MCP based photodetectors for cryogenic applications

Argonne Photodetector R&D

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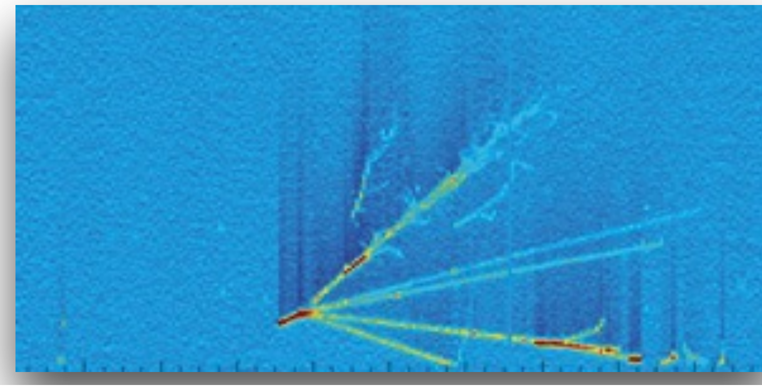
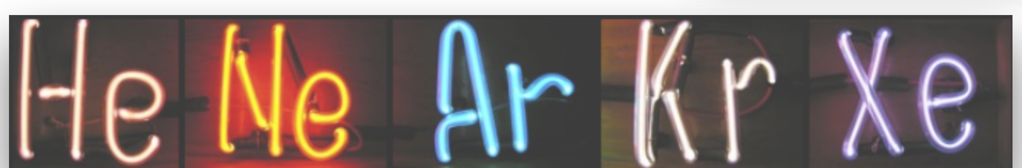
Noble Liquid Detectors for Particle Physics

- Many current and near term particle physics experiments using noble liquids as detector medium
  - Neutrino
    - µBooNE, SBND, LArIAT, DUNE
  - Dark Matter search
    - CLEAN, LUX, XENONnnn
  - Others
    - nEDM (He)
- Scintillation Light
  - Liquid is transparent to produced light
  - VUV: 128nm LAr   175nm LXe
  - Large signal (~10k γ/MeV for LAr)

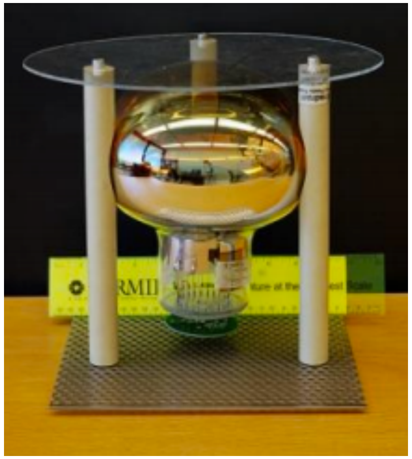
ArgoNeut data:

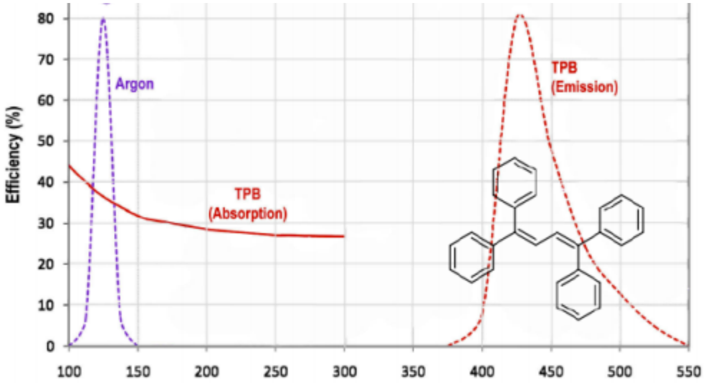




Current Photon Detection Methods in Noble Liquids

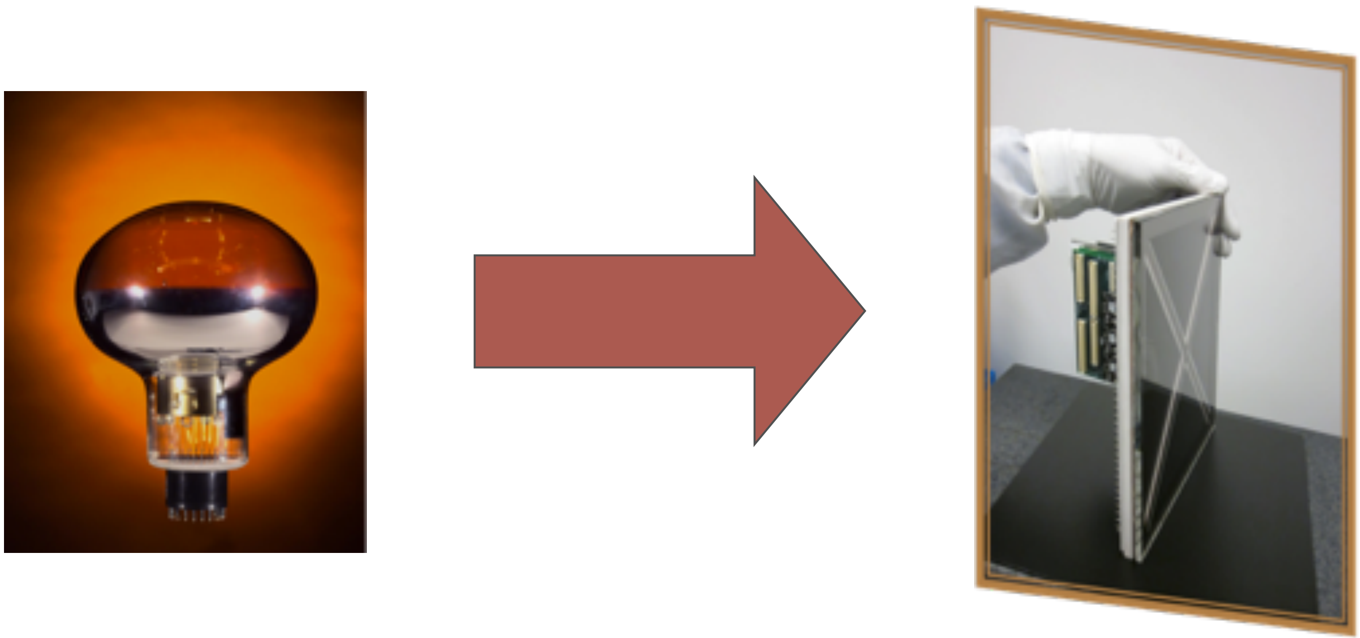
- Use SiPMs or PMTs + wavelength shifter
  - t_0 for reconstruction
  - background rejection
- Limitations
  - WLS degrades timing resolution
  - WLS handling
  - Limited position resolution





MCP-based PMTs as Alternative for Cryogenic Detector

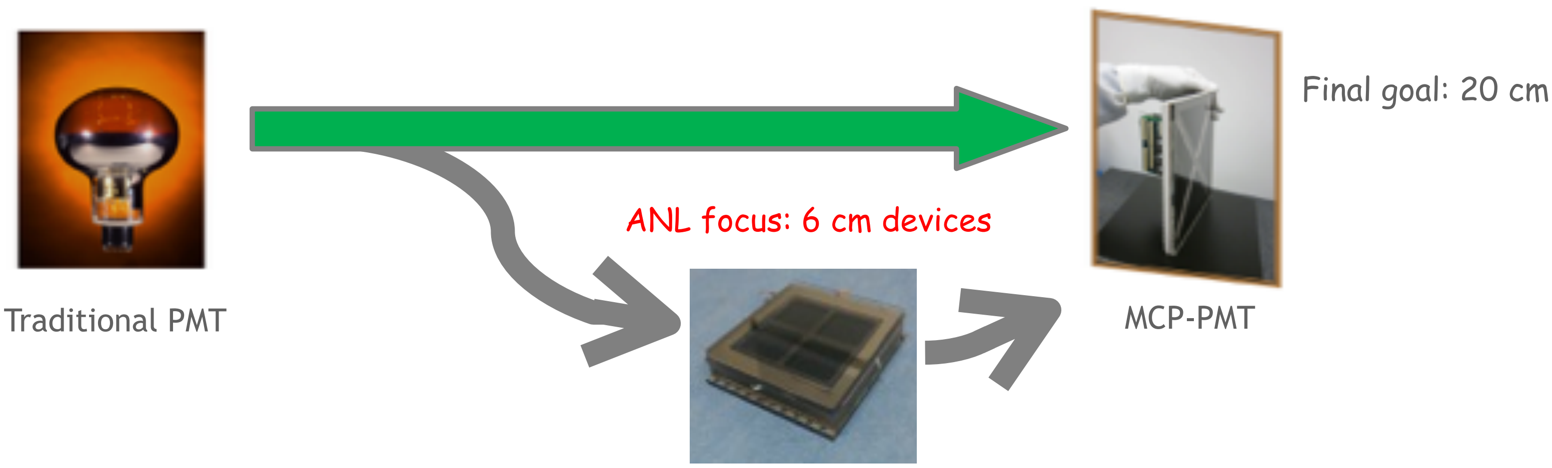
- Micro-channel plate (MCP) based photodetectors are capable of imaging, and having good spatial and temporal resolution.



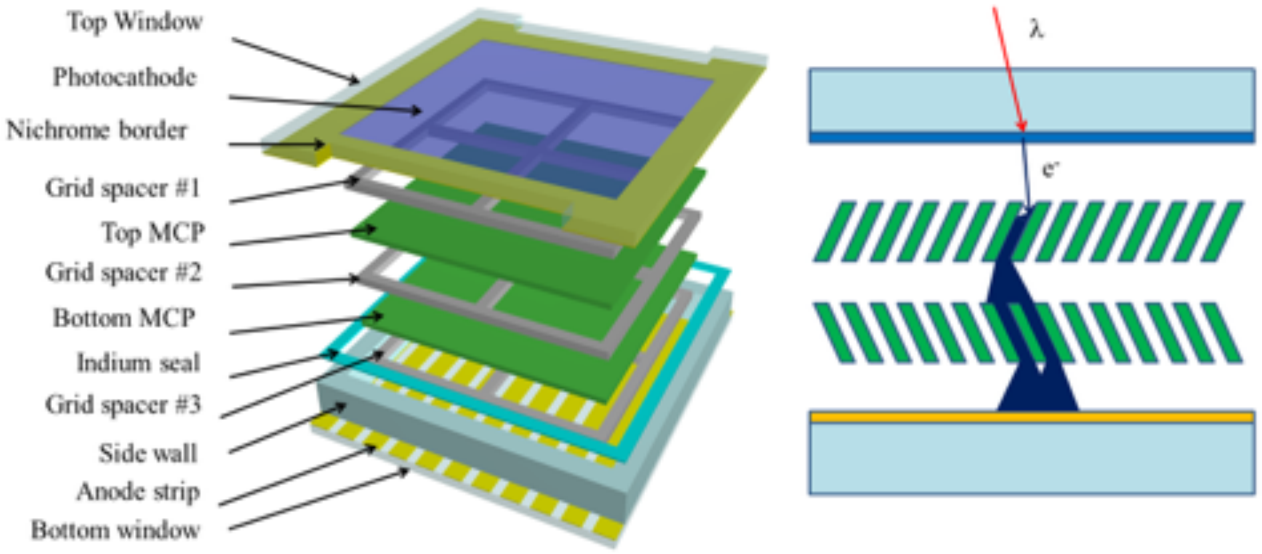
MCP-PMTs at Argonne

- The Argonne MCP Photodetector program seeks to develop improved, lower cost MCP photodetectors:
  - New MCP: borosilicate glass capillary array coated by Atomic Layer Deposition (ALD). Very robust, large-area (20×20cm^2).
    High gain: secondary emission layer engineered by ALD
  - New packaging: all-glass package with an thermopressure indium seal

Argonne is focused 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.



MCP-PMTs Components

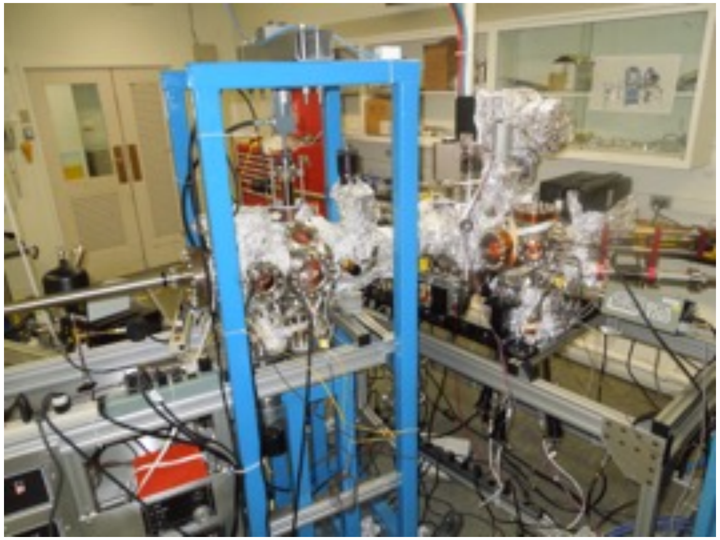


MCP-PMT Major Components:

- A glass anode plate with strip line readout
- A glass side wall which is glass-frit bonded to the bottom plate
- A pair of MCPs coated by Atomic Layer Deposition (ALD)
- A glass top window with a bialkali photocathode
- An indium seal between the top window and the sidewall.

Argonne Small Tube Processing System

- Production facility and R&D platform
- ~1 device / 2 weeks
- 6 functional detectors with internal resistive grid spacers to bias MCPs
- 4 functional detectors with modified design for individual MCP biasing
  - <50 ps time resolution for single-PE
  - <15 ps time resolution for multi-PE
  - <0.8 mm position resolution for large pulses



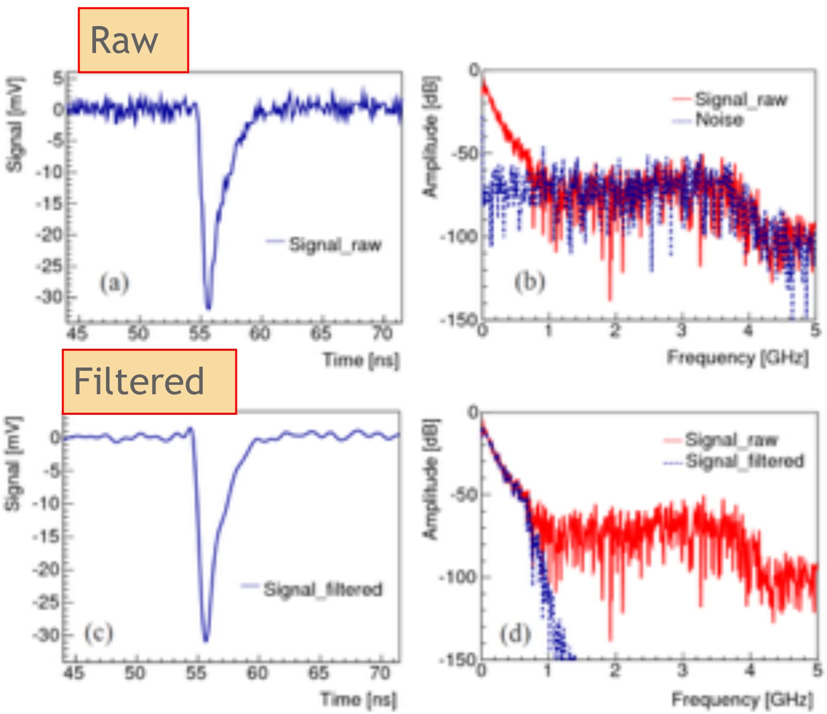
Argonne Small Tube Processing System

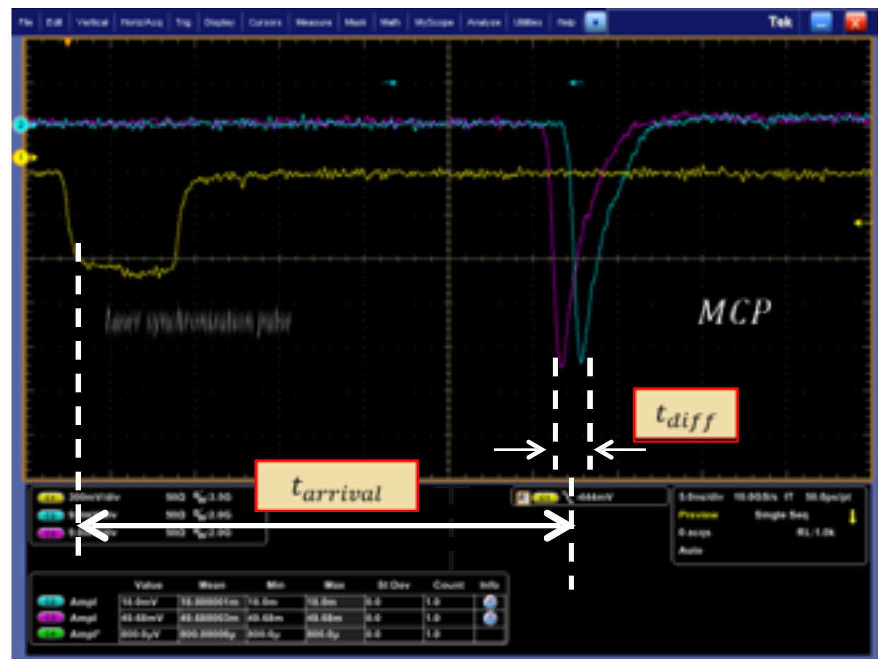
Typical MCP signal

- Pulse width: ~2-5 ns
- Rise time: ~700 ps
- Fall time: 2 - 3 ns

$\sigma(t_{arrival})$:
Transit time spread (TTS) resolution

$\sigma(t_{diff})$:
Differential time resolution

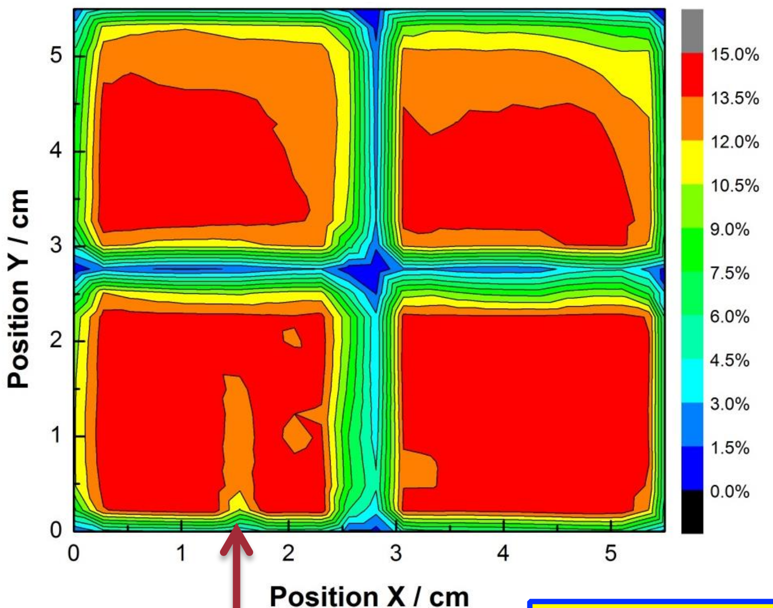




QE & Gain

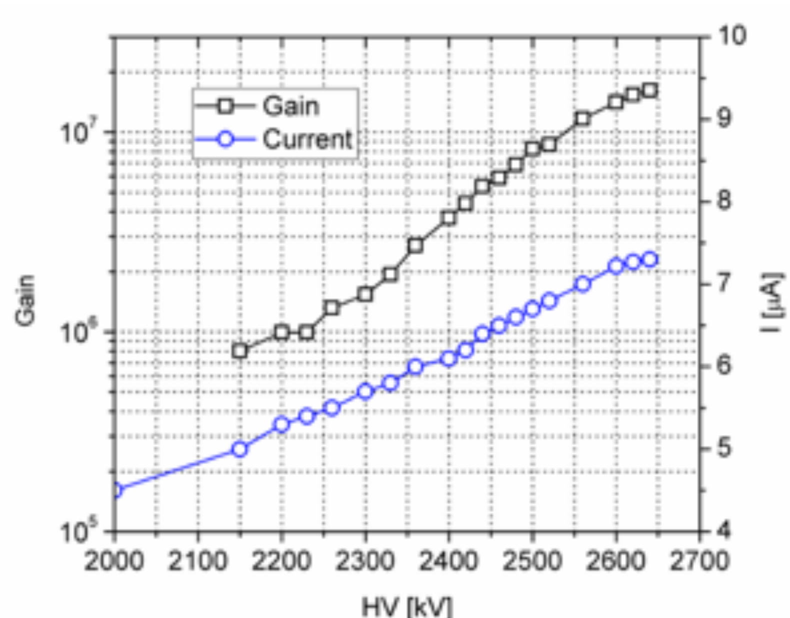
- Photocathode QE scan measured at 350nm
- Gain was measured in single photoelectron mode

QE scan



~14% average QE

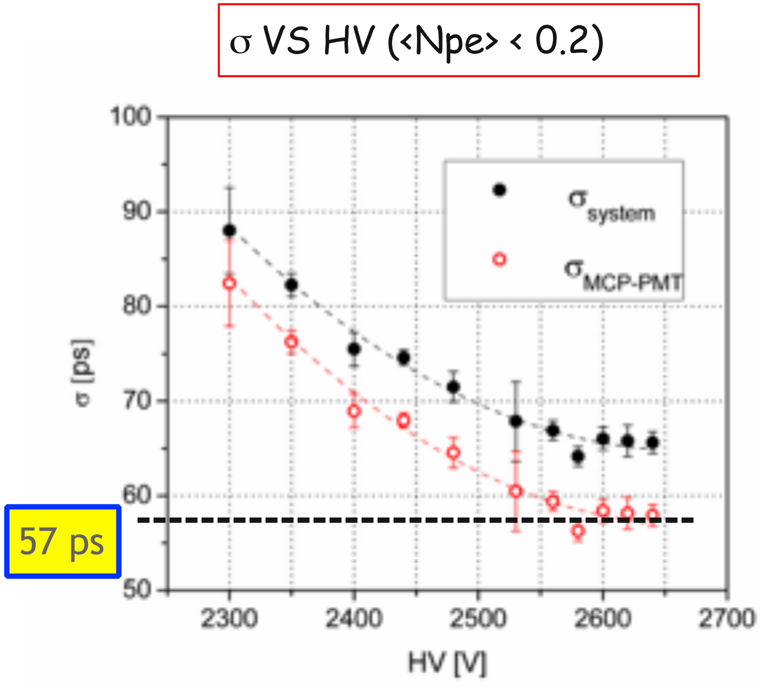
Gain VS HV

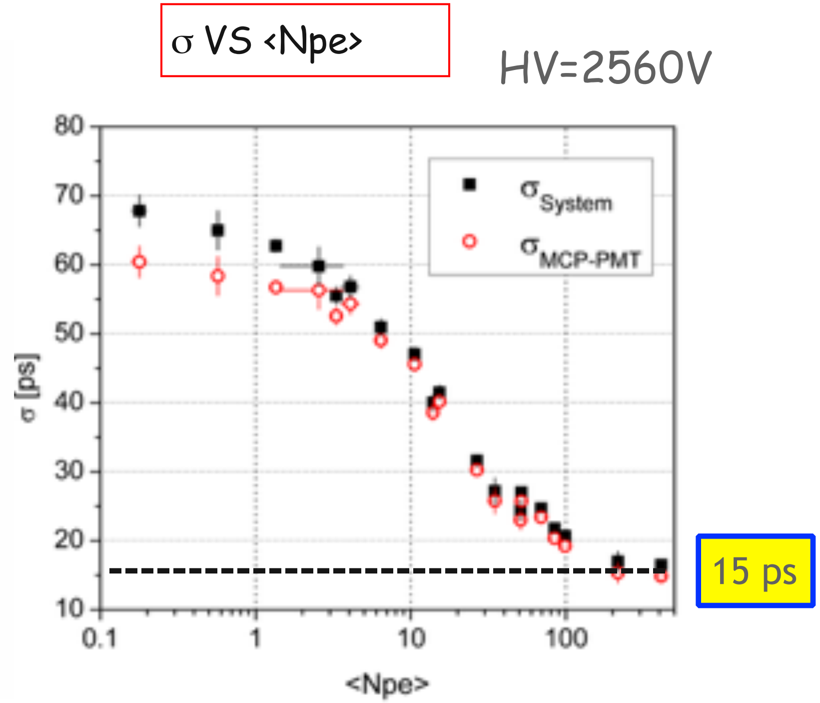


Gain: ~10^7

Time resolution

- The light intensity is calibrated by the number of photoelectrons. Results are independent of the quantum efficiency (QE) of the photocathode.

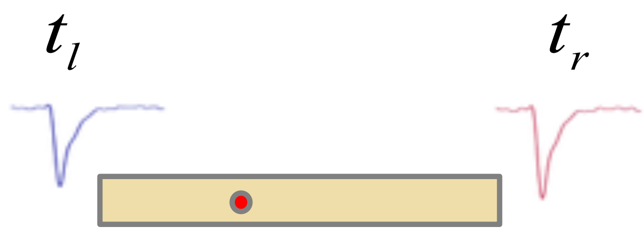


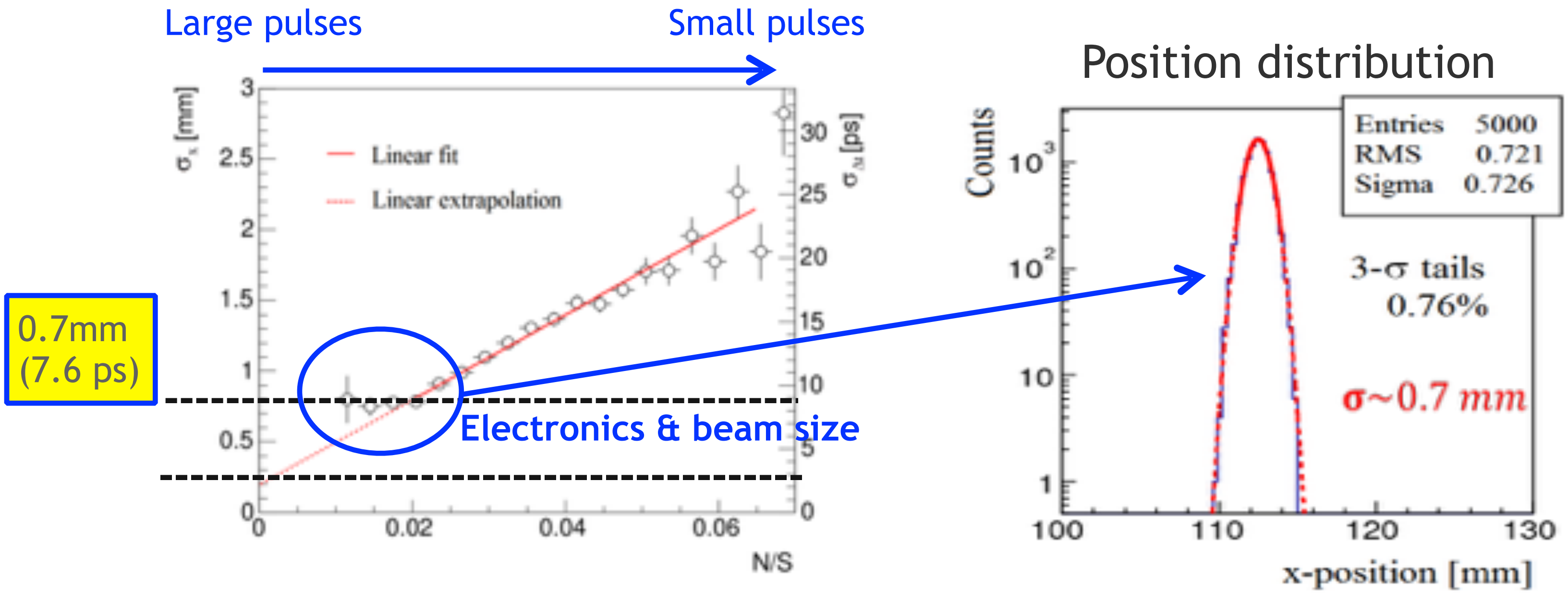


Position resolution / differential time resolution

- Dependent on the Noise/Signal ratio.
- Limited by the electronics (~7ps) and

the beam size (~1mm)

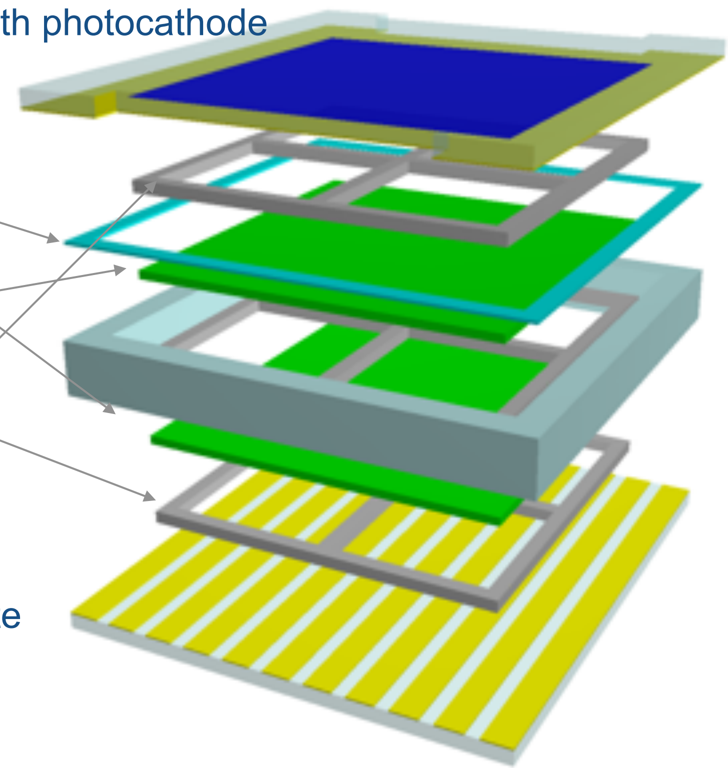




Customizing MCP-PMTs for cryogenic applications

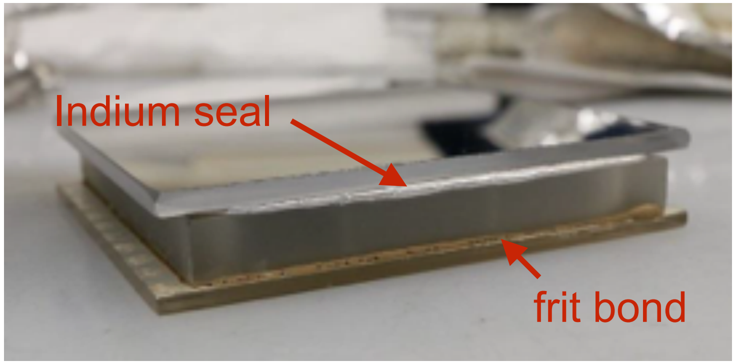
- Test the performance of individual components in cryogenic environment
- Tune, modify the component to achieve desired performance, e.g. fused silica or MgF window to replace borosilicate glass

6x6 cm^2 ‘small tile’



Testing the seals

- Structural integrity in cryogenic environment
  - Indium seal
  - Glass frit bond



- Dunked device in LN2
- Performed “slow” dunk and “fast” dunk
- for >48 hours at a time
- 4 devices tested (2 fully sealed) 1 failure
  - Failure due to hairline crack on sidewall

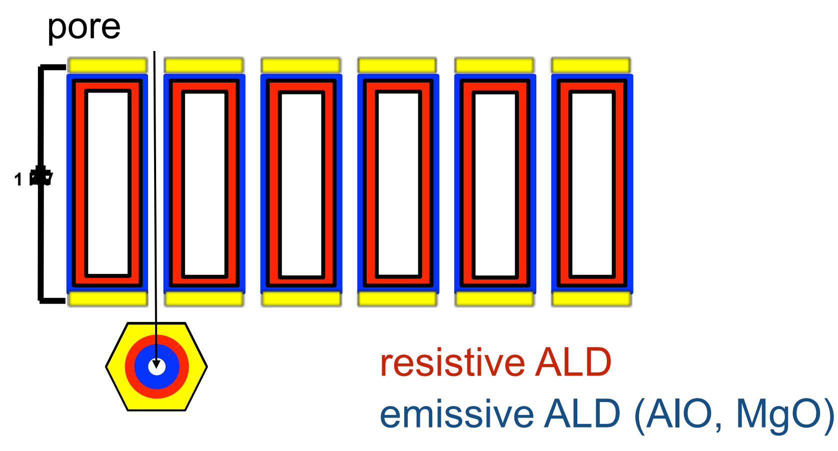
Tuning the MCP for cryogenic temperature

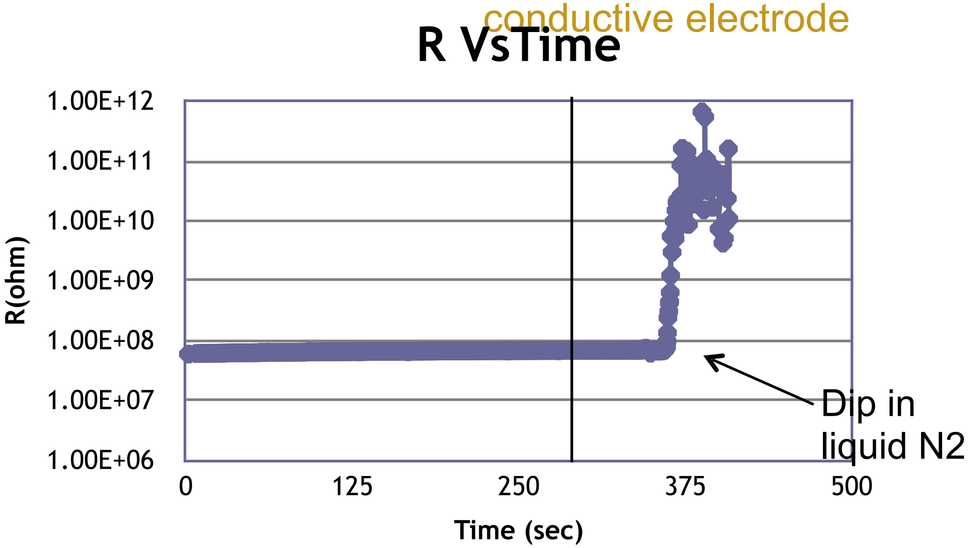
The Atomic Layer Deposition (ALD) : self-limited nanostructure deposition method.

Precursors applied separately — excellent control over material growth and hence the MCP parameters

Working with Argonne Energy System Division (Anil Mane and Jeff Elam) on development of resistive and SEE coatings for MCPs.

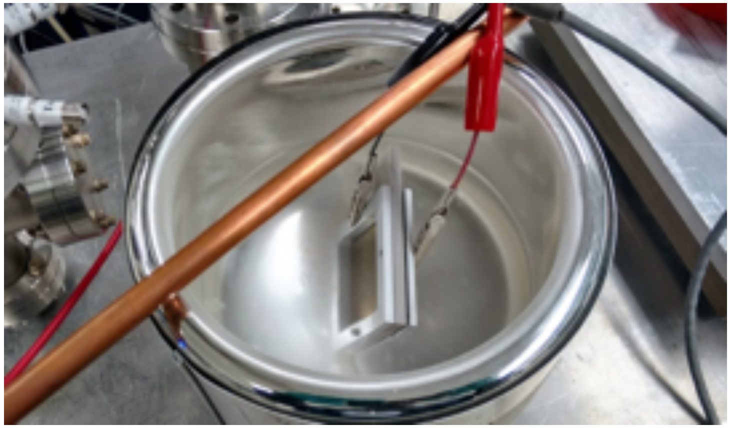
Have produced two MCPs with lowered room temperature resistance that hit target resistance at LN2

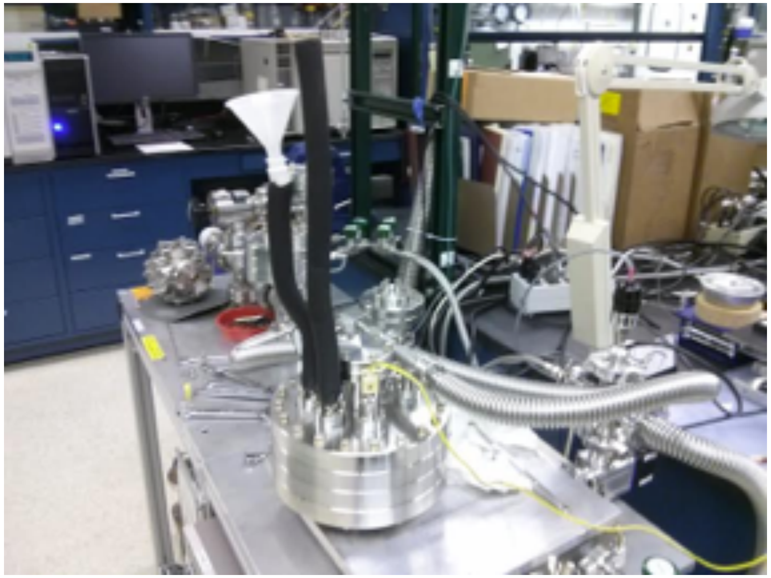




Tuning the MCP for cryogenic temperature

- **MCPs operational in cryogenic temperature developed**
  - Test stability at 87K
  - Cryogenic behavior of ALD materials being explored
  - Gain measurements underway

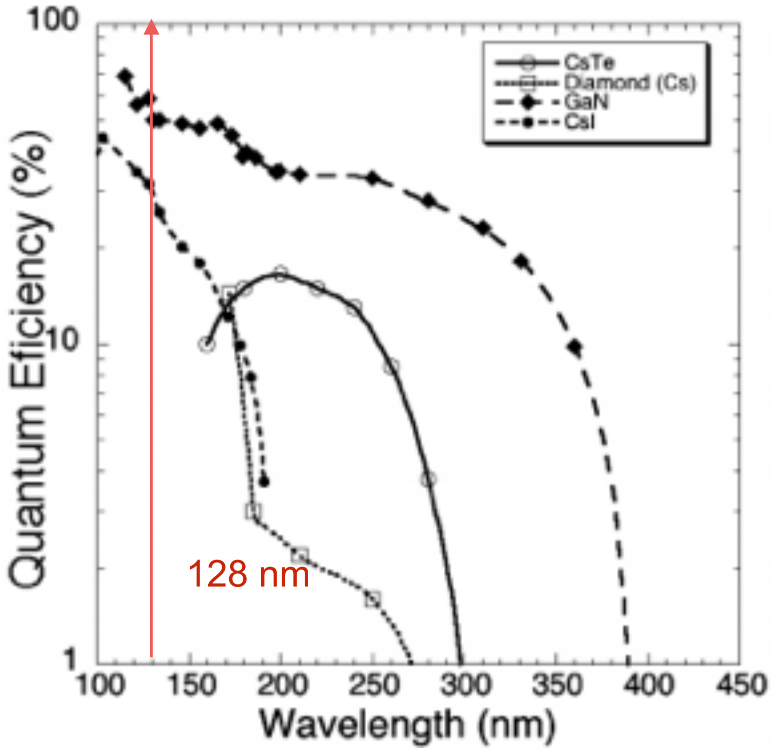




Photocathode for UV and low temperature

- Literature survey shows GaN, CsI works
  - Test cryogenic behavior
- Designed setup for testing QE vs temperature

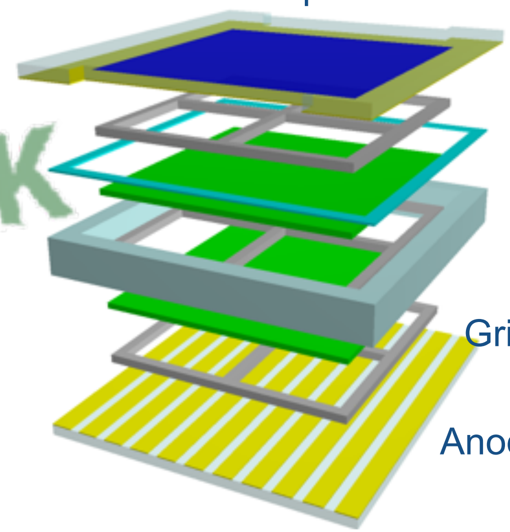
O. Siegmund *et al*



Testing/Simulation

- After preliminary tests at Argonne, seek to use the liquid argon test facilities at Fermilab.
- Looking at geometries and simulation
  - See how MCP-PMTs perform

Testing
Simulations
Physics capabilities



Plans for Argonne MCP-PMTs

Argonne MCP-PMT:

- Different geometries, smaller MCP pore size (10 μm)
- Pad readout
- Photocathode research
- Neutron detector

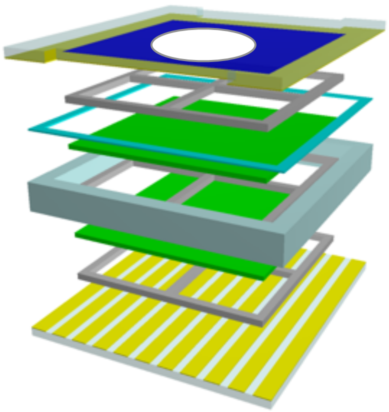
Other ideas welcome!

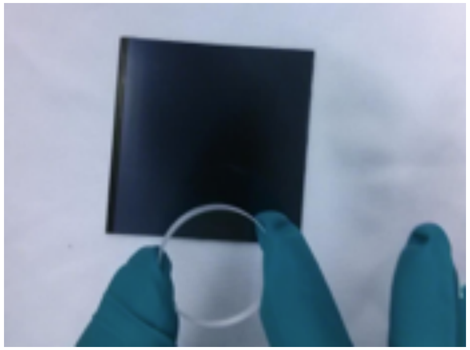
Open to collaboration with early adopters: Please tell us about your new ideas

Plans for Argonne MCP-PMTs

Cryogenic Applications

- Bare MCP detector for two phase detectors
- Use MgF top window (no WLS)





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Summary

- Argonne Detector R&D group has successfully produced working MCP based detectors.

- Developing MCP photodetectors to operate in liquid argon.
  - Tuning MCP resistance for cryogenic operation
  - Assessing candidate photocathode materials for low T operation

- Seeking to demonstrate operation at LAr temperature with tuned MCPs and appropriate photocathode