ANNIE Phase II Detector Design and Construction

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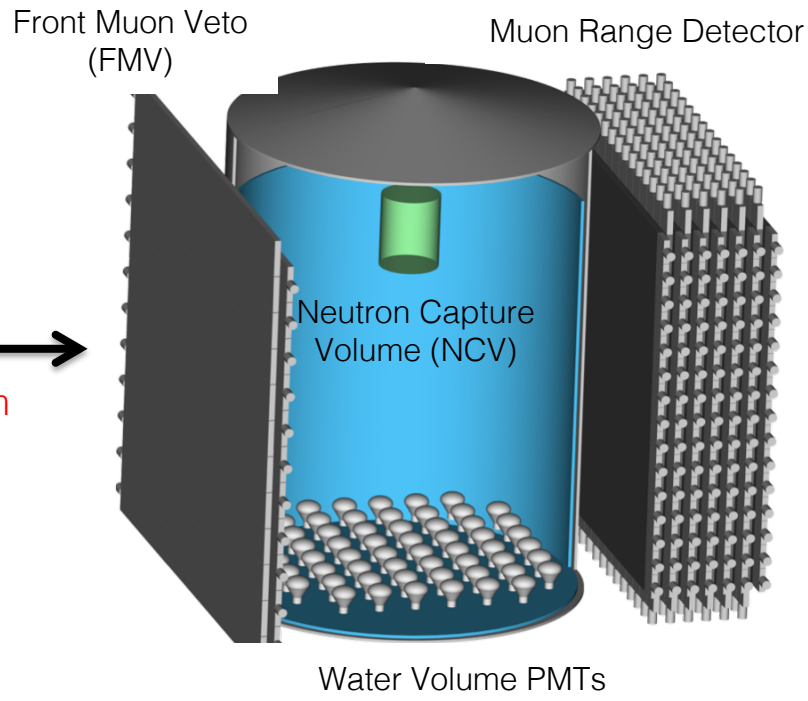
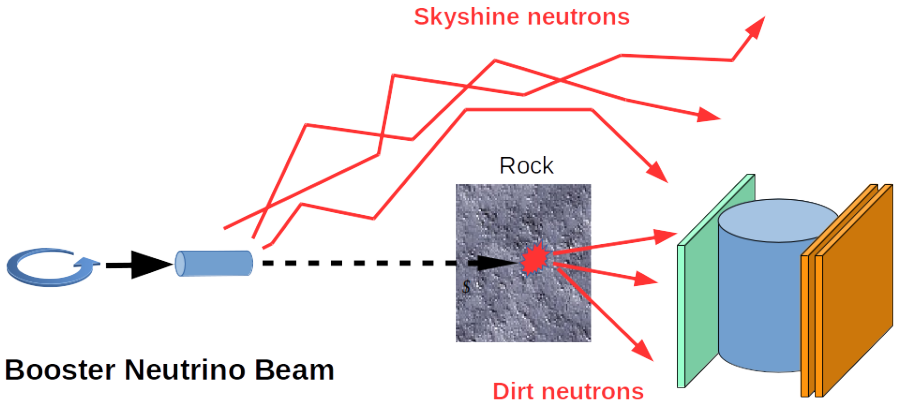
ANNIE Phase I

- 26 tons of ultra-pure water
- 2 layers of scintillator paddles in the front (FMV) and 2 layers of Muon Range Detector (MRD) were used
- 50 cm x 50 cm acrylic vessel (NCV) filled with 0.25% Gadolinum-loaded (Gd) liquid scintillator (EJ-335)
- 60x 8-inch PMTs act as a veto to the NCV
- Calibration studies with Cf-252 neutron source
- Data taking completed in September 2017

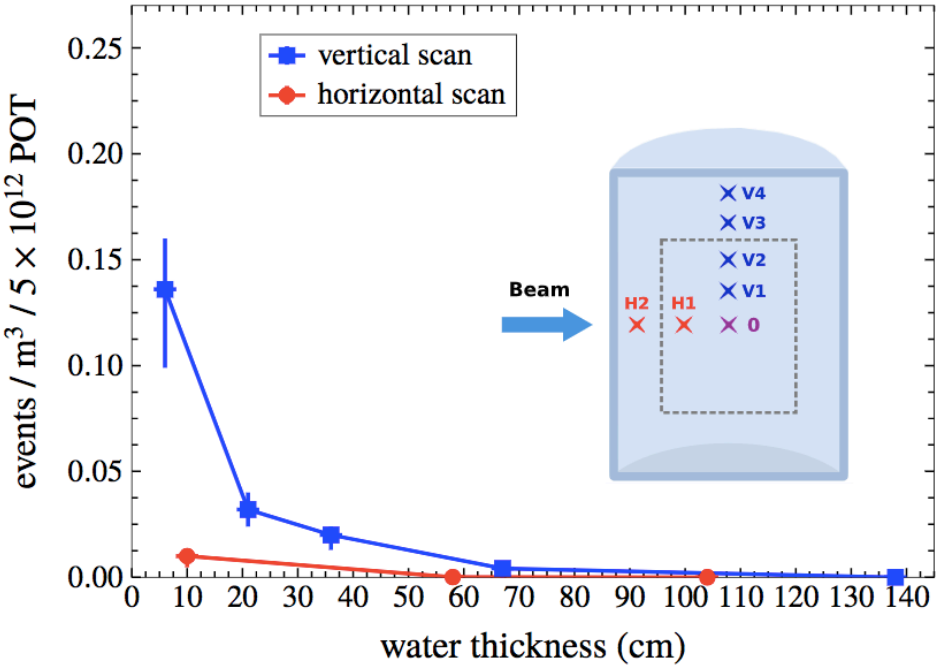




- The main physics goal of Phase I was measuring beam related background neutrons for the experiment.

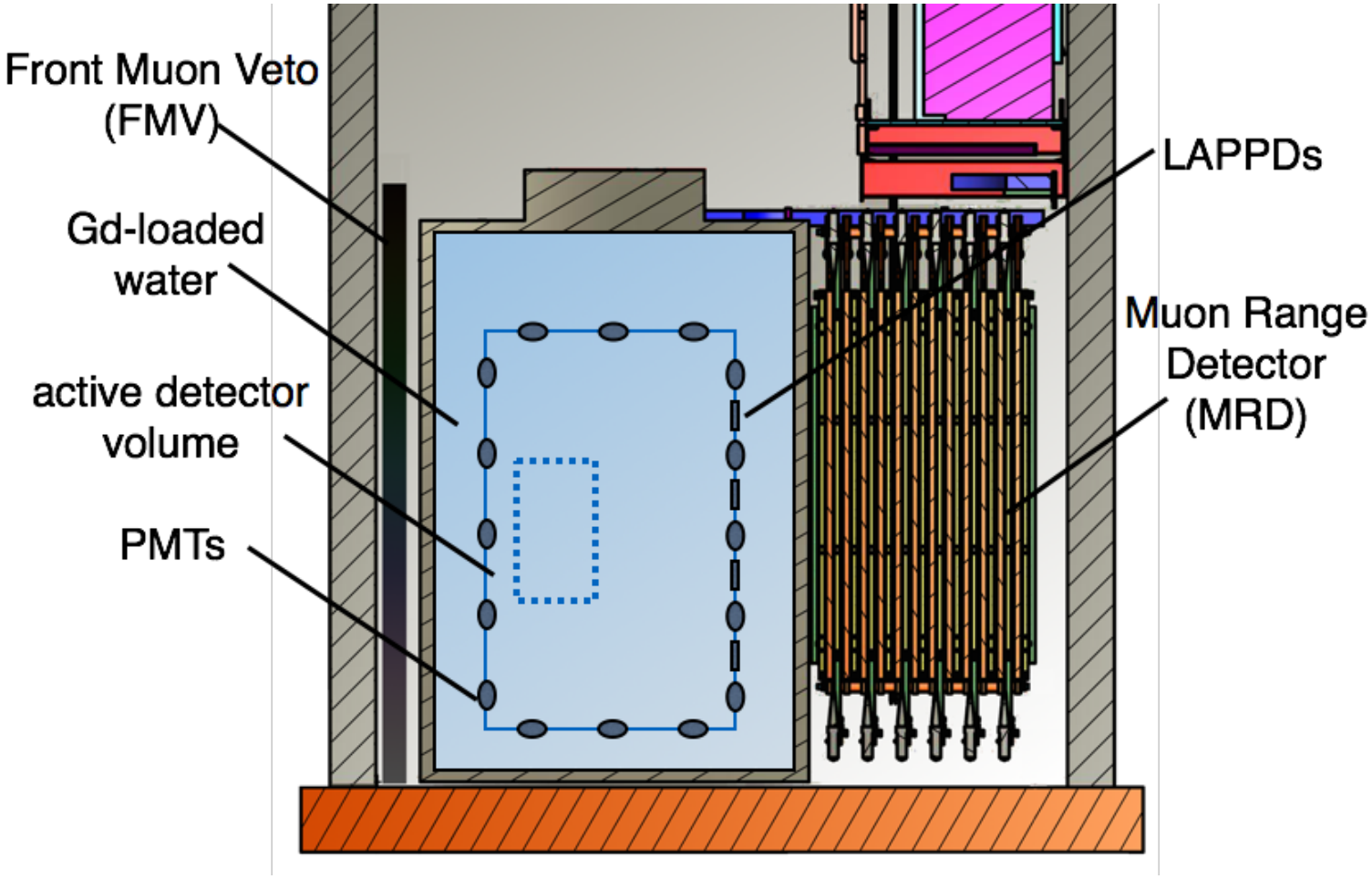
ANNIE Phase I

- We have detected neutron captures from both a calibration source and the beam
- Plot below is beam-correlated neutron candidate event rates



- Preliminary estimates based on measurements below the surface indicate neutron backgrounds in less than 2% of spills
- Backgrounds are acceptable and sufficiently shielded/mitigated by using 2 ft buffer.

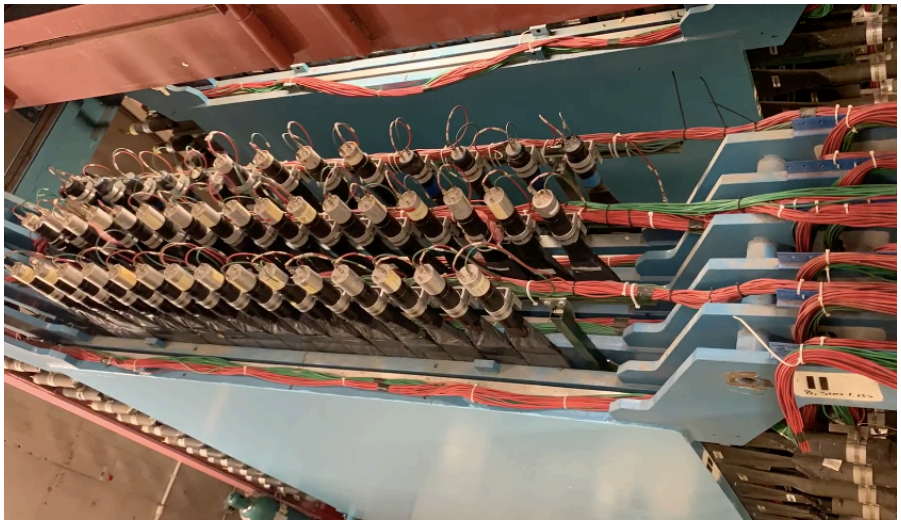
ANNIE Phase II Detector Design



Muon Range Detector (MRD) Refurbishment

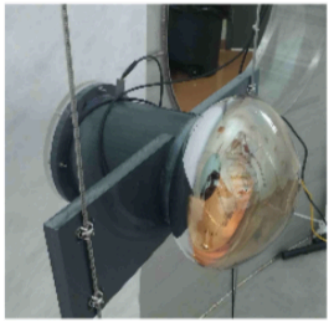
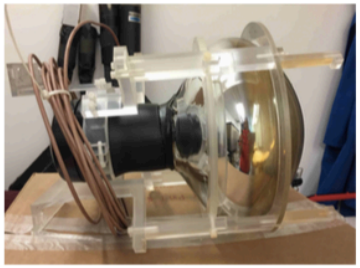
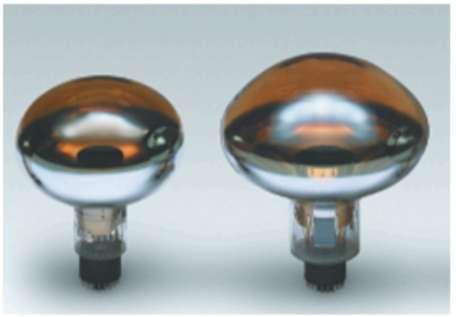
Front-view

Top-view



- MRD consists of 11 alternating layers (310 channels) with a 5 cm steel in between layers.
- It is for measuring the momentum and direction of the muons coming from the neutrino interactions in the tank.
- We refurbished the MRD from the old-SciBooNE experiment.
- 71 paddles were missing. We refurbished old-KTeV paddles and installed them on the MRD.

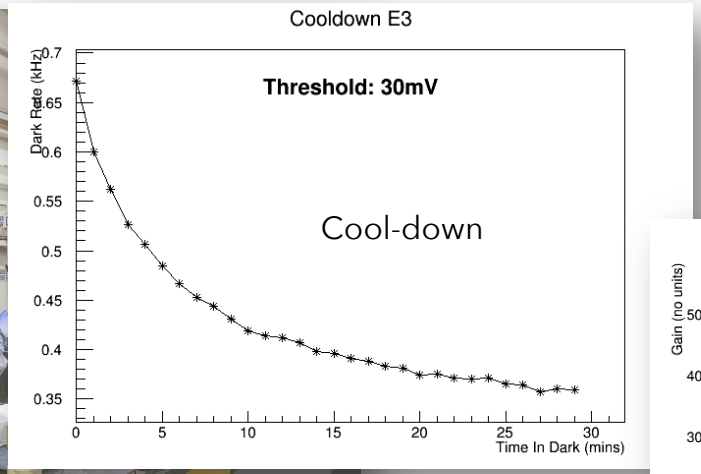
PMTs for Phase II

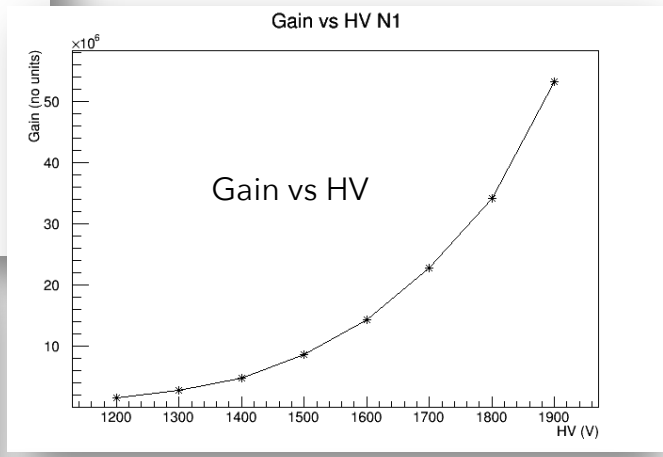





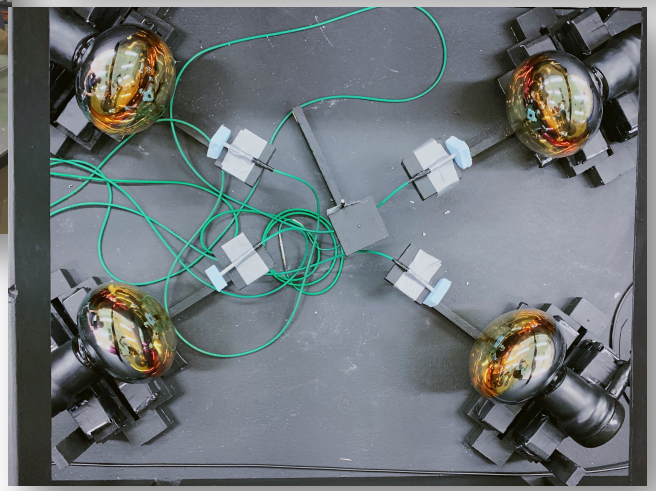
Manufacturer	ETEL	Hamamatsu	Hamamatsu	Hamamatsu	Hamamatsu
Origin	LBNE R&D	LUX	Watchboy	New	WATCHMAN
Type	D784KFLB	r7081	r7081	r5912	r7081
"Name"	LBNE (LB)	LUX (LX)	Watchboy (WB)	New (HM)	Watchman (WM)
Size	11"	10"	10"	8"	10"
HQE?	Yes	No	No	Yes	Yes
Quantity	22	20	45	40	10
At FNAL?	Yes	Yes	Yes	No	No

- ANNIE bought 40 HQE PMTs from Hamamatsu and the rest of them are loans from different experiments

PMT Refurbishment and Testing at Fermilab



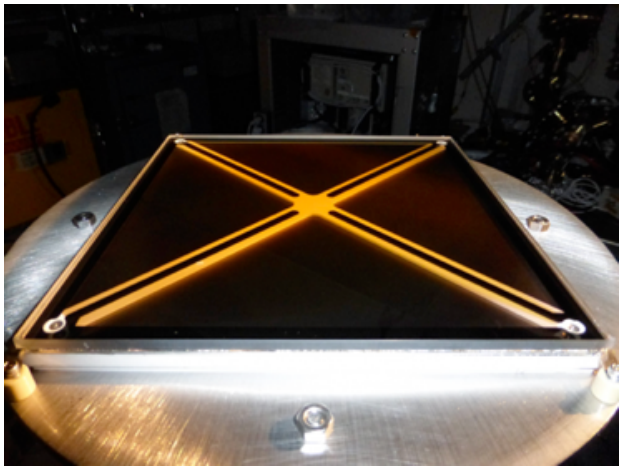




- Refurbishment and upgrade for the PMT holders and housing are completed
- We tested them one by one with an LED setup for Gain, After-pulse and Cool-down at Fermilab

LAPPDs for ANNIE Phase II

- First major application of Large Area Picosecond Photo-Detectors (LAPPDs) in a neutrino experiment.



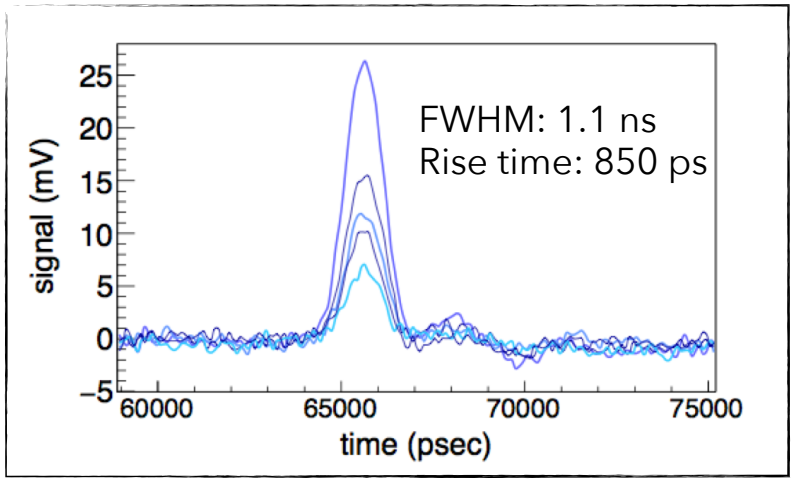
- A novel technology for photodetection with gain of $>10^6$
- Large area flat panel photocathodes.
- 8 in. x 8 in. square Micro Channel Plate (MCP).
- Excellent 60 psec time resolution.
- Multi-microstrip readout gives ~1 cm spatial resolution

Advantages and Physics Benefits:

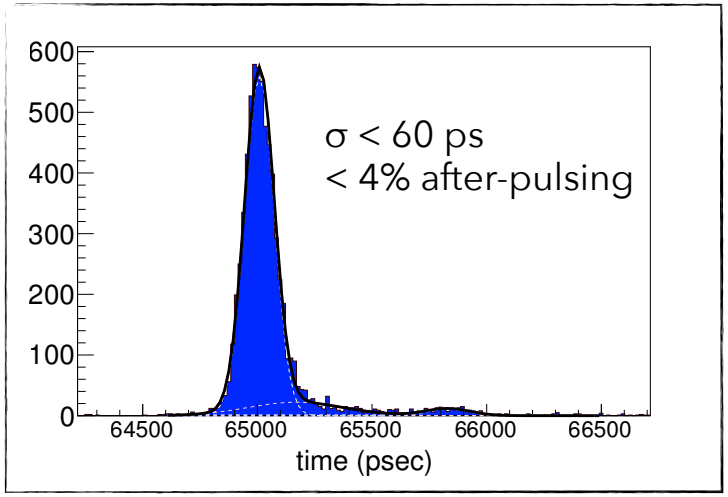
- Good spatial and time resolution allow identification of multiple individual photons.
- This will enable significant improvement for vertex and track reconstruction.
- This will improve energy resolution, background rejections and allows multiple particle detection.

LAPPD Characterization at ISU

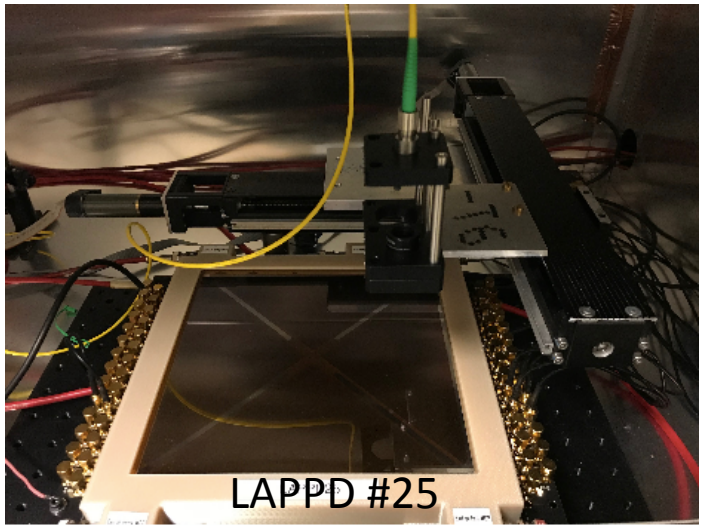
Typical Single-PE Pulses



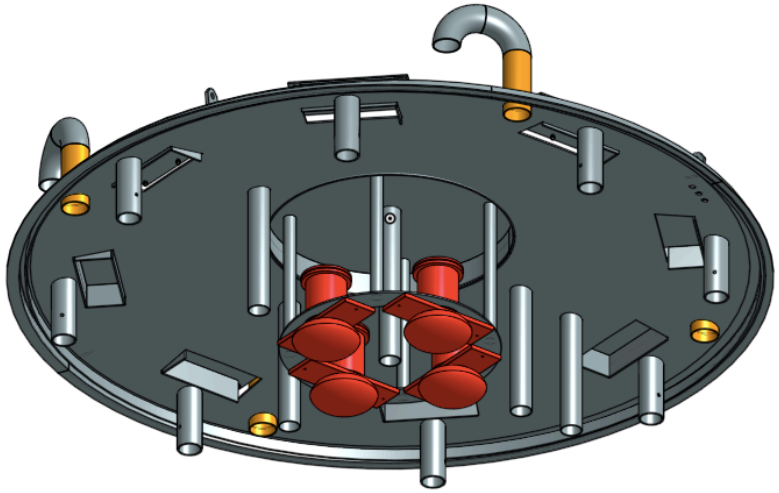
Transit Time Spread

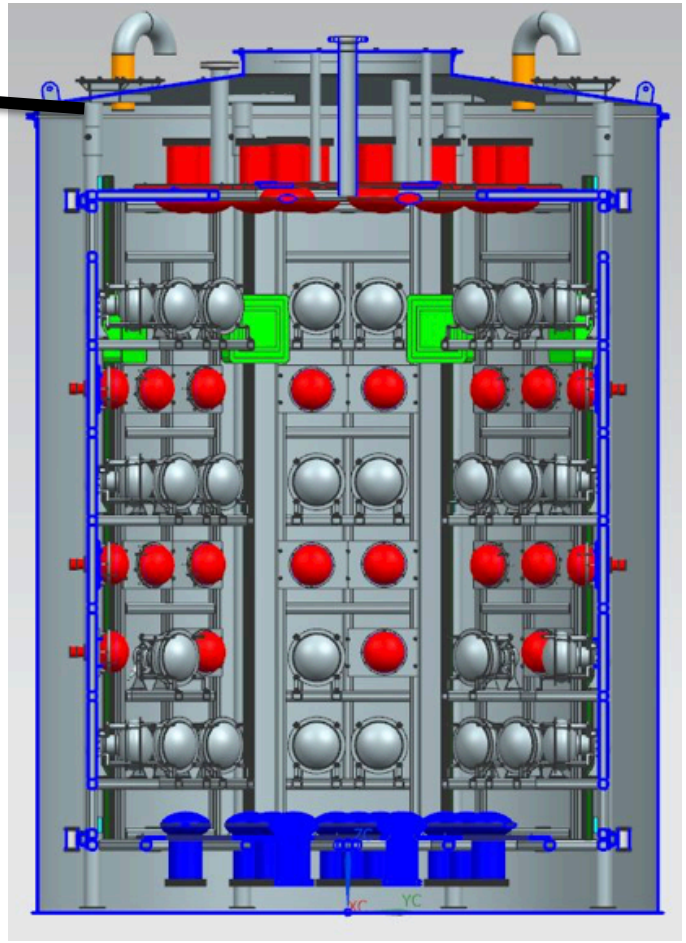


We'll have all 5 LAPPDs on hand for Phase II in 2-3 weeks.



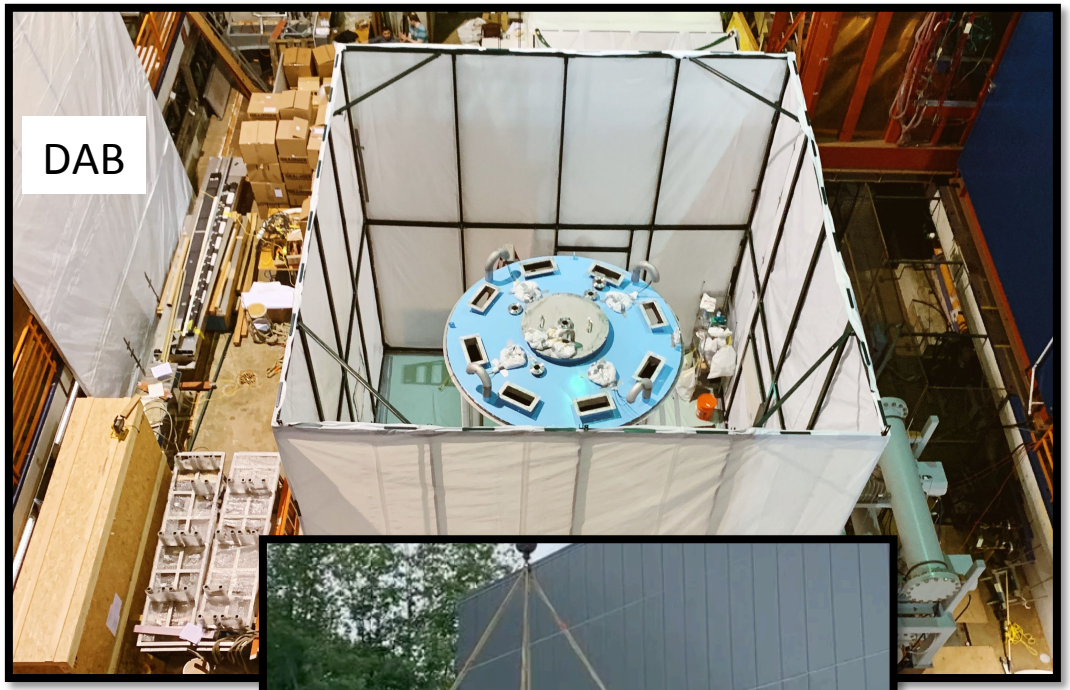
ANNIE Phase II Detector Upgrade



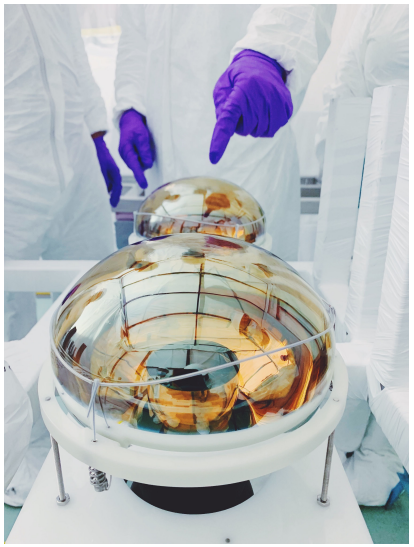


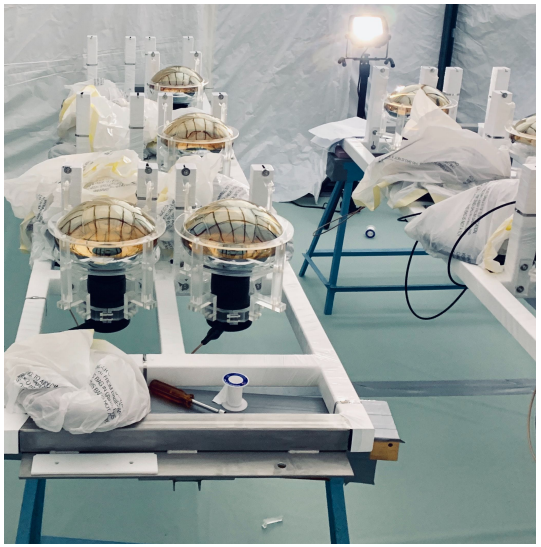
- The inner structure and tank top lid were designed and built at Fermilab.
- It was designed to hold 136 PMTs + 16 outer veto PMTs and many LAPPDs (~40).
- The inner structure was built from 304 stainless steel and went under passivation at a company nearby Fermilab.
- We did final electro-polishing for the welds and scratches on the inner structure.
- No tolerance for possible corrosion in the tank.
- Each material sample goes into the tank was tested in Gd-water at UC-Davis.

Phase II Detector Construction at DAB

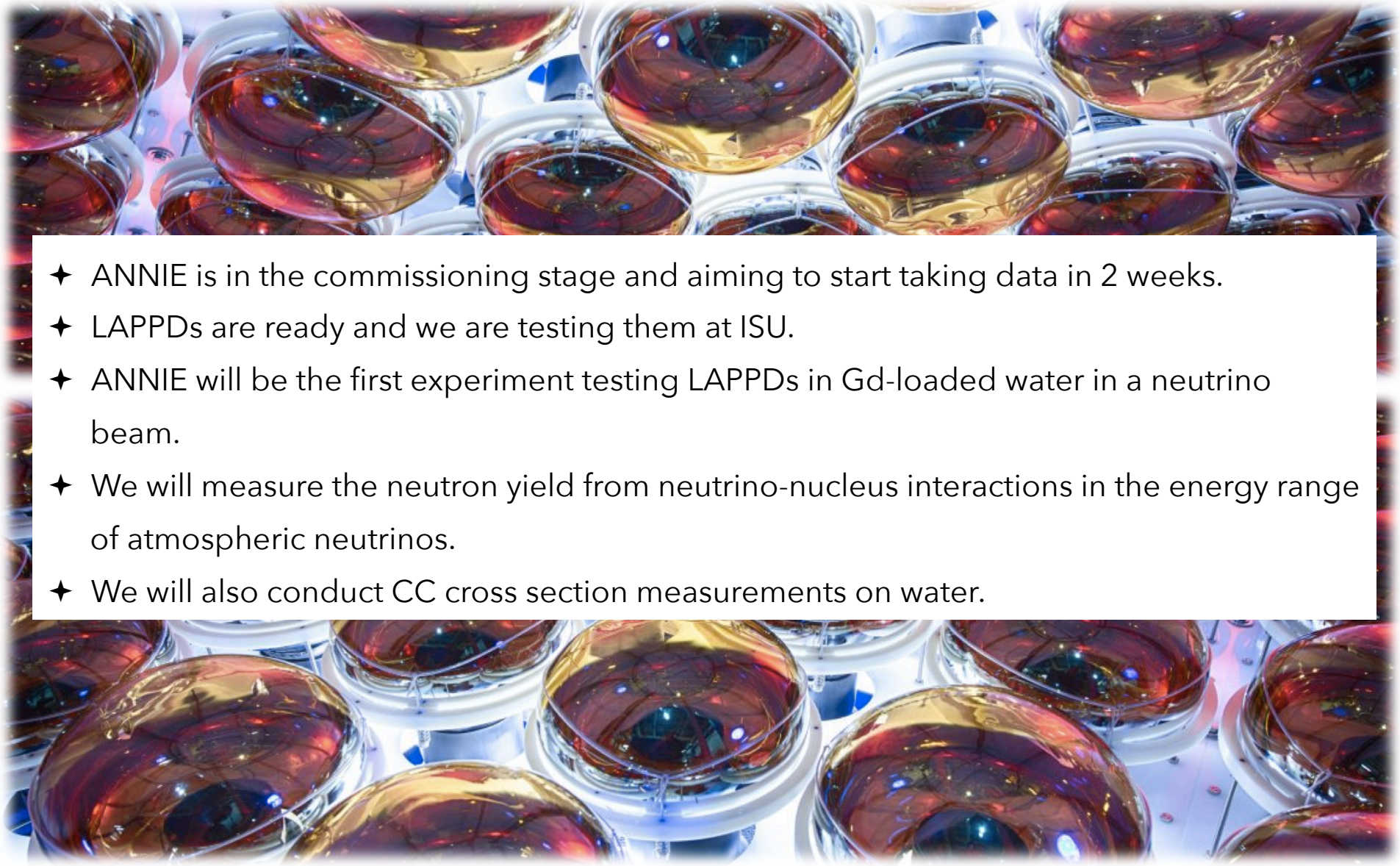


Phase II Detector Construction at DAB





CONCLUSIONS



- ANNIE is in the commissioning stage and aiming to start taking data in 2 weeks.
- LAPPDs are ready and we are testing them at ISU.
- ANNIE will be the first experiment testing LAPPDs in Gd-loaded water in a neutrino beam.
- We will measure the neutron yield from neutrino-nucleus interactions in the energy range of atmospheric neutrinos.
- We will also conduct CC cross section measurements on water.

BACKUP SLIDES

Neutron capture by Gd vs H

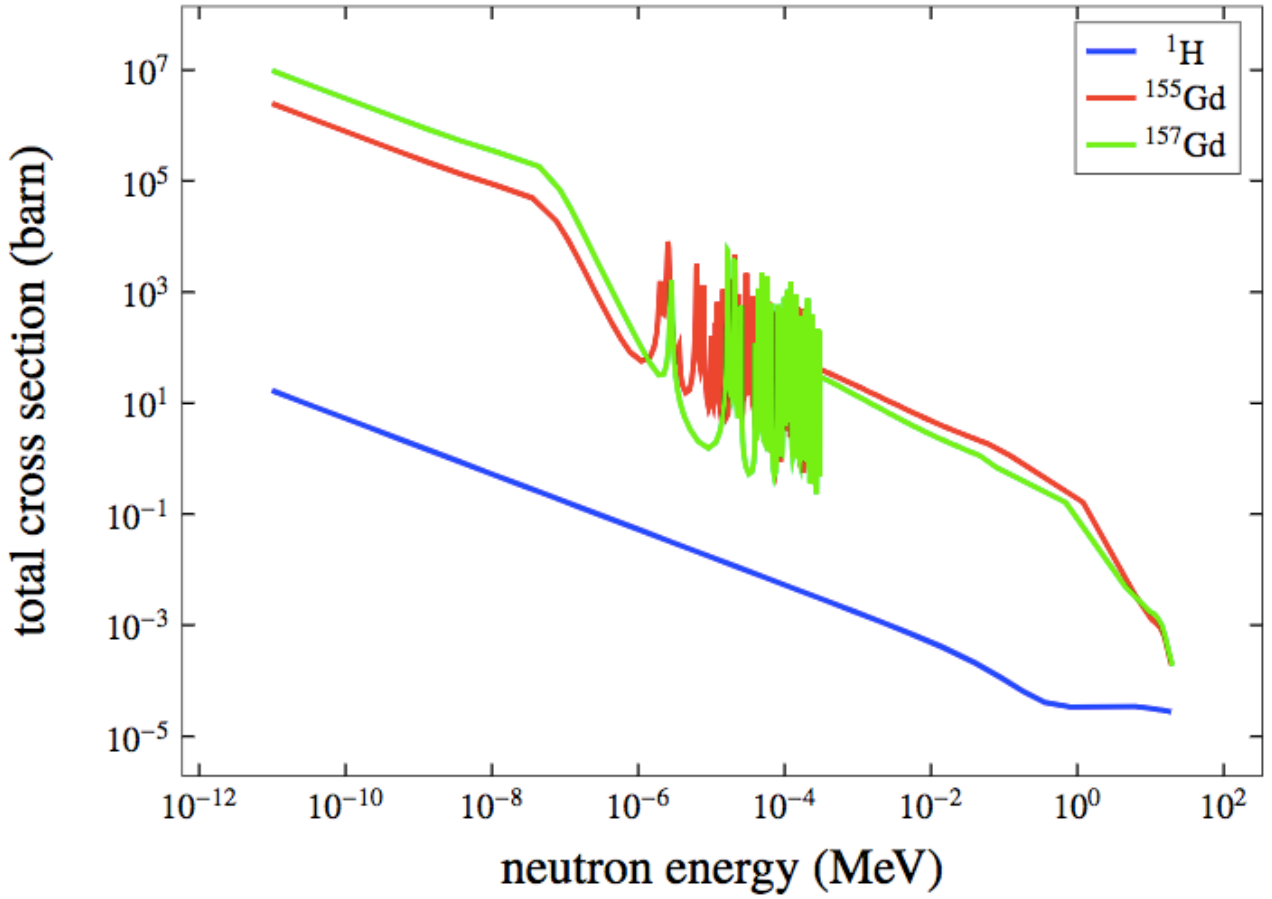
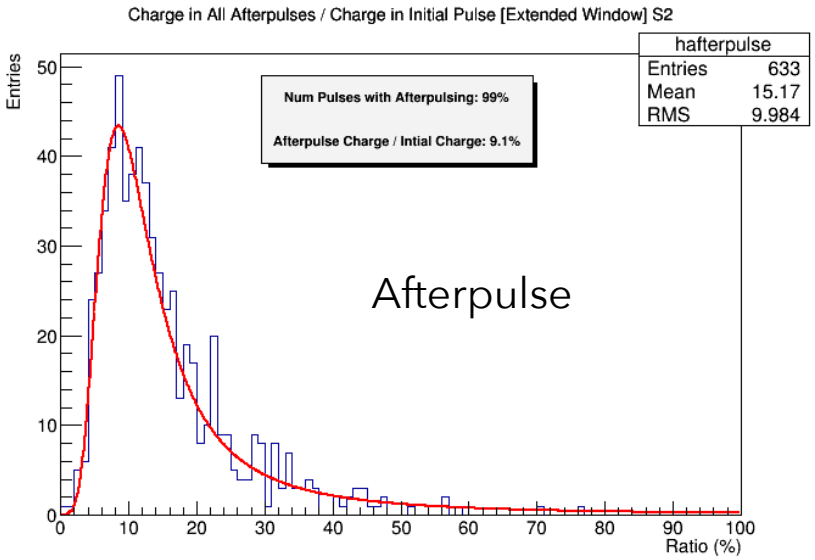
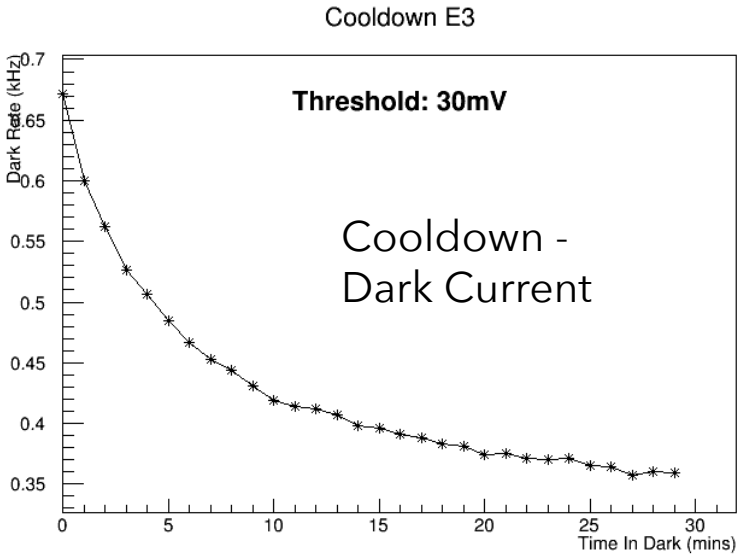


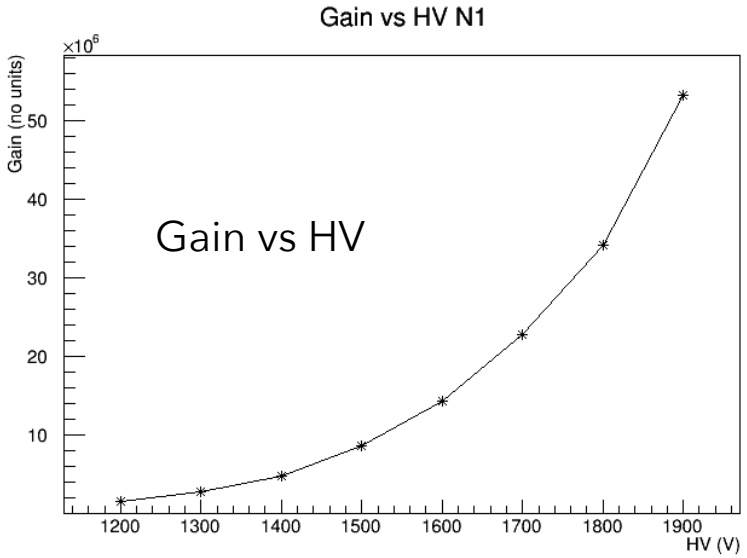
Figure 1. The neutron capture cross sections as a function of energy for two of the most abundant isotopes of Gd, compared with the capture cross section of ^{1}H (from ENDF/B-VIII.0 [3])

PMT Test Results

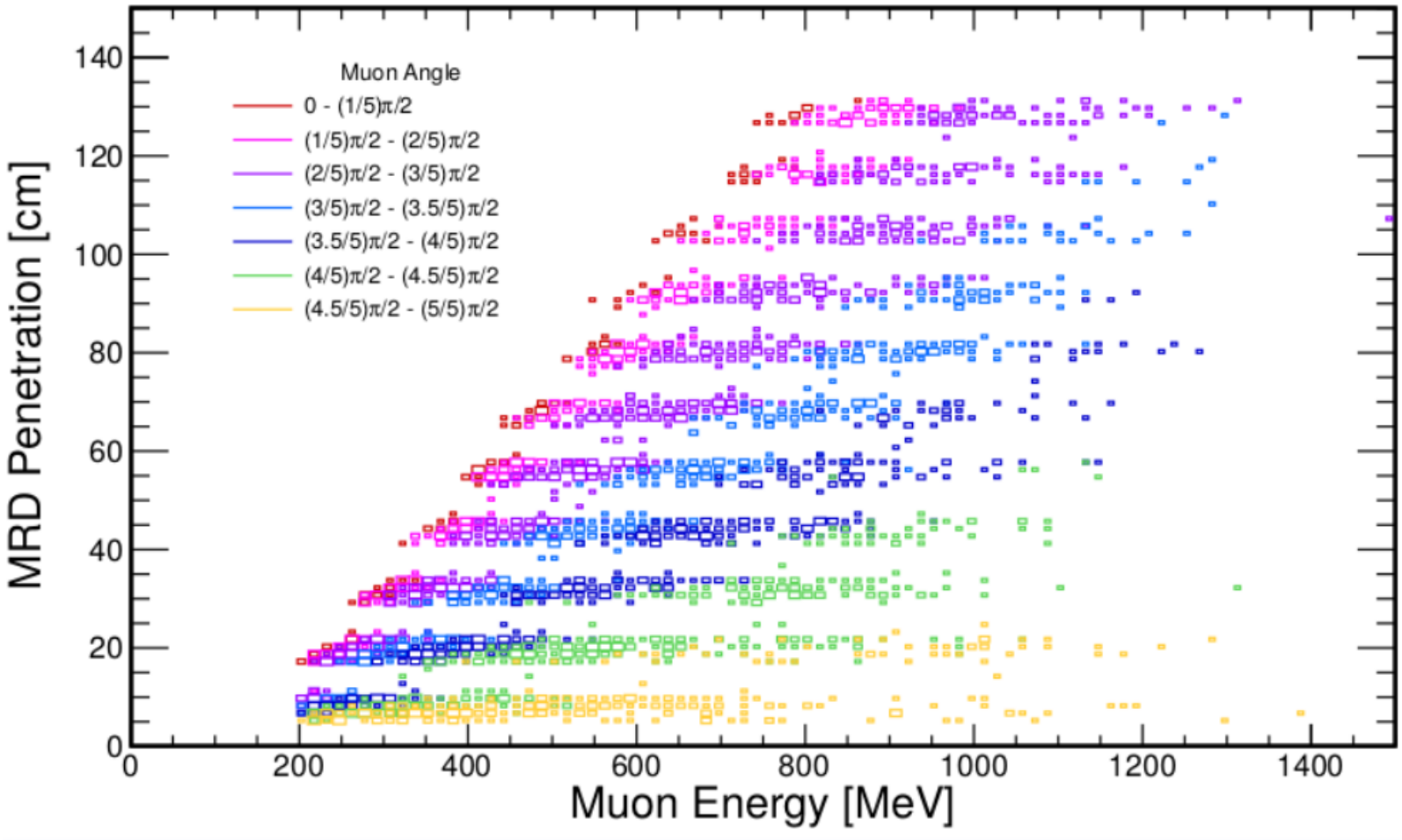


Test results of some of the 10 inch PMTs.





MRD Simulation



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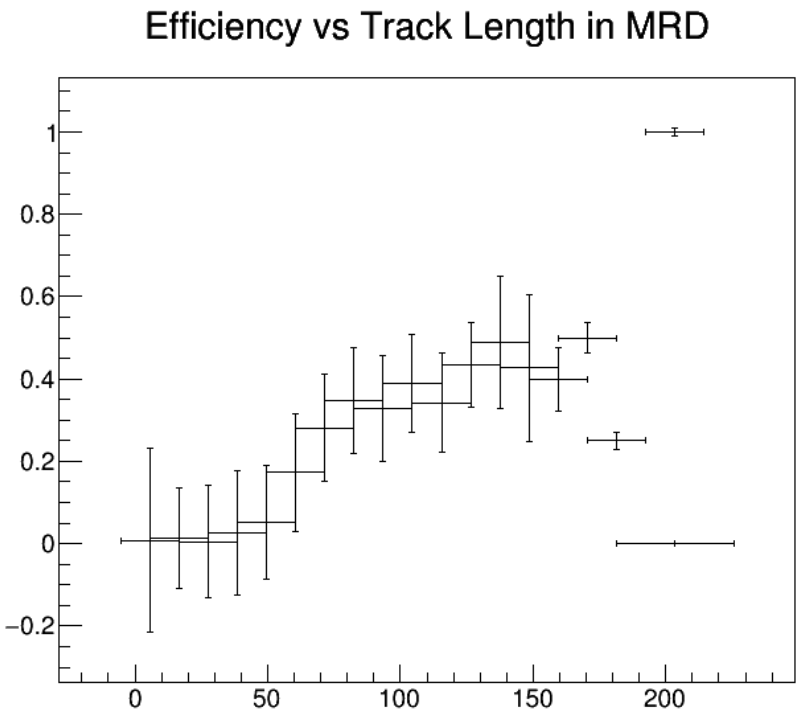
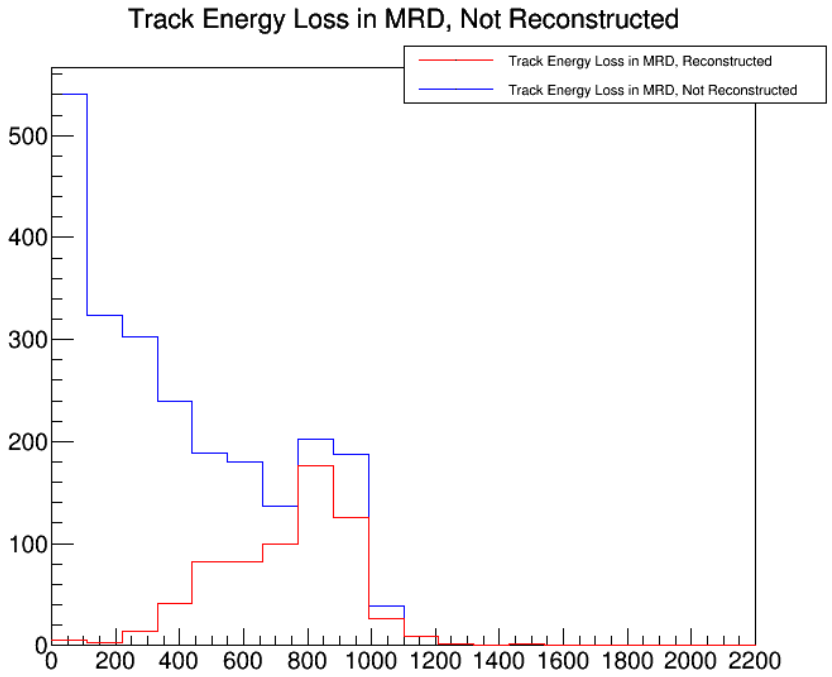


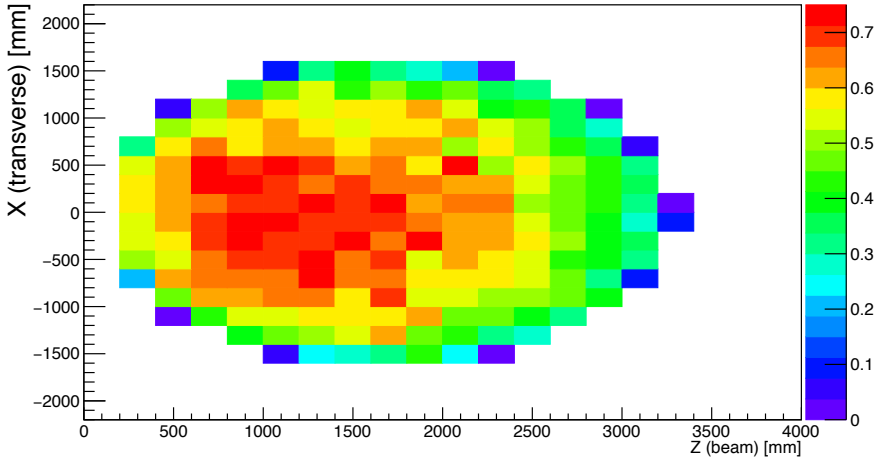


Phase II Simulations

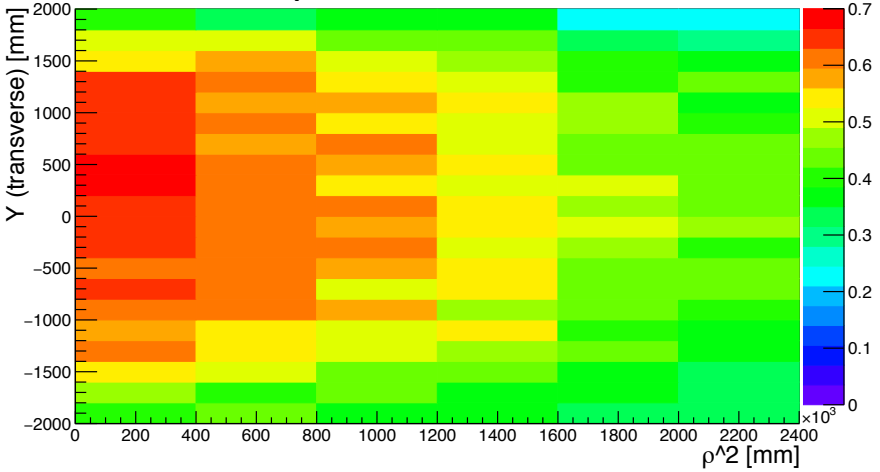
Neutron Detection Efficiency

- Neutron detection efficiency as a function of the interaction position in X (the transverse direction) and Z (the beam direction)

5 p.e. threshold



5 p.e. threshold

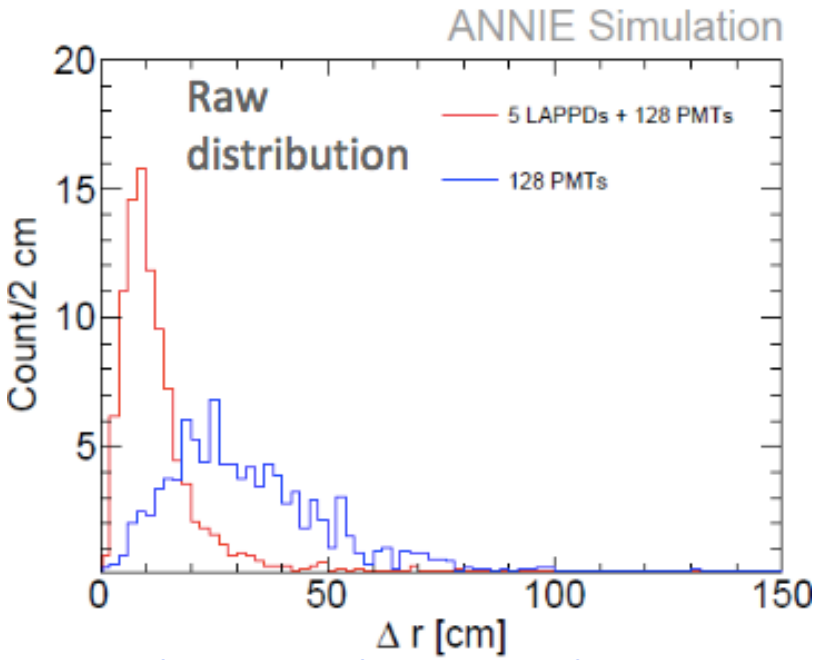


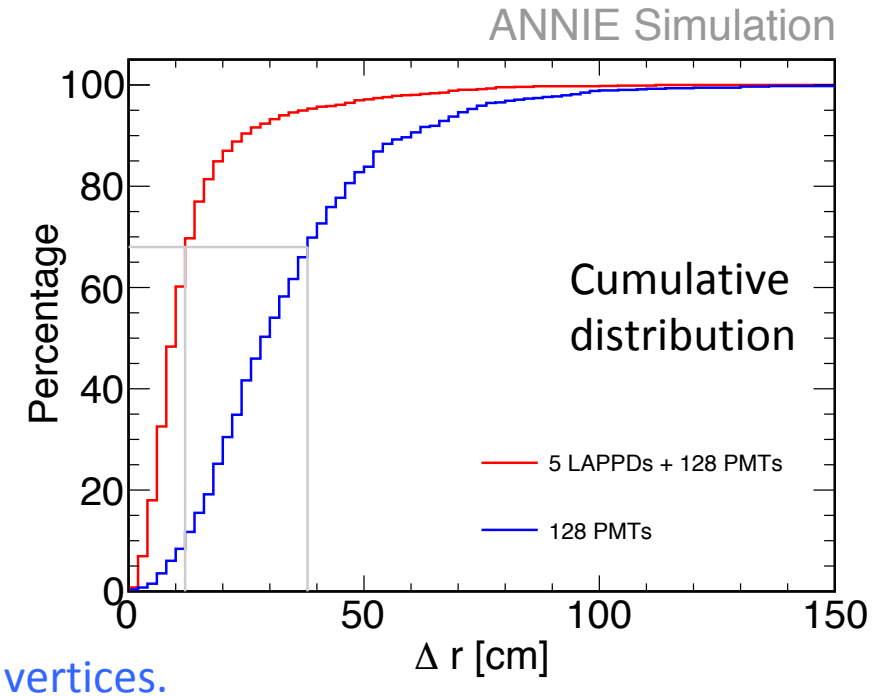
- The detector is large enough to fully contain neutrons
- Requested PMT coverage is sufficient to efficiently detect neutrons.

Phase II Simulations

Vertex Reconstruction and Fiducialisation

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





Distance between the true and reconstructed vertices.

128 conventional PMTs (20%)	: 38 cm resolution
5 LAPPDs +128 PMTs	: 12 cm resolution (more than a factor of 3)