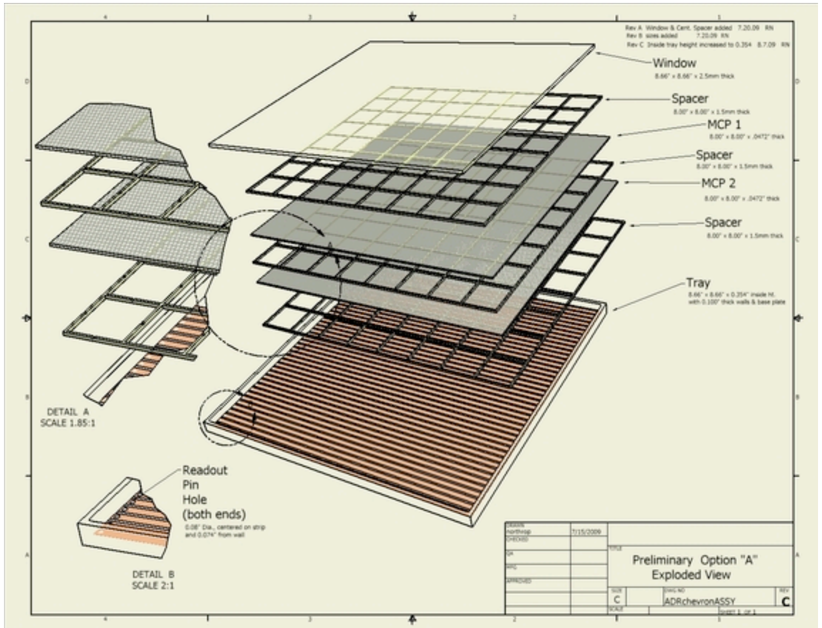
LAPPD Commercial Availability, Status, and Opportunities

Matt Wetstein (ISU) on behalf of the ANNIE collaboration

April 13, 2018

Introduction: What If?

Large Water-Cherenkov Detectors will likely be a part of future long-baseline neutrino experiments.



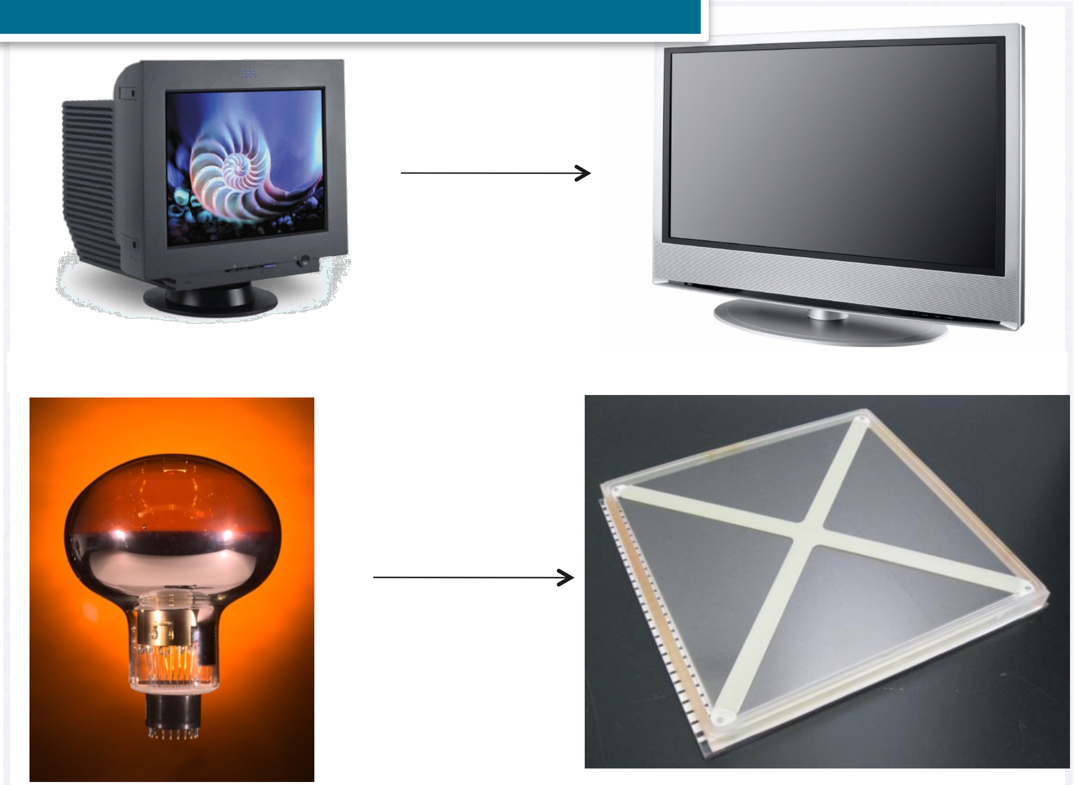
What if we could build cheap, large-area MCP-PMTs:

- ~ 100 psec time resolution.
- ~ millimeter-level spatial resolution.
- With close to 100% coverage.
- Cost per unit area comparable to conventional PMTs.

How could that change the next-gen WC Detectors?

- Could these features improve background rejection?
- In particular, could more precision in timing information combined with better coverage improve analysis?

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

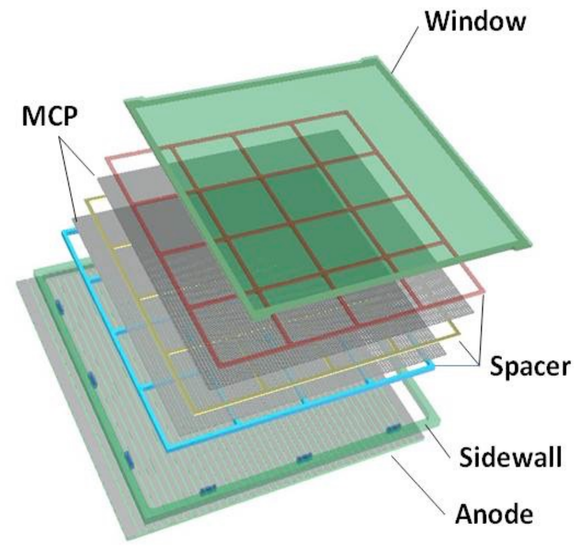
Glass body, minimal feedthroughs

MCPs made using atomic layer deposition (ALD).

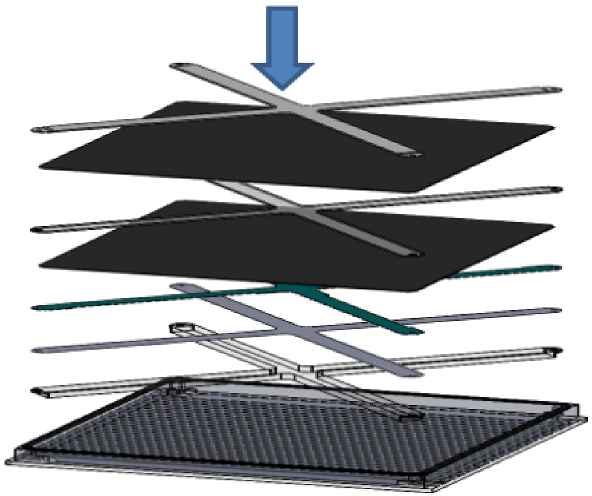
transmission line anode

fast and economical front-end electronics

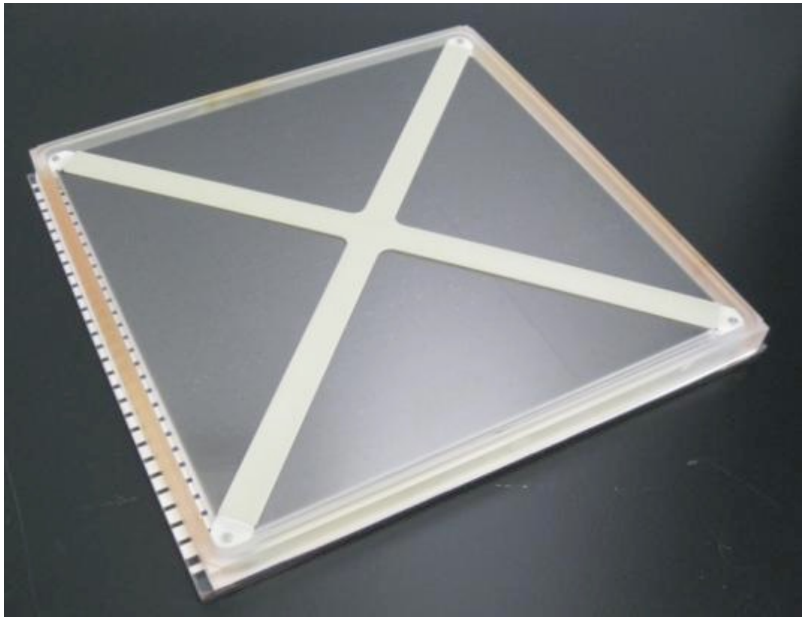
large area, flat panel photocathodes

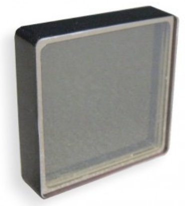


Design Drawing - September 2010



What is the LAPPD Concept





LAPPD detectors:

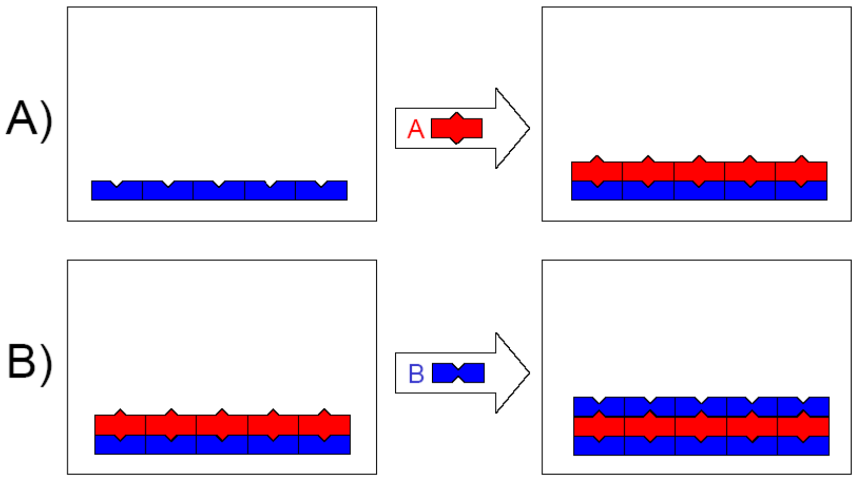
- Thin-films on borosilicate glass
- Glass vacuum assembly
- Simple, pure materials
- Scalable electronics
- Designed to cover large areas

Conventional MCPs:

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

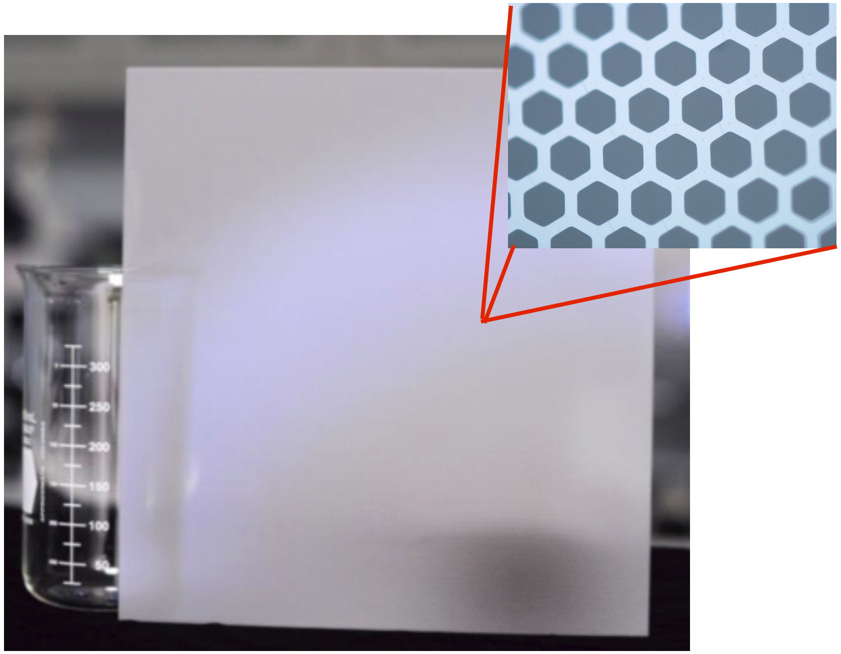
How to Make LAPPDs: Thin Films on Pyrex Glass

Atomic Layer Deposition



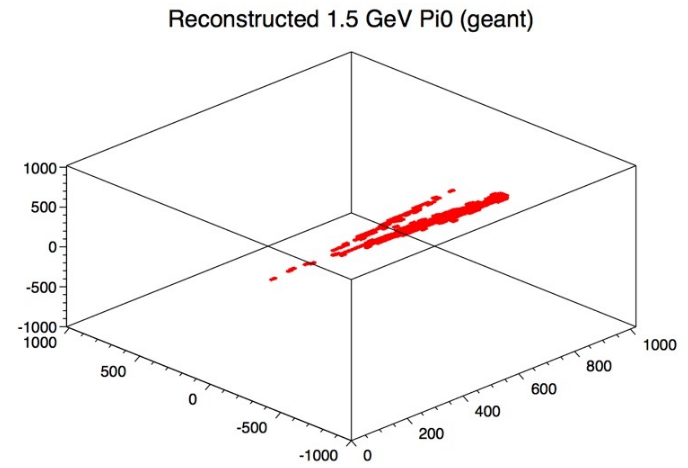
J. Elam, A. Mane

Porous Glass Substrate

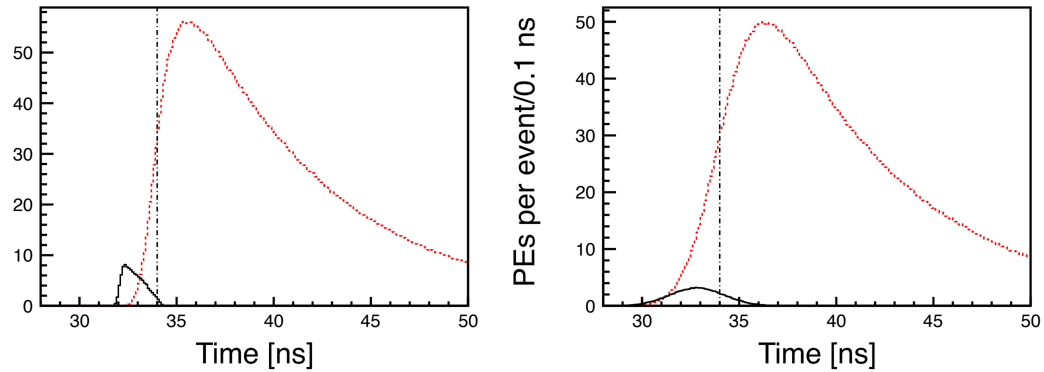


LAPPD applicability

- Fast timing is interesting in itself
    - better vertex reconstruction
    - ability to reconstruct overlapping events and tracks
    - better able to resolve structure of EM showers



- Timing may be even more interesting in combination with wbLS
    - Cherenkov = tracking
    - Scintillation = calorimetry



(a) Default simulation.

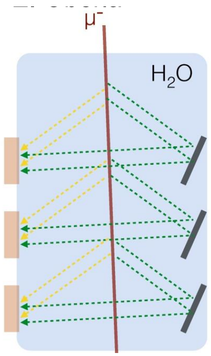
(b) Increased TTS (1.28 ns).

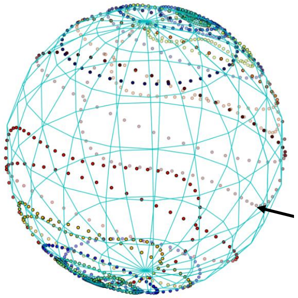
LAPPD applicability

- Imaging is an essential capability
  - Because LAPPDs are imaging photodetectors, their marginal value increases with more dense occupancy. Could we develop interesting schemes to better concentrate the light.
  - Rotation from spatial to time domain (Liouville Theorem)

Multi-bounce optics (U Chicago - Oberla, Frisch, Angelico, Elagin)

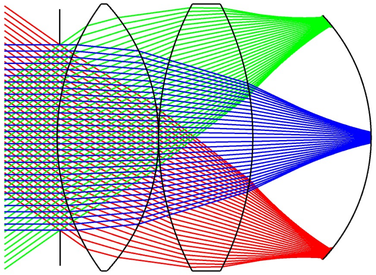
https://arxiv.org/abs/1510.00947





Plenoptic imaging (Dalmasson et al)

https://arxiv.org/abs/1711.09851



Timing + Imaging photosensors could enable a very different kind of Cherenkov/scintillator detector)

Commercial Status: Incom

- Incom has now frozen its process for producing glass-body LAPPDs and is now focusing on yields and optimizing QE
- Of the recent run, they have successfully sealed LAPPDs in 5 out of 7 trials (in addition to 5 earlier prototypes)
    - all 5 with gains well above 10^6
    - 4 with mean QE >10%
- Incom is commissioning a second processing chamber which could eventually bring their production rate to 1 per week - this can continue to scale as demands and yields grow
- Current pricing is not where they intend it to be in the longer run - it will go down with market scope and volume
- LAPPDs will likely benefit from a much broader market than HEP - medical imaging, security, x-ray imaging, etc
- Incom welcomes new, and interested early adopters, holding periodic Measurement and Testing workshops (next, May 15-17)

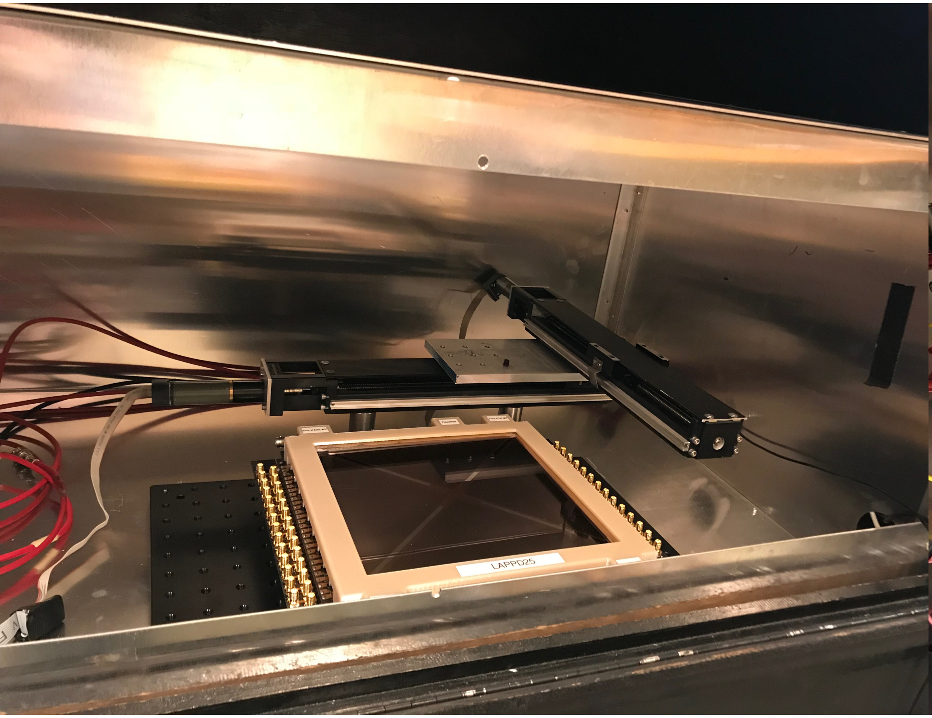
Commercial Status: Incom

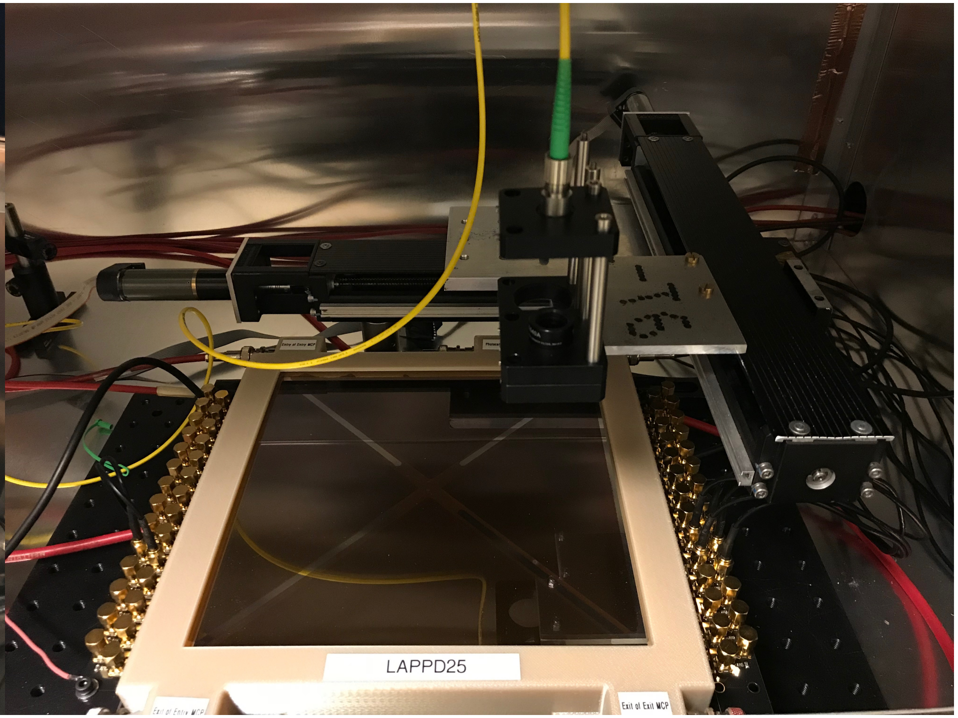
Trial #	LAPPD #	Sealed	Incom Inc. Cummulative Sealing Yield [%]	Performance	Disposition
1	22	Yes	100.0%	**Mean QE=10.6%±6%**	Sandia
2	23	NO	50.0%		
	24	ceramic tile trial	NA		GEN II Program experiment
3	25	Yes	66.7%	**Mean QE=10.2%±6%**	ANNIE
4	26	No	50.0%		
	27	ceramic tile trial	BA		GEN II Program experiment
5	28	Yes	60.0%	Electrical Short during Photocathode deposition **Mean QE=1.96%±0.6%**	DRS4 Data now being analyzed, Report Pending
6	29	Yes	66.7%	**Mean QE=13.0%±6%**	Currently in Dark Box Under Test
7	30	Yes	71.4%	**Mean QE=17.2%±2.5%**	Pending Dark Box Measurement & Test

ANNIE LAPPDs

- The ANNIE collaboration has purchased LAPPD-25 from Incom, Inc - the first purchase of a commercial LAPPD
- The detector has been tested, both at Incom and at the ANNIE test-stand at ISU.
- Characteristics of the tile -specifically gain and time resolution- solidly meet the needs for ANNIE Phase II
- We plan to acquire 4 more next year for Phase IIa

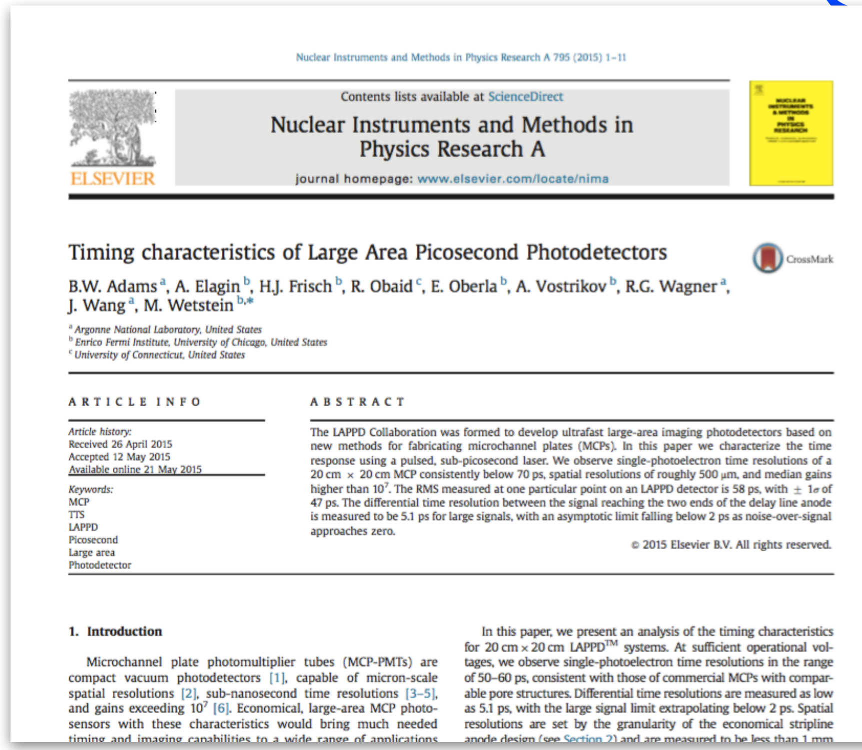
Iowa State - LAPPD Test Stand





- PiLAs laser (up to 30 psec resolution)
- 10 GHz, 20 Gs/sec scope
- PSEC4 electronics
- Dark box
- Motorized optics allow for position scans

Iowa State - LAPPD Test Stand



Nuclear Instruments and Methods in Physics Research A 795 (2015) 1–11

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Timing characteristics of Large Area Picosecond Photodetectors

B.W. Adams [a], A. Elagin [b], H.J. Frisch [b], R. Obaid [c], E. Oberla [b], A. Vostrikov [b], R.G. Wagner [a], J. Wang [a], M. Wetstein [b,*]

[a] Argonne National Laboratory, United States
[b] Enrico Fermi Institute, University of Chicago, United States
[c] University of Connecticut, United States

ARTICLE INFO

Article history:
Received 26 April 2015
Accepted 12 May 2015
Available online 21 May 2015

Keywords:
MCP
TTS
LAPPD
Picosecond
Large area
Photodetector

ABSTRACT

The LAPPD Collaboration was formed to develop ultrafast large-area imaging photodetectors based on new methods for fabricating microchannel plates (MCPs). In this paper we characterize the time response using a pulsed, sub-picosecond laser. We observe single-photoelectron time resolutions of a 20 cm × 20 cm MCP consistently below 70 ps, spatial resolutions of roughly 500 μm, and median gains higher than 10^7. The RMS measured at one particular point on an LAPPD detector is 58 ps, with $\pm 1\sigma$ of 47 ps. The differential time resolution between the signal reaching the two ends of the delay line anode is measured to be 5.1 ps for large signals, with an asymptotic limit falling below 2 ps as noise-over-signal approaches zero.

1. Introduction

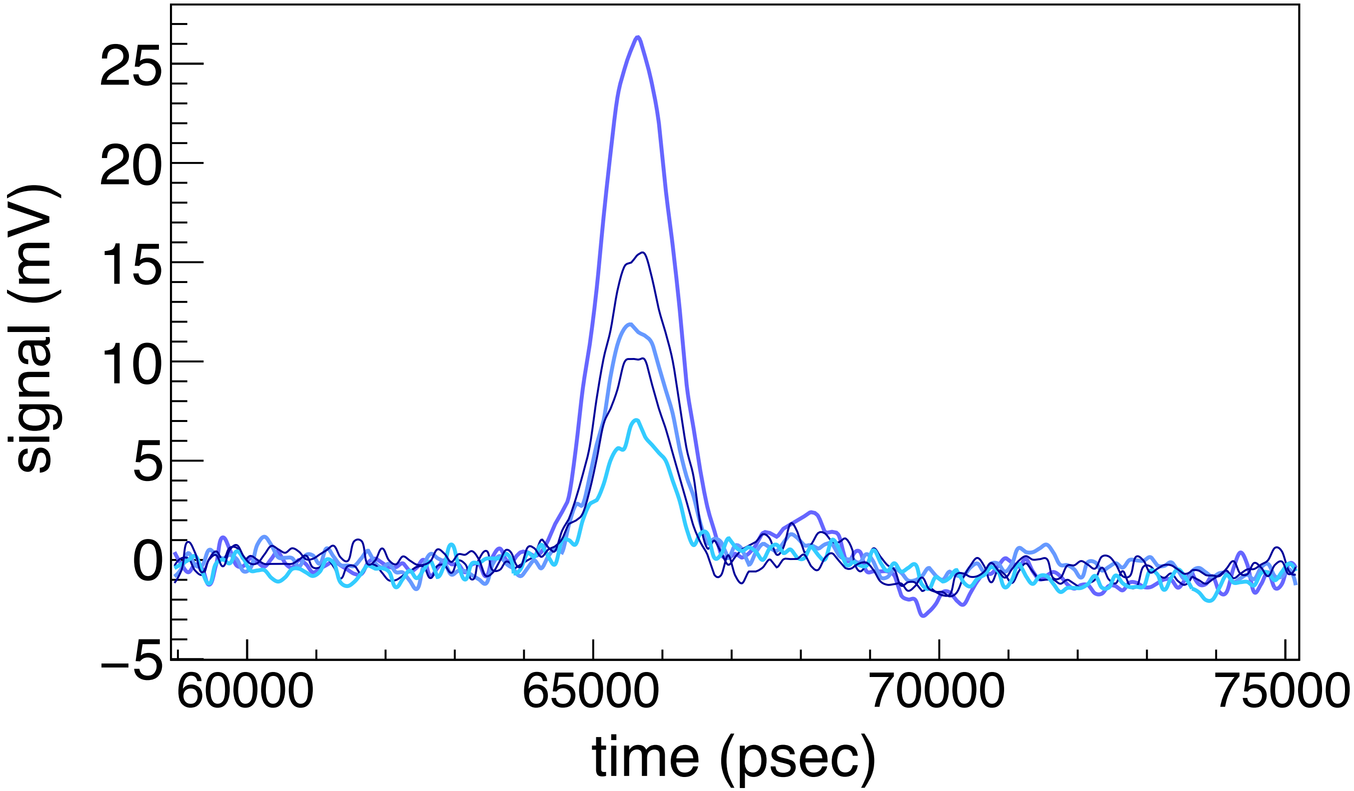
Microchannel plate photomultiplier tubes (MCP-PMTs) are compact vacuum photodetectors [1], capable of micron-scale spatial resolutions [2], sub-nanosecond time resolutions [3–5], and gains exceeding 10^7 [6]. Economical, large-area MCP photosensors with these characteristics would bring much needed timing and imaging capabilities to a wide range of applications

In this paper, we present an analysis of the timing characteristics for 20 cm × 20 cm LAPPD™ systems. At sufficient operational voltages, we observe single-photoelectron time resolutions in the range of 50–60 ps, consistent with those of commercial MCPs with comparable pore structures. Differential time resolutions are measured as low as 5.1 ps, with the large signal limit extrapolating below 2 ps. Spatial resolutions are set by the granularity of the economical stripline anode design (see Section 2) and are measured to be less than 1 mm

The ISU test stand is based on and built by the researchers who wrote *the* canonical papers on LAPPD testing and time resolution.

Results: Typical Single-PE Pulses

FWHM: 1.1 nsec
rise time: 850 psec

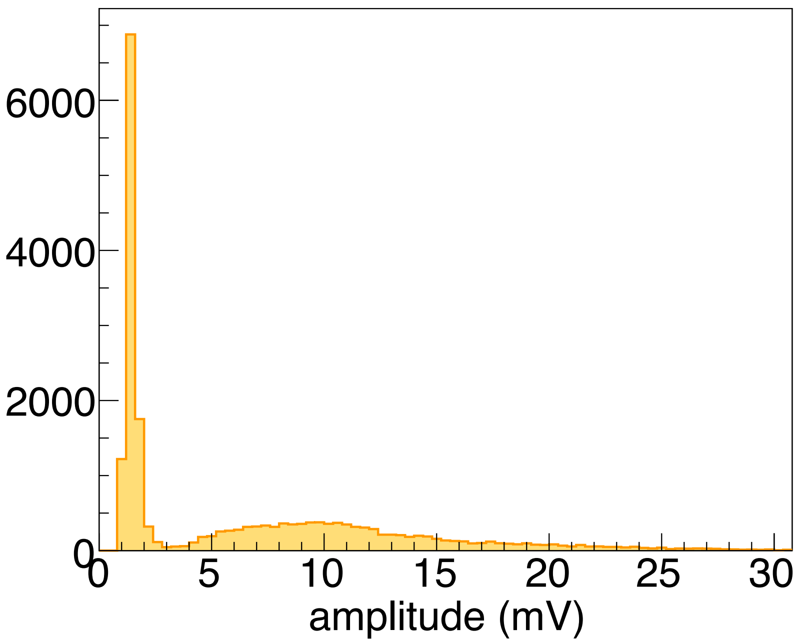


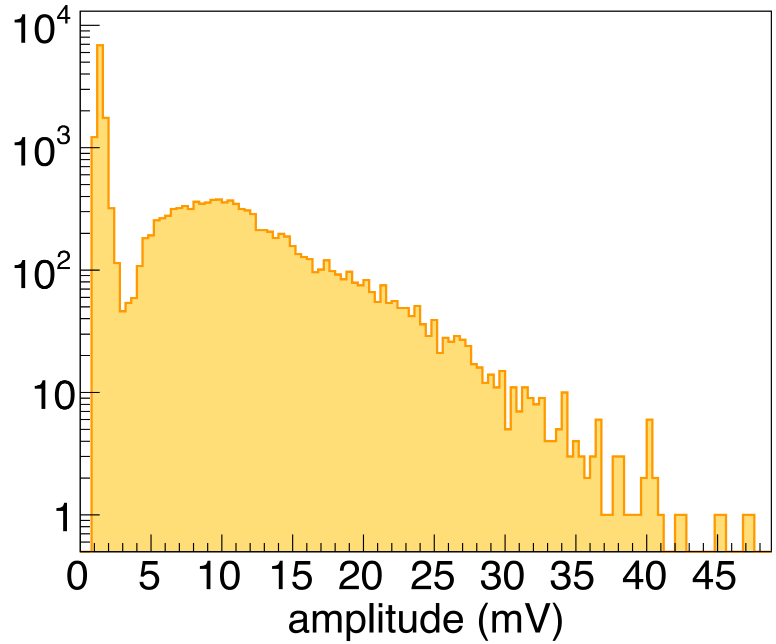
voltages: PC=350V MCP1=800V interMCP=200V MCP2=950V anode=200V

Results: Amplitude

We see very clean separation from pedestal

Pulses are typically above 5mV (single-sided) compared to <1 mV noise

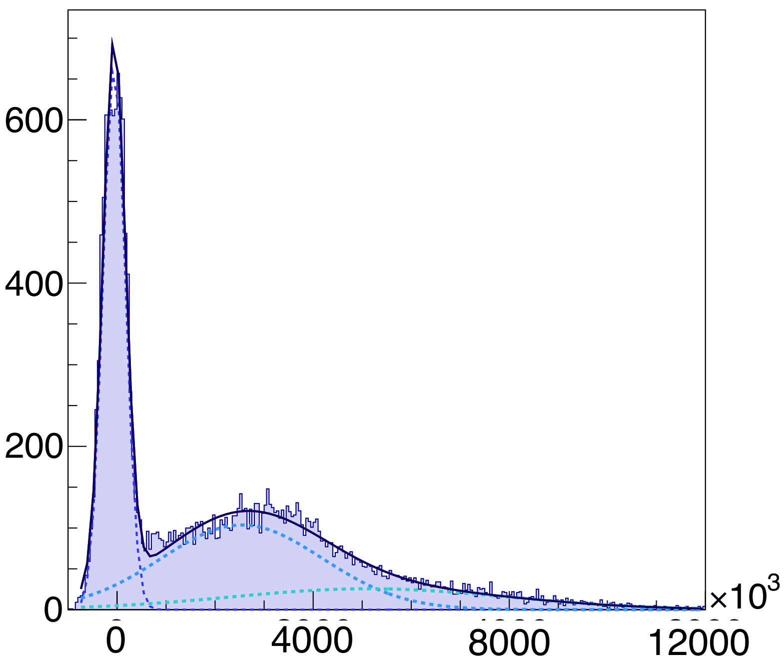


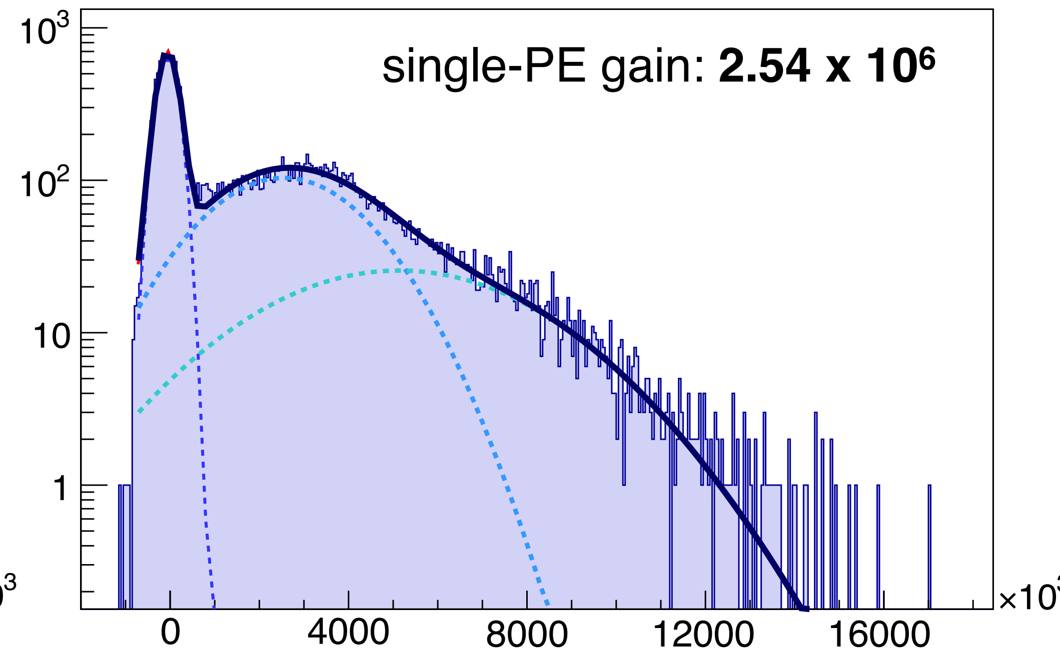


voltages: PC=350V MCP1=800V interMCP=200V MCP2=950V anode=200V

Results: Gain

Even at low operational voltages, we observe peak gains well above 10^6

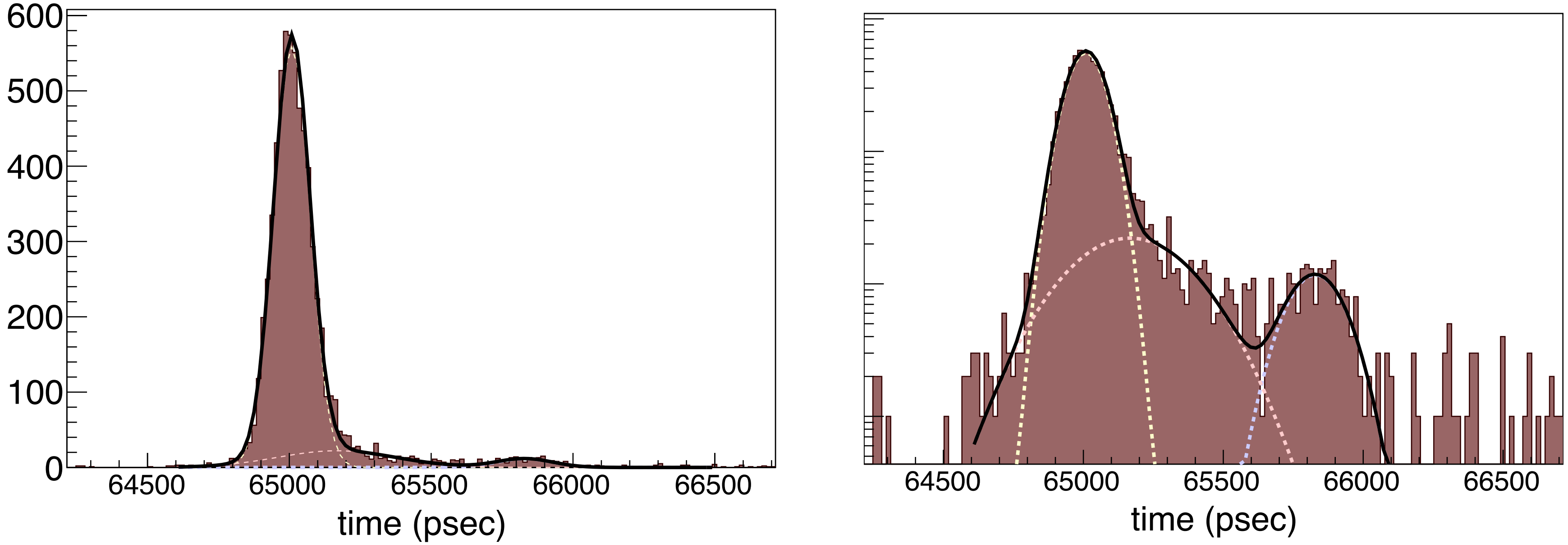




voltages: PC=350V MCP1=800V interMCP=200V MCP2=950V anode=200V

Results: Time Resolution

We observe 64 psec time resolution in the main peak of the TTS
with small contribution from after-pulses (~4%), typical of any photodetector

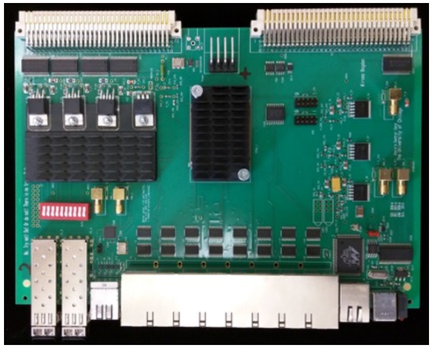


voltages: PC=350V MCP1=800V interMCP=200V MCP2=950V anode=200V

Results: Noise, Gain Uniformity, and QE

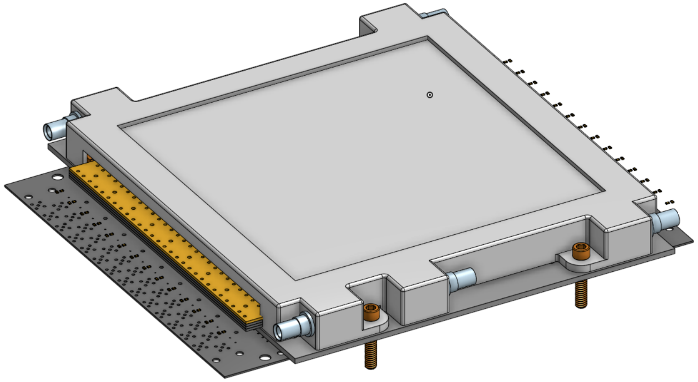
- In 10,000 triggers, there was not a single dark pulse candidate
- Given a readout window of 100 nsec, there must be less than 1 kHz of noise per channel
- Having scanned several channels across the length of the strip, so far we observe uniform gains, consistent with Incom's own measurements of the LAPPD-25 gain uniformity
- The quantum efficiency of Tile-25, while not meeting Incom's longer term goal of 20%, is respectable at around 10%
- Even with a small dead area in the photocathode, the collection efficiency should be sufficient, given the high light yields of ANNIE events

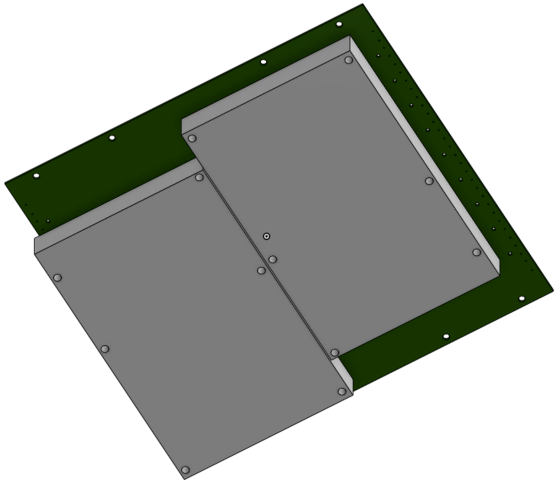
Application Readiness (electronics)



Near Term

- Readout close to the detector
- Two ACDC mezzanine cards attach to the pickup board
- New ANNIE Central Cards (ACC), provide clock and synchronization





Next Evolutionary Step

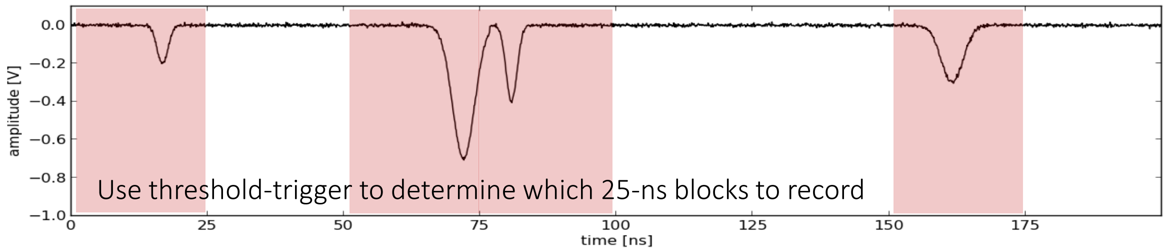
- Digitization of all 56 channels on a single integrated pick-up board
- PSEC-4a with 8x’s buffer (200 nsec) in a multi-hit buffering scheme for continuous readout
- Further simplified network topology, possible implementation of white rabbit

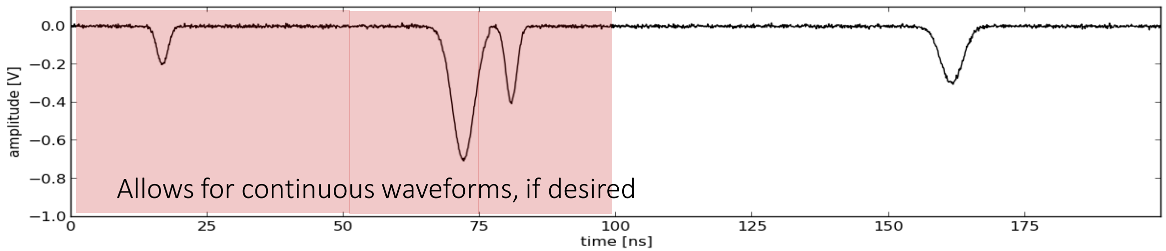
Application Readiness (electronics)

PSEC4a – multi-hit buffering

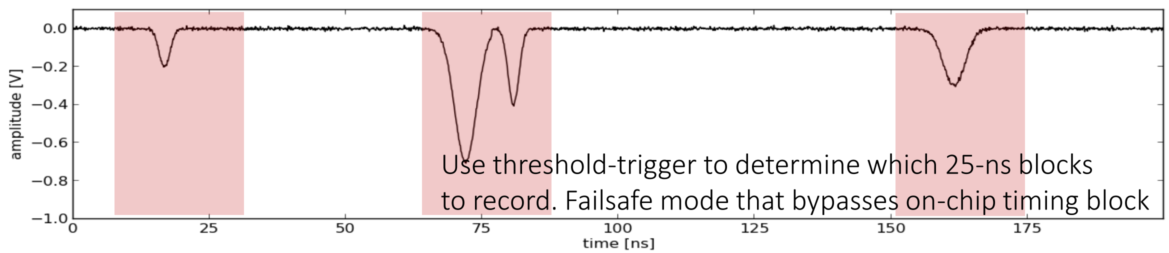
- How many buffers? Considering 2 options: 1024 or 2048 samples per channel
  - Layout space ($) / number of ADC's trade-off vs. typical event occupancy/timing characteristics
- Operation modes:

Clocked addressing: blocks around 40 MHz sample clock. Blocks time-stamped on ASIC





'Trigger-and-transfer': asynchronous blocks, 25 ns wide. (PSEC4-like operation, w/ multi-buffer)

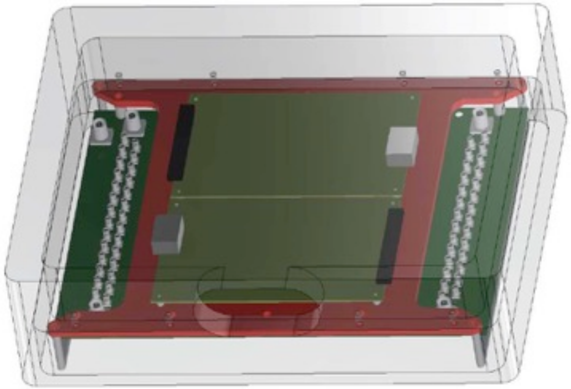


14

Application Readiness (waterproofing)

Near Term

- Water-proof housing to consist of PVC frame mounted on steel backplane
- Window not optically coupled to the LAPPD surface
- High voltage provided externally
- Communication through twisted pair connections



Next Evolutionary Step

- Single fiber for data transfer
- HV made internal to the housing
- Better strategy for optical coupling

Conclusions

- Incom is starting to produce quantities of successfully sealed LAPPDs for sale to early adopters
- ANNIE has purchased on of these early tiles, LAPPD-25
- LAPPD 25 provided clean single-PE separation and better than 70 psec time resolution with very little effort
    - We turned it on and it worked well.
    - More details to follow, including spatial scans
    - This tile solidly meets ANNIE specifications
- One of the important next frontiers for LAPPD technology is demonstration and application readiness
- ANNIE is an excellent opportunity for the community to prove out the technology and develop operational experience
- New collaborators and partnerships in developing LAPPD application-readiness are welcome

Conclusions

- Incom is starting to produce quantities of successfully sealed LAPPDs for sale to early adopters
- ANNIE has purchased on of these early tiles, LAPPD-25
- LAPPD 25 provided clean single-PE separation and better than 70 psec time resolution with very little effort
    - We turned it on and it worked well.
    - More details to follow, including spatial scans
    - This tile solidly meets ANNIE specifications
- One of the important next frontiers for LAPPD technology is demonstration and application readiness
- ANNIE is an excellent opportunity for the community to prove out the technology and develop operational experience
- New collaborators and partnerships in developing LAPPD application-readiness are welcome