Development of Large-Area Fast Micro-channel Plate Photo-detectors

Marcel Demarteau
Argonne National Laboratory

for the LAPPD collaboration

Fermilab Detector Retreat
Aurora, May 5, 2011

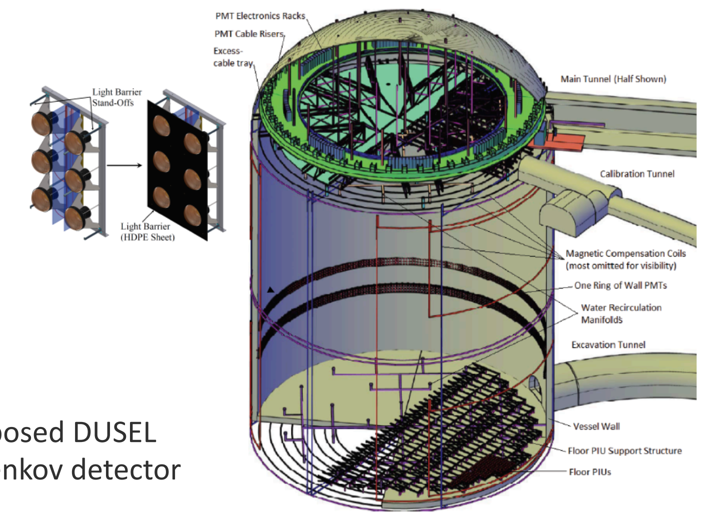
Outline

- Introduction
- Photo-Detector Development
  - Photo-cathodes
  - MCP
  - Anode and signal readout
  - Mechanical Design
- Simulations and Testing
- Concluding remarks

Photo Multiplier Tubes

- "Old" Technology
  - Used for decades
  - Robust, generally low noise
  - Simple biasing
- Time resolution ~2-3 nsec
- Spatial resolution limited by tube radius
- Total coverage offered is typically less than 40%
- Typical photocathode efficiency ~25%
- Few vendors

- Can this technology address the challenges of the next generation of H_2O Čerenkov experiments?



Proposed DUSEL Čerenkov detector

Large-Area Pico-second Photo Detector (LAPPD)

- Newly funded by DOE and NSF (fall '09)
  - 4 National Labs
  - 5 Divisions at Argonne
  - 3 US small companies;
  - Electronics expertise at UofC and Hawaii
  - Photocathode expertise at Washington University, St. Louis and UIC

- Premise:
  - Apply advances in material science and nanotechnology to develop new, batch methods for producing cheap, large area photo-detectors
  - Continued improvement in at least one parameter by an order of magnitude
  - Develop path to a commercializable product on a three year time scale (Currently approaching the end of year 2)

Large Area Picsecond Photodetector Collaboration

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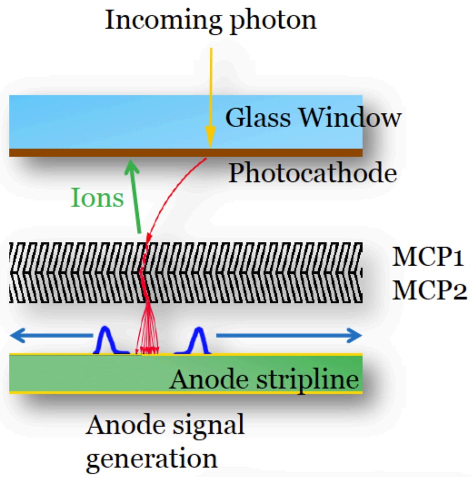
LAPPD Goals

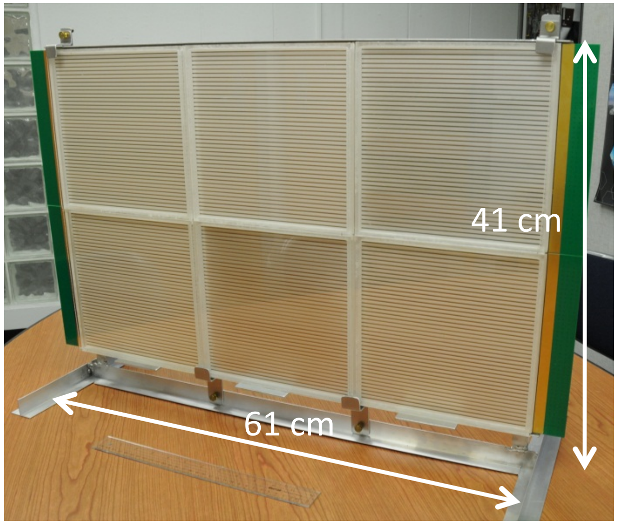
- Project with four primary goals:
  1. Large-Area Low-Cost Photo-detectors with good correlated time and space resolution (target 10 $/sq-in incremental area cost)
  2. Large-Area TOF particle/photon detectors with pico-second time resolution
     - < 1psec at 100 photo-electrons
  3. Understanding photo-cathodes so that we can reliably make high QE cathodes with tailored spectral response, and develop new materials and geometries
     - QE > 50%?, public formula
  4. Produce commercializable modules within 3 years
     - transfer technology to industry

http://psec.uchicago.edu/

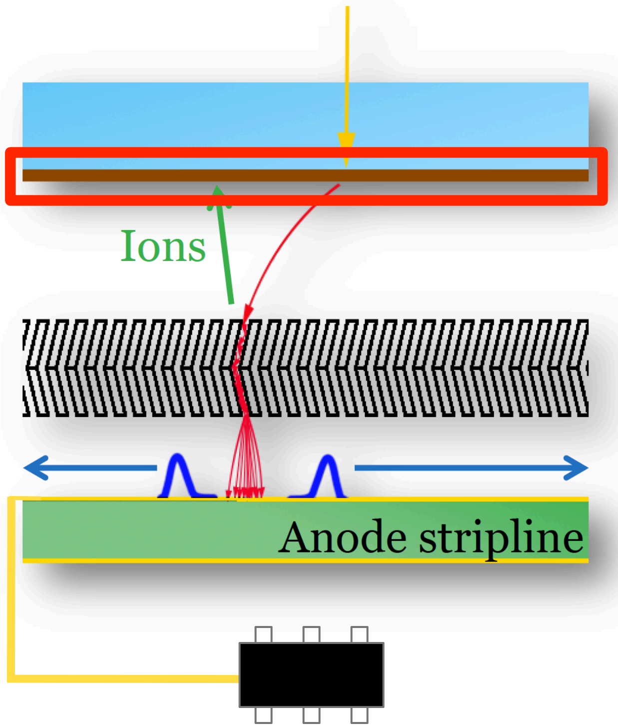
LAPPD: Approach



- Base on Existing Technology: Micro Channel Plate (MCP) photo-multiplier
  - Picosecond-level time resolution
  - Micron-level spatial resolution
  - Excellent photon-counting capabilities
  - Expensive
- New Aspect: Fully Integrated Approach
  - Exploit advances in material science and electronics to produce large-area MCP-PMTs:
    - Preserve time and space resolutions of conventional micro-channel plate detectors
    - At low enough cost per unit area



LAPPD Deconstructed



1. Photo-Cathode (PC)
   - Conversion of photons to electrons
   - Engineer III-V materials to develop robust high QE photo-cathodes
2. Micro-Channel Plates
   - Amplification of signal: two plates with tiny pores, held at high potential difference. Use Atomic Layer Deposition for emissive material on inert substrates to create avalanche
3. Transmission line, high speed readout
   - Anodes is a 50Ω scalable strip line silk-screen printing on glass ground plane (Borofloat 33)
4. Hermetic Packaging
   - Maintain vacuum and provide support. No internal connections; no penetrations
5. Electronics
   - Readout at both ends with fast custom CMOS SCA chip with 10GHz waveform digitization

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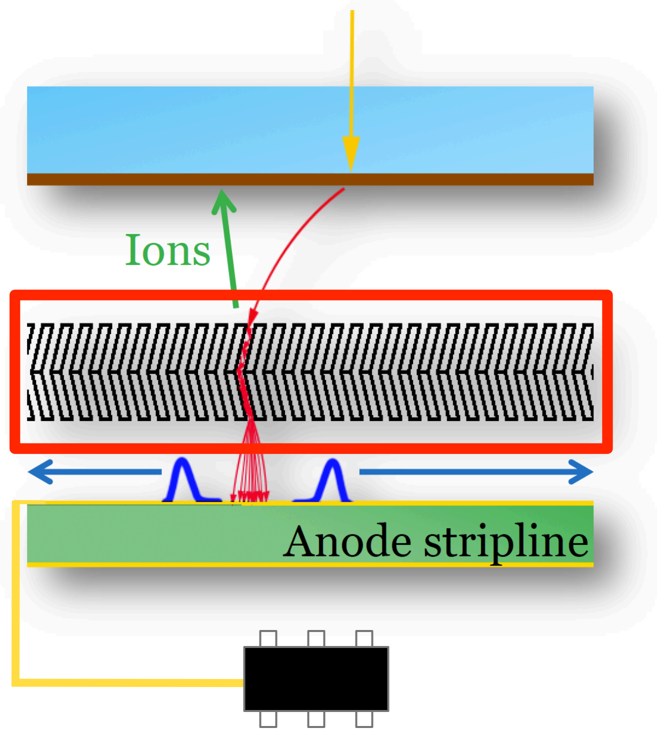

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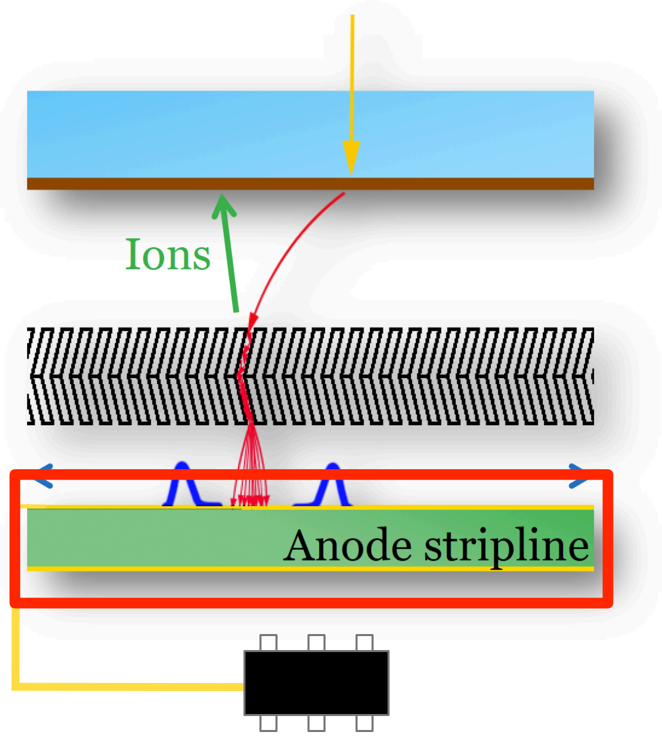

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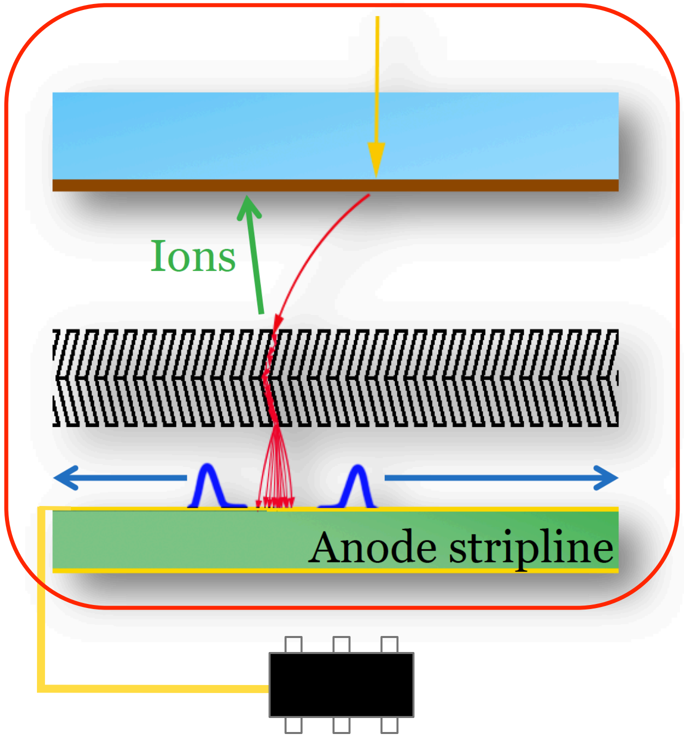

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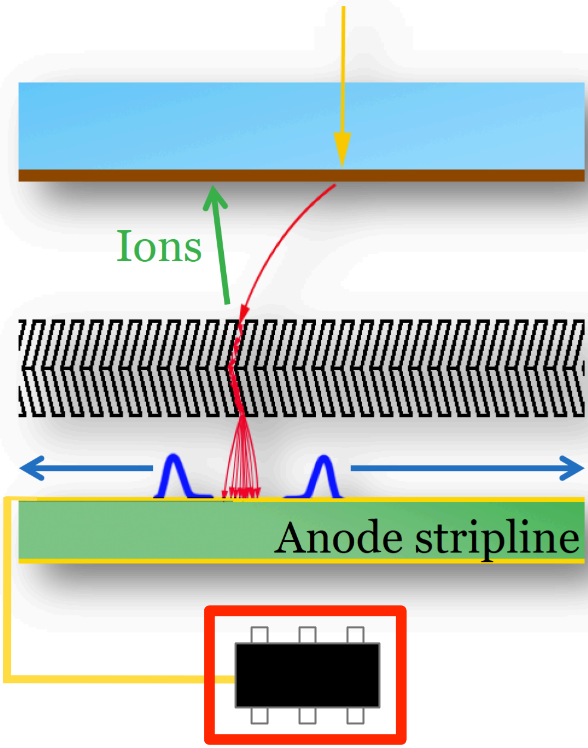

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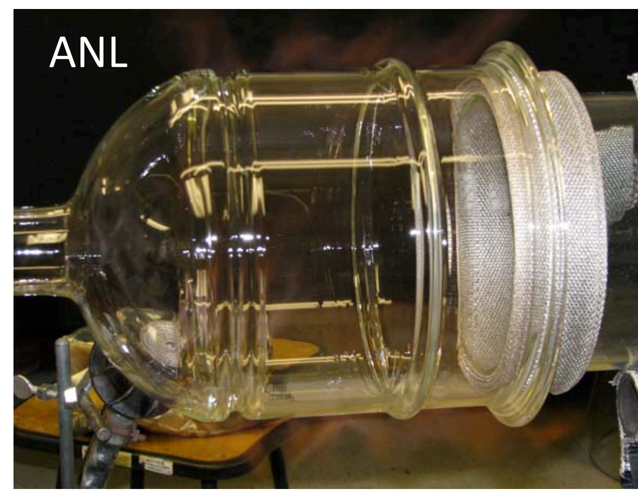
4. Hermetic Packaging
   - Maintain vacuum and provide support. No internal connections; no penetrations
5. Electronics
   - Readout at both ends with fast custom CMOS SCA chip with 18 GHz waveform digitization; optimized design yields pico-second timing resolution

Photo-Cathode Thrusts

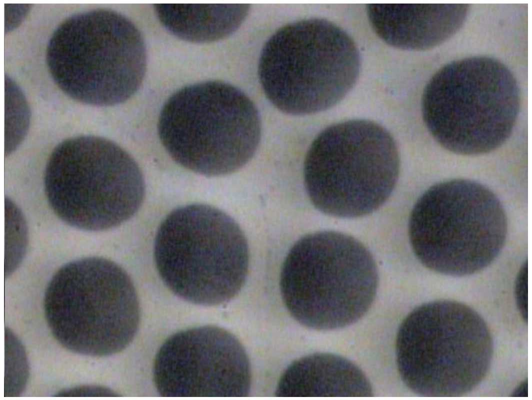
- Space Science Laboratory, Berkeley:
  R&D focus on scaling up of traditional bi-alkali to larger area

- ANL/Wash U/UICU:
  R&D focus on theory inspired design
  - New novel photocathode technologies like nano-structured photocathodes
  - III-V have the potential for high QE, shifting toward the blue and robustness
  - Simulations, testing & characterization

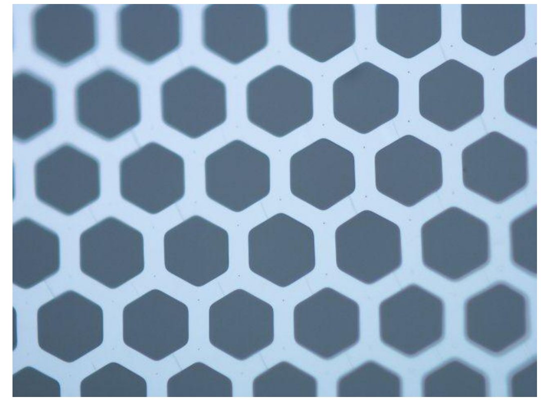
- Argonne:
  R&D focus on design for industrial production of large-area photocathodes for a tile factory
  - In the process of setting up in-house photo-cathode production facility (Greg Selberg, Anatoly Ronzhin)



MCP Development: Simplifying Construction



Conventional Pb-glass MCP



Incom Glass Substrate

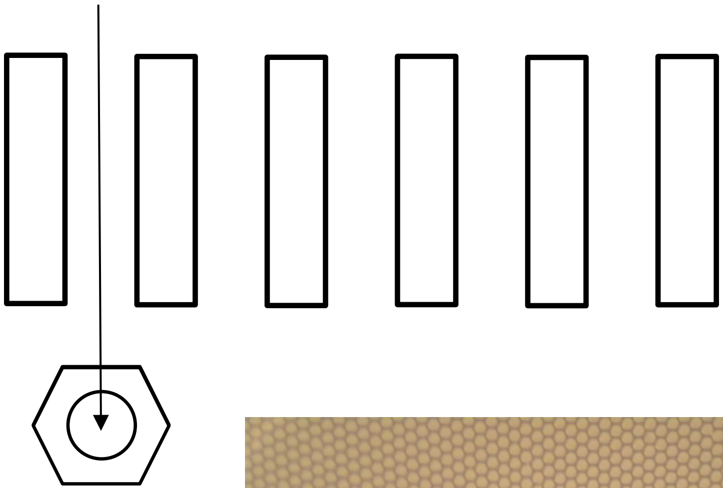
- Chemically produced and treated
- Pb-glass provides 3 functions:
  - Provides pores
  - Resistive layer supplies electric field in the pore
  - Pb-oxide layer provides secondary electron emission

- Separate the three functions:
  - Hard glass substrate provides pores
  - Separate Resistive and Emissive layer functions
  - Produce Tuned Resistive Layer (Atomic Layer Deposition, ALD) provides current for electric field
  - Specific Emitting layer provides secondary electron emission

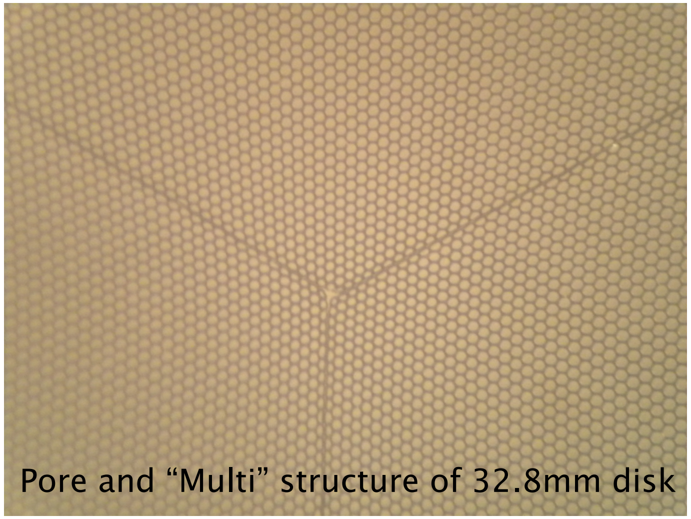
MCP Fabrication with ALD

- Start with glass capillary array (borosilicate), pulled to appropriate pore size

20 μm pores



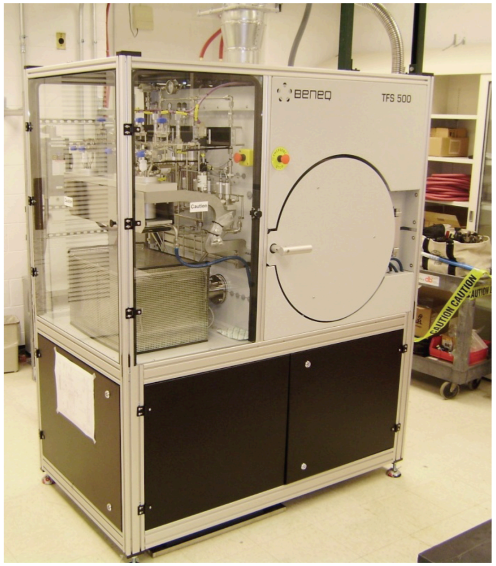
- Obtained MCP arrays with 33mm diameter, pore size 5 μm
- Goal is L/D = 40, D = 5 μm, 8”x8”

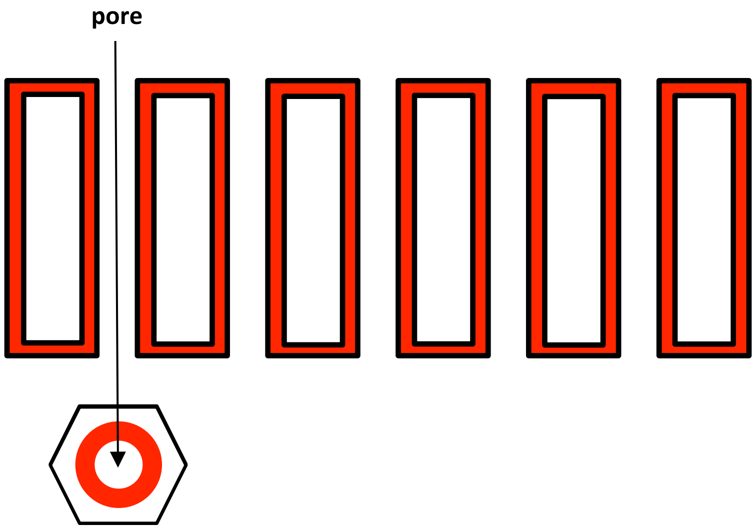


Pore and “Multi” structure of 32.8mm disk

MCP Fabrication with ALD

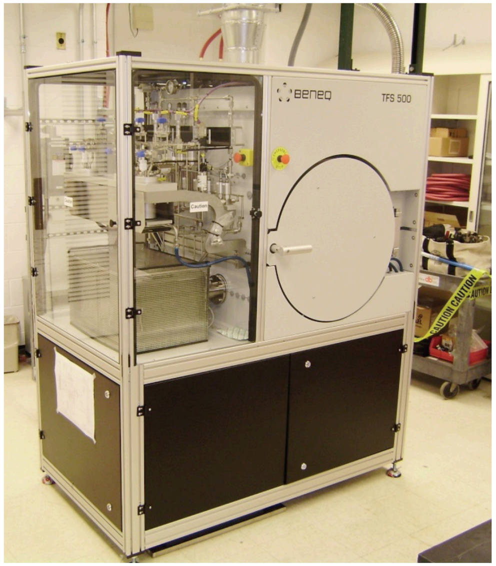
- Apply resistive coating, 17nm, using Atomic Layer Deposition, in Beneq reactor

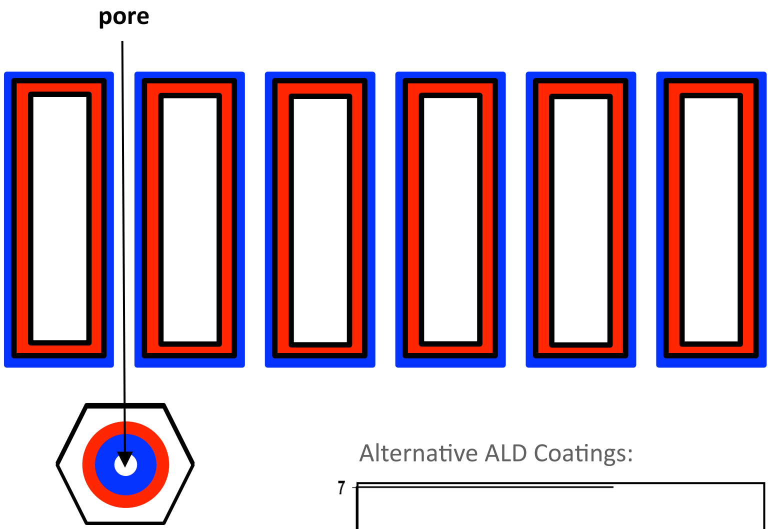




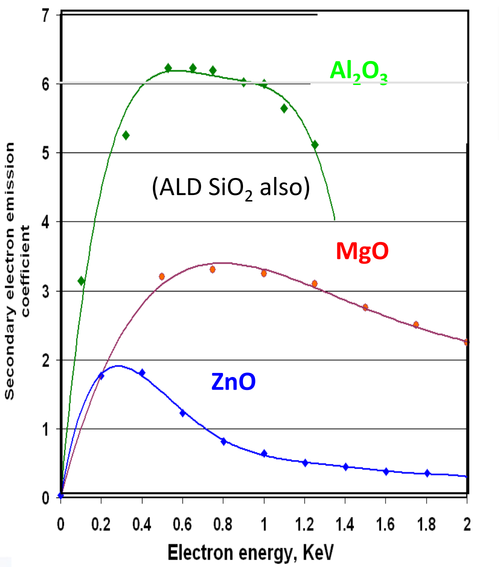
MCP Fabrication with ALD

- Apply emissive Al_2O_3 layer, using using Trimethyl Aluminum $Al(CH_3)_3$ and ALD





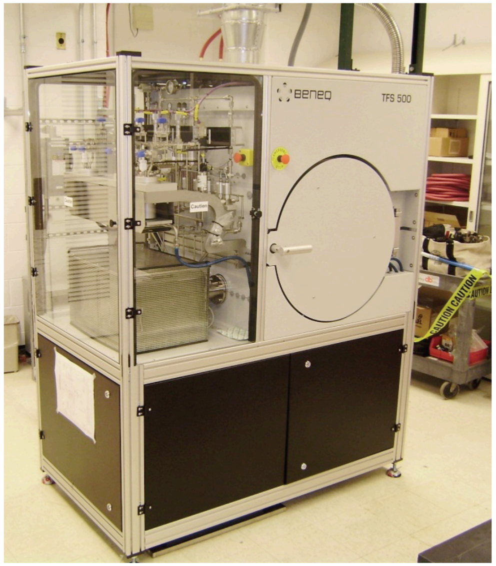
Alternative ALD Coatings:

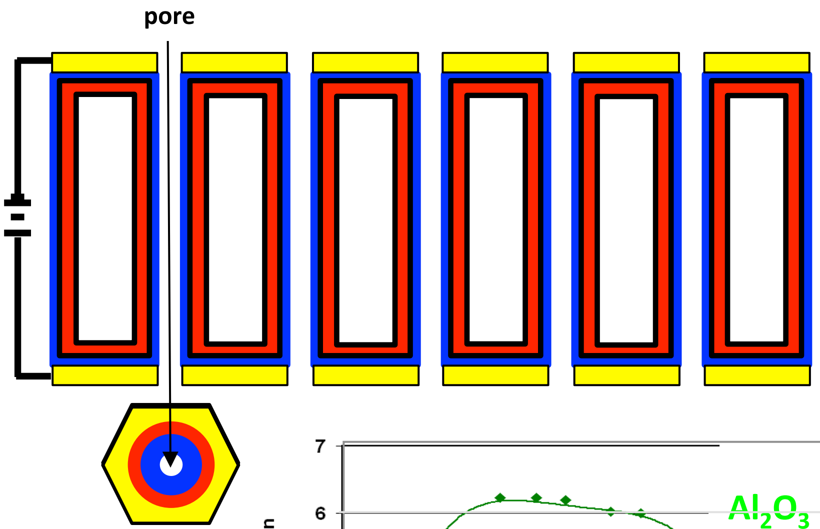


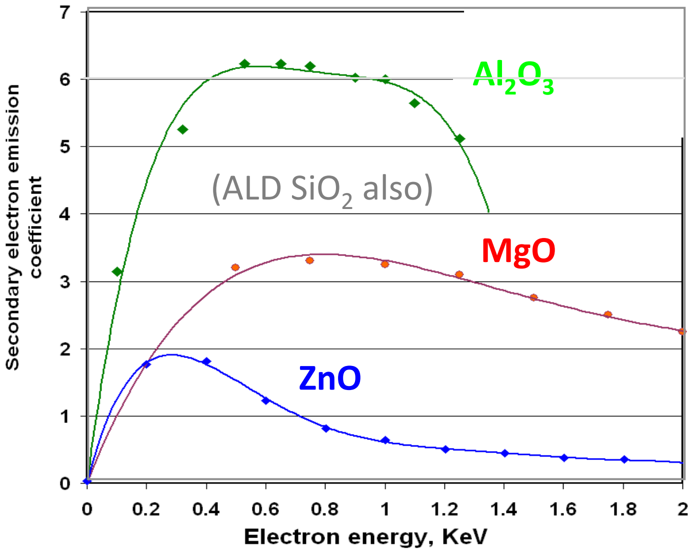
- Wide parameter space studied
  - Relative composition of materials
  - Temperature for ALD
  - Different materials and thicknesses
- Figure shows secondary electron emission coefficient as function of electron energy (keV)

MCP Fabrication with ALD

- Apply conductive coating for HV, using thermal evaporation or sputtering



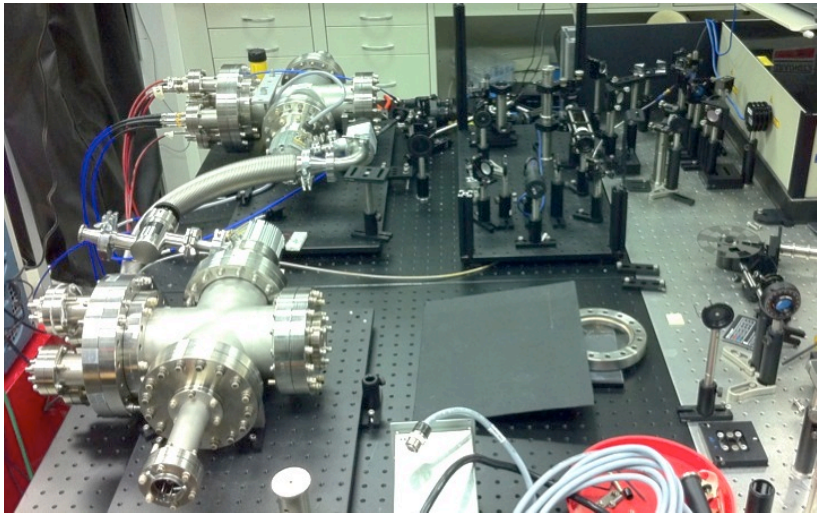


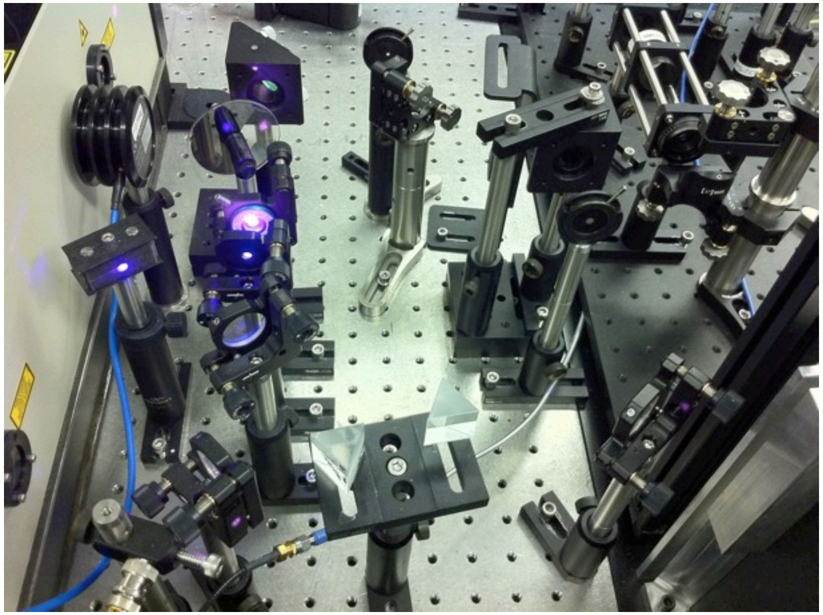


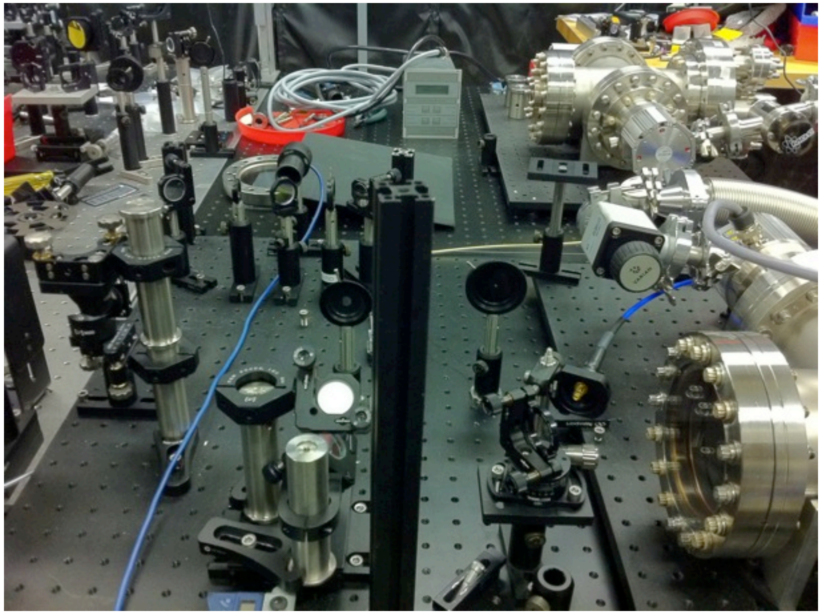
- First time applying new technology, a factor >5 improvement obtained in gain of ALD treated MCPs compared to commercial MCPs; area will be substantially increased

MCP Testing

- Full laser test setup with fs laser at APS
  - Clean UV beam
  - Laser power monitoring
  - Position scan
  - Absolute laser arrival time on MCP (in progress)
- Results compared with simulation

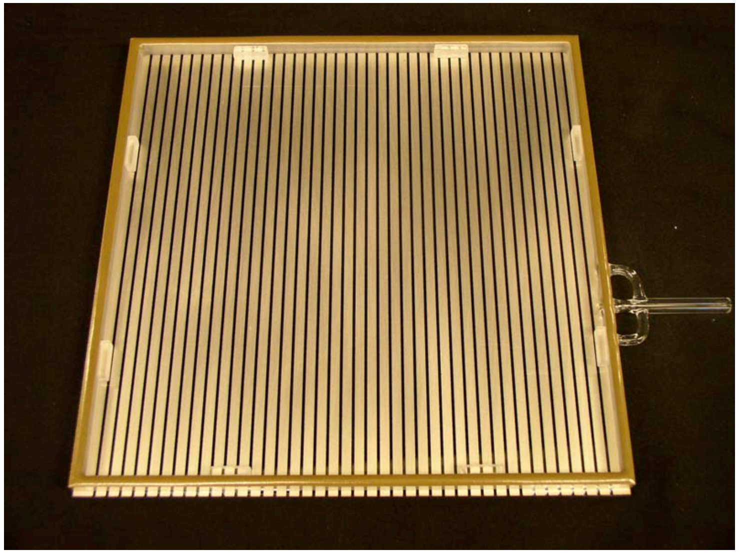


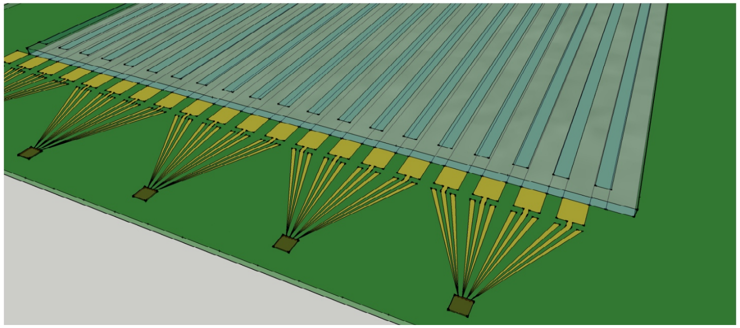




Anode and Signal Readout

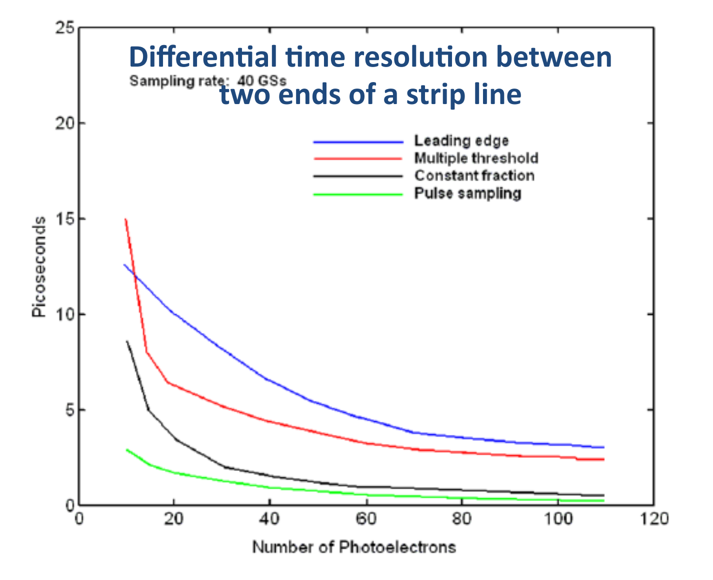
- Sealed tile construction: all glass
- Anode:
  - Silk-screened, no pins, penetrations, no internal connections
  - Transmission line readout both ends → gets position and time
  - Signal is differential between ground (inside, top), and PC traces (outside)
  - Simulations indicate that these transmission lines could be scalable to large detectors without severe degradation of resolution.
- Cover large areas with much reduced channel count.
- Tile Factory being setup
  - Greg Selberg, Anatoly Ronzhin

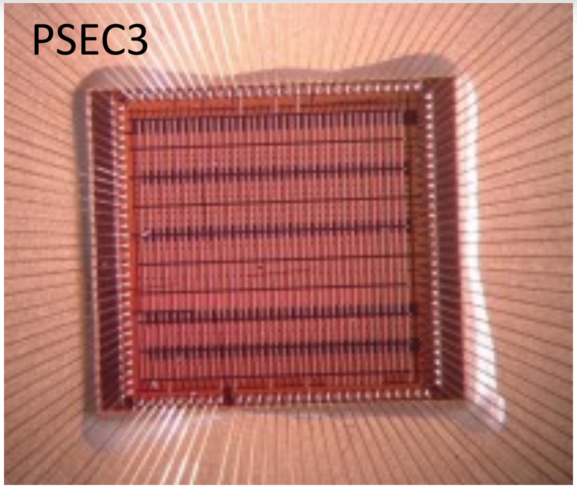




PSEC3 Waveform Sampling ASIC

- Resolution depends on # photoelectrons, analog bandwidth, and signal-to-noise.
- Simulations showed “pulse sampling” to give the best results
- ASIC (PSEC3) designed by UofC / Hawaii
  - 130nm IBM Process
  - 4 channels, 256 deep analog ring buffer
  - Sampling tested at (almost) 18 GS/sec
  - Each channel has its own ADC- 10 bits effective
  - Fastest waveform sampling chip by a factor of ~3

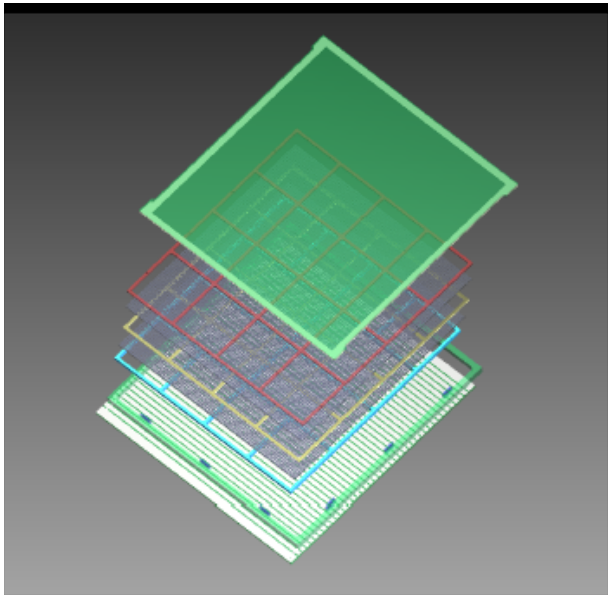


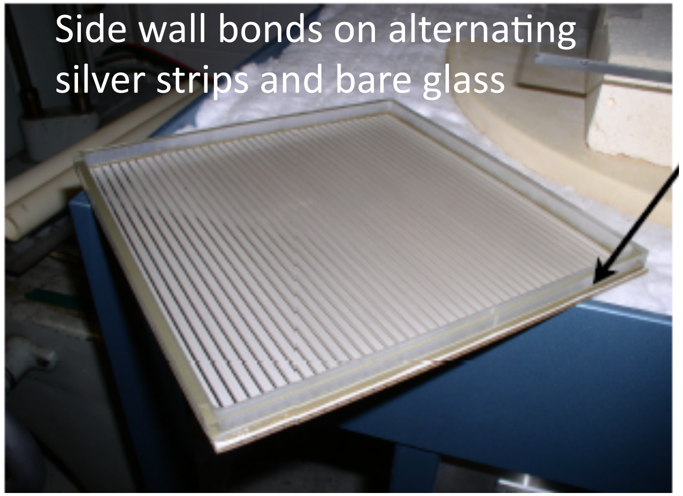


Hermetic Packaging

- All glass hermetic package:
  - Use inexpensive borosilicate glass for containment vessel
  - Avoid use of pins penetrating glass for HV and signal
  - Cheap, reliable, reproducible containment vessel fab.

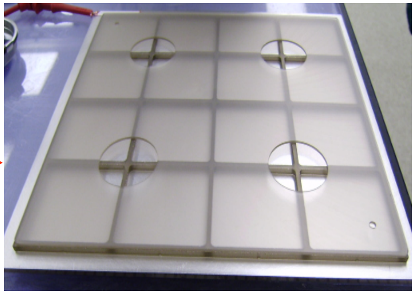
- Constraints:
  - Support vessel against implosive atmospheric pressure
  - Top photocathode window seal at low temp. (<120 C)
  - ~10 yr stability for seal with small leak rate
  - Minimum handling steps in fabrication
  - Avoid particulates in vacuum space
  - Materials chemically compatible with alkali metal photocathode



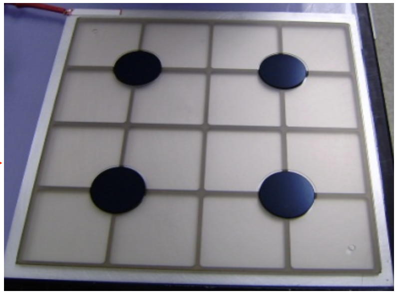


Construction of (Mock) Tile

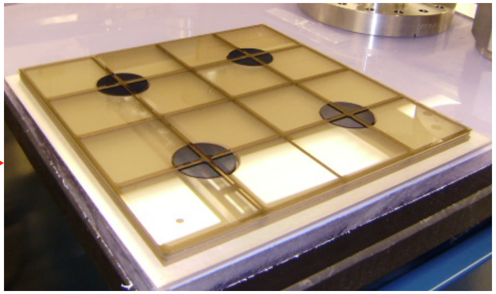
2.97mm bottom Grid Spacer



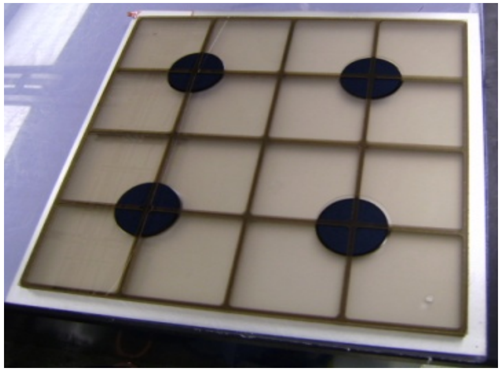
add Mock MCP



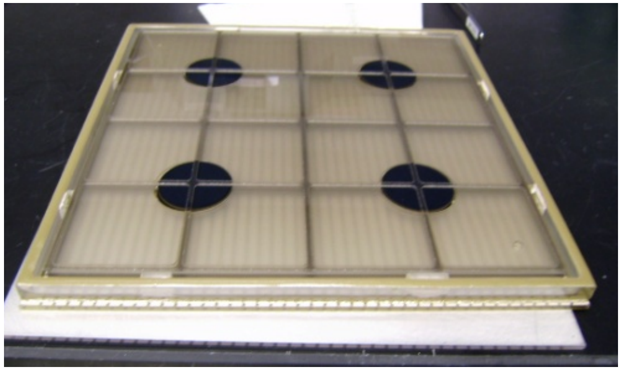
add functionalized MCPs



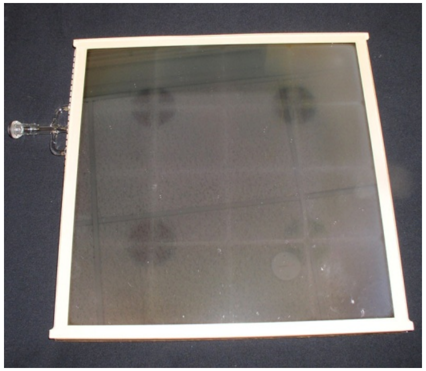
add 1.1mm Grid spacer



Add mock MCPs, 33mm functionalized MCPs & top 1.1mm Grid spacer



full stack in mock tile



Mock tile after sealing and evacuation

Simulation and Testing

Microscopic/Materials-Level

Macroscopic/Device-Level

Material Science Division, ANL

Constructing dedicated setup for low-energy SEE and PE measurements of ALD materials/photocathodes.

parts-per-trillion capability for characterizing material composition.

HEP Laser Test Stand, ANL

Fast, low-power laser, with fast scope.

Built to characterize sealed tube detectors, and front-end electronics.

Highly Automated

Berkeley SSL

Decades of experience.

Wide array of equipment for testing individual and pairs of channel plates.

Infrastructure to produce and characterize a variety of conventional photocathodes.

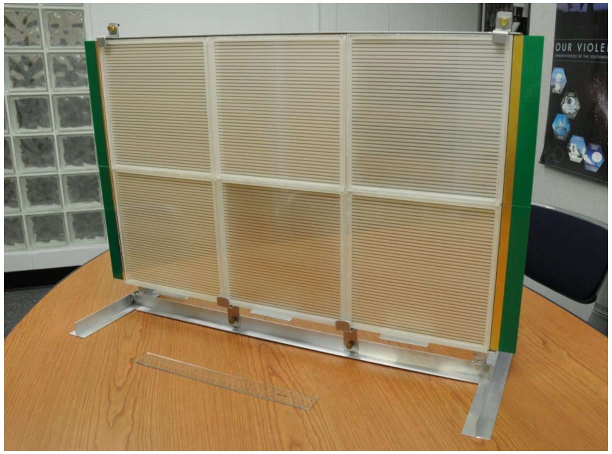
Advanced Photon Source, ANL

Fast femto-second laser, variety of optical resources, and fast-electronics expertise.

Study MCP-photocathode-stripline systems close to device-level. Timing characteristics amplification etc.

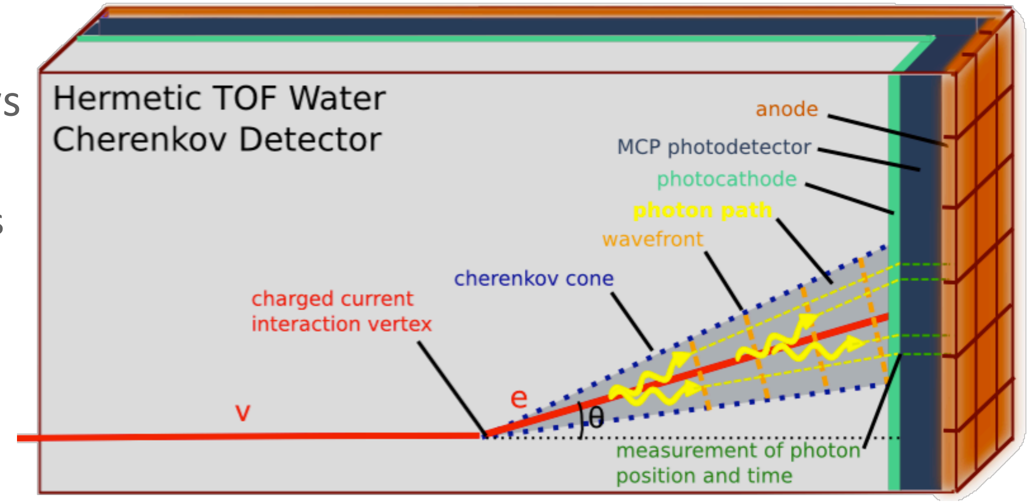
Future

- Construction of 8"x8" planar photo-detector imminent.
- Establishes the proof of principle; to be followed by construction of 3x2 array (not part of the DOE approved project)



- Exploring wide array of applications to bring technology into the field as quickly as possible through intermediate steps

- Large area H_2O Čerenkov detectors
- Pico-second timing resolution allows for π^0/e rejection
  - 100 ps time resolution corresponds to about 1 cm space resolution
  - Vertex separation many cm

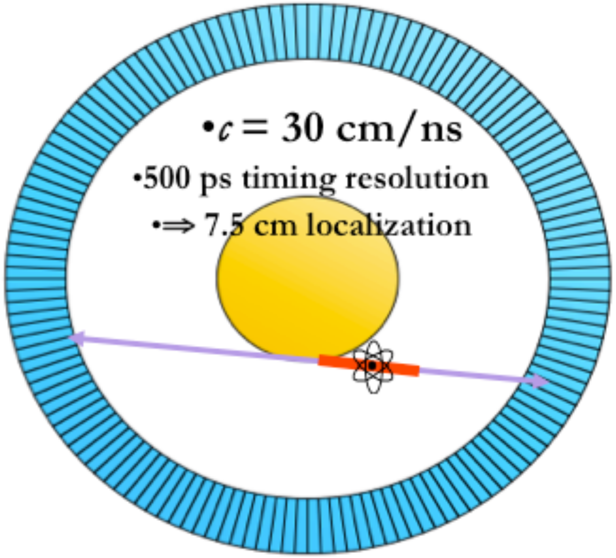


Applications

- Monitoring of neutrino flux of nuclear reactors (Homeland Security)
  - One m^3 – scale liquid scintillator (LS), water, and water-based LS detector
- LAPPD detectors provide for 100 psec time resolution, corresponding to 3cm space resolution ALONG photon direction; Transverse resolution on each photon should be sub-cm
- Questions that might be addressed:
  - Can one reconstruct tracks? Can one reconstruct vertices?
  - Can one distinguish a pizero from an electron and 2 vertices from one?

- PET Imaging
  - Can localize source along line of flight
  - Time of flight information reduces noise in images
  - Variance reduction given by $2D/c\Delta t$.
  - 500 ps timing resolution $\Rightarrow$ 5x reduction in variance!

  - Time of Flight provides a huge performance increase!
  - Largest Improvement in Large Patients



Concluding Remarks

- ANL is moving towards development of new sensors and detectors going back to basic underlying physics principle using advances in other disciplines. Other technologies being pursued

- LAPPD based on this philosophy and has met 1st and 2nd year milestones
  - Innovation in lots of areas- detectors, wave-form sampling, ALD, material science, photocathodes, …
  - Ultimate goal is to transfer technology to industry. Interest, but no money, from mass producers of tubes

- Lots of interesting applications in (and interest from) many areas of science: TOF at colliders, PET, Reactor Monitoring, HEP neutrino detectors, …

- Argonne amazingly deep in talent and resources; everyone is invited to tap those resources