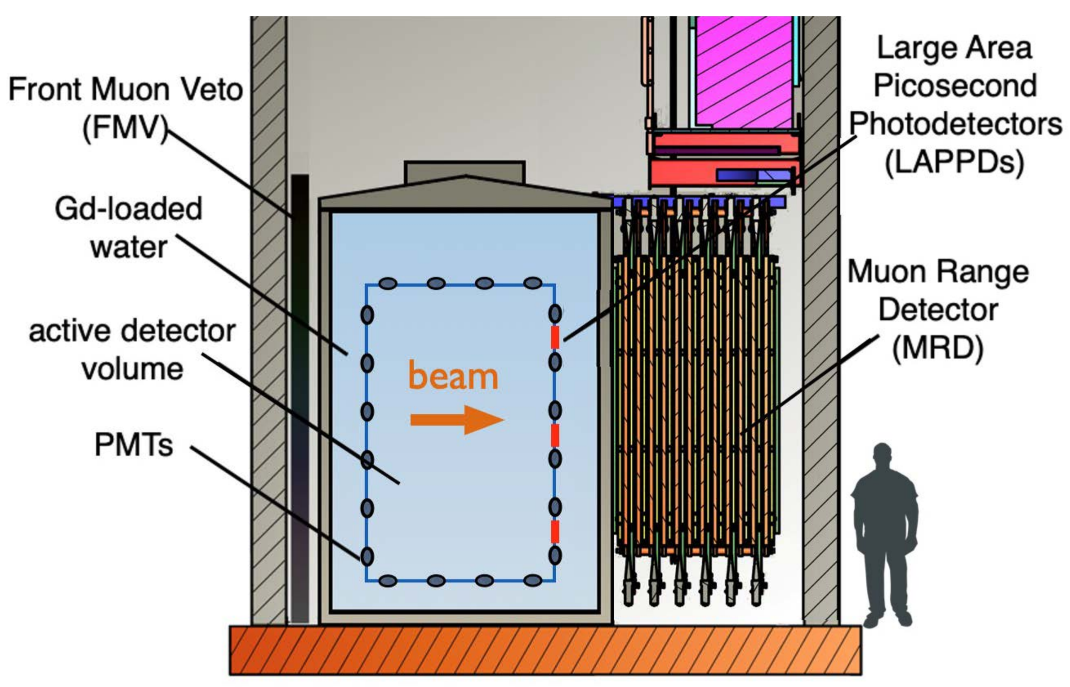
First Neutrinos on Large Picosecond Photodetectors in ANNIE

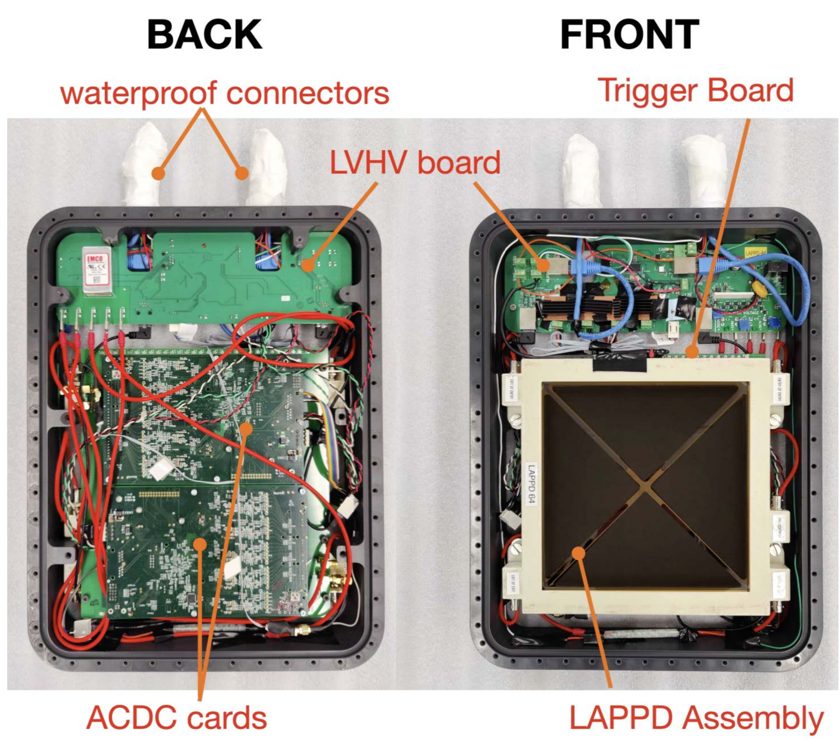
Amanda Weinstein, Matthew Wetstein on behalf of the ANNIE collaboration

Iowa State University of Science and Technology

The Accelerator Neutrino Neutron Experiment



Schematic of ANNIE detector.

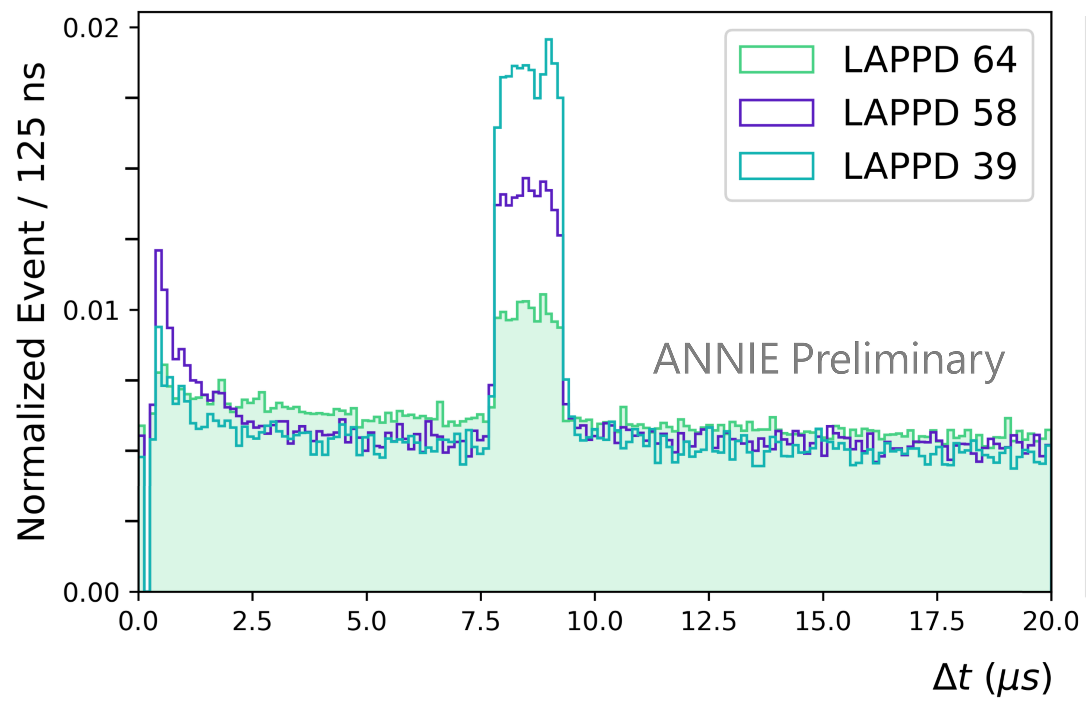


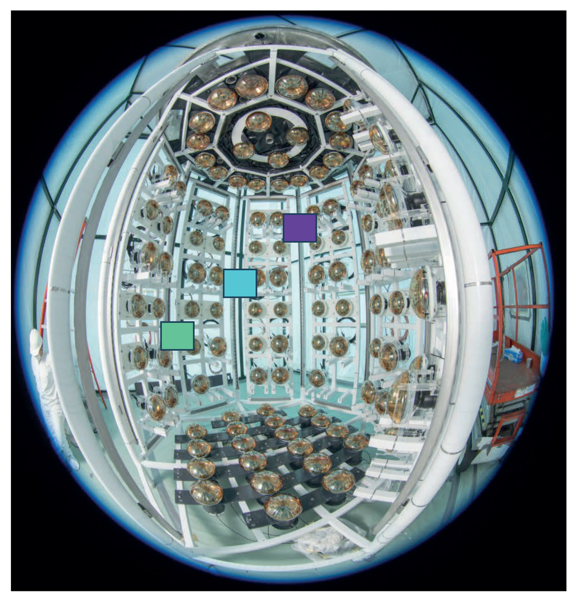
Front and back views of an ANNIE LAPPD with readout and slow controls electronics, packaged inside a waterproof housing.

ANNIE is a 26-ton water Cherenkov detector operating in the path of the Booster Neutrino Beam at Fermilab and studying neutrino-nucleus interactions. ANNIE also tests advanced detector technology, including the novel **Large Area Picosecond Photodetectors** (LAPPDs).

Multiple LAPPDs in ANNIE

Three Gen-I LAPPDs are currently deployed in a diagonal pattern at the front of the ANNIE tank. ANNIE is the first experiment observe beam neutrinos with LAPPDs.

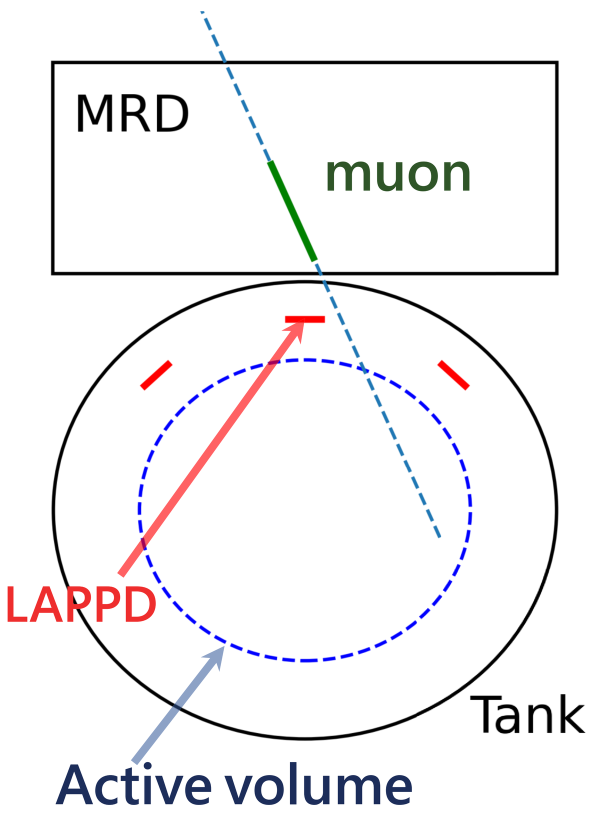




Left: Time difference between receipt of a *beam gate* presaging the arrival of a 1.6 μs BNB spill and an autonomous local LAPPD trigger within 20 μs of the beam gate, shown for all three LAPPDs .Plots are individually normalized to the total number of events, and the differences reflect both noise level and gain. The LAPPD readout electronics are synchronized to ANNIE's central GPS clock. **Right:** positions of the deployed LAPPDs.

Demonstrating LAPPD imaging capability with the first beam neutrinos in an LAPPD

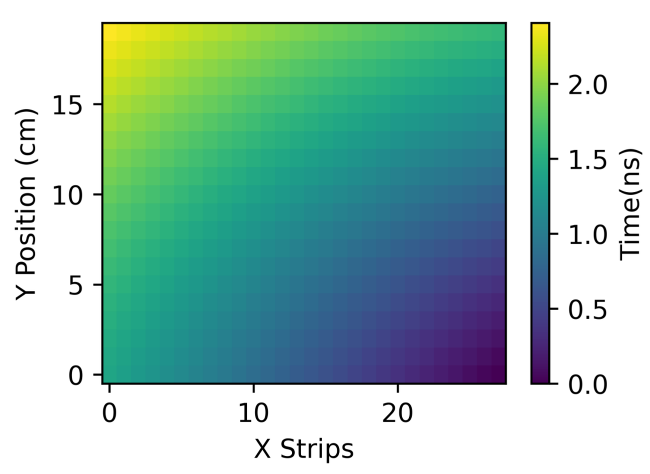
We use a transverse reconstruction technique on selected beam neutrino events from 2023 beam data, to show that a *single* LAPPD can provide significant independent constraints on muon track parameters. This technique already demonstrates the imaging capabilities of the LAPPD and provides the foundation for a 3D reconstruction that can fully demonstrate the LAPPD's exquisite imaging and time resolution.



Detector Top View

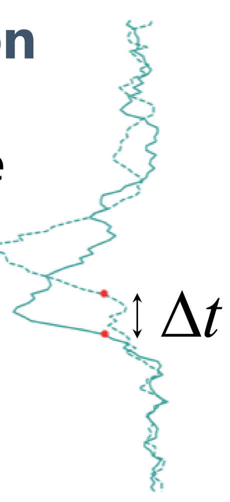
1. From track to light

Cherenkov photons from different points on the muon track (left) register on the front face of the LAPPD (right) at different positions and relative times (indicated by color).

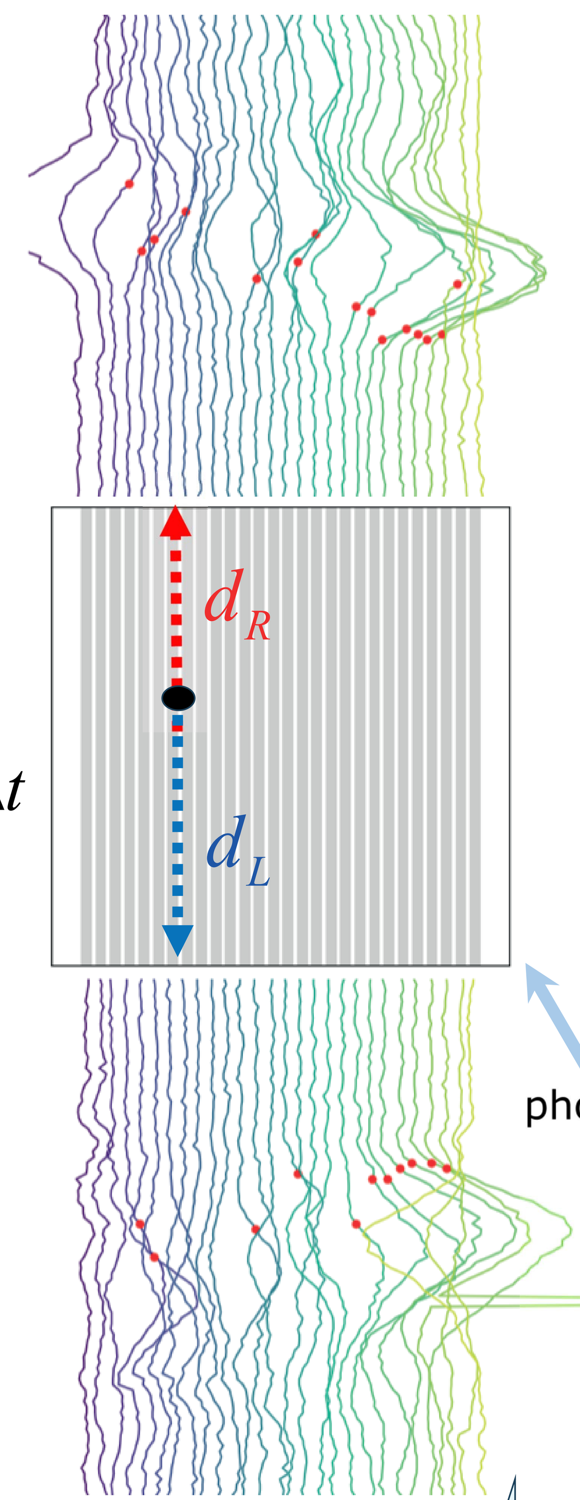


Vertical position

is resolved by the difference in pulse arrival time (red dots) at the two ends of a strip.



$$\Delta t = \frac{d_L - d_R}{v}$$



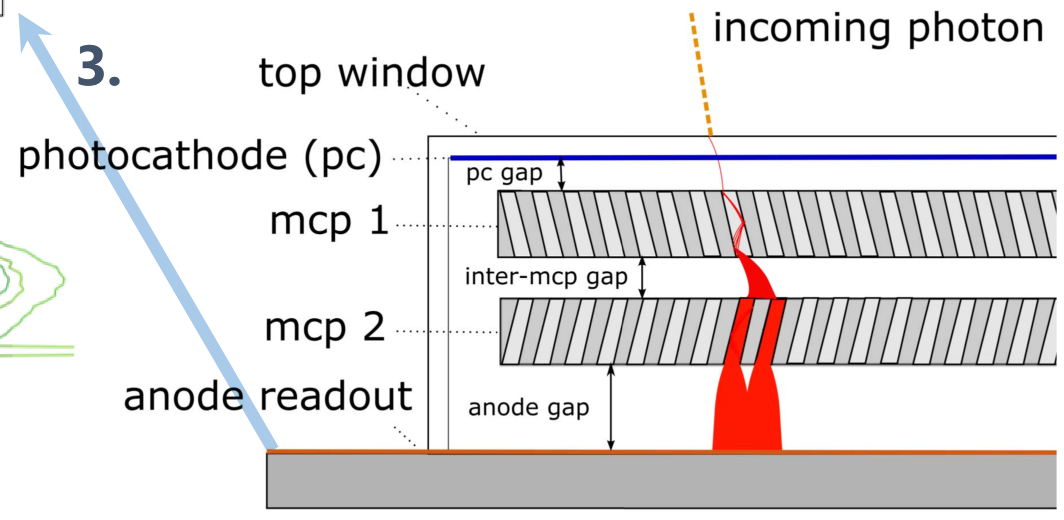
Horizontal position

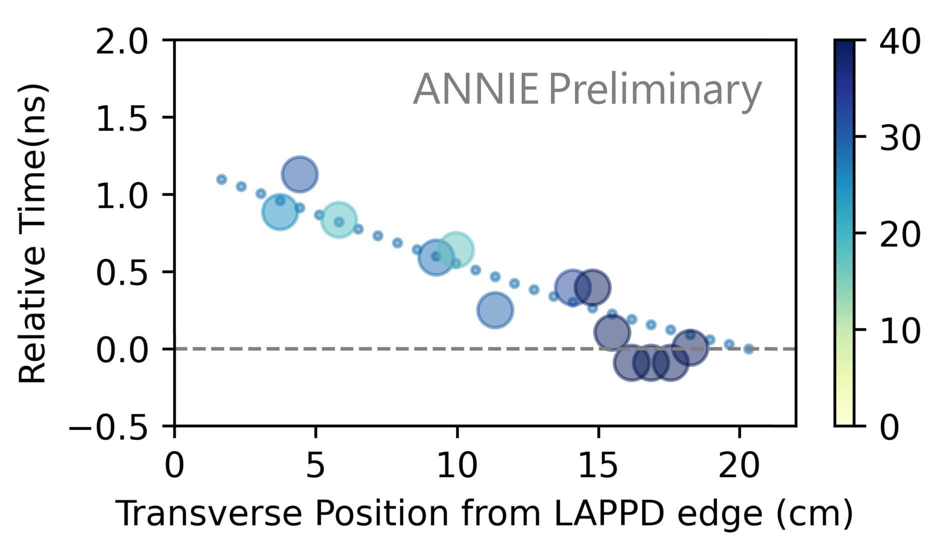
is coarsely (~7 mm) resolved by the strips and can be refined by modeling the sharing of charge between striplines as a function of distance from each strip.

2. From light to charge

Incoming photons are converted to electrons by the photocathode and amplified inside the pores of the MCPs. The resulting cloud of electrons drifts to the striplines of the anode[2] which are read out by custom digitizers through the analog pickup board [1,3].

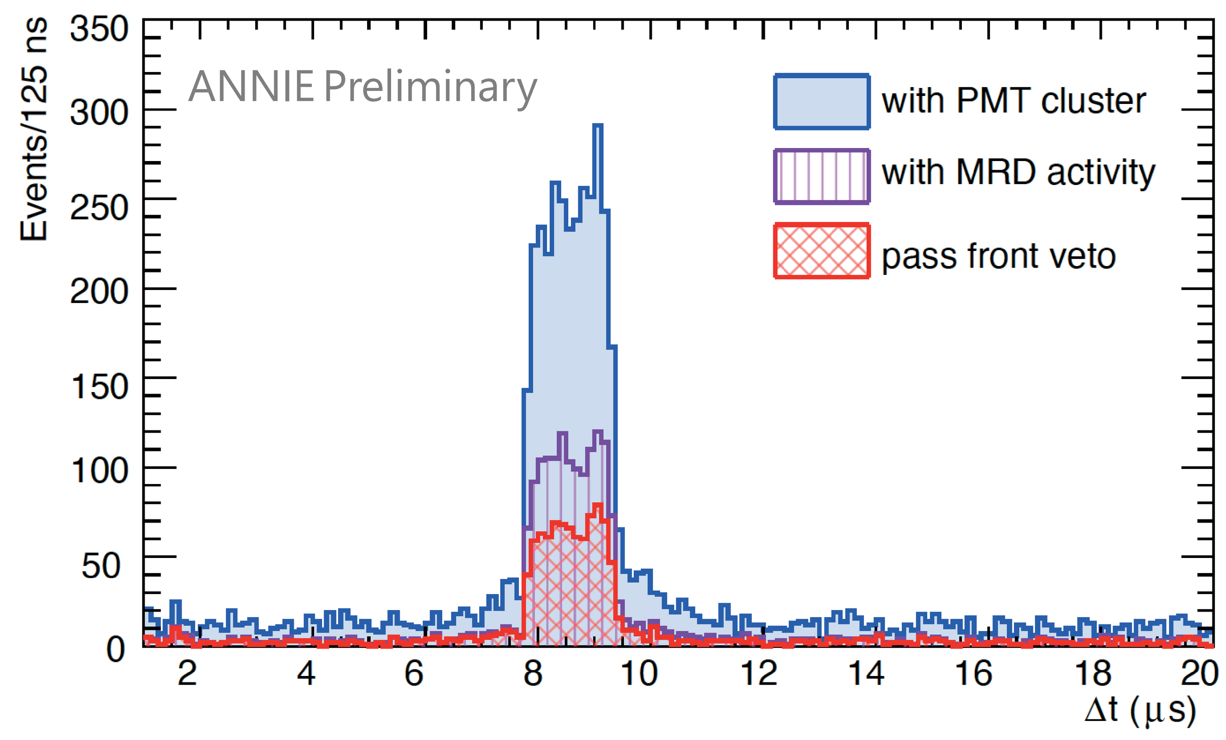
3.





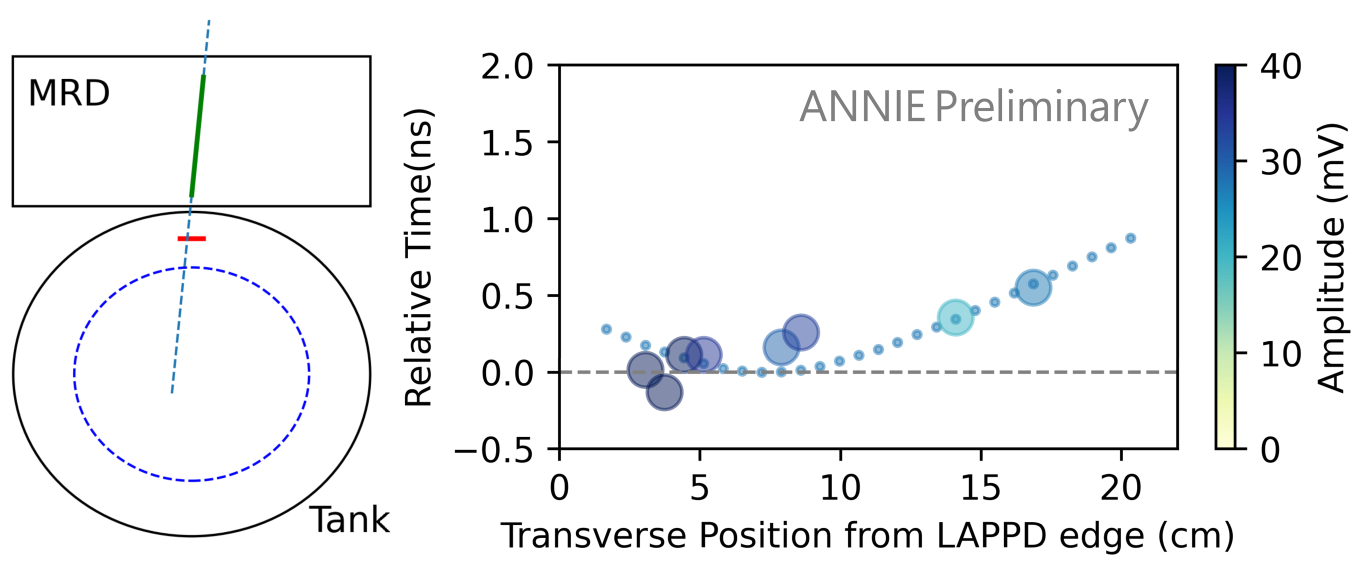
4. Transverse reconstruction

uses the average pulse arrival time on each stripline to produce a gradient of relative pulse arrival times as a function of position. This gradient can be compared to a predicted arrival time gradient based on independently reconstructed muon track parameters.



Neutrino Sample

From a 2023 data sample of ~7.7×10^{19} POT, taken when a single LAPPD was deployed at the central position, we select LAPPD events consistent with a neutrino interacting in the ANNIE tank. Events are required to have a cluster of five PMT hits in 50 ns (blue), activity in the MRD consistent with a muon track (violet vertical lines), and no activity in the front veto (red cross hatch).



Left: Top-down view of a reconstructed muon track (green line) in the ANNIE MRD, projected back (dashed line) into the active tank volume (dashed blue circle). **Right:** Relative arrival time of each pulse (dots) vs transverse position from the left edge of the central LAPPD. Dot color indicates pulse amplitude in mV.

Photon arrival times at each position on the central LAPPD front surface are estimated from MRD-based muon track parameters, then averaged with a flat prior for each strip to produce a predicted arrival time gradient (dashed line) that agrees well with the reconstructed pulse arrival times in the LAPPD. The gradient is sensitive to timing structure on the sub-ns scale.

References

1. B.A. Adams, et al.. NIM A 795 (2015) 1 – 11.
2. G.R. Jocher et al. NIM A 822 (2016) 25.
3. E. Oberla, et al. NIM A 735 (2014) 452-461.

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