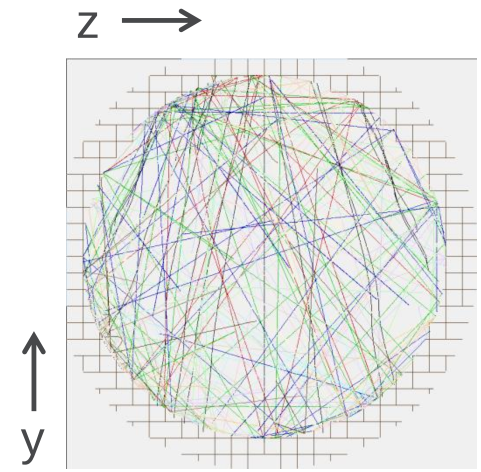
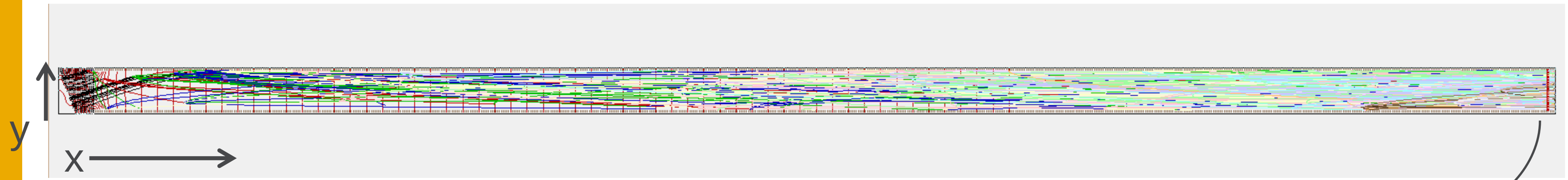
MCP SIMULATION: SINGLE MCP



One pore with chamfered end
1 grid unit = 1 micron scale (to us)

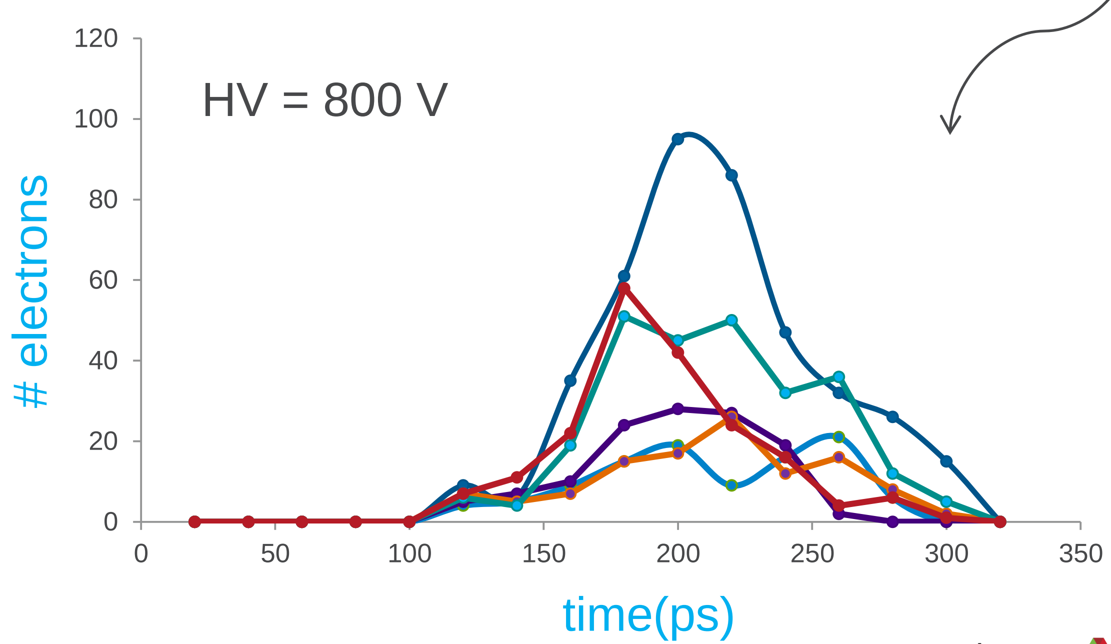
Reads left to right; uses widescreen monitors efficiently

Colors represent different "generations" of electrons as they are amplified down the pore.



TOF can be logged thru a crossing plane (or at an anode) – shown are a series of simulated detection pulses.

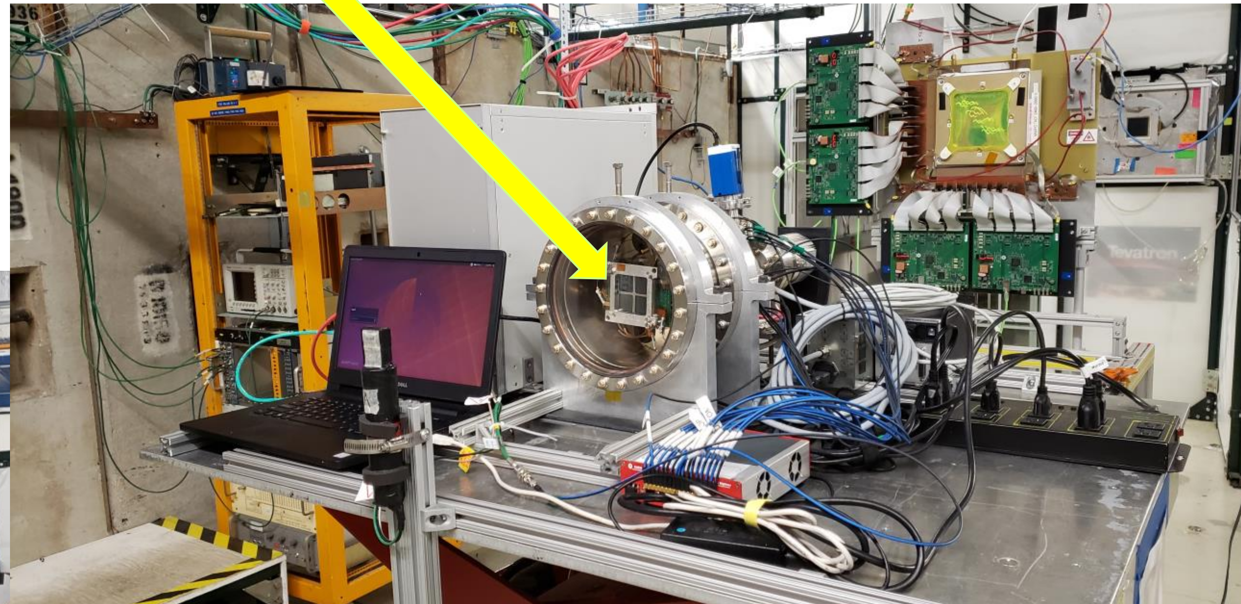
Each curve is a histogram of transit times for that initial e^- hit: Times are consistent pulse to pulse.



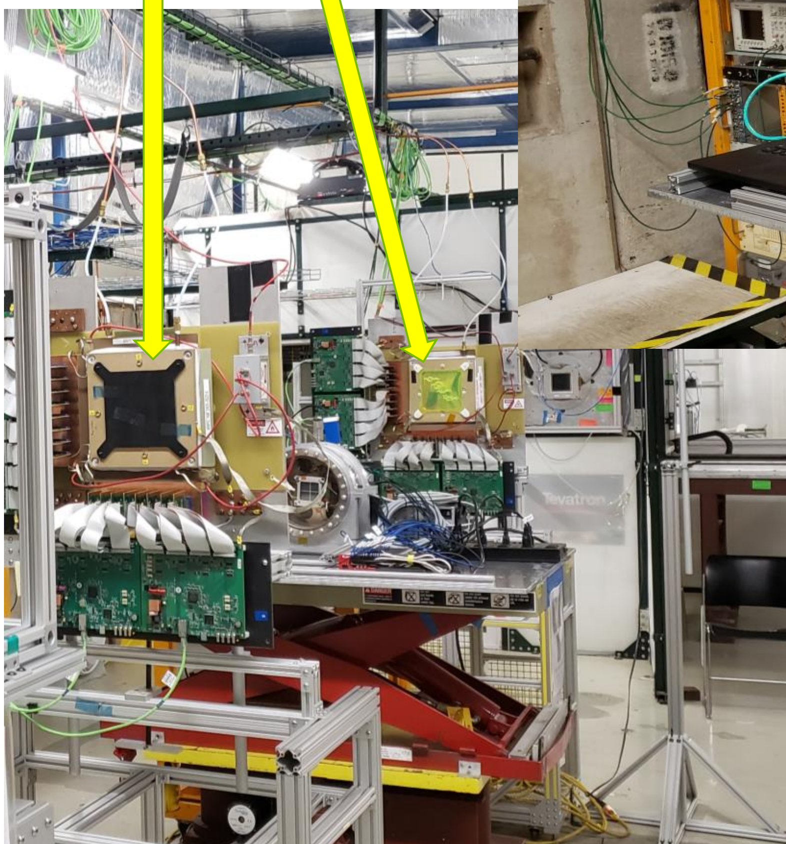
Argonne NATIONAL LABORATORY

FINE PIXELATED READOUT THROUGH GLASS/FUSED SILICA ANODE

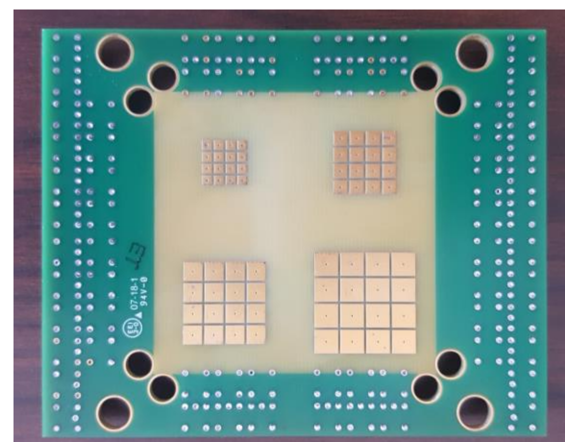
Argonne MCP stack (glass anode) in Fermilab test beam



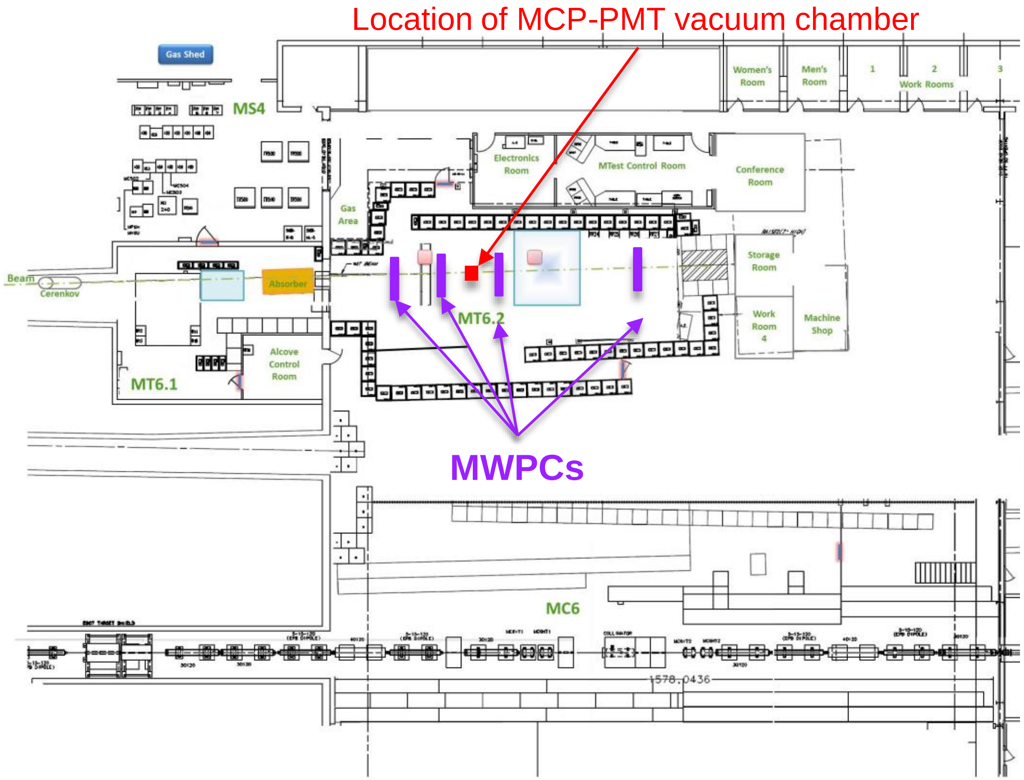
MWPC tracking used

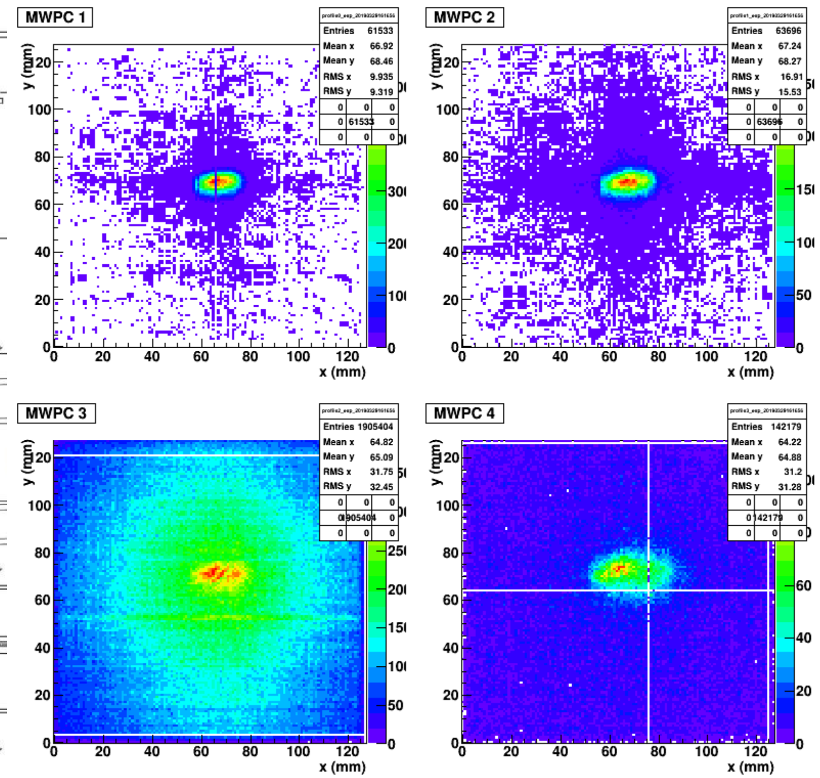


4 different pixel sizes (2x2,3x3,4x4 and 5x5 mm^2) implemented for testing



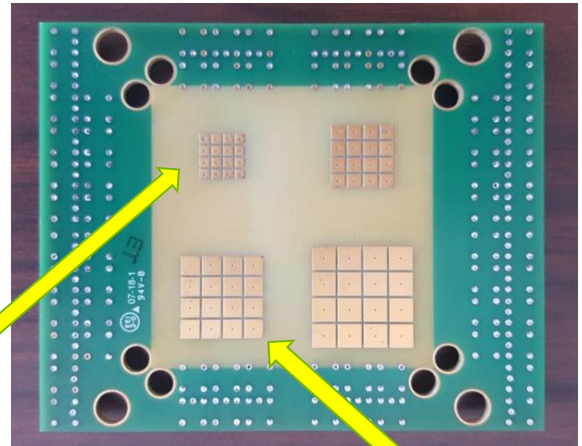
TRACKING SYSTEM





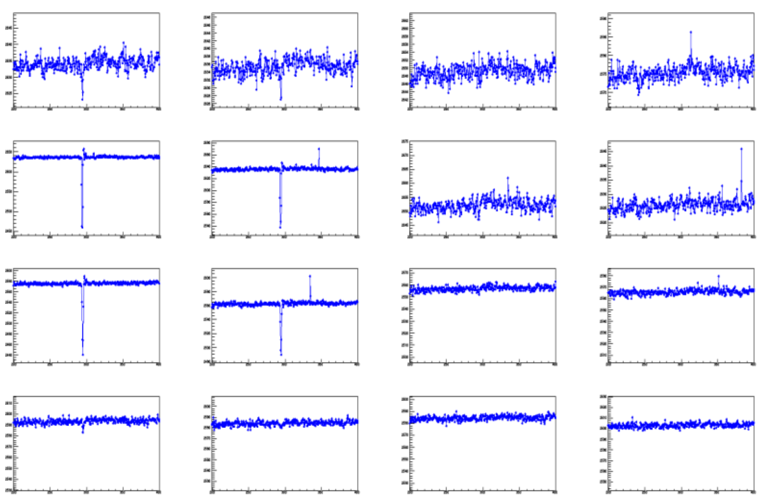
- 4 MWPC's for tracking, MWPC 1 and 2 upstream, and 3 and 4 downstream
- In MWPC 3 we got a lot of spray from hadronic interactions in the vacuum chamber

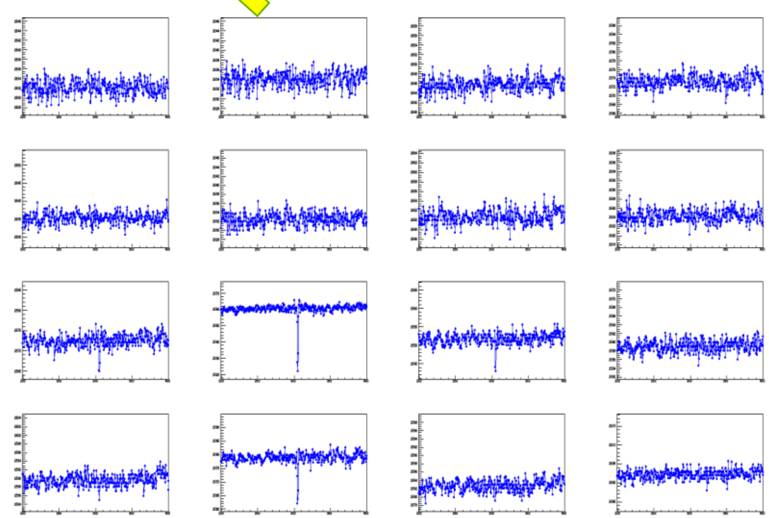
EVENT DISPLAY



2x2 mm² pixels

4x4 mm² pixels



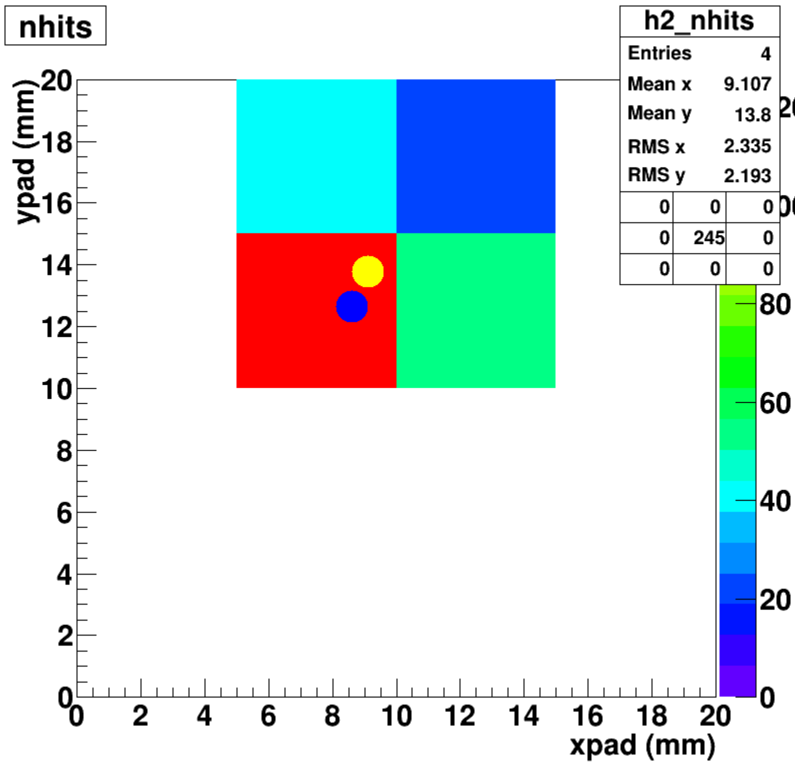


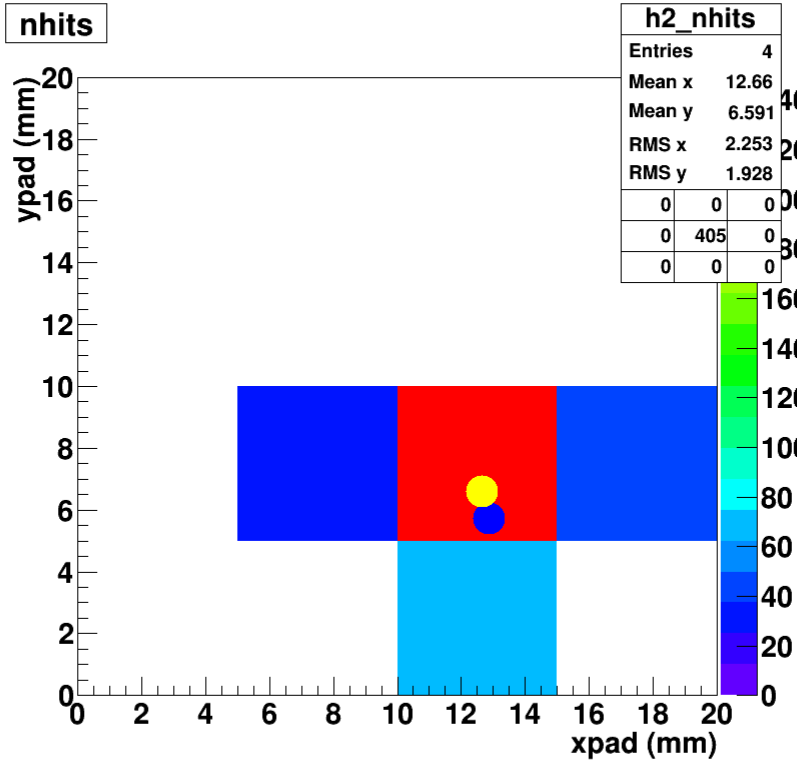
2x2 mm² pixel size is too small, signals spread onto several pixels.

Larger pixel size, signals are more confined, mainly on one pixel.

CENTER OF MASS CALCULATION FOR HIT POSITION

5x5 mm as example



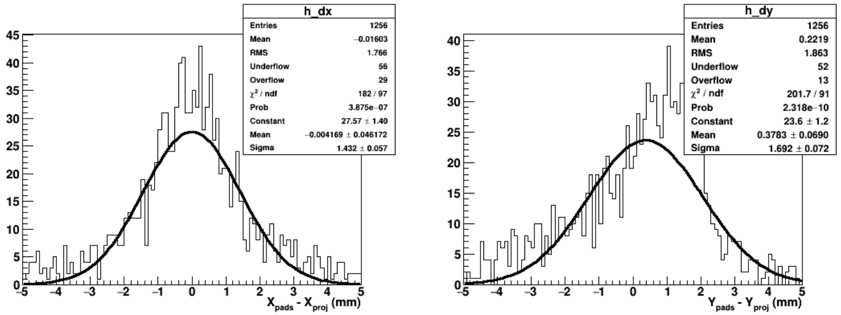


- Yellow dot is the center of mass of pad hits
- Blue dot is projection from MWPC tracking

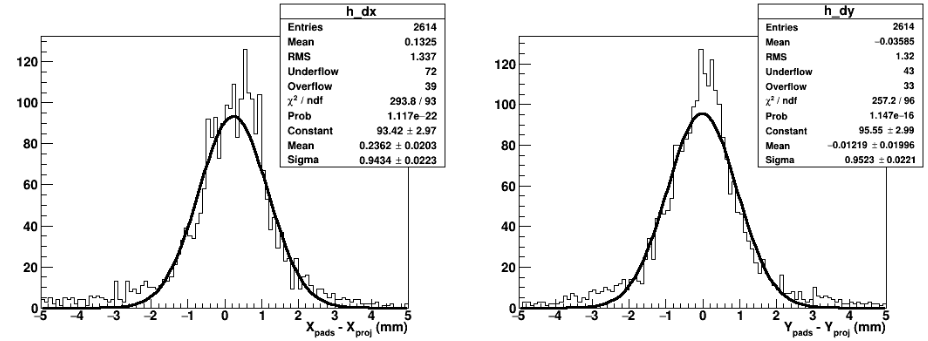
POSITION RESOLUTION

Difference between the pad mean position (CG) and the track pointing

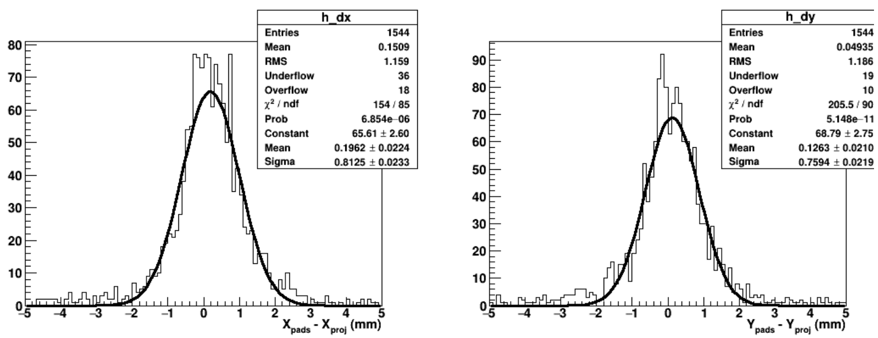
2x2 mm



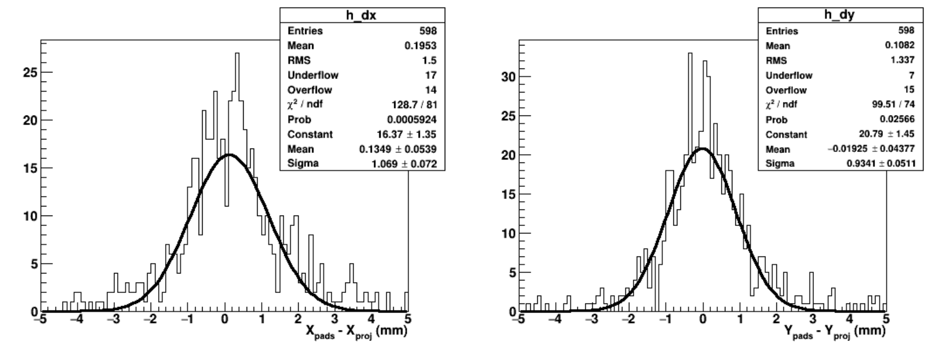
3x3 mm



4x4 mm



5x5 mm



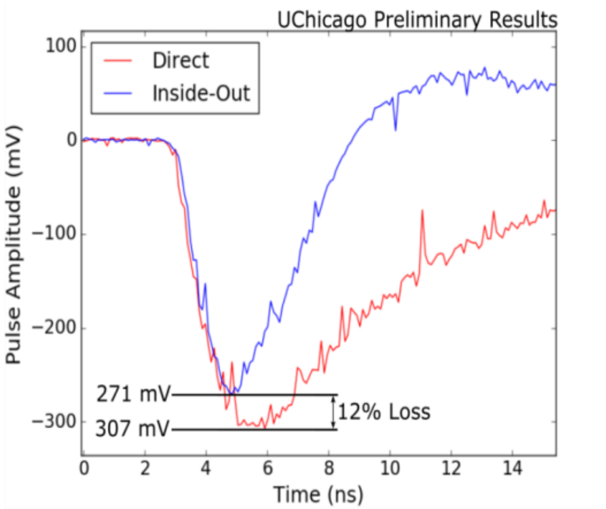
	X res (mm)	Y res (mm)
2x2 mm	1.4	1.7
3x3 mm	0.94	0.95
4x4 mm	0.81	0.76
5x5 mm	1.1	0.97

- All resolutions ~1 mm, satisfy the requirements for the EIC.
- Potentially limited by track pointing resolution capability of MWPCs (1 mm pitch)
- 2x2 may be worse due to leakage of signals (poor containment since it is a smaller area)

GEN II LAPPD

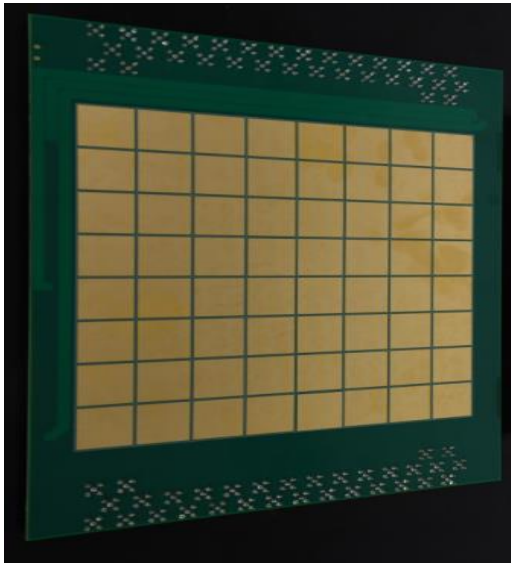
- A robust ceramic body,
- Capacitive signal coupling: to an external PCB anode
- Pixelated anodes: to enable high fluence applications

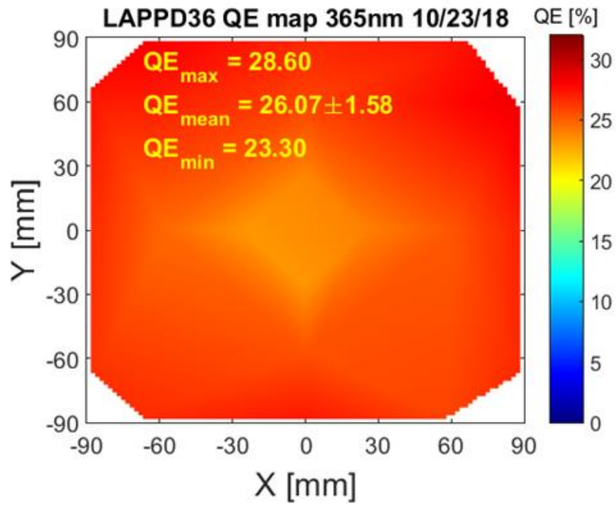
Credit to: Incom, Inc. LAPPD R&D group

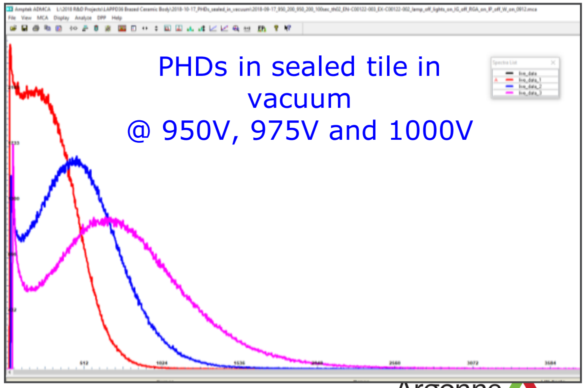


Tested at 25 x 25 mm^2

The MCP fast signal pulse was capacitively coupled through the ceramic, to strips or pads on the outside.







SUMMARY

- Large area picosecond photodetector (LAPPD^{TM}) was successfully commercialized with performance comparable to MCP-PMTs in market.
- R&D on optimization of LAPPD towards particle identification is on going, focusing on design development:
  - Magnetic field tolerance
  - Timing resolution
  - Pixel readout
- MCP-PMT with smaller pore size and reduced spacing exhibits significantly improved magnetic field tolerance and timing resolution.
- Angle dependence of MCP-PMT performance in magnetic field is an issue, simulation study is initiated to seek for solutions.
- Fine pixel of 3x3 mm^2 with position resolution of ~ 1 mm was achieved with Argonne MCP stack (glass anode) in Fermilab test beam.

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And many others …

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Thank you for your attention!

Questions?

BACK UP

PROTOTYPE PRICING AVAILABLE NOW

Credit to: Incom, Inc. LAPPD R&D group

- One price for all buyers.
- Provide program managers (PIs) with meaningful low volume (1-10 units) discounts.
- Encourages Pis to aggregate needs within their organization, department, or programs for tiles purchased, invoiced, billed and delivered to the same address.
- Provide visibility toward future high volume pricing (hundreds of units, for example).
- The projections shown do not preclude further cost reduction as high volume manufacturing is actually realized, including the potential for a $10,000 LAPPD.

# Sold	Unit Price	Sales
1	$ 50,000	$ 50,000
2	$ 47,044	$ 94,088
3	$ 43,440	$ 130,319
4	$ 41,461	$ 165,842
5	$ 40,111	$ 200,557
6	$ 39,095	$ 234,571
7	$ 38,284	$ 267,988
8	$ 37,611	$ 300,890
9	$ 37,038	$ 333,343
10	$ 36,540	$ 365,398
20	$ 36,100	$ 721,995
50	$ 33,334	$ 1,666,694
75	$ 30,000	$ 2,250,007
100	$ 28,633	$ 2,863,335
300	$ 27,702	$ 8,310,468
500	$ 24,414	$ 12,206,898
750	$ 23,021	$ 17,265,691
1000	$ 21,972	$ 21,972,132