Production and Testing of a Low-Cost Precision Timing MCP Photodetector

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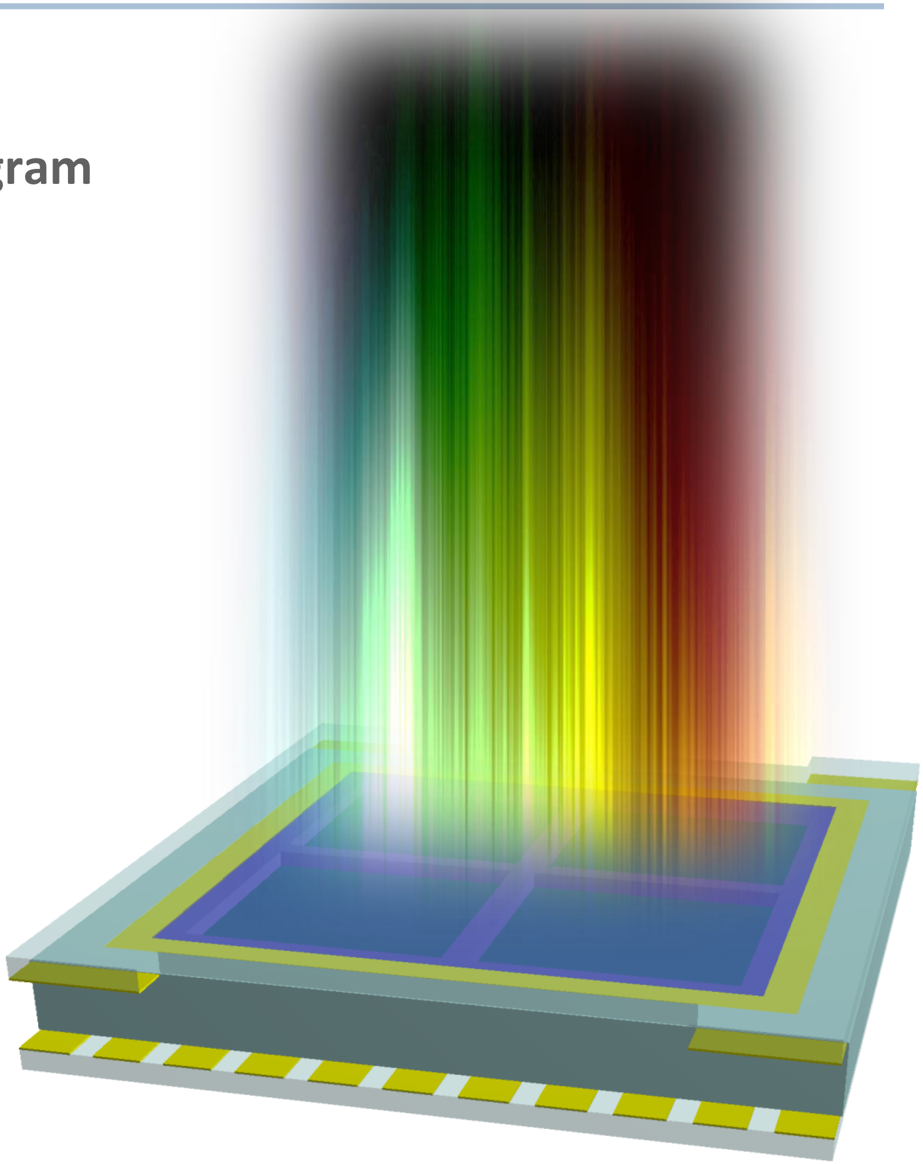
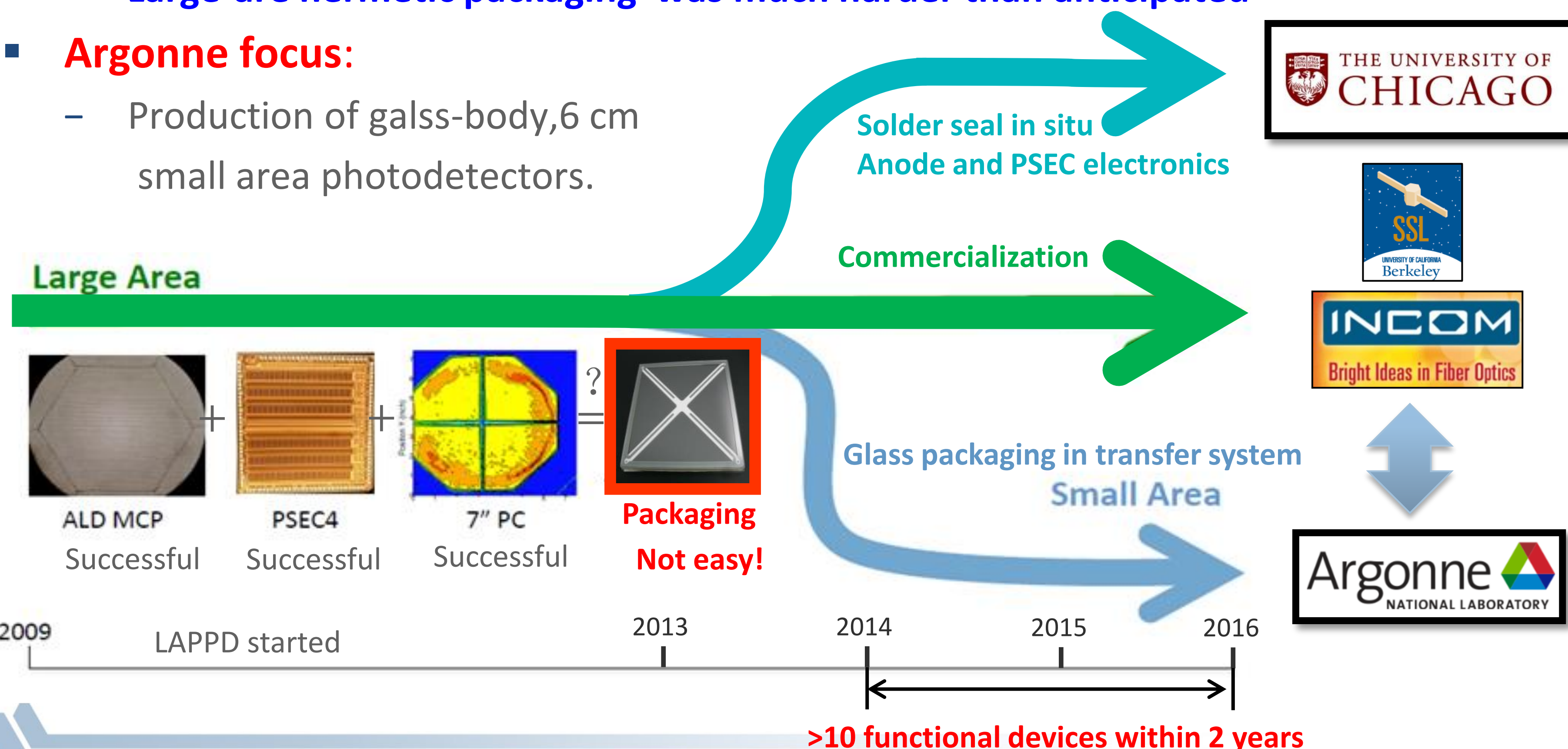
Outline

- **LAPPD project**
- **Argonne MCP photodetector program**
  - Production system
  - Tube processing
- **Testing and characterization**
  - Key performances
  - Optimization
- **Summary**

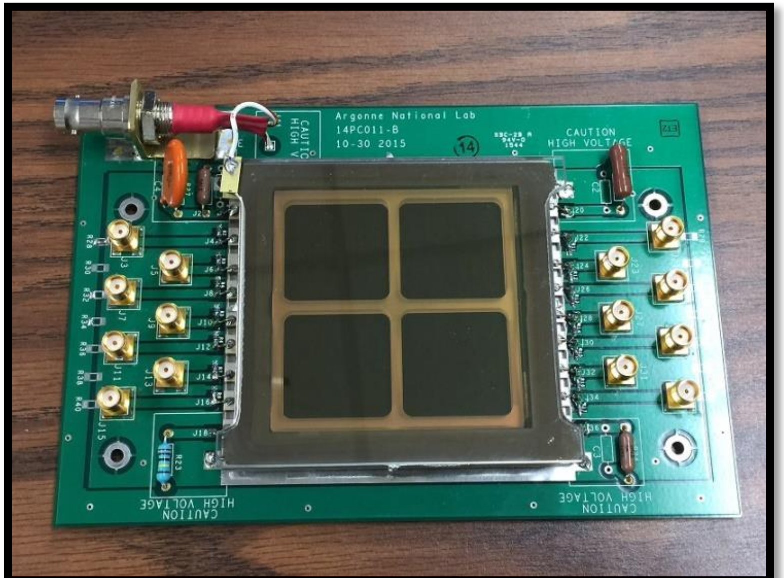


Large Area Picosecond PhotoDetector (LAPPD)

- **LAPPD:**
  - Reinvents photodetectors using transformational technologies
  - **Goal: large-area** (20 cm), fast-timing, low-cost
  - Success with MCPs, waveform sampling ASIC, large-area photocathodes
  - **Large-are hermetic packaging was much harder than anticipated**
- **Argonne focus**:
  - Production of galss-body,6 cm small area photodetectors.



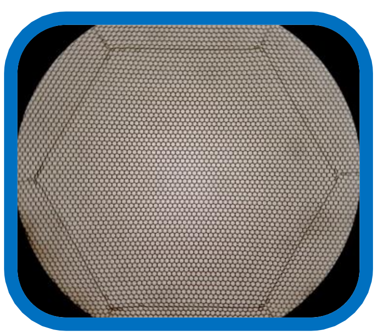
Argonne MCP photodetector program



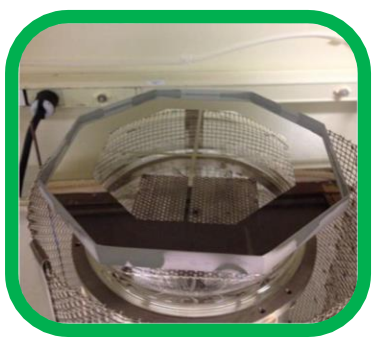
- **New techniques to reduce cost**
  - **New glass substrates** provided by INCOM. Inc.
  - **ALD functionalization** developed by ANL-ES (**filed to INCOM**.)
  - **All-glass hermetic packaging** (**invented by ANL-HEP, patented**) leads to significantly lower cost

6 cm × 6 cm, all-glass body

ALD-MCP



Photocathode

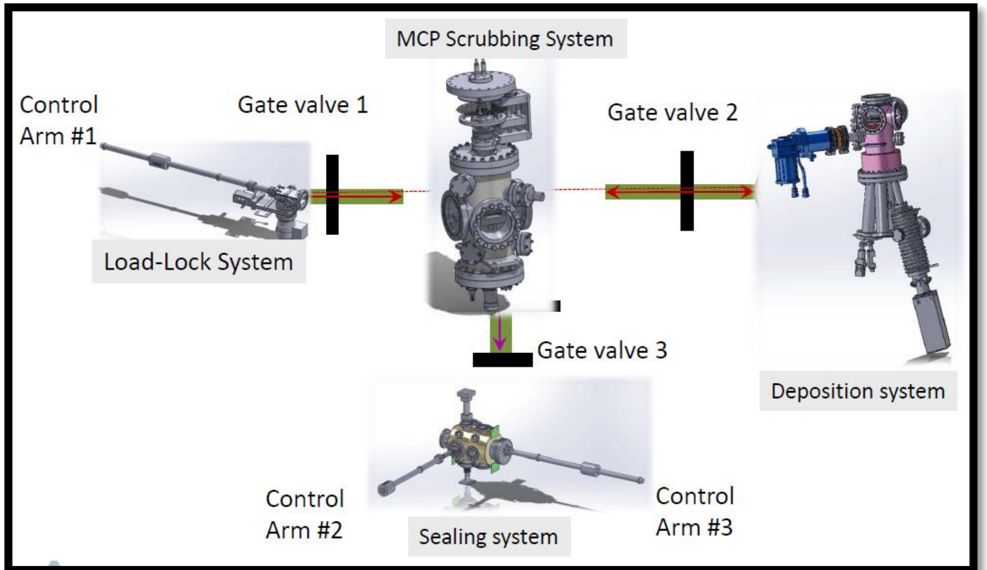


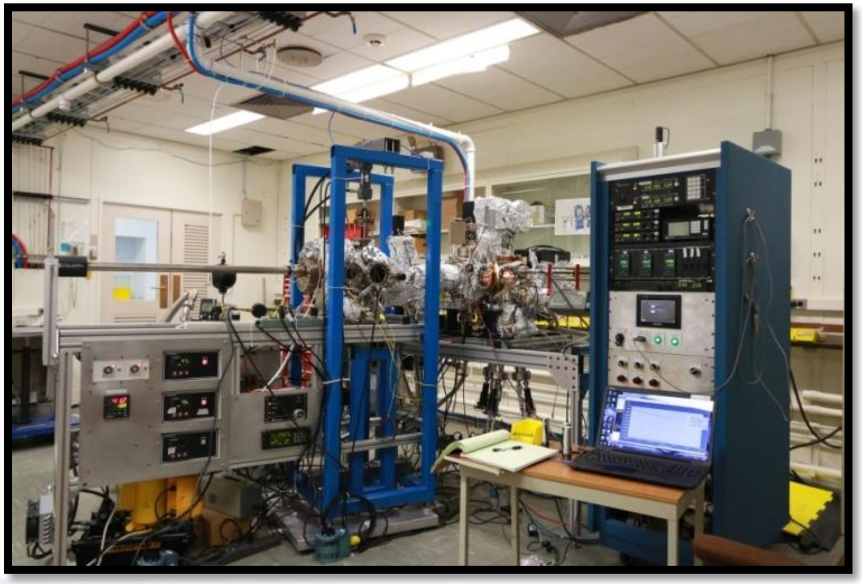
Packaging

Testing

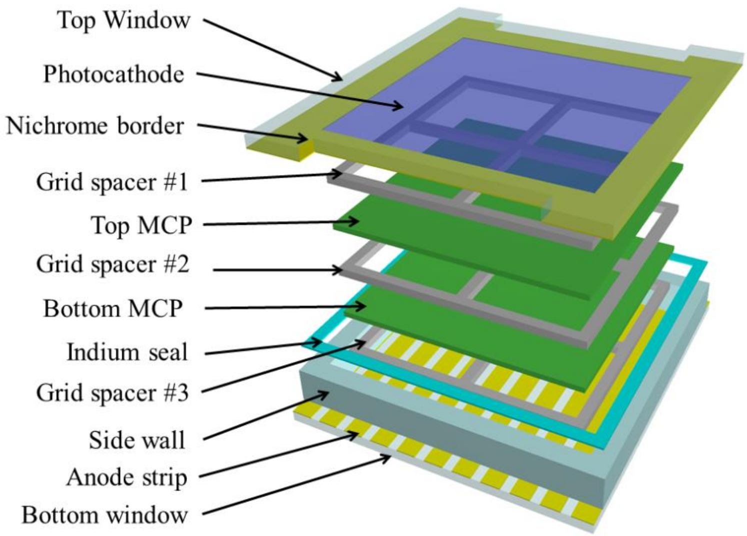
Small Single Tube Processing System (SmSTPS)

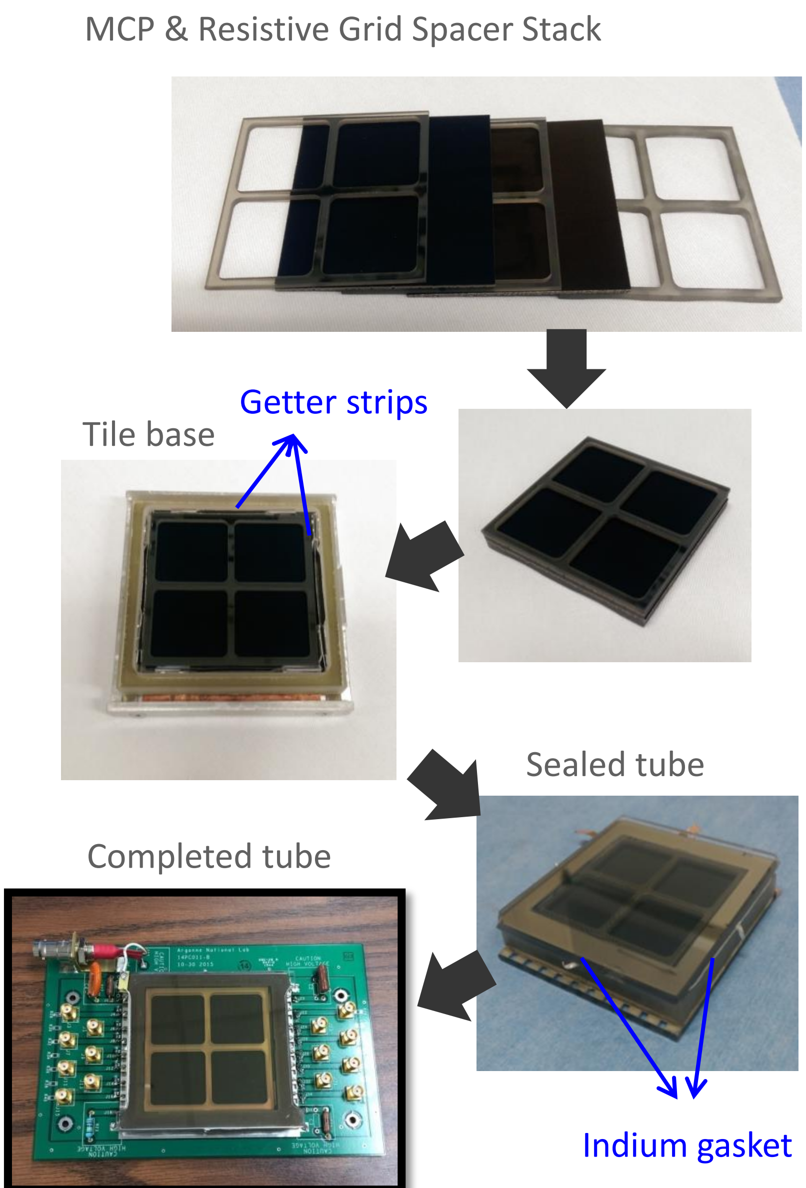
- The goal is to bring everything together and make a sealed device
- Unique features:
  - Vacuum transfer system : external magnetic arm
  - Each process is done in its own chamber: very flexible for R&D
  - **Thermo-compression seal** using hydraulic driven platens : demonstrated for large-area (8” tiles);
  - **Effusion cells** for bialkali photocathode deposition: efficient method for mass production
- Very flexible for R&D needs to address new requirements





Tube processing



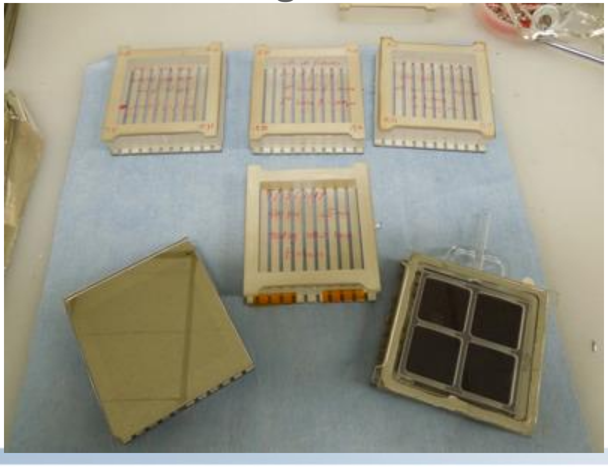


- **Tube processing is very challenging**
  - Baking & scrubbing
  - Getter activation
  - Photocathode deposition
  - Thermo-compression indium seal
- **Current status: 10^{-10} Torr, one tube / 2 weeks**

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 tube design: allows **HV optimization for each component**
  - Produced 10 detectors with a **100%** sealing yield.
- **The 3rd production run has just started:** 2 more working detectors
- **Now on track of providing photodetectors to the community.**

Sealing trials

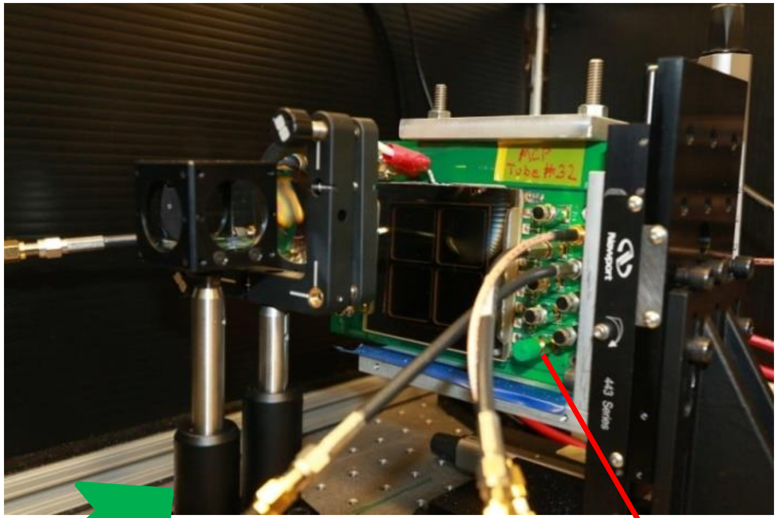


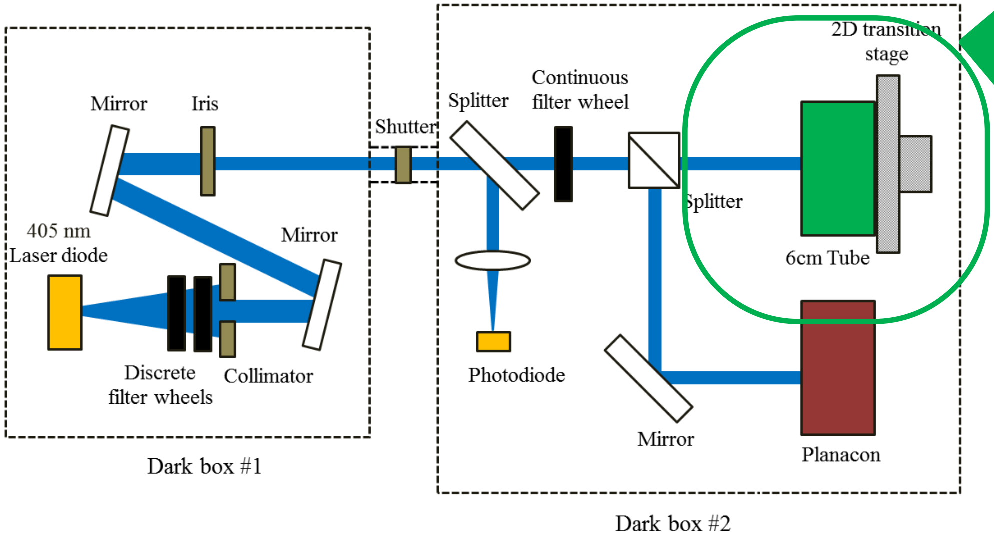
Working detectors

Blue 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

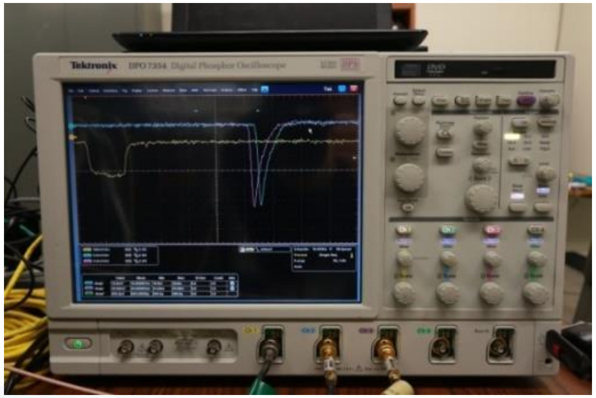
Dark box #2





40 Gs/s scope

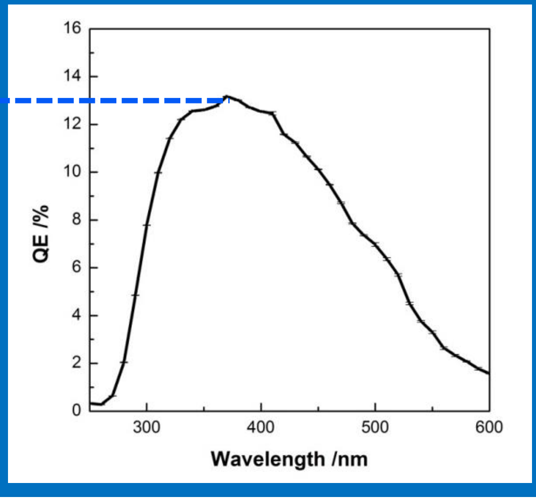
Readout board

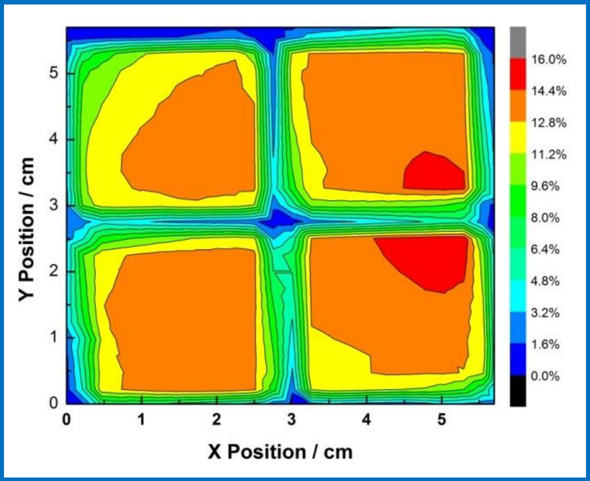


Key performances

QE Spectra response/ 2D map

QE = 13.2%
@ 370 nm



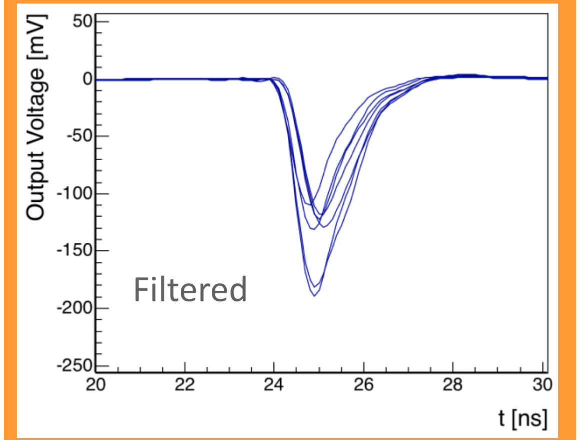


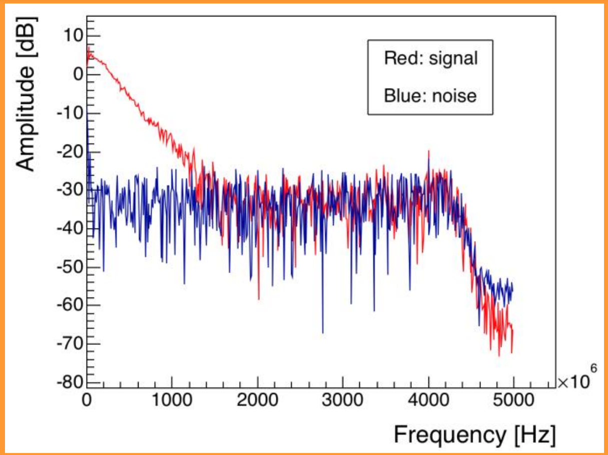
QE = 13 %

15.5%
maximum

Signals / frequency components

0.5 ns
rise time



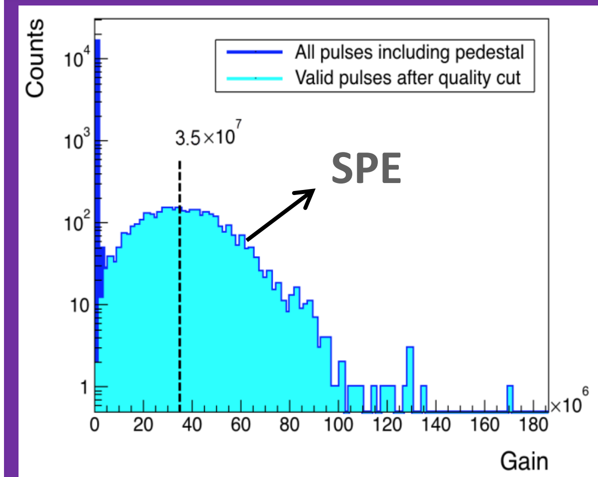


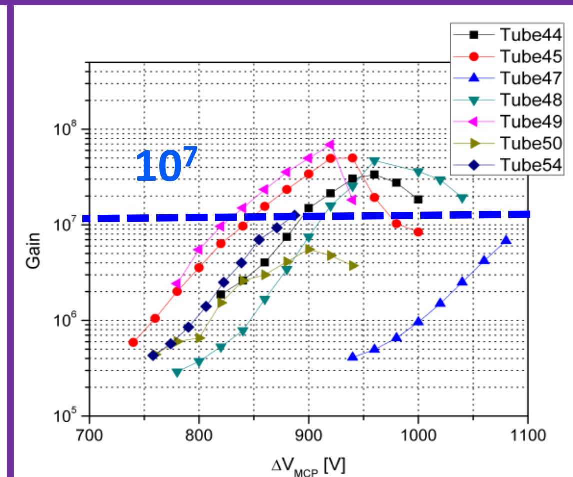
Signal bandwidth
up to1.3 GHz

Key performances

Gain distribution / Gain VS HV

Gain > 10^7



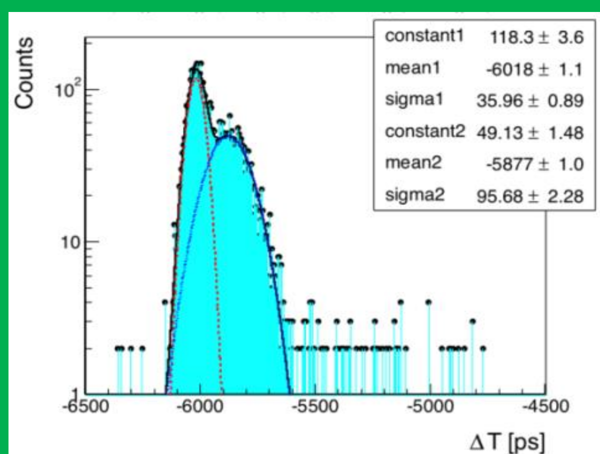


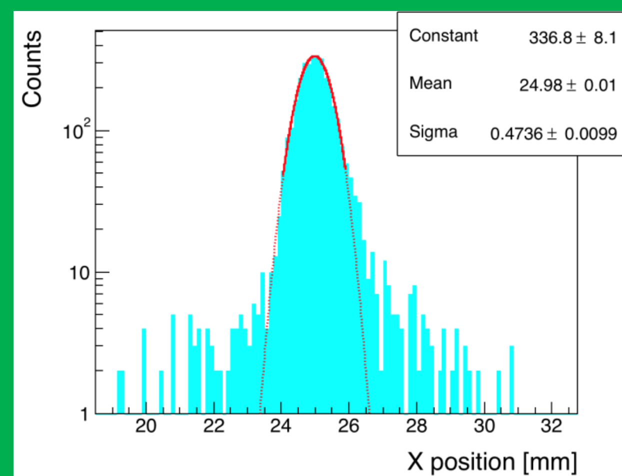
Gain VS HV_{MCP}

Timing / position distributions

σ_{IRF} ~ 35 ps for SPE

σ_{TTS} ~ 20 ps





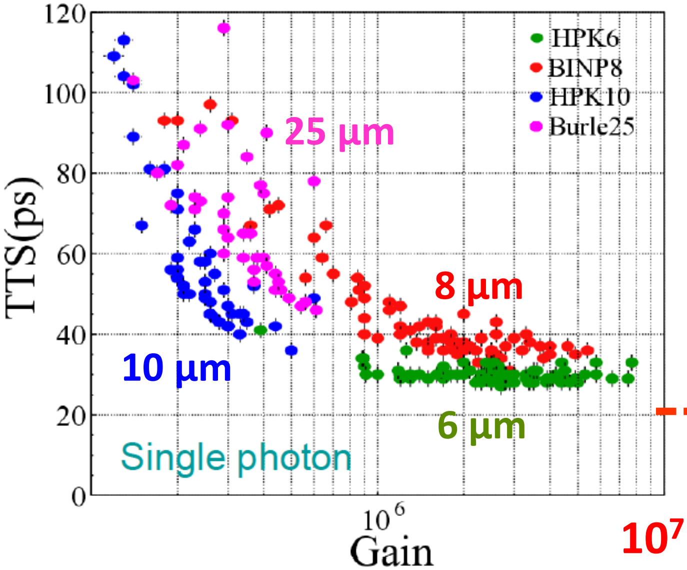
σ < 1 mm for SPE

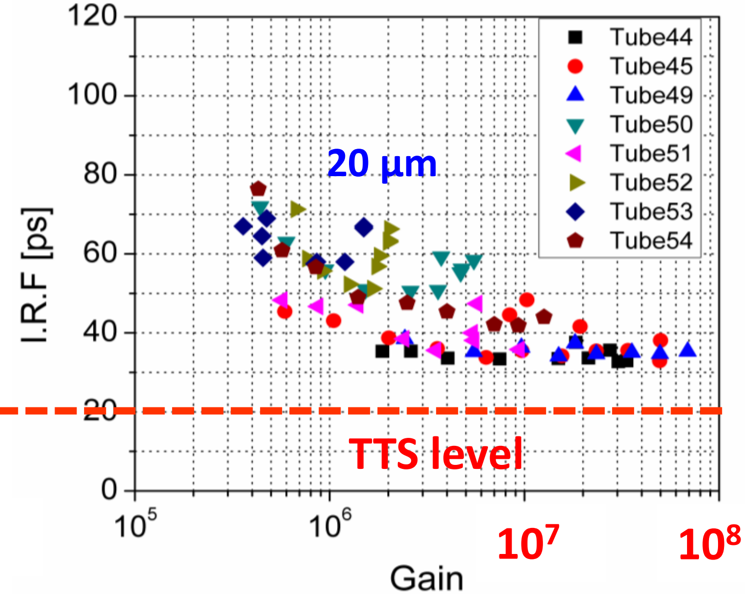
Comparison to commercial products

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

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

By Nagoya University

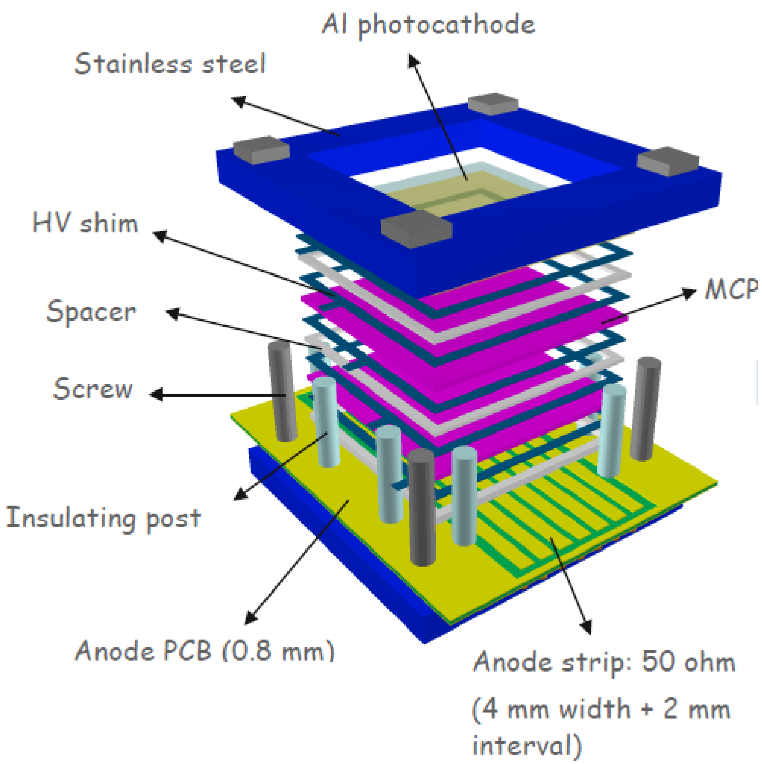




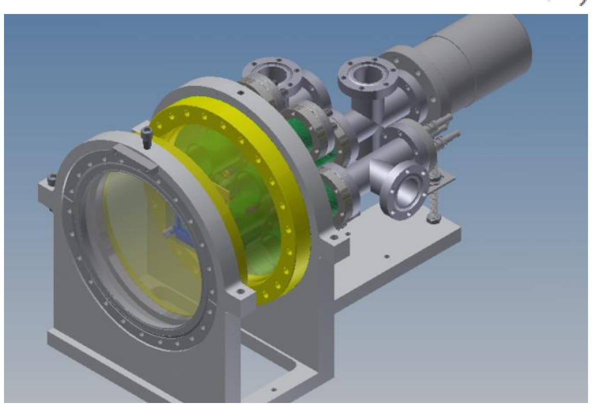
Argonne

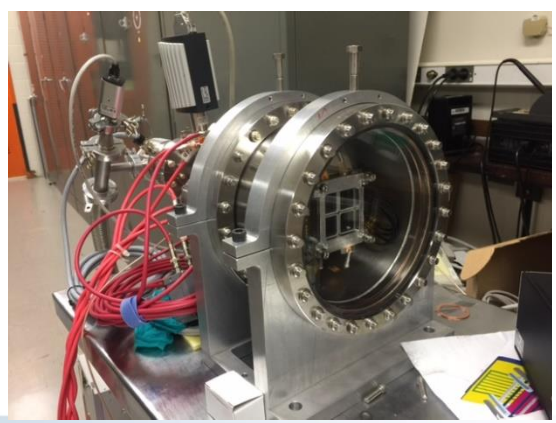
- **Pore size is an important parameter to obtain ultimate time resolution**

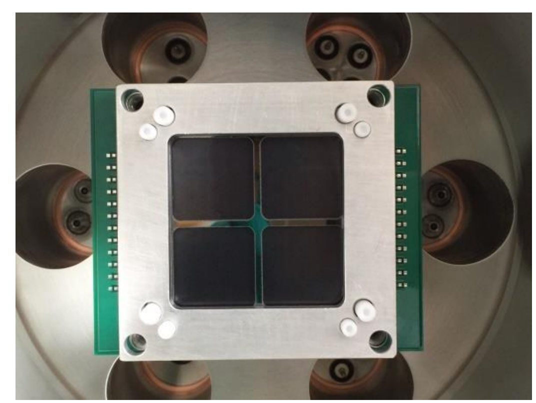
Detector optimization



- **Testing 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…

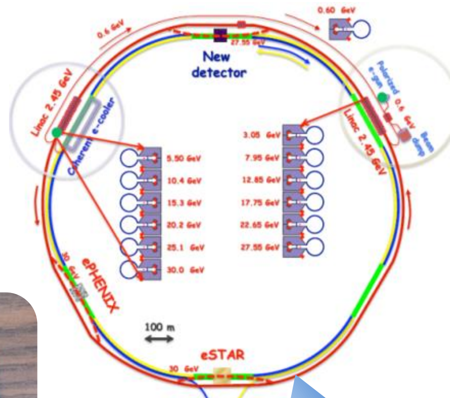




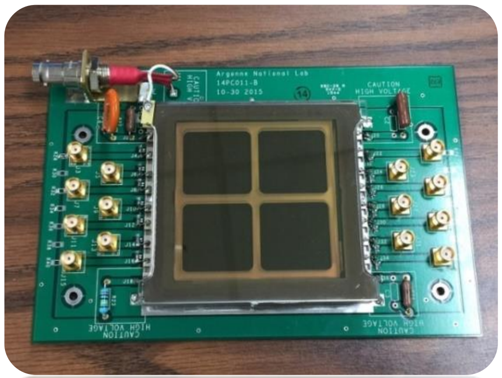


Future development path

EIC



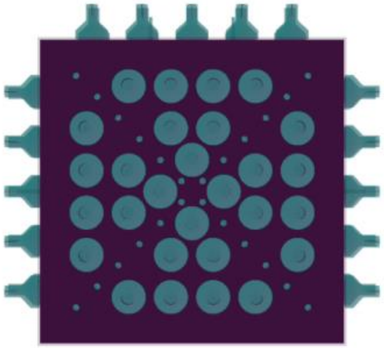
Others?



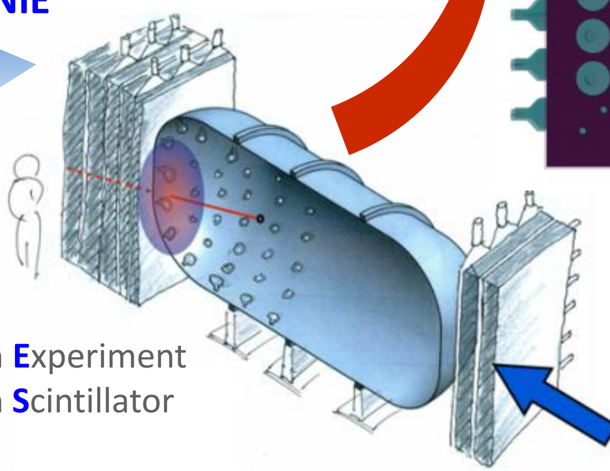
Today

Feedback
from users helps to
improve
the design

TARDIS



ANNIE



EIC: Electron **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 $\sigma_{I.R.F}$ ~ 35 ps (TTS ~ 20 ps);**
  - **Position resolution along the anode strip: < 1 mm**

- 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.

Acknowledgments

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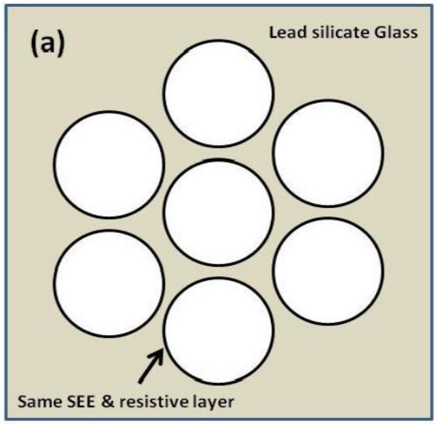
Thanks for listening!

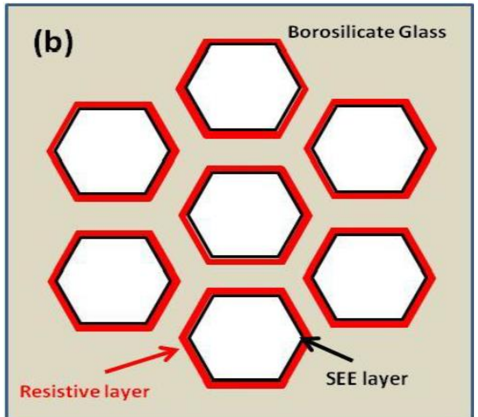
Backup

Micro-channel plate by Atomic Layer Deposition

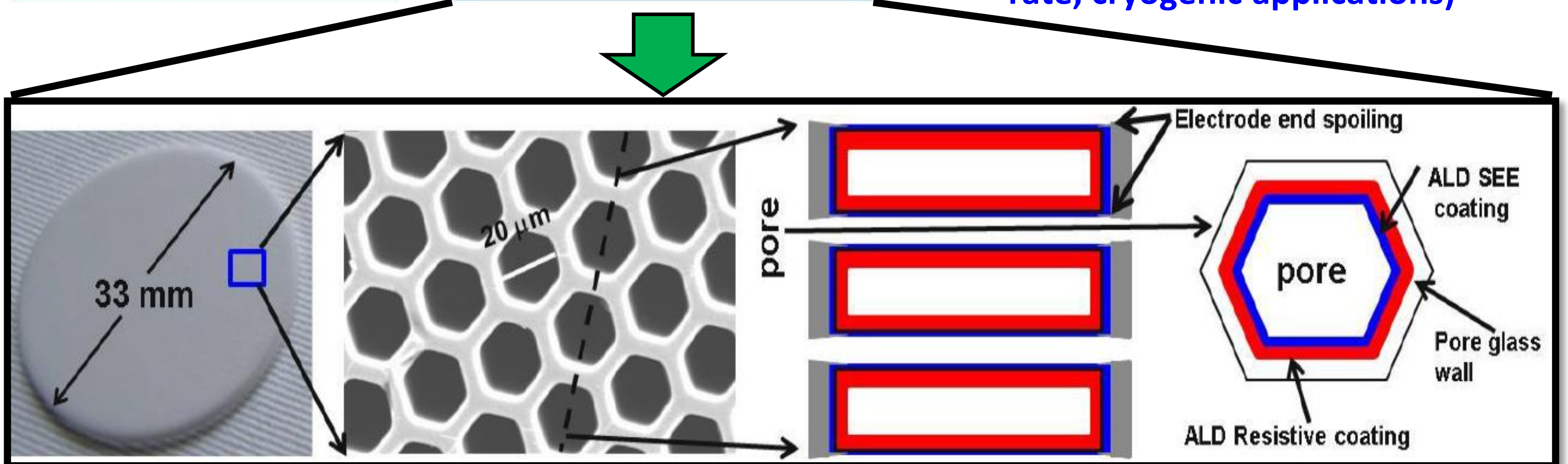
Conventional route



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. Flexible for R&D (high-rate, cryogenic applications)**

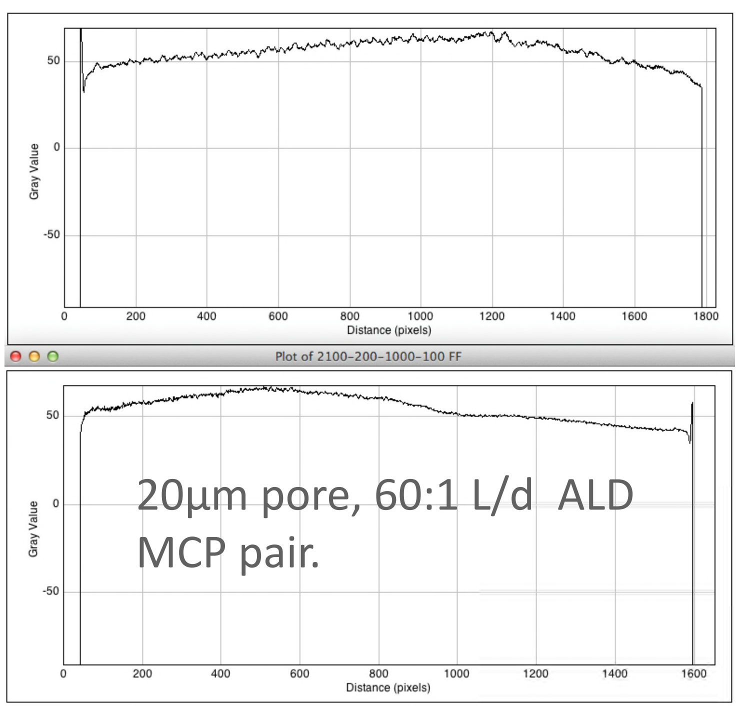


ALD = Atomic Layer Deposition

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 ~ 7×10^6
- Map shows <10% MCP gain variation

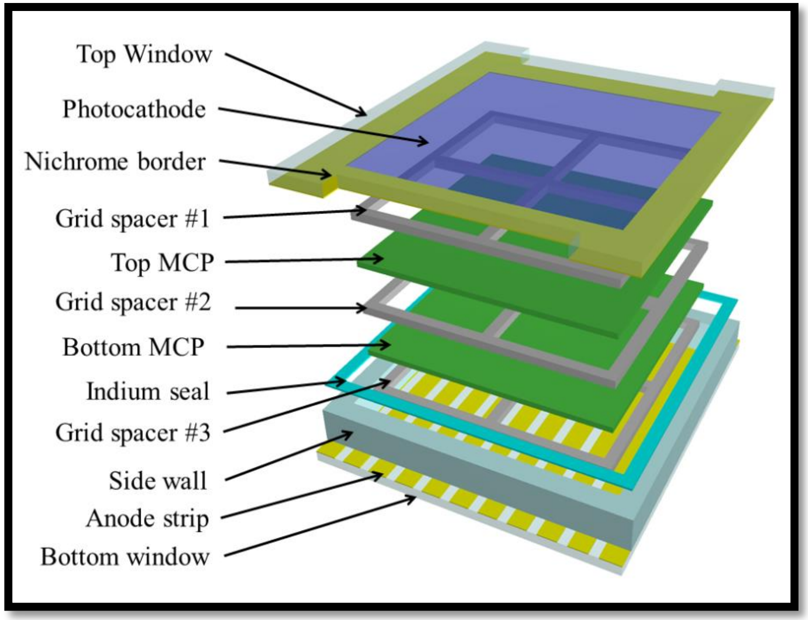
Relative gain

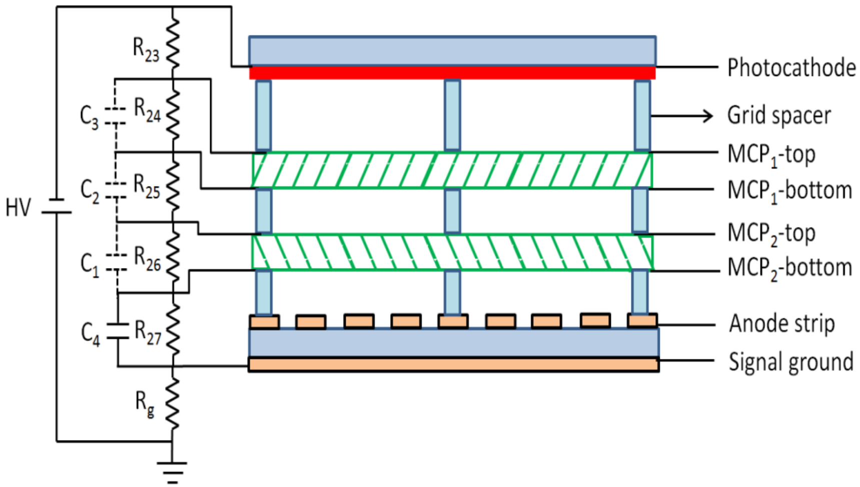


Average gain image "map"

ANL 6 cm × 6 cm photodetector

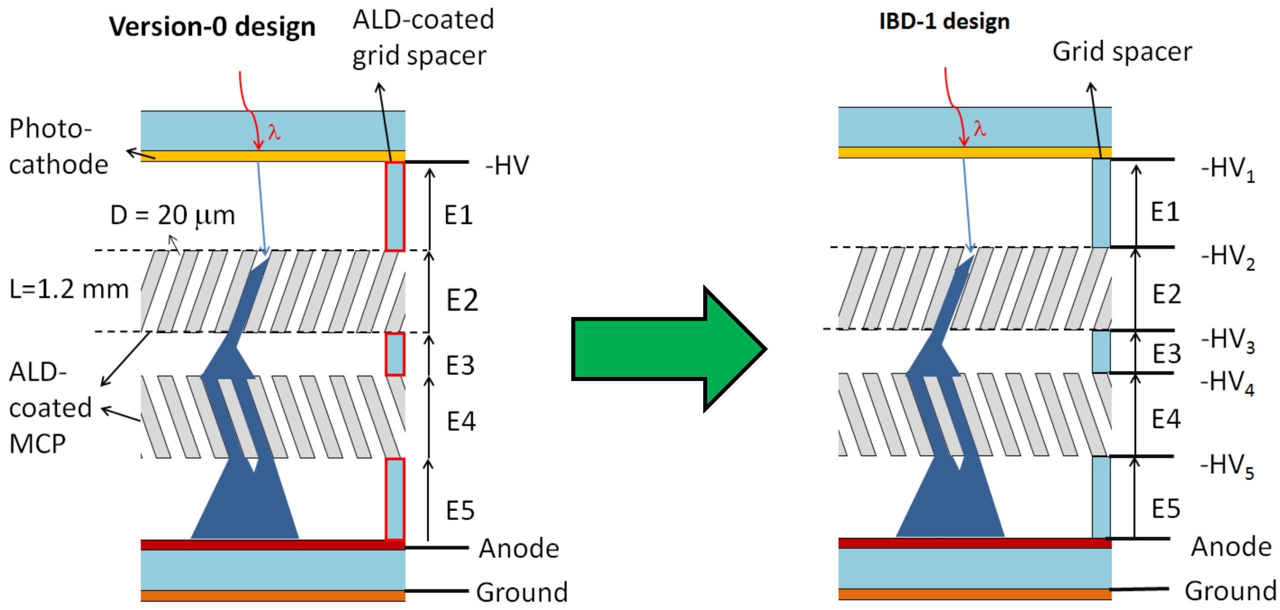
- A glass bottom plate with stripline anode readout
- A glass side wall that is glass-frit bonded to the bottom plate
- A pair of MCPs (20µm pore) separated by a grid spacer.
- Three glass grid spacers.
- A glass top window with a bialkali (K, Cs) photocathode.
- An indium gasket between the top window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



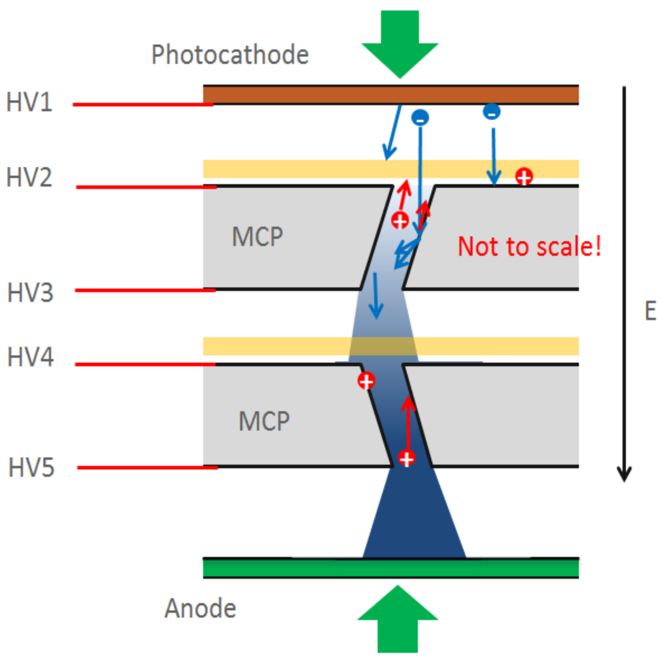


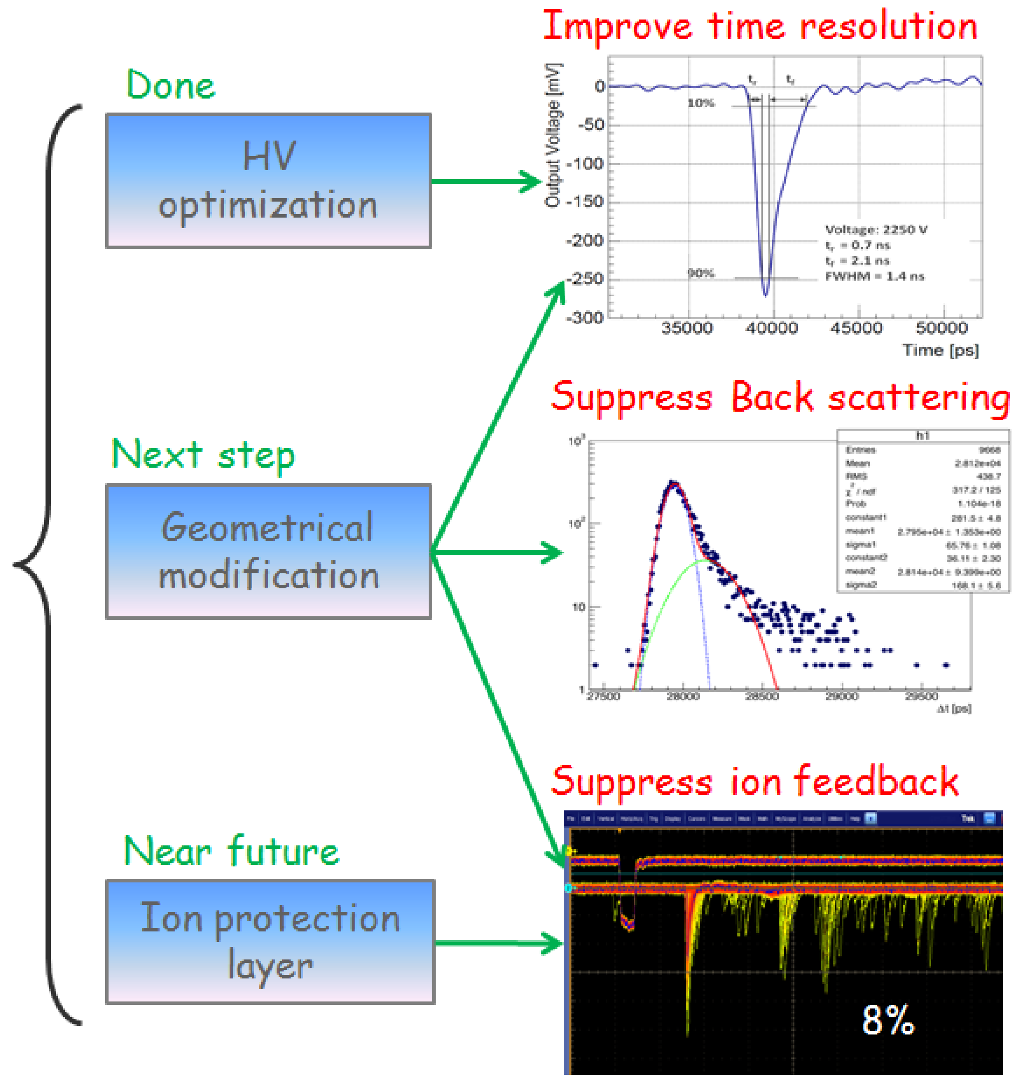
Design improvement

- **Internal resistor biased design (originnal 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 has filed a patent**



Detector optimization





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