The Accelerator Neutrino-Neutron Interaction Experiment (ANNIE)

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on behalf of ANNIE collaboration

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- Physics objectives
- Technical goals

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- Software & Simulations

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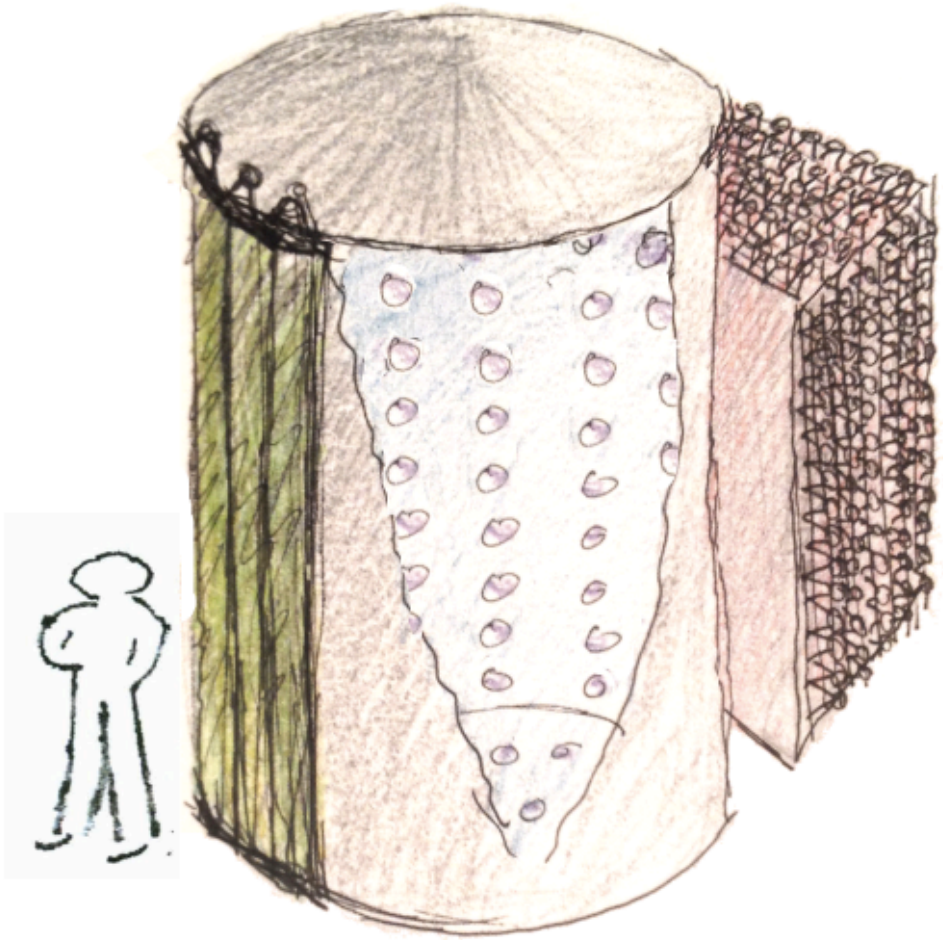
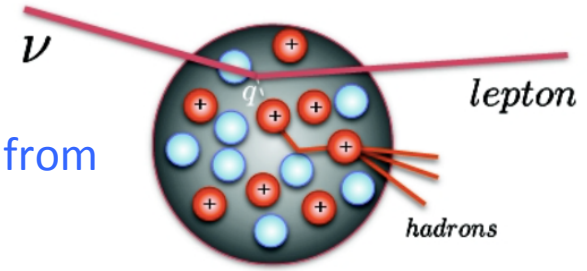
- Timeline



Motivation

Primary physics objectives:



Measuring the abundance of final state neutrons (neutron yield) from neutrino interactions in water as a function of energy.

Why do we want to measure neutron yield? It is relevant to studies of:

① Neutrino oscillation experiments:
- help understand critical systematics on energy reconstruction in long-baseline measurements.
- could help in explaining short baseline anomalies.
- possible handle for neutrino/antineutrino separation.

② Signal/background separation for proton decay measurements and supernova neutrino observations.

Technical goals:

① Testing Large Area Picosecond Photo-Detectors (LAPPDs) in a water Cherenkov experiment

② First Gd-loaded water Cherenkov detector to run in a neutrino beam.

ANNIE Overview

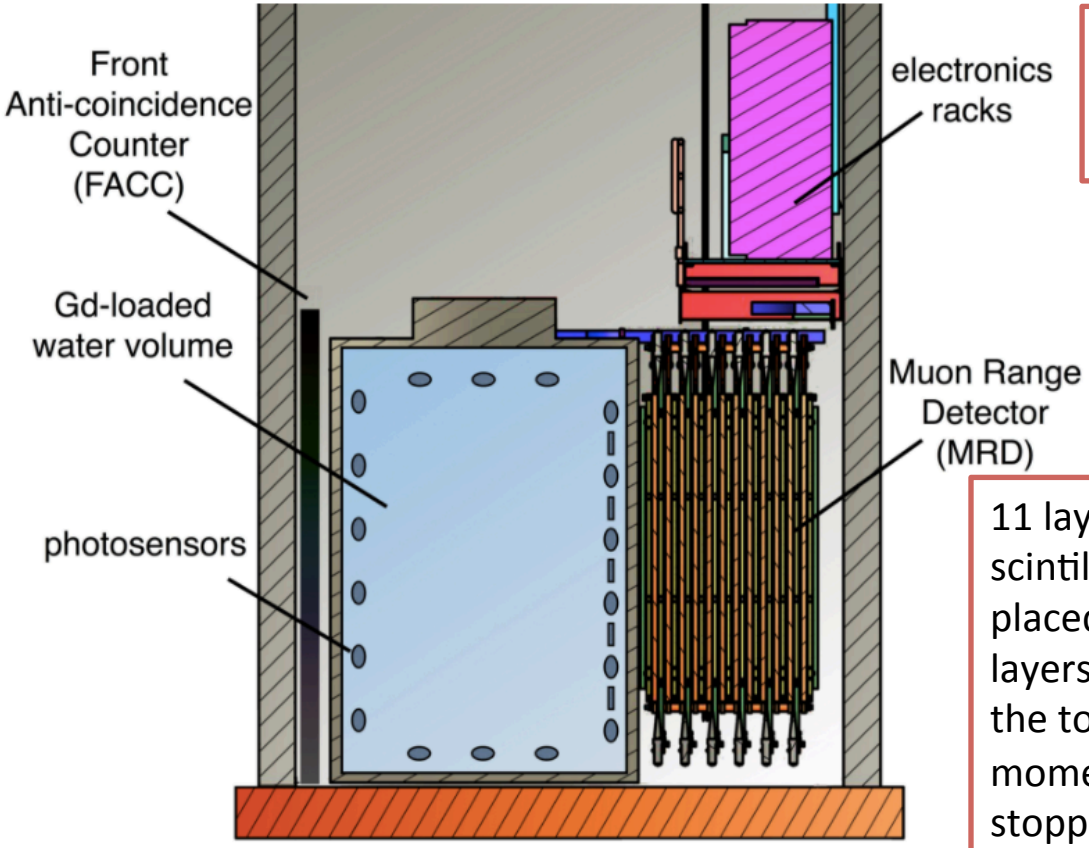
ANNIE is located at SciBooNE Hall along the Booster Neutrino Beam (BNB) at Fermilab.

- on-axis neutrino flux
- Spectrum peaks ~0.7 GeV (range of interest for atmospheric neutrinos)
- ~14×10^3 ν_μ charged-current interactions per ton of water per year.

Scintillator paddles to veto muons not originating in the tank.

26 tons of ultra-pure (UPW) water

>100 PMTs + 10-20 LAPPDs



Steel cylindrical tank (10 ft x 13 ft) 8m below the surface

11 layers of plastic scintillators (306 paddles) placed alternatively with 10 layers of iron to measure the total energy and momentum of muons stopping in MRD.

The Current State of the Detector

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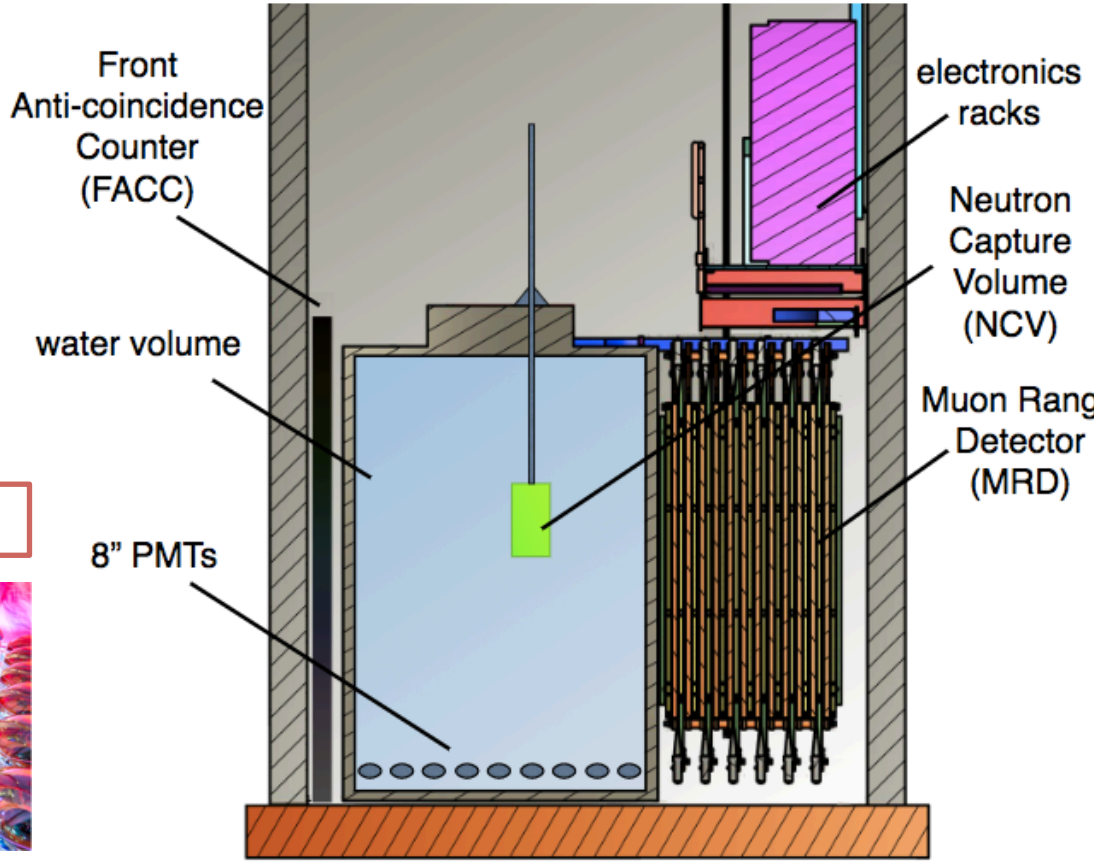
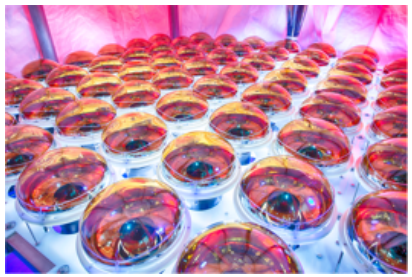
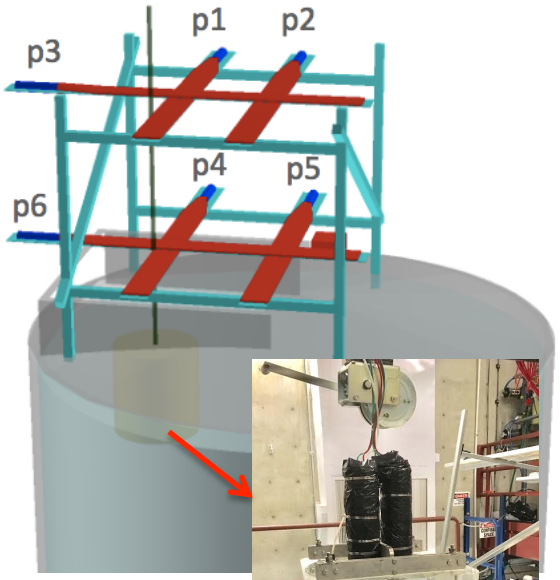


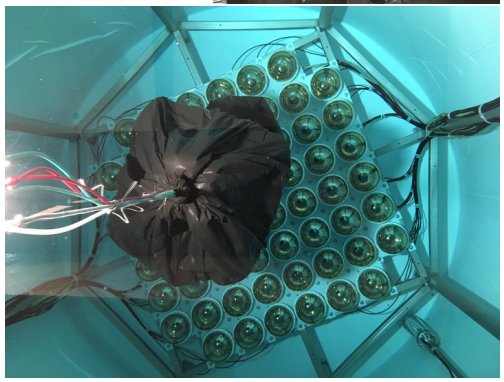
Movable acrylic vessel holding 25 gallons of Gd-loaded liquid scintillator.

60 Super-K PMTs



ANNIE Phase I





Physics goal is understanding neutron backgrounds. Sources of background neutrons:

- Skyshine neutrons from the beam dump
- Dirt neutrons from the rock

✓ The background neutron flux was measured at different locations in the tank.

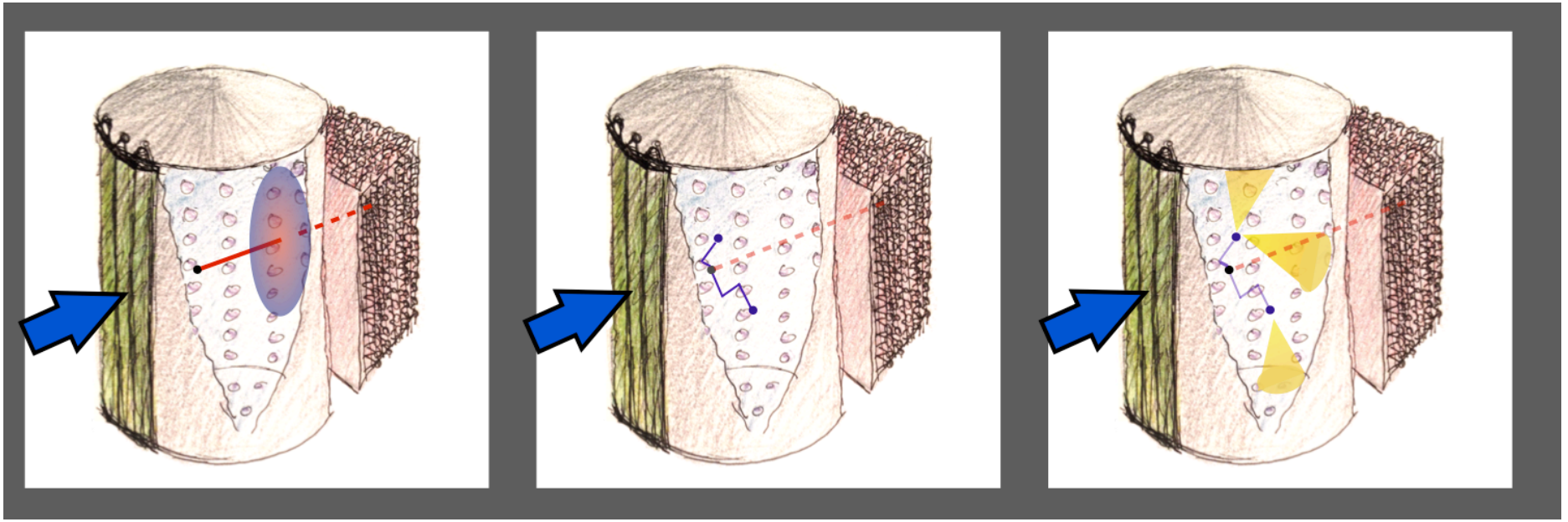
Triggers:

- Beam trigger
- Cosmic trigger (coincidence of 6 cosmic paddles)
- Calibration neutron source trigger
- LED calibration trigger (BG)

Calibration:

- ^{252}Cf source on top of the tank: the trigger PMT detects prompt γ from fission.
- Tank PMTs veto cosmic muons
- Two 3 in. PMTs monitor the NCV (optically isolated)

An event in ANNIE tank



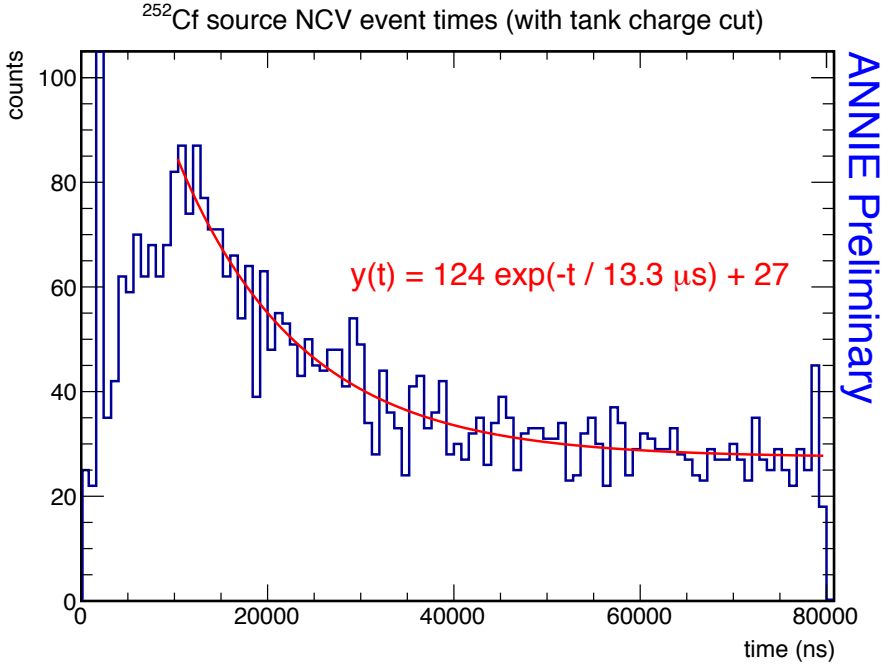
muon

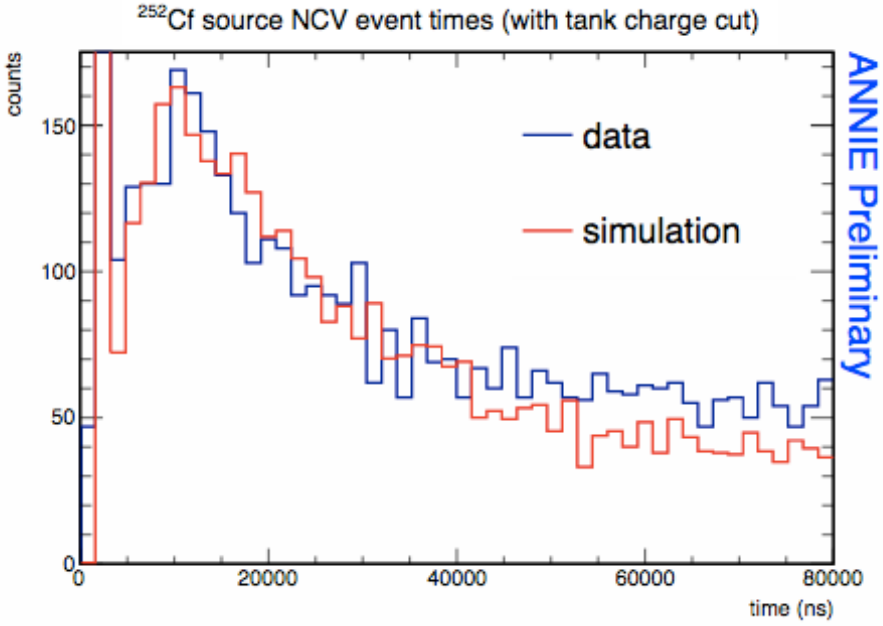
neutrons are produced

neutrons are captured and 8 MeV gammas are produced in several tens of microseconds.

Preliminary Phase I Results

- The ANNIE collaboration has been able to detect neutron captures, both from a calibration source and from the beam.
- Final luminosity normalized estimates of beam induced background neutrons are coming soon.
- Preliminary estimates put backgrounds at acceptable levels for the physics measurement.
- Much of the current work is focusing on data/MC agreement for calibration source runs.





Plots from S. Gardiner

ANNIE Moving Towards Phase II

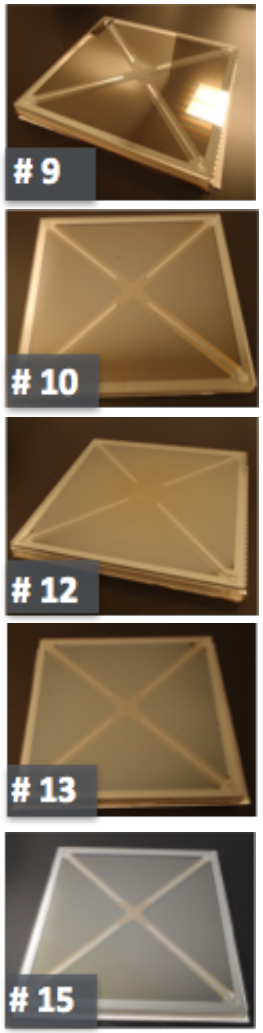
LAPPDs (20 cm x 20 cm) are:

- novel technology for photodetection with gain of 10^6
- based on microchannel plates
- with excellent timing (~ 50 psec for SPE) and spatial resolution (700 microns in both lateral dimensions)→ this will give us a significant improvement for vertex reconstruction.

ANNIE will host the first live test of this novel technology during Phase II.

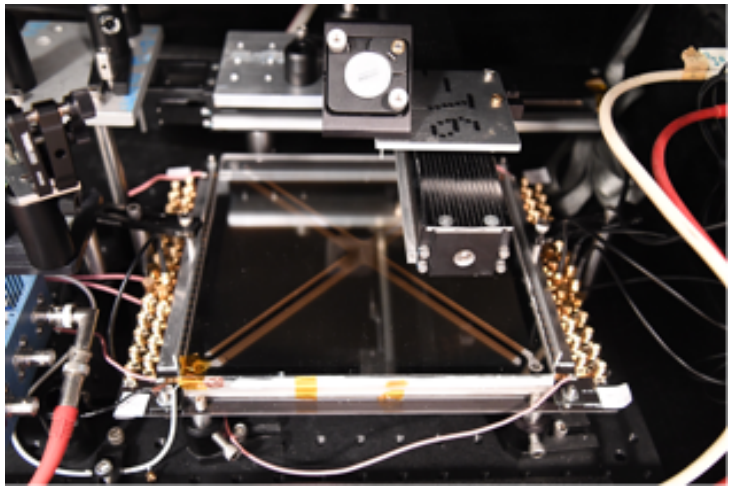
Incom has now produced multiple LAPPD prototypes, quickly approaching the specifications needed by ANNIE:

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

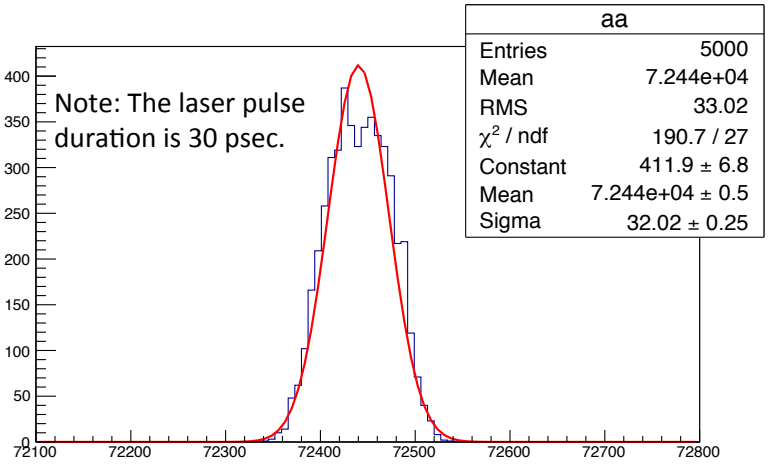


LAPPD Characterization Tests at ISU

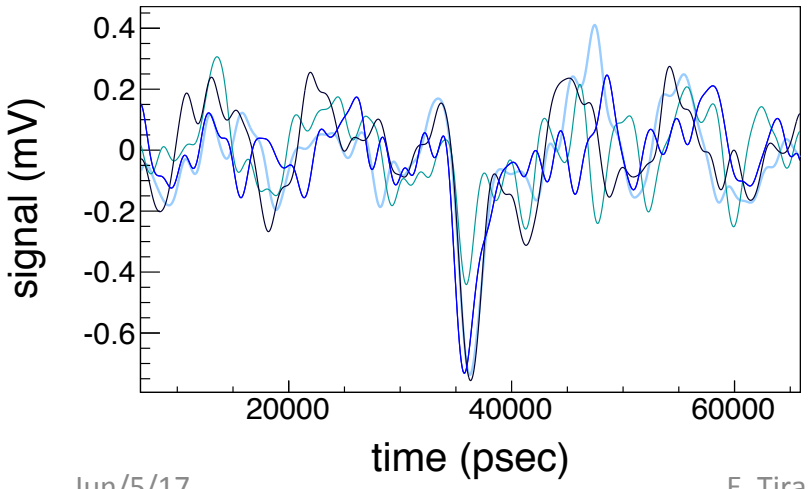
LAPPDs #9 and #12 were tested at ISU
w/ PSEC electronics provided by UChicago



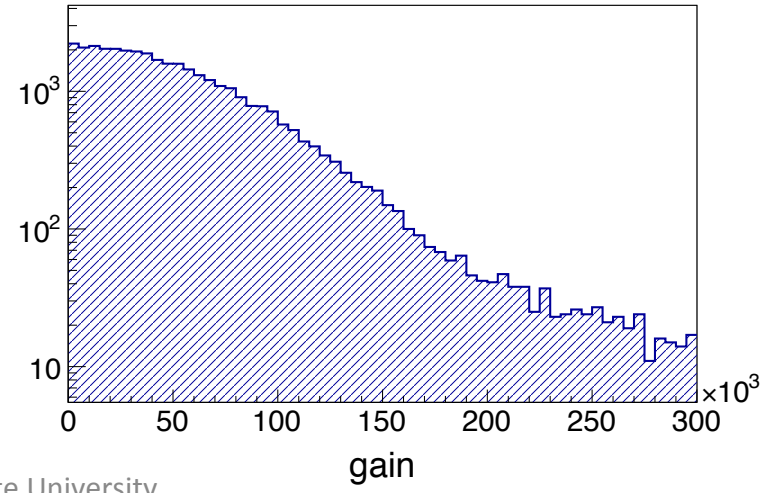
Multi-PE transit time spread (Tile #12)



example single PE-pulses Tile#9

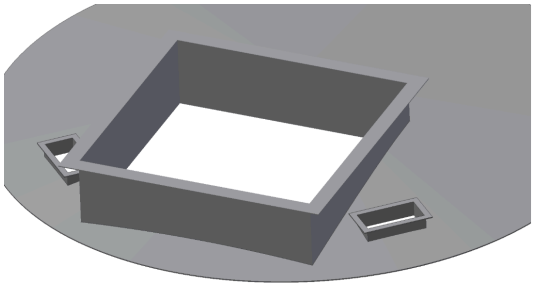


Tile #9 gain distribution

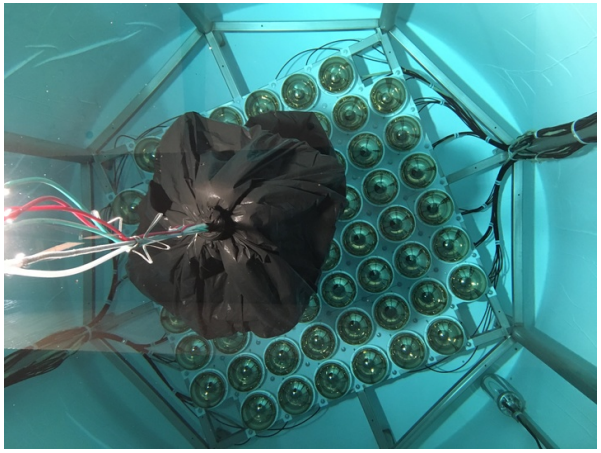


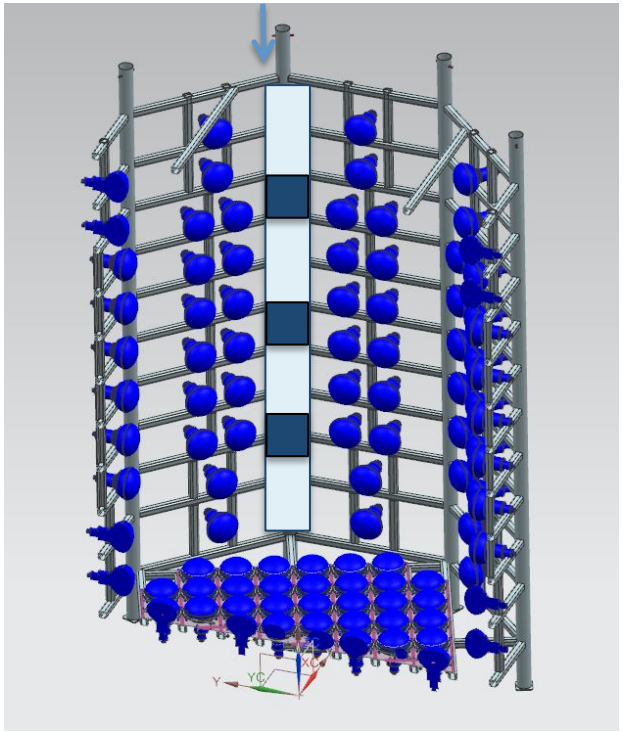
Phase I → Phase II

- Complete the tank inner structure
- Add the LAPPD System
- Add Gadolinium
- Finish refurbishing the muon range detector (reinstall paddles)
- Expand standard photocathode coverage w/ more PMTs
- Expand electronics channel count

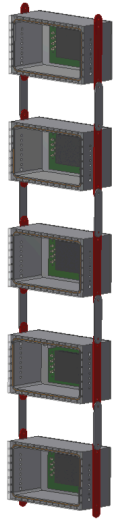


LAPPD Cassette





Small slots to insert the LAPPDs through guides.



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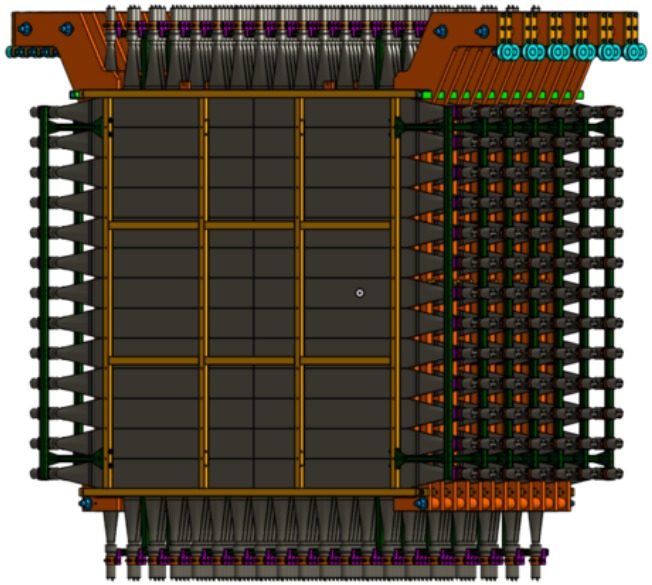
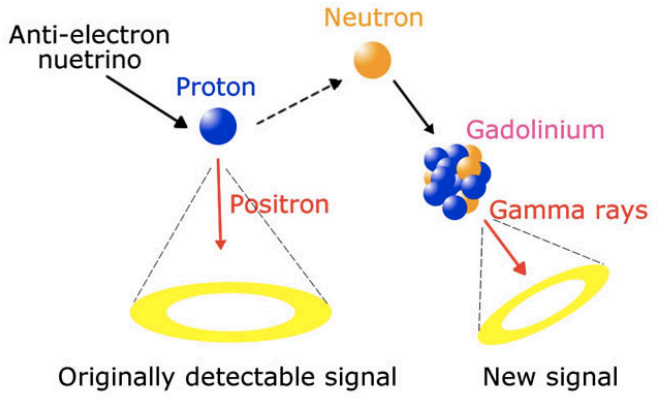


MRD has missing 71 paddles – still working on it.
Only the first two layers are powered during the Run I
All 306 channels will be powered up.

Gadolinium-Sulfate Loading:

- UPW will be loaded with Gd at 0.2% concentration
- Requires extensive material testing.
- Water purity/Gd-compatibility



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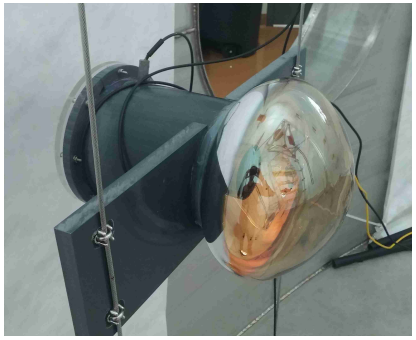
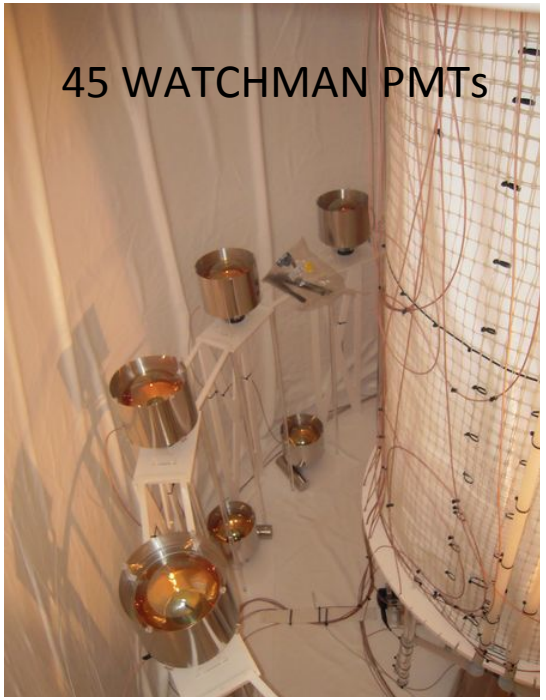
Acquired PMTs for ANNIE phase II



19 LUX PMTs

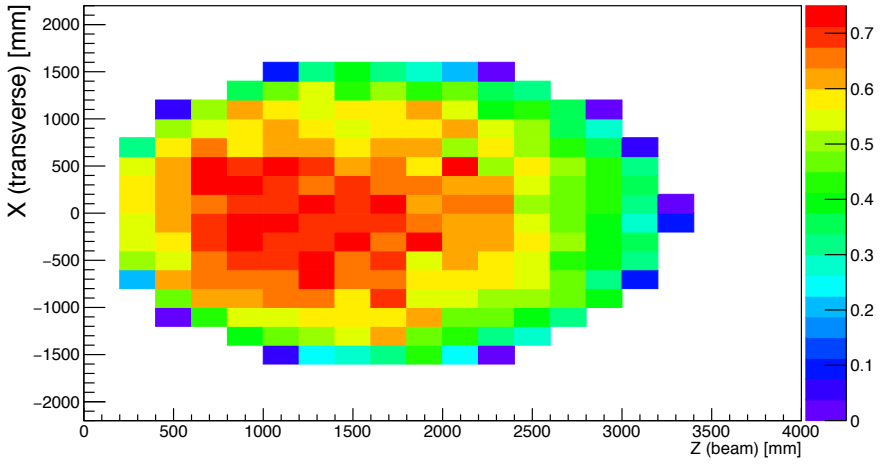
22 ETL (LBNE) PMTs



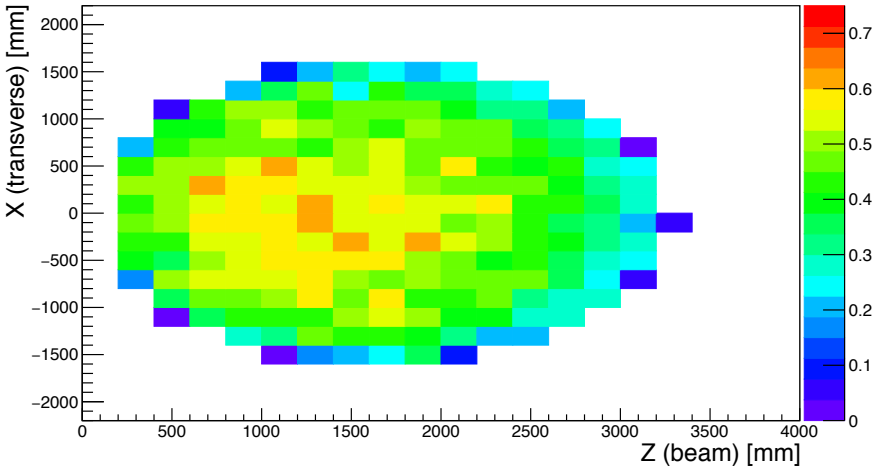
- Potentially buying 20 new HQE PMTs and looking other options to borrow from other experiments as well.

Phase II: Neutron Detection Efficiency

- Neutron detection efficiency as a function of the interaction position in X (the transverse direction) and Z (the beam direction)
- integrated between -1 and +1 meters in the vertical direction, Y.



5 p.e. threshold

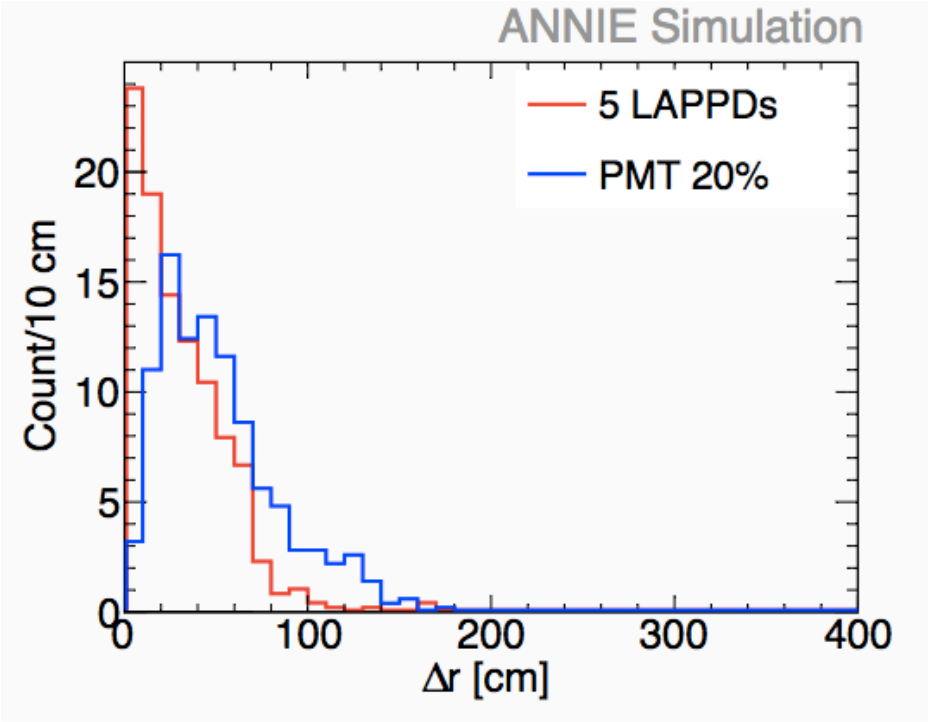


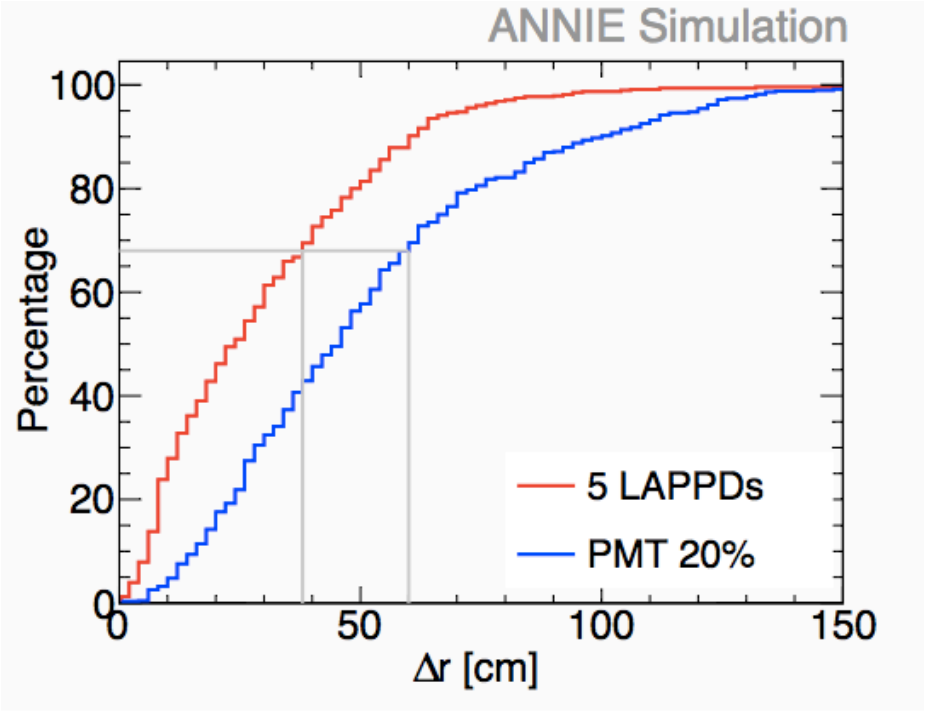
10 p.e. threshold

Plots from V. Fischer

Phase II: Vertex Reconstruction and Fiducialisation

- LAPPDs show substantial improvement in precision for vertex reconstruction.
- LAPPDs help to understand the topology of the events.





Plots from A. Back and J. Wang

Conclusion

- The ANNIE experiment will measure the neutron yield from neutrino-nucleus interactions in the energy range of atmospheric neutrinos.
- ANNIE will be the first experiment testing LAPPDs in a Gd-loaded water.
- Currently running in Phase I with the goal of measuring the background neutrons.
- Phase I results will be ready and published soon.
- Phase II planned for next year. LAPPDs and more PMTs will be added and making physics measurements.