

Optimization of the size of scintillation detectors in order to use in an array of 20 detectors which is going to be placed in the Sharif University of Technology

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DOI: 10. 7529/ICRC2011/V03/0219

Abstract: As a primary step of establishment of an extensive air shower array consisting 20 scintillation detectors we optimized an individual detector. Square shaped scintillators are placed under a metal pyramid Light Enclosure with a photomultiplier tube (PMT) at the vertex of it. A set of experiments are performed to optimize the height of light enclosures by comparing 4 different heights 0.1, 0.2, 0.3 and 0.4 m. These experiments are supported by a Monte Carlo simulation of detection process. In this article, by considering experimental and simulation results we concluded that 20 cm is an optimum height for light enclosures.

Keywords: Scintillator, Light enclosure, detector simulation

1 Introduction

Alborz observatory at Sharif University of Technology planned to extend its work by establishment of an array containing 20 scintillation detectors. This array will be placed in the biggest roof top of university campus. Required electronics are prepared but should be tested before usage. The aim of this array is to study extensive air showers with energies around the knee region of cosmic rays spectrum. Primary studies like detailed simulation of array shape and distance between detectors are under operation. Efficiency of array for different particle types and different energies and zenith angles will be revealed by this simulation.

In previous arrays in Alborz observatory [1, 2], size of used detectors was 1×1 square meters. Due to the fact that the number of plastic scintillators available in the Alborz observatory is limited, size of detectors reduced to 0.5×0.5 square meters, to enable us to expand our array. Extensive studies on performance of 1×1 square meters scintillators had been done before [3], but by resizing the scintillation detectors, Light Enclosure (LE) heights should be optimized to obtain suitable signals.

Experimental setup and data analysis are mentioned in the next two sections. After that simulation procedure is described and corresponding results are compared with experimental data.

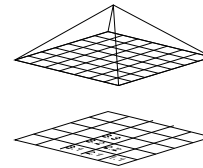


Figure 1: Bottom surface of detector was divided to 25 sections. Numbered sections were swept by small scintillator.

2 Experimental setup

By increasing height of LE, uniformity of time response of different parts of detector (from center to corner) improves but number of detected particles (events) decreases. To determine the optimum height, four LEs with heights of 10, 20, 30 and 40cm were made and series of experiments for each of them were carried out. Bottom surface of scintillator was divided to 25 sections, each $0.1 \times 0.1m^2$, as it is shown in Fig.1. It is enough to choose only six sections due to azimuthal symmetry (which are named 1.1, 2.1 and etc. in the Fig.1) and sweep them with an smaller ($0.1 \times 0.1m^2$) scintillator. In all experiments, coincidence method which measures the time difference between two scintillators signals, with electronic circuit similar to Fig.2 was used. Output of this circuit will be the time in which one particle passes through the both of detectors.

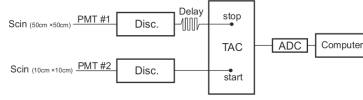


Figure 2: Electronic circuit used in coincidence method.

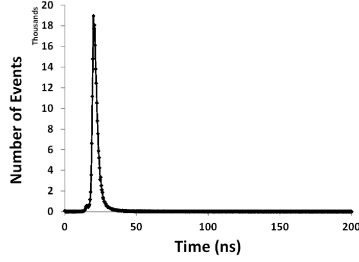


Figure 3: output of experiment for section 3.3 of LE 20cm.

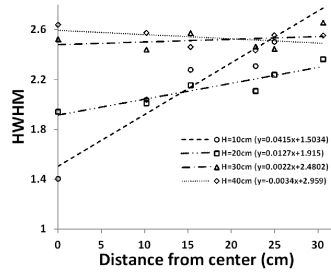


Figure 4: HWHM versus distance of center of section from center of detector.

3 Experimental Data analysis

Number of detected particles (events) versus time difference can be plotted by processing output of experiments (Fig. 3). By fitting a Gaussian function to this plot, HWHM can be obtained for each experiment. Uniformity of detector can be evaluated by comparing HWHM of different sections. If there isn't tangible difference in HWHM of different sections of detector, uniformity will be proved. Uniformity means that detectors response is similar when incident particle pass through different parts of it.

Fig. 4 shows HWHM of each section as a function of distance from the center of detector, for all 4 heights. Fitted lines are also shown in the figure and slope of each line is available in table 1. In the case of 10cm LE, slope of the line equals to 0.041 (ns/cm), which means that HWHM of signals changes significantly from center to corner of detector (about 1.2ns).

Mean HWHM (\overline{HWHM}) for specific LE can be calculated by using the following equation:

$$\overline{HWHM} = \sum_{i=1}^6 \frac{N_i}{N_T} \times HWHM_i \quad (1)$$

Where summation is done on 6 sweep section (Fig. 1), N_i is number of events in section i and $N_T = \sum_{i=1}^6 N_i$.

\overline{HWHM} is 2.11 ns for 10 and 20 cm heights and about 2.5 for 30 and 40 cm LE heights (Table 1). It's a foregone conclusion that lower \overline{HWHM} means that detector have better time response.

Beside these two parameters (slope of HWHM and \overline{HWHM}), total number of events which are calculated by adding events of swept sections, gives another criterion to compare different LEs. As the rate of cosmic rays is constant, one expects the number of particles crossing surfaces with equal areas at equal times to be the same. When different detectors detect different number of particles; it means that their efficiency are not the same. Better detectors should detect more particles in the same time. Excess of total events registered in detectors with 10 and 20cm LE heights (Table 1) reveals that their efficiency is better than two others. On another words, detectors efficiency decreases by increasing the height of LE as we expected.

10 and 20 cm height LEs are preferred because of their better time response (lower \overline{HWHM}) and better efficiency (more total count). But 10 cm height LE's uniformity is about 4 times less than that of 20 cm's.

4 Simulation procedure

When a particle hits the detector, loses some part of its energy in its path through the scintillator. Scintillator converts this energy into light. As we know plastic scintillators emit light in specific wavelength, so we can find the number of photons created in the scintillator. Created photons choose stochastic directions and pass different ways inside the detector. Photons annihilate by two ways: they may be absorbed in the walls of detector (LEs) or they may lose their energy through the interaction by the air molecules inside the detector. Remaining photons reach the PMT which we call them detected photons. This process is simulated by the following algorithm:

- 1- At the first step a particle passes the detector. This particle hits the scintillator at a certain point (x and y) and has a specific direction (θ and ϕ). By considering the path length of particle and knowing the energy loss per unit length and wavelength of emitted photons the number of created photons is obtained. By choosing one of the photons:
- 2- A random direction (θ and ϕ) would be assigned for photon.

Height of light enclosure	10cm	20cm	30cm	40cm
Total number of events	920578	92209	819142	867084
\overline{HWHM}	2.11	2.11	2.51	2.55
slop of fitted line	0.041	0.012	0.002	-0.003

Table 1: Total number of events, \overline{HWHM} and slop of fitted line for all heights.

- 3- Having the geometry of detector (pyramid shape LE) and equations of the detector surfaces, distance between start point of photon and coordinate of the hit point of photon in one of surfaces, is calculated.
- 4- At this stage 4 different conditions can happen:
 - a- Photon is scattered during its path in air
 - b- Photon reached the PMT
 - c- Photon is absorbed in the surface

If the case is *a* or *c* this photon would not be counted and should be put away. If photon reaches PMT, photon arrival time to PMT will be saved in output file. Otherwise we come back to step 2 again (new direction and etc.)

Steps 2-4 should be followed for each photon created in the scintillator medium. Finally the number of photons reaching PMT and arrival time of them is obtained. If n_i is the number of photons reached the PMT between t_i and $t_i + dt$, total number of successful photons will be $N_t = \sum_i n_i$.

5 Simulation results

To be able to compare with experimental results, simulation is done for 4 different LEs height: 10, 20, 30 and 40 cm. Like experiment, for each LE height, bottom surface of detector divided into sections with areas equal to $0.1 \times 0.1 m^2$ (Fig. 1). For three parts in the bottom surface simulation is repeated for 100 crossing particles. These sections are equivalent to sections 1.1, 2.2 and 3.3 in experiment, which are called here: *corner*, *middle* and *center* respectively. Incoming position of incident particle is changed through these regions. Fig. 5, shows the number of photons (output signals) reaching PMT as a function of time (in Nano second), for 3 sections of 4 heights when only one particle crosses the scintillator. Horizontal axis is the time and shows the time that takes photons reach the PMT. All graphs have the same scale in x direction (from 0.3 ns to 1.8 ns). Vertical axis shows the number of photons reached the PMT in every time interval ($dt=0.04$ ns).

These graphs are representing time behavior of detector. Increasing height results in delay in PMT signals (peaks move toward right in graphs). To ease of discussion we define peak time (peak- t) as a time in which number of photons reaching PMT becomes maximum (peaks in graphs of Fig. 5), and n_{peak-t} is number of detected photons between $peak-t - \frac{dt}{2}$ and $peak-t + \frac{dt}{2}$.

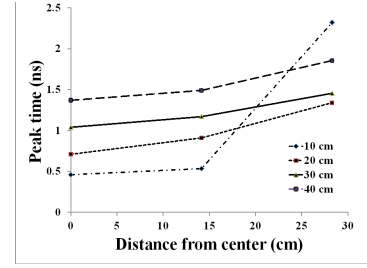


Figure 6: Average value of peak time for 100 incident particles as a function of distance from center for all LEs

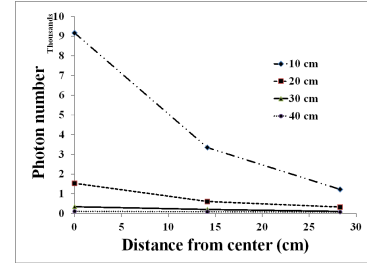


Figure 7: Average number of photons corresponding to peak time for 4 LEs.

When we move from *center* to *corner* of detector peak time increase, and by increasing height of LEs, peak time of these three parts tends to become closer.

In Fig. 6 peak time for 100 incident particles for all of LEs are plotted as a function of distance from the center of scintillator (3 bottom regions have different distances from center, for example in middle region distance is $10\sqrt{2}$ cm and etc.).

In a 10cm LE, by going from *center* to *corner* a remarkable change in peak time takes place. It seems that, it is hard for photons to reach PMT from edges of 10 cm LE. Note that in a graph correspond to corner of 10cm LE (in Fig. 5), peak time equals to 2.32 ns which is out of graph scale. This shows a sort of inhomogeneity in 10 cm LE. Among remaining LEs, 20 cm one beside its uniformity, have a faster response.

Another work is to find mean value of n_{peak-t} for 100 incident particles and compare corresponding values. This parameter is plotted in Fig. 7. In 10 cm LE there is about 9200 photons in 0.04 ns, when the incident particle goes

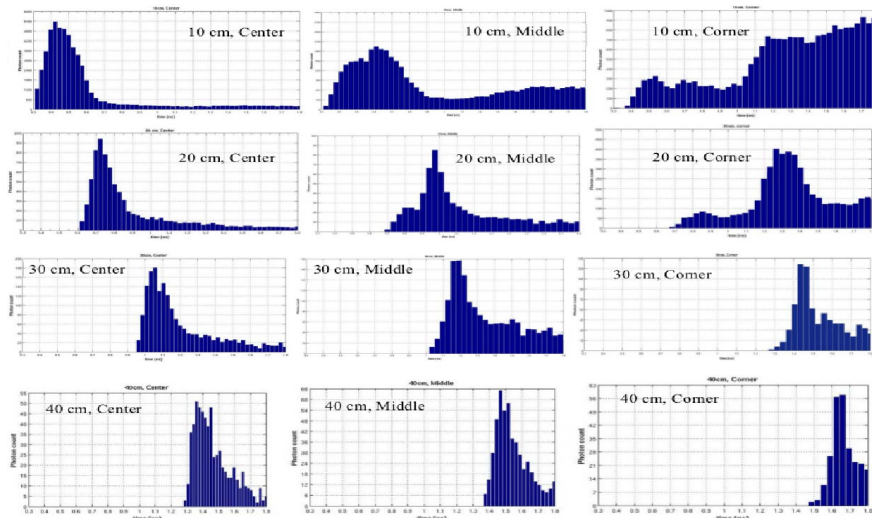


Figure 5: Number of photons reaching PMT for 4 LEs and 3 sections. Horizontal axes show the time in which photons reach PMT and has the same scale for all graphs (0.3 ns to 1.8 ns)

through the center of detector. This number reduces to about 3300 in the middle and 1200 in the corner part. Although number of detected photons in a 10 cm LE is very higher than 20 to 40 cm LEs, it suffers from remarkable variation in different sections of detector. Other LEs have slighter variation in different sections. On the other hand, mean n_{peak-t} for 30 and 40 cm LEs become very little (in the order of 100), which makes detection of particles difficult.

This simulation gives an overall description of the behavior of detector, but it is incomplete. Some important factors make conditions different from reality and consequently give a weak tool for comparison of simulation with experimental data. For example, in experiment we can't avoid noise and background particles and effect of electronic is also important. Further improvements somehow should include these effects.

6 Conclusion

Both experiment and simulation confirm that 10 cm LE, in spite of its more total count and low time response, has the worse uniformity among these 4 LEs. According to experiment 20 cm LE in one hand has a total count and low time response comparable with 10 cm LE, and in the other hand is more uniform than the former one. Despite the high uniformity of 30 and 40 cm LEs, low count and inappropriate time resolution persuade us to exclude these one. According to these points 20 cm would be better height for LEs.

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