Performance of ADRIANO2 calorimeter prototype with 120GeV protons

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Introduction to the REDTOP Experiment

REDTOP (Rare Eta Decays with TPC for Optical Photons) is a proposed Fermilab experiment that aims to study fundamental symmetry violations by capturing and analyzing the decay products of the eta meson. The experiment expects to produce 10^{13} eta mesons per year by colliding protons from a 1.8 GeV proton beam with a target made of 10 foils of beryllium. The REDTOP detector is composed of multiple sub-detectors, including the fiber tracker, Optical TPC, and ADRIANO (A Dual Read-out Integrally Active Non-segmented Option) calorimeter. ADRIANO is a dual-readout calorimeter that detects electromagnetic and hadronic particle showers using two optically separated media. Tiles made of optical standard lead-glass and scintillating plastic release photons via the Cherenkov effect and scintillation respectively, which are converted into photoelectric signals using SiPMs (Fig. 1, 2). These signals are used for particle identification purposes. Prototype testing with ADRIANO2 has been ongoing at Fermilab's Test Beam Facility in June 2019, December 2019, and June 2021 (Fig. 3).

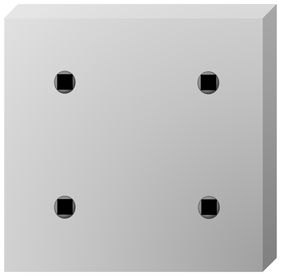

Fig. 1: Diagram of lead-glass/scintillating plastic tile with a silicon photomultiplier (SiPM) in each dimple

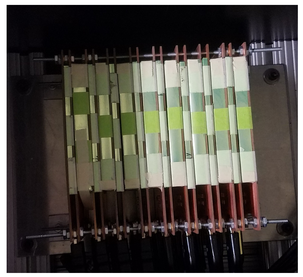

Fig. 2: Lead-glass and plastic tiles wedged between PCBs with SiPM sensors in ADRIANO2 prototype

Fig. 3: ADRIANO2 test beam prototyping performed in December 2019 at Fermilab's Test Beam Facility

Analysis

The energy loss of charged particles traveling through media follows the Bethe-Bloch formula, while the fluctuations of their energy loss due to ionization is characterized by a Landau distribution. We expect that the distribution of amplitudes (and proportionally, average number of photoelectrons) measured by the SiPMs of ADRIANO2 also closely follow Landau distributions. Scripts written in C++/ROOT were developed to convert the binary data from ADRIANO2's DAQ and extract the amplitudes of thousands of events to fit their distributions to a Landau (Fig. 4). SiPM channels 4-7 (optical lead-glass tile) and 16-19 (scintillating plastic tile) were selected as good analysis candidates due to their reliable signals across different beam conditions. Runs of the test beam with the same beam conditions were merged together to increase the sample size of the datasets.

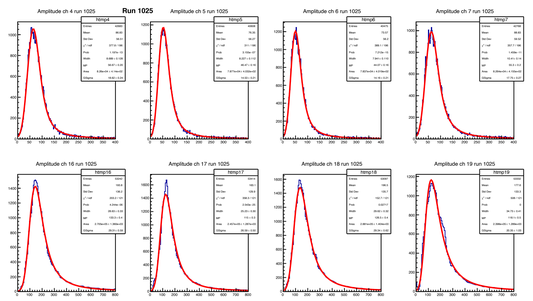

Fig. 4: Amplitude distributions of glass and plastic SiPM channels are fitted to Landau distributions (red curve).

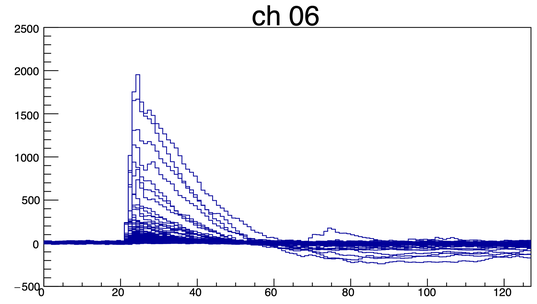

Fig. 5: A representative waveform from Run 1037, SiPM channel 6 (lead-glass).

Conclusions

The Landau-fitted amplitude distributions yielded a value for the most probable energy loss (MPV) for each channel and beam position, and Fig. 6 shows the distributions of the MPV values as a function of the distance away from the SiPM. The distributions approximate an exponential curve, as described by Beer-Lambert's Law. Therefore, the light travelling inside the two tiles on its path to the sensors undergoes an absorption process, due to the fact that the bulk materials are not fully transparent and the wrapping material has a reflectivity < 100%. From the exponential fit, we can conclude that the light attenuation (absorption) length for the glass tile is 79±8 mm and 67±9 mm for the plastic tile. Further calibration is underway to convert the units of the analog-to-digital conversion module (ADC) in the data acquisition system to an average number of photoelectrons.

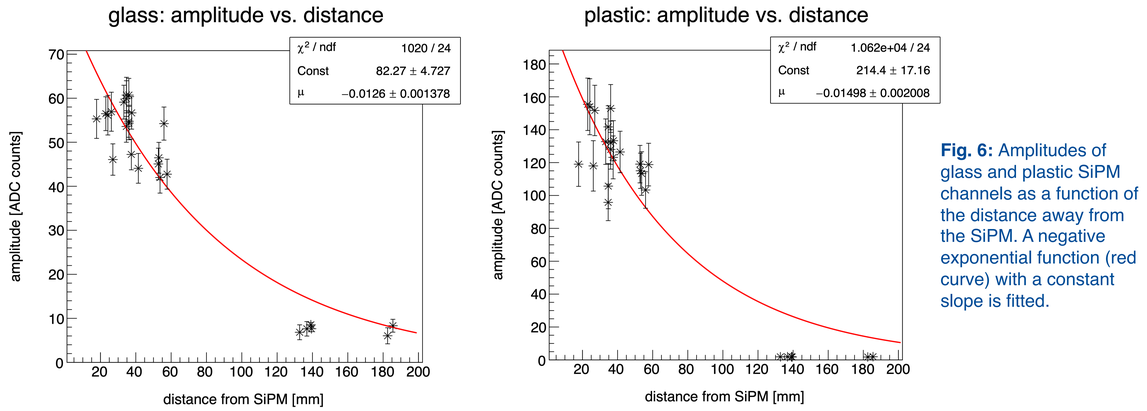

Fig. 6: Amplitudes of glass and plastic SiPM channels as a function of the distance away from the SiPM. A negative exponential function (red curve) with a constant slope is fitted.