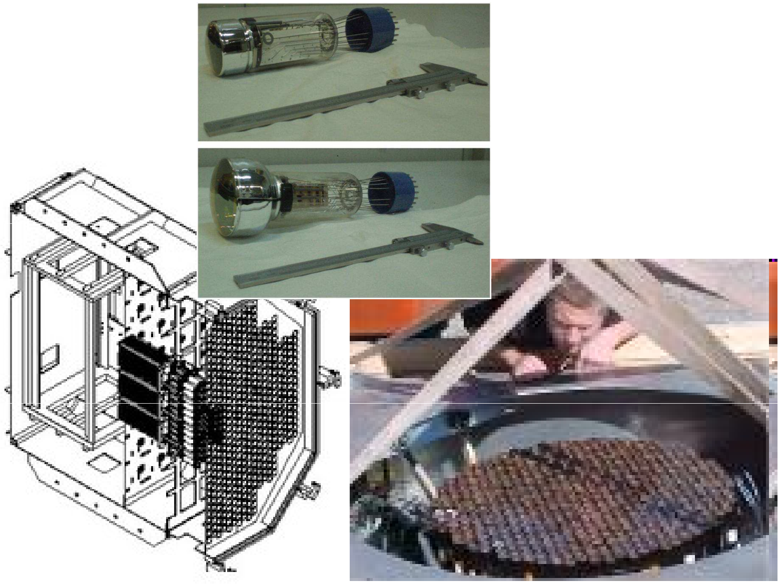
Large area photo detectors

Current

From sensors like this



TO

Future

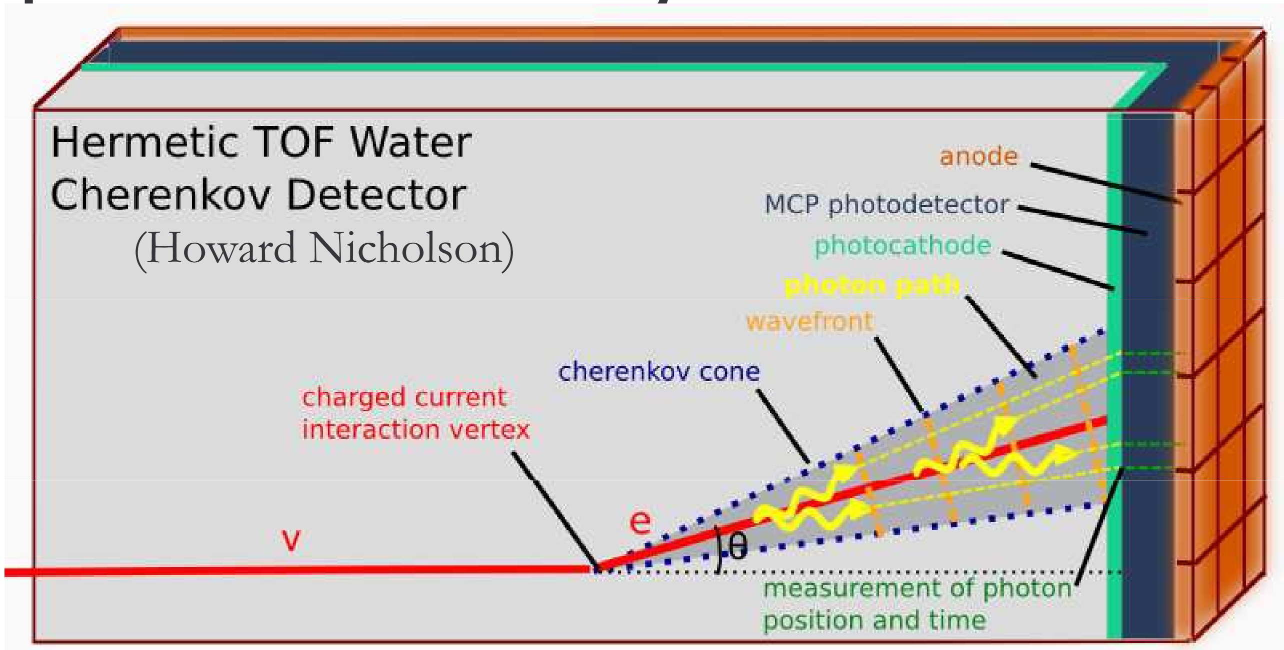
Something like this

Major goals:

- Use modern material science techniques
- Fast timing , order of ~psec
- Large area coverage i.e. reduce price
- (Re)establish knowledge base within labs
- Transfer technology to companies

Large H_2O Cherenkov detectors planned; ~$200M in photo tubes; reduce cost

Lepton Flavor Physics



- **Example- DUSEL detector with 100% coverage and 3D photon vertex reconstruction.**
- **Need >10,000 square meters (!) (100 ps resolution)**
- **Spec: signal single photon, 100 ps time, 1 cm space, low cost/m2 (5-10K$/m2)***

* Hermetic DUSEL specs TBD

Getting There: The LAPPD Collaboration

The Development of Large-Area Fast Photo-detectors

April 15, 2009

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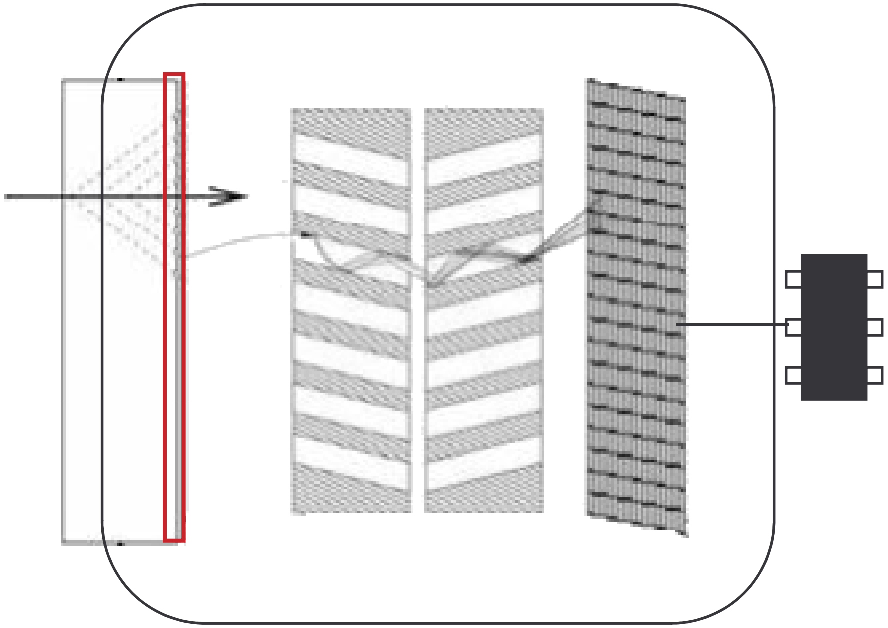
[1] Joint appointment Argonne National Laboratory and Enrico Fermi Institute, University of Chicago

- 4 National Labs
- 5 Divisions at Argonne
- 3 US small companies
- electronics expertise at Universities of Chicago and Hawaii
- 3 Universities (several more in pipeline)

Goals:

- exploit advances in material science and nanotechnology to develop new, batch methods for producing cheap, large area MCPs.
- To develop a commercializable product on a three year time scale.

Anatomy of an MCP-PMT

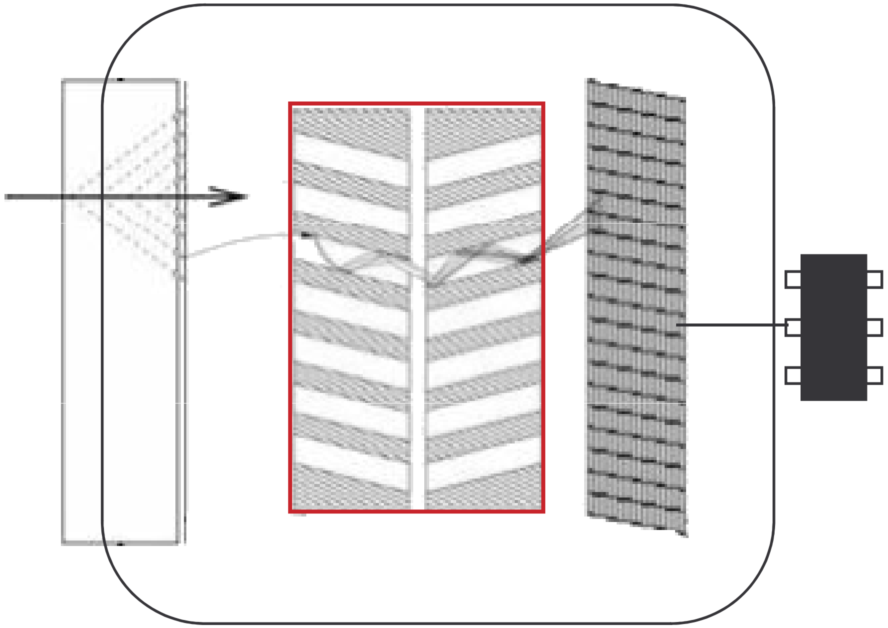


1. Photocathode
2. Multichannel Plates
3. Anode (stripline) structure
4. Vacuum Assembly
5. Front-End Electronics

Conversion of photons to electrons.

Slide by Matt Wetstein

Anatomy of an MCP-PMT

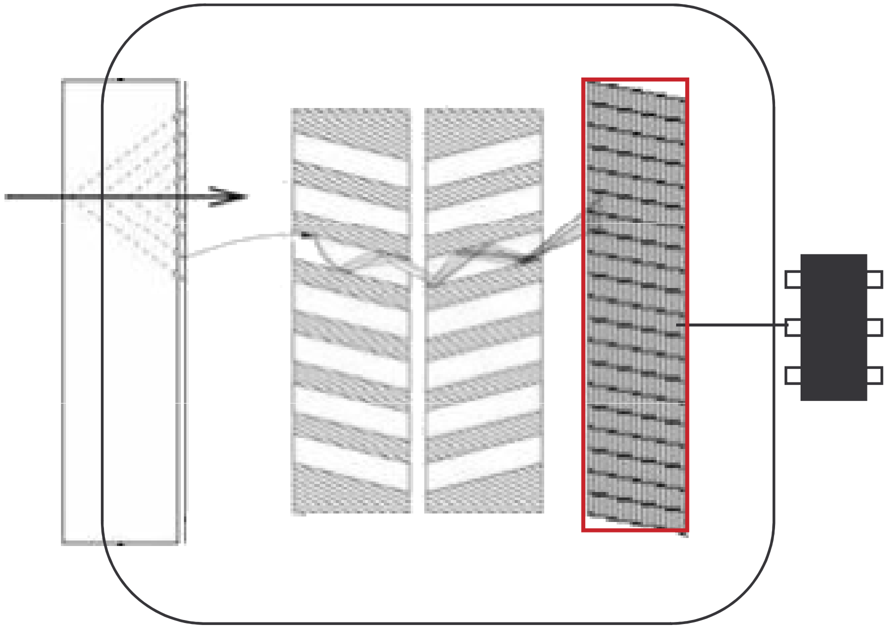


1. Photocathode
2. Microchannel Plates
3. Anode (stripline) structure
4. Vacuum Assembly
5. Front-End Electronics

Amplification of signal. Consists of two plates with tiny pores, held at high potential difference. Initial electron collides with pore-walls producing an avalanche of secondary electrons. Key to our effort.

Slide by Matt Wetstein

Anatomy of an MCP-PMT



1. Photocathode
2. Microchannel Plates
3. Anode (stripline) structure
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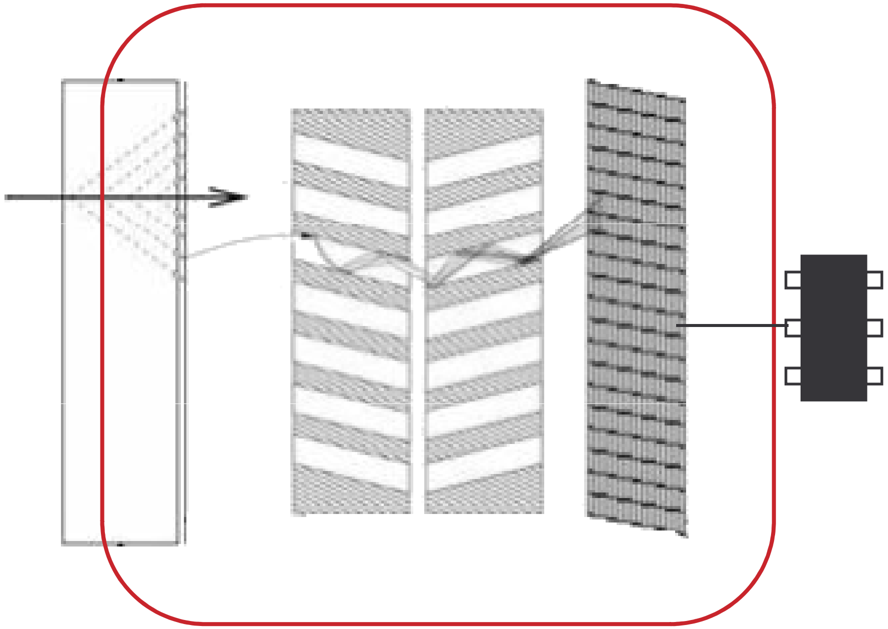
5. Front-End Electronics

Charge collection. Brings signal out of vacuum.

Slide by Matt Wetstein

Anatomy of an MCP-PMT

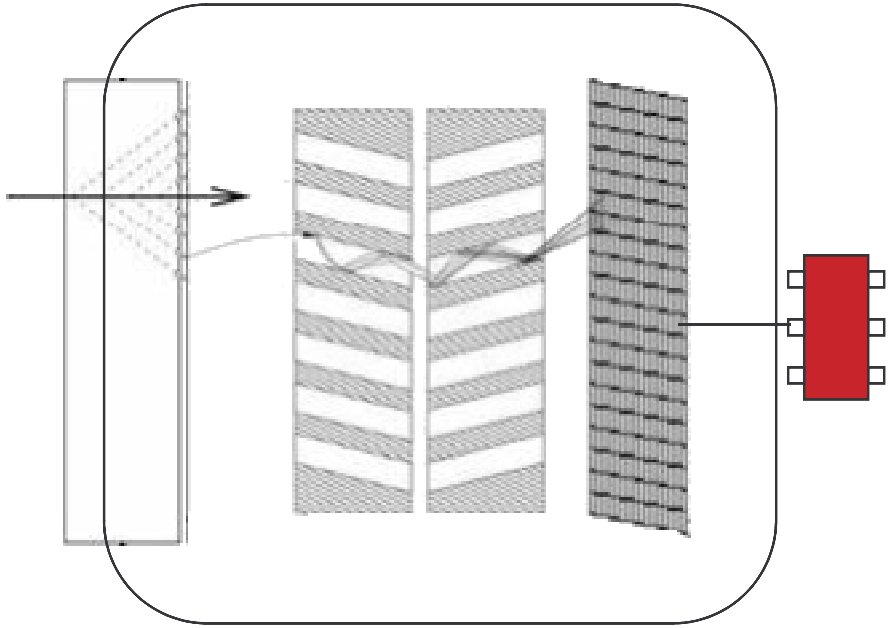


1. Photocathode
2. Microchannel Plates
3. Anode (stripline) structure
4. Vacuum Assembly
5. Front-End Electronics

Maintenance of vacuum. Provides mechanical structure and stability to the complete device.

Slide by Matt Wetstein

Anatomy of an MCP-PMT

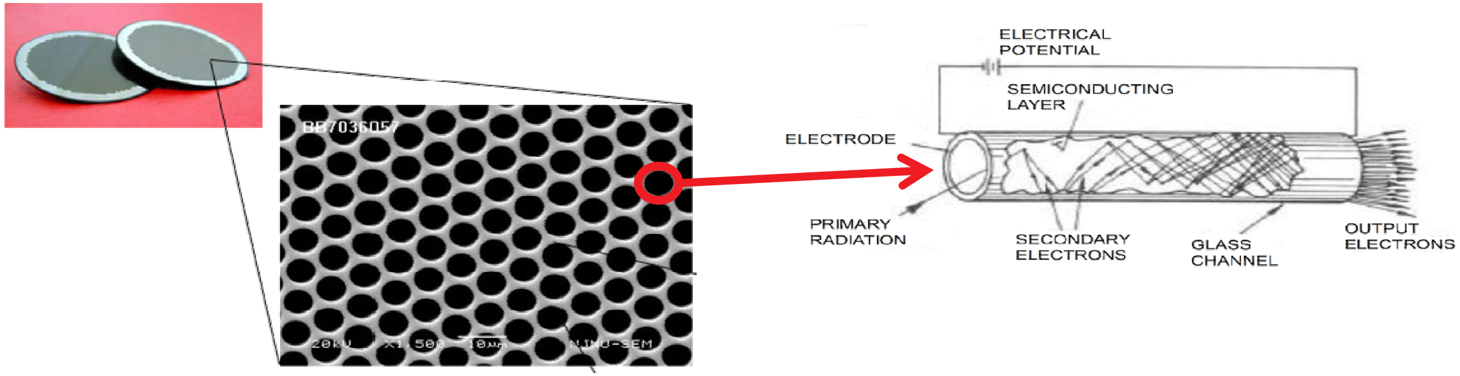


1. Photocathode
2. Microchannel Plates
3. Anode (stripline) structure
4. Vacuum Assembly
5. Front-end electronics

Acquisition and digitization of the signal.

Slide by Matt Wetstein

Channel Plate Fabrication



Conventional MCP Fabrication

- Pore structure formed by drawing and slicing lead-glass fiber bundles. The glass also serves as the resistive material
- Chemical etching and heating in hydrogen to improve secondary emissive properties.
- Expensive, requires long conditioning, and uses the same material for resistive and secondary emissive properties. (Problems with thermal run-away).

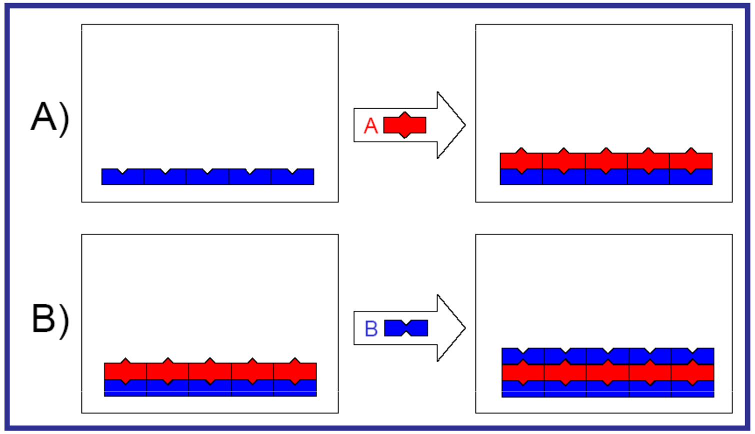
ALD Approach

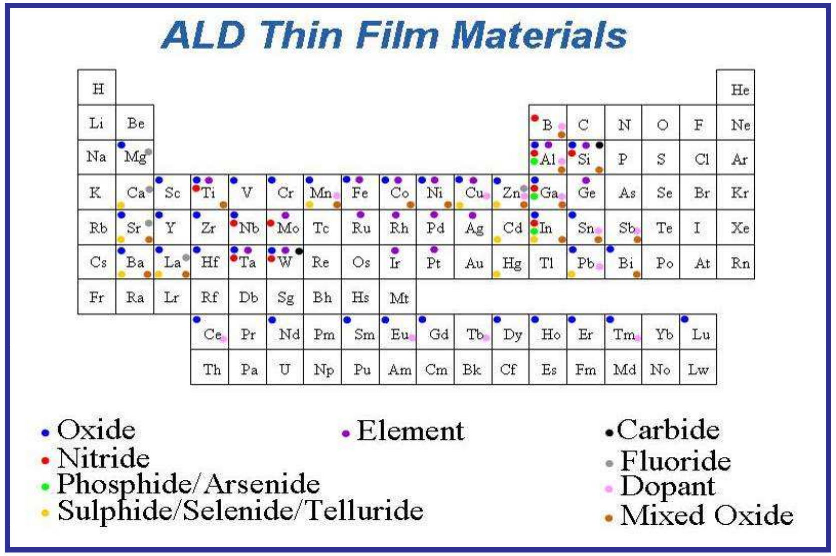
Separate out the three functions

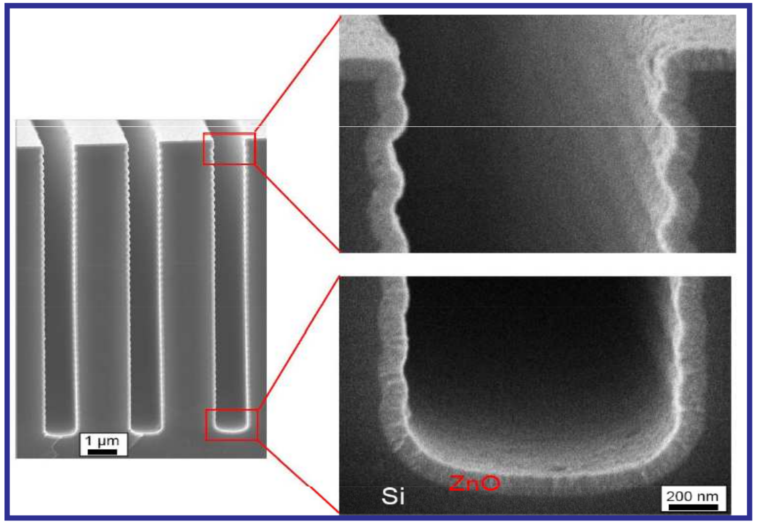
- Cheap passive substrate to provide pore structure.
- Separate resistive coating
- Separate secondary emissive coating
- Use ALD: a cheap industrial batch method. Hand-pick materials to optimize performance.

Atomic Layer Deposition

- A conformal, self-limiting process.
- Allows atomic level thickness control.
- Applicable for a large variety of materials.

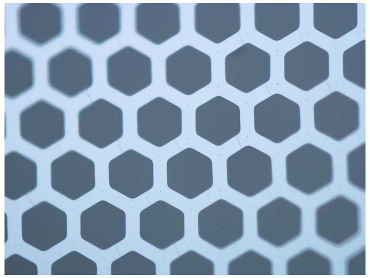




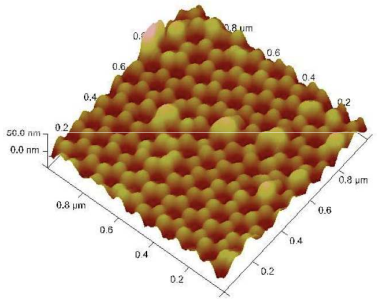


Channel Plate Fabrication w/ ALD

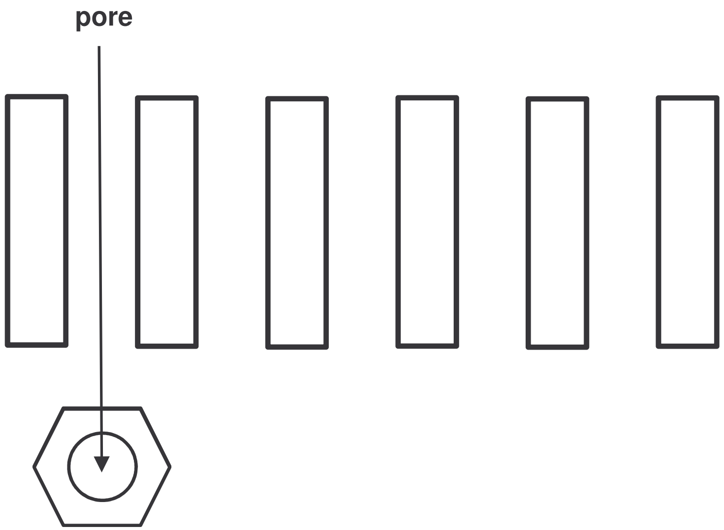
1. Start with a cheap, porous, insulating substrate that has appropriate channel structure.



borosilicate glass filters (default)



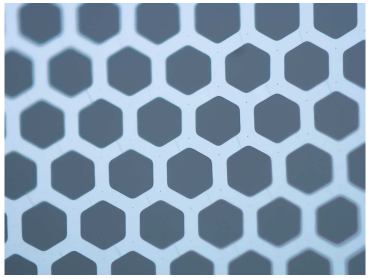
Anodic Aluminum Oxide (AAO)



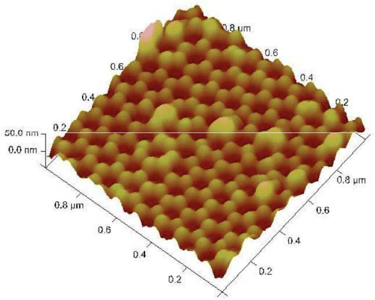
Slide by Matt Wetstein

Channel Plate Fabrication w/ ALD

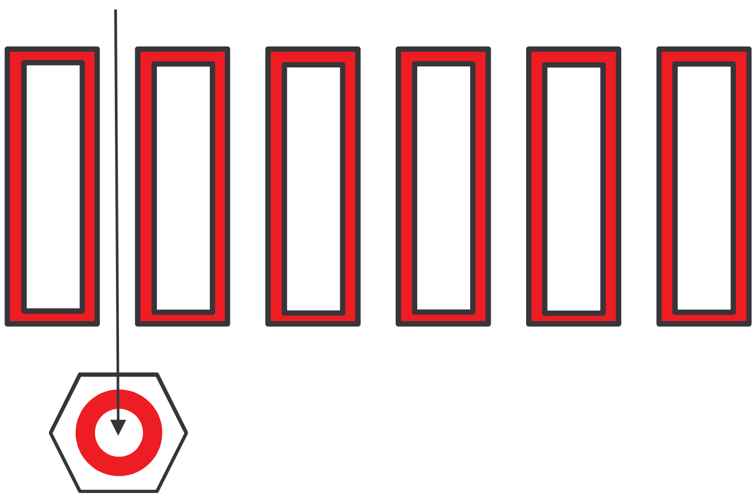
1. Start with a cheap, porous, insulating substrate that has appropriate channel structure.



borosilicate glass filters (default)



Anodic Aluminum Oxide (AAO)

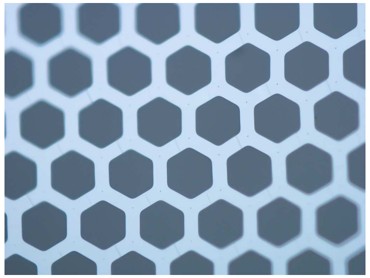


2. Apply a resistive coating (ALD)

Slide by Matt Wetstein

Channel Plate Fabrication w/ ALD

1. Start with a cheap, porous, insulating substrate that has appropriate channel structure.



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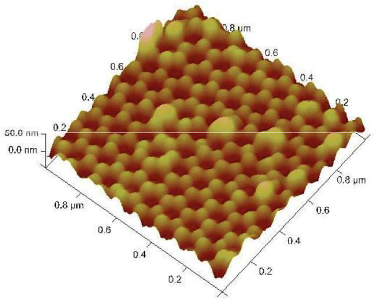
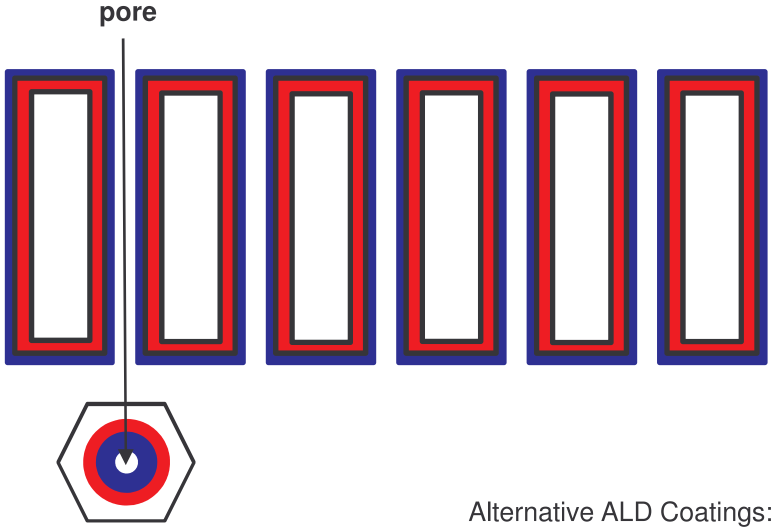
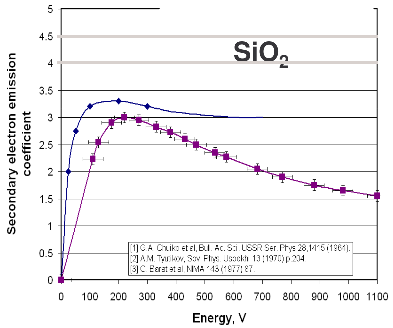


Anodic Aluminum Oxide (AAO)

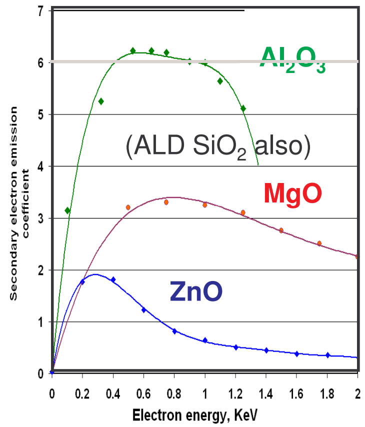


2. Apply a resistive coating (ALD)
3. Apply an emissive coating (ALD)

Conventional MCP's:



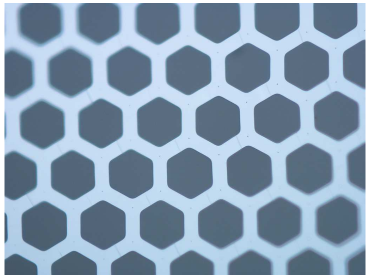
Alternative ALD Coatings:



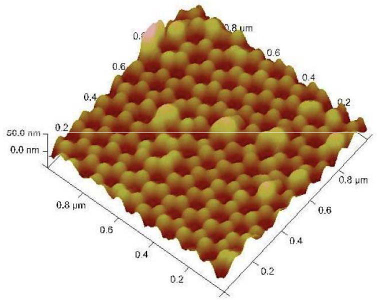
Slide by Matt Wetstein

Channel Plate Fabrication w/ ALD

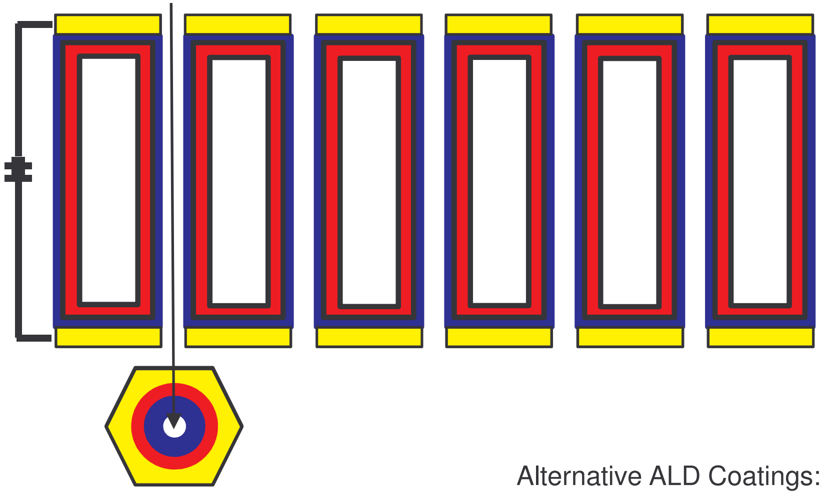
1. Start with a cheap, porous, insulating substrate that has appropriate channel structure.



borosilicate glass filters (default)

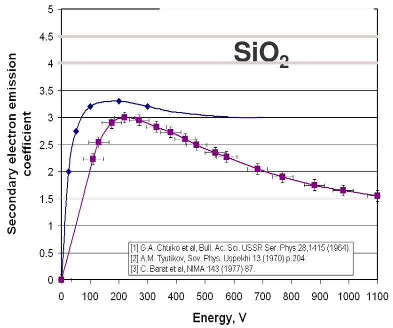


Anodic Aluminum Oxide (AAO)

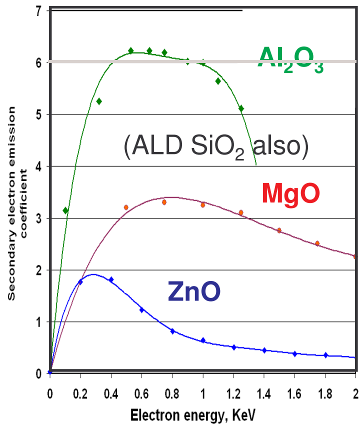


2. Apply a resistive coating (ALD)
3. Apply an emissive coating (ALD)
4. Apply a conductive coating to the top and bottom (thermal evaporation or sputtering)

Conventional MCP's:



Alternative ALD Coatings:



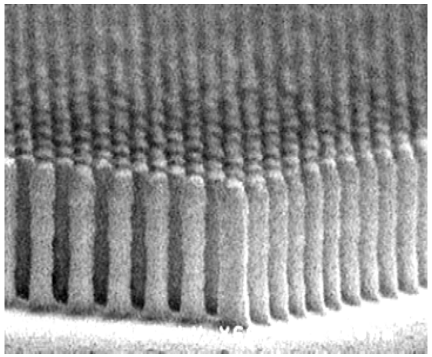
Photocathode Fabrication

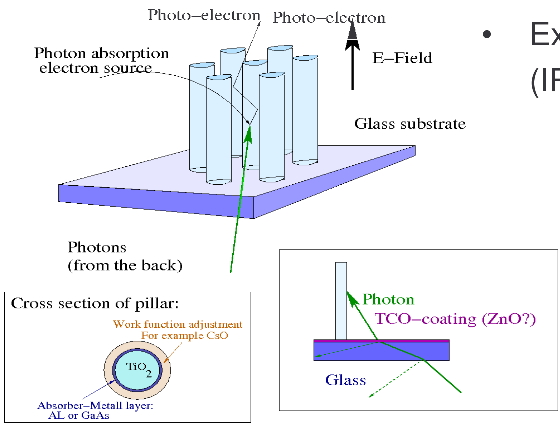
Default Position

- Scale traditional bi-alkalai photocathodes to large area detectors.
- Necessary resources and expertise available at Berkeley SSL.

In parallel with conventional photo-cathode techniques, pursue more novel photocathode technologies.

- Nano-structured photocathodes:
  - Reduction of reflection losses (light trap)
  - Heterogeneous structure permits multi-functionality (electrically, optically, electron-emission, “ion-etching resistant”)
  - Increased band-gap engineering capabilities
  - Expertise and know-how of multi-billion industry (IR-detectors)





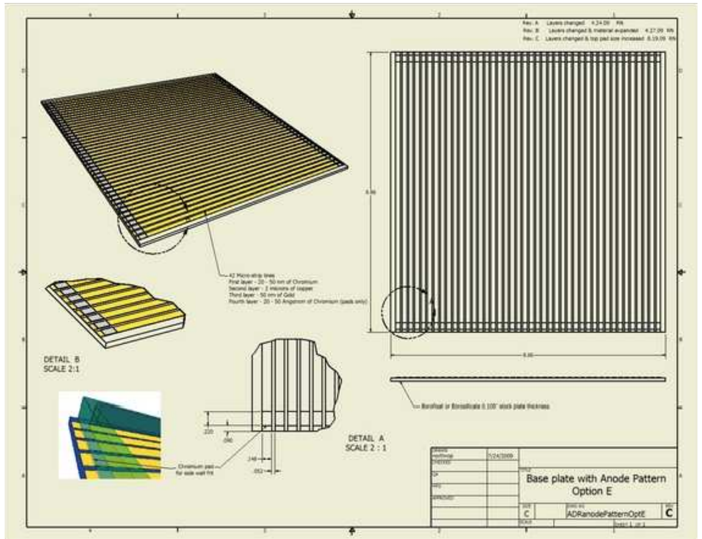
- Pure-gas fabrication
  - Would greatly streamline manufacturing process and reduce costs

Slide by Matt Wetstein

Device Assembly

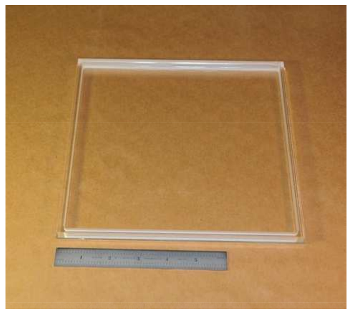
Default Position

- Use ceramic assemblies, similar to those used by conventional MCPs.
- Well developed technology, know-how available at SSL



Looking into sealed glass-panel technologies (flat screen TVs). Device construction must:

- Maintain 50Ω impedance through vacuum seal
- Avoid damage to photocathode during assembly
- Maintain integrity of channel plates, spacersAllow for vacuum tight sealing of outer “envelope” across uneven surfaces of varying composition
- Be able to handle high pressure and mechanical stress.

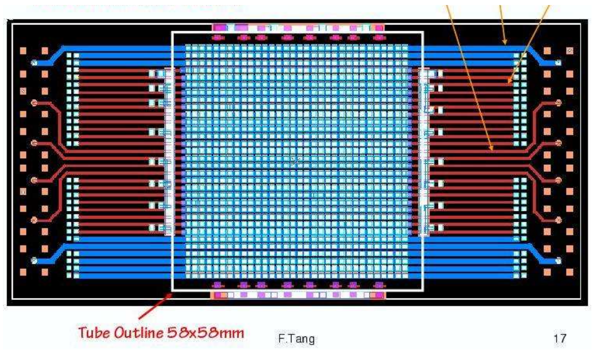


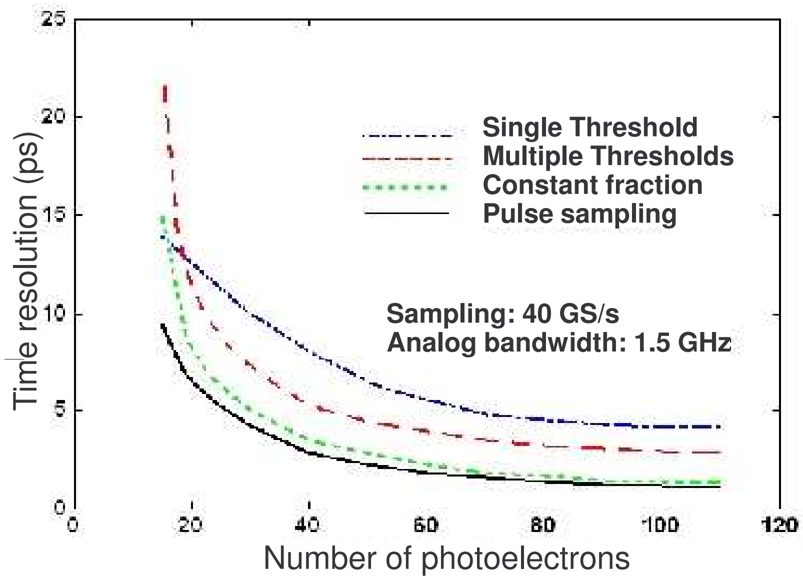
Working with various glass vendors and experts on these.

Slide by Matt Wetstein

Front End Electronics

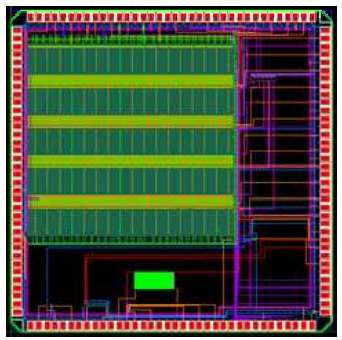
- Started as collaboration between U of Chicago and Hawaii.
- Resolution depends on # photoelectrons, analog bandwidth, and signal-to-noise**.**
- Wave-form sampling is best, and can be implemented in low-power widely available CMOS processes (e.g. IBM 8RF). Low cost per channel.
- 48-inch Transmission Line- simulation shows 1.1 GHz bandwidth- still better than present electronics, ie **readout for a 4-foot detector is same as a small one!**





- Transmission Line- readout both ends=> pos and time
- Cover large areas with much reduced channel account.
- US Patent

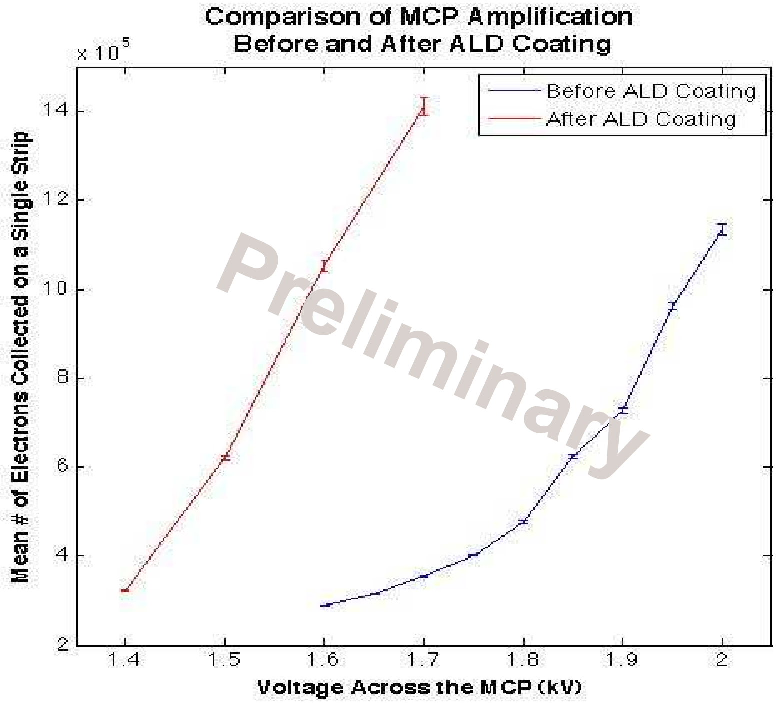
Chip submitted to MOSIS -- IBM 8RF (0.13 micron CMOS)- 4-channel prototype. Plan on 16 channels/chip- possibly 32 later.



Slide by Matt Wetstein

Early Achievements

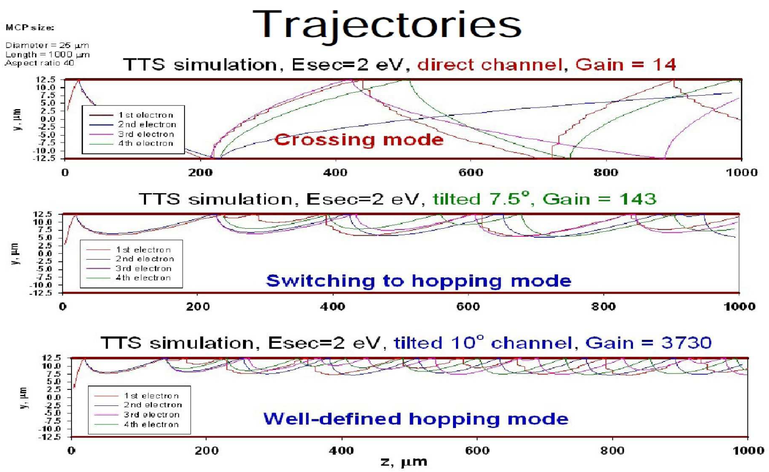
- Using our electronic front end and striplines with a commercial Photonis MCP-PMT, were able to achieve 1.95 psec timing, 97 µm position resolution.
- Now capable of quickly producing 33 mm ALD coated samples.
- Rapid development of testing capabilities underway.
- Preliminary results at APS show amplification in MCP after ALD coating!
- Some early collaboration between simulation and testing groups.

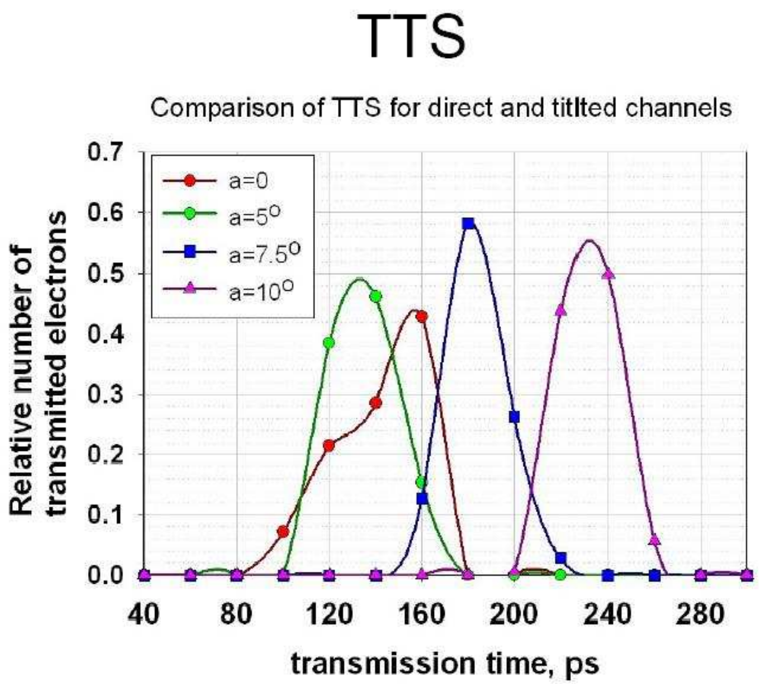


- After characterizing the Photonis MCP, we coat the plates with 10 nm Al_2O_3.
- The "after-ALD" measurements have been taken without scrubbing.
- These measurements are ongoing.

Simulation

- Working to develop a first-principles model to predict MCP behavior, at device-level, based on microscopic parameters.
- Will use these models to understand and optimize our MCP designs.





Slide by Matt Wetstein

Testing and Characterization

Microscopic/Materials-Level

Material Science Division, ANL

XPS….

Study ALD samples, microchannel plates, and photocathodes on a microscopic materials-level.

↓

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.

→

Macroscopic/Device-Level

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.

↑

HEP Laser Test Stand, ANL

Fast, low-power laser, with fast scope.

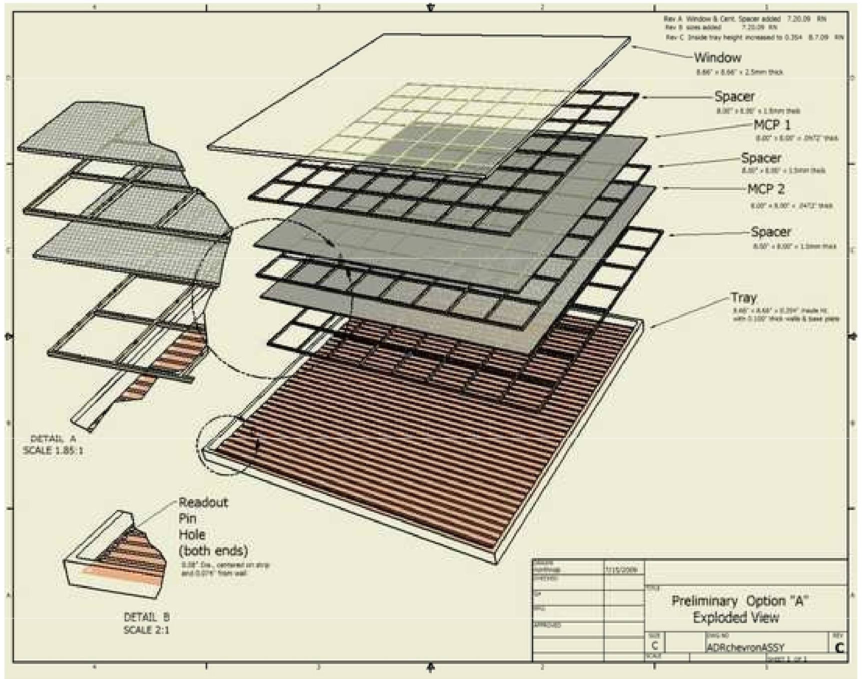
Built to characterize sealed tube detectors, and front-end electronics.

Highly Automated

Slide by Matt Wetstein

Tiling a CTA Camera

- CTA 12m D-C camera dimensions: 274.32×274.32 cm^2 (English: 9’×9’)
- Default Large Area MCP-PMT dimensions:8”×8” (20.3×20.3 cm^2)
  - dimension and pixel size can be adjusted to application
  - strip line readout option has 5mm×10mm dead space at edge for sidewall frame and strip connection to electronics.
    - frame can be reduced
    - pixel readout option would remove space dedicated to electronics
    - package several MCP substrates into single module further reduces dead space
- One camera option:
  - 13×13 array of MCP-PMT
  - 20.3×20.3cm^2 with 2.5mm sidewall

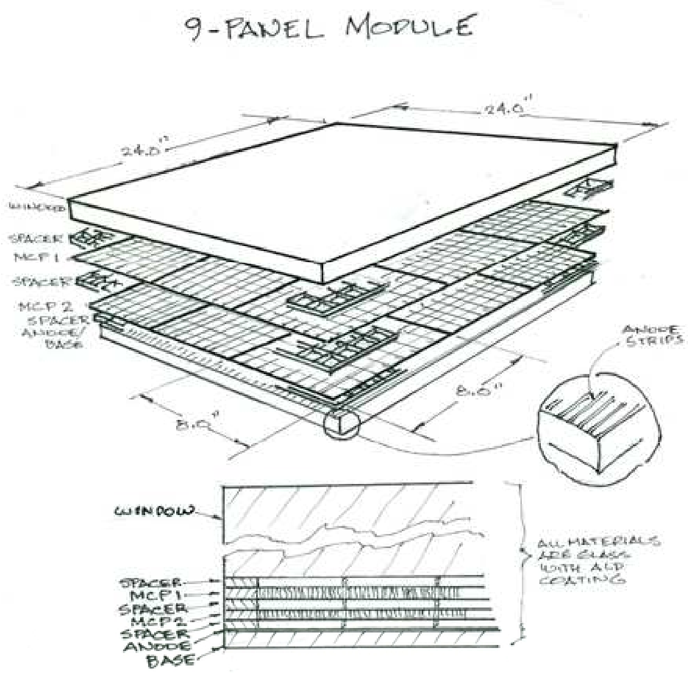


Strip line would be replaced with pixel array

Slide by Bob Wagner

Panel Module Option for CTA Camera

- Advanced containment option for continuous strip line readout
- Bottom/sidewall tray containing several MCPs to reduce dead space
- Would require larger assembly enclosure
  - if vacuum, expensive
  - if glove box, quite reasonable
    - plan to test photocathode effects for exposure to pure inert gas
- For CTA 4x4 panel module with 22.5×22.5cm^2 MCP panels, 2mm gap btw panels, 5mm sidewall
  Tile modules in 3×3 array for camera
- Requires consideably more development work.



Concept for module enclosing many MCP panels

Slide by Bob Wagner

Conclusions

- LAPPD Collaboration is well on its way. Lots of work remains. Preliminary achievements are encouraging.
- May make photo-detection significantly cheaper.
  - Reduce bottom-line manufacturing costs
  - Economic impacts of new vendor/alternative in the market
- Lessen the neutrino-community's dependence on a single vendor.
- If successful, this project presents a unique opportunity to think about how to do an analysis in a Water Cherenkov Detector.
  - New set of trade-offs.
  - Lots of room for out-of-the-box thinking.

Slide by Matt Wetstein

Backup Slides