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Simulation of ultra-high energy photon showers with PRESHOWER

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The new, publicly available Monte Carlo program PRESHOWER is presented. It allows detailed studies on conversion and cascading of UHE photons in the geomagnetic field. When coupled to a standard air shower simulation program, PRESHOWER enables complete simulations of UHE photon-induced showers.

1. PRESHOWER simulations

The identification of primary photons or specifying stringent limits on the photon flux is of major importance for understanding the origin of ultra-high energy cosmic rays (UHECR). In such a kind of studies it is necessary to simulate thoroughly the air showers induced by UHE photons. It implies a proper treatment of precascading of UHE photons in the geomagnetic field (preshower effect) [1,2]. This effect has a significant impact on observable properties of the subsequent atmospheric showers [3–6]. An accessible, documented Monte Carlo code dealing with the preshower effect and which could complement the existing air shower simulation programs is lacking, however. Moreover, as pointed out in Ref. [3], a numerical error has been found in the standard reference [1] used as a basis in most of the preshower physics studies existing so far. In this paper, the first publicly available Monte Carlo program PRESHOWER is presented, which allows a detailed simulation of the particle cascade initiated by UHE photons in the geomagnetic field and which is free of the error mentioned above. For technical details and more examples of the PRESHOWER applications the reader is referred to Ref. [3].

2. Preshower effect and the structure of the program

At energies above 10^{19} eV in the presence of the geomagnetic field, a photon can convert into

an electron-positron pair before entering the atmosphere. The conversion probability depends on the primary photon energy E_0 and on the magnetic field component transverse to the direction of photon motion (B_{\perp}). The resultant electrons subsequently lose their energy by magnetic bremsstrahlung (synchrotron radiation). The probability of emitting a bremsstrahlung photon depends on the electron energy and also on B_{\perp} . If the energy of the emitted photon is high enough, it can create another electron-positron pair. In this way, instead of the primary high-energy photon, a cascade of less energetic particles, mainly photons and a few electrons, will enter the atmosphere.

In PRESHOWER, for any initial photon energy and arrival direction as well as for any geographical position, an UHE photon conversion into an electron-positron pair and subsequent synchrotron radiation are calculated according to the physics description in Ref. [1] and [7]. The local geomagnetic field vector is determined from the IGRF model [8]. An example of a preshower particle spectrum simulated with PRESHOWER at an altitude assumed as the top of the atmosphere is shown in Fig 1.

With a good approximation, preshower particles travel along the trajectory of the primary particle and arrive at the top of the atmosphere at the same time [3]. The resultant atmospheric shower can be simulated as a superposition of subshowers induced by the preshower particles. The observable properties of air showers initiated

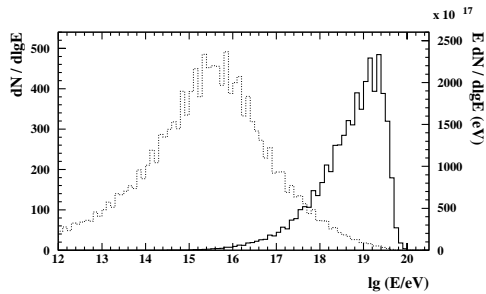


Figure 1. Unweighted (dotted) and weighted by energy (solid) preshower particle distribution at the altitude of 112 km a.s.l. simulated for the parameters of the highest energy cosmic ray (320 EeV) recorded by the Fly’s Eye experiment.

by non-converted photons differ significantly from the characteristics of hadron-induced showers.

3. Examples of applications

PRESHOWER can be used both as an independent tool (see Ref. [3] for examples) or together with a shower simulation code. So far, PRESHOWER was coupled to the CORSIKA [9] air shower simulation package and is freely available with it since the release 6.2. Combining PRESHOWER with an extensive air shower simulation code offers the possibility of investigating signatures of photon-initiated showers. In particular, features can be studied that help to discern such showers from the ones induced by hadrons. Some known indicators of the type of primary particle that initiates a shower include the atmospheric depth of shower maximum development [3,6] and the number of muons in a shower observed on the ground [5,10,11].

Dedicated simulations with PRESHOWER+CORSIKA of photon-induced shower profiles with the parameters of the highest energy cosmic ray were performed to compare the measured depth of shower maximum with the value expected if the event would have been initiated by a photon [12]. The probability for such a hypothesis was found to be 13%, i.e. non-negligible, while the previous analyses tended to neglect the possibility of a photonic origin of the highest energy CR event. A similar method of dedicated

simulations was applied for the analysis of the 6 AGASA events above 10^{20} eV with available information on muon densities on the ground [11]. The measured muon densities were compared with the simulations which allowed determination of the probabilities of the photonic origin of each event. On this basis, a preliminary, new upper limit of 50% on the photon fraction in cosmic rays above 10^{20} eV was derived. It offered a serious constraint for the models of cosmic ray origin that predict the presence of photons in the CR flux arriving at the Earth.

In summary, the publicly available PRESHOWER code is an important step towards the complete simulation of UHE photon showers. Already now, it is used by several research groups.

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