ANNIE: Overview and Physics Goals

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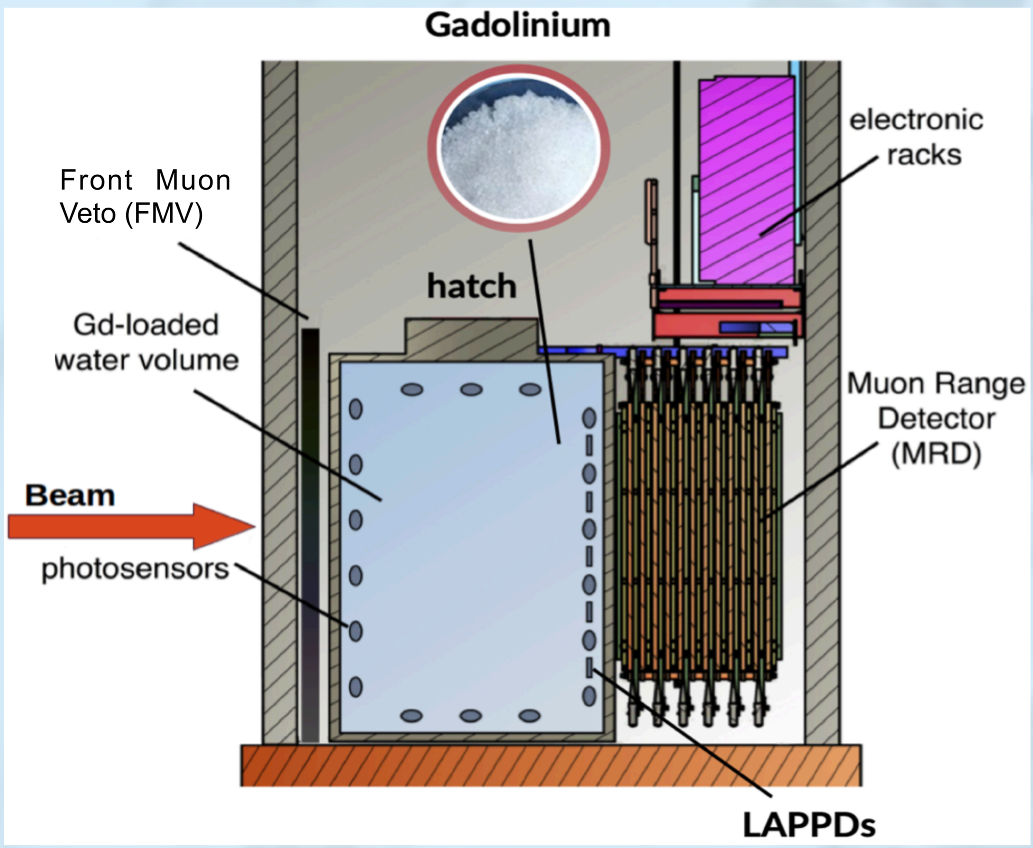
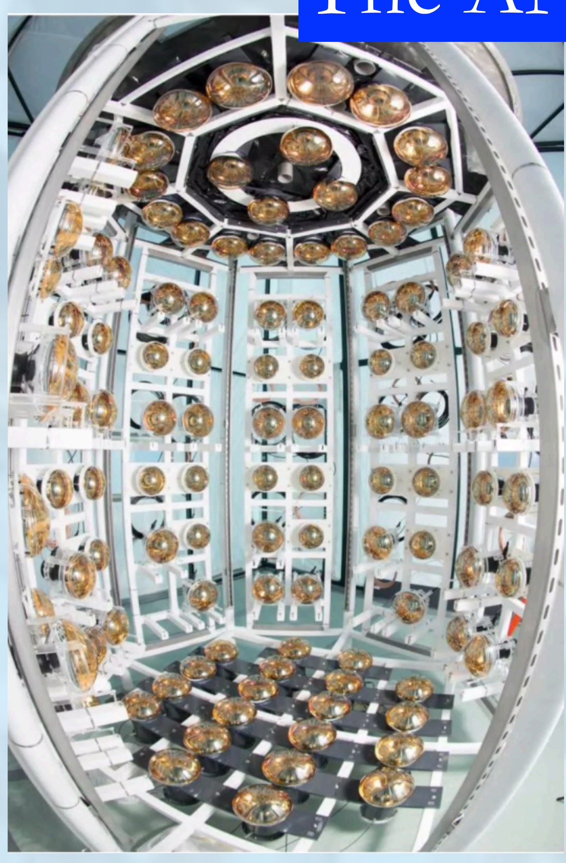
The Accelerator Neutrino Neutron Interaction Experiment (ANNIE) is a 26-ton Gd-doped water Cherenkov detector installed in the Booster Neutrino Beam (BNB) at Fermilab. The main physics goal of the experiment is to measure the final state neutron multiplicity of neutrino-nucleus interactions to improve the systematic uncertainties in oscillation experiments. Complementing this goal, ANNIE tests novel technologies such as water-based liquid scintillator (WbLS) and Large Area Picosecond PhotoDetectors (LAPPDs). This poster provides an overview of the experiment describing the status and physics goals.

The ANNIE experiment





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

Physics Motivation:

- Account of final state hadrons to fully understand neutrino interactions → improve the neutrino energy estimation in neutrino searches
- Precise measurement of neutrino cross-section in a variety of targets (water/liquid argon) and energy ranges

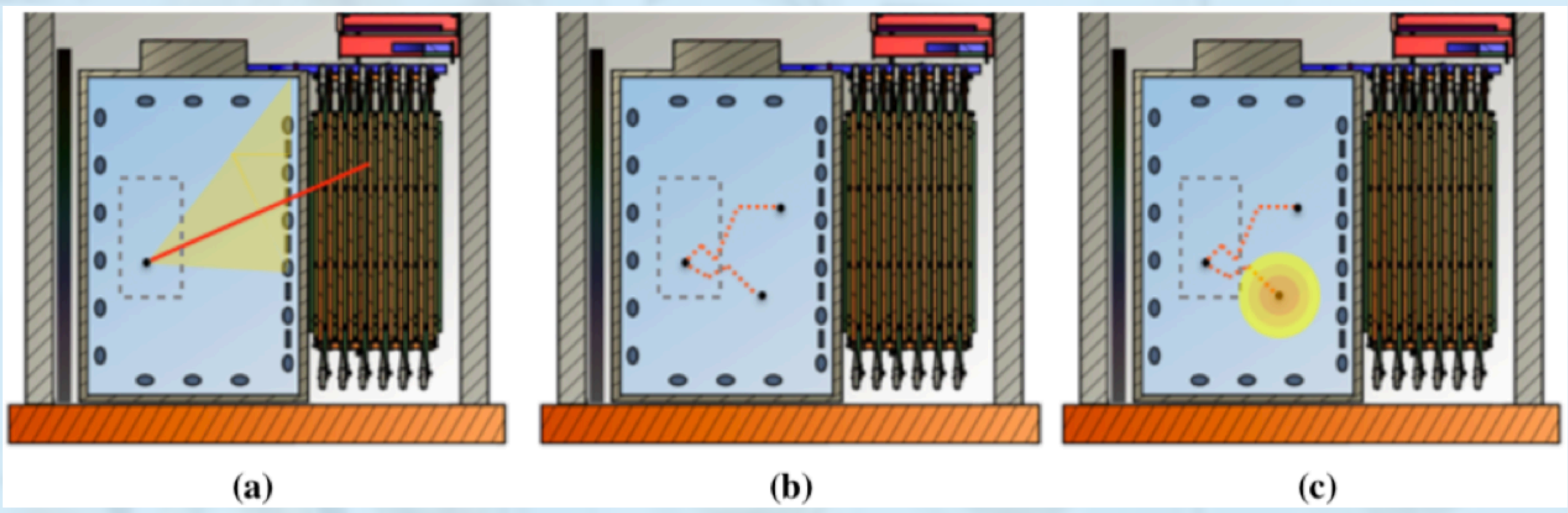
Physics Goals:

- High statistics measurement of final state **neutron multiplicity** of ν_μ with nuclei
- Measurement of CC inclusive **cross section of** ν_μ on oxygen

Technological Goals:

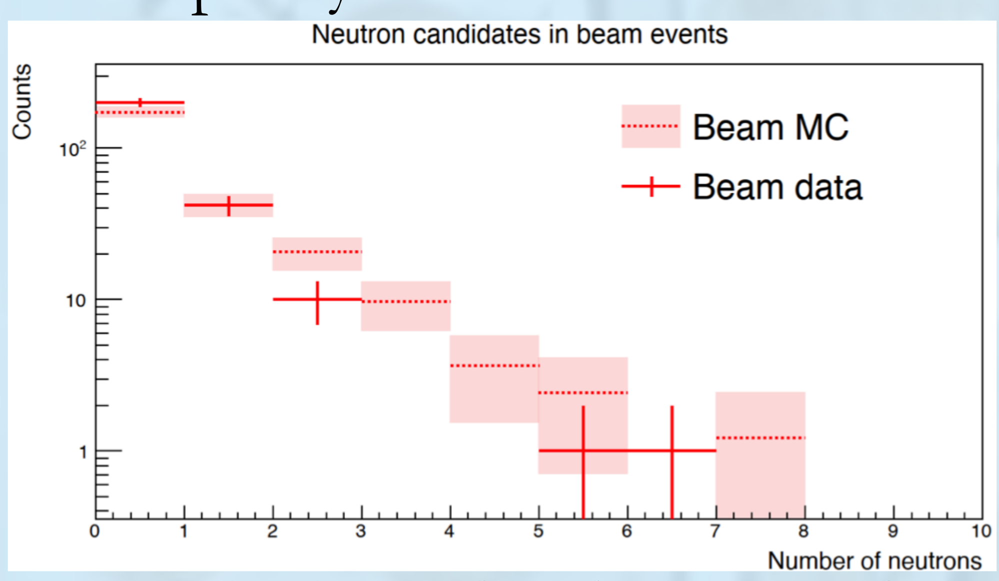
– Test bed for new detector technologies: LAPPD & WbLS

Neutrons Detection in ANNIE



(a) Neutrino CC interaction in the fiducial volume. The Cherenkov radiation from the muon is detected by PMTs and LAPPDs. The muon ranges out in the MRD.
(b)Neutrons scatter and thermalize within a few microseconds.
(c)Neutrons capture on Gd, producing gammas from the de-excitation of Gd nucleus.

Neutron multiplicity measurements from data taken in 2021.



Neutron multiplicity distribution in data and Monte Carlo (MC). Simulation models tend to over-predict high-neutron yield events, and under-predict zero-neutron interactions.

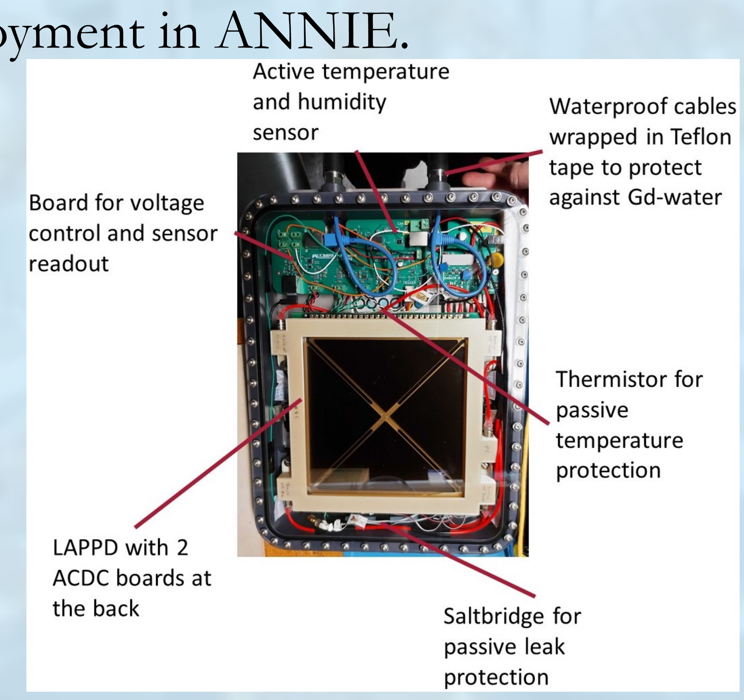
New Technologies

Large Area Picosecond PhotoDetectors (LAPPDs)

LAPPDs are microchannel-based fast-timing photosensors

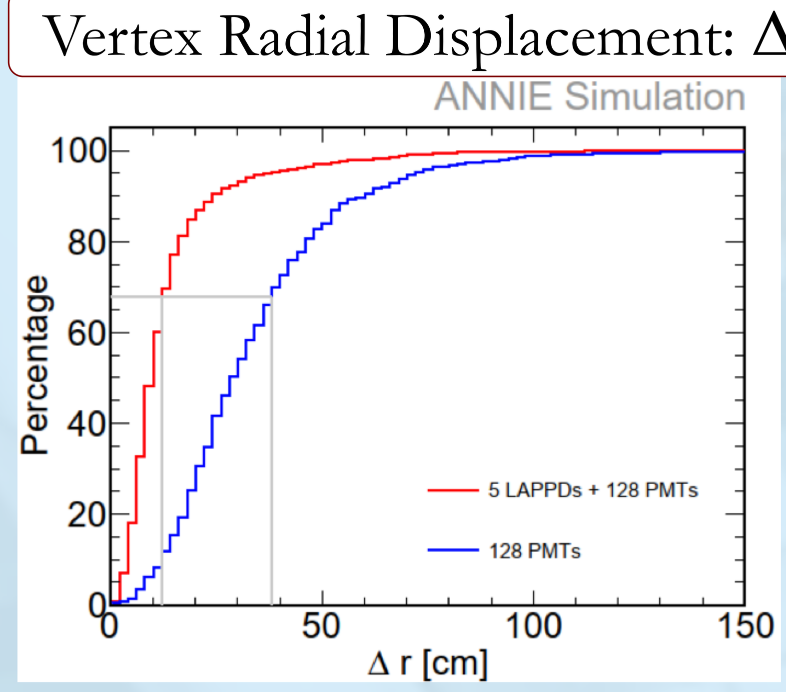
- Flat, Large-area: 20 cm × 20 cm
- Picosecond timing: ~60 ps for SPE
- Quantum efficiency: >20%, uniform
- Position resolution: sub-mm

The interior of a LAPPD "package" before deployment in ANNIE.



Why LAPPDs in ANNIE?

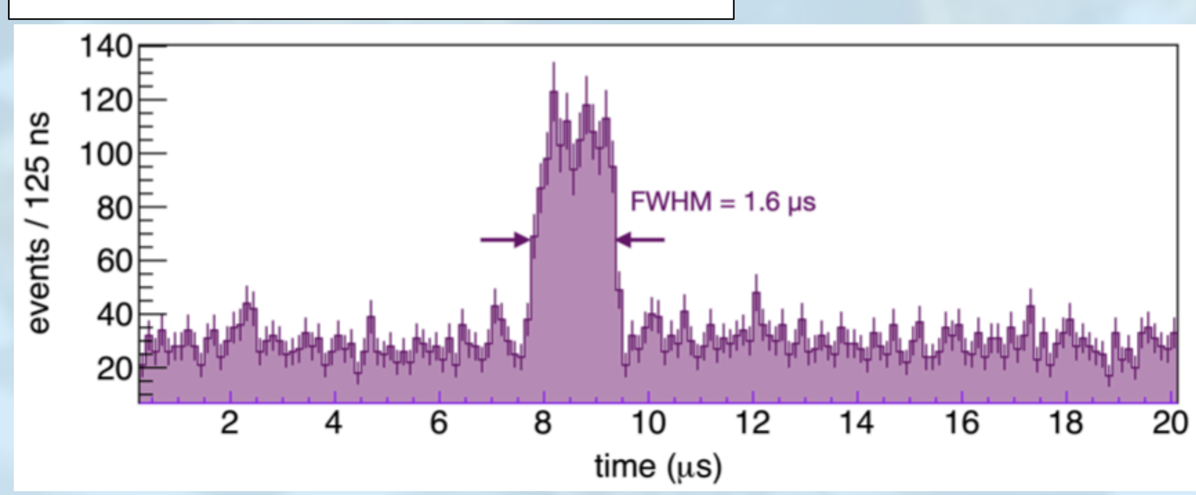
Vertex Radial Displacement: Δr



Cumulative distribution for reconstructed events in ANNIE with 128 PMTs only and 5 LAPPDs + 128 PMTs.

The addition of 5 LAPPDs improves the vertex reconstruction (more than a factor of 3!).

The beam time distribution.



Since the deployment of the first LAPPD in March 2022, **the LAPPDs are detecting neutrinos!**

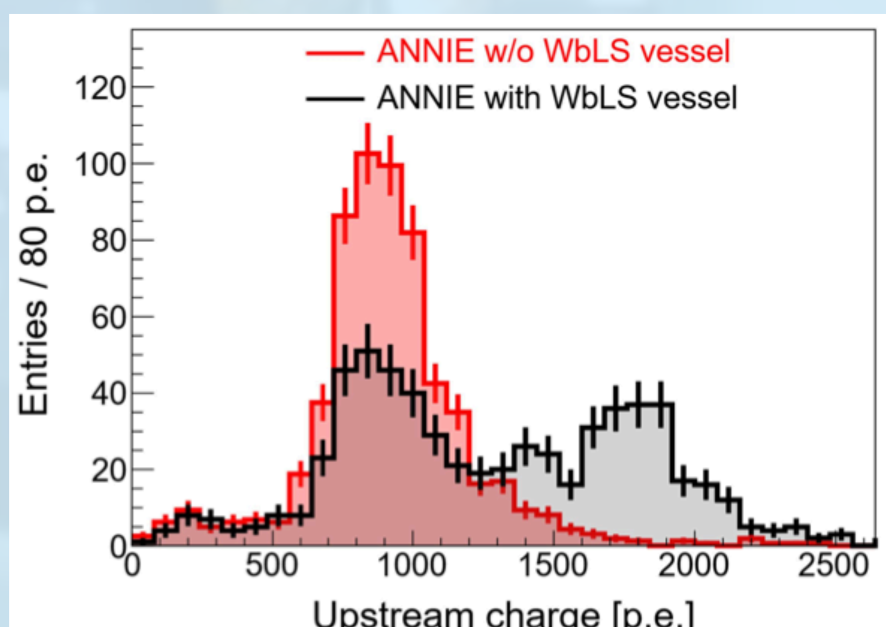
Water-based liquid scintillator (WbLS)

- Novel detection medium capable of Cherenkov-Scintillation separation
- Mixture of water and scintillator with tunable light yield and timing profile

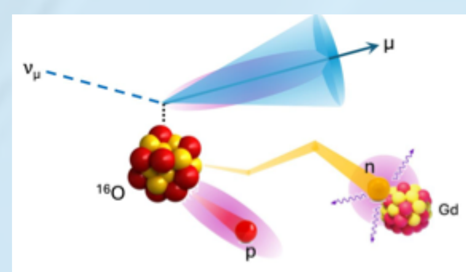
WbLS allows for hybrid event detection:

- Isotropic scintillation & directional Cherenkov signal
- Good energy resolution & directionality
- Increase of light yield

Acrylic cylindrical vessel with WbLS was deployed in **2023**, taking combined data in ANNIE for about two months.



Increase of charge for tracks passing through the WbLS vessel compared to water.



Neutrino interaction in WbLS