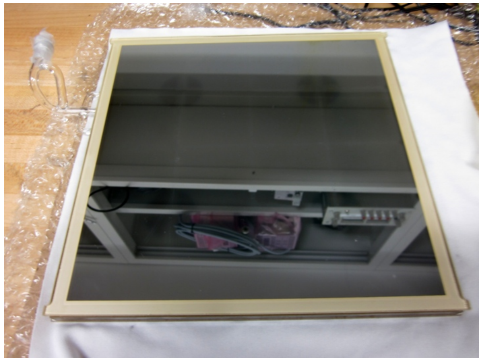
LAPPD Status and Early Adoption

Matt Wetstein, ISU

on behalf of the LAPPD collaboration

Reinventing the unit-cell of light-based neutrino detectors



- single pixel (poor spatial granularity)
- nanosecond time resolution
- bulky
- blown glass
- sensitive to magnetic fields

- millimeter-level spatial resolution
- <100 picosecond time resolution
- compact
- standard sheet glass
- operable in a magnetic field

Key Elements of the LAPPD Detector

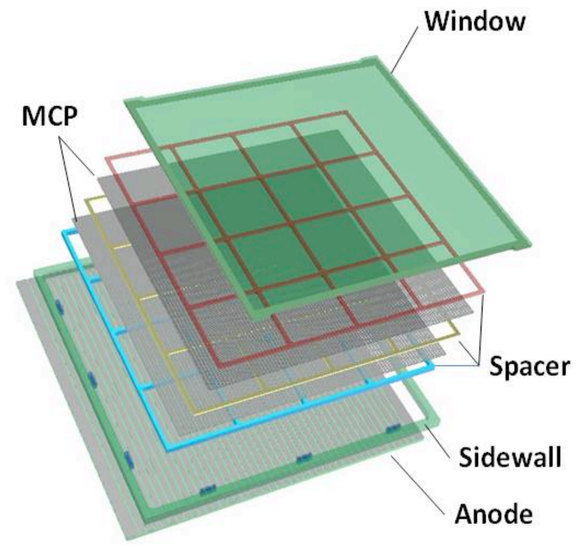
Glass body, minimal feedthroughs

MCPs made using atomic layer deposition (ALD).

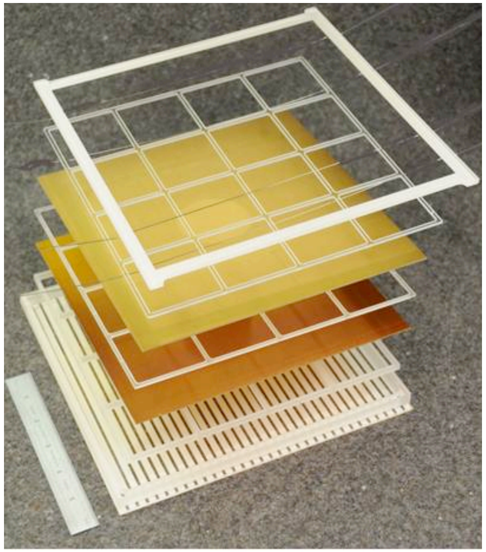
transmission line anode

fast and economical front-end electronics

large area, flat panel photocathodes

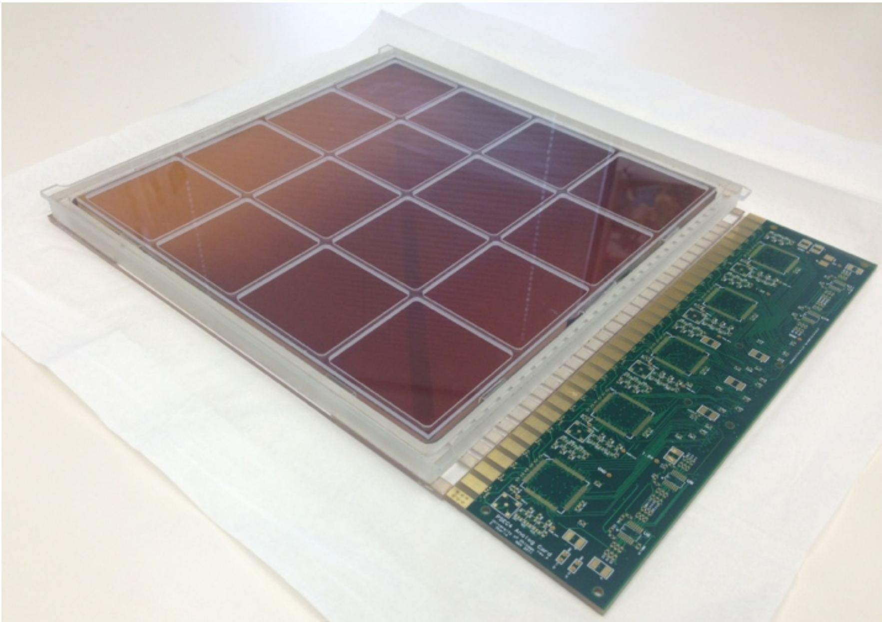


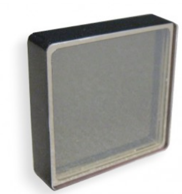
Design Drawing - September 2010



Actual Glass Parts - April 2012

What is the LAPPD Concept





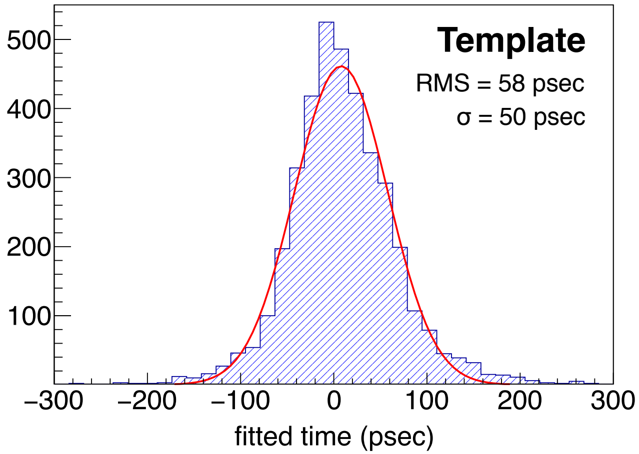
LAPPD detectors:

- Thin-films on borosilicate glass
- Glass vacuum assembly
- Simple, pure materials
- Scalable electronics
- Designed to cover large areas

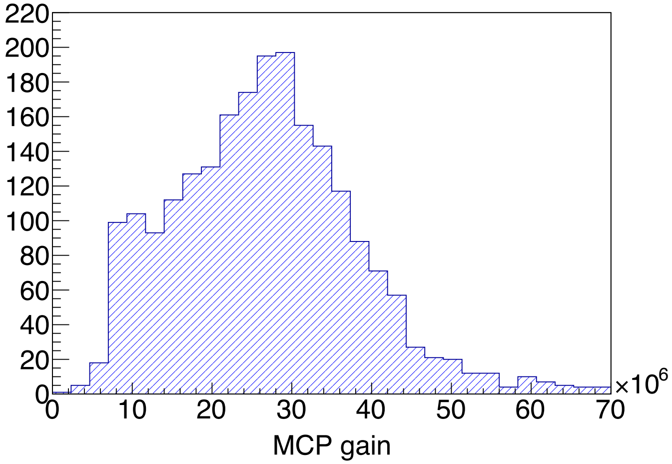
Conventional MCPs:

- Conditioning of leaded glass (MCPs)
- Ceramic body
- Not designed for large area applications

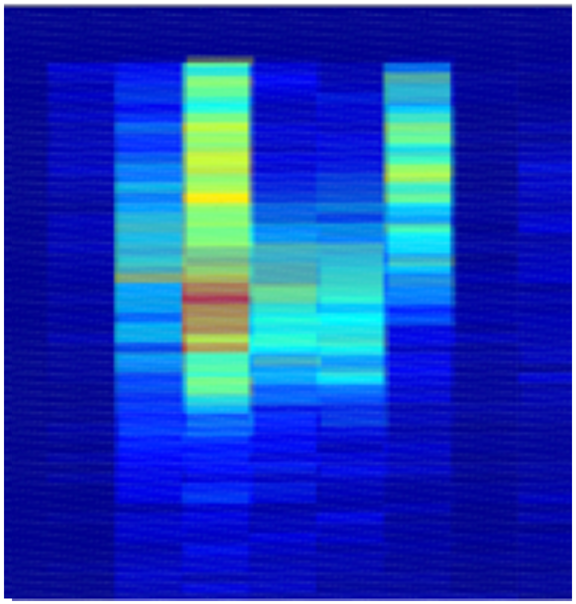
LAPPD Characteristics



<60 psec, single PE resolutions

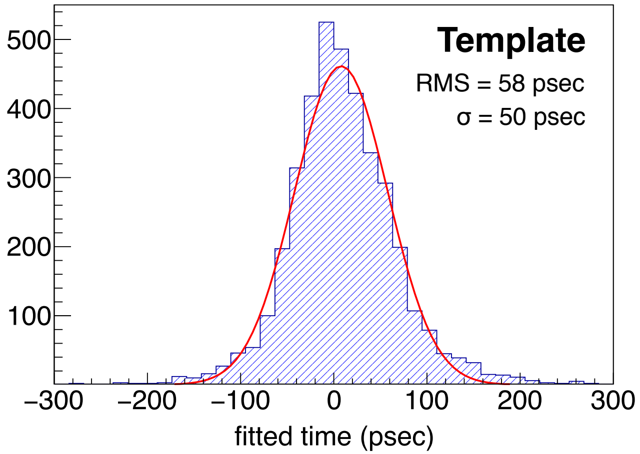


10^7 gains



imaging and single photon resolution

LAPPD Characteristics



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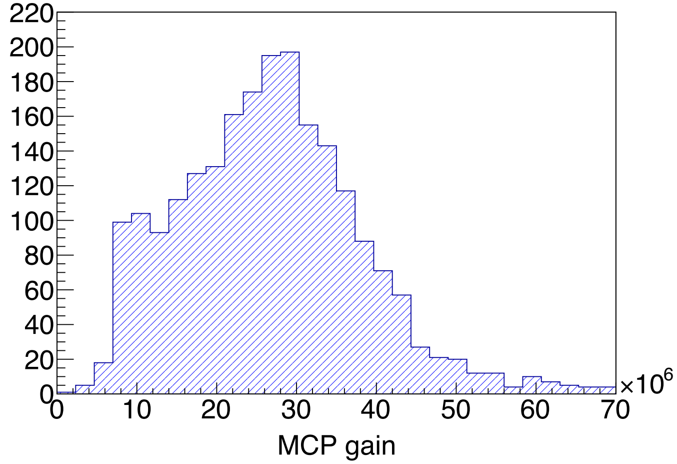
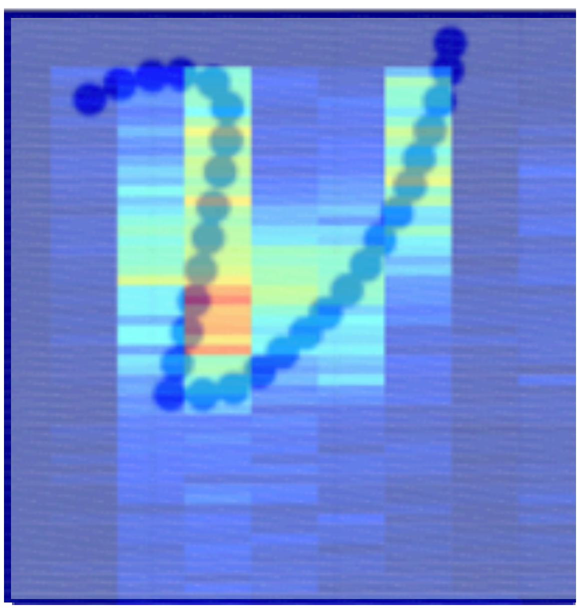


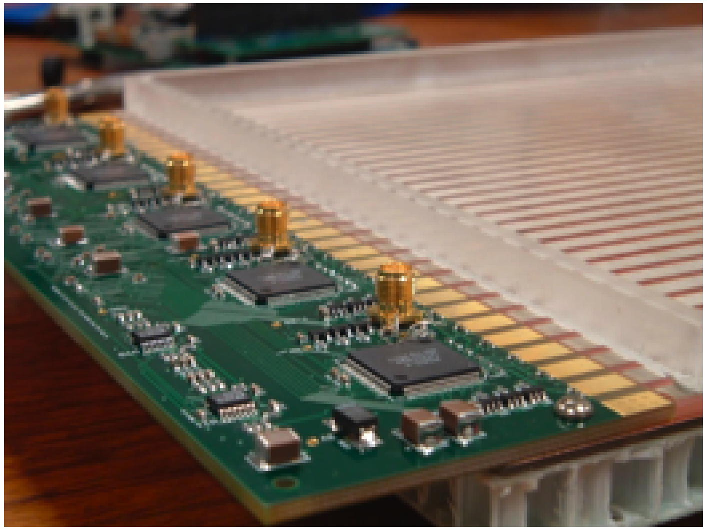
10^7 gains

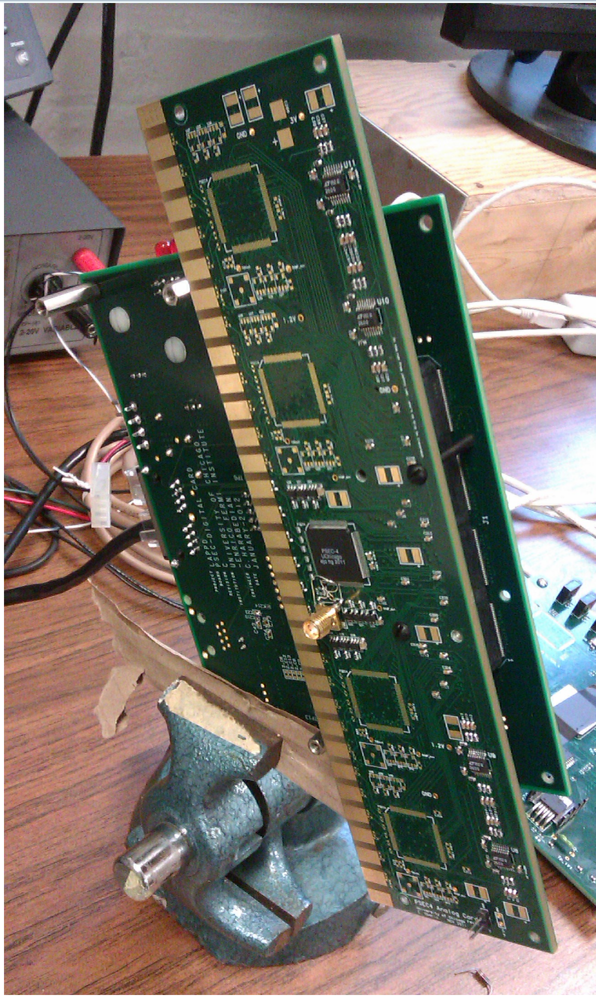
3.4 cm



imaging and single photon resolution

Front-end Electronics





Psec4 chip:

- CMOS-based, waveform sampling chip
- 17 Gsamples/sec
- ~1 mV noise
- 6 channels/chip

AC-DC card:

- Readout for one side of 30-strip anode
- 5 psec chips per board
- Optimized for high analog bandwidth (>1 GHz)
- Analysis of the individual pulses (charges and times)

Central Card:

- Combines information from both ends of multiple striplines

LAPPD project covered the whole system, including readout electronics

Post Scripts: PSEC4/PSEC4B

Batch of 400 PSEC4 chips has been ordered by ISU for ANNIE:
= 2400 channels
= 40 LAPPDs

Eric Oberla is working on a design for a PSEC4b:

- 4-fold increase the buffer depth to allow multi-event buffering.
- Would enable continuous operation for low rate applications (eg neutrinos)
- design is under way, but looking for feedback from the community

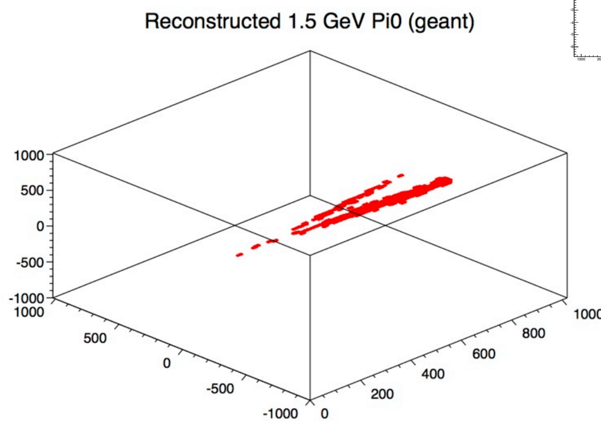
Simulations/Reco

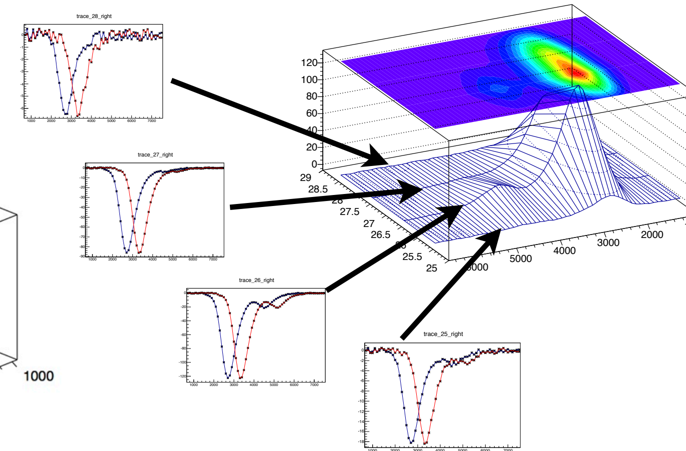
We have a standalone package for simulating LAPPD response.

We also have a light detector simulation: WChSandBox

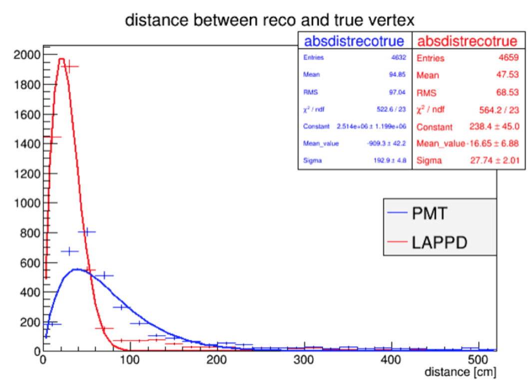
...and an accompanying reconstruction package (developed by Queen Mary, Imperial, and Sheffield)

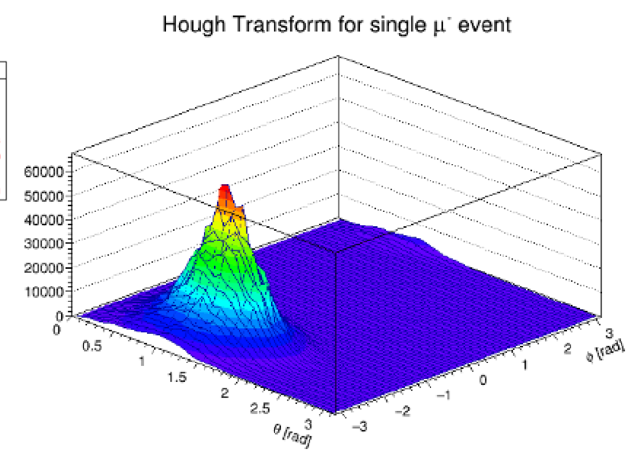
Happy to share these tools and also interested in building a common framework





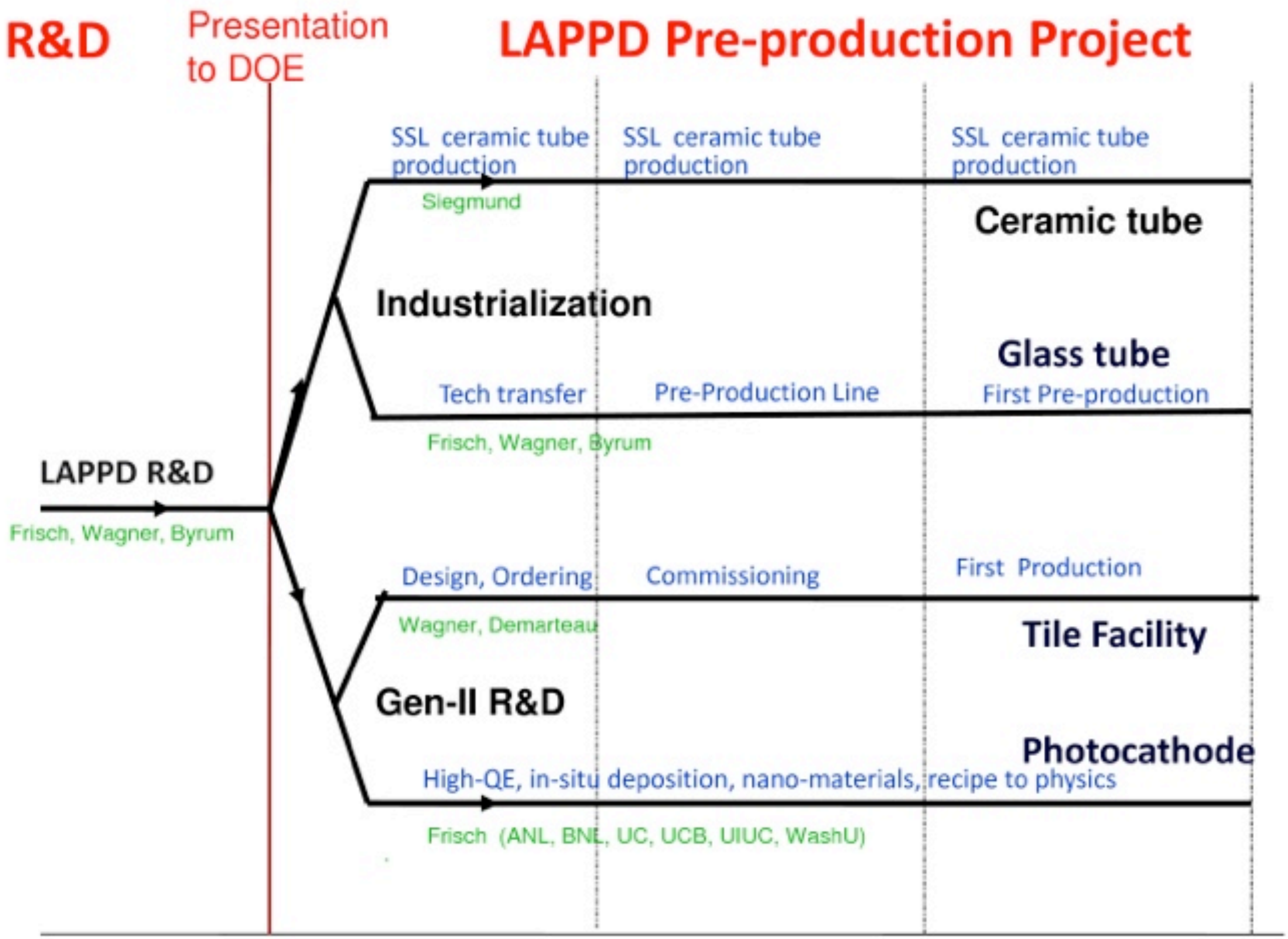
M. Wetstein (ISU)





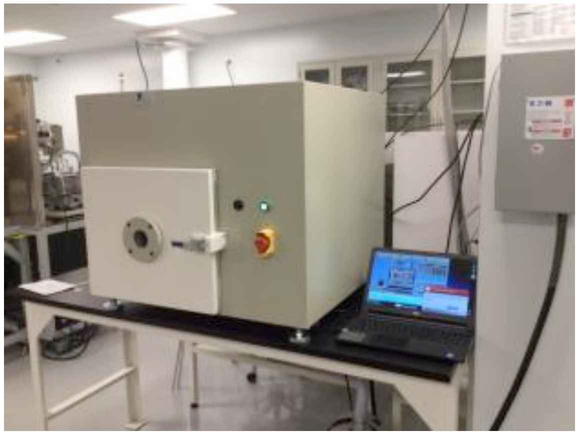
M. Malek (Sheffield)

LAPPD2 - What's Next



Commercialization Status (Incom)

Plasma cleaner rec'd 9/2015



Vacuum oven due 10/2015

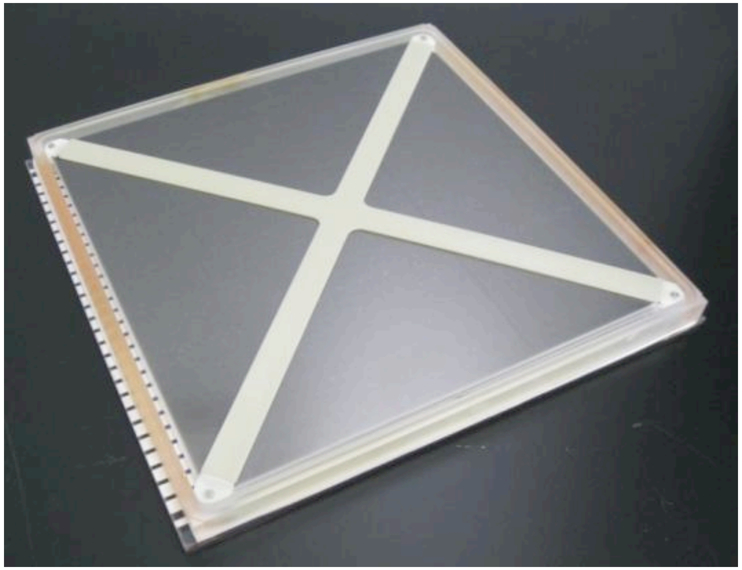
LAPPD integration and sealing tank rec'd 9/2015

Beneq ALD coater with load-lock installed 6/2015

Thermal evaporator commissioned 12/2014

Measurement & test station, commissioned 8/2015

Commercialization Status (Incom)



Milestones

- Early-November: seal 1st LAPPD tile at UC Berkeley, Space Sciences Laboratory
- Mid-November: seal a mock tile at Incom that includes anode/ sidewall, glass capillary arrays (not MCPs), X-spacers, top window, no photocathode
- Mid-December: seal 1st LAPPD tile at Incom
- End-December: seal 2nd LAPPD tile at UC Berkeley, Space Sciences Laboratory
- Mid-January: seal 2nd LAPPD tile at Incom

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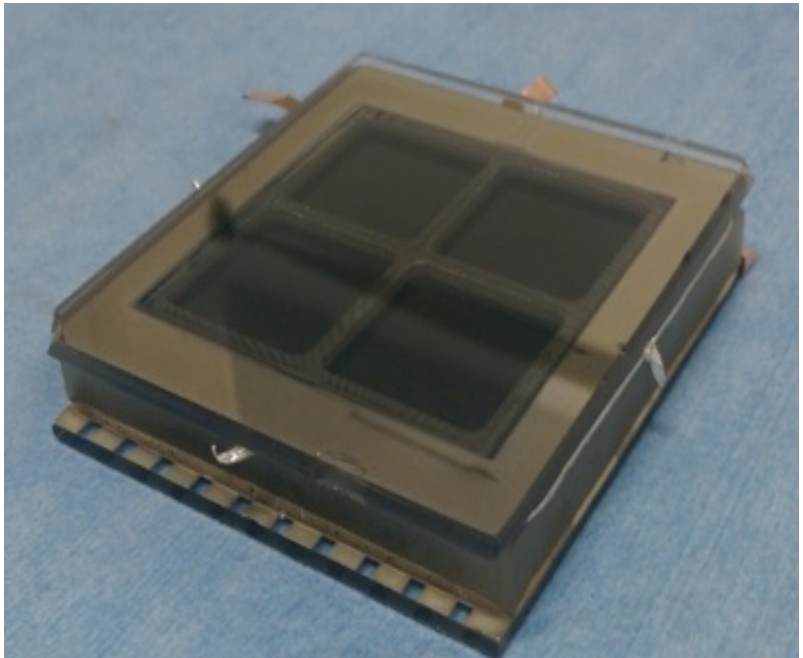
ANL 6cm tiles

Small numbers available for distribution and testing.

Yields and performance are good and improving.

>10% QE, ~50 psec time resolution



Completed Tube with Photocathode

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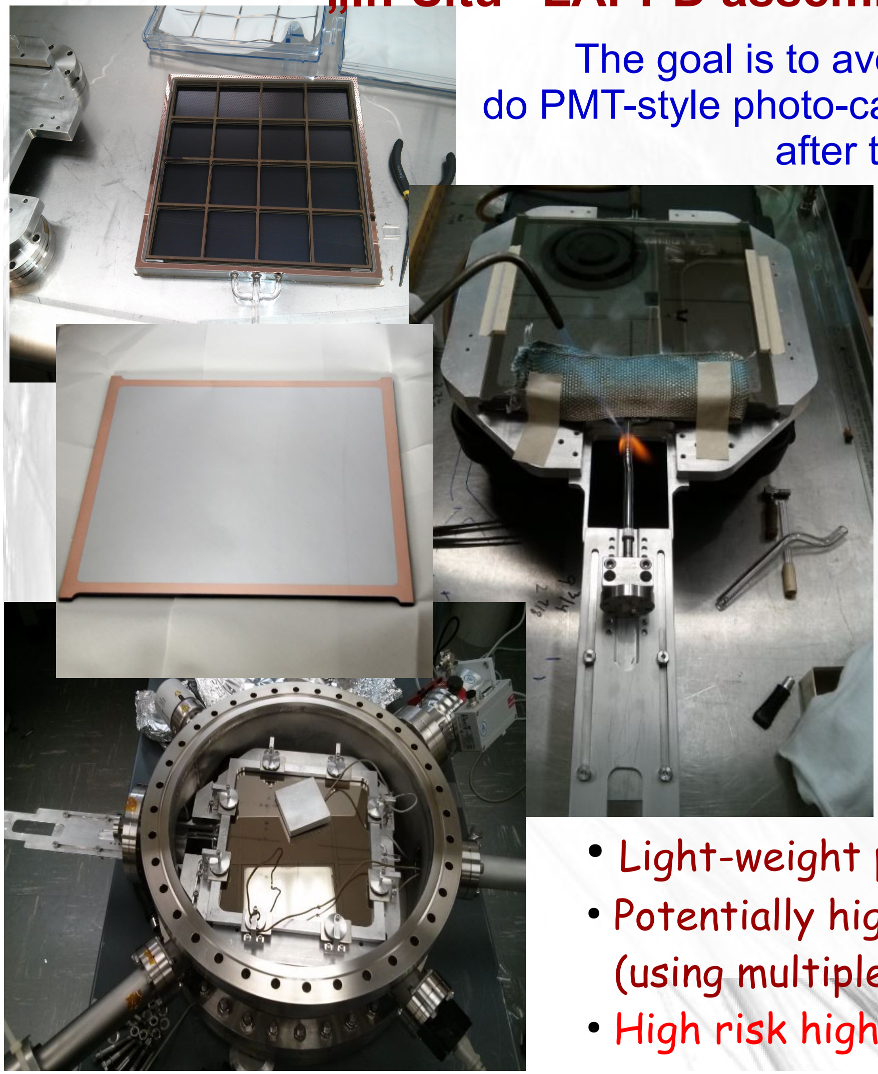
U Chicago - Gen II LAPPDs

credit: Andrey Elagin (UC)

„In-Situ“ LAPPD assembly at UChicago

The goal is to avoid vacuum transfer process and do PMT-style photo-cathode activation through a glass tube after the detector is sealed.



Step 1: deposit Sb on the top window (air stable, very thin oxide layer forms on the surface)

Step 2: complete hermetic packaging via indium seal using metallization along the perimeter of the glass-body detector

Step 3: bake at high temperature (350C)

Step 4: activate Sb layer by bringing Cs/K vapors through a small glass tube attached to the detector body

Step 5: flame seal the glass tube

- Light-weight processing chamber
- Potentially high production yield (using multiple chambers)
- High risk high reward path

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Early Adopters

First LAPPDs will not be “cheap” (by HEP standards)

- small volumes
- high operational costs
- small market

Good news is: LAPPD technology is viable outside of particle physics (medical imaging, security, neutron and x-ray imaging, etc)

HEP community will benefit from economy of scale.

Gen II could significantly reduce costs.

In the mean time, Incom is very interested in HEP early adopters and is willing to help with costs and availability, *especially* for those who can provide detailed testing/feedback

Successful early demonstrations are critical!

Next Steps

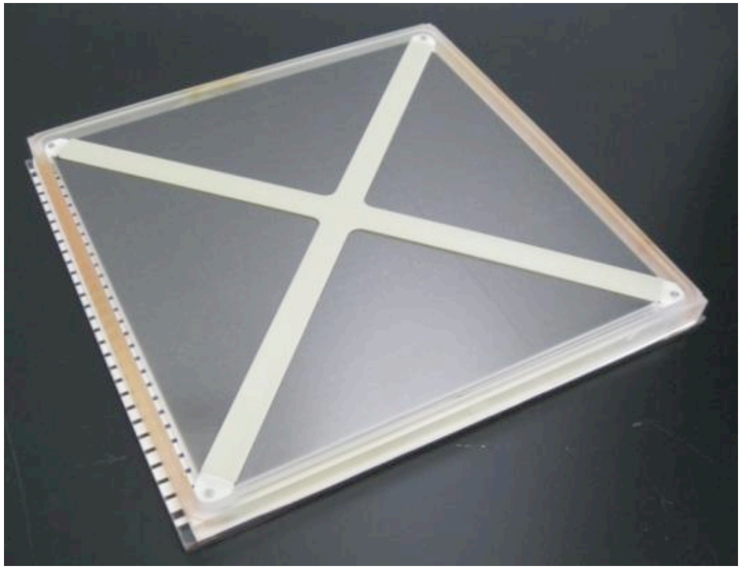
- Application readiness
- Successful demonstration
- Rethinking WCh/scintillator detectors

ANNIE detector components at FNAL

Additional Slides

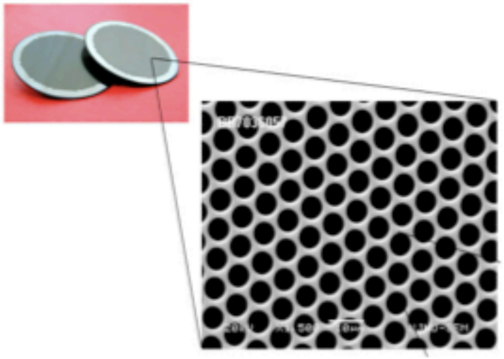
Commercialization Status

- Plasma cleaner
  - To clean GCAs before coating
  - To clean tile components before sealing
- Vacuum oven
  - To bake GCAs prior to coating
  - To post-anneal MCPs after ALD
  - To condition indium for LAPPD sealing
- Thermal evaporator
  - For electroding MCPs and metalizing LAPPD components
  - Commercial coating service, e.g. for ANL and UChicago
- ALD coater
  - For coating resistive and emissive layers
  - Coating of 20 cm (8”) MCPs beginning in November
- Measurement & test station
  - Now measuring resistance & gain on 33 mm MCPs
  - Installing cross delay-line readout, 20 cm format testing, timing measurement capability
- Integration and sealing station
  - For assembly of LAPPD tiles
  - Completing system installation



- Major funding provided by DOE under TTO and SBIR grants
- Extensive technical support from Argonne National Laboratory, University of Chicago, and UC Berkeley, Space Sciences Laboratory

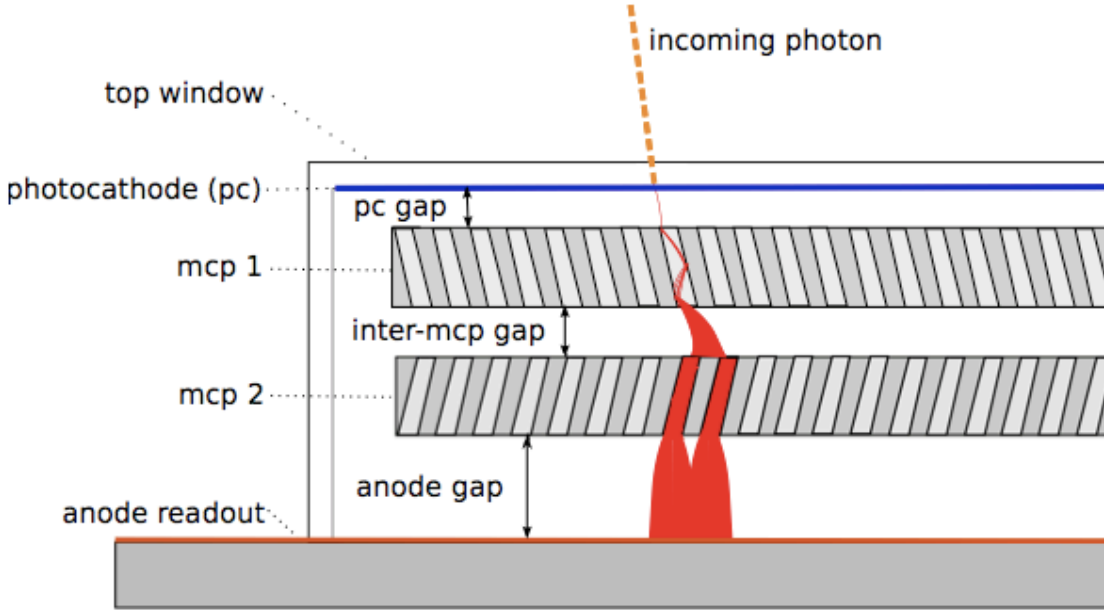
What is an MCP-PMT?



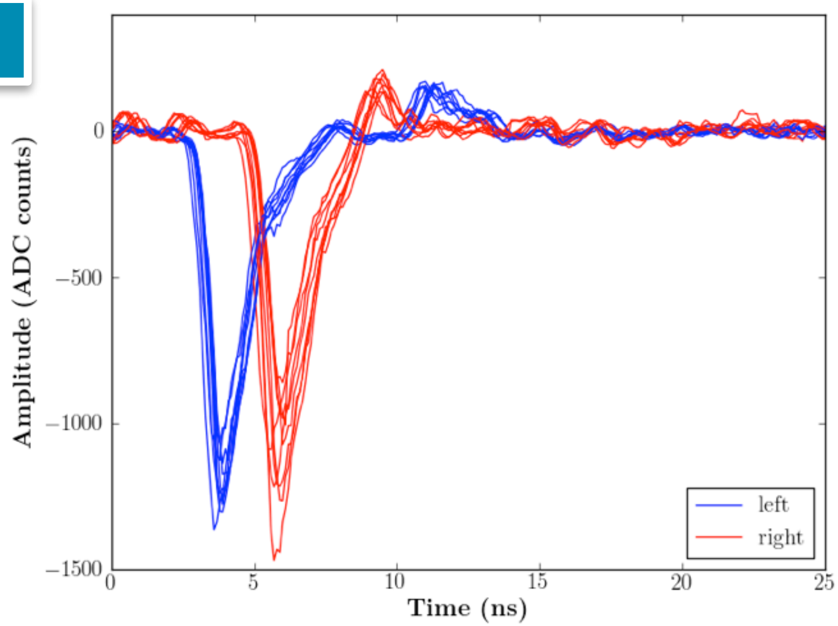
Microchannel Plate (MCP):

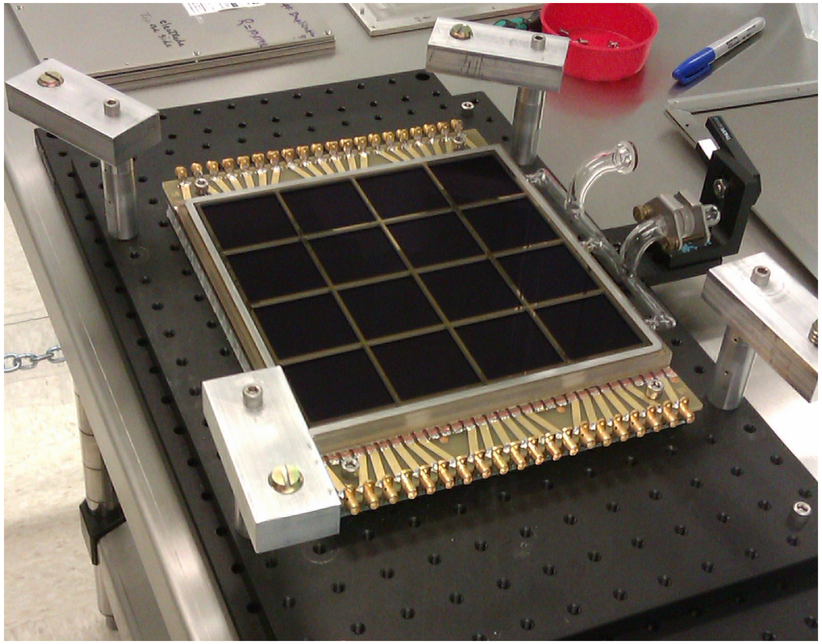
- a thin plate with microscopic (typically <50 μm) pores
- pores are optimized for secondary electron emission (SEE).
- Accelerating electrons accelerating across an electric potential strike the pore walls, initiating an avalanche of secondary electrons.

- An MCP-PMT is, sealed vacuum tube photodetector.
- Incoming light, incident on a photocathode can produce electrons by the photoelectric effect.
- Microchannel plates provide a gain stage, amplifying the electrical signal by a factor typically above 10^6.
- Signal is collected on the anode

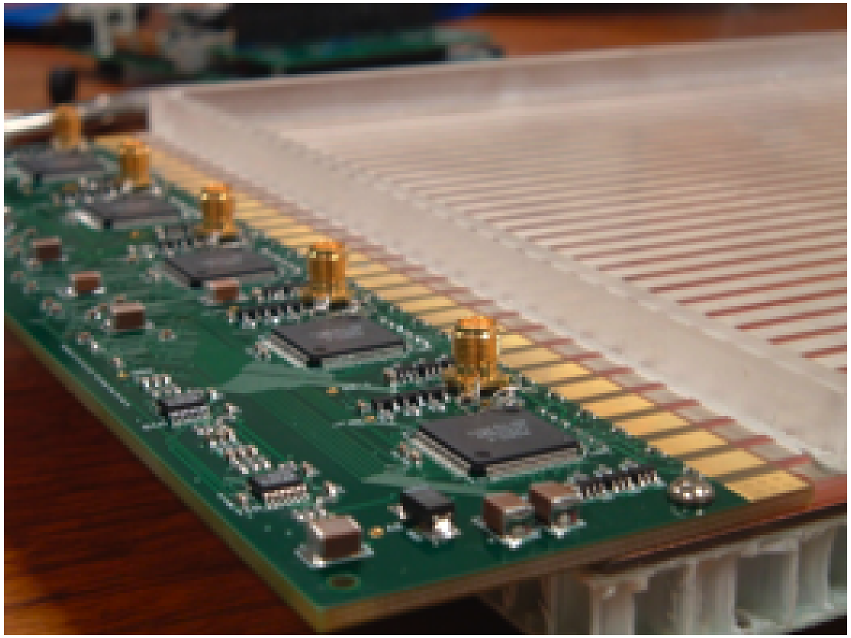


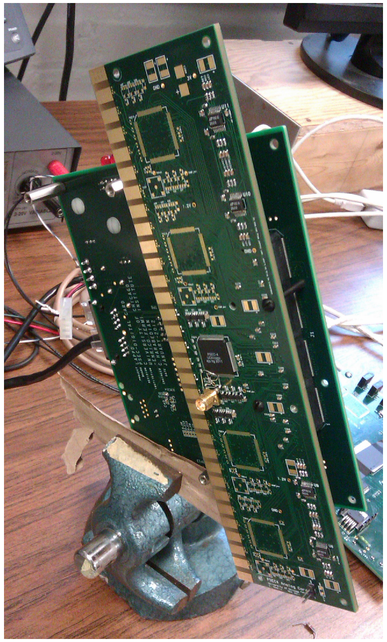
LAPPD





- As an R&D project, the LAPPD collaboration attacked every aspect of the problem of building a complete detector system, including even waveform sampling front-end electronics
- Now testing near-complete glass vacuum tubes ("demountable detectors") with resealable top window, robust

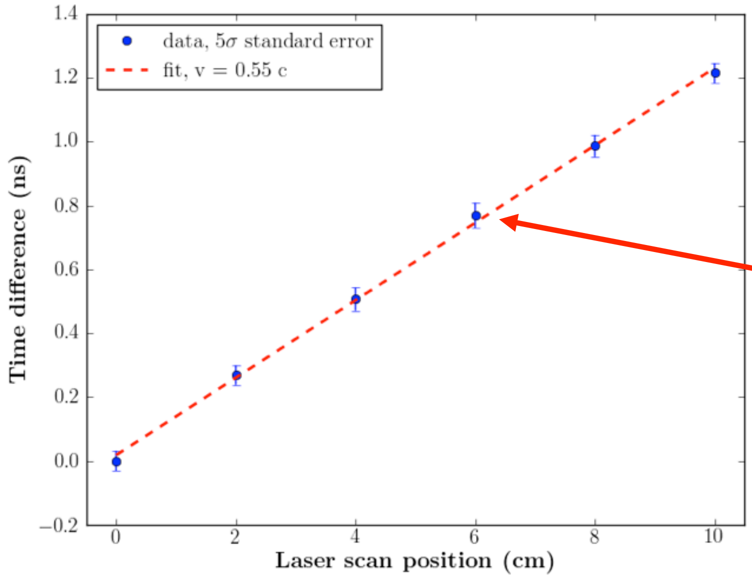


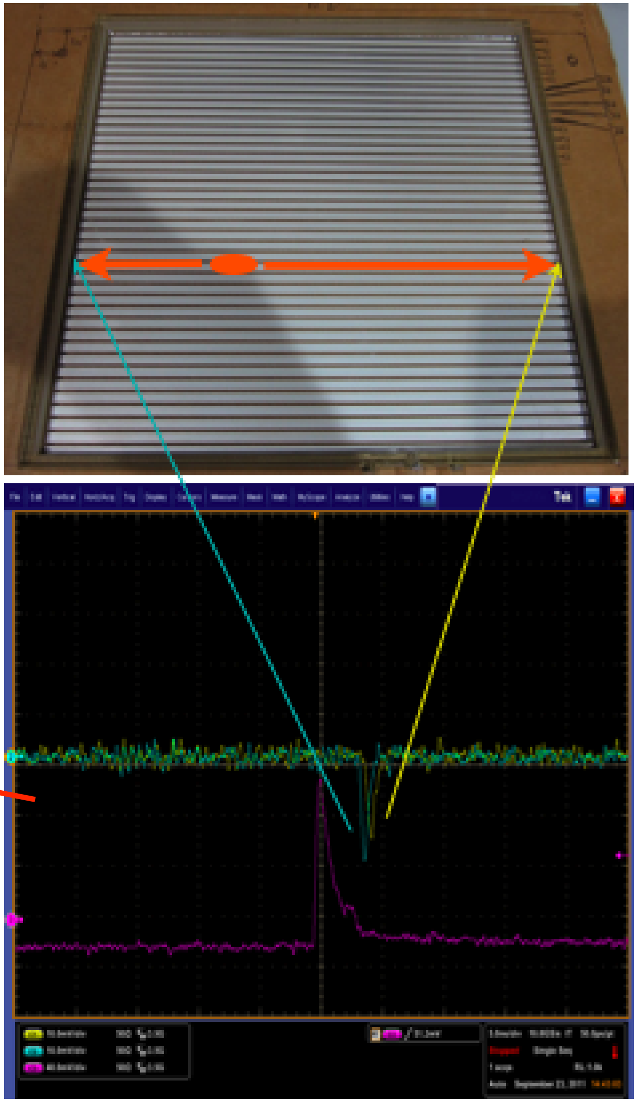


Anode Design: Delay Lines

Channel count (costs) scale with length, not area
Position is determined:

- by charge centroid in the direction perpendicular to the striplines
- by differential transit time in the direction parallel to the strips



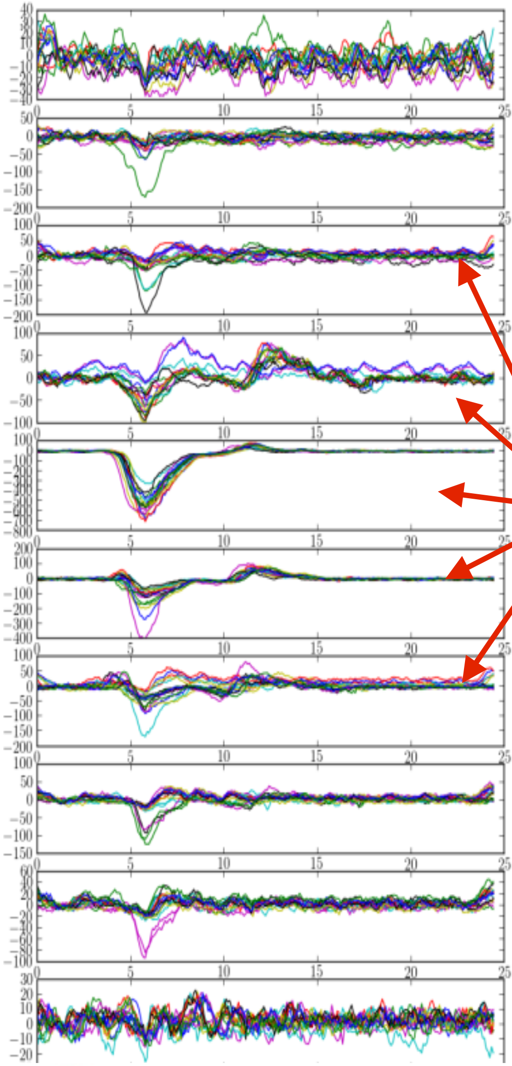


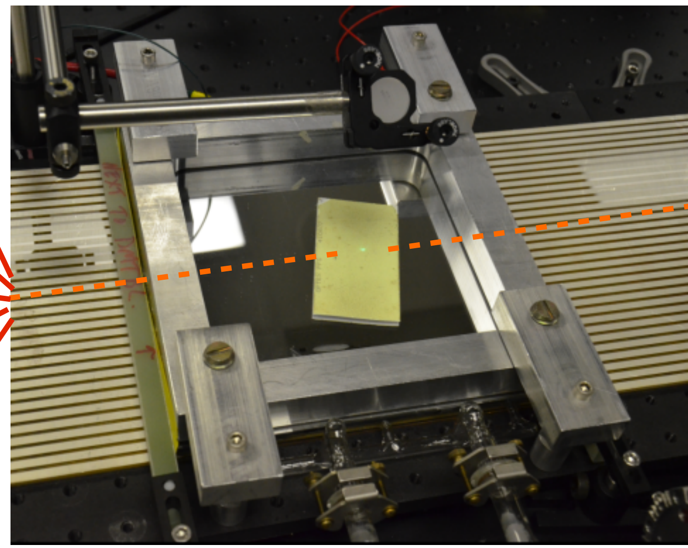
Slope corresponds to ~2/3 c propagations speed on the microstrip lines. RMS of 18 psec on the differential resolution between the two ends: equivalent to roughly 3 mm

Anode design

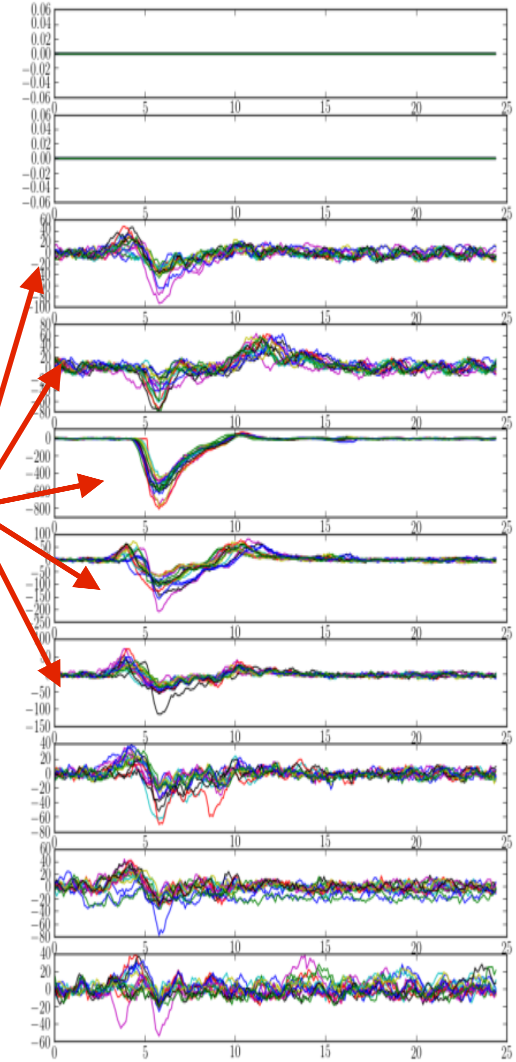
Transverse position is determined by centroid of integrated signal on a cluster of striplines.

Pulses on 10 striplines
Left Side





Credit: Eric Oberla



Right Side
Pulses on 10 striplines

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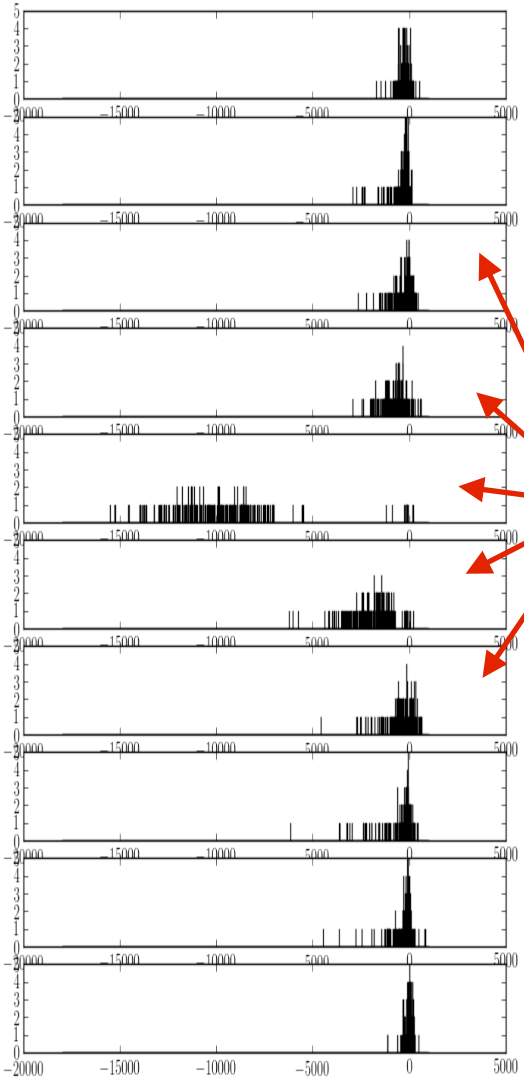

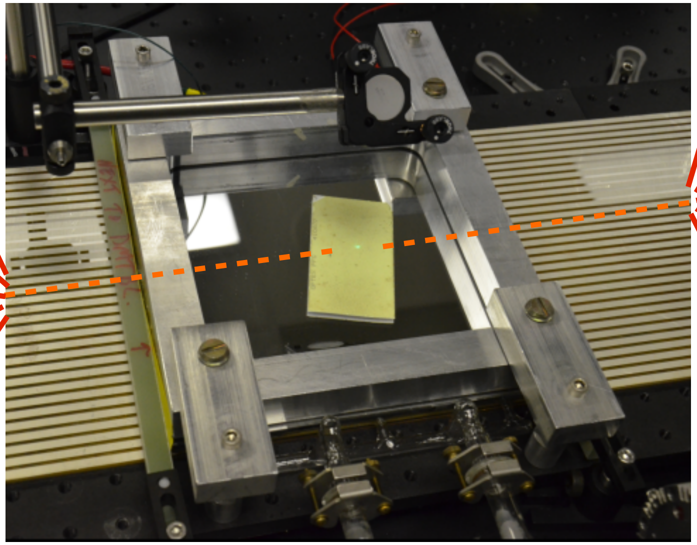

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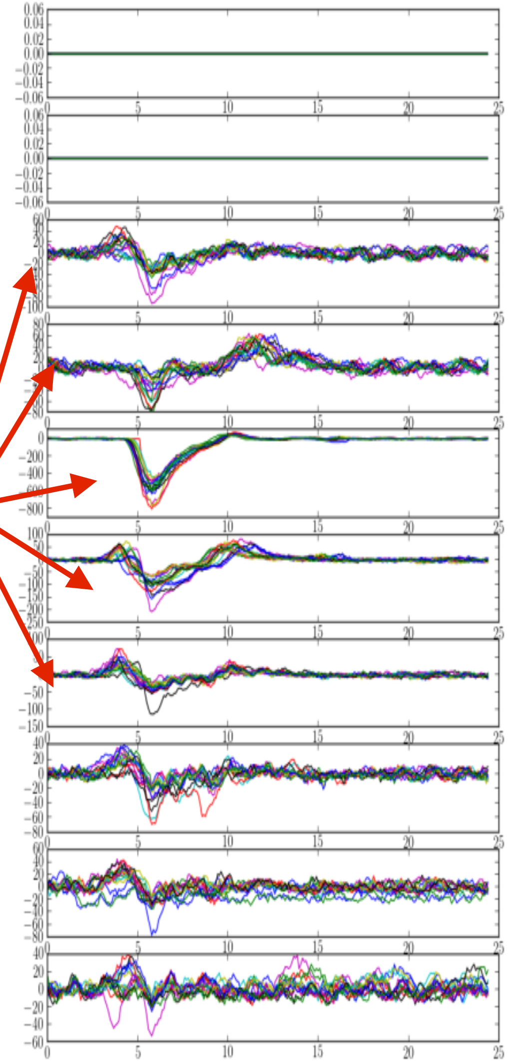


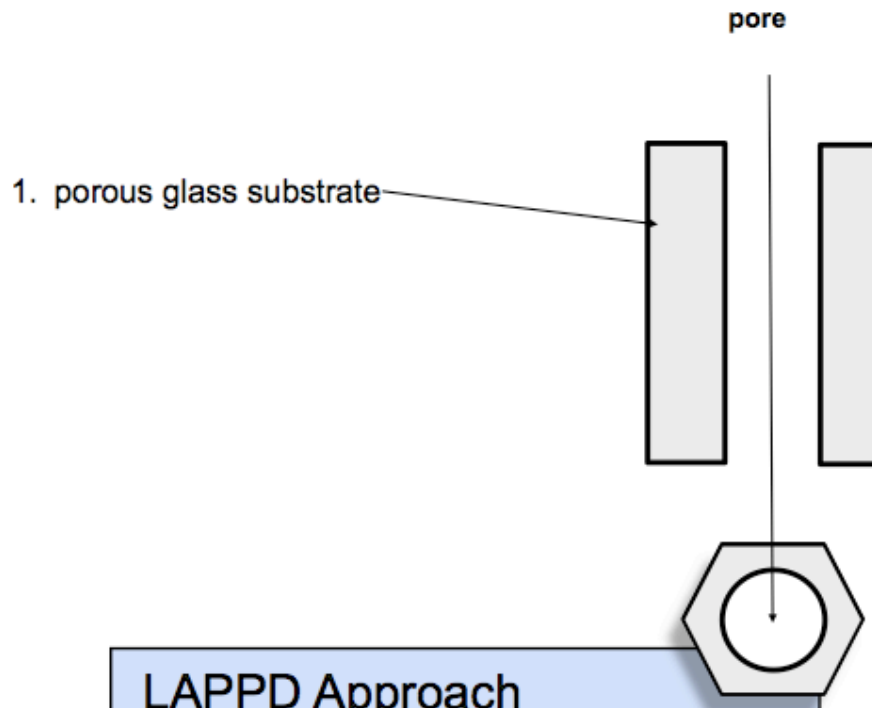
Right Side
Pulses on 10 striplines

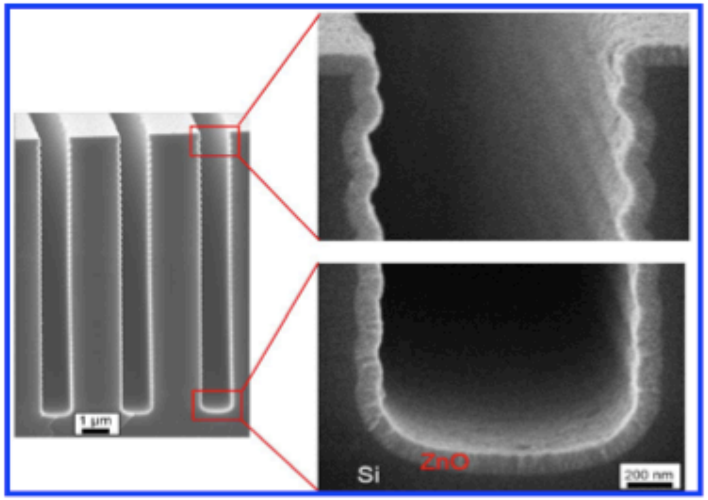
Our Approach

J. Elam, A. Mane, Q. Peng (ANL-ESD),
N. Sullivan (Arradiance), A. Tremsin (Arradiance, SSL)

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).





LAPPD Approach

- Separate out the three functions
- Hand-pick materials to optimize performance.
- Use Atomic Layer Deposition (ALD): a cheap industrial batch method.
  - ALD is diffusive, conformal and allows application of material in single atomic monolayers

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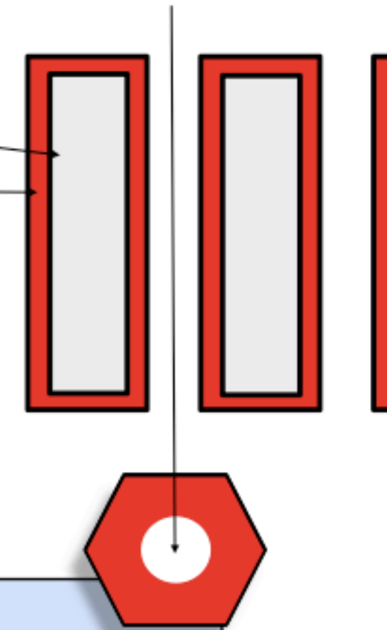
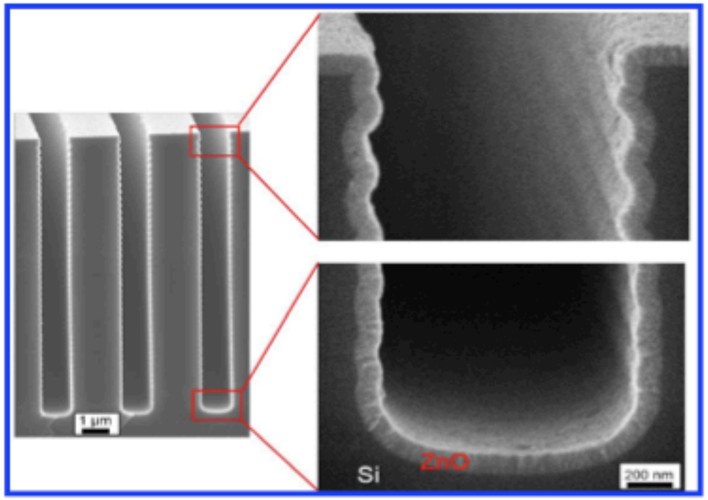
pore

1. porous glass substrate
2. resistive coating (ALD)





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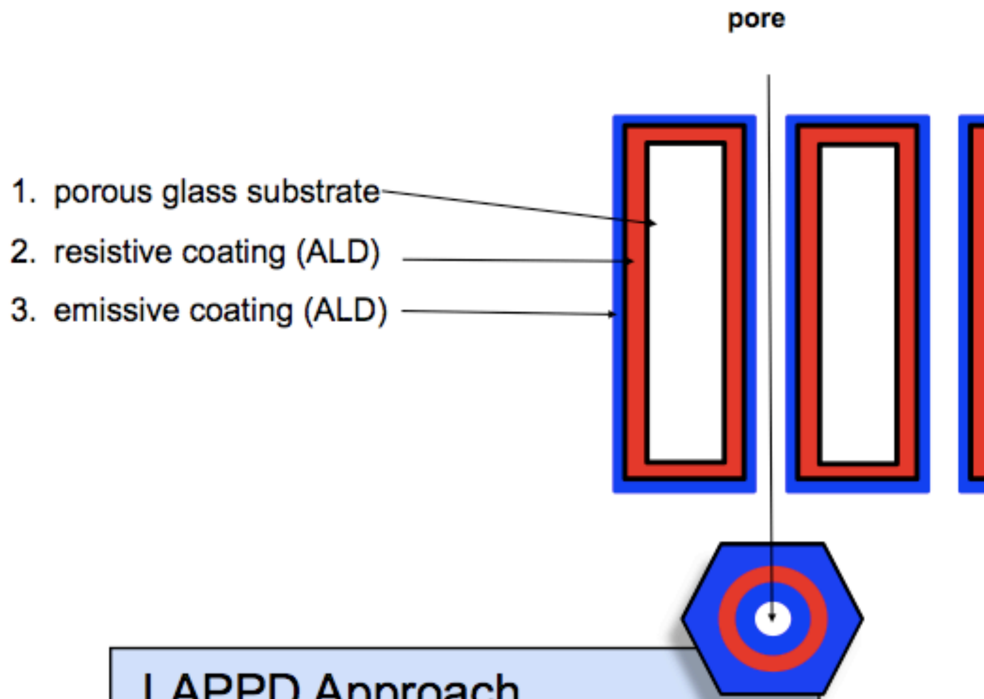

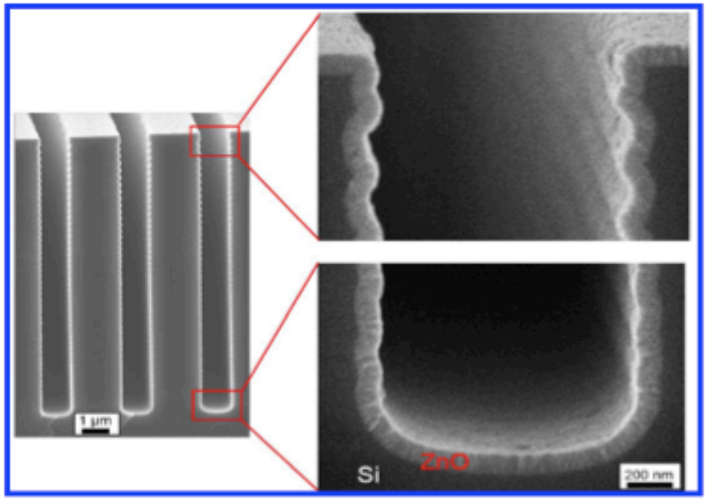

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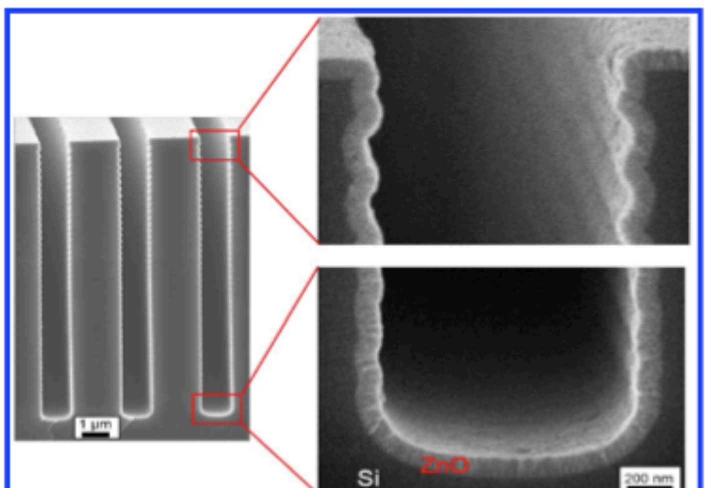
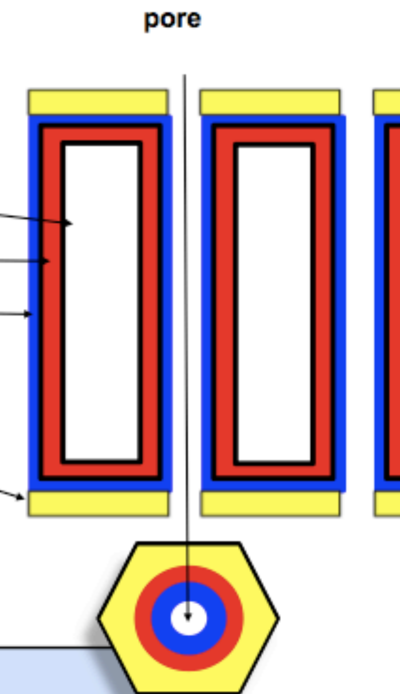


1. porous glass substrate
2. resistive coating (ALD)
3. emissive coating (ALD)
4. conductive coating
   (thermal evaporation or sputtering)



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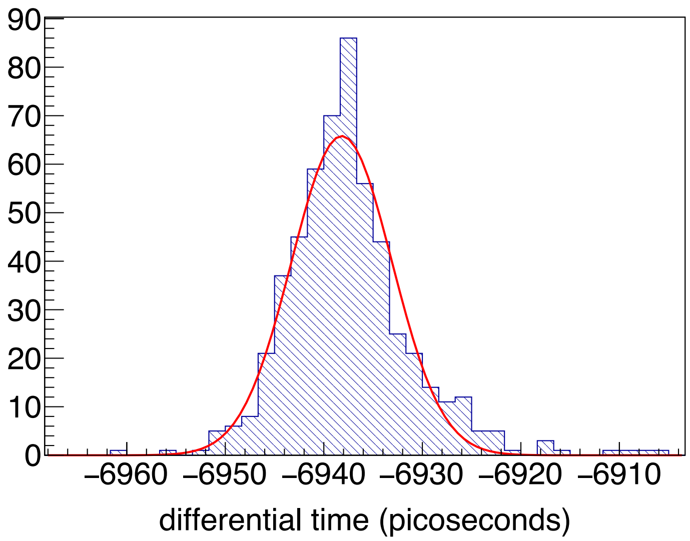
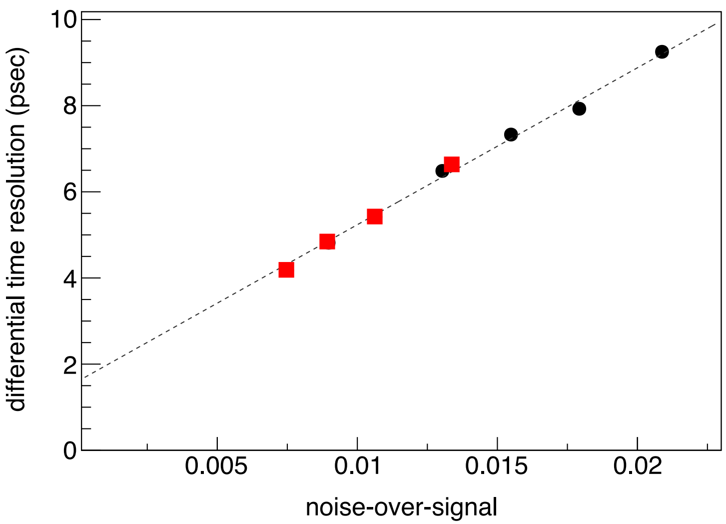
LAPPD Characteristics



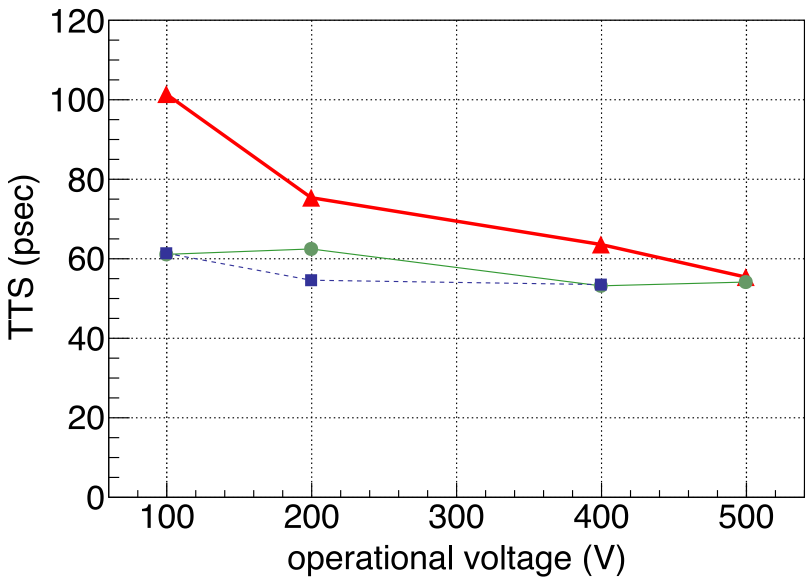
<10 psec, differential time resolution

(2mm spatial resoution)

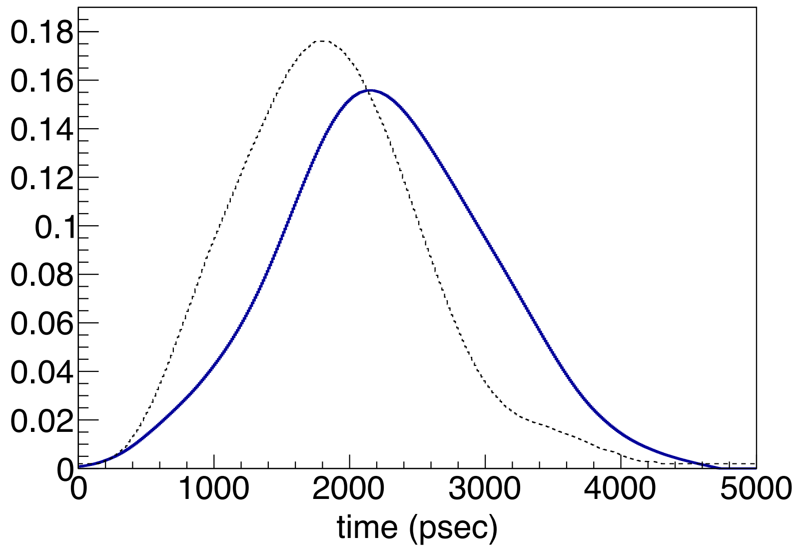


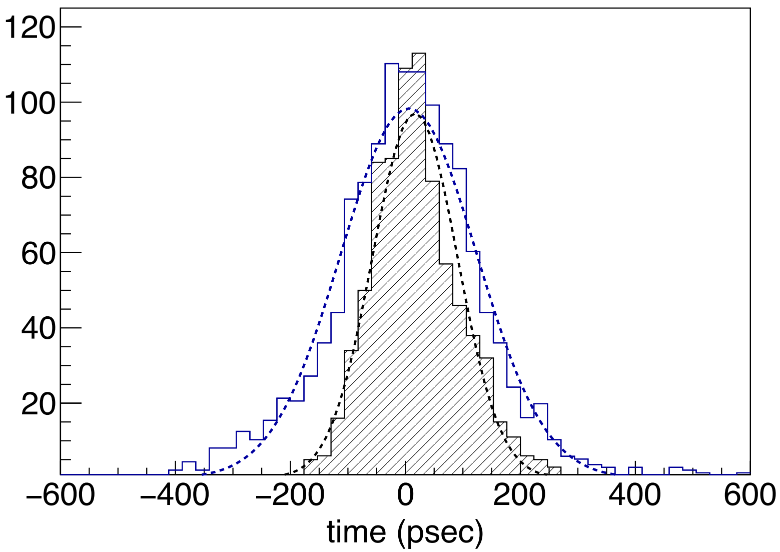
large signal resolutions extrapolating <2 psec

LAPPD Characteristics

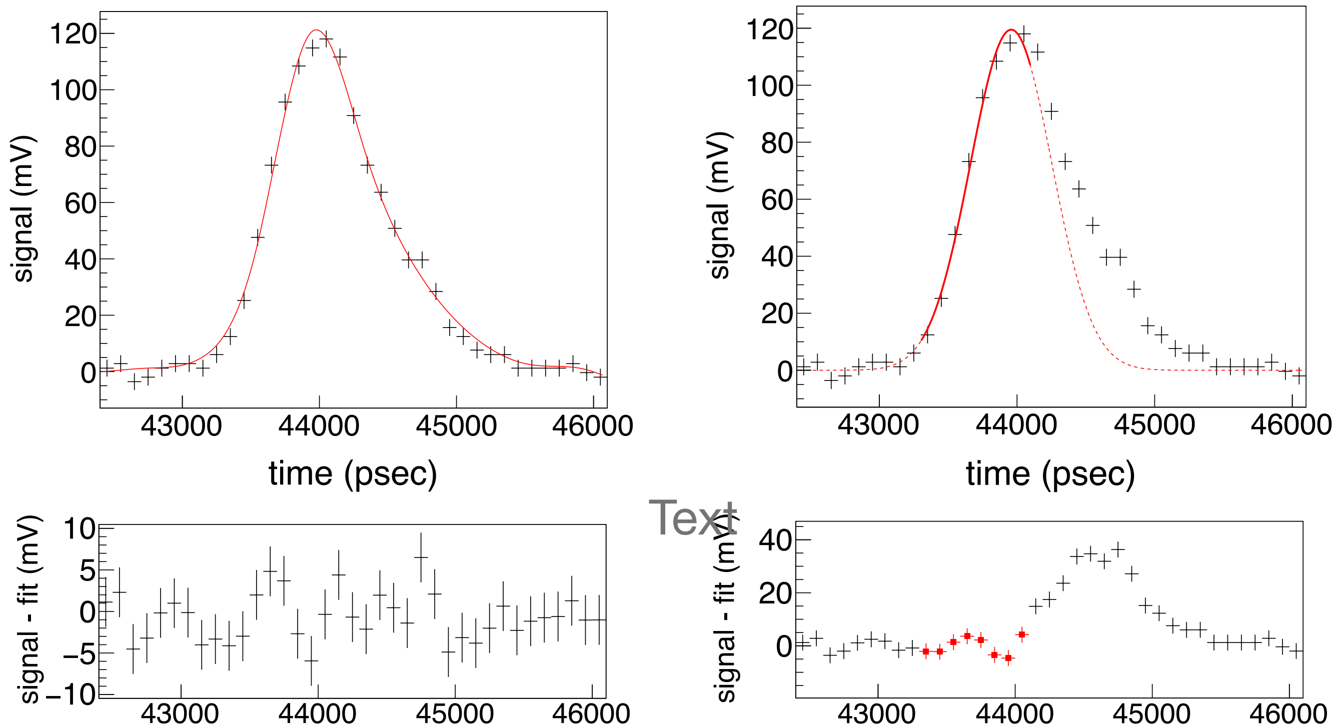


Resolutions improve with larger voltages across the gaps





LAPPD Characteristics

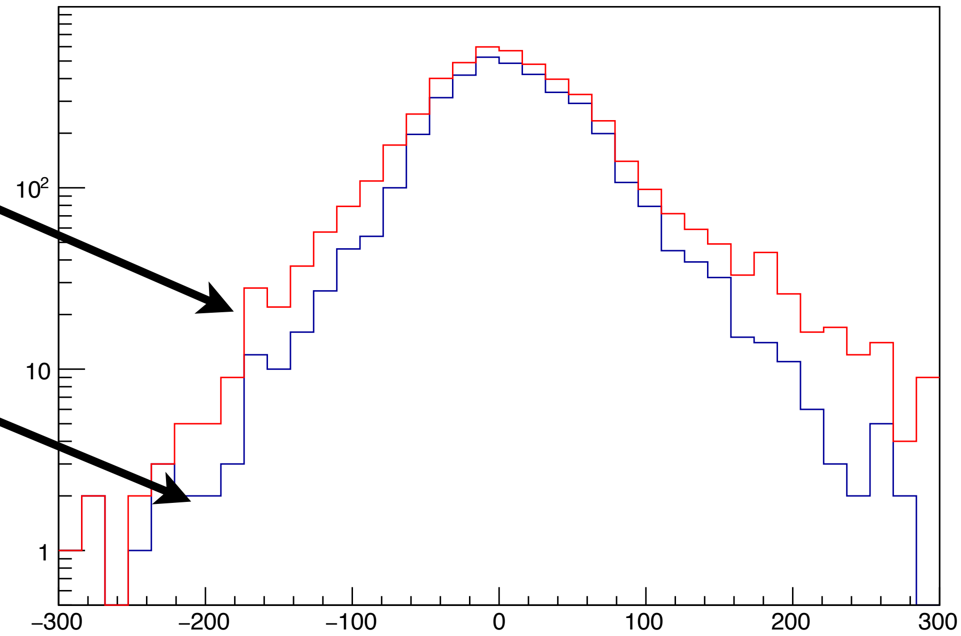


- Pulse shape fitting gives the best time resolution (see J-F Genat et al, NIM A 607 (2) (2009) 387)
- It also provides a strong handle for rejecting after pulses and identifying double pulses.

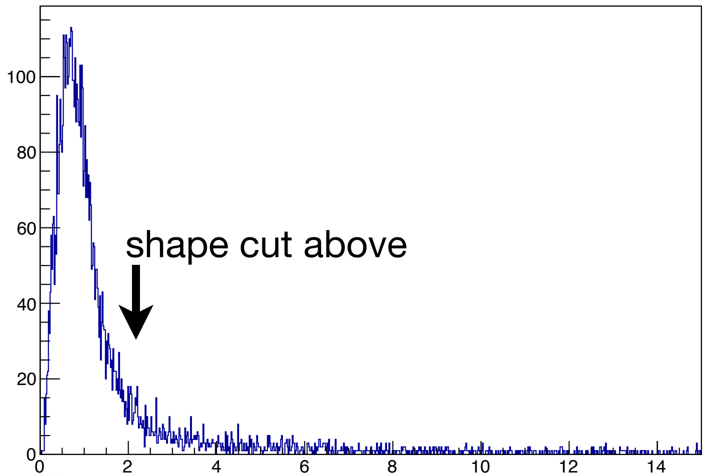
LAPPD Characteristics

No shape cut
RMS = 70 psec

shape cut
RMS = 58 psec
~20% loss

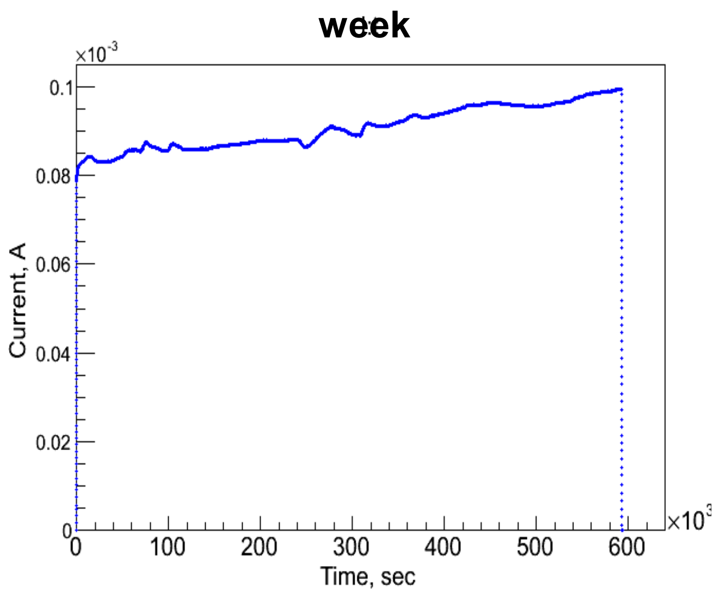


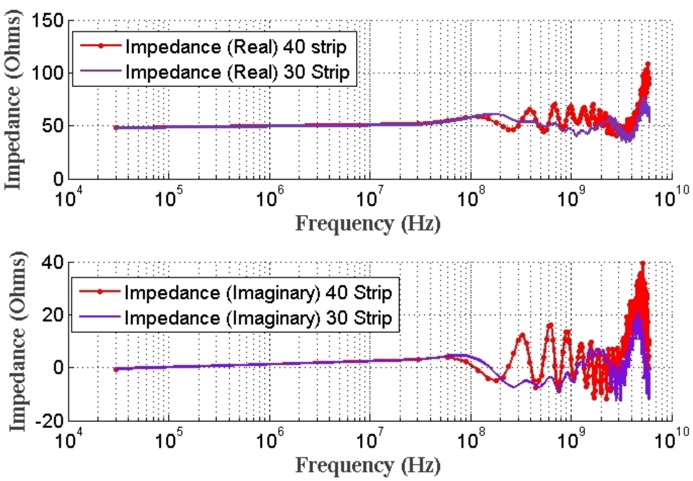
chi2 per deg free

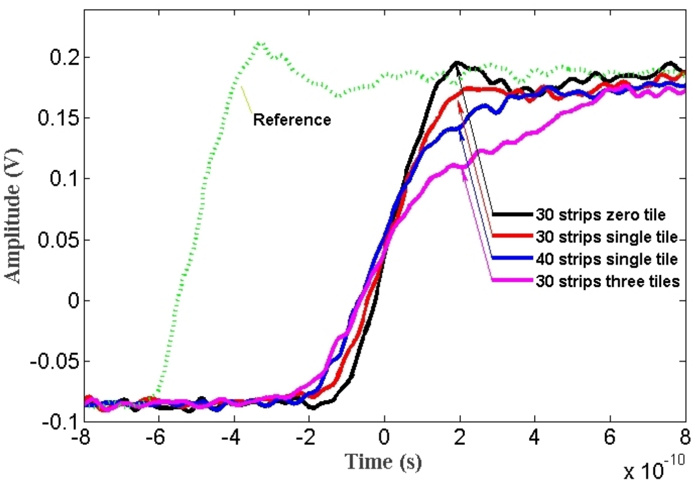


What we measure...Also:

- RF properties
- Losses in anode
- Lifetime and stability issues
- Dark current

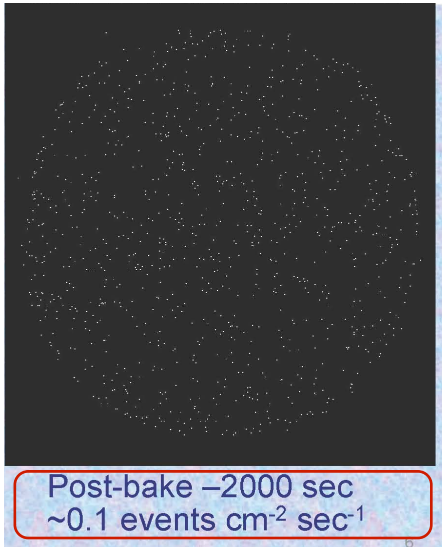




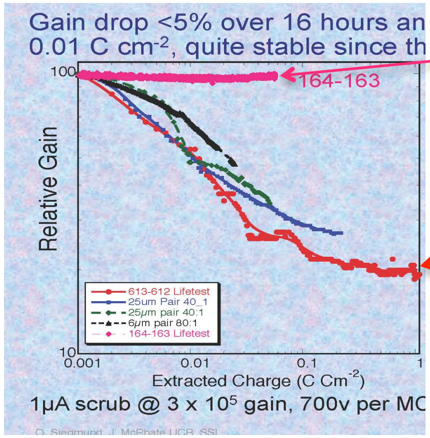


MCP Quality

Low noise



Short break-in



Measured ANL ALD-MCP behavior

Typical MCP behavior- long scrub-times

Measurements by

O.H.W. Siegmund, J. McPhate, A.S. Tremsin, S.R. Jelinsky, R. Hemphill

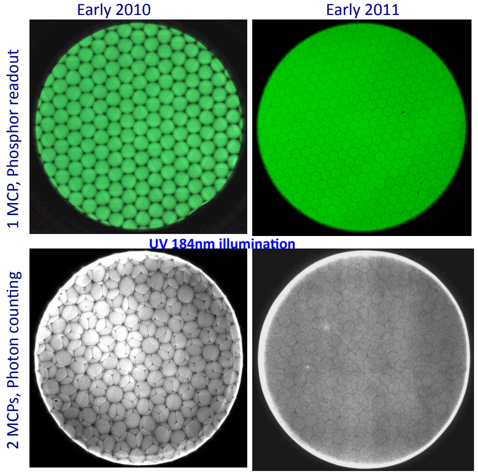
Berekeley SSL

Samples by

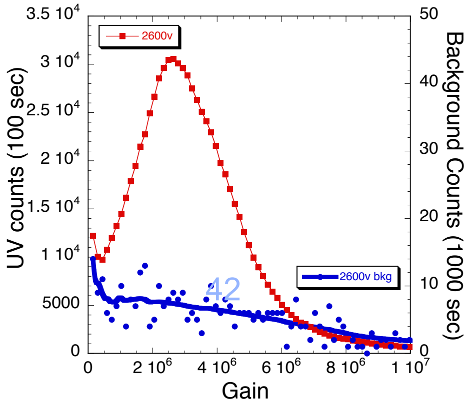
J. Elam, A. Mane, Q. Peng

ANL

Rapidly improving substrates (Arradiance)



bkgd rate of 0.099 evts cm^{-2} sec^{-1} at 1.3 kV per plate



Factors That Determine Time Resolution

At the Front End:

- Sampling rate (f_s)
  Nyquist-Shannon Condition
- Analog bandwidth (f_{3DB})
- Noise-to-signal ($\Delta u/U$)

credit: Stafan Ritt (Paul Scherrer Institute)

$$\Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3 f_s \cdot f_{3dB}}}$$

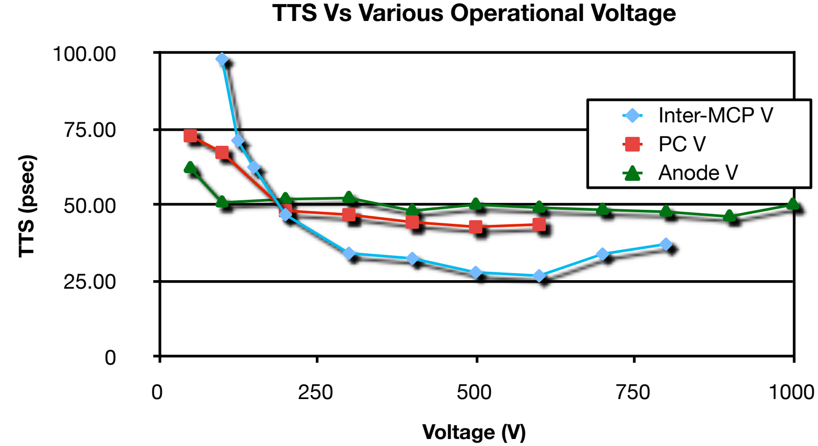
Assumes zero aperture jitter

	U	Δu	f_s	f_{3db}	Δt
today:	100 mV	1 mV	2 GSPS	300 MHz	~10 ps
optimized SNR:	1 V	1 mV	2 GSPS	300 MHz	1 ps
next generation:	100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
next generation optimized SNR:	1V	1 mV	10 GSPS	3 GHz	0.1 ps

Intrinsic to the MCP:

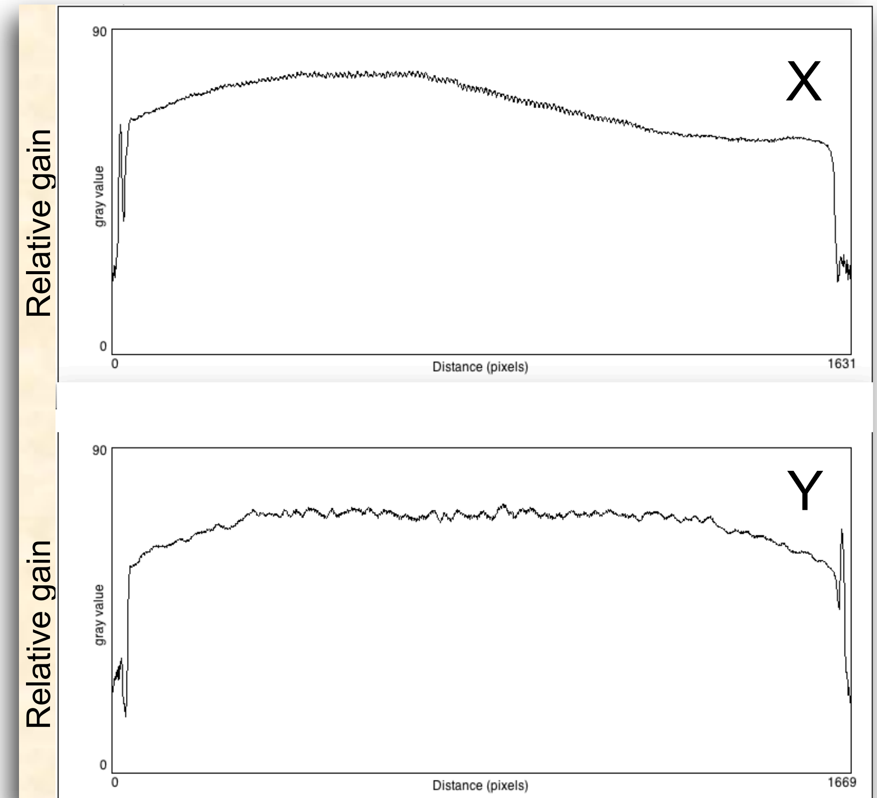
- Operational voltages
- Gain
- Geometry
  - Pore size
  - Continuous vs discrete dynode

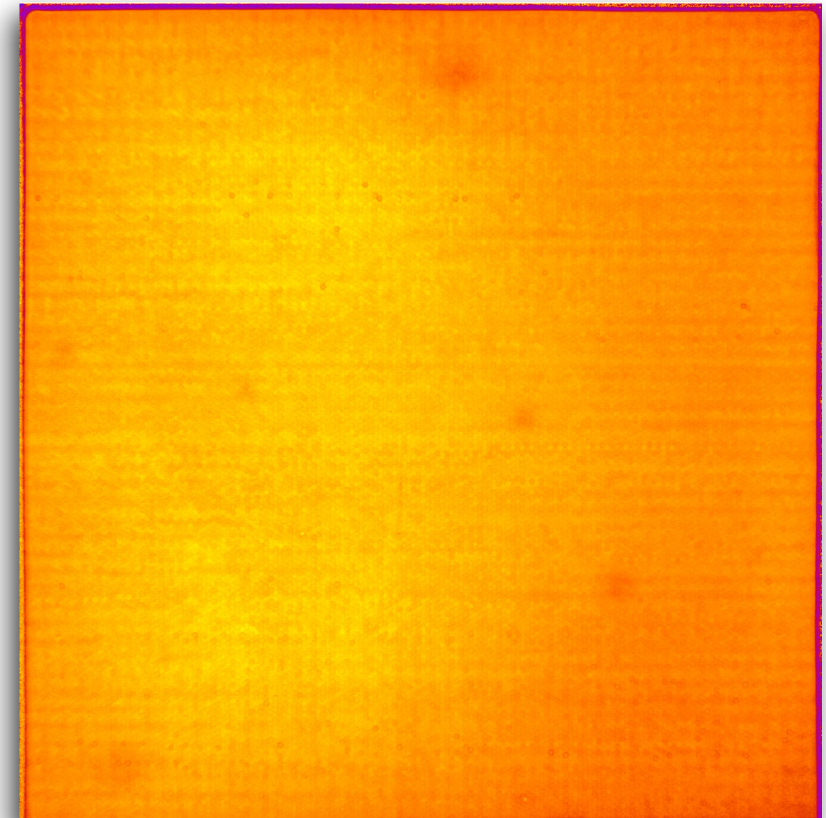
B Adams (APS-ANL), M Chollet (APS-ANL), A Elagin (UoffC/ANL), R Obaid (UofC), A Vostrikov (UofC), M Wetstein (UofC/ANL)



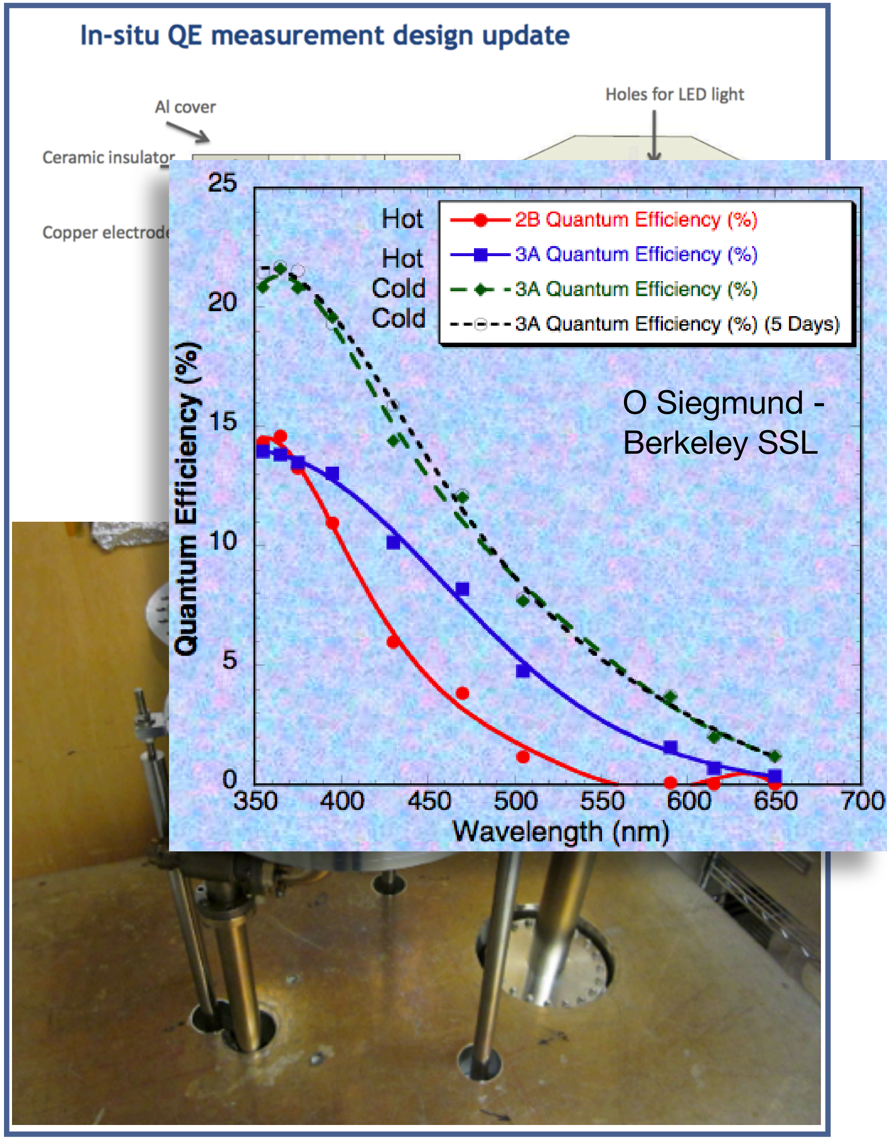
see: workshop on factors that limit time resolution in photodetectors: http://psec.uchicago.edu/workshops/fast_timing_conf_2011/

LAPPD - Gain Uniformity





Large Area Photocathodes



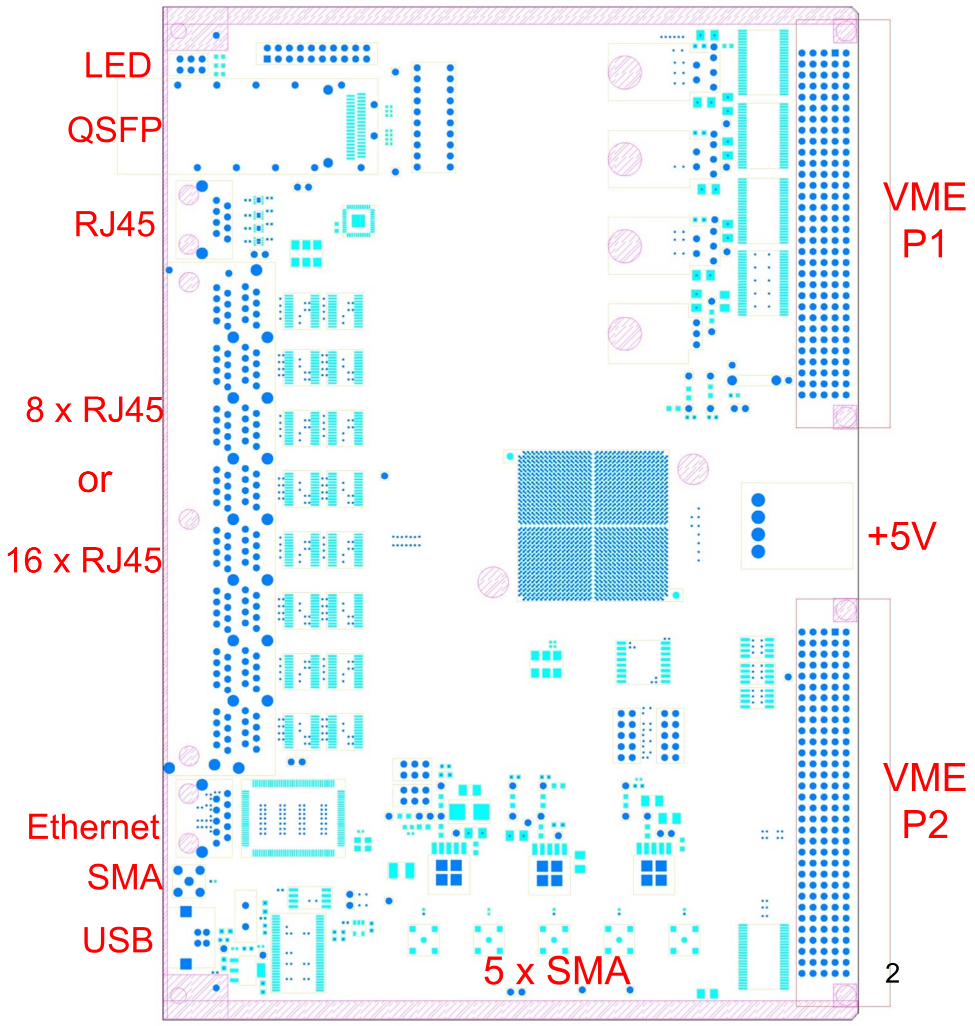
- Two main parallel paths:
  - scale traditional bi-alkali photocathodes to large area detectors. Decades of expertise at Berkeley SSL. Significant work at ANL to study new methods for mass production lines.
  - Also pursuing a deeper microscopic understanding of various conventional photocathode chemistries and robustness under conditions relevant to industrial batch processing. Could lead to a longer term photocathode program as part of the new ANL detector center
- Achievements:
  - Commissioning of 8" photocathode facility at UCB-SSL
  - Completion of ANL photocathode lab
  - Acquisition of a Burle-Photonis photocathode deposition system. Progress in adapting it to larger areas.
  - Successful development of a 24% QE photocathode in a small commercial

K. Attenkofer(ANL-APS), Z. Yusof, J. Xie, S. W. Lee (ANL-HEP), S. Jelinsky, J. McPhate, O. Siegmund (SSL) M. Pellin (ANL-MSD)

New Central Card and DAQ Dev

Mircea Bogdan (UC) has a new design for the PSEC central card to allow very large channel-counts.

Prototypes boards are being ordered and will be tested in early 2016.



LAPPDs Application Readiness (water proofing)

LAPPD Water Proofing

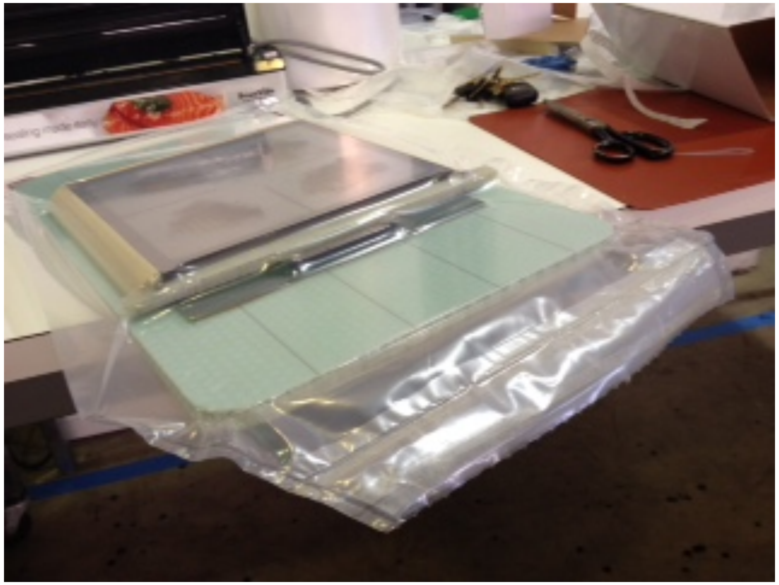
Exploring two paths:

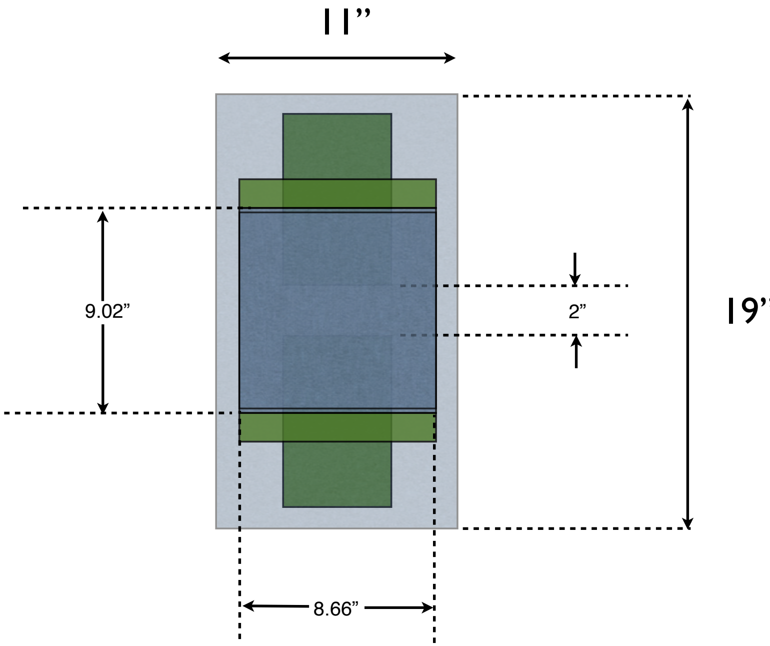
- “Sous Vide”: sealing the LAPPD assembly (w/ front end) in a plastic envelope
- Water-proof box

LAPPD Water Proofing

Sous Vide concept:

- LAPPD is packaged with front-end electronics mounted in the water
- Electronics are in direct thermal contact with the water (cooling comes free)
- Use polyethylene bags (Gd-compatible)
  - thick (abrasion resistance)
  - index of refraction (1.4) is between water and glass - nice optical transition

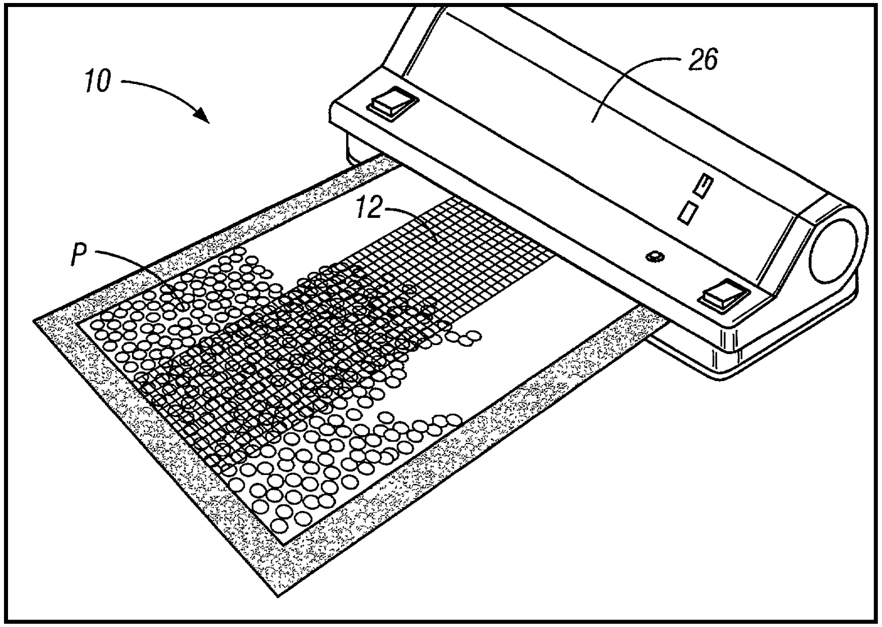




LAPPD Water Proofing

Sous Vide concept:

- Our student was able to make simple custom bags to fit the assembly with polyethylene exterior but nylon inner structure (Sous Vide patent) to allow easy evacuation.
- Eliminating sharp edges was challenging
  - were able to eliminate LAPPD corners with round offs and RTV
  - heats sinks were relplaced with copper ribbon
  - silicone sheets placed over circuit boards



LAPPD Water Proofing

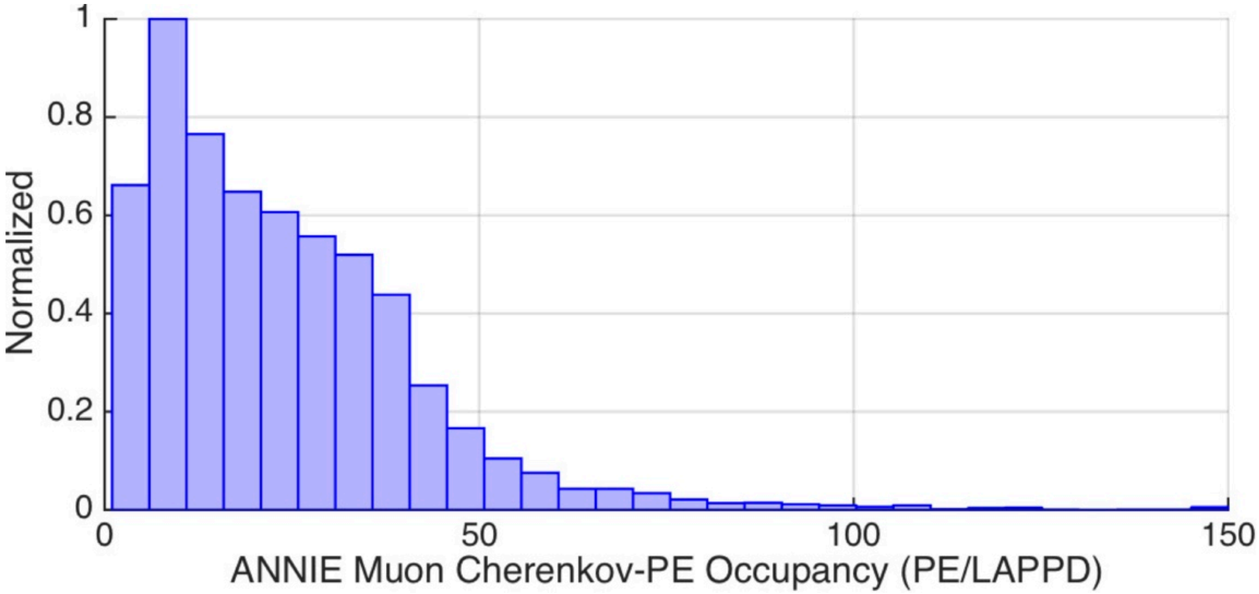
Status:

- We got as far as sealing a test assembly and dunking it in water
- Need to work on feedthroughs (a major challenge)
- Need to study robustness
- Need an operational test

- We lost our undergraduate researcher
- Rich Northrop (UC engineer) has not begun his phase of the work
- This will start soon

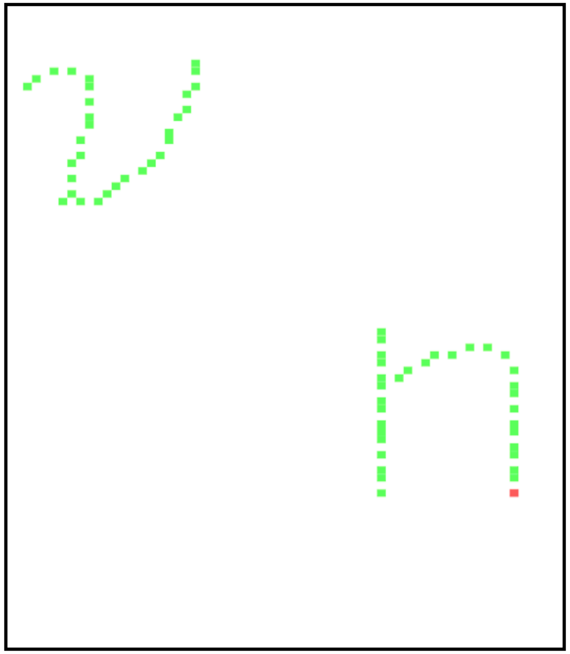
LAPPD Reco

ANNIE Details



LAPPD Analysis Chain

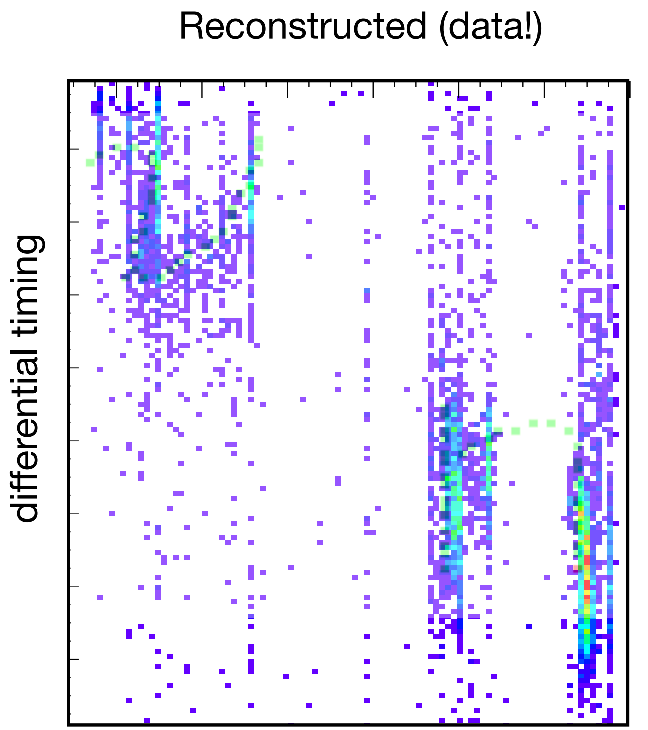
laser scan positions



Full LAPPD/PSEC analysis chain (D. Grzan):

- Able to realistic simulate response of 8” LAPPD (and PSEC digitization) to any pattern of light
- Able to quickly (10 minutes) process toy PSEC4 data

LAPPD Analysis Chain



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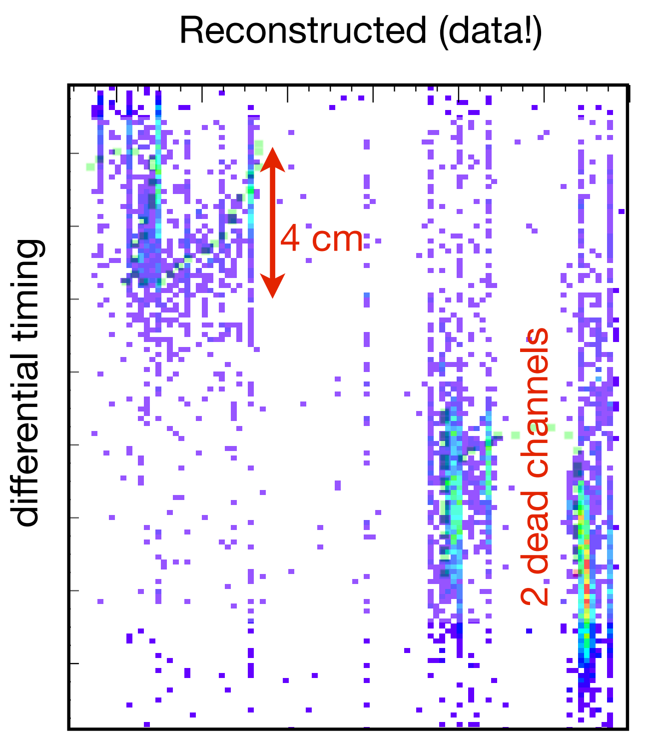
LAPPD Analysis Chain



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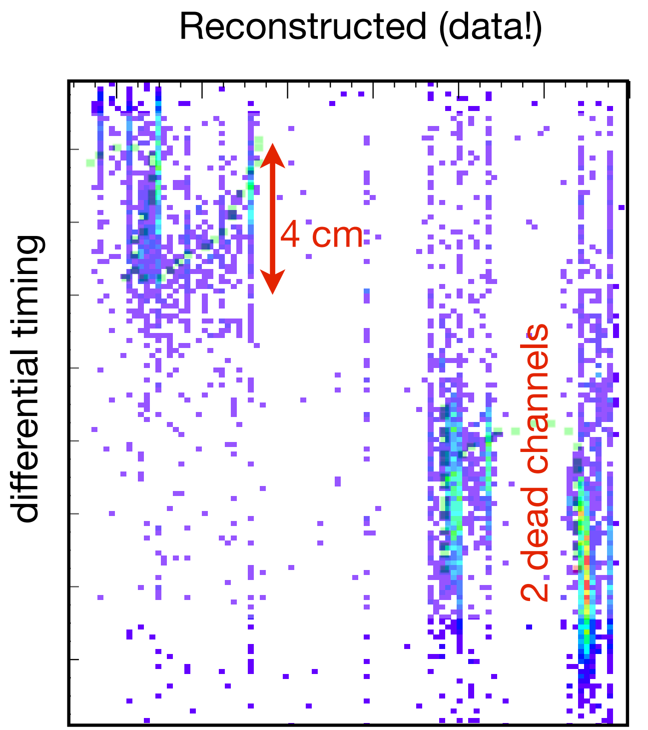
LAPPD Analysis Chain



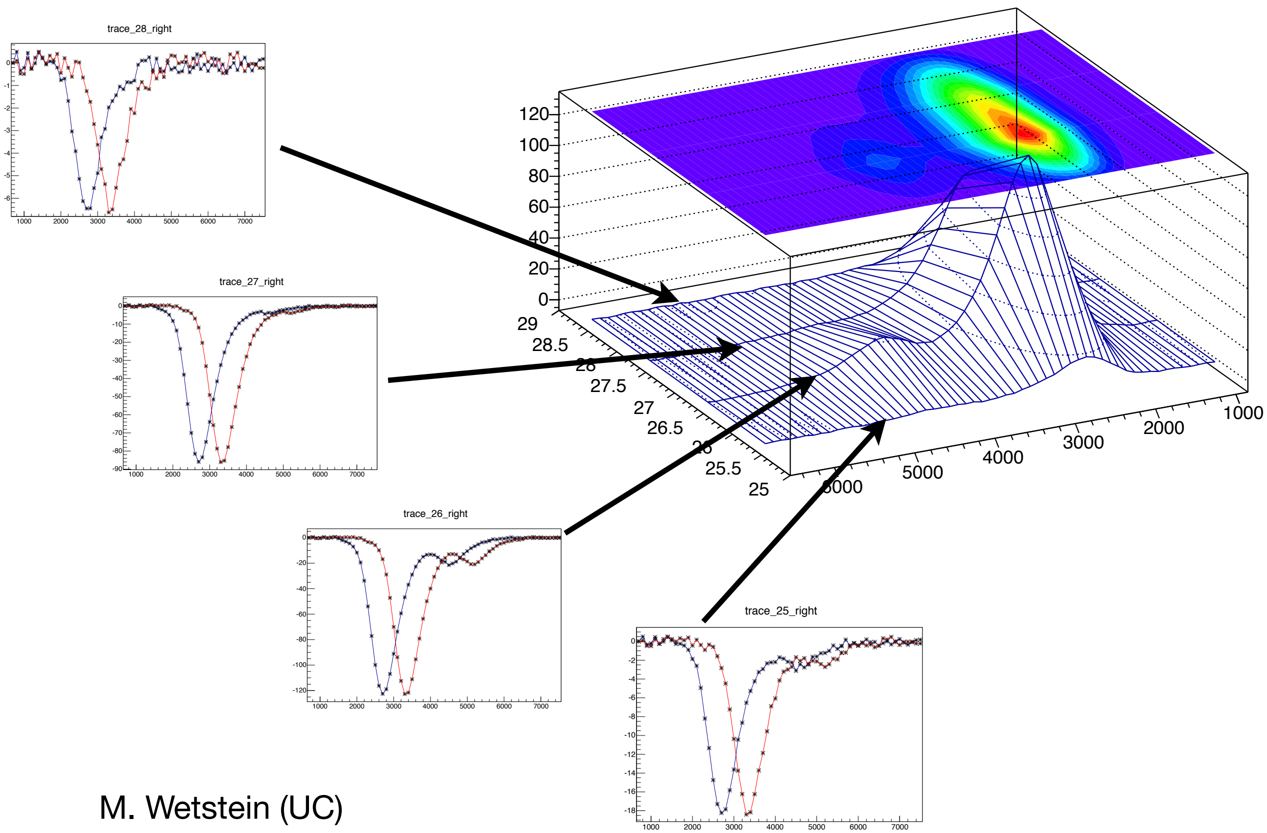
Full LAPPD/PSEC analysis chain (D. Grzan):

- Able to realistic simulate response of 8” LAPPD (and PSEC digitization) to any pattern of light
- Able to quickly (10 minutes) process toy PSEC4 data

New imaging trials starting before November.

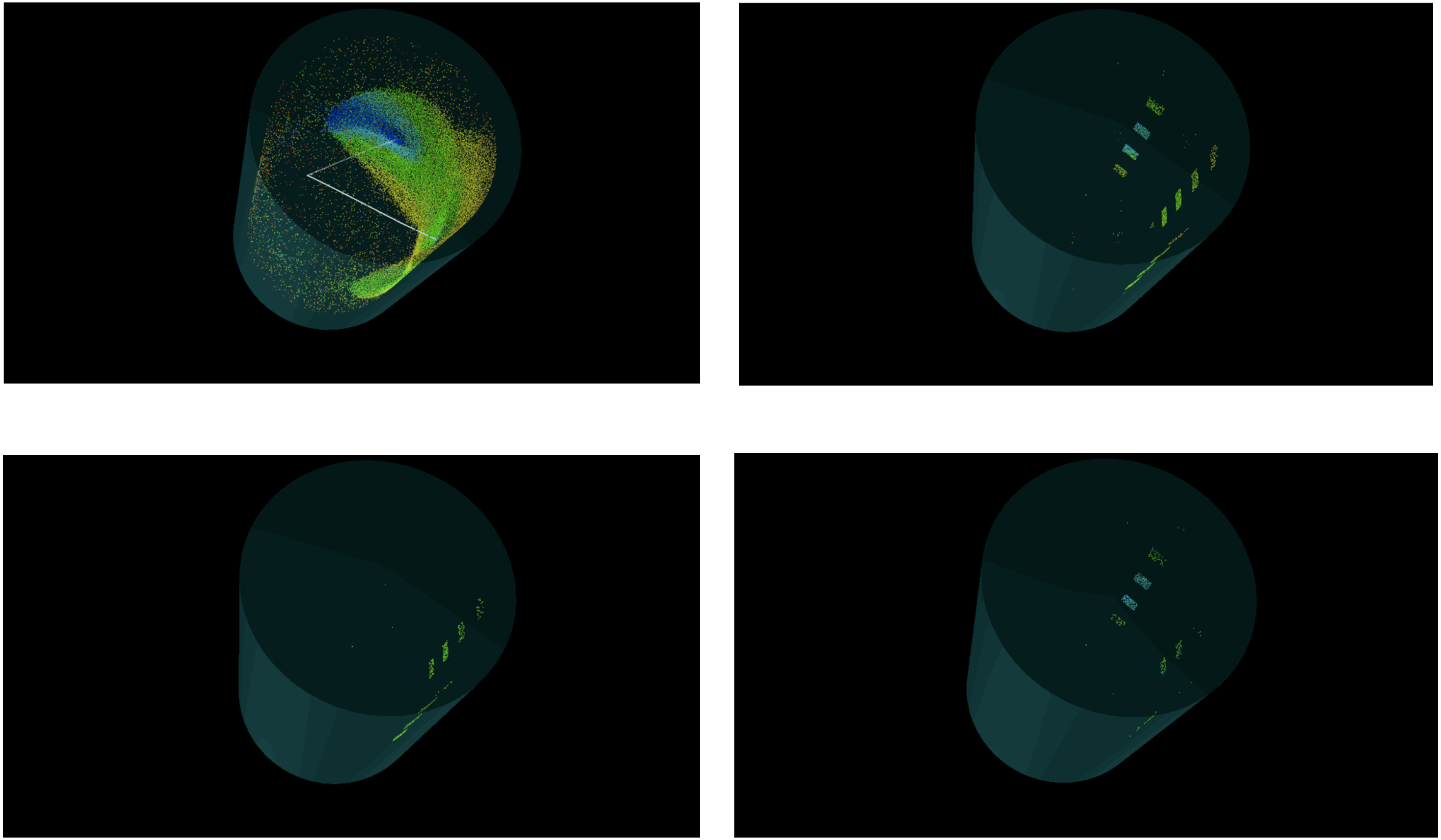
LAPPD Response Simulations

We've been working on using data from the demountable testing to build realistic models of the LAPPD response for use in physics simulations.



M. Wetstein (UC)

ANNIE Details



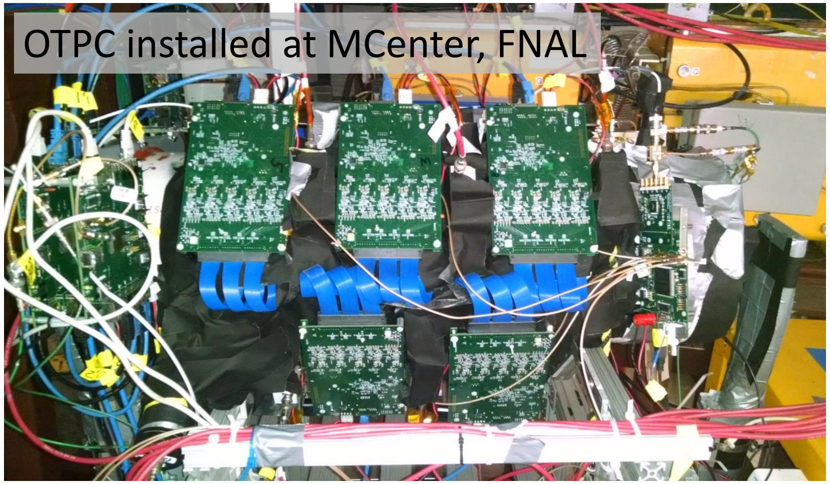
muon

pion

Timing and Scintillation

1A: LAPPD Self Triggering

Eric Oberla (UC grad student) finished implementing self-triggering in the PSEC electronics firmware. Operated a 180 channel system on a test beam experiment, using the feature.



A picture of the optical TPC installed at MCenter at Fermilab. Along the tube axis, 5 PSEC ACDC cards instrument 5 Planacons in a stereo configuration. One additional Planacon and ACDC card instrument the front of the tube. This 180 channle system is controlled by two Central Cards.

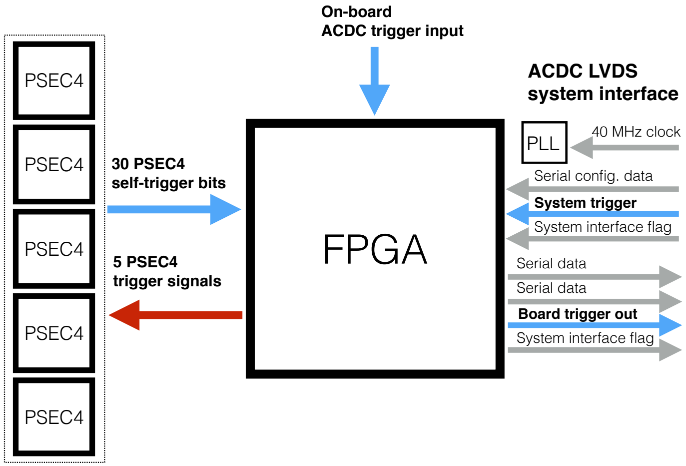
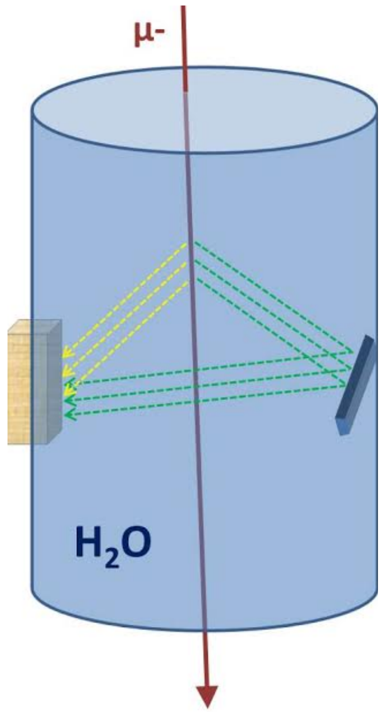
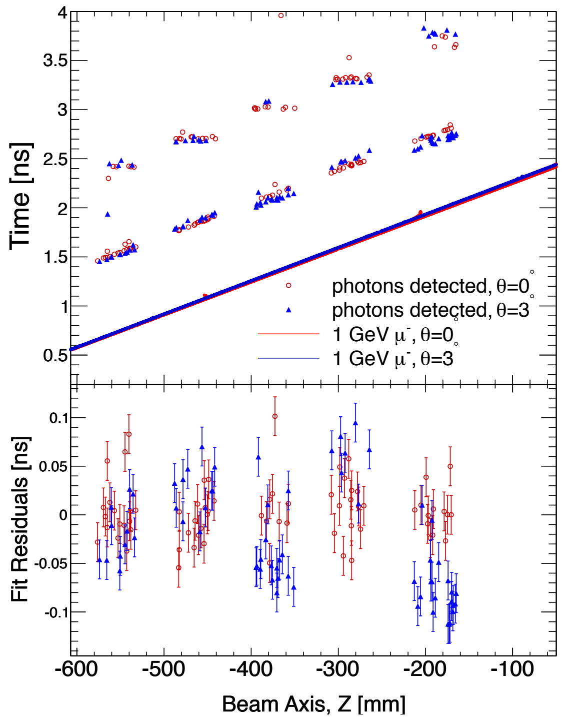
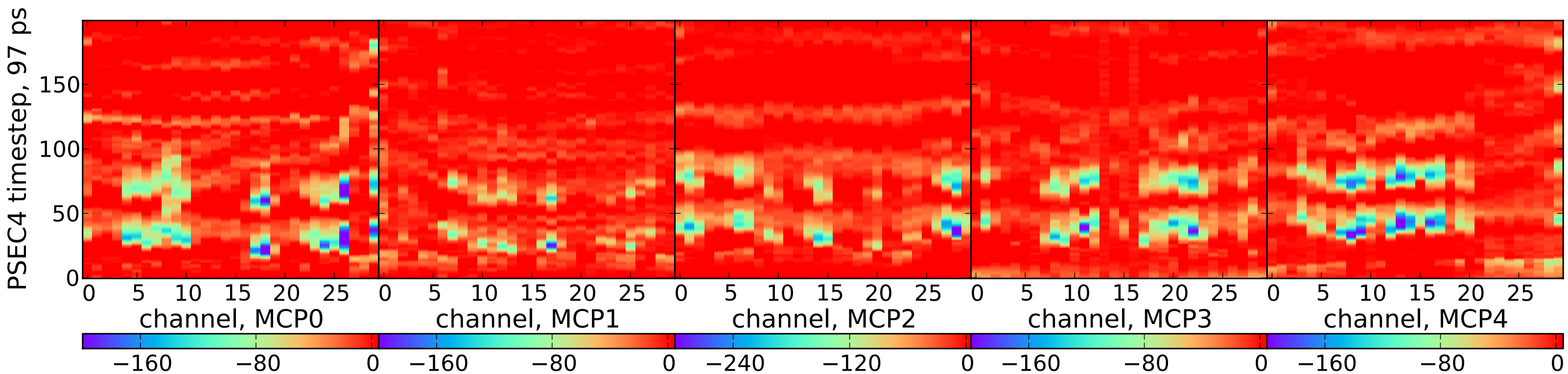


Diagram illustrating the level-0 system trigger for the OPTC, which relied heavily on coincidence with self-trigger bits from PSEC4 chips.

1A: LAPPD Self Triggering

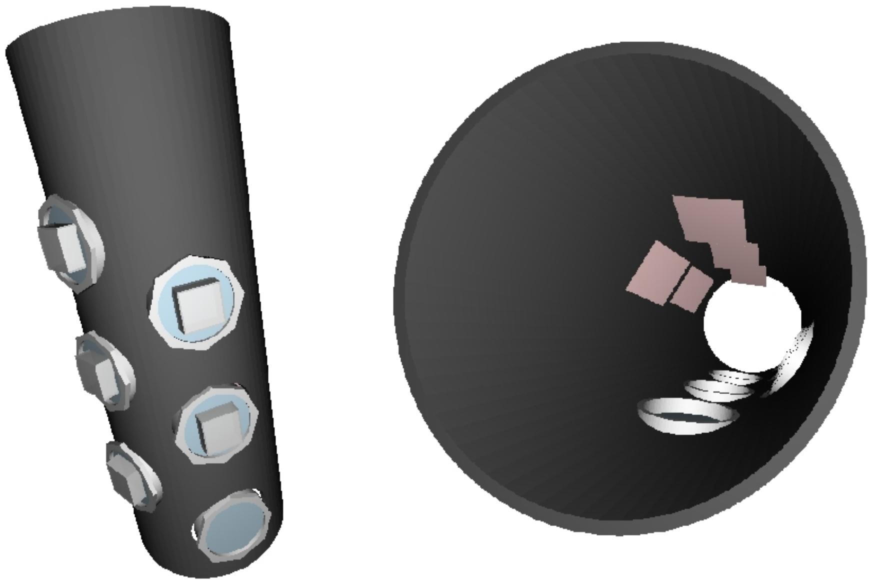


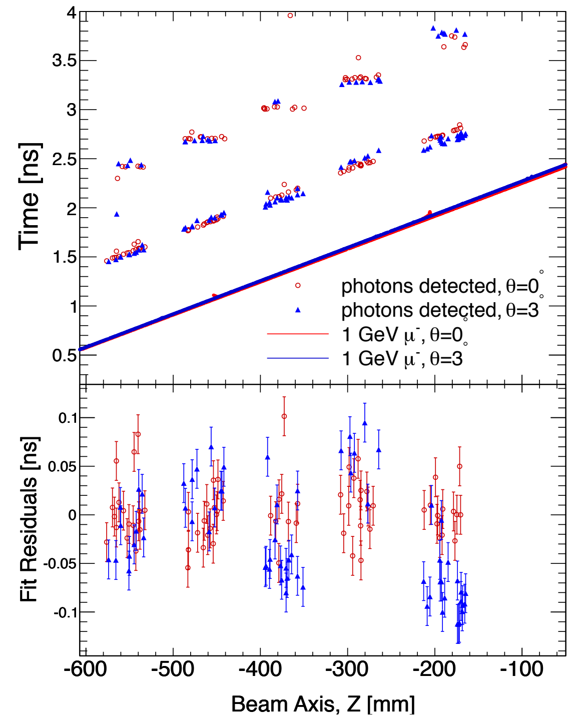


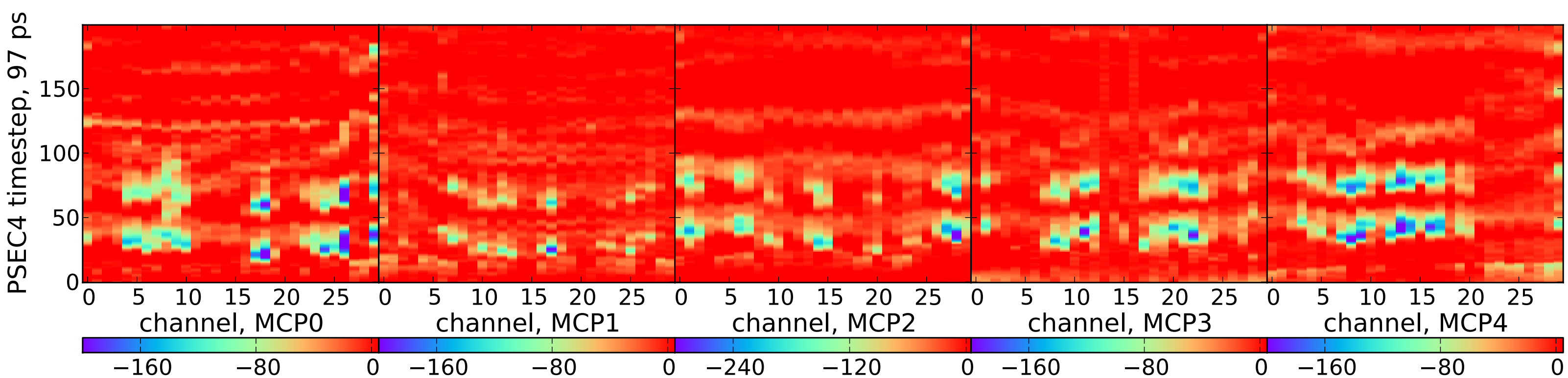


(a)

1A: LAPPD Self Triggering

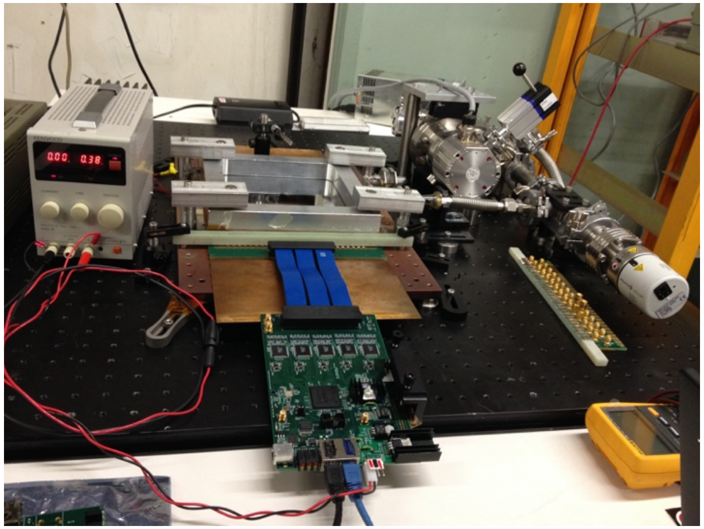


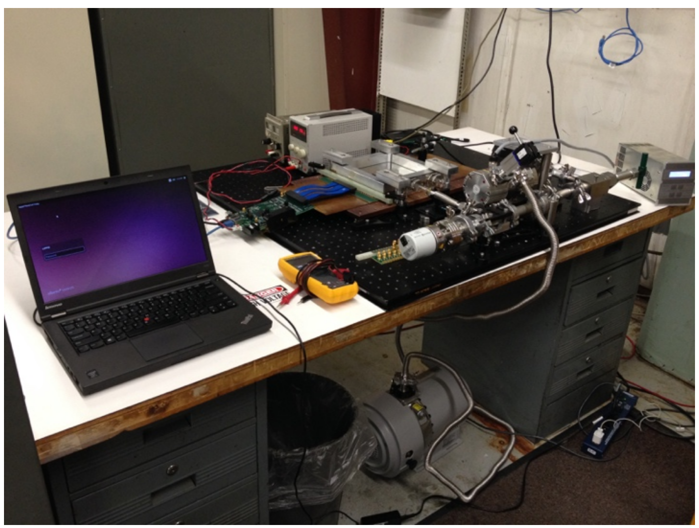




(a)

1B: New Demountable Setup at FNAL



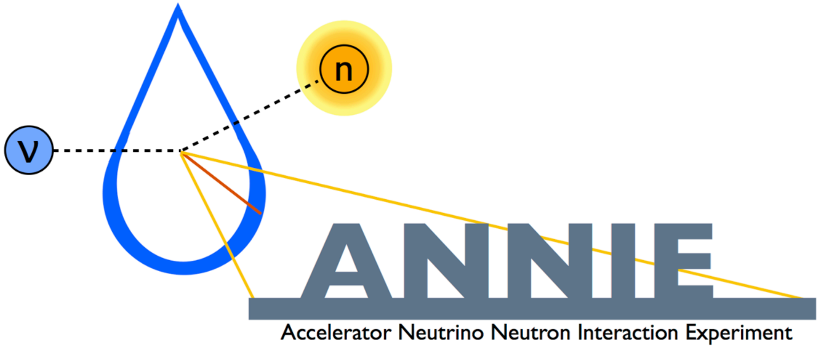


- The detector setup was moved to FNAL
- Work on this began early in summer 2015, after replacement of several broken parts and approval from FNAL.
- Demountable is under vacuum.
- Efforts were slowed by an electrical problem related to the HV assembly, external to the detector.
- Problem was identified and fixed at the end of September.
- Signal and response to UV light was observed by on Sept 29.
- PSEC electronics were connected and tested on pulser signals and shown to work.
- Data taking will resume this month

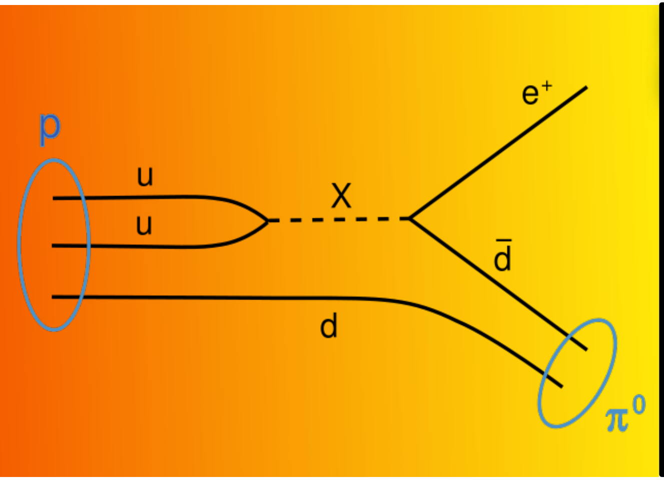
ANNIE Overview

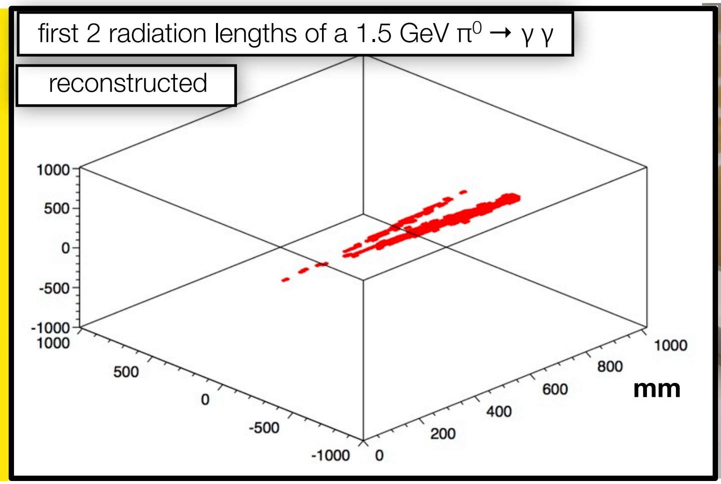
What is ANNIE?

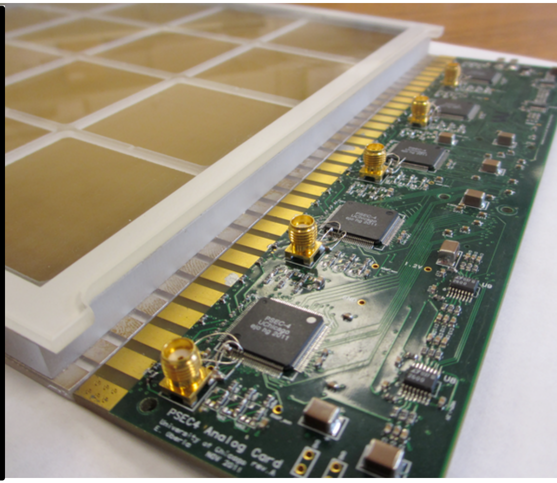
- A measurement of the abundance of final state neutrons from neutrino interactions in water, as a function of energy.



for understanding neutrino-nucleus interactions and addressing a limiting factor in proton decay and supernova neutrino physics





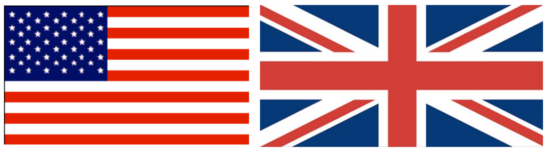


- A new technological path for the long-term Fermilab program
- A community that broadens the Fermilab user base

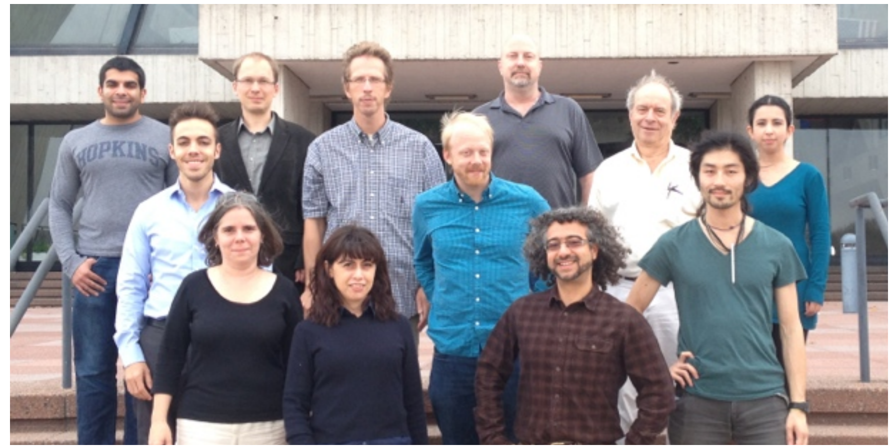
The Collaboration

34 collaborators

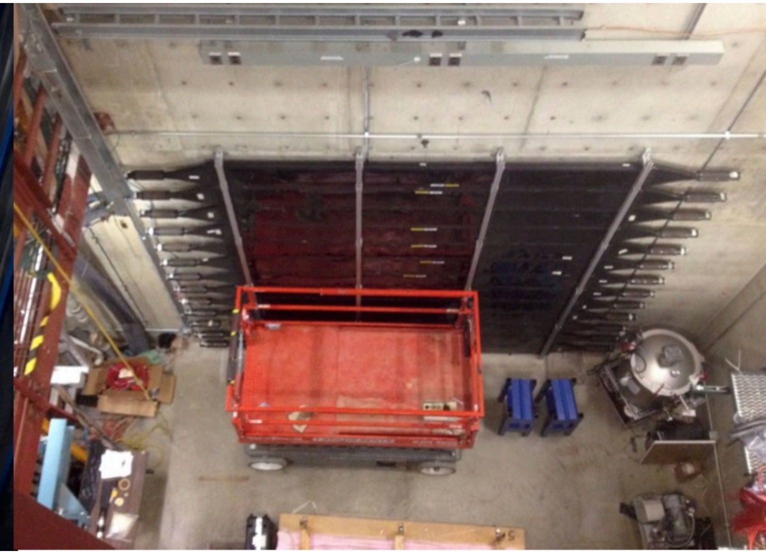
15 Institutions



- Argonne National Laboratory
- Brookhaven National Laboratory
- Fermi National Accelerator Laboratory
- Imperial College of London
- Iowa State University
- Johns Hopkins University
- MIT
- Ohio State University
- Ultralytics, LLC
- University of California at Davis
- University of California at Irvine
- University of Chicago, Enrico Fermi Institute
- University of Hawaii
- Queen Mary University of London



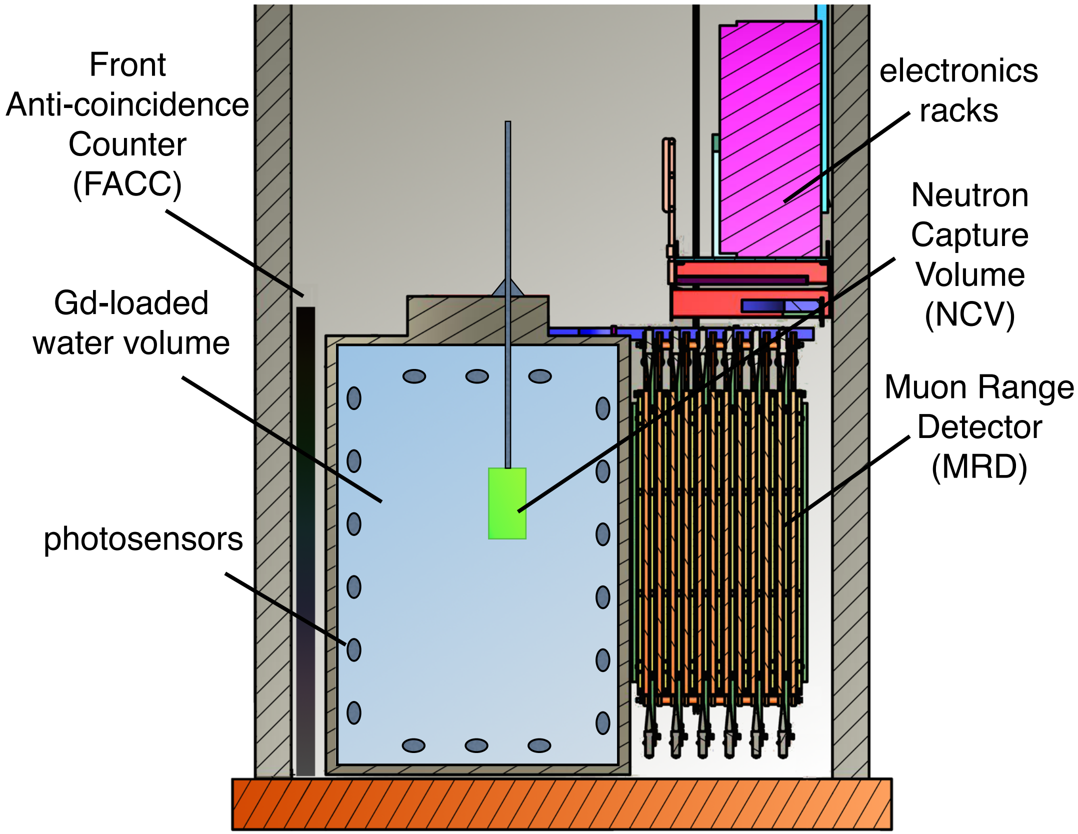
LAPPDs and ANNIE



ANNIE Run I is in the staging phase:

- will use waveform sampling electronics and test large PSEC systems
- we have a commitment from Incom for 20 LAPPDs in Phase II (10% forward coverage)
- first application of Gd neutron tagging in a high-E neutrino beam

ANNIE Details



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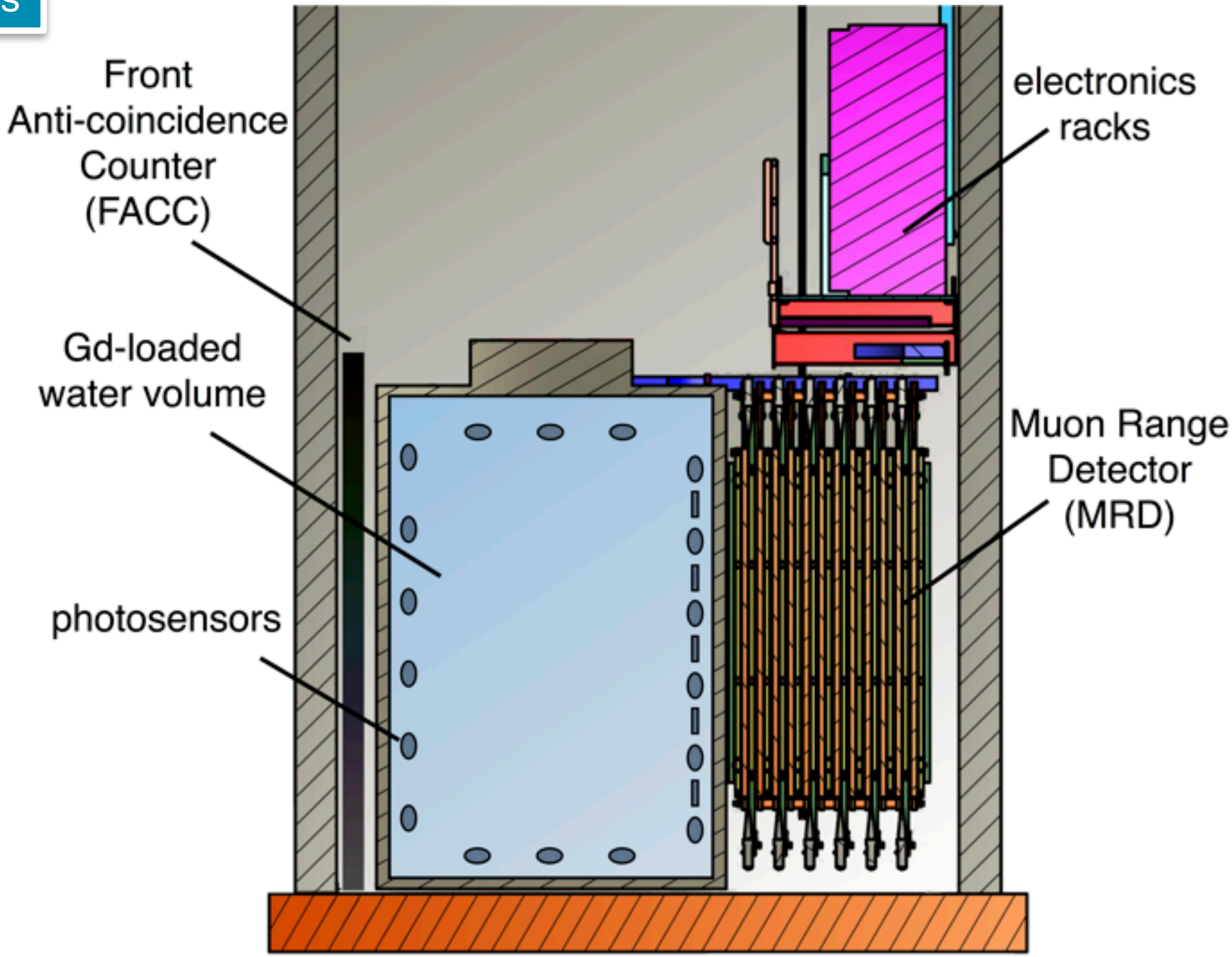

ANNIE Details