UCDAVIS

ANNIE: The Accelerator Neutrino Neutron Interaction Experiment:

Phase I Status and Phase II plans

Jingbo Wang

Department of Physics, UC, Davis

UCDAVIS
UNIVERSITY OF CALIFORNIA

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Outline

- ANNIE goals
- ANNIE detector
- Status of ANNIE Phase I
- Plans of ANNIE Phase II
- Summary

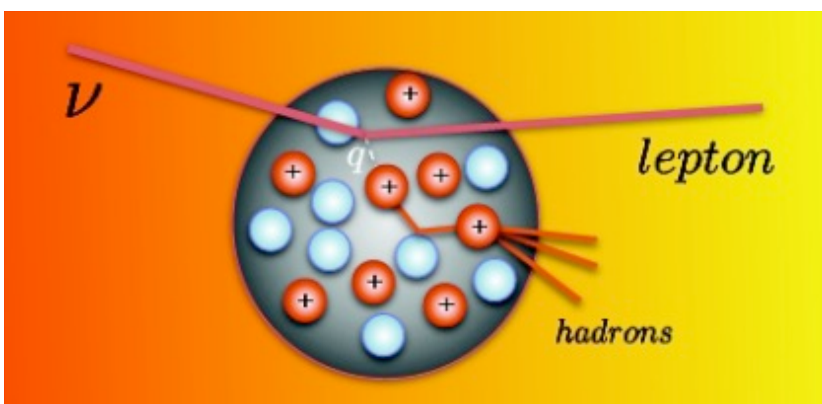
ANNIE physics goal

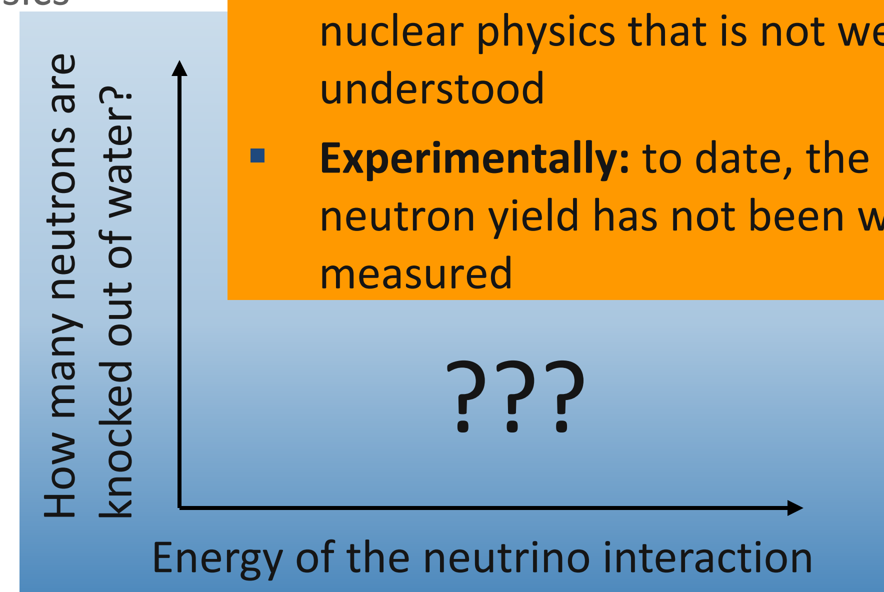
- A Water Cherenkov detector deployed at the Fermilab BNB beamline.

Primary Physics goal:

- A measurement of the abundance of final state neutrons ("neutron yield") from neutrino interactions in Gd-doped water, as a function of energy. (arXiv:1504.01480).
- Significant impact in:
  - Neutrino-nucleon interactions physics
  - Proton decay searches
  - Supernova neutrino observations

- **Theoretically:** This depends on nuclear physics that is not well understood
- **Experimentally:** to date, the neutron yield has not been well measured

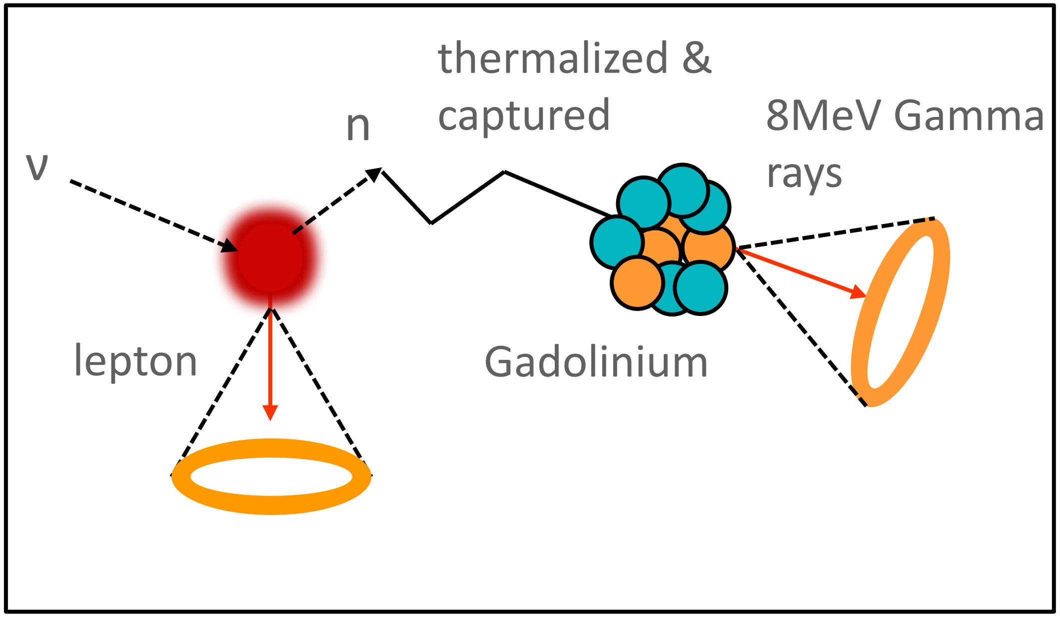


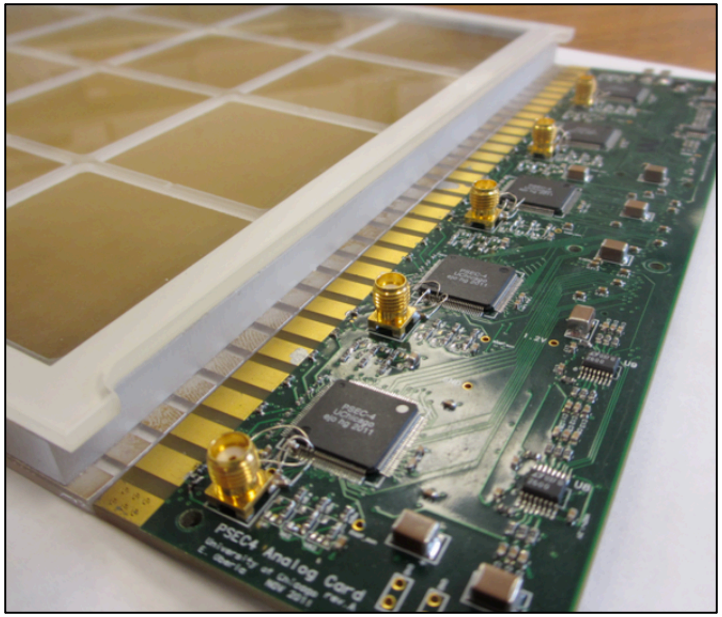


ANNIE technical goals

ANNIE is a test for new technologies:

- The first use of Gd-doped water in a beam experiment: large capture cross section for final state neutrons from neutrino interactions.
- Large-Area Picosecond Photodetectors (LAPPDs) (<100 ps time resolution) in a neutrino experiment for the first time! Use of precision timing to localize interaction vertices in the small fiducial volume



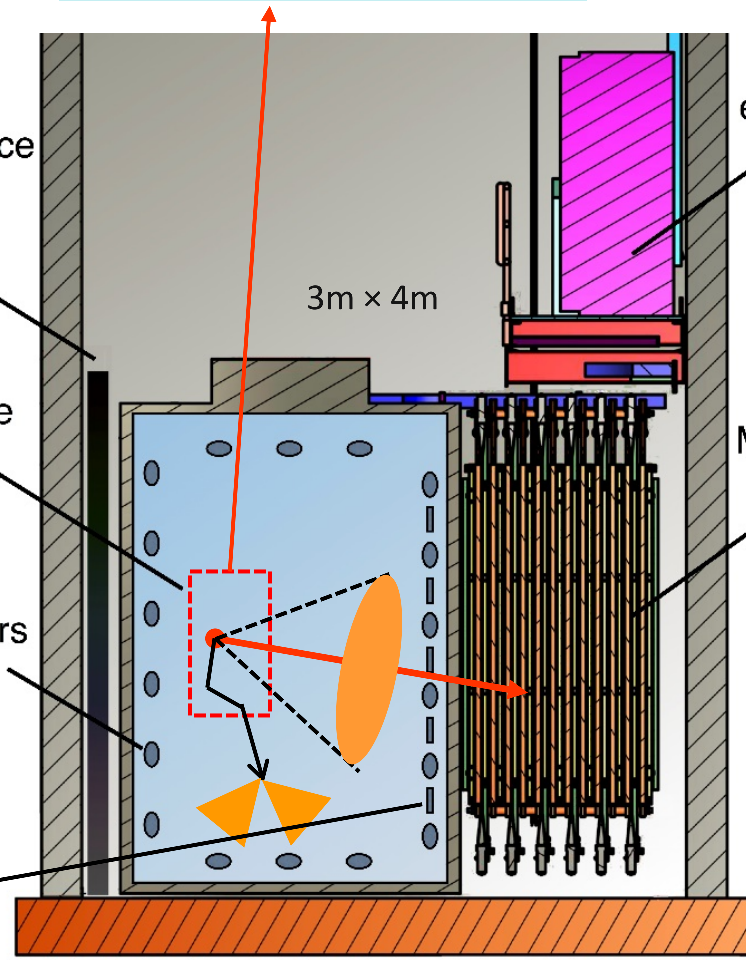


ANNIE detector

FACC to **veto muons** not originating in the tank

Fiducial volume selected by offline analysis

At Fermilab booster neutrino beam



Gd-loaded water for neutron captures from neutrino interactions

DAQ system

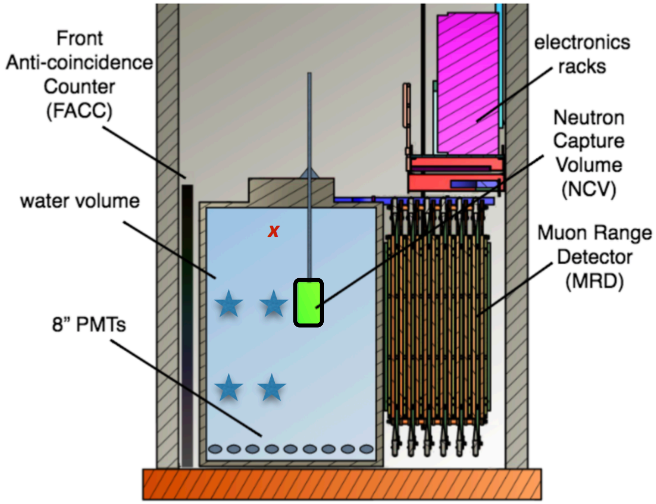
>100 PMTs for gammas from neutron capture

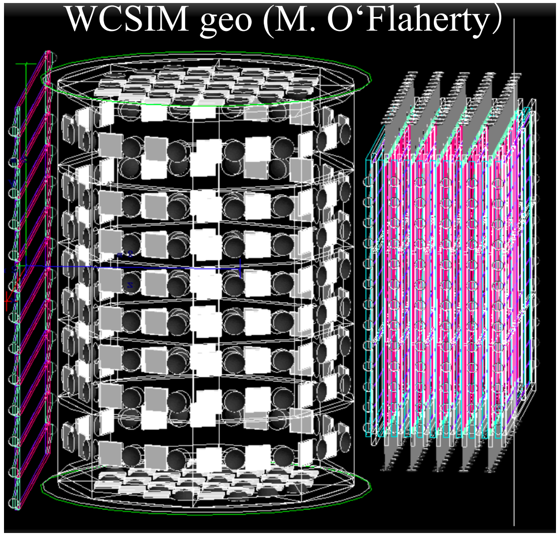
LAPPDs with < 100 ps time resolution for improved track and vertex reconstruction.

MRD for **muon range** measurement. Vertical and horizontal paddles for track reconstruction

ANNIE phased approach

- **Phase I - Test experiment (2015 - 2017):**
  - Build detector
  - Measure neutron backgrounds
  - Ready to test first LAPPDs
- **Phase Ib (2017)**
  - Demonstrate LAPPD readiness
  - Test and characterization of LAPPD+PSEC
- **Phase II: Physics run (2017 - 2021)**
  - Physics Run (1 year) with full Gd-doped water, enhanced PMT coverage (130), limited LAPPD coverage (about 5 LAPPDs), focus on CCQE-like events.
  - Physics Run (2 years) with full LAPPD coverage (up to 20 LAPPDs), study neutron yields for CC, NC and inelastic scattering

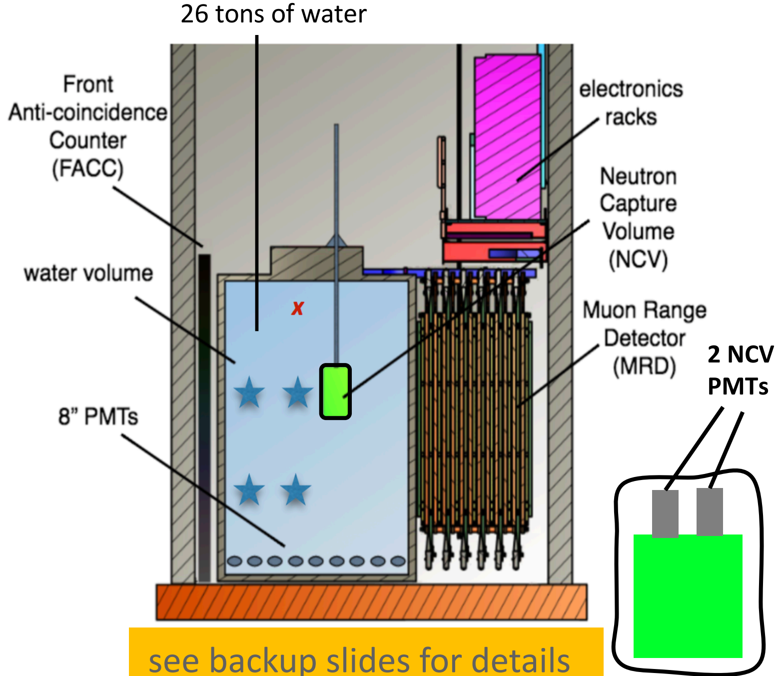




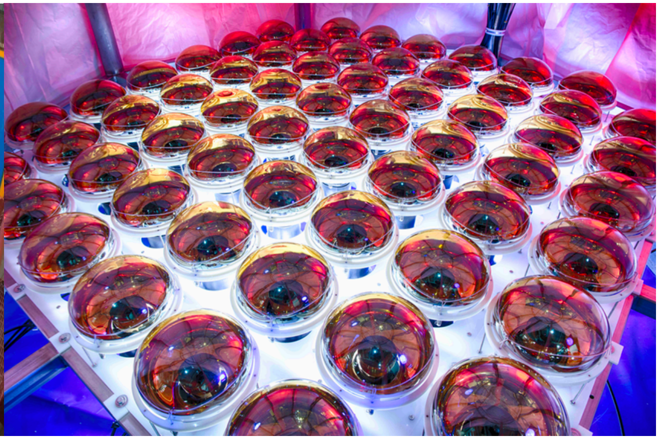
simulations of optimal configuration under way

Phase I status

- **Built and commissioned the detectors**
  - Filled with 26 tons of ultrapure water
  - Equipped with 60 8-inch PMTs at the bottom
  - 2 MRD layers
- **Measured rate of background neutrons**
  - Movable neutron capture volume (NCV)
  - NCV filled with 0.25% Gd-loaded liquid scintillator (EJ-335)
  - NCV optically coupled to two PMTs
  - NCV isolated from the rest of the tank
  - NCV calibrated by 2.5 µCi Cf-252 source.
- **Achieved stable data taking gained experience**

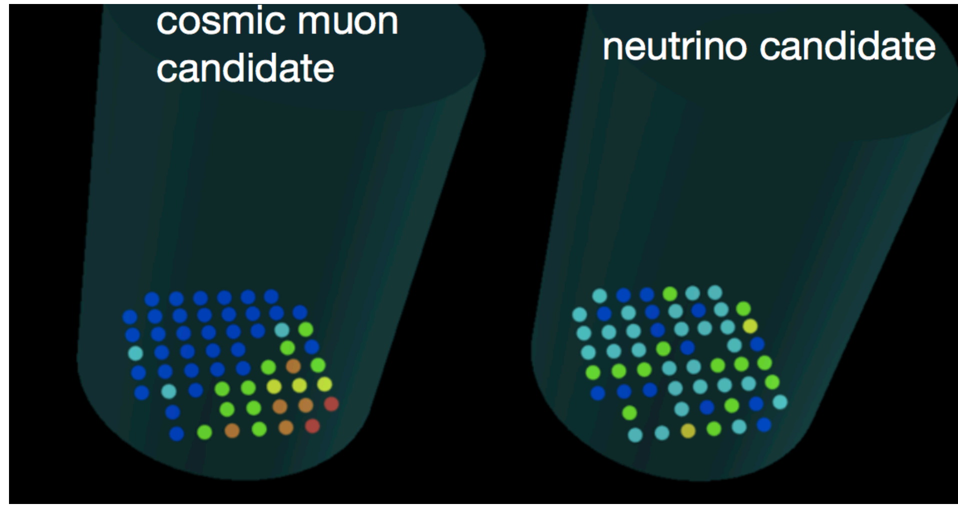


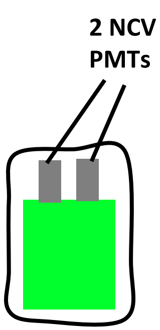
see backup slides for details

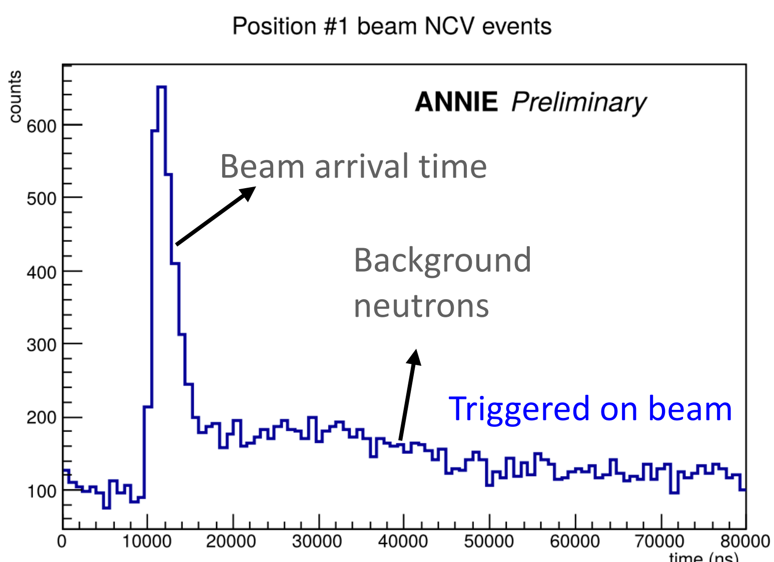


Phase I data analysis

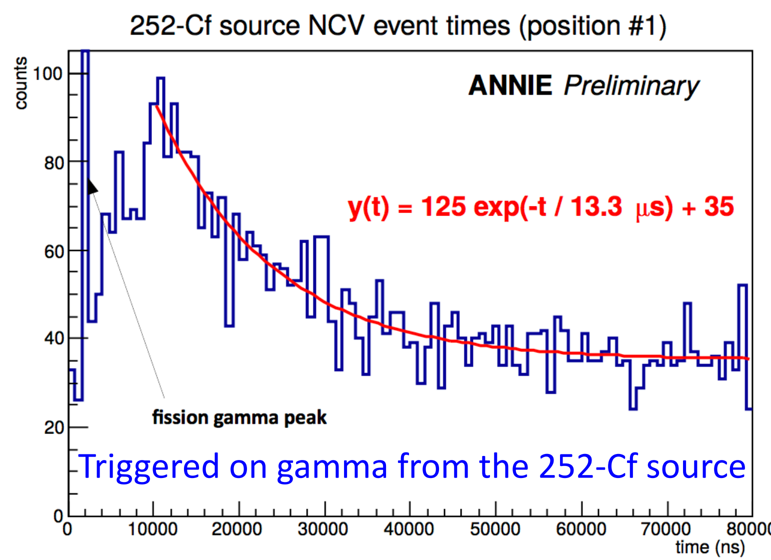
- Observed cosmic muons and beam neutrinos using 60 bottom PMTs
- Measured neutron captures using NCV, both from the beam and a calibration 252-Cf source
- The long-lived excess events after the beam indicates neutron capture detection







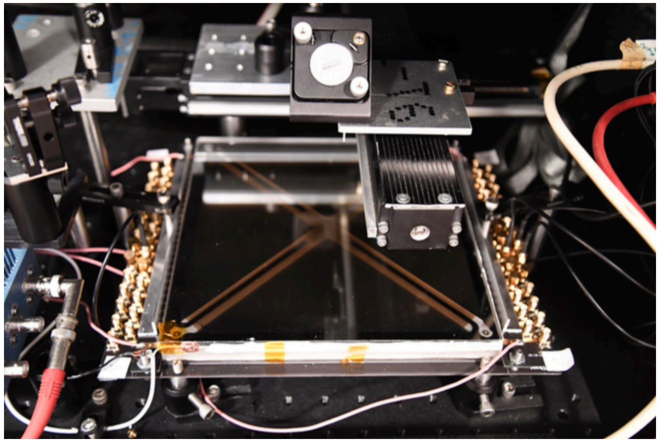
S. Gardiner



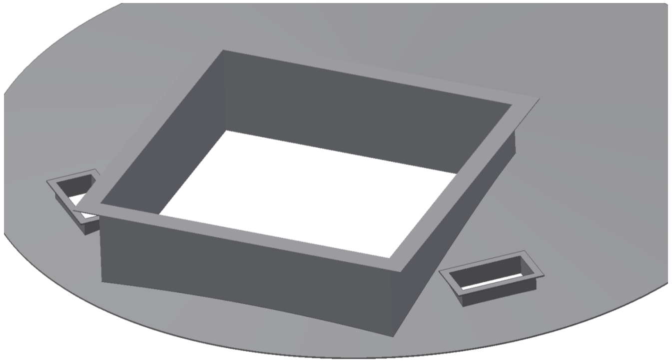
Moving to Phase Ib

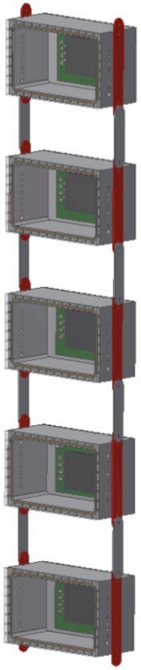
- Completed an LAPPD test facility and characterized one 6 cm MCP detector (from ANL) and two prototype LAPPDs (from Incom.)
- Tested a working PSEC electronics
- Began work on the waterproof housing and the LAPPD holder
- New mechanical design allows LAPPDs to be installed in the existing ANNIE detector

LAPPD test facility



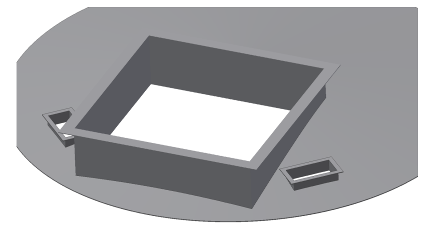
Top lid of ANNIE tank

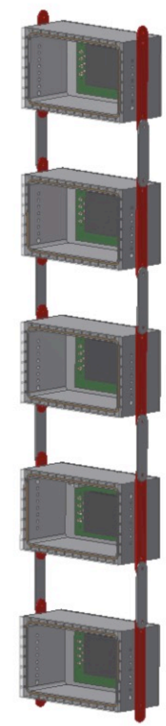


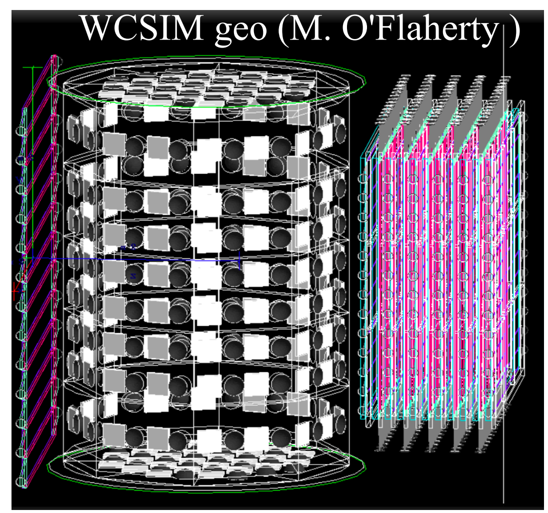


Plans for Phase II

- Need **additional PMT coverage and up to 20 LAPPDs as well as electronics** in order to carry out the physics measurement of ANNIE
  - Move the tank to staging area
  - Refurbish the MRD to enable all 10 layers
  - Reconfigure the inner structure to install full complement of PMTs and LAPPDs.
  - Fill ultrapure water loaded with 0.2% of Gd sulfate
- A lot of simulation/analysis work ongoing



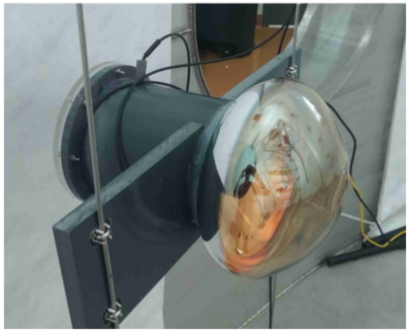




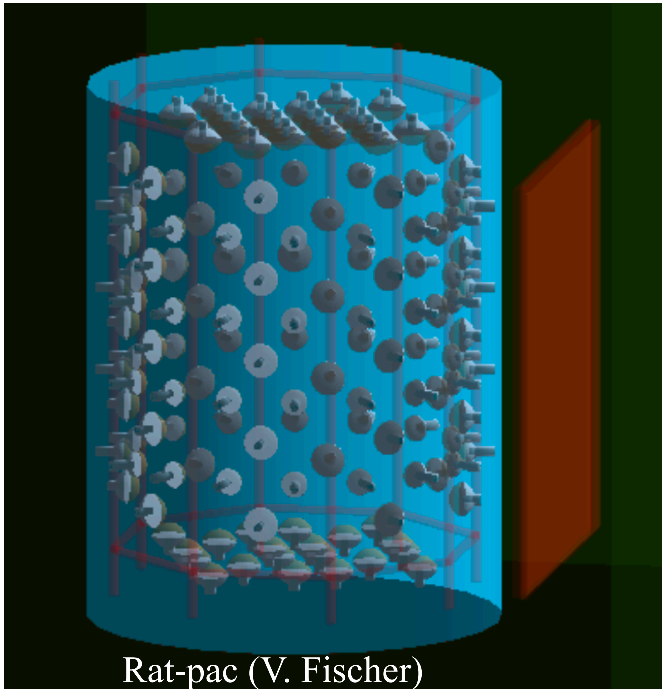
PMT status

- Sufficient PMTs have been identified for Phase II run
- Need to design PMT holders to mount PMTs to the top and side of the inner structure.
- PMTs to be tested at UC Davis

20 LUX 10" PMTs

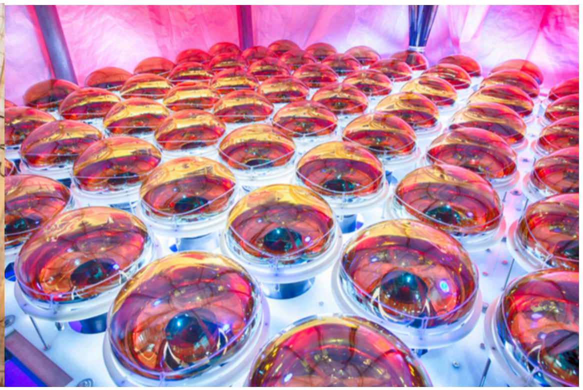


22 ETL (LBNE) 11" PMTs

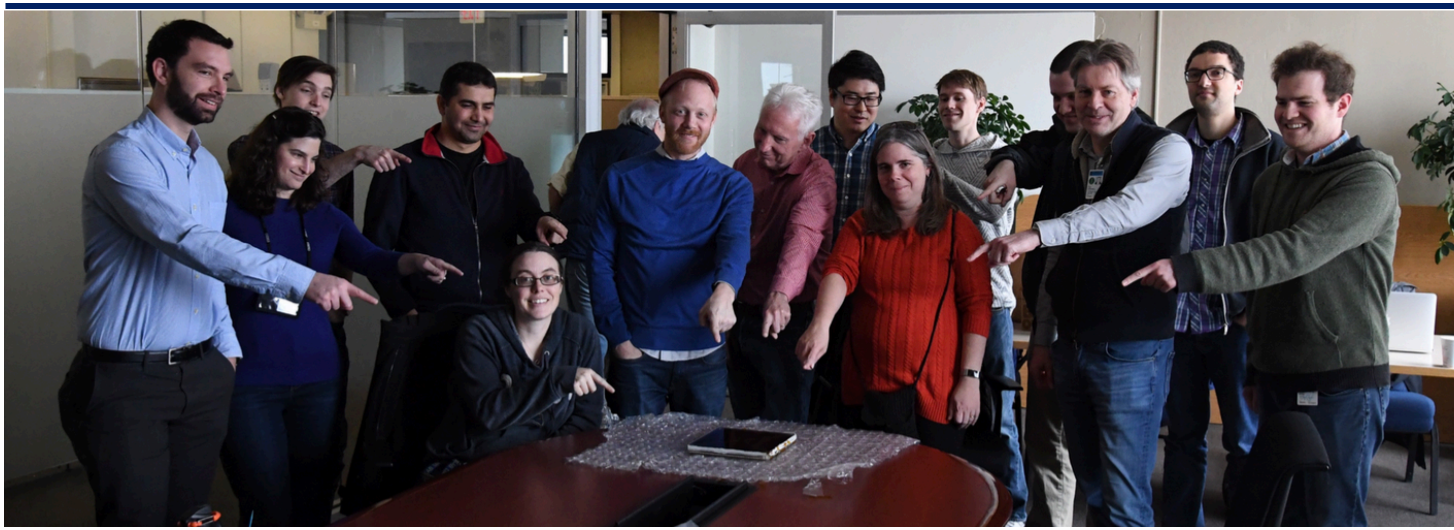


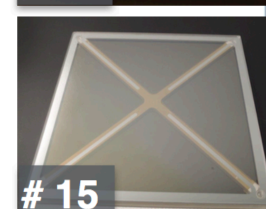
45 WATCHBOY 10" PMTs

Potentially 60 SuperK 8" PMTs



LAPPD status





- **Incom has now produced multiple LAPPD prototypes, quickly approaching the specifications needed by ANNIE**
  - Tile #9 fully sealed detector with an aluminum photocathode
  - Tile #10 sealed detector with multi-alkali photocathode (~5 % QE)
  - Tile #12: ~10% QE
  - Tile #13: half the photocathode with >20% QE
  - Tile #15: uniform photocathode >25% QE
- **Tile #12 tested at ISU: 32 ps time resolution for multi-PE (see backup slide)**

Please refer to Incom's talk in the photodetector session

Vertex reconstruction in Phase II

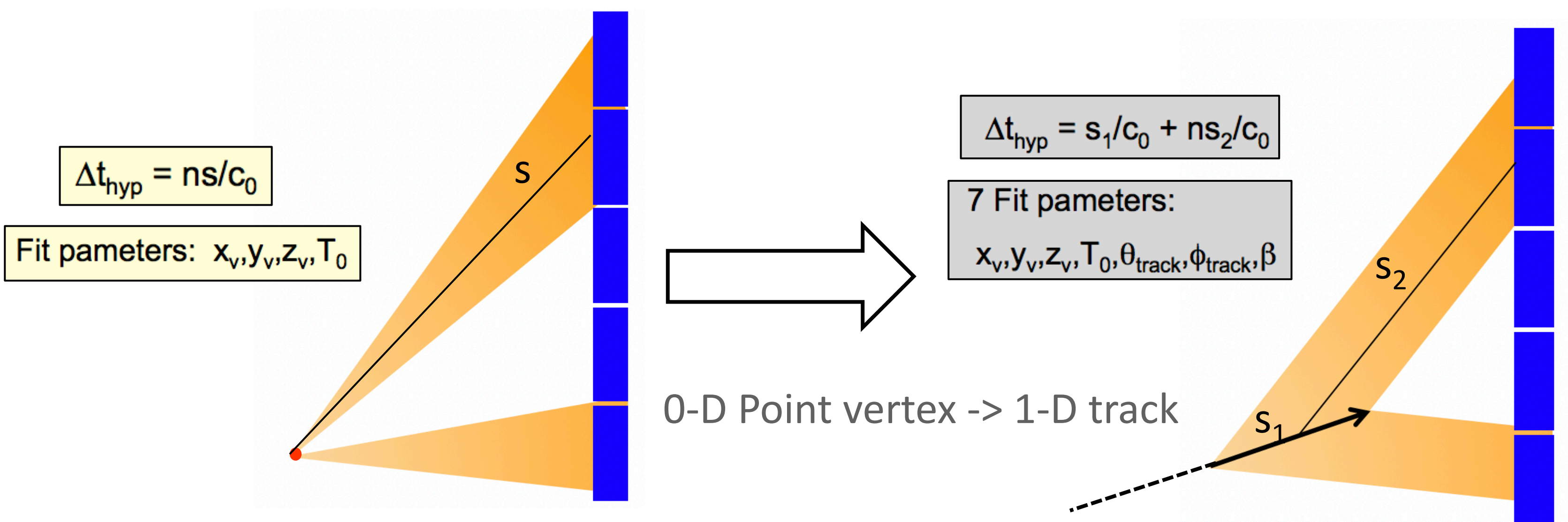
Basic reconstruction concept

1st Step:

- Conceptualize Cherenkov light as coming from a point source...
- Calculate hypothesized time (Δt_{hyp}) for the photon to reach the detector
- Adjust the point location to minimize the point time residual

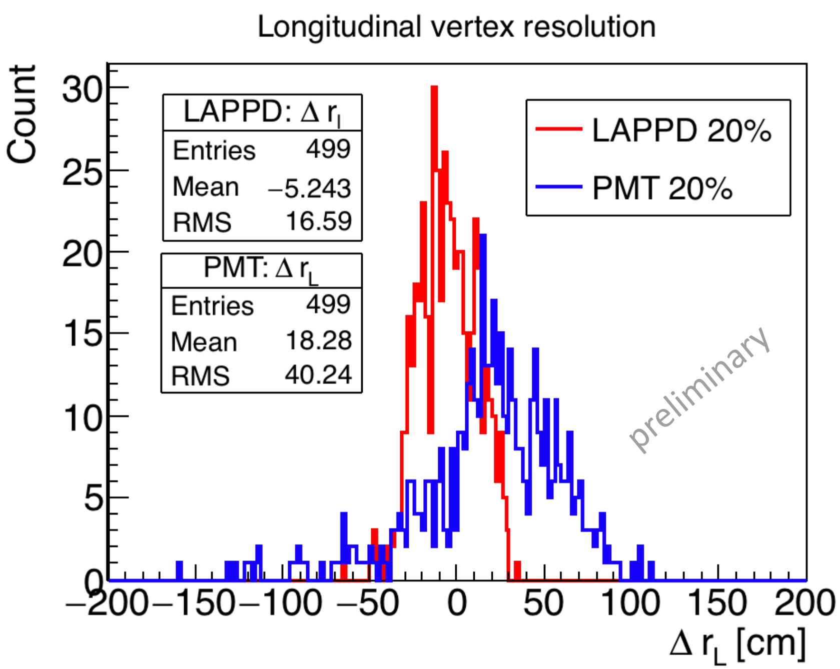
2nd Step:

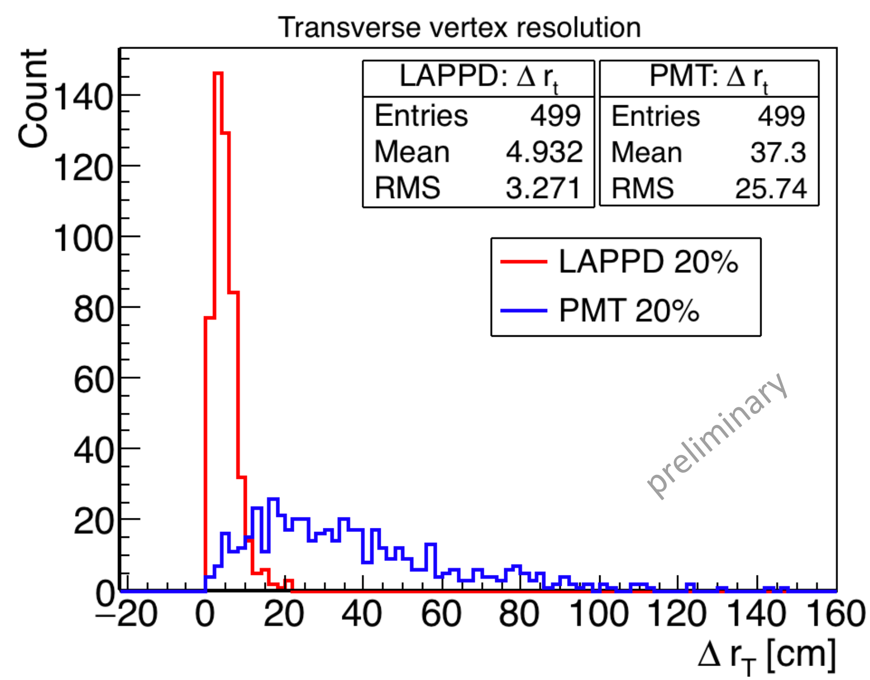
- Adjust the point location and the track direction to minimize the extended time residual (Δt_{hyp})



Vertex reconstruction in Phase II

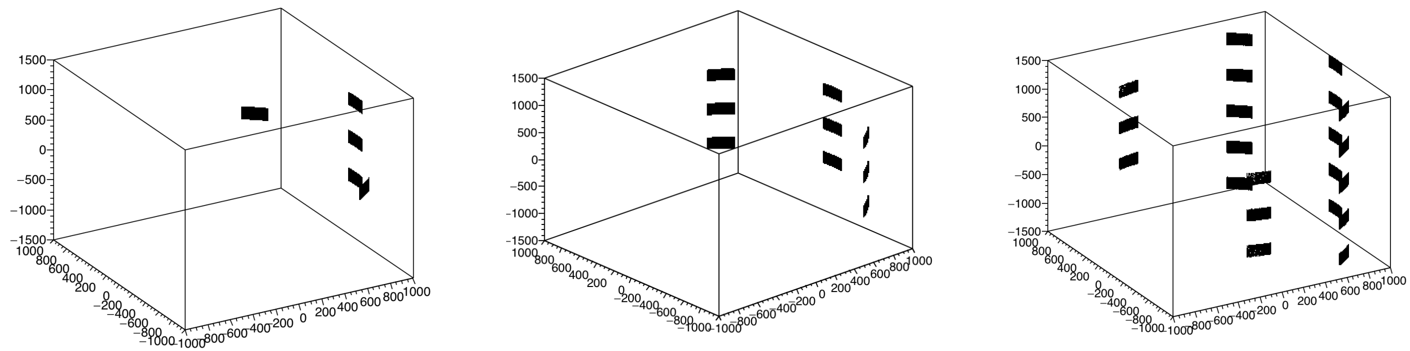
- **Comparison between LAPPDs and PMTs**
  - Sandbox simulation files: 20% LAPPD coverage VS 20% PMT coverage
  - 500 events
  - 122 LAPPDs (100 ps time resolution) or PMTs (1 ns time resolution)
  - Simulate a range of neutrino energies
  - Reconstruct full muon tracks

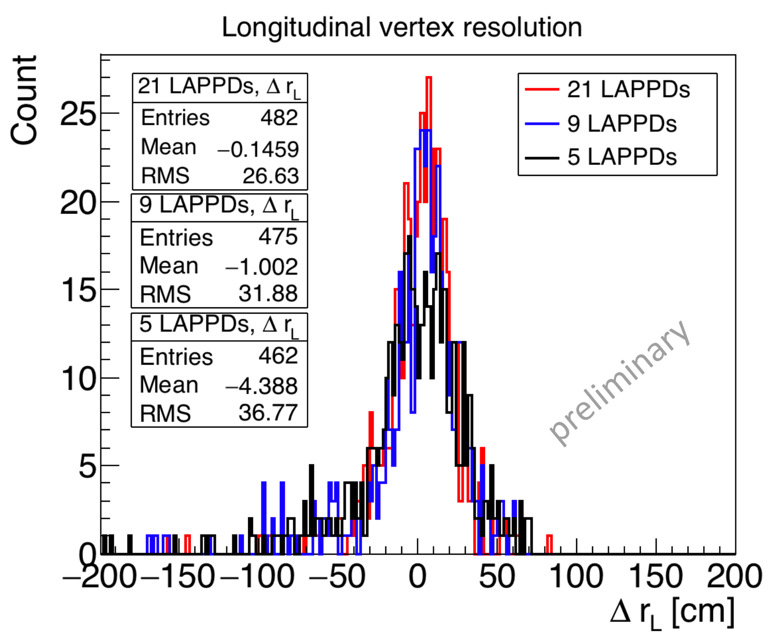


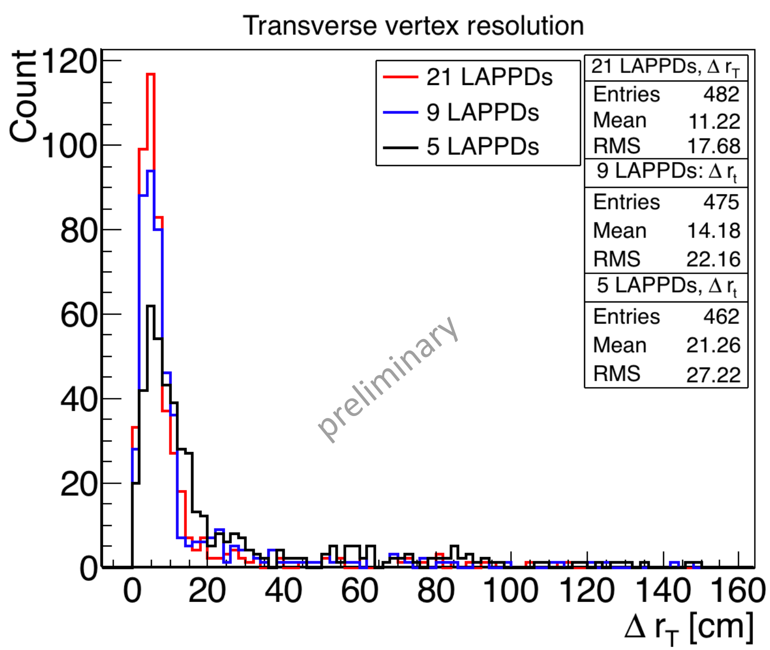


Vertex reconstruction in Phase II

- **Study on the number of LAPPDs**







Summary

- **ANNIE Physics goal:**
  - Measure the neutron yield from neutrino interactions in Gd-doped water, as a function of energy
- **ANNIE Technical goal:**
  - First Gd-doped water Cherenkov detector to run in a neutrino beam
  - First application of LAPPDs in water and for high energy physics

- **ANNIE Phase I is measuring the neutron background at different positions**

- ***LAPPD readiness*** *is well underway: currently being tested, water proof housing and mechanical design available.*

- ***ANNIE Phase-II (2017 - 2021)*** *with the deployment of LAPPDs is being planned. Simulations and analysis are under way to determine the track reconstruction capability as a function of the number of LAPPDs*

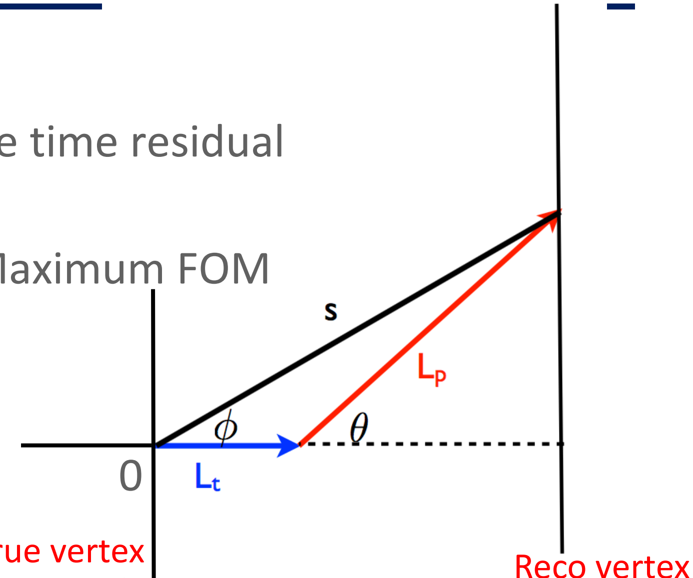
Thanks for your listening!

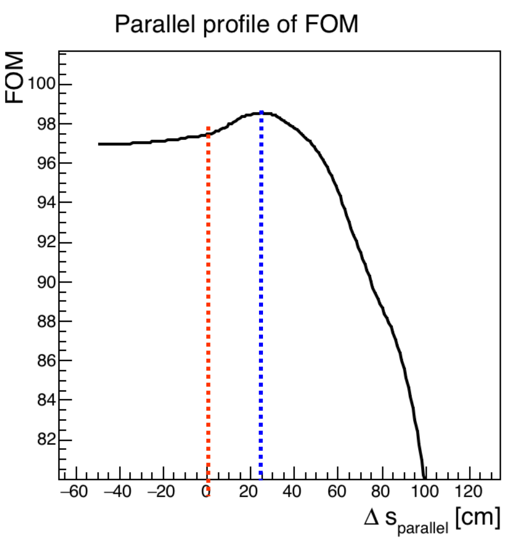
Backup slides

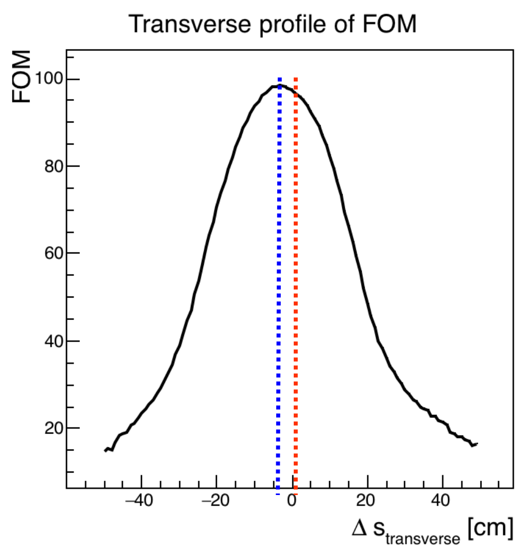
Vertex figure of merit (time property)

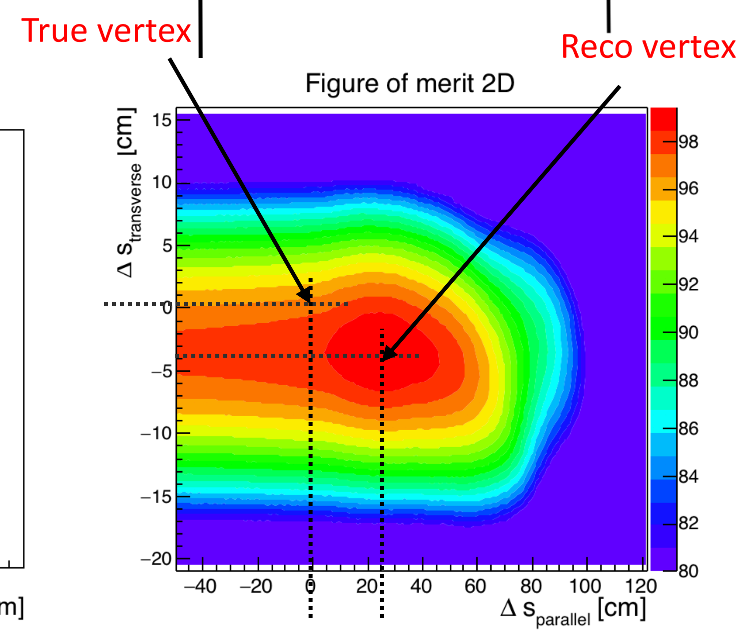
- Adjust the vertex position around the true vertex
- The time figure of merit (FOM) is obtained from the time residual distribution
- The reconstructed vertex takes the position with Maximum FOM
- Cone FOM is not taken into account in these plots

Event# = 0
True vertex
Reco vertex



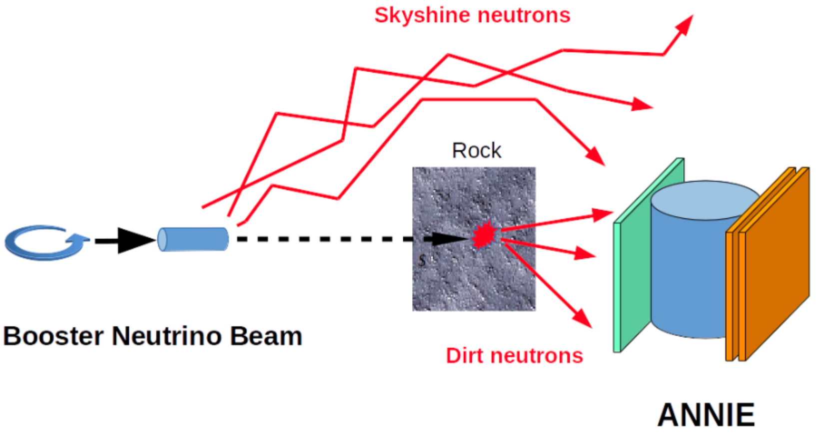






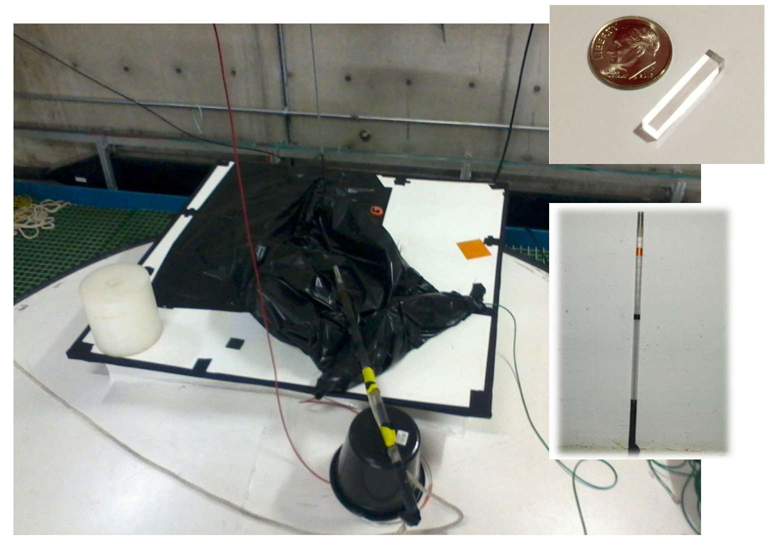
Neutron Capture Volume (NCV)

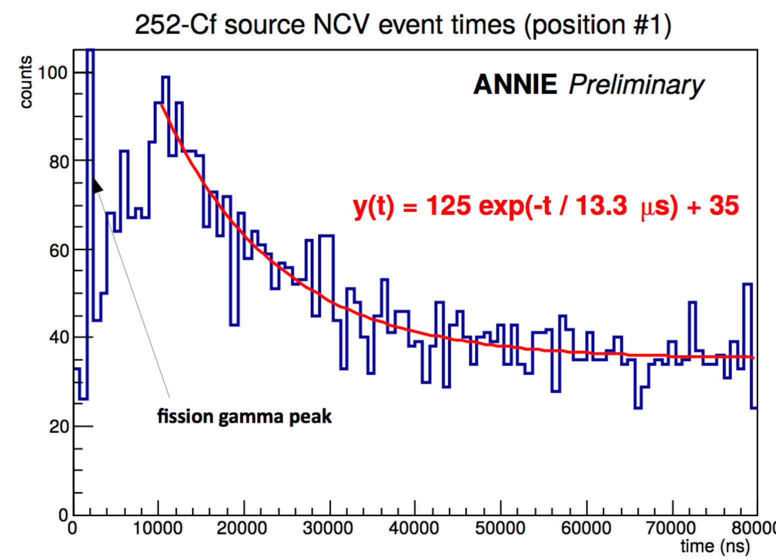
- **Neutron background source:**
  - Dirt neutrons: Neutrons originating from neutrino interactions downstream of the dump.
  - Skyshine neutrons: Neutrons from the beam dump entering the detector.
- **Neutron Capture Volume (NCV) vessel**
  - Movable 50 cm x 50 cm acrylic
  - Filled with 0.25% Gd-loaded liquid scintillator (EJ-335)
  - Optically coupled to two PMTs
  - Optically isolated from the water volume
- **NCV calibration**
  - 2.5 µCi Cf-252 source (5.4 mCi in Jan 1988) and LYSO crystals
  - Gammas from fissions (3.092% branching ratio) induce scintillation in LYSO crystal



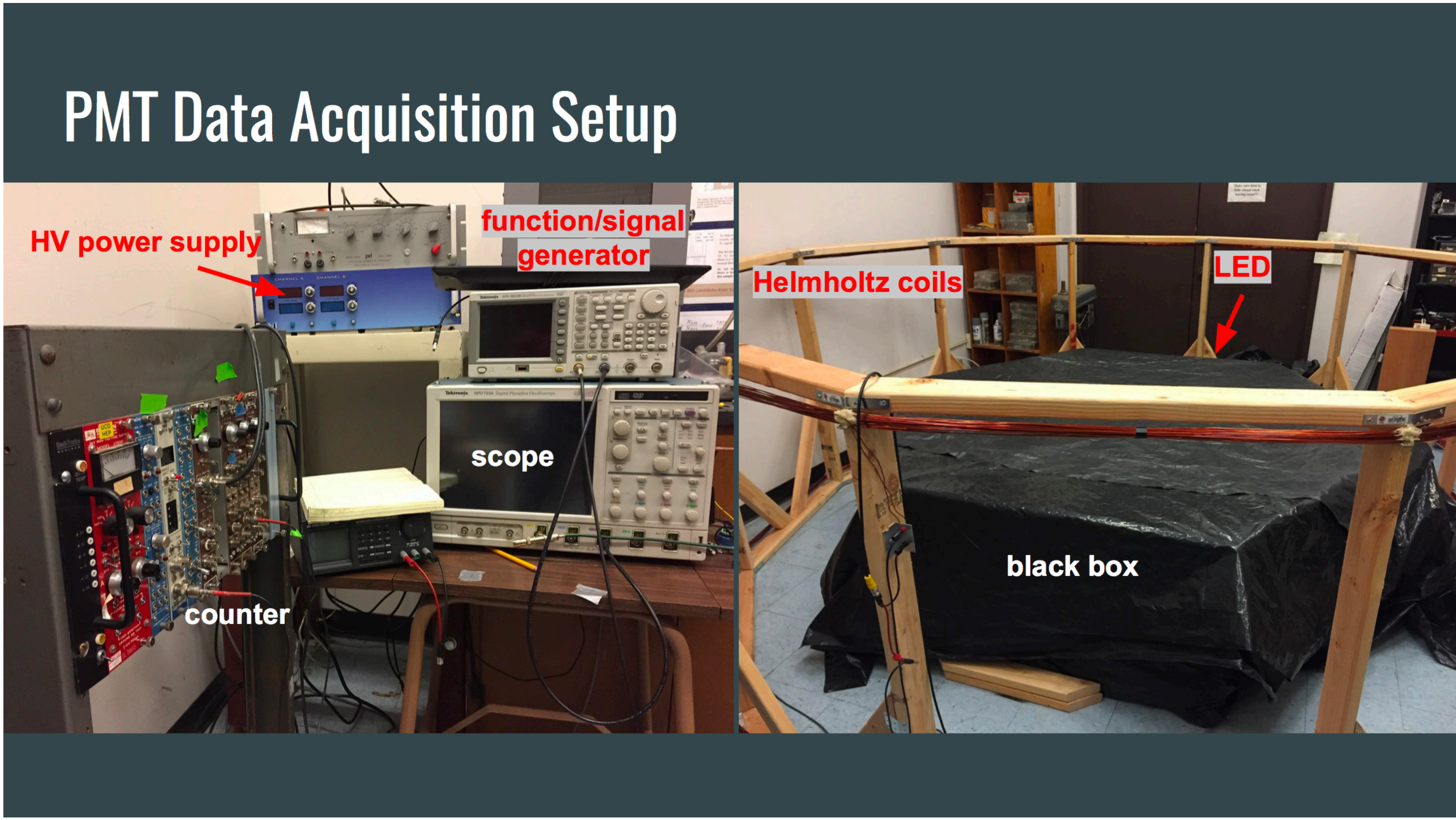
Neutron source calibration

- A triggered Cf252 source is used to understand the NCV response to neutron captures
- LYSO crystals
  - 176-Lu (2.6% natural abundance) is unstable to beta decay
  - High threshold to suppress beta decay background (low trigger rate)
- Trigger PMT watches scintillating LYSO crystal for prompt γ rays from fissions
- Two PMTs watch the NCV
- Tank PMTs used to veto cosmic ray muons
- Goals:
  - prove we can see neutrons
  - measure the efficiency of the NCV



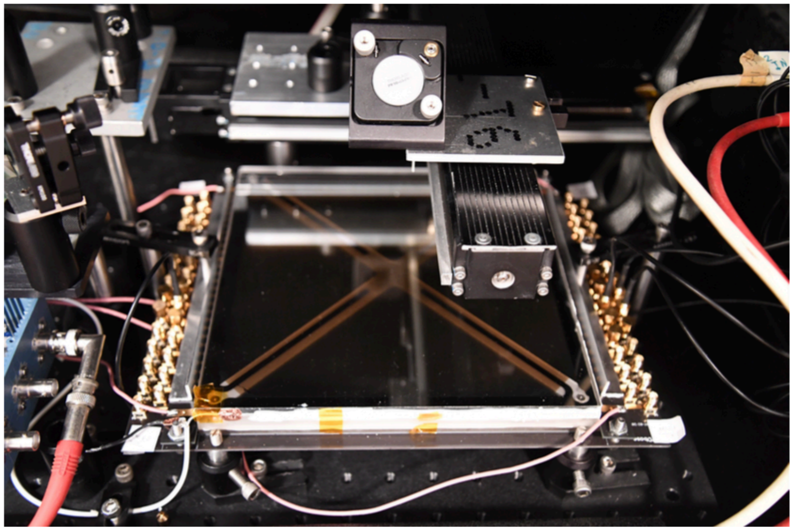


PMT test stand at UC Davis

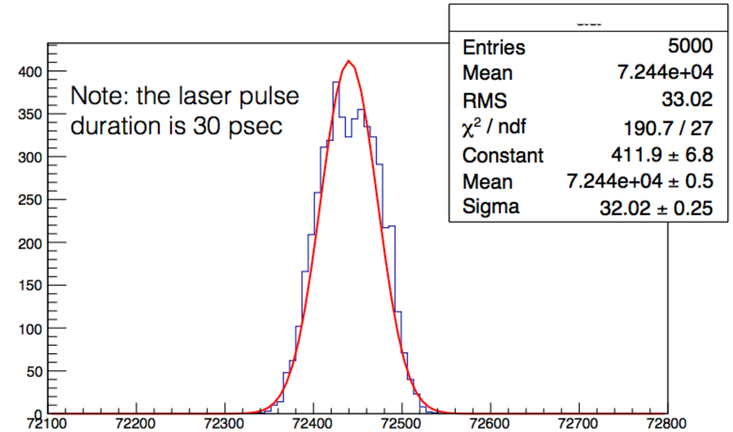


Julie. He, UC Davis

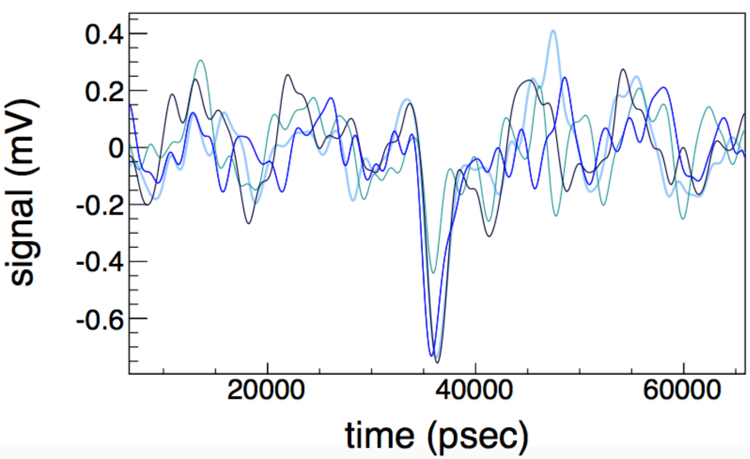
LAPPD test at ISU



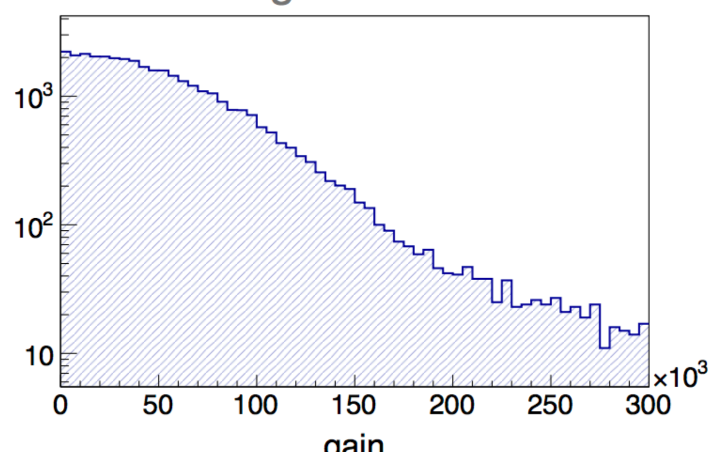
multi-PE Transit Time Spread (Tile #12)



example single-PE pulses (Tile #9)



Tile #9 gain distribution



M. Wetstein, ISU