LAPPDs for ND-GAr

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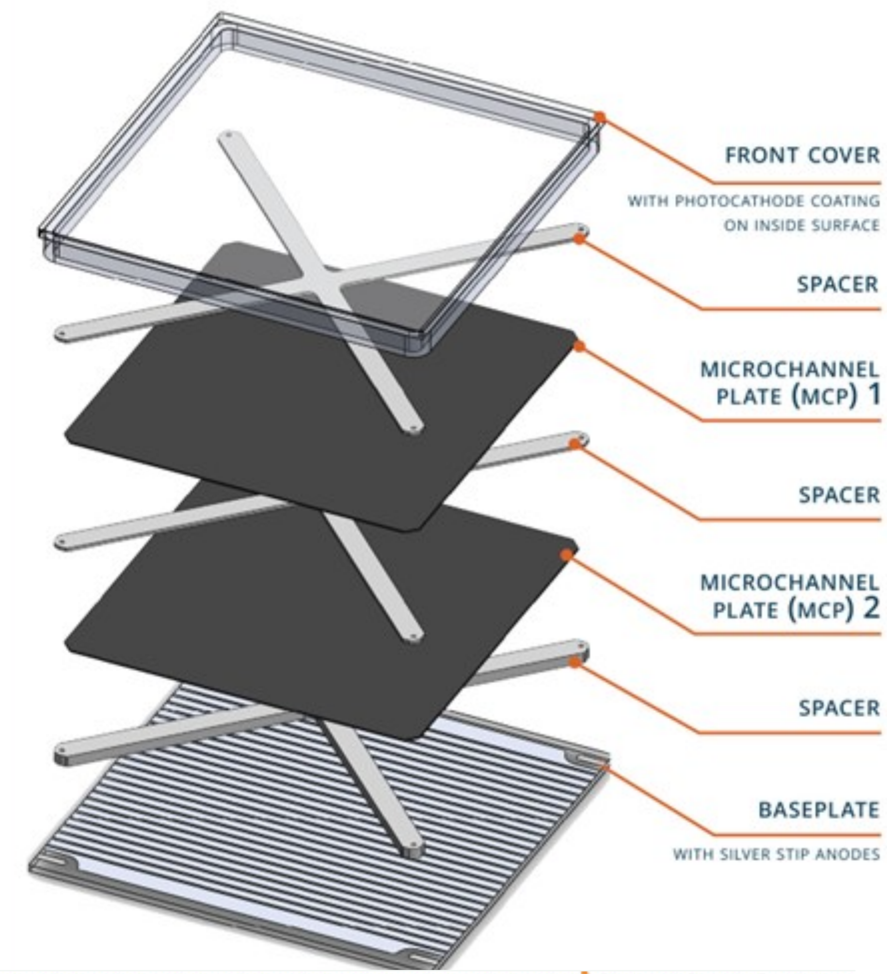
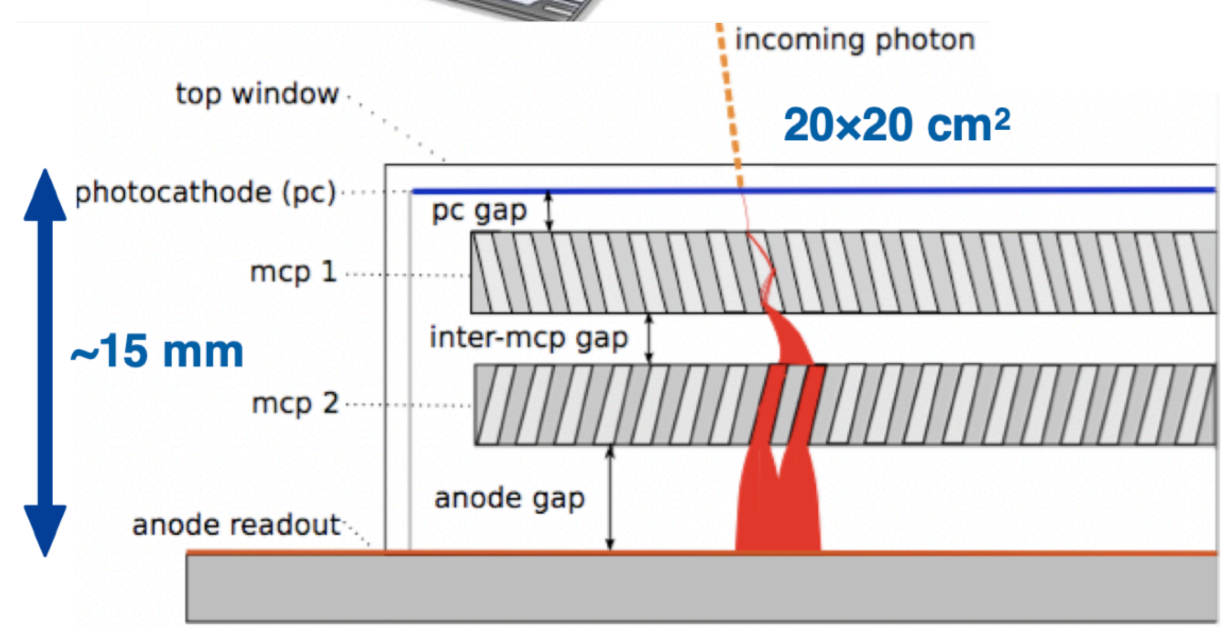
What are LAPPDs?

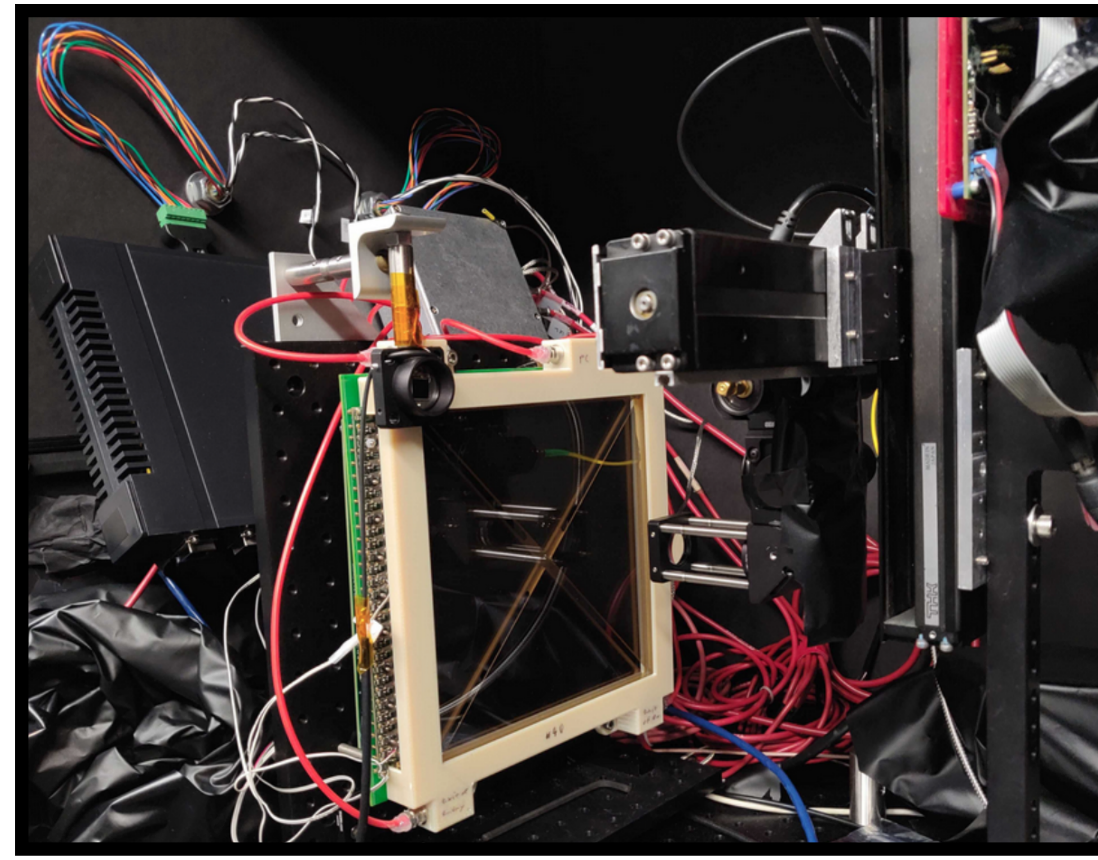
- LAPPDs were developed by a consortium of universities, national laboratories and industry.
  - Currently manufactured by Incom, Inc
- Key innovation is an microchannel plate (MCP) made of a glass substrate with layers of conductor/resistive materials delivered atomic layer deposition techniques.
- Photoelectrons are multiplied by two layers of MCPs. The electron cascades then hit one or more strip anodes.
- Reading out the signal at both ends of the strip the time differential can be used to determine position in that dimension. The second dimension is given the position of the strip.

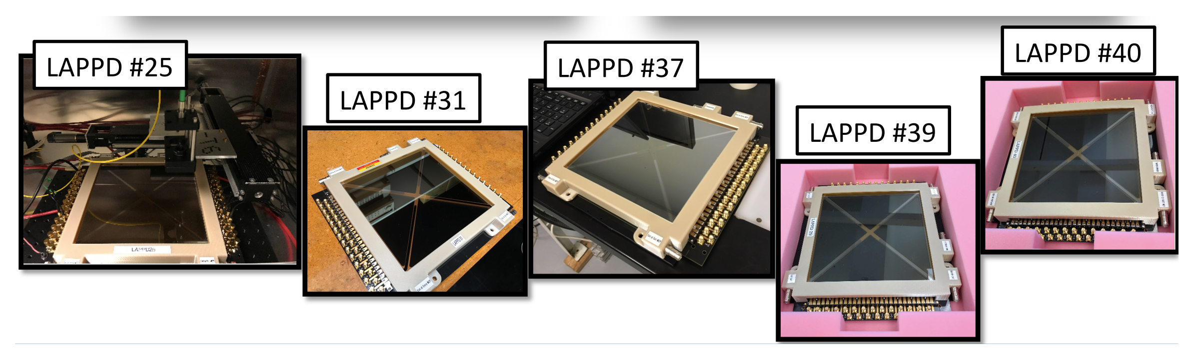




What are LAPPDs?

- Large Area Picosecond Photo-Detectors (LAPPDs) are 20 x 20 cm tiles based on microchannel plates (MCPs) with resistive and emissive coating and microstrip anode readout.
- Fast photodetector capabilities (~<100 psec time resolution) and excellent position resolution (mm-cm scale).
- The ANNIE collaboration owns 5 LAPPDs at Fermilab currently being deployed.
- We have taken LAPPDs from prototypes in test stands to a deployable technology.

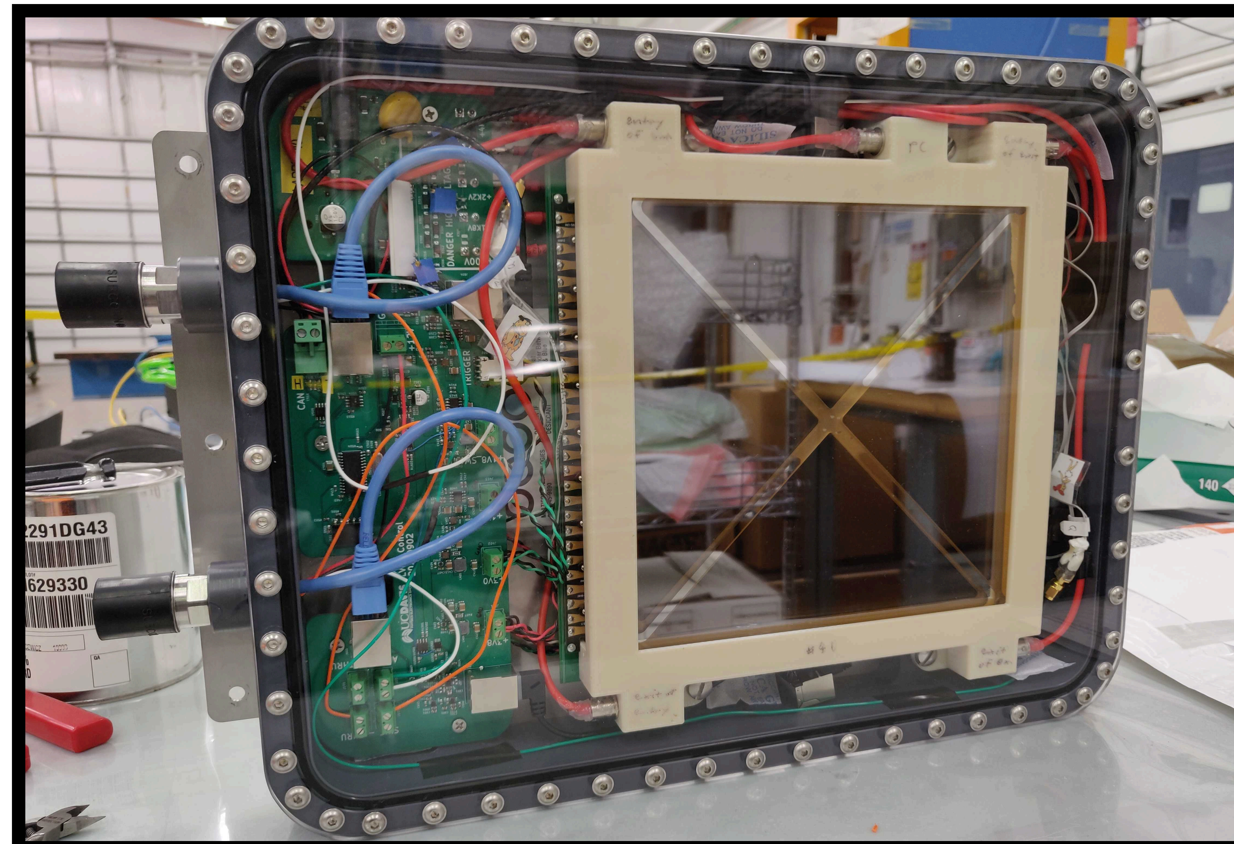


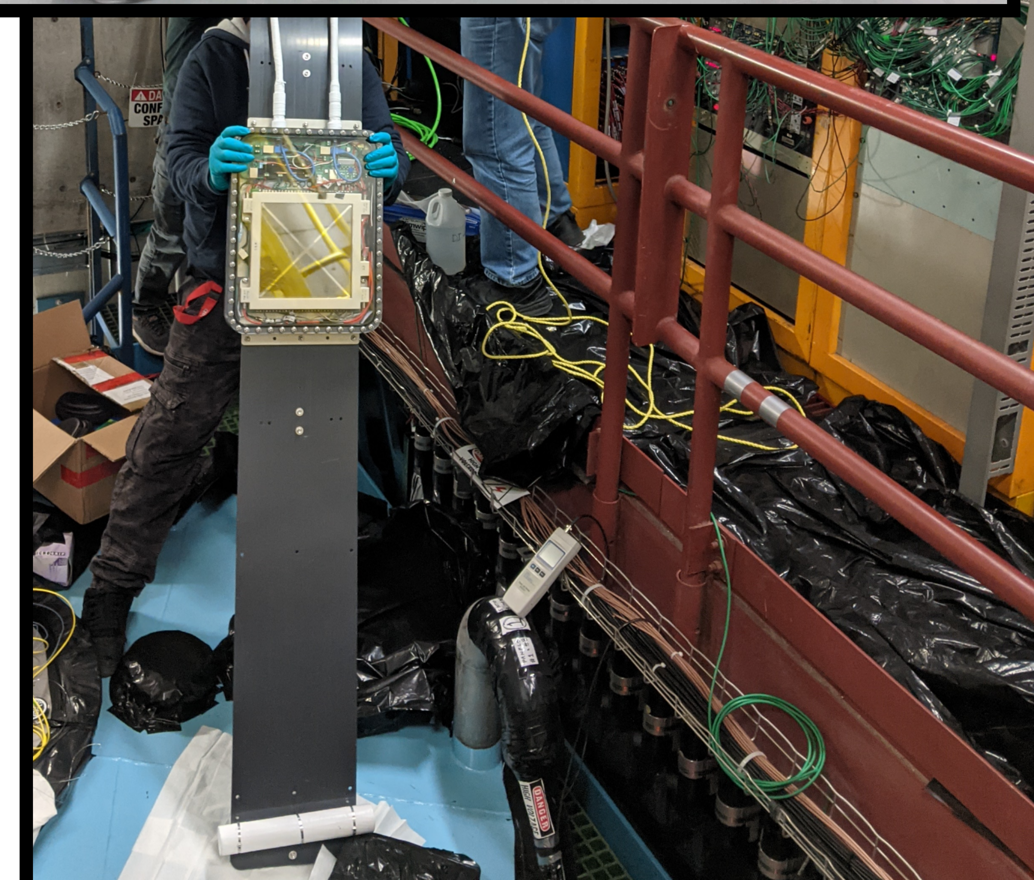


Performance of Large Area Picosecond Photo-Detectors (LAPPD)
https://doi.org/10.1016/j.nima.2019.162834

Using LAPPDs IRL

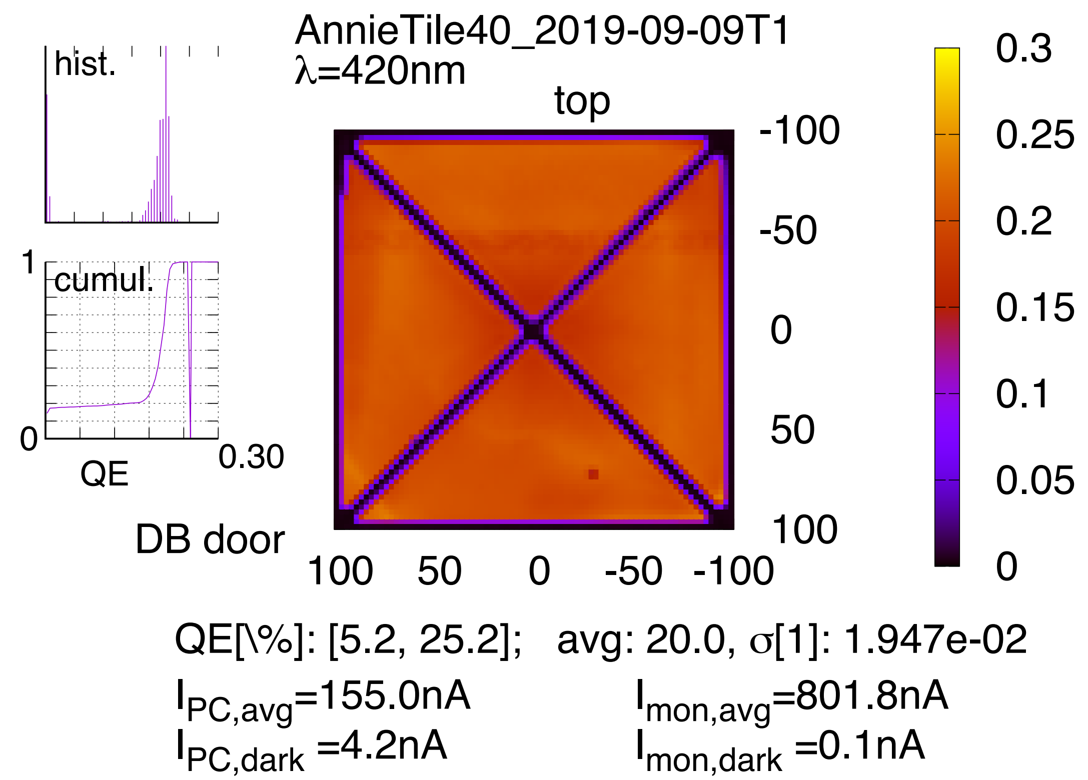
- For ANNIE we designed a waterproof housing, a trigger and readout, and the slow controls for monitoring and HV/LV delivery.
- The LAPPD package and associated electronics are composed of:
  - a waterproof housing with acrylic window, steel backplane and PVC sidewalks
  - a board (Analog Pickup Board) that mounts to the back of the LAPPD and brings signals to the two readout mezzanine cards
  - two readout cards (ACDC cards) per LAPPD which use five PSEC4 chips per ACDC. Each PSEC4 chip can record up to 30 channels with a sampling of 10 Gsps at 12 bit.
  - a board for voltage control and sensor readout (LVHV card)
  - active and passive temperature and humidity sensors
  - and externally an ANNIE-central-card (ACC) that collects data from up to 4 LAPPDs and handles the sync and trigger of the system.

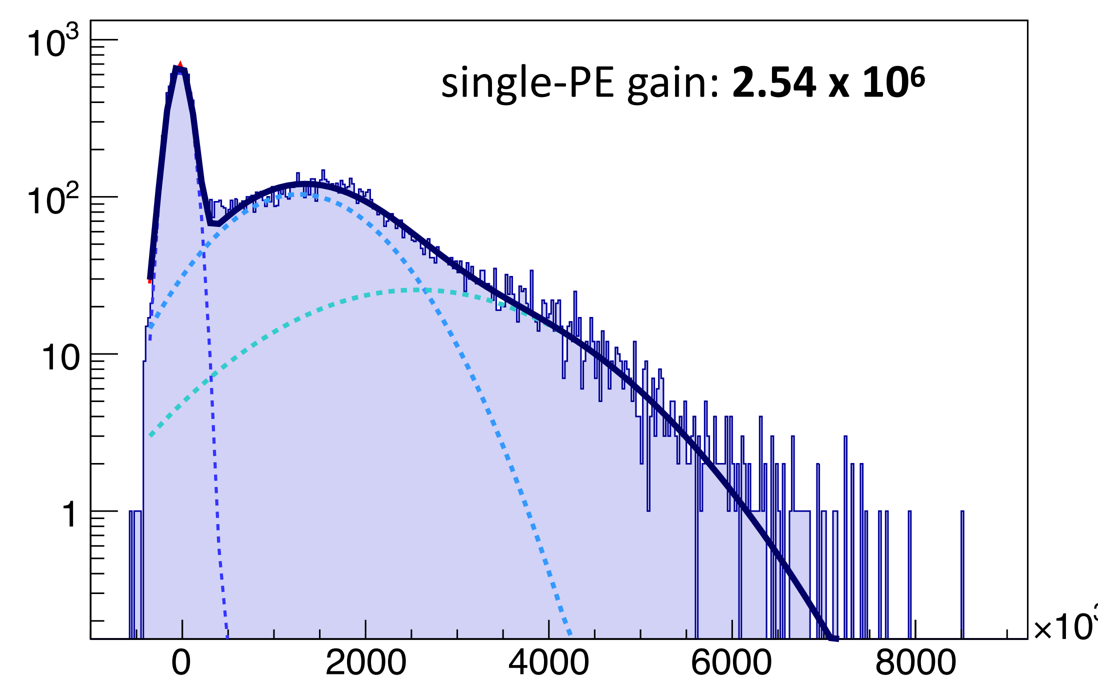




Status of LAPPDs for ANNIE

- Characterization underway at Fermilab. Systematic tests of 5 LAPPDs at dedicated facility. Quantum Efficiency (QE) gain and timing calibration automated scans.
  - They meet the originally stated requirements: QE~20%, gains >10⁶, time res < 100 ps.
  - The newest four LAPPDs exceed those requirements.
- **The first LAPPD (#40) has been fully characterized and has been deployed.**





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- Characterization underway at Fermilab. Systematic tests of 5 LAPPDs at dedicated facility. Quantum Efficiency (QE) gain and timing calibration automated scans.
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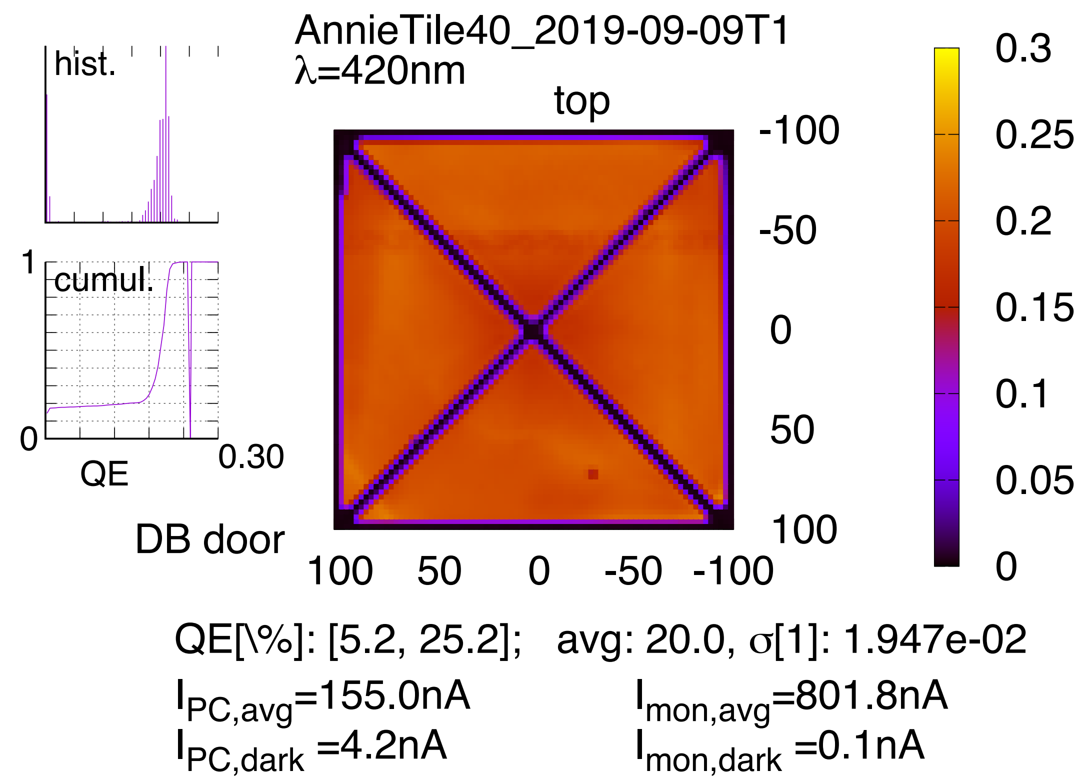
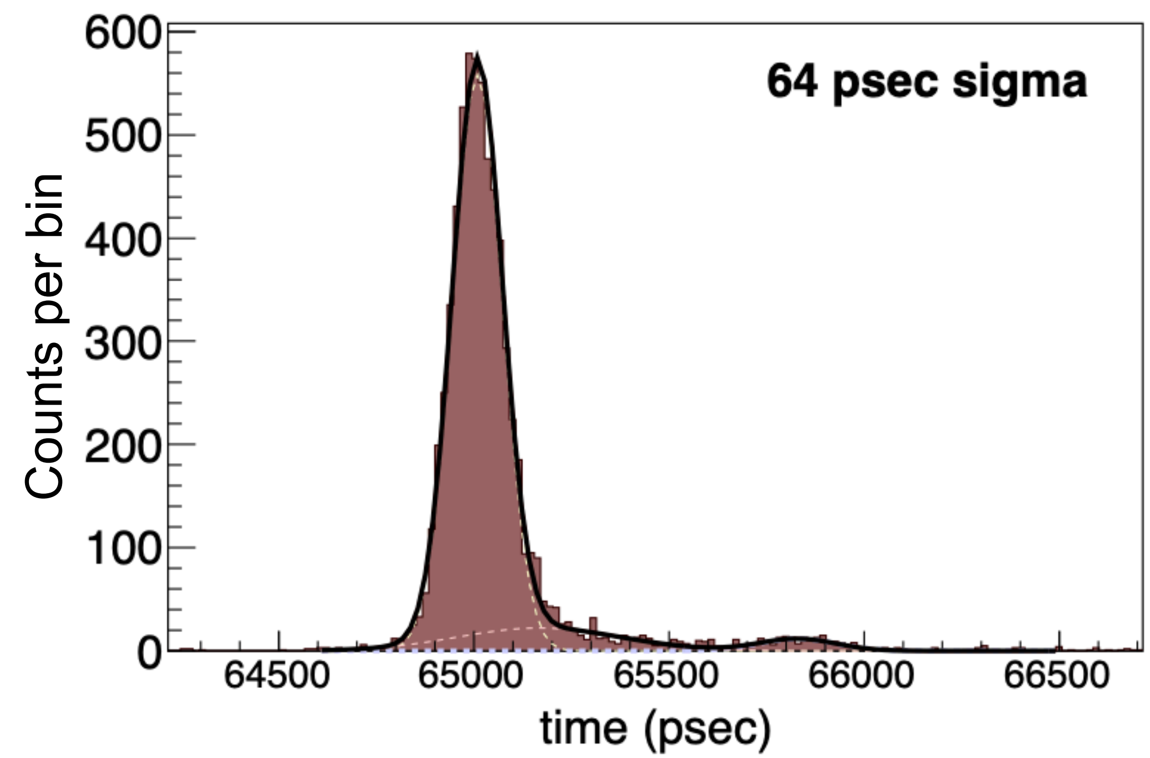
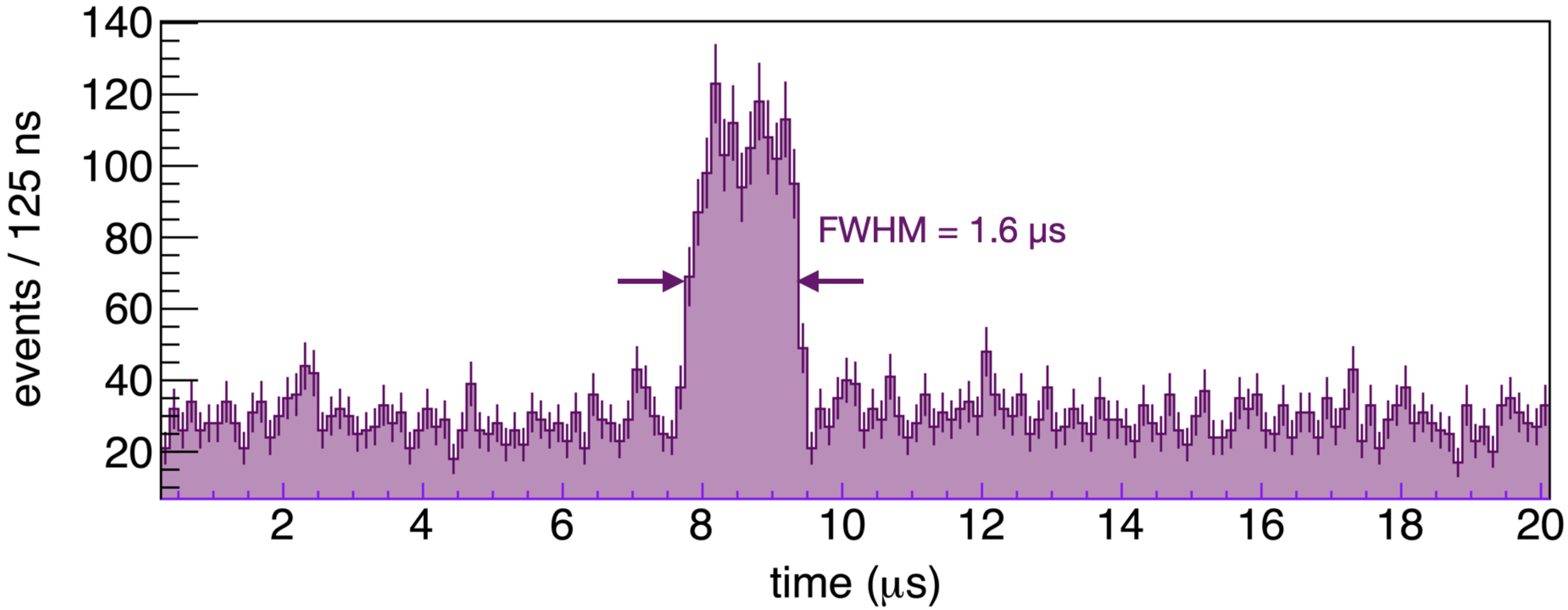
- **The first LAPPD (#40) has been fully characterized and has been deployed.**
- **Two additional LAPPDs have been deployed and are in commissioning.**





ANNIE First LAPPD Neutrinos

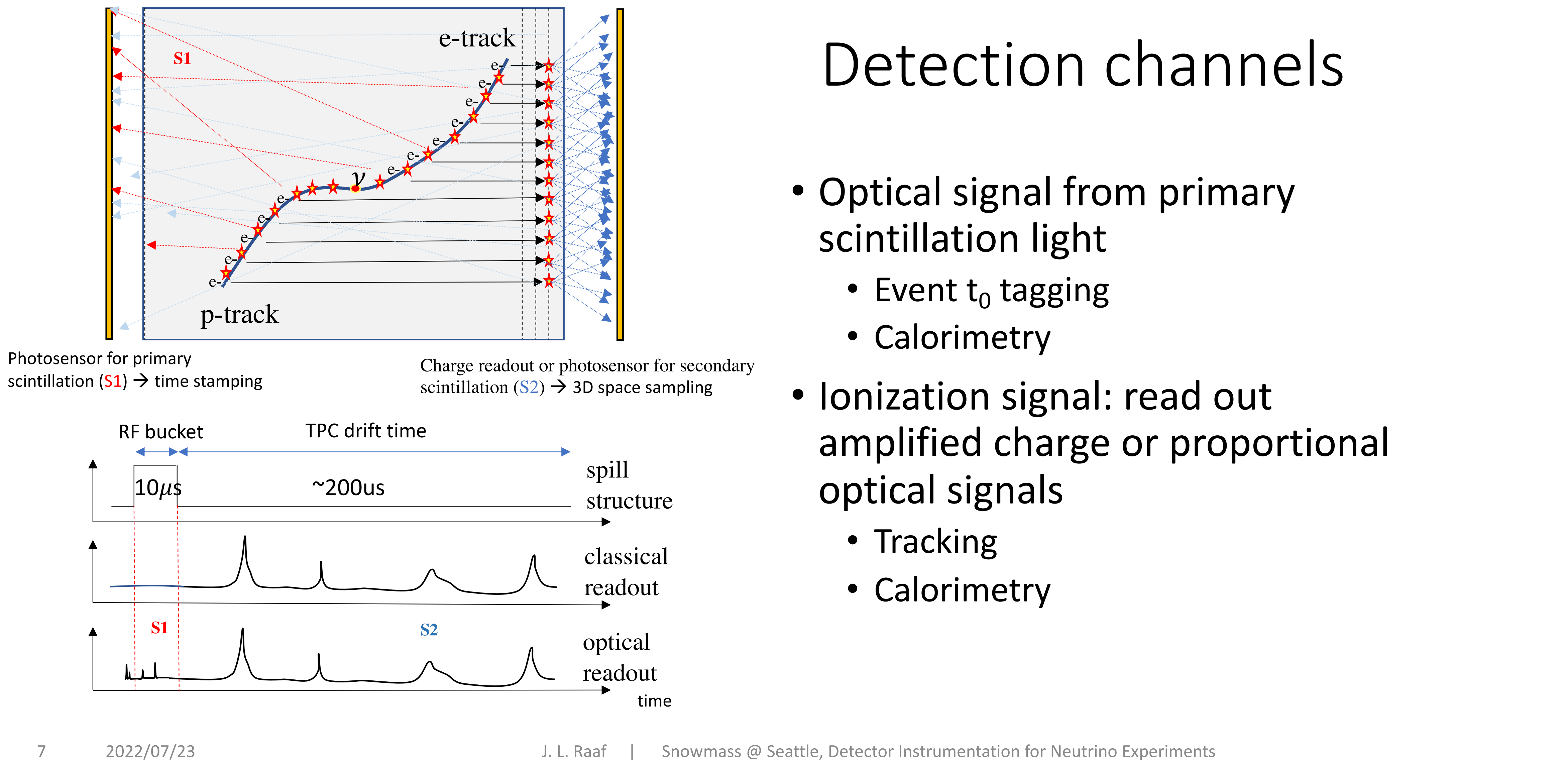
- The excess above background are LAPPD-triggered events in-time with the BNB. The excess has a width of 1.6 μsec.
- Background can be further reduced using simple cuts and information from other detector systems.



World's first: neutrinos observed with LAPPD!

LAPPDs for ND-GAr

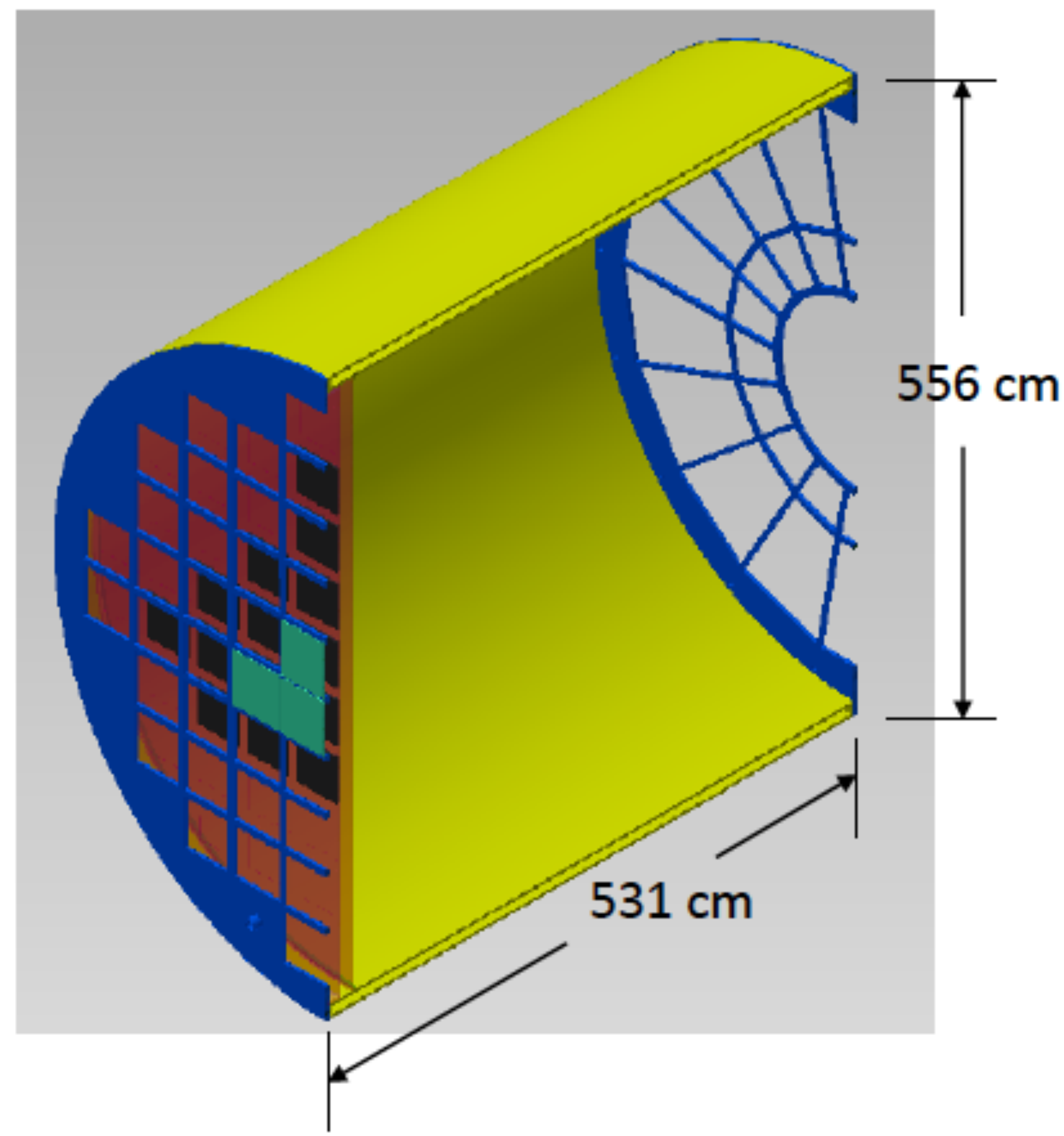
- A light collection system is desirable for ND-GAr to use the optical signal from primary and secondary scintillation.



- LAPPDs are a candidate since they can cover large areas per photodetector, do not require cooling and handle sub-nanosecond timing.

LAPPDs Coverage and Cost

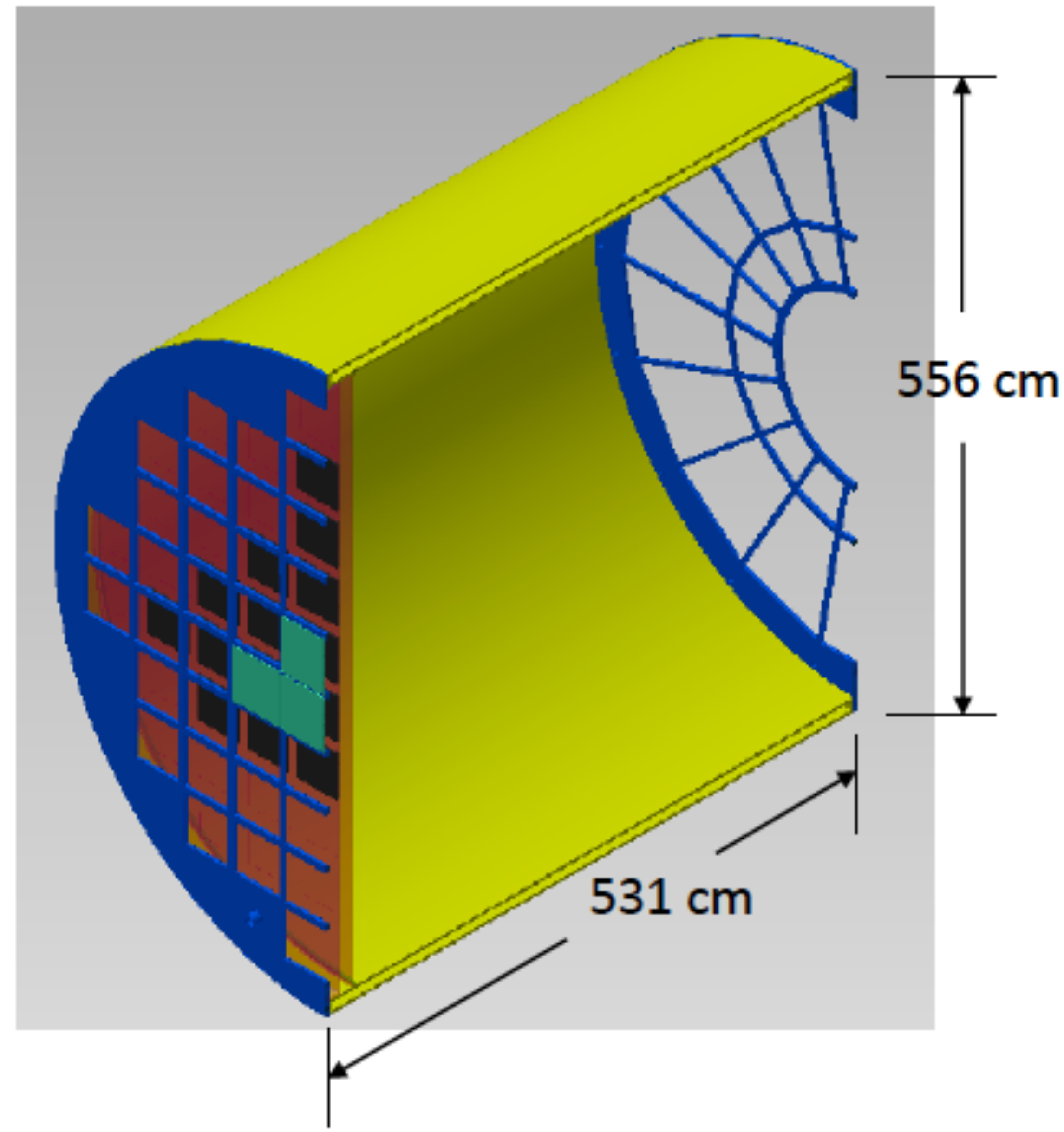
- How many LAPPDs do we need?
  - For near 100% coverage scaling by area: ~500 LAPPDs
  - Scaling from the proposed SiPM system , it's a factor of 3:
    3 x (125-150 SiPM 35x35cm modules) = 375-450 LAPPDs
  - So let's take 400 LAPPDs, that's 22400 channels (at 28x 2 channels for LAPPD).
  - At current prices the cost for a system like this would be: ~$15M, with long lead times.
    - It would require a significant ramp up in production which could lower costs and lead time.



Is 100% coverage the ultimate goal? what pixelation is required?

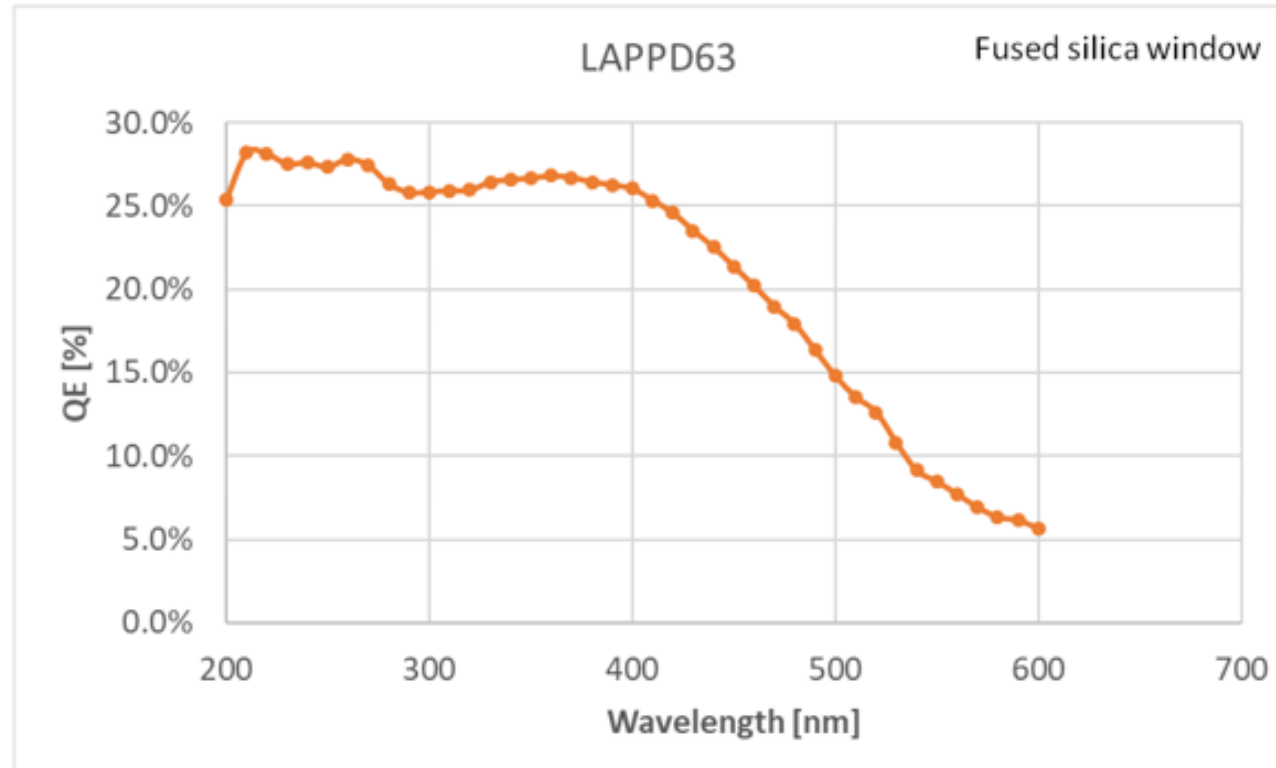
LAPPDs Coverage and Cost

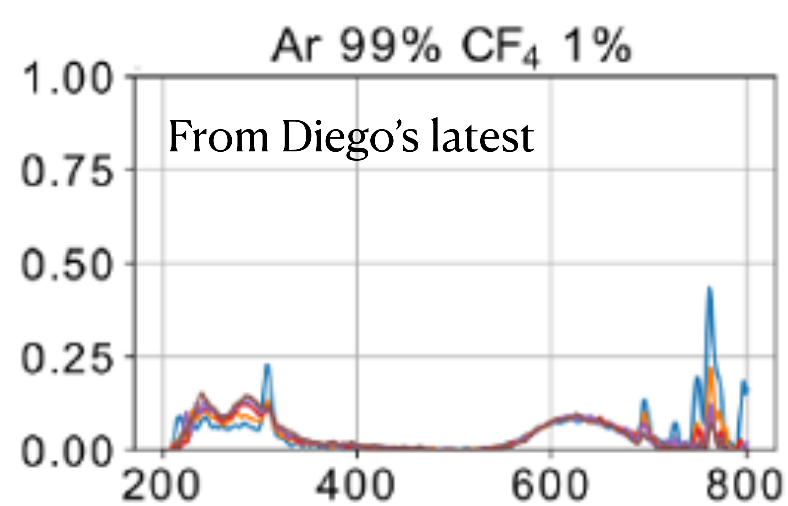
- Alternatively, a system with 20% coverage could have 80 LAPPDs or a SiPM module replacement scheme (33%) would be 125 LAPPDs.
- Corresponds to 4480-7000 channels (at 28x 2 channels for LAPPD).
- The cost for a system like this would be: ~$3-5M at current prices.
- Could be delivered within a few years at current production levels.
    - Possibly less if it is possible to reuse some of the existing LAPPDs.



LAPPD Current Wavelength Capabilities

- Current generation of LAPPDs use bialkali photocathodes with QE dropping off above 400 nm.
- Depending on the choice of quencher/wavelength shifter, this might need modifying photocathode composition or using a wavelength shifter coating (with some loss in timing resolution).
  - However in the latest studies, there is UV emission that can be captured as is. Studies needed.

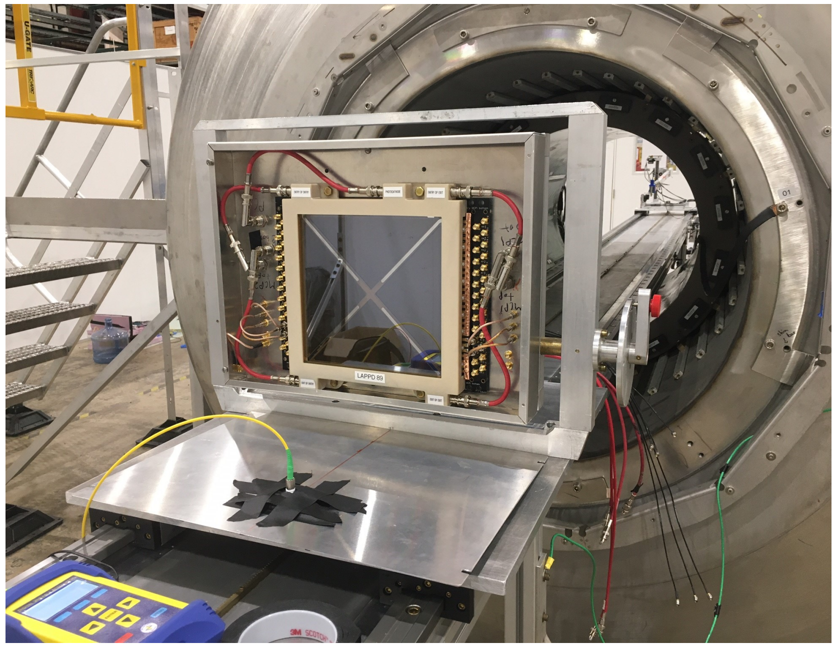


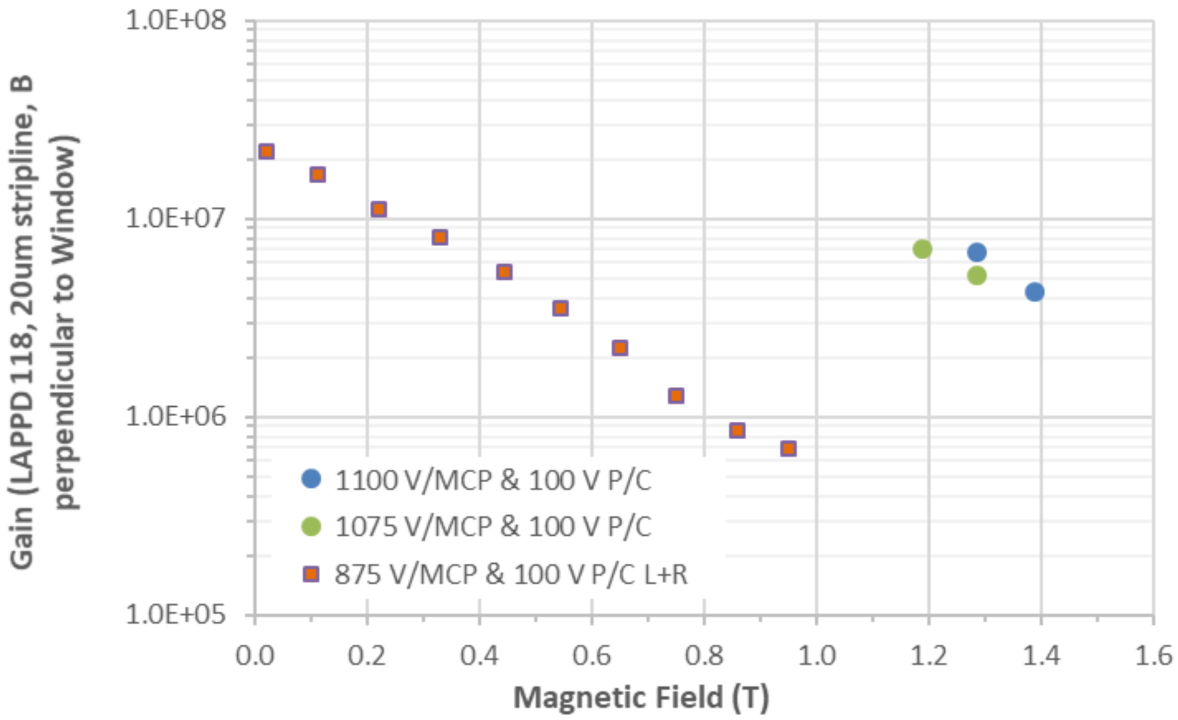


What is the peak emission of the preferred quenchers? What is possible with/ wavelength shifting? Is it needed?

LAPPDs in a Magnetic Field and Dark Rates

- Studies by Incom at Argonne have placed LAPPDs in a solenoid magnet. Field perpendicular to the LAPPD.
- The gain decreases with increasing magnetic field strength and demonstrated to recover with higher MCP voltage.
- Dark rates decreased even at the 0.02 T field so Incom is optimistic that raising the voltage will not increase the noise.
- Expect an update on the dark rates soon.





What are acceptable dark rates (current spec ~100 Hz/cm^2)? other electronic noise?

LAPPDs under Pressure

- Considered pressure-qualifying the LAPPD directly.
  - Finite-elements analysis done by Incom indicate that it could tolerate a few atm but 10 is likely too much.
  - Possible to redesign window but still need to deal with electronics exposed to medium.
- Therefore the preferred solution is to design a housing.
  - Acrylic / Aluminum Spherical Housings qualified up to 12 atm
  - Successfully used in deep water Cherenkov experiments.

Open Questions to be simulated

- Coverage and Granularity
  - What percentage photodetector (LAPPD) coverage is needed? for what Physics?
  - What is the trade off between pixels per photodetector and coverage at lower pixelation?
- Noise
  - What physics metrics set noise target?
  - What are tolerable dark rates, electronics noise?

We hope to start work on this during the fall in close collaboration with the group developing the optical readout.