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 emissions

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

LAPPD and PMT hits

Vertex and track reconstruction in water tank

Track Length in Water

Track Reconstruction in MRD

Track Length in MRD

Neutrino and Muon Energy Reconstruction

Momentum transfer study for CCQE events

Credit: Jingbo Wang
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 to 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.
  \[ Q^2_{QE} = 2E_\nu Q^2 \left( E_\mu - p_\mu \cos \theta_\mu \right) - m_\mu^2 \]
- 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
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?