LAPPDs in ANNIE

From Test Bench to Full Experiment

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on behalf of the ANNIE collaboration

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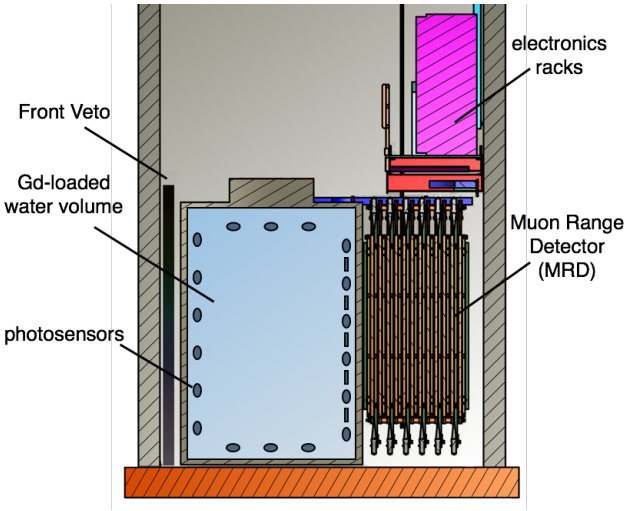
U.S. DEPARTMENT OF ENERGY

ANNIE: Accelerator Neutrino Neutron Interaction Experiment

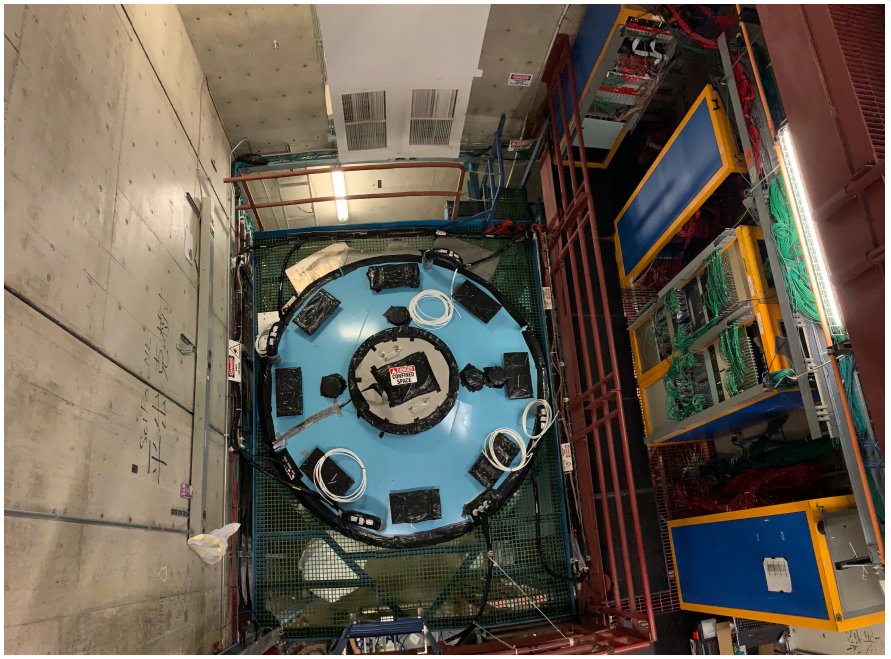
ANNIE is a neutrino experiment deployed on the Booster Neutrino Beam

- A physics measurement aimed at better understanding neutrino-nucleus interactions
- An R&D effort to develop and demonstrate new neutrino detection technologies/techniques
- First application of LAPPDs in an HEP experiment - culmination of over a decade of work



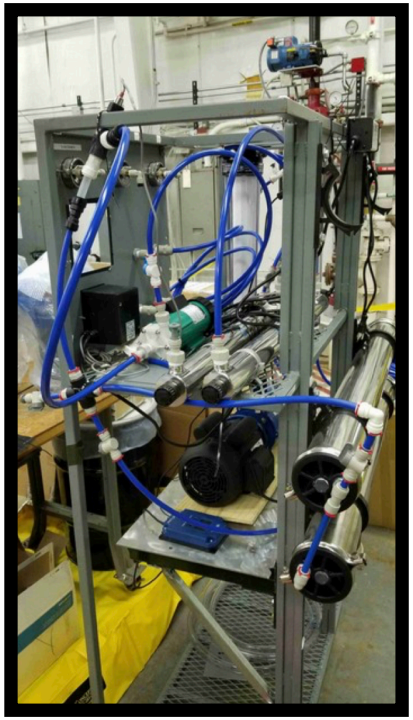
We have an international collaboration, 16 full-member institutions, 45 collaborators

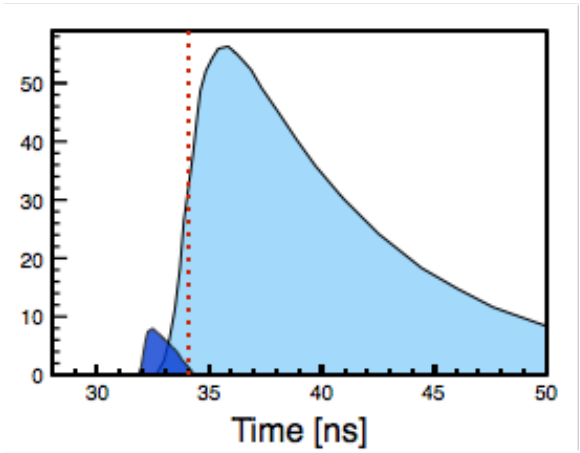
ANNIE in pictures



ANNIE Technological Program

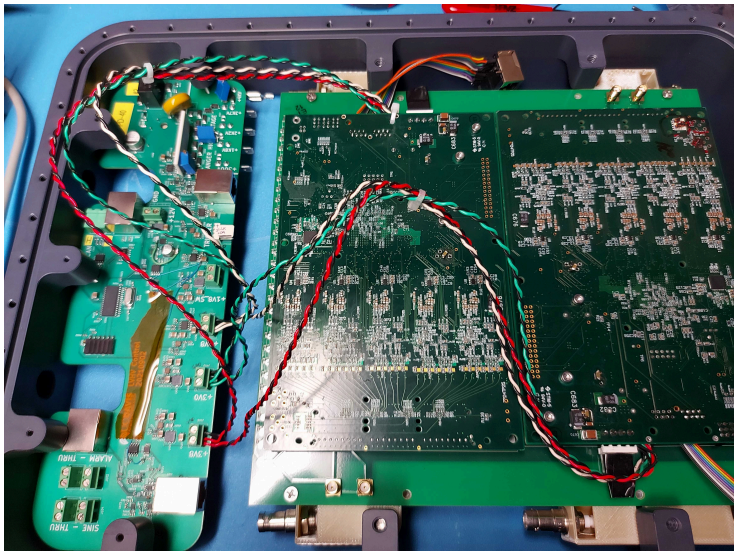
- ANNIE is an R&D platform to test neutrino detection technologies
- In December 2020, ANNIE became the first Gd-loaded water neutrino experiment
- This week, ANNIE will become the first HEP experiment to use LAPPDs
- In the near future ANNIE intends to study WBLS
  - First on a small subvolume (possibly deployed this summer)
  - Phase III would fill the active volume with WBLS

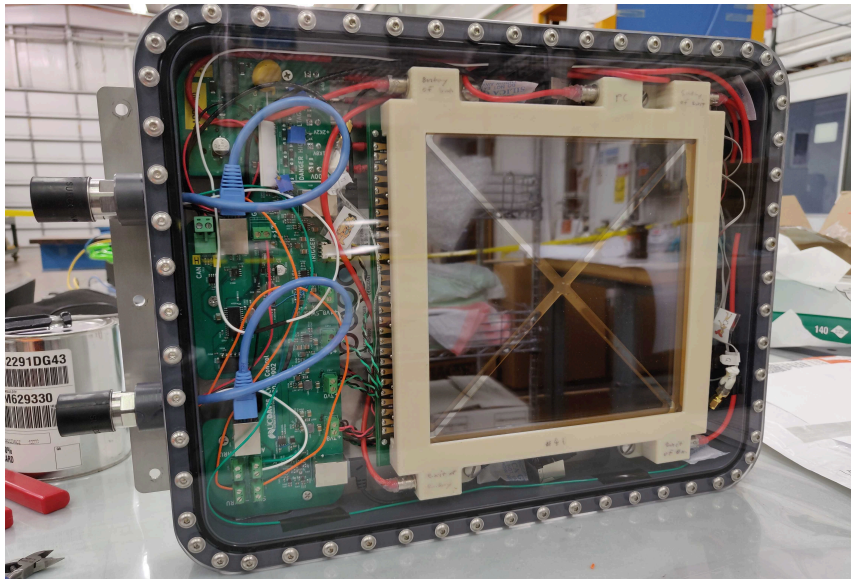


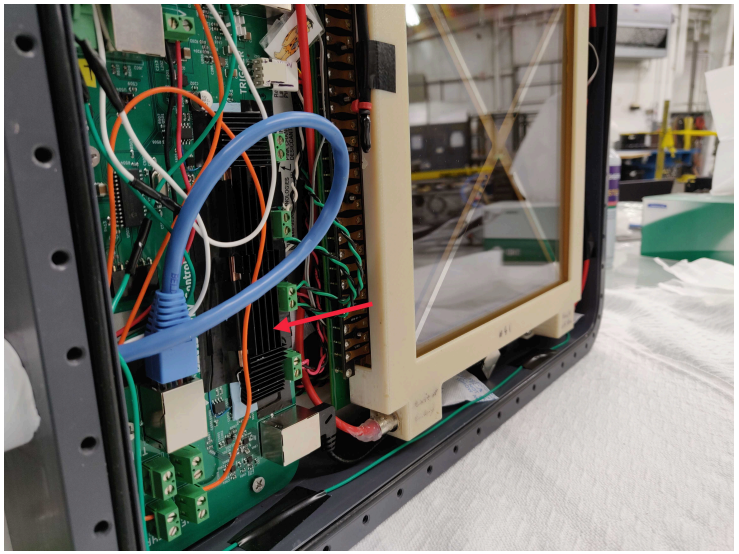


First LAPPD in ANNIE

- LAPPD-40
- Complete LAPPD module built, thoroughly tested and vetted
- Has been operated underwater, passed bucket test
- Ready for first deployment *this week*





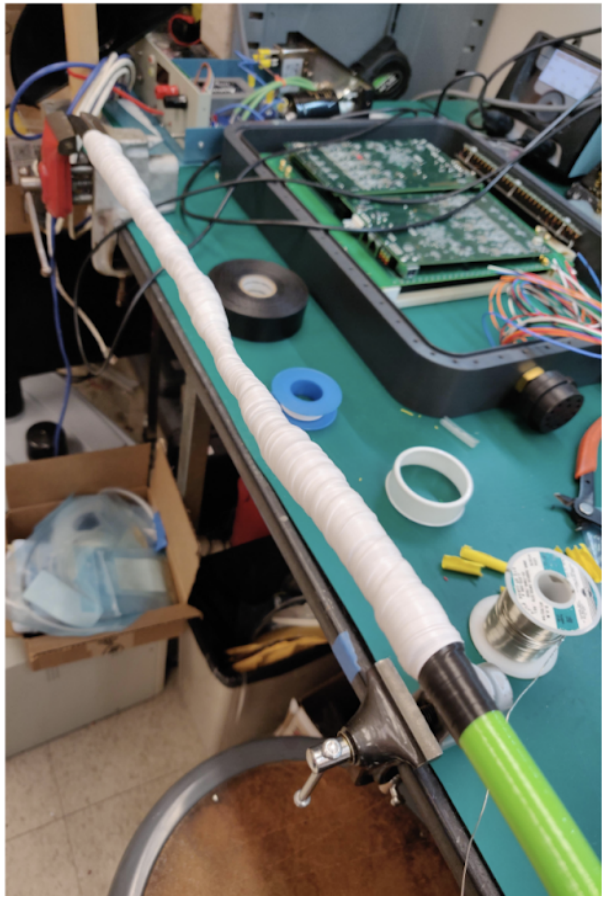


Steps to Operating LAPPDs in ANNIE

- Characterizing the LAPPDs (QA/QC)

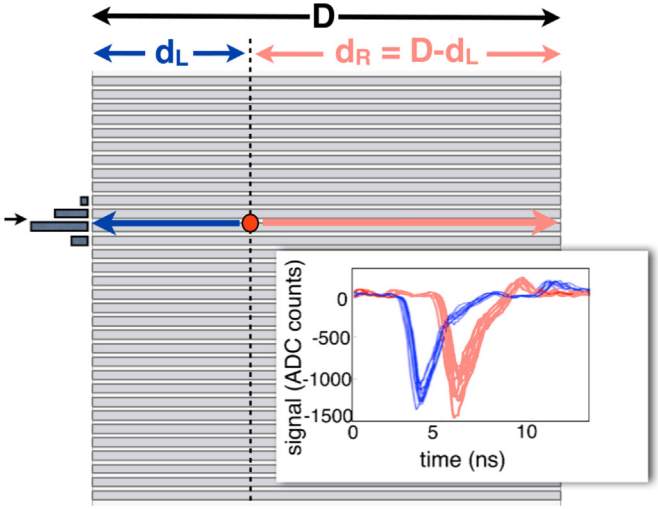
- Developing a deployable package
  - Trigger and readout
  - Slow controls
  - Mechanical
  - Software and firmware development
  - Iterative cycle of design, implementation, testing
    - Gradual integration of system components into LAPPD characterization system
    - Parallel development of calibration, analysis chain

- Integrating LAPPDs with the full detector
  - Integration with DAQ and timing system
  - Calibrating LAPPDs in-situ (laser + diffuser ball)

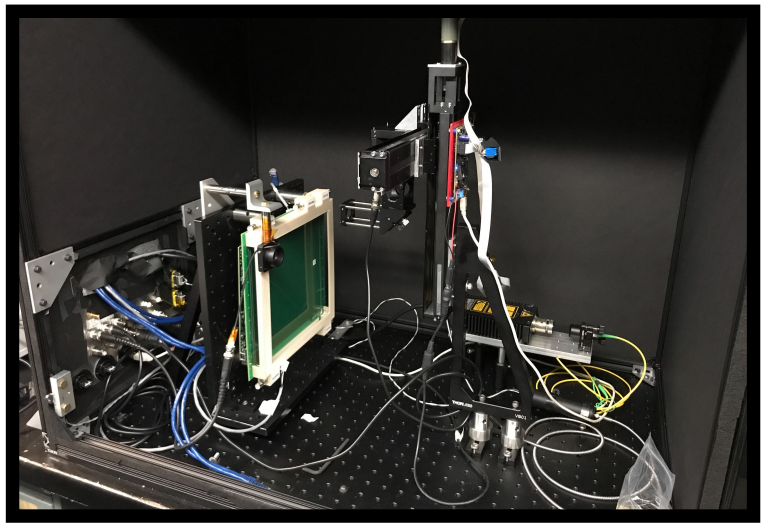


Standalone LAPPD characterization

- Built a new test facility at Fermilab
- Informed by prior work testing the earliest LAPPDs
- More adapted to systems-level testing
- QE scanning with pico-ammeters
- Gain and timing:
    - PiLAS laser (30 ps pulse duration)
    - 2D Motor scanning stage



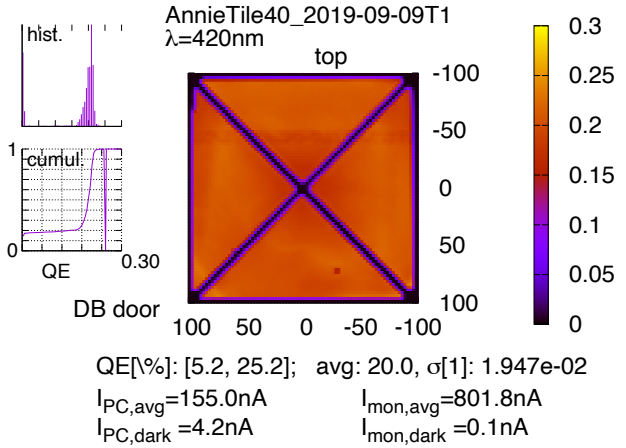
ANNIE currently uses Gen I LAPPDs.
May use Gen II in the future.



LAPPD QA Results

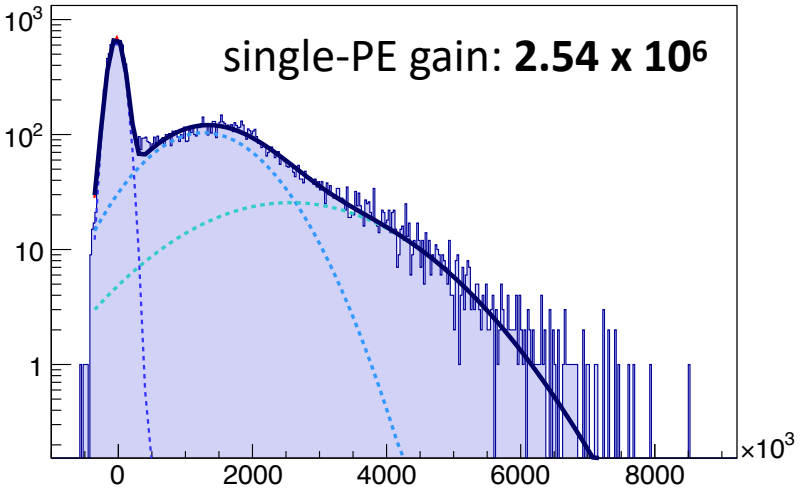
The ANNIE collaboration ordered 6 LAPPDs

- 5 in-hand to go in this beam year
- A sixth to be chosen from recent Incom units and deployed for the next beam year

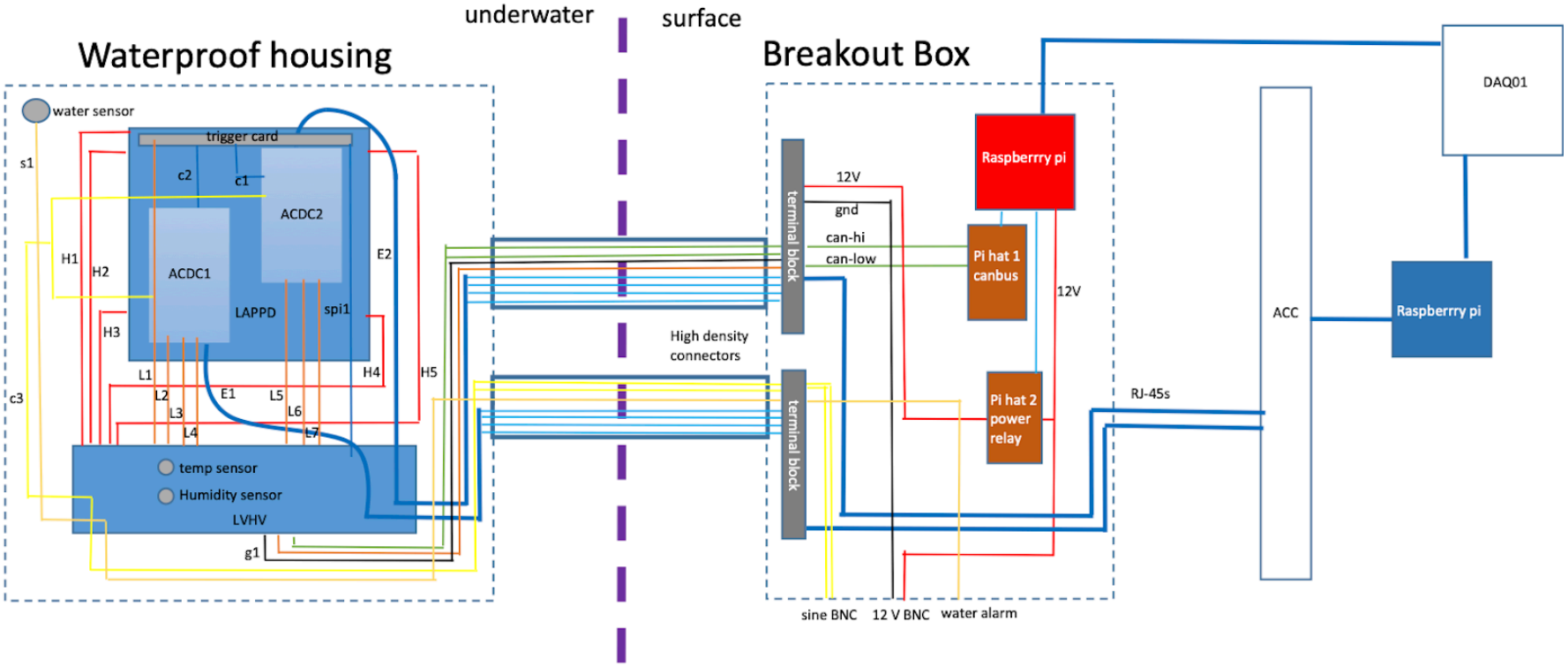


All 5 LAPPDs meet ANNIE specifications

- Uniform QE>20%
- Uniform gain > 10e6
- Intrinsic time resolution ~50ps



The Challenges of Transition from Tabletop to Experiment



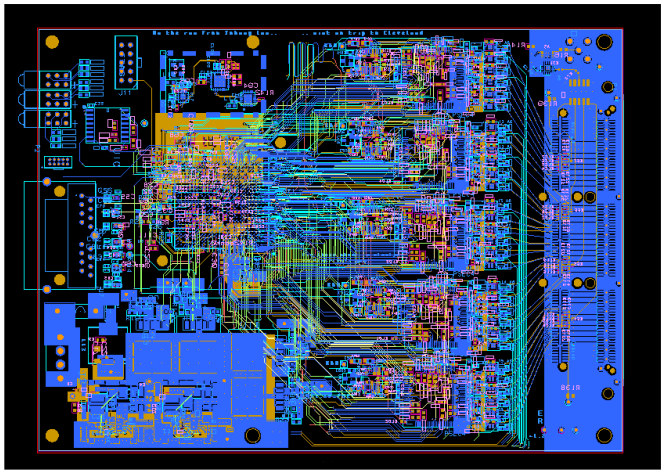
One single LAPPD rivals the complexity of the entire rest of the ANNIE

LAPPD System Elements

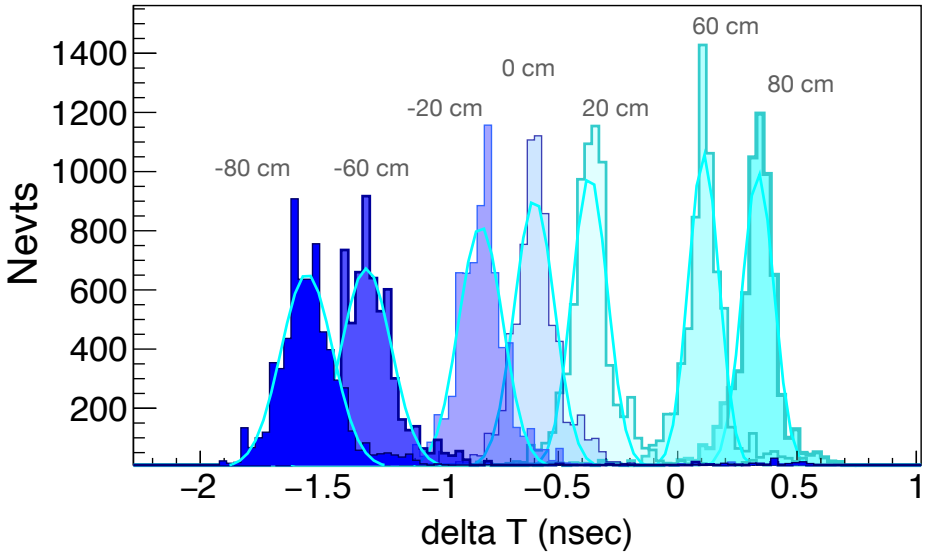
- Trigger and readout
  - Surface to water comms (7-10 m cable distances)
  - 60-channel readout close to LAPPD (noise and thermal issues)
  - Timing synchronization and gates from beam
  - Precision self-triggering

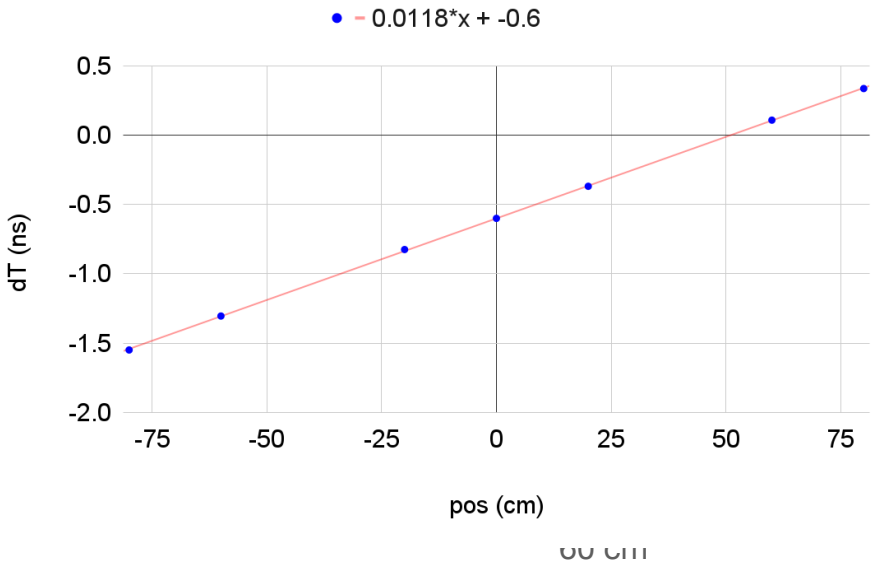
- Slow controls
  - Environmental monitoring
  - HV delivery to LAPPD (voltage divider needs to be tuned for each LAPPD)
  - LV delivery to readout electronics

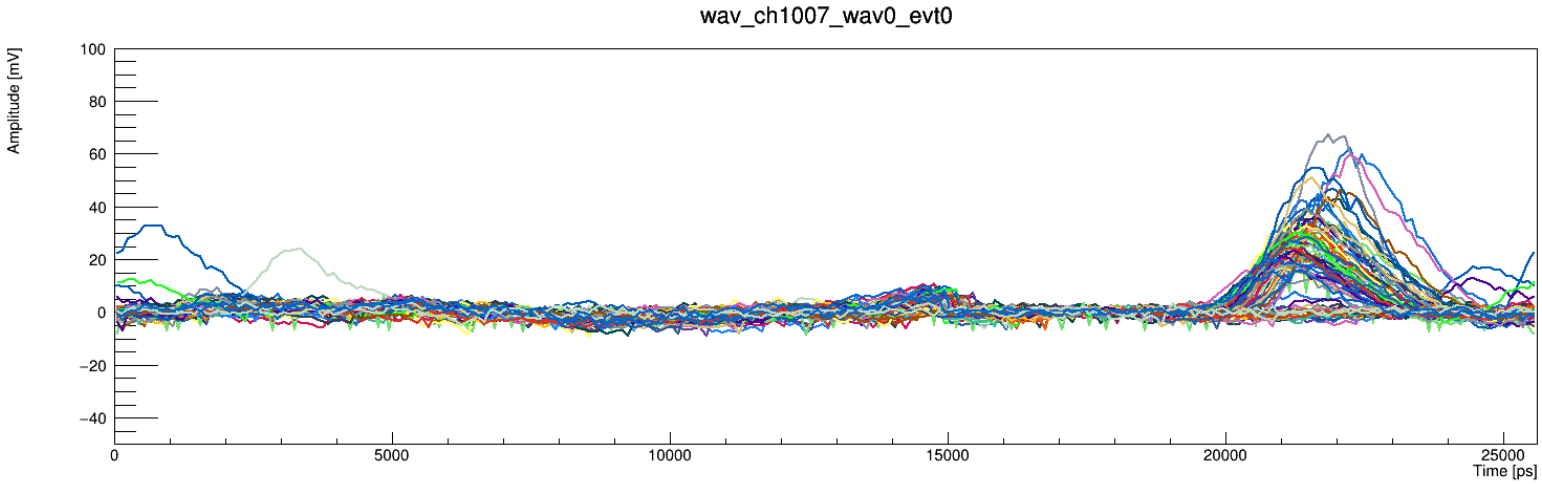
- Mechanical design
  - Waterproof housing, cables
  - Deployment mechanism
  - Temperature management



Our Success in Meeting Those Technical Challenges







Achieving Timing Precision Goals

Timing precision = LAPPD innate performance + all other system elements

$$\sigma_{LAPPD} \oplus \sigma_{Trigger} \oplus \sigma_{Pulse} \oplus \sigma_{trigger\ board\ jitter} \oplus \sigma_{algorithmic\ limitations}$$

Intrinsic LAPPD res 50 psec

Reference signal uncertainty Probably << 100ps

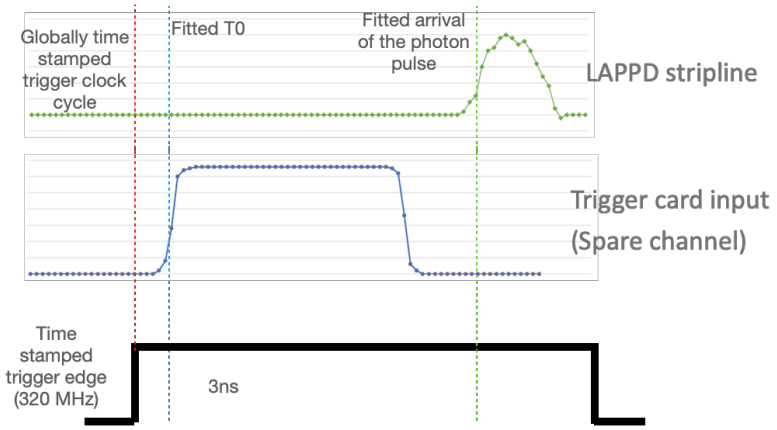
Laser pulse 30 psec

self-trigger response Not fully known but upper limit of 250ps… Probably better

Will eventually be small but currently may be over 100 ps

Target resolution:

- <200ps for global timestamp
- <100ps for relative time resolution within a single LAPPD



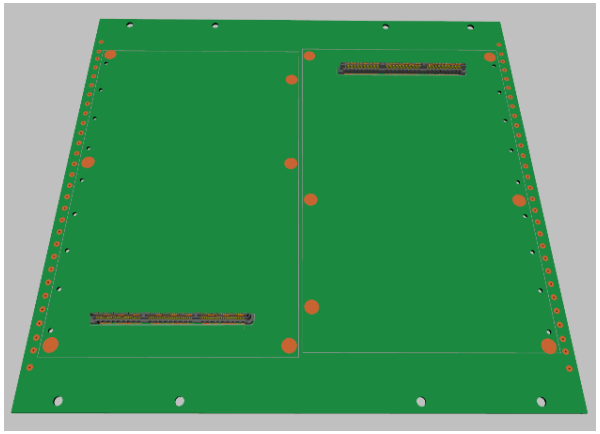
Operating LAPPDs for a larger range of Use Cases

- Physical scale:
  - Use cases which require communications over longer distances have special requirements
    - Grounding is critical (and cable length matters)
    - AC-coupled comms wherever possible
    - Where not possible: receivers that accommodate wide voltage swings
- Consider temperature management holistically for confined space
  - Board design/power delivery
    - Switching power supplies + linear regulators over small voltage gap
  - Heat sinks
  - Thermal conductivity of waterproof housing
- Lessons in scaleability (# LAPPDs)

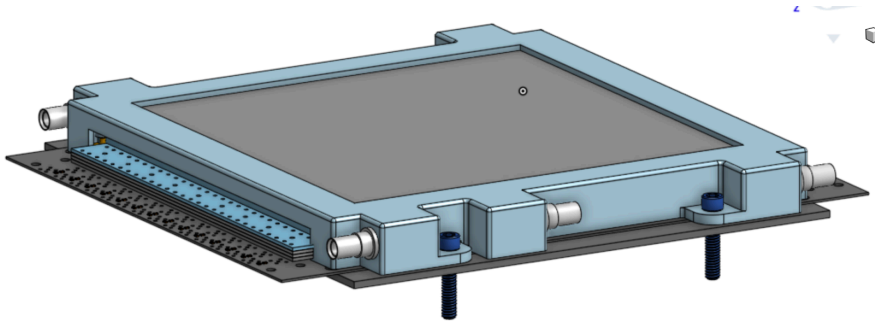
Importance of Building Community Standards

We need to develop shared interfaces, standards for LAPPD & electronics

- Changing some interfaces requires special certification
  - e.g HV
  - e.g Analog-to-digital bridge
- Optical interface concerns
- An “API” with modular components addresses scaleability concerns



Similarly, we would benefit from software and simulations standards



- This same system is being used by U Chicago and FNAL at the Fermilab testbed
- Collaborators in the UK will be reproducing and helping improve on this system

Progress and Next Steps in Simulation

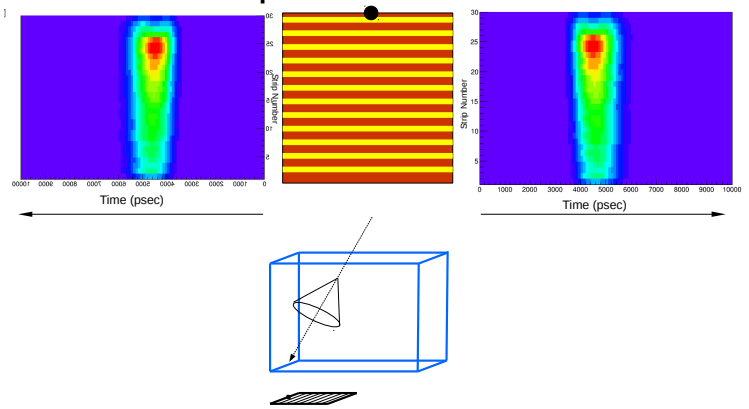
ANNIE currently approaches LAPPDs in two steps:

- Record the truth level photon hits on a square glass sensitive area in geant
- Generate and digitize the LAPPD response in a separate step

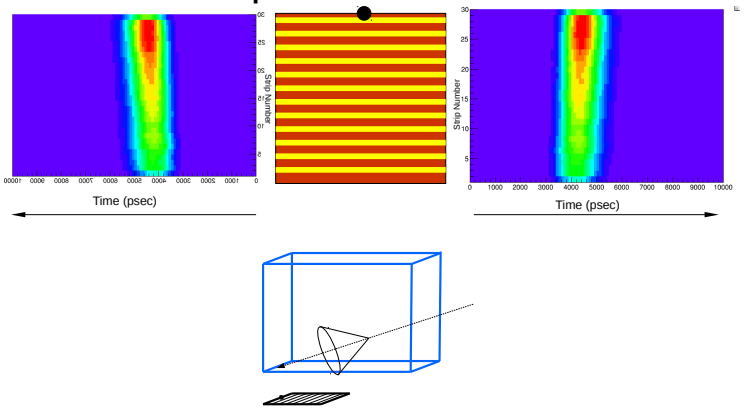
A standalone simulator/digitizer class exists and will be publicly available (will likely be adapted for pixel readout)

Full, modular LAPPD implementation in large detector, géant simulations should be a coordinated effort

60° - Perpendicular Orientation



30° - Perpendicular Orientation



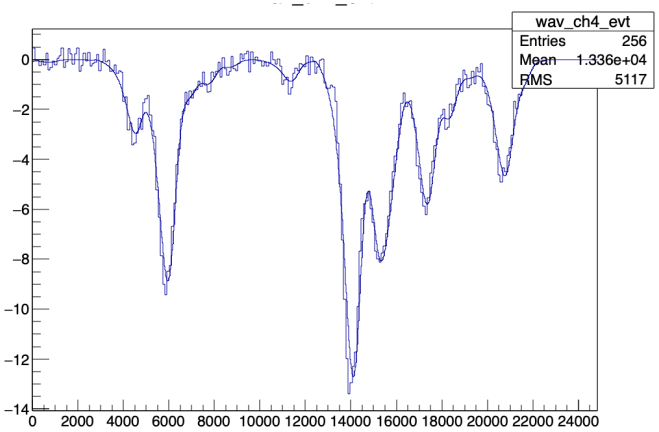
Progress and Next Steps in Reconstruction

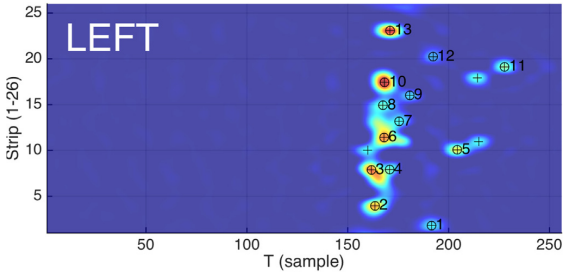
- ANNIE has a standalone LAPPD simulator class which will soon be made publicly available
  - Analog response
  - Digital response
  - Could be generalized for pixelated readout

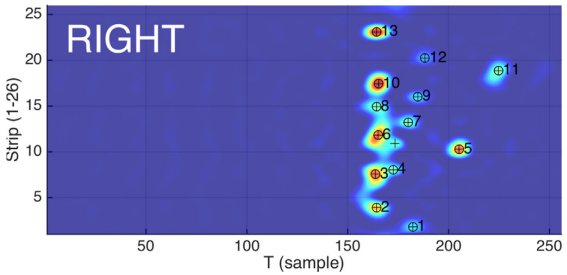
- We also have tools for multi-photon pileup and pattern recognition (machine learning)

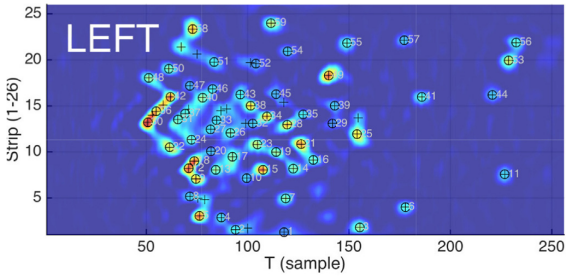
- Next step: apply these tools to real data

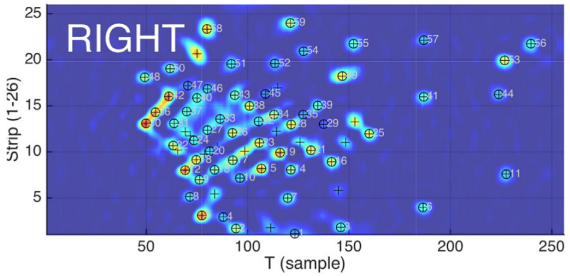
The community would benefit from share software and simulations standards.





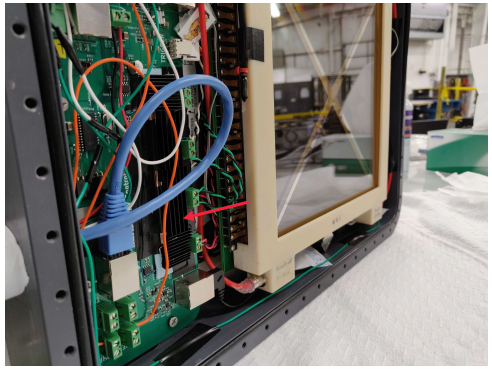


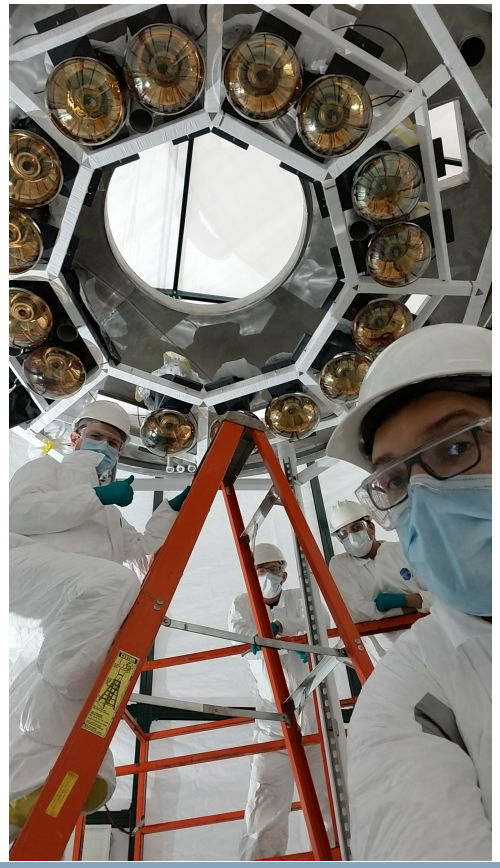




We're happy to be a resource

- LAPPDs are now a deployable technology
- We have learnt many lessons that we are ready to share with the community
- There are many benefits to establishing common frameworks and transferring knowledge
- We welcome collaboration on addressing existing challenges with Incom and other interested parties





Thank you

Further Reading

Disambiguation:

1. *Multiple-photon Disambiguation on Stripline-anode Micro-Channel Plates*, Nucl Instrum Methods in Phys. Res. Sect. A 822 (2016) 25 arXiv:1805.01077

LAPPD time resolution:

2. *Timing Characteristics of Large Area Picosecond Photodetectors*, Nucl Instrum Methods in Phys. Res. Sect. A 785 (2015) 1-11 10.1016/j.nima.2015.05.027

Cherenkov Scintillation Separation

3. *Measuring Directionality In Double Beta Decay and Neutrino Interactions With Kiloton-Scale Scintillation Detectors*, J. Instrum 9 P06012 (2014) arXiv:1307.5813

Test stand:

4. *FEATURED ARTICLE: A Test Facility for Large-area Microchannel Plate Detector Assemblies Using a Pulsed sub-Psec Laser,* Rev. of Sci. Instrum 84, 061301 (2013) 10.1063/1.4810018

LAPPD project history:

5. *A Brief Technical History of the Large Area Picosecond Photodetector (LAPPD) Collaboration https://arxiv.org/abs/1603.01843*