PROSPECT: Optical Calibration System

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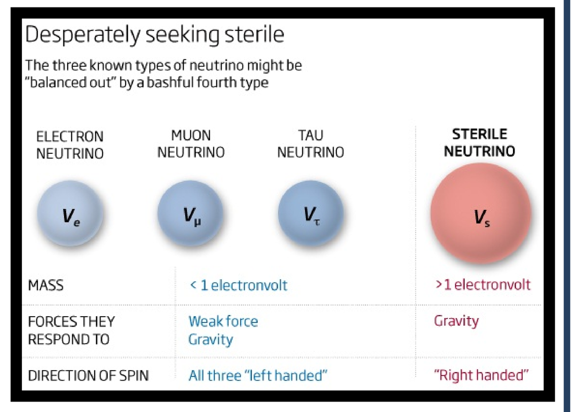
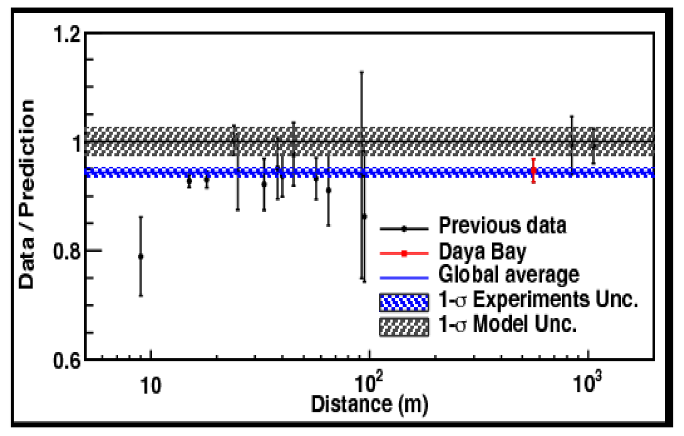
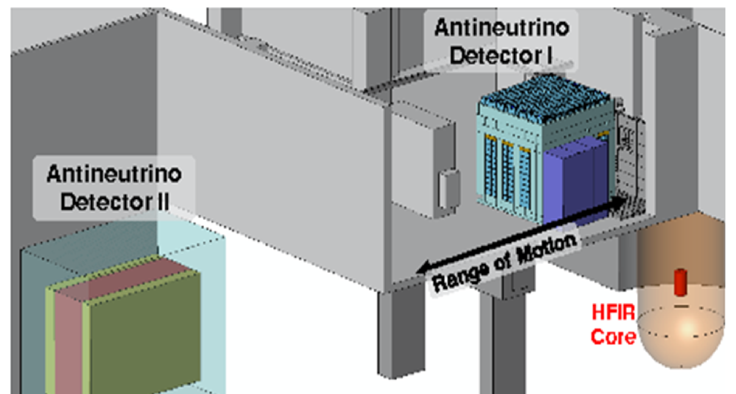
The Precision Reactor Oscillation and SPECTrum Experiment (PROSPECT), is a two phase, short baseline, reactor neutrino experiment that addresses the neutrino flux deficit in pass neutrino experiments [1]. Prospect first phase consists of a mobile detector near the reactor core; the second phase adds a larger detector further away from the core. The PROSPECT Phase 1 detector uses photomultipliers tubes (PMTs) and a segmented designed to detect photons emitted through neutrino interaction, specifically inverse beta decay. Four rectangular reflector panels, held together by pinwheel-like connectors, made up a cell of the detector. In order to accurately calculate the location and energy of neutrino interactions, an Optical Calibration System is developed. The system will generates multiple laser pulses at nanosecond scale, diffused by a modified pinwheel at a fixed distance, that will be picked up by each PMT in the detector. Various of test was performed to determine the effectiveness of a 450nm fiber pigtailed diode laser as it coupled with several modules including an optical fiber splitter, an optical diffusor, and an attenuator. These tests will be evaluate accordingly to eliminate environmental anomalies, to analyze the differences between glass and plastic fiber, and to understand the efficiency of the pinwheel diffuser prior for the unit implementation into PROSPECT's detector.

I. Introduction

- **Neutrinos:**
  - Weak subatomic particles.
  - Comes in tree flavors: electron, muon, and tau neutrinos (Each with their respected antiparticle).
- **Flux and Spectrum:**
  - Measurements of solar neutrino show large deficit - Corrected by the discovery of neutrino oscillation (2015 Nobel Prize).
  - Neutrino flux in nuclear reactors from previous experiment still showed about 5% deficit when taking neutrino oscillation into account.
  - Possibility of a sterile neutrino, which only interact with gravity, or just what we don't quite understand the early reactor physics yet.
- **PROSPECT:**
  - The project proposed a short baseline experiment in attempt to eliminate most of the anomalies.
  - PROSPECT planned to make precise measurement of the antineutrino spectrum at this baseline.

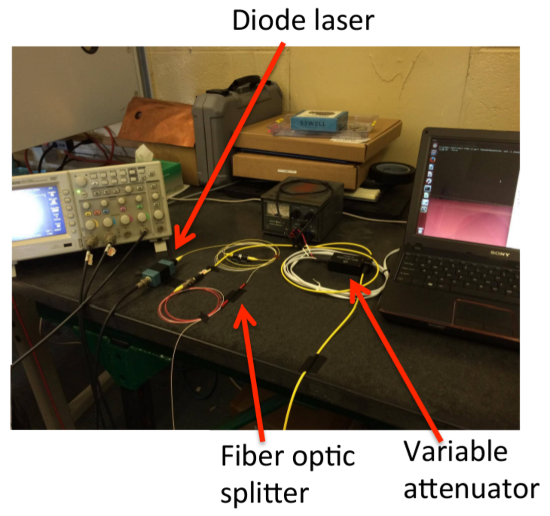


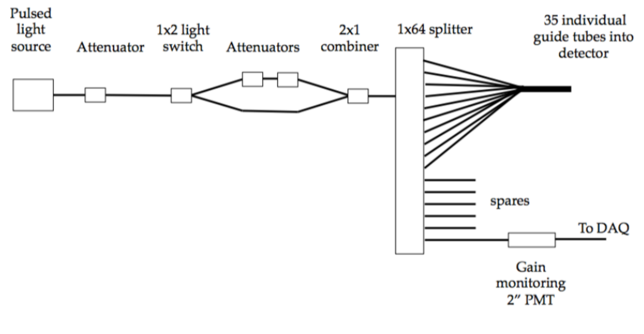




II. System Design

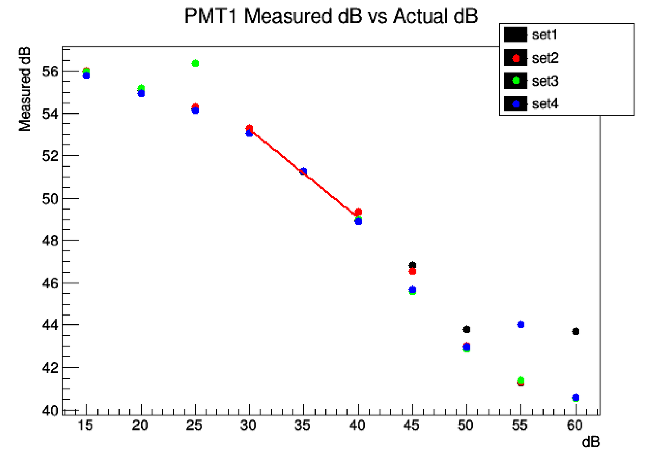
- **The Optical Calibration Unit:**
  - The idea is to prompt a signal at a fixed distance at each cells to compare with neutrino interactions data.
  - A short wavelength laser will be use to sent nanoseconds pulses to each of the cells in the detector.
- **The Prototype:**
  - A short wavelength laser.
  - A custom one by two ports glass fiber splitter.
  - A 3D printed pinwheel diffuser, an attenuator, and two PMTs.

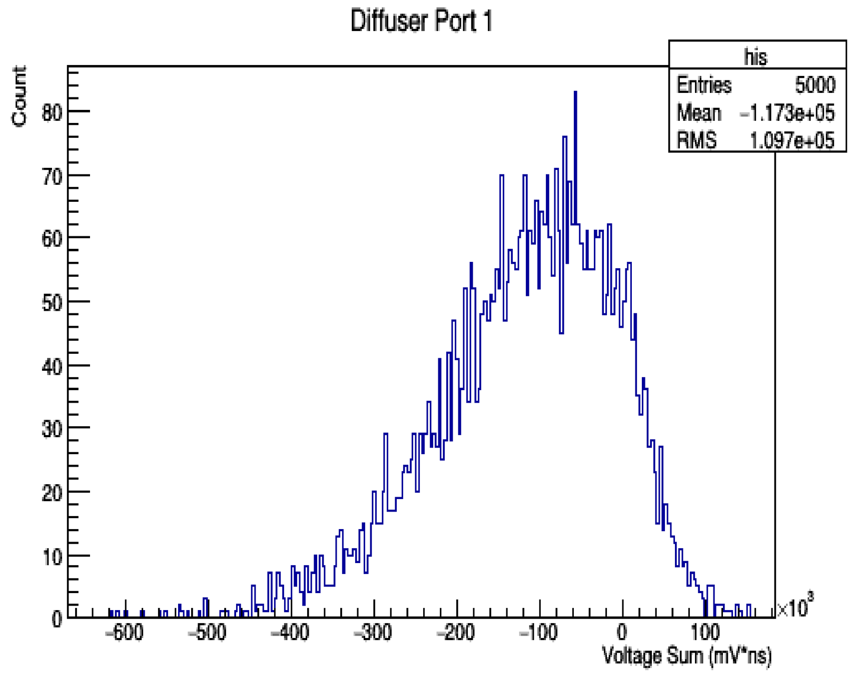




III. Tests and Results

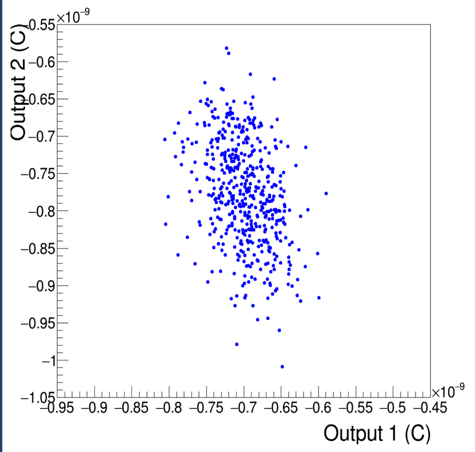
- **Attenuation Test**
  - PMTs can saturate due to too much light input and or background light.
  - An attenuator is use to account and eliminate PMTs saturation.
  - Four different set of data were taken of pulses at different attenuation factor to determine the attenuation range at which the PMTs can operate without showing any sign of saturation.
  - A range from 30 dB to 45 dB is safe to attenuate the laser pulse



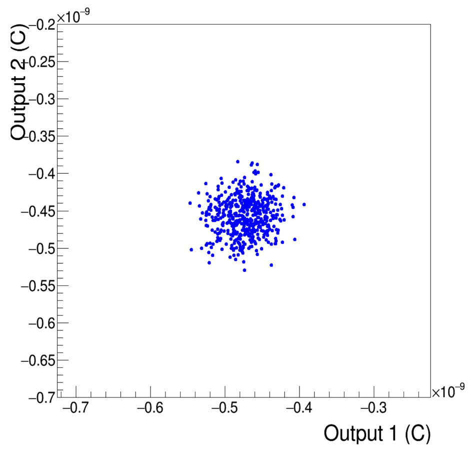


- **A Take on Single Photo-electron Events**
  - Single photo-electron events, SPE, are often use to calibrate PMTs.
  - A small scale SPE test is performed with the prototype to build a framework for the unit.
  - A larger scale SPE will be perform when the system is implement for stability.
  - The integral over these pulses plot shows a peak at about 100 mV*ns.
  - The assumed peak is treated as the charge of a single photo-electron and will be use in future tests.

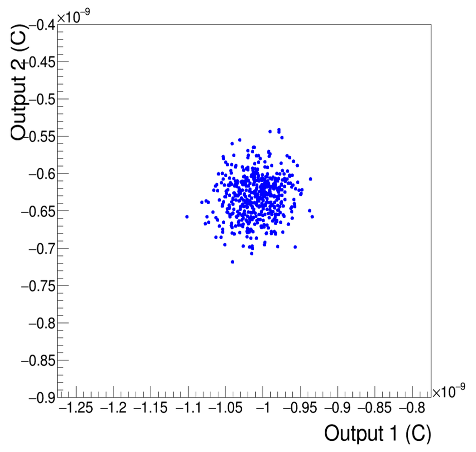
- **Commercial Splitter versus Custom Splitter Test vs Diffuser**
  - Two ports of the commercial splitter are compared with the two ports of the custom splitter and two output of the optical pinwheel connector diffuser.
  - This test's aim is to show the instability of the commercial splitter, verify the stability of the custom splitter, and eliminating unwanted environmental factors.
  - An integral over the pulses of each of the ports from the commercial splitter, custom splitter, and diffuser are taken, converted to the amount of electrical charges via SPE speak mentioned in previous test, and reported as a scatter plot to show a stability spread.



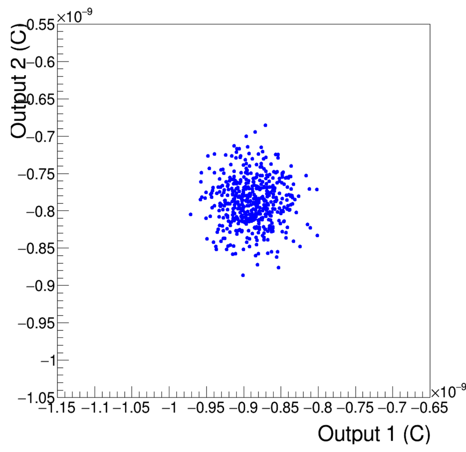
Graph 1: Commercial 1 by 8 Ports Splitter



Graph 2: Custom 1 by 2 Ports Splitter



Graph 3: Diffuser Port 1 vs Port 3



Graph 4: Diffuser Port 2 vs Port 4

- The commercial splitter showed a larger spread between the the two outputs compare to the custom splitter and the diffuser.

- **Fiber Type Testing**
  - The plastic and glass cable were suspected to have different delayed in performance.
  - Charts shows an increase in the pulse rise time and pulse width with increase in distance for both cable.
  - NOTE: Neither of the cable shows a dramatic different.
  - Calculation (shown bellow) of the attenuation factor applied to both cable also shown little to no different in rise time comparison.

Glass Cable (PMT 2) at 5 cm, Plastic Cable (PMT 1) at 2 cm		
Average Value (ns)	Run 1 (ns)	Run 2 (ns)
Glass Rise Time	7.807	7.779
Plastic Rise Time	7.906	7.897
Glass Pulse Width	18.69	18.86
Plastic Pulse Width	17.80	17.81

Both Cables at 5 cm (Plastic PMT 1 and Glass PMT 2)				
Average Value (ns)	Run 1 (ns)	Run 2 (ns)	Run 3 (ns)	Run 4 (ns)
Glass Rise Time	7.183	7.097	7.468	7.776
Plastic Rise Time	7.344	7.332	8.921	8.390
Glass Pulse Width	14.88	16.03	21.23	18.14
Plastic Pulse Width	16.98	16.23	17.79	17.89

Both Cables at 10 cm (Plastic PMT 1 and Glass PMT 2)		
Average Value (ns)	Run 1 (ns)	Run 2 (ns)
Glass Rise Time	7.874	7.661
Plastic Rise Time	9.568	8.852
Glass Pulse Width	21.70	20.07
Plastic Pulse Width	17.68	18.03

Both Cables at 25 cm (Plastic PMT 1 and Glass PMT2)		
Average Value (ns)	Run 1 (ns)	Run 2 (ns)
Glass Rise Time	12.32	11.25
Plastic Rise Time	47.61 - saturation (reject)	48.35 - saturation (reject)
Glass Pulse Width	22.32	21.27
Plastic Pulse Width	17.37	17.89

- **Calculation:**

Glass:

Attenuation: $\leq$ 50 dB/km at 430 nm

$$\frac{50\ dB}{1\ km} \times \frac{1\ km}{1000\ m} \times 1\ m = 0.05\ dB$$

$$10^{-0.005} = 0.988$$

Plastic:

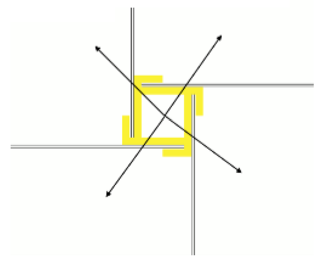
Attenuation: $\leq$ 0.13 dB/m at 450

$$\frac{0.13\ dB}{1\ m} \times 5.2565\ m = 0.683\ dB$$

$$10^{-0.0683} = 0.854$$

IV. Future Works

- Add reflector panels to the pinwheel diffuser and then test for the diffuser output with respected to the reflector panels.
- Create a simulation with 4 adjacent cells geometry with pinwheel diffuser at the center to test for efficiency of laser output.
- Conclude on the final calibration unit design and apply the system to the current PROSPECT prototype detector as well as the full detector.



Other Projects

- "PROSPECT: The Precision Reactor Oscillation and Spectrum Experiment" – Thomas Langford, Sat Oct 15, 2:36pm
- "Development and Characterization of 6Li-doped Liquid Scintillator Detectors for PROSPECT" – Jeremy Gaison, Sat Oct 15, 2:12pm
- "Development of the PROSPECT Source Calibration System" - Arina Bykadorova, CEU Poster

References

[1] arXiv:1512.02202 [physics.ins-det]
[2] PROSPECT in a Nutshell [Online]. Available: http://prospect.yale.edu/