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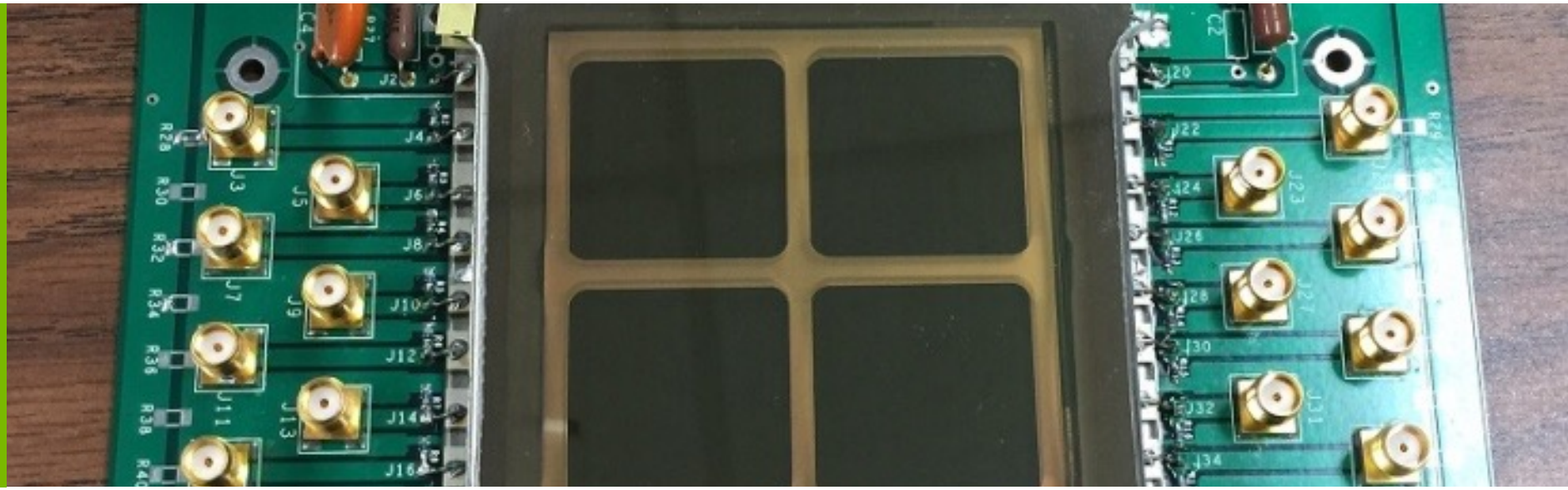


# Micro-channel Plate Based Photodetectors at Argonne


**Argonne National Laboratory**
**HEP Division, Instrumentation Group**

**RANJAN DHARMAPALAN**


CPAD 2016

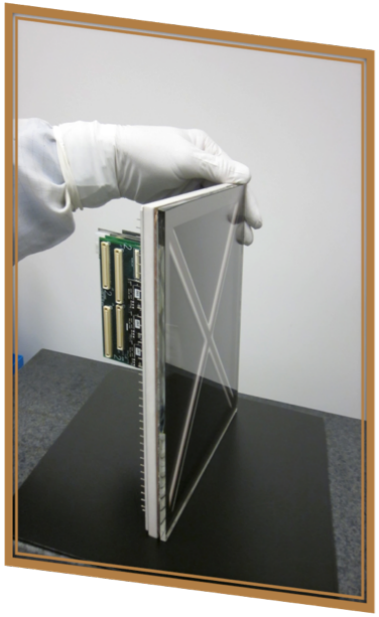
9th October 2016
Pasadena, CA

# Motivation

## Large Area Picosecond Photodetector (LAPPD)

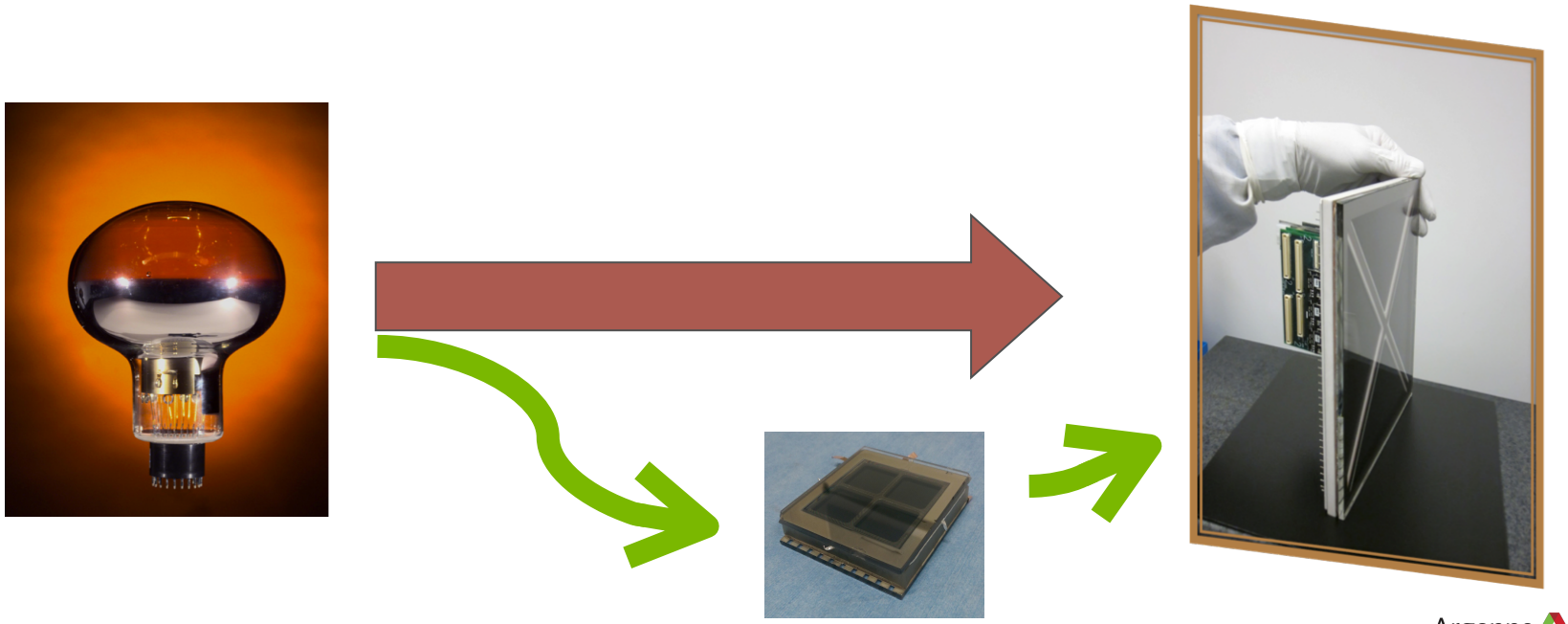
The Argonne Collaboration began in 2009 with DOE OHEP funding: to reinvent photodetectors using new technologies:

- New MCP: borosilicate glass capillary array coated by Atomic Layer Deposition (ALD). Very robust, large-area. High gain: secondary emission layer can be engineered by ALD
- New packaging: all-glass package with an indium seal

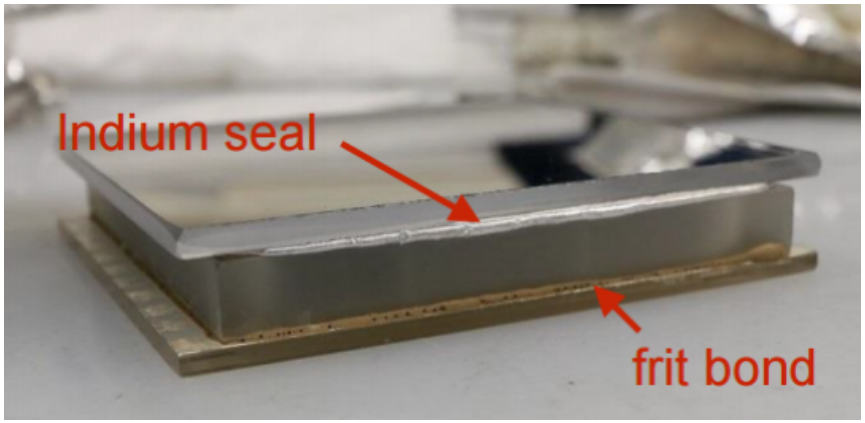


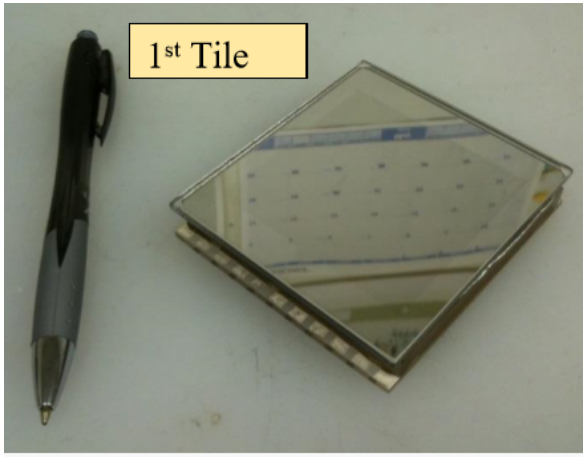
# Argonne MCP-PMTs

- Argonne is focussed on producing 6x6 $cm^2$ small form-factor detectors, as a way to optimize the manufacturing process, for testing and getting devices out to the community.



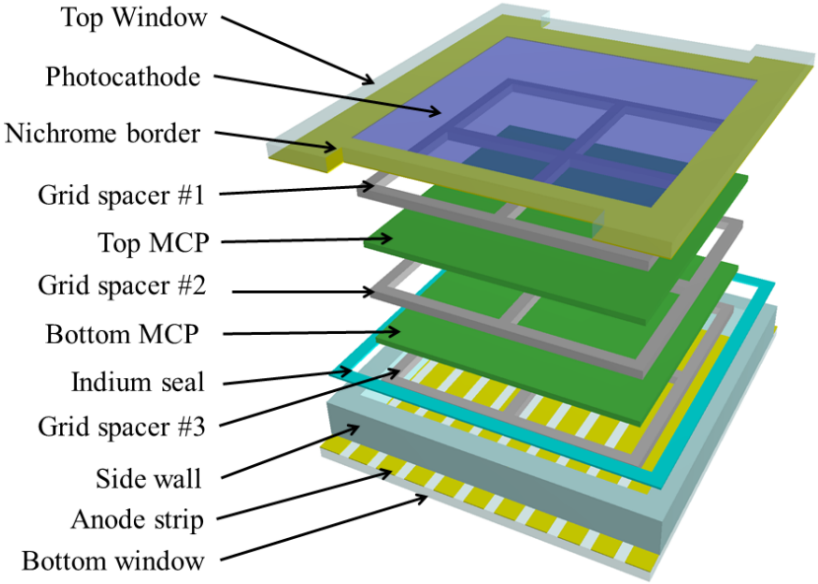
# Argonne MCP-PMT Photodetector Program Goals

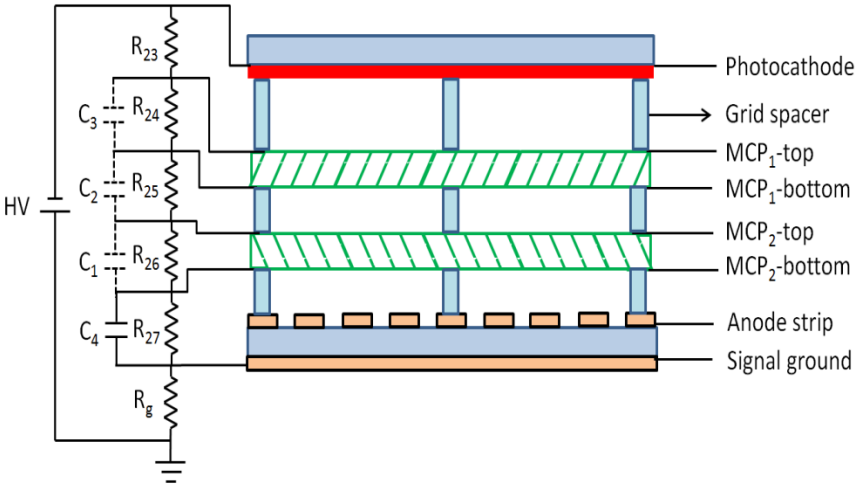



- Demonstrate the feasibility of the production of glass body MCP photodetectors
- Produce the first functional devices and provide them to the community for evaluation and incorporation into experiments
- Support the industry for commercialization of large-area devices, ALD, glass package, thermal pressure seal, testing…
- Provide a flexible platform for further R&D efforts (high B-field application, cryogenic application , VUV response, thermal neutron detection…)

# ANL 6 cm × 6 cm Photodetector



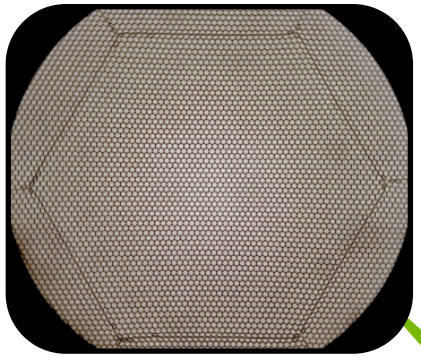




- A glass bottom plate with stripline anode readout
- A glass side wall that is glass-frit bonded to the bottom plate
- A pair of MCPs (20μm pore) separated by a grid spacer.
- Three glass grid spacers.
- A glass top window with a bi-alkali (K, Cs) photocathode.
- An indium gasket between the top window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

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

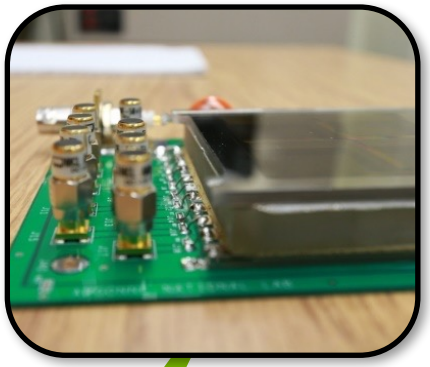
# Argonne MCP Photodetector Program

ALD-MCP

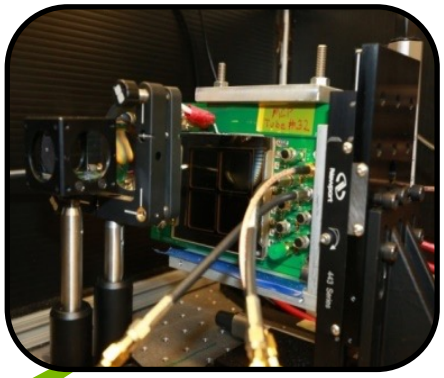


Photocathode

Packaging

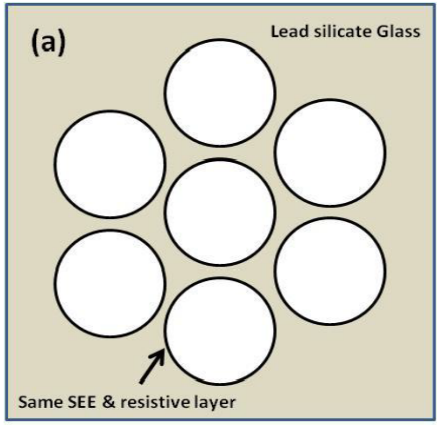


Testing

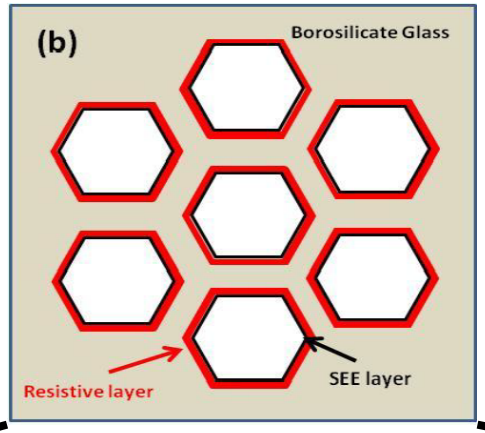


# Micro-channel plate by Atomic Layer Deposition

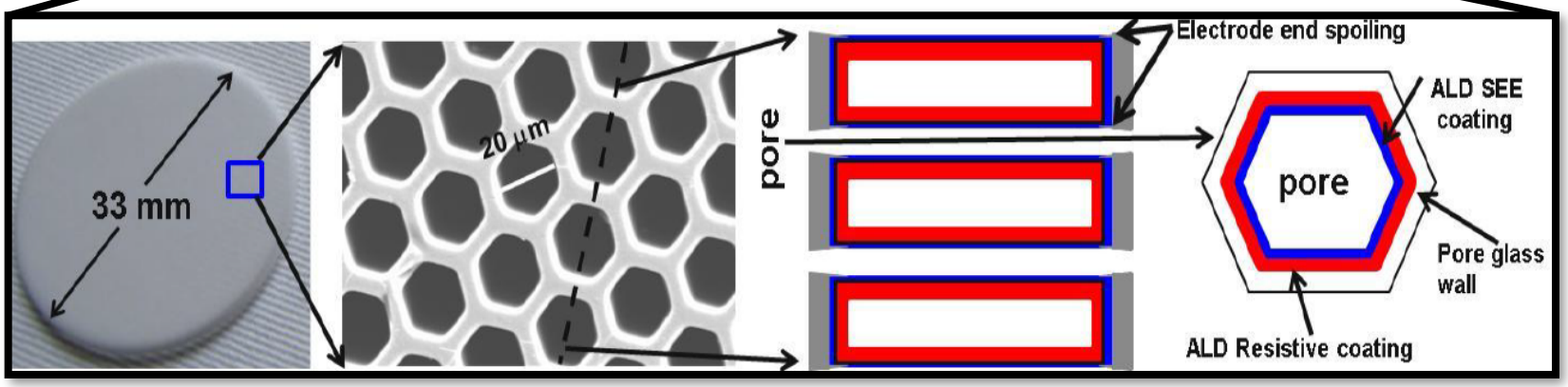
## Conventional route




## ALD route

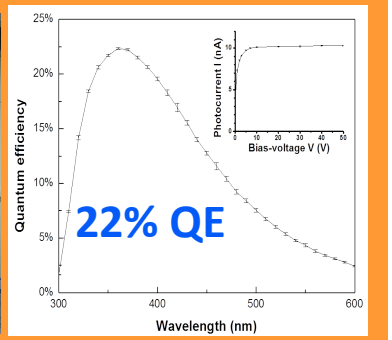



- **Conventional MCP:**
  - Pb-glass provides **pores**
  - Pb-glass provides **resistive layer**
  - Pb-Oxide **emissive layer**
- **ALD-MCP:**
  - New glass substrate from Incom.
  - **Resistive/emissive layers by ALD**
  - **Price reduced. Freedom to tune capabilities (high-rate, cryogenic applications)**

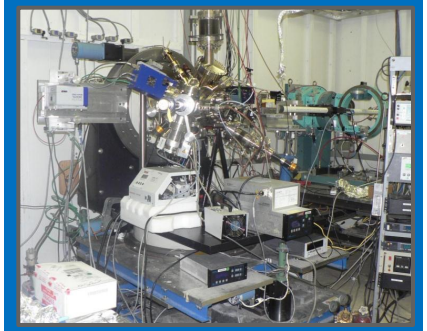


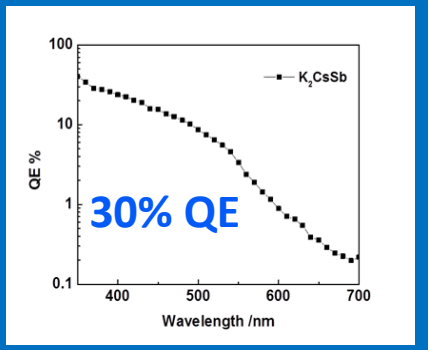
# Photocathode development at Argonne

Commercial Burle facility




X-ray study to enhance QE



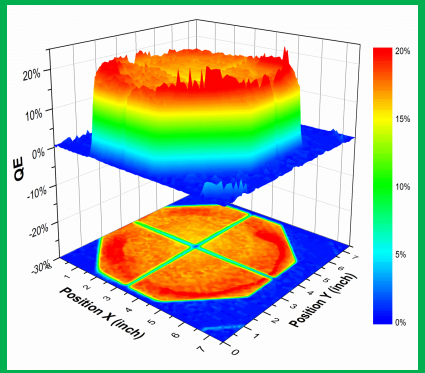



Improving QE; study VUV photocathode

Jan. 2011 | Jan. 2012 | May. 2013 | May. 2015 | Recent

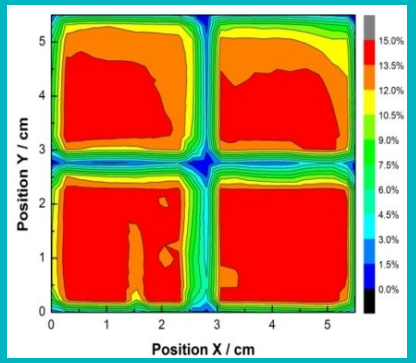
7” photocathode

20% QE

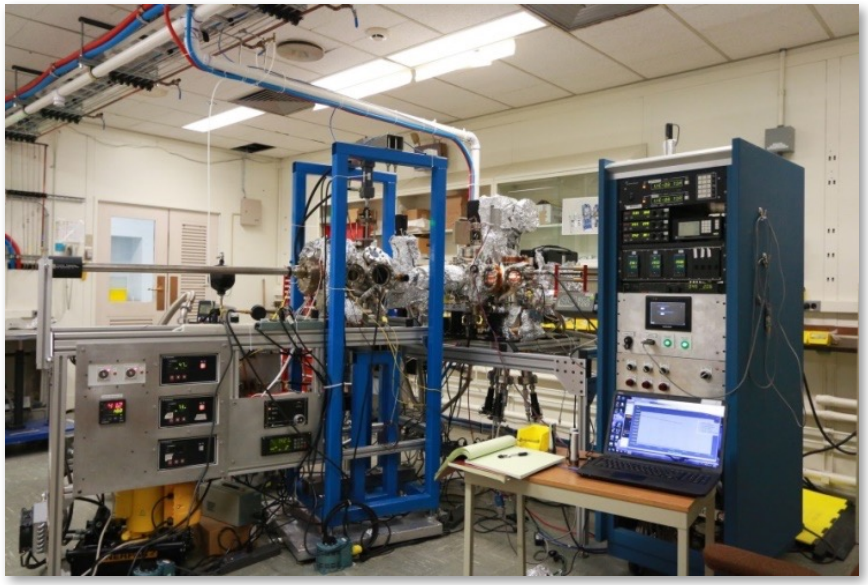


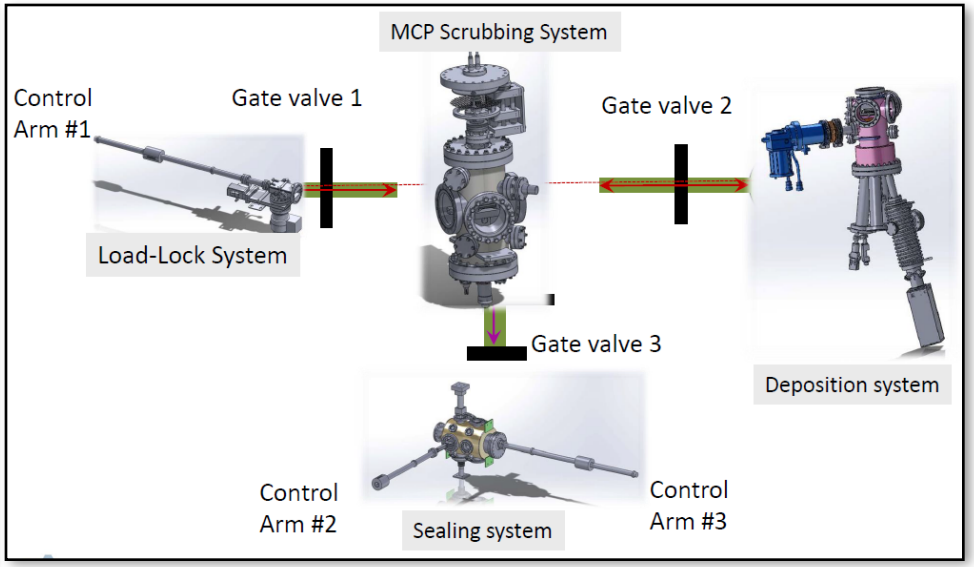

6 cm sealed tube

13% QE, goal is 20%



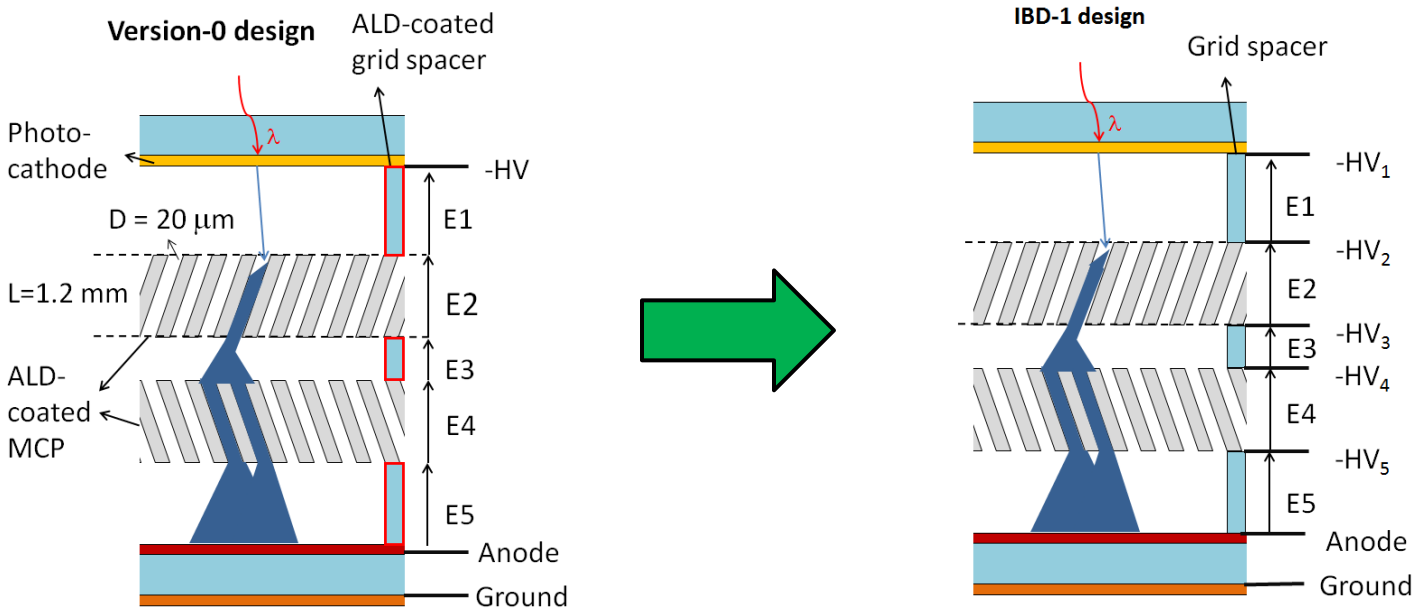
# Small Single Tube Processing System (SmSTPS)






- 6x6 $cm^2$ MCP photodetector assembly
- Features:
  - Vacuum transfer system : external magnetic arm
  - Each process is done in its own chamber: very flexible for R&D
  - **Thermo-pressure indium seal** using hydraulic driven plates : demonstrated for large-area (20 cm × 20 cm tiles);
  - **Effusion cells** for bi-alkali photocathode deposition: efficient method for mass production
- Serves as a flexible platform for R&D needs to address new requirements
- Current status: $10^{-10}$ Torr, one tube / 2 weeks

# IBD-1 Design MCP-PMTs

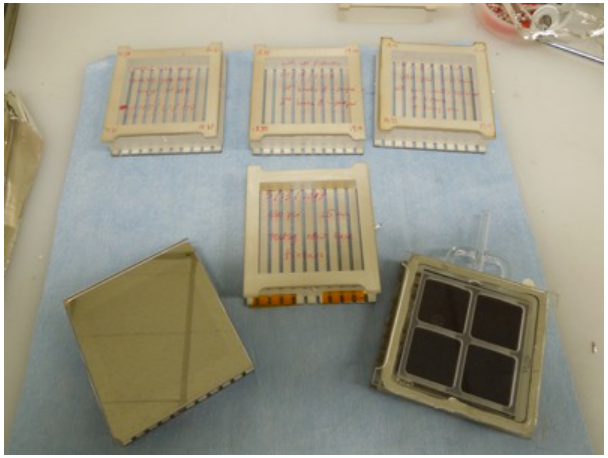



- **Internal resistor biased design (original LAPPD design): grid spacers are resistively coated**
  - No direct way to measure QE in sealed tube
  - Need fine matching between component resistances
  - Can't optimize each internal component
- **Independently biased design (IBD-1): grid spacers are insulators**
  - **Performances significantly improved after HV optimization: 65 ps -> 35 ps**
  - **This new biasing design in glass-body has filed a patent**

# Status of the tube production

- **The 1st production run began in 07/2014 and concluded in 12/2014**
  - Addressed many issues (baking and scrubbing, sealing, outgassing control…)
  - Produced 6 working devices, **3 long-lived (>1 year).**
  - Discovered limitations of the first design: no HV access to the internal components
- **The 2nd production run began in 06/2015 and concluded in 12/2015**
  - Improved design: allows **HV optimization for each component**
  - Produced 10 detectors with a **100%** sealing yield and 90% production yield.
- **The 3rd production run has just started:** more working detectors
- **Now on track of providing photodetectors to the community.**

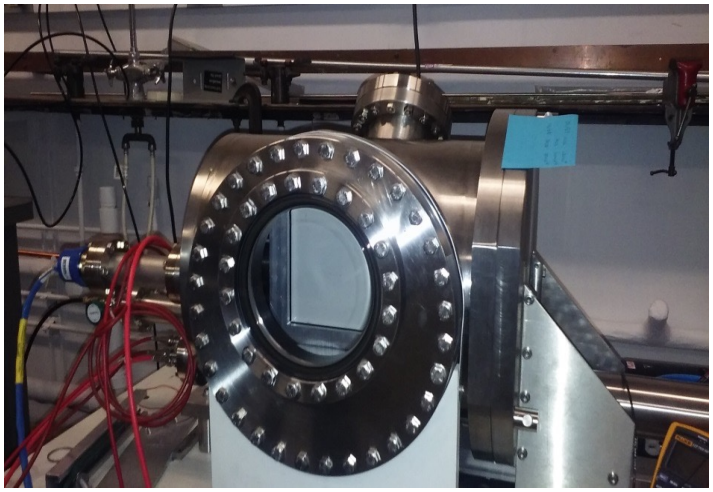
Sealing trials



Working detectors

# Testing and Characterization

Phosphor screen chamber for MCP test



Photodetector laser test stand

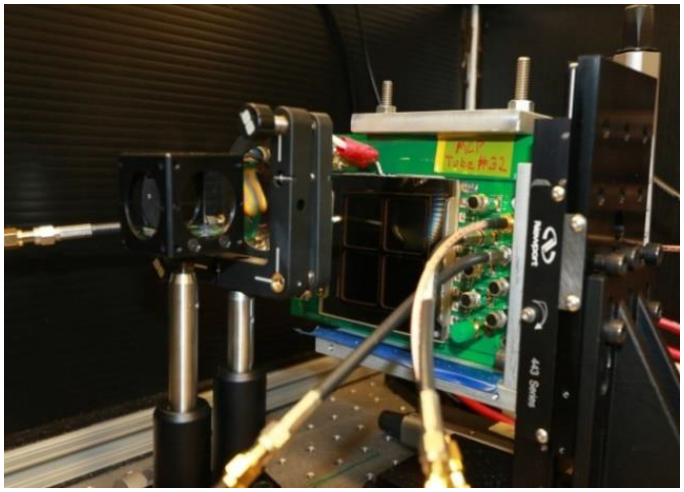
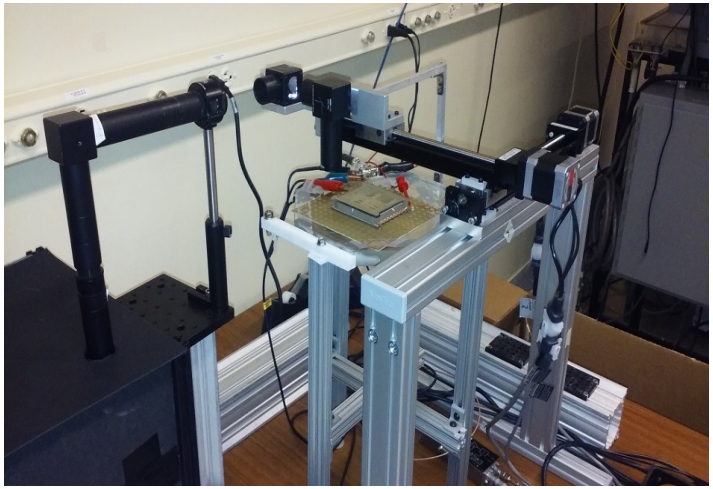
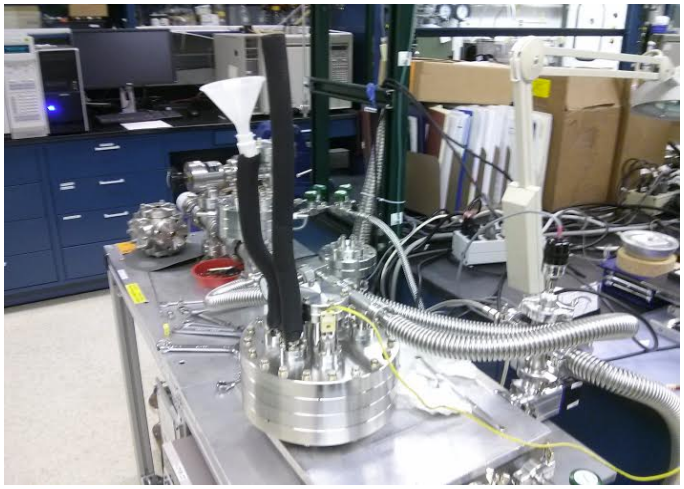


Photo cathode test stand



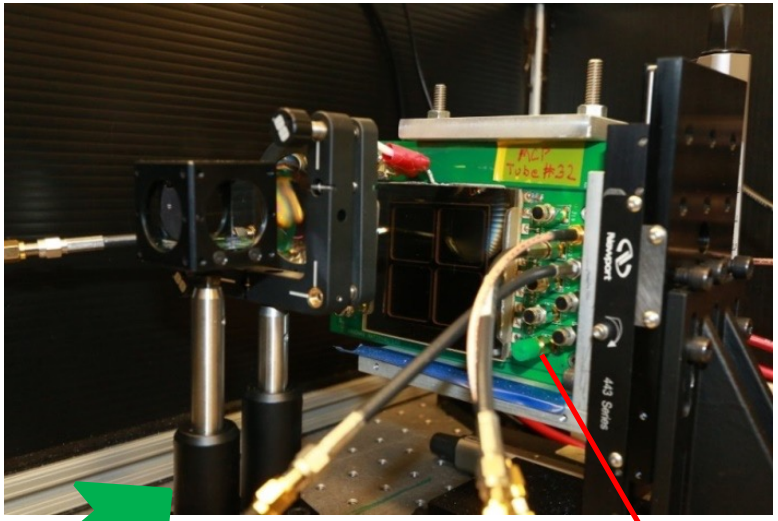
Cryogenic test setup

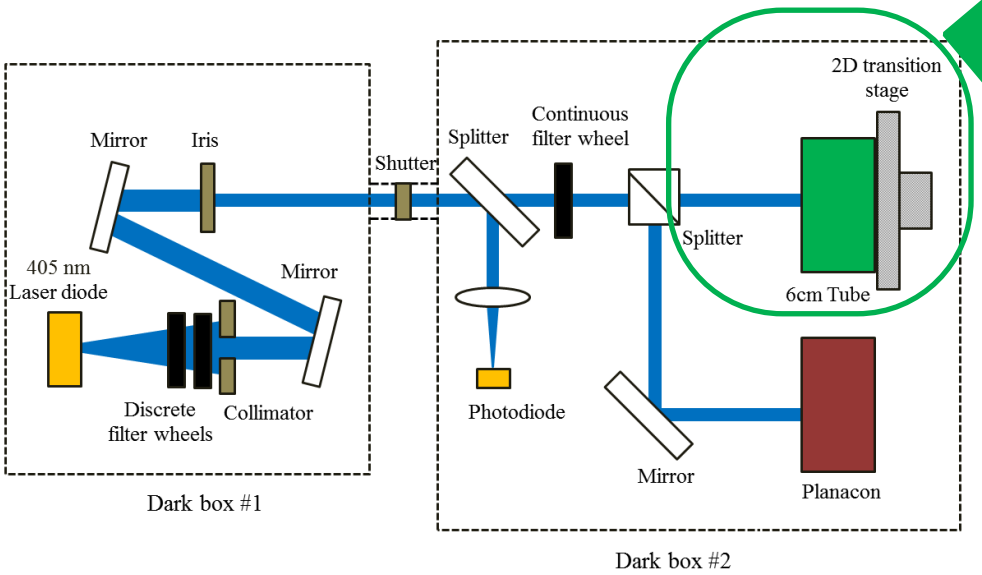


# Laser Test Facility

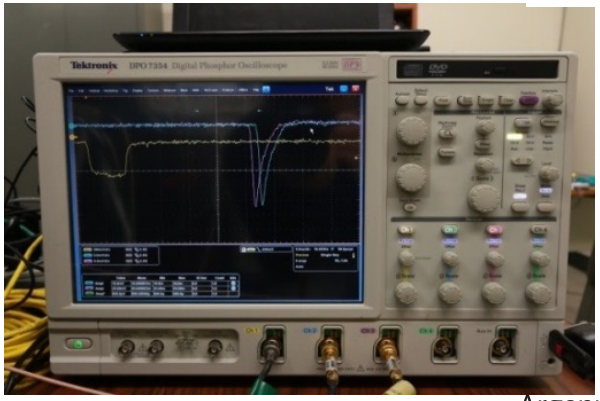
- Hamamatsu PLP-10 pulsed blue laser
- Wavelength: **405 nm**
- Pulse duration: FWHM = 70 ps (**σ = 30ps**)
- Frequency: 2 Hz – 10 MHz
- Beam size: ~1 mm
- Start signal: laser synchronization pulse
- Translation stage: um precision
- Readout: Programmable Oscilloscope
- Data analysis: Waveform sampling, offline

Dark box #2





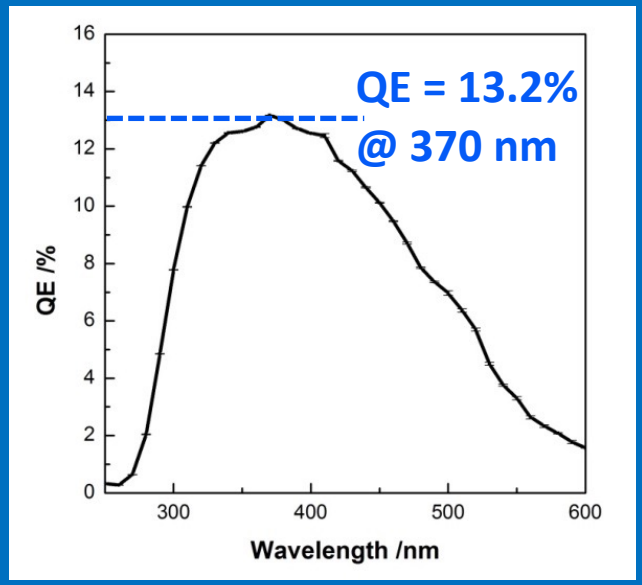

40 Gs/s scope



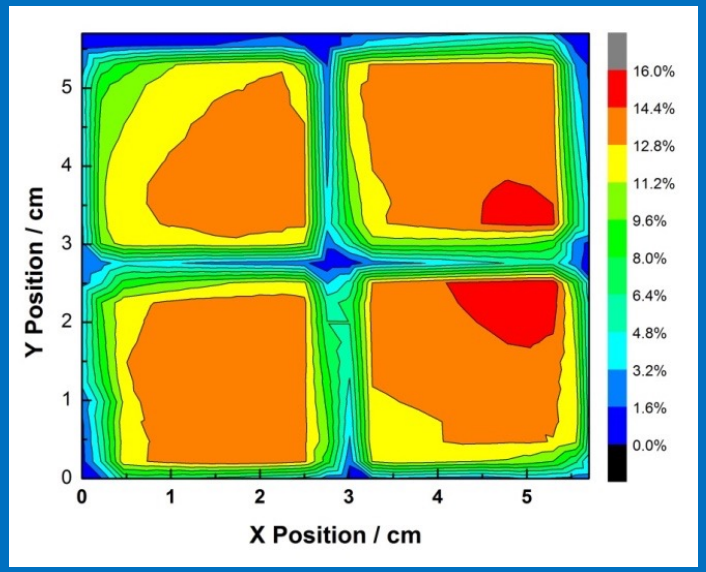
Readout board

# Key performances: Quantum efficiency

QE Spectra response




QE 2D map

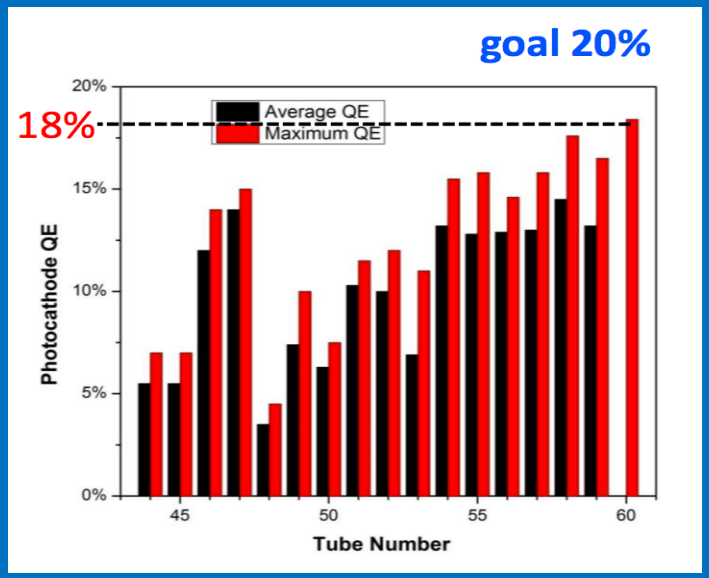



**QE = 13 %**

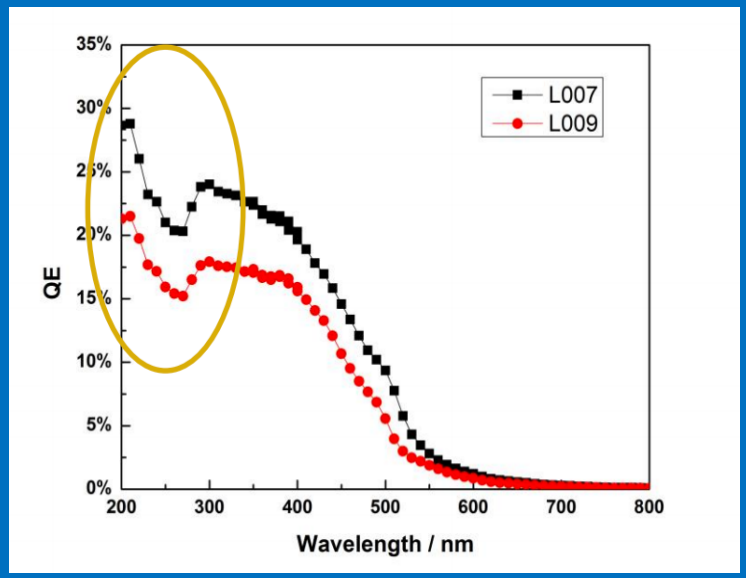
**15.5% maximum**

# Key performances: Quantum efficiency

**Improving QE**



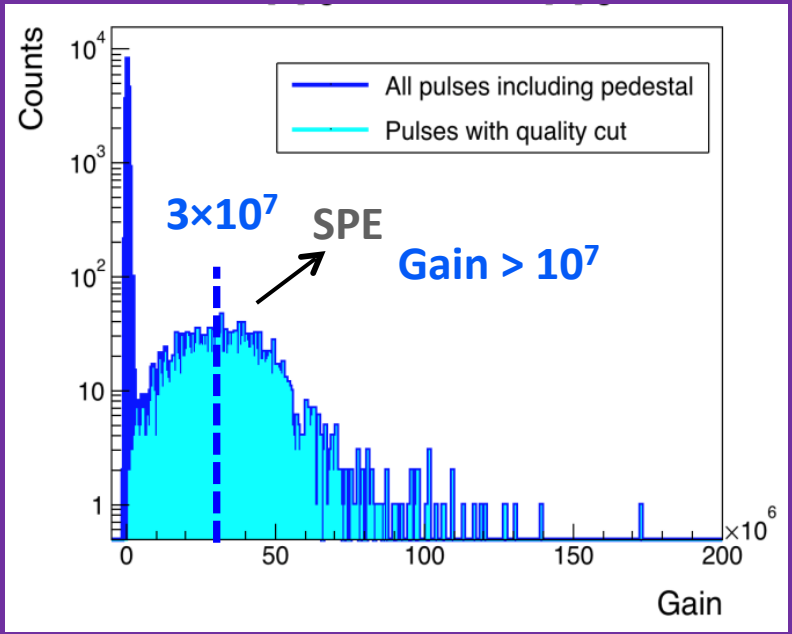

**Towards UV**



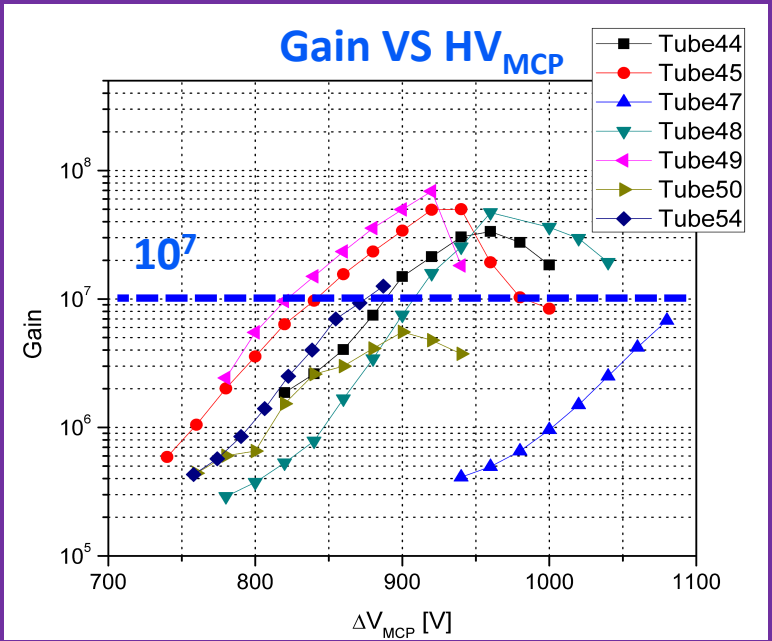

With quartz window
Interesting observation from x-ray study:
Enhanced UV photo response for bialkali photocathode!

# Key performances: Gain

**Gain distribution**

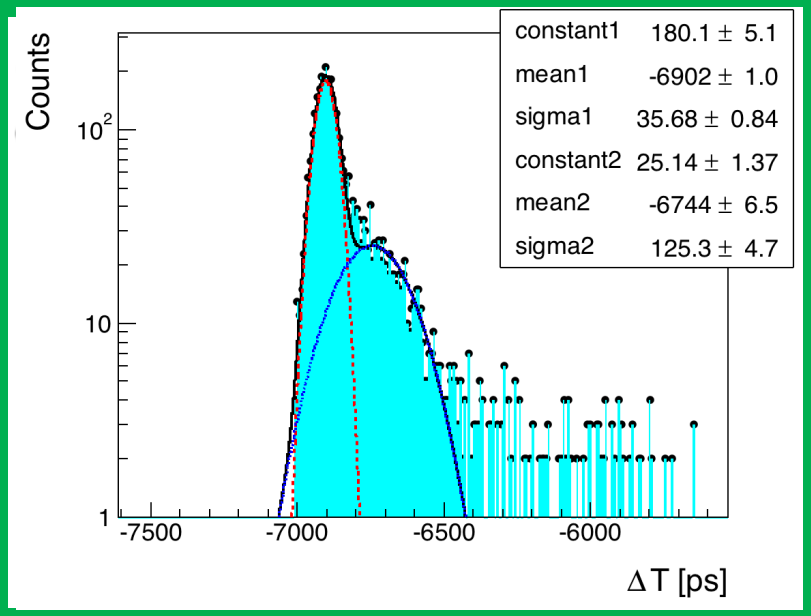



**Gain VS HV**

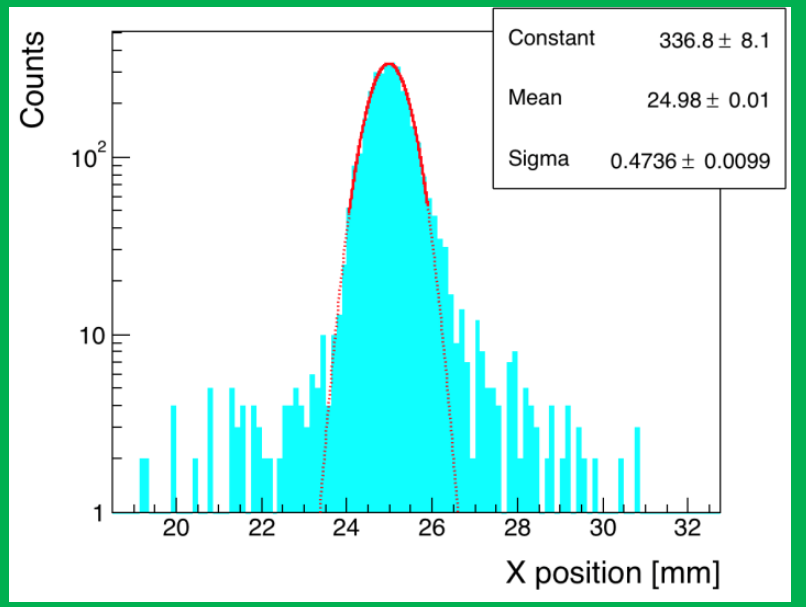


# Key performances: Timing & Postion

**Timing distributions**




**Position resolution**



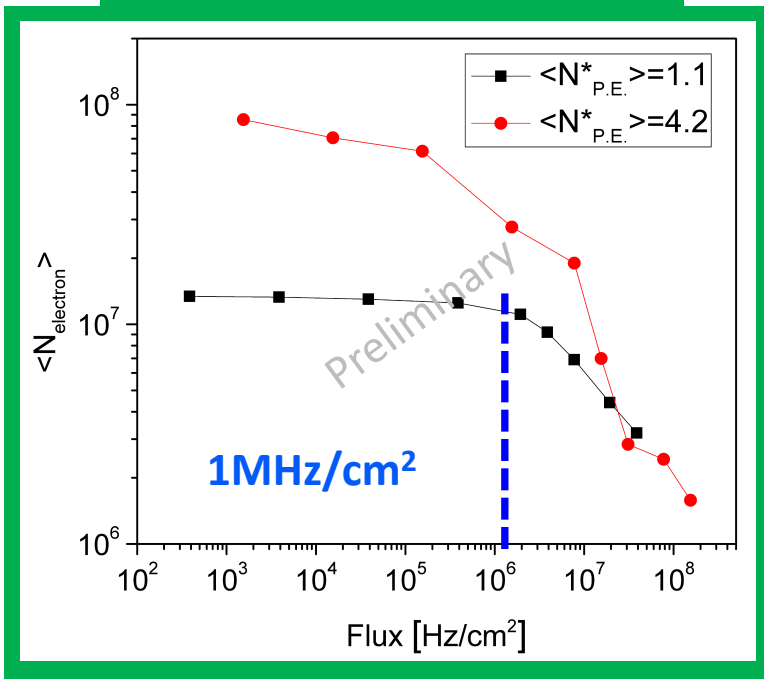

**$\sigma_{IRF}$ ~ 35 ps**
**for SPE, including**
**Laser jitter**

**σ < 1 mm**
**for SPE**

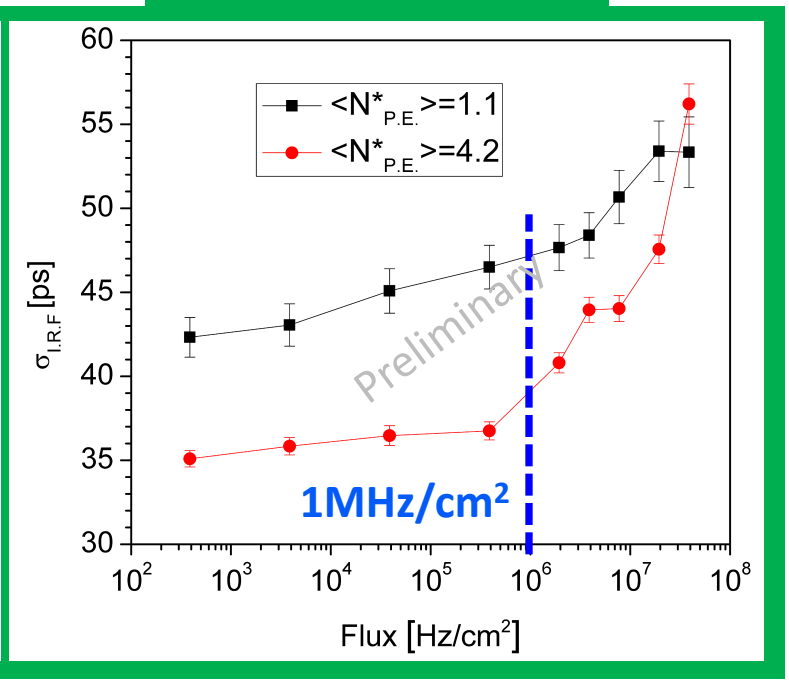
# Key performances: Rate capability

- **Rate capability** was recently measured with a pulsed laser
- Beam size is diffused: $\sigma_x = \sigma_y = 2.0$ mm, $A^* \sim 0.5$ cm$^2$

**Number of electrons VS flux**




**Time resolution VS flux**




- **HV = 2800 V, without pre-amplifier**

# Datasheet

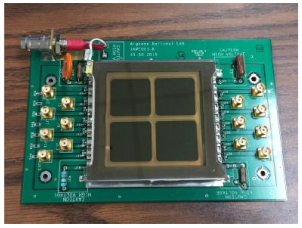
- We use the pulsed blue laser (405 nm) facility to test and characterize the 6 cm tubes.
- Standard tests are performed for each tube
  - QE spectrum response
  - QE uniformity scan
  - Overall uniformity scan
  - Gain VS HV
  - Time resolution VS HV
  - Position resolution
- Each tube will be sent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

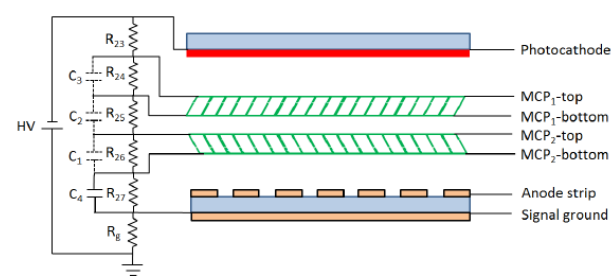
| | |
|---|---|
| Window Material | Borosilicate glass |
| Window Mask | NiCr |
| Photocathode Type | Bialkali |
| Multiplier Structure | MCP chevron (2), 20 μm pore, 60:1 L:D ratio |
| Stack Structure | Independently Biased Design (IBD) |
| Anode Structure | 0.47 cm sliver strip line, 0.23 cm interval |
| 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 | | - | $1 \times 10^7$ | - | - |
| 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

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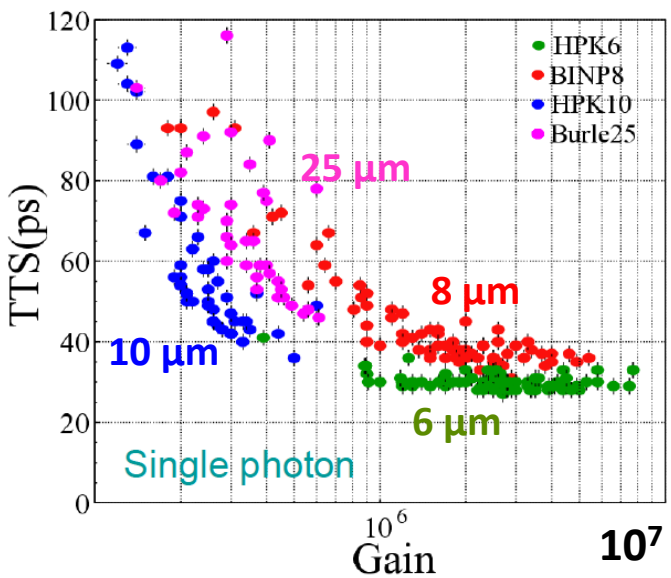
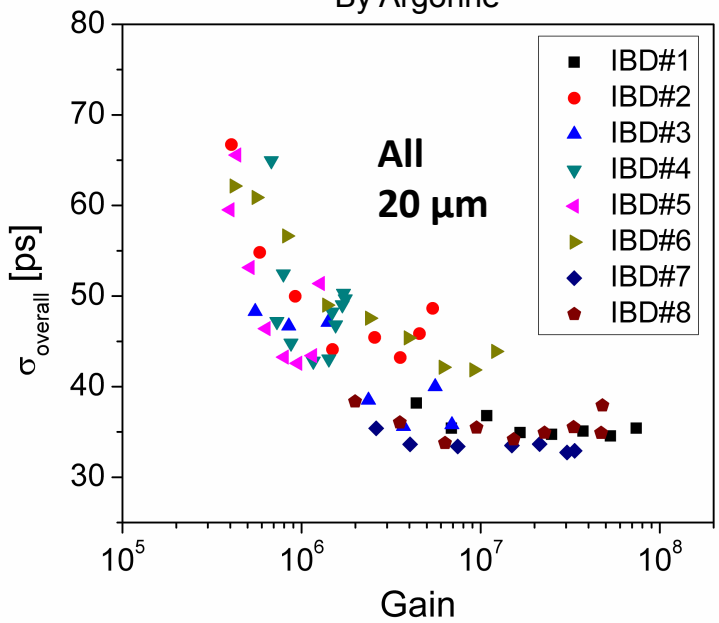
# Comparison to commercial products

| MCP-PMT | HPK6 R3809U-50-11X | BINP8 N4428 | HPK10 R3809U-50-25X | Burle25 85011-501 | ANL 6cm tube |
|---|---|---|---|---|---|
| PMT size(mm) | 45 | 30.5 | 52 | 71x71 | 85×76 |
| Effective size(mm) | 11 | 18 | 25 | 50x50 | 60×60 |
| **Channel diameter(μm)** | **6** | **8** | **10** | **25** | 20 |
| Length-diameter ratio | 40 | 40 | 43 | 40 | 60 |
| Max. H.V. (V) | 3600 | 3200 | 3600 | 2500 | 2900 |
| photo-cathode | multi-alkali | multi-alkali | multi-alkali | bi-alkali | Bi-alkali |
| Q.E.(%) (λ=408nm) | 26 | 18 | 26 | 24 | 13 |

By Nagoya University

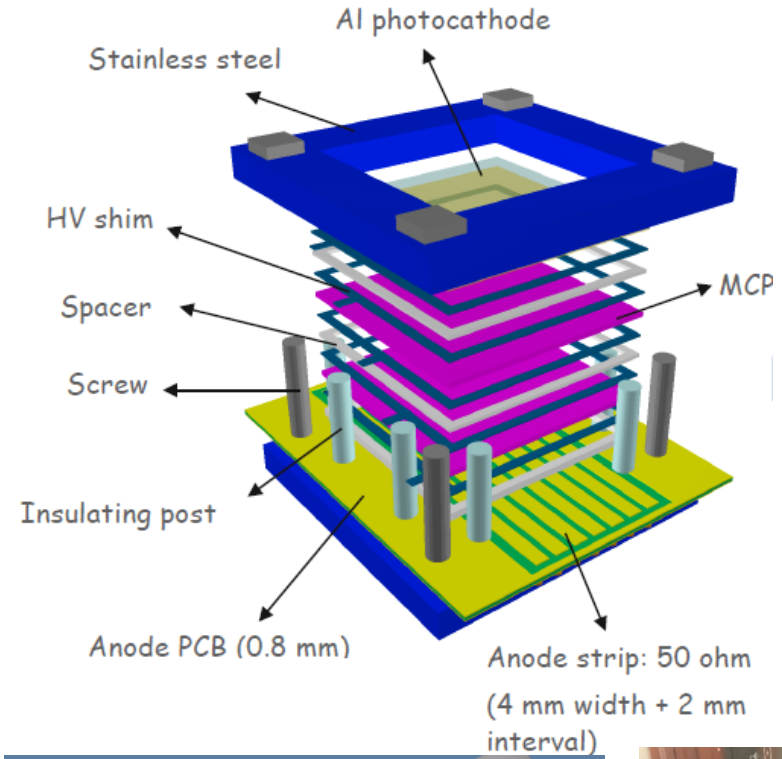



By Argonne

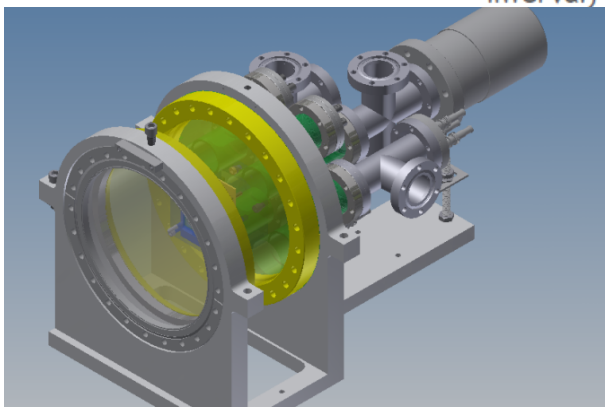


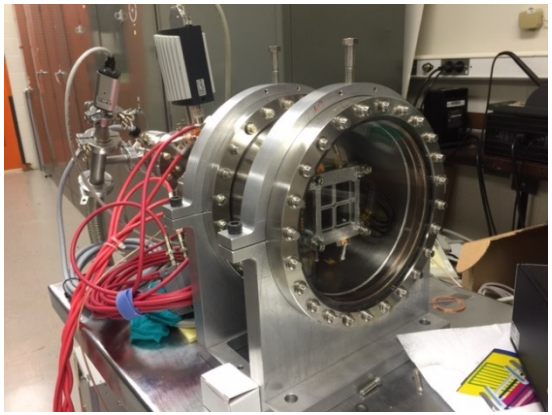

- **Pore size is an important parameter to obtain ultimate time resolution**
- **Argonne measurement includes laser jitter, the Transit Time Spread (TTS) is close to 20 ps (need to be confirmed by a faster laser)**

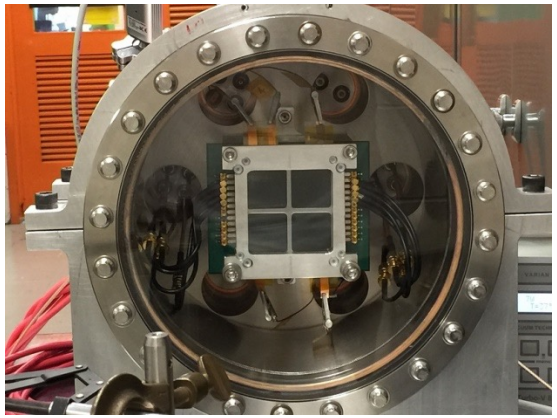
# Detector optimization




- **Test chamber**
  - The internal MCP/spacer stack can be assembled in arbitrary configuration
  - Allow to optimize the detector design without building a lot of sealed tubes
  - To do: improvement on timing and B-field performance
  - Allow to study other ideas: neutron detection, x-ray detection…

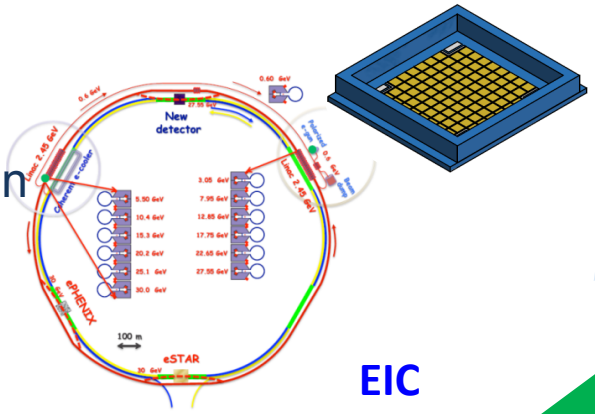






# Future development path

- High QE over 20%
- Geometry optimization
- Pad readout design
- …

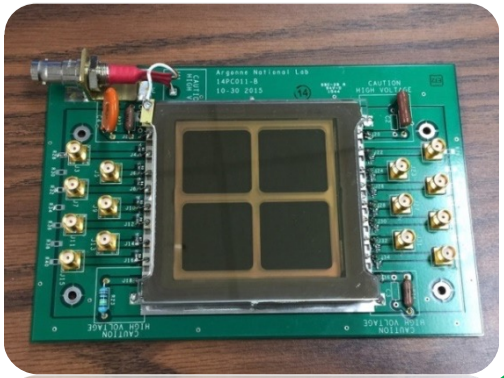




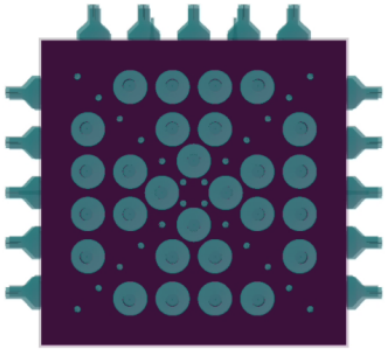

Others: SoLID, BELLE II…

EIC

Today



Feedback from users helps to improve the design



TARDIS

ANNIE

annie

**EIC**: **E**lectron **I**on **C**ollider
**ANNIE**: The **A**ccelerator **N**eutrino **N**eutron **I**nteraction **E**xperiment
**TARDIS**: **T**iming and **A**dvanced **R**econstruction **D**one **I**n **S**cintillator

# Summary

- The Argonne MCP photodetector program has been successful, benefiting from advances in different disciplines.
  - **Completed >13 working Photodetectors; achieved 100% sealing yield**
  - **Gain > $10^7$;**
  - **Time resolution including the laser jitter: $\sigma_{I.R.F}$ ~ 35 ps;**
  - **Position resolution along the anode strip: < 1 mm**
  - **Rate capability > 1 MHz/cm$^2$ for single photoelectrons**

- The Small Tube Processing System is an **ideal R&D platform** for addressing new requirements and studying new ideas (VUV photocathode, cryogenic application, thermal neutron detection…).

- On track of providing photodetectors to the community for evaluation and testing: ANNIE, TARDIS, Proto-DUNE, EIC, BELLE II…

- You are welcome to discuss with us about your requirements and ideas.

# backups

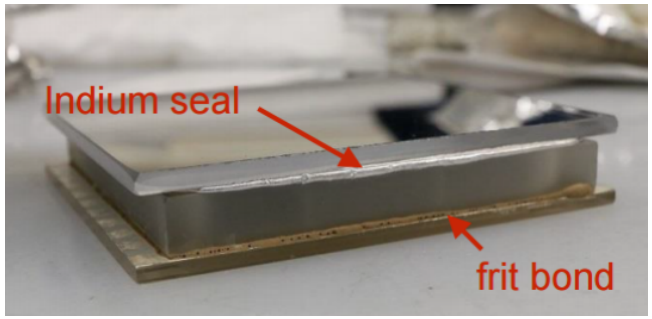
# Cryogenic detector

- **Structural integrity**, mainly the indium seal and frit bond, cause some worry
  - Work already done: sealed and devices 'dunked' into liquid nitrogen
  - → MCP photodetector with glass package DO survive in cryogenic environment

- **Detector window:** quartz or $MgF_2$ with VUV photocathode (CsI) for direct VUV detection

- **Cryogenic MCP**
  - Current MCP resistive coating will lose its conductivity at cryogenic temperature
  - → Working on tuning the ALD recipe to bring down resistivity

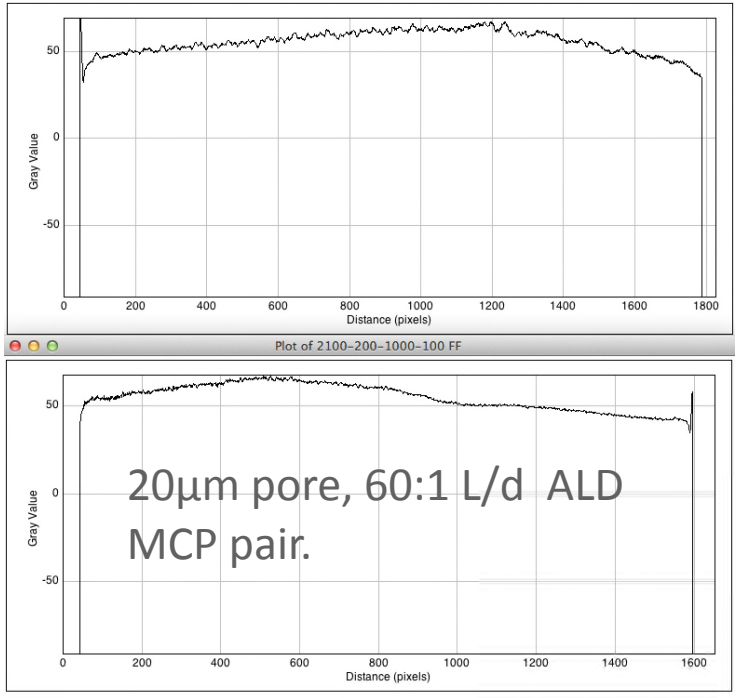
  Also need to verify the ALD secondary emission layer properties at cryogenic temperature



# Performance of ALD-MCP

- 20 µm pore, 60:1 L/d ALD MCP pair.
- Uniformity was measured for a 20cm x 20cm MCP pair with MgO Secondary Emission Layer.
- Average gain ~ $7 \times 10^6$
- Map shows <10% MCP gain variation

Relative gain



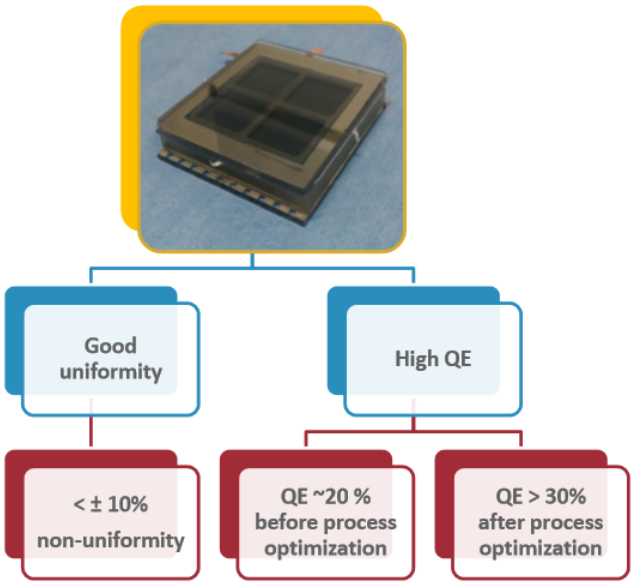

**Average gain image "map"**

- Transformative Technology
- Worlds largest MCPs
- Competitive gain
- Competitive life times
- Lower background, dark current
- Mechanically robust

20 cm × 20 cm

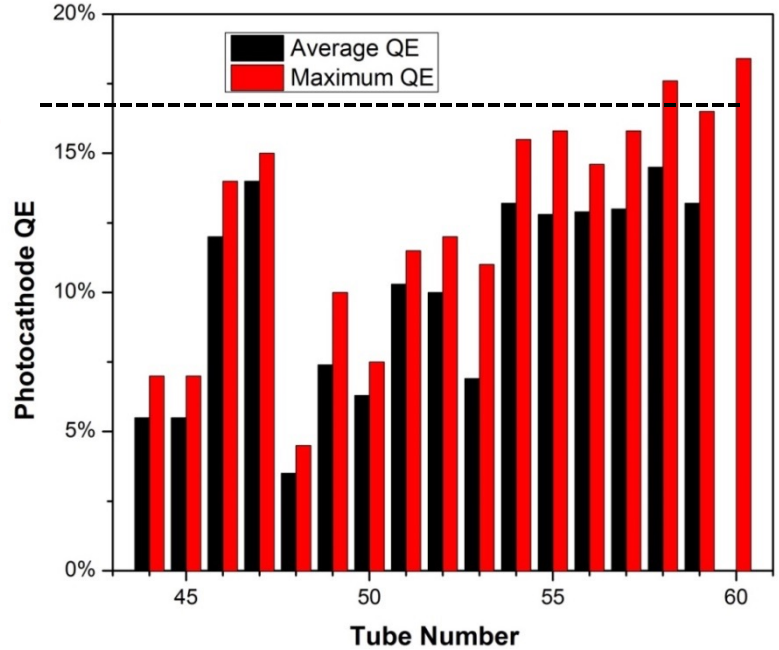
# QE improvement

Goals:




goal 20%

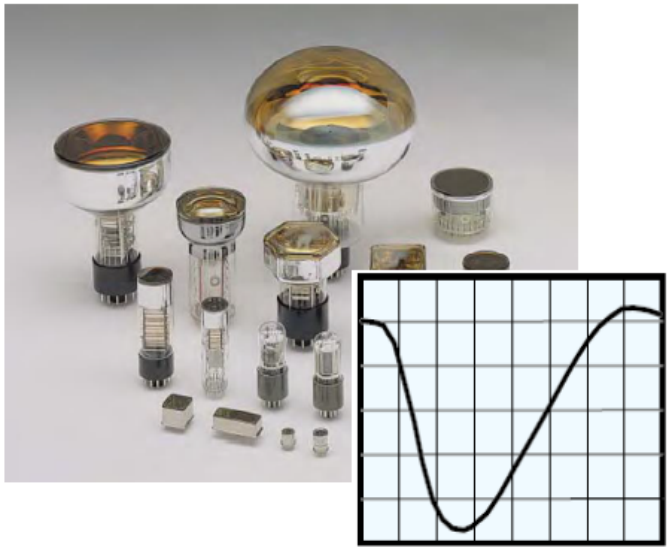
18%




- **Understanding the issues:**
  - ✓ Anti-reflection layer is missing; plasma generator under repair)
  - ✓ Halogen lamp heater not uniform; need a rotation stage
  - ✓ MCP outgas and getter material activation may contaminate the chamber
  - ✓ Cooling time is too long
  - ✓ Enhance light collection by means of internal reflective surface coating

# Motivation

## Traditional PMTs vs MCP-PMTs

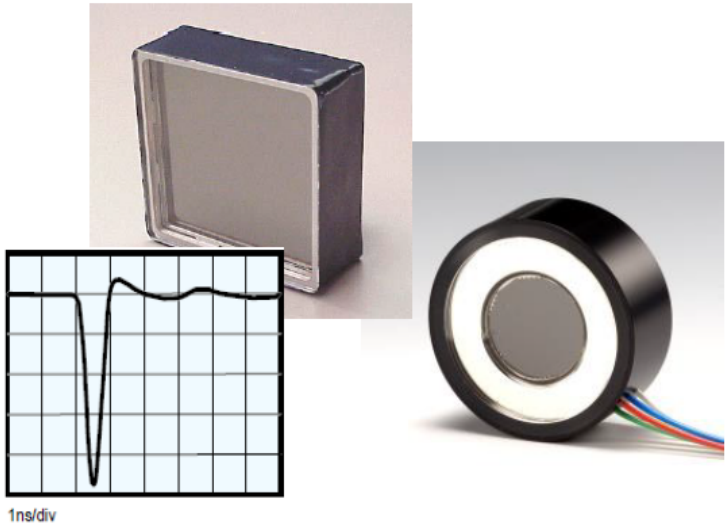



- Successful technology over decades
- Sensitive to single photons
- Good Quantum efficiency
- Rather fast: several hundred ps time resolution
- But…

  Limited position resolution

  Not suitable to high B-field

  large-area PMTs are still bulky

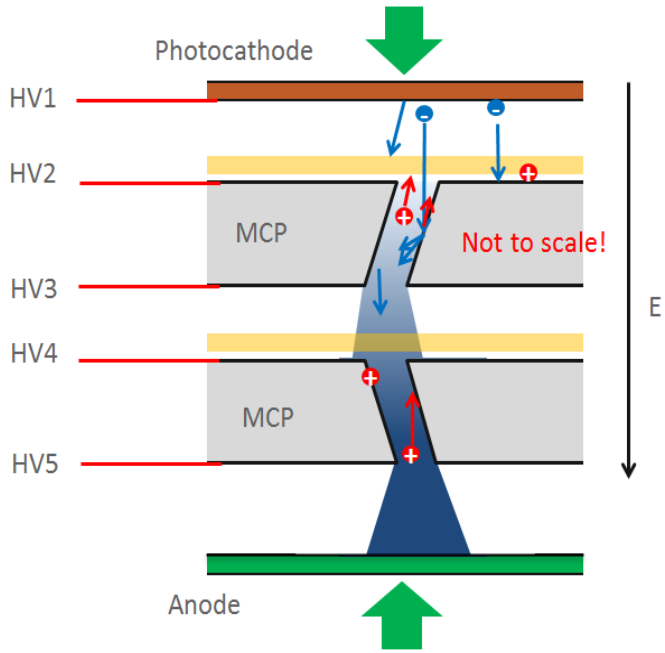



- Compact structure
- Tens of picosecond level time resolution
- Micron-level position resolution
- Good B-field performance
- But…

  High cost

  Limited size area

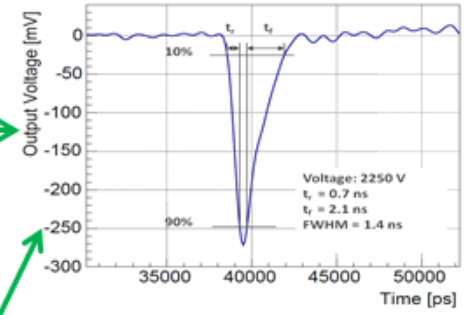
# Detector optimization




Done

HV optimization

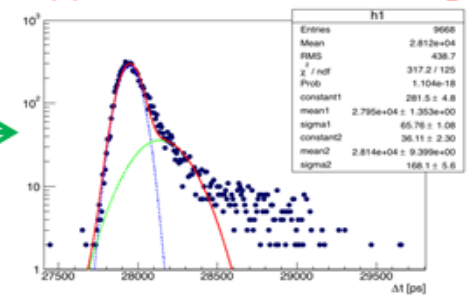
Improve time resolution




Next step

Geometrical modification

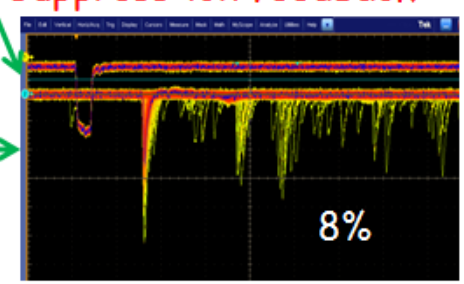
Suppress Back scattering




Near future

Ion protection layer

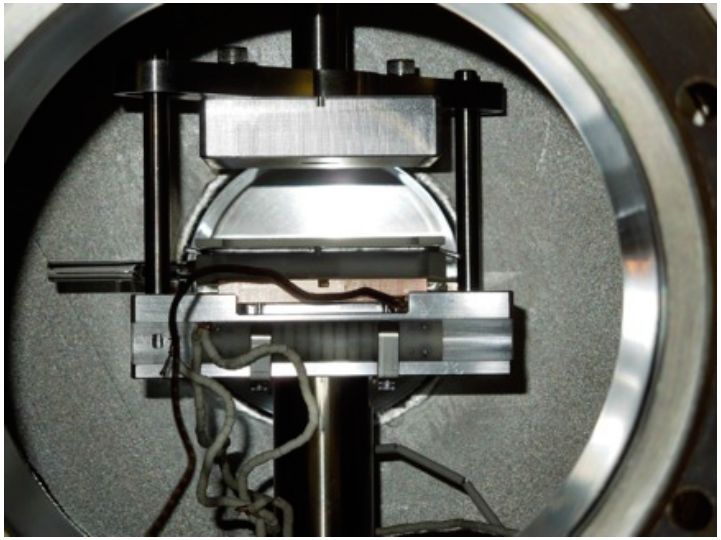
Suppress ion feedback




Aluminum Ion protection layer significantly suppresses the ion feedback, but lose 50% of electrons.

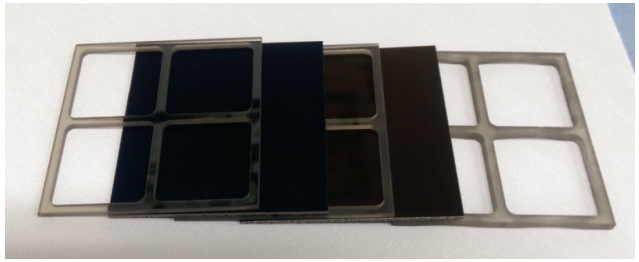
# Tube processing

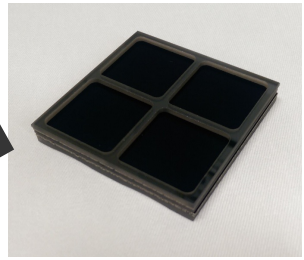
hydraulic driven platens



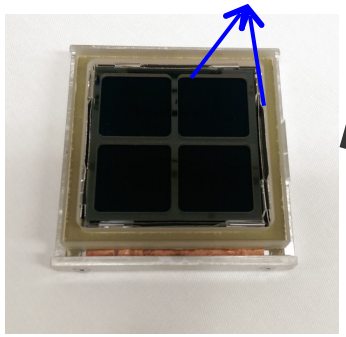
- **Tube processing steps**
  - Baking & scrubbing
  - Getter activation
  - Photocathode deposition
  - Thermo-pressure indium seal
- Solved problems and achieved a reliable seal
- Current status: $10^{-10}$ Torr, one tube / 2 week
- Production rate can be improved

MCP & Resistive Grid Spacer Stack

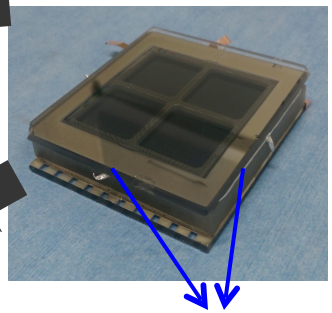




Tile base Getter strips

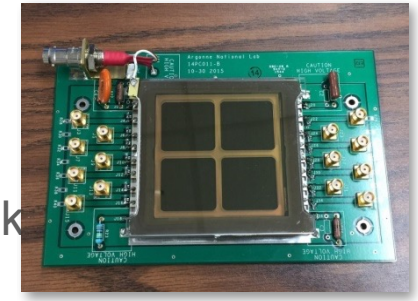


Sealed tube



Indium gasket

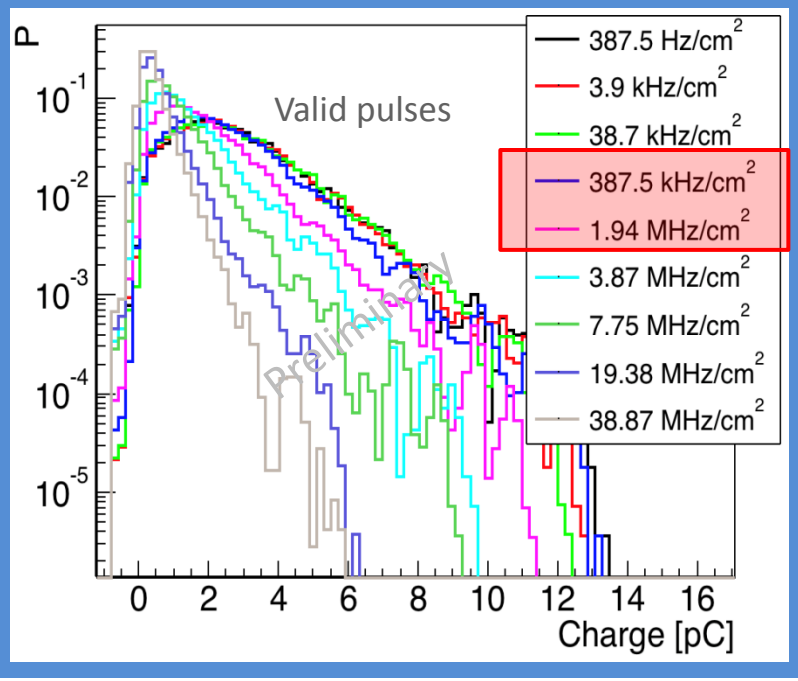
Completed tube



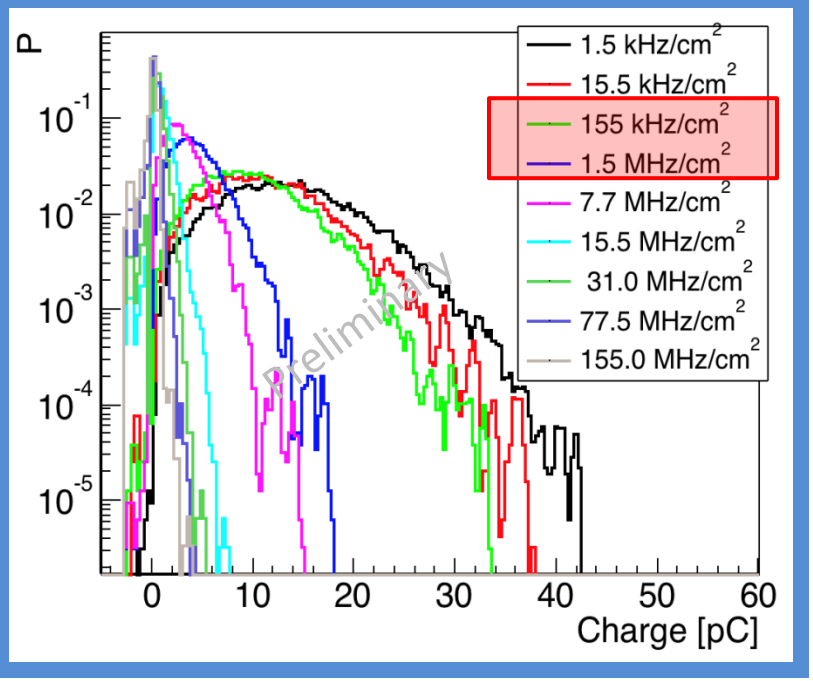
# Key performances

- **Rate capability** was recently measured with a pulsed laser
- Beam size is diffused: $\sigma_x = \sigma_y = 2.0$ mm, $A^* \sim 0.5$ cm$^2$
- **HV = 2800 V, without pre-amplifier**

Charge distribution at 1.1 $\langle N^*_{pe} \rangle$




Charge distribution at 4.2 $\langle N^*_{pe} \rangle$



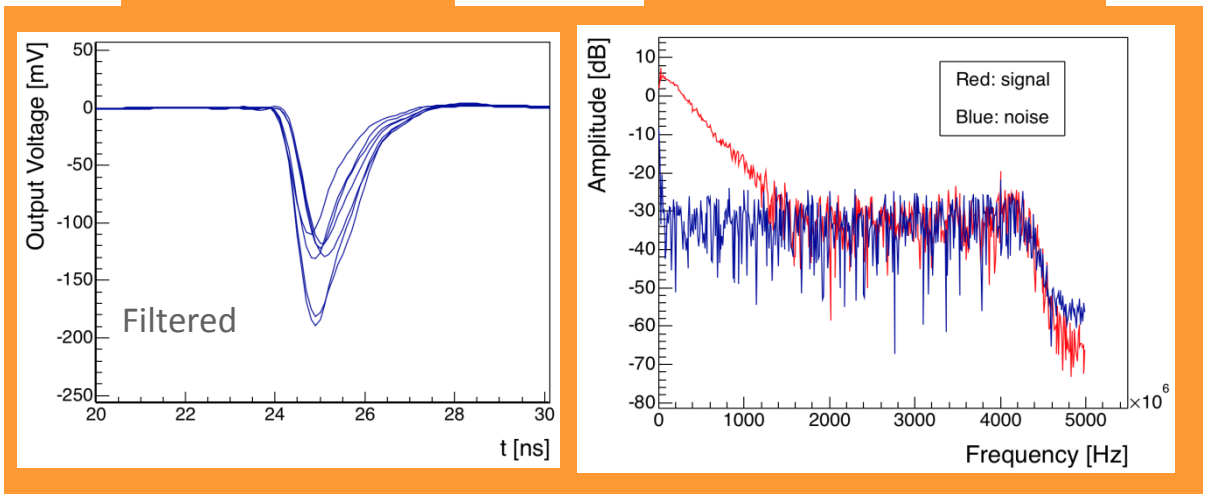

**The spectrum shifts to left with the increase of the beam flux**

**See a fast drop between 155 KHz/cm$^2$ and 1.5 MHz/cm$^2$**

**Filtered signals**

**Frequency components**

**0.5 ns rise time**




**Signal bandwidth up to1.3 GHz**

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