EMPHATIC

Optical Reflectors in an ARICH Detector for a Hadron Production Experiment

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ABSTRACT

EMPHATIC (Experiment to Measure the Production of Hadrons At a Testbeam In Chicagoland) is a low-cost, table-top-sized, hadron-production experiment located at the Fermilab Test Beam Facility (FTBF) that will measure hadron scattering and production cross sections that are relevant for neutrino flux predictions. High statistics data will be collected using a minimum bias trigger, enabling measurements of both interacting and non-interacting cross sections. Particle identification will be done using a compact aerogel + heavy gas hybrid ring imaging Cherenkov (RICH) detector, a time-of-flight (ToF) wall, and a lead glass calorimeter array. The ARICH focuses on the kaons, pions and protons separation with multi-track capability up to 8 GeV/c. Here we show the study of performance and implementation of optical reflectors in the ARICH system for phase 1 of the experiment to reflect Cherenkov light outside of the PMT array acceptance onto the PMT array increasing the angular acceptance of the experiment with a low-cost improvement.

INTRODUCTION

Neutrino experiments use realistic simulations of production beam lines to predict neutrino fluxes and spectra and a necessary component is modeling of hadron production and interactions in the production target and beam line material like magnetic horns, decay volume walls, etc. Uncertainties on hadron interaction modeling typically dominate the total error on the neutrino flux prediction, these measurements are also important for atmospheric neutrino flux calculations as well.
EMPHATIC will focus on measurements with beam energies below ~15 GeV which are not currently accessible in NA61/SHINE
beam line but will also do measurements connecting production from ~2 GeV to 120 GeV beams on a broad range of target materials relevant for out-of-target interaction modeling. Figure 1 shows a schematic of the EMPHATIC spectrometer.

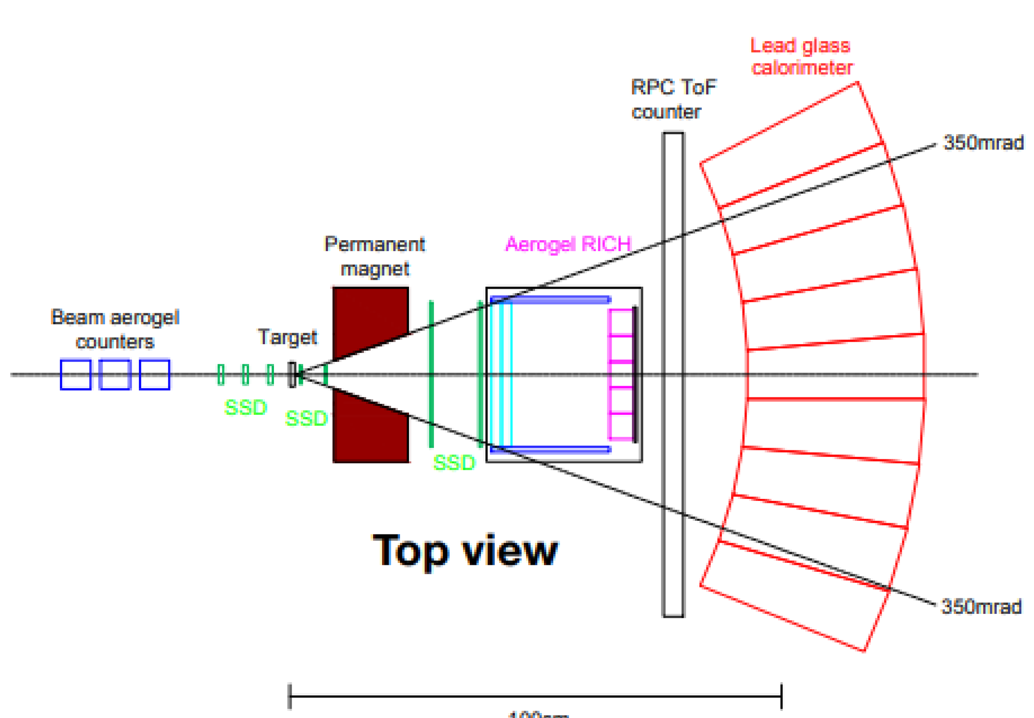

Figure 1. Schematic view of the EMPHATIC spectrometer.

EMPHATIC will provide new detection methods with independent systematic effects from NA61/SHINE using silicon tracking and a focusing aerogel ring-imaging Cherenkov for identification of forward particles with momenta above 2 GeV/c. Aerogel plates with a total thickness of approximately 4 cm are followed by multi-anode PMTs. The angular acceptance of the detector will be increased by using mirrors to reflect the Cherenkov light outside of the PMT array acceptance, which is the object of study of this work.

METHODOLOGY

As previously mentioned, the detector to be used in the EMPHATIC experiment will be a RICH detector with an Aerogel radiator (ARICH). The work done here involves the development of a simulation and its associated data analysis for mirror performance. In practice, we want to find the most suitable mirror material to be used. The simulation was done in the Geant4 program which uses Monte Carlo method to simulates the passage of particles through matter.

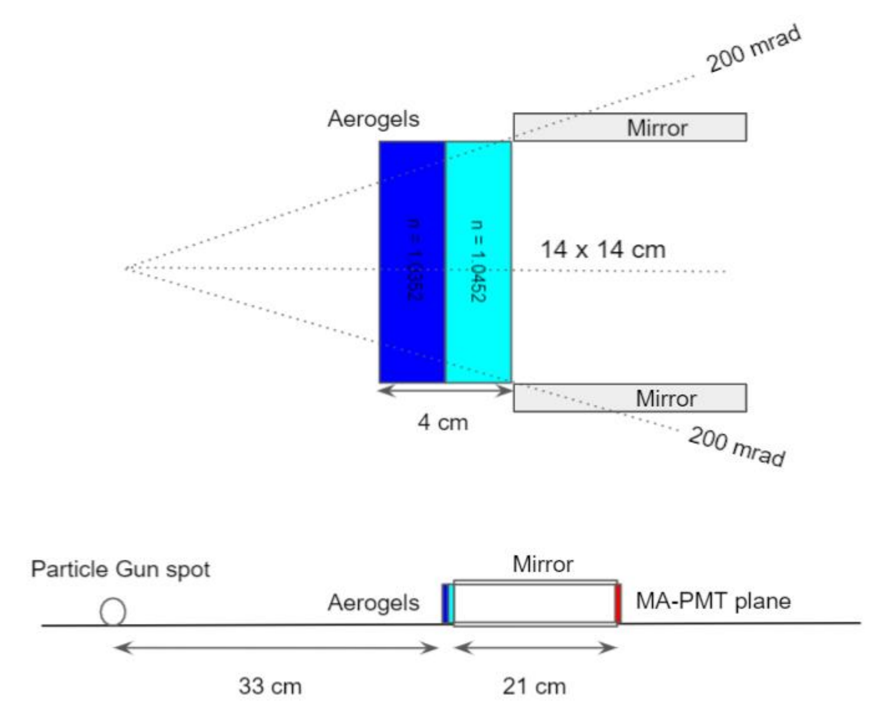

Figure 2. Schematic view of the simulation geometry

The geometry of the simulation is represented in the Figure 2. The particles are produced from a point source with a given direction and momentum. The first of two layers of aerogel radiator are 33 cm downstream from the particle source. Each layer consists of one piece of aerogel measuring 14 cm x 14 cm x 2 cm. An array of PMTs are placed 21 cm downstream from the front of the first layer of aerogel. In the simulation the PMT array consists of a large sensitive volume. The size of the PMT volume matches the current design of PMTs array with 16 x 16 cm. The PMT Quantum efficiency was considered to correct the results to be realistic to what the hardware can detect.

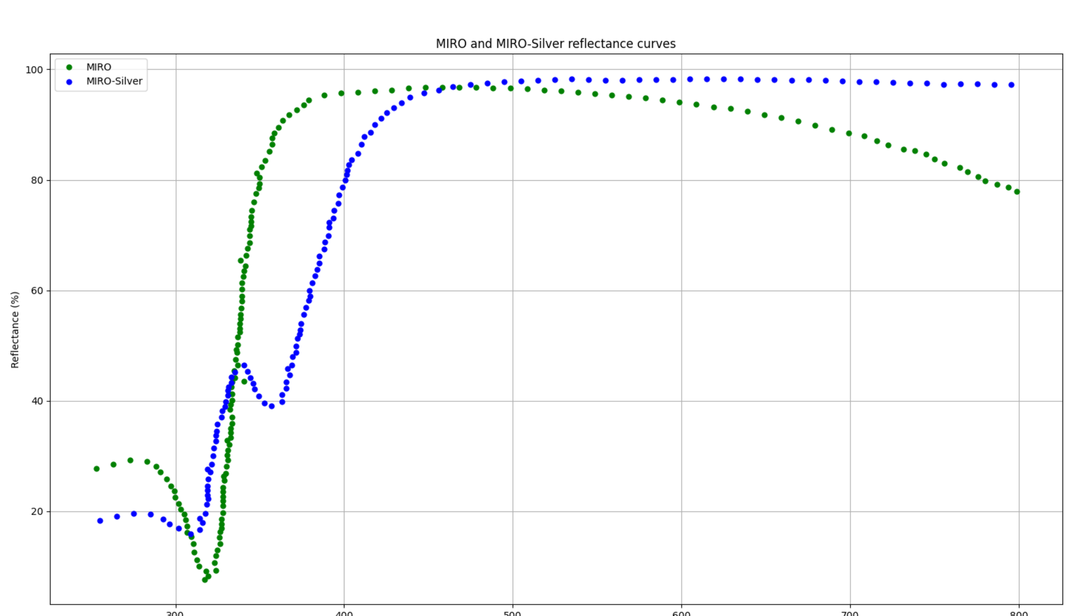

Figure 3. Reflectance curves for MIRO and MIRO-Silver materials.

In practice, we want to find the most suitable mirror material to be used. In our initial tests we chose two materials from the company Anomet®: MIRO and MIRO Silver whose reflectance curves are shown in the Figure. The ARICH detector is designed for separating protons, kaons and pions up to 8 GeV. For this specific study of the mirrors, we are only interested in the photons generated so any of previous particles can be used. In the following results we use for pions at 7 GeV with an incidence angle of 0 mrad to 120 mrad which is the allowable angular range given by the magnet in the spectrometer.

RESULTS

As a first analysis we should look the wavelength distribution generated by the aerogel radiators. The distribution is shown in Figure 4. Characteristic of the Cherenkov radiation, we see that the spectrum generated by the aerogel tends towards the low wavelength (high energy) region. However, with the existence of the Rayleigh scattering effect that happens inside the aerogel we see how the distribution changes due to the scattering of the low wavelength photons being more prominent.

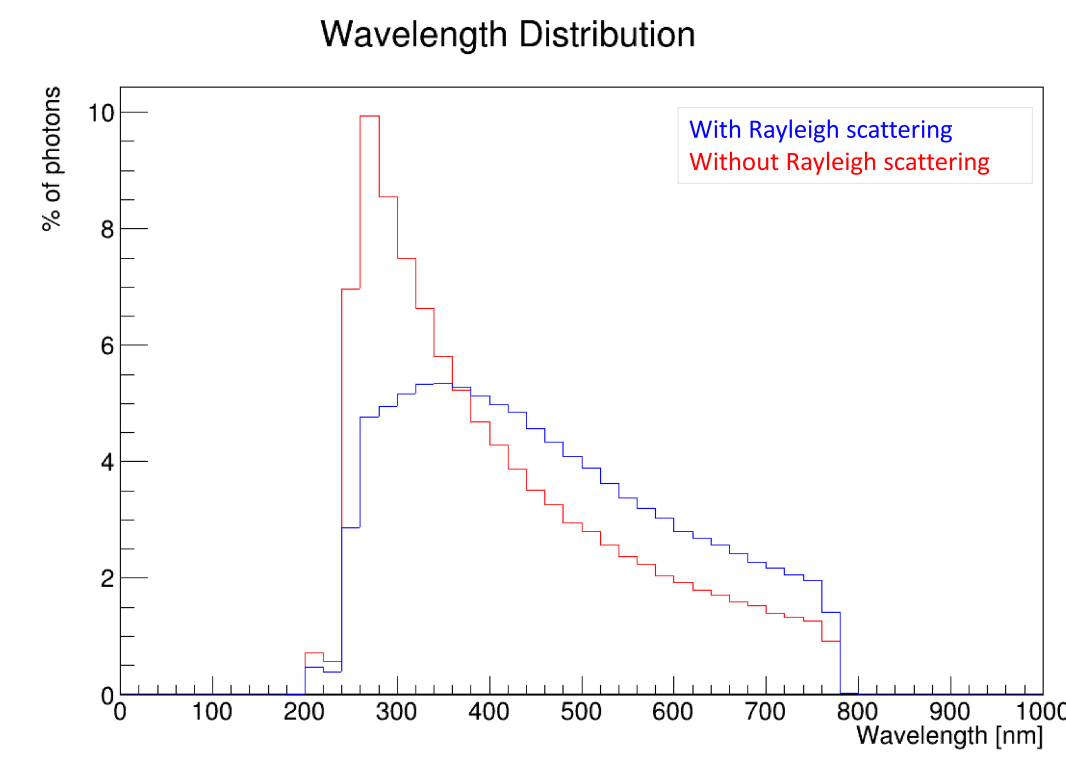

Figure 4. Distribution of the wavelengths generated by the aerogel without and with the effect of Rayleigh scattering.

With all the distributions acquired from the simulation, we made a correction based on the quantum efficiency of the PMT. This procedure is shown in the Figure 5. For each wavelength acquired from the simulation we made an interpolation with the data of the Q.E. and we assign a weight to that wavelength and thereby reproduce the corrected distribution.

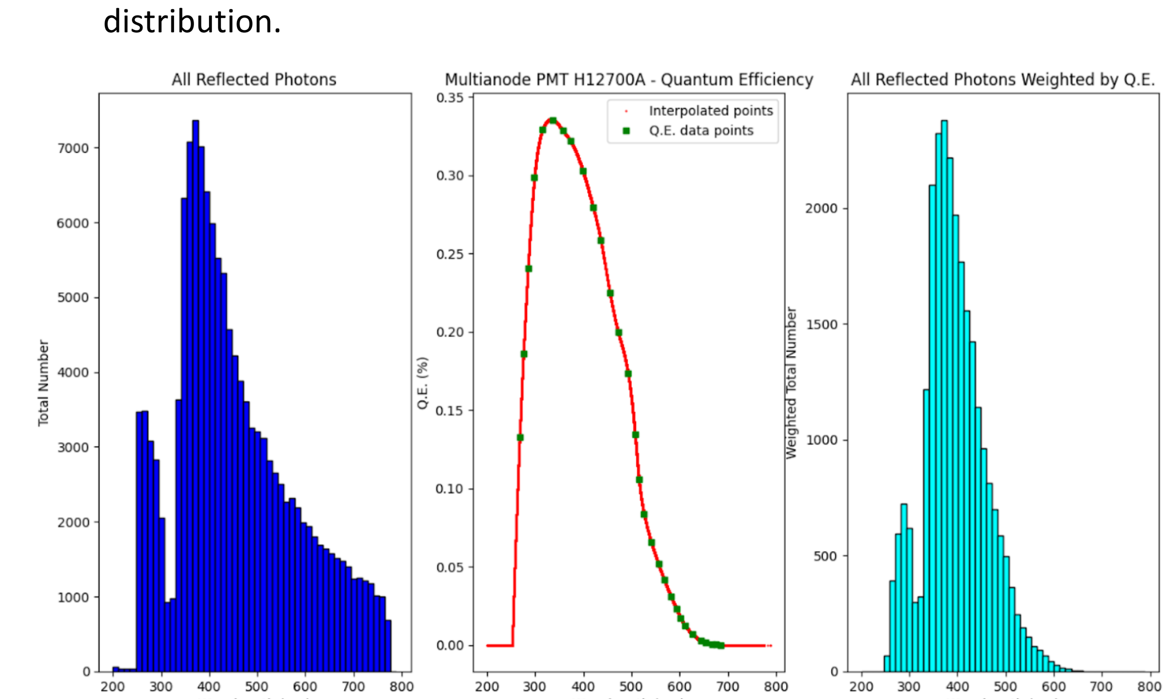

Figure 5. In the first frame we have a histogram with the initial distribution of reflected photons. In the second frame we have the QE data points of the PMT and the interpolated points. In the third table we have the corrected histogram.

Analyzing a thousand events per incident angle, we calculate the area of histogram for photons generated in the simulation and look for the differences in the total number of reflected photons, the total number of reflected scattered photons and in the total number of reflected not-scattered photons between the materials of the mirror's candidates.

Figure 6 shows how the total reflected photon ratio differs for each material according to the angle of the incident pion.

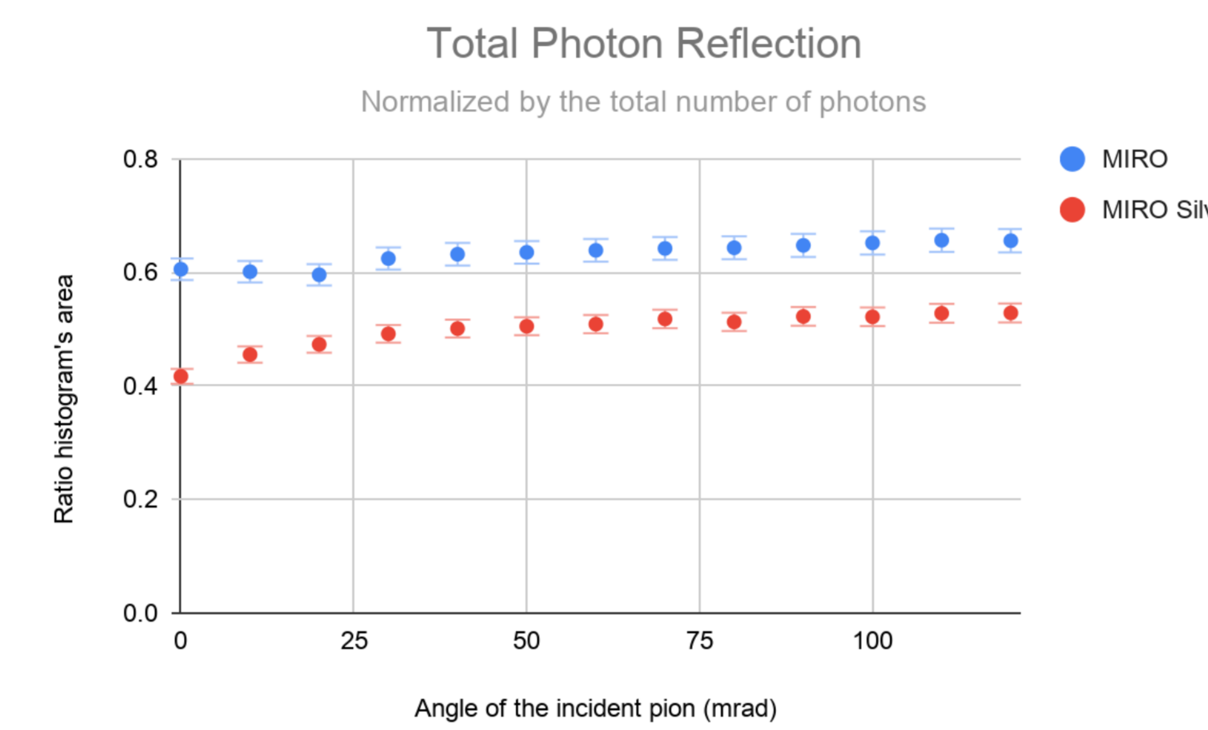

Figure 6. Photon ratio reflected per angle.

In figure 7 we see the ratio between the not-scattered and scattered photons that have been reflected.

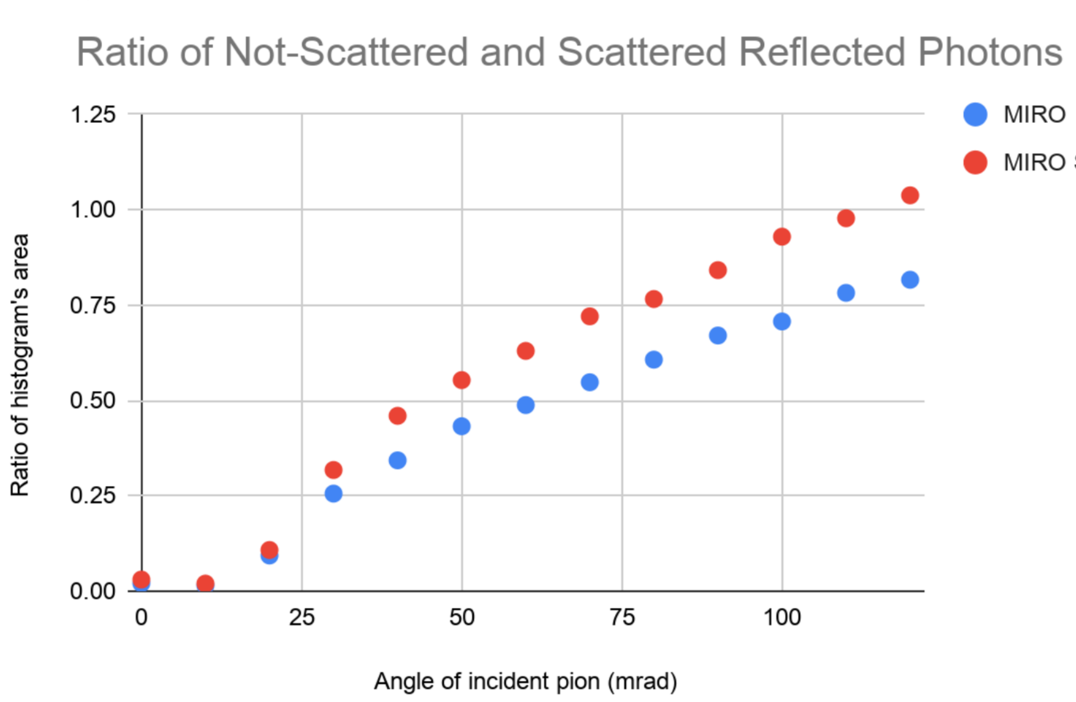

Figure 7. Ratio between photons not-scattered and scattered among the reflected photons.

CONCLUSION

We note that the contribution of photons with short wavelength is more important for the choice of mirrors, we see that the Cherenkov radiation spectrum is more prominent in this range, which shows that the material that has greater reflectance in this region will have a better efficiency as evidenced in Figure 6.
However, light scattering is an undesired effect since these photons do not have the correct momentum direction for the PID. When comparing the ratio between scattered and non-scattered light we see an inversion between the materials showed in Figure 7.
Further analysis is underway to see how this inverted behavior affects the PID. In addition, we are doing an experimental investigation of the materials by mapping the surface with a laser to analyze the collection of light.

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