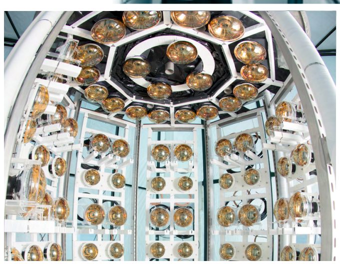
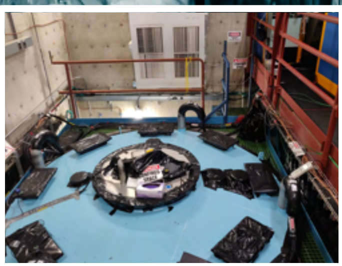


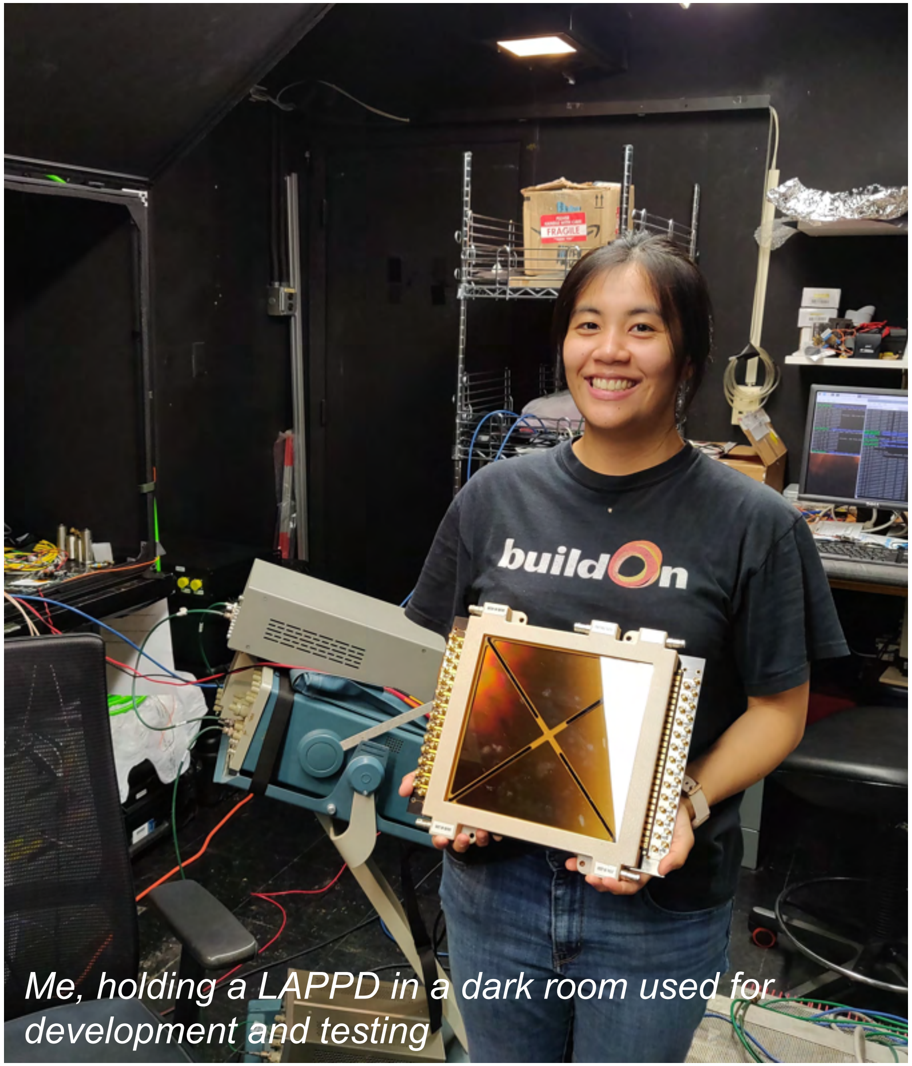




First Deployment of a Large Area Picosecond PhotoDetector in a Physics Experiment

Julie He
University of California, Davis
Lawrence Livermore National Laboratory

NSSC3 Kickoff Meeting and Advisory Board Review
April 19-20, 2022

Introduction



Me, holding a LAPPD in a dark room used for development and testing

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4th year PhD candidate
Neutrino Physics,
Detection Technology

Prof. Robert Svoboda
Physics & Astronomy
University of California, Davis
June 2023 🤞

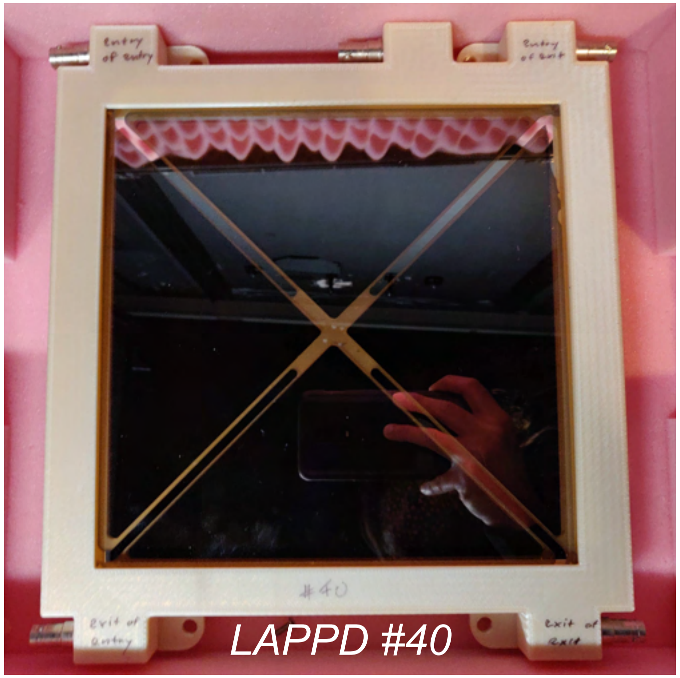
Adam Bernstein &
Steven Dazeley, LLNL

Mission Relevance: **Development of new photodetection technology for applications such as neutron detection**

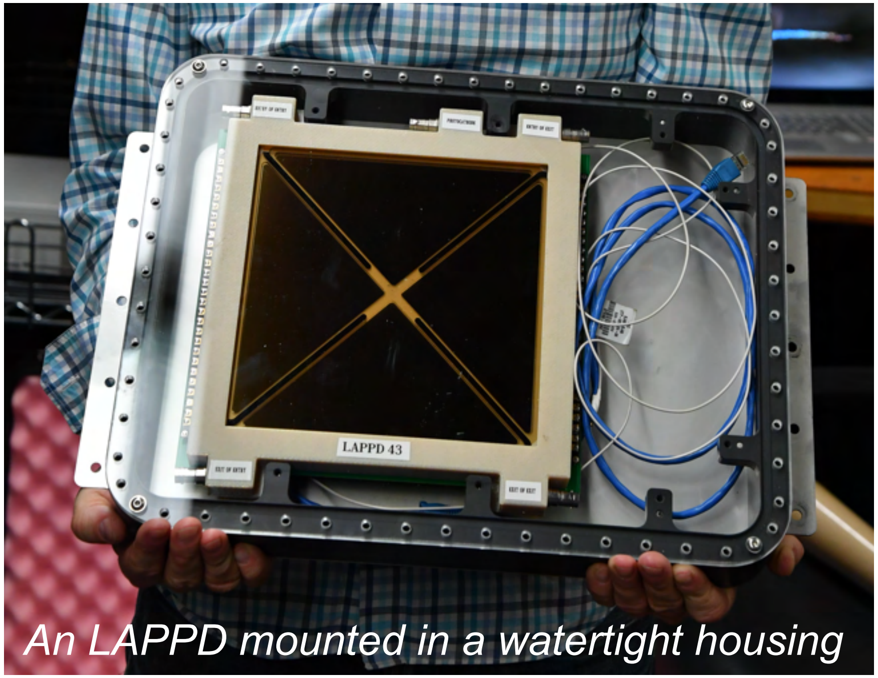
What is the LAPPD?

Large **A**rea **P**icosecond **P**hoto**D**etector

- 20 cm x 20 cm (8" x 8") photodetector based on MCP (microchannel plate) technology
- 28 anode striplines, with readout of both ends
- Sub-centimeter spatial resolution with picosecond timing
- Uniform, high quantum efficiency



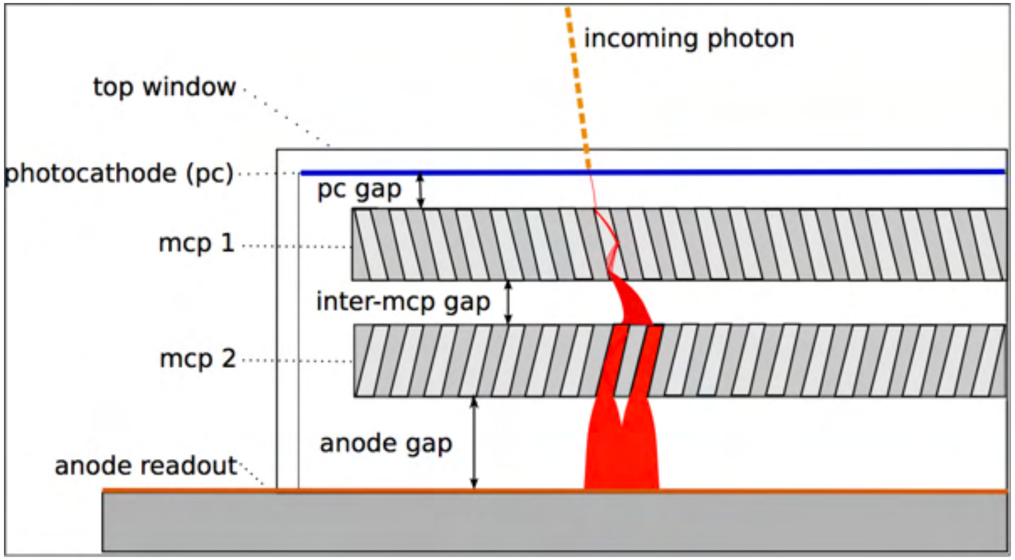
LAPPD #40



An LAPPD mounted in a watertight housing

The Technology Behind the LAPPD

- Consists of 2 microchannel plates (MCPs) with a resistive coating of ~100 nm applied via atomic layer deposition (ALD)
- Alkali photocathode
- High gain uniformity of 10^7 (comparable to conventional PMTs)
- ~60 ps timing resolution in main peak of transit time spread (TTS)
- <4% contribution from after-pulses (typical of any photodetectors)



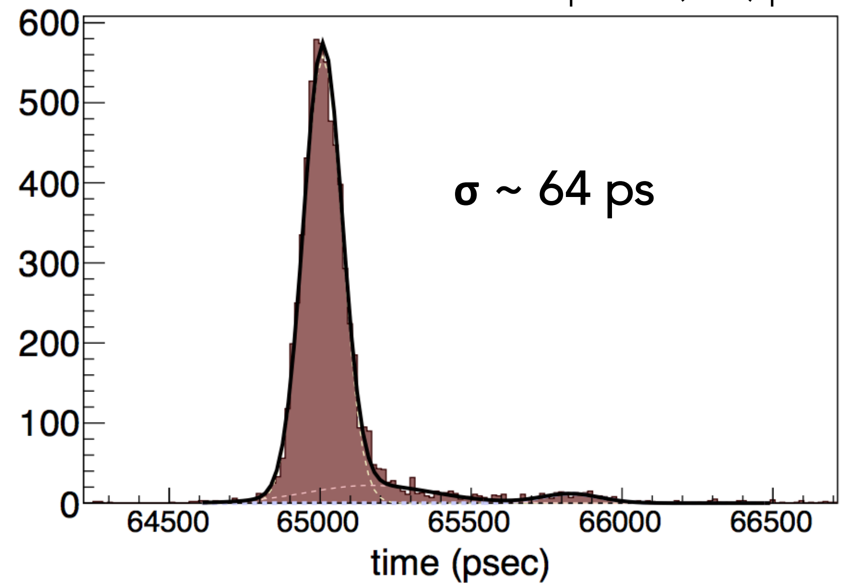
A diagram of the interior of the LAPPD

What Makes LAPPDs Better?

What makes LAPPDs better than conventional photomultipliers?

- Smaller form factor
  - Thickness of an LAPPD tile (window + MCPs + etc.) ~15mm
- High (> 20%) and very uniform (90% uniformity) quantum efficiency
- Better spatial resolution (centimeter level)
  - More "pixels"
- Fast timing (picosecond level)

Transit Time Spread (TTS) plot



The Many Hats of the LAPPD

LAPPDs are

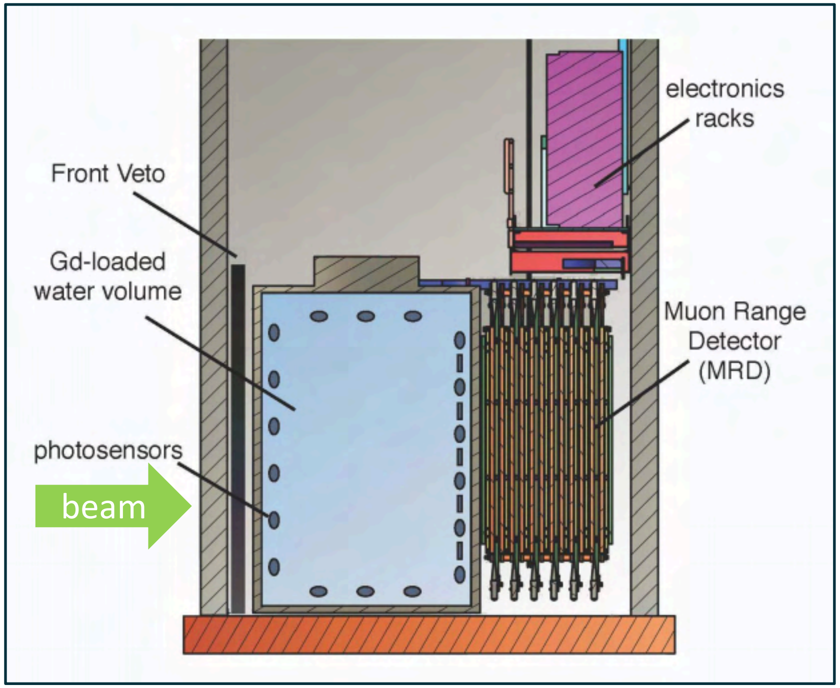
- Being developed as neutron cameras with the aid of scintillators (Sandia)
- Used in satellites due to their high precision and low power consumption (e.g. to detect gamma ray bursts)
- Potential detectors in medical imaging
- Deployed for the first time in physics experiments, such as ANNIE

Images: Incom

What is ANNIE?

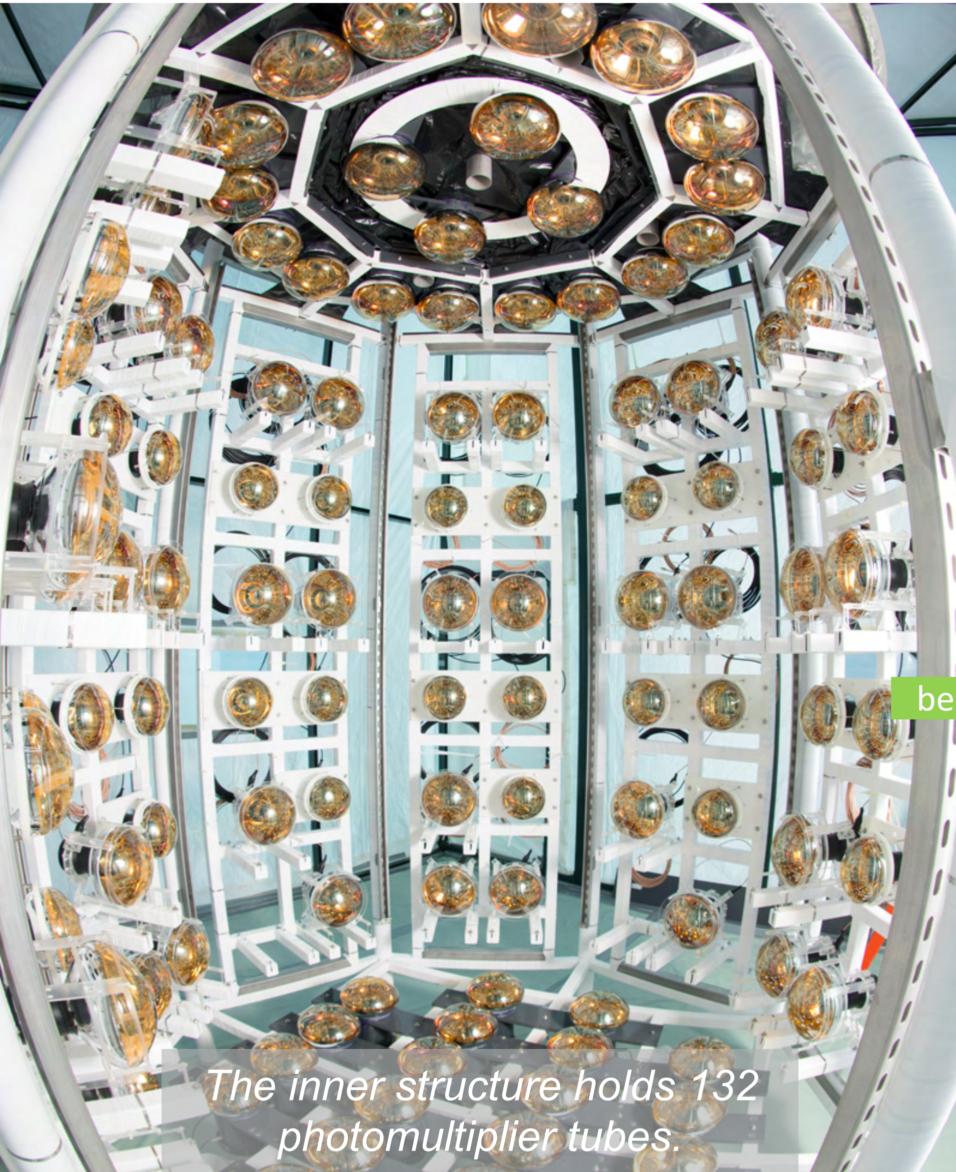
Accelerator **N**eutrino **N**eutron **I**nteraction **E**xperiment

- 3-m dia. x 4-m tall (10-ft x 13-ft) cylindrical **water Cherenkov detector**, located 100 m down-stream in Fermilab's Booster Neutrino Beam (BNB)
- Equipped with **132 conventional PMTs** and **5 novel Large Area Picosecond Photodetectors**
- Completed Phase I ✅
  - Background characterization
- **Currently in Phase II**:
  - Commission full detector
  - Deployment of LAPPDs
  - Physics data-taking; neutron multiplicity measurement

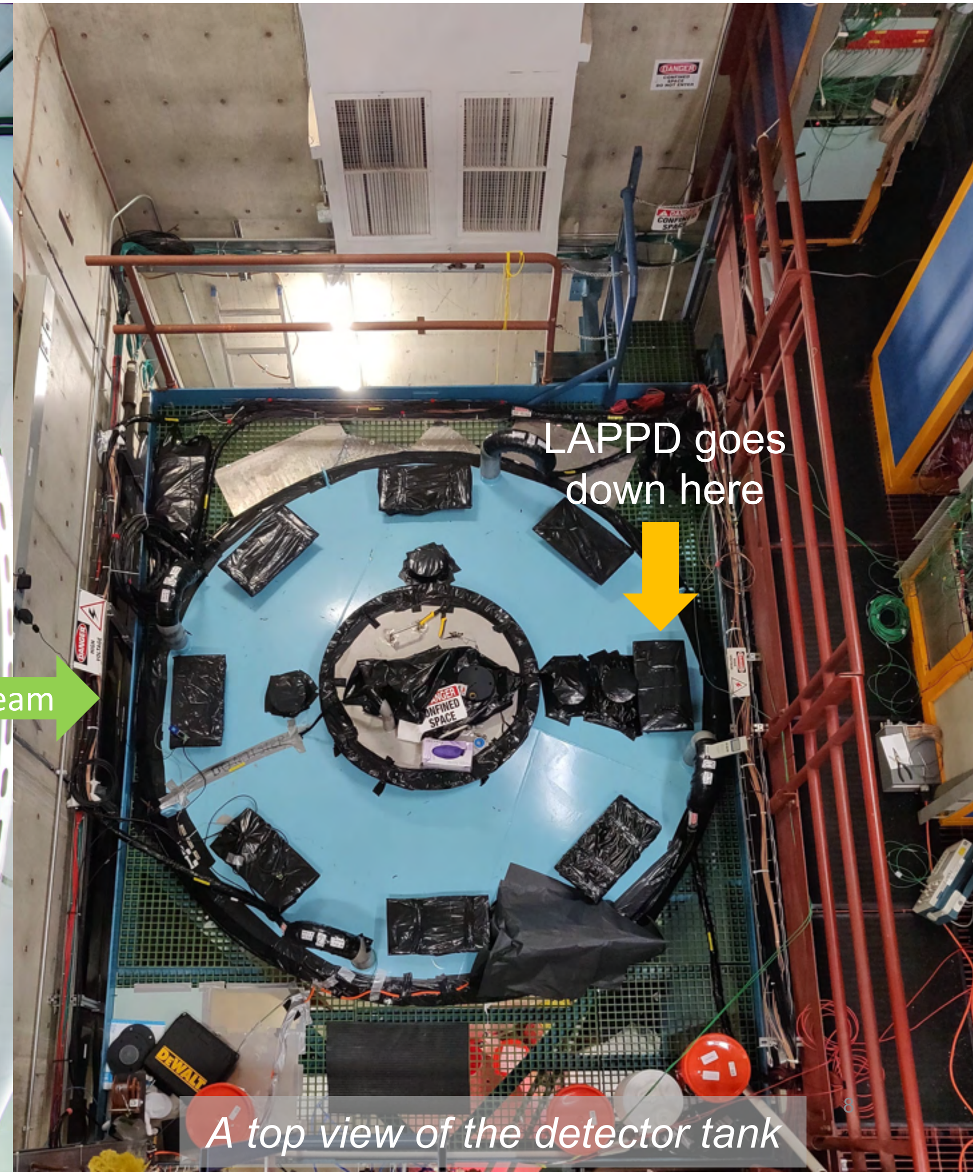


ANNIE detector diagram

A Sneak Peak Into ANNIE…



The inner structure holds 132 photomultiplier tubes.

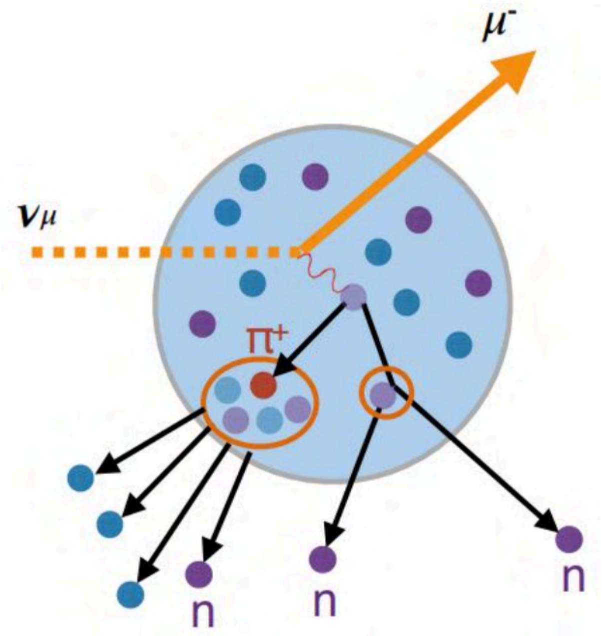


A top view of the detector tank

ANNIE's Physics Goals

Measurement goals:

- **Final state neutron multiplicity** of neutrino-nucleus interactions
  - Important for quantifying atmospheric background of DSNB and proton decay searches
- **Neutrino cross section on water**, specifically on oxygen
  - Beneficial to long-baseline neutrino oscillation experiments by helping reduce the associated systematic uncertainties

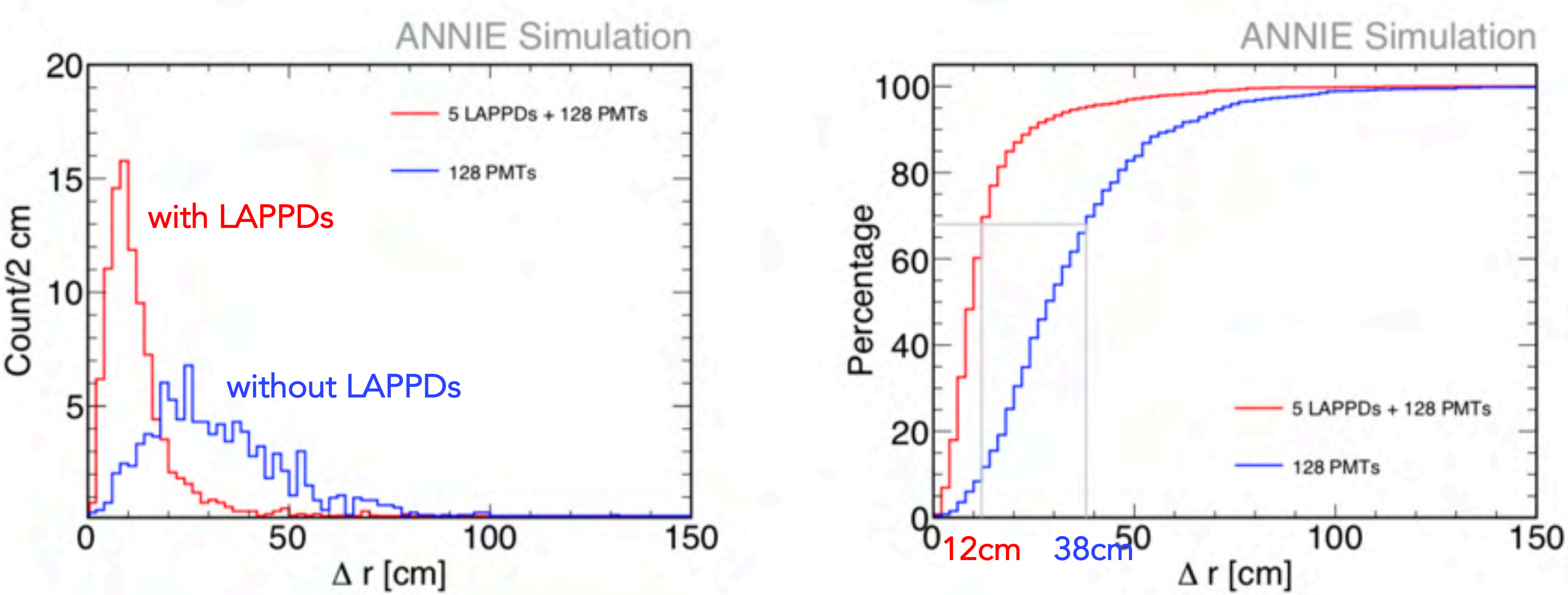


Unique capabilities of ANNIE:

- Detector sits on a neutrino beam — **high statistics** measurement
- **High sensitivity to neutrons** (gadolinium-loaded water)

Why LAPPDs Are Good for ANNIE

- 5 LAPPDs will be deployed in the ANNIE detector
- Improves vertex reconstruction ability to more accurately determine the energy of the produced lepton
  - LAPPDs will provide us better timing, spatial, and angular information

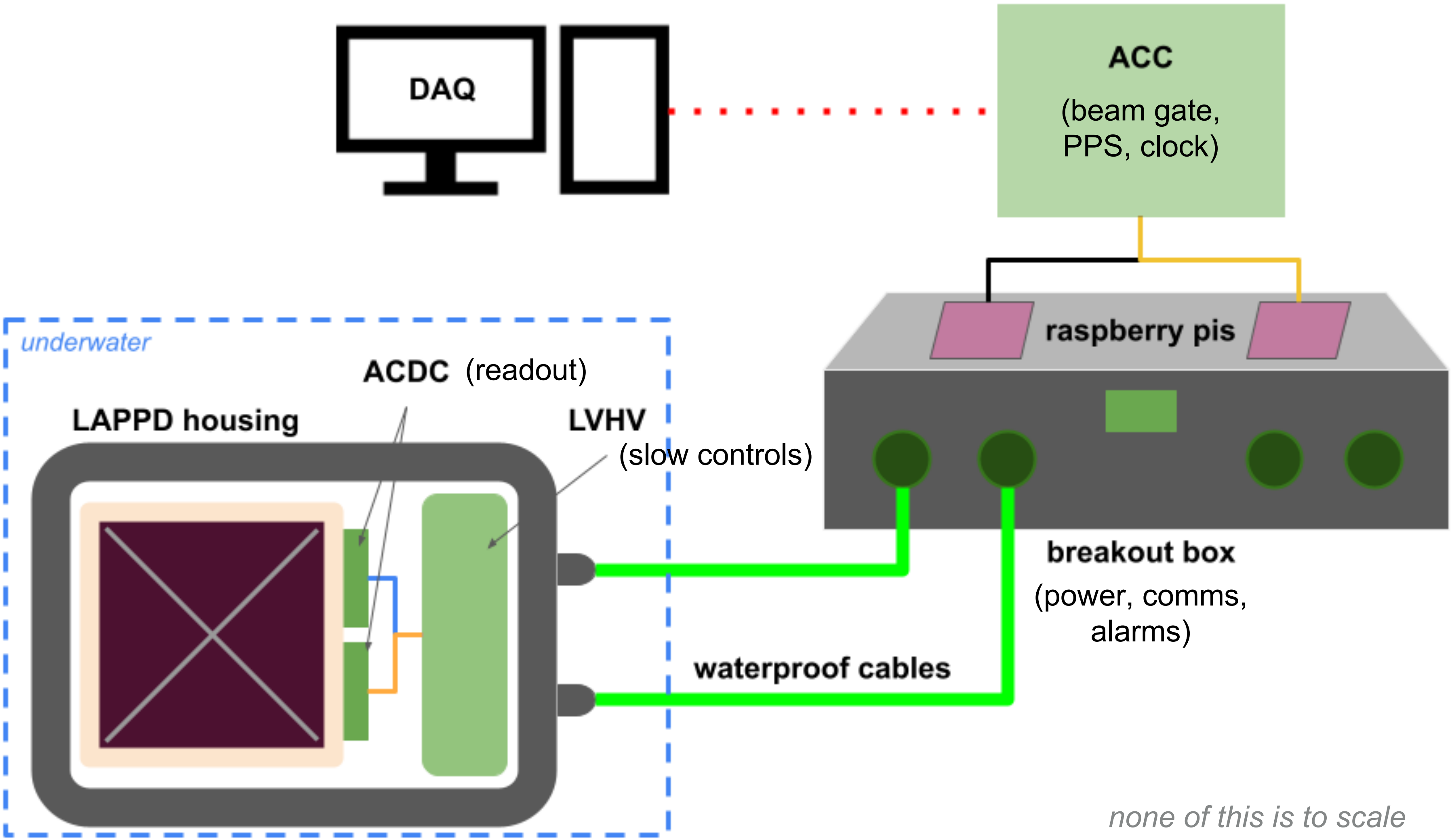


With the addition of just 5 LAPPDs, we can see a vast improvement in position resolution, for example.

Challenges of LAPPD Deployment

- This is a **new photodetection technology** so many system components are **custom made**
  - Cabling
  - Watertight housing
  - Readout electronics
  - Breakout box
- **First in remote deployment** (compared to having channels read out by digitizers in the immediate vicinity) in water
  - Concerns about water-tightness, heat dissipation
- Ran into electronics communications problems
  - Grounding issues
  - Conflicts on communication and data lines
- Despite the challenges, we’ve made a lot of progress towards first deployment of LAPPDs in ANNIE !

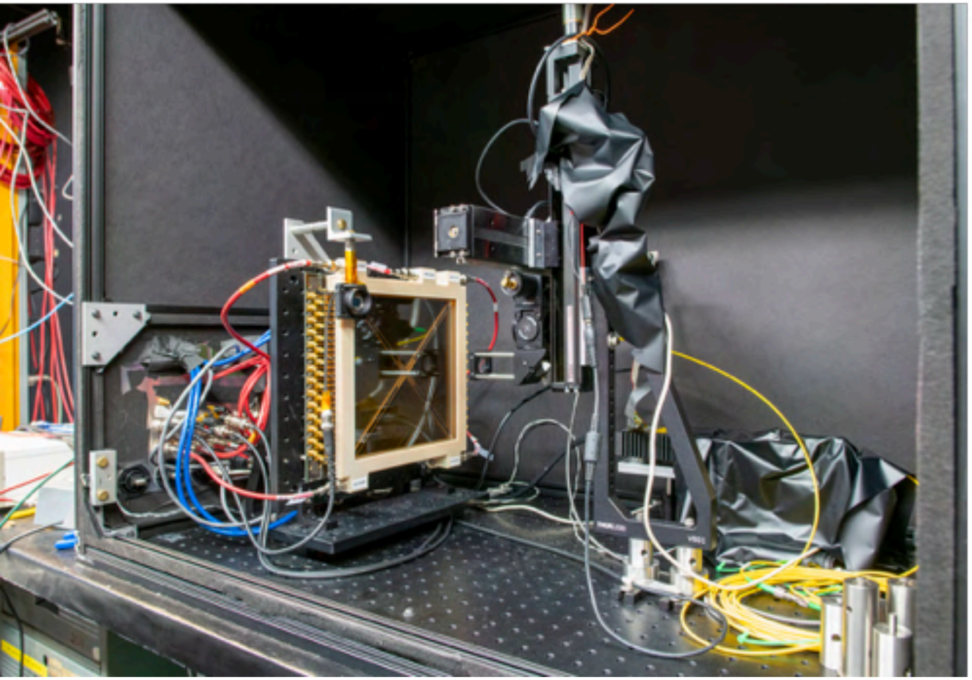
Full System Diagram: End Goal



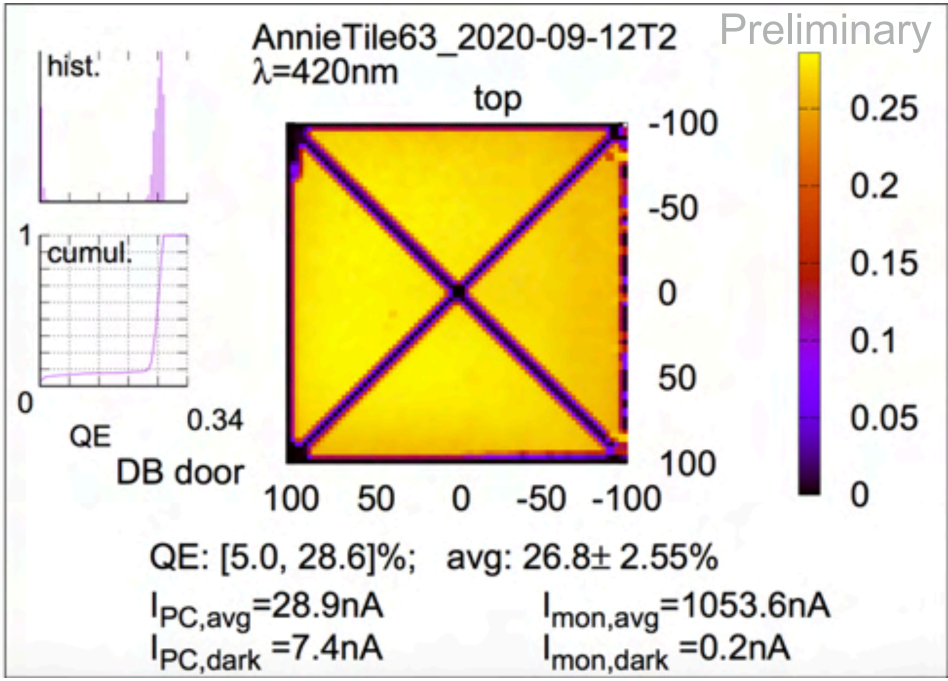
none of this is to scale

LAPPD Characterization

- Characterized quantum efficiency (QE) and timing capabilities of LAPPD
  - QE scans were performed with an LED
  - Laser scans were used for timing measurements
  - Also performed parallel and transverse (to striplines) scans to study cross-talk, etc.



An LAPPD mounted in a dark box setup.



A plot of the quantum efficiency of LAPPD #63.

LAPPD System Integration

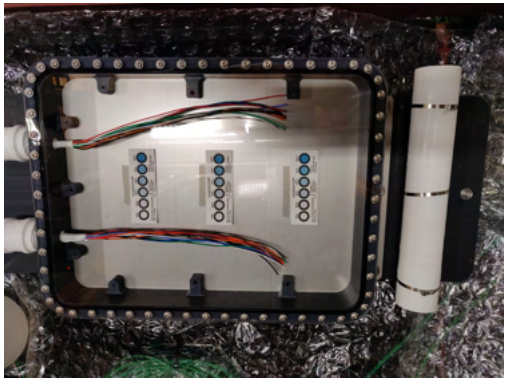
Some of the work I carried out at UC Davis

- Put together power and data waterproof cables
- Designed waterproof housing and deployment panel & mechanism
- Wrote the slow controls software to monitor temperature & humidity, set voltages, and so on

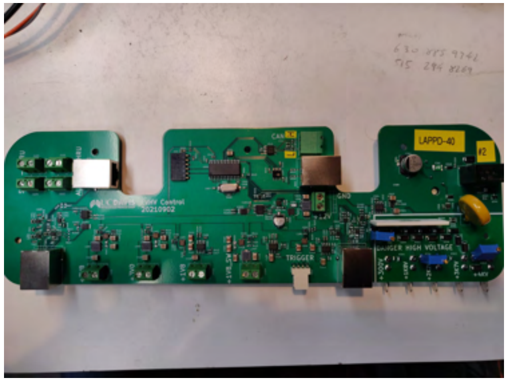
… at FNAL (Fermi National Accelerator Laboratory)

- Tested the power and data transfer capability of cables
- Tested water-tightness of housing and deployment mechanism
- Tested the slow controls software with all relevant electronics and debugged LVHV board (slow controls)

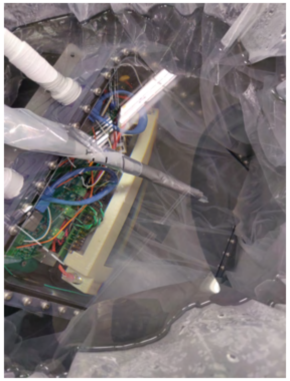
Waterproof cables



Waterproof housing

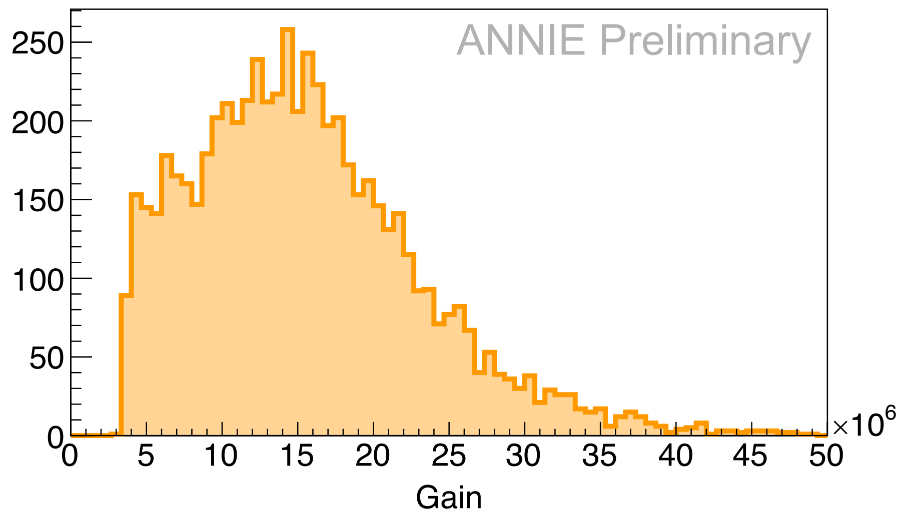


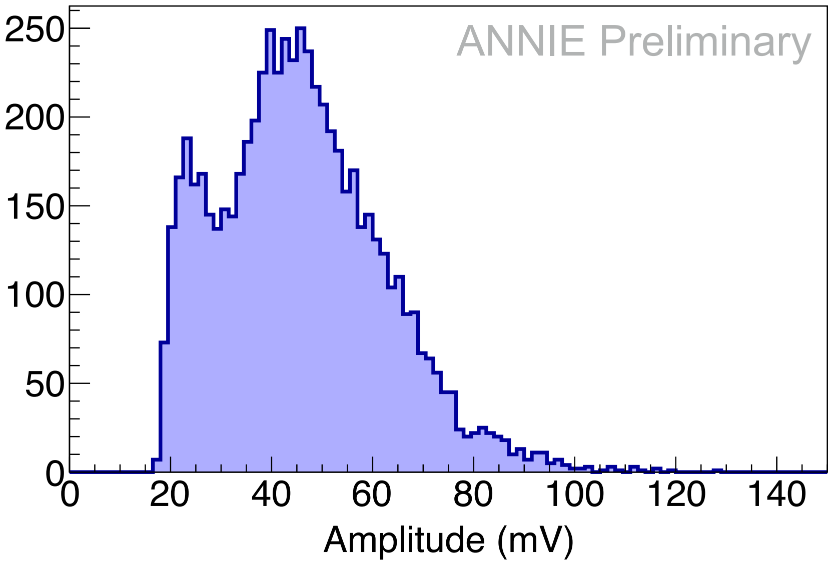
LVHV board



Soak test

Benchtop Results with Custom Electronics





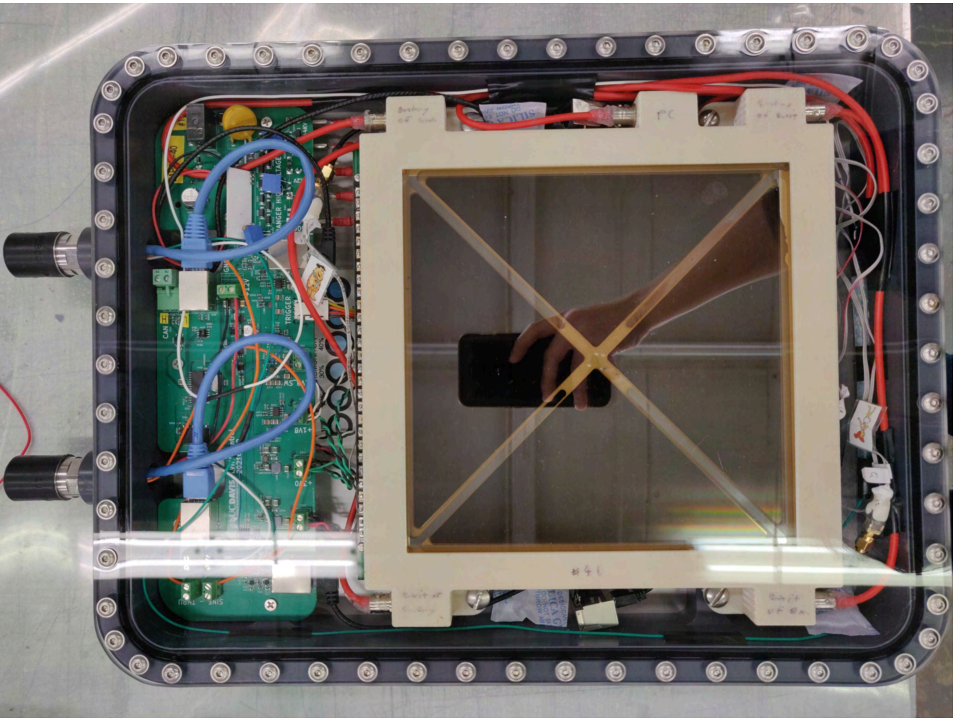
- Data taken with a green LED with settings that produce low levels of light

- Trigger board thresholds set to ~20 mV for individual channels

- Measured gain: 1.36×10^7
- Incom predicted gain: $\sim 6 \times 10^6$

First LAPPD Deployed!

- After much prolonged anticipation, ANNIE deploys its first LAPPD
- Some recent challenges:
  - Heat dissipation
  - Integration of thermistor, salt bridge, and slow controls monitoring



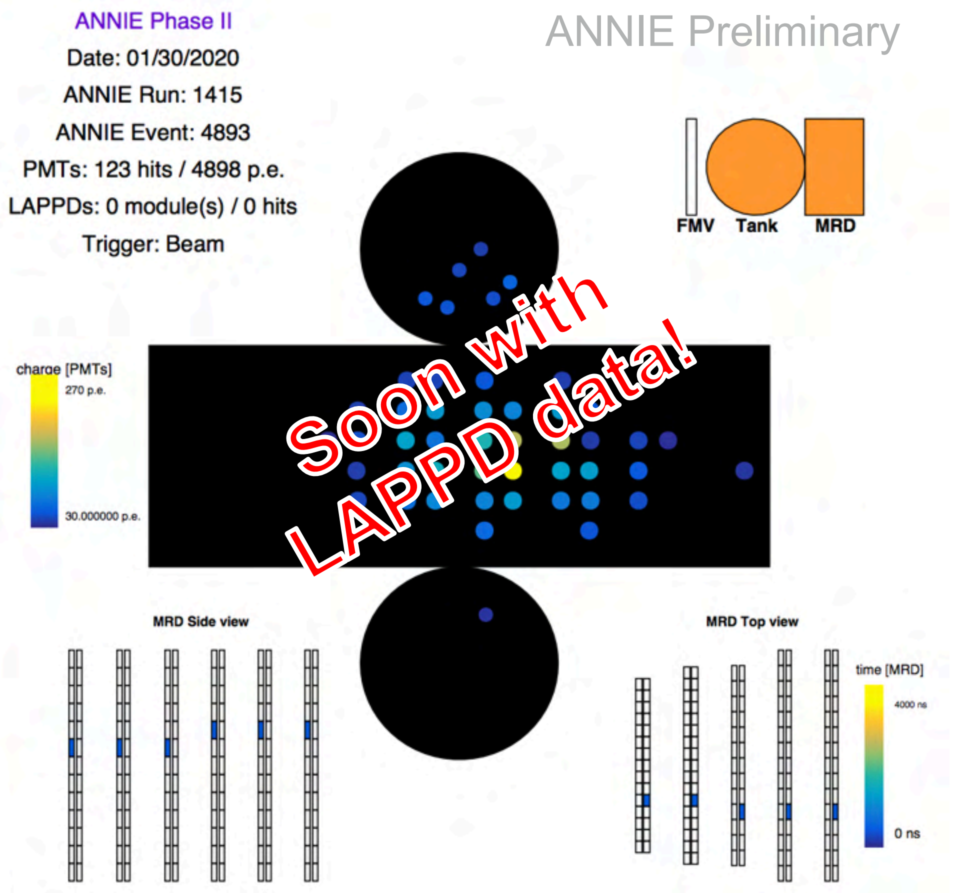
LAPPD #40 and all its electronics inside the waterproof housing

LAPPD cables coming out of the ANNIE tank!

Coming Soon…

First ANNIE event with LAPPD data is coming soon!

- Need to integrate LAPPD DAQ software with main ANNIE DAQ
- Need to fine-tune the data acquisition window



Only 4 more to go!

Summary

- Large Area Picosecond PhotoDetectors (LAPPDs) are a novel technology with sub-centimeter spatial resolution and fast timing
- LAPPDs have potential in many applications, including physics experiments
- ANNIE will take advantage of LAPPDs to pursue its physics goals, notably the measurement of neutron multiplicity of neutrino-nucleus interactions
- ANNIE recently deployed its first LAPPD 🎉

ANNIE Collaboration

Spring Collaboration Meeting 2021

annie

We can do ANNIE-thing!

NSSC Experience

NSSC Post-bac Affiliate 2017-2018

- **Nuclear Analytical Technique (NAT) Summer School** as an instructor and participant

NSSC Graduate Affiliate 2018-present

- **UPR 2018** (Ann Arbor, MI)
- **GW Nuclear Policy Boot Camp 2021**
- Continued involvement with the NAT Summer School

From these workshops and programs

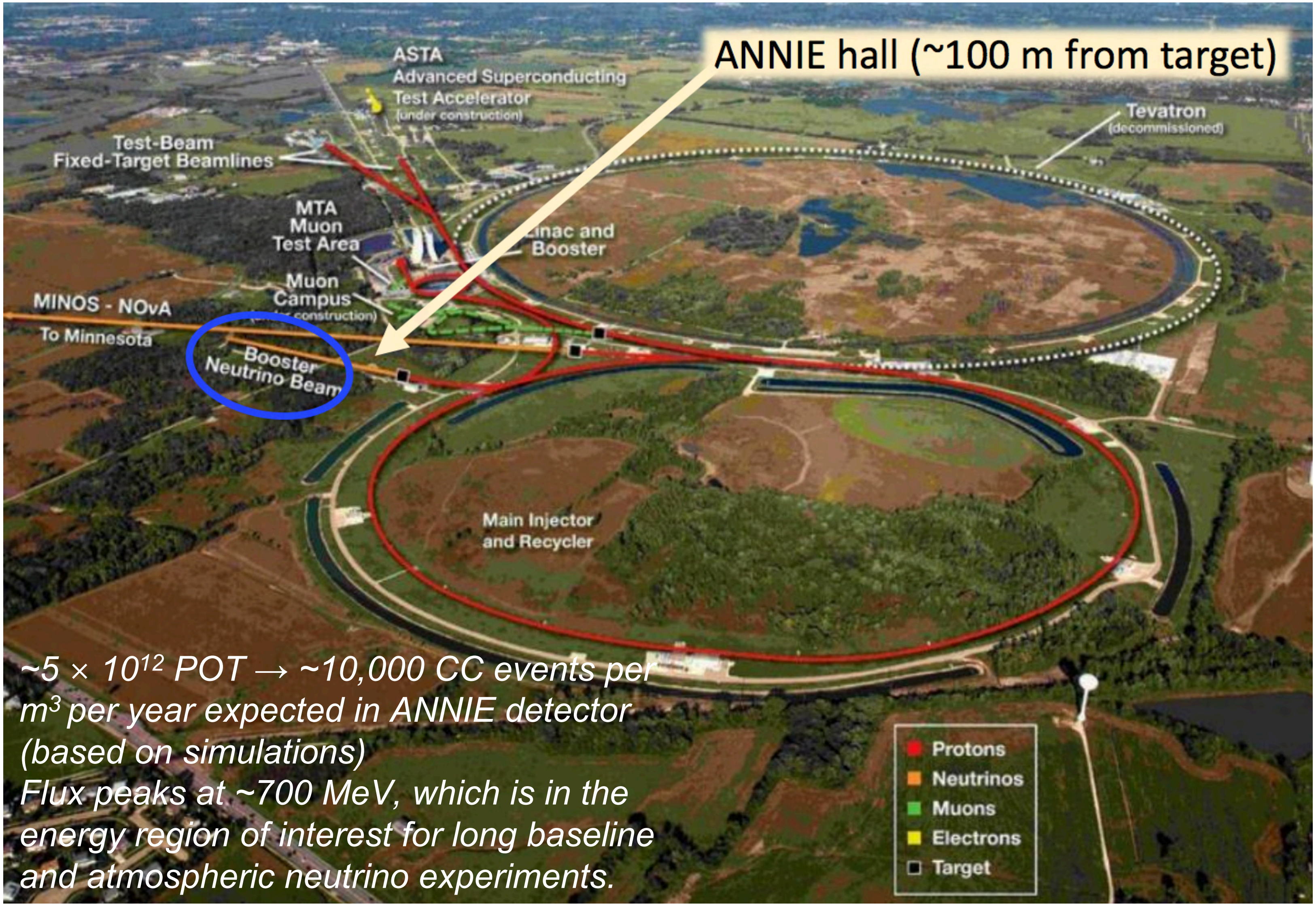
- Many skills were gained (e.g. hardware, software)
- Exposed to many great opportunities for career advancement and networking

Acknowledgements

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number **DE-NA0003996.**

BACK-UP

Fermilab's Booster Neutrino Beam



~5 × 10^{12} POT → ~10,000 CC events per m^3 per year expected in ANNIE detector (based on simulations)

Flux peaks at ~700 MeV, which is in the energy region of interest for long baseline and atmospheric neutrino experiments.

The Insides of an LAPPD

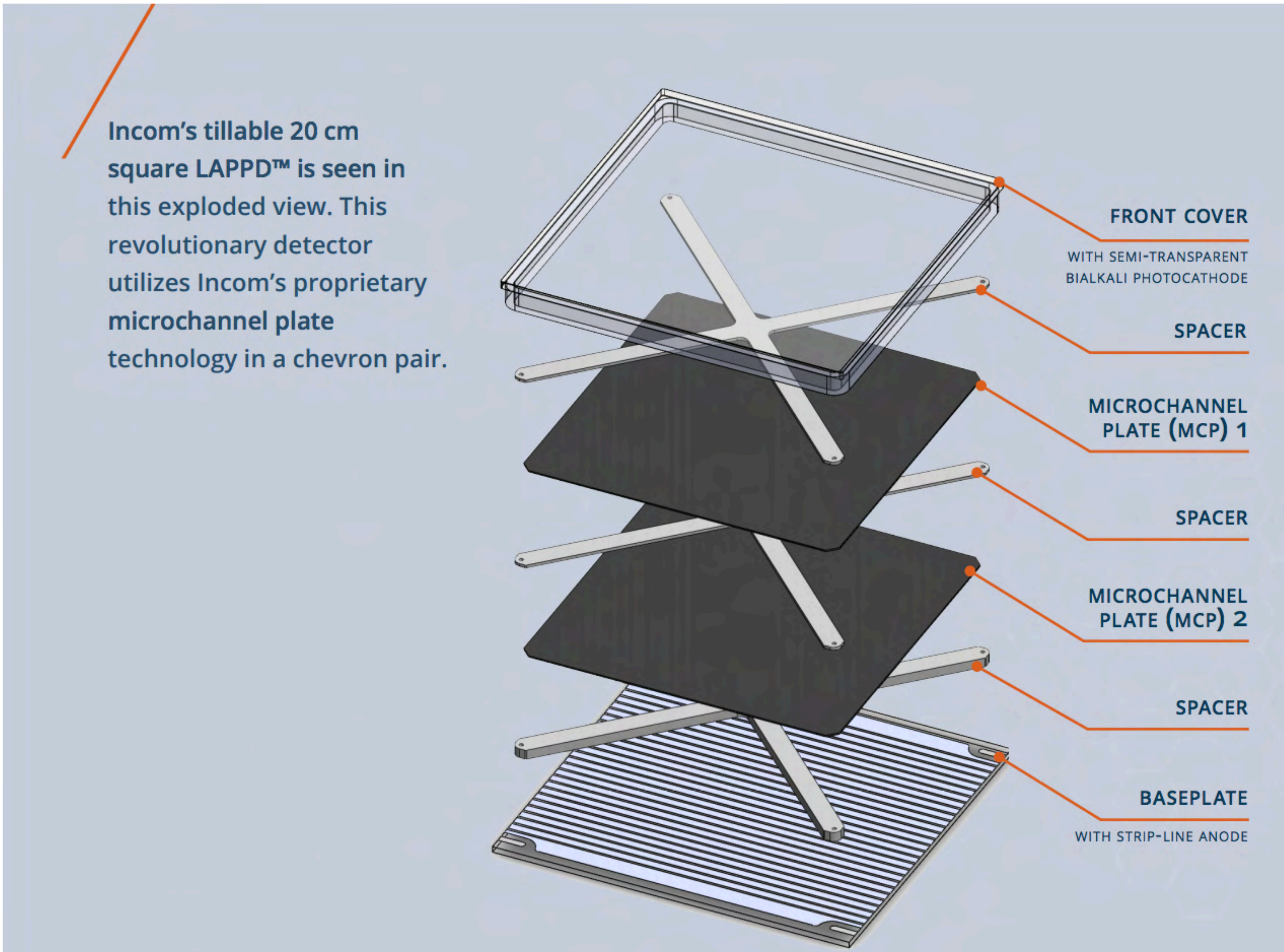
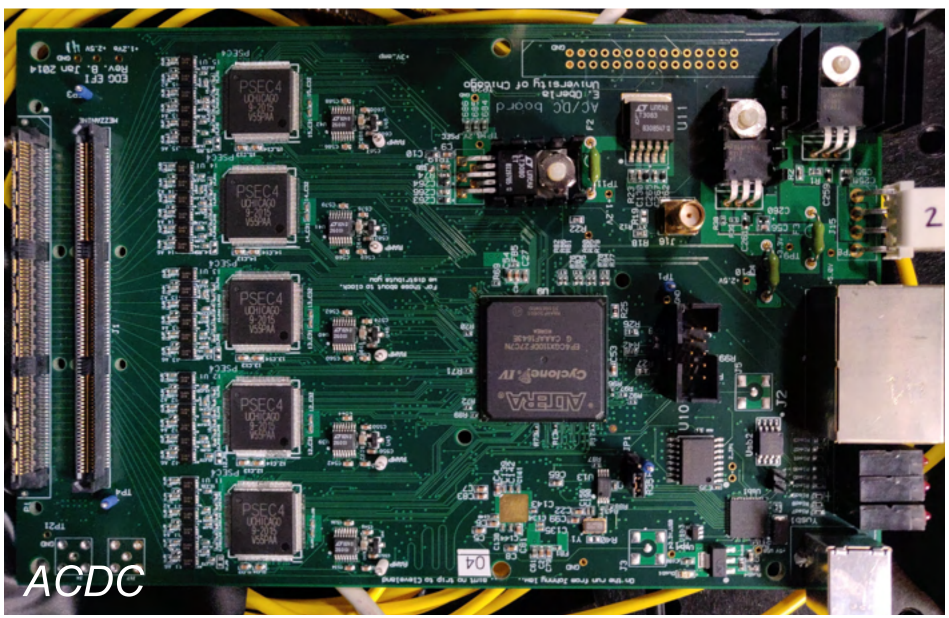


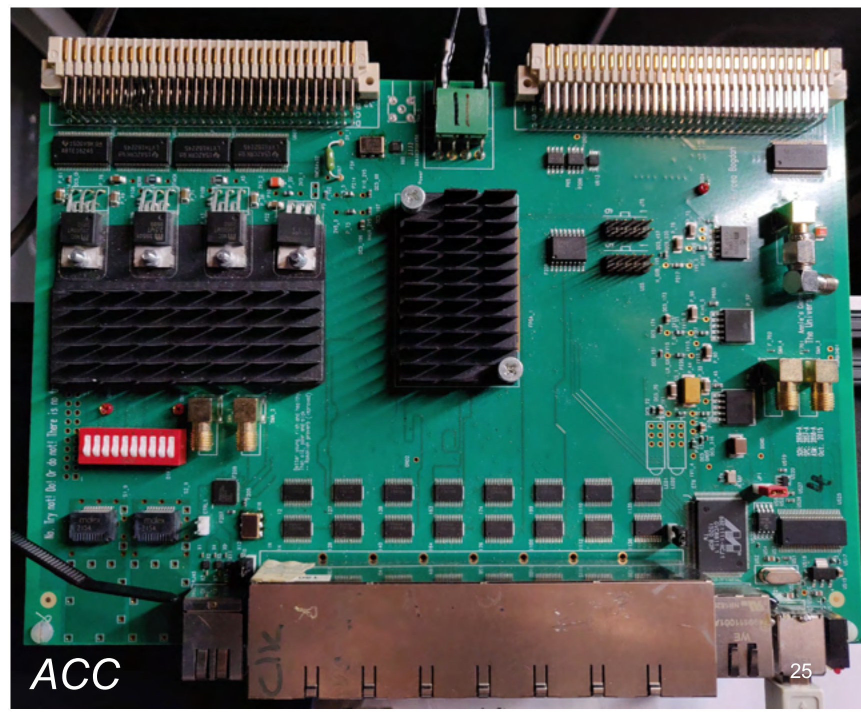
Image from Incom's LAPPD product sheet

Readout Electronics: ACC/ACDC

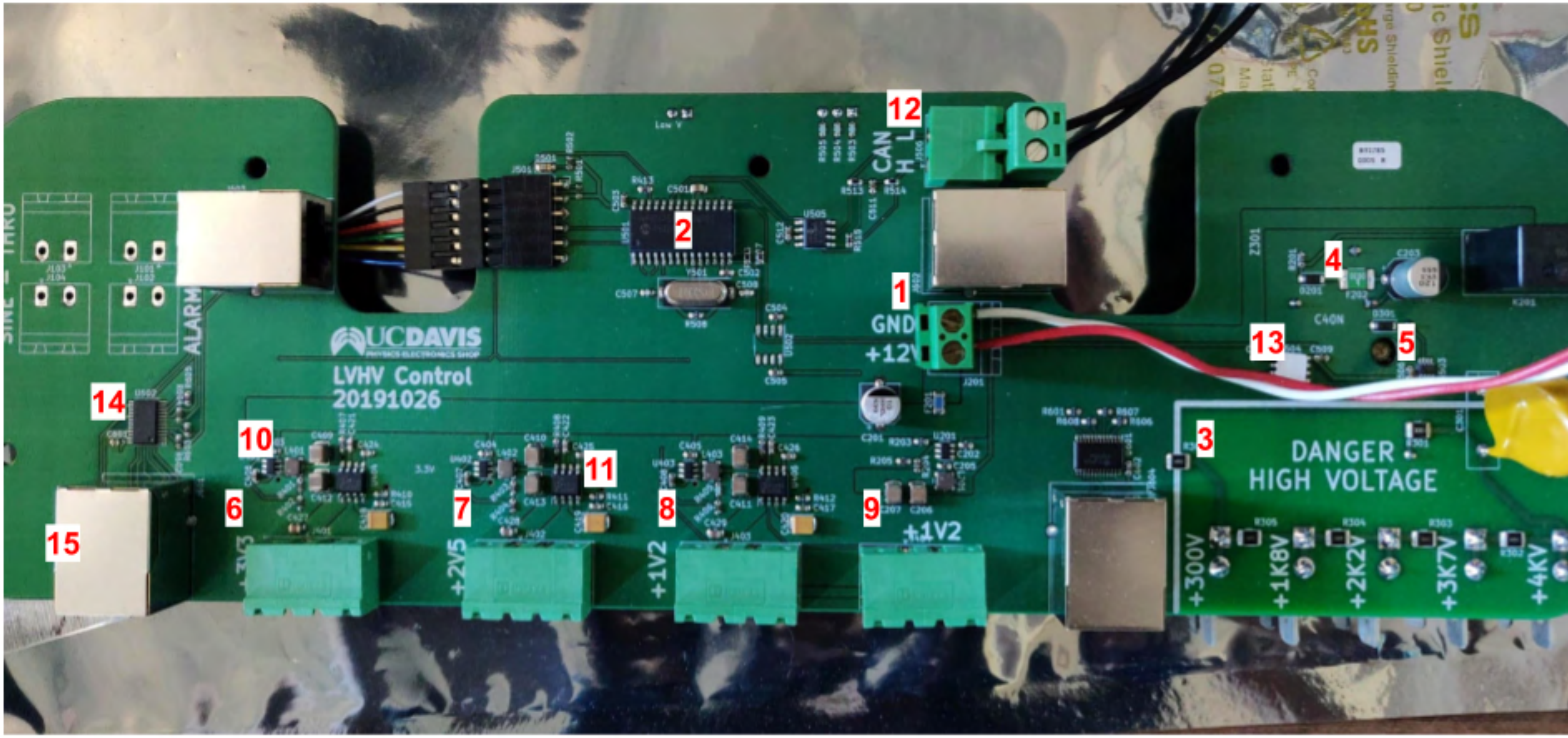
- The ACDC and ACC cards were designed (at U Chicago) to read out the 28 striplines of the LAPPD
- ACDC card: reads 30 channels, 5-15 GSa/s, 1.5 GHz bandwidth; fast sampling rate for precision timing (but some dead time); each LAPPD is equipped with 2
- ACC card: controls up to 8 ACDC cards; point of communication between user and ACDC



ACDC


ACC

Slow Controls: LVHV Board



1 - Power input (+12V, GND)
2 - PIC microcontroller
3 - HV components
4 - polyfuse

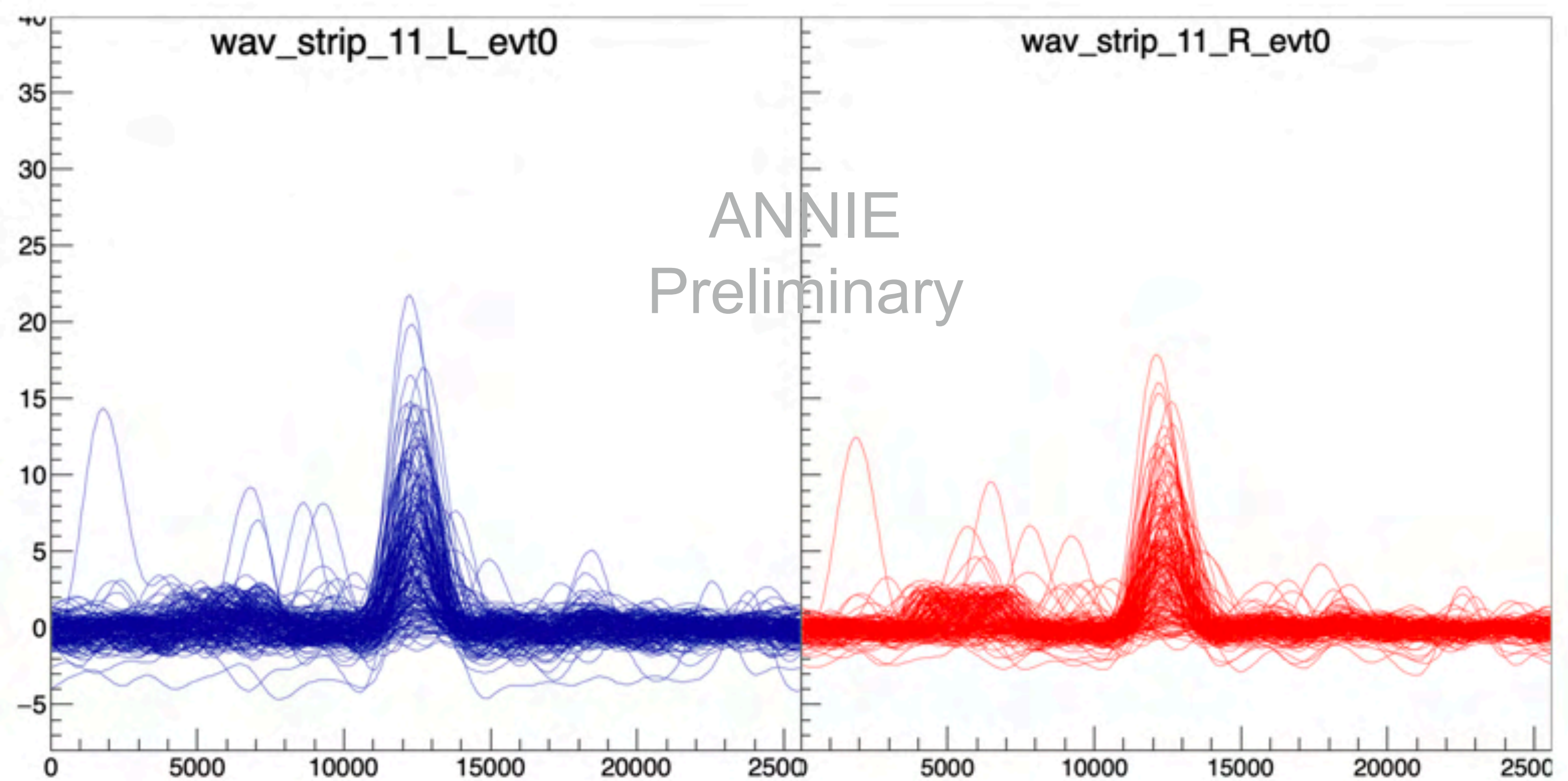
5 - LTC2631-HZ DAC
6-9 - LV lines (+1.2, +2.5, +3.3V)
10 - TPS562200 step-down converter
11 - ADP7158 linear regulator

12 - CAN bus
13 - HIH6030-021 RH&T sensor
14 - FIN1104 LVDS high-speed repeater
15 - RJ45 port

The LVHV board monitors the humidity, temperature, and voltage output inside the watertight housing. It also mediates the transfer of data between the ACDC and ACC boards.

LAPPD Waveforms Acquired!

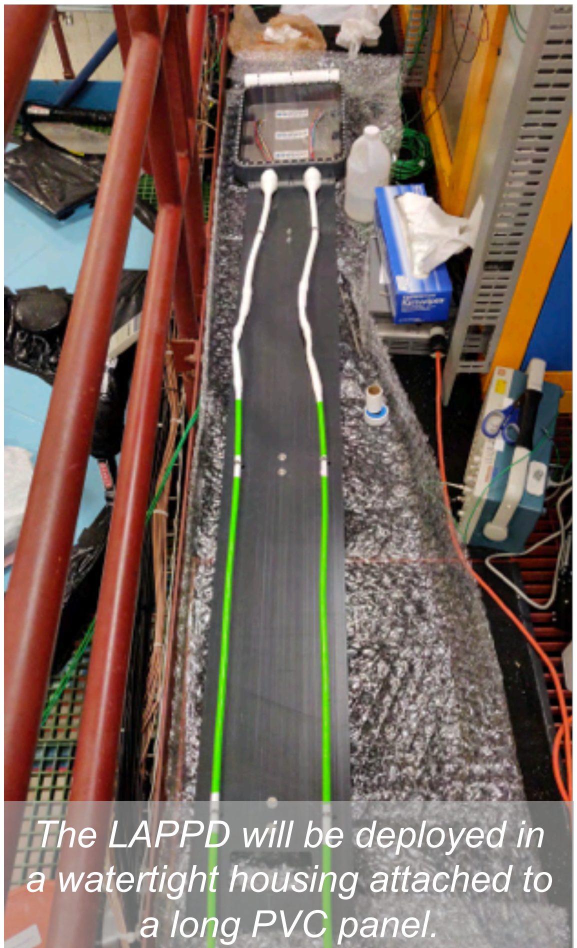
- Developed and improved LAPPD data acquisition software
- Made significant progress on data analysis software



Processed waveforms that have been smoothed out using FFT. These are pulses read out from the left and right sides of the anode stripline.

LAPPD Deployment Tests

- Tested the deployment mechanism of LAPPD with great success!

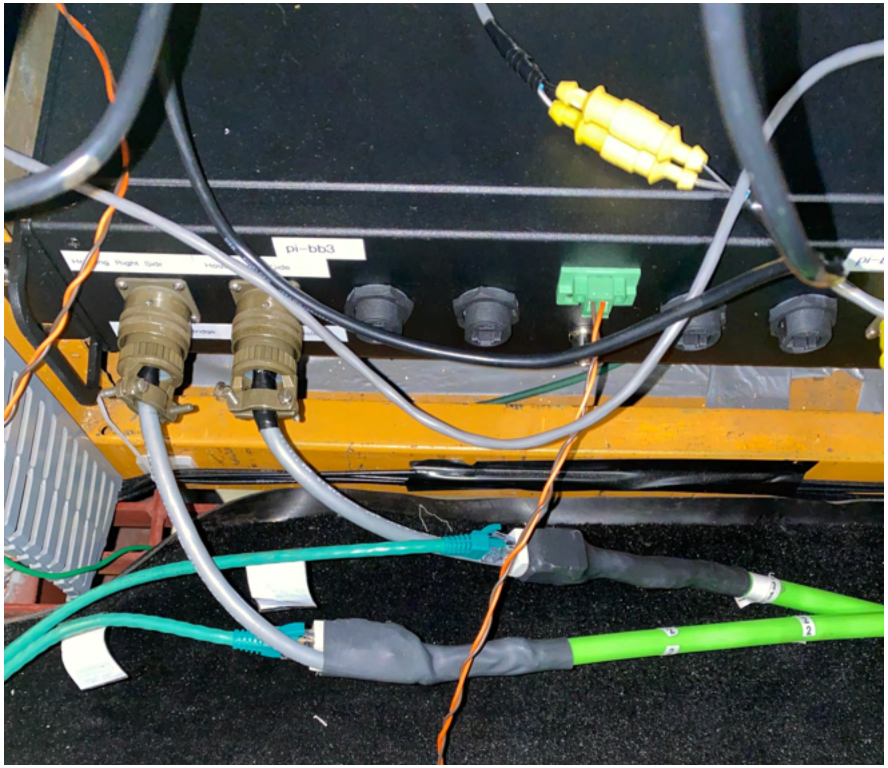


The LAPPD will be deployed in a watertight housing attached to a long PVC panel.

Waterproof cables are used for data transfer and communication with LAPPD electronics.

Legend says she is still holding those cables to this day…

Actual LAPPD Deployment



Left: LAPPD housing situated at the middle of the deployment panel with cables coming out of the top
Right: Cables come out of the tank and plug into this breakout box located in one of the electronics rack

LAPPDs See First Light!