PMT Testing for SciBooNE at Fermilab

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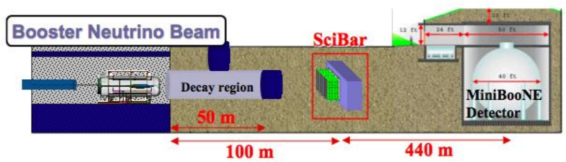
1 SciBooNE (SciBar at the Booster Neutrino Beam)



My work this summer focused on testing photomultiplier tubes (PMTs) for SciBooNE, a new experiment at Fermilab. SciBooNE consists of bringing the SciBar detector, currently at the K2K (KEK to Kamioka) experiment in Japan, to put in the Booster Neutrino Beamline at Fermilab. The Booster Neutrino Beam is an 8 GeV neutrino beamline which currently supplies beam to the MiniBooNE detector. SciBar, along with the Electromagnetic Calorimeter (EC), also coming from Japan, and the Muon Range Detector (MRD), being built at Fermilab, will be placed about 100 m past the target in the beamline, as a sort of near detector for MiniBooNE.

SciBooNE's main goal is to measure cross-sections for neutrino interactions, for general knowledge as well as for use in the T2K (Tokai to Kamioka) and MiniBooNE experiments. Its placement will also allow it to act as a near detector for MiniBooNE. The MRD, which is the detector whose construction I was involved in, is meant to find the energy of muons from neutrino interactions by "ranging out" muons. The detector consists of layers of iron interspersed with layers of plastic scintillator. Muons are tracked through the detector until they run out of energy from interactions in the iron and stop, and the distance they go can be measured by how many planes of scintillator they pass through. Each plane of scintillator is made up of paddles, and each paddle is read out with a PMT. There are a total of 362 PMTs in the detector, and we had to obtain and test them all this summer.

2 Photomultiplier Tubes for the MRD

The PMTs for the MRD all come from previous experiments at Fermilab. The main makers of tubes are the companies EMI, RCA, Hamamatsu, and Amperex. At the moment, we hope not to use the Amperex tubes since the bases we have been able to find for them are mismatched and badly understood. The largest group of one type of tubes that we have are EMI 9954KB tubes from the KTeV experiment at Fermilab. There are 149 of these tubes. We also expect to have about 100 RCA 6342A tubes and 60 Hamamatsu R2154-05 tubes (all with bases) after obtaining some from other institutions by the end of the summer.

I catalogue phototubes in our lab space at Fermilab.

The greatest challenge we had in obtaining enough tubes was finding matching bases (which are needed to divide the high voltage and send the appropriate voltage to each dynode in the PMT). While the KTeV tubes were already matched with the appropriate bases, for many of the tube types we had various types of bases, some of which worked with the tubes and some of which did not.

After matching tubes to bases, however, we still needed to run tests on the tubes. Testing is still in progress, but I was involved in the development of the testing procedure for the experiment, which is included below.

3 Photomultiplier Tube Testing Procedure

The testing that will occur on all the PMTs can be divided into the following stages:

1. A period after the tube is placed in the dark box in which it is allowed to dark-adapt.
2. Testing of the voltages coming out of the pins of the base, which occurs on the next four tubes to go into the dark box, while the first four are dark-adapting.
3. A test using the LED light source in DC mode which measures current in the tube as a function of voltage when the light source is on.
4. A measurement of the dark rate of the tube at its approximate operating voltage.

5. A check that the pulse shape for the tube is reasonable for that type of tube.

6. A count of afterpulses in the tube.

The motivation behind the first step is clear, as it is necessary to allow the tube to dark-adapt before measuring the dark rate, and allowing the tube to become dark-adapted will reduce the noise rate. The tube will be left in the dark box for 30 minutes to dark-adapt before other tests are conducted. During this time, testing of the bases for the next four tubes to go into the dark box can occur. For this test, the tester will run a voltage through the base and measure the voltage through each pin. This can be recorded on the appropriate section of the testing form. Eventually, these numbers will allow us to determine a reasonable range of voltages for each pin and discard bases which are too far outside of this range.

Next a current vs. voltage measurement will be made. For each type of tube (that is, the EMI tubes which are all similar, the RCA tubes, and the Hamamatsu tubes), there will be a "standard eyeball" - that is, a tube which responds to the LED with some standard current at its operating voltage (which was chosen from an efficiency measurement made on the test counter). This tube will be placed in the dark box with the LED running in DC mode, and the current it emits when run at its operating voltage will be considered the standard current for that type of tube. Since the pulse shape and other factors which may be different for each different type of tube may affect this current reading, there will be a standard eyeball for each type of tube. For the RCA and Hamamatsu tubes, in order to avoid building and then dismantling two more counters, 3 representative tubes of each type were tested with the LED at various high voltages, and the current was measured at each. Then when these tubes are built into counters and their operating voltage is found, the current corresponding to that voltage for that tube can be looked up and considered the standard current for that tube type.

Each tube will then be tested with the LED, and its voltage will be adjusted by increments of 50 volts around a starting point determined by the specifications of the tube type until the current from the tube is as close as possible to the standard current for that type of tube. Specifically, the voltage will be tested at several points on all four tubes at once until all of them have achieved the standard current. These measurements will be used to interpolate a voltage to ± 10 volts that will give closest to the standard current for that tube. This voltage will give an approximate operating voltage for the tube. A better operating voltage will then be determined once the tube is built into the counter.

This test is meant to somewhat standardize the relative pulse heights between the different tubes, since tubes of the same type (and therefore presumably very similar in pulse shape and quantum efficiency) should have about the same pulse height for the same amount of current going through the tube. Because of difference in pulse shape and quantum efficiency, however, it is probably necessary to test each type of tube separately.

Next a dark rate measurement will be made. After the tube has had time to become dark-adapted, the dark rate will be measured as the number of pulses in 10 seconds when the LED is not on. If the dark rate is less than 1000 Hz, the tube will be considered acceptable for use in a counter.

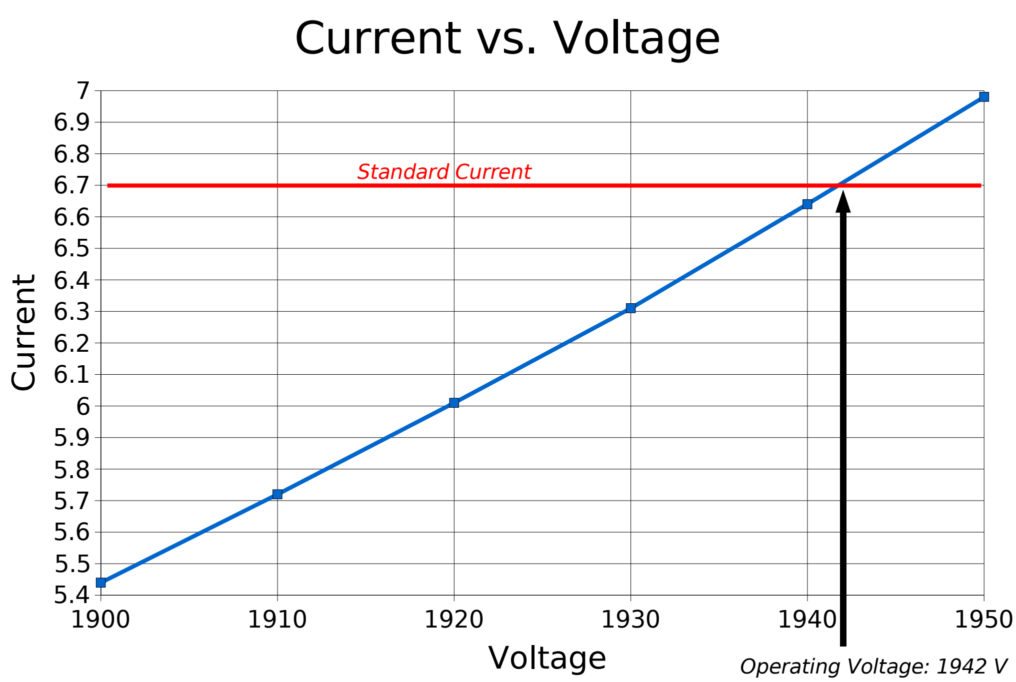
A visual inspection of the shape of pulses coming from the PMT when the LED is pulsed for 5 nanoseconds using a pulse generator should next be conducted using the oscilloscope.

More discussion is needed to determine what would be a reasonable range of pulse shapes and what specific deviations should be looked for. For the moment, we will determine a "standard" pulse shape for each type of tube, and the tester can decide if the pulse shape looks normal or abnormal by visual inspection, and then comment on any abnormalities, attaching a screenshot of the shape if necessary.

Finally, afterpulses will be looked for, since gas in the PMT can cause afterpulses hundreds of nanoseconds after the main tube pulse. With the LED pulsing for 5 nanoseconds, afterpulses should be counted using the oscilloscope for 1 microsecond after the main pulse. One hundred single pulses of height greater than 10 mV will be measured. The number of afterpulses within 1 microsecond of these 100 main pulses will be recorded.

4 Further information

Results of the PMT tests are not yet entirely available. Below is sample data from testing on one of the PMTs. This tube, with serial number MRD-108, is an EMI 9954KB tube from the KTeV experiment. This data was taken on July 25, 2006, by Y. Nakajima. The plot shown gives the results of the current vs. voltage test and position of the approximate operating voltage for the tube.



The current vs. voltage plot with standard current and operating voltage marked, for tube MRD-108, tested by Y. Nakajima

From the tests that have been done, however, the procedure seems to be working well. We may have to make minor changes to deal with, for example, amplification of the signal from the 10-stage Hamamatsu and RCA tubes to match better the signal size of the 14-stage EMI tubes. The procedure we have, however, is flexible enough to deal with this kind of modifications. Full documentation of the procedure, along with the data collection form and instructions for the tester, is available on my website, home.fnal.gov/ hannahnp/sciboone/sciboone.html.