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Tile Detector with Wavelength Shifting Fiber Readout

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Abstract: At low beam intensity, ion chambers and the Digital Beam Imager are not able to produce a beam uniformity measurement. Plastic scintillator with PMT readout has been used to calibrate the beam in the past. The paper examines the use of scintillator tiles readout using wavelength shifting fibers and PMTs to create a low intensity device similar in function to the 256-pixel ion chamber for measuring the relative flux in 1x1 cm^2 regions over a 32 x 32 cm^2 area.

Introduction

NSRL Users sometimes make use of low intensity beams where the rates are so low that neither the pixel ion chambers nor the Digital Beam Imager can measure the beam. We have to trust that the beam keeps its shape and uniformity when the intensity is turned down using either the ion source (EBIS Q106 or Tandem Chopper) or the R-line D6 collimator or both. We are aware that the intensity controls often induce a tilt to the beam profile. As long as we can see it, we can compensate for it. But there are no doubt cases where we can't see the tilt. What is needed is a beam monitor that can respond to beam intensities on the order of 100 ions per square cm per spill.

This can be accomplished with a scintillator tile array using wavelength shifting fiber readout. The schematic array is shown in Figure 1 with optional PMT readout on either vertical or horizontal PMTs. The questions that this study intends to answer include:

- Is there sufficient light transmitted from the scintillator tiles into the wavelength shifting fibers to count the ions that hit the tile?
- Is the attenuation length of the fibers too short to give good signals at the PMT?
- Do ions create signals when they traverse the fibers?
- How can the tile-fiber detector be used to monitor beam uniformity?

To address these questions we asked for a sample of wavelength shifting fiber from the Kuraray company [1]. They sent us 4 fibers, each was 3 meters long. Two of the fibers were 2mm diameter,

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and two were 1mm diameter. The fibers were Y11(200)M 1.00mmD type. The Y11 fiber is not designed to scintillate in response to the passage of a charged particle. We used a scintillator tile from Bicron that was 1 x 1 cm2 to indicate the passage of charged particles. Light given off by the tile would be captured by the fiber and transmitted to the PMT, in theory. The absoption and emission spectra of the Y11 fiber is shown in Figure 2. This matches well with the emission spectrum of the EJ-212 scintillator planned for use as the scintillating tile, shown in Figure 3. The peak in the EJ-212 emission occurs around 425 nm, while the Y11 fiber has its peak absorption very near 425 nm. The Y11 emission peak is close to 470 nm, at a wavelength where the PMTs we plan to use have a quantum efficiency of approximately 20%, Figure 4.

Is there enough light?

To test this arrangement we mounted a pair of PMTs in the NSRL Dark Box. We had 1" PMTs from Hamamatsu (H7415 assemblies). We began comparing the gain of the two PMTs by placing them vertically upright with the scintillating tile on top. The tile was excited with a 0.1 μCurie Am-241 alpha source (5.46 MeV). This produced very clean peaks for both tubes at HVs of 1090 and 1080 volts for PMT-1 and PMT-2 respectively.

Next we mounted the PMTs horizontally in the dark box and fixed the 2mm fiber in the center of the PMT by passing the fiber through a foam cookie on the face of the PMT. Although this centered the fiber on the face, it did not give good optical contact. Subsequent testing was conducted with optical grease making the contact between the fiber and the PMT. The remainder of the fiber was coiled up inside the dark box.

The optical connection between the tile and the fiber was achieved by greasing the edge of the tile and placing the greased edge of the tile in contact with the fiber. This was usually sufficient for the tile to adhere to the fiber. The Am-241 source was placed on the tile, and we observed the response of the PMT. Although the light output of the fiber was significantly less than from the tile itself, we were able to measure the spectra under a variety of conditions. We began by mounting the two PMTs on either end of the same fiber, with the tile greased to the midpoint of that fiber. The two signals from the PMTs were passively split with one part going to a discriminator and the other part going to the analogue input of an ADC in the NSRL Data Acquisition System (DAQ). The discriminator thresholds were set to -50 mV, and the widths to 200 ns. The output of the two discriminators were put into coincidence, and the coincidence output provided the ADC gate and trigger for the DAQ.

Figure 5 shows the response of the PMTs to the Am-241 alpha source on 2mm fibers as a function of PMT high voltage. The pedestals for the two ADCs were 100 and 85 respectively. At the lower voltages, the signal was indistinguishable from the shoulder produced by the discriminator cutoff. Figure 6 shows the spectra obtained at voltages of 1700, 1800, 1900, and 2000 volts where the peak is separated from the shoulder. Attempting to repeat the measurement with the 1mm diameter fiber proved difficult, as the signal level was much smaller than observed with the 2mm fiber, as expected. Even at 2000 volts, the Am-241 peak is in danger of being lost in the tube noise. This is the cause for concern.

The Am-241 source is an alpha particle emitter with a mean energy of 5.46 MeV. The source is bare, and the air gap between the source and the tile is small, less than 1 mm, so the energy deposit in the tile is essentially the entire 5.46 MeV. The range of a 5.46 MeV alpha in scintillator is on the order of 40 microns, so no energy I lost. When the tile is placed on the face of the PMT, the alpha response is a clear peak. Now a minimum ionizing particle will deposit 2 MeV per centimeter in plastic scintillator, or 0.4 MeV in the 2mm thick tile. A 2200 MeV proton is minimum ionizing, and the tile detector should be able to resolve a high energy proton beam of that energy. This is only 7% of the energy from the alpha, so it is important to be able to see a clear alpha signal from the tile.

We also used a Sr-90 source to excite the tile. Sr-90 is a beta emitter with an end point at 0.546 MeV, as shown in Figure 7. Sr-90 decays to Y-90 100% of the time. Y-90 decays by beta decay to Zr-90 which is stable. The Y-90 beta decay spectrum has an end point of 2.28 MeV. When using the Sr-90 source, we see no clear peak, since the electron energy is not monoenergetic. But the electrons produce triggers in the detector indicating that it is sensitive to signals below the 5.46 MeV level. Similarly, using a Cs-137 gamma source to excite the tile shows...

What is the attenuation length of the fibers?

We placed the tile at three locations along the 3 meter long fiber: 10 cm, 150 cm, and 290 cm. The Am-241 source excited the tile, and PMTs read out the signal at both ends. of the fiber. The tile was connected to the fiber with optical grease, as were the fiber ends connected to the PMTs. Both PMTs were operated at 2000 volts. Discriminator settings of -50 mV and 200 ns were set. The DAQ was triggered with a two-fold coincidence and the Table 1 gives the resultant peak measurements.

Table 1: Source response as a function of distance from the PMT.

Source Location	Tube 1: Peak – Pedestal	Tube 2: Peak - Pedestal
10 cm	1007/945	117/118
88 cm	452/493	118/125
150 cm	390	146
212 cm	366/338	175/166
290 cm	296	371

The fiber manufacturer, Kuraray, measures the attenuation length as greater than 3.5 meters when evaluated in the region between 1.0 and 3.0 meters. There is substantial early signal loss because of overlap between the absorption and emission spectra, which is why the manufacturer's attenuation length measurement starts at 1.0 meter. After this initial loss, however, the light propagation is good. For attenuation lengths of greater than 3.5 meters, we will have no concerns for our detector which will have maximum fiber lengths of less than 1.0 meter. When fitting our data to a single exponential, ignoring the data points at 10 cm from the PMT, we obtain attenuation lengths of 4.4 meters using PMT1. PMT2 gives an attenuation length of 2.1 meters, but the signal level is close to the discriminator threshold making the small pulse height readings unreliable. Results are shown in Figure 8. Our measurements are largely consistent with the Kuraray statement that

Do the fibers scintillate?

When ions pass through the tiles, we get enough light to trigger our detector. But the tiles represent only 1 square centimeter of cross section. In a 20 x 20 cm^2 beam, the fibers represent 10 x 0.2 = 2 cm^2 of cross section, so if they produce scintillation light it could easily overwhelm the light signal from the tiles. Additionally, light from the tiles must be trapped in the tiles (only 16% of the light produced) and get transmitted into the fiber where it is absorbed and re-emitted with a 3% trapping efficiency. So light that is produced in the fibers has much less loss to contend with.

After initial tests with the Am-241 source on the tile, we placed the source on the fiber instead of the tile and were overjoyed to see no increase in the trigger rate. We quickly realized that the alpha particles released in the Am-241 decay have a range of only 38 microns in polymethyl methacrylate (PMMA), the cladding material for the Y11 fibers. The cladding thickness is 2% of the diameter, or 40 microns for a 2mm diameter fiber.

A more conclusive test required the Sr-90 beta source, with electrons up to 2.28 MeV which could easily penetrate the cladding, The stopping power of PMMA is 2.15 MeV/cm for a 1-3 MeV electron. We replaced the Am-241 source with the Sr-90 source, and saw that the discriminator fired at a high rate, consistent with most of the electrons causing a trigger. This shows that wavelength shifting fibers do produce scintillation light in quantities large enough to compete with the signals we expect from the tile. Since the fibers present a larger area to the beam than the tiles do, this represents a serious problem for this detector design.

How can the tile-fiber detector be used to monitor beam uniformity?

Since the fibers scintillate, the only way to build a tile detector is to have dual readout, with fibers on two sides of each tile, and demand coincidence of the two fiber signals. This will require instrumentation of twice as many channels of electronics as the basic design, but it achieves the functionality we need. To test this approach we used optical grease to attach the tile to two separate fibers going to two separate PMTs. With this arrangement we were able to measure good coincidence rates when exciting the tile with the Sr-90 source, but not see any significant coincidences when exciting either of the fibers alone. In other words, there was no light cross talk across the tile.

Where do we go from here?

At this point we need to test the design using beam. A pair of PMTs will be instrumented inside a long aluminum tube that is hinged to allow access to the tile and fiber inside. Fibers will be glued to the tubes and to opposite sides of the tile. Performance in proton and iron beams will determine whether we can go further with this design or not.

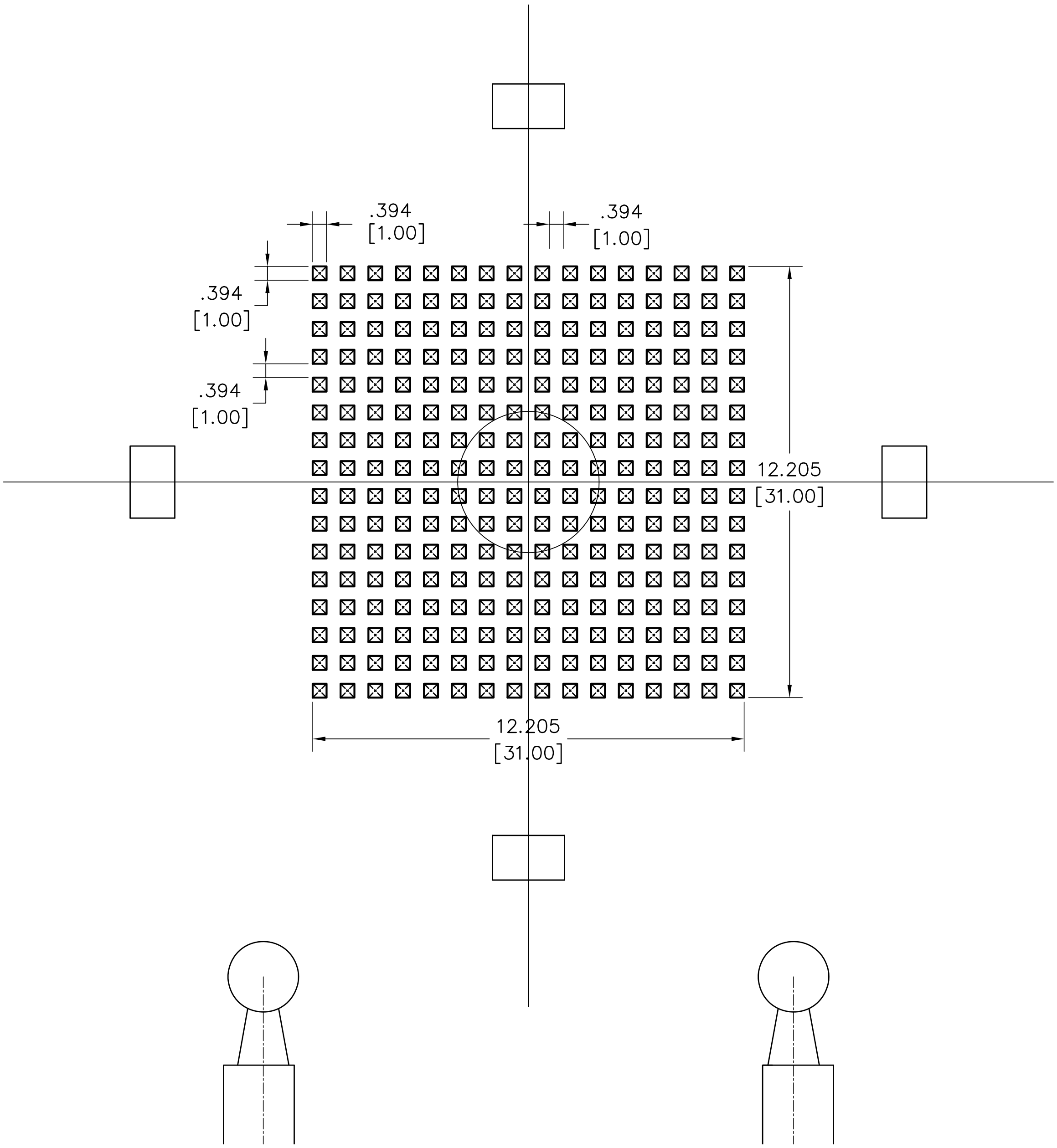

Figure 1: Schematic of a 256 tile detector designed for wavelength shifting fiber readout. Two possible PMT arrangements show vertical or horizontal placement.

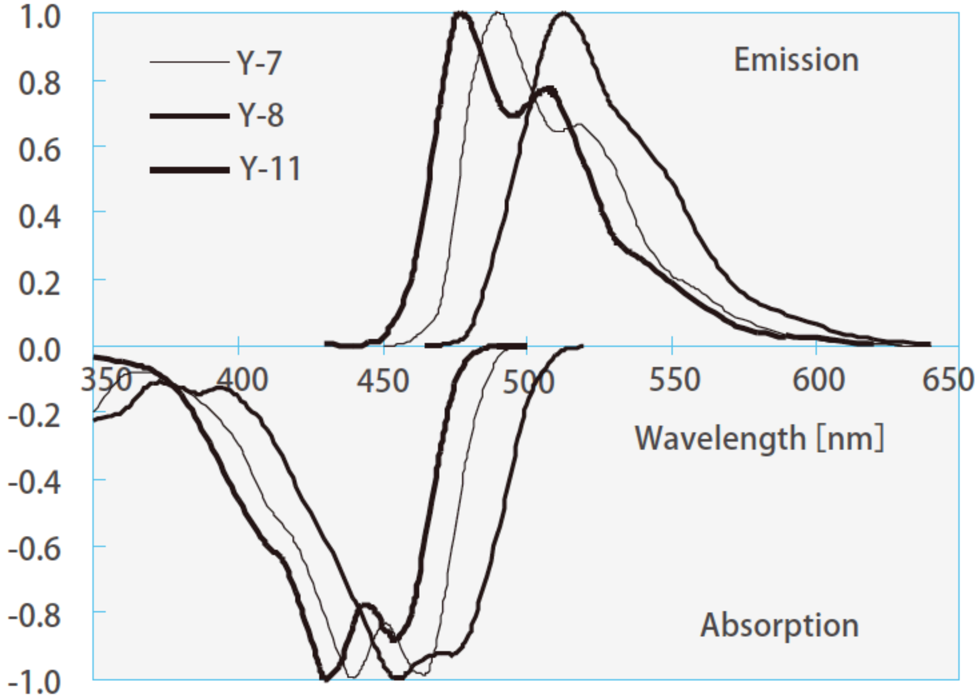

Figure 2: Absoption and Emission spectra of Kuraray Y11 fiber.

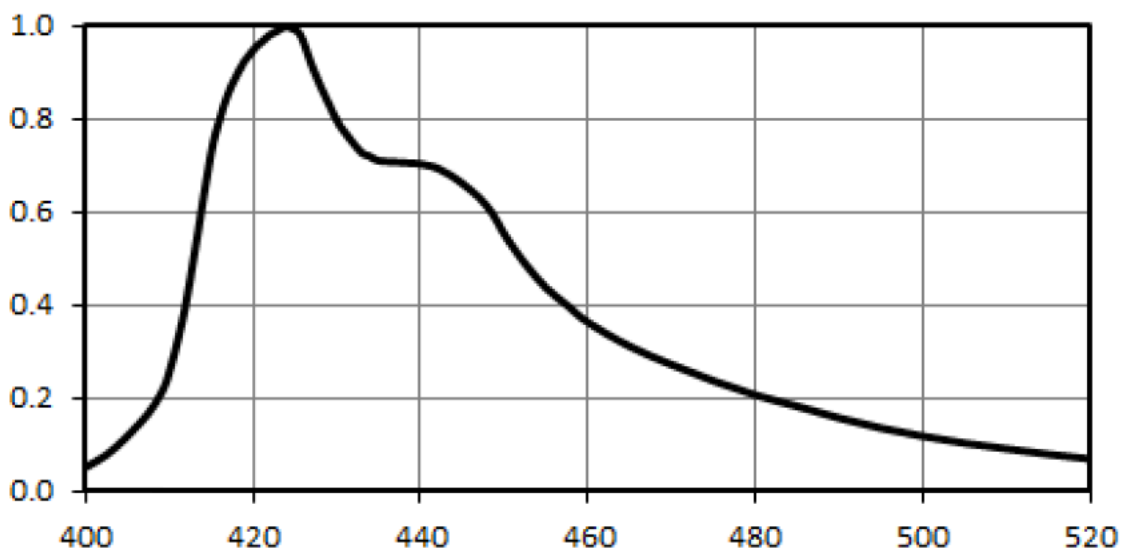

Figure 3: Emission spectrum of EJ-212 scintillator.

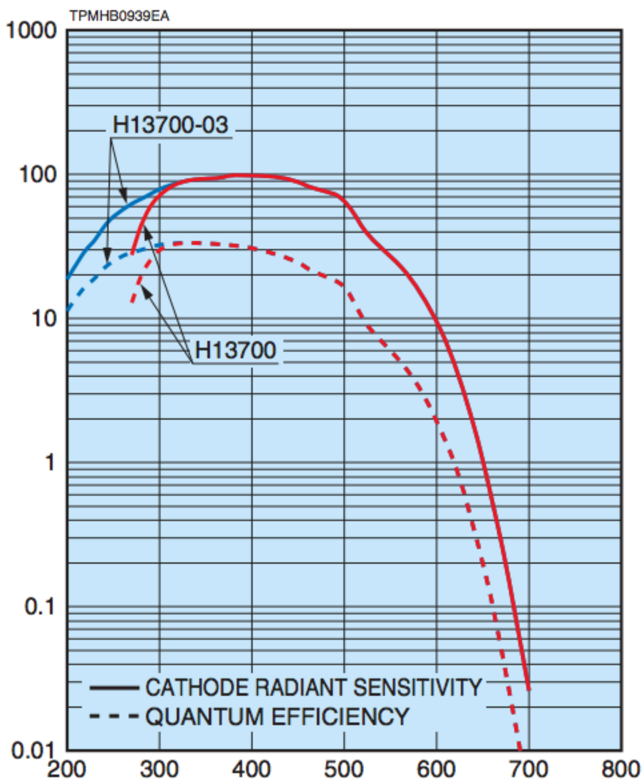

Figure 4: Quantum efficiency of the Hamamatsu H13700 PMT being considered for use in the tile detector.

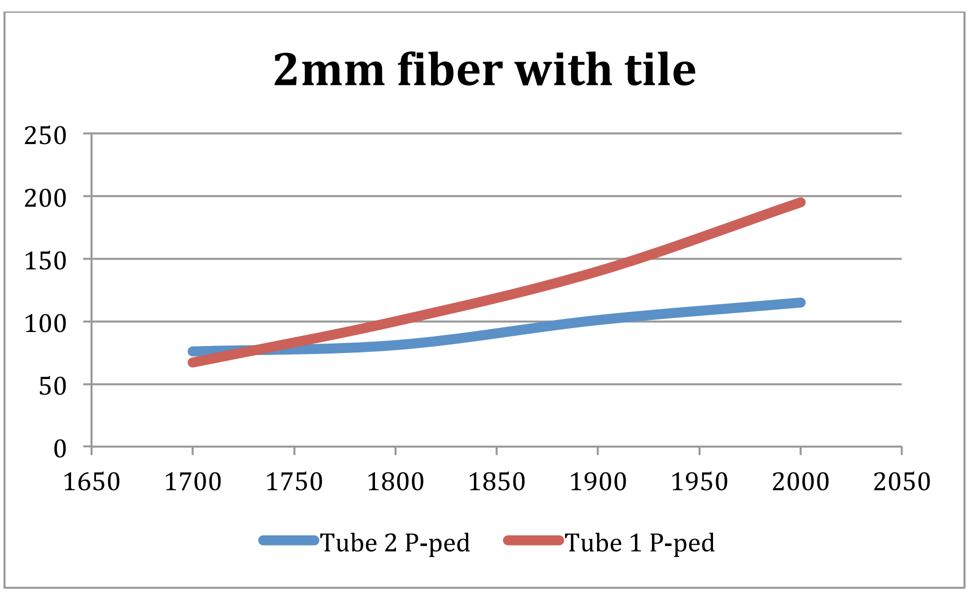

Figure 5: PMT response as a function of high voltage. PMT-1 is red, PMT-2 is blue. The vertical scale is peak location of the Am-241 alpha response.

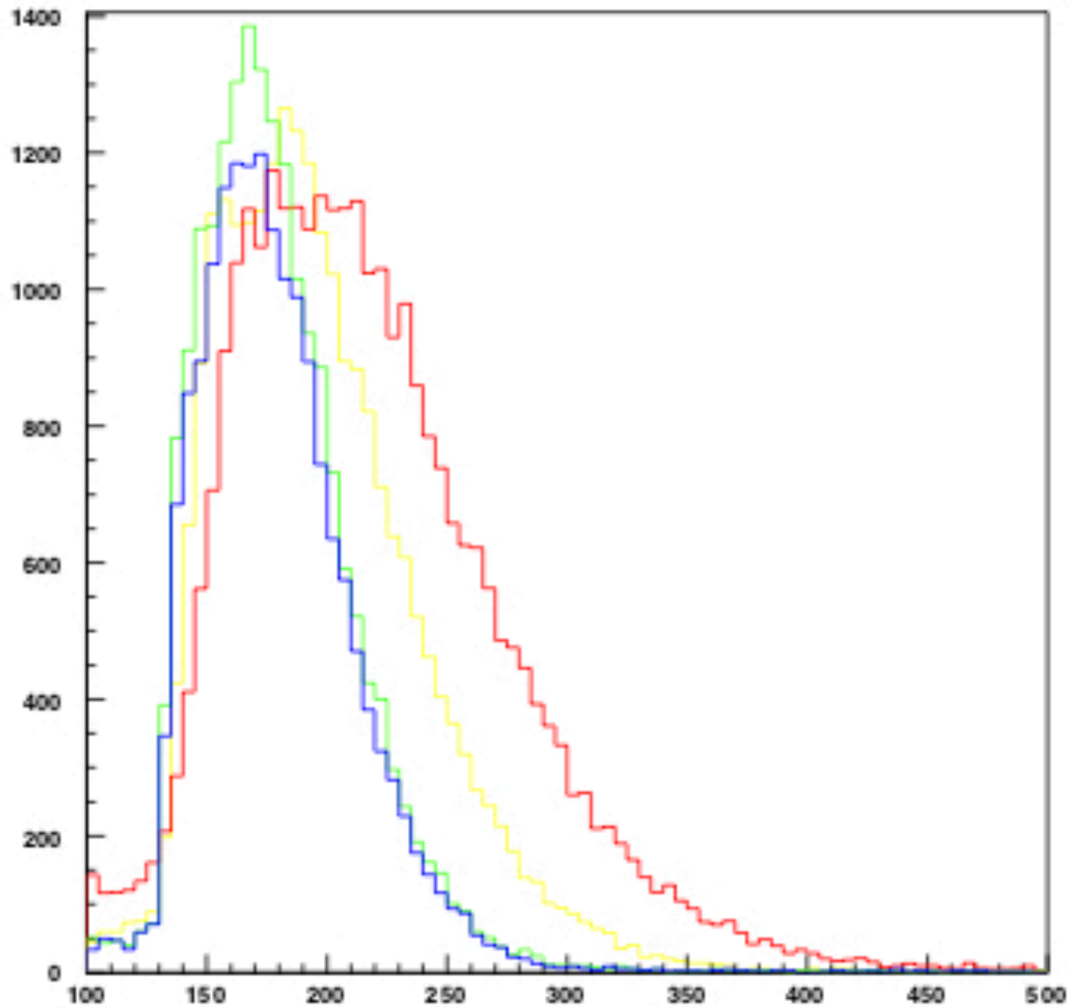

Figure 6: showing the response of scintillating tile to the Am-241 alpha source with 2mm wavelength shifting fiber readout, as a function of PMT voltage. 1700 volts is blue, 1800 is green, 1900 is yellow, and 2000 is red.

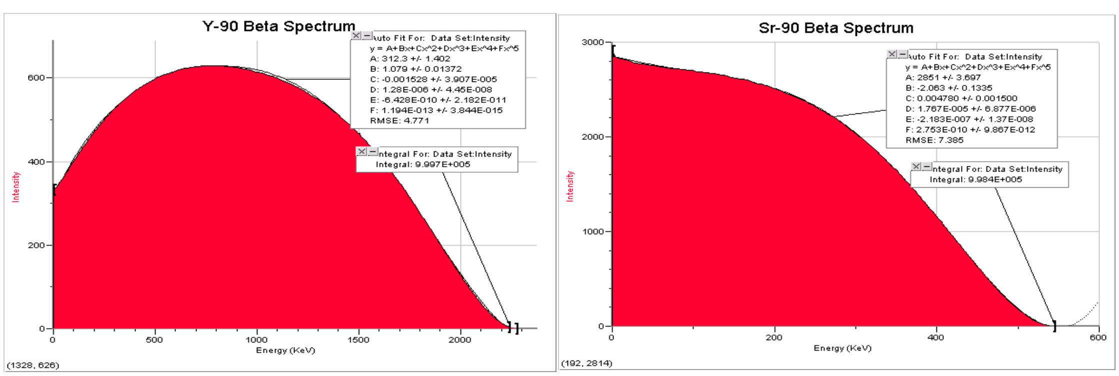

Figure 7: Simulated Beta decay spectra from Y-90 and Sr-90.

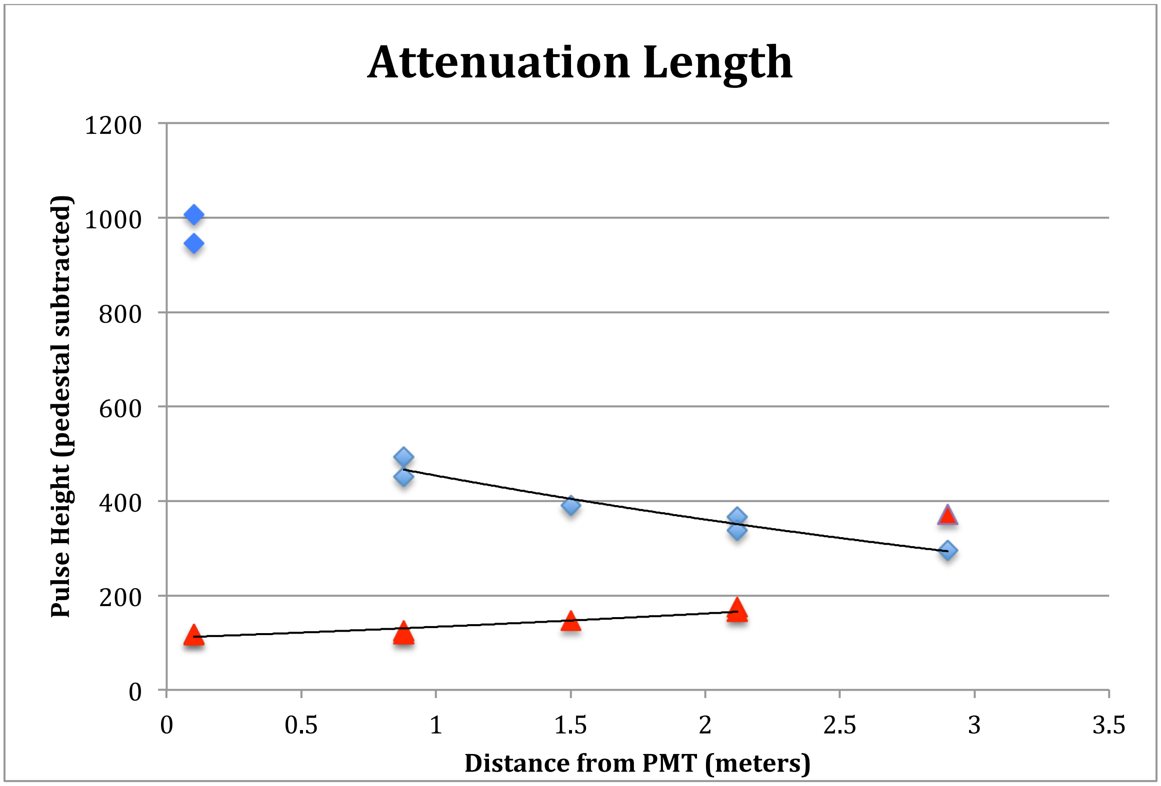

Figure 8: Attenuation length measurement for 2mm fiber readout of a scintillating tile.