Deployment of water-based liquid scintillator in ANNIE

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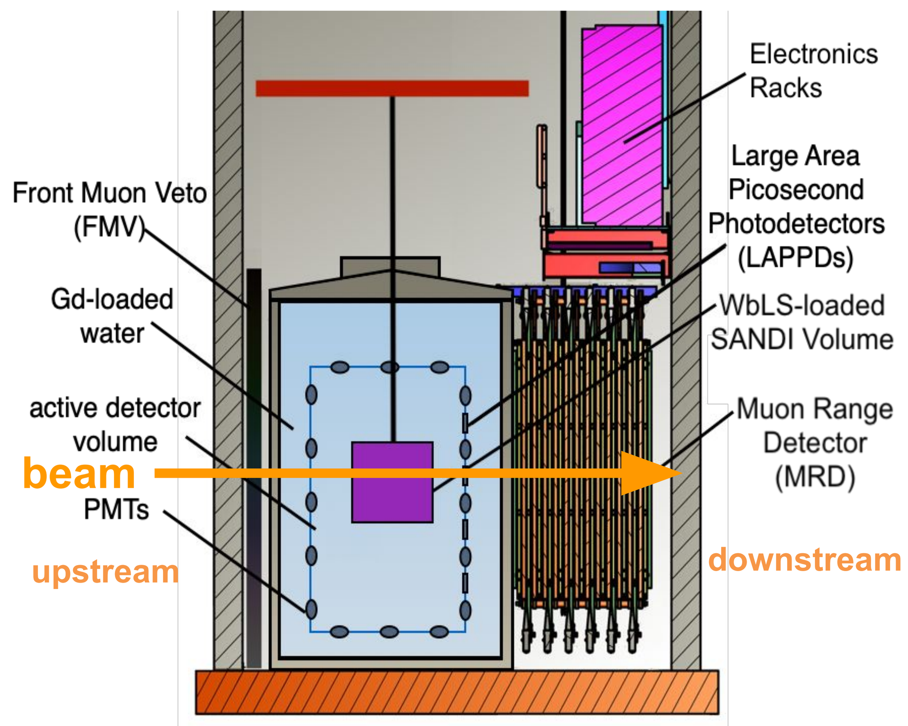
ANNIE Experiment

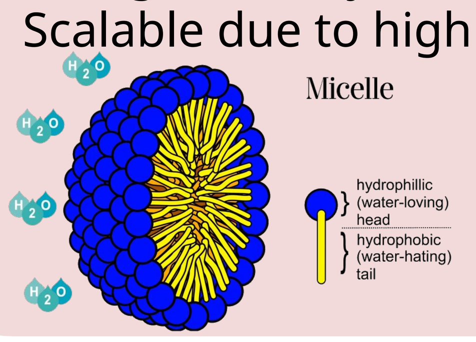
- 26-ton Gd loaded water cherenkov detector
- Located at the Booster Neutrino Beam in Fermilab
- Three main detector elements: Muon range detector (MRD), front muon veto (FMV) and ANNIE tank
- Goals: neutron multiplicity produced by interaction of ν_μ with nuclei and CC cross section of ν_μ
- Test bed for new detector technologies: Large area picosecond photon detectors (LAPPD) and Water-based liquid scintillators (WbLS)



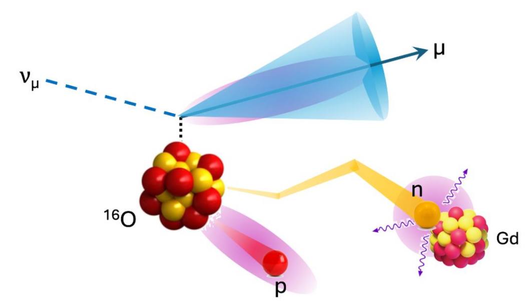
A schematic of the ANNIE detector. The FMV provides the veto signal, the tank is filled with Gd-loaded water and houses PMTs, and MRD provides muon track reconstruction capabilities

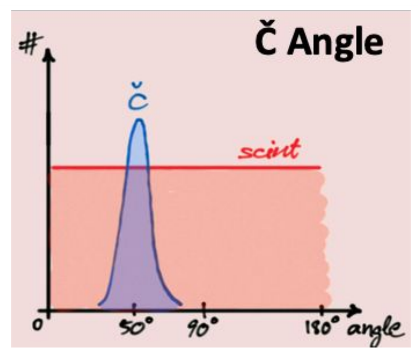
Water-based liquid scintillator (WbLS)

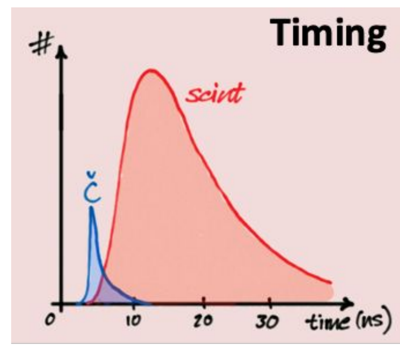
- Novel detection medium capable of Cherenkov-Scintillation separation
- Mixture of water and scintillator with tunable light yield and timing profile
- Micelles of surfactant with liquid scintillator in the center
- Hybrid event detection:
  - Good energy resolution + directionality
  - Sensitive to low energy particles
  - Background rejection
  - Scalable due to high transparency

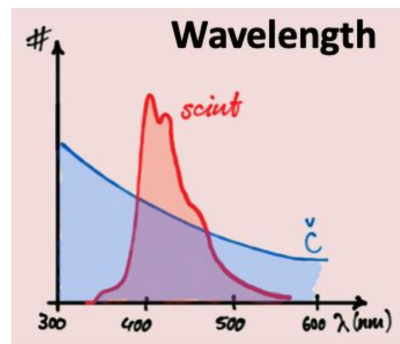


Check out talk by Minfang Yeh on Saturday 9 A.M. and Poster #586

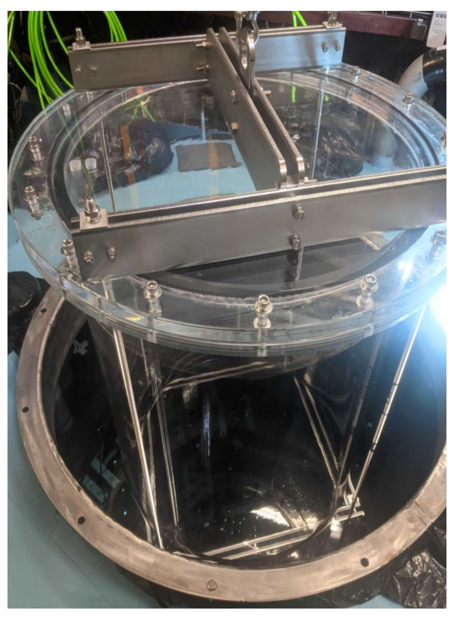






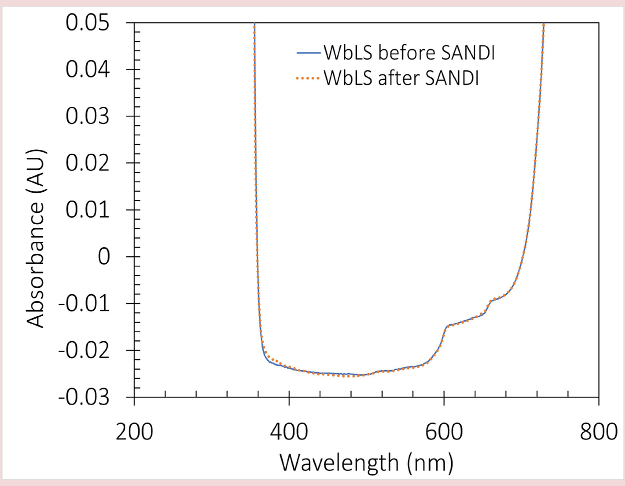


Methods of Cherenkov Scintillation separation in WbLS



Acrylic SANDI vessel for the WbLS deployment

Deployment and long term stability

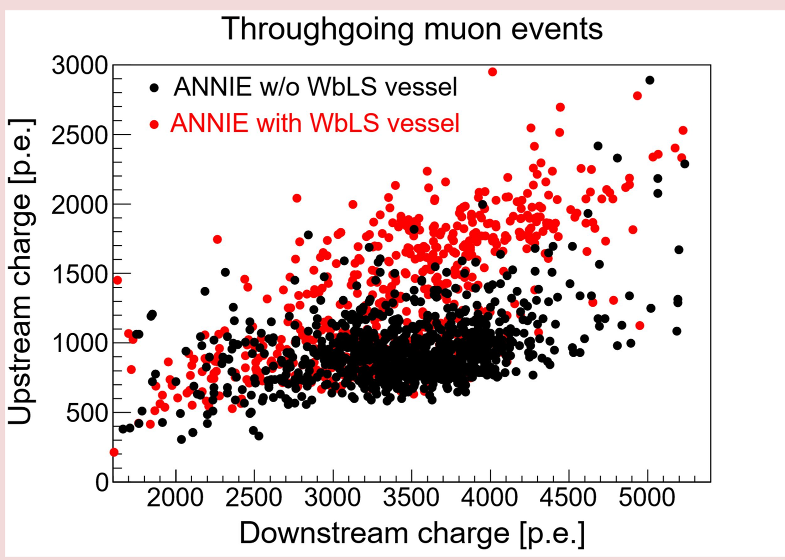


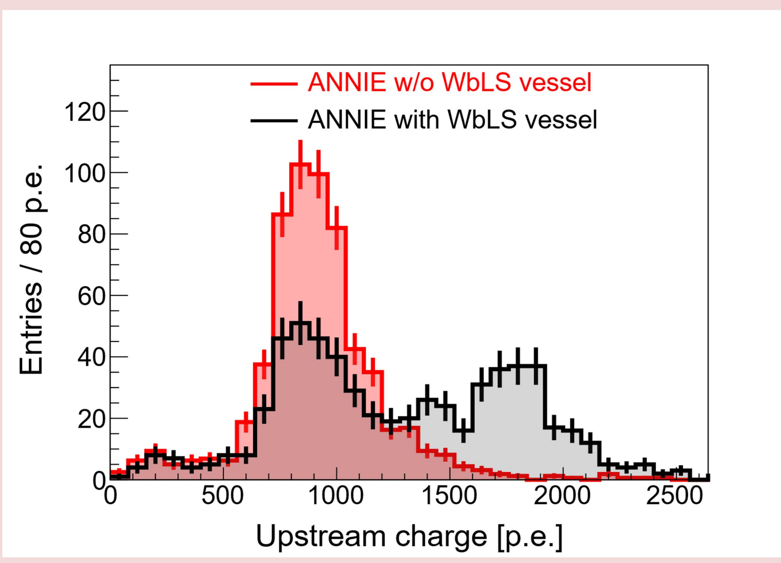
Absorption spectra of WbLS

- ANNIE WbLS : polyethylene glycol- based surfactants + diisopropyl naphthalene (liquid scintillator) + 2,5-diphenyloxazole (fluor)
- Produced at BNL and shipped to Fermilab
- 366 L of WbLS deployed in acrylic cylinder "SANDI"
- Deployed from March to May 2023
- Lowered into ANNIE tank using stainless steel cables
- Optically stable over 9 months of shipping, storage and deployment
  - Variation within statistical uncertainty

Scintillation from muons

- Estimate impact of scintillation light using throughgoing muons, i.e. muons which pass through all the three detector components.
- Muons through WbLS produce both Cherenkov and scintillation light
- Cherenkov light:
  - Detected by PMTs downstream
  - Indirect cherenkov light from reflections detected by downstream PMTs
- Direct scintillation light detected by both upstream and downstream PMTs



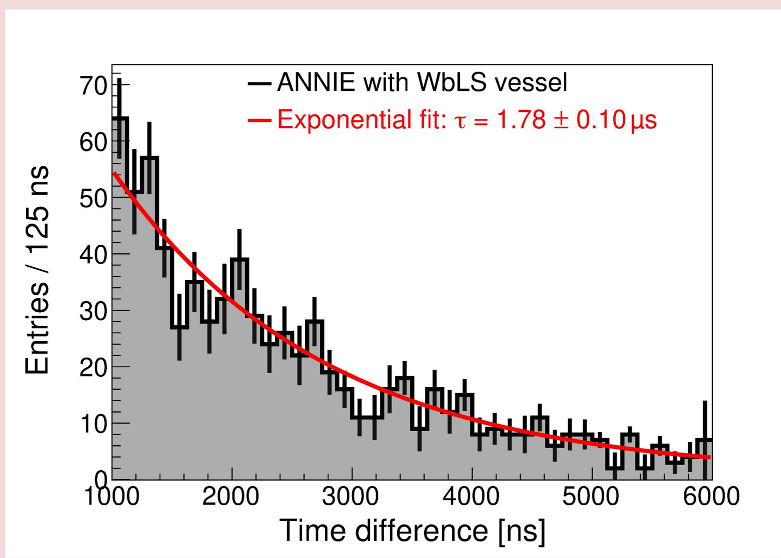


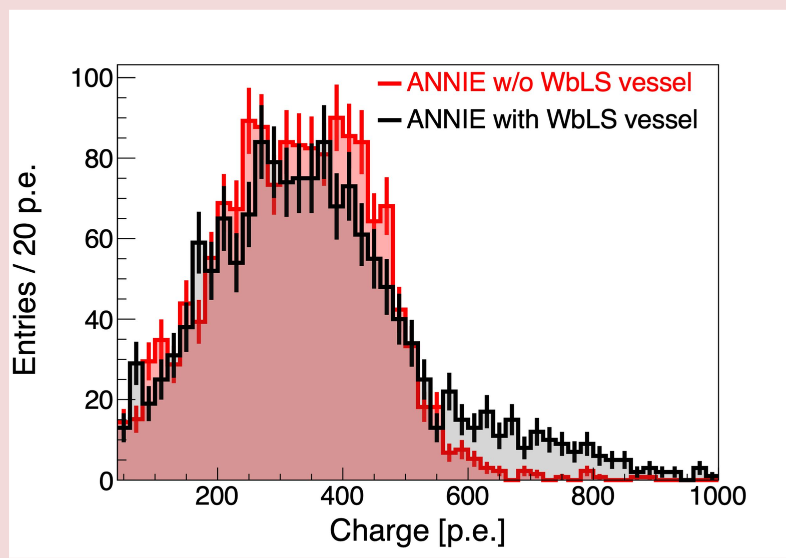
Distribution of charge with and without the SANDI vessel.

- Two event populations for WbLS events:
  - True WbLS events with high upstream charge
  - Misreconstructed events, overlapped by events w/o WbLS vessel
- Two peaks in upstream charge with WbLS:
  - True WbLS (Cherenkov + scintillation) events at 1800 p.e.
  - Misreconstructed/ wrongly selected Cherenkov events at 800 p.e.
- Increase of p.e. for tracks through WbLS compared to water
  - Not an intrinsic light yield of WbLS, includes effective absorption

Scintillation from Michel electrons

- Michel electrons have well known energy spectrum → compare energy spectrum with water and WbLS to estimate the impact of scintillation light
- Event selection: prompt muon event followed by an electron event
- Sample purity :
  - Extract decay time of muon from time distribution of selected michel electron candidates
  - Good agreement with the expected muon lifetime



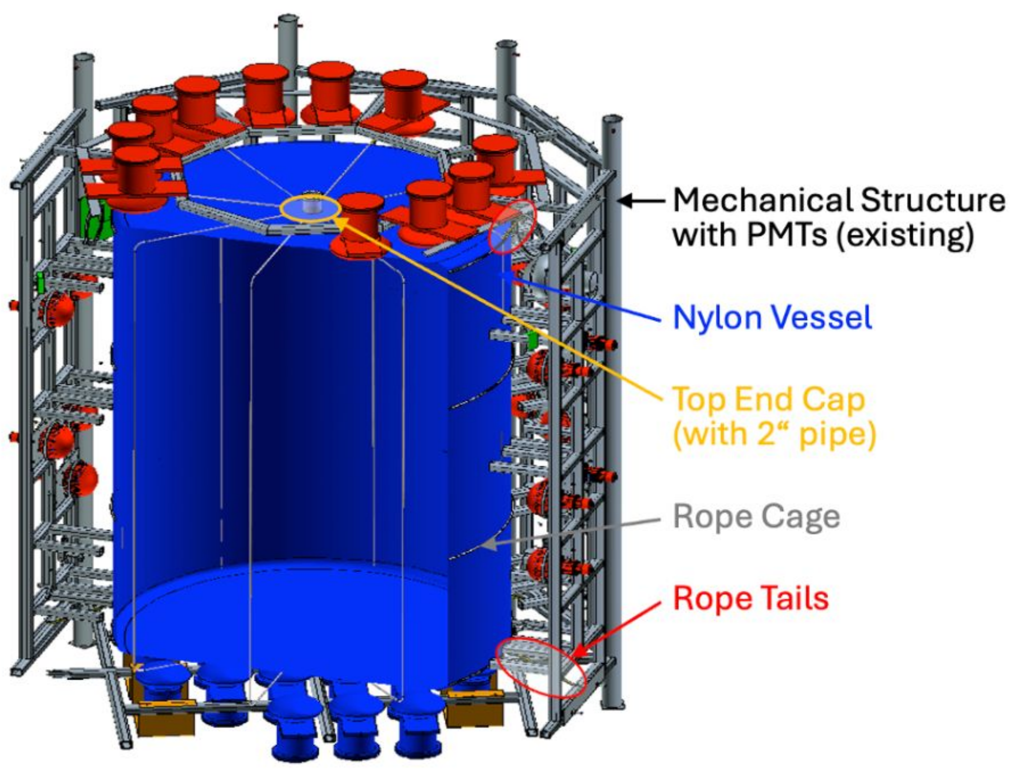


Timing distribution of the selected michel electron candidates (left). Charge distribution of the michel electron events with and without SANDI (right).

- Two types of michel electron events:
  - Michel electron events created inside WbLS volume (Cherenkov + Scintillation)
  - Michel electron events in water (Cherenkov photons only)
- Increase in photoelectrons (PE) detected for Michel electrons created inside SANDI:
  - Relative increase in detected PE estimated using the ratio of the mean number of detected PE by the two event types
- Increase of (77 ± 8) % in detected photoelectrons

Conclusion and Outlook

- Conclusion:
  - ANNIE successfully deployed WbLS and demonstrated the detection of both cherenkov and scintillation light
  - Two independent analysis to estimate the increase in detected light
  - WbLS used in ANNIE stable over full deployment period
- Outlook:
  - Re-deployment of Gd-doped WbLS for neutron capture
  - Demonstrate timing separation of scintillation and Cherenkov signal with LAPPDs
  - Planned: Deployment of 8-ton nylon vessel filled with WbLS



Proposed design of 8t WbLS vessel

https://iopscience.iop.org/article/10.1088/1748-0221/19/05/P05070

This work was supported by the U.S. Department of Energy Office of Science and Fermilab and by Deutsche Forschungsgemeinschaft grants 490717455 and 460377837.