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Direct and Diffuse Light Components in Large Area Scintillation Counter

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Abstract

Large area scintillation counters are still the main element in extensive air shower arrays which aim to detect UHE γ-ray sources. Despite the fact that they have been in use for a relatively long time, their behavior is not easy to characterize except in special cases; e.g. thin scintillator and large scintillator-to-PM distance. This work attempts to provide a general formula for different experimental set-ups. The effects of changing the height of the air light guide and the scintillator thickness on the mean arrival time for direct and diffuse light components was studied by Monte Carlo simulation. The use of the derived formula together with the Monte Carlo results provide a good agreement with the experimental data.

1 Introduction

Large area scintillation material coupled to a photomultipier tube (PM) either directly or through light guide have been used for a long time in many experiments measuring the density and arrival time of the shower particles. There have been many attempts to derive a theoretical equations to describe the time and density responses of such a detector (Barnaby and Barton, 1960, Keil, 1970, and Jiang and Lambert, 1987). Generally, a great deal of disagreement exists between theoretical calculations and experimental measurements for such a detector. This is interpreted as being due to incorrect values of some physical parameters; e.g. light attenuation coefficient, speed of light in scintillator, reflectivity of the diffuse material, and rise and decay time of scintillator.

It is the purpose of this work to present a summary of a study concerning theoretical, simulated and experimental results that are in reasonable agreement. The application of the theory should be helpful for the construction of large area detectors.

2 Theoretical Model

The inside walls of the light guide and the outside surfaces of the scintillator are normally painted with a reflecting white paint. The total light that reaches the PM in this type of detectors is classified into two main components. Scintillation light emitted from the scintillator can reach the PM directly (direct light). It can also reach the PM through a number of reflections (diffuse light) from the walls of the light guide and/or the outside surfaces of the scintillator. The diffuse light component can be subdivided into two parts (Abdou et al.). The first one (diffuse I) corresponds to light that reaches the PM directly, after being subjected to one or more reflections inside the scintillator. The second one (diffuse II) corresponds to light that only reaches the PM after at least one reflection on the inside walls of the light guide.

The detector is characterized by a scintillator thickness T and a light guide height H. When a particle with sufficient energy hits the scintillator, it loses part of its energy to the scintillation material which results of the production scintillation light along its path. The detection probability of the emitted light along this path can be considered to have a Gaussian shape with a peak at certain point along the path of the particle. Instead of dealing with the whole line path, one can take this point to represent all light emission along the particle trajectory. This can be done once the dependence of its position inside the scintillator on the detector geometry is known. Assuming an isotropic light source inside the scintillator at a depth y and a distance x from the scintillator-air boundary to the center of the PM, the mean arrival time for the direct light component can be given by

$$< t_d >= \frac{n_a}{c} \cdot r + \frac{n_s \varepsilon}{c} \cdot T + \tau$$

where r and εT is the distance in air and scintillator, respectively, $n_a = c/V_a$ is the refractive index of air, $n_s = c/V_s$ is the refractive index of scintillator, and $\tau = \tau_s + \tau_E$; τ_s is time delay in the scintillator and τ_E is the delay in the electronics. In case of diffuse I component, light travels an average distance (αT) before it reaches the scintillator-air boundary. βr and γT are the mean distances traveled by the diffuse II light in the light guide and inside the scintillator, respectively. The mean arrival time for diffuse I and II components are given by

$$< t_I >= \frac{1}{V_a} \cdot r + \frac{\alpha}{V_s} \cdot T + \tau$$

$$< t_{II} >= \frac{\beta}{V_a} \cdot r + \frac{\gamma}{V_s} \cdot T + \tau$$

The mean and r.m.s. of the time of the total light is then given by

$$< t >= \frac{f_d + f_I + \beta f_{II}}{V_a} r + \frac{\varepsilon f_d + \gamma f_I + \alpha f_{II}}{V_s} T + \tau$$

$$\sigma^2 = \left(\frac{f_d + f_I + \beta f_{II}}{V_a}\right)^2 \sigma_r^2 + \left(\frac{f_{II} r}{V_a}\right)^2 \sigma_\beta^2 + \left(\frac{T}{V_s}\right)^2 \left(f_d^2 \sigma_\varepsilon^2 + f_I^2 \sigma_\gamma^2 + f_{II}^2 \sigma_\alpha^2\right) + \sigma_\tau^2$$

where f_d, f_I and f_{II} are the fractional of light in the three components and σ_i is the r.m.s. of the variable i.

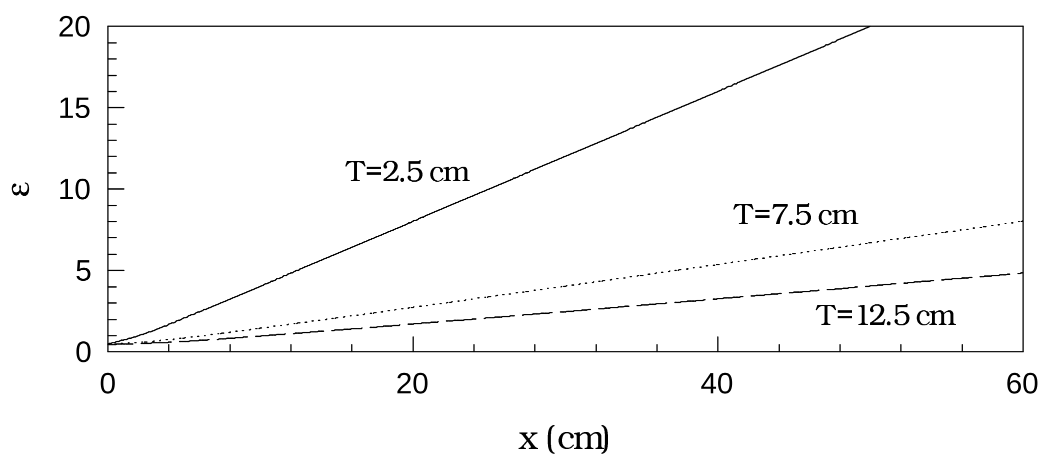

Fig. 1. Results of Monte Carlo simulation of the variation of the parameter ε of the direct light component with the distance x for different scintillator thickness.

To verify these results, Monte Carlo simulations were performed to calculate the variation of the parameters ε, α, β and γ. The program simulates a vertical line inside the scintillator from which light is emitted in random directions. This line represents the passage of a charged particle through the material. It is assumed that the particle travels through the whole scintillator thickness without being subjected to considerable multiple scattering or changes in the energy loss. Each emitted photon is assigned a wave length from the emitted light spectrum of the scintillator. The light is then followed in the scintillator and air until it reaches the PM or is absorbed. The program takes into account the attenuation inside the two media; air and scintillator. If the light hits the PM, the fraction transmitted through the PM's glass is calculated and the PM's quantum efficiency is taken into consideration. Each calculated parameter is weighted by the fraction of light collected by the PM. The values of these parameters represent the distances and directions traveled by the light which suffers the lowest attenuation and has the highest probability of being detected by the PM.

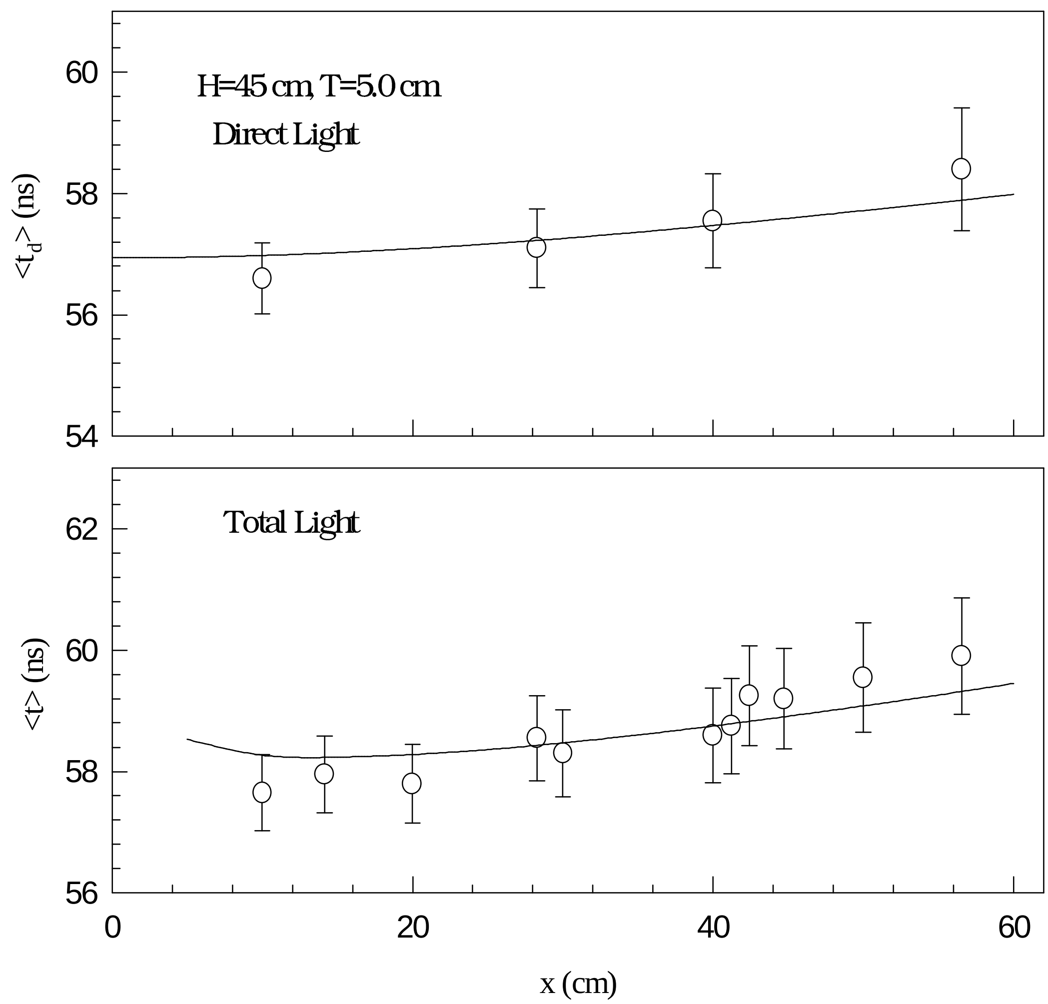

Fig. 2. The measured average time as a function of the distance x for the direct light component and the total light using 3.5 GeV electrons. The solid lines are the results of the calculations of the present model.

An example of the Monte Carlo result is given in Fig. 1 which shows the dependence of the weighted average value of ε on the distance x. Fig. 2 shows the results of the present model compared with experimental measurements carried out using 3.5 GeV electrons beam (Blancke, 1987). The detector module is $5\times90\times90$ cm^3 NE-102A plastic scintillator.

The parameters estimated from Monte Carlo simulation are expected to differ whenever large area scintillation counters are employed in the measurements of the electromagnetic component of air showers. This is mainly due to the fact that detectors are subjected, in this case, not to a fixed energy, but rather to an energy spectrum.

3 Conclusion

This investigation clearly demonstrates that the disagreements between theoretical calculations and experimental results are not because of incorrect values of any physical parameter. It is rather due to the use of wrong values for the length of the distance traveled by light in both scintillator and air. The traveled distance in the scintillator is relatively large and it increases with increasing distance, x. This is purely a geometrical effect, not a physical one. When the correct distances in both scintillator and air guide are put in to the derived formula the estimated mean arrival time agrees with the experimental measurement.

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