Iranian Journal of Physics Research, Vol. 12, No. 3, 2012

Research note

Angular deviation of secondary charge particles in 10^{14}-10^{16} eV extensive air showers: Constrains on application of hodoscopes

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(Received 7 October 2011 , in final from 9 April 2012)

Abstract

Deviation angles of secondary electrons and muons in simulated extensive air showers were studied. The angles have wide distribution, whose width depends on energy cuts imposed on shower particles. In this work, variation of deviation angles with the energy of secondary particles, shower energy, primary direction, and core distance was investigated. The results put limitations on application of hodoscopic devices in cosmic ray and gamma ray observations.

Keywords: cosmic rays, extensive air showers

1. Introduction

When cosmic rays or gamma rays with energies more than 10^{14} eV enter the atmosphere, they can generate swarms of secondary particles of different types. This phenomenon is known as extensive air shower (EAS) [1]. The shower particles may reach the ground level. Arrays of charge particle detectors are commonly used for observation of EASs [2]. These array detectors sample the density of particles and arrival time of shower front. The direction of the parent (primary) particle is assumed to be normal to the shower front. Continuation of the path of the primary particle to the ground level defines shower axis. The traditional technique for reconstruction of shower direction is based on differences of arrival times of secondary particles in separated detectors (timing method) [3]. It has been proposed to utilize charge particle tracking devices, generally referred to as hodoscopes, in EAS arrays for better shower direction estimation [4]. Secondary particles generally deviate from the shower axis. We define the deviation angle as the angle between momentum of a secondary particle and the shower axis. In this work, the distribution of secondary particles deviation angle has been investigated for simulated showers initiated by 10^{14}, 10^{15}, and 10^{16} eV photons and protons. Electrons[1] and muons are the major contributors to the shower front, and have the most efficient detection probabilities, compared to heavier charge particles, mainly hadrons. Hence, we only consider electrons and muons in the analysis. Another important consideration is the threshold energy for a secondary particle to be detected (energy cuts, E_c). Array detectors usually have thresholds around few MeV for thin shielding [5], up to few GeV for thick shielded muon detectors [6]. Since unshielded detectors at the ground level cannot differentiate muons from electrons, additional layers of matter are often put above the detectors, to block electrons, and make muon detectors. The shielding increases the threshold energy even for muons, and prevents low energy muons from being detected.

2. Simulation of extensive air showers

The direction of high energy gamma rays points back to their sources. Improvement of shower direction estimation is vital for gamma ray astronomy. This is not the case for cosmic rays at energies below 10^{17} eV, since they are essentially deflected by diffusive magnetic fields of the Galaxy. However, the accurate measurement of arrival direction of cosmic rays can reveal local effects such as geomagnetic fields, and Compton-Getting effect [7]. Hence, both gamma rays and protons are considered as primary particles for the simulation of EASs in this work. All the showers were produced by CORSIKA (v. 6.702) Monte Carlo code [8]. Local condition for the EAS array at Sharif University of Technology, Tehran has been assumed [9].

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[1] In this paper, electrons and positrons are referred to by electron.

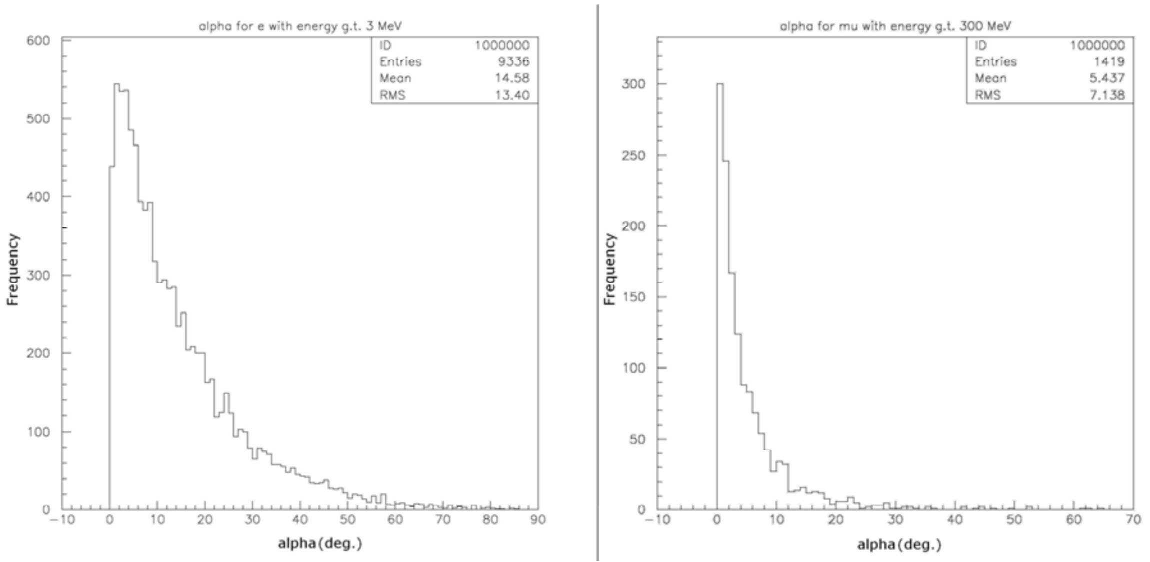

Figure 1. Histogram of deviation angles (α) of secondary particle of a shower initiated by a 10^{14} eV gamma ray. Left: electrons with energy greater than 3MeV. Right: muons with energy greater than 300 MeV.

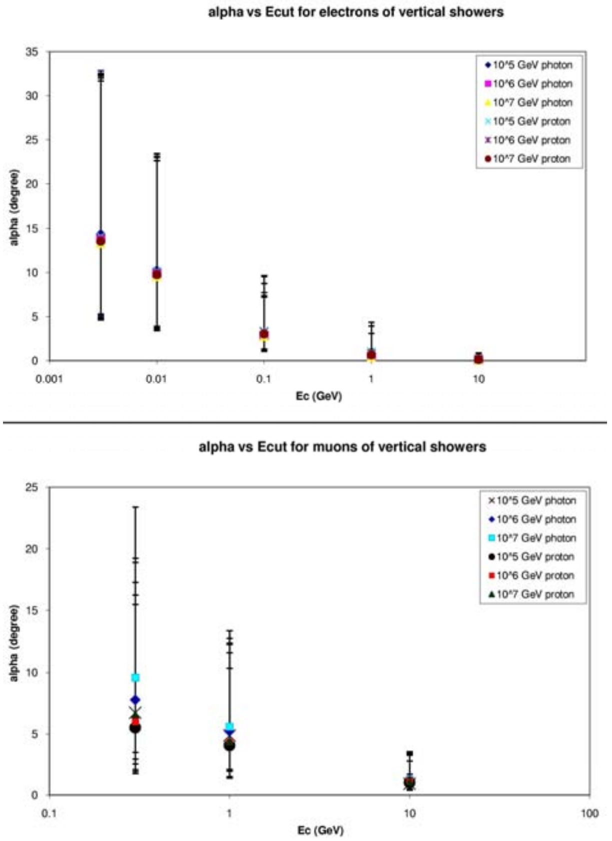

Figure 2. Secondary particle deviation vs. threshold energy, for showers initiated by primaries of different type and energy. Above: secondary electrons. Below: secondary muons.

GHEISHA2002 model for low energy and QGSJET01 model for high energy hadronic interactions were taken as options for the code compilation. In order to generate more realistic results, EGS option was selected, which provides detailed simulation for electromagnetic interactions. 140 showers for each kind of primaries have been generated. 10^{14}, 10^{15}, and 10^{16} eV are the energies of simulated showers. For 10^{14} and 10^{15} eV primaries , six zenith angles; 0, 10, 20, 30, 40, and 50 degree has been considered for shower generation. At least 10 showers for each zenith angles have been produced.

3. Deviation angle of secondary electrons and muons

The deviation angle for a secondary particle, denoted by α, is defined as the angle between momentum vectors of the particle and the primary one. For each secondary electron and muon having energy greater than a threshold, the angle α has been calculated in each simulated shower. These angles have wide distributions even for a single vertical shower. Two examples are presented in figure 1. In order to observe the influence of detector threshold energy on the results, variation of average α with the energy cuts (E_c) for all vertical showers is shown in figure 2. In this figure, the size of each upper (lower) error bar is the square root of variance of the corresponding α values which are greater (less) than the average. The results show decreasing α with E_c for both types of particles. The high energy electrons (E_c >1 GeV) have less deviations than muons of the same energy. Figure 2 also shows that, the energy of the primary particle (shower energy) has almost no correlation with the deviation angle of shower particles.

The zenith angle of the shower axis has a minute effect on secondary particles deviation. This can be seen in figure 3. At lower energy cuts, the effect is more visible, and almost vanishes at high energy cuts. At low energy cuts, higher zenith angle showers have higher deviation for electrons, but the case is reversed for muons; i.e. higher zenith angle showers, have lower deviation for muons.

Assuming a simple conic shape for shower structure,

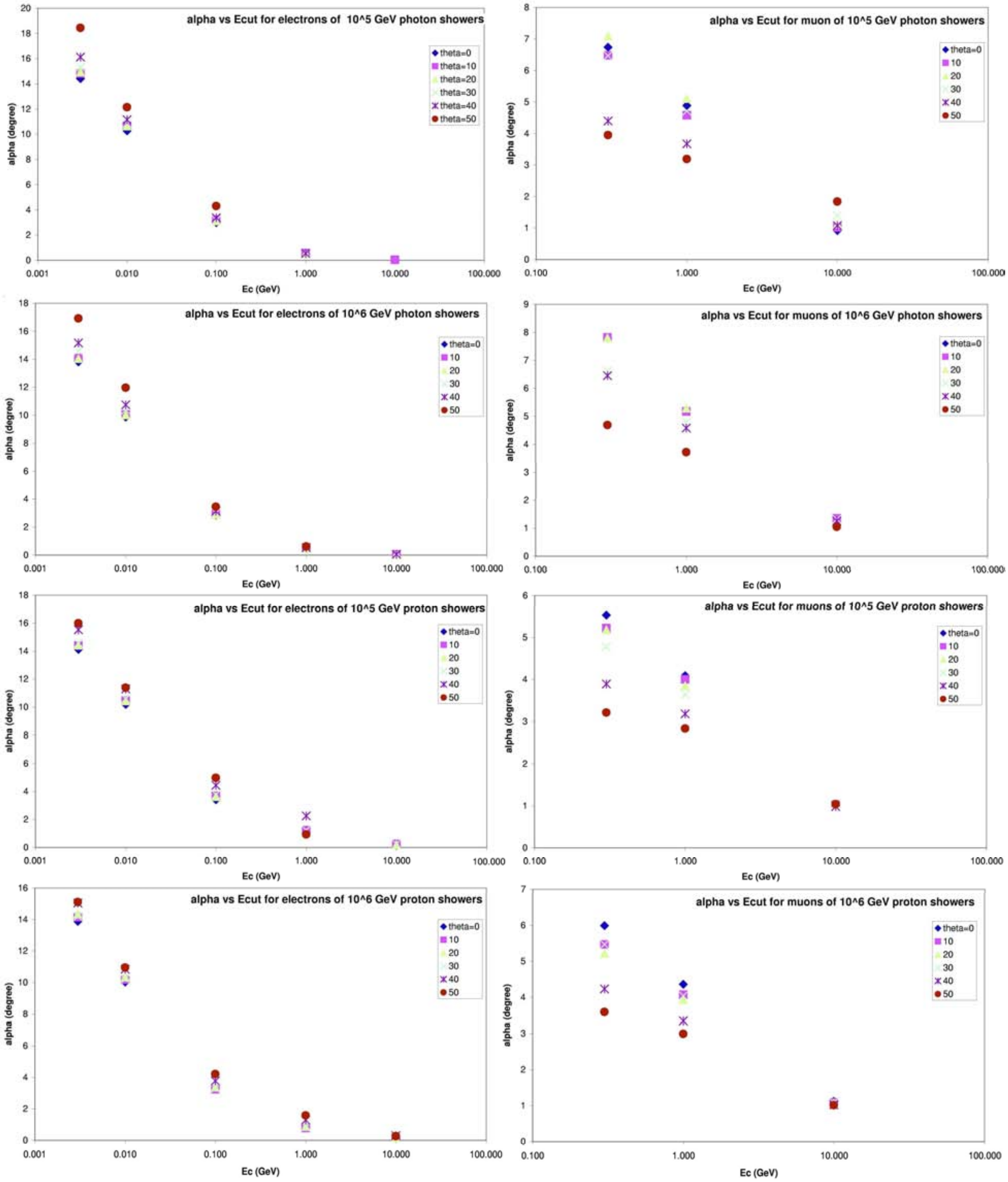

Figure 3. Variation of secondaries deviation angle (α) with E_c for EAS initiated by primaries of different type, energy, and zenith angle (θ). Since the error bars are almost of the same size shown in figure 2, they are not indicated here for better comparison of average values.

one expects more deviation angles for particles farther from shower core. In this model, deviation angle expected to be linearly proportional to the core distance. For our simulated showers, variation of α with distance of secondary particles from shower core, r, has also been studied. In figure 4, some examples are presented. As was expected, the deviation angles increase with distance from shower core. However, α and r do not seem to have linear relation, especially at low energy cuts.

4. Discussion

The results of this work show that direction of motion of low energy electrons in an EAS, which are the dominant population of shower particles, widely deviate from

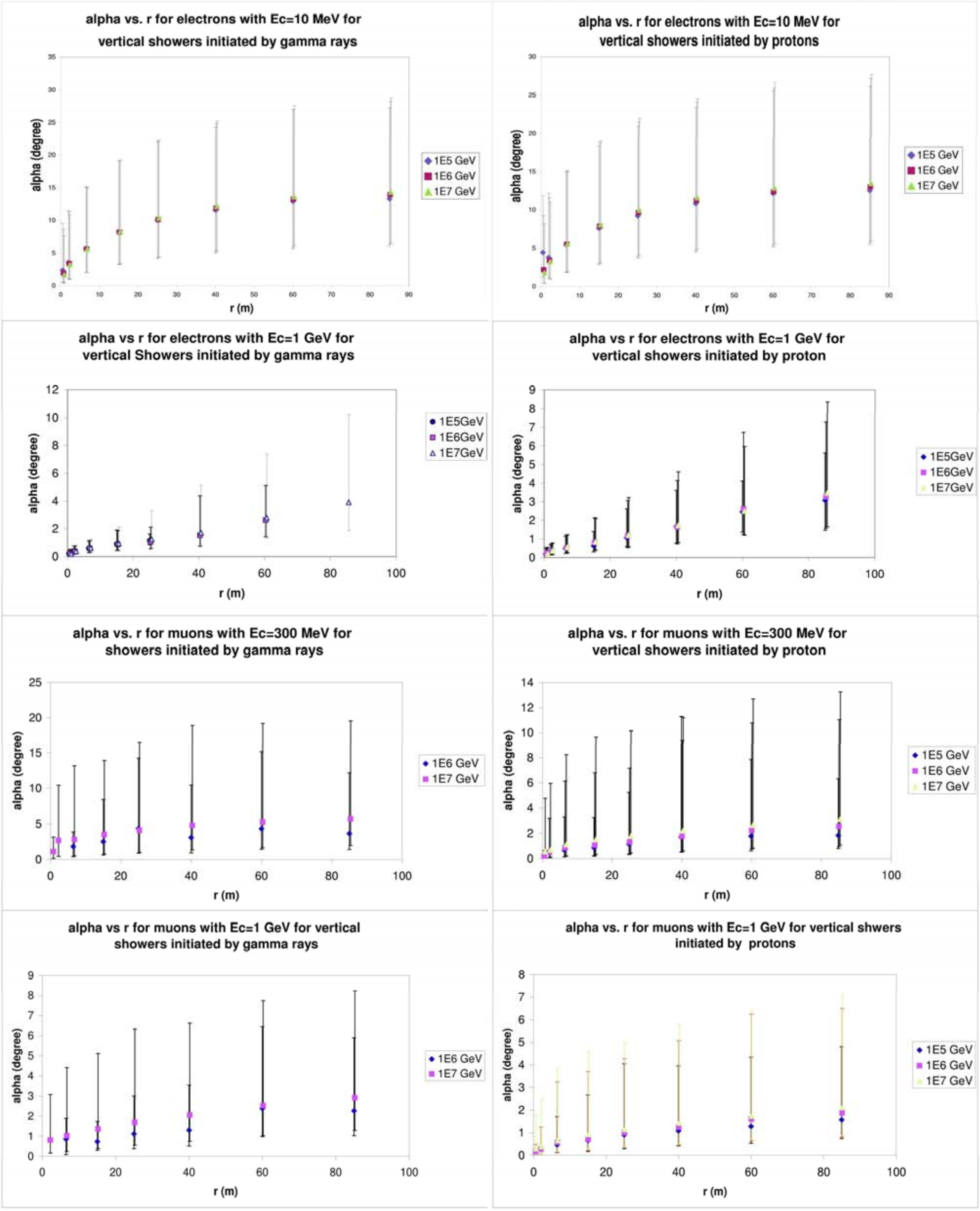

Figure 4. Variation of secondary particles deviation angle with shower core distance (*r*) for different threshold energies. Left: For gamma ray initiated shower. Right: For proton initiated showers. The particle type and energy cuts are given above the plots.

shower axis. The same is true for low energy muons. Thus, a single hodoscope with low energy threshold in an EAS detection array, cannot improve the accuracy of shower direction estimation. However, a high energy threshold (>1GeV) hodoscopes can provide an accuracy about one degree, which is comparable to the traditional array timing method [10], if it can exclude muons, and only take the electrons into account. A more useful setup is one with a few high threshold ($Ec>1$ GeV) hodoscopes near the core of EAS, since in the core region ($r<10$ m), particles have low deviations, $\alpha <1°$ for both electrons and muons. Such tracking devices have been utilized in KASKADE array [11]. A more advanced setup could be an array of hodoscopes. In this case, the average direction of all secondary tracks registered by all hodoscopes may provide a better estimate for shower axis direction.

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