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Effects of the near-earth thunderstorms electric field on intensity of the ground cosmic ray electron at YBJ

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Abstract.It has been found that most of the near-earth thunderstorms electric field strength at YBJ (4300 m a.s.l., Tibet, China) is within the range of 1000 V/cm according to the ARGO-YBJ experiment. In this work, Monte Carlo simulations were performed by using CORSIKA to study the intensity change of the ground cosmic rays in near-earth thunderstorms electric field. We found that the number of electrons in secondary particles at YBJ was changed with the strength and polarity of the electric field. In the negative field, the number increases with the increasing electric field. Nevertheless, it increases, or does not change obliviously or even declines with different energies of primary particles in the different positive fields. Our results are consistent with the observations obtained from ARGO-YBJ experiment during thunderstorms. What is more, these preliminary results provide important information in understanding the acceleration mechanism of secondary charged particles caused by electric field.

Keywords: near-earth thunderstorms electric field, cosmic rays, Monte Carlo simulations, YBJ

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1. Introduction

It was first mentioned by Wilson that the secondary electrons in cosmic rays can be influenced by the electric field in thunderstorms [1]. Gurevich et al. put forward the relativistic runway electron avalanche (RREA) in 1992 [2], that air showers of sufficient energy can start an avalanche of runaway electrons in thunderstorms electric field.Ionization electrons that are produced in collisions of shower particles with air molecules are accelerated in thunderstorms electric field. Under the right conditions, they can gain enough energy to ionize further molecules, which makes the electron number increase exponentially.

Over the years, it caught much attention that the cosmic rays will suddenly increase during a thunderstorm. Many scientists have carried out lots of ground-based experiments to detect the thunderstorm ground enhancements (TGEs), trying to find high-energy electrons accelerated by the thunderstorms electric field. In 1985, Alexeenko et al. [3] found that the intensity of ground cosmic rays changed during a thunderstorm by using Baksan data for the first time. These changes have nothing to do with air pressure, temperature, but are associated with electric field. Through analyzing the data of the Norikura experiment, Tsuchiya et al. found that the counting rates of photons and electrons were related to the electric field [4]. Several TGE events were detected through analyzing ASEC experimental data by Chilingarian et al. [5, 6]. It seems that these ground experimental observations are consistent with RREA mechanism. In 2010, Buitink et al. performed Monte Carlo simulations to calculate the effects of electric field configurations on $10^{16}-10^{17}$ eV proton shower development [7]. Their results show that the RREA maybe occurs at high altitudes.

A short duration increase of the single particle counting rate with low energy occurs accompanied with strong atmospheric electric field, while decrease happens in the counting of particles with higher energy in ARGO-YBJ experiment (located at YBJ, Tibet, China) [8, 9]. In this paper, Monte Carlo simulations were performed to study the effects of near-earth thunderstorms electric field on intensity of the ground cosmic ray electron at YBJ.

2. Simulation parameters

CORSIKA (COsmic Ray SImulations for KAscade) is a detailed Monte Carlo program to study the evolution and properties of extensive air showers in the atmosphere [10]. The CORSIKA7.3700, which includes the electron transport in the electric and magnetic fields proposed by Bielajew [11], was used in our simulations. The high energy hadronic interaction model is QGSJETII-04; the low energy hadronic interaction model is GHEISHA.

Studies have shown that the atmospheric electric field roughly distributed within the altitude scope of $4-12$ km during a thunderstorm [12]. The effect on the total number of electrons and positions can be neglected in the electric field which is far from detectors [7]. It has been found that the near-earth thunderstorms electric field changes dramatically and the strength is mostly within 1000 V/cm from ARGO-YBJ data in 2012. In our simulations, the range of atmospheric electric field is $-1000-1000$ V/cm at altitudes from 6300 m to 4300 m (corresponding to the atmospheric depth $484-606$ g/cm^2). Here, we defined the positive electric field was downward.

According to the energy threshold of ARGO-YBJ (a few tens of GeV in scaler mode and a few hundred of GeV in shower mode), the primary particles are chosen as vertical protons with energies 30 GeV, 100 GeV and 770 GeV. In view of the acceleration of the field, we set the energy cutoff below which electrons and positrons are discarded at 0.1 MeV in the simulation.

3. Simulation results

Firstly, the number of electrons and positrons as a function of electric field was simulated with primary proton of 30 GeV. Fig.1 shows the percent change of the particle number for 30 GeV proton shower at YBJ in different electric fields. The black cross data points correspond to the percent change of the sum of electrons and positrons. The red solid circle and blue solid square points correspond to positron and electron, respectively. When the field strength increases, the effect on the percent change of particle number becomes different.

As shown in Fig.1, when the electric field is negative(accelerating the electrons), the number of electrons increases, while the positrons reduces, and the total number of electrons and positrons increases with the increasing strength of electric field.

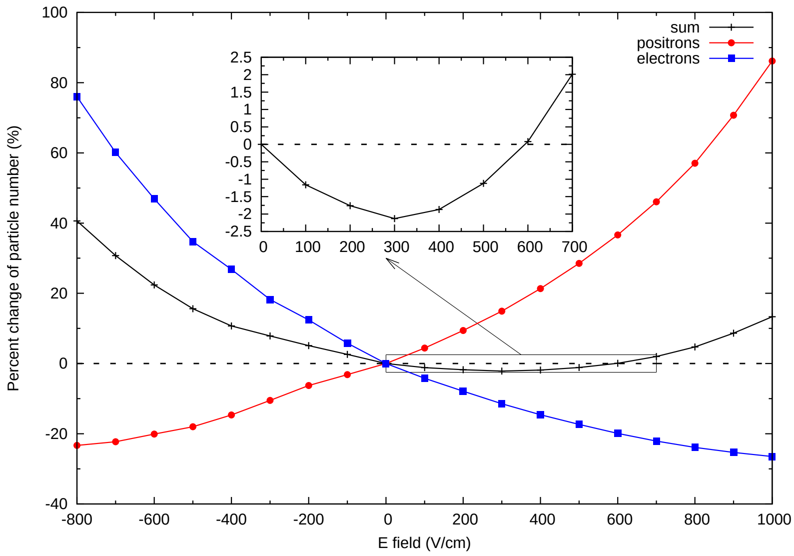

Fig. 1: Percent change of particle number as a function of electric field strength at YBJ(The illustration is the enlarged view of the total number in reducing range)

When the field is positive (accelerating the positrons), the number of electrons reduces, while the number of positrons increases. In the range 0−600 V/cm, the total number declines and the decrease is about 2.5%. In the positive field greater than 600 V/cm, the total number increases with the increasing strength of electric field.

In the series papers of ARGO-YBJ, they reported that the change of ground cosmic ray intensity is also associated with the primary energy. In this work, different primary energies (30, 100, 770 GeV) were stimulated in different positive fields. Fig.2 shows the percent change of total number of particles as a function of electric field strength for different primary energies at YBJ. The black solid square data points correspond to primary energy of 30 GeV and the red solid circle and blue solid triangle points to energy of 100 GeV and 770 GeV, respectively. As we can see from Fig.2, the variation tendencies of these three different primary energies are almost the same. In 0−600

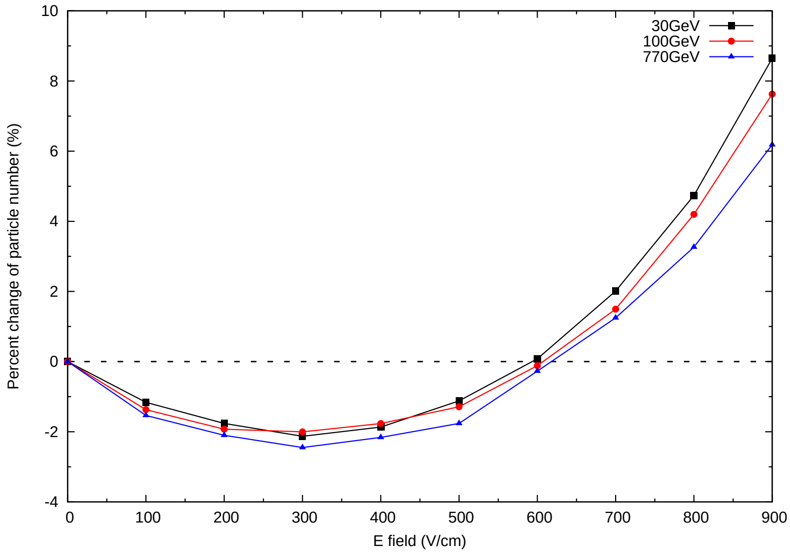

Fig. 2: Percent change of the total number of electrons and positrons as a function of electric field strength for different primary energies at YBJ.

V/cm field, an obvious decline of the total number can be seen.The degree of decline is about 3% at YBJ.

Fig.3 shows the percent change of the total number of electrons and positrons as a function of atmospheric depth for different primary energies in 400, 500, 600 and 700 V/cm. As we can see from the figure, the number drops quickly, then it increases with increasing atmospheric depth, The black solid square data points correspond to the primary energy of 30 GeV and the red solid circle and blue solid triangle points to 100 GeV and 770 GeV, respectively. At YBJ, the total number declines in 400 V/cm and 500 V/cm, and it is no significant change in 600 V/cm. However, the increase occurs in 700 V/cm. The degree of decrease or increase is related to the primary energy to some extent.

4. Discussion

The total number of electrons and positrons in cosmic rays declines in thunderstorms electric field is probably related to several factors such as the polarity of electric field, the strength of electric field, the proportion of electron and positron, the energy of primary particle and so on. Here we take the primary proton of 30 GeV as an example to discuss it in detail.

Fig.4 shows that the percentage of positron (electron) in the total number at different atmospheric depth in absence electric field. It shows that the percentage of electron increases with the increasing atmospheric depth, while the positron decreases. At YBJ, the number of electrons is about 1.8 times of that of positrons. The phenomenon that the number of positrons is less than the number of electrons is mostly caused by Compton scattering effect [13].

Fig.5 shows that, in the negative electric field, the percentage of electrons keeps increasing with the increasing atmospheric depth, while the percentage of positrons keeps declining. At YBJ, the percentage of electrons is about 4.0 times of that of positrons in -800 V/cm.

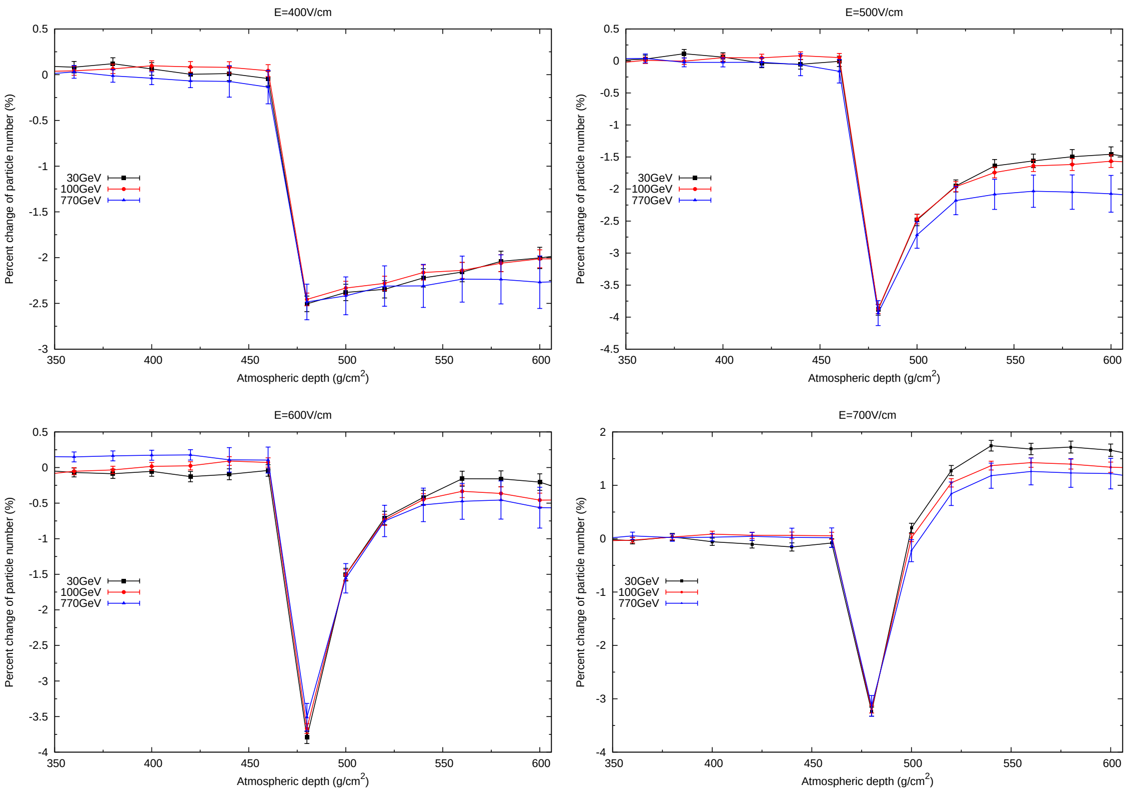

Fig. 3: Percent change of electrons and positrons as a function of atmospheric depth for different primary energies shower in different electric fields.

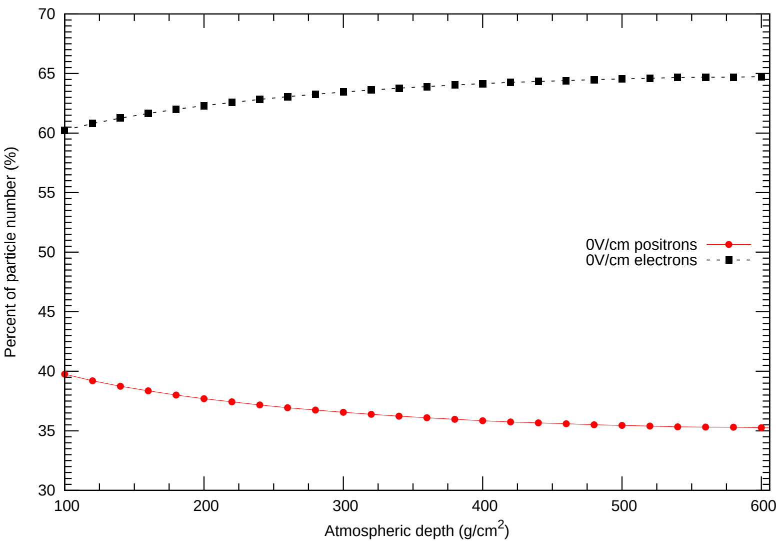

Fig. 4: Percent of electrons and positrons number as a function of atmospheric depth in absence electric field.

As shown in Fig.6, the situation becomes somewhat complicated when a positive electric field is switched on. The electron-positron ratio decreased with the increasing atmospheric depth. When

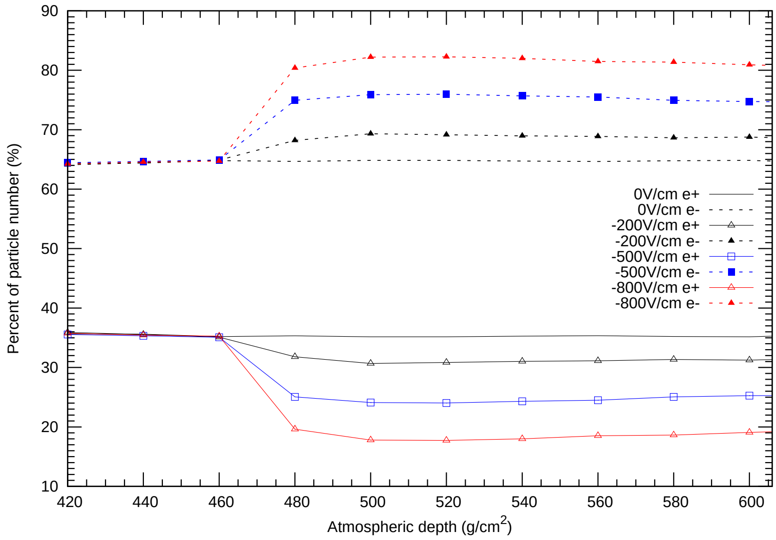

Fig. 5: Percent of electrons and positrons number as a function of atmospheric depth in different negative fields.

the strength of electric field is less than 600 V/cm, the number of electrons is still greater than positrons. For example, the number of electrons is 1.2 times of that of positrons in electric field of 500 V/cm at YBJ. While the electric field is greater than 600 V/cm, the number of electrons is less than the positrons. For instance, the number of electrons is about 89% of that of positrons in electric field of 800 V/cm at YBJ.

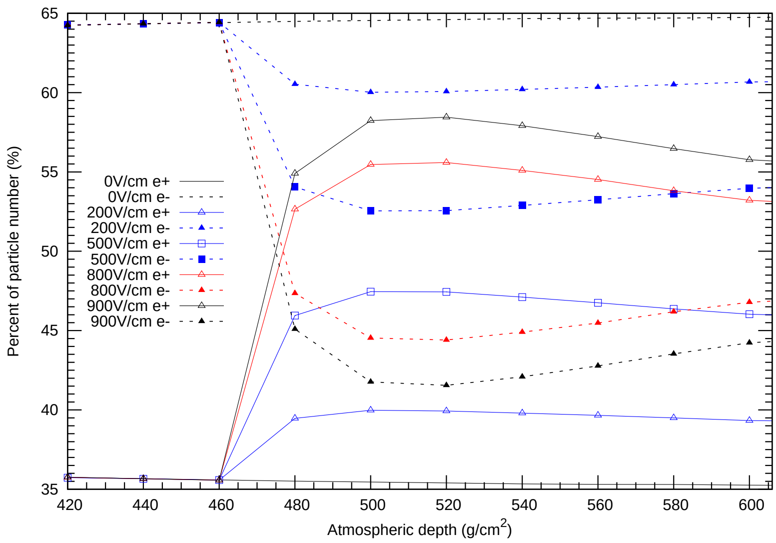

Fig. 6: Percent of electrons and positrons number as a function of atmospheric depth in different positive fields

The number of electrons is greater than positrons, which is caused by Compton scattering effect. Meanwhile electrons are more easily affected by electric field than positrons in the same strength field [7]. So the total number of electrons and positrons may decline in a certain positive electric field. In our simulations, the decline phenomenon occurs in the positive electric field less than 600 V/cm.

5. Conclusion

In this paper, Monte Carlo simulations were performed with CORSIKA7.3700 packages to study the intensity change of ground cosmic rays in near-earth thunderstorms electric field. The total number of electrons and positrons increases with the strength of the field in the negative field or in the positive field greater than 600 V/cm, while a certain degree of decline ($\sim$3%) occurs in the positive field less than 600 V/cm. Our simulation results are consistent with the experimental observations of ARGO-YBJ.

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