Development of planar microchannel plate photomultiplier at Argonne National Laboratory

Junqi Xie ***on behalf of the detector R&D group***

Argonne National Laboratory, Argonne, IL

Email: jxie@anl.gov

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Motivation: Standard PMT & MCP-PMT

Standard photomultipliers

- ✓ Successful technology over decades
- ✓ Large area available at low cost
- ✓ Rather fast: several hundred ps timing
- ➢ But……
  - Bulky
  - Limited response range (glass envelope)
  - Limited position resolution
  - Not suitable to high magnetic field

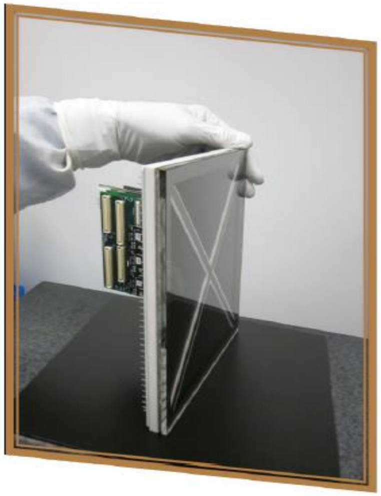
MCP-based photomultipliers

- ✓ Compact design
- ✓ **Picosecond-level** time resolution
- ✓ **Micron-level** spatial resolution
- ✓ Good magnetic field performance
- ➢ But……
  - Few venders, high cost
  - Limited sizes

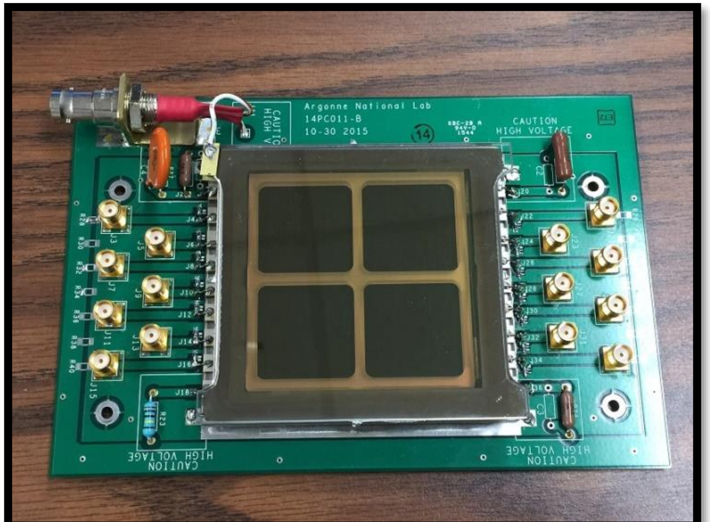
Background: Large Area Picosecond PhotoDetector (LAPPD)

- To address the limitations of commercial devices, the **LAPPD** project reinvents photodetectors using transformational technologies.
- Goals: large-area (20 cm x 20 cm), picosecond-timing, mm-position
- Applications: picosecond timing, mm-spatial on large-area
  - ✓ High energy 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 currently working on commercialization of LAPPD detectors

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



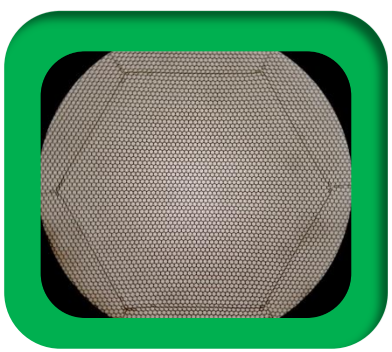
Argonne MCP photodetector program



6 cm × 6 cm

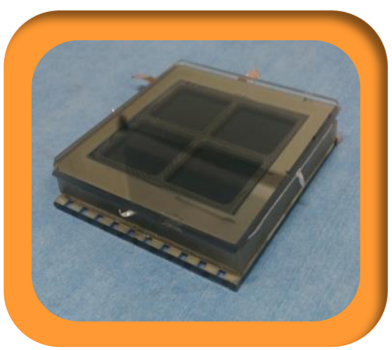
- Produce the first functional devices and provide them to the community for evaluation and incorporation into experiments
- Support the industry for commercialization of large-area devices
- Provide a flexible platform for further R&D efforts (VUV-UV-Vis response, B-field application, cryogenic application…)

ALD-MCP

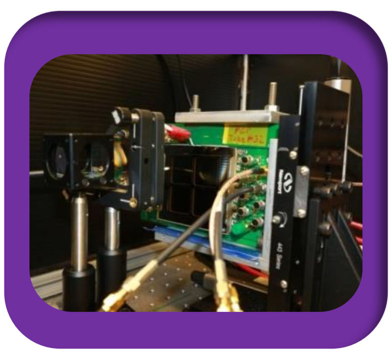


Photocathode

Packaging



Testing



Argonne 6 cm × 6 cm photodetector

- 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.

R_{23} = 2 MΩ

R_{24} = 5 MΩ

R_{25} = 1.5 MΩ

R_{26} = 5 MΩ

R_{27} = 2 MΩ

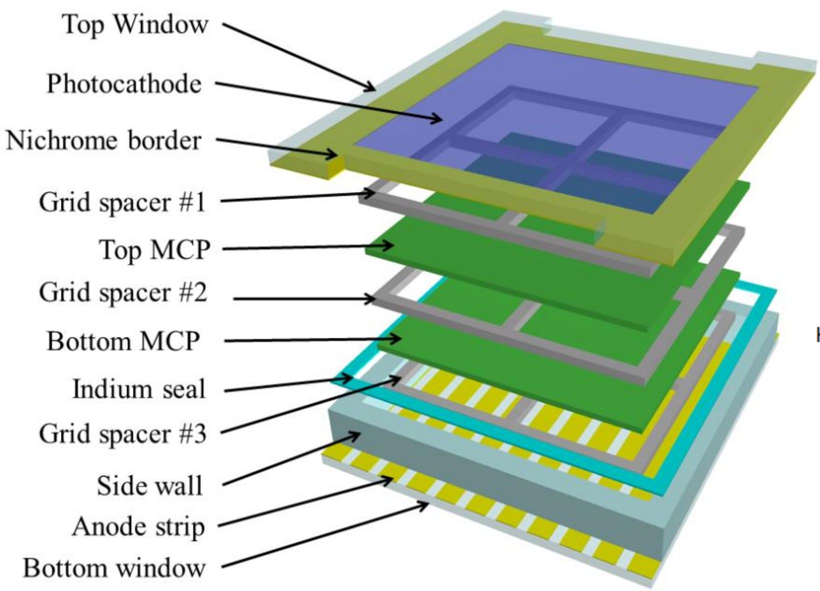
R_g = 100 Ω

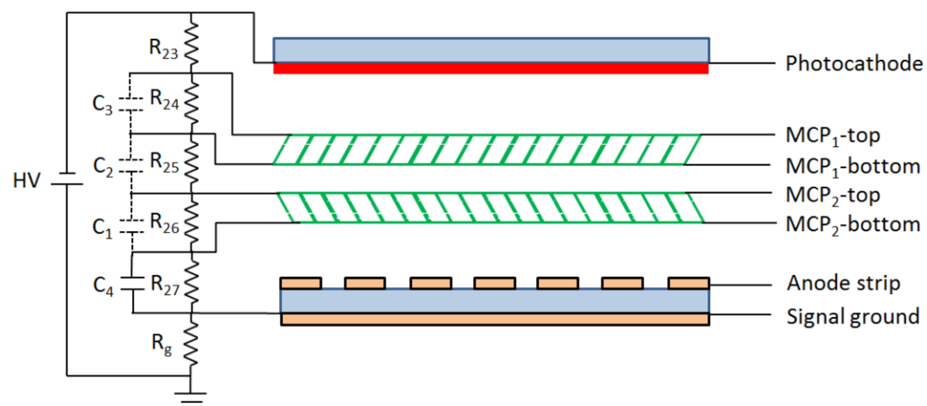
R_{MCP1} = 24 MΩ

R_{MCP2} = 25 MΩ

C_4 = 1 µF

Dash line: not installed yet





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

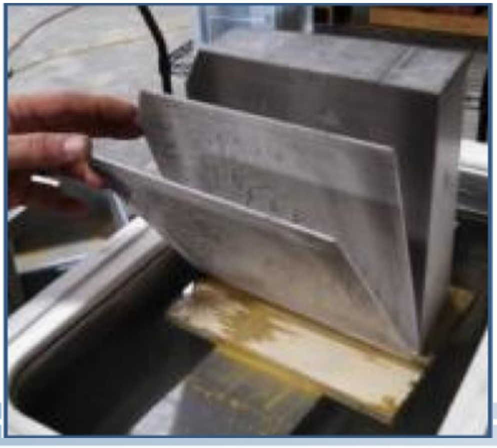
A very flexible platform for R&D efforts!

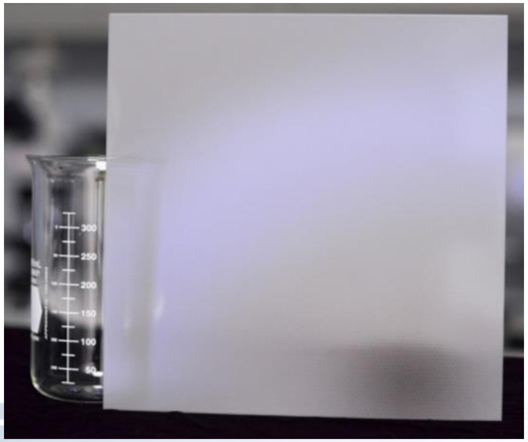
Next generation micro-channel plates - 1.GCAs

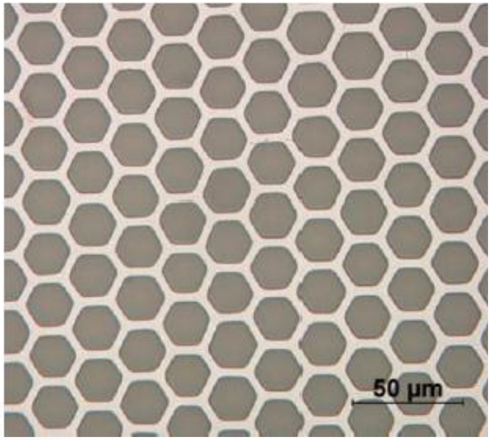
- **Conventional Pb-silicate glass MCP:** Based on optic fiber production, chemical etching and thermal processing
  - × Expensive lead-silicate glass
  - × Complex, labor consuming technology
  - × Large deviation of channel diameters within MCP
  - × Difficult to produce large area MCP

- **"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*



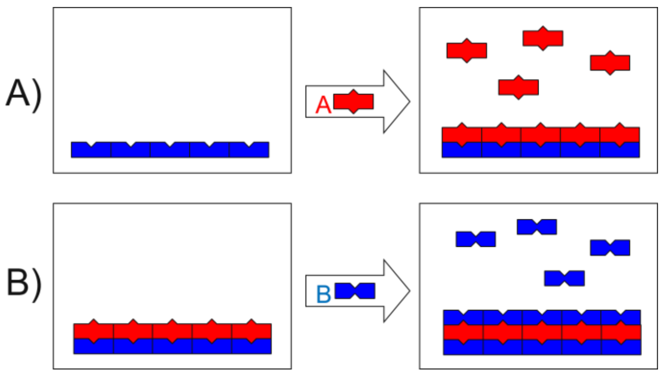




Next generation micro-channel plates - 2.ALD

- **"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

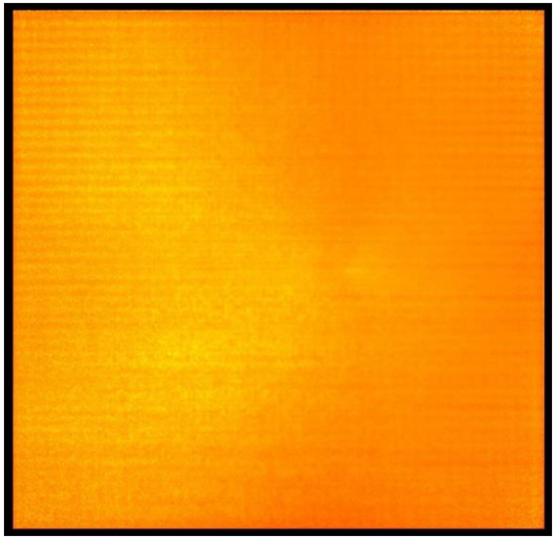


MCP after functionalization

MCP parameters

- Pore size: 20 µm
- Thickness: 1.2 mm
- L:D ratio: 60:1
- Open area ratio: 65%
- Average gain: 7×10^6
- Gain variation: <10%

Average gain image "map"

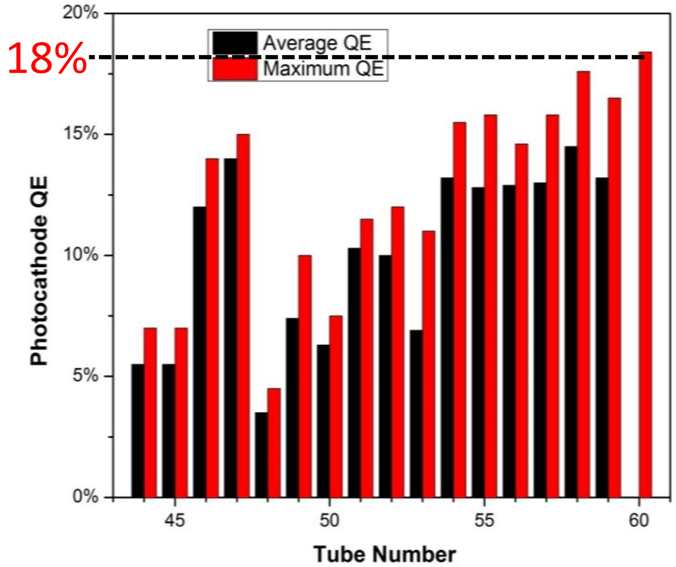


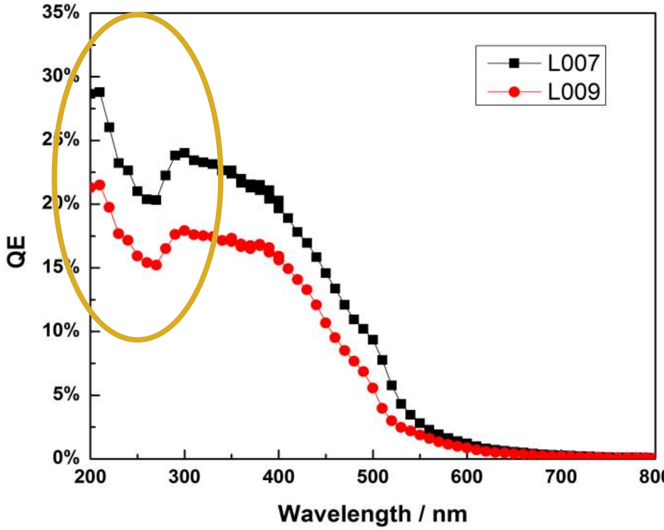
M. Minot et al., Nucl. Instr. Meth. A ***787*** *(2015) 78-84*

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

Photocathode development

goal 20%



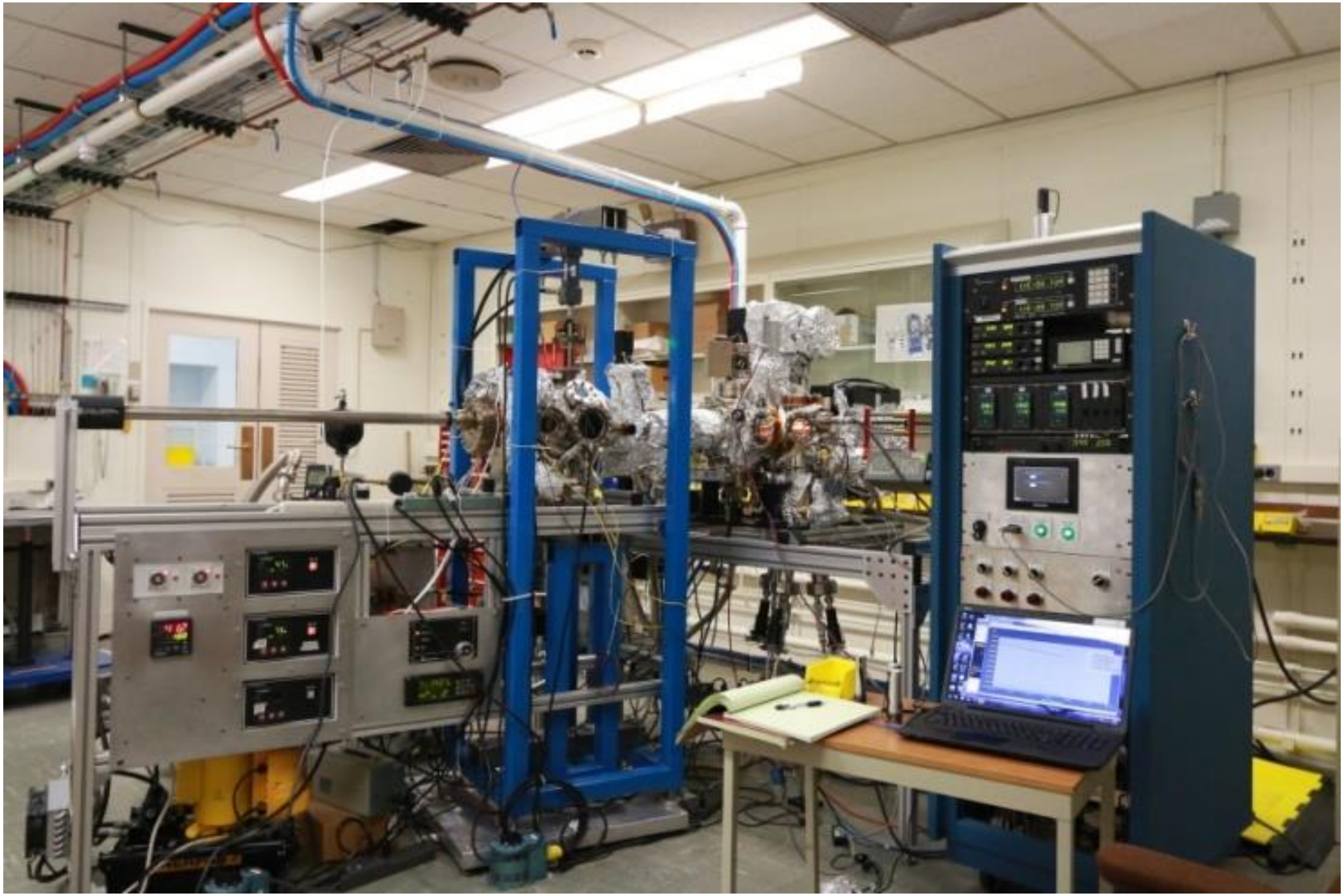


Interesting observation from x-ray study: Enhanced UV photo response for bialkali photocathode through quartz window

Photocathode QE of functional detectors gradually increases as we improve our growth parameters and detector components.

Further investigation of the X-ray data for structure, composition details are undergoing to explain this observation

Photodetector fabrication lab



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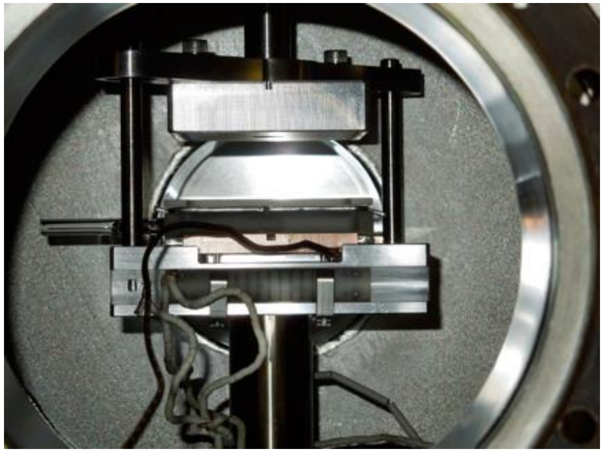
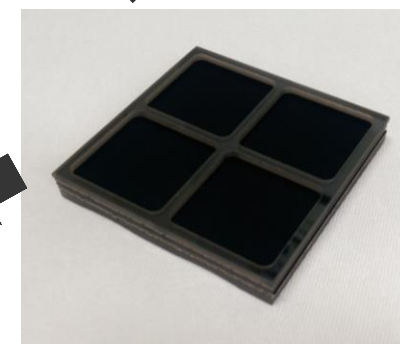
Hermetic packaging

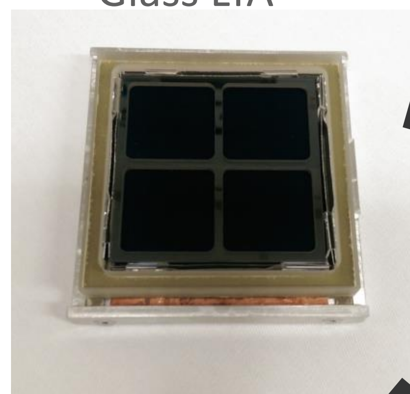
hydraulic driven platens



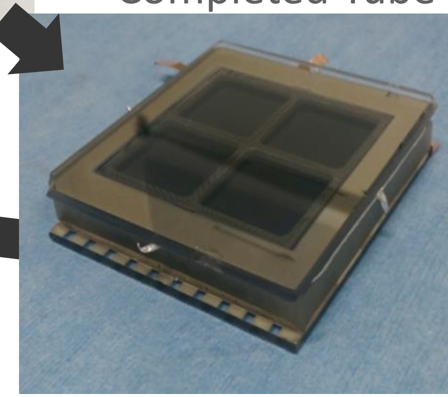
MCP & Resistive Grid Spacer Stack



Glass LTA



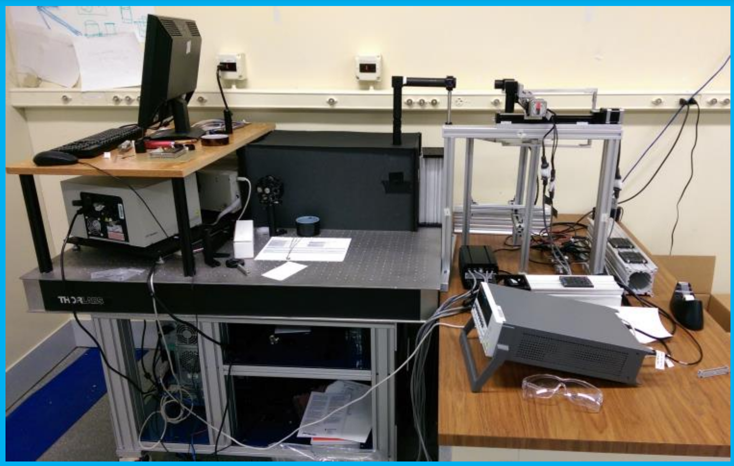
Completed Tube



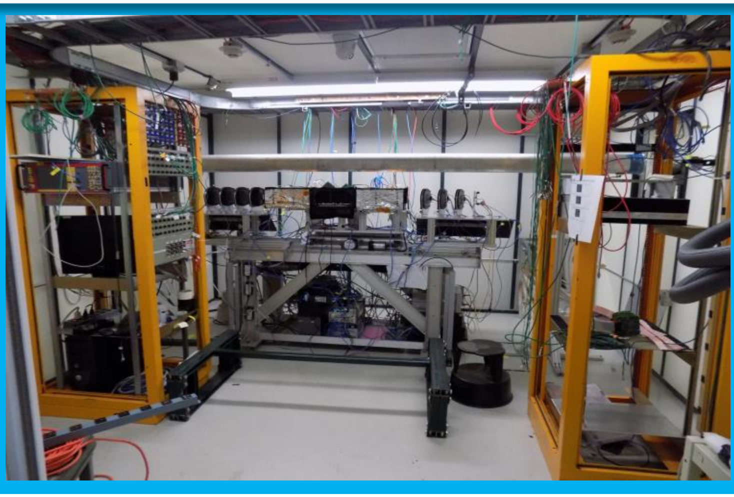
- **Tube processing is very challenging**
  - Baking, scrubbing, getter activation, compression sealing

Test facilities

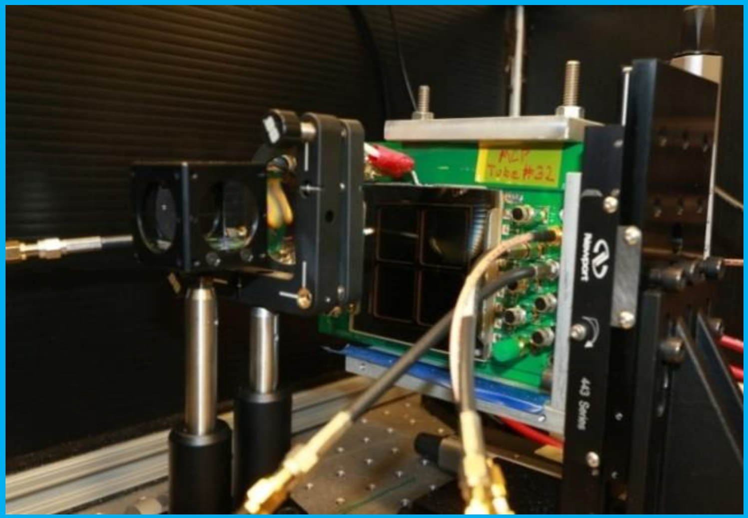
Optical table for QE measurement

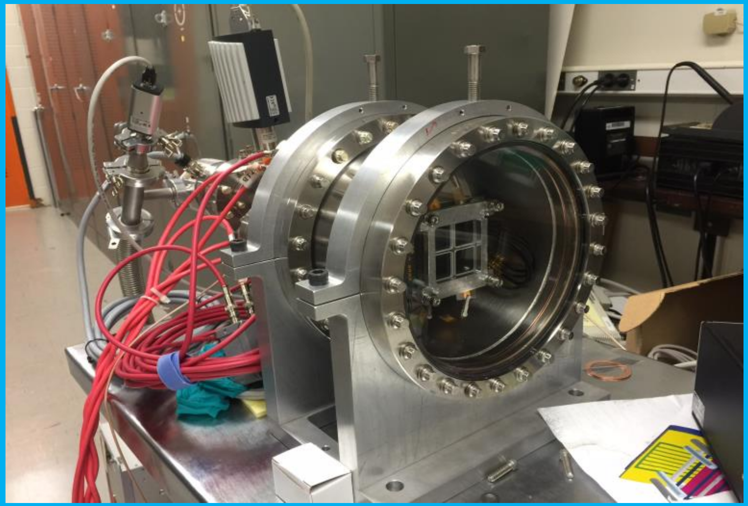


Fermilab Test Beam Facility



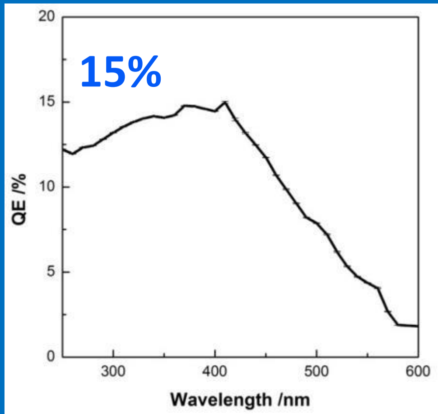
Blue laser facility: 70 ps pulse duration

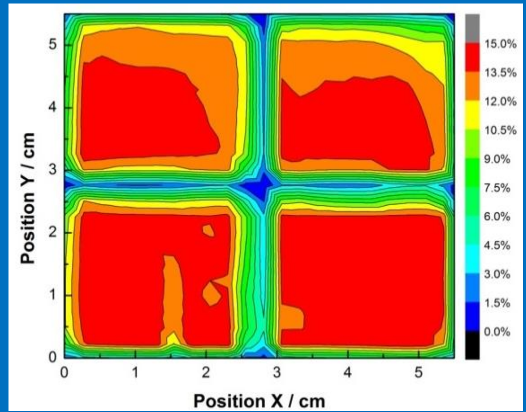




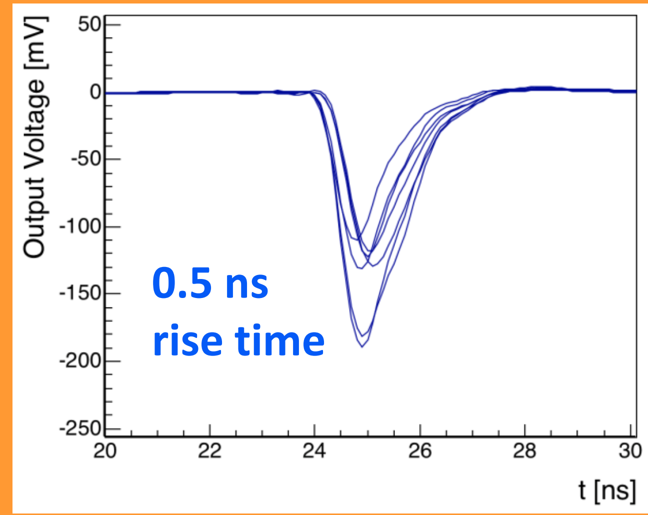
Key performances

Spectra response



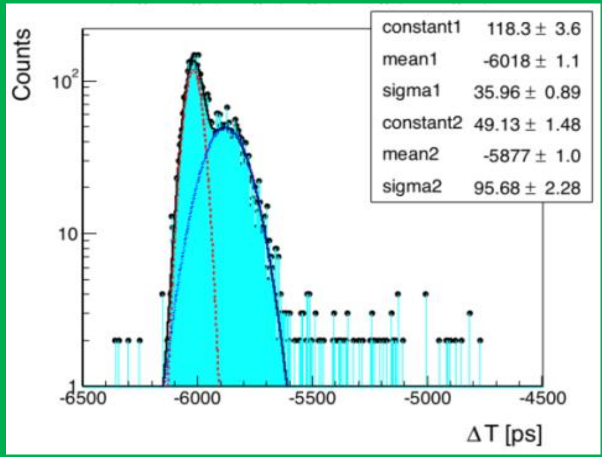


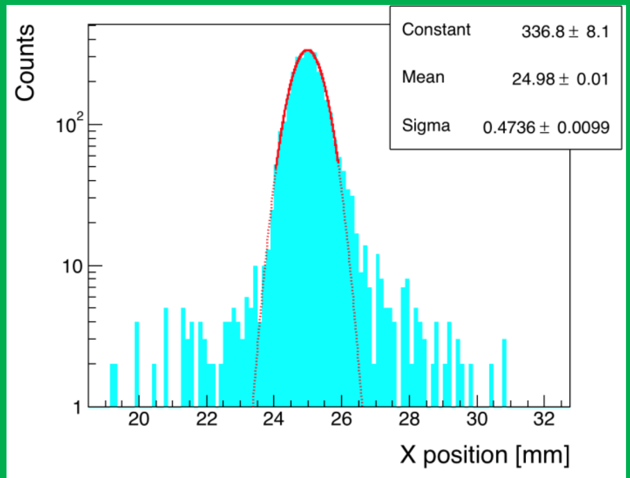
Signal component



$$\sigma_{I.R.F.}{}^{2} \sim \sigma_{.T_{MCP}}{}^{2} + \sigma_{.T_{laser}}{}^{2}$$

Timing / position distributions





σ_{IRF} ~ 35 ps for SPE

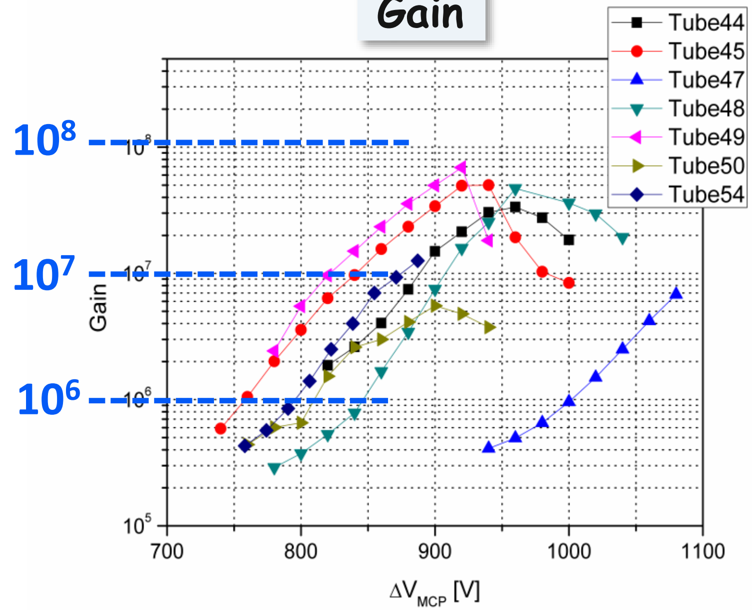
σ_{TTS} ~ 20 ps

σ < 1 mm for SPE

Key performances

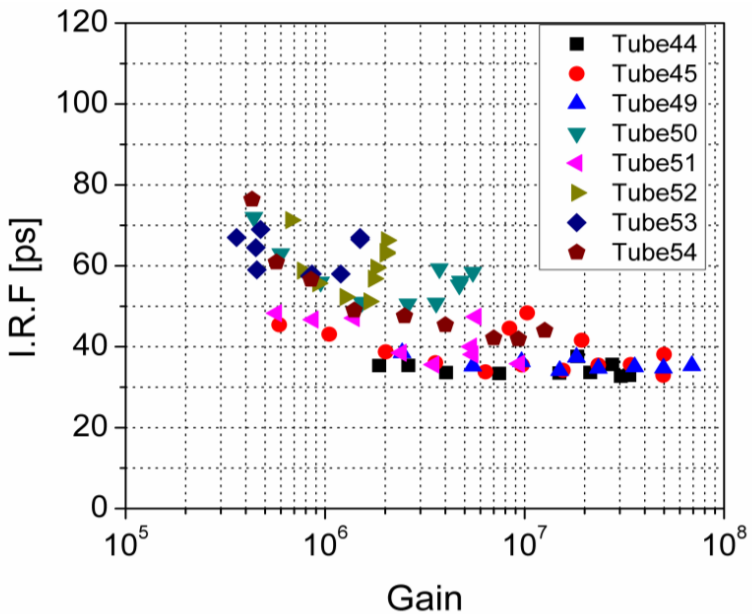
- Gain as high as **7X10^{7}**
- Time resolution **$\sigma_{overall}$ ~35 ps, TTS <20 ps**
- Laser start time jitter: **σ_{laser} ~30ps**
- Rate capability: **> 75KHz/cm^{2}**

Gain

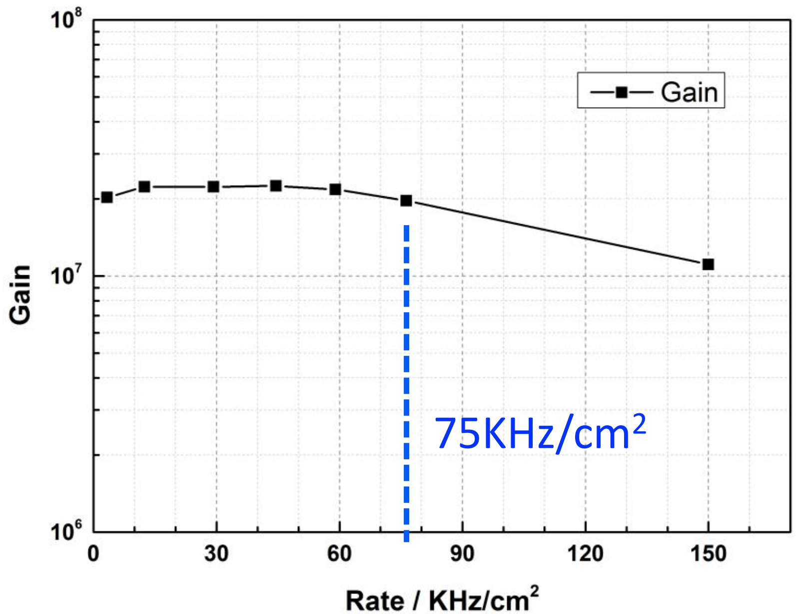


Overall time resolution

$$\sigma_{I.R.F.}{}^2 \sim \sigma_{.T_{MCP}}{}^2 + \sigma_{.T_{laser}}{}^2$$



Rate capability



Datasheet for early users

- We use the pulsed blue laser (405 nm) facility to test and characterize the 6 cm tubes.
- Standard tests are performed for each tube
  - QE spectrum response
  - QE uniformity scan
  - Overall uniformity scan
  - Gain vs HV
  - Time resolution vs HV
  - Position resolution
- Each tube is sent out to the users with a detailed datasheet

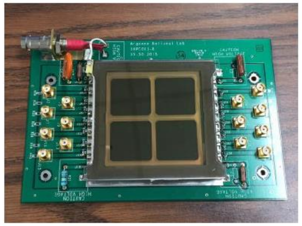
Argonne NATIONAL LABORATORY

High Energy Physics Division

6 cm x 6cm Photodetector Data Sheet
Photodetector Tube No.: # 44
Mfg Date: Jun. 10, 2015

DESCRIPTION

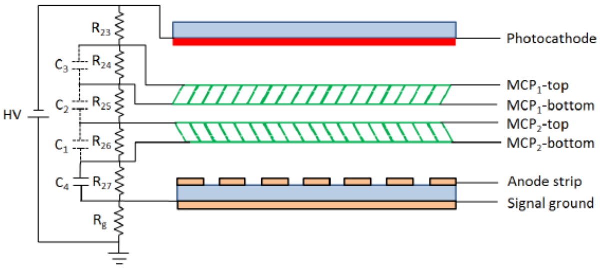
Window Material	Borosilicate glass
Window Mask	NiCr
Photocathode Type	Bialkali
Multiplier Structure	MCP chevron (2), 20 μm pore, 60:1 L:D ratio
Stack Structure	Independently Biased Design (IBD)
Anode Structure	0.47 cm sliver strip line, 0.23 cm interval
Active Area	6 cm x 6 cm
Package open-area-ratio	65 %



CHARACTERISTICS

Parameter		Min.	Typ.	Max.	Unit
Overall High Voltage		-	-2900	3100	V
Voltage Divider Current		-	230	-	μA
Photocathode	Spectral Response	300	-	600	nm
	Quantum Efficiency	-	6%@350nm	7.0%@380nm	-
Gain at -2900 V		-	1×10^7	-	-
Time Response	Rise Time	-	0.62	1.4	ns
	Fall Time	-	1.85	2.2	ns
	I.R.F. (σ)[1] / I.R.F. (FWHM)	-	35 / 90	-	ps
	T.T.S. (σ)[2] / T.T.S. (FWHM)	-	18 / 57	-	ps
Spatial Response	Differential Time resolution (σ)	-	13 (Single-PE)	-	ps
	Position Resolution (σ)	0.7 (Multi-PE)	-	1.3 (Single-PE)	mm

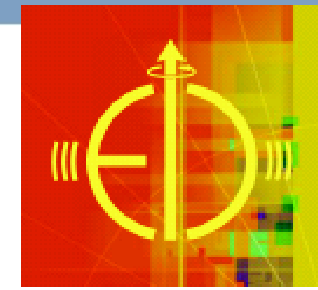
CONNECTION SCHEMATIC

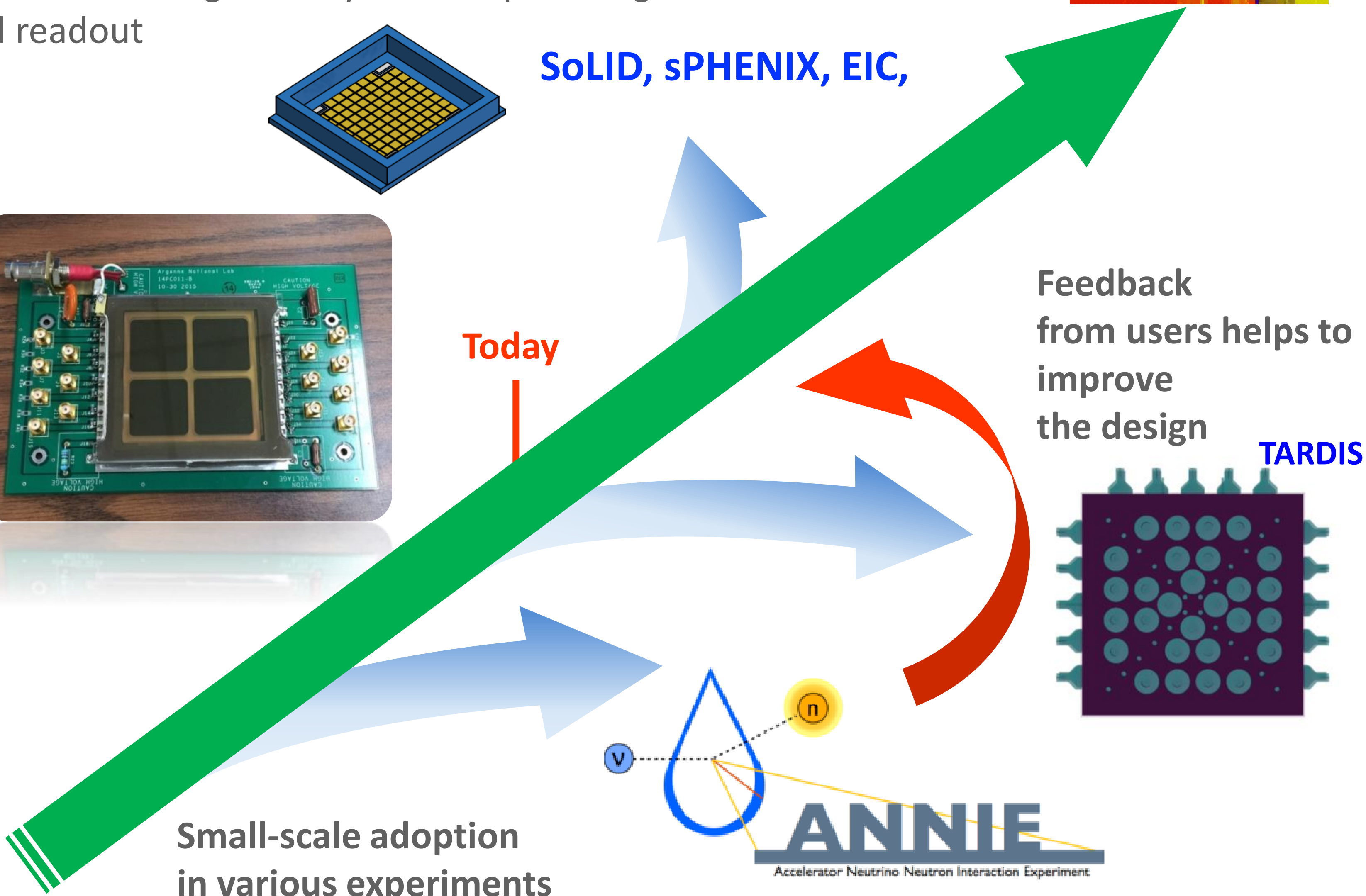


R_{23} = 2 MΩ
R_{24} = 5 MΩ
R_{25} = 1.5 MΩ
R_{26} = 5 MΩ
R_{27} = 2 MΩ
R_g = 100 Ω
R_{MCP1} = 24 MΩ
R_{MCP2} = 25 MΩ
C_4 = 1 μF
Dash line: not installed yet

Future development path

- Higher QE over 20%
- Optimization in geometry for < 10 ps timing
- Pad readout
- ……





Summary

- The Argonne MCP photodetector program has been highly successful, benefiting from advances in different disciplines
- A very flexible platform was built for detector R&D efforts
- Current detectors exhibit excellent performance: high gain over 10^7, timing resolution of 35 ps for single photoelectron, 20 ps for multi-photoelectrons, rate capability over 75KHz/cm^2
- The success of the photodetector program brings in lots of interests from many areas of science: TOF at colliders, HEP neutrino experiments, medical imaging, nuclear physics experiments
- We have sent out devices to early users for evaluation and incorporation to experiments, optimization is undergoing
- The system will serve as an R&D platform to address new requirements and study new ideas
- You are welcome to share you requirement and work with us together on ideas!

Acknowledgments

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Argonne National Laboratory, Argonne, IL USA, 60439

K. Attenkofer, M. Chiu, Z. Ding, M. Gaowei, J. Smedley
Brookhaven National Laboratory, Upton, NY USA, 11973

C. Craven, M. Minot, B. Worstell
Incom, Inc., Charlton, MA USA 01507

A. Camsonne, P. Nadel-Turonski, Y. Qiang, Z. Zhao, C. Zorn
Jefferson Lab, Newport News, VA USA, 23606

H. Padmore, S. Schubert, J. Wong
Lawrence Berkeley National Laboratory, Berkeley, CA USA, 94720

A. Elagin, H. Frisch
University of Chicago, Chicago, IL USA 60637

The LAPPD collaboration & The EIC PID consortium

Thank you for your attention!

Questions?