Initial Look at Reconstruction in ANNIE

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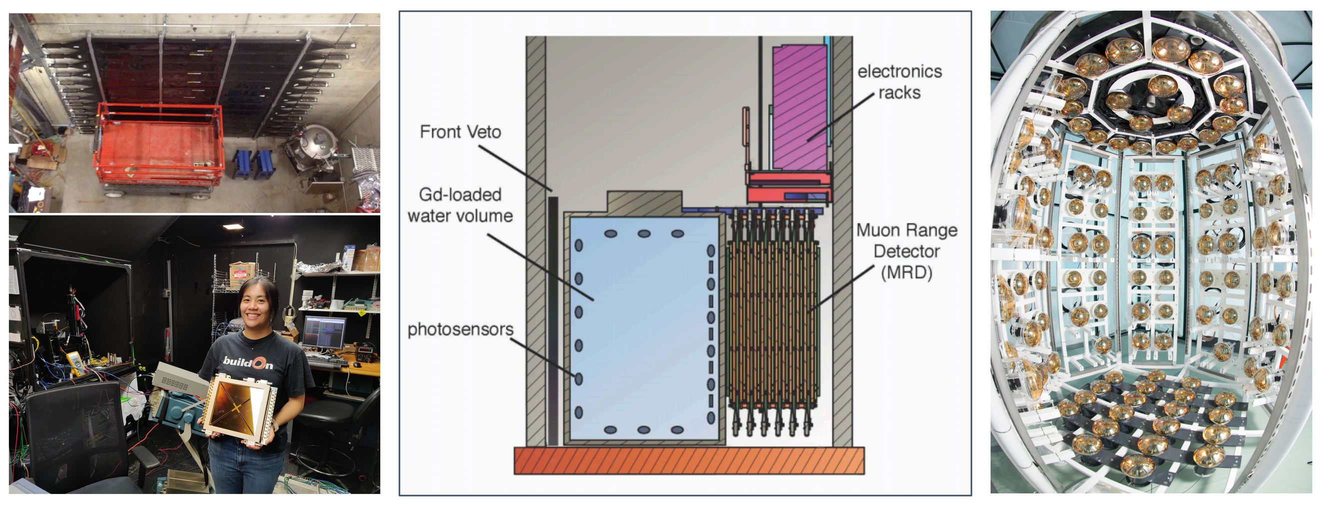
ANNIE

The **A**ccelerator **N**eutrino **N**eutron **I**nteraction **E**xperiment is a neutrino beam physics experiment located at the Fermi National Accelerator Laboratory (FNAL/Fermilab):

- 3-m diameter by 4-m tall cylindrical, water Cherenkov detector filled with 26 tons of 0.1% gadolinium-loaded water
- 132 conventional photomultiplier tubes (PMTs) and 5 novel Large Area Picosecond PhotoDetectors (LAPPDs)
- Front Muon Veto (FMV) and Muon Range Detector (MRD)
- Located ~100 m from the target in the Booster Neutrino Beam (BNB; ~700 MeV peak)



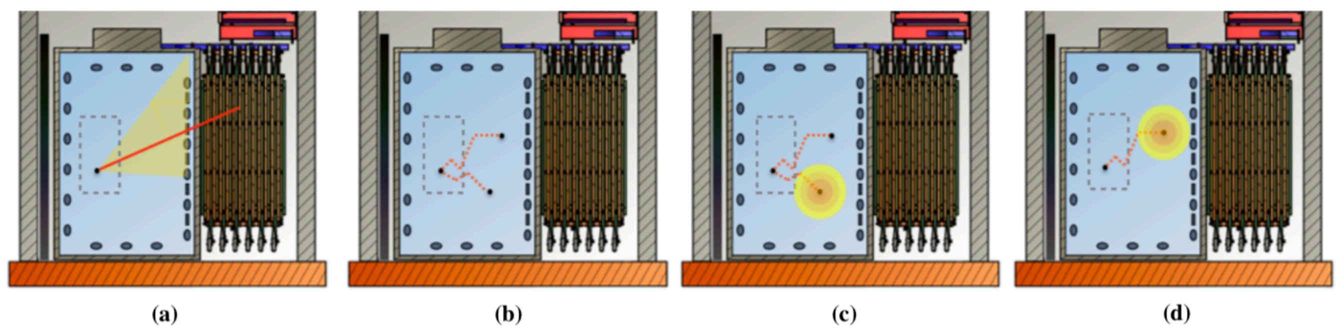
(top left) A view of the FMV from above. (bottom left) LAPPD and me. (middle) A detector diagram of ANNIE. (right) Inner structure.

Physics Goals

- High statistics measurement of final state neutron multiplicity of ν_μ and oxygen interactions
  - Helps constrain associated systematic uncertainties for long baseline, ν oscillation experiments
- Measurement of CC inclusive cross section of ν_μ on oxygen
  - Potential joint-analysis of water/liquid argon cross section with SBND
- Testbed for novel technology: LAPPDs (see poster #481), Gd-doped water, water-based liquid scintillator (WbLS; see poster #518)

Neutrino-Nucleus Interactions

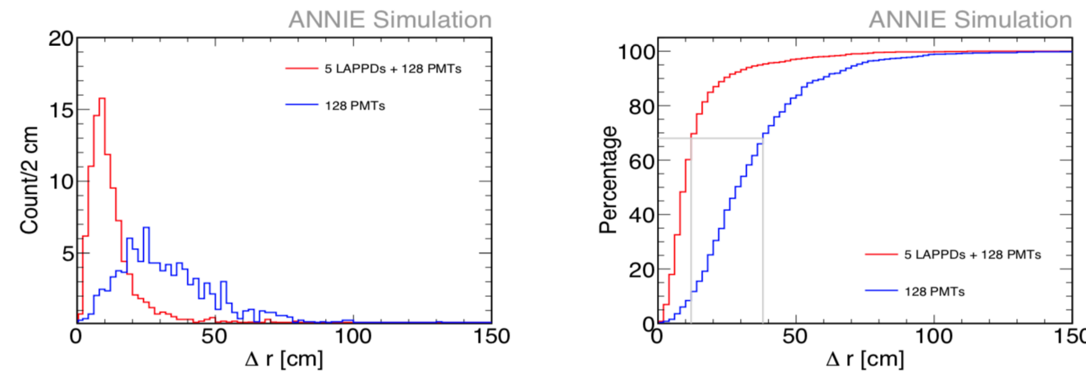
A typical event in ANNIE



(a) Neutrino interacts with oxygen nucleus and a muon is created. The muon creates Cherenkov radiation as it travels through the water target, illuminating a cluster of PMTs, and ranging out in the MRD
(b) Neutrons are produced in Final State Interactions (FSIs) and thermalize within a few microseconds
(c) Neutrons capture on gadolinium (Gd), producing flashes of light from the de-excitation of Gd nucleus
(d) More neutron captures

Current Status of ANNIE Reco

ANNIE aims to use LAPPDs to perform reconstruction, since they have excellent timing, spatial, and angular resolution.
A vertex and energy reconstruction technique using PMT-only data was developed for use in data acquired before LAPPDs were available, as well as for a benchmark for LAPPD reconstruction.
LAPPDs can be used to upgrade technique presented in this poster.



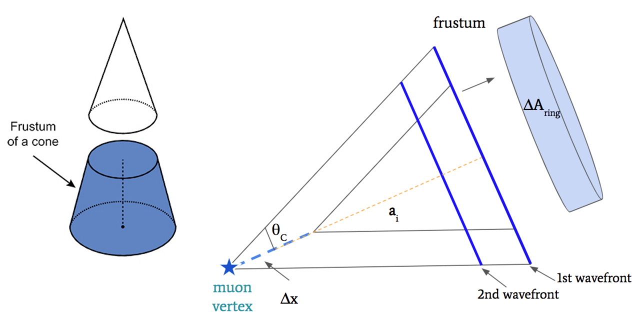
LAPPDs improve vertex reconstruction ability so that more accurate determination of the muon/neutrino energy can be achieved. With the addition of just 5 LAPPDs, we can see a vast improvement in the position resolution, nearly a factor of three.

Vertex Reconstruction with PMT Data

Imaging the Cherenkov Ring/Disk Edge

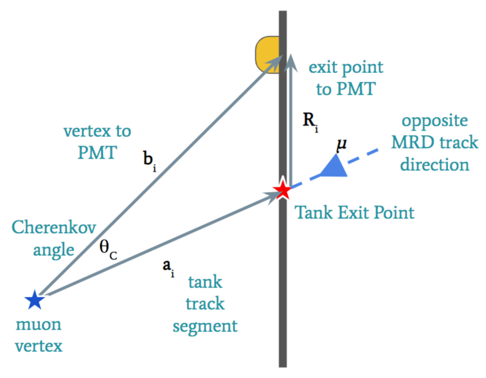
Muons with sufficient energy lose little energy due to ionization and will mainly lose energy due to Cherenkov radiation when traversing through water. This means that a constant number of photons is created per unit distance traveled.
This technique relies on two ideas:

1. When the muon travels some distance Δx, the light emitted forms a frustum, whose surface area is equivalent to a ring, ΔA_{ring}. The number of photons divided by the ring area is the photon density, η.



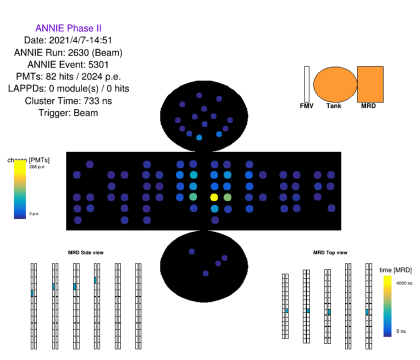
$$\eta = \frac{\#\ photons\ in\ ring}{A_{ring}\Delta x}$$

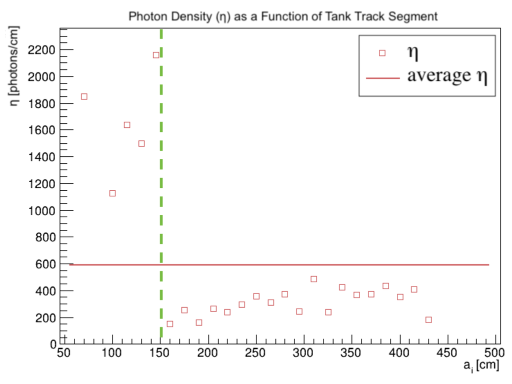
2. Each PMT that detects a Cherenkov photon will have a tank track segment associated with it. This indicates where the photon was emitted.



Combining the two ideas above, a plot of photon density (η) vs track segment (a_i) can be made that indicates the distance in the tank where the muon was created and where the Cherenkov cone begins.

(left) Event display of a beam event.

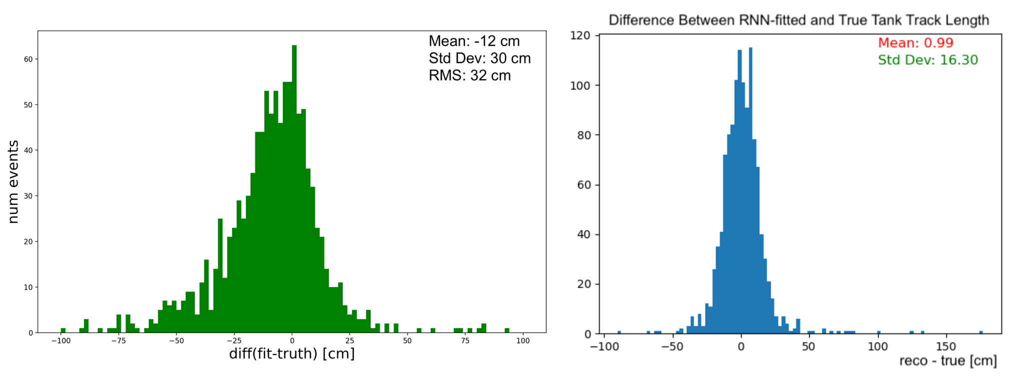




(right) η vs a_i plot. High η values are observed close to the exit point and decrease deeper into the tank.

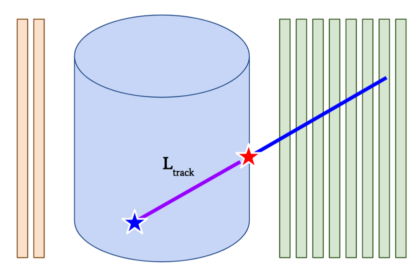
Using the η vs a_i graphs, a track length in the water can be fit, by identifying the change in photon density as we move back into the water target.

(left) Manually fitting the tank track by eye.

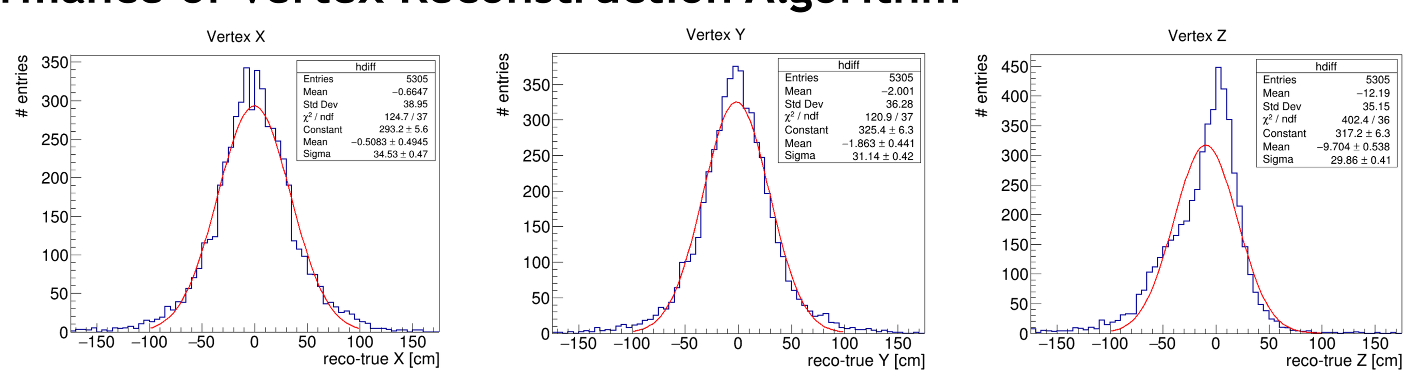


(right) Fitting the tank track with a RNN model.

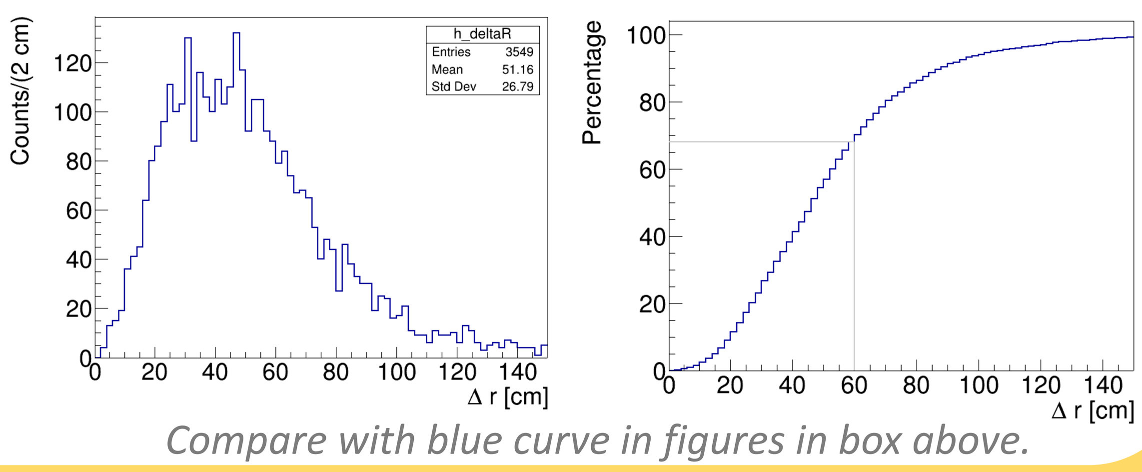
The fitted track length in the tank is used to determine the muon vertex. This is done by taking the fitted length and moving backwards into the tank from the tank exit point.



Performance of Vertex Reconstruction Algorithm



We have implemented a realistic vertex reconstruction using PMT data that is comparable to early estimates of reconstruction performance.

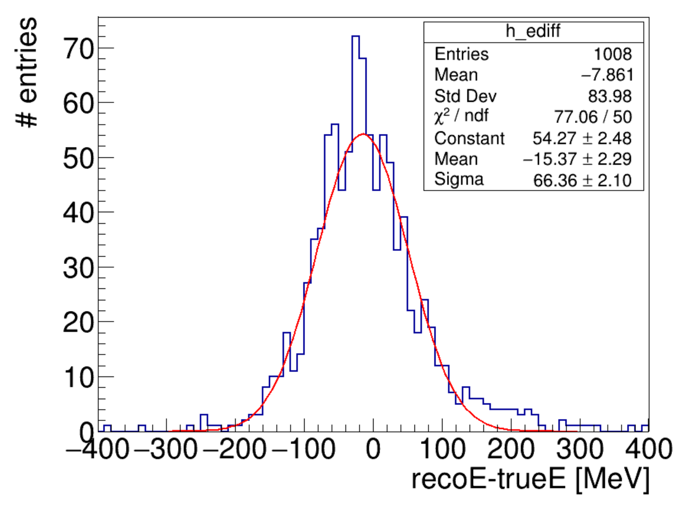


Compare with blue curve in figures in box above.

Energy Reconstruction

Energy reconstruction is performed by using the Bethe-Bloch formula to calculate a dE/dx based on an initial energy estimate:

1. Multiply tank track length by dE/dx (water) = 2 MeV/cm and MRD track length by dE/dx (iron) = 11 MeV/cm to get initial estimate of total energy.
2. Input the initial energy estimate into the Bethe-Bloch formula to get an updated dE/dx value and multiply it by a fixed amount of distance traveled by the muon (e.g. 5 cm).
3. Repeat for every fixed distance traveled until there is no more muon track remaining.



Assuming a peak energy of 700 MeV, this energy reconstruction method gives a resolution of ΔE/E ≈ 10%.

Conclusions

ANNIE has already acquired LAPPD data. Vertex and energy reconstruction with PMT data are essential for ANNIE data acquired before LAPPDs were installed, as well as a benchmark for LAPPD reconstruction.

References

A. R. Back et al. *Accelerator Neutrino Neutron Experiment (ANNIE): Preliminary Results and Physics Phase Proposal*. 2017.
D. E. Groom et al. "Muon Stopping Power and Range Tables 10 MeV-100 TeV". In: *Atomic Data and Nuclear Data Tables* 78.2 (2001).

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