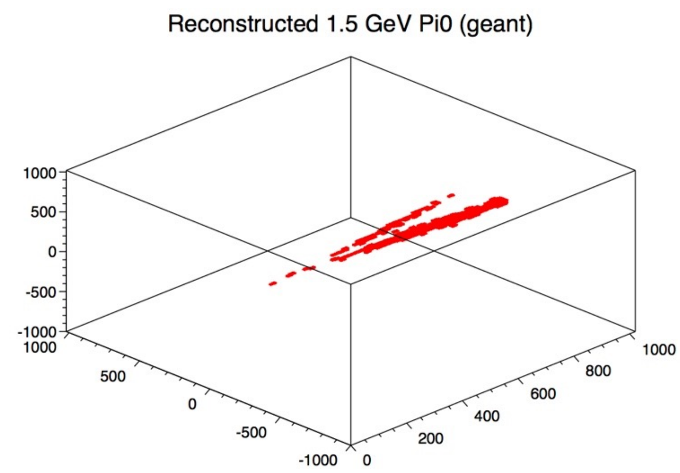
LAPPD Testing and Readiness for ANNIE

Matt Wetstein (ISU) on behalf of the ANNIE collaboration

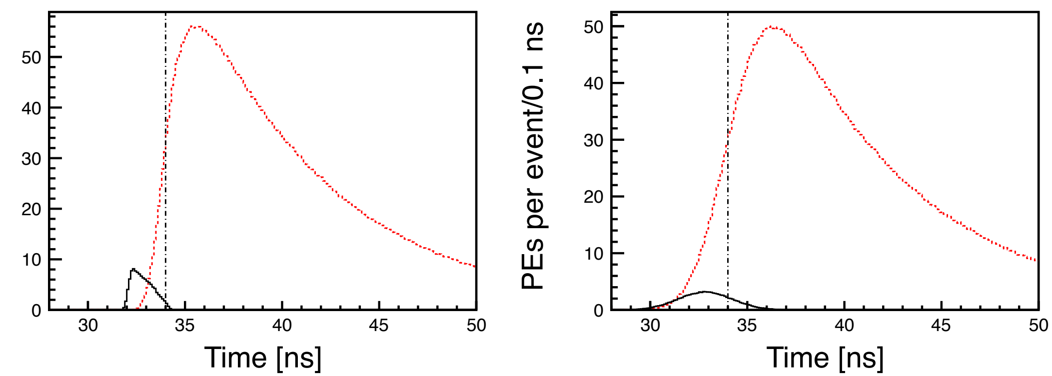
Dec 12, 2018

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.

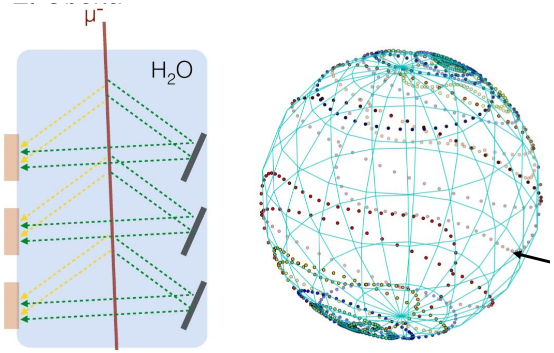
(b) Increased TTS (1.28 ns).

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)

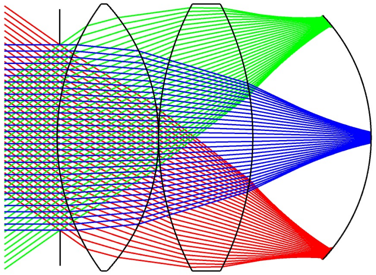
Multi-bounce optics (U Chicago - Oberla, Frisch, Angelico, Elagin)

https://arxiv.org/abs/1510.00947



Plenoptic imaging (Dalmasson et al)

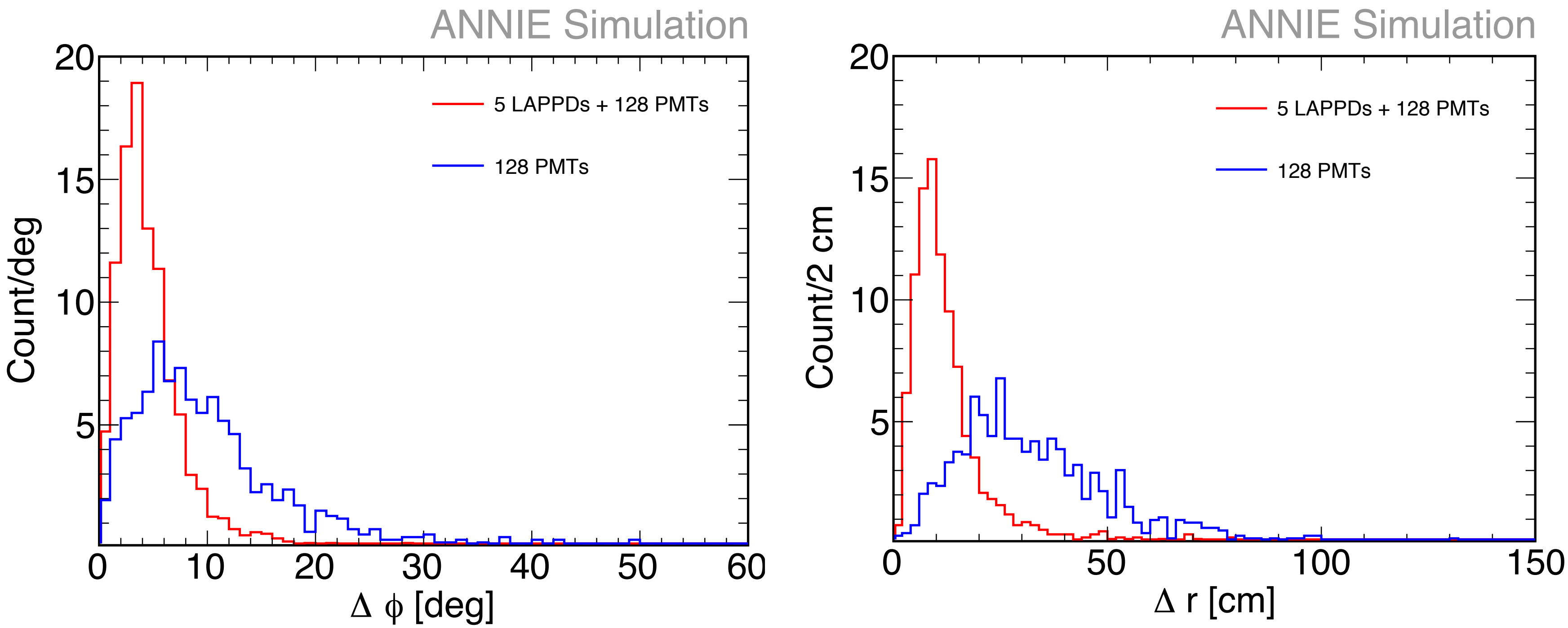
https://arxiv.org/abs/1711.09851



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

LAPPD applicability

- Even a small number of LAPPDs can make a big difference in the right context

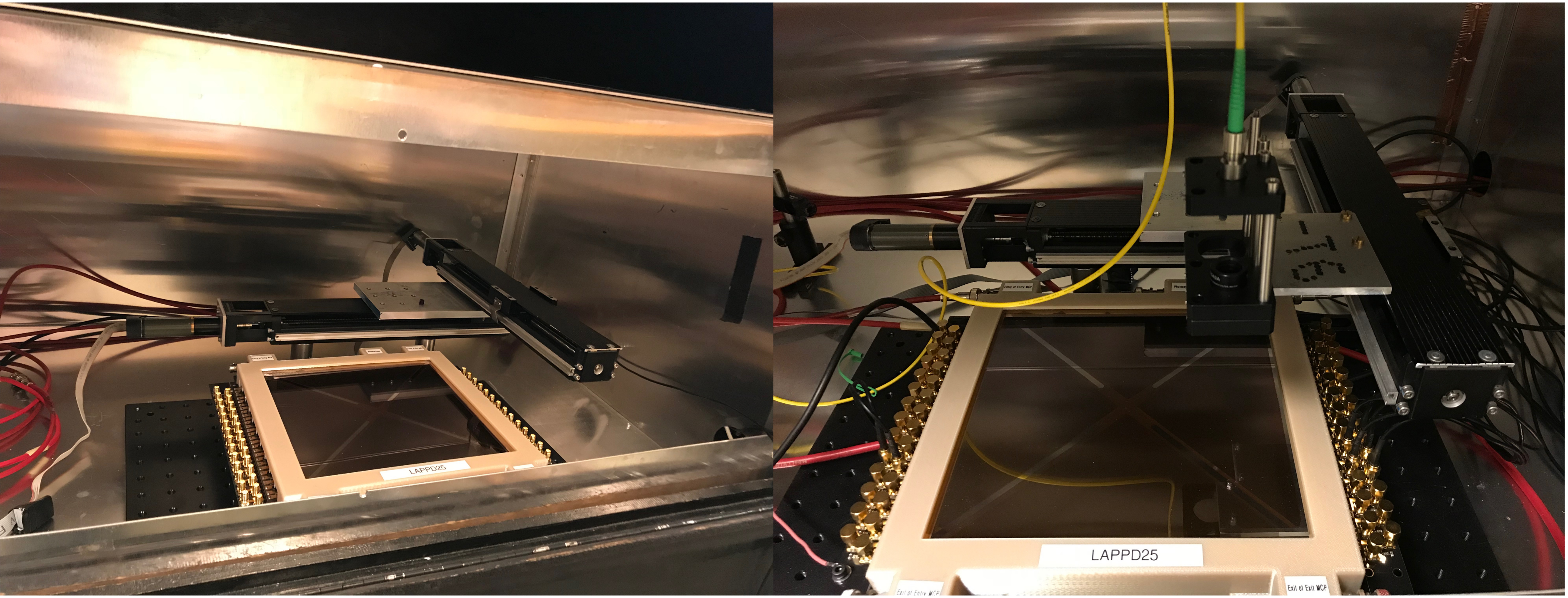


- In ANNIE, the addition of 5 LAPPDs greatly improves reconstruction of muon track parameters

ANNIE LAPPDs

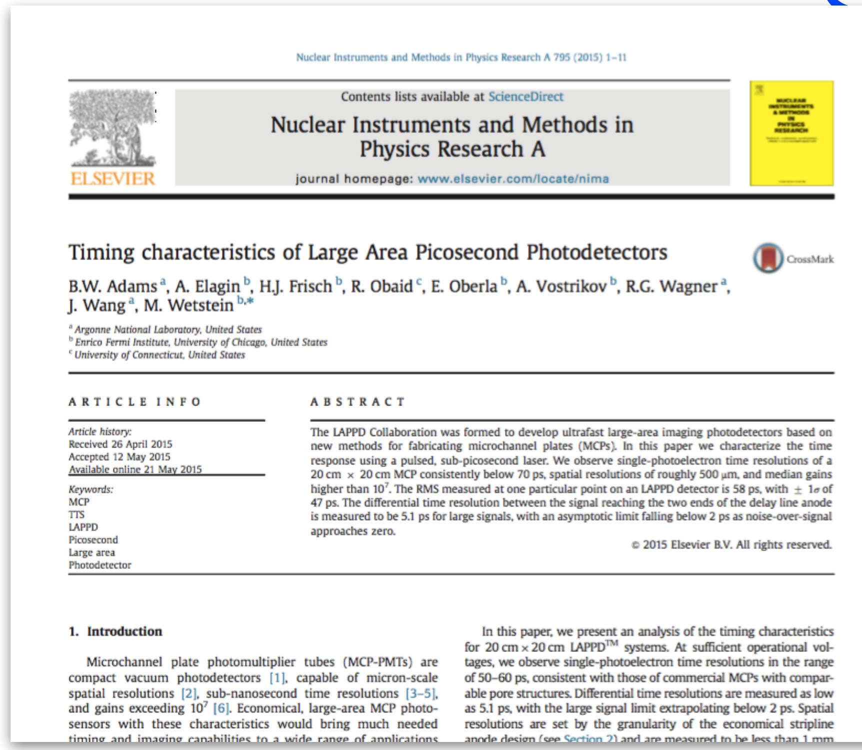
- The ANNIE collaboration is days is purchasing its third LAPPD, which will shipped from ANL in roughly 1 week
- Testing of the other two LAPPDs is ongoing
- Characteristics of the tiles -specifically gain and time resolution- solidly meet the needs for ANNIE Phase II
- We plan to acquire two more within the next 3 months 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



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Timing characteristics of Large Area Picosecond Photodetectors

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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.

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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 photo-sensors with these characteristics would bring much needed timing and imaging capabilities to a wide range of applications

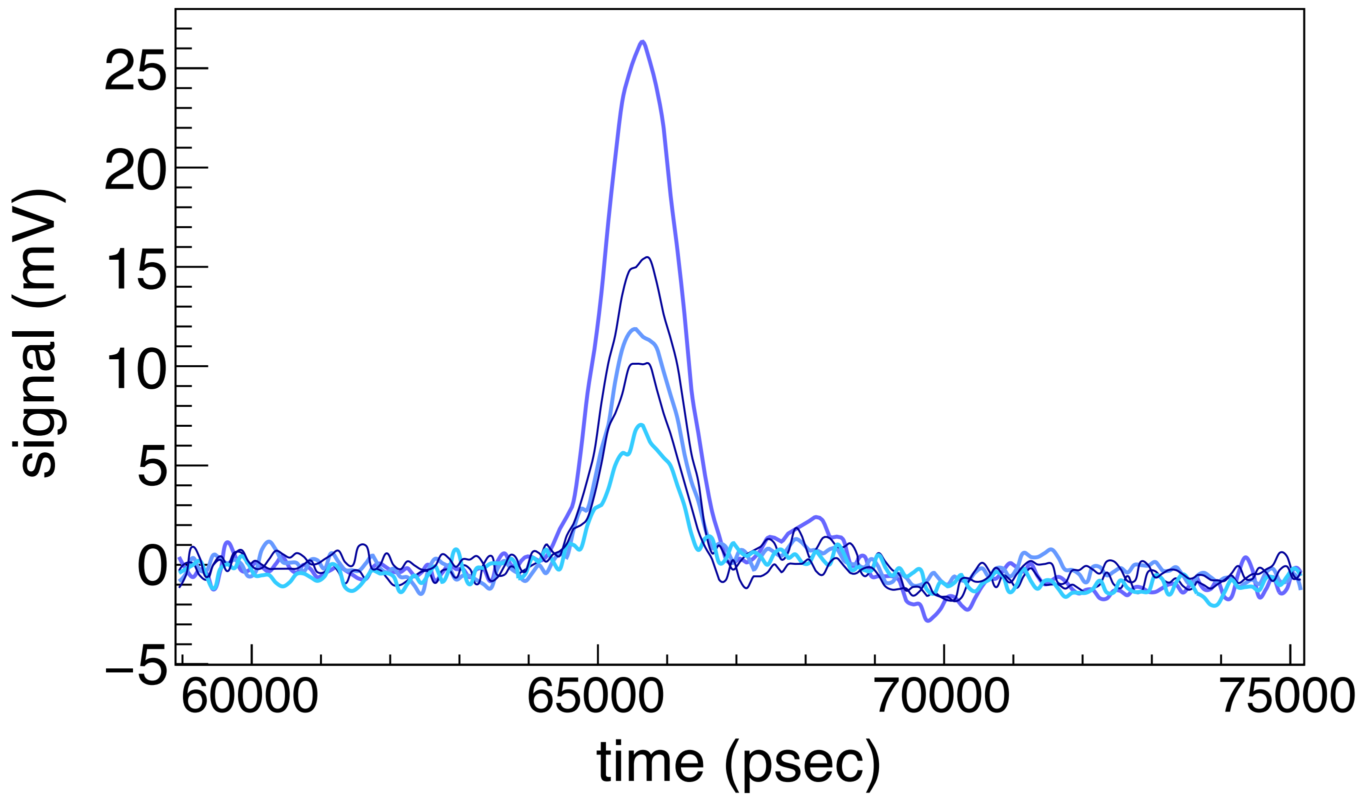
In this paper, we present an analysis of the timing characteristics for 20 cm × 20 cm LAPPD™ systems. At sufficient operational voltages, we observe single-photoelectron time resolutions in the range of 50–60 ps, consistent with those of commercial MCPs with comparable pore structures. Differential time 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

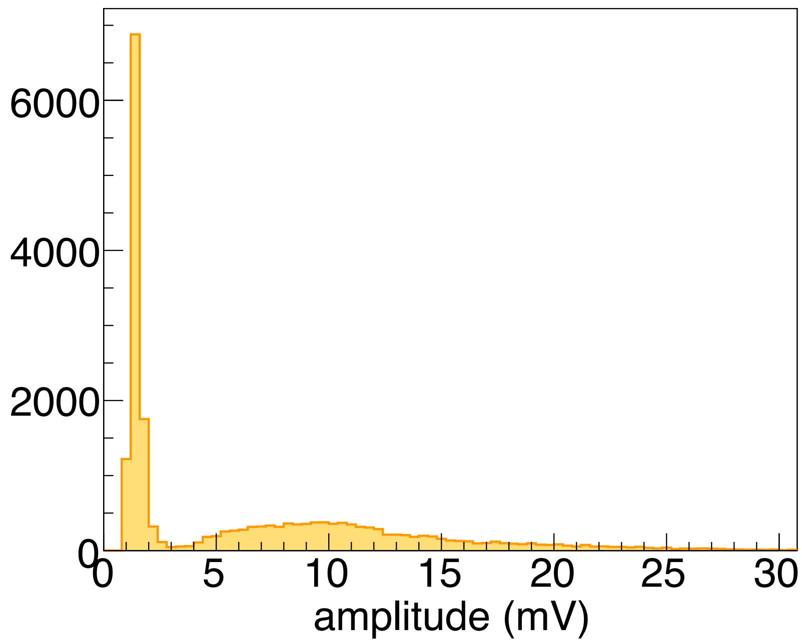


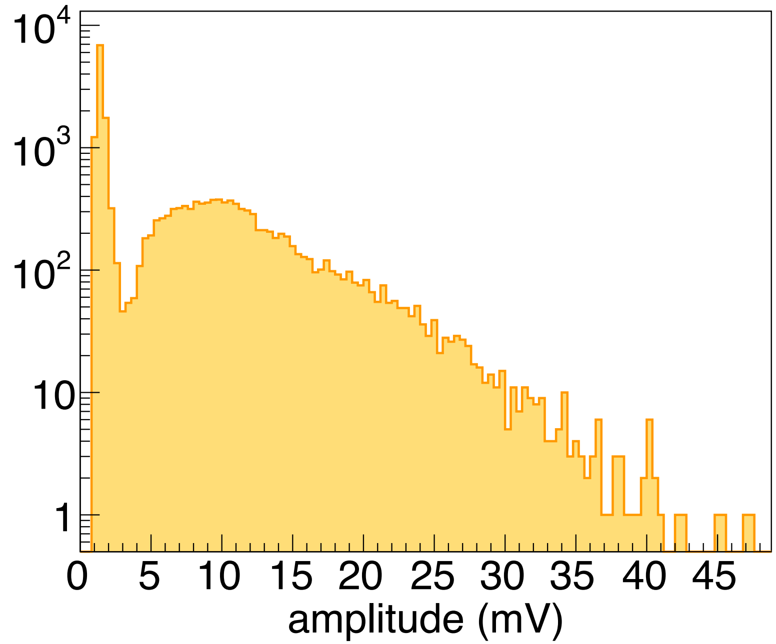
voltages: PC=350V MCP1=800V interMCP=200V MCP2=950V anode=200V

Results: Amplitude

We see very clean separation from pedestal

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

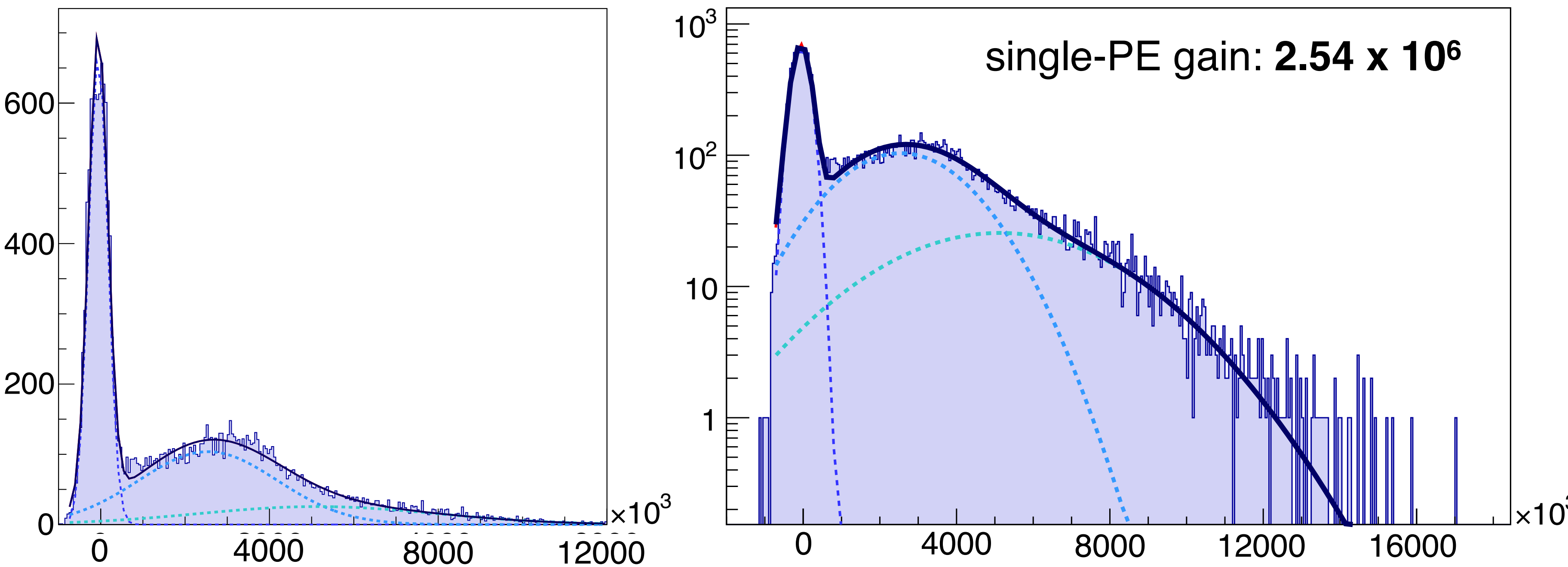




voltages: PC=350V MCP1=800V interMCP=200V MCP2=950V anode=200V

Results: Gain

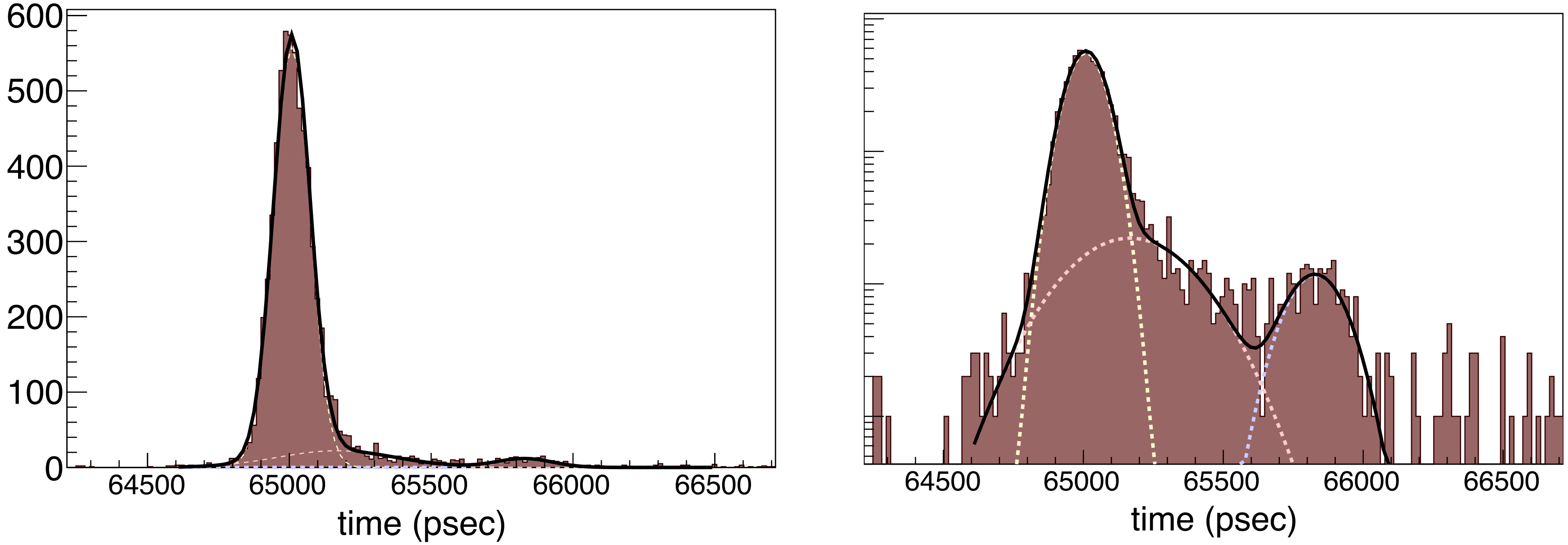
Even at low operational voltages, we observe peak gains well above 10^6



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

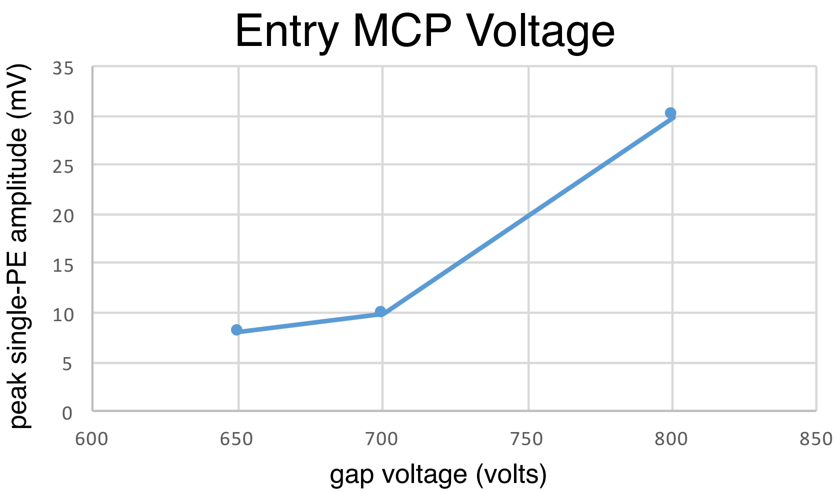
Results: Time Resolution

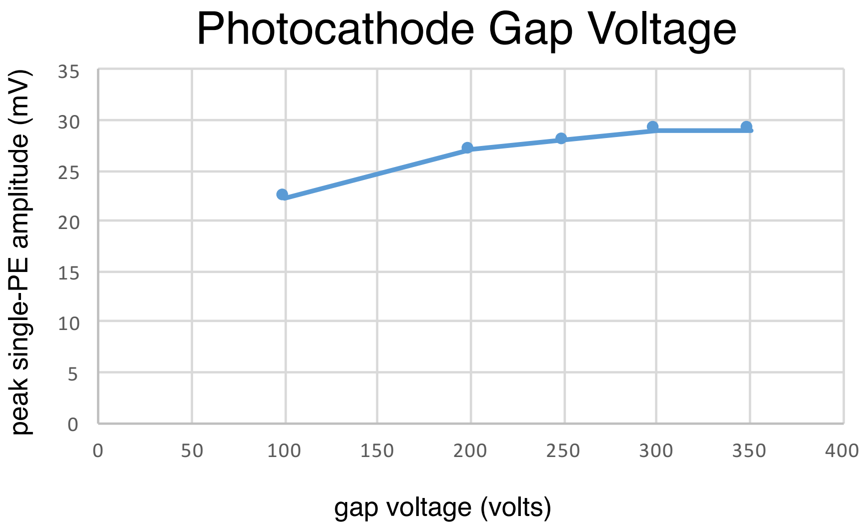
We observe 64 psec time resolution in the main peak of the TTS
with small contribution from after-pulses (~4%), typical of any photodetector



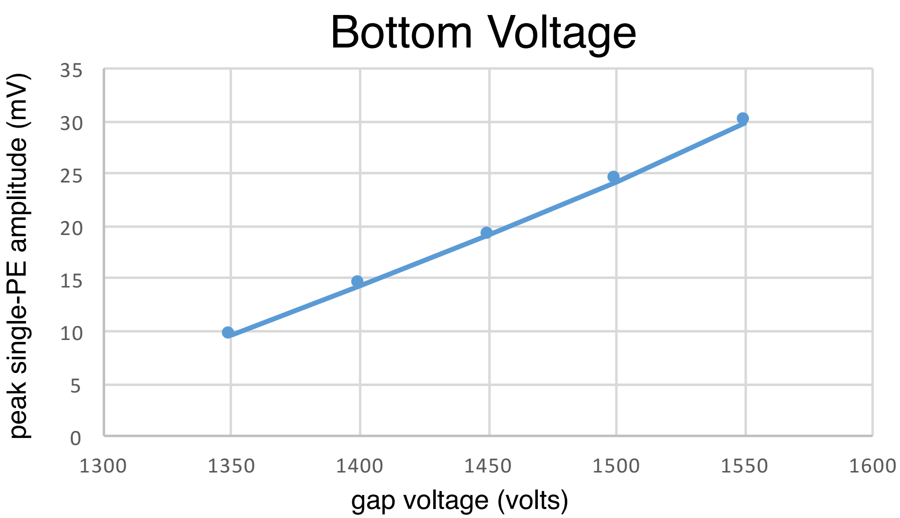
voltages: PC=350V MCP1=800V interMCP=200V MCP2=950V anode=200V

LAPPD 25: Voltage Response

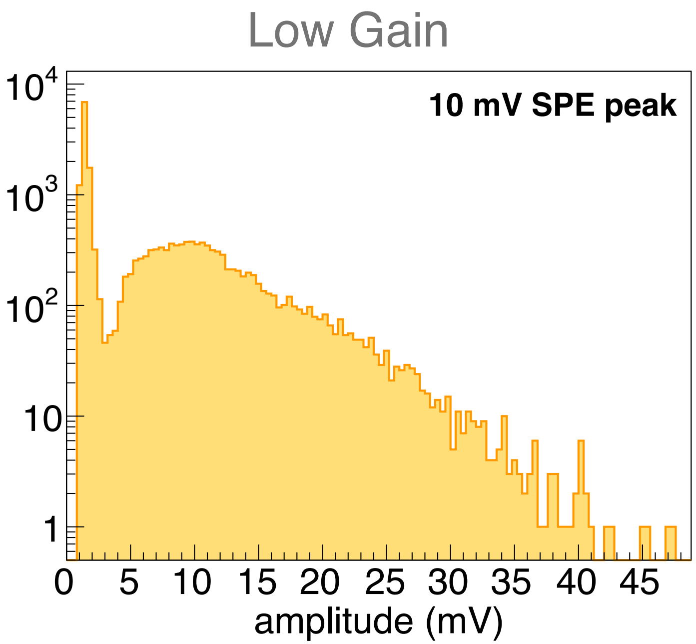


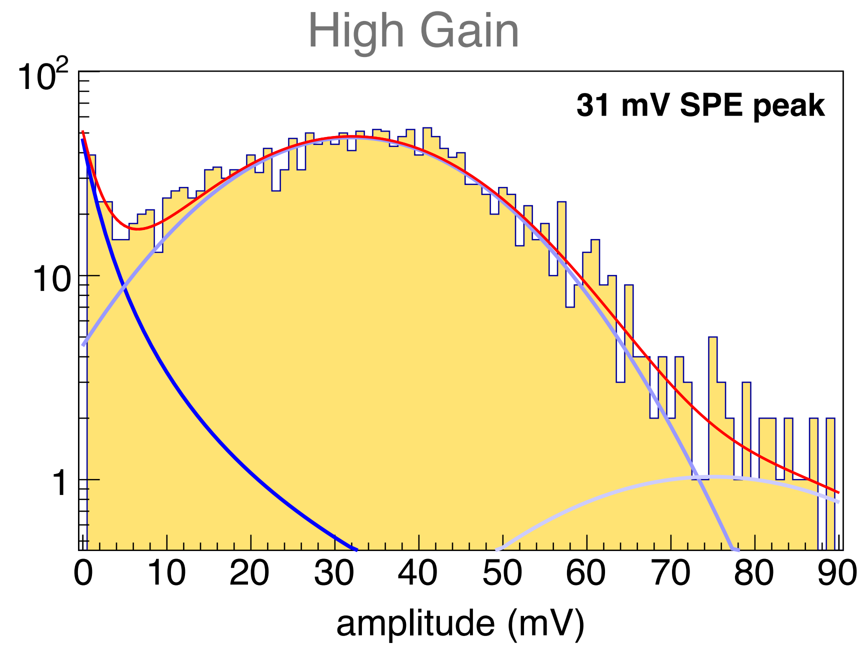


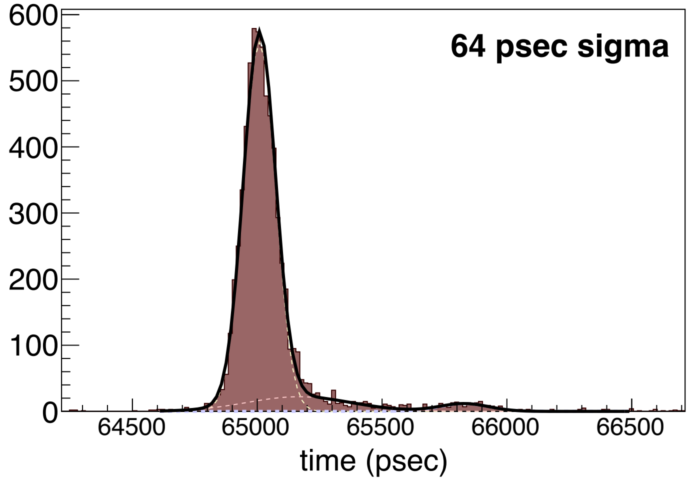
- We varied the voltages to see if we could improve the gain
- At higher voltages, the LAPPD gets noisy, but these gains provide good sPE separation so we're not concerned

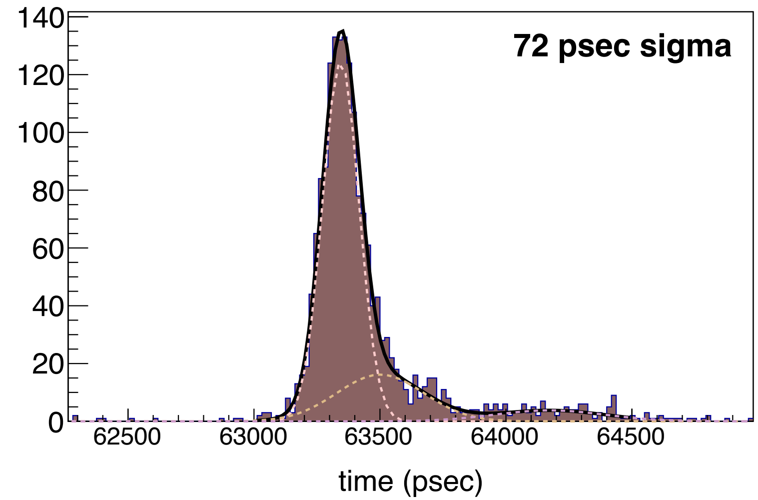


LAPPD 25: Voltage Optimization

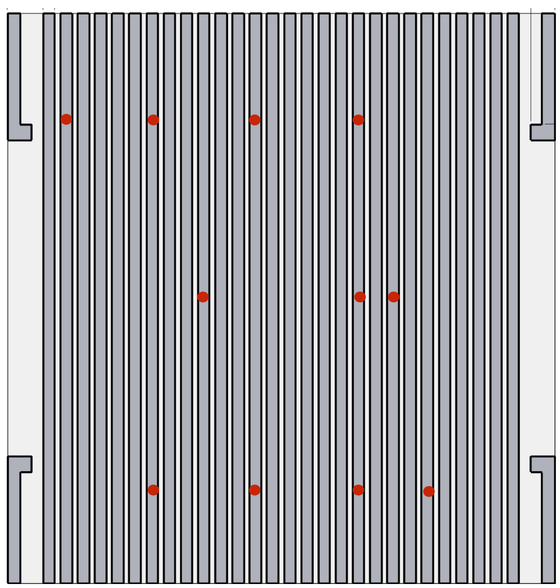


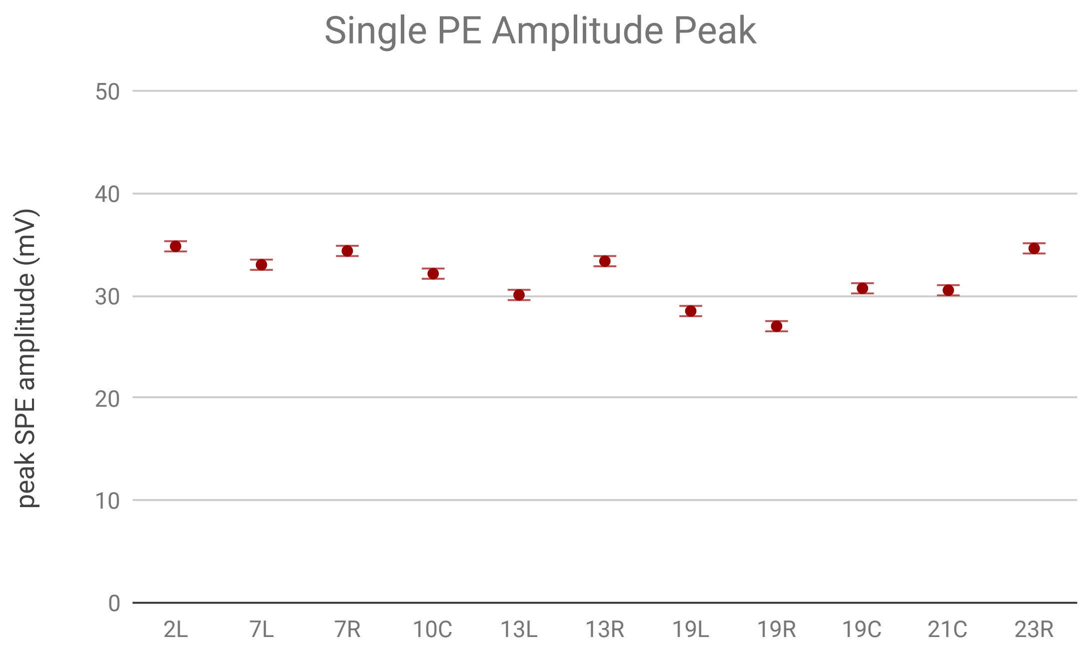






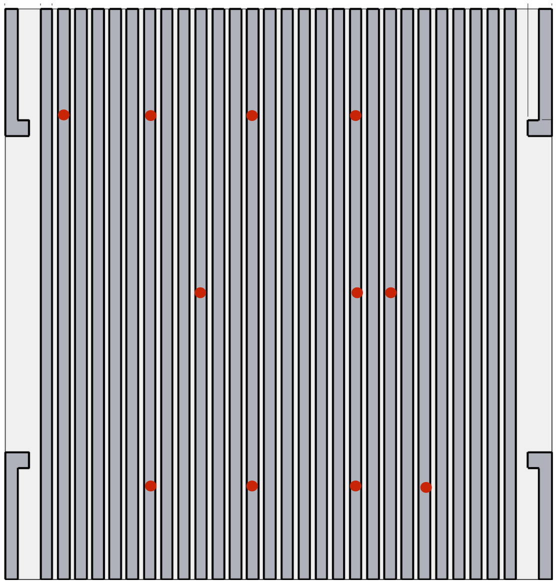
LAPPD 25: Single PE Gain Uniformity

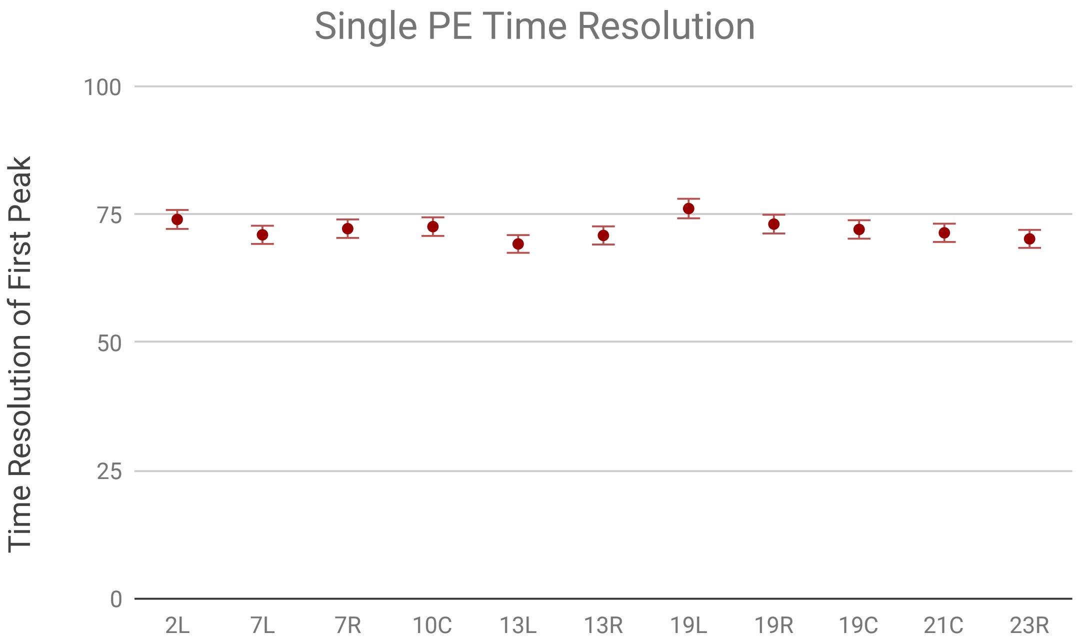




- We recorded 10k triggers as 11 random positions on the tile
- SPE peak amplitude was taken from the mean of the first Gaussian in a 2 PE + pedestal fit
- More systematic scans will become easier with the multichannel PSEC electronics

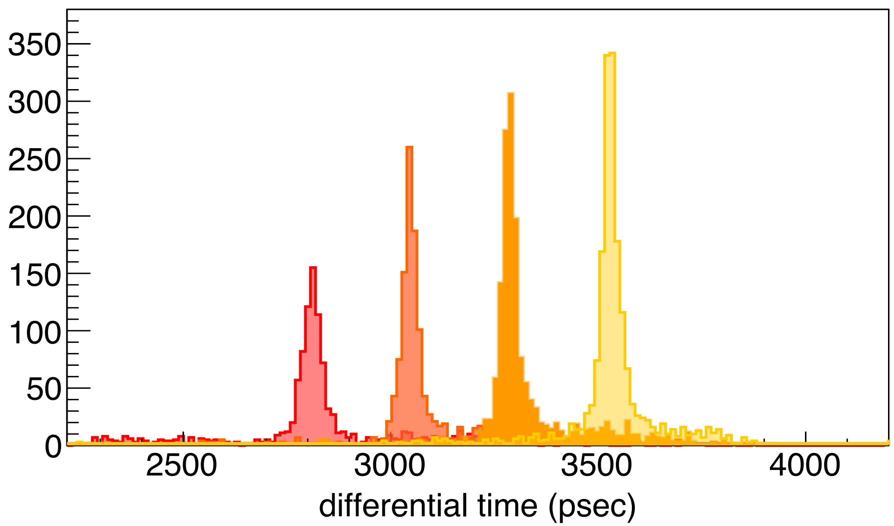
LAPPD 25: Single PE Timing Uniformity

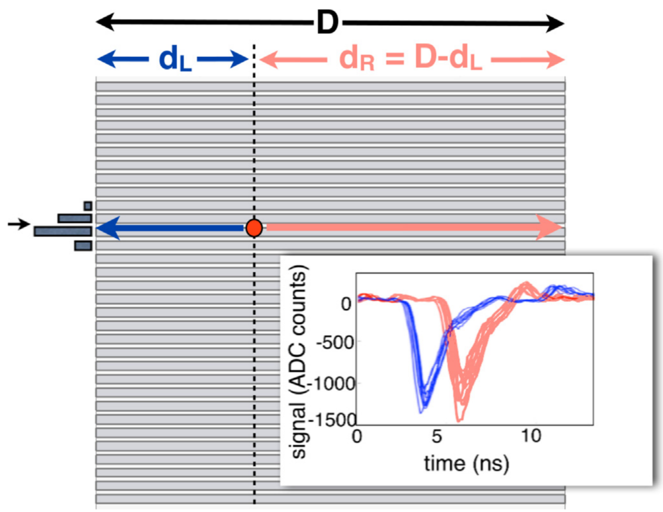


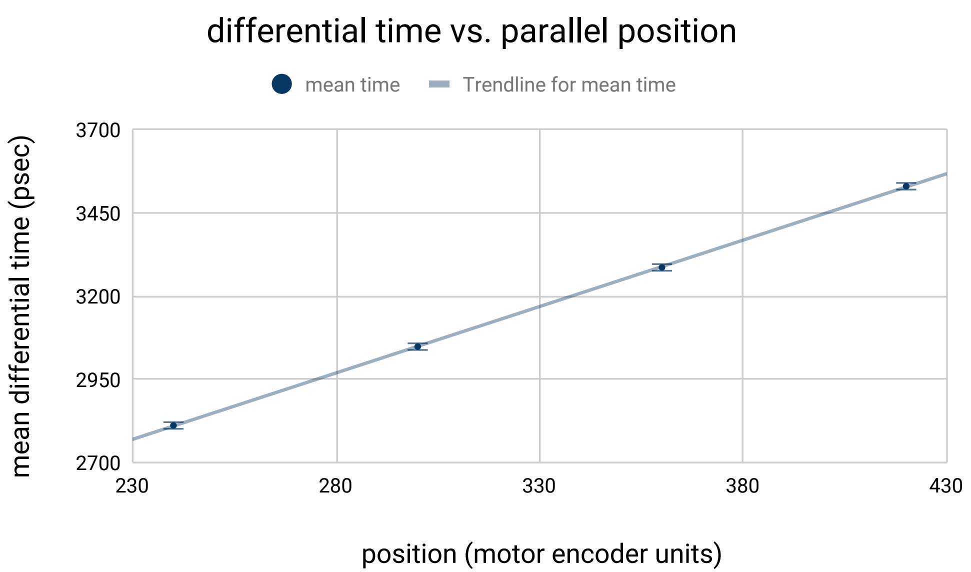


- We recorded 10k triggers as 11 random positions on the tile
- SPE time resolution is taken from the width of the main Gaussian in a 3 gaussian fit for TTS and after pulsing
- After pulsing constitutes a small (<10%) fraction of the pulses

LAPPD 25: Differential Timing / Parallel Position





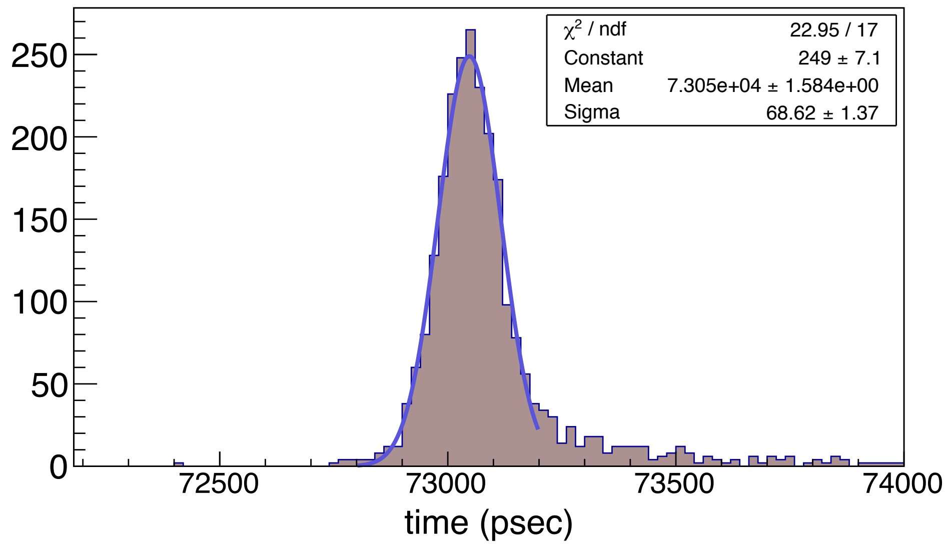


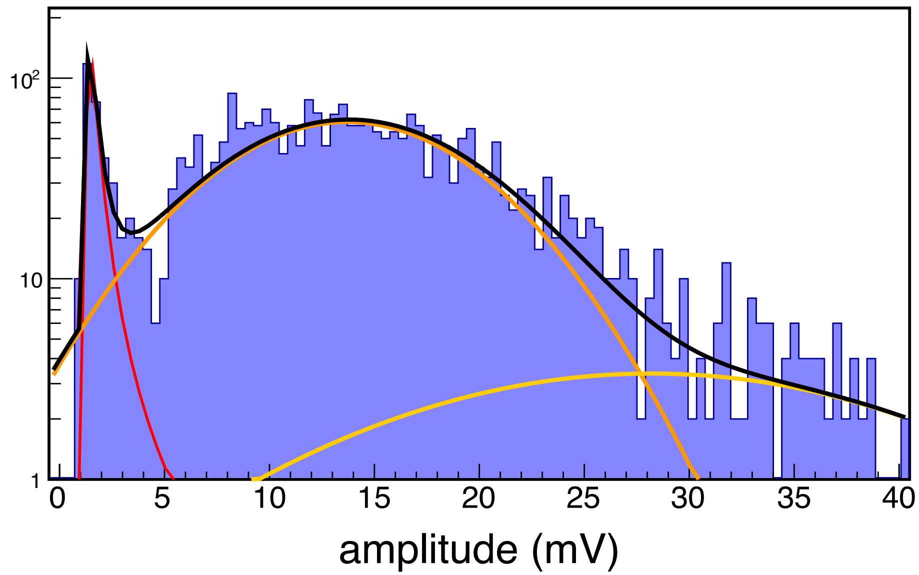
- Position in the direction parallel to the striplines can be determined from the time difference between the two ends
- 25 picosecond single-PE differential time resolution corresponds to 4.35 mm resolution in the parallel direction

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

LAPPD 31: First Plots

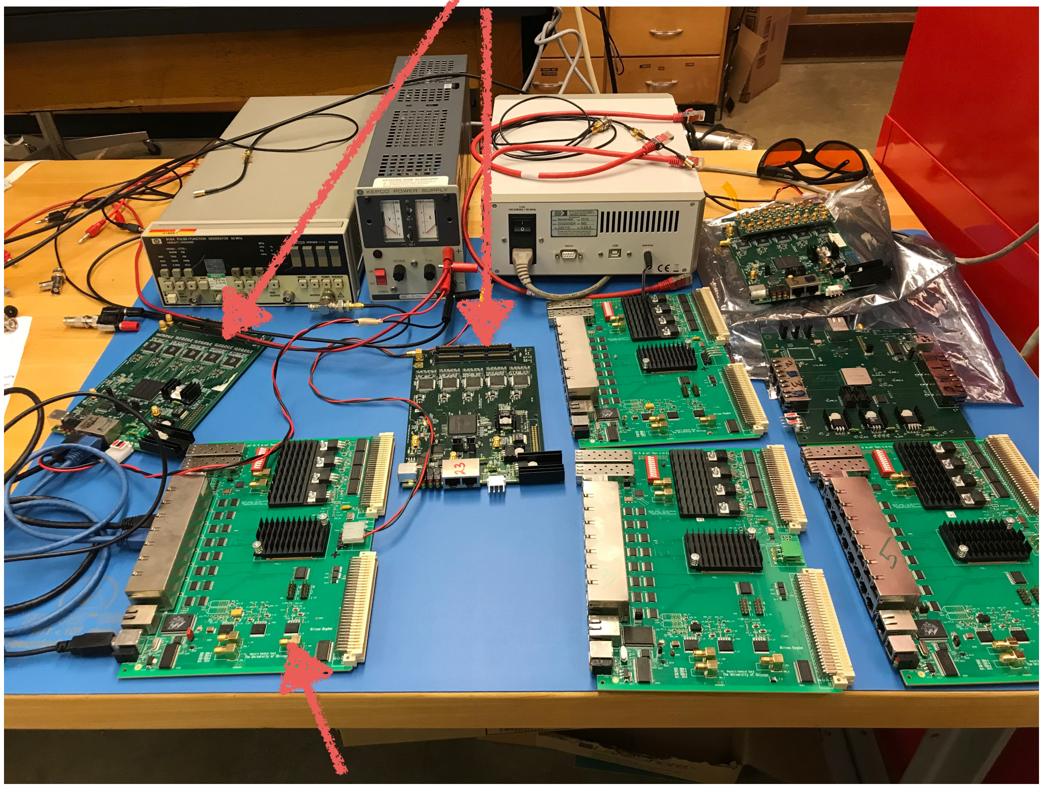




- These data were taken over 30 min at a best-guess for the voltage.
- More results to follow soon!

Application Readiness (DAQ)*

Two 30 channel ACDC cards

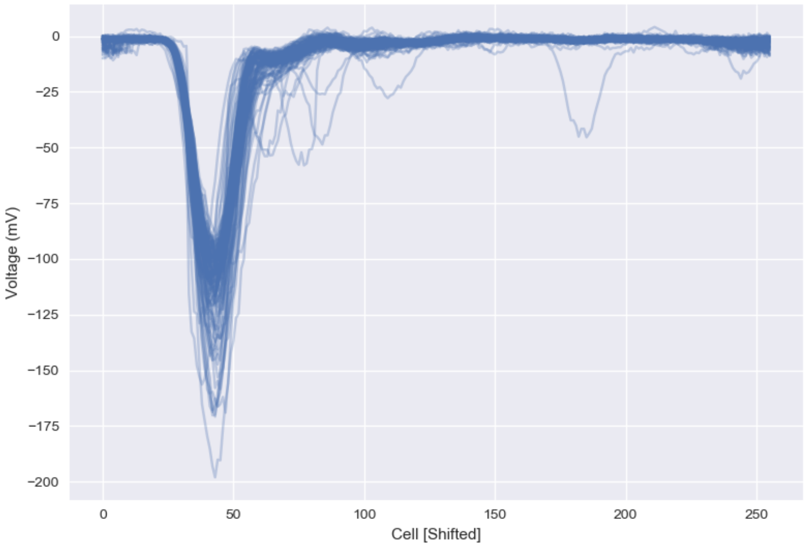


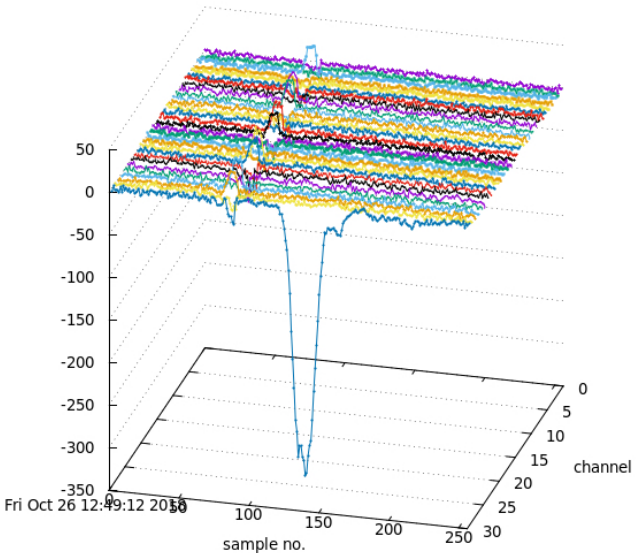
ANNE Central Card (ACC)

*powered by Monster Energy Drink

MONSTER ENERGY

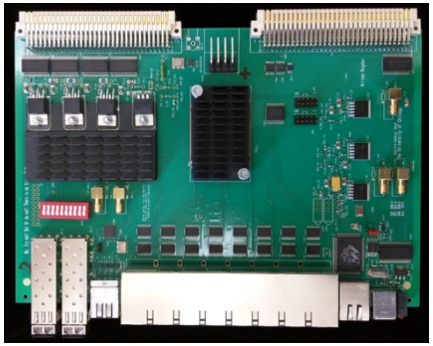
Application Readiness (software/integration)





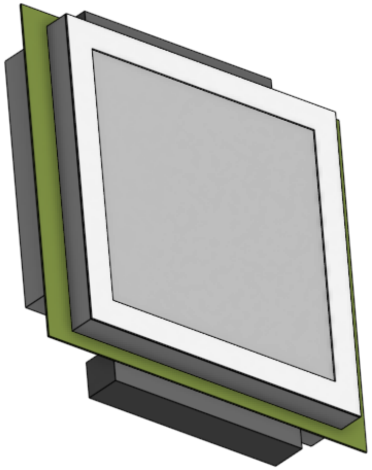
- Jonathan Eisch (ISU) has rewritten large blocks of firmware to enable stable communication and timing.
- We've made significant progress testing and understanding the hardware, thanks to close collaboration with Evan Angelico (UC)
- ToolDAQ is the modular, highly threadable DAQ software framework developed by Ben Richards (Queen Mary)
- Miles Lucas has made significant improvements to the usability of the software and is almost done integrating the readout with our ToolDAQ software
- ANNIE can offer a stable, field tested DAQ and software framework. Our reconstruction (ToolAnalysis) operates in the same framework of our DAQ. Theia collaborators are encouraged to use (and develop) this system.

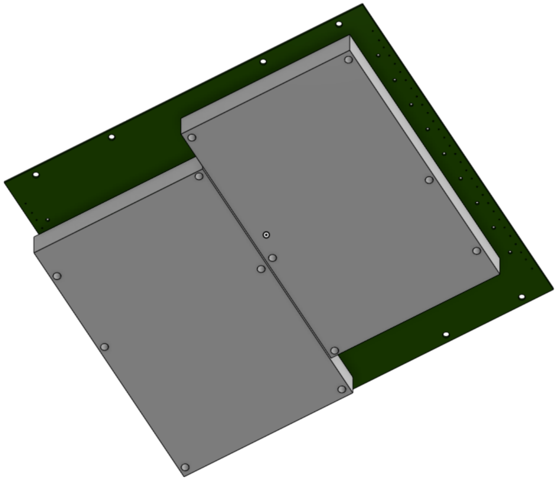
Application Readiness (electronics)

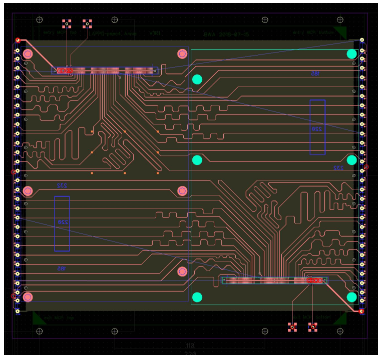


Current Design

- Readout close to the detector
- Two *ACDC* mezzanine waveform digitizers attach to the *pickup board*
- New *ANNIE Central Cards (ACC)*, provide clock and synchronization
- *LV-HV* board provides power and slow controls







Next Evolutionary Step

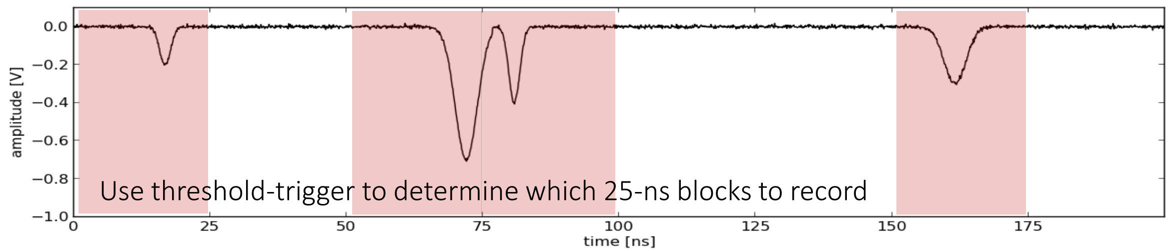
- Digitization of 60 channels on a single integrated ACDC cards
- PSEC-4a with 8x’s buffer (200 nsec) in a multi-hit buffering scheme for continuous readout
- Further simplified network topology, possible implementation of white rabbit

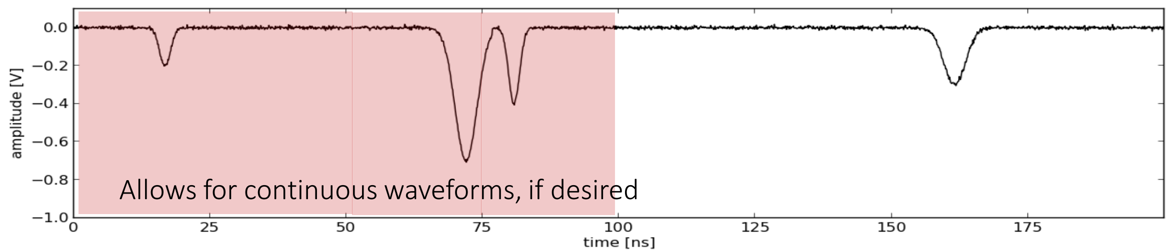
Application Readiness (electronics)

PSEC4a – multi-hit buffering

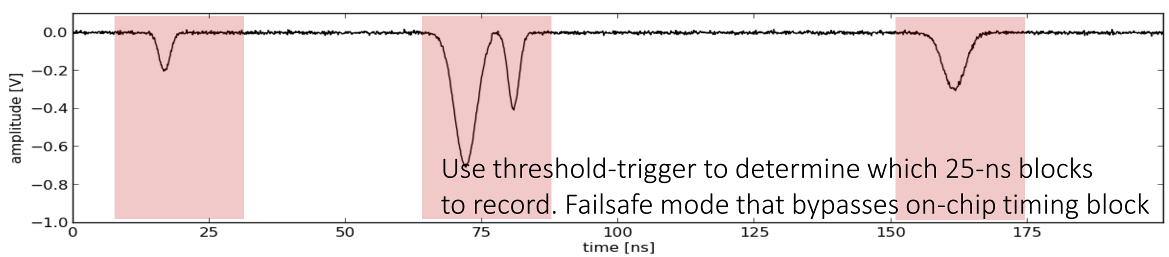
- How many buffers? Considering 2 options: 1024 or 2048 samples per channel
  - Layout space ($) / number of ADC's trade-off vs. typical event occupancy/timing characteristics
- Operation modes:

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)



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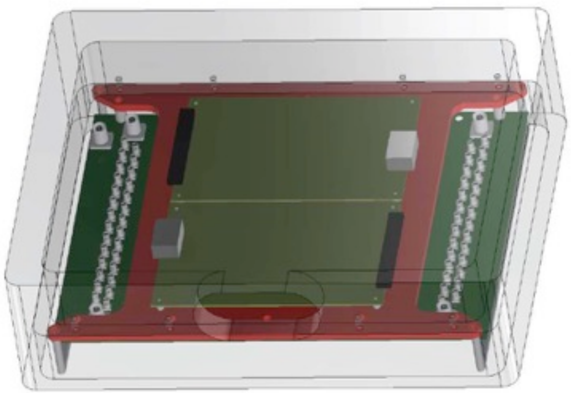
Application Readiness (waterproofing)

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

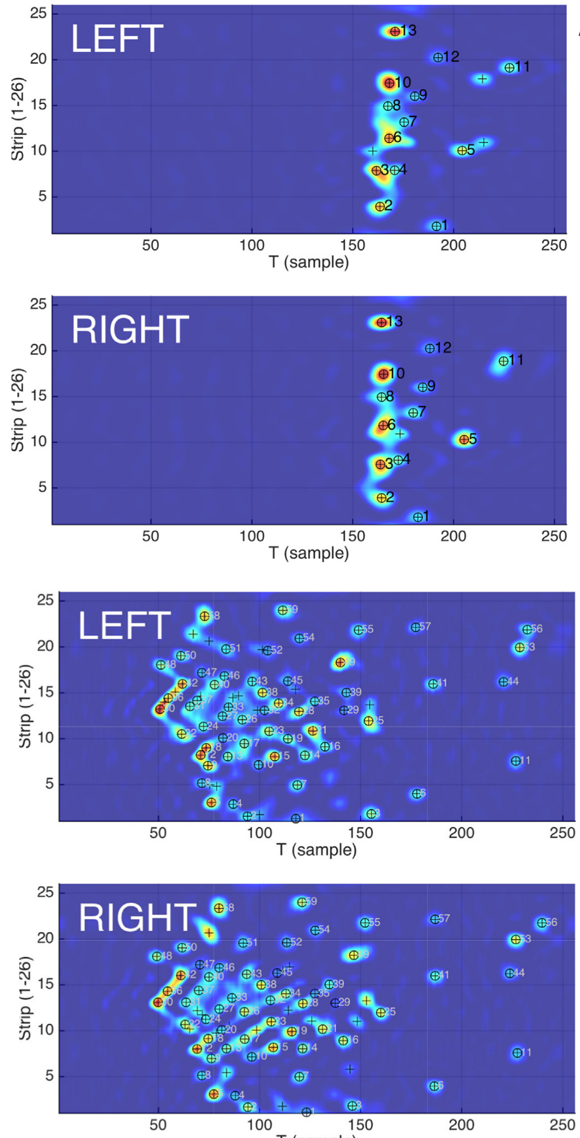


Next Evolutionary Step

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

Application Readiness (simulations/reconstruction)

- Deconvolving the two-sided readout of the LAPPD is not trivial, especially in high light environments
- It essentially adds an additional step between signals and “hits”
- We are working on a feature extraction approach that simultaneously fits pulses to the 2D time-vs-voltage distribution for both sides of the readout
- D. Grzan (ISU/Davis) wrote the original 1D version
- ANNIE MC in ToolAnalysis now accurately models the LAPPD readout
- Feature extraction will soon be added as a tool in the reconstruction chain



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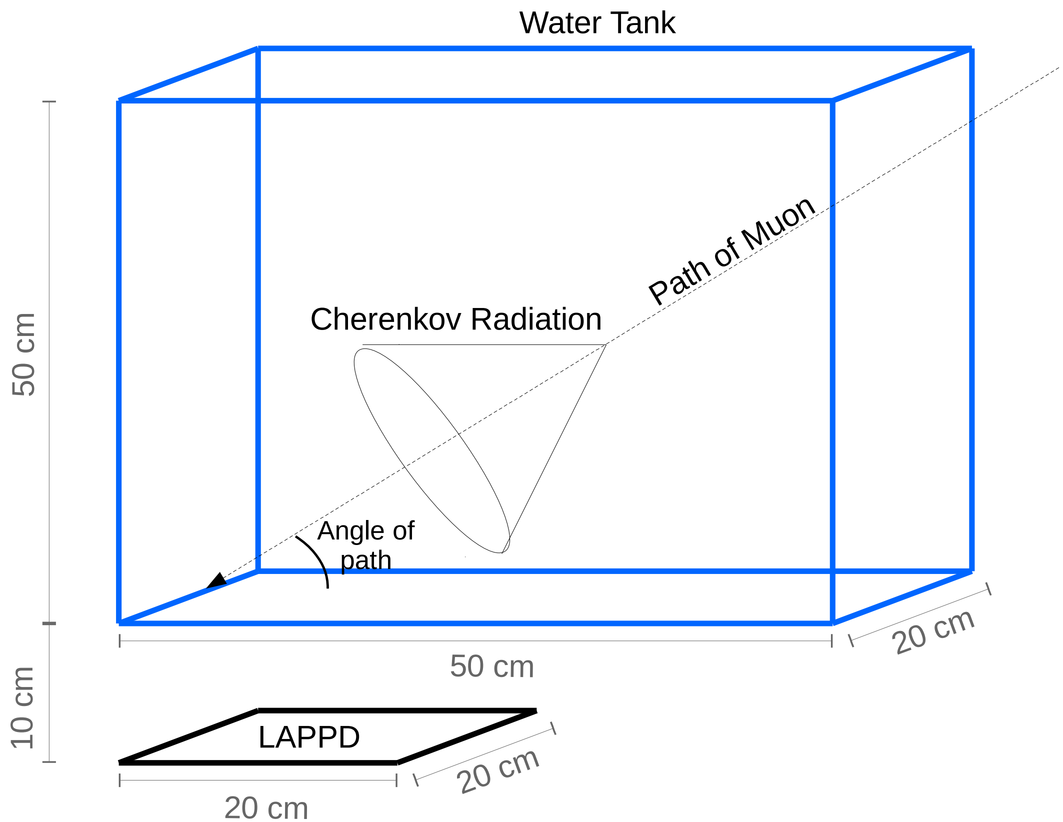
*Multiple-photon disambiguation on stripline-anode Micro-Channel Plates: Nim A 822 (2016) 25-33 credit: D Grzan

Simulated Scenario

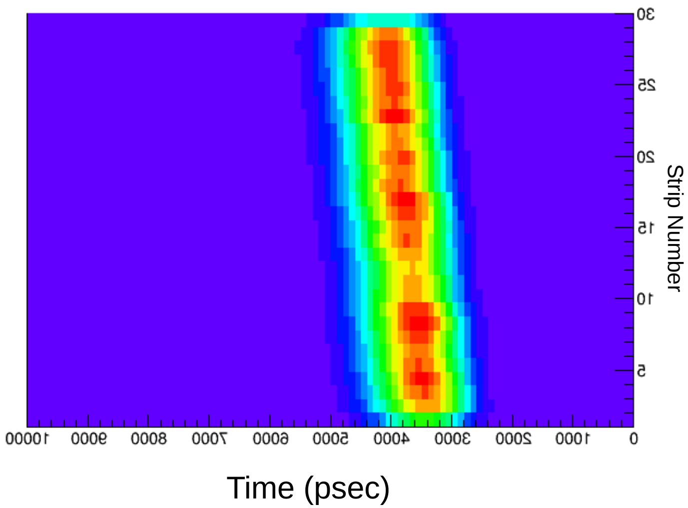


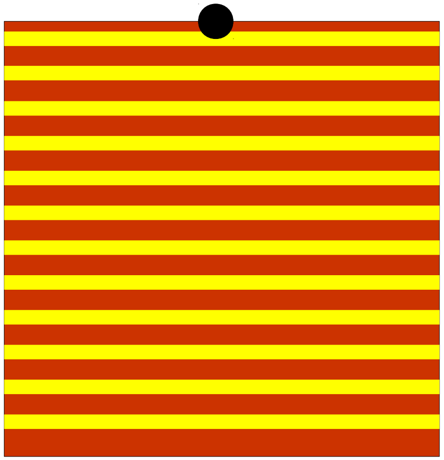
*All of the dimensions and quantities shown can be easily changed within code to give different results

- A root macro was created to simulate Cherenkov radiation hitting an LAPPD in this way
- The output are two Voltage vs Time histograms (one for each side of the strips) showing the voltage coming off of each strip as a function of time

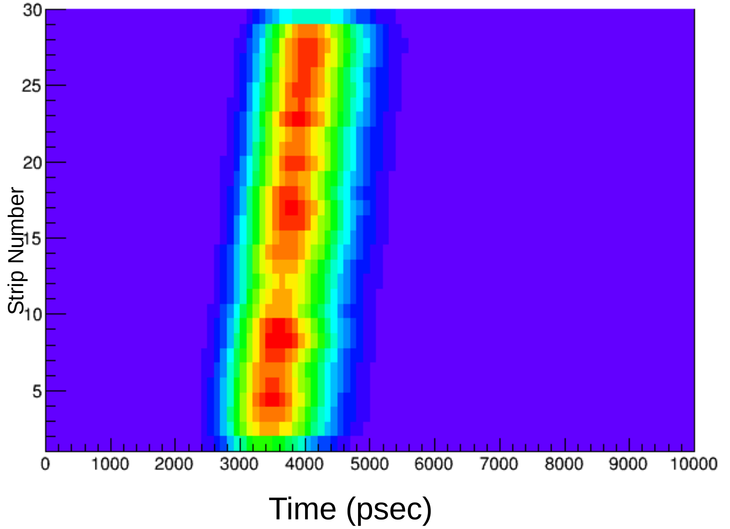
simulated data   credit: D Grzan

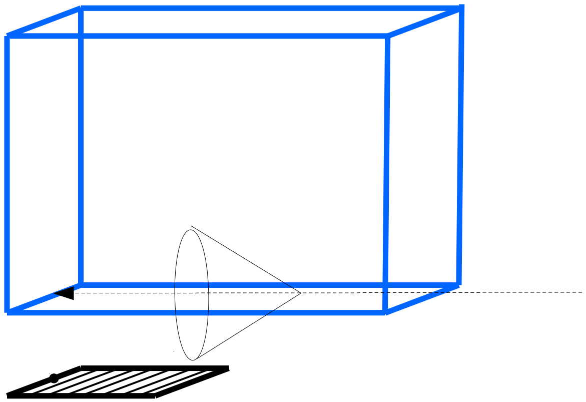
0° - Perpendicular Orientation





LAPPD

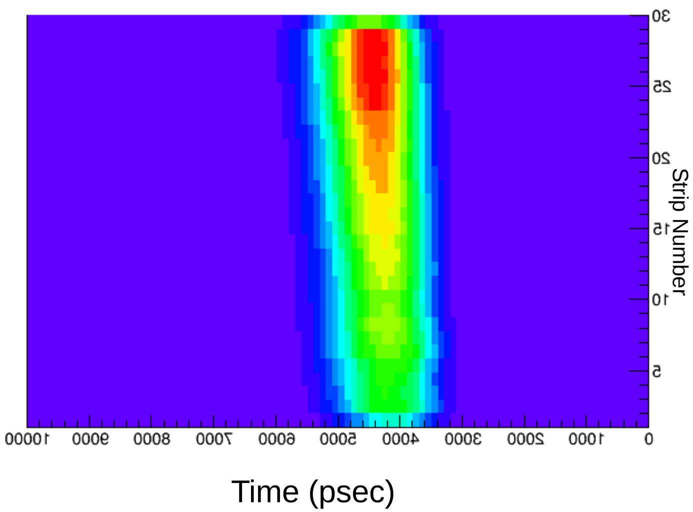


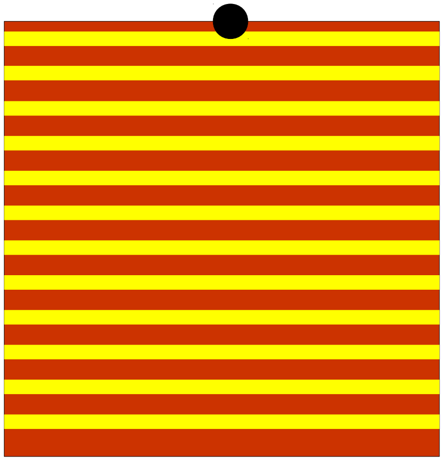


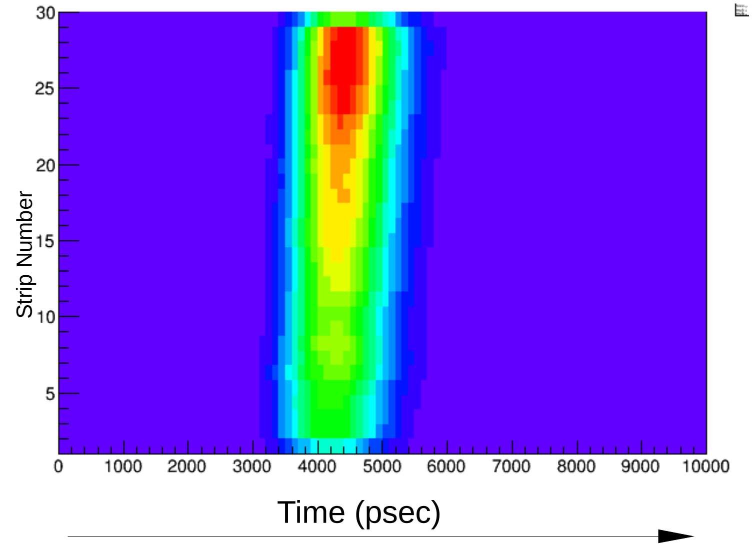
*Red indicates higher voltage amplitude and blue represents lower voltage amplitude

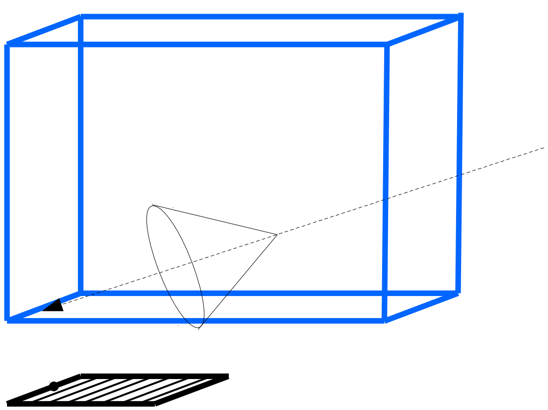
simulated data   credit: D Grzan

30° - Perpendicular Orientation



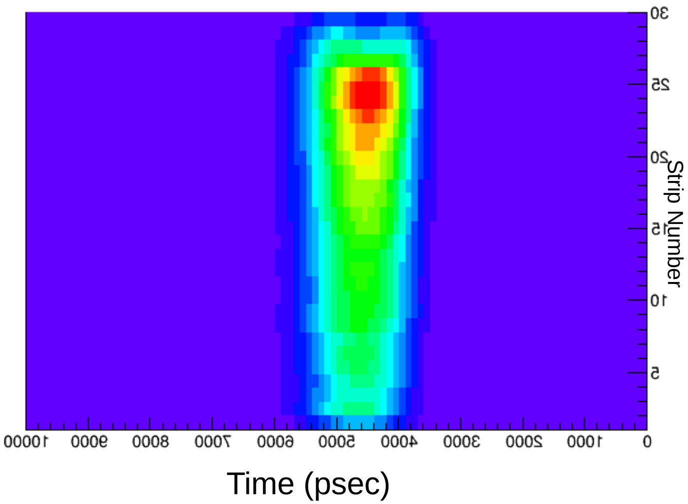


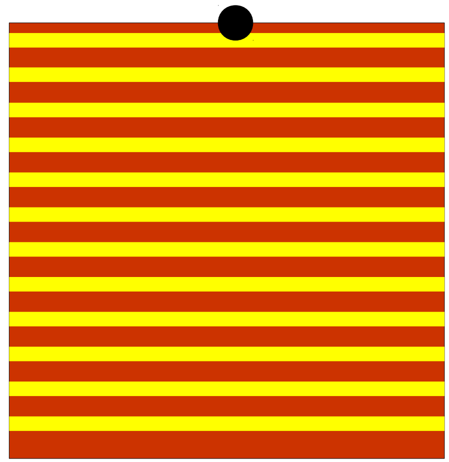


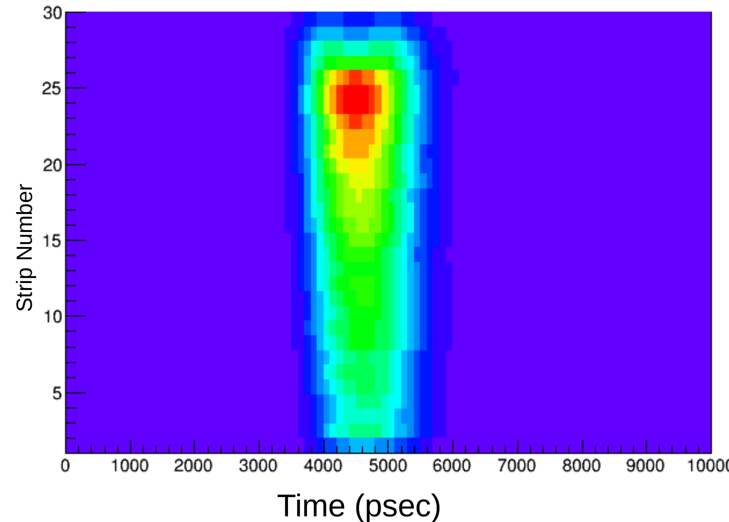


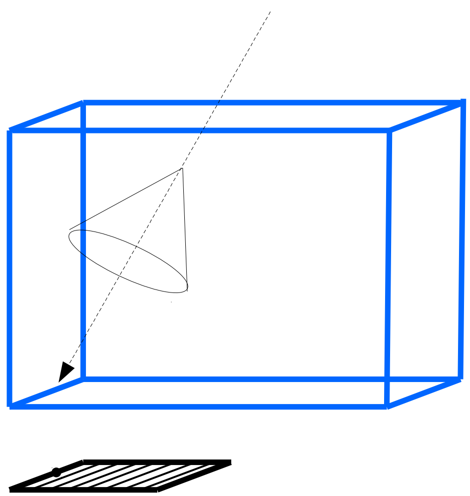
simulated data credit: D Grzan

60° - Perpendicular Orientation



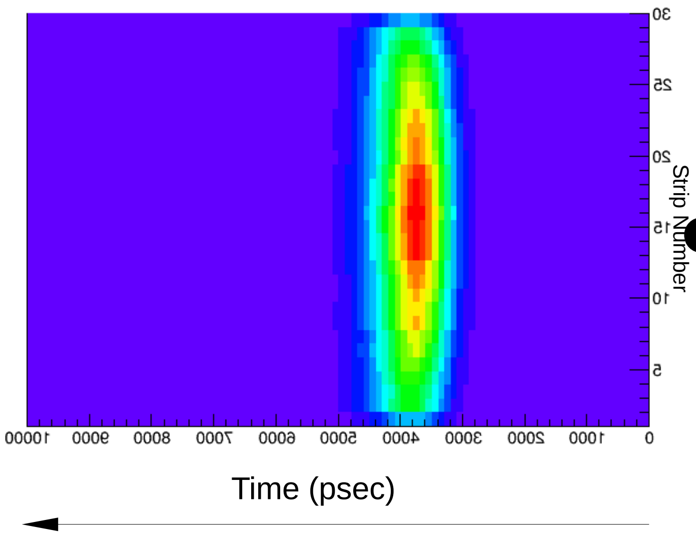


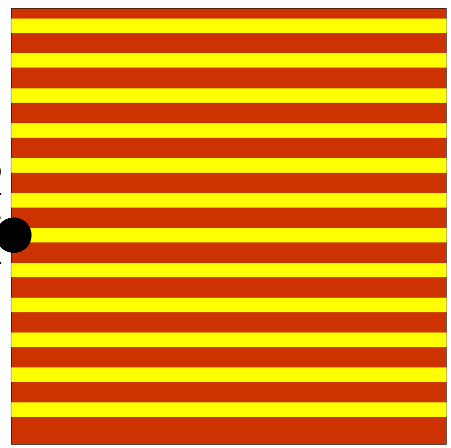


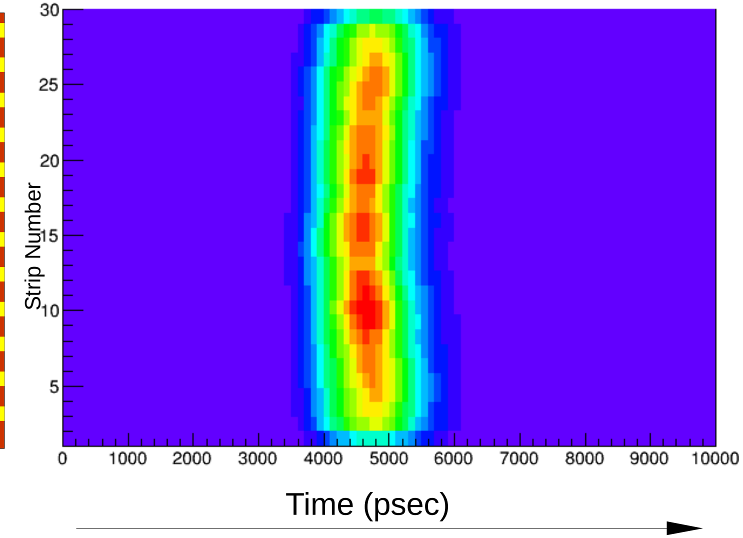


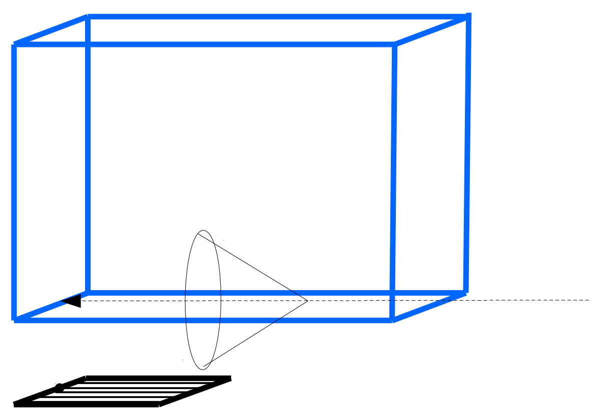
simulated data credit: D Grzan

0° - Parallel Orientation



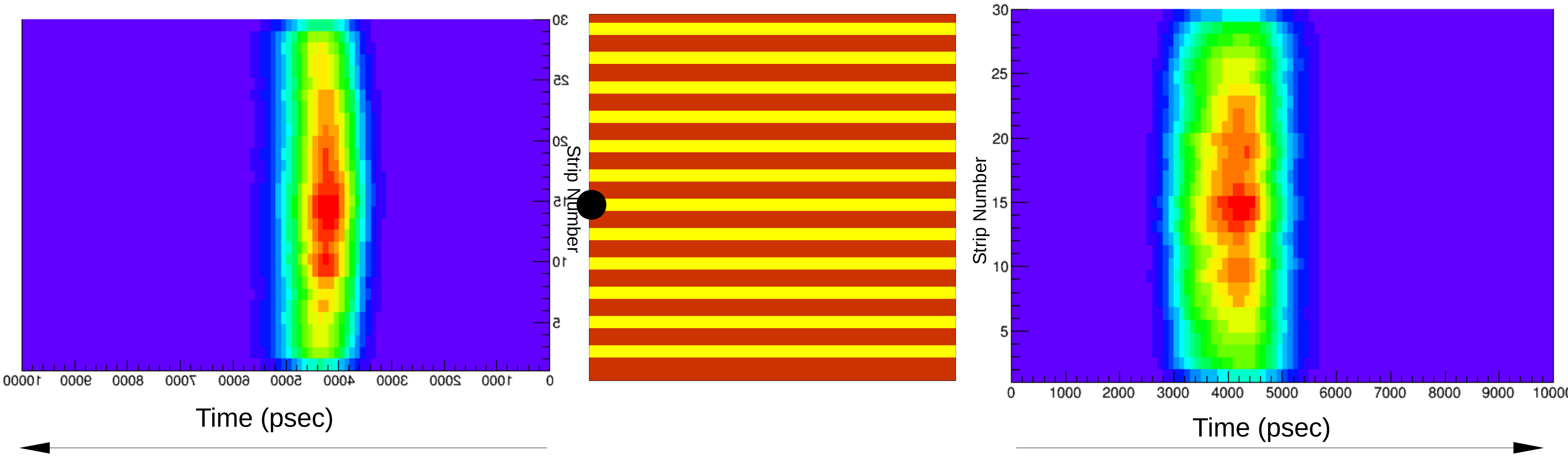


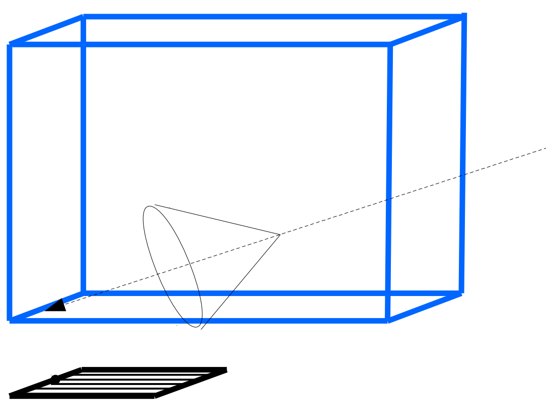




simulated data   credit: D Grzan

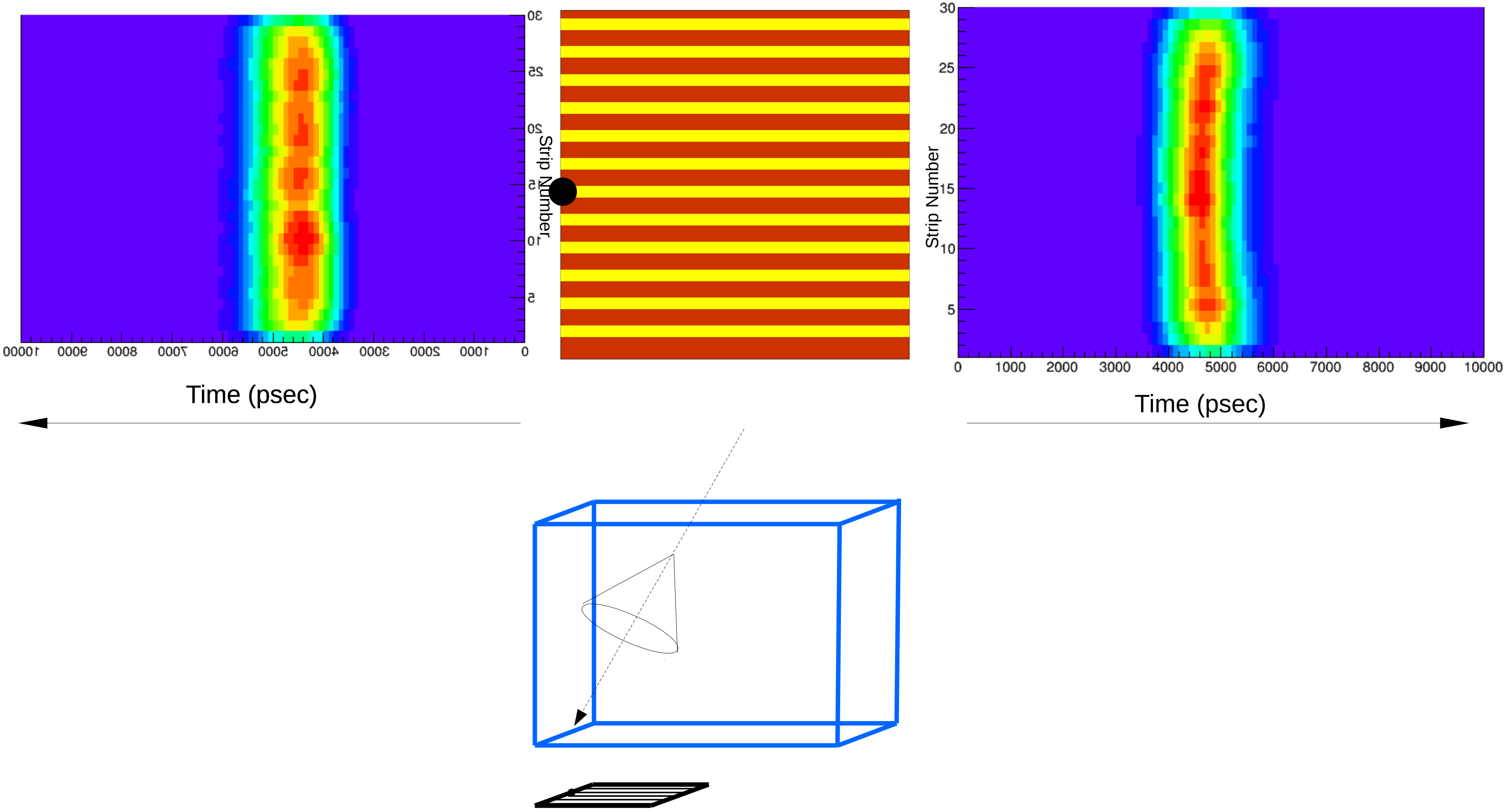
30° - Parallel Orientation





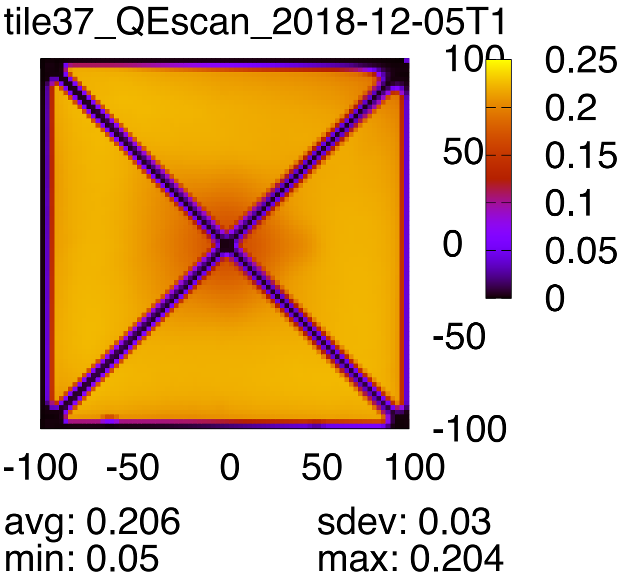
simulated data credit: D Grzan

60° - Parallel Orientation



Conclusions

- Incom is starting to produce quantities of successfully sealed LAPPDs for sale to early adopters
- ANNIE has purchased two of these early tiles, LAPPD-25 and LAPPD-31, with LAPPD-37 arriving before years end.
- 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.
    - This tile solidly meets ANNIE specifications
- LAPPD-31 looks promising as well
- LAPPD-37 will have >20% QE and better voltage stability
- 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



coming soon!