PROCEEDINGS OF SCIENCE

First results from the LAPPDs in ANNIE

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The Accelerator Neutrino Neutron Interaction Experiment (ANNIE) is a 26-ton gadolinium-doped water Cherenkov detector with a submerged water-based liquid scintillator filled vessel. It is on-axis of the Booster Neutrino Beam (BNB) at Fermilab, and its main physics goal is to measure the neutrino cross-section which will improve the systematic uncertainties of next-generation long-baseline neutrino experiments. The first such measurement will be the final state neutron multiplicity of neutrino-nucleus interactions in water. ANNIE is also the first large-scale high energy physics experiment to deploy multiple Large Area Picosecond Photodetectors (LAPPD), a novel photon detector technology with a timing resolution of <100 ps and a sub-centimeter spatial resolution which will help to improve the vertex reconstruction. This work will give an update on the status of the LAPPD deployment as well as first results from neutrino beam induced events recorded by the LAPPDs.

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1. The ANNIE Experiment

The Accelerator Neutrino Neutron Interaction Experiment (ANNIE) is a 26-ton gadolinium doped water Cherenkov detector on-axis of the Booster Neutrino Beam (BNB) at Fermilab in the USA. The main detector setup, as seen in figure 1 consists of a Front Muon Veto (FMV) to tag muons created upstream in the dirt in front of the tank. Next is a cylindrical tank (4 m high and 3 m in diameter) filled with high purity water loaded with gadolinium sulfate $Gd_2(SO_4)_3$ and instrumented with 132 photomultiplier tubes (PMT) and 5 LAPPDs. Last is a Muon-Range-Detector (MRD), a sandwich of iron and scintillator plates to detect muons leaving the tank by energy deposition in the plates. Additionally the tank currently also holds a 365 kg acrylic vessel filled with water-based liquid scintillator (WbLS).

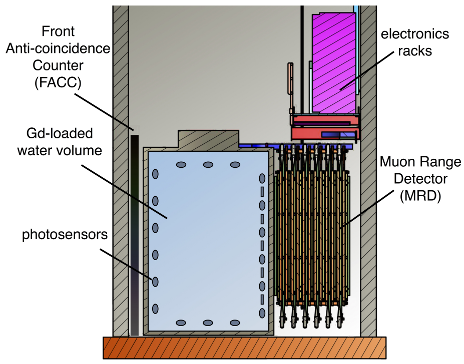

Figure 1: Schematic representation of the ANNIE detector setup. [1]

ANNIE aims to measure the neutrino cross-section in water which will improve the systematic uncertainties of next-generation long-baseline neutrino experiments. To do so, ANNIE measures the final state neutron multiplicity of neutrino-nucleus interactions in water. It will also improve the understanding of backgrounds for Diffuse Supernova Neutrino Background (DSNB) and atmospheric proton decay searches.

2. Large Area Picosecond Photodetectors

The Large Area Picosecond Photodetector (LAPPD) is a novel photo detector technology that uses two micro-channel plates (MCPs) to amplify the photoelectron signal. It offers a timing resolution of about 60 ps and a sub-centimeter spatial resolution while having an active photosensitive area of 20×20 cm. Figure 2 shows the schematic setup on the left side while the LAPPD as deployment-ready module is shown on the right side.

A LAPPD works on the same principle as conventional PMTs. A photon creates a primary electron in the cathode, which is then multiplied by two layers of MCPs. The MCPs are oriented in different directions to prevent electrons moving straight through. The created electron cascade hits one or more of the strip-anodes. By reading out the signal at both ends of a strip a time difference can be calculated to determine the position in one dimension. Information in the second dimension is given by the position of the strip itself.

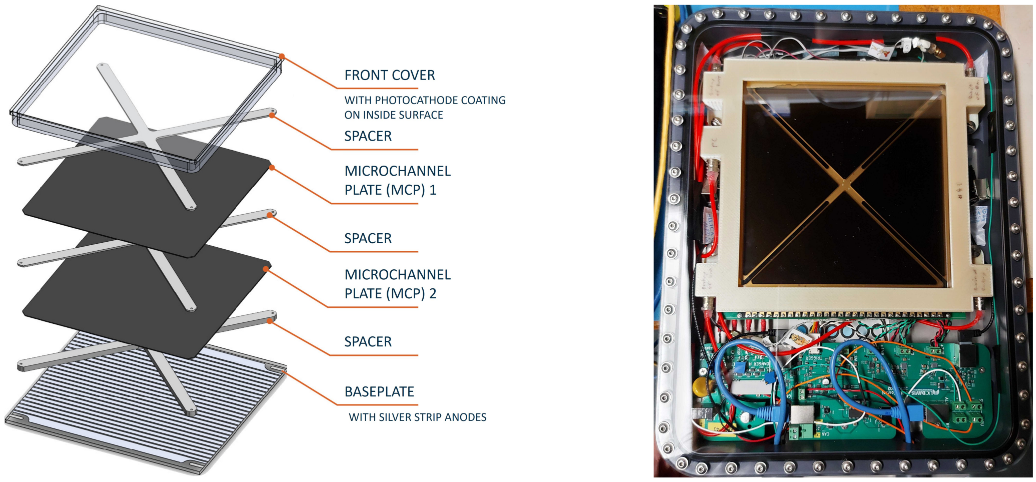

Figure 2: The left picture shows the LAPPD schematic setup. From the top: a boro-silicate glass + cathode cover window, two levels of spacers and MCPs and a baseplate with strip line anodes at the bottom [2]. The right picture shows the complete LAPPD package as used in ANNIE. It contains the LAPPD with its mounted ADCs as well as a slow control board for sensor readout and voltage control.

Due to the excellent timing and spatial resolution, LAPPDs have a large impact on the reconstruction capabilities of ANNIE. By adding five LAPPDs to the already existing PMTs the accuracy of the vertex and direction resolution of reconstructed events can be vastly improved (see figure 3), which in turn allows for a more precise reconstruction of the muon and thus neutrino energy.

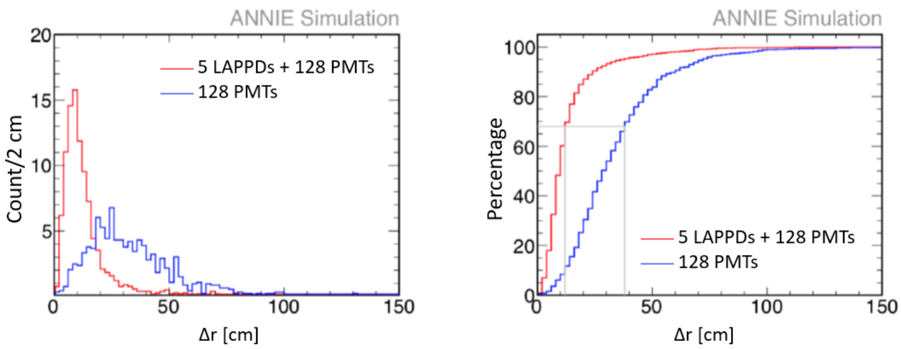

Figure 3: ANNIE simulation for, on the left side, the vertex and on the right side, the direction resolution for reconstructed events with only PMTs (blue) and PMTs and 5 LAPPDs (red). [3]

3. First LAPPD Deployment and Beam Data

The first deployed LAPPD (LAPPD 40, deployed since March '21), as seen in 2 on the right side, delivered the first ever LAPPD beam data. The left plot in figure 4 shows the distribution for the time difference between the beam acquisition window start and the event timestamp. A clear excess of events can be seen with a FWHM of 1.6 μs, which coincides with the BNB beam window. It can thus be concluded that the LAPPD sees light from events induced by the neutrino beam.
Strip multiplicity (seen in the right plot in figure 4) is defined as the number of LAPPD strips with

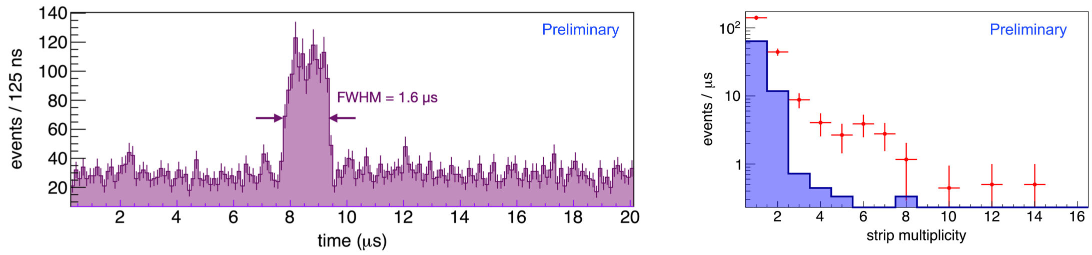

Figure 4: The left plot shows the event time distribution from the LAPPD. Shown is the time from the beam acquisition window start to the event timestamp. An excess of events with a FWHM of 1.6 μs can be seen, which matches the BNB beam window. The right plot shows the strip multiplicity with the rate normalized to events/μs for on-beam data (red) and off-beam data (blue).

signal over threshold, the rate is normalized to events/μs. The blue bars show strip multiplicity for off-beam time, the red data points show on-beam data. In comparison, all multiplicities show a higher value during beam-on times with higher multiplicities being significantly more frequent.

4. First deployment of multiple LAPPDs

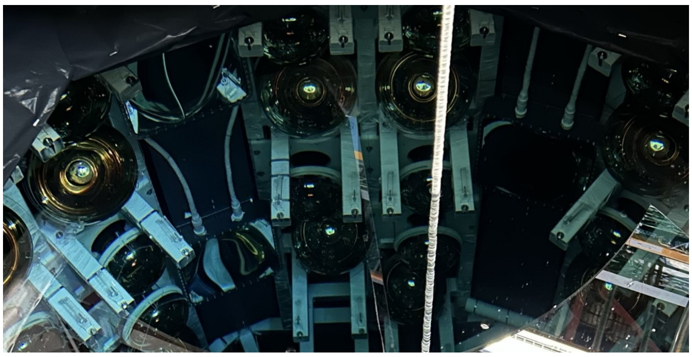

Figure 5: Inside view of the ANNIE tank. All deployed LAPPDs as well as some of the mounted PMTs can be seen.

Since the start of 2023 two more LAPPDs (LAPPD 63 and 64) have been deployed. They as well as LAPPD 40 can be seen within the ANNIE tank in figure 5. After the successful deployment and commissioning, the first beam data with multiple LAPPDs was already taken and the analysis of the data is ongoing. The preparations for the deployment of the last two LAPPDs are underway.

References

[1] A. R. Back et al., *Accelerator Neutrino Neutron Interaction Experiment (ANNIE): Preliminary Results and Physics Phase Proposal*. 2017. arXiv:1707.08222 [physics.ins-det].

[2] *LAPPD - Large Area Picosecond Photodetectors schematic setup* . Accessed on 23.10.2023.

[3] E. Drakopoulou, *ANNIE Phase II Reconstruction Techniques*. 2018. arXiv:1803.10624 [physics.ins-det].