Study of capabilities of the HAWC observatory to detect GRBs

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Abstract. We describe the simulation of atmospheric air showers originated by gamma rays with energies in the 0.1-1 TeV range. We study the properties of the secondary particles at a height above level of 4100 m corresponding to the height of the array of water Cherenkov detectors (WCDs) of the HAWC (High Altitude Water Cherenkov) Observatory. In particular we study the pile-up effect of the secondary particles as they arrive at the HAWC Observatory to discern the way in which the PMTs of the WCDs of HAWC can distinguish isolated secondary particles as a function of their signal thresholds. This study is relevant to the application of the single-particle counting technique often used to try to detect gamma ray bursts (GRBs) with ground-based experiments.

1. Introduction

Gamma ray bursts (GRBs) in the keV to MeV energy range have been studied in great detail by satellite-borne experiments. Recent experiments like the LAT detector onboard the Fermi satellite are detecting GRBs with much higher energies, up to several GeVs. Up to now there are no GRBs detected with ground based experiments, except for the fact that the Milagrito experiment, a predecessor to Milagro, observed evidence for TeV emission from GRB970417a coincident with the BATSE detector [2]. In this paper we describe several properties of extensive air showers produced by high energy gamma rays at a detection altitude of 4100 m a.s.l. These results illustrate the capabilities of a ground-based experiment like the HAWC Observatory to detect the high energy components of GRBs.

2. HAWC observatory

The High Altitude Water Cerenkov detector observatory is under construction by a collaboration of scientists from México and USA at Sierra La Negra volcano, México, at an altitude of 4100 m a.s.l. (latitude: 18°59′41″ N and longitude: 97°18′28″ W). It will make use of a compact array of water Cerenkov detectors (WCDs) to survey the sky in the search of steady and transient gamma-ray sources in the 0.1-100 TeV energy range [1]. When completed, HAWC will consist of 300 WCDs of 7.3 m in diameter and 5 m in height. Each tank will hold three photomultipliers tubes (PMTs) that detect Cerenkov radiation from particles that get the ground level. HAWC’s low energy sensitivity and
continuous operation are unique and essential to measure the prompt emission from GRBs. HAWC can detect GRBs out to $z \sim 1$ if, as predicted, their TeV fluence is comparable to their keV fluence, while for closer GRBs lower fluences can be detected.

3. Single particle technique

This technique is very simple, it is based on the measurement of the numbers of single pulses on the PMTs of the ground detectors during fixed periods (i.e., each 5 ms intervals, or less frequently depending on the temporal accuracy desired) and the study of the behavior of these rates vs. time. During the arrival of GRBs one expects significant increments on the rates of arrival of single particles (or single pulses when the particles pile up) at the ground detectors. Observation of one of such excesses in coincidence with a GRB as seen by a satellite would be an unbiased signature for GRBs with a component of high energy photons [2].

4. Simulations

We have used CORSIKA V6970 to simulate 10 000 extended atmospheric showers (EASs) originated by vertical gammas for each energy in the energy range $0.01$ – $1$ TeV in steps of $10$ GeV, for a total of 1 000 000 simulated EASs, all of them corresponding to vertical gamma rays. The reported properties of these EASs correspond to an altitude of 4100 m a.s.l., i.e., the location of the HAWC Observatory. Figure 1 shows the mean number of gammas, electrons, positrons, muons and anti-muons contained in these EASs at 4100 m a.s.l. as a function of the energy of the primary gamma ray.

![Figure 1. Monte Carlo simulation of the mean number of gammas, electrons, positrons, muons and anti-muons contained in extended air showers at 4100 m a.s.l. as a function of the energy of the primary gamma ray. We used CORSIKA V6970 to obtain these results.](image)

What one immediately can see that about 90% of the particles that reach the ground are photons. This means that one can study the properties of EASs by focusing only on secondary gammas. Another important property is the lateral extension of the secondary gammas as they reach the ground, see figure 2. This lateral distribution has been calculated with the distances measured from the center of the shower (core) to each of the positions where the secondary gammas intercept the ground plane. The lateral distribution shown in figure 2 corresponds to vertical primary gammas with an energy of 1 TeV. Note that most of the secondary gamma particles that reach the ground are located within a distance of 1 m from the core center.
Figure 2. Lateral distribution for secondary gammas from average vertical showers simulated at the HAWC site with primary energies of 1 TeV.

Note also in the distribution of secondary gamma particles there is a second maximum around 10 m. Other important piece of information is the average number of secondary gamma particles that reach a given HAWC detector as a function of the distance from the shower core (along an axis parallel to the magnetic north pole).

Figure 3 shows the average number of secondary gamma particles that reach a given HAWC detector as a function of the energy of the primary gamma ray for different distances between the center of the HAWC detector and the shower core. For example, for showers with energy of 1 TeV there is twice the number of gammas that reach a HAWC tank localized at the origin than one localized 7.2 m away.

Figure 3. Average number of secondary gamma particles that reach a given HAWC detector as a function of the energy of the primary gamma ray for different distances between the center of the HAWC detector and the shower core. This simulated data correspond to EASs generated by vertical gamma rays.

Finally, we studied the structure of the arrival times of the secondary gamma particles that reach the HAWC detectors. This effect is important in order to take into account the cases where the PMT pulses do not correspond to single particles but, due to this pile-up effect, correspond to groups of particles arriving packed together with time separations lower than the typical width of single-particle pulses, which is of the order of 10 ns. Figure 4 shows the distribution of the arrival times and energies of the secondary gamma particles that pile-up within 10 ns for showers generated with energies of 1 TeV, with their vertical axes in coincidence with the detector axis of one HAWC detector.
Figure 4. Energy and time distribution for secondary gammas within a given HAWC tank for an average vertical showers of 1 TeV.

Figure 5. Percentage of secondary gamma particles that reach a HAWC detector piled up within 10 ns as a function of the energy of the primary gamma rays. The simulated showers are generated with their vertical axes in coincidence with the detector axis of one HAWC detector.

5. Conclusions

We have described the Monte Carlo simulation of extensive air showers originated by gamma rays with energies in the 0.1-1 TeV range. We studied the properties of the secondary particles at a height above see level of 4100 m, corresponding to the height of the array of water Cherenkov detectors of the HAWC Observatory. In particular we studied the pile-up effect of the secondary particles as they arrive at the HAWC detectors to discern the way in which the PMTs of the WCDs of HAWC can distinguish isolated secondary particles. The percentage of piled-up secondary gamma particles varies between 66% and 71% for primary energies in the 0.1-1 TeV range (see figure 5). We will extend this study to the pile-up effect of inclined showers generated at different distances from the HAWC detectors.

Acknowledgments

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References

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