GEOMAGNETIC FIELD AND LANDAU-POMERANCHUK-MIGDAL EFFECT IN EXTENSIVE AIR SHOWER SIMULATIONS

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Abstract. *The influence of the effect of the interaction with the Earth's magnetic field and that of the Landau-Pomeranchuk-Migdal effect on the development of extensive air showers initiated by extremely high energy cosmic rays are calculated for several cases based on the simulation system AIRES. The observable calculations are analyzed.*

. Introduction

In recent years the interest in extremely high-energy cosmic rays has increased apidly. The study of cosmic rays at these energies has become a current topic in the eld of cosmic ray physics. However, unfortunately, until now the nature of extremely igh-energy cosmic rays is little known with certainty. The reason is that the data are nadequate, both in terms of the numbers of observed events and in the detailed characterzation of these events. Cosmic rays at these energies are rare, the flux of cosmic particles ith energy larger than 10^{20} eV is less than one per square kilometer per century. This nplies that primary cosmic rays can not be detected directly. It is necessary instead to neasure the products of particle cascades generated in the atmosphere by the interaction f extraordinarily energetic cosmic rays.

An atmospheric particle shower begins when the primary cosmic particle interacts ith the Earth's atmosphere. This is, in general, an inelastic nuclear collision that genrates a number of secondary particles carrying a fraction of the primary energy. The enerated secondary particles in turn interact again similarly as their predecessors. This ultiplication process continues until a maximum is reached. Then the shower attenutes as far as and more and more particles fall below the threshold for further particle roduction.

A detailed knowledge of the physics involved is necessary to interpret adequately neasured observables and infers something about the primaries. This is a complex problem nvolving many aspects: interaction of extremely high-energy particles including hadronic nd electrodynamical processes, properties of the atmosphere and geomagnetic field, etc.

For searching extremely high-energy cosmic rays the international Pierre Auger roject has been established with the participation, at present, of about 20 countries the world among which it stands Vietnam [1]. The research of Auger cosmic rays is oncerned with the analysis of the structure of extensive air showers containing a very large umber of particles. Computer simulation is now the most convenient and powerful tool hat can be used to quantitatively analyze the particle showers. In this paper the Auger hower observables are considered for several typical cases based on computer simulation extensive air showers including the effect of the interaction with the Earth's magnetic eld and Landau-Pomeranchuk-Migdal one.

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II. Consideration of air shower observable

The charged particles created in an Auger shower interact with the Earth's magnetic field. One of the effects of such an interaction is that of curving the particles' paths. In order to calculate the influence of this effect on several air shower observables we have performed numerical simulations based on AIRES [2,3] with the following initial conditions:

- Primary particle: Proton.
- Primary energy: 10^{19}eV.
- Zenithal angle: 70^0.
- Azimuthal angle: 90^0.
- Magnetic field intensity: 52.800 nT,
- Inclination: $64^0.8$.
- Ground level: $920g/cm^2$,
- Relative thinning level: 10^{-6},

and two injection altitudes 9350 m (case A) and 100Km (case B).

Here we have chosen the Millard county (Utah, USA) site where the geomagnetic field is intense and therefore the differences between the simulations with and without field can be appreciated better. The reason for selecting these two cases (A&B) was to investigate the influence of the geomagnetic field in two different phases of the shower development: (A) shortly after reaching it's maximum and (B) when the shower is about to vanish completely.

Some results obtained from calculations have shown that

- ***For case A***

$$X_{\max}^{\text{geof}} = 581.191g/cm^2, \qquad X_{\max} = 583.084g/cm^2,$$
$$N_{\max}^{\text{geof}} = 7732.481 \times 10^6, \qquad N_{\max} = 8093.683 \times 10^6,$$
$$N_{e\pm}^{\text{geof}} = 85.8935 \times 10^6, \qquad N_{e_\pm} = 46.3673 \times 10^6,$$
$$N_{\mu}^{\text{geof}} = 23.0243 \times 10^6, \qquad N_{\mu} = 22.0958 \times 10^6,$$

- ***For case B***

$$X_{\max}^{\text{geof}} = 327.0243g/cm^2, \qquad X_{\max} = 325.945g/cm^2,$$
$$N_{\max}^{\text{geof}} = 7511.613 \times 10^6, \qquad N_{\max} = 7660.268 \times 10^6,$$
$$N_{e\pm}^{\text{geof}} = 4.0516 \times 10^6,, \qquad N_{e_\pm} = 3.6293 \times 10^6,$$
$$N_{\mu}^{\text{geof}} = 13.6900 \times 10^6, \qquad N_{\mu} = 13.3200 \times 10^6,$$

here $X_{\max}^{\text{geof}}, N_{\max}^{\text{geof}}, N_{e\pm}, N_{\mu}^{\text{geof}}$ and $X_{\max}, N_{\max}, N_{e\pm}, N_{\mu}$ are the shower observable calculated with and without field, respectively.

We note that there are not noticeable differences in $X_{\max}^{\text{geof}}$ and $X_{\max}$ (maximum position), $N_{\max}^{\text{geof}}$ and $N_{\max}$ (number of charged particles), $N_{e\pm}^{\text{geof}}$ and $N_{e\pm}$ (number of electrons and positions reaching the ground level), and Nm (number of muons reacLing the ground level).

From the numerical simulations performed with taking into account the geomagnetic field [4], we also note that the ground level energy distributions of gammas and of electrons and positrons change in the same way: in the both cases the number of particles that reach the ground increases for low energy particles and decreases for high energy ones. The correlation between the respective distributions can be understood taking into account that ground electrons, positrons or gammas surely come from "near by" electromagnetic cascade whose intrinsic mechanisms constantly generate gammas from $e^{\pm}$ and vice versa, being the energies of the secondary lower (at most equal) than those of the respective primaries. It is therefore clear that the structure of both energy distributions should be similar. When the geomagnetic field is considered, the trajectory of electrons and positrons is helicoid. This generally leads to an increase of the particles' paths and therefore to larger continuum energy losses (ionization losses), diminishing (enlarging) the average number of high (low) energy particles that reach the ground level.

At very high-energies (¿ 10^{14} eV) the Landau - Pomeranchuk - Migdal (LPM) effect occurs. It drastically reduces the cross sections of electron bremsstrāhlung and pair production processes of atmospheric showers. The influence of this effect on the development of air showers created by extremely high energy cosmic rays have been calculated by us using computer simulation with the following initial conditions:

- Primary particle: Gamma, Proton
- Primary energy: 10^{20}eV, 7.10^{20}eV
- Zenithal angle: 60^0
- Azimuthal angle: 0^0
- Injection altitude: 100Km
- Ground level: $1000 g/cm^2$
- Relative thinning level: 10^{-5}

Analyzing the simulated data we note that the impact of the LPM effect is evident for showers initiated by gammas with primary energy larger than 10^{20}eV. It affects the position of $X_{\max}$ (the maximum of the shower), the number of particles at $X_{\max}$, etc.

The LPM effect affects the gamma shower lengthening and consequently moving the average position of $X_{\max}$ deeper into the atmosphere.

For gamma initiated showers with primary energies less than 10^{18}eV we have not found appreciable differences between the calculation results with and without the LPM effect.

We lead below some results from calculations with showers induced by gamma with primary energies 10^{20}eV, 7.10^{20}eV.

- ***For primary energy*** $\boldsymbol{10^{20} eV}$

$$
\begin{aligned}
X_{\max}^{\text{LPM}} &= 720.862 g/cm^2, & X_{\max} &= 638.686 g/cm^2, \\
N_{\max}^{\text{LPM}} &= 55.53355 \times 10^9, & N_{\max} &= 57.58701 \times 10^9, \\
N_{e^\pm}^{\text{LPM}} &= 15.03924 \times 10^9, & N_{e_\pm} &= 8.28774 \times 10^9, \\
N_{\mu}^{\text{LPM}} &= 0.07455 \times 10^9, & N_{\mu} &= 0.05898 \times 10^9.
\end{aligned}
$$

- ***For primary energy 7.10^{20}eV***

$$X_{max}^{LPM} = 804.696 g/cm^2, \qquad X_{max} = 736.307 g/cm^2,$$
$$N_{max}^{LPM} = 187.162 \times 10^9, \qquad N_{max} = 283.370 \times 10^9,$$
$$N_{e\pm}^{LPM} = 150.2579 \times 10^9, \qquad N_{e_\pm} = 164.121 \times 10^9,$$
$$N_{\mu}^{LPM} = 0.4664 \times 10^9, \qquad N_{\mu} = 0.7936 \times 10^9.$$

For showers created by proton with primary energies up to 7.10^{20}eV, we have nc found any significant influence of the LPM effect. Because in this case the Electro-magneti shower where the LPM effect takes place begins later, when the primary energy is share among the secondary particles reducing the primary proton energy in 2 - 4 orders (magnitude.

We present here some results from calculations with showers induced by proto with primary energy 10^{20}eV, 7.10^{20}eV.

- ***For primary energy 10^{20}eV***

$$X_{max}^{LPM} = (450.272 \pm 9.14) g/cm^2, \qquad X_{max} = (449.125 \pm 8.40) g/cm^2,$$
$$N_{max}^{LPM} = (63.11962 \pm 2.2418) \times 10^9, \qquad N_{max} = (59.77826 \pm 3.8564) \times 10^9,$$
$$N_{e\pm}^{LPM} = (1.74975 \pm 0.51031) \times 10^9, \qquad N_{e_\pm} = (2.1844 \pm 0.93485) \times 10^9,$$
$$N_{\mu}^{LPM} = (0.146481 \pm 0.008) \times 10^9, \qquad N_{\mu} = (0.13698 \pm 0.0053) \times 10^9.$$

- ***For primary energy 7.10^{20}eV***

$$X_{max}^{LPM} = (471.019 \pm 6.56) g/cm^2, \qquad X_{max} = (481.509 \pm 11.13) g/cm^2,$$
$$N_{max}^{LPM} = (386.212 \pm 10.96) \times 10^9, \qquad N_{max} = (382.965 \pm 11.46) \times 10^9,$$
$$N_{e\pm}^{LPM} = (27.4895 \pm 3.732) \times 10^9, \qquad N_{e_\pm} = (29.8508 \pm 5.985) \times 10^9,$$
$$N_{\mu}^{LPM} = (0.9426 \pm 0.023) \times 10^9, \qquad N_{\mu} = (0.9635 \pm 0.03) \times 10^9.$$

III. Conclusion

Based on numerical simulations, we have calculated the influence of the effect of tl interaction with the Earth's magnetic field and that of the Landau-Pomeranchuk-Migd effect on the development of extensive air showers induced by extremely high-energy cosm rays for several typical cases. The analysis of obtained calculation results has shown th the geomagnetic field does not noticeably influence the considered observables. While tl influence of the Landau-Pomeranchuk-Migdal effect is evident for air showers created l gamma with primary energy larger than 10^{20} eV, for air showers initiated by primai proton with energy up to 7. 10^{20} eV this effect does not cause any significant influence.

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ferences

1. *Perre Auger project*, design report, the Auger Collaboration, Fermilab in USA, 1995.
2. S.J.Sciutto. AIRES, *Pierre Auger Observatory*, Technical Note GAP - 97 - 029, 1997.
3. Le Van ngoc, Vo Van Thuan, Nguyen Hao Quang. Code System for Extensive Air Shower Simulation, *Proceedings of the third national conference on nuclear physics and technique*, Dalat, March 1999, p 15-18.
4. Le Van Ngoc, Vo Van Thuan, Dang Quang Thieu. *Study on analyzing some air shower observable at super high-energies*. INST, internal report - 2000.

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TRƯỜNG ĐỊA TỪ VÀ HIỆU ỨNG LANDAU - POMERANCHUK - MIGDAL TRONG CÁC MÔ PHỎNG MƯA RÀO KHÍ QUYỂN RỘNG

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Ảnh hưởng của trường địa từ và hiệu ứng Landau - Pomeranchuk - Migdal tới sự it triển của các mưa rào khí quyển rộng được tạo ra do tương tác của các tia vũ trụ ıg lượng cực lớn được tính đối với một số trường hợp dựa trên hệ mô phỏng AIRES. : đặc trưng quan sát được tính đvàược phân tích .