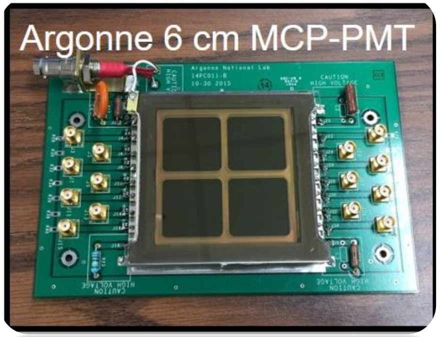
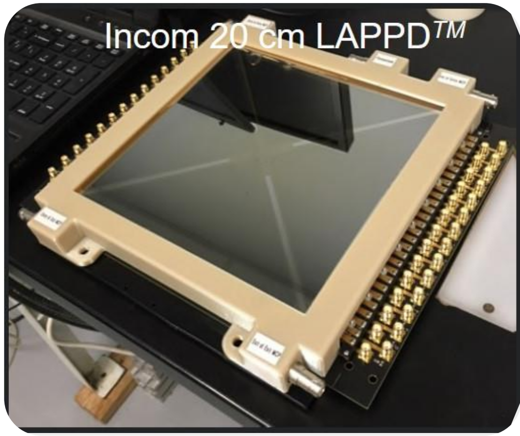
DIRC2019 WORKSHOP

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





Large Area Picosecond PhotoDetector (LAPPD^{TM})

*Image from M. Minot et al., Nucl. Instr. Meth. A **936** (2019) 527-531*

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Sep 11, 2019
Castle Rauischholzhausen, Gießen Germany

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”.

J. Xie, NDIP 2017, Tours, France, *M. Minot et al., Nucl. Instr. Meth. A* ***936*** *(2019) 527-531*

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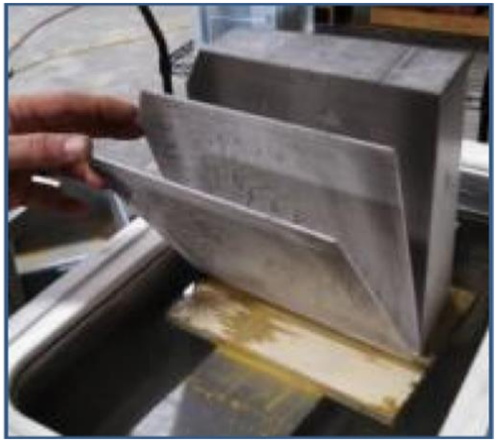
NEXT GENERATION MICRO-CHANNEL PLATES – 1.GCAS

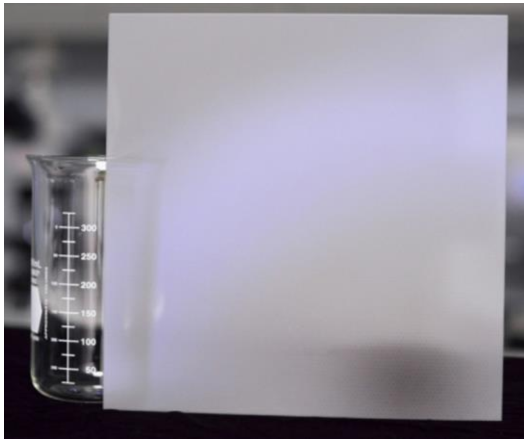
- **Conventional Pb-silicate glass MCP:** Based on optic fiber production, chemical etching and thermal processing
  - × Expensive lead-silicate glass
  - × Complex, labor consuming technology
  - × Large deviation of channel diameters within MCP
  - × Difficult to produce large area MCP, brittle after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

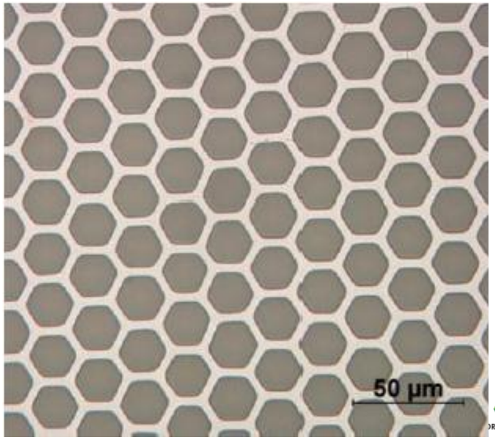
- **"Next generation" MCPs - Break through 1: Production of large blocks of hollow, micron-sized glass capillary arrays (GCAs)** based on the use of hollow capillaries in the glass drawing process

  - ✓ 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*





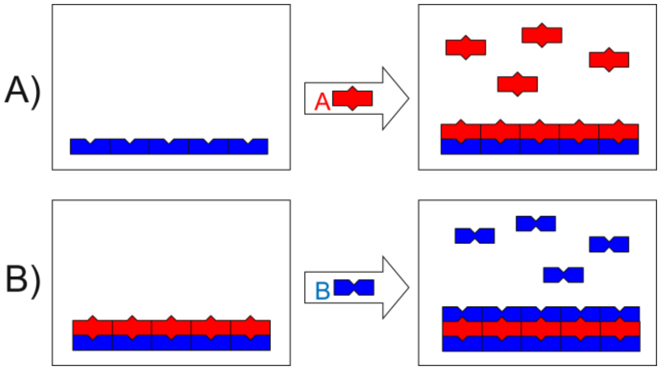


NEXT GENERATION MICRO-CHANNEL PLATES – 2.ALD

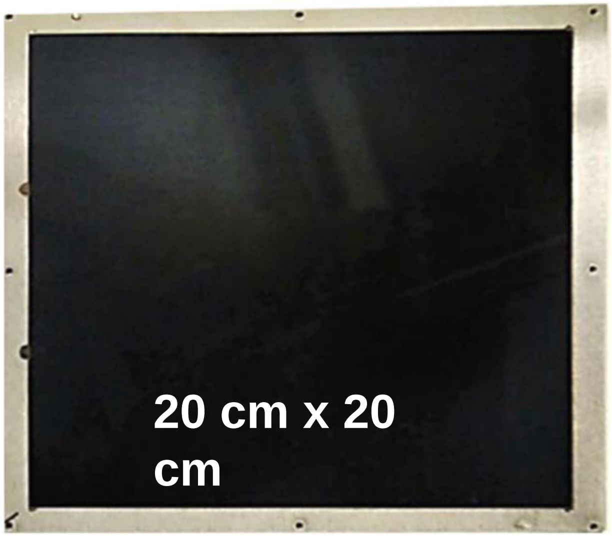
- **“Next generation” MCPs - Break through 2: Functionalization of the glass capillary arrays with atomic layer deposition (ALD) methods**

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

Self-terminating surface reactions



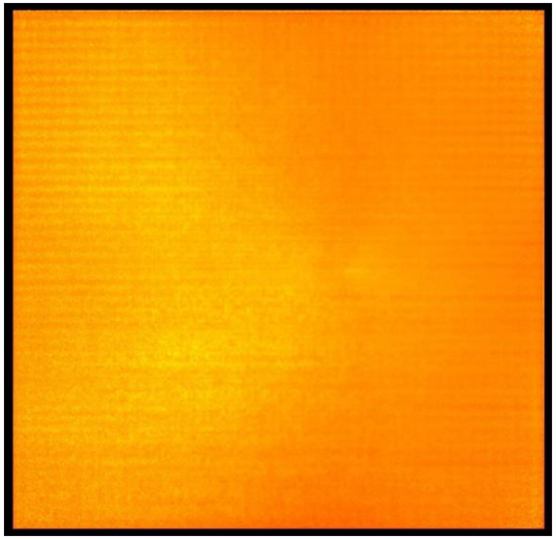
MCP after functionalization



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”



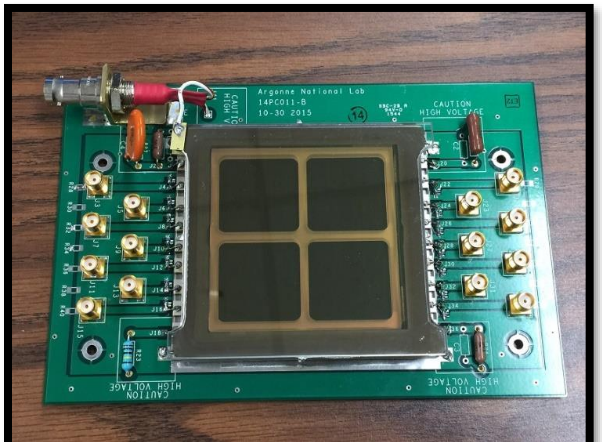
M. Minot et al., Nucl. Instr. Meth. A ***787*** *(2015) 78-84*

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

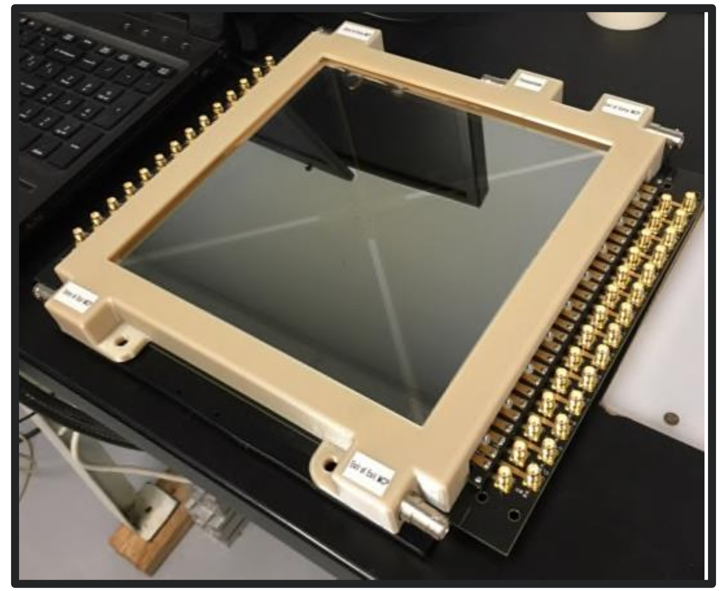


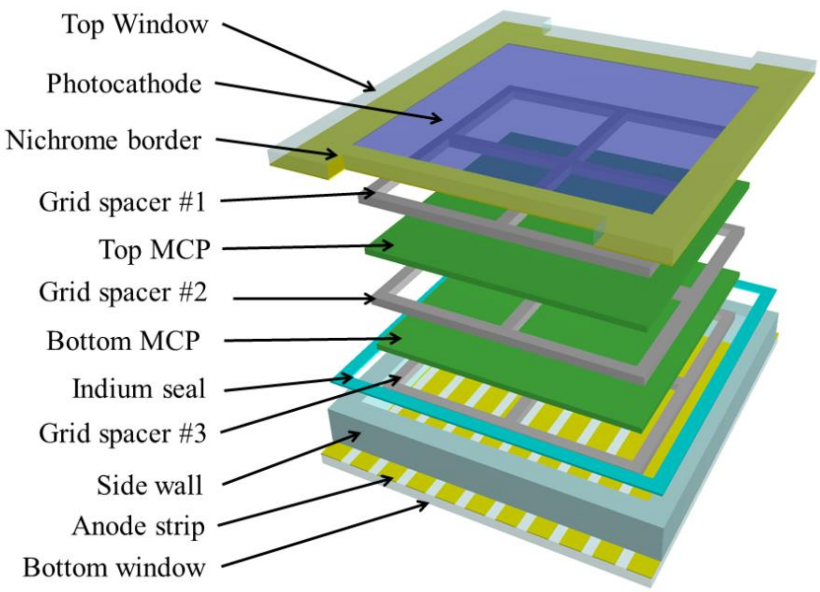
*Image from M. Minot et al., Nucl. Instr. Meth. A **936** (2019) 527-531*

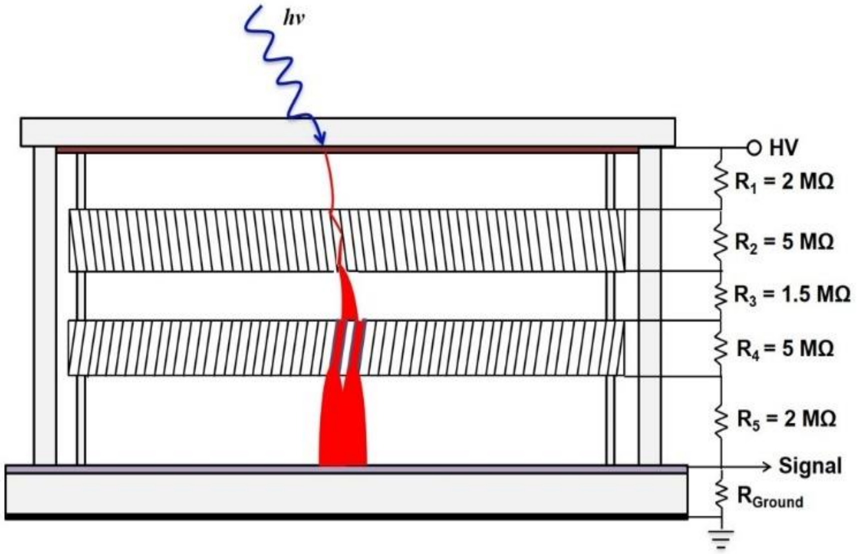
- The Argonne 6 cm MCP-PMT and Incom 20 cm LAPPD^{TM} share the same MCPs and similar internal configuration and signal readout.
- The Argonne 6 cm MCP-PMT serves as R&D test bed for performance characterization and design optimization; Incom 20 cm LAPPD^{TM} is the final commercialized product.
- Close 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.

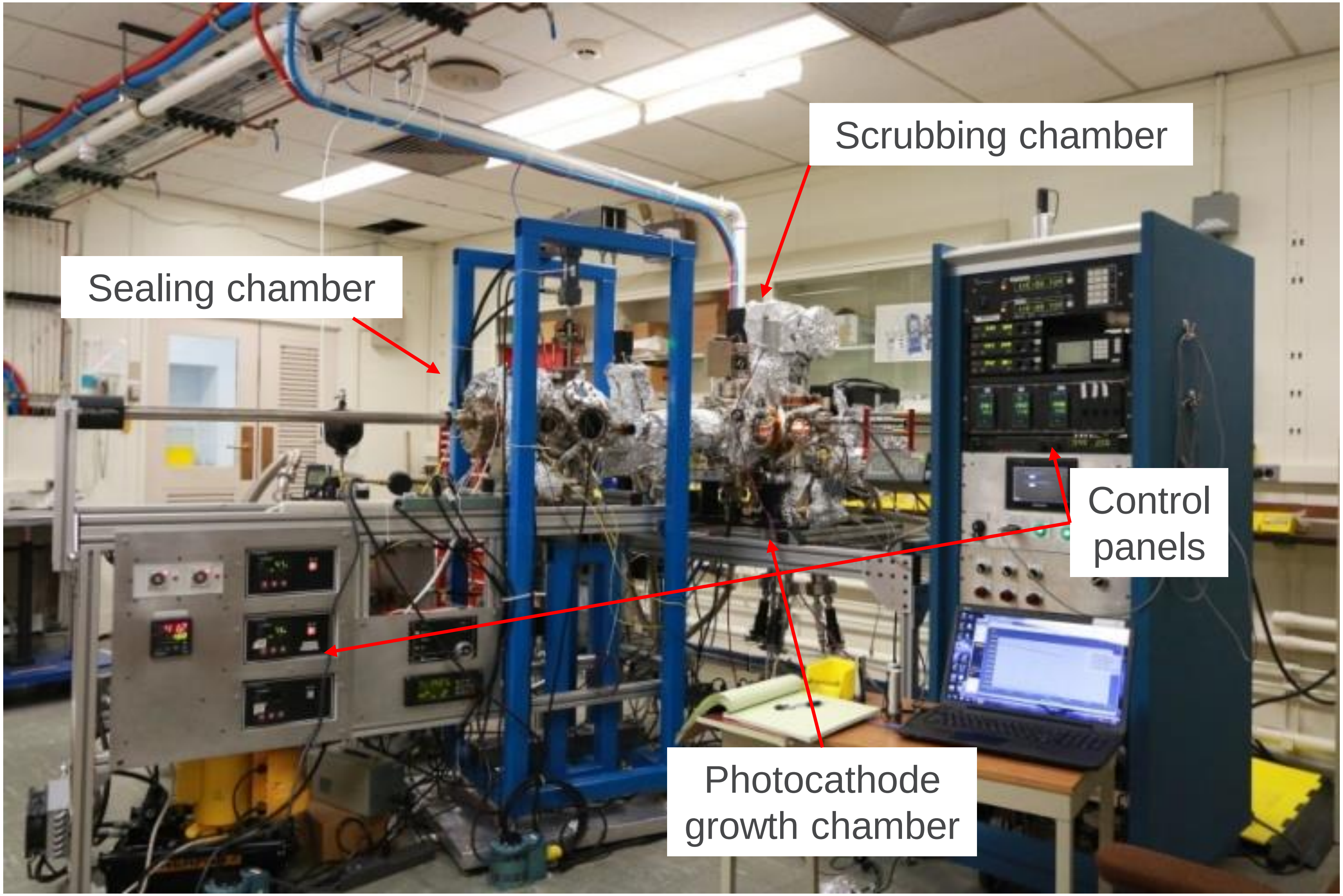




*J . Wang et al., Nucl. Instr. Meth. A **804** (2015) 84-93*
*M. Hattawy et al., Nucl. Instr. Meth. A **929** (2019) 84-89*

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.

*J . Wang et al., Nucl. Instr. Meth. A **804** (2015) 84-93*

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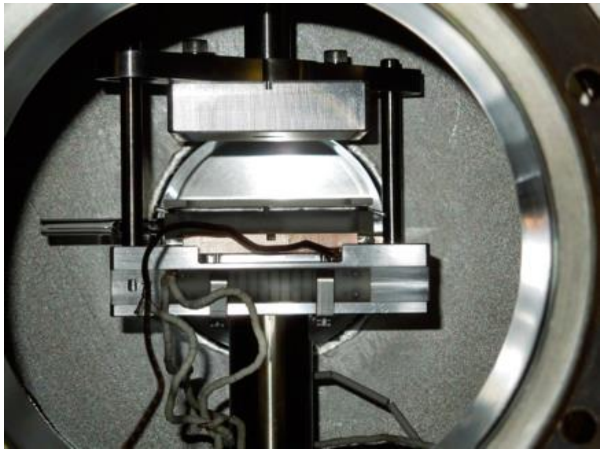
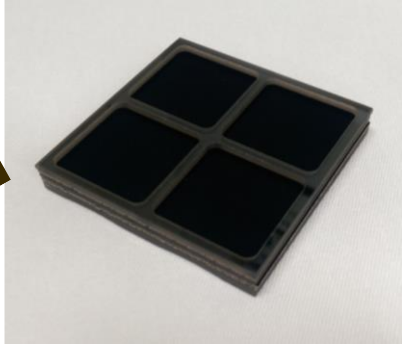
HERMETIC PACKAGING

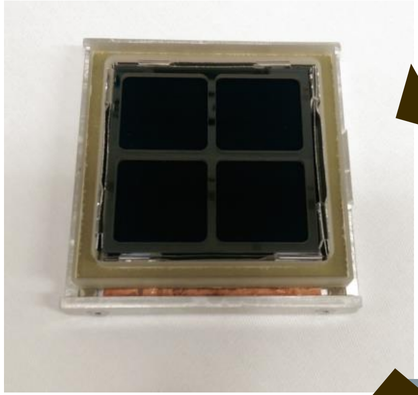
Hydraulic driven platens



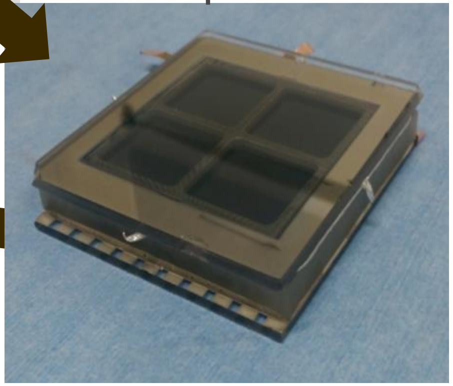
MCP & Resistive Grid Spacer Stack



Glass LTA



Completed Tube



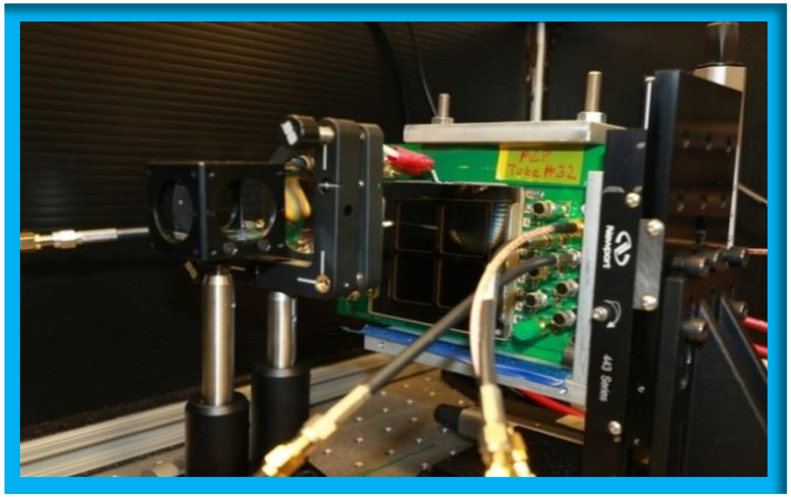
- **Tube processing is very challenging**
- **Achieved 95% sealing yield**

*J . Wang et al., Nucl. Instr. Meth. A **804** (2015) 84-93*

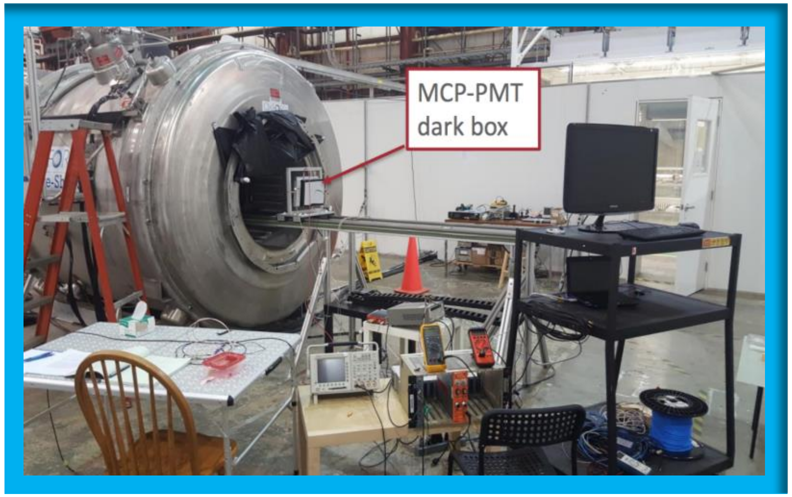
TEST FACILITIES

Optical Table for photocathode test

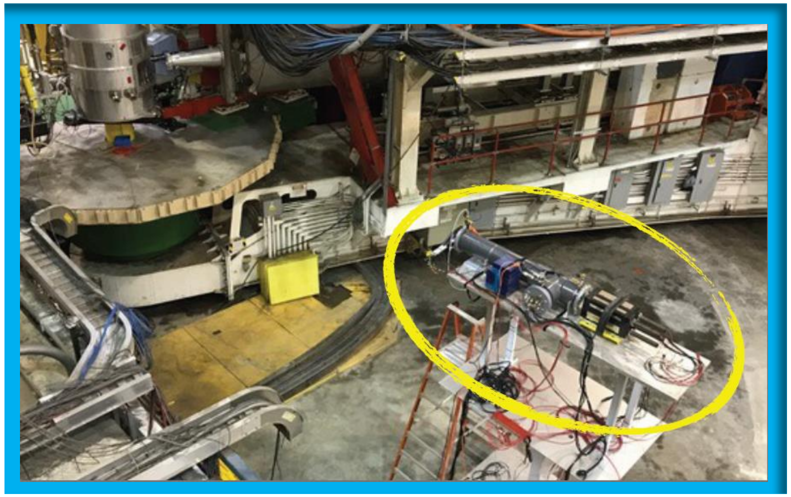
ps-Laser Facility for timing characterization



ANL g-2 Magnetic Field Test Facility



Jlab Hall C / Fermilab Test Beam Facilities

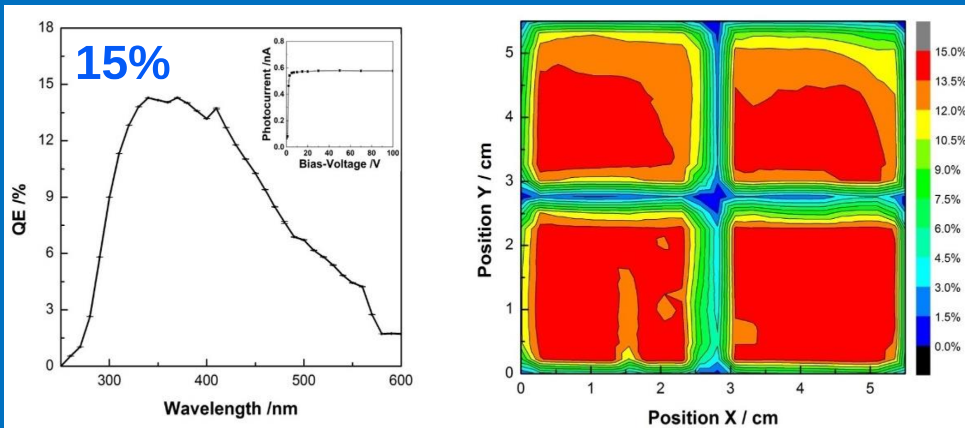


M. Hattawy et al., Nucl. Instr. Meth. A ***929*** *(2019) 84-89*

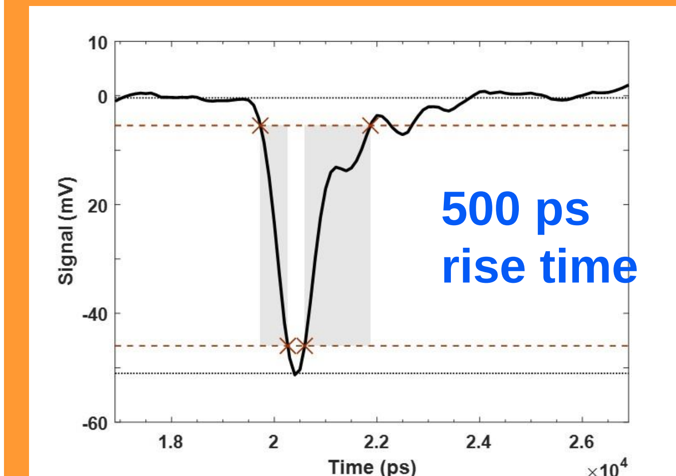
ARGONNE MCP-PMT KEY PERFORMANCE

WITH 20 MICRON MCP PORE SIZE

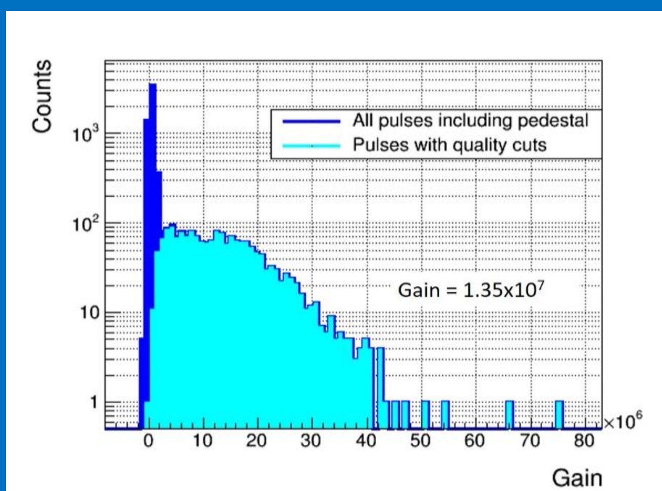
Spectra response



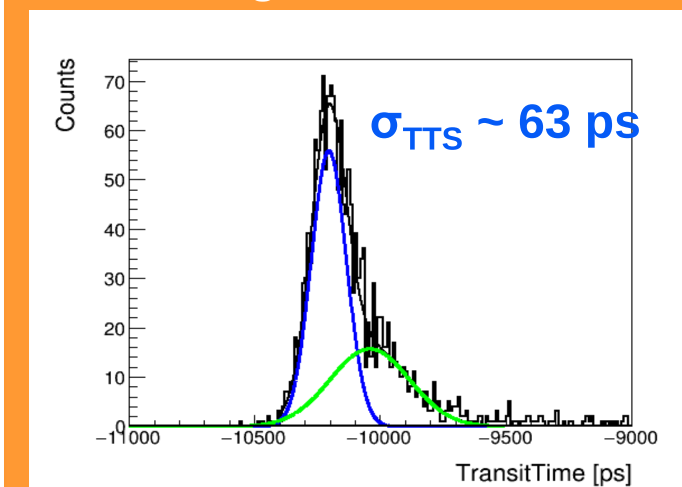
Signal component



Gain > 10^7



Timing resolution



J . Xie et al., Rev. Sci. Instrum. **90** (2019) 043109

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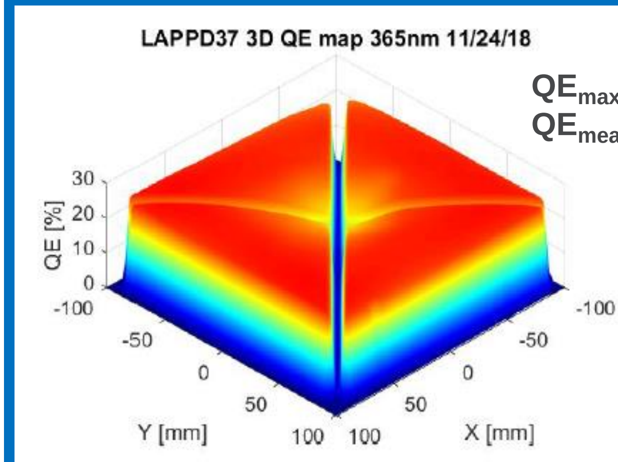
COMMERCIALIZED STANDARD LAPPD^{TM} KEY PERFORMANCE

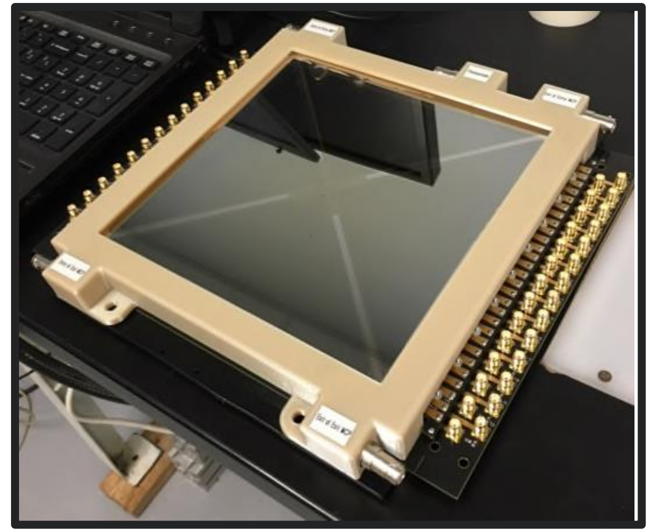
WITH 20 MICRON MCP PORE SIZE, STRIPLINE READOUT

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

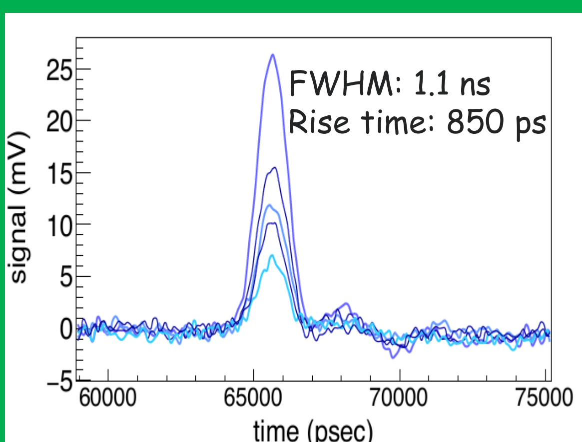
Spectra response

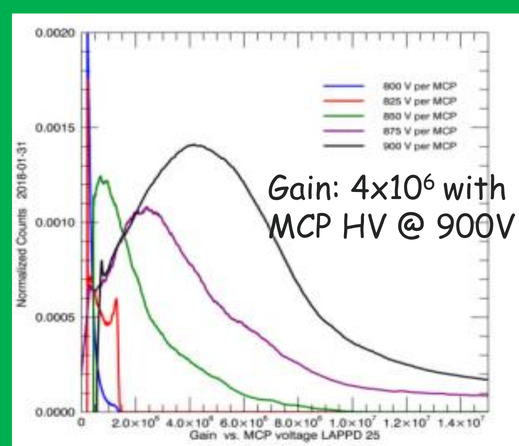


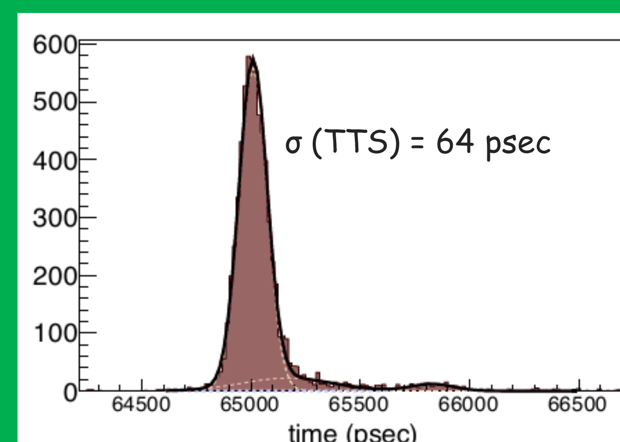
QE_{max} = 26.1%
QE_{mean} = 24.3% ± 2.5%



Gain & Timing





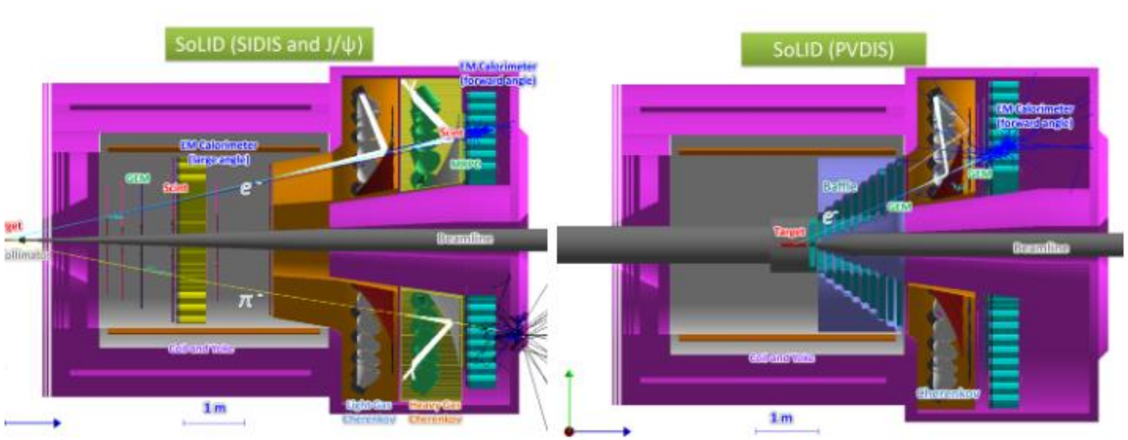


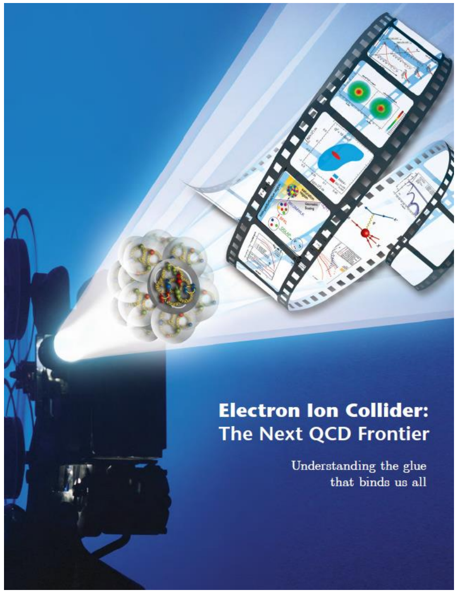
*M. Minot et al., Nucl. Instr. Meth. A **936** (2019) 527-531*

WITH THE SUCCESS OF STANDARD LAPPD^{TM} COMMERCIALIZATION

NEXT …

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

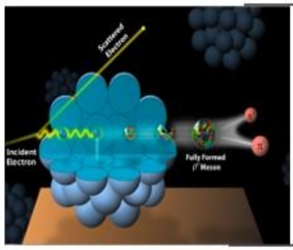




Near-term: SoLID **Long-term: EIC**

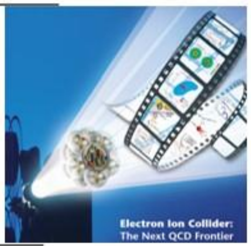
SoLID (Solenoidal Large Intensity Device) Preliminary Conceptual Design Report, 2018

Electron Ion Collider: The Next QCD Frontier, arXiv:1212.1701



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

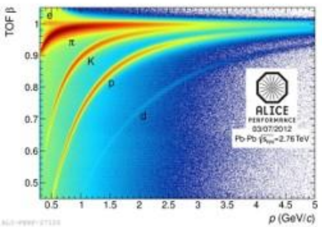
never been measured before



probe the "cell"

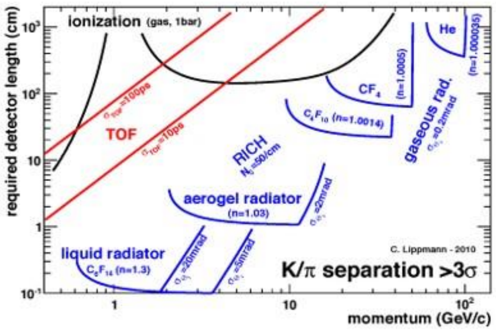
Deep Inelastic Scattering (DIS):

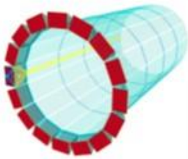
PID is critical for EIC Detector



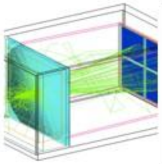
PID

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

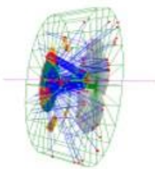




DIRC
PANDA prototype
to US



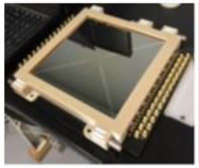
mRICH
GSU Prototype test
@ GSU



dRICH
Simulation only
@ INFN

Sensors & Electronics

Thick GEMs and Micromegas for gas RICH



Low-cost LAPPD fits for Every sub-system

SiREAD for LAPPD electronics

INFN, Rate capability issue

Argonne & Incom

Univ. of Hawaii & Incom

*A.Del Dotto et al., Nucl. Instr. Meth. A **876** (2017) 237-240, C.P.Wong et al., Nucl. Instr. Meth. A **871** (2017) 13-19*

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.

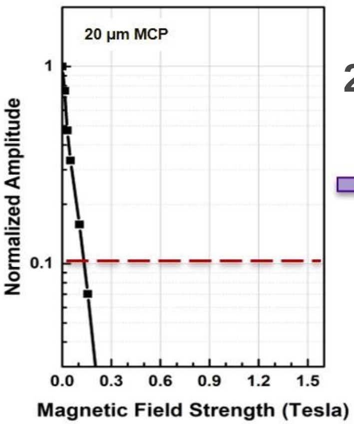
- **Large-Area Picosecond PhotoDetector (LAPPD)**
  - Promising but still not fully applicable for EIC needs.

- **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

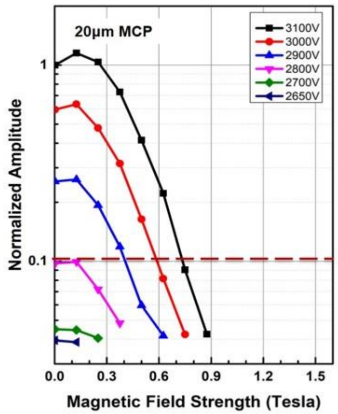
ANL version 1
Internal resistor chain



0 < B < 0.15 T

2017

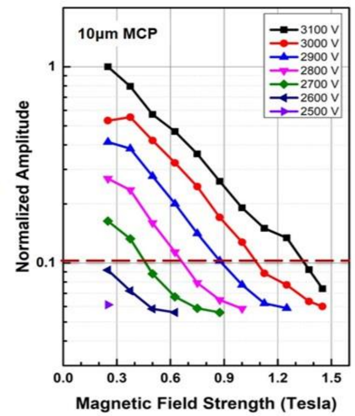
ANL version 2
IBD design 20 µm MCP



0 < B < 0.7 T

2018

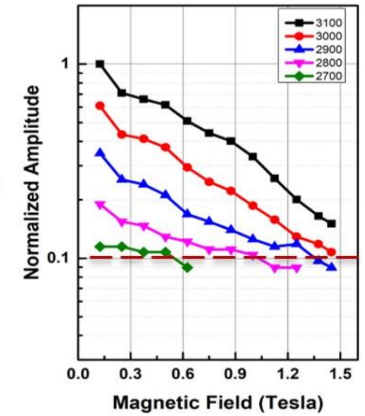
ANL version 3
IBD design 10 µm MCP



0 < B < 1.3 T

2019

ANL version 4
IBD design 10 µm MCP
reduced spacing



0 < B < at least 1.5 T

Babar and CLEO Magnets: 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:

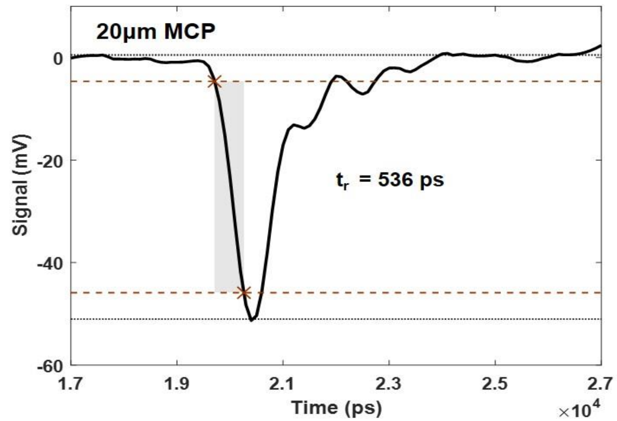
Smaller pore size is planned: 6 µm, version 4 -> 5 (future)

*M. Hattawy et al., Nucl. Instr. Meth. A **929** (2019) 84-89*

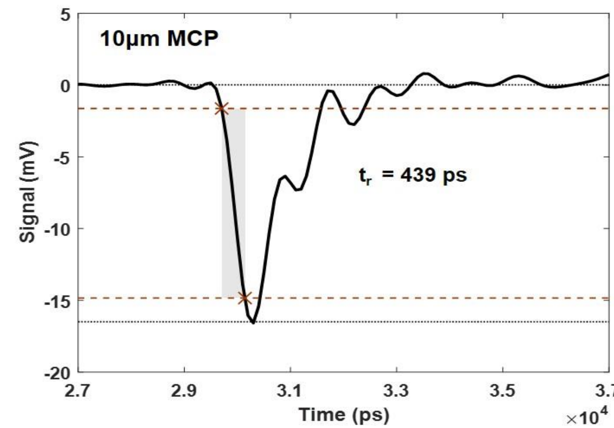
MCP-PMT TIMING RESOLUTION IMPROVEMENT

Rise time

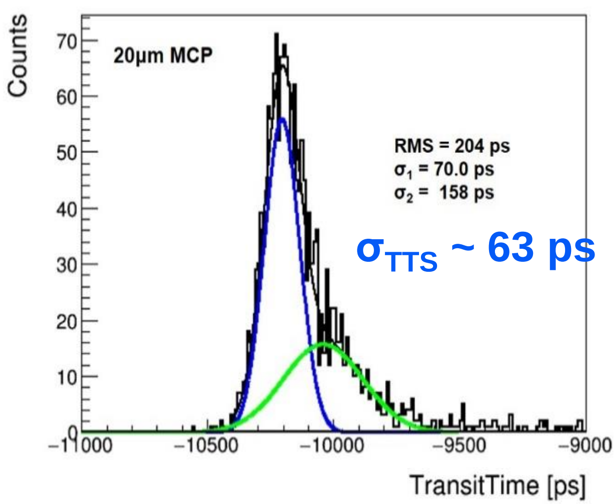
ANL version 2

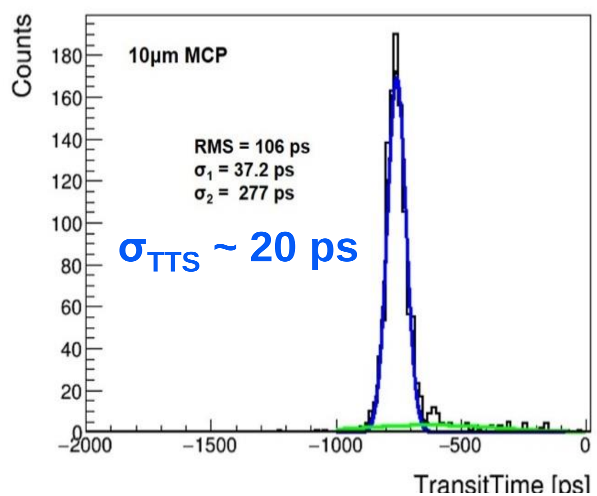


ANL version 3



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

*J . Xie et al., Rev. Sci. Instrum. **90** (2019) 043109*

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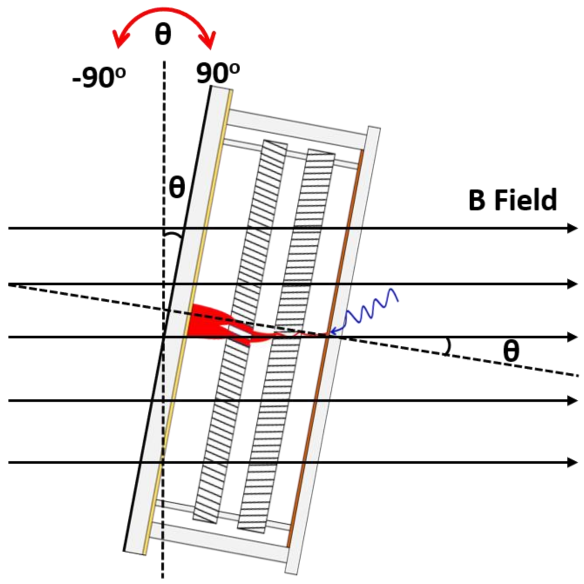
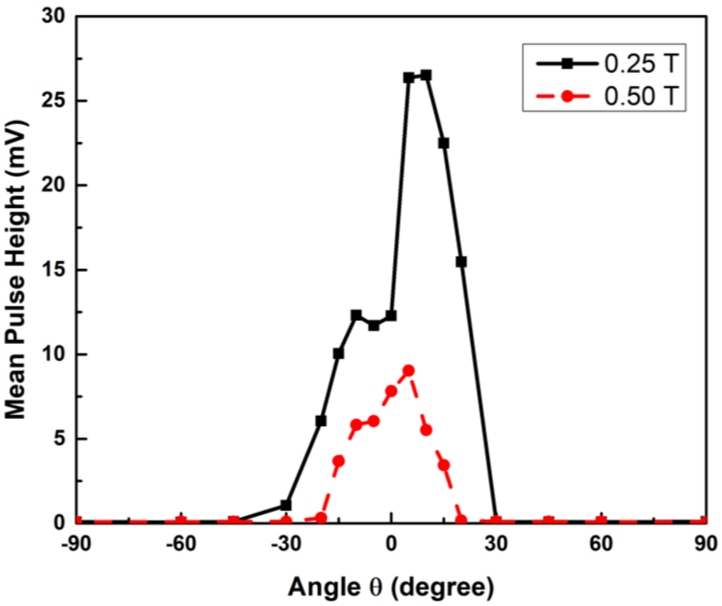
ANGLE DEPENDENCE ISSUE





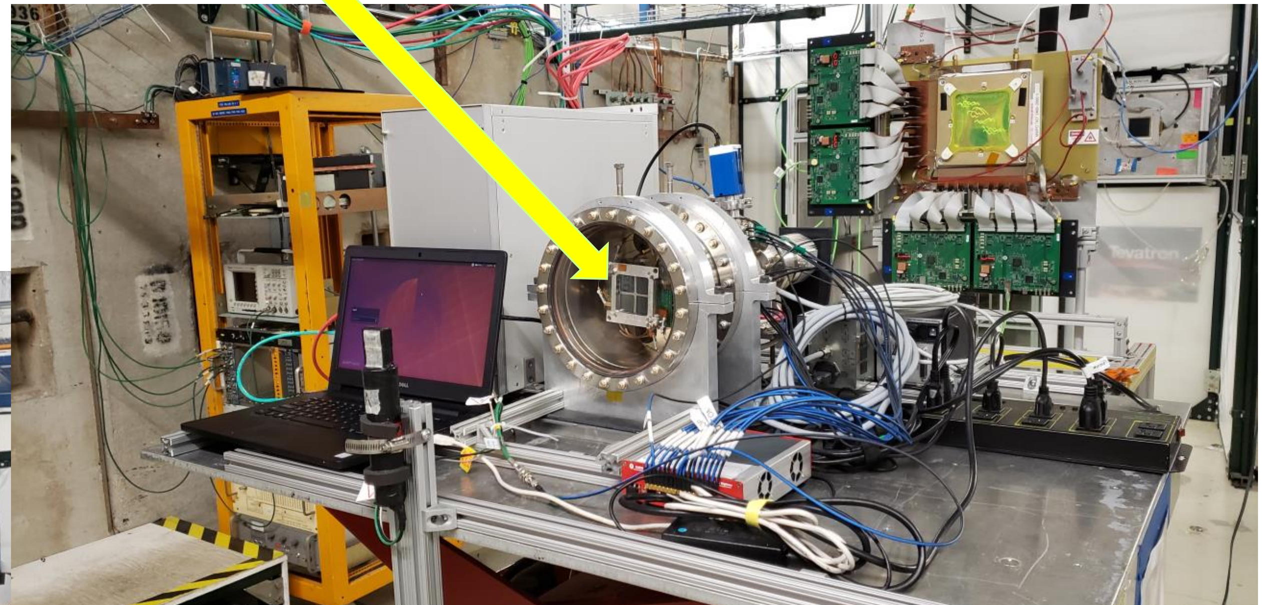
- The MCP-PMT performance in magnetic field is clearly angle related, due to the 8º MCP bias angle, the highest gain is obtained around 8º.
- Notice the two peaks around ±8º, indicating the effect from upper and lower MCP bias angles are different.

- **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 will be useful to explain the different effect, seeking solution.

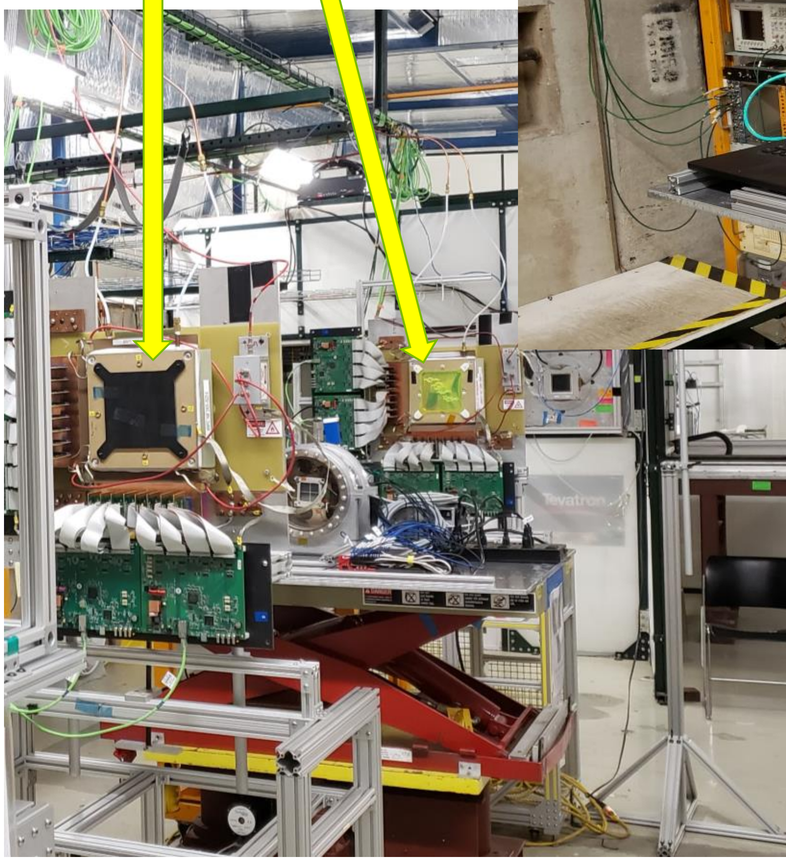
*M. Hattawy et al., Nucl. Instr. Meth. A **929** (2019) 84-89*

FINE PIXELATED READOUT THROUGH GLASS/FUSED SILICA ANODE

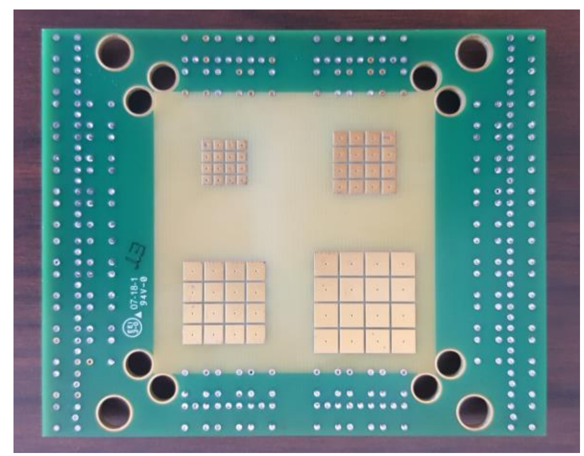
Argonne MCP stack (glass anode) in Fermilab test beam



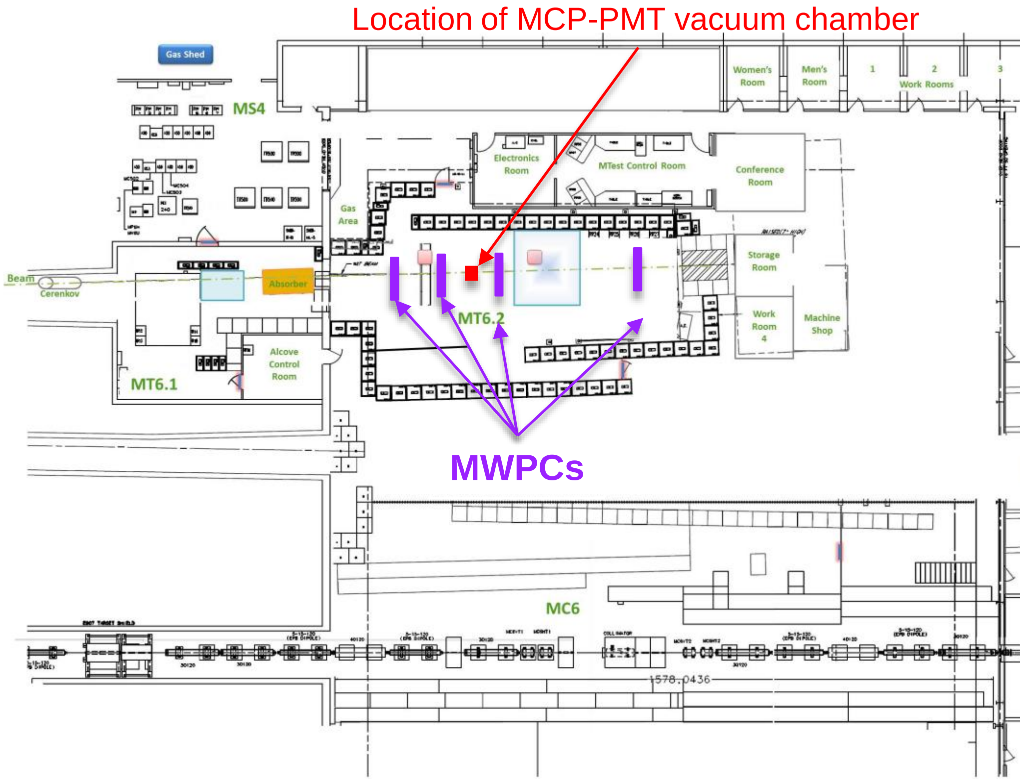
MWPC tracking used

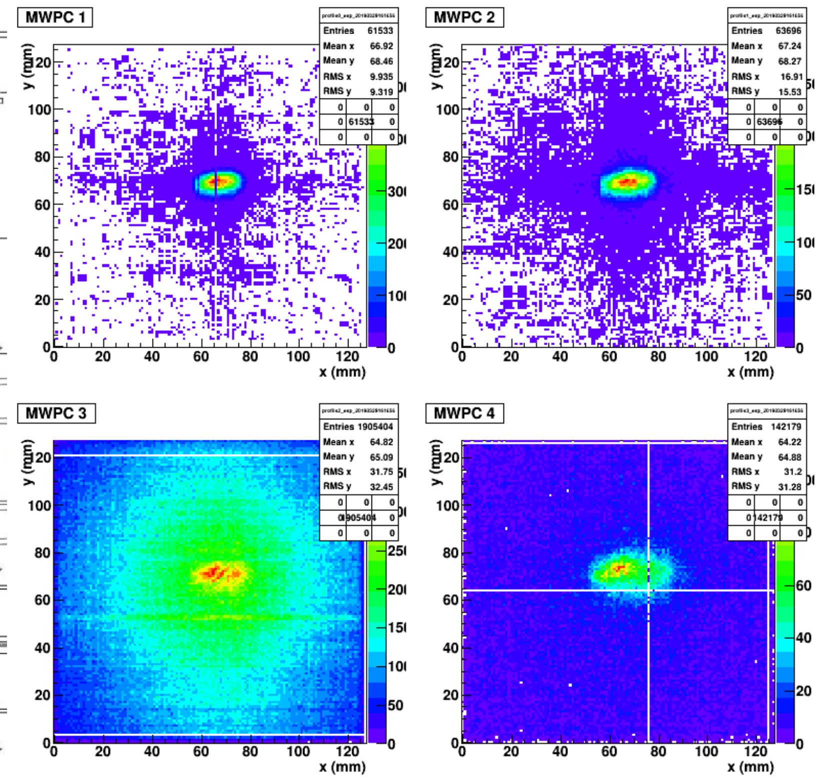


4 different pixel sizes (2x2,3x3,4x4 and 5x5 mm^2) implemented for testing



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

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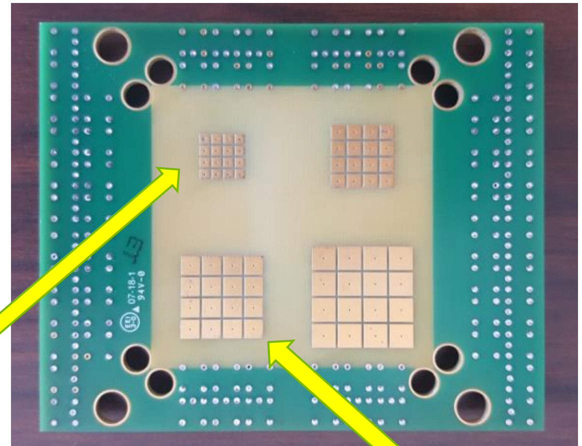
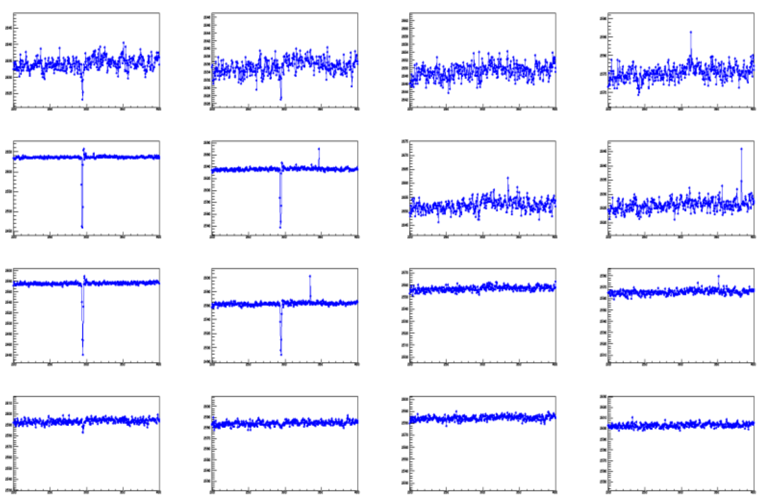
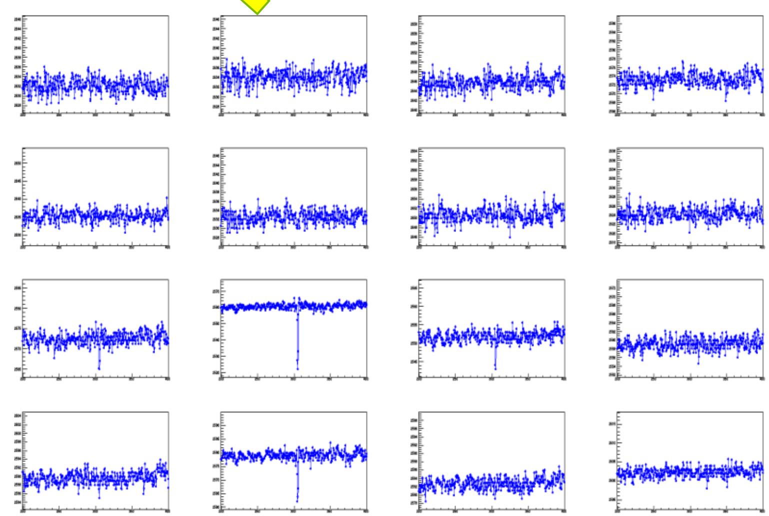
EVENT DISPLAY



2x2 mm^2 pixels

4x4 mm^2 pixels



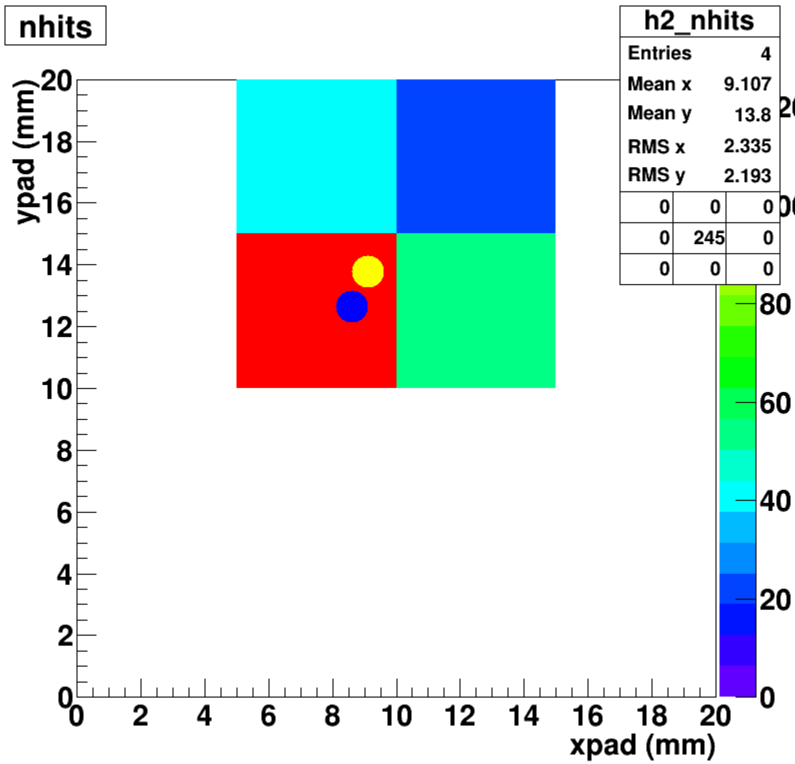


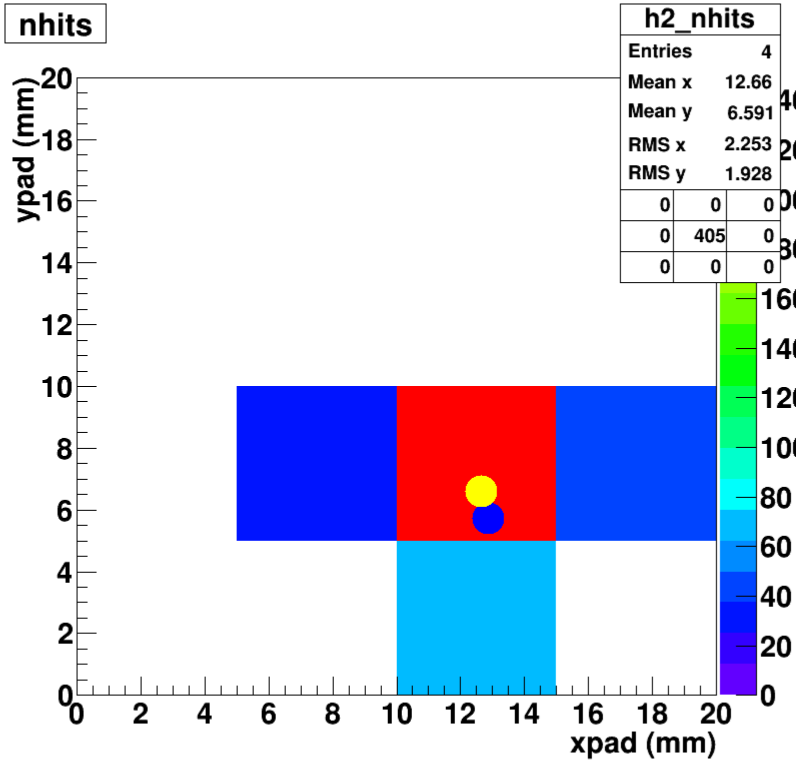
2x2 mm^2 pixel size is too small, signals spread onto several pixels.

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

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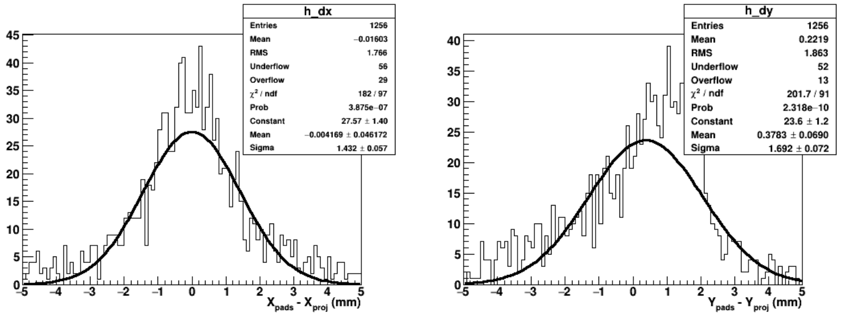
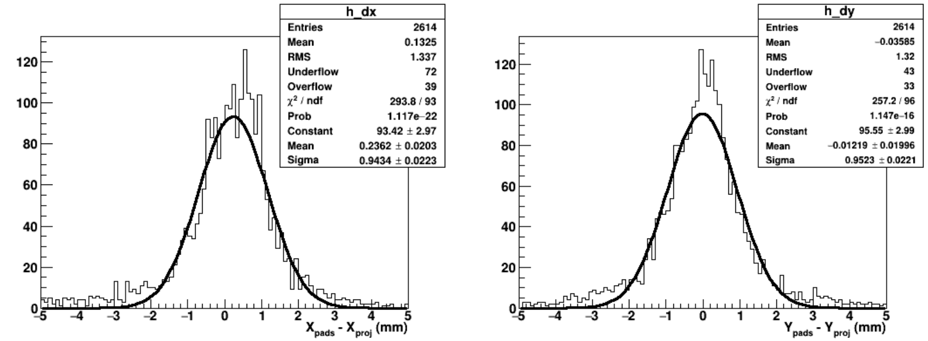
POSITION RESOLUTION

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

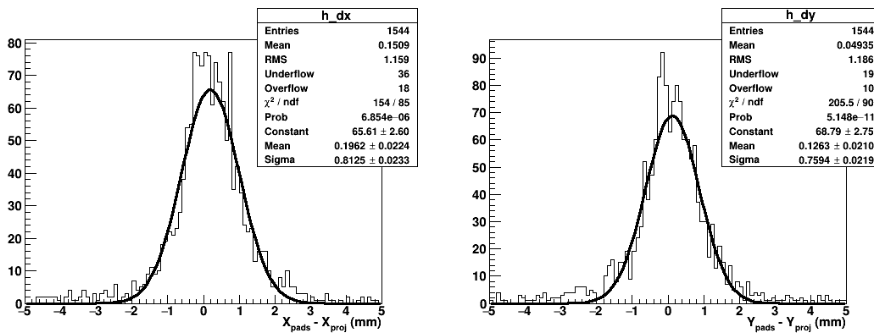
2x2 mm



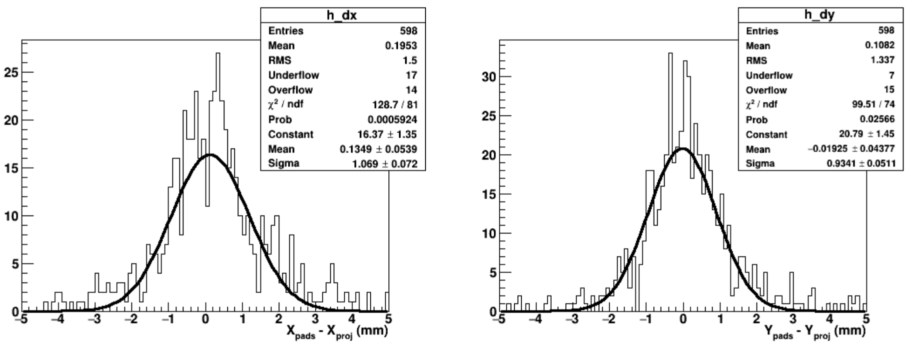
3x3 mm



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 with small pixels, reaching the requirements for EIC Cerenkov sub-systems.
- 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)

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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, seeking 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?