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The EAS counting rate during thunderstorms

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Abstract. Some episodes in which perturbed atmospheric conditions during thunderstorms affect the counting rate of Extensive Air Showers have been observed by the EAS-TOP array. The most significant of them are discussed. They consist of increasing EAS counting rates of duration ∼10-20 minutes accompanied by similar effects in the single ionizing particle rate. The entity of the effect is ∼10-15%, and is larger for showers hitting a large number of detectors. The effect is compatible with an additional acceleration of secondary shower electrons by strong atmospheric electric fields.

1 Introduction

The idea that secondary electrons from cosmic rays could be accelerated to higher energies by atmospheric electric fields during thunderstorms dates from the 20's (Wilson, 1925).

In the last decades several measurements (on the ground or flying on baloons and planes) have observed increments of the low energy particle counting rate in presence of thunderstorms and also X-ray production due to the bremsstrahlung radiation emitted by the accelerated particles (see for example Shaw (1967); McCarthy (1985); Eack (1996); Alexeenko et al. (1985)).

In a previous paper (Aglietta et al., 1999) we presented the observation of significant increases in the single particle counting rate in coincidence with perturbed weather conditions, made by the air shower array EAS-TOP. In some cases, during electrical thunderstorms, these events were accompanied by noticeable increases in the Extensive Air Showers counting rate. In this paper we will concentrate our discussion on the characteristics of such events.

2 The EAS-TOP array

EAS-TOP, a multicomponent detector of EAS, has been working since 1997 up to 2000 at Campo Imperatore (National Gran Sasso Laboratories) at 2000 m a.s.l.

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The electromagnetic detector consists of 35 plastic scintillator modules (each of area 10 m^2 and thickness 4 cm) spread over an area of $\sim 10^5$ m^2 (Aglietta et al., 1988). Each scintillator operates at an energy threshold $E_{th} = 3.0 \pm 0.5$ MeV ("external" detectors). Ten out of the 35 detectors have an additional wooden cover that increases the energy threshold of charged particles to $E_{th} \sim 25$ MeV ("covered" detectors).

The data set used in this analysis includes:

1) EAS data: Extensive Air Showers generated by cosmic rays of energy $E > 80$ TeV; the trigger condition requires at least 4 contiguous detectors hit inside a time coincidence of 300 ns; the trigger rate is ∼29 Hz.

2) SP data: the single particle counting rate of any individual scintillator recorded every 100 seconds. The average SP counting rate is $n_c \sim 500$ and 400 m^{-2} s^{-1} respectively for "external" and "covered" detectors.

3 The observations

3.1 Single particle counting rates

The SP counting rate is mostly due to secondary particles (muons and electrons) generated in the atmosphere by low energy primary cosmic rays. Besides the well known "standard" modulations of the secondary flux (due to atmospheric pressure variations, the 24 hours anisotropy and the solar activity) significant increases in the SP counting rate of the "external" detectors have been observed during rainfalls (Aglietta et al., 1999). The increase usually starts at the beginning of the rain and reaches a magnitude of the order of ∼5-15% in a time of ∼ 0.5-1 hour; when the rain stops, the counting rate returns to its normal value in a few hours. A typical event, occurred on July 11 1996, is plotted in Fig.1: curve *a* shows the SP counting rate of an "external" detector, curve *b*) the SP counting rate of a "covered" one. The effect is shown by the slow counting rate increase of the "external" detector, beginning at ∼1:30 UT and reaching its maximum at ∼2:30

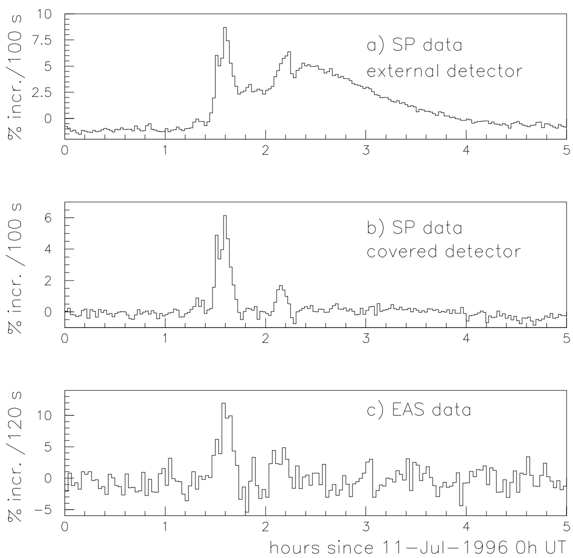

Fig. 1. EAS-TOP data during the July 11 event. Curve *a*: percent increase of the single particle counting rate of one "external" detector; curve *b*: single particle counting rate of one "covered" detector; curve *c*: extensive air shower rate.

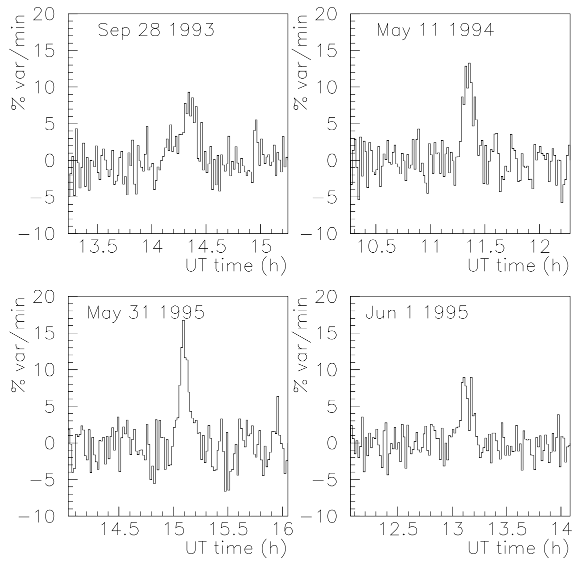

Fig. 2. Percent variation per minute of the showers counting rate during 2 hours around four EAS increase events.

UT (the higher peaks of smaller duration visible at $\sim$ 1:40 UT and $\sim$ 2:10 UT are discussed in the next subsection).

Similar increasing effects has been observed at the same site in coincidence with the EAS-TOP data in a series of measurements performed with a NaI(Tl) scintillation detector at energies E $<$ 3 MeV (Brunetti et al., 2000). The comparison of a particle spectrum obtained during such episodes with a spectrum obtained in normal conditions has shown that the increase is due to the gamma decay of Radon daughters, and is probably caused by the radioactive aerosol transported to the ground by the rain. A similar "washout" effect has been observed by the same group in a different site (Cecchini et al., 1997).

The counting rate increases observed by the NaI(Tl) detector and those observed by EAS-TOP show the same temporal characteristics; furthermore the effect observed by EAS-TOP is energy dependent (i.e., present at a very low level in "covered"detectors, see Fig.1) suggesting that the high energy tail of the "washout" effect can be responsible for the observed SP increases.

3.2 EAS counting rates

During some of the rainfall increases, characterized by the presence of tunderstorm and lightning activity, significant excesses in the air shower counting rate have been observed, lasting $\sim$ 10-20 minutes, superimposed to the longer duration SP increases. The curve *c* of Fig.1 shows the EAS counting rate during the July 11 1996 event. The EAS rate has a peak of about 20 minutes duration, reaching 14% at its maximum, followed by a less significant increase $\sim$30 minutes later, and several non-statistical fluctuations for $\sim$2 hours; two peaks in coincidence are also visible in *a* and *b*. In *a* the peaks are superimposed to the long duration increases ascribed to the "washout" effect previously discussed.

In order to study this phenomenon we concentrated our attention on five among the most intense of such episodes and we analyzed the characteristics of the showers detected during the events. After a carefull analysis, aimed at investigating the possibility of instrumental effects, we concluded that the effect is due to a real increase of the number of showers triggering the detector. All showers recorded during the increases have been well reconstructed, and showed similar features in all the five events, suggesting that the increases are due to the same physical effect. In the following we will discuss these common characteristics.

1) Time duration and amplitude.

The typical duration of the events is 10-20 minutes and the peak has an almost symmetrical shape. The EAS counting rate during four increases are shown in Fig.2, the fifth event considered is the one of Fig.1 curve *c*.

The maximum amplitude of the EAS increases is 10-15%. Since the reconstruction of the shower size and core position is possible only for the small fraction of showers whose core falls inside the EAS-TOP boundary, a comparative analysis of the shower sizes cannot be performed. The amplitude of the effect however depends on the number of modules N_d hit by the showers, increasing significantly for larger N_d. Large N_d values imply the selection of showers with larger sizes and cores closer to the array. Fig.3 shows the integral distribution of N_d during the event occurred on July 11, 1996, compared with the same distribution obtained in "normal" conditions (i.e. in a time interval of 100 minutes starting 2 hours before the increase and normalized to the actual increase duration). While for $N_d \geq 4$ the difference between

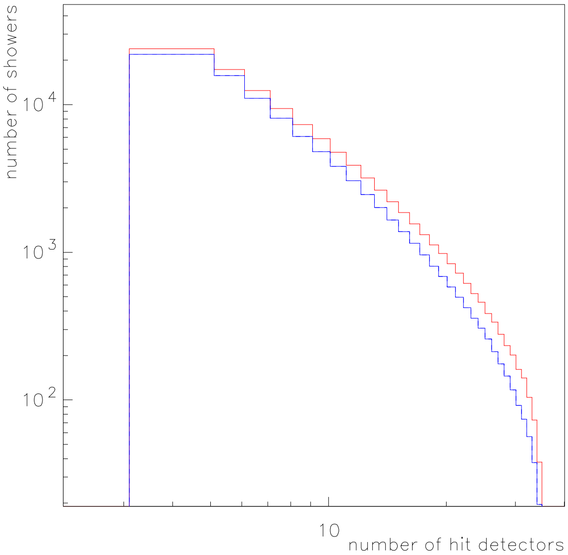

Fig. 3. Integral distribution of the number of hit detectors per shower during the EAS increase of July 11 1996 (red line) and in condition of umperturbed weather conditions (blue line).

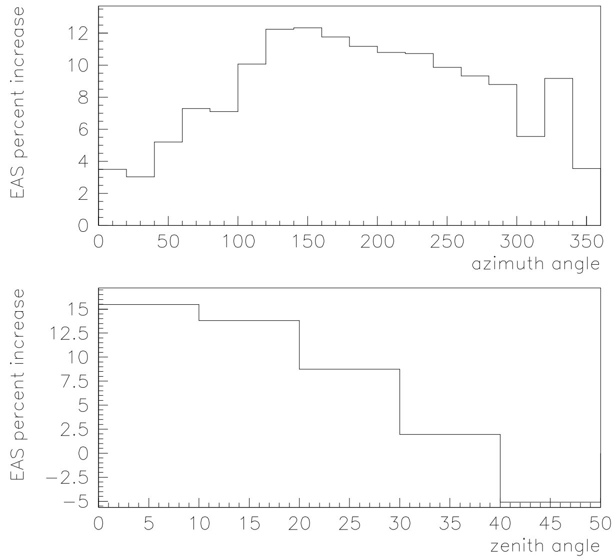

Fig. 4. Percent increase of the number of showers as a function of the azimuth and zenith angles detected during the five EAS increases added together. The azimuth angle is measured from North towards West.

the two distributions is $\sim 8\%$, for $N_d \geq 30$ it reaches the value of $\sim 80\%$. The energy range of showers hitting such large number of detectors is $\sim 10^{15}$-10^{16} eV. A similar effect is observed in all the considered events.

2) Arrival directions of showers.

Analyzing the shower arrival direction distribution during the five events we observe that the EAS increases are larger for small zenith angles and non uniform in azimuth. Fig.4 shows the percent increase as a function of the zenith and azimuth angles during the five events (added together). In all events the increase is maximum for zenith angles smaller than 20° and for azimuth angles around 180°, corresponding to the South.

Considering that the array is located on a mountain slope with an average tilt of ~10° towards South, the maximum of the increase seems to be due to showers with arrival directions about perpendicular to the ground.

3) Time spread of the shower front.

The time spread of the shower particles, i.e. the “thickness” of the shower front seems to be slightly larger during the increases than in normal conditions. To evaluate the shower thickness we considered 15 overlapping roughly circular sub-arrays of 150 m diameter, each of them consisting of 6 or 7 detectors. Working with sub-arrays we can neglet the curvature of the shower front, since in first approximation the shower front is almost flat inside a single sub-array. For a given shower, we determine its arrival direction in every sub-array and the plane that fits the spatial and temporal distributions of particles. Fig. 5 shows the distribution of the distances of the particles from the best fit plane for the showers detected during the July 11 1996 event, compared with

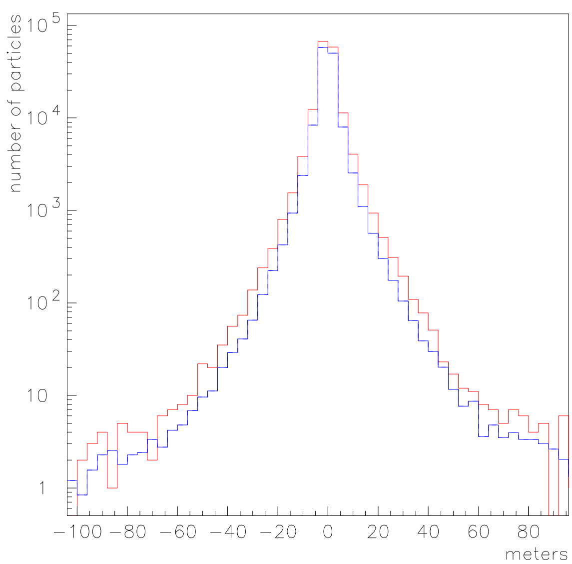

Fig. 5. Distance of the shower particles from the best fit plane of the shower front during the EAS increase of July 11 1996 (red line) and during normal conditions (blue line).

the distribution obtained in normal conditions. In the figure the distances are positive for particles "behind" the plane (delayed particles) and negative for particles "before" the plane (anticipated particles). The r.m.s. of the distribution is 6.3 m during the event and 5.6 m in normal conditions, suggesting the presence of a further source of temporal spread of the order of 50% of the normal one. A similar effect is observed in the other four events considered, the spread increase contribution ranging between 25 and 50%.

4 Conclusions

Episodes of increasing counting rates of EAS at threshold energy ∼80 TeV have been recorded by EAS-TOP during thunderstorms. The characteristics of such events are compatible with an origin due to the acceleration of secondary shower electrons by strong atmospheric electric fields.

A strong lightning activity in an interval of 10 minutes preceding the July 11 1996 event has been observed (Brunetti et al., 2000) with 5 lightning strokes within a distance of 9 kilometers supporting the idea of the presence of close electrical fields (in the case of the other four events the lighting activity is not known).

According to Gurevich (1992, 1999) EAS electrons with energy $E > E_c$ ∼0.1-1 MeV moving inside an atmospheric electric field of magnitude larger than 1-2 KV cm^{-1} are accelerated and initiate a particles avalanche. Due to collisions with air molecules they can generate knocked-out electron with energy E $> E_c$ that in turn are accelerated and produce new knocked-out electrons and so on, the number of electrons increasing exponentially ("runaway" process).

Following this idea, the observed EAS counting rate increases could be the result of the passage of a charged thundercloud over the EAS-TOP site, with a strong electric field about perpendicular to the ground. The electric field could amplify the shower sizes, according to the "runaway" process, producing an increase of the number of detected showers. The electric field could also increase the observed thickness of the shower disk due to the time required by the acceleration process.

Such suggestions could be investigated and supported by EAS measurements, accompanied by simultaneus measurement of the actual electric field.

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