Accelerator Neutrino Neutron Interaction Experiment

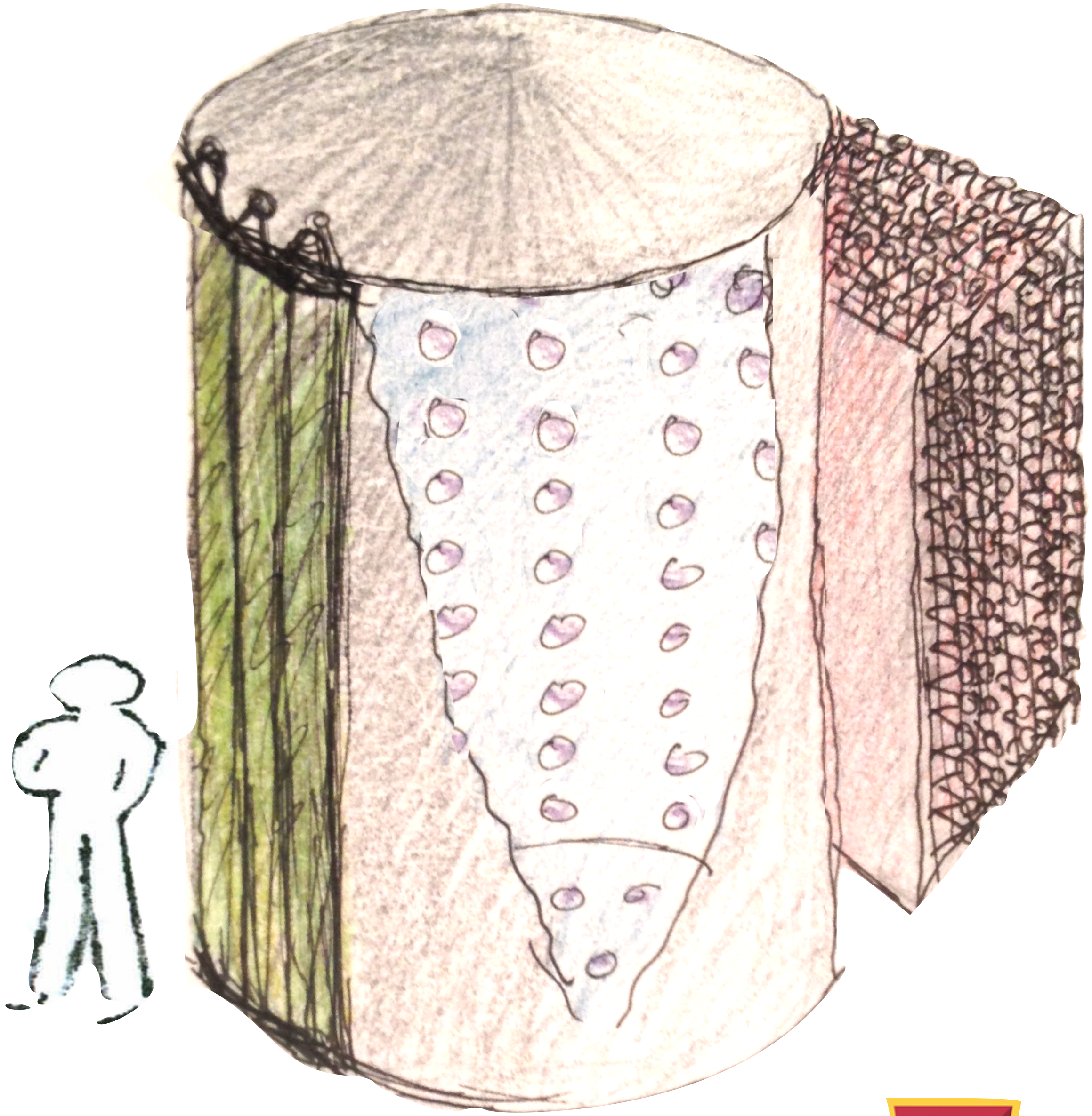
ANNIE in Ten Minutes

Jonathan Eisch
Iowa State University

New Perspectives 2016, Fermilab, June 13-14 2016

Overview

- Science Goals and Motivation
- Experiment Description
- Technology Development
- Operation Timeline



The ANNIE Collaboration

- 2 Countries
- 11 Institutions
- 30+ Collaborators

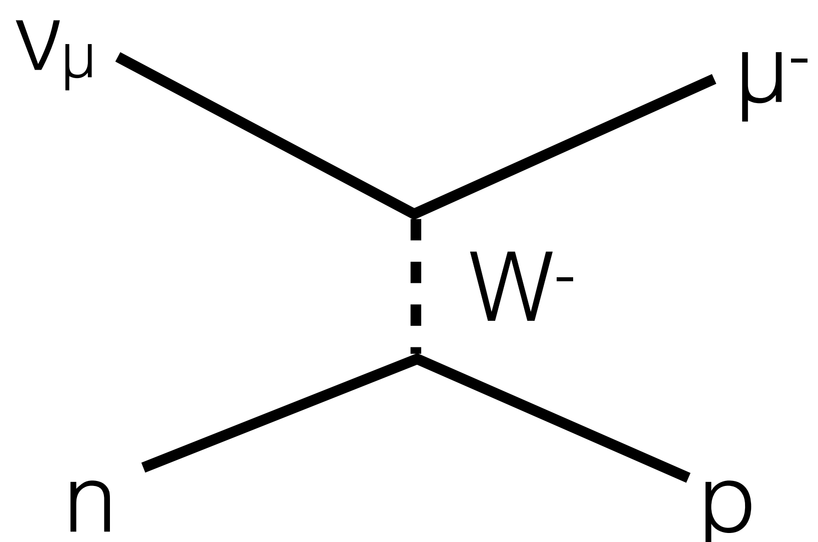
- Argonne National Laboratory
- Brookhaven National Laboratory
- Fermi National Laboratory
- University of California at Berkeley
- University of California at Davis
- University of California at Irvine
- University of Chicago
- Iowa State University
- Ohio State University
- University of Sheffield
- Queen Mary University of London

Motivation

- Primary science goal: Measure the abundance of final state neutrons from neutrino interactions in water as a function of energy.
  - Understanding neutrino-nucleus interactions
  - Reduce backgrounds in proton decay experiment
  - Better detection of supernova neutrinos
- Develop new detection technologies
  - Large Area Picosecond Photo Detectors (LAPPD)
  - Waveform digitization with 100ps samples

Understanding Neutrino-Nucleus Interactions

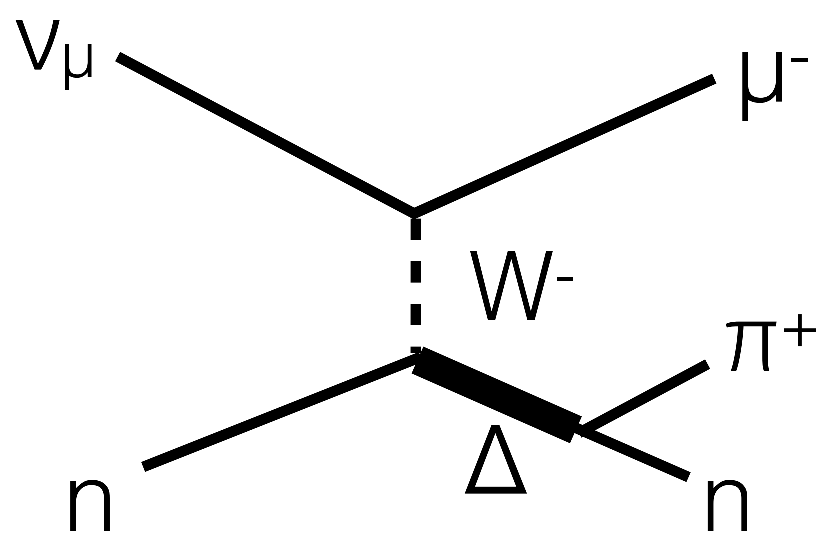
- The simplest case; a charged-current quasi-elastic (CCQE) neutrino interaction:



- (This interaction produces no neutrons.)
- The neutrino energy can be estimated by reconstructing only the muon.
- Everything is relatively nice and easy.

Understanding Neutrino-Nucleus Interactions

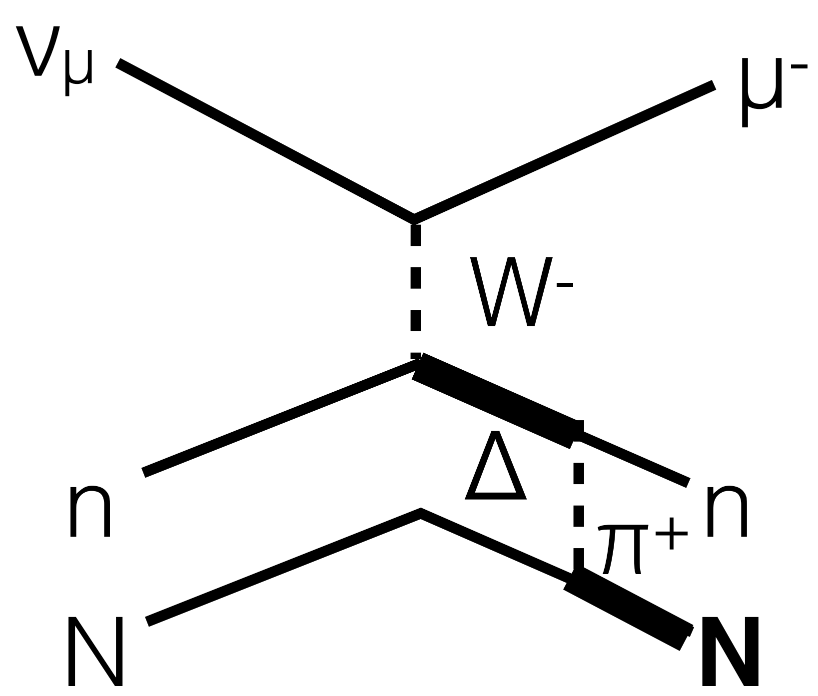
- The neutrino can also inelastically scatter producing a short-lived excited state:



- Now there is a final-state neutron.
- The charged pion can be detected, reducing confusion with CCQE.

Understanding Neutrino-Nucleus Interactions

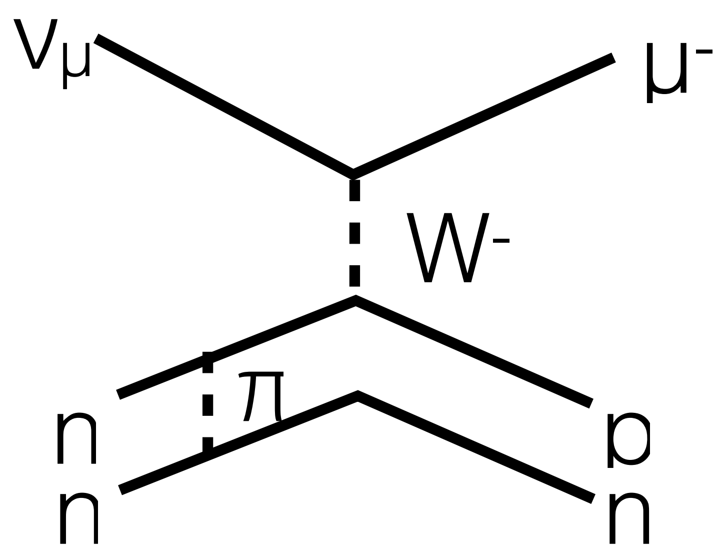
- But within a nucleus, there are other nucleons that can complicate matters:



- Now there is at least one final-state neutron.
- The pion now doesn’t leave the nucleus and instead is absorbed by the spectator nucleons.

Understanding Neutrino-Nucleus Interactions

- Another possibility is scattering off a correlated neutron-neutron pair in the nucleus (2*p*-2*h*):



- This results in the liberation of at least a proton and neutron.
- The kinematics of the correlated pair breaks down the assumption of CCQE scattering off of a nucleon with average momentum properties and a results in different interaction cross section.
- There are many other possibilities involving diagrams like this, most of which include final state neutrons.

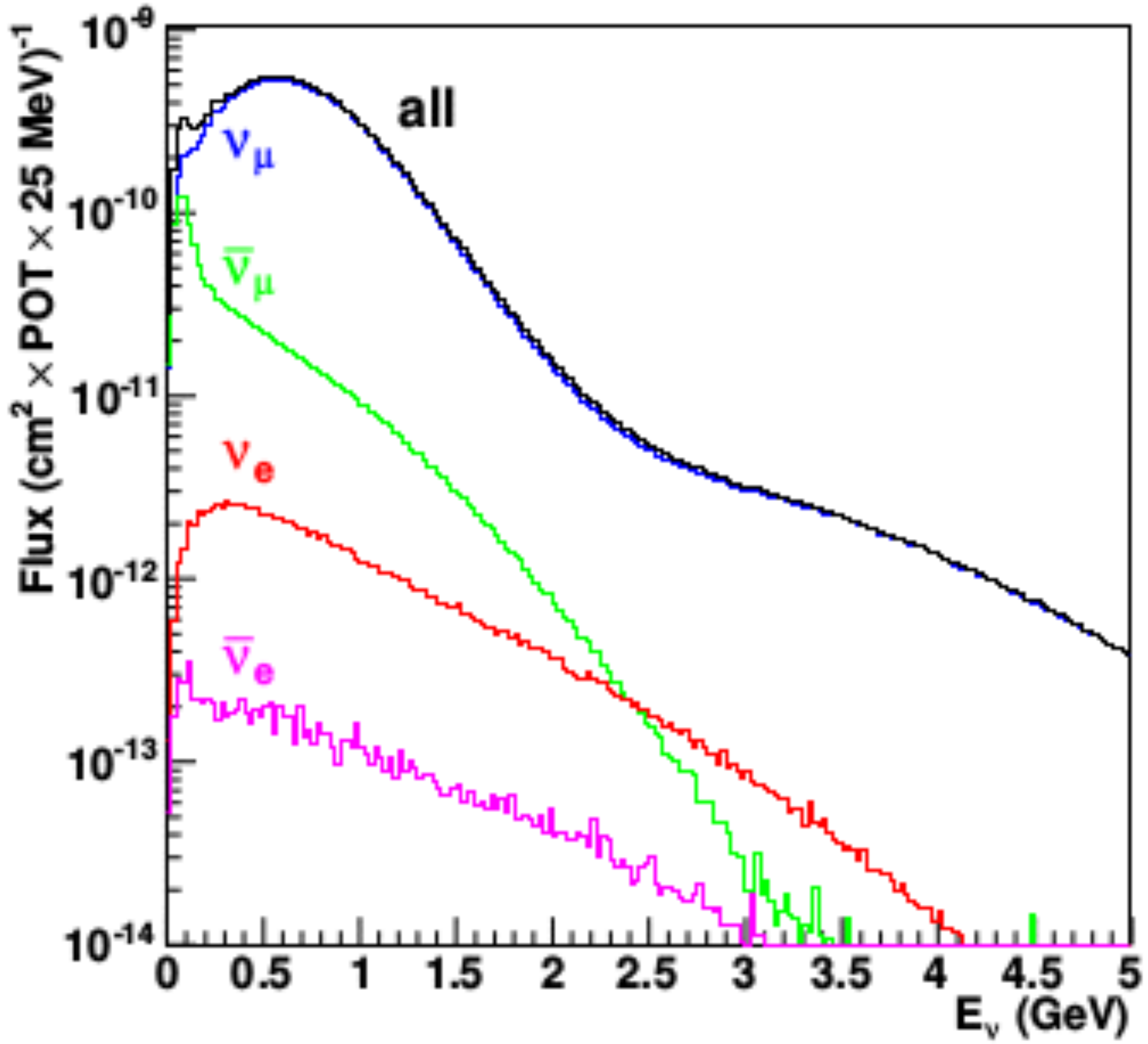
Experiment Description

- Muon neutrino beam (BNB)
  - Provides high-purity muon neutrino sample.
- Forward veto detector
  - Remove contamination
- Water interaction and detection volume
  - Neutrinos interact in the water, muons and other secondary particles are tracked and neutrons are captured on the dissolved Gadolinium.
- Muon Range Detector (MRD)
  - Measure muon energy and direction with multiple layers of segmented particle detectors and steel absorber panels.

The Booster Neutrino Beam

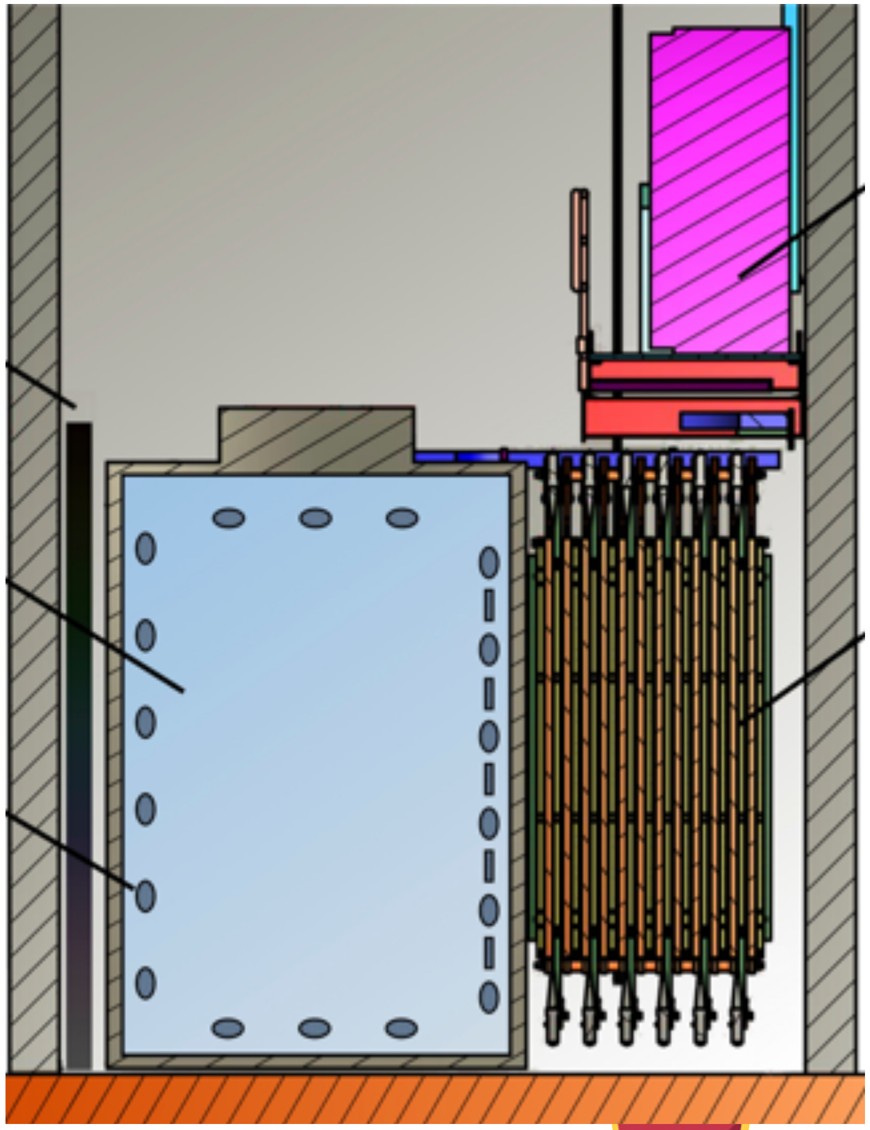
- 700 MeV peak energy
- 100m from the ANNIE detector at SciBooNE Hall
- 93% ν_μ purity
- 4×10^{12} POT per 1.6 µS spill at 5 Hz
- One ν_μ charged-current interaction in the ANNIE water volume every 150 spills.

Neutrino flux at SciBooNE Hall



The ANNIE Detector

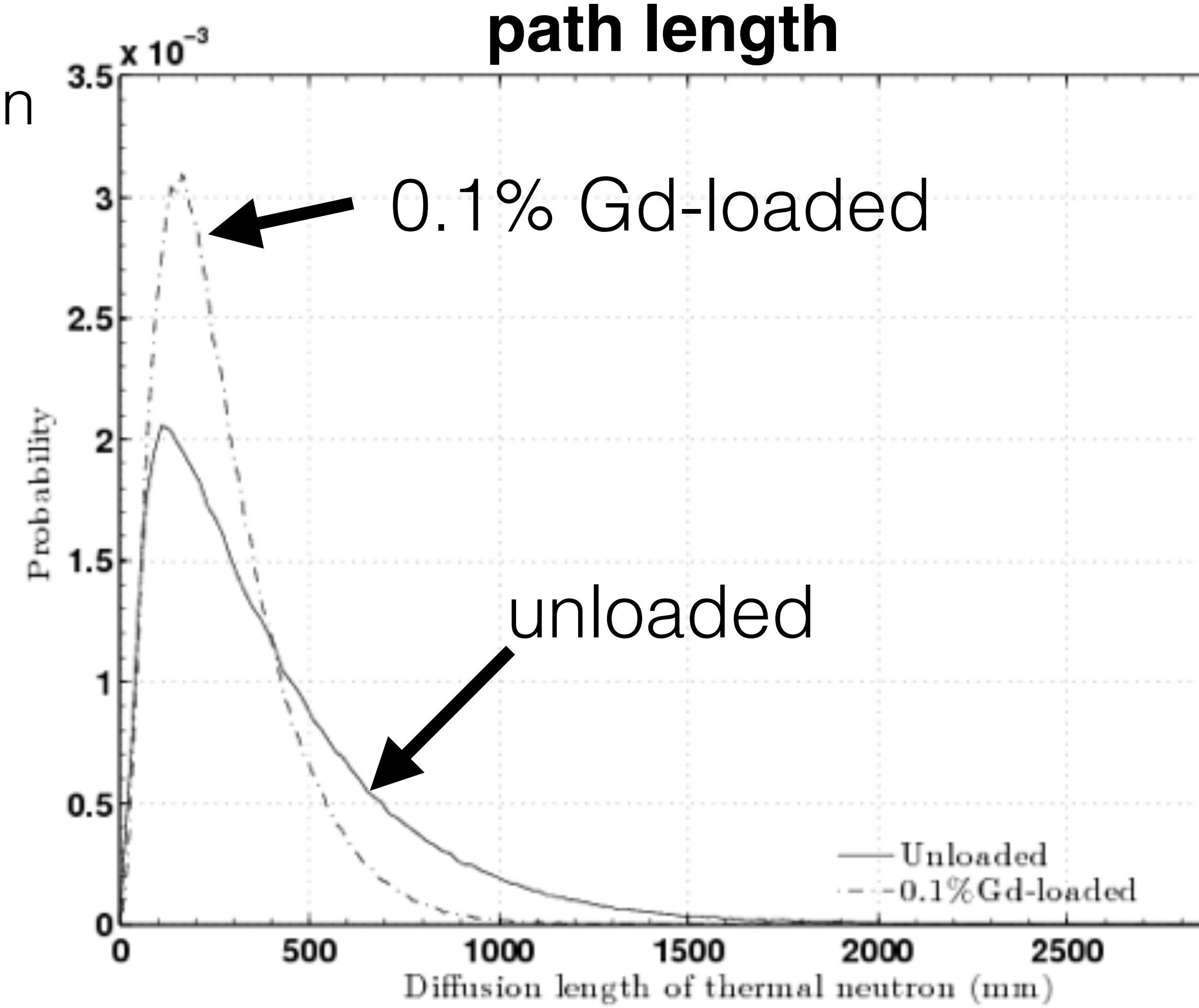
- ANNIE is the **A**ccelerator **N**eutrino **N**eutron **I**nteraction **E**xperiment
- 26 ton water-Cherenkov detector
- Located in SciBooNE Hall on axis with the BNB beamline.
- 10 foot diameter, 13 feet tall steel tank with a plastic liner
- Filled with ultra-pure water doped with Gadolinium sulfate.
- Detection volume instrumented with conventional PMTs with 500 MHz full waveform digitization and newly developed high-speed photo-detectors.
- Also includes an upstream muon veto detector and the SciBooNE Muon Range Detector (muon tracker) installed downstream.



Neutron Capture on Gadolinium

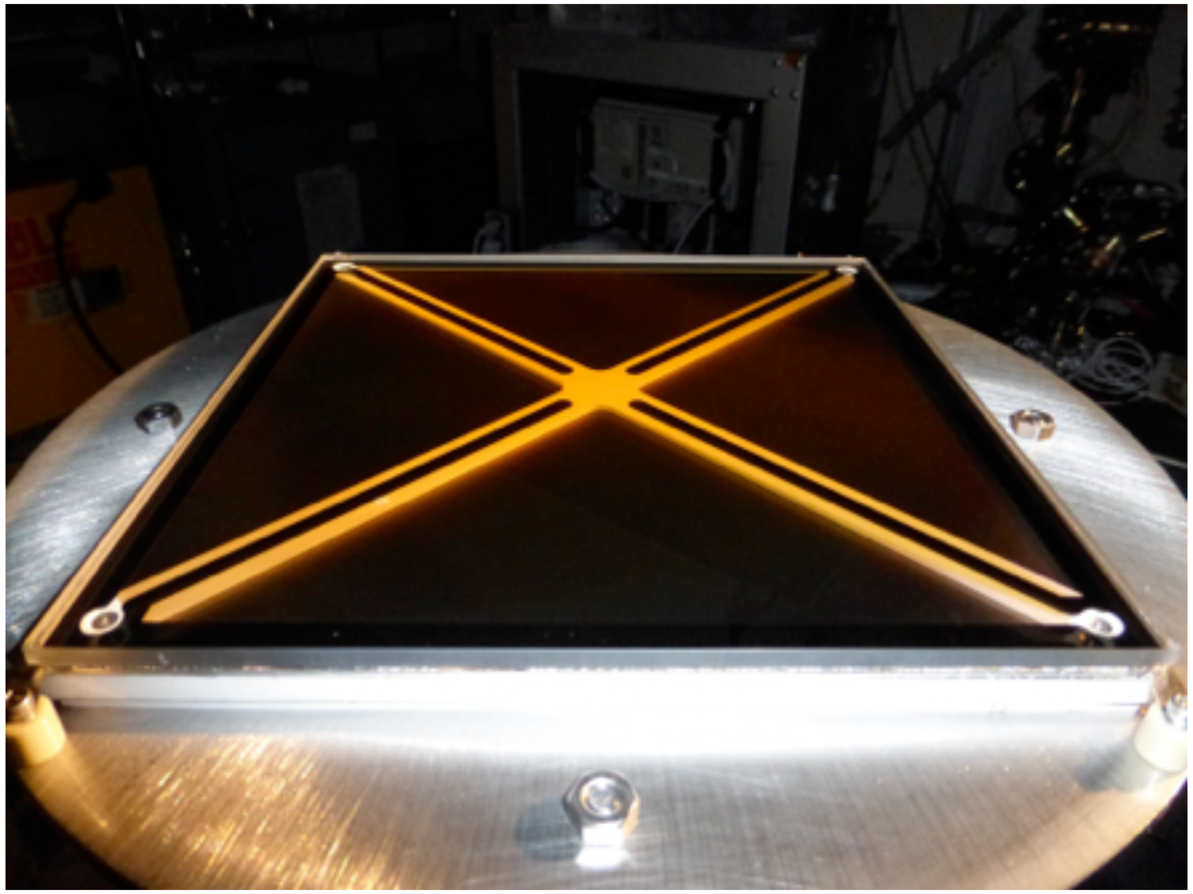
- Neutron capture doesn't have a minimum neutron energy.
- In pure water, n thermalizes and is captured on a free proton.
  - Capture time ~200 μs
  - E_γ=2.2 MeV
- Neutron capture cross section for Gadolinium is ~150000 times that of a free proton.
  - Capture time ~20 μs
  - E_γ=8 MeV
- This technique will also be used to reduce backgrounds in the searches for proton decays and supernova neutrinos.

Thermal Neutron diffusion path length



Large Area Picosecond Photo Detectors (LAPPDs)

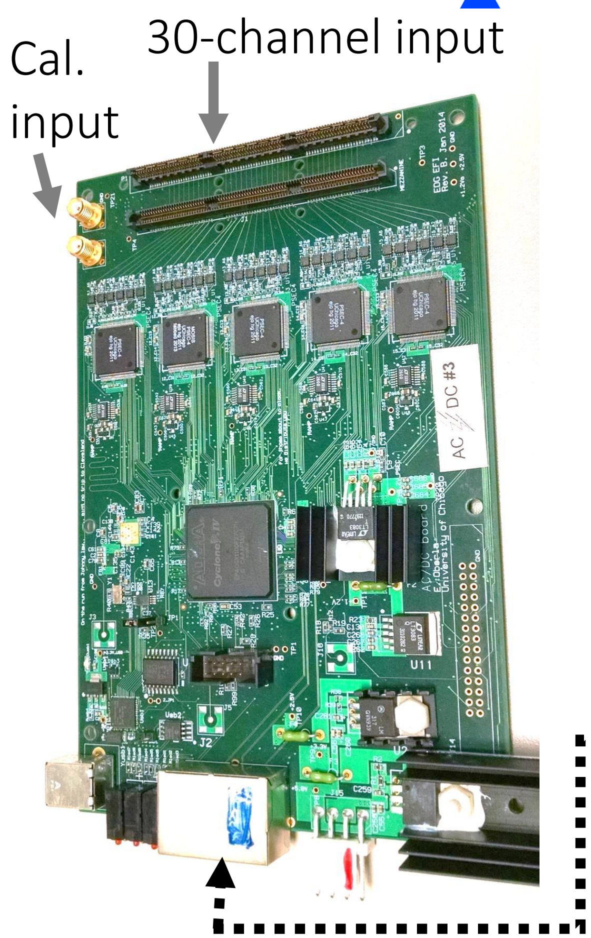
- 8” square MicroChannel Plate (MCP)
- 60ps time resolution
- Multiple-anode readout gives ~1 cm spatial resolution
- Good spatial and time resolution allows multiple individual-photon detection.
- Centimeter-level vertex and track reconstitution improves energy resolution, background rejection and allows multiple particle detection
- Thin profile maximizes fiducial volume.
- Flat square shape simplifies mounting.

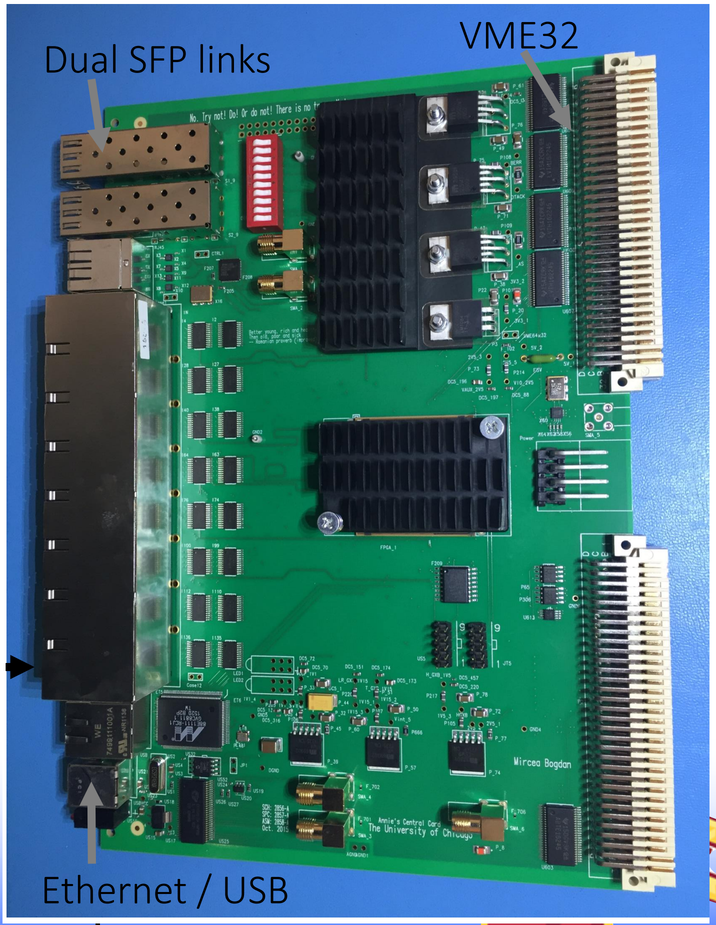


Incom USA Inc.

High Speed Digitization

- High-speed synchronized multi-channel digitization is needed to take advantage of the fast LAPPDs
- The PSEC4 chip samples at 10GHz
- Each newly-developed ANNIE Central Card supports 240 channel synchronized readout and advanced logic for triggering and data reduction.
- PMTs digitized at 500 MHz with a deep buffer for full-waveform likelihood reconstruction.
- Data reduction and event reconstruction methods developed for ANNIE will benefit future large-volume water-based high channel count detectors.





Timeline

- Installation (complete)
- Phase 1 - Test Experiment (in progress)
  - Operate with conventional PMTs and pure water with a small movable Gd-loaded liquid scintillator filled vessel to measure neutron backgrounds as a function of position inside the tank.
- Phase 1b - Demonstration of LAPPD readiness (funded for FY 2017)
  - Obtain and characterize an LAPPD
  - Add smaller MCP prototypes to the ANNIE tank
- Phase 2 - Physics Run (proposed, FY 2018+)
  - Change to Gd-loaded water
  - Add LAPPDs and additional PMTs

ANNIE:

The **A**ccelerator **N**eutrino **N**eutron **I**nteraction **E**xperiment

- ANNIE will measure the neutron yield from neutrino-nucleus interactions in water.
- First application of LAPPDs in water for high energy physics.
- First Gd-doped water Cherenkov detector in a neutrino beam.
- ANNIE Phase 1 is currently taking data on the Booster Neutrino Beam at Fermilab.
    - *See the next talk by Vincent Fischer*

Backup slides

Proton Decay

- Proton decay is predicted by Grand Unification Theories of the strong and electroweak forces at $\sim 10^{15}$ GeV.
- The main background is from atmospheric neutrino interactions.
- Atmospheric neutrino interactions are thought to produce at least one final state neutron.
- Proton decays are expected to produce a final-state neutron less than 10% of the time.
- Effectively tagging neutron producing events would result in a signal efficiency of better than 90%.

Supernova Neutrinos

- Supernova explosions throughout the universe produce a diffuse background of neutrinos.
- The flux and spectrum provide information about their rate and neutrino temperature.
- The main detection channel for water-Cherenkov detectors is from positrons from inverse β decay.
- Above 20 MeV the dominant background is from the decay of muons below the Cherenkov threshold.
- Understanding neutron yields could help statistically discriminate between various backgrounds.