August 12, 2022

LAPPD Performance Analysis for the ANNIE Experiment

James Morrissette, Undergraduate at Iowa State University

Abstract

The Large Area Picosecond Photodetectors (LAPPDs) are intended to provide ANNIE with spatial information on the multitude of Photoelectron (PE) hits that come from neutrino-nucleus interactions in the detector tank. In order to provide multiplicity and the spatial timing information of these hits, the response for the collision of a single PE and the LAPPD is needed. Calibration data of LAPPD 40 and 25, the later being the control, from the dark box was reanalyzed using a branch of ToolAnalysis and '*Ampfit',* a custom ROOT script. From this analysis it was determined that LAPPD 40 has a significantly lower gain than LAPPD 25, making the single PE response from LAPPD 40 less defined.

Introduction

The Accelerator Neutrino Neutron Interaction Experiment (ANNIE) is a water Cherenkov neutrino experiment that seeks to better understand neutrino-nucleus interactions and demonstrate new technologies such as Large Area Picosecond Photodetectors (LAPPDs) and Gadolinium-enhanced water. *Figure 1* shows an LAPPD module this and all other figures can be found in the appendix.

Neutrinos from the Booster Neutrino Beam (BNB) are directed into a 26-ton water-based neutrino detector. The beam passes through a Front Muon Veto designed to reject neutrino interactions outside of the water target. Neutrinos can interact with the atoms inside the water volume. These interactions will generate muons which will produce Cherenkov light. That light could be used to backtrack to where the collision happened, which will shed light on the energy of that interaction. The muons will continue on into the Muon Range Detector, which will discern the energy of the exiting muon depending on the distance it penetrates into the steel.

The inside of the 10 ft (diameter) X 13 ft (height) cylindrical tank is lined with 132 conventional photomultiplier tubes with diameters 8 in or 10 in as seen in *Figures 2* and 3, and along the vertices are configurable LAPPD rails. This photodetector array will account for the light produced from neutrino-nucleus interactions and provide the data needed to create the tracks back to the original interaction point.

Neutrons from the interaction lose energy by scattering in the water volume until they are captured by Gadolinium 157 and 159 in the 0.1% Gd-loaded water. In this solution, neutron capture is ~90% more efficient. The neutrino-nucleus interaction causes neutrons to be ejected from the nuclei and will be captured by one of the Gadolinium atoms in ~30μs(Beacom and Vagins). This capture will emit about ~8MeV delayed gamma cascade which is detectable by the photosensors.

Motivation

One of the primary goals of this experiment is to provide a first demonstration of LAPPDs in a neutrino experiment. They will provide high resolution time and spatial information on the multitude of photons detected during a single event. In order to provide multiplicity and the spatial timing information of these hits, the LAPPD response to a single PE is needed.

When a photon collides with a LAPPD, the photon momentum will be absorbed by the photocathode and eject an electron, which is amplified by the "avalanche effect" in the microchannel plates and converted into a voltage signal. Where the maximum amplitude will be what is considered the "response" from the PE.

Ideally, one would want to make calibration measurements and build an understanding of the single PE LAPPD response *in situ.* However, two barriers prevent that possibility: The first is that the trigger threshold is too high to resolve individual photons from the detector's laser system. Secondly, typical neutrino events can produce many hundreds of photons which would overshadow the smaller signals of the single PE. Thus, this study seeks to understand the LAPPD performance from older test-bench data taken with an unbiased trigger, recording data whether or not the LAPPD produced a response.

Methodology

Single PE response can be determined most straightforwardly using calibration data from the dark box. The dark box as seen in *Figure 4*, is an enclosure to hold the LAPPD and prevent outside light from entering. This allows us to illuminate the LAPPD with single photons. The LAPPD was calibrated using a PiLAS pulsed laser. Two LAPPD modules were tested. LAPPD 40 which was tested December 2020 and is currently deployed; and LAPPD 25 which was tested February 2021, and is currently not deployed. LAPPD 40 was tested at 1000 V - 1000 V and 975 V - 975 V, and 25 was tested at 950 V - 850 V and 950 V - 950 V. An example diagram of a PE hit is shown in *Figure 5*.

The data was processed using the LAPPDana ToolChain in ToolAnalysis, which is available in github (Richards). Tool analysis searches for LAPPD signals as seen in *Figure 6* and measures the maximum amplitude of each pulse which stores it in a ROOT tree.

A histogram of the amplitude distribution was made from the tree and saved in a ROOT file. A script was coauthored that fits the distribution to functionally follow the format of *Figure 7*. This format fits the background noise to a landau curve and gaussian curves representing the PE peaks. These peaks will progressively get wider with increasing multiplicity due to being less likely and have larger voltage amplitude signals. This script is detailed in the appendix.

Conclusions and future work

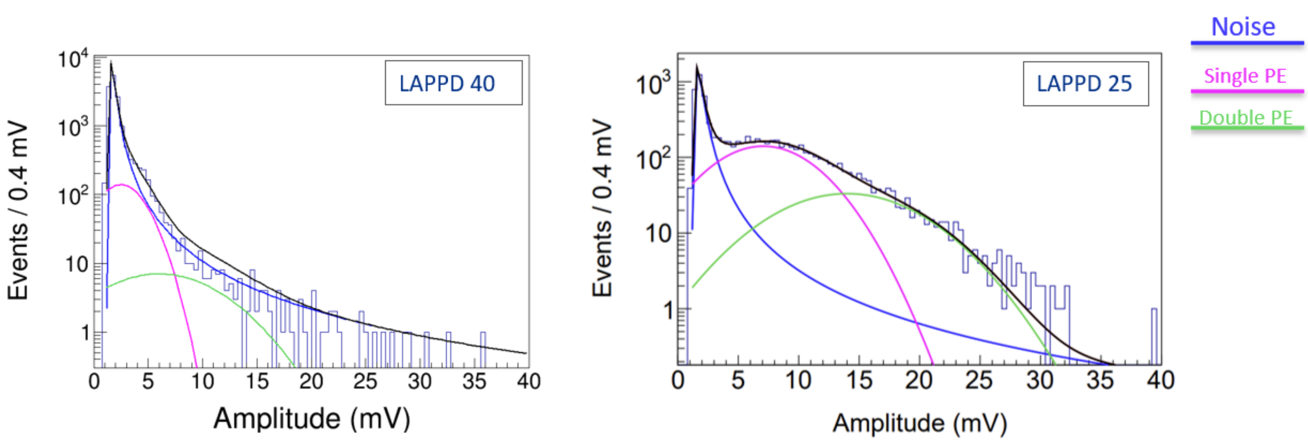


Figure 8 Histograms of Both LAPPD 40 and 25data after being processed with AmpFit.

The AmpFit script was able to generate the two histograms above with additional graphs listed in the appendix under the “Histogram” section. AmpFit was able to clarify that both LAPPDs experienced a similar number of single PE signals and that LAPPD 25 was able to see a larger number of double PE signals. Furthermore it is easy to see that both the single and double PE peaks for LAPPD 25 appeared at larger amplitudes than what was shown from LAPPD 40. This lack of definition communicates that LAPPD 40 has a lower gain than LAPPD 25. The issue could stem from the data between the two LAPPDs being taken at different voltages, potentially signifying that one of the microchannel plate amplifiers inside of LAPPD 40 is faulty.

In the near future, this work should be repeated on other LAPPDs at varying operational voltages to create a better understanding of the overall response of the single PE peak. Once that is completed, the single PE response fits should be implemented into the LAPPD simulations. It should be verified that the simulations reproduce what is seen in data for large signal events.

Acknowledgments

I wish to express my gratitude to my supervisor Matthew Wetstein, for his patience and guidance and to Carrie McGivern for her support throughout this internship. I would also like to thank The ANNIE Collaboration, namely Yue Feng, Marvin Ascenio, Julie He, and also Emily Pottebaum. Additionally, I would like to thank Spencer Pasero and Cortez L. Watkins for encouraging me to apply for this internship. Finally, big thanks to the SIST committee, Fermilab, and Iowa State University for creating a space for this opportunity.

References

1. Beacom, John F., and Mark R. Vagins. “Antineutrino Spectroscopy with Large Water Čerenkov Detectors.” *Physical Review Letters*, vol. 93, no. 17, 2004, https://doi.org/10.1103/physrevlett.93.171101.

2. Richards, Benjamin. “ToolAnalysis.” *Github*, 2018, https://github.com/marvlad/ToolAnalysis. Accessed 10 Aug. 2022.

Appendix

Ampfit

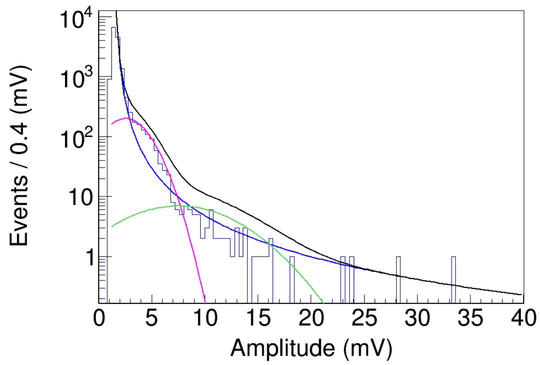
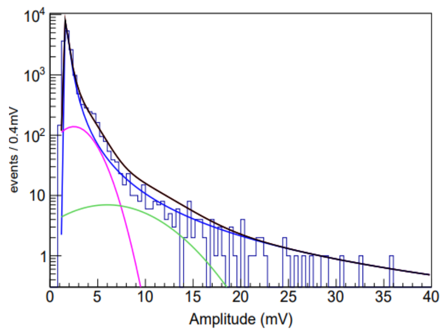
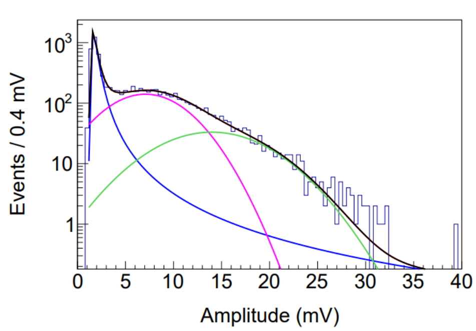
C++ code. Comments describe what the code is doing. This is a snapshot of the specific version used to fit the data from LAPPD 40 being tested at an operational voltage of 975V - 975V.
Please note that the script is written in text and is not a screenshot.

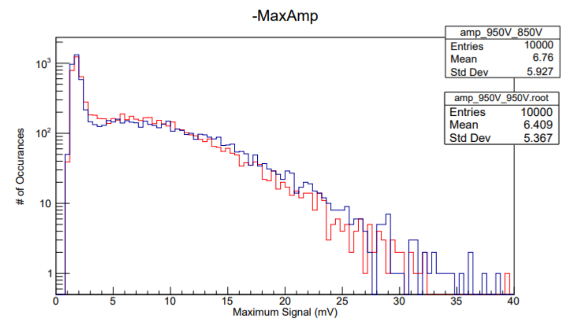
```
/*
blue - the landau distribution  of
pink - the single PE peak
green - double PE
red -triple PE
black - Sum of all the previous curves
*/

double AmpFit()
    {
// this section imports the histograms that were made using the -MaxAmp
tool

        TFile* tf = new
TFile("LAPPD40_975V_975V/amp_975V_975V.root","READ");
        TH1D* timehist = (TH1D*) tf->Get("amp_975V_975V");
        timehist->Draw();


// this section applies guesses to the height, mean and width of the
curves. This and the following sections can be repeated for additional PE
peak multiplicities.

        TF1* mydgaus = new
TF1("mydgaus","landau(0)+gaus(3)+gaus(6)",1,40); //1,15 is a fit range
      //blue, represents
      mydgaus->SetParameter(0,1.06236e4);
      mydgaus->SetParameter(1,1.486);
        mydgaus->SetParameter(2,0.469e-1);
        //pink 1 pe
      mydgaus->SetParameter(3,2e2);//height
      mydgaus->SetParameter(4,3.5);// mean
```

```
        mydgaus->SetParameter(5,2.5);//width
        //green 2 pe
        mydgaus->SetParameter(6,12.0);
      mydgaus->SetParameter(7,5.0);
        mydgaus->SetParameter(8,5.0);
        //red

//this section applies limits to the height, width and mean of the curves

      Parameter limits
        mydgaus->SetParLimits(3,100,4.5e2);//pink
        mydgaus->SetParLimits(4,2.5,6.0);
        mydgaus->SetParLimits(5,2.0,4.0);

        mydgaus->SetParLimits(6,7,15);//green
        mydgaus->SetParLimits(7,6.0,9.0);
        mydgaus->SetParLimits(8,5.0,10.0);

//This section groups the parameters and makes the fit

      timehist->Fit("mydgaus","","",1,40);
        //blue
        TF1* mysgaus1 = new TF1("mysgaus1","landau",1,40);
      mysgaus1->SetParameter(0,(mydgaus->GetParameter(0)));
      mysgaus1->SetParameter(1,(mydgaus->GetParameter(1)));
      mysgaus1->SetParameter(2,(mydgaus->GetParameter(2)));
        //pink
        TF1* mysgaus2 = new TF1("mysgaus2","gaus",1,40);
      mysgaus2->SetParameter(0,(mydgaus->GetParameter(3)));
      mysgaus2->SetParameter(1,(mydgaus->GetParameter(4)));
      mysgaus2->SetParameter(2,(mydgaus->GetParameter(5)));
        //green

        TF1* mysgaus3 = new TF1("mysgaus3","gaus",1,40);
      mysgaus3->SetParameter(0,(mydgaus->GetParameter(6)));
      mysgaus3->SetParameter(1,(mydgaus->GetParameter(7)));
      mysgaus3->SetParameter(2,(mydgaus->GetParameter(8)));

        //red
```

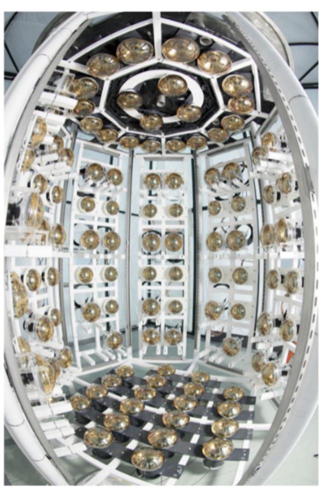
```
        //black
        TF1* mydgaus2 = new

TF1("mydgaus2","landau(0)+gaus(3)+gaus(6)",1,40);
      mydgaus2->SetParameter(0,(mydgaus->GetParameter(0))); //
      mydgaus2->SetParameter(1,(mydgaus->GetParameter(1)));
      mydgaus2->SetParameter(2,(mydgaus->GetParameter(2)));
      mydgaus2->SetParameter(3,(mydgaus->GetParameter(3)));
      mydgaus2->SetParameter(4,(mydgaus->GetParameter(4)));
      mydgaus2->SetParameter(5,(mydgaus->GetParameter(5)));


        mydgaus2->SetParameter(6,(mydgaus->GetParameter(6)));
        mydgaus2->SetParameter(7,(mydgaus->GetParameter(7)));
        mydgaus2->SetParameter(8,(mydgaus->GetParameter(8)));
/*      mydgaus2->SetParameter(9,(mydgaus->GetParameter(9)));
        mydgaus2->SetParameter(10,(mydgaus->GetParameter(10)));
        mydgaus2->SetParameter(11,(mydgaus->GetParameter(11)));
*/

//the section below draws each of the lines
      mysgaus1->SetLineColor(4); // blue
      mysgaus1->Draw("SAME");
      mysgaus2->SetLineColor(6); // pink
      mysgaus2->Draw("SAME");
      mysgaus3->SetLineColor(8); // green
      mysgaus3->Draw("SAME");
      mydgaus2->SetLineColor(1); // black
      mydgaus2->Draw("SAME");
```

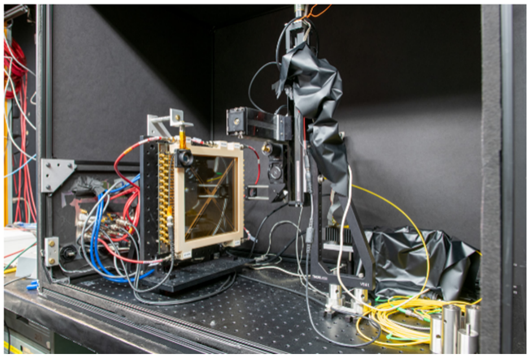
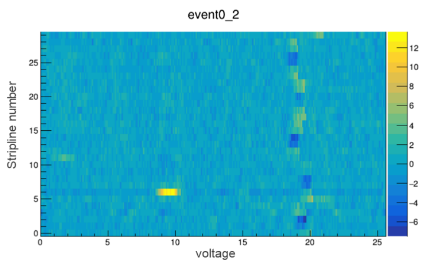
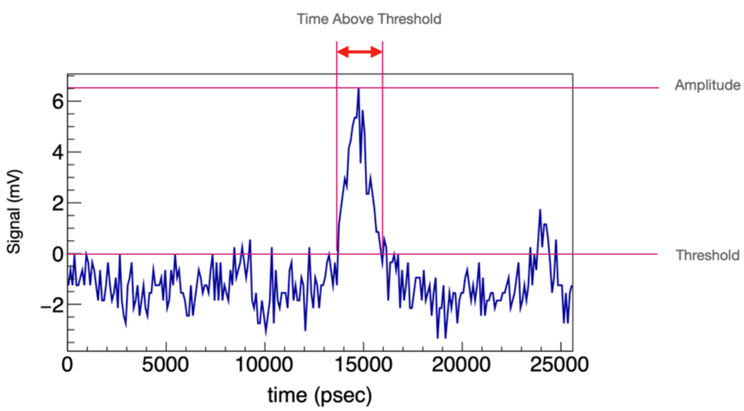
Histograms

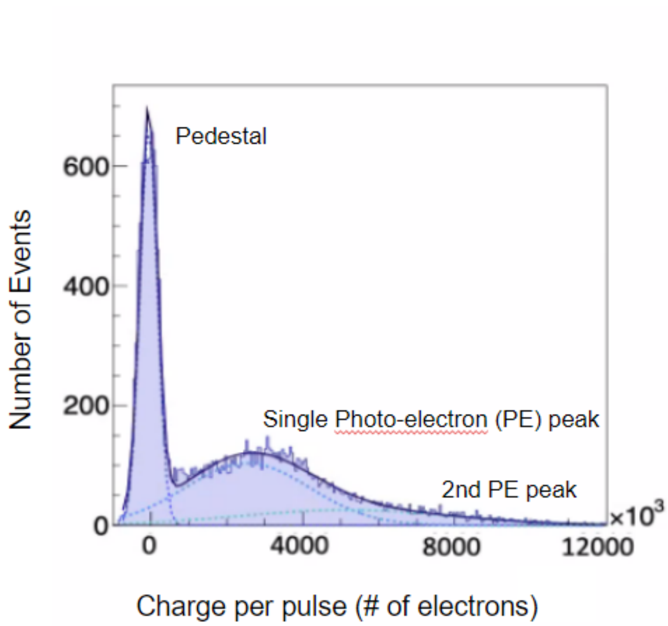
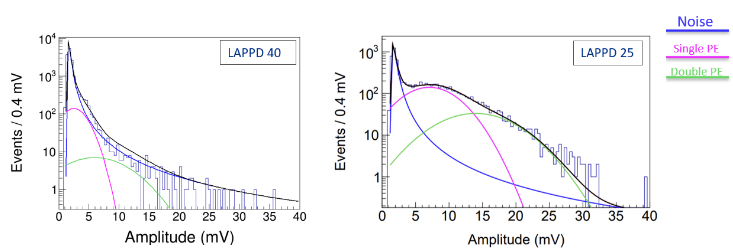
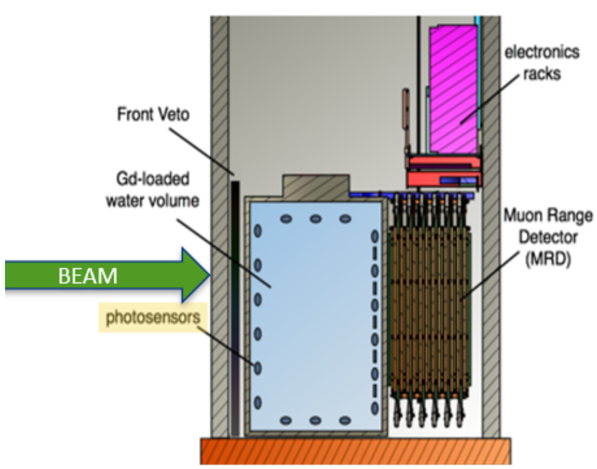
LAPPD #, operational V	Histogram	Description
40, set at 975 V - 975V		the single PE mean is 2.5 mV and the width of the curve from mean to x intercept is 2 mV.
40, set at 1000 V - 1000 V		The mean of the single PE is 2.5 mV and the width of curve from median to x intercept is 2mV.
25, set at 950 V - 950 V		Representative of both 950 V - 950 V and 950 V - 850 V due to close similarities. The mean of LAPPD 25 at 950 V - 950 V is 7.24158 mV and the width from the mean to the x-intercept being 3.76883 mV.

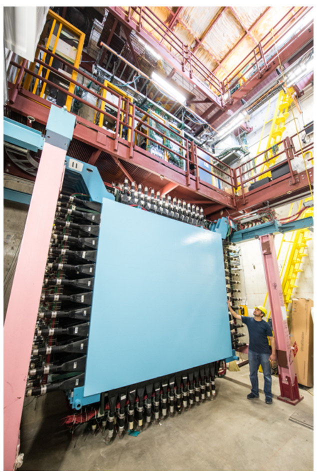
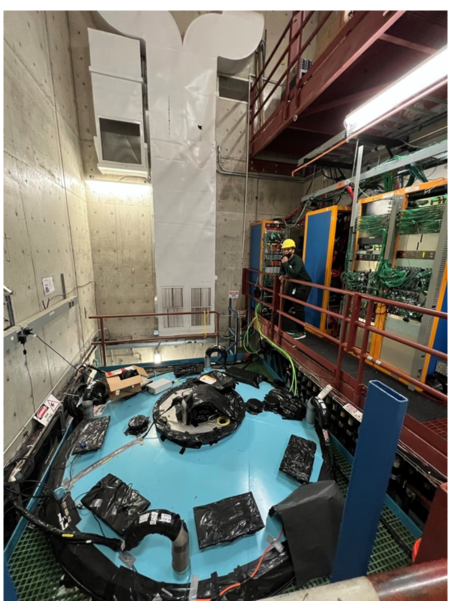
Overlay of 25, set at 950 V - 950 V (Red) and 950 V - 850 V (blue)		Close similarities caused concerns that the voltage was not actually changed during data collection.

Pictures

	Figure	Description
1		Inside look at empty tank.
2		LAPPD inside a waterproof housing unit.
3		Fisheye view of the empty tank.

4		An LAPPD in the darkbox with an open cover.
5		This spatial diagram is created from the voltage response from a PE peak and correlating that response to a stripline number.
6		A typical voltage signal response from LAPPD after a PE hit.

<table>
<tr>
<td>7</td>
<td>
</td>
<td>AmpFit was written to fit histograms of the LAPPD signal response to the PE peaks. Generically these histograms follow the same anatomy depicted in this graph. Where the pedestal peak accounts for how much background noise there was and the following peaks are multiplicities of the Single PE peak.</td>
</tr>
<tr>
<td>8</td>
<td>
</td>
<td>Main takeaway is that there is a stark difference in gain between the two LAPPDs based on how across the PE peaks are on the x axis.</td>
</tr>
<tr>
<td>9</td>
<td>
</td>
<td>This schematic of the ANNIE experiment setup depicts the BNB coming in from the left through the front veto.</td>
</tr>
</table>

10		Picture of me by on the lower level of ANNIE. To my right in the back is the water cherenkov detector tank. In front of me is the MRD. Also always wear your helmets!
11		Picture of the MRD before the tank was installed.
12		This is me looking down at the tank from the middle floor.