Planar microchannel plate photomultiplier with VUV-UV-Vis full range response for fast timing and imaging applications

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9th International Workshop on Ring Imaging Cherenkov Detectors (RICH 2016)
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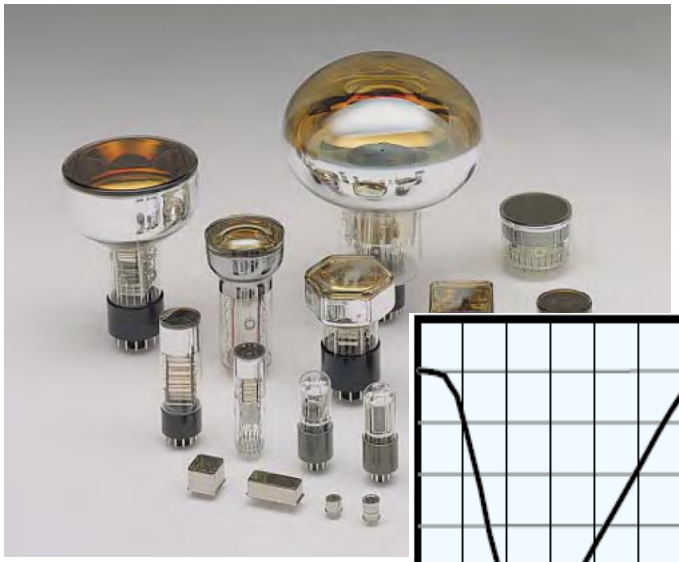
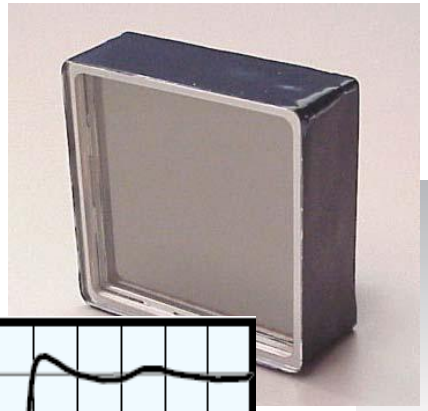
Motivation: Standard PMT & MCP-PMT





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

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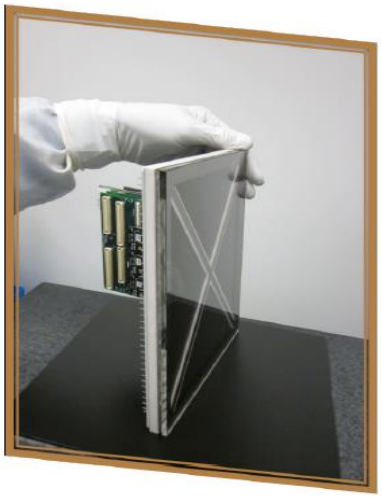
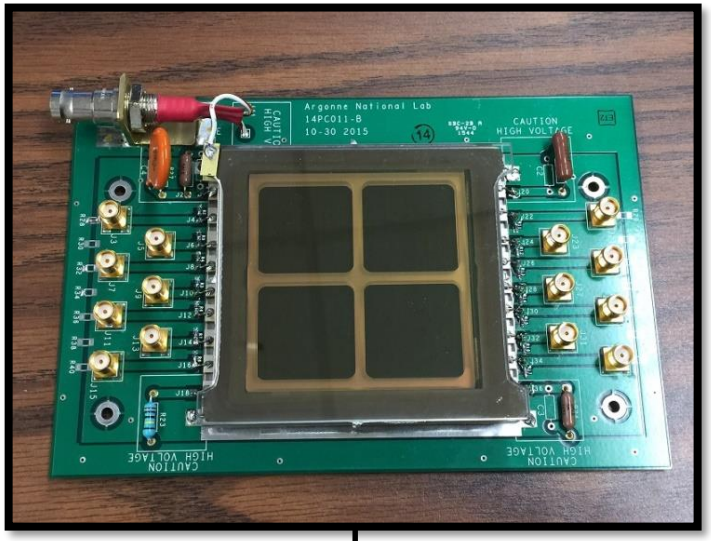


Argonne MCP photodetector program



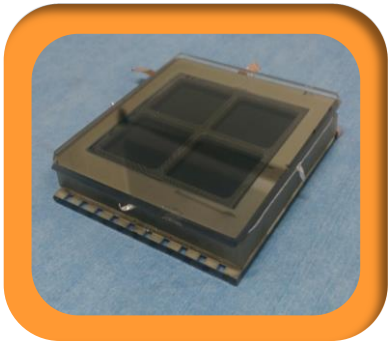
- Produce the first functional devices and provide them to the community for evaluation and incorporation into experiments
- Support the industry for commercialization of large-area devices
- Provide a flexible platform for further R&D efforts (VUV-UV-Vis response, B-field application, cryogenic application…)

6 cm × 6 cm

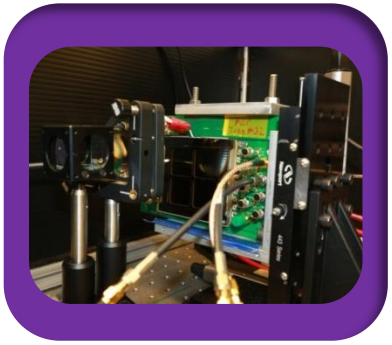
ALD-MCP

Photocathode

Packaging

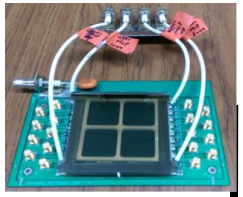


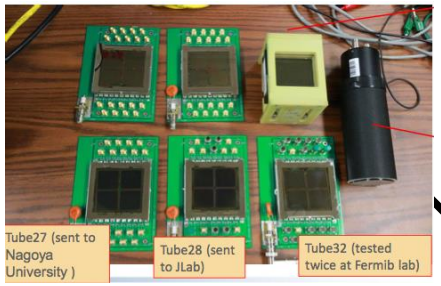
Testing



Argonne MCP photodetector program progress

Dec 2015
10th IBD-1 tube
91% yield



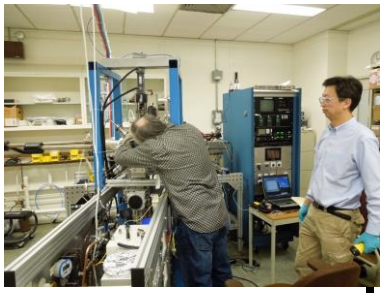


Sep/Oct 2014
Tubes 27, 28, 32
First long-life tubes sent to 1st users

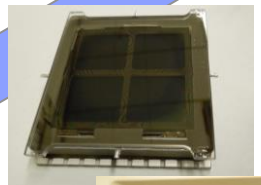
Jun 2015
First IBD-1 tube complete

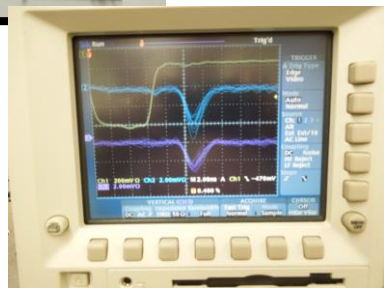
Fabrication optimization

Jan 2015
Begin IBD-1 design



Jul 2014
Tube #20
First signals





Apr 2014
System complete
First seal tests

Sept 2013
Begin assembling/modifying chambers

Initiated 6cm×6cm MCP-PMT effort at Argonne to integrate into first working devices complete set of successfully developed LAPPD techniques

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

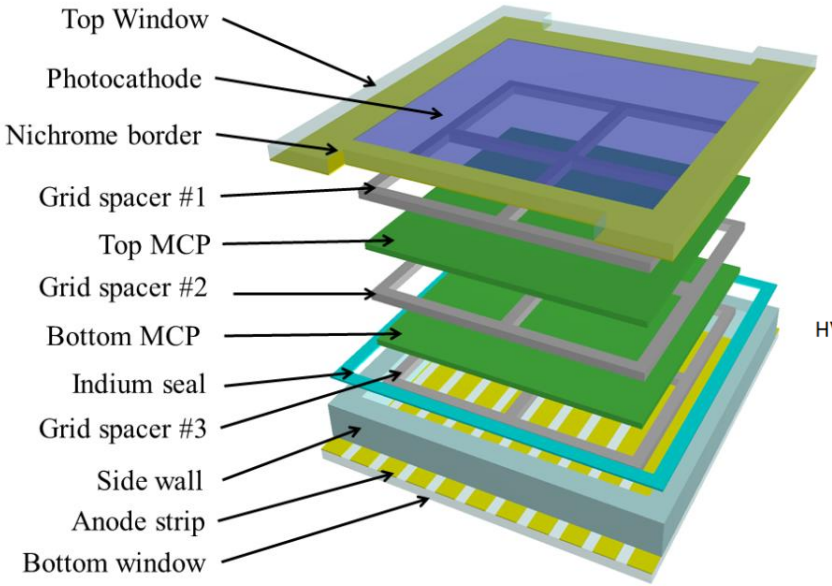
R_g = 100 Ω

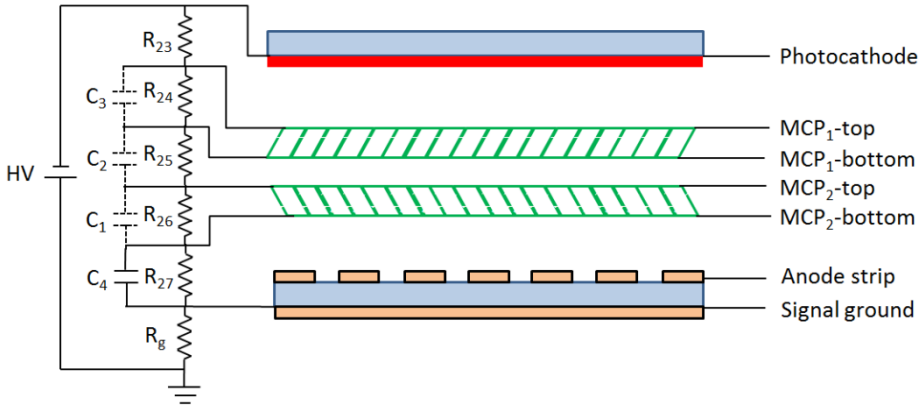
R_{MCP1} = 24 MΩ

R_{MCP2} = 25 MΩ

C_4 = 1 μF

Dash line: not installed yet





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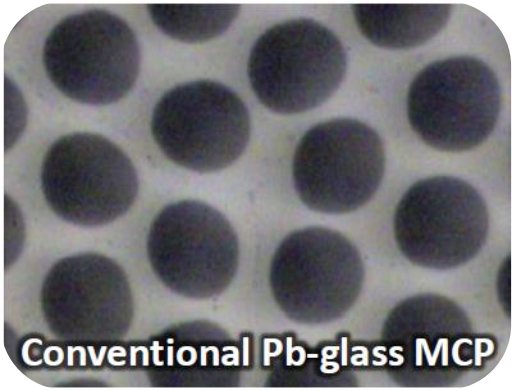
A very flexible platform for R&D efforts!

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

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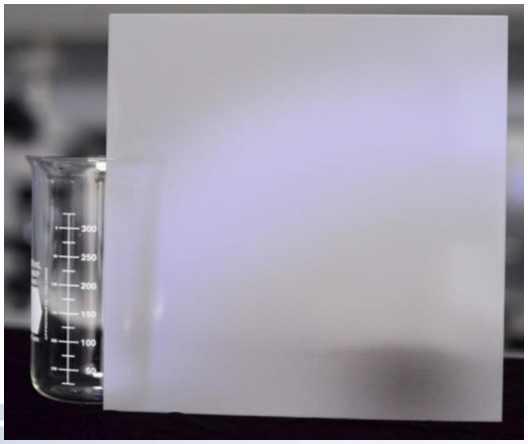
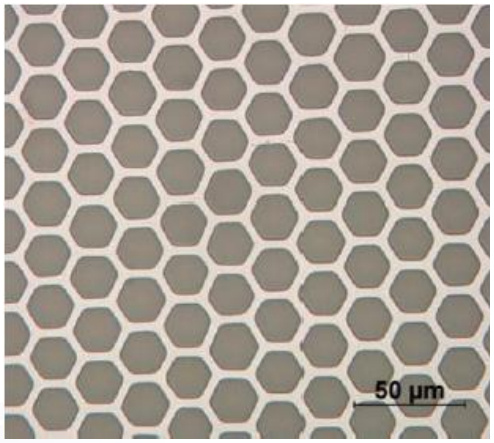
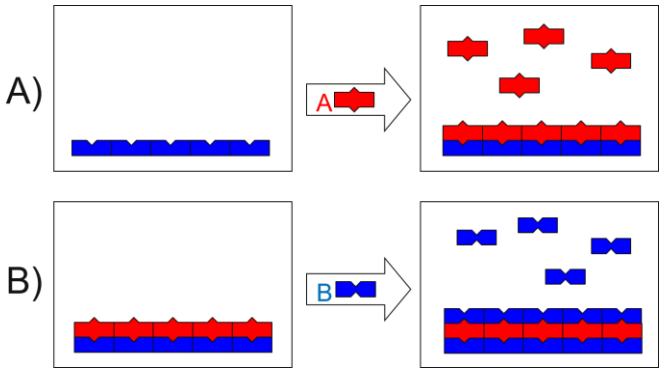




Next generation micro-channel plates – 2.ALD

- **"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

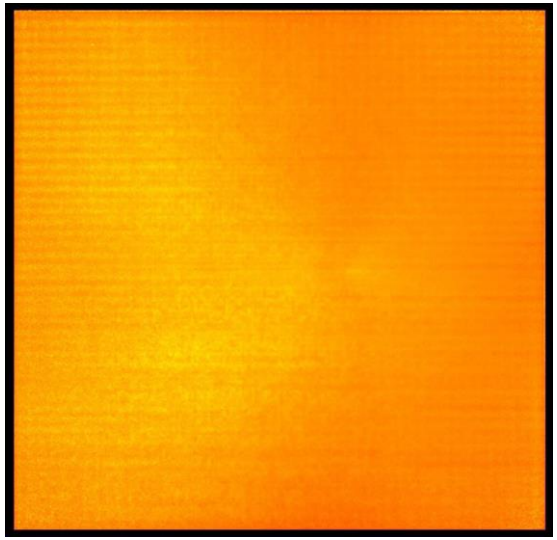


MCP after functionalization

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"



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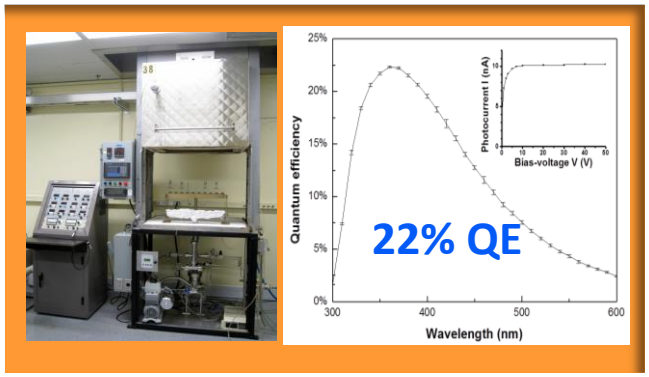
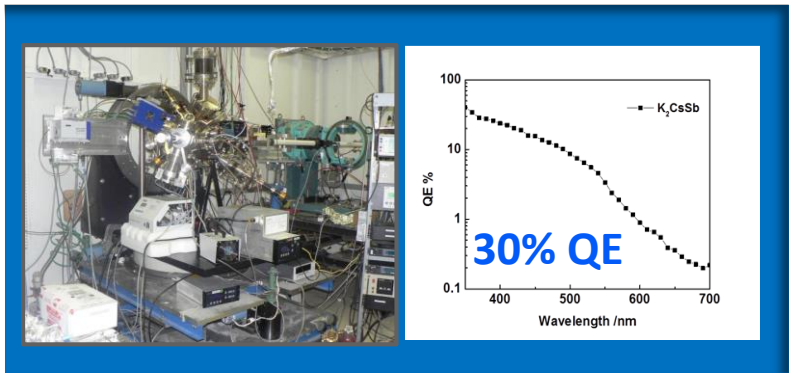
The Argonne ALD technique has been licensed to Incom, Inc. for commercialization.

Photocathode development

Commercial Burle facility



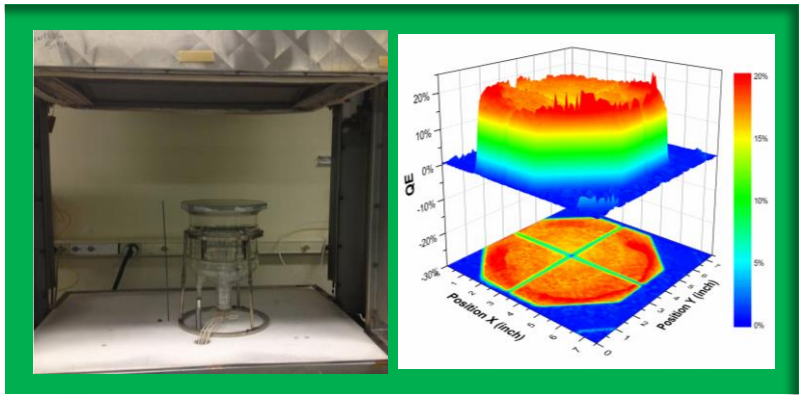
X-ray study to enhance QE



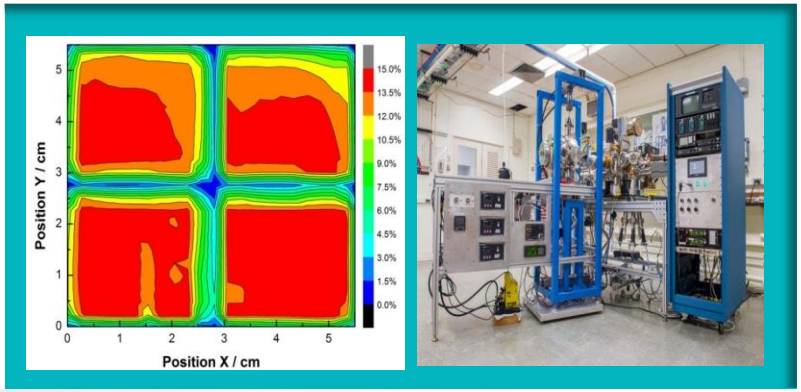
Improving QE within production facility

Jan. 2011 — **Jan. 2012** — **May. 2013** — **Jan. 2016** — **Recent**

7” photocathode **20% QE**

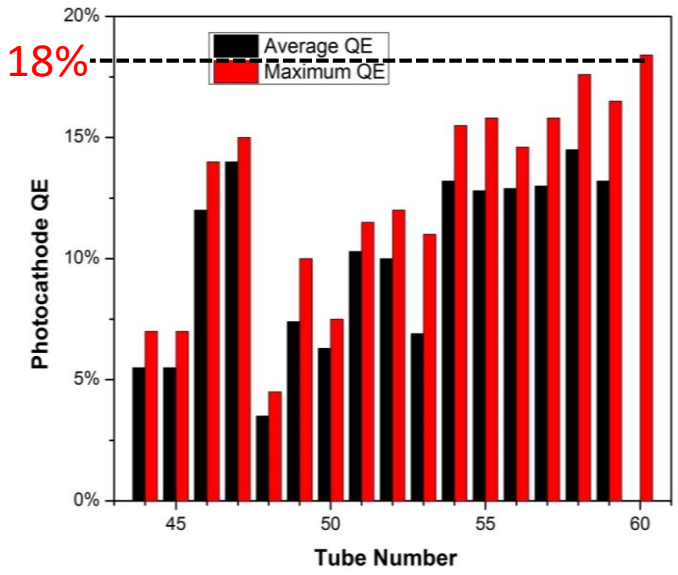


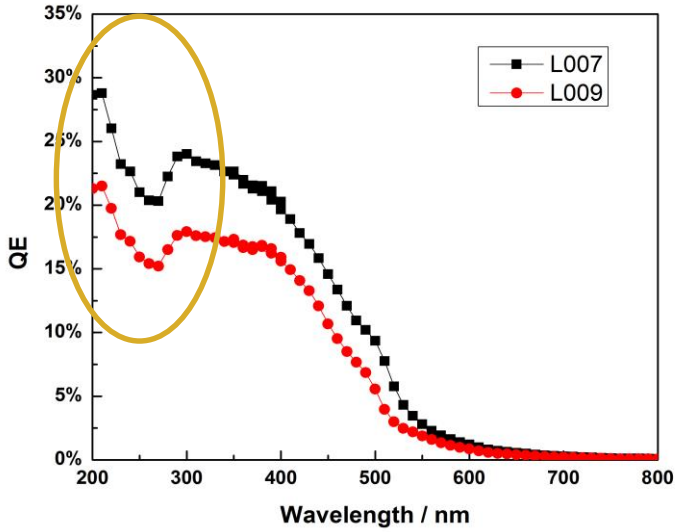
6 cm sealed tube **13% QE, goal is 20%**



Photocathode with VUV-UV-Vis full range response

goal 20%





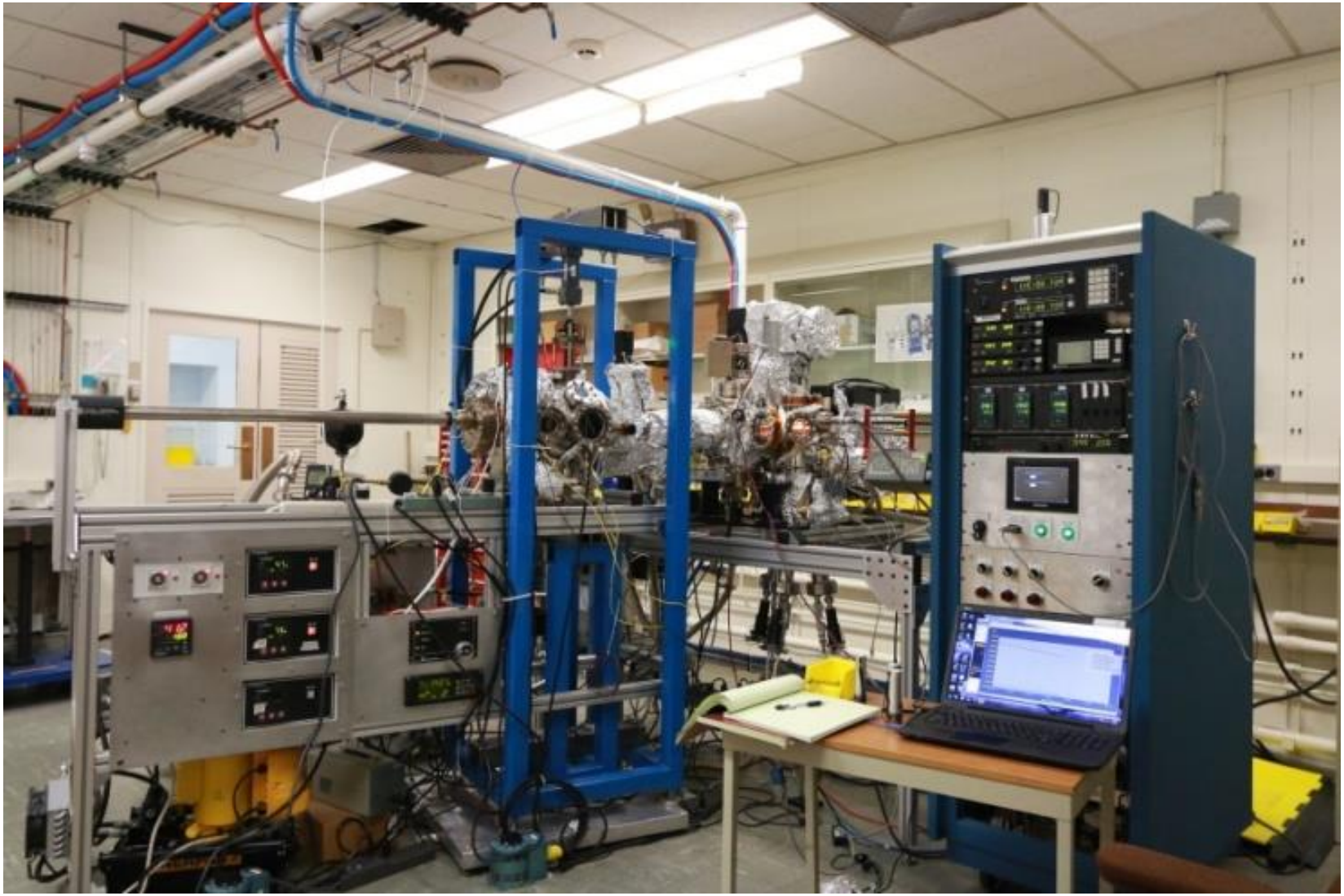
Photocathode QE of function detectors gradually increases as we improve our growth parameters and detector components.

With quartz window

Interesting observation from x-ray study: Enhanced UV photo response for bialkali photocathode!

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

Photodetector fabrication lab



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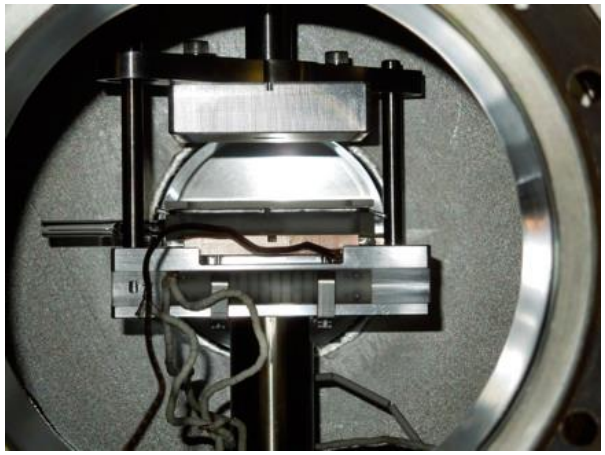
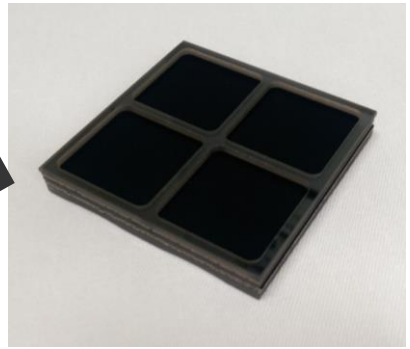
Hermetic packaging

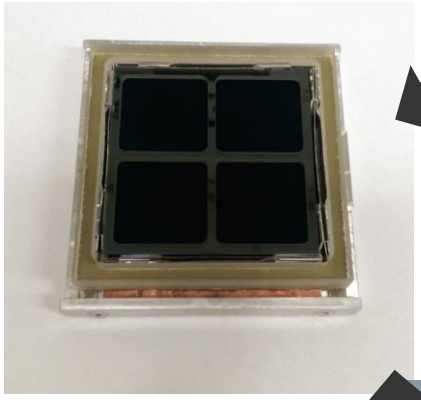
hydraulic driven platens



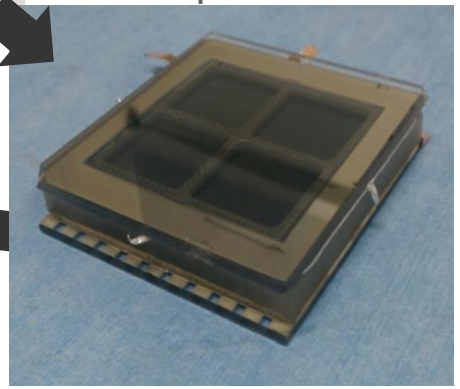
MCP & Resistive Grid Spacer Stack



Glass LTA



Completed Tube

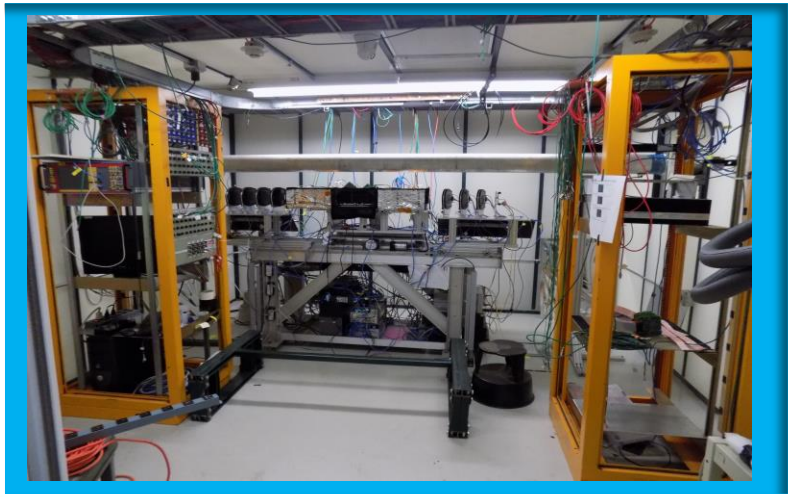


- **Tube processing is very challenging**
  - Baking, scrubbing, getter activation, compression sealing

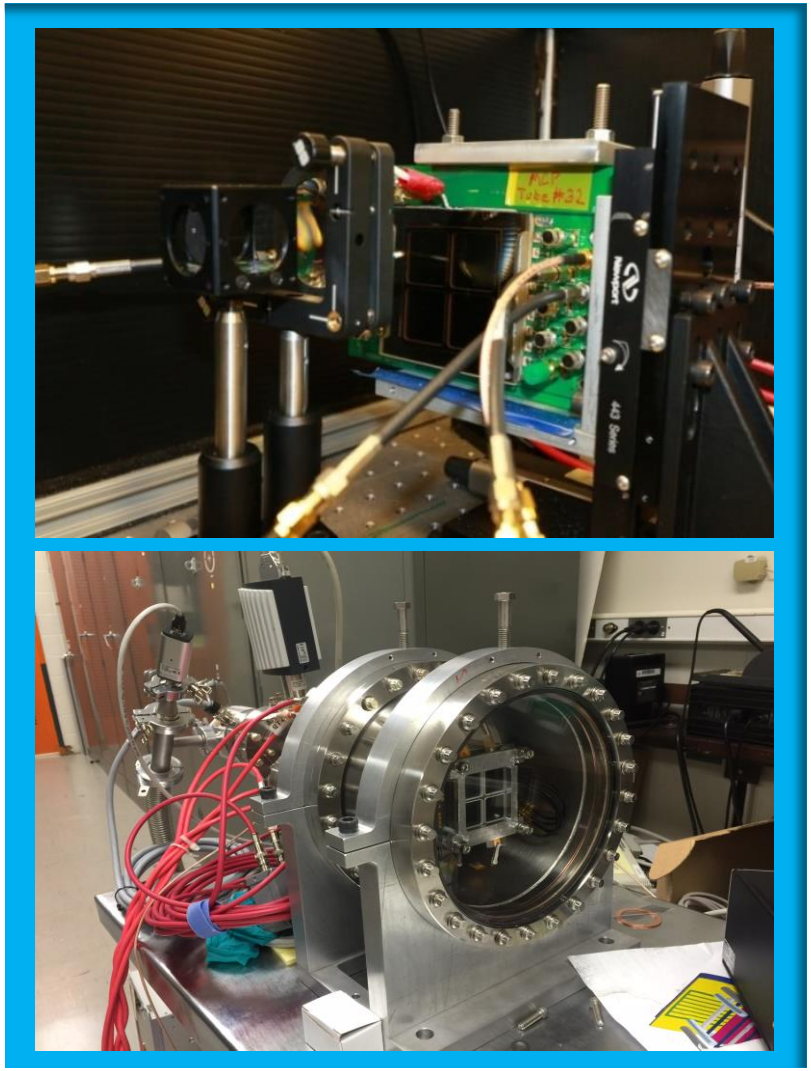
Test facilities

Optical table for QE measurement

Fermilab Test Beam Facility

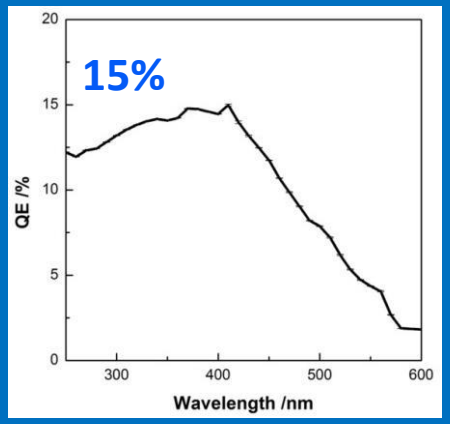


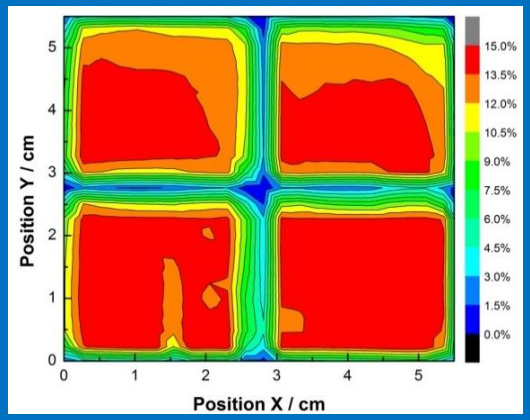
Blue laser facility: 70 ps pulse duration



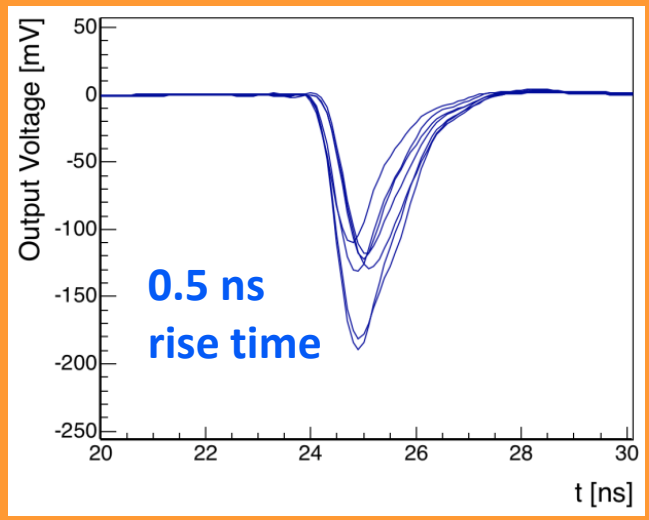
Key performances

Spectra response





Signal component

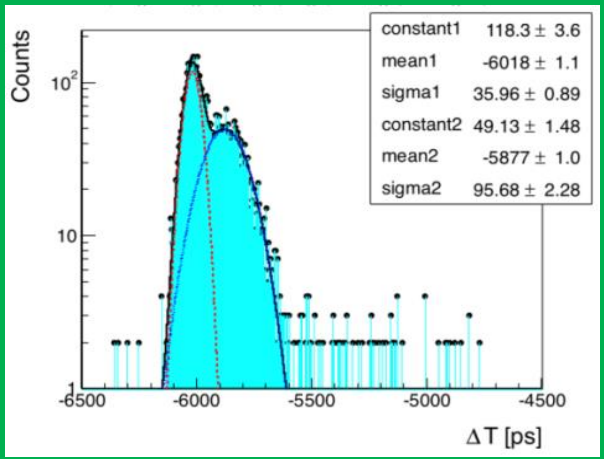


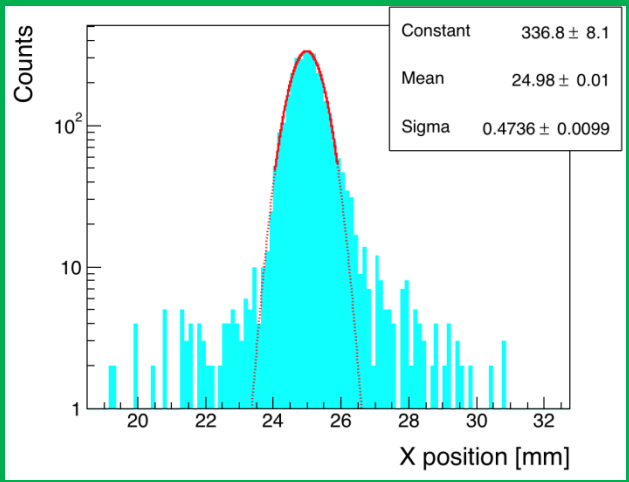
$$\sigma_{I.R.F.}{}^2 \sim \sigma_{.T_{MCP}}{}^2 + \sigma_{.T_{laser}}{}^2$$

Timing / position distributions

σ_{IRF} ~ 35 ps for SPE

σ_{TTS} ~ 20 ps



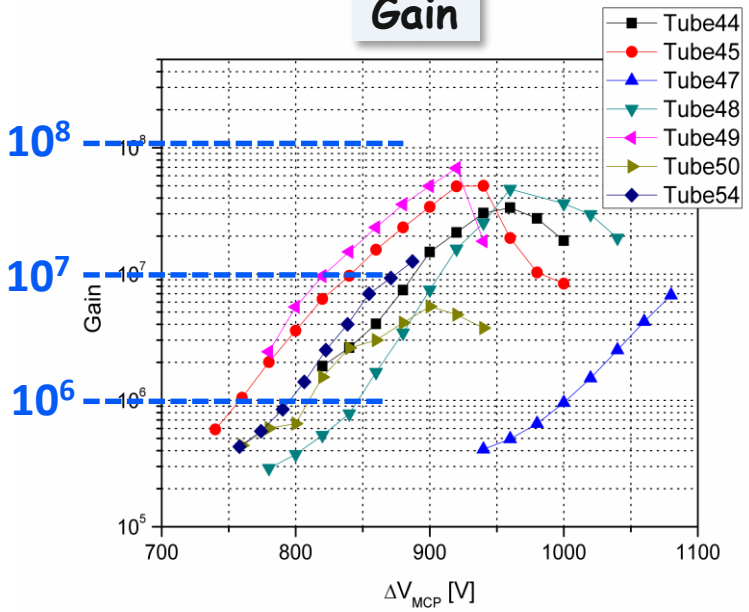


σ < 1 mm for SPE

Key performances

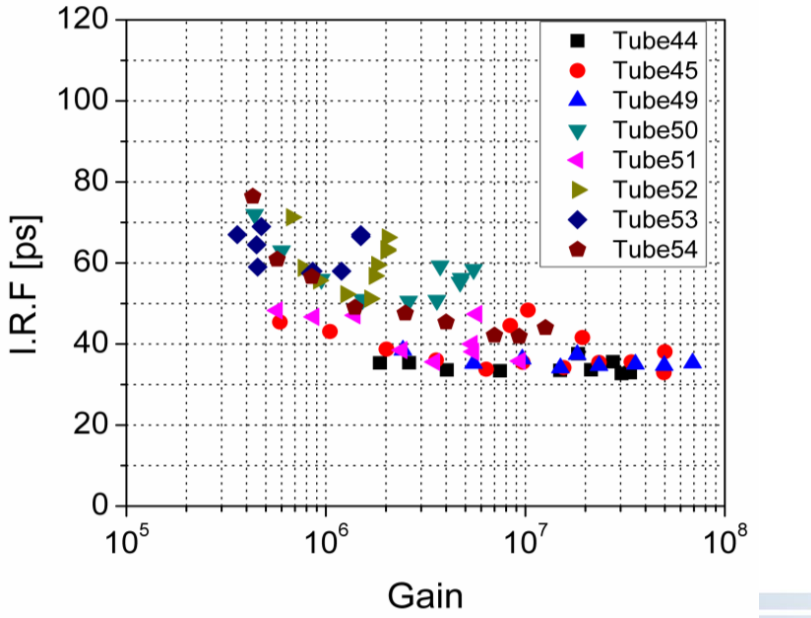
- Gain as high as **7X10^7**
- Time resolution **$\sigma_{overall}$ ~35 ps, TTS <20 ps**
- Laser start time jitter: **σ_{laser} ~30ps**
- Rate capability: **> 75KHz/cm^2**

Gain

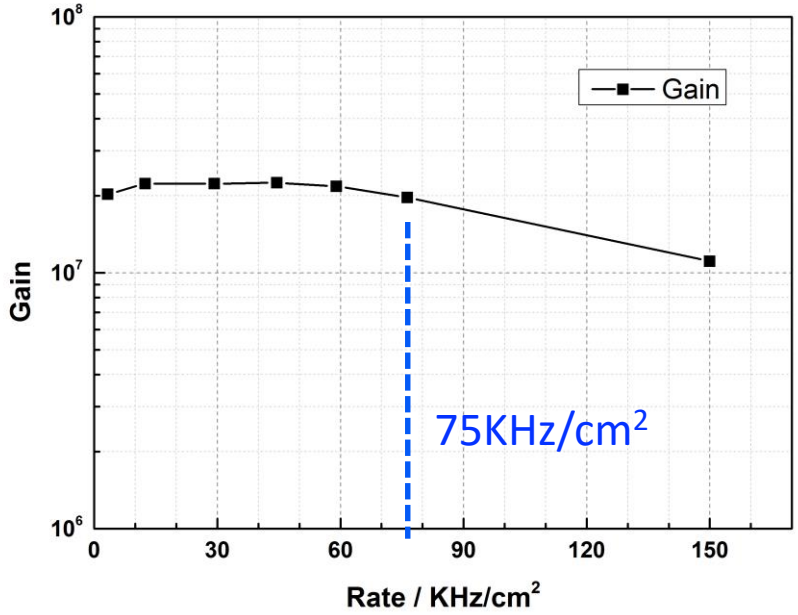


Overall time resolution

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



Rate capability



Datasheet for early users

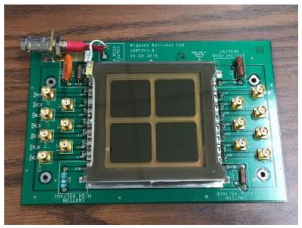
- We use the pulsed blue laser (405 nm) facility to test and characterize the 6 cm tubes.
- Standard tests are performed for each tube
  - QE spectrum response
  - QE uniformity scan
  - Overall uniformity scan
  - Gain vs HV
  - Time resolution vs HV
  - Position resolution
- Each tube is sent out to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

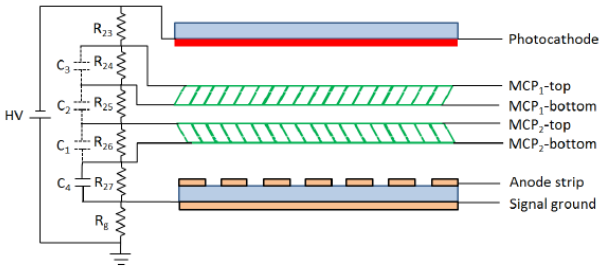
Window Material	Borosilicate glass
Window Mask	NiCr
Photocathode Type	Bialkali
Multiplier Structure	MCP chevron (2), 20 μm pore, 60:1 L:D ratio
Stack Structure	Independently Biased Design (IBD)
Anode Structure	0.47 cm sliver strip line, 0.23 cm interval
Active Area	6 cm x 6 cm
Package open-area-ratio	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. $(\sigma)^1$ / I.R.F. (FWHM)	-	35 / 90	-	ps
	T.T.S. $(\sigma)^2$ / 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



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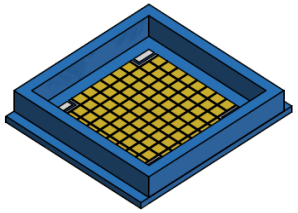
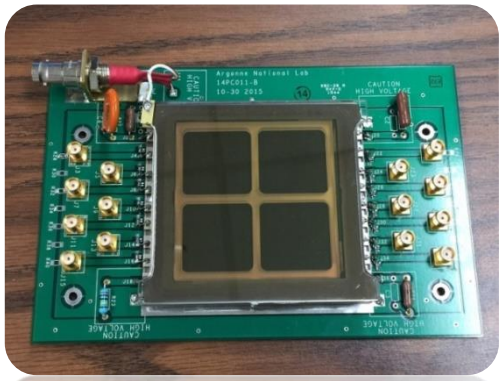
R_{26} = 5 MΩ
R_{27} = 2 MΩ
R_g = 100 Ω
R_{MCP1} = 24 MΩ
R_{MCP2} = 25 MΩ
C_4 = 1 μF
Dash line: not installed yet

Future development path

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



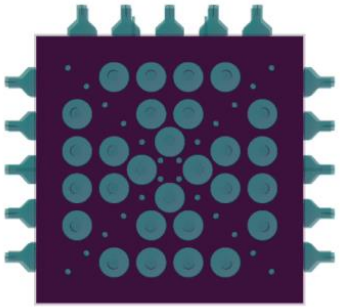


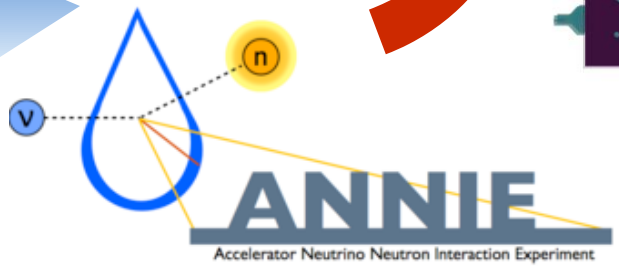
SoLID, sPHENIX, EIC, Belle II

Today

Feedback from users helps to improve the design

TARDIS





Small-scale adoption in various experiments

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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Thank you for your attention!

Questions?