Observing the effect of the atmospheric electric field inside thunderstorms on the EAS with the ARGO-YBJ experiment

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Abstract: The strong atmospheric electric fields inside thunderstorms can have a significant effect on the electromagnetic component of cosmic ray air showers. Detecting this effect is particularly important in understanding the relation between the showers and lightning. Some episodes in which intensely changed atmospheric electric field during thunderstorms affect the counting rate of single particle have been recorded by ARGO-YBJ experiment. One of the episodes is discussed carefully, which happened in the morning of July 20, 2009 (Beijing Time). A short duration ($\sim$20 minutes) significant increase of the single particle counting rate with low energy occurs accompanied with strong atmospheric electric field, while a decrease happens in the counting of particles with higher energy.

Keywords: extensive air shower (EAS), atmospheric electric field, thunderstorm, the ARGO-YBJ experiment

1 Introduction

When the primary cosmic rays (CRs) go through the air, lots of new secondary particles will be generated due to the ionization of atmospheric atomic nucleus. This is a well known phenomenon called extensive air shower (EAS). In 1925 Wilson published the hypothesis of runaway electrons and advanced that the secondary electrons generated from EAS will be accelerated to higher energies via atmospheric electric fields permeating in the air during thunderstorms[1]. Under fair weather conditions atmospheric electric fields(AEFs) are small, but the strong fields inside thunderstorms can have a significant effect on the electromagnetic component of a shower. Studying this effect is particularly important in understanding the relations between the shower and lightning. In order to study the relationship between the AEF during thunderstorms and secondary particles of EAS, some experiments have been founded and confirmed the influence of electric field on the secondary particles in shower. ARGO-YBJ experiment is a large observation station designed for VHE γ astronomy and many fundamental issues of CR, including the effect above. Based on the data obtained from the ARGO-YBJ experiment, many interesting events are detected and in this paper one of them is chosen as a typical example to analyze the effect.

2 The ARGO-YBJ experiment

The ARGO-YBJ experiment is an extensive air shower detector located at an altitude of 4300m a.s.l. at the Yangbajing Cosmic Ray Laboratory. The detector is composed of a single layer of Resistive Plate Chambers (RPCs), operated in streamer mode[2] and grouped into 153 units called "clusters". The clusters are disposed in a central full coverage carpet and a sampling guard ring. The detector is connected to two independent data acquisition systems, corresponding to the shower and scaler operation[3].

In the scaler mode, the single particle counting rate of each individual cluster is given out in every 0.5s putting in coincidence in a narrow time window (150ns). Each cluster has 4 channels to record the counting rates referred to n$\geq$ 1, 2, 3, 4, respectively, 4 counting rates about 40kHz, 2kHz, 300Hz, 120Hz[4]. In order to make the RPCs running in a steady circumstance, an additional detector control system (DCS) has been installed to monitor the meteorological parameters such as atmospheric pressure, outdoor and indoor temperature, humidity inside the hall and the AEF on the roof of the hall[5].

3 Data analysis and Discussion

In the past four years, using the scaler mode and the AEF data from the ARGO-YBJ experiment we have been monitoring the 4 channels counting rate variations during thun-

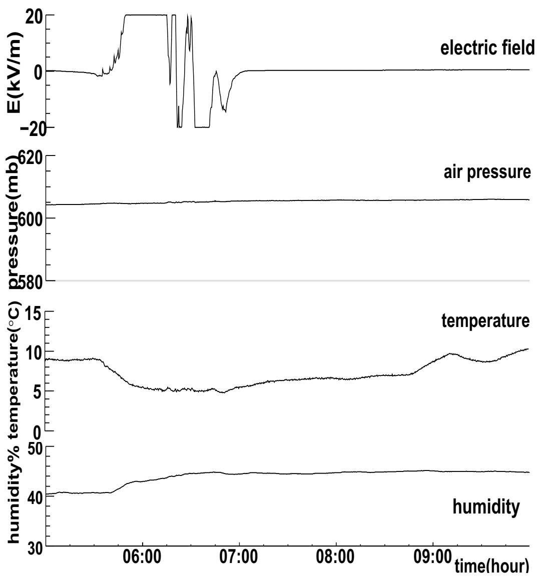

Figure 1: AEF strength and meteorological parameters (atmospheric pressure, temperature, humidity) variations with time (Beijing time) in the morning of July 20, 2009

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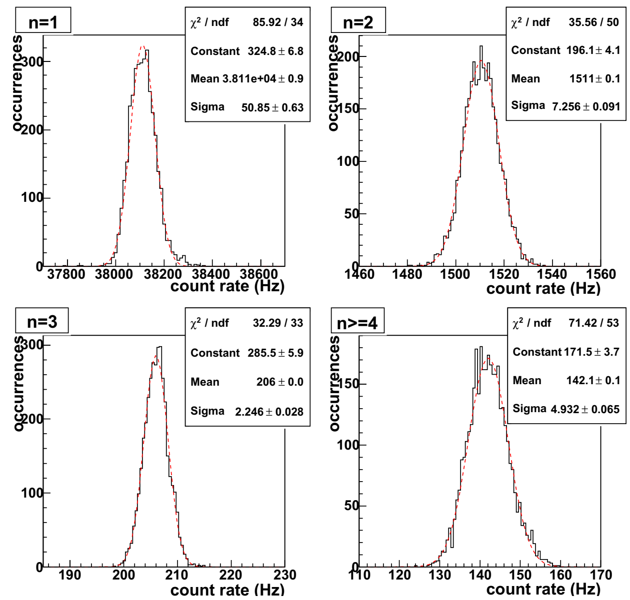

Figure 2: Statistical distributions and the Gaussian fit of the 4 channels counting rates n=1, 2, 3 and n≥ 4 in the morning of July 20, 2009. The σ is given out by the Gaussian fitting, which is basically consistent with standard deviation calculated, 54.78, 7.35, 2.26 and 5.03 corresponding to n=1, 2, 3 and n ≥ 4 respectively.

derstorms and found numbers of rates increasing and decreasing events. For example, in the summer of 2010 three events happened on Aug. 23, Sep. 29 and Sep. 30. Due to the space limits, here we will not go into details one by one. But as a typical event, here only shows the phenomenon happened on July 20, 2009. The complete statistical analysis on the event's characteristics will be done in the follow-up work.

Figure 1 shows that at the site of ARGO-YBJ there is a thunderstorm in the morning of July 20, 2009 (local time in Beijing). During the thunderstorm the AEF begins to increase at ~5:42 quickly to a value larger than 20 kV/m, and decreases rapidly to a value smaller than -20kV/m till ~7:12 it returns normal. The temperature and humidity have about 4 degrees decrease and 5% increase simultaneously, while the pressure has no significant change. It is known that the main factor of meteorological effects influencing the cluster counting rates is atmospheric pressure, which can make about $0.7\%/mb$ change of the EAS counting rats [4]. During this thunderstorm the increment of the atmospheric pressure relative to the mean value of long interval is smaller than 0.6mb. Therefore initially we will not consider the influence of other atmospheric parameters on the EAS except for the AEF. A correction of meteorological effects will be made when calculating the percent variations of counting rates for 127 clusters. In addition, during this interval the background counting rates of 4 multiplicity channels for No. 54 cluster follow a Poisson distribution as shown in Figure 2.

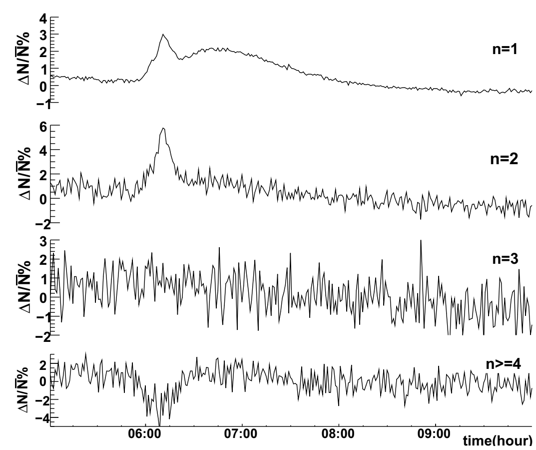

Figure 3: Variations of 4 channels SPT counting rates of No.54 cluster during this thunderstorm. The data from 5:00 to 6:00 and from 8:00 to 10:00 is considered as the background, which is averaged in a minute. ΔN represents the difference between the data and mean value $\bar{N}$.

In a clear day the magnitude of AEF at Yangbajing maintains stable to be about 0.2kV/m, while it changes violently during the thunderstorm, whose absolute value is larger than 20kV/m. The counting rates of No. 54 cluster are checked during the thunderstorm on July 20, 2009, and

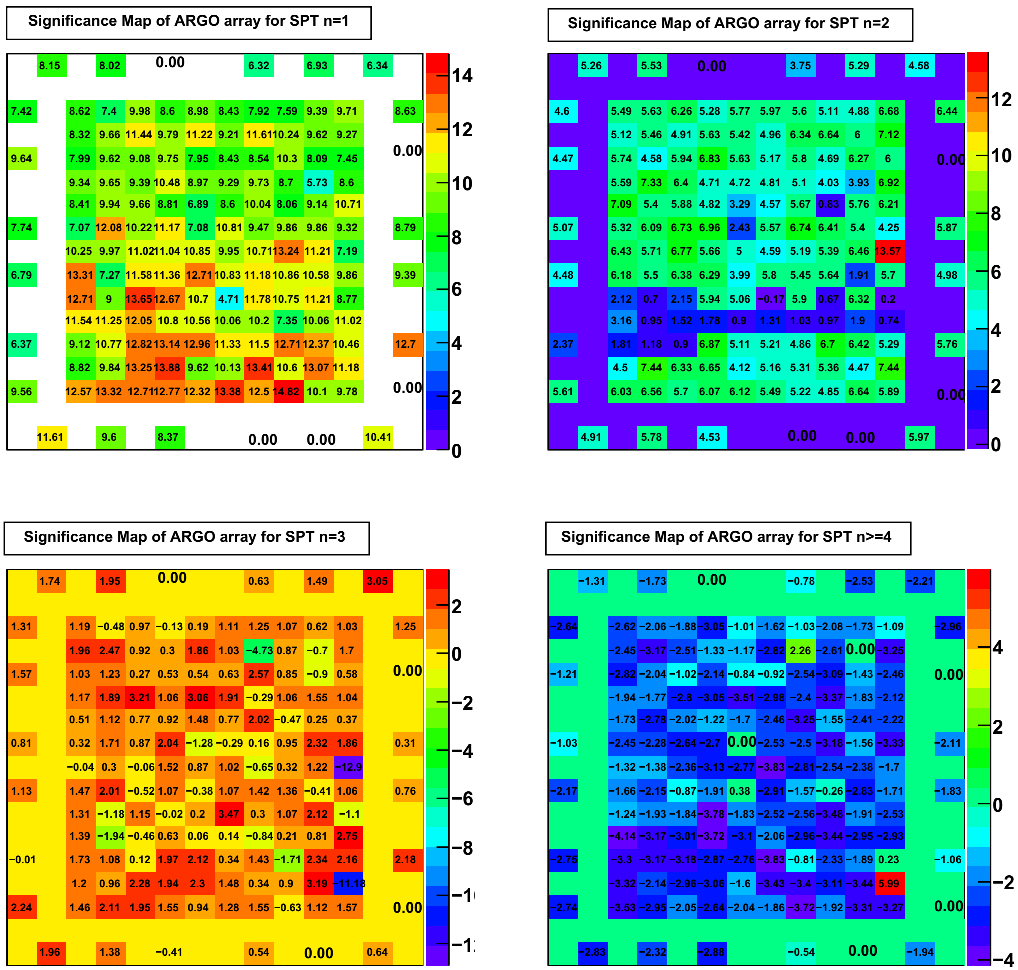

Figure 4: Statistic significance distributions of counting rates of each ARGO-YBJ cluster, corresponding to n=1, 2, 3 and n $\geq$ 4 respectively, when the maximum increase or decrease appears (at ~6:10) during the thunderstorm. Each box represents a cluster and the significance of each cluster has been given in the boxes. The number in each box is obtained by the equation $\Delta N/\sigma$, where σ is the standard deviation (r.m.s.).

the result is shown in Figure 3. Figure 3 shows that the counting rates change with the variation of AEF, and n=1, 2 counting rates have significant increases and reach maximum value at about 6:10. The multiplicity channel n=1 counting rate has two peaks, and the increase lasts about half an hour, in the meanwhile the multiplicity channel n=2 counting rate has one peak, and the increase lasts about 20 minutes. It is very interesting that the multiplicity channel n=3 counting rate has no significant change and n=4 counting rate has a decrease, which lasts about 20 minutes. All the clusters have been checked and the increase and decrease significance at 6:10 when the counting rates of No.54 cluster reach maximum (for n=1,2) and minimum (for n$\geq$4)value are shown in Figure 4. Each box represents a cluster and the significance of each cluster has been given in the boxes. 127 clusters of ARGO-YBJ experiment have recorded these changes with high statistics significance (the maximum statistics significance of n=2 is larger than 3σ and n=1 is larger than 5σ, where σ is the standard deviation of background).

The counting rates of 127 clusters during the thunderstorm are minute-averaged into one cluster. The percent variations of the 4 channels counting rates (after correcting meteorological effects) during the thunderstorm are shown in Figure 5. Figure 5 demonstrates that at the beginning of the thunderstorm, the AEF starts to increase radically immediately, but the counting rates vary by a time delay. Obviously, after the AEF increases exceeds 20kV/m, counting rates begin to change. Unfortunately, because the scale of the monitoring apparatus used in experiment is not large e-

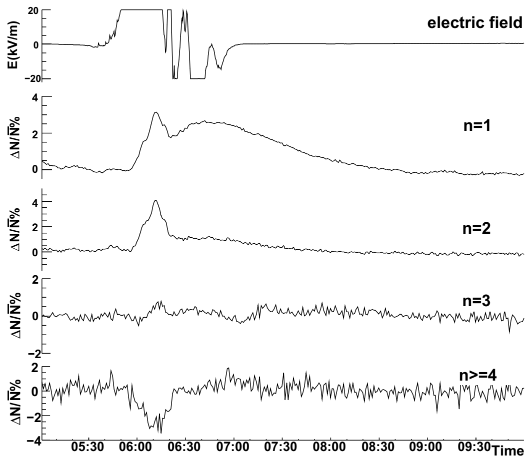

Figure 5: Variation for the AEF strength and 4 channels mean counting rates of one cluster (after correction of meteorological effects) during the thunderstorm in the morning of July 20th, 2009. The data from 5:00 to 6:00 and from 8:00 to 10:00 is considered as the background, which is averaged in a minute. ΔN represents the difference between the data and mean value $\bar{N}$.

nough, the exact AEF value at which counting rates begin to change can not be acquired.

From Figure 5 we can see that the counting rate of n=1 shows a fast increase, lasting $\sim$20 minutes, of magnitude 3.23%(statistics significance $\sim 118\sigma$), superimposed to a slower and longer 2.23% increase which may be related to the gamma ray emission from radioactive aerosols transported to the ground, as Radon daughters does[6]. The SPT counting rate of n=2 demonstrates a similar peak up to 4.08%(statistics significance $\sim 73\sigma$) with the fast increase of n=1, which is partly from hybrid effect[7]. The counting rate of n=3 has no significant increase. It is interesting to note that decreases (-2.09% with the statistics significance $\sim 33\sigma$) happen in n$\geq$4 in coincidence, demonstrating that counting rate increases are for lower energy particles and decrease for higher energy particles.

According to the reference [8], secondary particles such as electrons with high energy will lose their energy primarily through the process of bremsstrahlung and get energy from the air electric field. The particle reaches an equilibrium energy when

$$U(x) = \frac{qEz_0X_0}{X}$$

Where U is the particle energy, q is the particle charge, X the atmospheric depth, $X_0 \approx 36.7 g/cm^2$, and $z_0 \approx 8.4$km. Particles below this energy are accelerated, while for particles above this energy radiation losses dominate. So the results observed may be understood as follows.

The fast increase occurring in n=1, 2 counting rate seems to be caused by the acceleration of AEF. The counting threshold energy of n=3 maybe approximately equal to the equilibrium energy value. The decrease in n$\geq$4 counting rate could be a result of dominating bremsstrahlung.

4 Summary and Discussion

Using the data obtained from ARGO-YBJ experiment, we analyze the variations of the AEF and 4 multiplicity channels counting rates of EAS during the thunderstorm happened in the morning of July 20, 2009. The AEF change intensely during the thunderstorm, and can influence the EAS counting rate significantly. The counting rates of lower energy (n=1,2) increase while the higher (n$\geq$4) decrease.These may be explained by the acceleration of AEF and bremsstrahlung loss.

Lots of events which are similar to the one happened in July 20, 2009, for example, three events have been recorded in the day of Aug. 23, Sep. 29 and Sept. 30 in the summer of 2010. We're going to perform a more complete statistical analysis on the event's characteristics. Moreover, it is necessary to extend the observing scale of the air electric field. The relation between the lightning and the EAS counting rate would also be studied in next work.

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