Neutron veto scintillator study

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We analyzed various scintillators, both plastic and liquid, to determine their relative and absolute light yields and determine their effectiveness for use in the Cryogenic Dark Matter Search (CDMS) neutron veto. The 2,5-diphenyloxazole (PPO), DPA, and Trimethyl borate (TMB) concentrations were varied in both plastic and liquid scintillators. They were then exposed to barium-133, cesium-137, californium and the light output was measured using a photomultiplier tube (PMT) and recorded using a data acquisition system. The data was formed into histograms based on the integral of the recorded waveforms—an indication of the particle's energy level. Finally, plotting the light yield vs. PPO, DPA and TMB concentration revealed that increasing PPO decreased light yield to a cap, adding DPA increased overall light yield significantly, and TMB something.

I. MOTIVATION

Since dark matter has not yet been observed, the Cryogenic Dark Matter Search (CDMS) plans to boost the sensitivity of its detectors significantly in the new SuperCDMS experiment. This creates a need for better methods of filtering out background events from the dark matter events; in other words, the greater sensitivity would create more false positives unless preventative measures are implemented. Neutrons are one of the worst background particles we need to block. They have no charge and, unfortunately, behave very similarly to the predicted dark matter particles known as weakly interacting massive particles, or WIMPs. Neutrons require a special kind of protection—a neutron veto—that will detect their presence before they enter the WIMP detector, and "veto" the data collected for a short period around that event. This neutron veto will surround the detectors, but be surrounded by a passive shielding, so it will not see many charged particles. In this way, we can remove neutrons from the CDMS background and have greater confidence in the events out detector sees.[1]

There are several factors we need to consider, then, when choosing a scintillator for the neutron veto. These scintillator blocks will need to physically be quite large, and will have some absorption length. We don't want to lose the light from events to absorption or we will miss events, so we need to maximize the light yield of the scintillator chemically. Also, we need to have good pulse-shape discrimination (PSD) to tell the difference between neutrons and gammas. Plastic scintillator is easier to work with, so it would be a nicer choice for the experiment, but historically plastic scintillators have much worse PSD than liquid scintillators. However, a team at Livermore found that by increasing the concentration of PPO in plastic scintillators, the PSD is improved, making it comparable to liquid scintillators. This solves the PSD problems of plastics, but we still wanted to maximize the light yield. The Livermore team improved their light yield with 9,10-diphenylanthracene

(DPA). We wanted to test their DPA results and improve upon them using TMB as well. In this way, we would produce the ideal plastic scintillator with good PSD and high light yield.

II. SCINTILLATOR TESTS

A. Experimental setup

Since we did not have the necessary equipment in Wilson Hall, we moved to Lab 6 for testing. There, we obtained a dark box, pmt, data acquisition system, and cesium-137 and barium-133 as our radioactive sources. Our setup coupled a scintillator to the pmt using optical grease and a clear plastic cone (since the scintillator and pmt had different diameters). We supplied the PMT with 1800 V from a high-voltage power supply and channeled its output to the waveform digitizer (DAQ). To set the threshold on the DAQ to an appropriate level, we also wired up an LED and placed it in the dark box, using an oscilloscope to tune its voltage to single photoelectron levels. Once the DAQ was properly calibrated, we were ready to begin.

B. Increasing PPO concentration

First we tested scintillators with increasing PPO concentrations, from 1% up to 35%. The scintillators were made through polymerization of polystyrene or polyvinyl toluene with PPO in two sizes: 1 cm by 2.5 cm disks, and 5 cm by 2.5 cm tubes. Testing these samples with cesium-137, and subtracting a background spectrum from the data, resulted in plots like the one shown below.

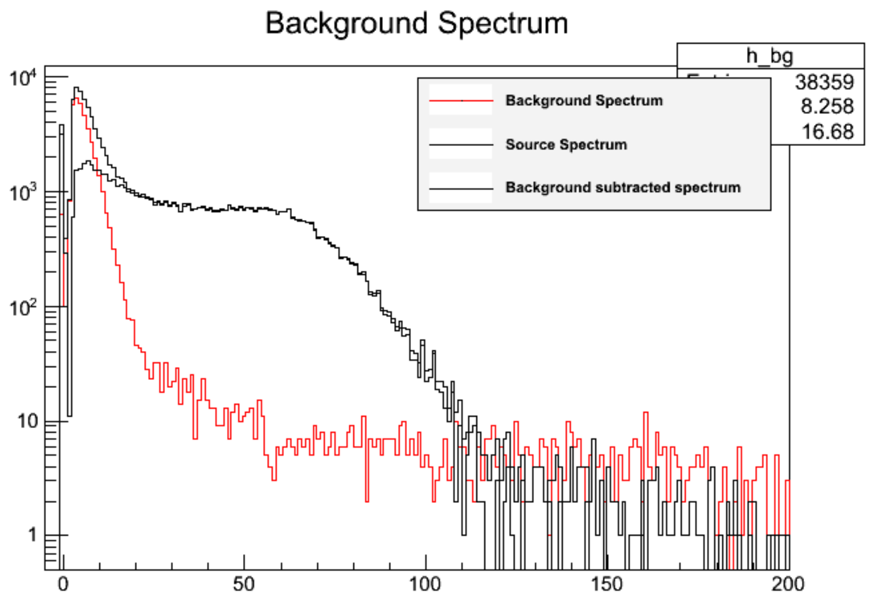

Figure 1: Number of Events vs. Number of Photoelectrons. Here we can see the source, background, and background subtracted spectrums for a 1% PPO in polystyrene sample.

The background spectrum is shown in red. We can see a large bump above the background spectrum that must have been caused by the source. This is the Compton shoulder for cesium-137. Where the Compton shoulder occurs along the x-axis (number of photoelectrons) indicates the light yield of the particular sample. We found that as the PPO concentration in the samples increased, the light yield seemed to increase slightly, though the data was inconsistent across different sample lengths. Our results are plotted below.

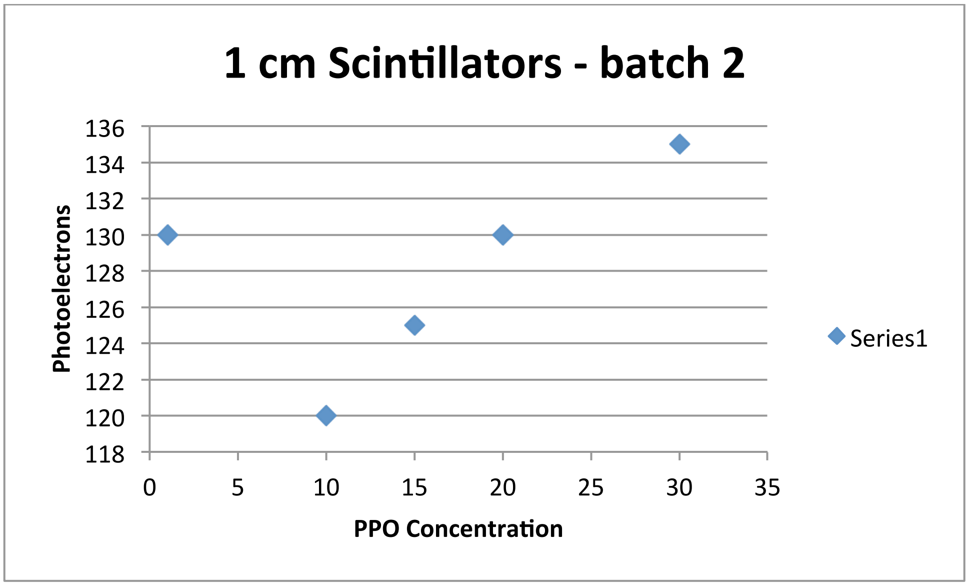

Figure 2: Number of Photoelectrons vs. PPO Concentration for 1 cm polystyrene scintillator disks.

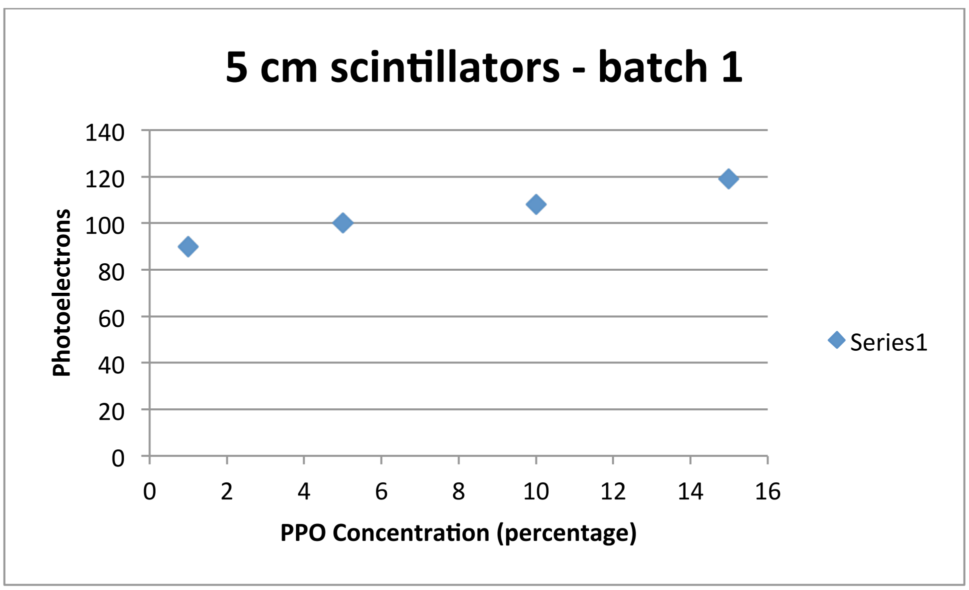

Figure 3: Number of Photoelectrons vs. PPO Concentration for 5 cm polystyrene scintillator tubes.

C. Adding DPA

The Livermore team improved their light yield by adding a secondary wave-shifter in DPA. We also polymerized a number of cocktails with 0.2% DPA and tested them with cesium-137. Like with the plain PPO samples, we collected data, subtracted off the background, and looked for a Compton shoulder in the results. The data looked very similar to that with plain PPO, but as you can see below, the bump falls off much further along the x-axis, indicating a higher light yield.

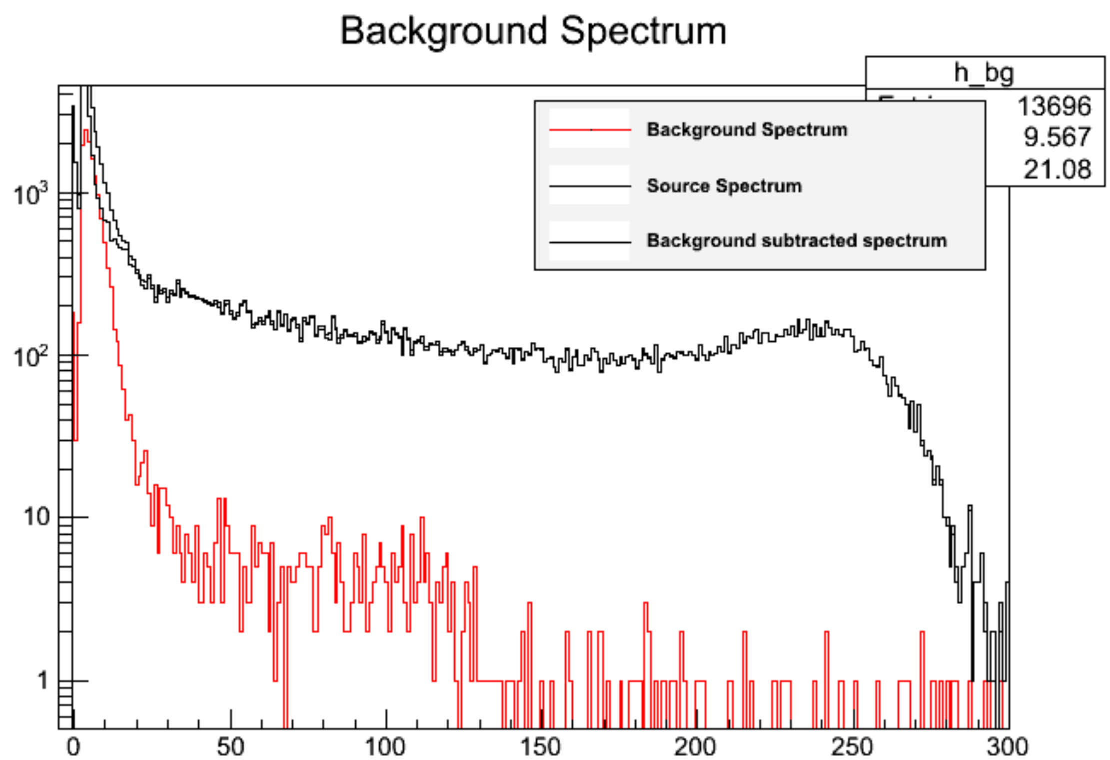

Figure 4: Number of Events vs. Number of Photoelectrons.
We can see the extended Compton shoulder here caused by the added DPA.
This particular sample was polystyrene with 30% PPO and 0.2% DPA.

We then plotted the photoelectrons produced by each cocktail on the same graph to visibly see the effects of DPA. As you can see from the below graph, DPA significantly increased the number of photoelectrons produced by the scintillator regardless of PPO concentration.

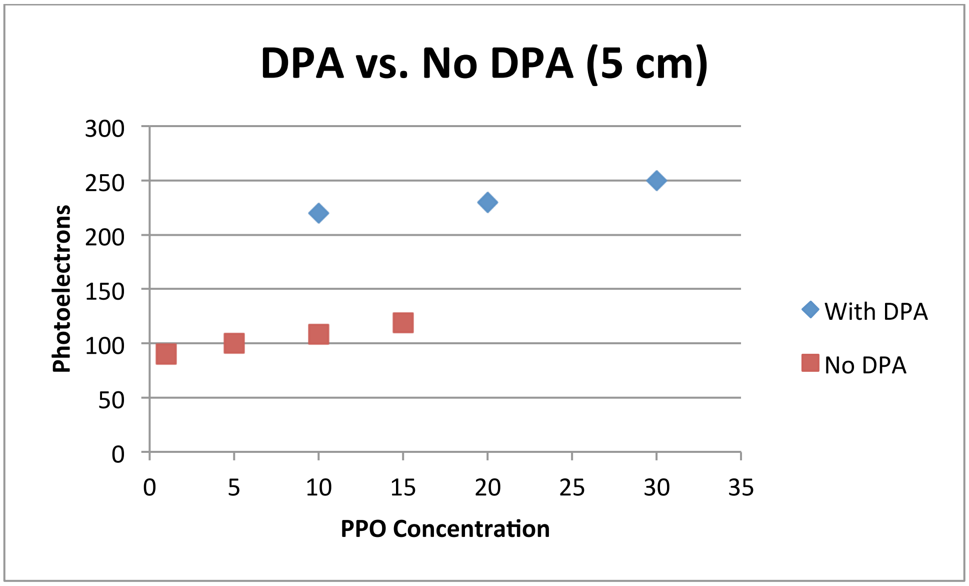

Figure 5: This plot shows the significant increase in number of photoelectrons generated by samples with DPA over samples without.

D. Adding TMB

Lastly we added trimethyl borate to the plastic samples. The TMB was added for its ability to capture particles. We did not collect sufficient data with TMB samples to come to any conclusions, but preliminary results suggested that the TMB improved pulse-shape discrimination between alphas, gammas and neutrons as shown later on.

E. Liquid vs. solid

We also worked with some liquid scintillators. Several samples purchased from Eljen worked quite well and had high light yields. One sample contained a quantity of boron and served as a good backdrop for our boron-loaded plastic samples and our LAB liquid samples. Unfortunately, our LAB liquid cocktails had a very low light yield. This made it virtually impossible to get any meaningful data from testing them. We tried several different configurations, even wrapping the vials in reflective Teflon tape, but were unable to get enough light from them to learn anything.

III. PULSE-SHAPE DISCRIMINATION WITH NEUTRON SOURCE

Lastly, we tested the pulse-shape discrimination properties of our samples using a Californium (neutron) source. The Eljen boron sample seemed to have good pulse-shape discrimination as we could clearly see two bands—one for gammas and one for neutrons—when the californium source was present as shown below.

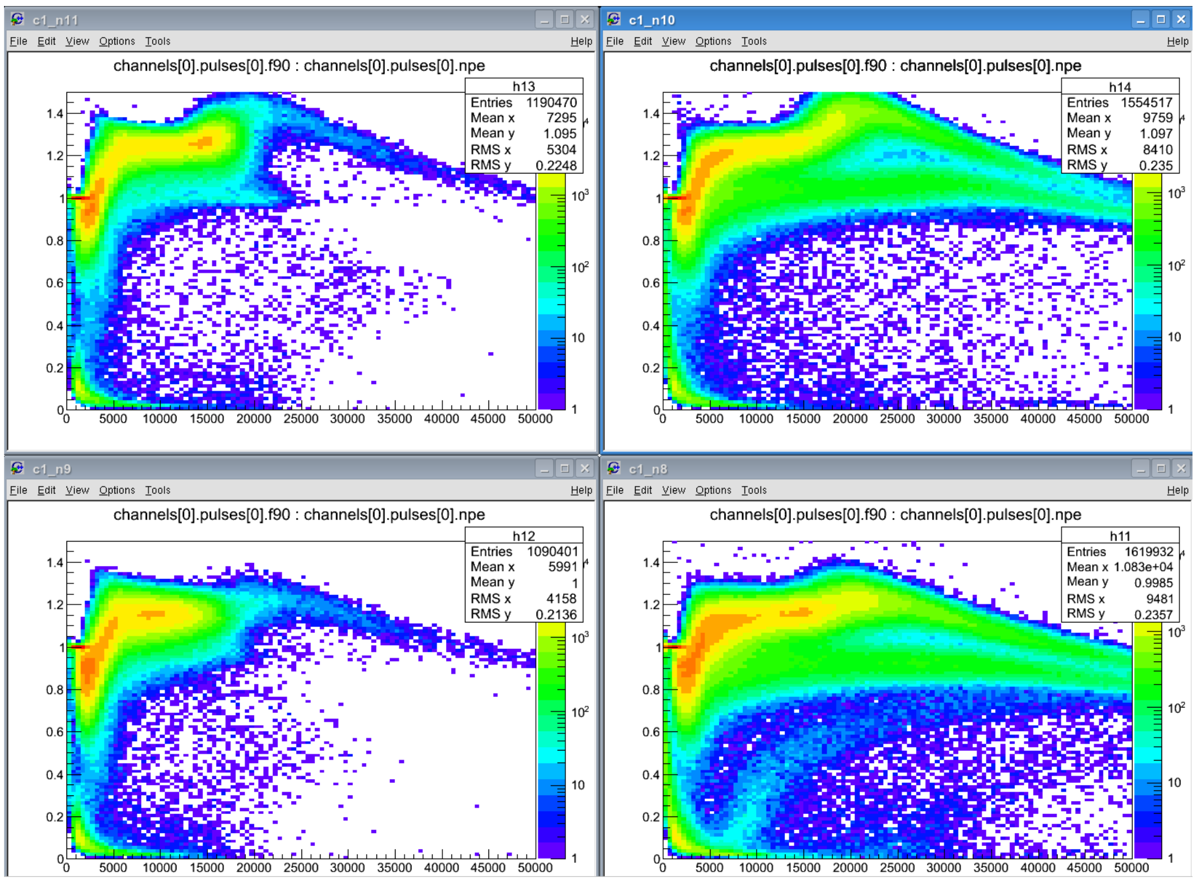

Figure 6: Top row is Eljen cocktail without boron; bottom row is Eljen cocktail with boron. Left side is PSD data with barium-133 while right side is PSD data with californium-252. All are F90 PSD vs. Energy. We can see that there is a second large green band caused by the neutron source, and a smaller blue band in the boron-loaded sample with the neutron source, possibly caused by alphas.

The images on the right are the pulse-shape discrimination with the neutron source, while those on the left are with barium-133; the top row of images are the Eljen cocktail without boron, while the bottom row is boron loaded. We can see a second large green band in both images on the right, which is caused by the neutrons. Further, we can see a second bluish region in the bottom right image (the boron-loaded sample), which could be caused by alphas. However, we were not confident in the PMT when we took this data as it was behaving oddly, and future tests with other PMTs were more inconclusive. In the future, we will tune the data acquisition system to the new PMT and try taking more data that way.

IV. CONCLUSION

In conclusion, we found that increasing concentrations of PPO generally increase the light yield of our samples, at least up to 30%. We also found that adding 0.2% DPA to the samples greatly increased their light yield over samples without DPA. Adding boron to the samples looked like it may have helped the PSD properties, but without additional data the results were inconclusive. The ideal scintillator cocktail for our experiment, then, will likely contain 30% PPO, 0.2% DPA, and some level of TMB for its neutron capture properties, though we don't yet know what concentration would be ideal.

V. FUTURE WORK

As mentioned previously, we need to take more data with the boron-loaded samples to test their pulse-shape discrimination properties. This will require finding the single photoelectron peak for our new PMT tuning the data acquisition system to it. We also would like to take better data with our liquid LAB samples. The samples had too small of a light yield to learn anything useful from them, but we might be able to get around that. The samples were in small glass vials that were clear on all sides as opposed to the larger Eljen containers that were reflective everywhere except where the PMT would interface. We were probably losing a lot of light from the LAB samples simply because of the container they were in. If we move that liquid scintillator to a better container, we will probably get much better data from them.

VI. ACKNOWLEDGEMENTS

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REFERENCES

[1] Z. Ahmed et al., Dark Matter Search Results from the CDMS II Experiment, Science 327, 5973 (2010).