The ANNIE Experiment: Results from Phase I

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for the ANNIE Collaboration

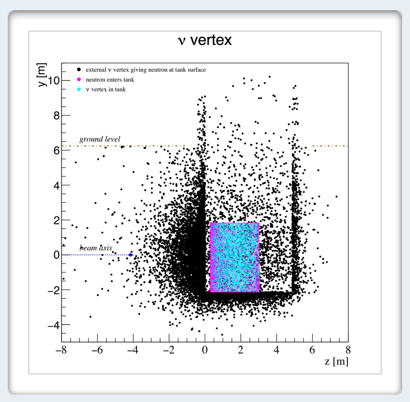
http://annie.fnal.gov

ANNIE: The Accelerator Neutrino Neutron Interaction Experiment

Experimental Goals:

1. Measure the production of neutrons from ν_μ interactions as a function of Q^2 to constrain neutrino-nucleus interaction models.
2. Demonstrate the power of new fast-timing, position-sensitive detectors (LAPPDs) in a physics experiment.

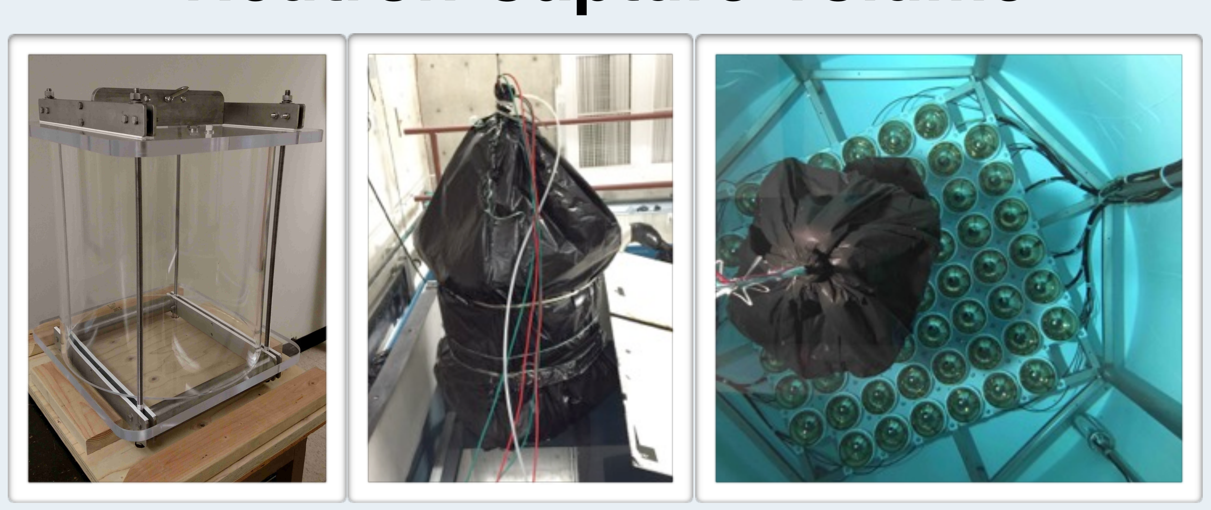
Phase 1: Measurement of Beam-correlated neutron backgrounds



The first phase of the ANNIE Experiment used a moving Neutron Capture Volume (NCV) to measure the neutron flux at several positions within the ANNIE detector volume to confirm the rapid falloff of "skyshine" neutrons from the neutrino-beam target and "dirt" neutrons from neutrino interactions outside the detector volume.

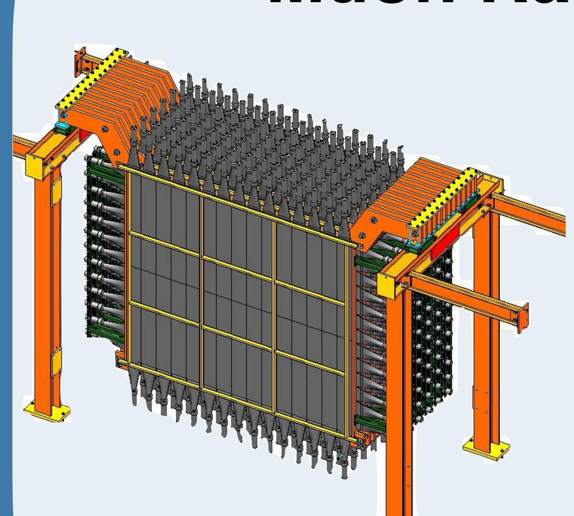
On the left: The distribution of neutrino-interaction vertices that contribute neutrons that reach the tank (black points), Magenta points are where the neutrons enter the tank and cyan points are neutrino interactions within the tank.

Neutron Capture Volume



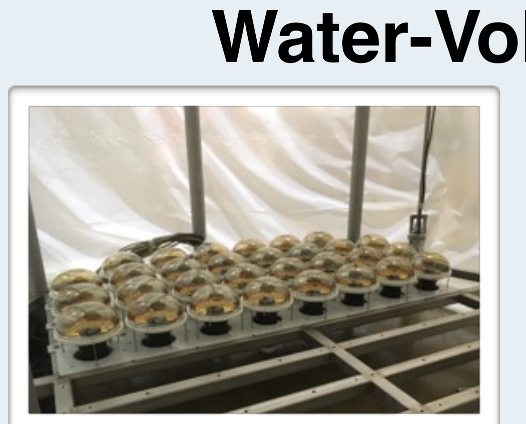
The NCV was filled with 95 liters of Eljen EJ-335 (0.25%) Gadolinium doped liquid scintillator. Two waterproofed PMTs were optically coupled to the top of the acrylic vessel. To optically isolate the NCV from the water volume while running in "Hefty mode", it was wrapped in commercially available polyethylene liners.

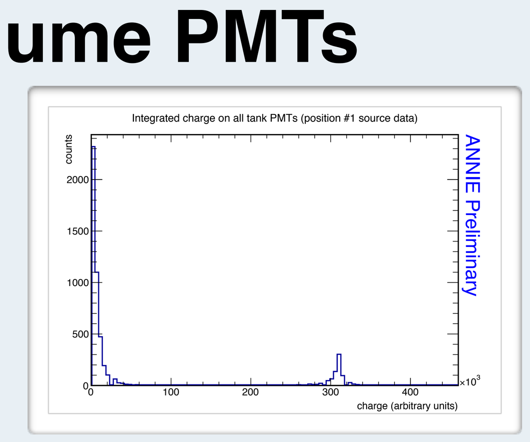
Muon Range Detector



The Muon Range Detector (MRD) was inherited from the SciBooNE experiment and is being fully refurbished by the ANNIE Collaboration. It consists of alternating layers of plastic scintillator and steel plates. The scintillator layers are segmented strips and alternate between horizontal and vertical orientation to allow for x-y tracking of particles passing through multiple layers.

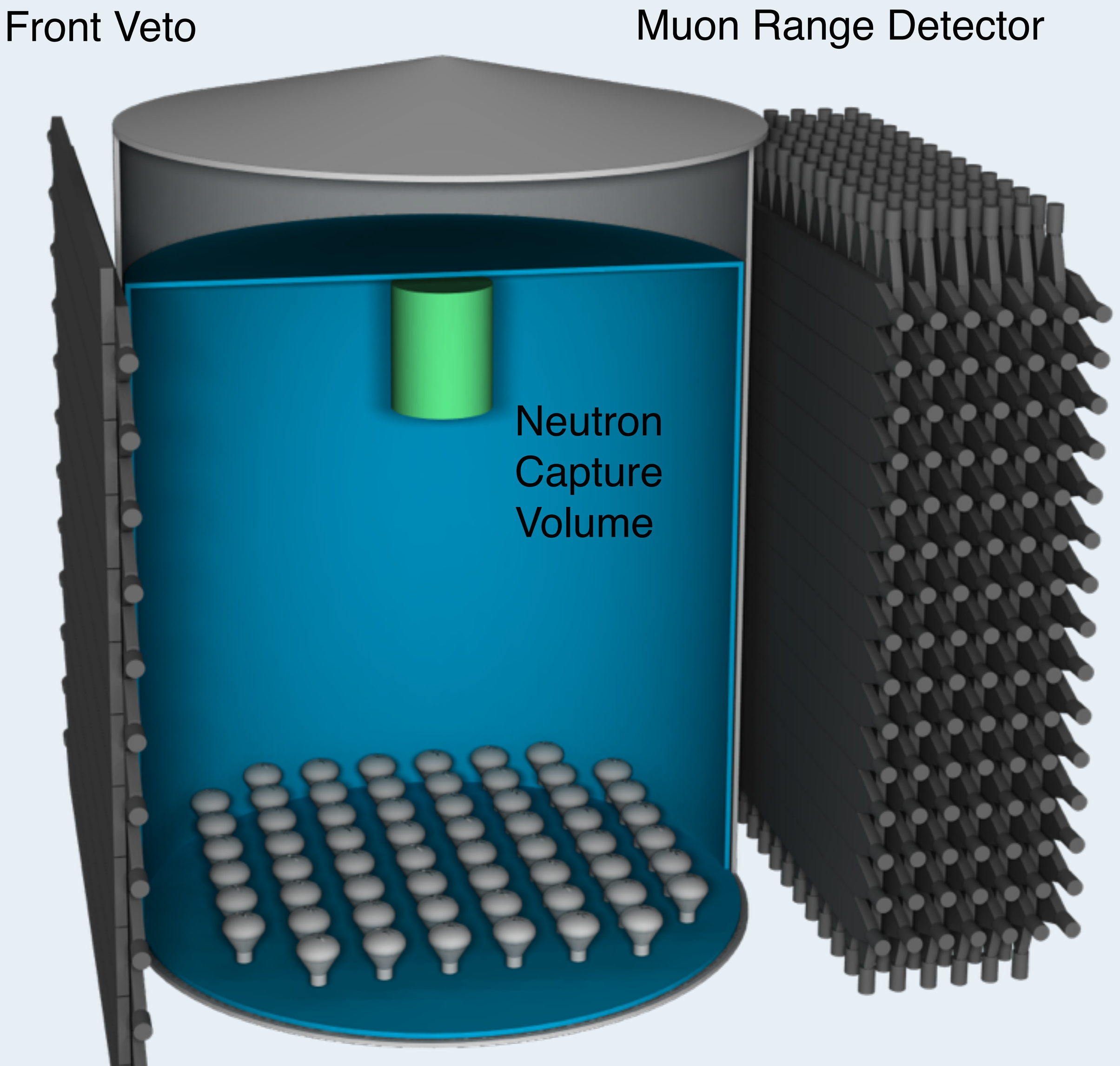
Water-Volume PMTs



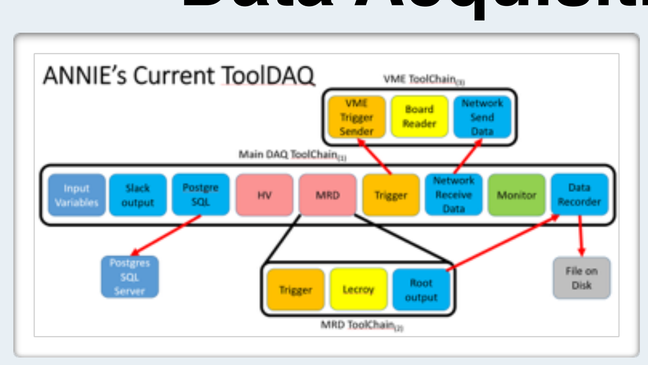


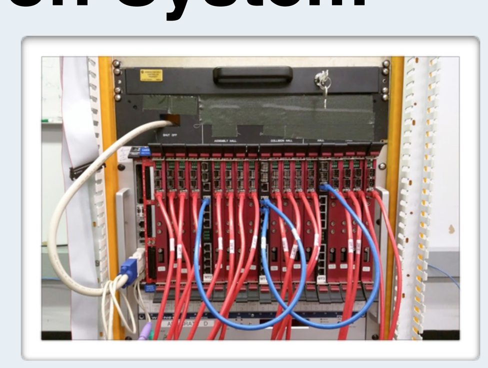
In Phase I, the 60 upward-pointing PMTs (shown being installed on the left) act as an active veto for charged-current neutrino interactions in the water volume and to cosmic-ray muons entering from above. The plot on the right shows a charge cut used to remove random cosmic-ray muons from our source calibration sample.

The ANNIE Detector



Data Acquisition System





The ANNIE Experiment uses a modular, scalable Data Acquisition System ("DAQ") using 500MSPS continuous digitizing ADCs to record the full waveform (up to 80μs) from the water volume PMTs and other utility signals for sub-nanosecond precision signal timing. The Forward Veto and Muon Range Detectors are digitized using a CAMAC-based TDC system, and all triggering and synchronization signals are timestamped within the FPGA-based trigger system. All of the subsystems are read out by the ToolDAQ-based DAQ system asynchronously for maximum detector live-time and reliability and are combined offline with external beam data using UTC timestamps.

The ANNIE Collaboration

- University of California, Berkeley
- University of California, Davis
- University of California, Irvine
- University of Chicago
- University of Edinburgh
- Fermi National Accelerator Laboratory
- Iowa State University
- Lawrence Livermore National Laboratory
- Ohio State University
- Queen Mary University
- University of Sheffield

Acknowledgements

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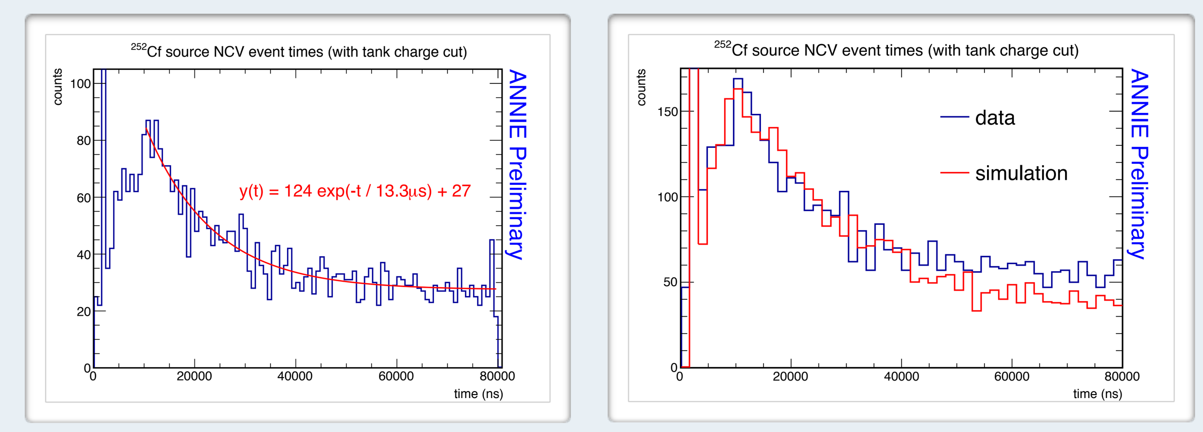
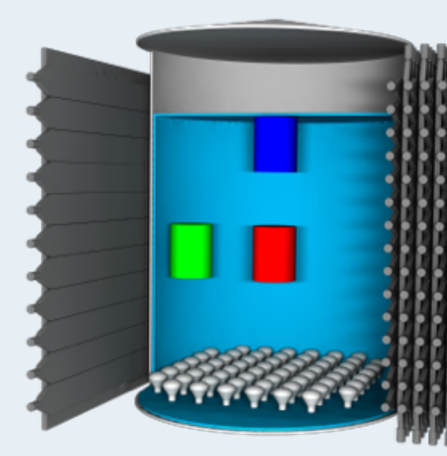
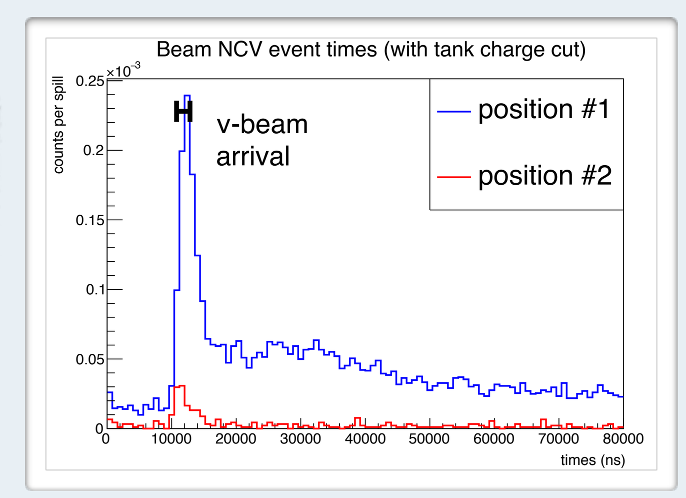
Neutron Capture on Gadolinium



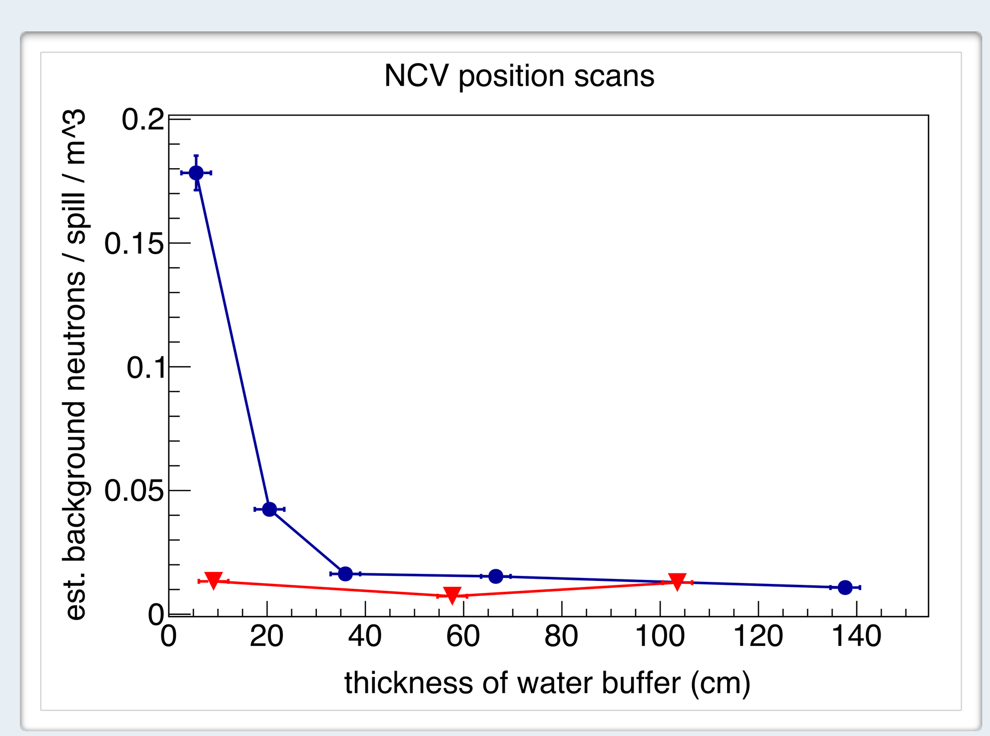
The NCV efficiency was calibrated using an "active source" consisting of a ^{252}Cf neutron source and a LYSO (Lutetium Yttrium Oxyorthosilicate) scintillation crystal coupled to a 1-inch PMT. The signal from the PMT was used to trigger on scintillation light in the LYSO crystal from gamma-ray interactions from the Californium fission which also emits the neutrons. The gamma-ray signal also produces events in the NCV, which are shown in the first microseconds of the event time distributions shown above. Following a thermalization time of about 10-microseconds, the neutrons capture with the expected time constant of about 13 microseconds.

Results





The beam-spill averaged event count time series is shown above for two representative positions, at the surface of the water (position #1, blue) and in the center of the tank (position #2, red). At the top of the tank, the unvetoed random background can be seen before the neutrino-beam arrival (10000ns). During the beam spill, and in the following several microseconds, the signal is dominated by proton recoils from slowing neutrons. After another ten microseconds, the neutrons have thermalized and begin capturing at the characteristic 13-microsecond exponential rate for this Gadolinium concentration, as seen in the neutron source calibration. During the Phase II physics run, these thermalized neutrons from outside the detector would be a background for the neutron multiplicity measurement.



The integrated neutron capture counts for seven positions within the tank are shown in the figure above. The blue points show five different locations along the central axis of the tank from just below the water surface to the center of the tank (blue to red with intermediate locations). The red points show three positions along the middle of tank in the beam direction, from near the front wall of the tank to the position at the enter of the tank (green to red).

Background neutron rates are measured to be small (less than 0.02 neutrons per spill per m^3) under half a meter of water overburden, allowing the future Phase II analysis to use the entire simulation-optimized 2.5 ton fiducial volume.