Study of light propagation in scintillator-fibre configurations

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Introduction

Rejection of muon background is an important pre-requisite for a rare particle detection experiment. For this reason, the laboratories for neutrino detection are constructed deep underground. It is possible to have such laboratories on surface or at shallow depths if one can efficiently reject the muon background. In this work, we present preliminary simulation studies made on different configurations of plastic scintillator and Wavelength Shifting (WLS) fibres readout by Silicon Photomultiplier (SiPM). These studies are in contexts of Cosmic Muon Veto detector planned for India-based Neutrino Observatory [1] (INO). Three layers of scintillator strips are planned to cover the INO detector from top and four sides.

Detector setup

We consider a plastic scintillator strip of width 5 cm (X-direction) and length 500 cm (Y-direction) with two different thicknesses; 1 cm and 2 cm. The scintillator has two elliptical grooves (for WLS fibre) separated by 2.5 cm (in X-direction) along the length of the fibre. The semi-minor (x) and semi-major (z) axes of grooves are 0.75 mm and 1.5 mm respectively. The scintillator is covered by Tyvek paper with an air gap 1 mm. The length of the WLS fibre is 500 cm and two different diameters of 1.5 mm and 1 mm are considered in this study. All four ends of fibers are read out by SiPMs of size 2 mm×2 mm with 40×40 pixels with 80% quantum efficiency. Refractive indices for scintillator and air are 1.58 and 1.000293 respectively. The refractive indices of core and cladding of WLS fibre respectively are 1.62 and 1.5.

Simulation method

We developed C++ based code for the simulation study of our detector. In the first step, 10000 muons are generated on the top surface of the scintillator with angle of incidence as per the $\cos^2\theta$ distribution within $\theta < 60^o$. Energy deposited by muon in the scintillator is taken from Landau distribution with:
MPV $\mu = \frac{2h}{\cos\theta}$ (MeV);
Width $\sigma = (0.12)\frac{2h}{\cos\theta}$ (MeV);
where h is height of the detector (in cm).

Number of photons produced per MeV energy deposition (by muon) in scintillator is taken as 10000 [2]. The photons are produced randomly at any point along muon path with direction cosines uniform in 4π. The total pathlength travelled by the photon was taken randomly from exponential distribution with attenuation length of scintillator and WLS fibre being taken as 20 cm and 197.3 cm respectively.

The photons generated will be propagated in the scintillator. If a photon comes out of a scintillator surface it undergoes diffused reflection by tyvek paper with 5% inefficiency and re-enters the scintillator. Photon travelling inside the scintillator may enter the nearest elliptic groove if it falls in its path. It can be either accepted in the WLS fibre or comes out of the other side of the groove. Photon accepted in the WLS fibre will be absorbed at some point along its path inside the fibre and at that point a new wavelength-shifted (green) photon is emitted with direction cosines distributed uniformly in 4π.

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TABLE I: Configurations of Scintillator-Fibre

Cases	Fibre Diameter (mm)	Scintillator L×W×H (cm^3)
case:A	1	500, 5, 2
case:B	1.5	500, 5, 2
case:C	1.5	500, 5, 1

The photon undergoes multiple total internal reflections inside WLS fibre, if the angle of incidence $\theta_i > \theta_c$ (critical angle) of the core-cladding interface. Photons which transmit into the air gap from fibre end may fire pixels of SiPM with active region 74%. A muon is called successfully detected if the total number of pixels fired in all 4 SiPMs is greater than the defined threshold on number of pixels. Thus, the Efficiency (ε) of the detector is:

$$\varepsilon = \frac{\text{Number of muons detected}}{\text{Total number of incident muons}} \quad (1)$$

Outcome of the study

In the first study, we consider 3 different scintillator-fibre configurations as given in Table I. In Fig. 1 efficiency curves are plotted as a function of threshold on number of pixels for 3 cases. It is seen that efficiency is best for the case:B and similar for other two cases. In the case:A less photons enter the WLS fibre because of its small diameter as compared to case:B. In case:C scintillator thickness is smaller than that in case:B hence photon production is less.

In the second study, we consider the configuration corresponding to case:B. The gap between the two fibres is then varied and efficiency is obtained for each case. Fig. 2 shows the efficiency as a function threshold on number of pixel for different gaps between the two fibres symmetrically placed in the detector. From this study we noticed that when the fibres are close to the centre or to the edges then the efficiency drops.

Summary

If the detector thickness is decreased from 2 cm to 1 cm then the efficiency decreases because of less photon production but it can be compensated by increasing the WLS fibre diameter from 1 mm to 1.5 mm. The study also concludes that when the fibres are close to the centre or to the edges then the efficiency goes down because less number of photons enter into the grooves. The cases with all other gaps considered in the study have similar efficiencies.

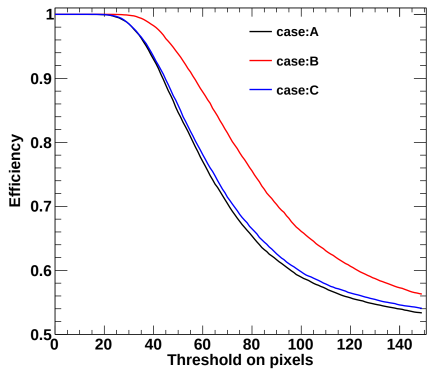

FIG. 1: Efficiency curves for different detector configurations.

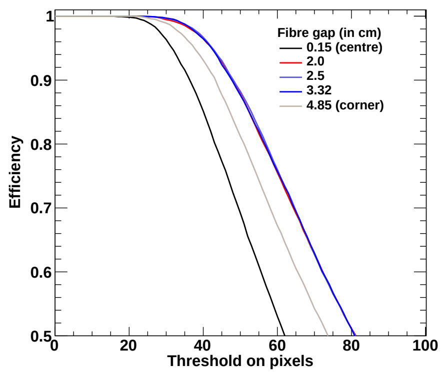

FIG. 2: Efficiency curves with different gaps between two WLS fibres.

References

[1] S. Ahmed *et al.* [ICAL Collaboration], Pramana **88**, 79 (2017).

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