Ultrahigh Energy Gamma Ray Cascading in the Geomagnetic Field and Its Development in the Atmosphere

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Abstract

Extensive simulations of the longitudinal development of air showers from ultrahigh (UHE) energy gamma rays have been carried out. The shower development is affected by the geomagnetic cascading before entering the atmosphere and by the Landau-Pomeranchuk-Migdal effect in the atmosphere. AIRES code as well as our original code have been used for cascade simulations in the atmosphere. The analysis of the results shows that the longitudinal development of the showers depend strongly on both primary energy and incident direction. This feature may provide reliable conclusions about the photon fraction in the UHE ($> 5 \times 10^{19}$eV) cosmic ray flux.

1. Introduction

The primary cosmic ray composition, especially the gamma ray content, is a powerful discriminator between the models of UHE cosmic ray origin.

Two effects must be taken into account for a study of air shower development in the case of gamma ray primaries - the Landau-Pomeranchuk-Migdal (LPM) effect and cascading in the geomagnetic field. Both effects start to affect shower development approximately at the same energies and their influence is opposite. The LPM effect leads to a significant elongation of the shower development in the atmosphere and large fluctuations, while cascading in the geomagnetic field before entering the atmosphere significantly weakens the influence of the LPM effect.

Recently these effects are studied intensively (see e.g. [1] and references therein). Commonly used standard codes like CORSIKA, AIRES, etc. include the LPM effect, but they do not contain procedures for simulation of electromagnetic showers in the geomagnetic field. The number of such codes now increases and

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the main results seems to agree well enough.

The aim of the present paper is to present some results from our extensive simulation of longitudinal shower development including geomagnetic cascading. These results are obtained by our original codes for geomagnetic cascading, AIRES code (version 2.2.1) [2] and two totally independent Monte Carlo programs for electromagnetic shower simulation in the atmosphere at UHE.

2. Simulation

We developed independently two program codes for geomagnetic cascading using the cross sections for synchrotron radiation and magnetic pair production as given in [1]. Both codes use the same geomagnetic field model. For shower simulation in the atmosphere we use AIRES code and codes developed independently by Hirosaki group [3] and Sofia group [4]. The details of simulation with AIRES are given in [1]. In simulations by the other two codes we follow the shower development in the atmosphere by direct simulation that includes the LPM effect down to a threshold energy E_{thr}, bellow which the LPM effect is not effective. The subthreshold particles are then replaced by analytical approximations.

3. Results

The simulations were carried out for two locations: Utah (lat = 39.5°N, long = 113.0°W) and Malargue (Auger Southern Observatory, 35.2°S, 69.2°W).

The main results from our simulations for the location of Utah using AIRES are presented in [1]. Figure 1 shows the typical shower profiles for secondary photons and electrons in the geomagnetic field for primary gamma ray of $10^{20} eV$ and different threshold energies. The zenith angle is 40° and the azimuth corresponds to the north (strong field). For comparison in this figure we show also a shower profile for a gamma ray arriving from south (weak field). This picture differs too much from cascade development in matter.

The main results for the location of Malargue as well as the comparison between different program codes will be presented at the Conference. Below some preliminary results are shown for the location of Malargue.

Figure 2 shows the average shower profile of 10^{21}eV primary gamma ray arriving in Malargue site. The incident direction (zenith angle of 50°and azimuth of 360°) corresponds to a weak field. For comparison, shower profiles for only LPM showers (no magnetic cascading) and for showers with no LPM effect included, are also drawn in the figure. The data for this figure are obtained by the following approximation. All particles above the energy 10^{12}eV arriving at the top of atmosphere after geomagnetic cascading are set as an input of the atmospheric shower simulation program. In this case conversion probability is 100%, the mean number of photons is 636, the mean number of electrons is 2.9. The

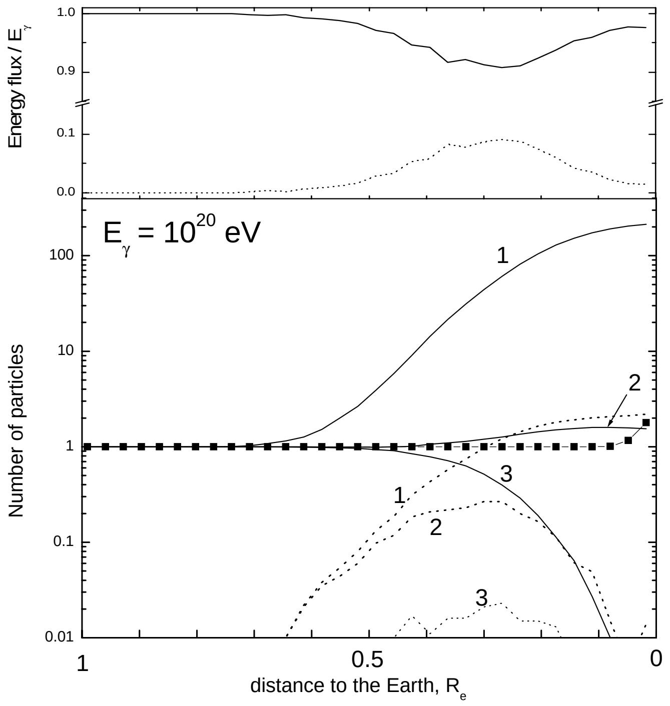

Fig. 1. Shower profile (bottom panel) in the geomagnetic field for primary gamma ray with energy $10^{20} eV$ and different threshold energies: 1 - 10^{16}eV, 2 - 10^{19}eV, and 3 - 5×10^{19}eV. The zenith angle is 40°. The azimuth is from the true north. Solid and dotted curves are for photons and electrons, respectively. The line with symbols shows the number of photons with energies $> 10^{16}$eV in showers from the south. The energy flux carried by photons (solid curve) and electrons (dotted curve) is shown on the top panel for azimuth from the north.

energy E_{thr} is 10^{17}eV.

For the same location and incident direction with a strong field the mean number of photons is 543 for 10^{20}eV and 3943 for 10^{21}eV, for electrons - 1.9 and 10.1, respectively.

4. Discussion and conclusions

Our study shows that the longitudinal shower development in the energy region above $\sim 10^{19.5}$eV has very specific dependence on both the primary energy and incident direction. The future observation of these longitudinal shower characteristics and their fluctuations could be the possible key for studying the UHE gamma ray flux.

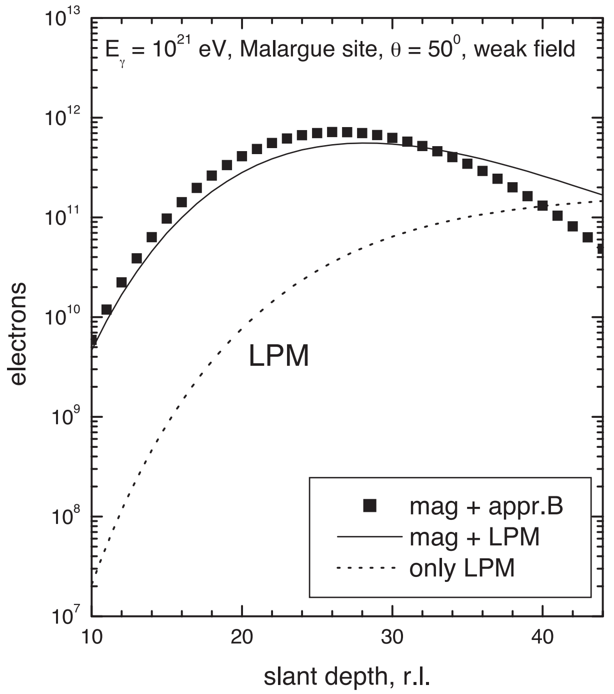

Fig. 2. Shower profile for 10^{21}eV primary gamma ray

5. References

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