Experiment 949
Post Mortem Examination of Range Stack Sector 1, Layers 18-21
and Comparison to some new E949 Counters
Tech Note 7 (same as E787 Tech note 376)

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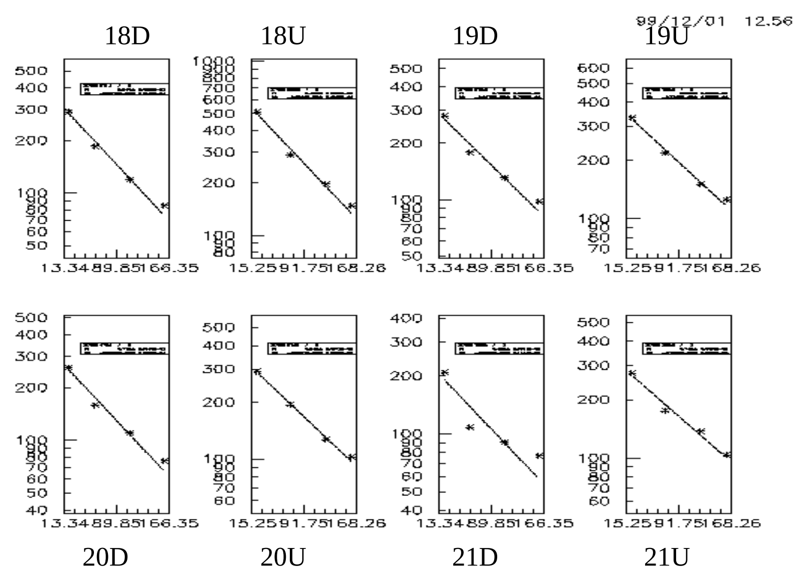
As part of the installation of the Barrel Veto Liner upgrade for E949, an examination was made of range-stack module sector 1, layers 18-21. These tests can provide a direct comparison of some calibration constants determined during the data runs with those determined on the bench. Though statistics is limited, we find that there is general agreement between attenuation lengths, photoelectron yield, and scintillator thickness determinations. We compare the results on the old counters to some new counters tested before insertion into the upgraded E949 detector. We find that the performance of the new counters is better than the old counters.

Bench Tests

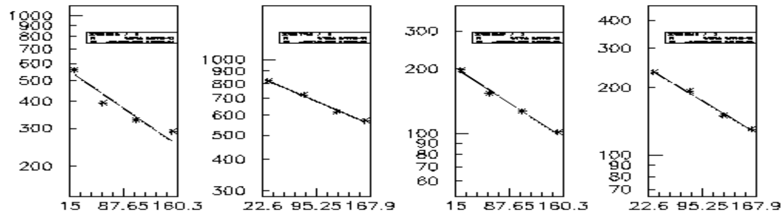
The module containing Sector 1, Layers 18-21 was successfully removed from the detector with no breakage to the counters or to the epoxied joints between the scintillators and the light guides. After transporting to the Physics building, it was set up in the 'yellow room' for tests on its optical performance. The external light guides, silastic cookies, photomultiplier tubes, and bases that were used on these counters for the 1998 run were reinstalled. A series of four pairs of 10cm x 10 cm counters that were previously used for the BVLiner tests were mounted around the module. Cosmic-ray triggers were used to measure the counter performance.

Results for the 4 counters are shown in the following Figure. Plotted are the ADC counts fitted to the peak channel, vs. the distance from the photomultiplier tubes.

ADC counts



The signal coming from phototube 21D was defective, and results in this counter were not reproducible. The plots below come from similar tests made on the new layer 18 and 19 scintillators taken at the same high voltage setting as the plots above.

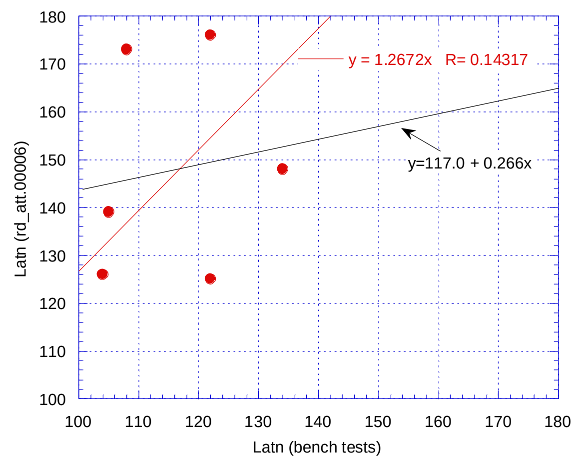


New18D New18U New19D New19U

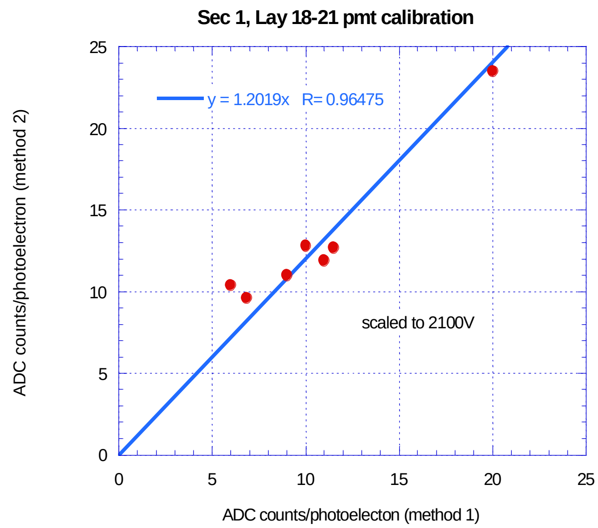
We summarize the results for attenuation lengths (Latn in cm) in the table and figure below.

Counter	Latn old counter (bench test)	Latn old counter (rd_att.00006)	Latn new counter (bench test)
18D	104	126	209
18U	105	139	265
19D	122	176	236
19U	134	148	221
20D	108	173	-
20U	122	125	-
21U	-	125	-

We estimate an uncertainty of about ±10% for the attenuation lengths as determined on the bench based upon repeatability studies. In addition, there is likely a systematic difference between the bench tests and the rd_att determinations of Latn. This is because the nearest of the four measured points was less than 30 cm from the light guide coupling, whereas for the rd_att file, the attenuation lengths were determined very close to the center of the counters.



The single photoelectron sensitivity was determined for each photomultiplier tube in two ways. Method 1 utilized a test-bench setup in which a ^{241}Am doped plastic scintillator was positioned onto a small photomultiplier tube. The discriminated signal from this tube provided a trigger to an ADC unit. A small amount of light from the doped scintillator (an average of ~0.1 photoelectron) impinged upon the tube that was being tested. Method 2 used a set of small trigger counters that was set up surrounding the light guides of the Sector 1, Layer 18-21 counters. Cosmic ray triggers caused a small amount of Cerenkov light to be detected. For method 1, a x10 amplifier provided the necessary gain boost to see the one photoelectron peak; for method 2, the tubes were driven at higher high-voltage setting, and the results were scaled accordingly.



We can now determine the absolute brightness of the range stack counters by converting the number of ADC channels to the number of photoelectrons (Npe), using the average of the two methods described above. The table summarizes the absolute brightness, extrapolated to the center of the scintillator. We assume a most probable energy loss of 3.6 MeV for the assumed thickness of 1.9 cm of plastic for the old counters, and scale to half that thickness for the thinner new layer 19 counter.

Counter	Npe/MeV per side old counter	Npe/MeV per side new counter
18D	8.7	24.1
18U	14.9	35.7
19D	9.2	19.1
19U	10.7	15.2
20D	9.8	-
20U	7.3	-
21U	5.6	-

To compare with the absolute number of photoelectrons found in the table rd_npe.00006, we take the geometric mean of the two sides of the same counter:

Counter (Sector 1, Layer #)	Npe/MeV per side center of old counter (bench test)	Npe/MeV per side old counter (rd_npe.00006)	Npe/MeV per side center of new counter (bench test)
18	11.4	10.1	29.3
19	9.9	10.7	17.0
20	8.5	8.3	-
21	-	5.6	-

I estimate that the uncertainty in the absolute calibration for the bench test is ~20%.

Discussion

The above results show that there is reasonable agreement between the absolute photoelectron yield determined from the data taken during the 1998 run and the bench tests done after disassembly. The attenuation lengths may have some systematic differences, but both bench test and data run results point to rather poor performance for the old range stack scintillator. The initial tests with the new layer 18 and 19 show significant improvement both in brightness and in attenuation lengths. One cannot explain the difference in absolute brightness between the new counters and the old counters based purely upon the large differences in attenuation length. If one extrapolates the attenuation length curves to the intercept at zero scintillator, the new counters are brighter than the old by roughly a factor of 1.7. The composition of the BC408 has nominally been the same for decades, so the difference must be due to some deterioration of the short distance behavior of the scintillator (since the long distance effects are extrapolated out), or else due to some external differences, such as in the light guides.

Physical inspection

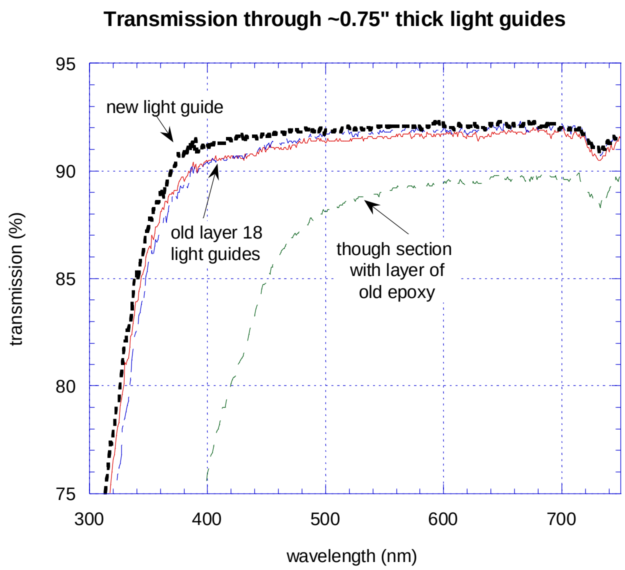
Upon completion of the optical tests, the old module of Sector 1 Layers 18-21 was disassembled. We found that the four individual counters were very difficult to separate from each other. Generally, we found that epoxy used to join the scintillator to the guides had flowed between the surrounding aluminum foil and the scintillator or between the foil and the light guides. This effectively destroyed the internal reflection in these areas. In addition, there were areas in which aluminized mylar tape was secured to the light guide surface, also harming the total internal reflection. There were two places in which black (!!!) plastic shims, used to build up the thickness of the light guide to match to the thickness of the scintillator, were also found epoxied for ~1cm along the light guides. These observations show that the mechanical strength considerations seem to have dominated over ‘optical purity’, at least in this sector 1 Layer 18-21 sample.

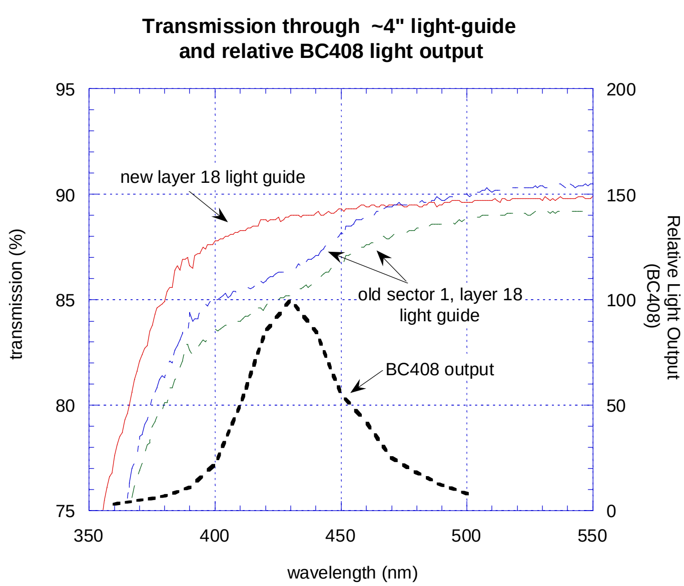
The table below summarizes some dimensions found. The thickness was determined from several measurements made along one edge of the scintillator. The calculated thickness comes from the rd_pmu calibration table, where the assumed saturated energy deposit of 3.04 MeV was scaled to the assumed thickness of 1.905 cm. The calculated thickness may be systematically higher than the measurement, but the variation between layer 18 and layer 19 isn’t too far off.

	Dimensions (cm)				
	Minimum thickness	Maximum thickness	Calculated thickness (from rd_pmu)	Minimum width	Maximum width
Layer 18	1.946	1.978	2.041± 0.005	20.97	21.03
Layer 19	1.831	1.854	1.869± 0.021		
Layer 20	1.816	1.862	-		
Layer 21	1.913	1.948	-	21.49	21.54

Light Guide transmission tests

The internal light guides for layer 18 were deliberately broken from the scintillator in order to measure transmission characteristics in a spectrophotometer. The figure below shows the transmission through one of the old light guides in three different areas. The light passed through ~ ¾" of plastic in all cases shown here. In one case, light transmission was measured through the couple of mils of epoxy that was stuck on the face of a light guide for several cm. For comparison, a similar measurement was made through a section of the new light guide used in the new layer 18. Most notably, we see that the epoxy, presumably BC600, has yellowed significantly. In addition, there is a small difference in transmission below ~500nm, seen when comparing the old light guide to the new.





The next figure shows the transmission though two sections of the old light guide, and one section of a new light guide, where the measurement was through the ~10cm width of the light guide. Also shown is the emission spectrum of the wave-shifting component in BC408. It becomes apparent that the optical quality of the light guide material is affecting the transmission of the scintillator light. We expect that the effect of this poorer acrylic would decrease the light by ~ 30 to 40% when extrapolated to the entire ~100 cm length of the internal light guide. In addition, if one considers the effect of the yellowed epoxy, both from the necessary epoxy joint between the scintillator and the light guide plus the extra epoxy on the side of the light guide and scintillator, it is easy to see that factors outside of the scintillator quality may be causing a substantial fraction of the loss in light yield. No significant differences in transmission characteristics were noted between one section of old light guide that was inside compared to outside the magnet, where one might expect the radiation doses to have differed.

Conclusions

Measurements were made on counters from sector 1, layer 18-21 of the old E787 range stack after they were removed from the detector. We find general agreement between bench test measurements and the calibrations determined from the data runs. Though bench test statistics are quite limited, I find it especially encouraging that parameters which describe the range stack performance can be pulled out from calibration techniques using kaon decay data.

The old scintillator attenuation lengths are relatively short. In addition, the photoelectron yield is rather paltry, even when corrected for the short attenuation lengths. A significant contribution to the poor performance stems from problems in the optical quality of the light guide material, yellowing epoxy, and a liberal amount of epoxy located in places that harm the internal reflection of light within the light guides. Initial measurements with new scintillator and new light guides show that the new layer 18 may have ~2.5 times the photoelectron yield per MeV at the center of the detector as the counter it replaces.

It might be interesting for E949 to consider replacing the internal light guides, especially on the counters in the pnn(1) stopping region, as a relatively low material cost option. Manpower costs would not be low, however. This should be considered only if it can be determined that extra photoelectrons would lead to improved $\pi-\mu$ separation and also only if newly purchased UVT acrylic can be found with very high quality. We might also consider new scintillator in the modules that are important in the pnn(1) stopping region. These are layers 15-17 (where $\pi-\mu$ separation is most critical because of higher μ background) and maybe layers 11-14. Though expensive, this might be a wise long-term investment as well.