The Accelerator Neutrino-Neutron Interaction Experiment (ANNIE)

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on behalf of ANNIE collaboration

Iowa State University

All Experimenters' Meeting, Fermilab
July 24, 2017

The Current State of the Detector (Phase I)

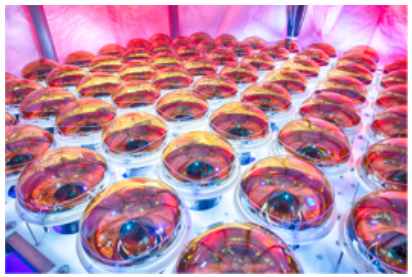
ANNIE is located at SciBooNE Hall along the Booster Neutrino Beam (BNB) at Fermilab.

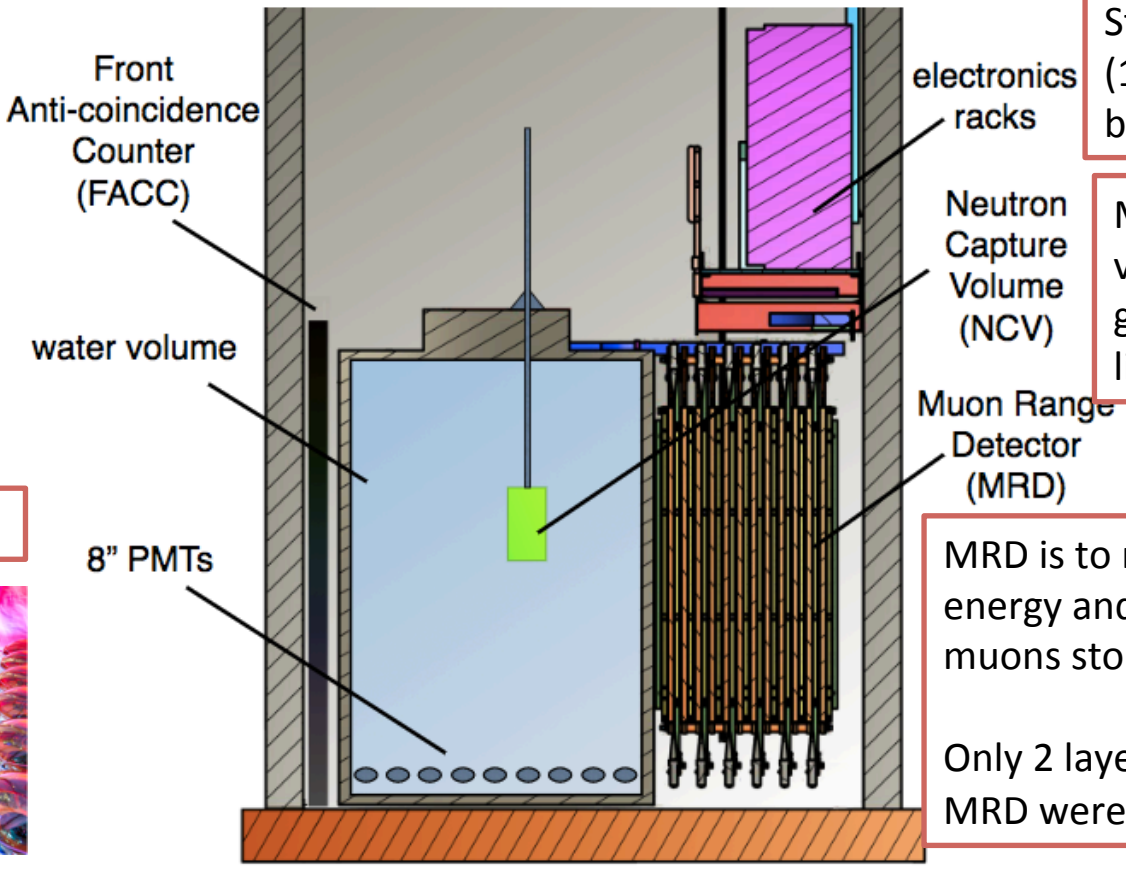
- on-axis neutrino flux
- Spectrum peaks around 0.7 GeV (range of interest for atmospheric neutrinos)
- Expect 14×10^3 ν_μ of charged-current interactions per ton of water per year.

Scintillator paddles to veto muons not originating in the tank.

26 tons of ultra-pure (UPW) water

60 Super-K PMTs





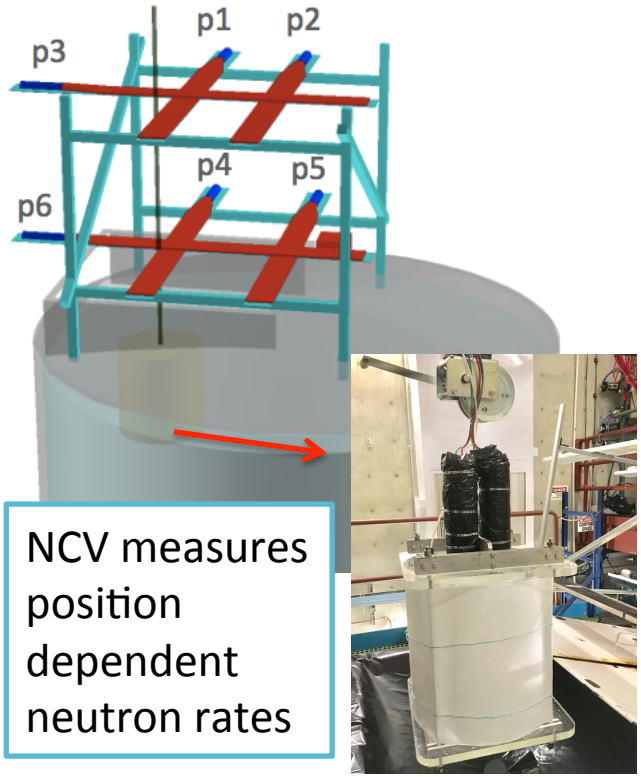
Steel cylindrical tank (10 ft x 13 ft) 8 m below the surface

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

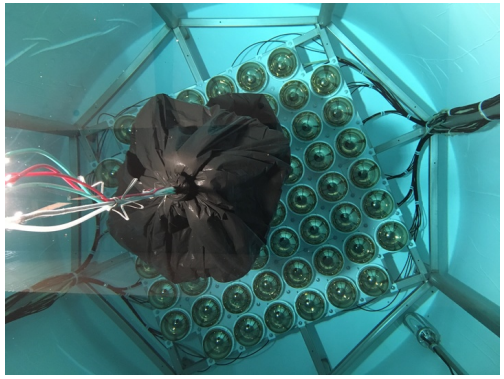
MRD is to measure the total energy and momentum of muons stopping in MRD.

Only 2 layers of the SciBooNE MRD were powered up.

ANNIE Phase I



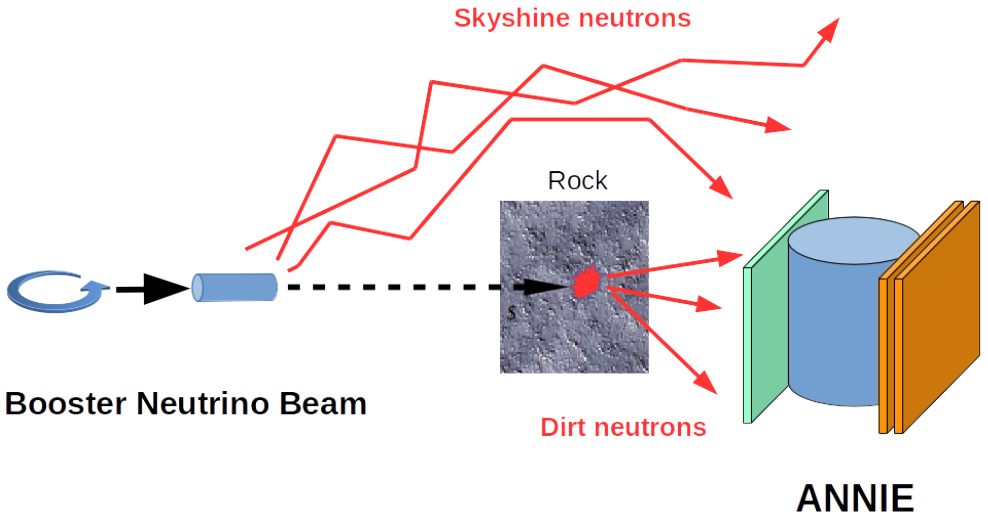
NCV measures position dependent neutron rates



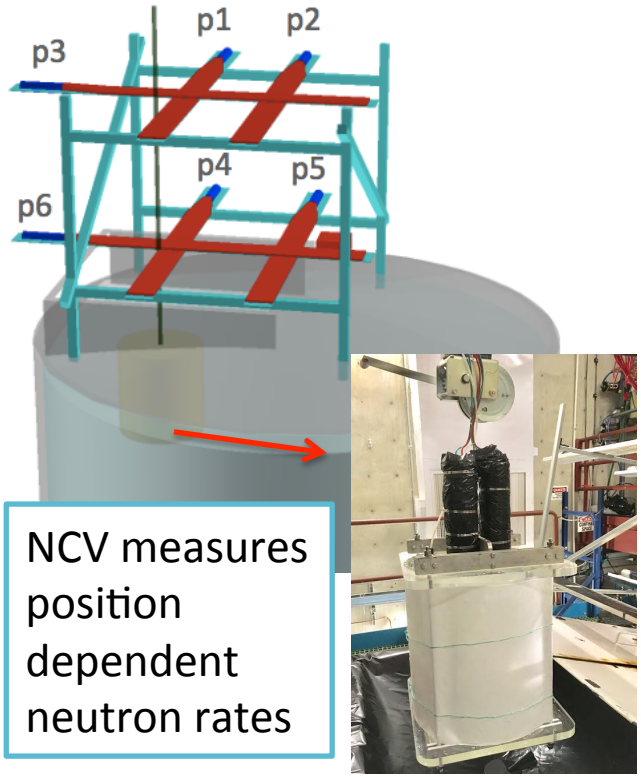
The main physics goal of Phase I is understanding neutron backgrounds. Potential background neutrons in ANNIE:

- Sky-shine neutrons from the beam dump
- Dirt neutrons from the rock

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



ANNIE Phase I



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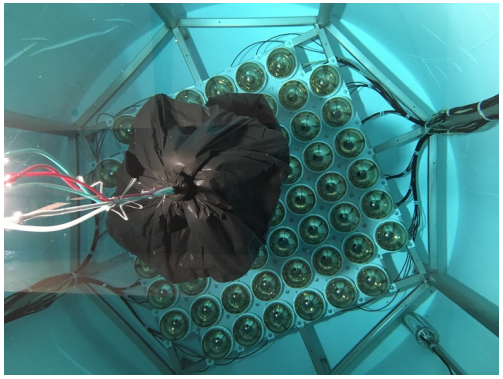


Triggers:

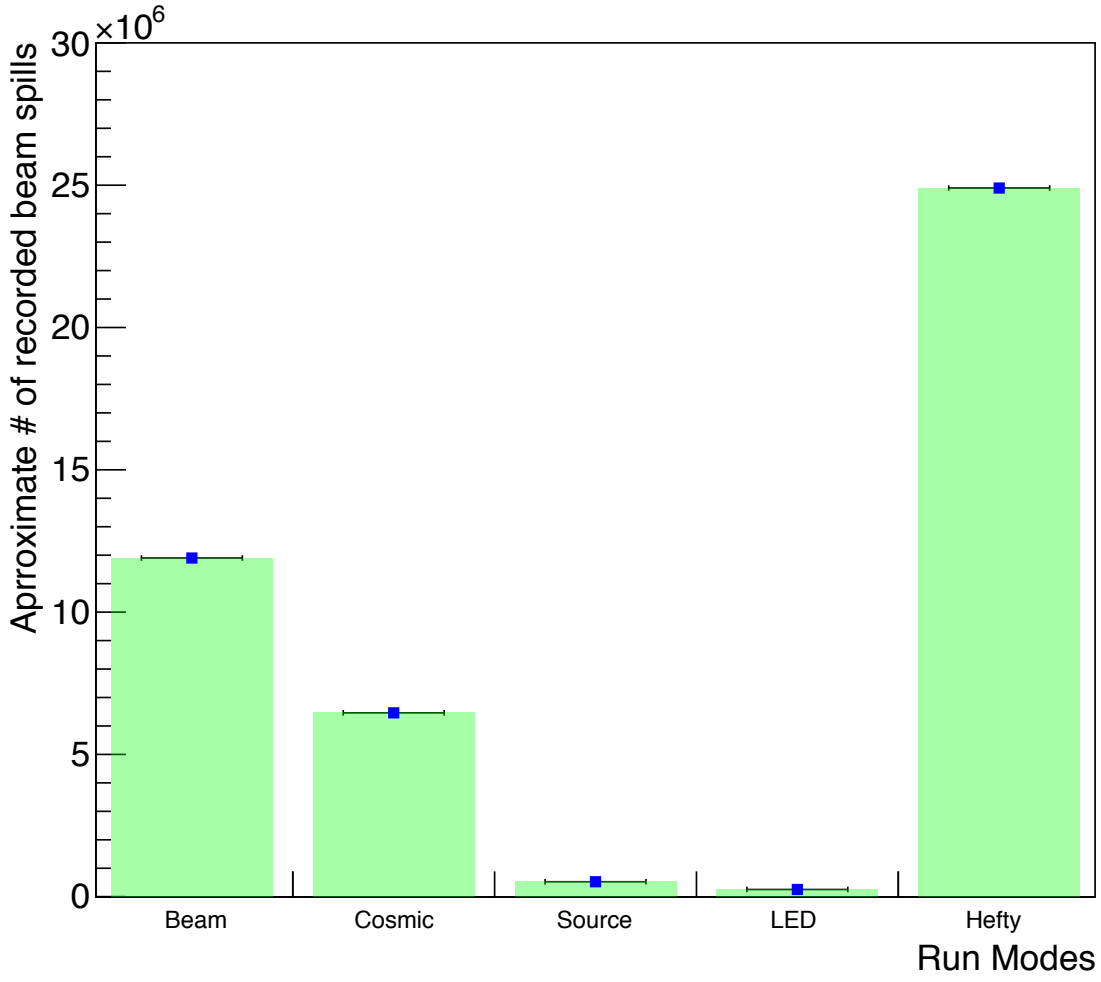
- Beam trigger
- Cosmic trigger (coincidence of 6 cosmic paddles)
- Calibration neutron source trigger
- LED calibration trigger (blue, green)

Calibration:

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

Data Taking Progress

- ANNIE was built by April 2016 and it has been taking data since May 2016.
- Currently taking cosmic and source (Cf-252) data. It will be turned off in two weeks.



Execution of Phase I

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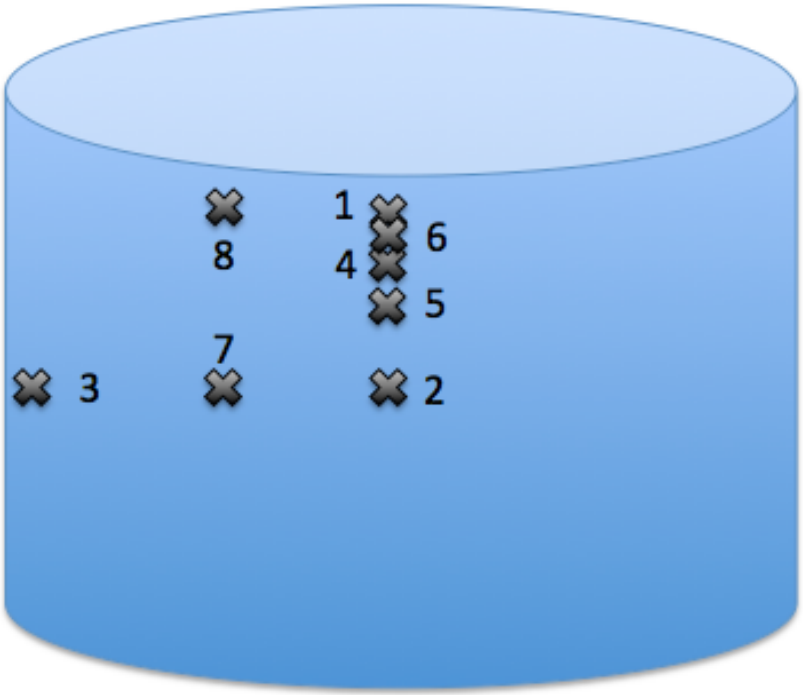
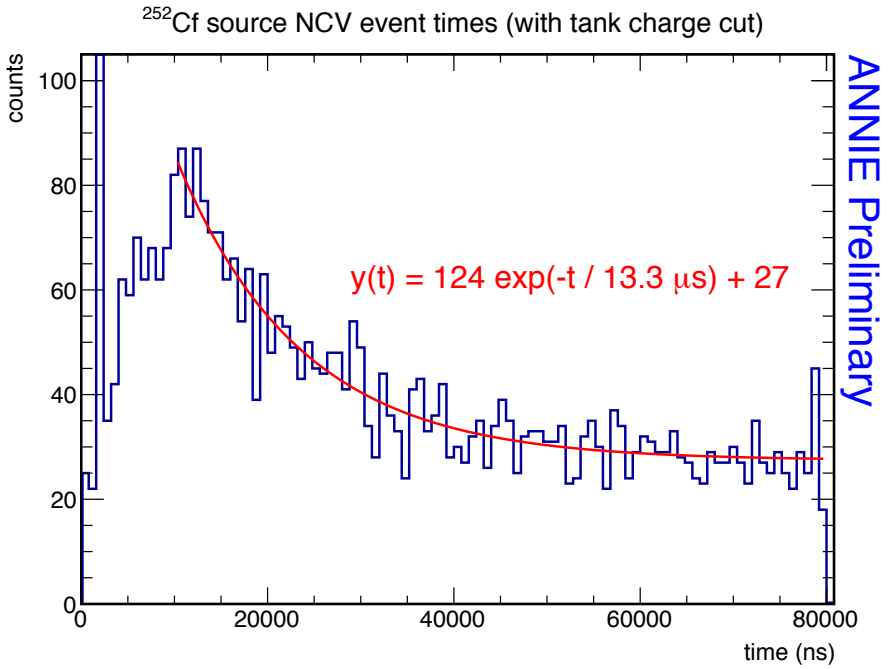


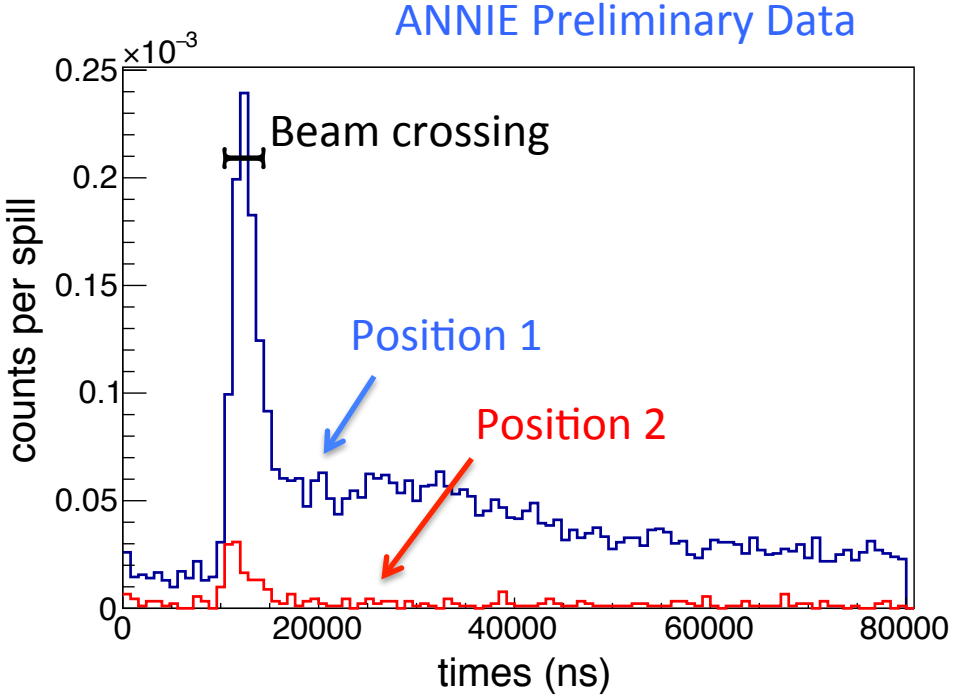
The NCV was moved to 8 positions, scanning the neutron rates as a function of distance from the beam and the top.

Preliminary Phase I Results

Plots from S. Gardiner

- We have detected neutron captures, both from a calibration source and from the beam.
- Preliminary estimates based on measurements below the surface indicate neutron backgrounds in less than 2% of spills.
- Final luminosity normalized estimates of beam induced background neutrons are coming soon.



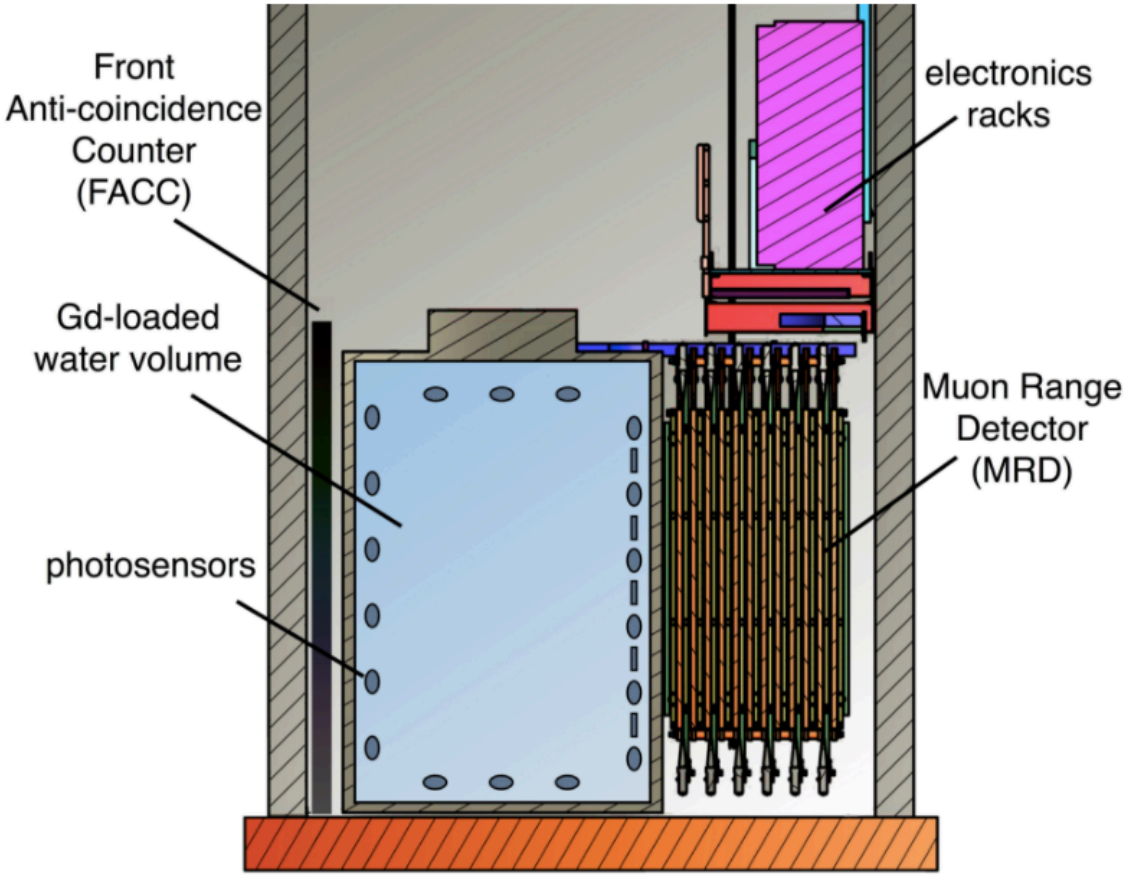


- **Backgrounds are acceptable and can be mitigated with <2 ft of buffer.**

ANNIE Phase II (Summer 2018)

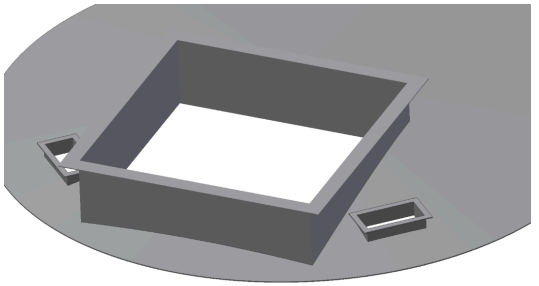
- 26 tons of Gd-loaded (0.2 %) water
- >100 PMTs + 10-20 LAPPDs
- The missing paddles of the MRD will be refurbished.

MRD: 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.

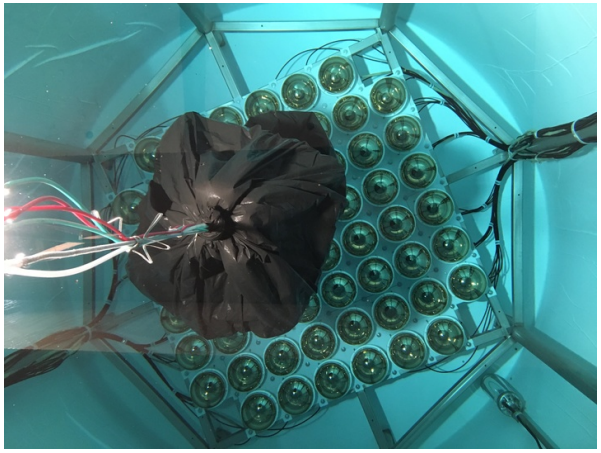


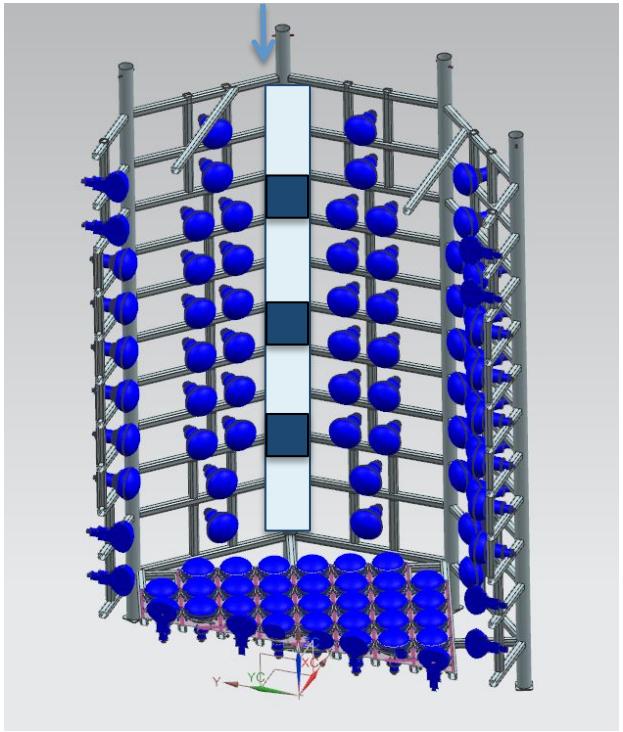
More details about the upgrade

- 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

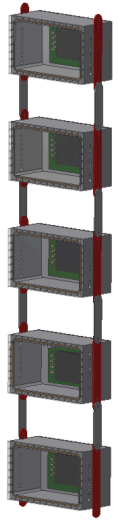


LAPPD Cassette





Small slots to insert the LAPPDs through guides.

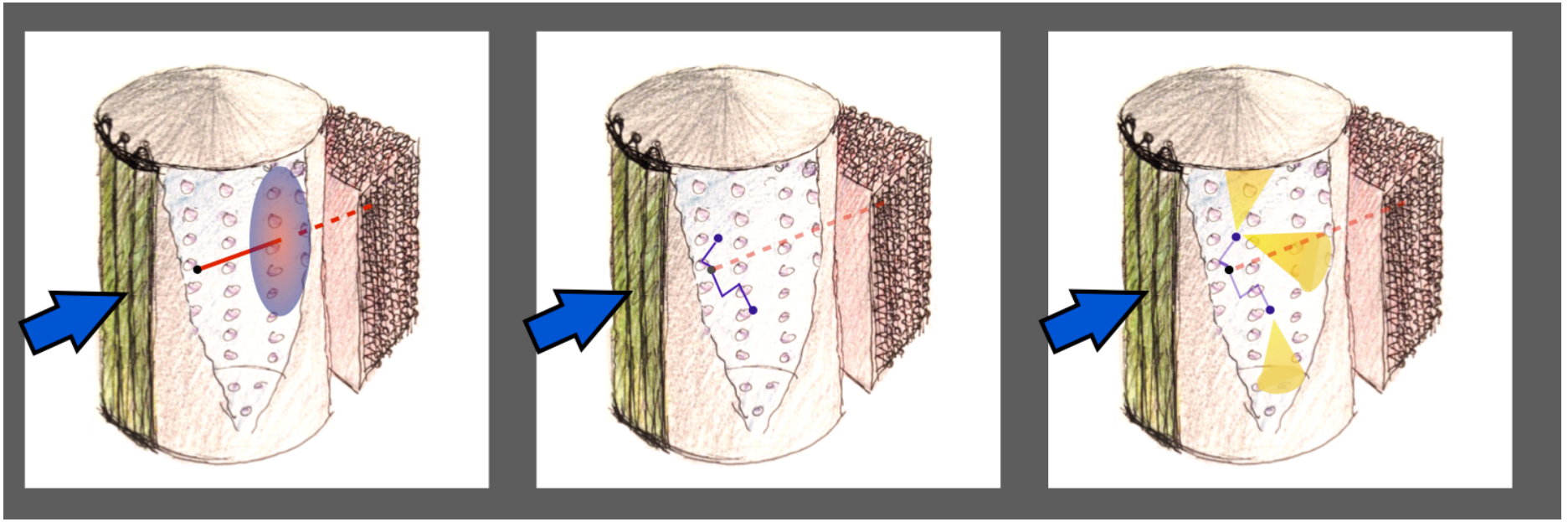


Conclusion

- Phase I: We built it and backgrounds are acceptable.
- LAPPDs are here - testing them at ISU.
- Phase II planned for next year. LAPPDs and more PMTs will be added and making physics measurements.
- It was approved by PAC last week. We appreciate Fermilab's support.
- ANNIE will be the first experiment testing LAPPDs in Gd-loaded water.

Backup Slides

An event in ANNIE tank



muon

neutrons are produced

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

ANNIE Moving Towards Phase II

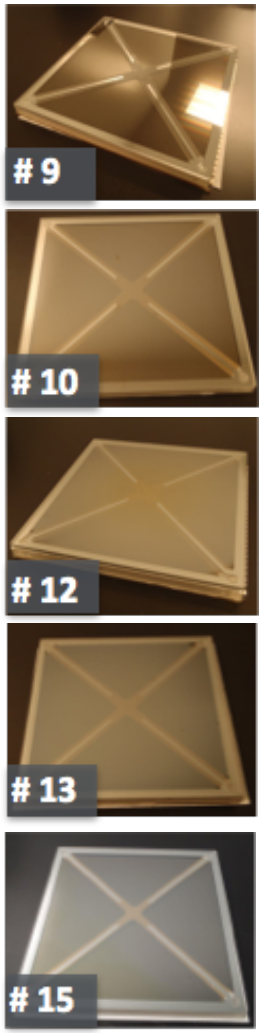
LAPPDs (20 cm x 20 cm) are:

- 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.

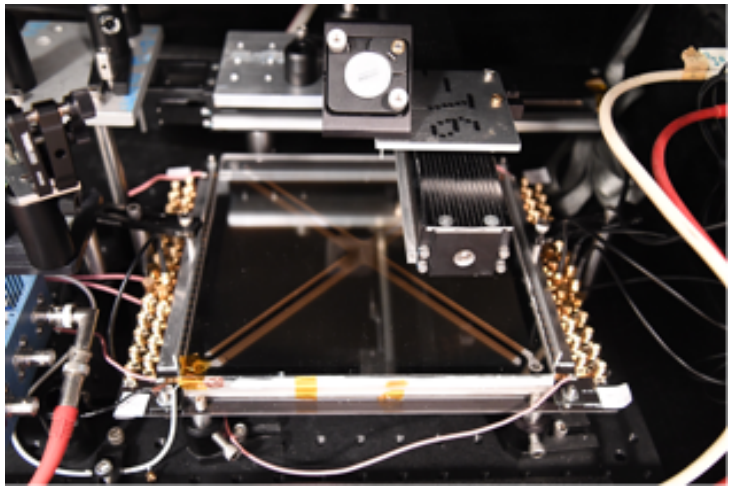
Incom has now produced multiple LAPPD prototypes, quickly approaching the specifications needed by ANNIE:

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

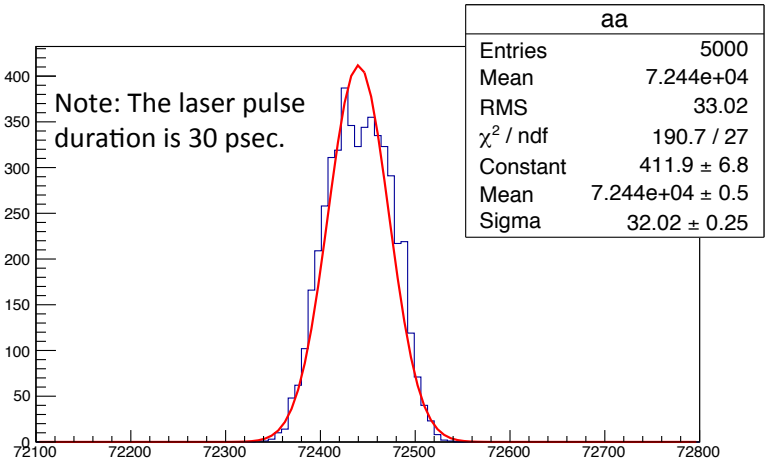


LAPPD Characterization Tests at ISU

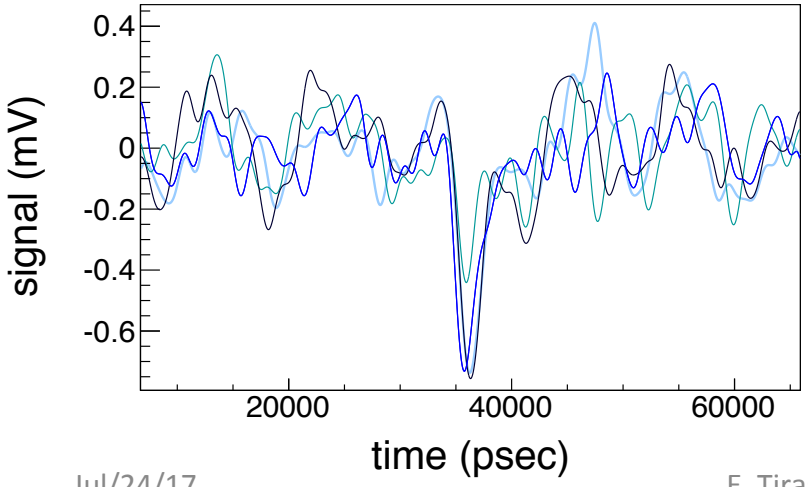
LAPPDs #9 and #12 were tested at ISU
w/ PSEC electronics provided by UChicago



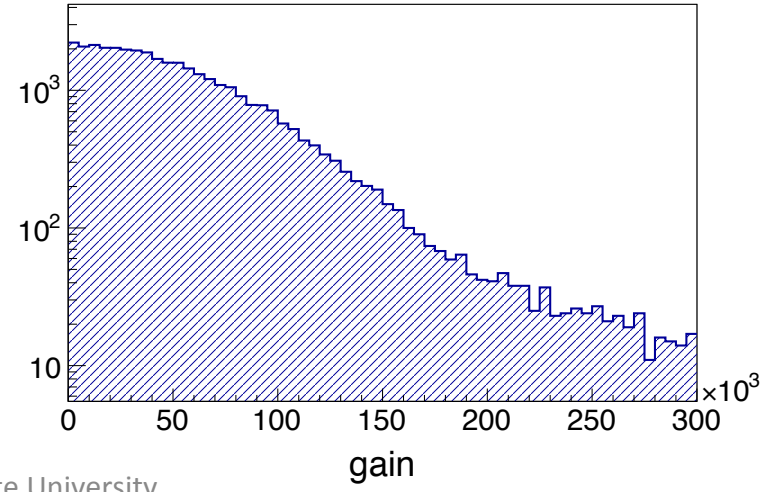
Multi-PE transit time spread (Tile #12)



example single PE-pulses Tile#9



Tile #9 gain distribution



Phase I → Phase II

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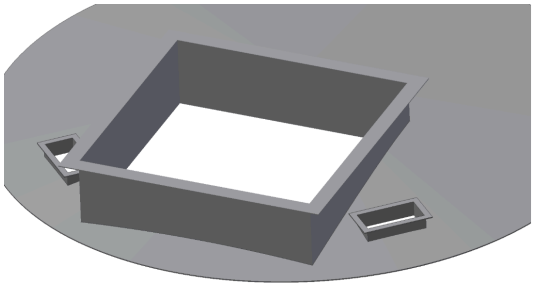

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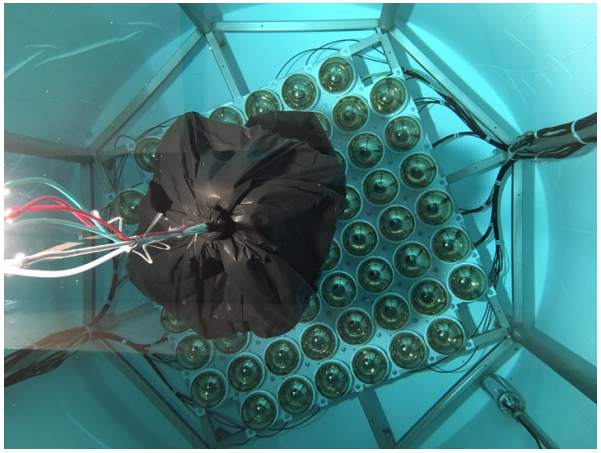

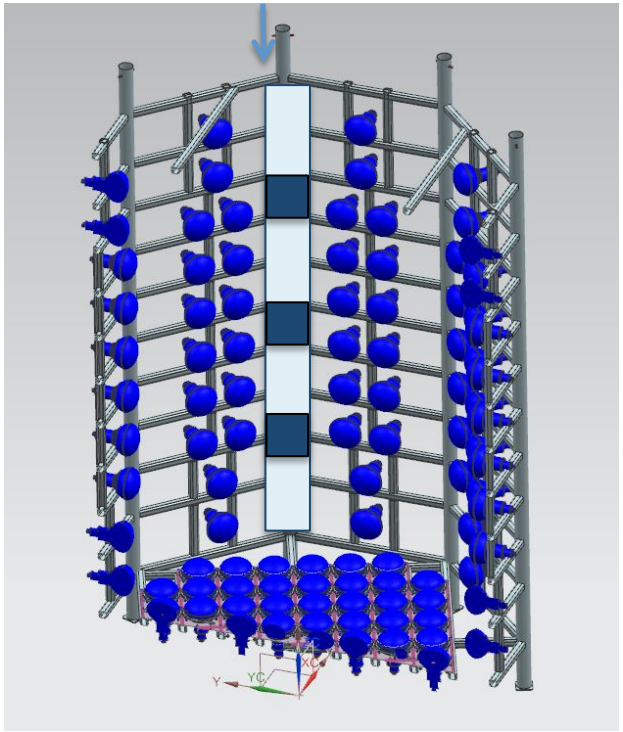

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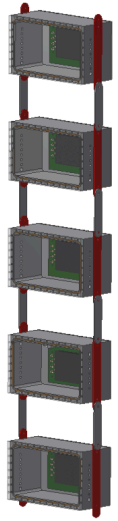

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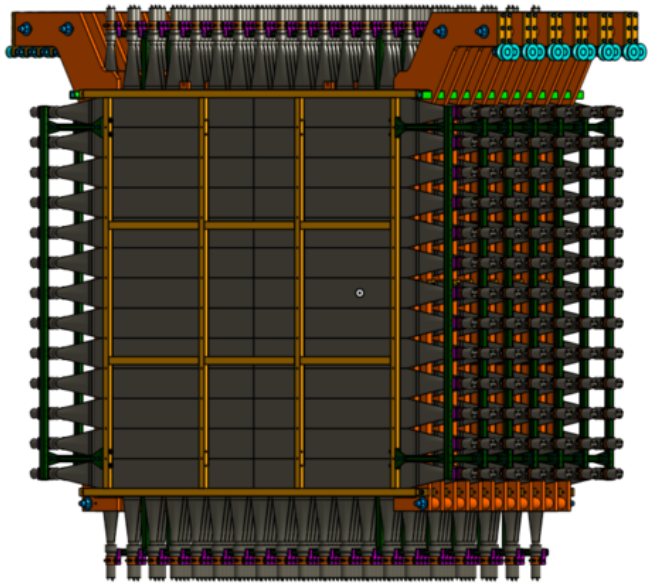
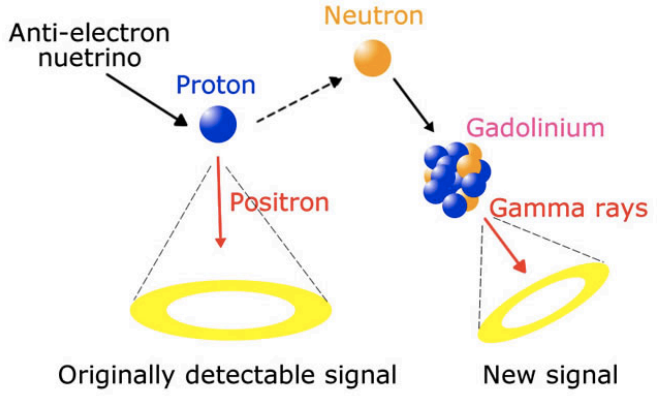


MRD has missing 71 paddles – still working on it.
Only the first two layers are powered during the Run I
All 306 channels will be powered up.

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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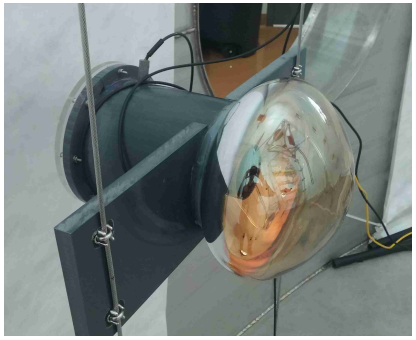
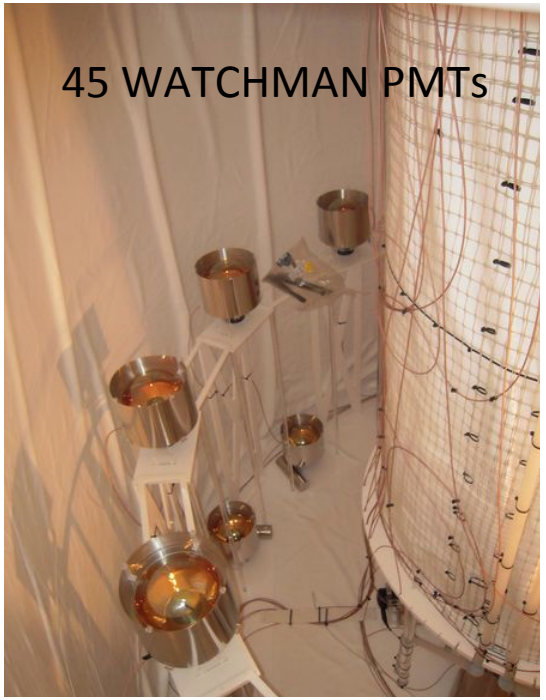
Acquired PMTs for ANNIE phase II



19 LUX PMTs

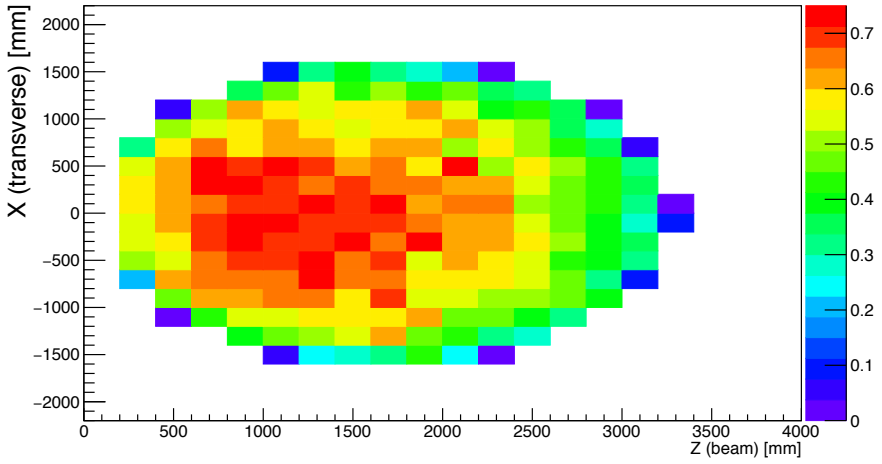
22 ETL (LBNE) PMTs



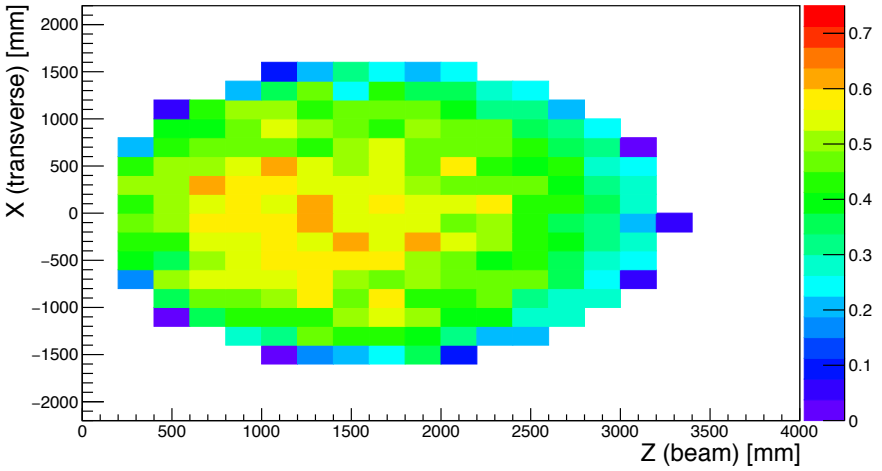
- Potentially buying 20 new HQE PMTs and looking other options to borrow from other experiments as well.

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

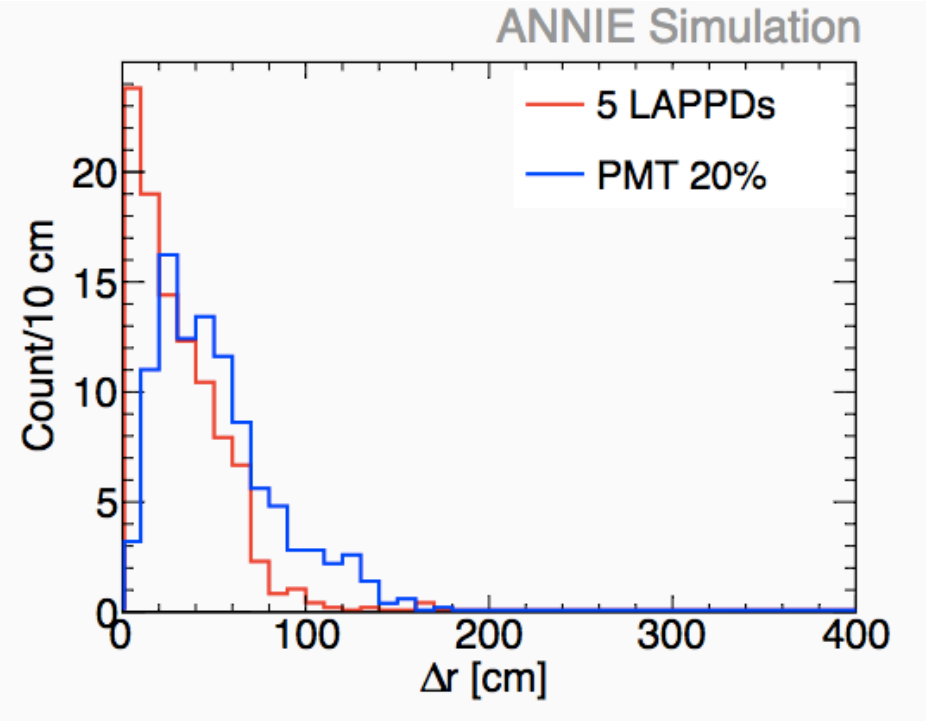


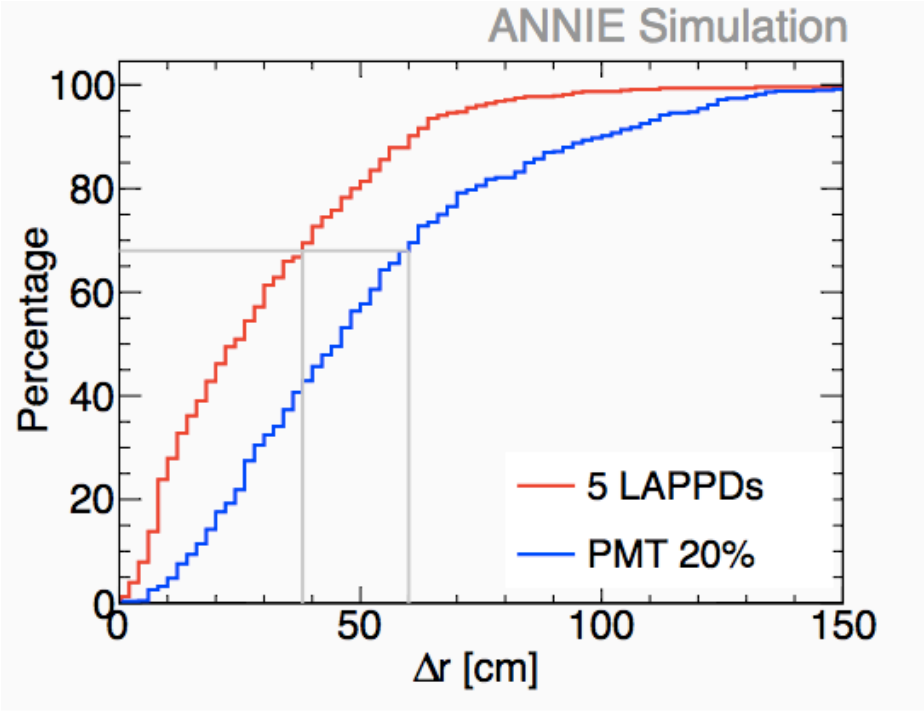
10 p.e. threshold

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