University of Chicago

Argonne NATIONAL LABORATORY

LAPPD

Integration-Level Testing of Sub-Nanosecond Microchannel Plate Detectors for Use in Time-Of-Flight HEP Applications

M. Wetstein, B. Adams, M. Chollet, S. Jokela, Z. Insepov, V. Ivanov, J. Elam, A. Mane, Q. Peng
for the LAPPD Collaboration

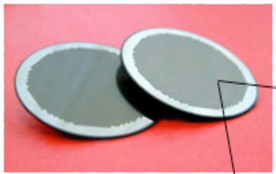
TIPP

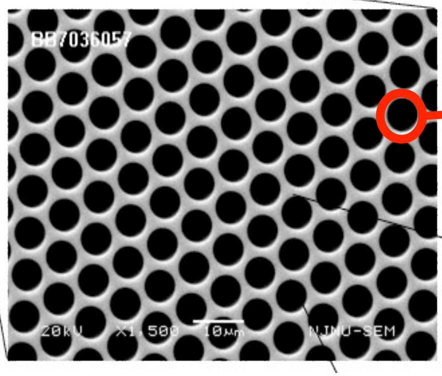
June 13 2011

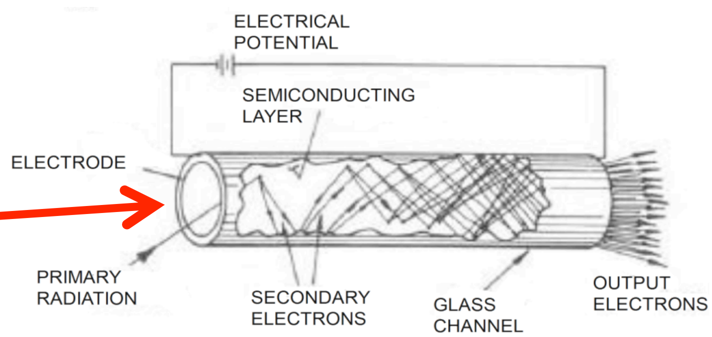
U.S. DEPARTMENT OF ENERGY

Making MCPs Faster, Bigger, and Cheaper:

- Microchannel Plate (MCP): A high-gain structure consisting of a thin plate with microscopic (typically <50 μm) pores.
- The material in these plates is optimized for secondary electron emission (SEE).
- Plates are held at high voltages (typically a few kV) so that electrons will accelerate and strike the walls, initiating an avalanche of secondary electrons.
- Known for good gain (>10^3), excellent timing resolution (<100 psec) and spatial resolution (<1 mm).
- Unfortunately, they are also typically expensive.



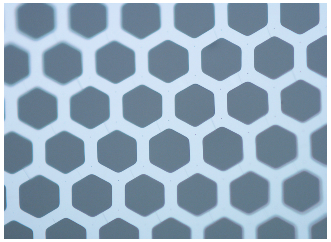




Making MCPs Faster, Bigger, and Cheaper:

LAPPD (Large-Area Picosecond Photodetector) Project:

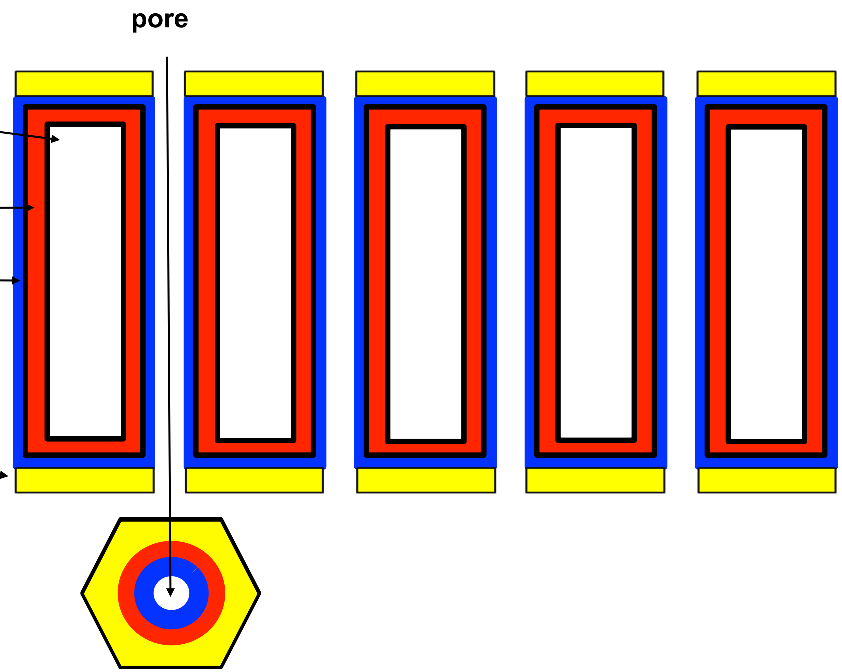
Make large-area MCPs with low-cost, bulk materials, applied independently using atomic layer deposition (ALD), an established chemical process used by industry...



borosilicate glass filters

ALD Group
J. Elam, A. Mane, Q. Peng

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



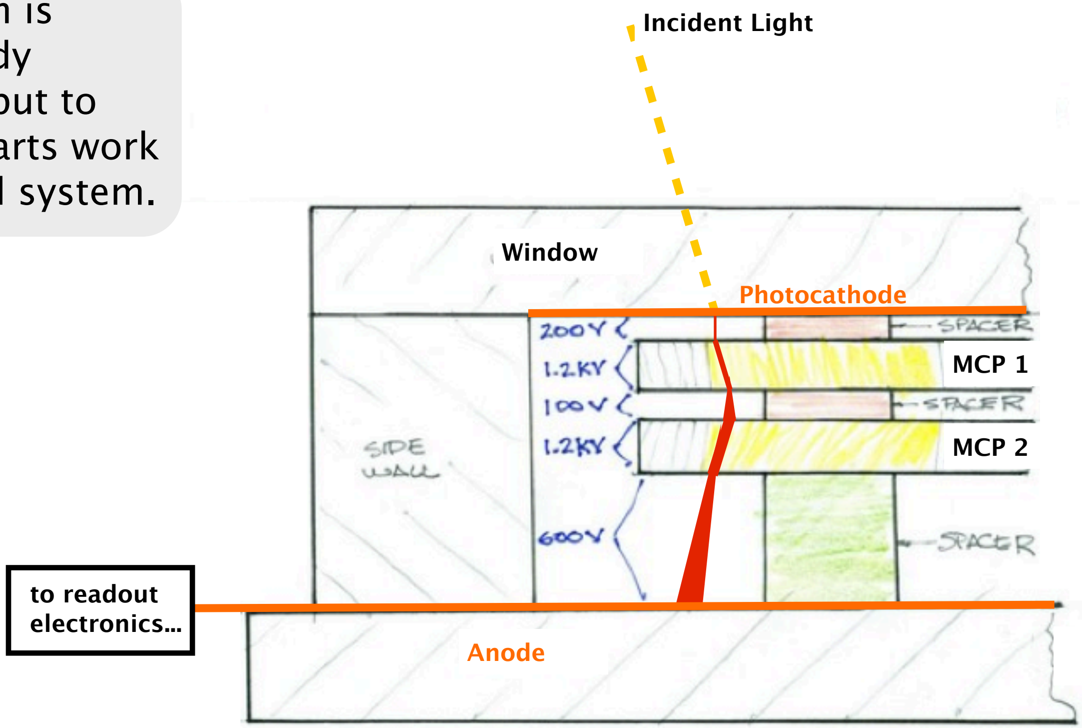
Characterization program:

Microchannel plates, themselves, exist within the context of a larger detector system, a microchannel plate photomultiplier tube (MCP-PMT). The goal of the LAPPD collaboration is the development of a **complete** 8”x8” sealed tube detector.

A strong testing program is essential not only to study individual components, but to understand how these parts work together in an integrated system.

The LAPPD collaboration has several testing facilities:

- MCP testing at Berkeley SSL
- Material characterization at Argonne Material Science Division
- Photocathode characterization lab
- MCP characterization at Arradiance
- MCP gain and electrical testing at the ANL-ALD lab
- MCP testing at the Advanced Photon Source (APS)



Characterization program:

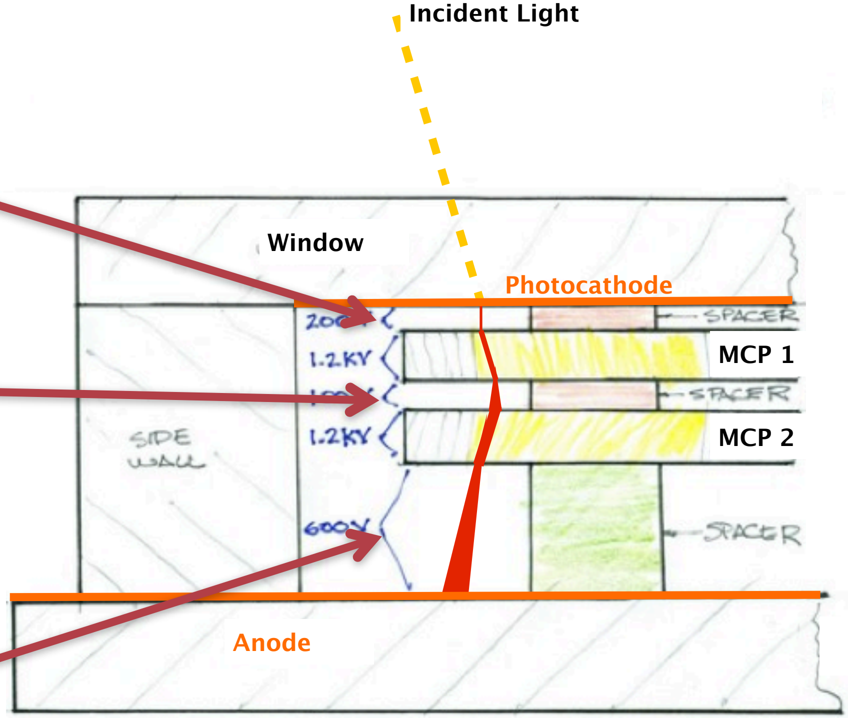
Gap spacing voltages:

Determine optimal operational voltages. How do these optimal voltages depend on particular choice of MCPs? Explore tradeoffs between gain, timing, saturation.

Gap 1: "first strike"
Impacts on variability of transit time and amplification

Gap 2: Impact on saturation of MCP pair, spatial spread of signal

Gap 3:spatial and temporal spreading of the charge cloud. Space charge effects. Interface with anode.

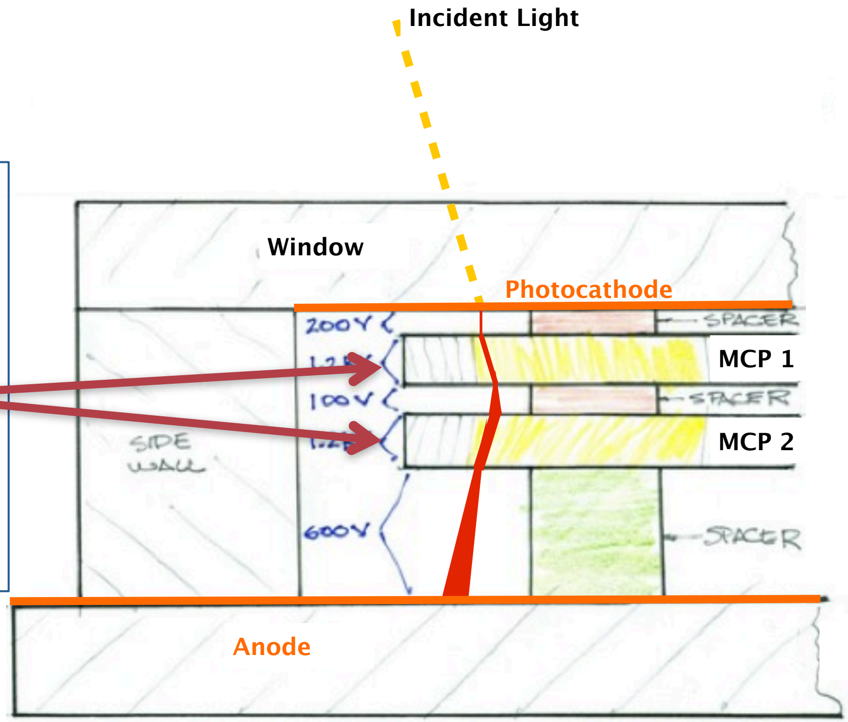


Characterization program:

MCP performance:

What impact do each of the electrical, secondary electron yield (SEY) and geometric properties have on the overall timing, gain, and saturation of the MCP?

- Geometry (pore size, L/D)
- Chemistry (SEE, resistive layer)
  - Plate quality
  - Uniformity
  - Noise
  - Stability
- Resistivity
  - Saturation
  - Relaxation time

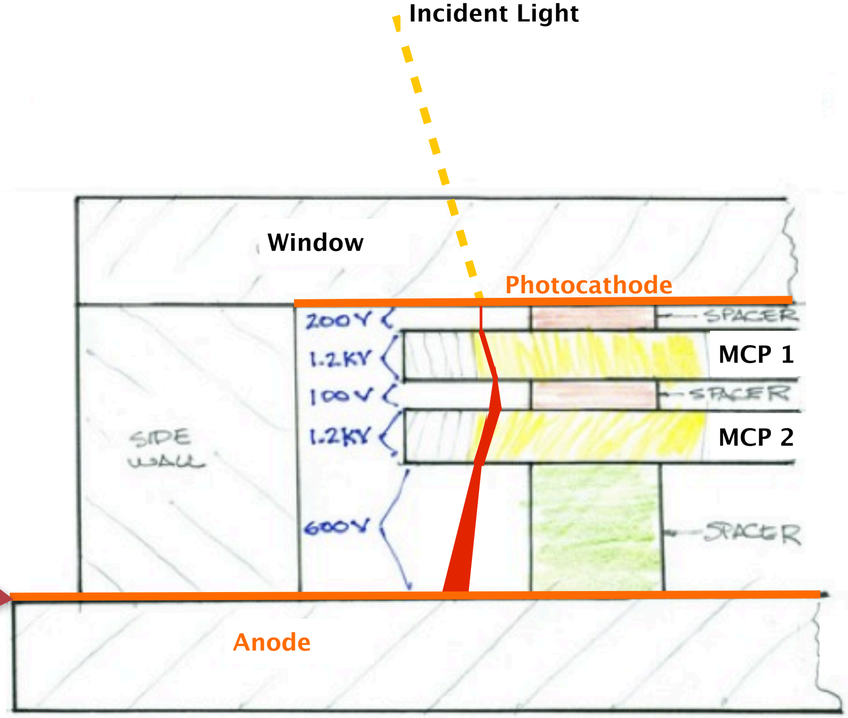


Characterization program:

Anode Design:

What is the best anode design for a particular application. How does one reduce channel counts and cost without sacrificing timing or spatial resolution? How to maintain multi-GHz analog bandwidth and 50 ohm impedance?

Anode Structure, Signal Processing



An Opportunity:
Goals of the ANL MCP-Characterization Lab

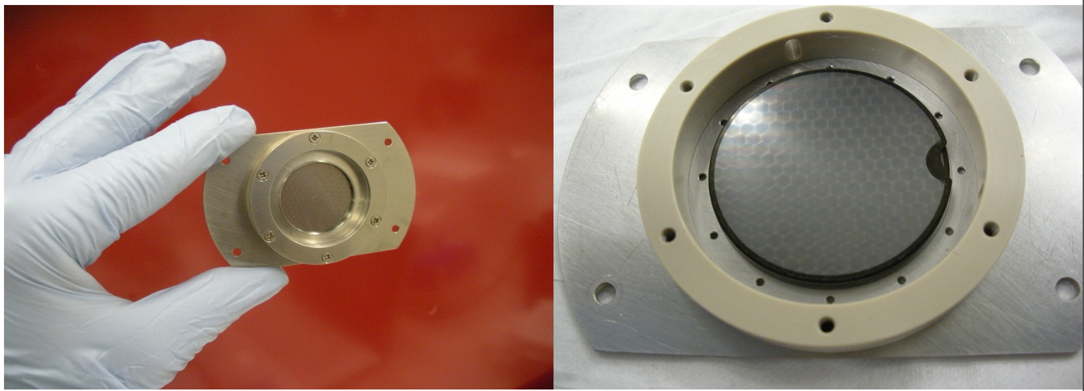
- ALD gives us the unique ability to vary electrical, secondary electron yield (SEY) and geometric properties of MCPs **independently**.
- Compared with commercial MCPs, which are typically made from a single material (lead-glass), we can produce MCPs with much wider variety of properties, **other properties held fixed**.
- Can explore limiting cases and place stronger constraints on MCP models.

ANL MCP-Testing Program

A unique collaboration between the HEP division and the Advanced Photon Source (APS)

33mm samples

Improving Fundamental Understanding
Develop Working Experience
Proof of Principles
Guide Design



8" testing

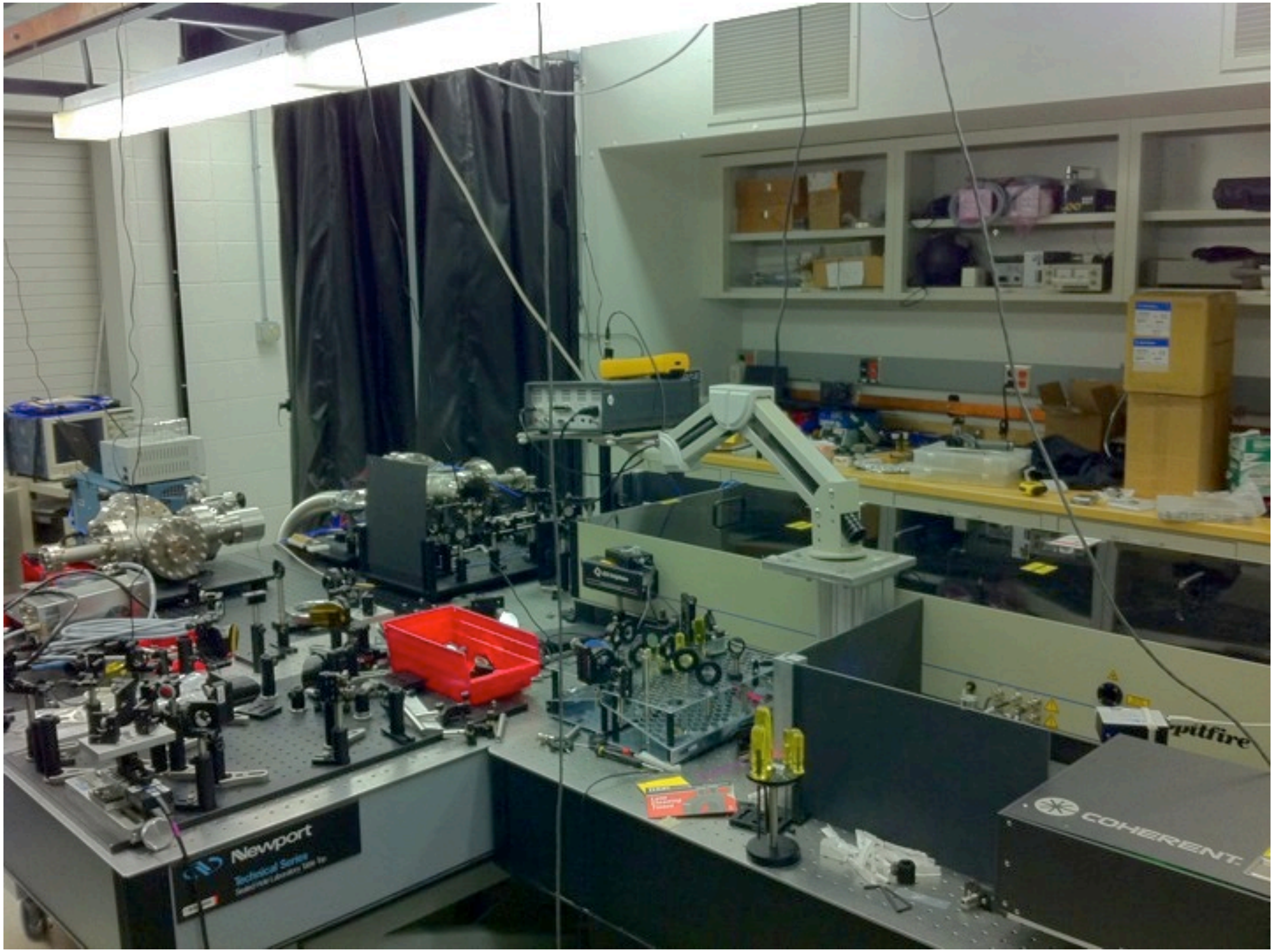
Understanding scalability
Developing operational experience

sealed-tube testing

Working out the challenges of a complete system
Developing operational experience

Facilities and Resources:

Facilities and Resources:



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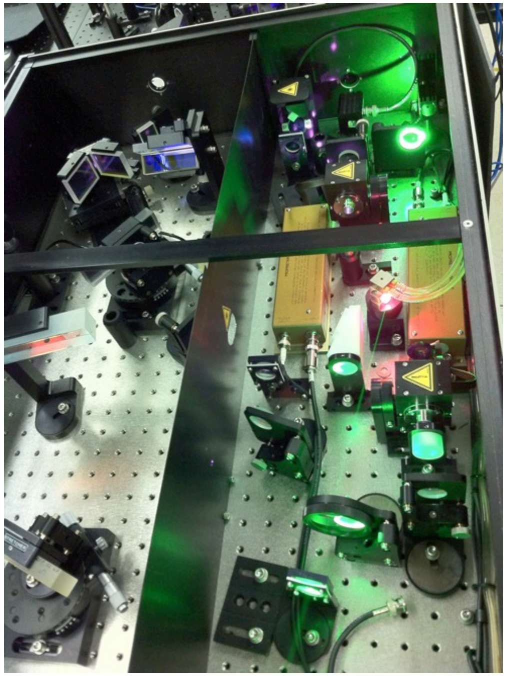
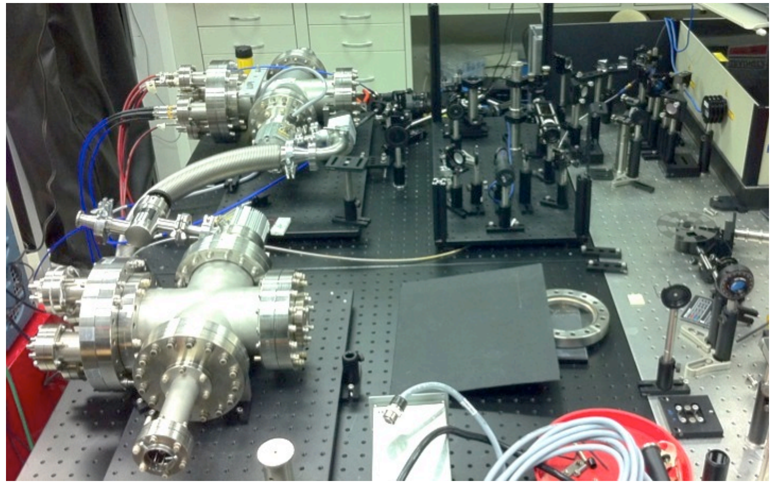
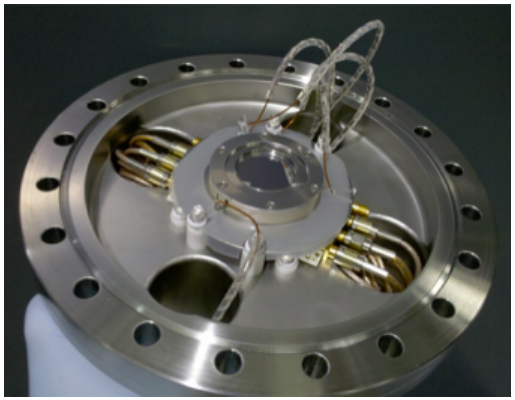
Facilities and Resources:

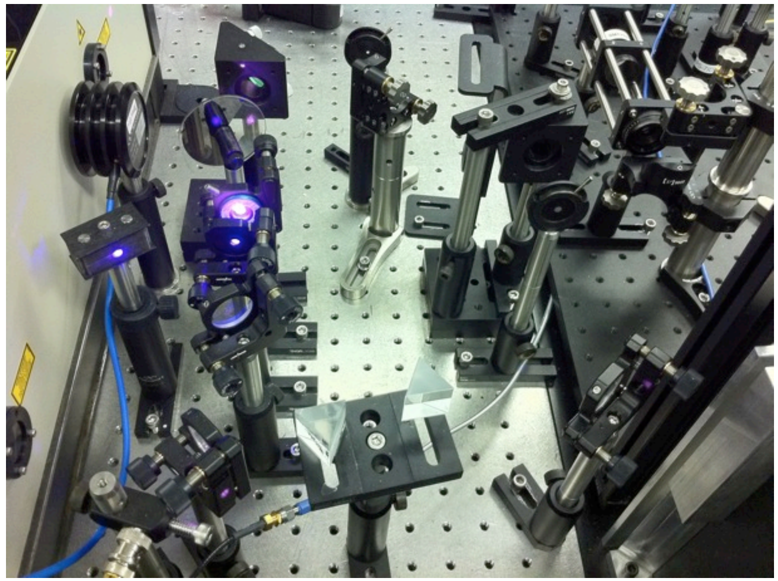
ANL MCP Characterization Lab:

- A fast (sub-psec), pulsed laser with precision optics
  - 800 nm Ti:Sapph laser
  - pulse durations O(10) femtoseconds
  - 1000 Hz repetition rate
  - non-linear optics to produce UV(266 nm) and blue light (400nm)
  - average power ~800 mWatt
  - optics capable of micron-level translations and potential to focus on single pores
- Vacuum systems for testing 33 mm photocathode-MCP-anode stacks approximating a complete device
  - Capable of holding variable stacks of 1-3 MCPs and simple photocathode
  - able to accommodate multiple readout designs
  - capable of 10-7 torr
  - 2 complete systems with parts for a third
- 8” MCP testing system (now commissioning)
- Fixtures for testing sealed-tube detectors (now commissioning)
- multi-GHz RF electronics
  - several oscilloscopes with 3-10 Gz analog bandwidth
  - high gain, low noise RF amplifiers
  - high-frequency splitters, filters, etc



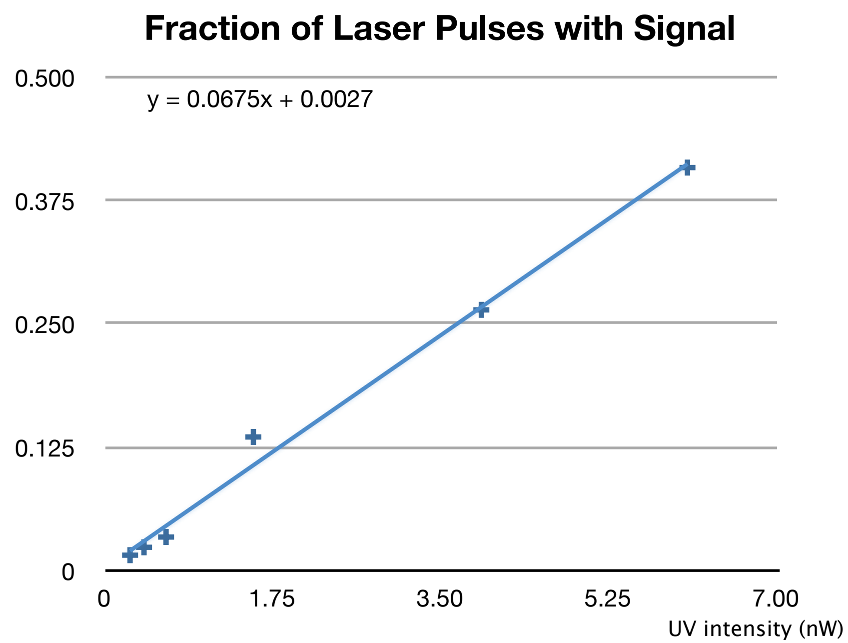


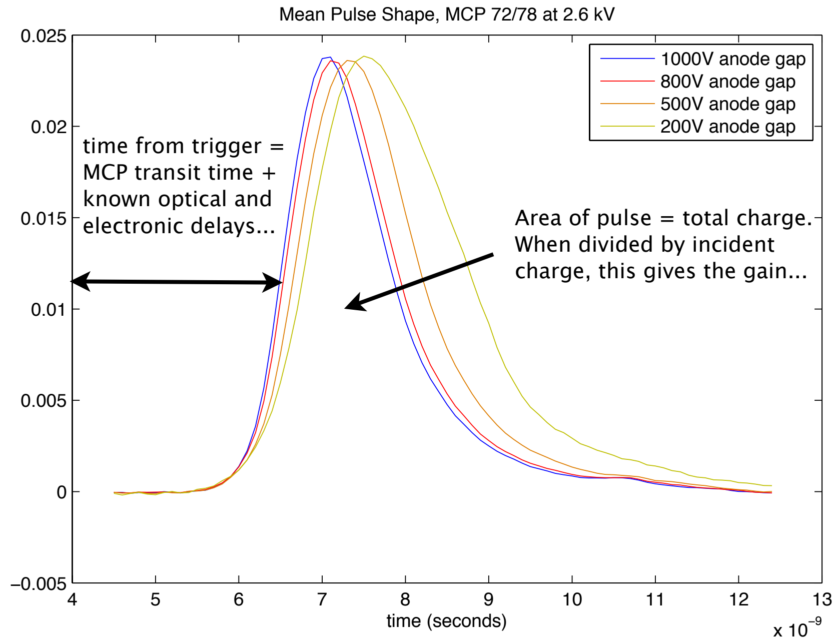




Methodology

- Control the number of photoelectrons (PEs) by attenuating the laser to the point where only a small fraction of pulses produce signal.
- Trigger on laser pulses to achieve very precise measurements of transit time
- Control size and position of beam to isolate individual spots on the MCP
- Record each pulse separately to produce statistical distributions.
- Integrate and fit the pulses to determine arrival time and gain.
- Able to discriminate between signal pulses and dark-current (random firing of the MCP)





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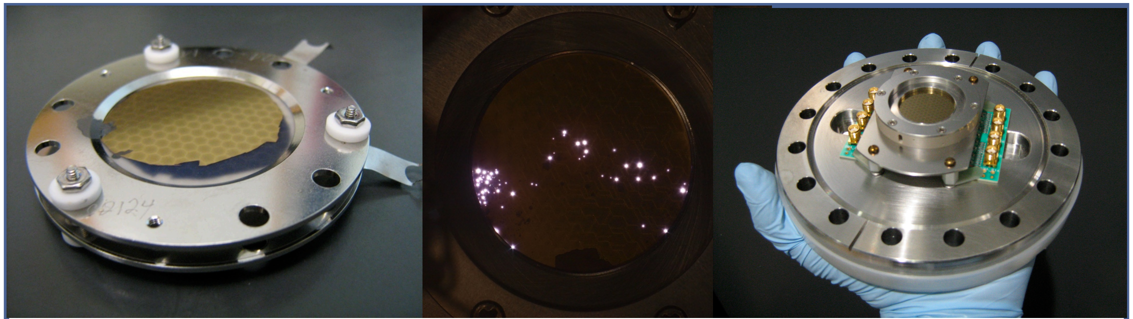
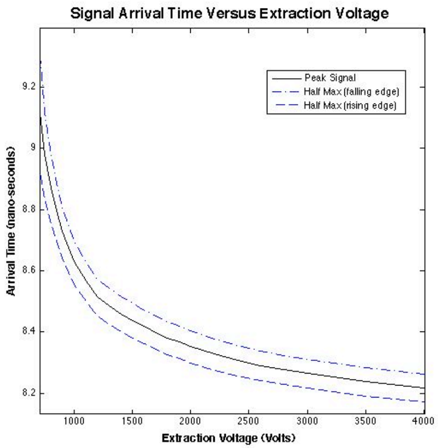
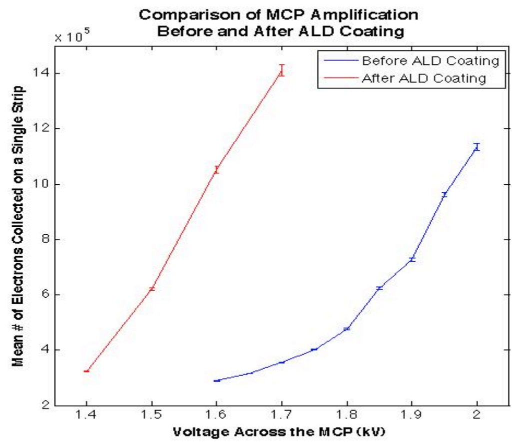
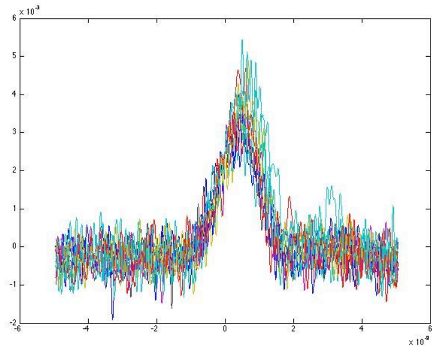
Year 1 achievements:

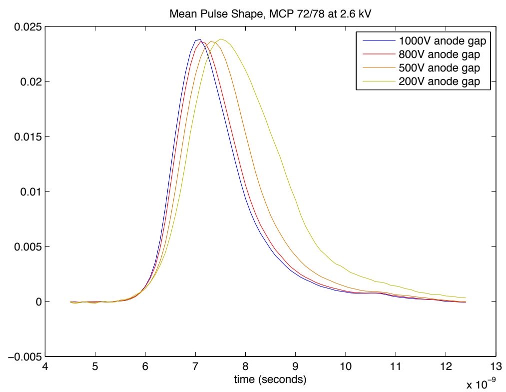
- Early study of timing characteristics from a Cesium-Iodide Photocathode
- Demonstration of enhanced gain from ALD coating on a commercial plate
- Developed operational experience working with MCPs
- Observation of first signals from ANL-fabricated, ALD-based MCPs
- Design and commissioning of characterization chambers





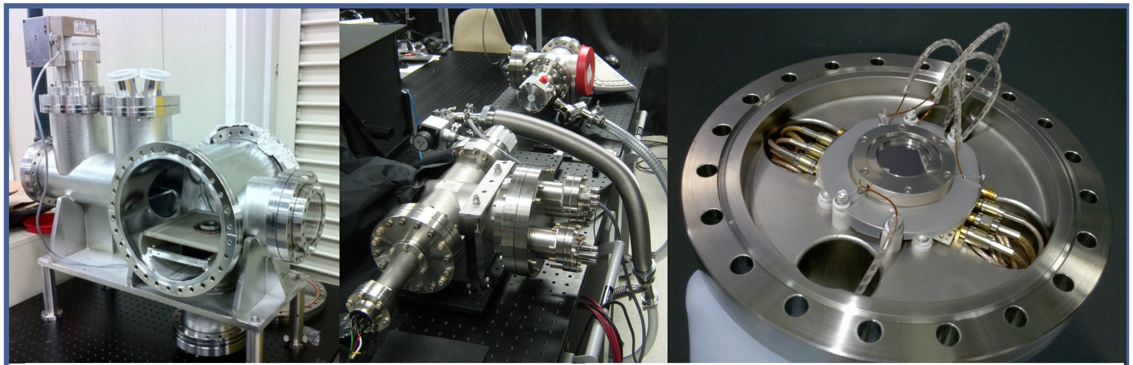




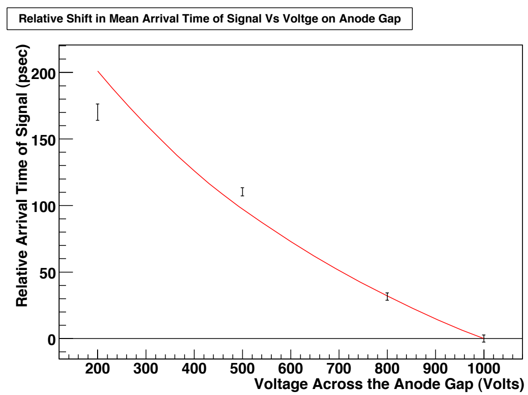


Year 2 achievements:

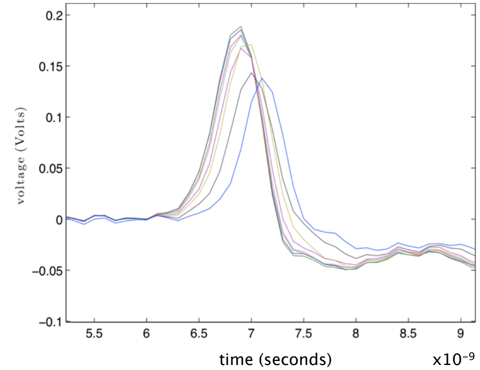
- Completion of laser characterization lab for systematic MCP testing in the time domain.
- Developed operational experience performing current-based, average gain measurements.
- Demonstrated > 10^5 amplification on Argonne-made, 33mm ALD functionalized glass plates.
- Demonstrated better than 200 psec time resolutions for single photoelectons in ALD MCPs
- Developed protocol for pulsed, single-photoelectron characterization.
- Close work with simulations and material characterization to improve fundamental understanding of MCP performance.
- Designed system for characterization of 8” MCPs, sealed tubes and lifetime testing



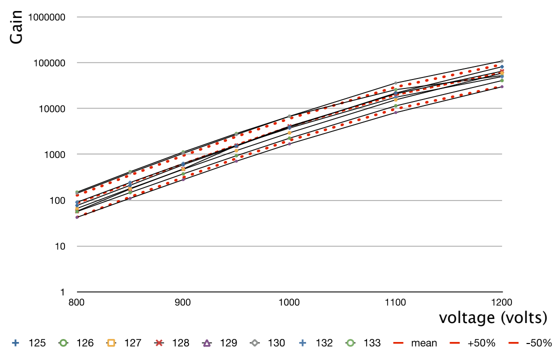
Relative shift in mean arrival time of signal VS anode-gap voltage



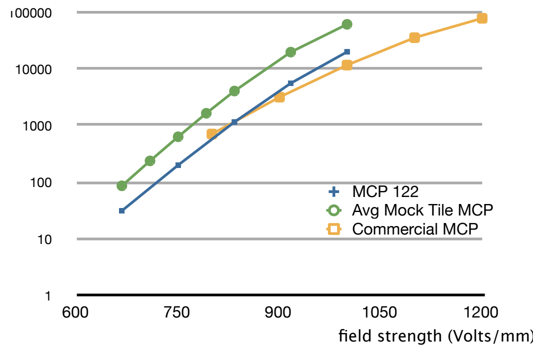
Average pulse shape for single MgO MCP at 1.5 kV, different photocathode voltages



Gain curves for mock tile MCPs

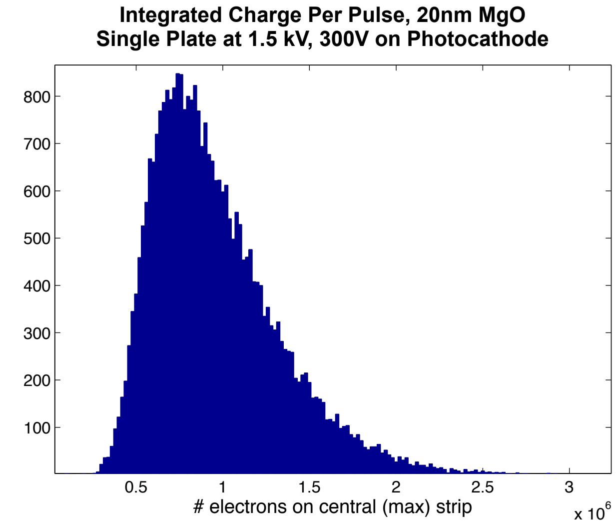


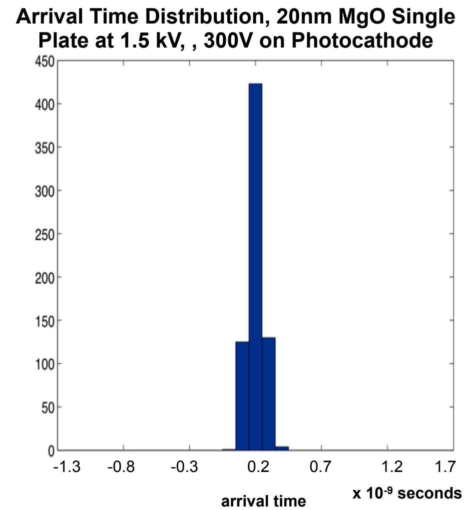
Comparison of ALD-MCP gains with commercial MCP

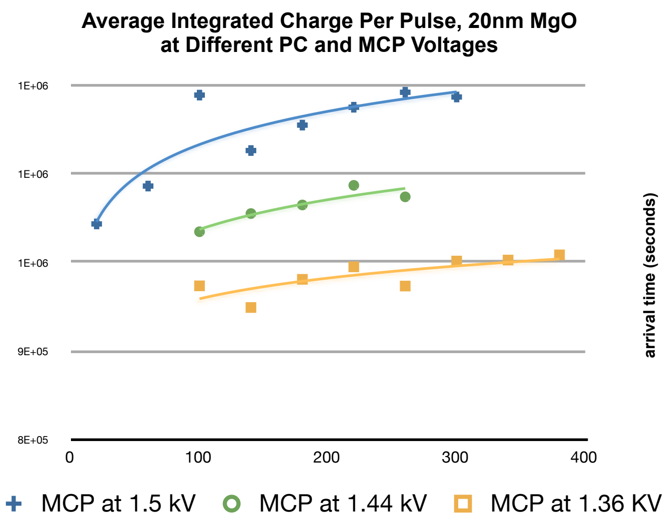


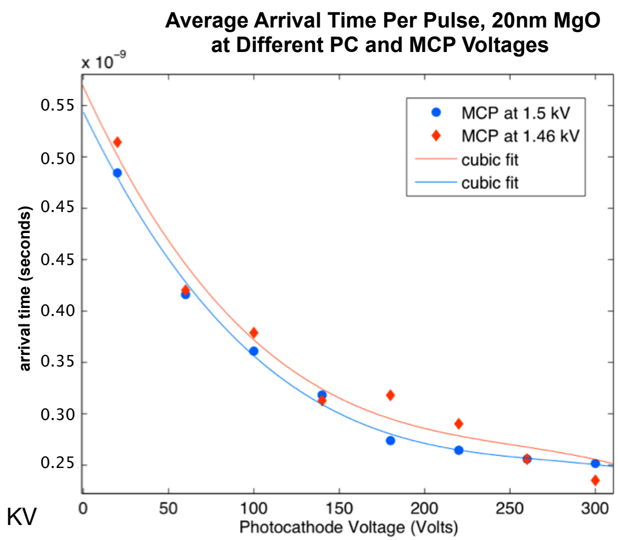
Current Work:

- Systematic comparison of gain and timing for MCPs with identical resistance, but three different SEY (secondary electron yield) compositions.
  - 20nm Al_2O_3
  - 20nm MgO
  - 2nm MgO
- Testing operation of single plates at high voltages.
- Comparison of MCP stacks with a common bottom plate.
- Systematic tests conducted for many different operational voltages, with the hope of placing strong constraints on models for avalanche formation.
- Plans for direct comparison of data with simulations and an upcoming publication







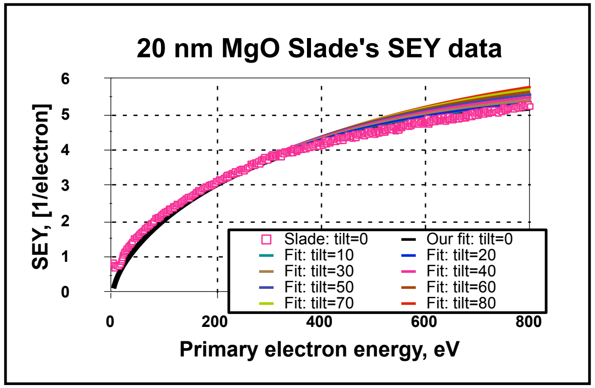


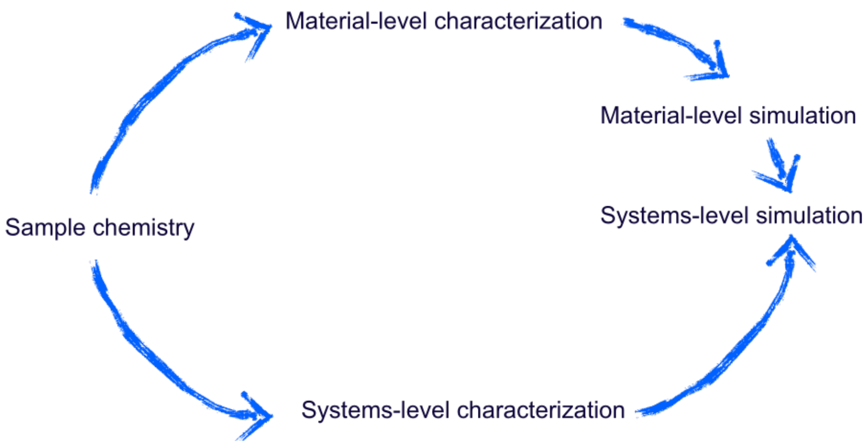
Current Work:

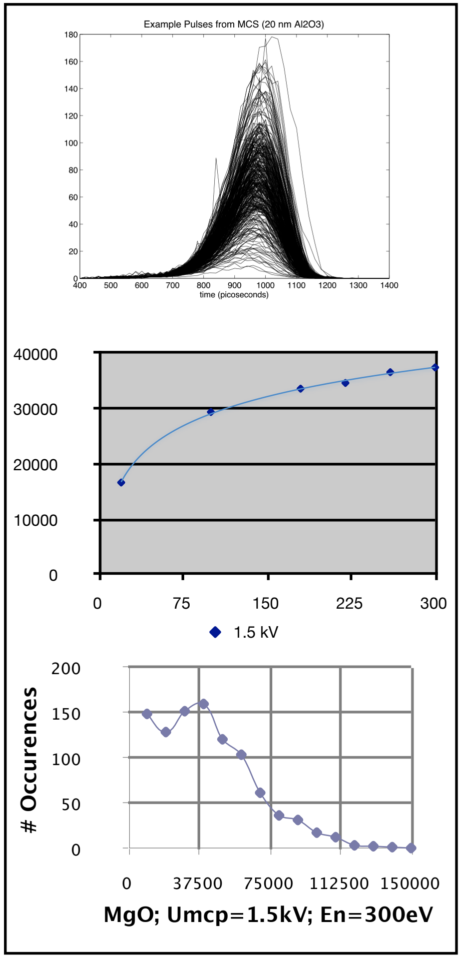
Complete MC-Data Cycle

- 3 MCP samples made with Identical resistance, but different SEY chemistry
- Simulations based on material-level characterization of SEY layers, guided by material-level simulations.
- MCP-level simulations to be tuned to data for 1 of the 3 MCP samples, taken at multiple operational voltages.
- Once tuned, predictions will be made on the performance of the other two samples, to be compared with data, afterwards...

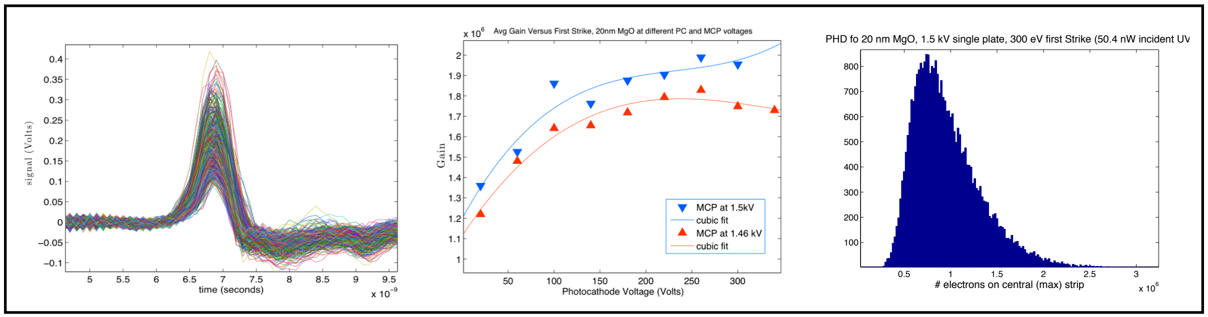
S. Jokela, Z. Insepov







V. Ivanov



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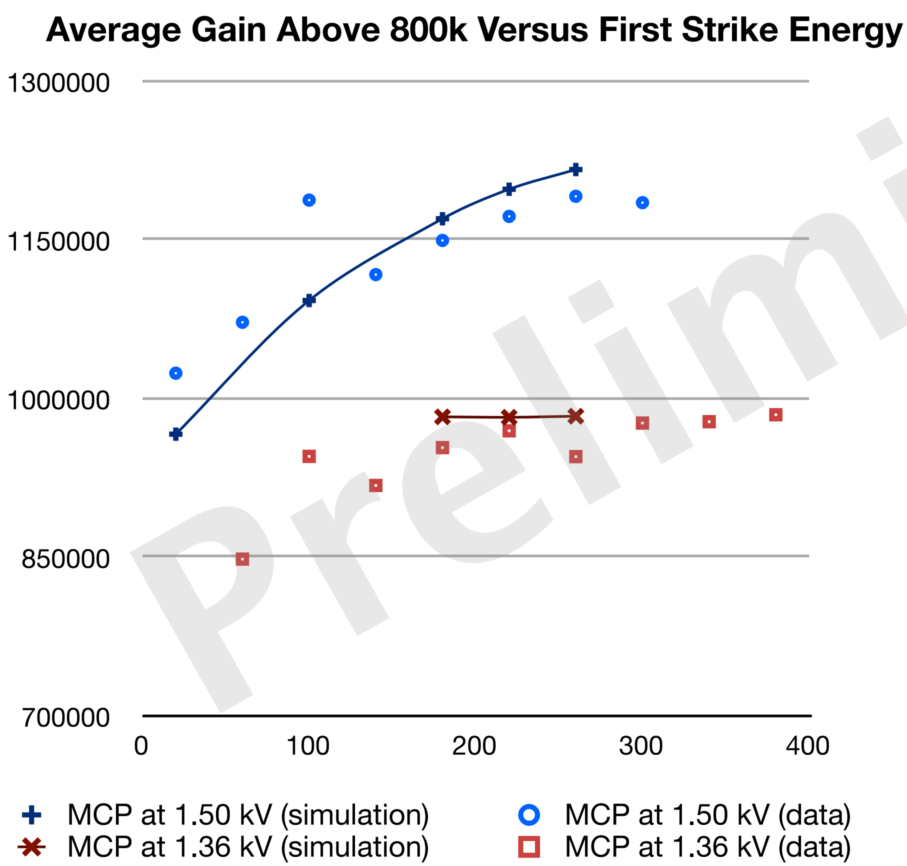
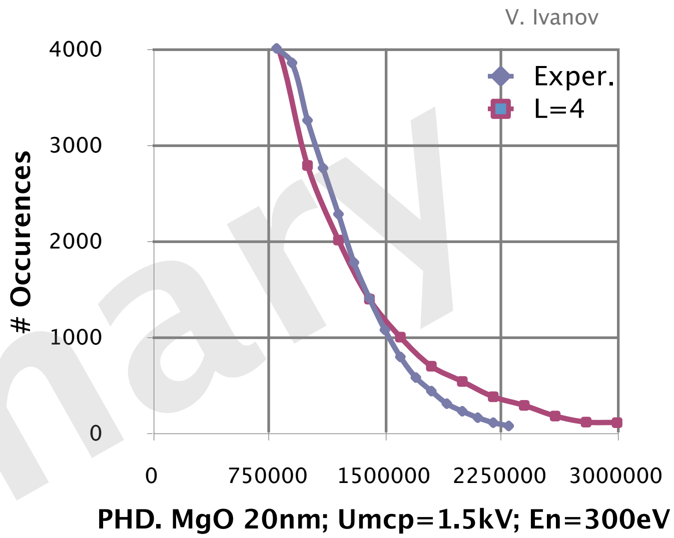
Current Work:

20 nm MgO SEY layer

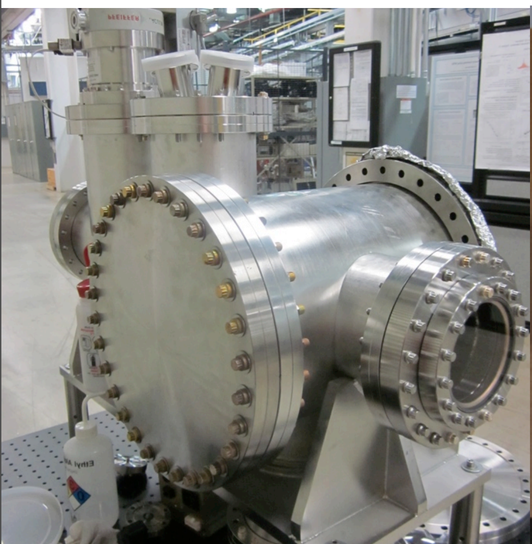


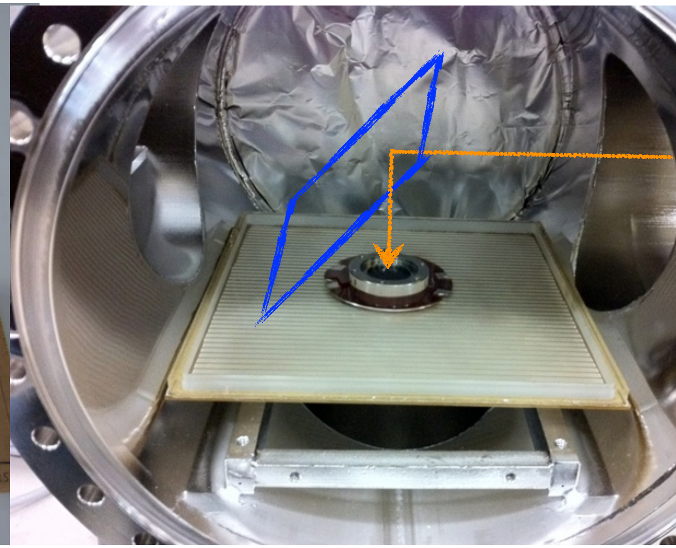


- Still tweaking the model. We expect even better agreement
- The model is tuned to the data, but only for this sample with 20nm MgO SEY coating.
- Once tuned, the simulation will be used to make a priori predictions of our other two samples, before the data results are revealed.
- Coming soon!

8” MCP Testing:

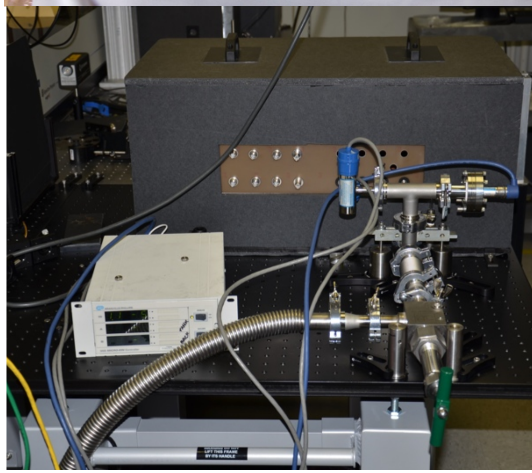
- 8” testing chamber is complete and successfully held 10^{-7} torr.
- Fixtures for mechanical assembly of 8” MCP stack designed to use spare glass parts for the sealed tube body.
- In the commissioning process.
- Chamber will be used to test, both:
  - 8”MCPs and
  - 33mm samples on 8” transmission lines
- Looking forward to our first 8” MCP samples.

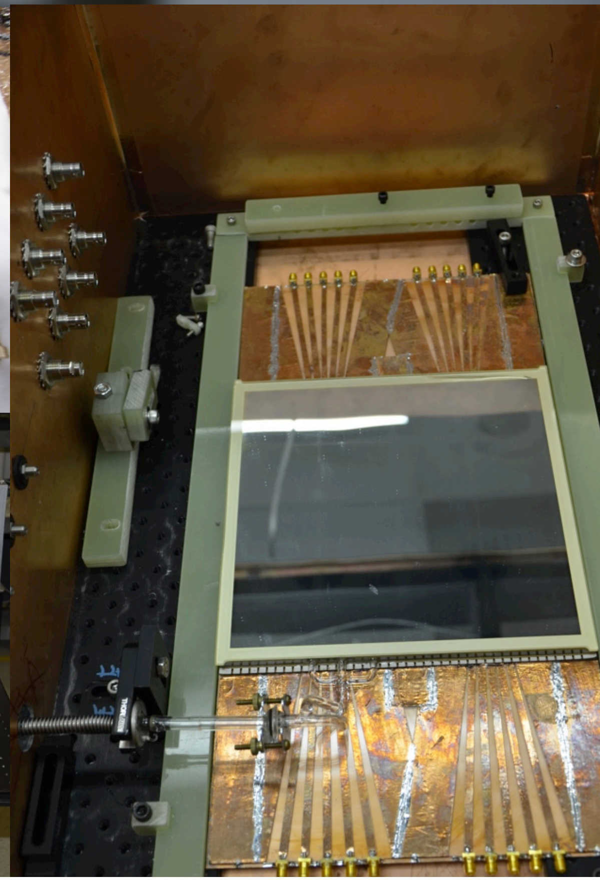




Sealed Tube Testing

- Received our first functional, sealed-tube MCP (“mock-tile”), built to the specs of an 8” MCP stack, but with 4 pairs of working, 33mm MCPs
- Constructed a system for mechanical support, electrical connection, vacuum connection, and signal readout from tile.
- Successfully coupled the tile to our vacuum system and achieved a vacuum of ~10^{-5} torr (as measured just outside the pump-port).
- Working out some technical difficulties.
- In the midst of basic electrical testing.
- Several new sealed-tubes are currently being made.





Conclusions and Future Prospects:

Near Term:

- Systematic test of a 12 sample ensemble of MCPs with varying resistive and secondary emissive chemistries.
- Commissioning of the 8” testing system, successful operation of first working 8” MCPs
- Demonstration of first working sealed-tube detector
- Comparison of several anode designs, testing of PSEC chip on MCP signals
- Commissioning of aging/ scrubbing experiment

Long Term:

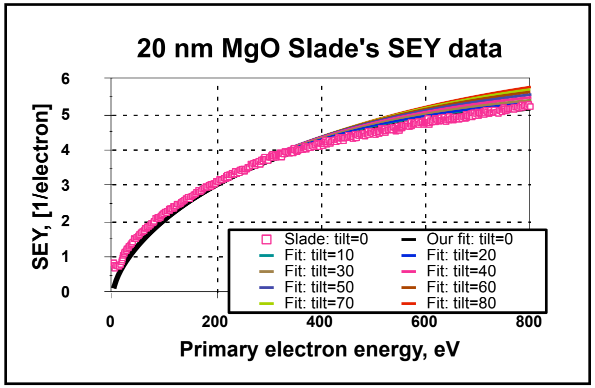
- Systematic batch testing of identical MCPs
- Integration of testing methods with Tile Factory
- Single pore testing, aging and saturation studies (double-pulsed measurements)
- Tests of potential single-MCP detectors

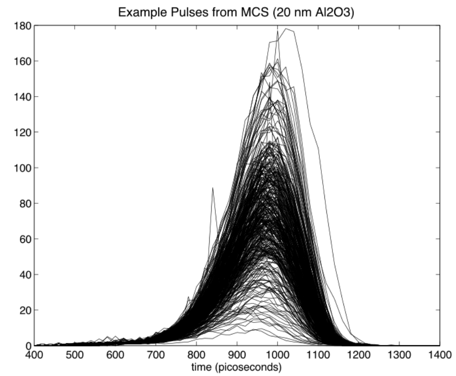
Thanks!

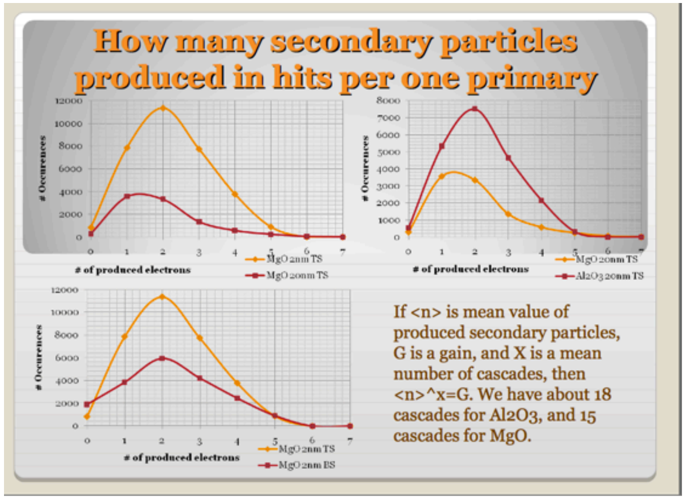
Details in Simulations:

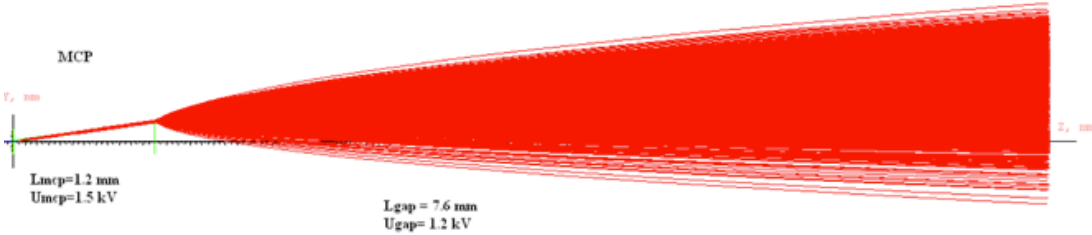
The LAPPD Simulations Program

- Goal to develop a predictive, pseudo-physical MCP model to help guide MCP design.
- Help improve understanding of what is going on inside the pores.
- Takes experimental materials characterization as input.
- Two components:
  - true secondary electron yield (SEY)
  - specular reflection of incident primary electron, eg backscattering or BS
- SEY at normal incidence is measured.
- SEY at grazing incidence is extrapolated using a theoretical material model
- quasi-elastic reflection of the primary electron is derived from a theory.
- Normalization of the BS probability is a tunable parameter (controls the fraction of highly energetic electrons in the pore).



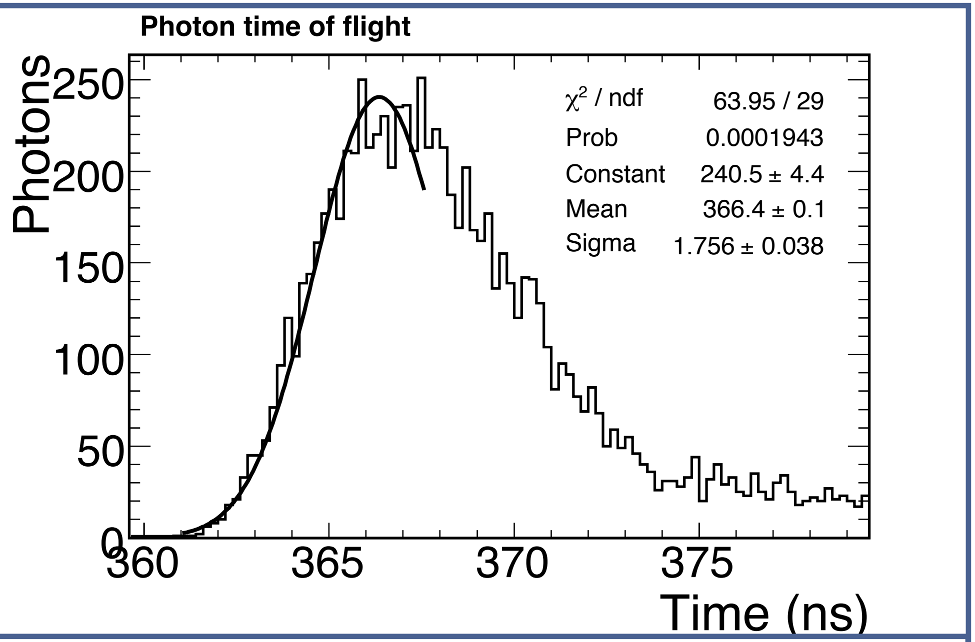


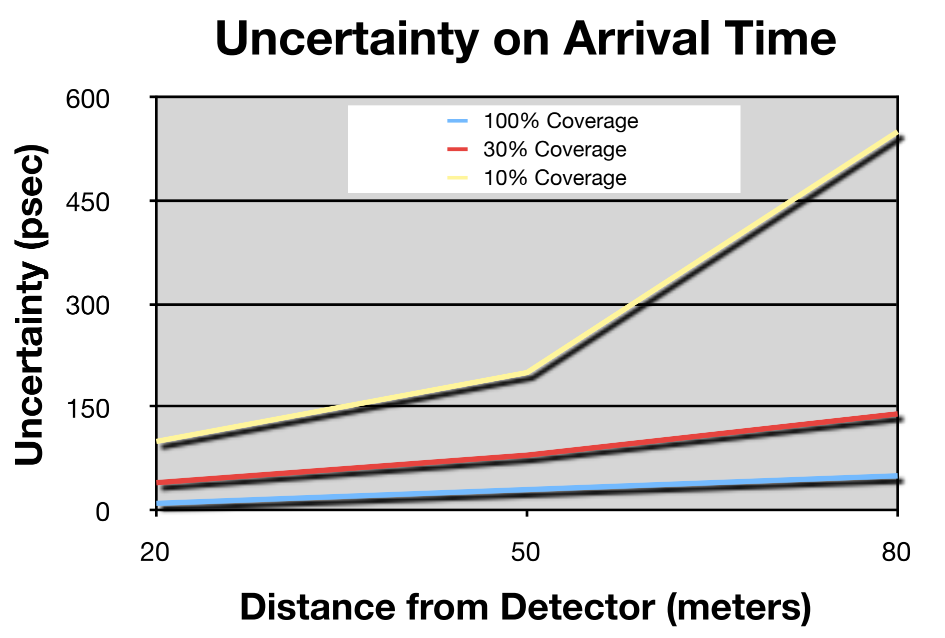




Backup Slides: Applications in Water Cherenkov

- A concern in using fast timing are the effects of frequency dependent dispersion, scattering and absorption.
- Using a fast toy MC originally developed by J. Felde we study the time of arrival for photons in an spherical detector.
- For a 50m detector with 100% coverage, the rise time (t_{90}-t_{10}) is of the order of 2 ns which cannot be sampled with standard PMT technology.
- For a given detector size, the rise time stays constant and the uncertainty in the position of the leading edge becomes smaller if larger photodetector coverage is considered.
- A combined improvement in photodetector coverage (for reduced





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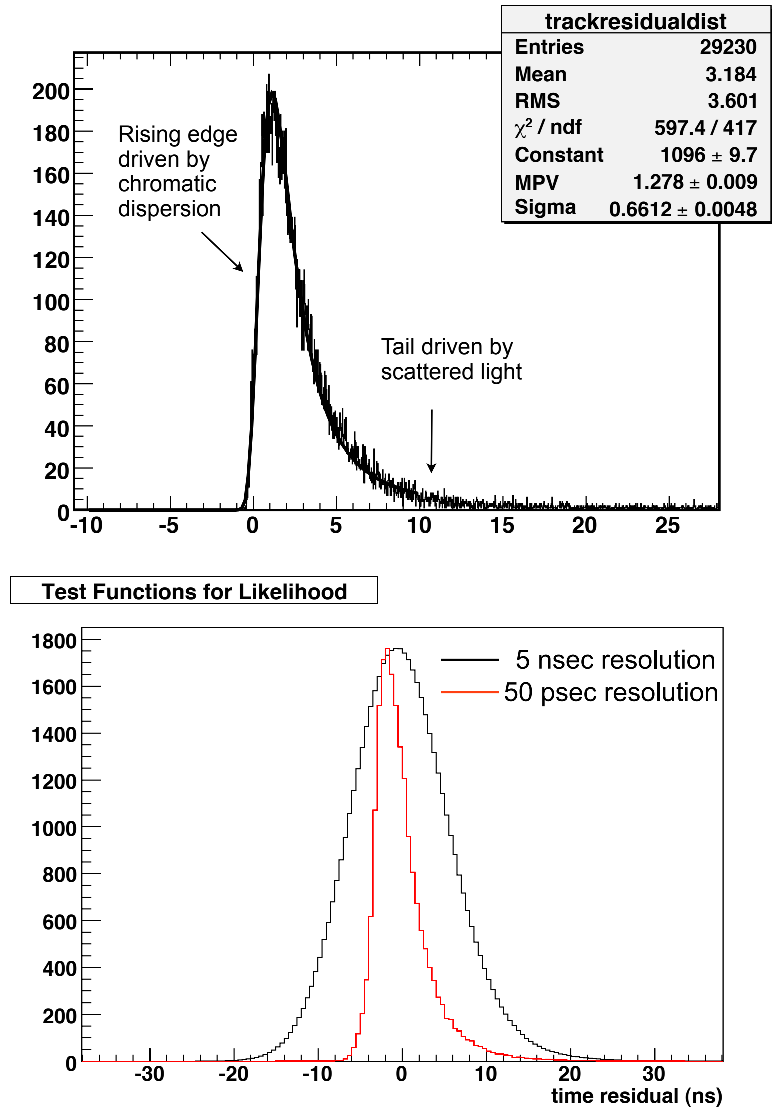
Backup Slides: Applications in Water Cherenkov

- Collaboration among the hi-res WCh working group has produced a new platform for testing algorithms on WCh detectors with interactively modifiable photodetector properties.
- These efforts have already identified promising features in observables, such as timing residuals, that could potentially be used to improve track reconstruction and better identify pi0 backgrounds.
- GEANT-based studies are being done in less idealized conditions:Including effects of

Z. Djurcic (ANL), G. Davies (Iowa State),

M. Sanchez (Iowa/ANL), M. Wetstein (U Chicago/ANL),

T. Xin (Iowa State)



M. Wetstein (UC, ANL/HEP)

Backup Slides
Does this fit in with the LBNE timeline?

- This project is just starting year 3 of a 3 year time-table. We have no intention or expectation for LBNE waiting for us.
    - We're not likely to be ready for the first detector and don't want to interfere with any time-tables.
    - Could be ready for upgrades or a second detector.

- LBNE is not the only application we're interested in:
    - Collider physics: time-of-flight to determine flavor.
    - Medical PET imaging
    - Homeland security

too soon to tell…

But, keeping cost down is a major objective:

- Made from inexpensive materials.
- Use industrial batch processes.
- Inexpensive electronics, trying to reduce number of necessary readout channels.

In addition to the bottom-line cost of the detectors are secondary effects.

- Market impact.
- Possible savings on civil construction. Detector can be built closer to walls.

Cost/unit area is not the only relevant factor. Physics gains could be worth a little more.