

Construction and testing of a prototype for SuperCDMS neutron veto

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We assisted in assembling and testing a neutron veto prototype for the SNOLAB phase of CDMS. As part of this, we analyzed various glues for the attachment of fibers to the prototype. Through analysis with a spectrophotometer, we were able to determine which glues would be effective. Additionally, we investigated several different options for the fluors and concentrations of our scintillator. By using a fluorimeter, we compared the spectra we obtained with the spectrum of the fibers. We constructed a prototype for the neutron veto for SuperCDMS and filled it with scintillator. The prototype contained eight silicon photomultipliers (SiPMs), which we characterized by using an LED setup and a cooling system. We filled the prototype and began to use radioactive sources to test the light yield of this system.

## I. MOTIVATION

As a part of the SNOLAB phase of Cryogenic Dark Matter Search (CDMS) for the detection of weakly interacting massive particles (WIMPs),<sup>1</sup> it is necessary to have a neutron veto, since neutrons have the same signature as WIMPs. Without some way of identifying when neutrons are present in the detector, it would be impossible to say with any degree of certainty that a WIMP was present in the detector versus a neutron. Since neutrons react often, and WIMPs only interact rarely, an event in the main detector and an event in the neutron veto imply the presence of a neutron rather than a WIMP. Our goal this summer has been to test a prototype of a neutron veto in order to determine methods for improving light yield from the veto.

We had to test several different types of glue, especially how each type of glue interacted with the scintillator and the wavelength shifting (WLS) fibers.<sup>2</sup> Additionally, we needed to test the impact different concentrations of the fluor 1,4-bis[2-methylstyryl]benzene (bis-MSB) had on our scintillator by analyzing the emission spectra of several samples. We also learned about the best methods for assembling our prototype and we characterized the SiPMs at different temperatures and different bias voltages.<sup>3</sup>

## II. PROTOTYPE SETUP

Our prototype consists of an inner acrylic box, which is filled with a scintillator, and an outer steel box. The inner box is lined with a reflector called Lumirror and has 16 WLS fibers threaded in groups of four through two of the sides. On the outside of the acrylic box, on the same sides where the WLS fibers have been placed, are aluminum plates, called cold plates, with tubes from a cooling system running through them. Mounted on these plates are eight SiPMs from Hamamatsu, four on each side. The SiPMs each have a fiber guide attached to them, and the fibers themselves are attached to the fiber guides, which are small round plastic pieces with a

hole centered over the photosensitive portion of the SiPM. Each SiPM utilizes four of the WLS fibers. There is also an expansion tank attached to the outside of the inner box to allow for fluctuations in the volume of the box and the scintillator as the temperature is changed.

The outer box, shown in Figure 1, is painted black and serves the purpose of containing any vapors or minor spills from the inner acrylic box, as well as a dark box to limit light from outside sources. On the sides of the outer box are feedthroughs for signal cables and USB cables from the SiPMs. The lid has a small hole in the top that is covered by electrical tape and a plastic cover to accommodate the expansion tank.

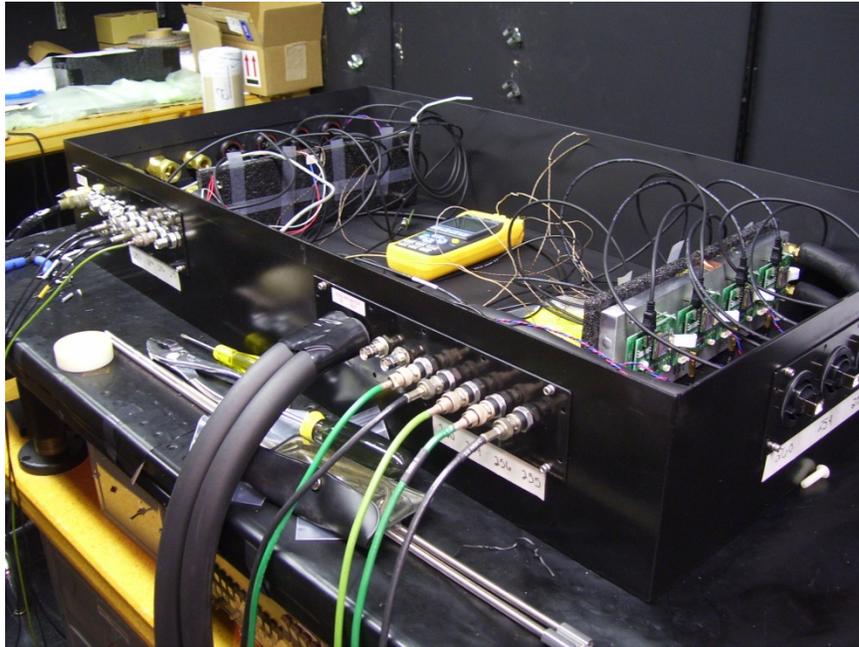


FIG. 1. The outer box of the neutron veto prototype with the SiPMs and cables attached.

In order to take data, we use a CAEN V1720 data acquisition system (DAQ),<sup>4</sup> a power supply to provide +/- 5 volts for the SiPMs, two computers, a cooling system, and a device that monitors both the temperature of the cold plates and the oxygen percentage of the box. Due to the hazardous nature of trimethyl borate (TMB), a component of our scintillator that is needed to capture neutrons, we needed to keep the oxygen levels low—ideally less than three percent. As

of now, the TMB has not yet been added. One of the computers in our setup was needed to communicate with the DAQ and record the data. Once this was recorded, it was uploaded to a server for further analysis. The other computer had programs that allowed us to both modify bias voltages on the SiPMs and control an LED driver that we used as a source of photons while we were still preparing the scintillator and the inner acrylic box.

### III. GLUE TESTING

We needed a type of glue that would hold our prototype together, but not negatively impact the scintillator. Also, since we would be gluing fibers as well, we needed to test that the glue did not ruin the fibers and that the scintillator did not react with the glue in a way that would either damage the fiber or impair the transmission of photons. We started out with four different types of glue and tested these first on the fibers themselves. In order to do this, we constructed a small acrylic box, similar to what would be in our prototype, drilled holes in the side, and then attached the fibers using the four different glues. Once the glues had set, we partially filled the box with linear alkyl benzene (LAB),<sup>5</sup> the base of our scintillator. Only two glues, the five-minute epoxy and the RTV appeared to work.<sup>6</sup>

Since only two glues had passed the fiber testing, we felt we did not need to test any glues with the scintillator that had failed to work with the fiber. We also added another glue, DP-100,<sup>7</sup> to the testing, since it had been used successfully by the NOvA experiment with similar fibers in another experiment. In order to test these glues, we placed some glue at the bottom of an acrylic cuvette, filling enough cuvettes in this manner that each type of glue would be tested with both pure LAB and a mixture of LAB and 30% TMB by mass. We then used a spectrophotometer to get initial spectra for the cuvettes. For the first week, we tested the cuvettes almost daily. After that, our tests became less frequent, and we began to analyze our data.

From this test, we were able to determine that the mixture containing TMB in the proportions we planned to use in the final scintillator reacted negatively with the RTV, causing it to lose contact with the cuvette and float in the solution, but the mixture did not seem to react at all with the five-minute epoxy. Since we did not begin to test the DP-100 at the same time as the other glues, our initial conclusion was that the five-minute epoxy would be our best choice. However, once we tested the DP-100 and found that there were no apparent reactions between the scintillator components and the glue, we decided that we would use DP-100 instead.

#### IV. SCINTILLATOR TESTING

Our plan for the scintillator was to use a combination of LAB and 30% TMB by mass. However, we knew that for the light yield of the fibers to be close to optimal, we needed to add some secondary wavelength shifters to our scintillator. To match the absorption of the fiber, we found that a combination of bis-MSB and 2,5-Diphenyloxazole (PPO) could shift the light into the wavelength range we wanted. To investigate the effectiveness of this combination, as well as to determine the best concentrations for our purposes, we mixed up a batch of concentrate solution with LAB, two grams per liter of PPO, and 65 milligrams per liter of bis-MSB. We also mixed a dilute solution with LAB and the same concentration of PPO as in the concentrate solution, which we called the master solution, but the dilute solution did not contain any bis-MSB.

We then filled eight cuvettes with different ratios of the master to dilute solution, with one cuvette containing pure LAB to show the emission of the acrylic cuvette itself, since LAB does not really fluoresce. The ratios of master to dilute that we tested were zero to one, one to zero, one to one, four to one, nine to one, one to four, and one to nine. Using a fluorimeter, we took spectra of all of our samples, some of which are shown in Figure 2. Then, we found an

absorption spectrum from NOVA for the Kuraray Y11 fiber,<sup>8</sup> which is very similar to the fibers we are using in our prototype. We compared the fiber absorption spectrum with the emission spectra from our samples, as shown in Figure 3, and found that the spectrum in closest agreement with that of the fiber was the one part master to nine parts dilute solution. The final concentration was two grams per liter of PPO and 6.5 milligrams per liter of bis-MSB.

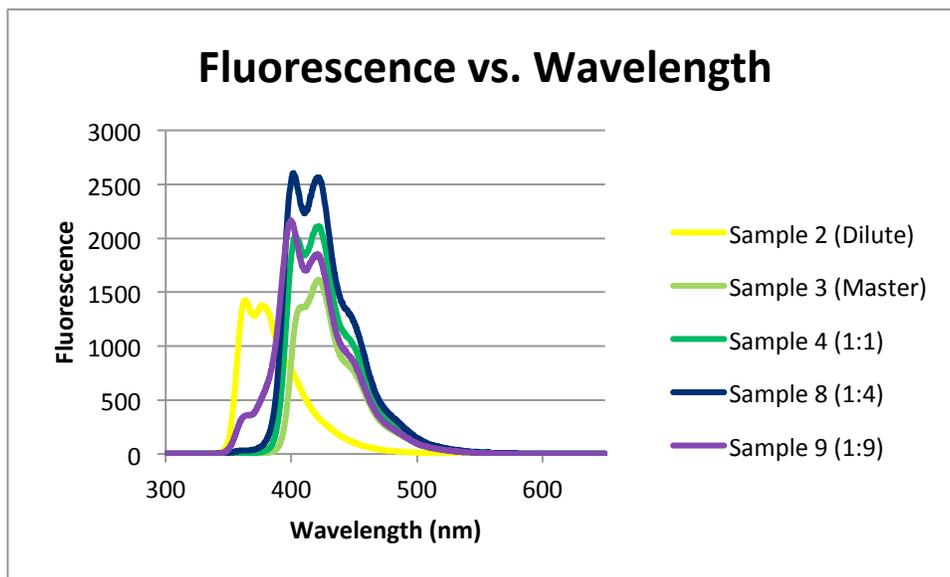


FIG. 2. Fluorescence spectra for the dilute, master, one to one, one to four, and one to nine samples.

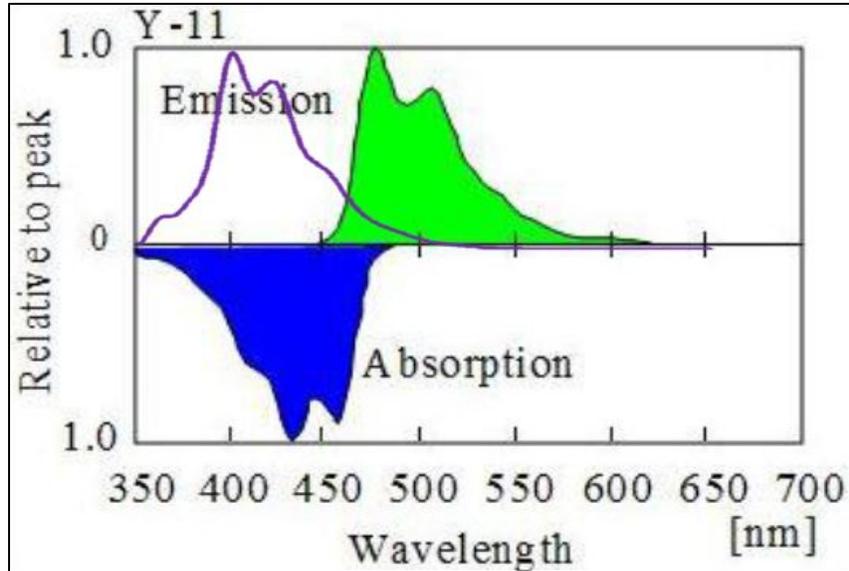


FIG. 3. Emission (green) and absorption (blue) spectra for the Kuraray Y11 fiber, overlaid with the emission spectrum for the one part master to nine parts dilute solution.

## V. SIPM CHARACTERIZATION

Before we could fill our prototype with scintillator, we needed to characterize our SiPMs at different temperatures to find the ideal operating temperature and voltage because ideally we want well-defined peaks, so we need high gain and low cross talk and dark rate. Our process for characterizing the SiPMs involved setting a temperature on the cooling system starting with 20 °C, which we called room temperature. We would then make sure that the SiPMs were set for the operating voltage recommended by Hamamatsu. We recorded a run of 100,000 events at these settings, and then we stepped down the voltage by 0.2 volts each time until the peaks were flattened.

When we reached the end of the visible pulses at 20 °C, we turned the cooling system down to 10 °C, repeating the process of stepping down the bias voltage. We lowered the temperature by 5 °C each time until we reached -10 °C, although, as we approached colder

temperatures, we no longer began at the recommended voltage in order for our SiPMs to remain functional.

During this process, it was interesting to note that the SiPMs consistently read 5–10 °C above the temperature set on the cooling system, which could mean that our cooling system was not as efficient as we had hoped. We analyzed the data by creating histograms of the analog to digital conversion (ADC) counts versus bias voltage and using the distance between adjacent peaks to calculate the gain. Then, as seen in Figure 4, we graphed the ADC counts versus bias voltage for different SiPMs at different temperatures in order to find how the gain, which is proportional to the ADC counts, changed based on both temperature and bias voltage. We noticed that there was a linear correlation between gain and bias voltage. Additionally, we noticed that the relationship between bias voltage and temperature at a constant gain was linear, as shown in Figure 5.

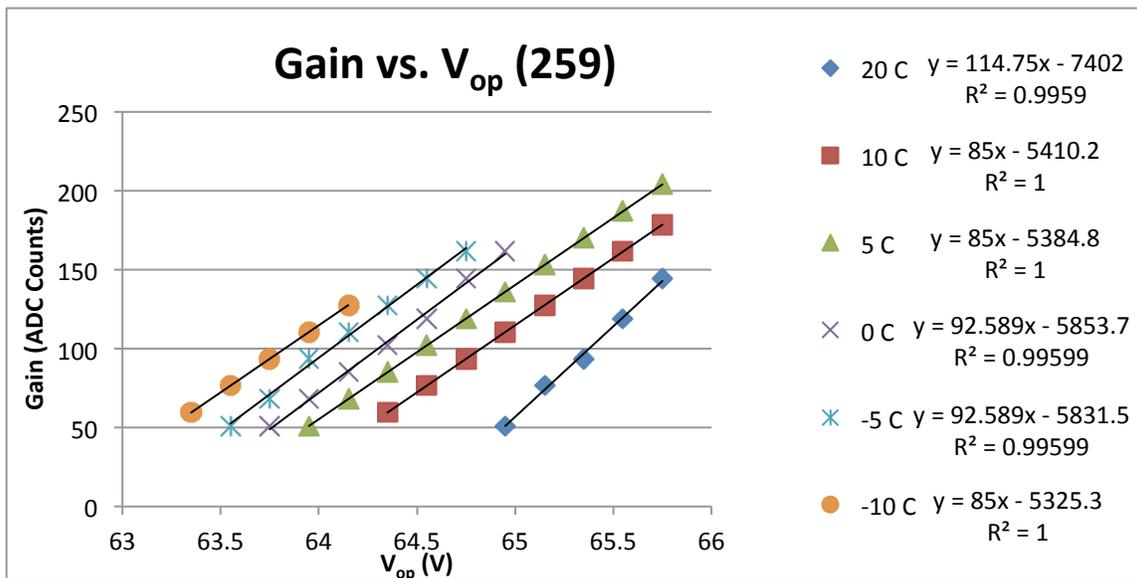


FIG. 4. Gain versus operating voltage (bias voltage) for several different temperatures – SiPM number 259.

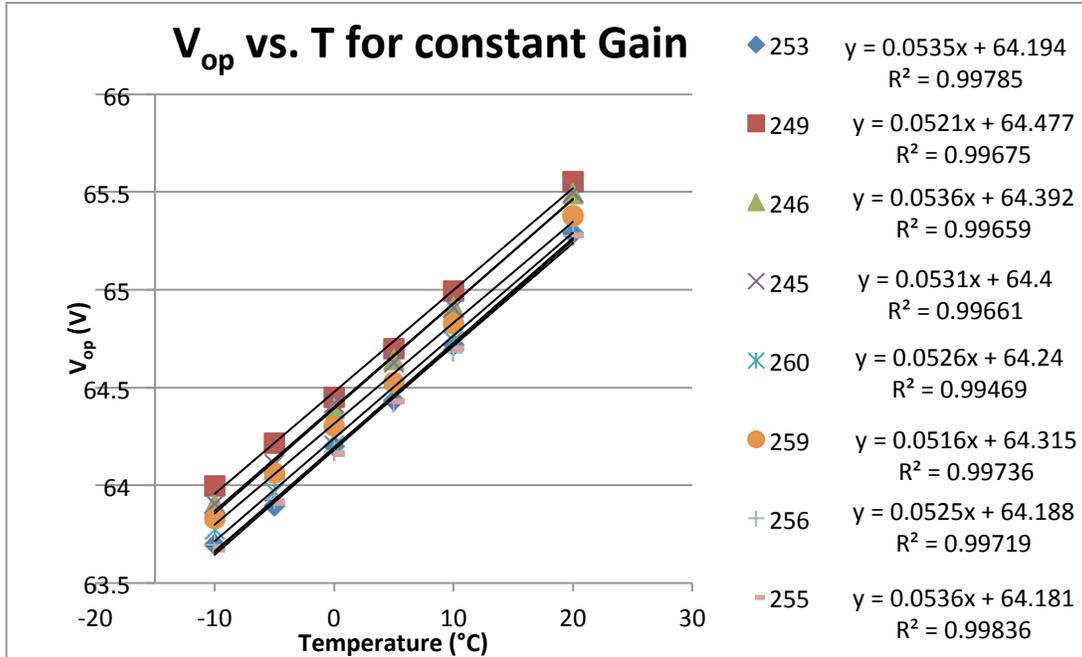


FIG. 5. Operating voltage versus temperature for a constant gain, ADC count of 100, all SiPMs.

## VI. DATA COLLECTION

Once the scintillator had been chosen, the boxes completed and the prototype assembled and filled with scintillator, we could begin to take data. We used a sodium source (Na-22), a cobalt source (Co-60), and a barium source (Ba-133) for gamma radiation, and a californium source (Cf-252) for neutron radiation, all of which were placed on top of the box.

## VII. CONCLUSIONS

In our glue tests, we determined that DP-100 was the most effective for the attachment of fibers. For the actual construction of the inner acrylic box, we used a water-thin solvent to bond the acrylic together and a thicker cement to patch the cracks. When we tested the scintillator, we found that the emission spectrum from the solution of one part master solution to nine parts dilute solution was the closest match to the absorption spectrum of our fiber. We were able to characterize our SiPMs at different temperatures down to -10 °C, although we did take data and determine the gain and nominal operating voltage at -20 °C.

## VIII. FUTURE WORK

We hope to be able to continue taking data using radioactive sources. Additionally, we hope to be able to add TMB to our scintillator in the future, since we currently only have LAB, PPO, and bis-MSB in our acrylic box.

## IX. ACKNOWLEDGMENTS

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