The ANNIE Experiment

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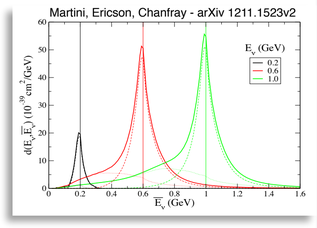
Accelerator Neutrino-Neutron Interaction Experiment

ANNIE is a water Cherenkov neutrino-neutron experiment in Fermilab's Booster Neutrino Beamline

GOAL is to measure the abundance of final state neutrons from neutrino-nucleus interactions in water, as a function of energy

ν-Nuclei Interactions?

To turn neutrino physics into a precision science we need to understand the complex multi-scale physics of neutrino-nucleus interactions

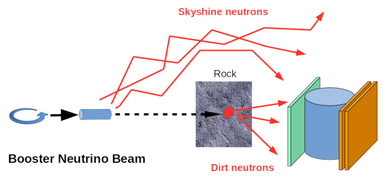


- Dominant source of systematics on future long baseline oscillation physics
- Source of uncertainty and controversy in short baseline anomalies

We need comprehensive and precise measurement for a variety of targets/E_ν

Run I

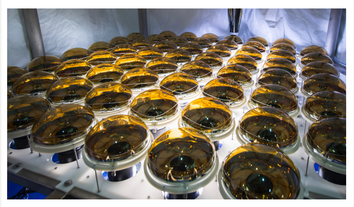
- Proof of concept
- Measure neutron background rates in the Hall : skyshine, dirt neutrons

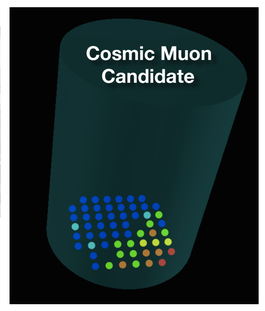


Run II

- A key physics measurement in understanding the nature of neutrino-nucleus interactions
- Application of a new photodetector technology for detecting neutrinos

ANNIE Run I



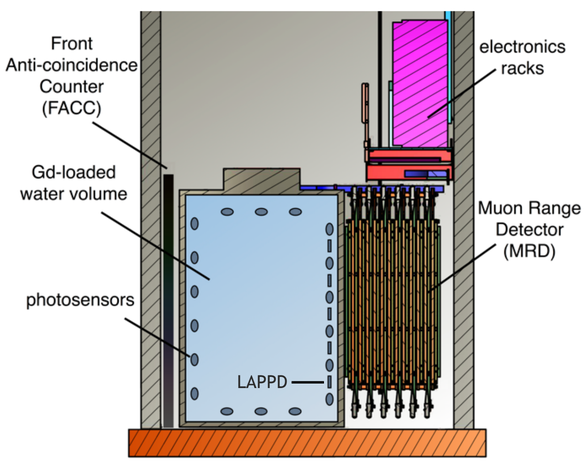


Run I

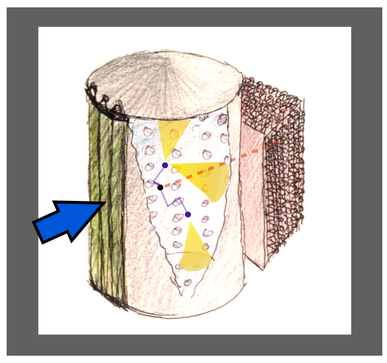
- Currently taking data
- Extended run into 2016-2017 to demonstrate LAPPD readiness

See M. O'Flaherty's poster for Run I progress

Run II Detector System



- Up to 20 LAPPDs, downstream side of tank
- Full radial PMT coverage with 200 PMTs
  - (combination of) 8" Hamamatsu, HQE 10" Hamamatsu, and 11" ETEL
- Full tank (~26-tons) of 0.1% Gd-loaded water (0.2% of $Gd_2(SO_4)_3$)
- Full MRD coverage, 10 layers (alternating horizontal/vertical)
- Combined waveform sampling electronics with fast electronics (PSEC4) to read conventional PMTs and LAPPDs



Neutrino Interaction with Neutron Yield :

- No hits on the forward Veto
- A matched muon track created in water volume to one in the MRD
- Vertex determined using LAPPDs in water
- Detect flashes of light due to neutron thermalization and Gd capture

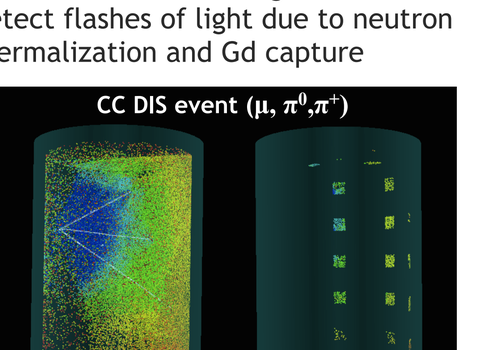
LAPPDs

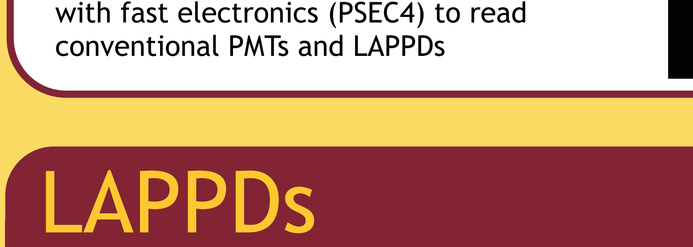
Large Area Picosecond PhotoDetector

LAPPD's timing resolution is essential for neutrino vertex reconstruction

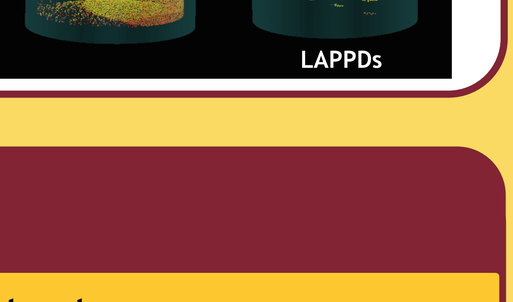
Promising new technology for detecting neutrinos

- Large, flat-panel, microchannel plate-based photosensors
- 50-100 picosec time resolutions and <1 cm spatial resolutions
- Based on new, potentially economical industrial processes with applications in particle physics, nuclear physics, X-ray science, and medical imaging
- LAPPD design includes a working readout system





- Tracks are reconstructed from the timing of the light arrival, LAPPDs help to discriminate between single and multi-track events
- ANNIE scale (3 m cubic) detector, assuming 100% LAPPD coverage

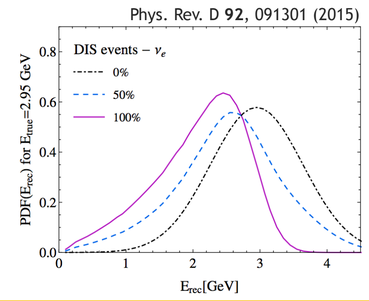


Physics Impact

Neutrino Energy Reconstruction

Energy reconstruction will be essential for DUNE, Hyper-K, T2K, and NOvA

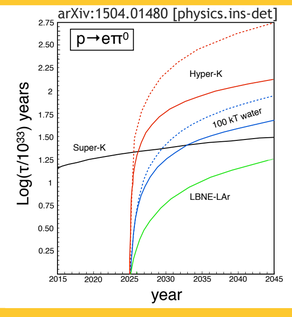
- Detector resolution and effects can introduce missing energy and inelastic events faking quasi-elastic interactions
- Can significantly impact systematic uncertainties
- ANNIE is unique in that it can provide neutron data to complement the proton data taken in other experiments



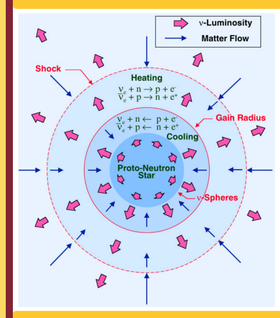
Proton Decay

Allows for access to physics at the GUT scales

- Easily seen in water Cherenkov detectors
- Neutron tagging is needed to reduce atmospheric neutrino interactions (main background)
- Proton decay is expected to produce neutrons <10% of the time, while atmospheric interactions could produce one or more final-state neutrons at least one final-state neutron
- ANNIE can provide more precise neutron multiplicity measurement relevant to atmospheric neutrino induced events



Supernova Neutrinos



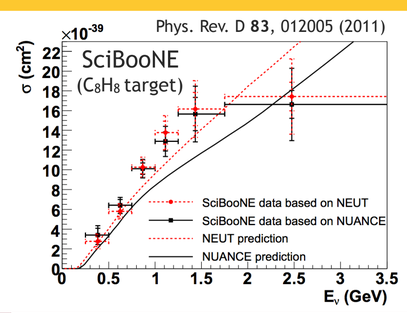
Neutrinos provide an excellent probe into stellar dynamics

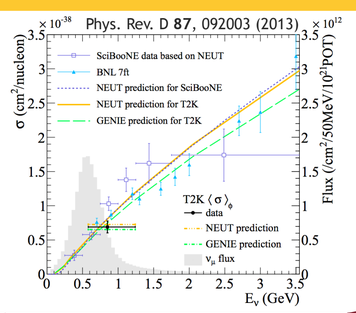
- Neutrinos (and gravitational waves) provide a window into a core collapse inner dynamics
- Within 10 sec of a collapse, >98% of energy is carried away by neutrinos
- Main detection comes from positrons emitted by the inverse beta decay (~88% of events)
- Above ~20 MeV, the dominant background is due to the decay of sub-Cherenkov threshold muons from atmospheric neutrino interactions
- Understanding neutron yields can be used to help statistically discriminate spallation backgrounds from diffuse relic supernova neutrinos

Cross Sections in Water

Neutrino cross section measurements

- SciBooNE and T2K have made ν_μ charged-current inclusive cross sections on carbon
- No similar statistics sample on water (oxygen) target exists
- ANNIE could contribute to this measurement





Summary

- ANNIE (Run II) seeks to measure the abundance of final state neutrons from neutrino interactions in water, as a function of energy
- ANNIE (Run I) is currently taking data and will run into 2017 demonstrating LAPPD readiness
- The Run II proposal plans on a realistic delivery schedule of 20 LAPPDs in 3 years by Incom, Inc., additional conventional PMTs and waveform sampling electronics are also proposed
- ANNIE's planned 5 year physics program will play a role in a variety of physics topics