Reconstruction Techniques in ANNIE

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NEW PERSPECTIVES IN PARTICLE PHYSICS

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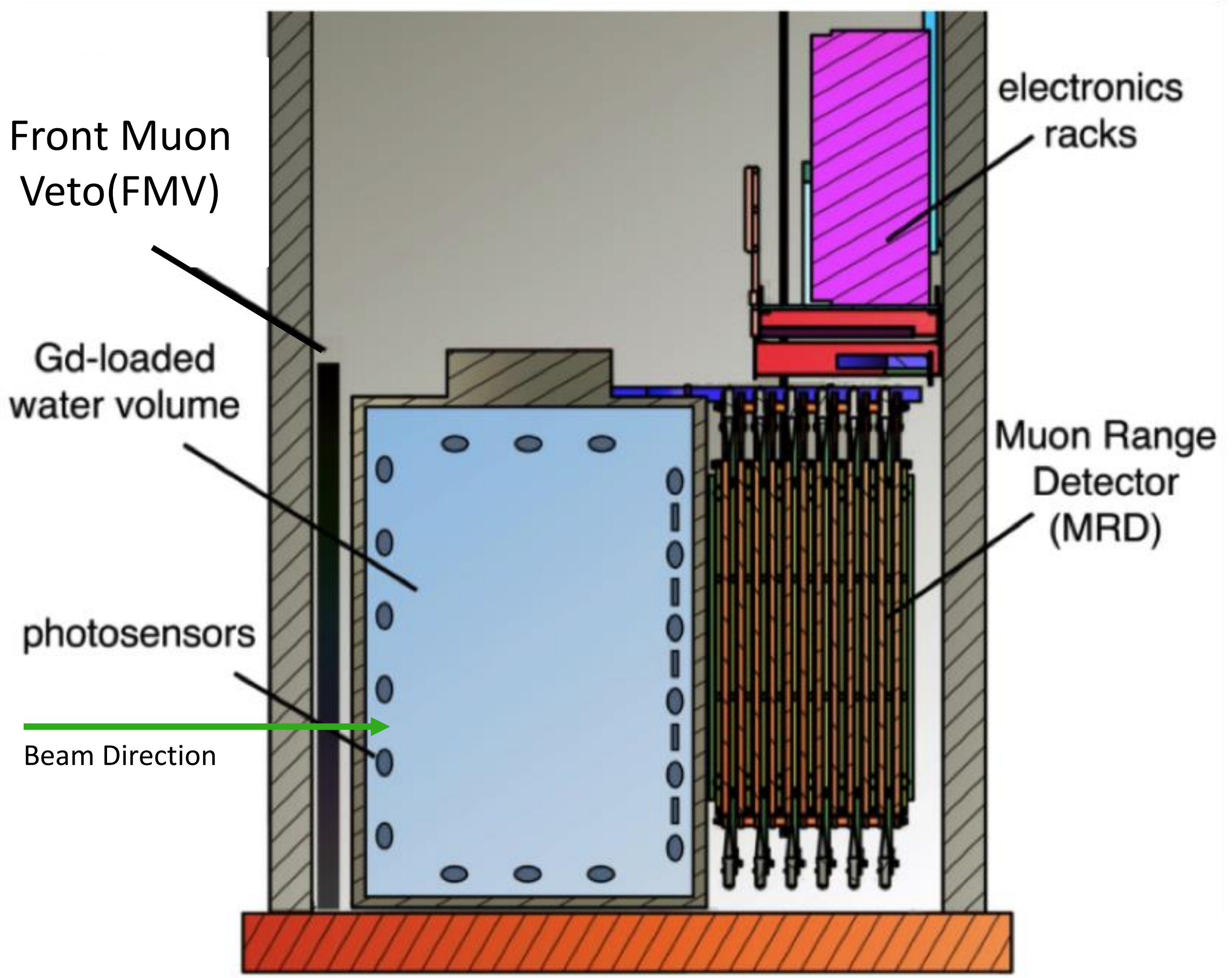
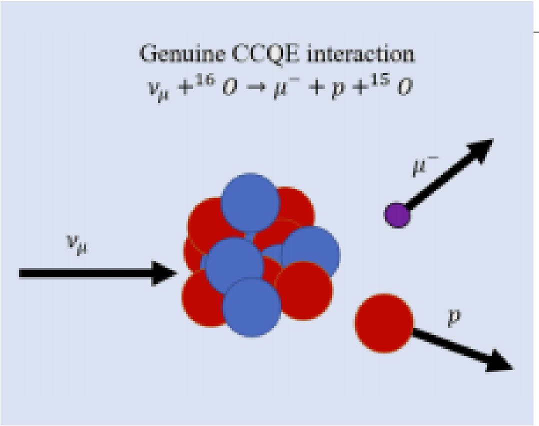
The ANNIE Detector

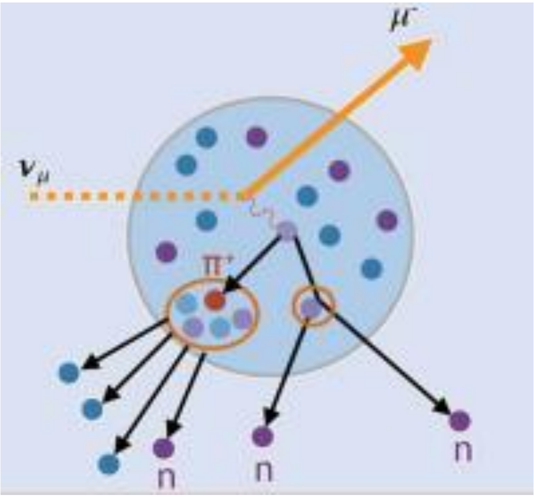
26-ton Gd-doped water Cherenkov neutrino detector

- Photodetectors within the tank
- Scintillators up and down beam direction
  - Small FMV to filter background
  - MRD penetration for energy and momentum reconstruction



Goals





Charged Current Quasi-Elastic Interactions

- Assume only two outgoing particles, but More complicated reactions are possible
- Can seem identical, but for neutron emmissions

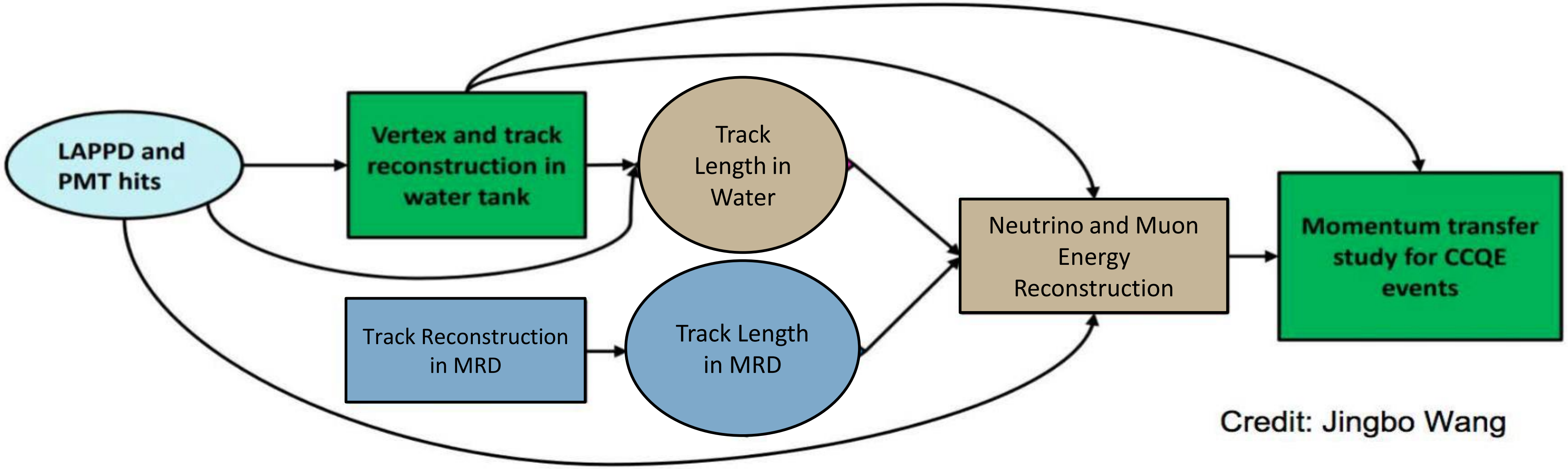
Neutrino Cross-section measurements

- GeV-scale Interactions are not well defined
- Detector on known beam can provide further examples and statistics

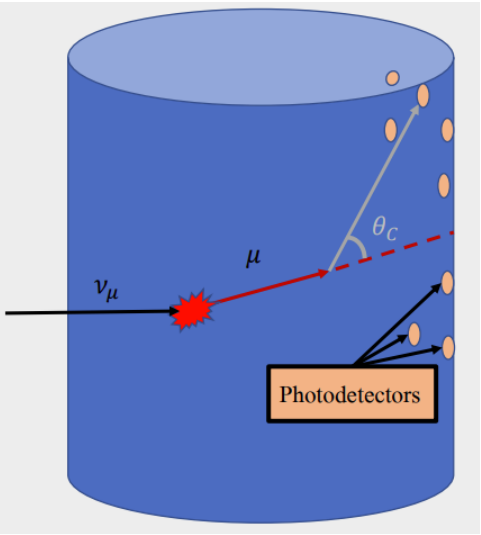
Staging new technologies

- LAPPDs
  - One deployed
  - Five planned

Event Reconstruction



Event Reconstruction

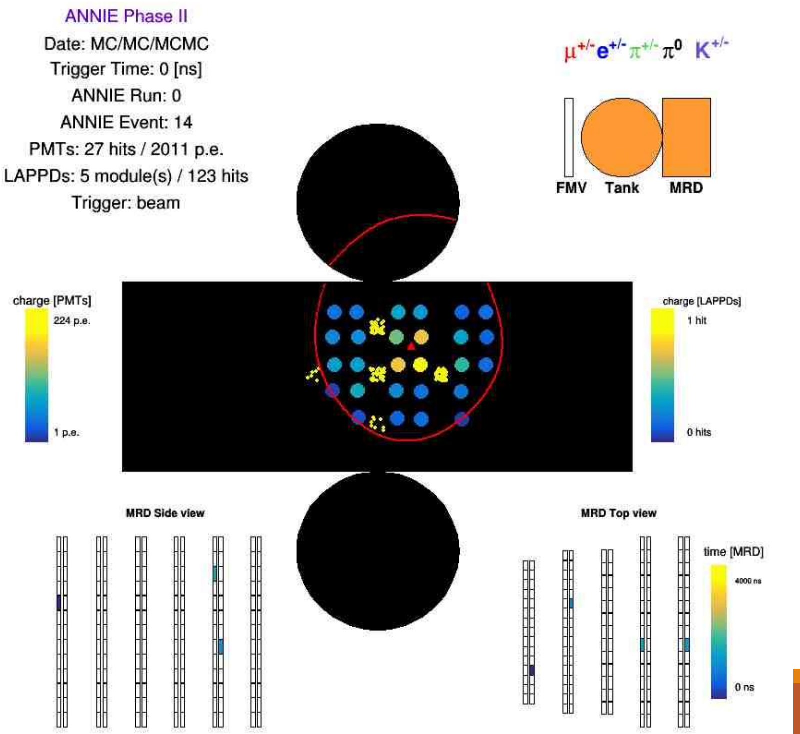


After a neutrino charged-current interaction in the tank, a muon traverses the tank, emitting Cherenkov radiation.

- Emissions picked up by PMTs.
- Using charge and time residual information, the path and origin of the muon can be reconstructed.

Muon continues into MRD

- Saps momentum and stops particle
- Based on penetration depth, energy and momentum of muon can be determined.



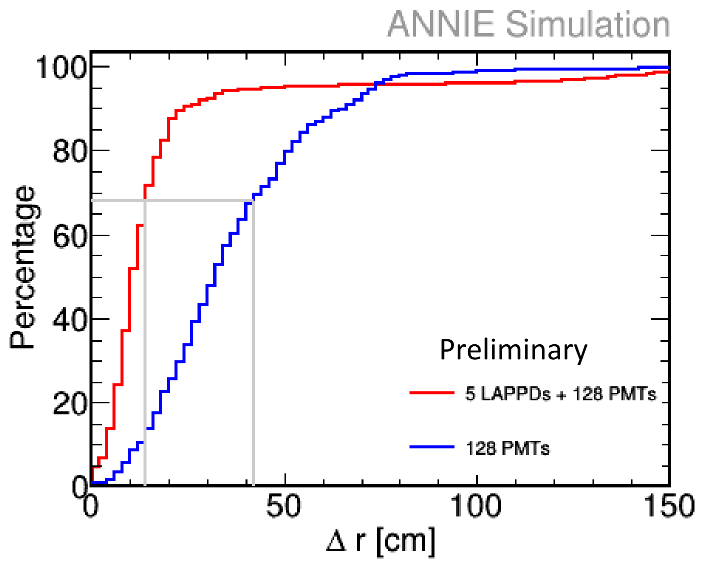
Simulated Reconstruction

Vertex

Cherenkov ring detected by photodetectors

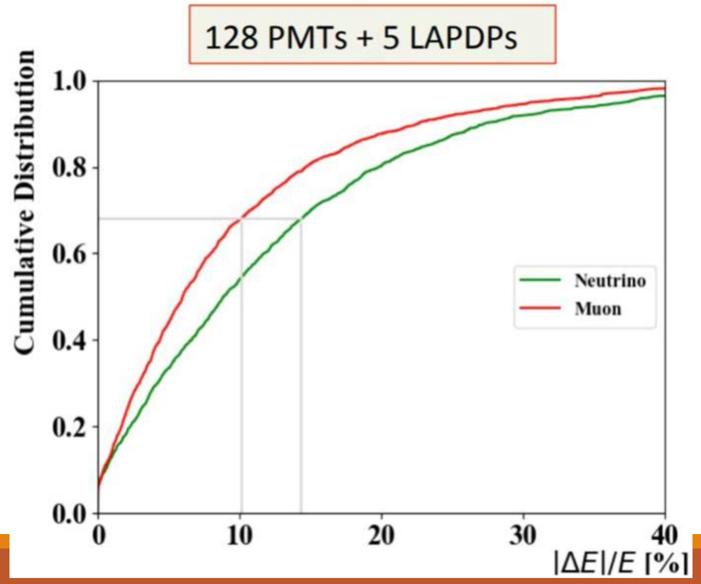
- From distribution and timing, we can draw conclusions about the position of the event

Results improved by LAPPDs



Energy

- Information from the reconstructed vertex and the MRD track used reconstruct energy profile for the interaction
  - 1σ-resolution of 10% muon energy and 14% neutrino energy achieved
- Machine learning techniques used

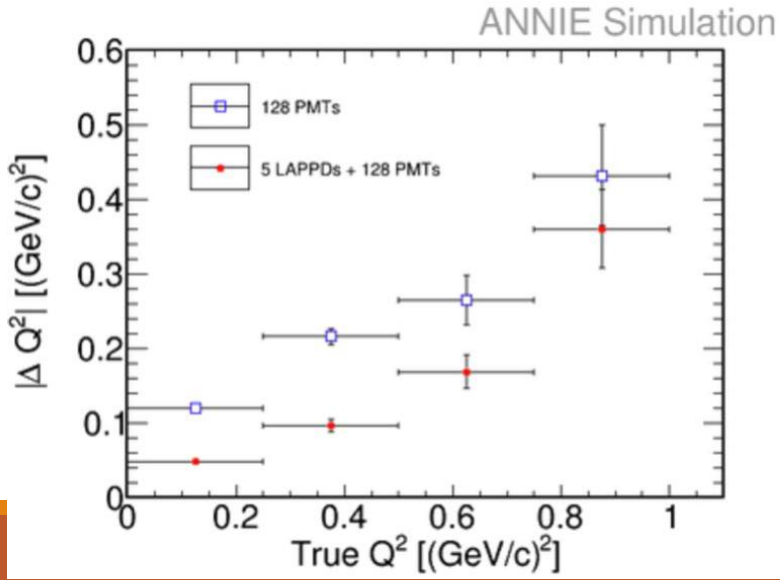


Momentum Transfer

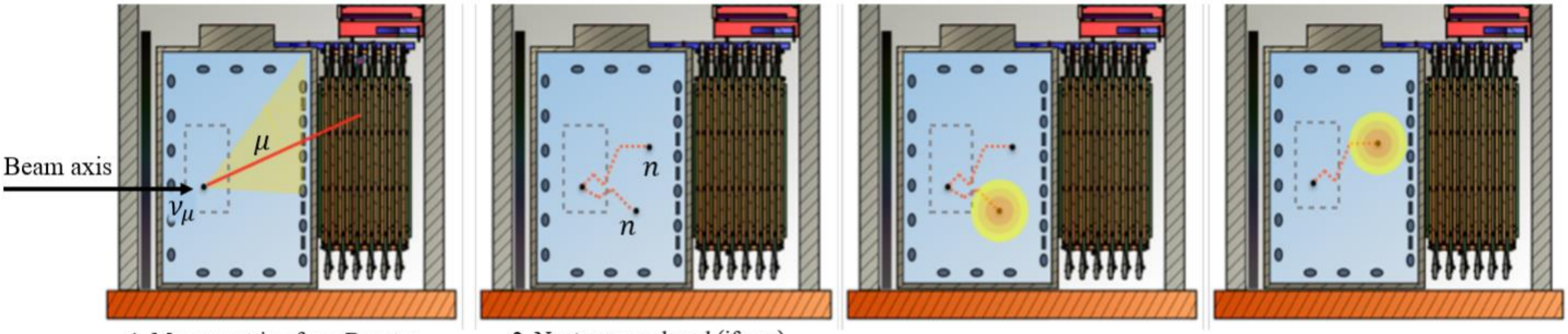
- CCQE events can be completely described by energy of initial neutrino, and the resulting energy and momentum in released muon.

$$Q^2_{QE} = 2E^{QE}_{\nu}(E_\mu - p_\mu \cos\theta_\mu) - m^2_\mu$$

- LAPPDs improve Q^2 resolution significantly



Neutron Multiplicity



1. Muon neutrino from Booster Neutrino Beam interacts with nucleus in target volume; muon stops in MRD

2. Neutrons produced (if any) undergo thermalization in target volume

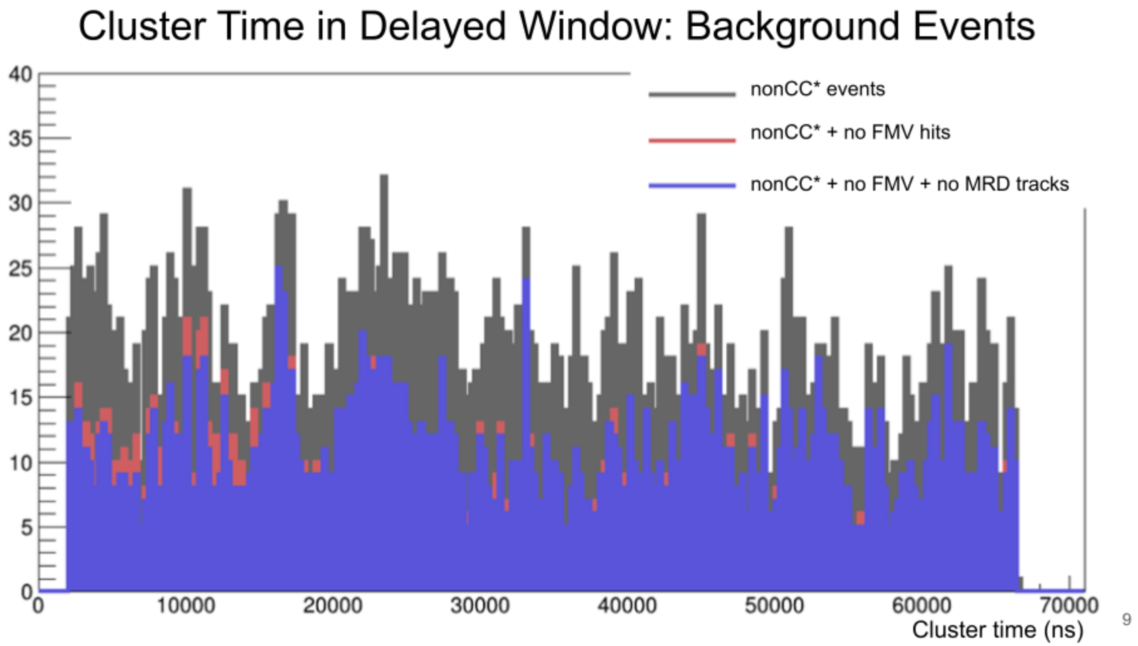
3. Neutrons capture on gadolinium; gadolinium's de-excitation signal (Cherenkov light from ~8 MeV gamma cascade's Compton scatter electrons) is detected

Neutron Backgrounds

Neutrons unrelated to tank neutrino interactions

- “Dirt neutrons”: interactions up-beam of detector
- “Skyshine neutrons”: entered tank from atmosphere

nonCC events selected below energy threshold



Credit: Emily Pottebaum

Neutrons from Beam Data

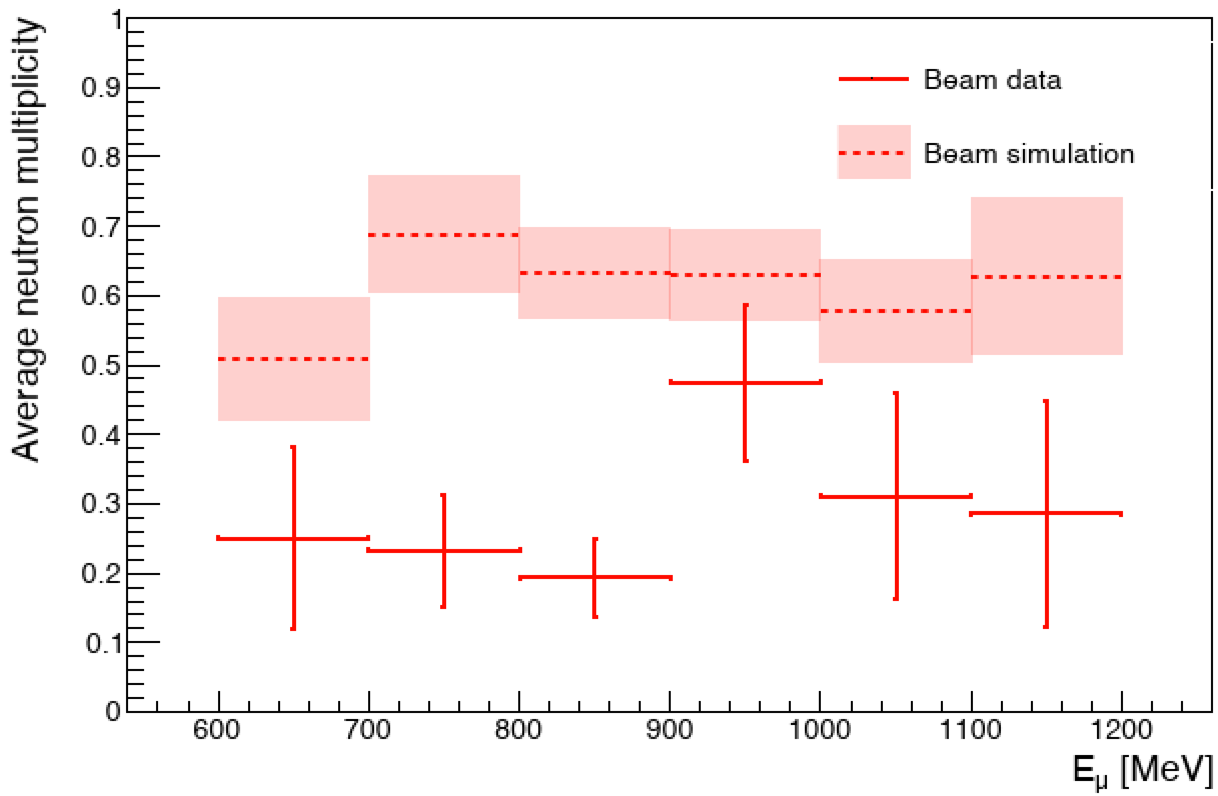
Using Data taken in February-April 2021

Neutrons are visible

Counting not efficient

- Expected to improve with implementation of other analyses

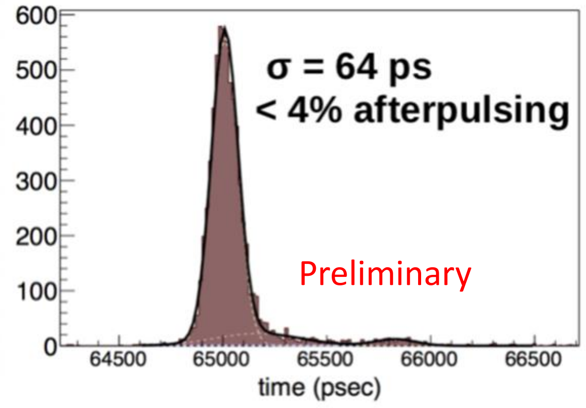
Neutron Multiplicity

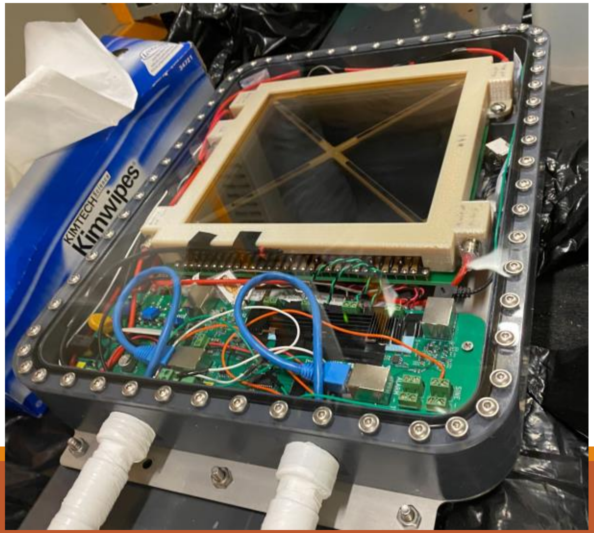


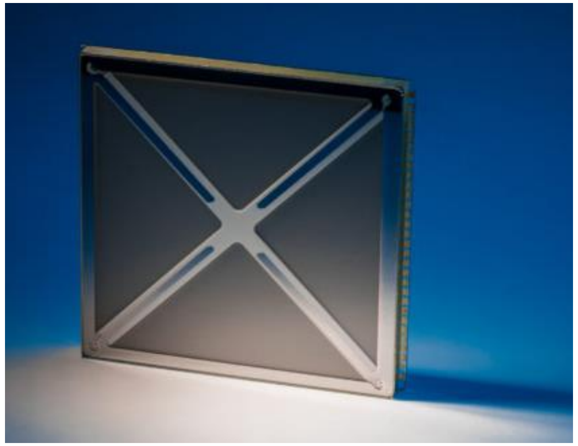
Credit: Michael Nieslony

Technological Goal: LAPPD

- ANNIE is also a staging ground for Large Area Picosecond Photo-Detectors (LAPPDs)
  - Multi-channel, 8x8in square
  - Fast signal (~50ps resolution)
  - 5 planned for physics measurement
- LAPPDs have been tested in the lab
- First LAPPD has been deployed in the water
  - As of March 29
  - 4 more coming soon





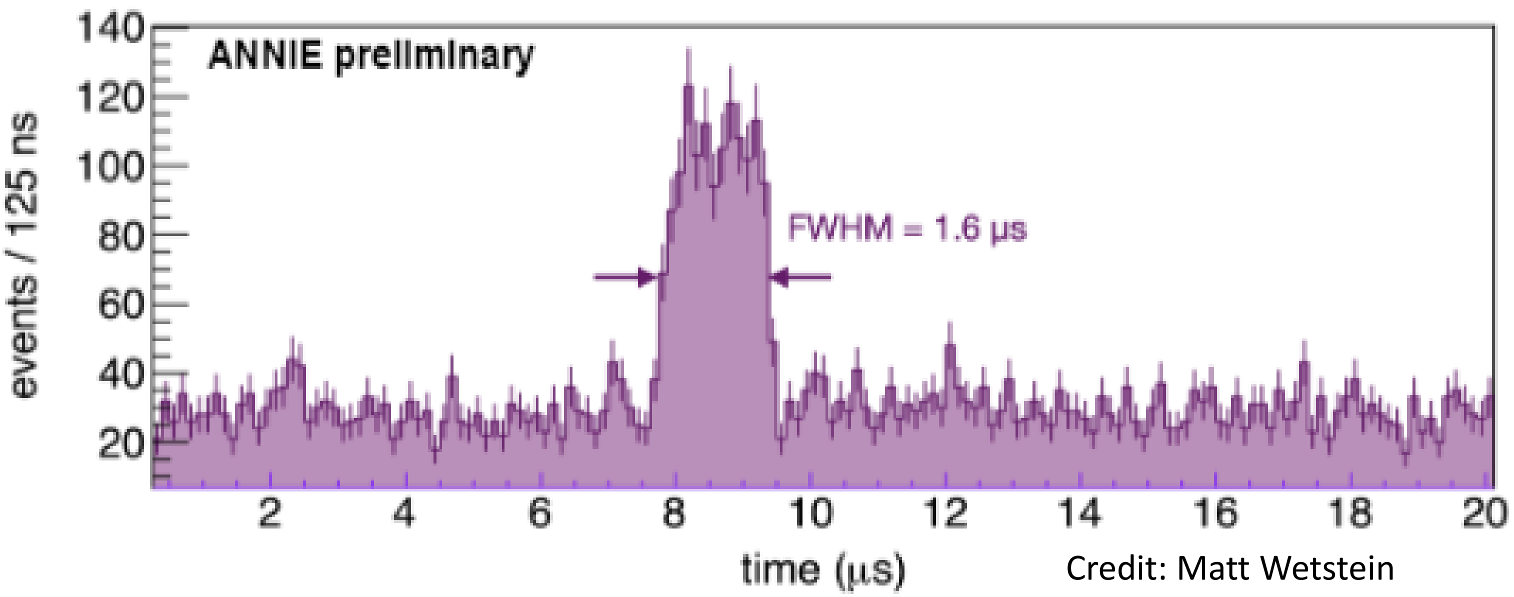


LAPPD Results

With an LAPPD in the tank, response to events are being seen

First neutrinos have been detected

Analysis of these event responses is underway



Credit: Matt Wetstein

Conclusions

ANNIE analysis is ongoing in several directions

- Reconstruction of neutrino events in position, muon energy and momentum transfer
- Neutrons, background and emitted by CC Events
- Implementation of new photodetector LAPPD

Physics results expected soon

Thank You

And are there any questions?