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Radio-detection of UHECR by the CODALEMA experiment

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Abstract: The principle of the CODALEMA experiment is based on an original approach of the detection of radio transients associated with extensive air showers induced by ultra high-energy cosmic rays. Since September 2006, CODALEMA has been under operation with a new setup at the Nançay Radio Observatory, France. It uses 16 broadband dipole antennas associated with 13 particle detectors generating the trigger and allowing the primary cosmic ray energy estimation. We will present evidence for the radio detection of cosmic rays above 10^{17} eV, based on an event-by-event analysis and we will discuss the radio characteristics of these showers.

Introduction

Radio emission associated with the development of Extensive Air Showers (EAS) initiated by high-energy cosmic rays was investigated in the 1960's [1]. Since 2002, with the availability of fast electronics, several groups have undertaken the task of reinvestigating the phenomenology of radio pulses. The experiments CODALEMA, located at the Nançay radio Observatory in France and LOPES in Germany obtained firm evidences for a radio emission counterpart of cosmic ray air showers [2,3,4].

The new CODALEMA setup including arrays of active dipoles and ground particle detectors is described in details in an other contribution of this conference [5].

Event selection

The results thereafter presented have been deduced from a sample of events taken since the beginning of December 2006 and corresponding to 104 effective days of data acquisition. The trigger of the experiment is generated by coincidences of the scintillators stations. For the period of study we have a sample of 15029 internal events air showers (an event is classified as "internal event" if the 5 central particle detectors are flagged and the central station gets the maximum signal). Among these events, 101 events detected by the antennas meet the following criteria: a time coincidence and an angular difference of the arrival direction within respectively 200 ns and 20° between the information reconstructed from the particle and radio detectors. The direction of the particle showers is determined by triangulation independently made with the two arrays, using arrival times from the digitised signals. The shower energy of the "internal events" is determined by the Constant Intensity Cut (CIC) method [6] with a precision of around 30 %. Finally if we take into account the "internal events" criterion we have 31 radio-detected cosmic rays for the period.

Radio detection efficiency

The energy distribution as above determined for internal events measured by the ground particle array and detected by the dipole array are displayed in Figure 1. Moreover we select only showers inside a radius of 200 m around the central scintillator station. The energy threshold of the ground particle array is around 10^{15} eV; the two distributions converge when energy increases suggesting a rise in the radio-detection efficiency. The efficiency plot of the Figure 2 allows to estimate the radio-detection threshold at 10 % at 9.10^{16} eV.

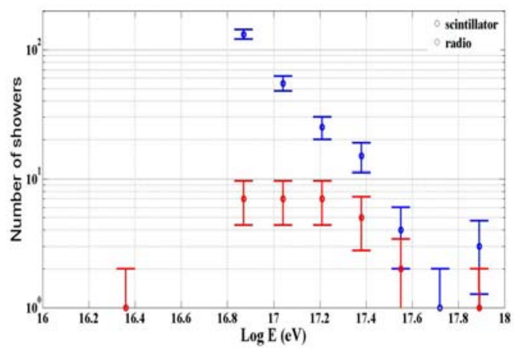

Figure 1: Distribution of the energy measured by the ground particle detector array (top, blue dots) and the distribution of the radio-detected showers for “internal events” (bottom, red dots).

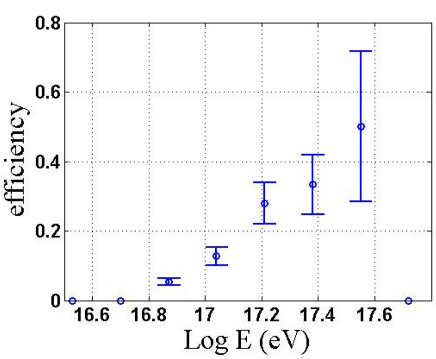

Figure 2: Efficiency of radio detection versus energy deduced from the scintillator analysis.

Because of the low number of events available we do not establish the efficiency at higher energy, nevertheless we should expect a full efficiency around 10^{18} eV.

Geomagnetic effect

Figure 3 shows the sky map of the 101 events reconstructed using the antenna information. Being strongly correlated with their particle detector information counterpart, they are clearly associated to air showers. A noticeable deficit of events coming from the southern direction can be observed whereas the azimuth angle distribution measured by particle detectors is compatible with a uniform distribution. In Figure 4, the zenith angle distribution shows the classical zenithal dependence.

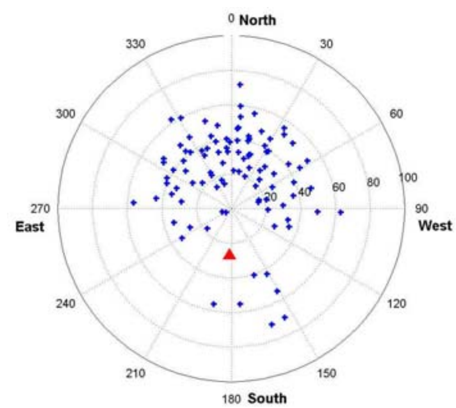

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Figure 3: Sky map of the arrival directions of 101 cosmic ray showers recorded by the CODALEMA dipoles in coincidences with particle detectors, after time and angular selections. The red triangle represents the geomagnetic field orientation. Dotted internal circles refer to indicated values of zenith angles up to the horizon; the external values stand for azimutal angles.

Such north-south asymmetry was previously observed at the end of the 60’ at Haverah Park [6]. A probable explanation of this radio-detection deficit in the south celestial hemisphere could issues from the geomagnetic field oriented at 27° from the zenith and south azimuth. Indeed, one can expect a suppression of the geosynchrotron emission when the showers axis are aligned with the terrestrial magnetic field.

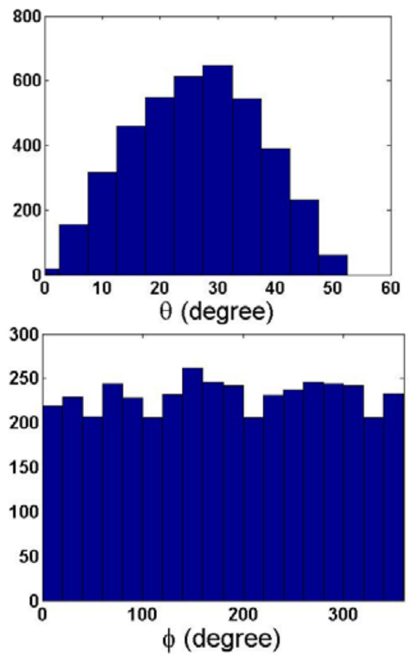

Figure 4: Zenith (top) and azimut (bottom) angular distributions of the internal showers and E > 10^{16} eV detected by the particle detector array used as a trigger.

The distribution of the angle α between shower axis and geomagnetic field (Figure 5) associated with each radio-detected event seems to confirm the radio-detection suppression for small values of α (below 15°). Moreover, we observe an obvious dependence of the radio event rate on the geomagnetic angle. Figure 6 displays the shower energy as a function of the α angle. We notice that we detect less showers of low energy (~10^{17}) when α is small (~20°) and on the contrary more events when α is close to 70°, i.e. when the arrival direction of the shower is close to the perpendicular direction to the geomagnetic field, where the shower charge deviation is maximum.

With the previous CODALEMA setup [2] using conic helix log-periodic antennas, this effect has not been highlighted. The helix antenna gain pattern is maximum for a zenith angle of 20° towards south, which allows a best detection of showers of low energy (10^{17} eV) for the south arrival direction. The current CODALEMA setup features only active dipoles. The gain pattern, in contrary to conic helix antennas is symmetric for southern and northern arrival directions. That could explain why we observe this deficit in the south close to the geomagnetic orientation.

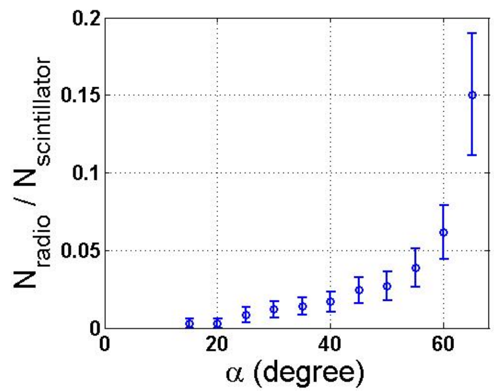

Figure 5: Distribution of α, this distribution is corrected for the acceptance distribution of the trigger calculated from histograms of the Fig. 2.

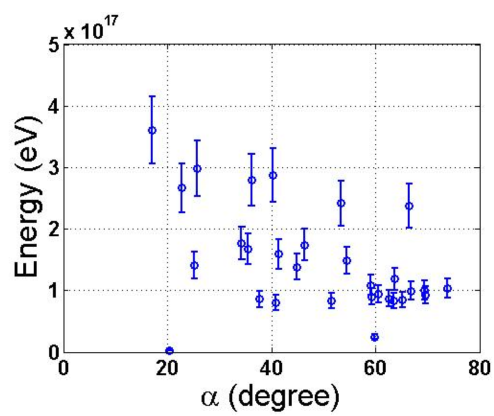

Figure 6: Primary cosmic ray energy (eV) versus the α angle. With the present counting, no radio signal is detected below 17°.

This result seems to be consistent with the contribution of the geomagnetic emission process in the generation of radio signal from air shower induced by cosmic rays. However, this observation alone does not exclude other possible radio emission contributions.

Electric field lateral profile

As in the first configuration of CODALEMA using conic helix log-Periodic antennas we find again a satisfactory dependence of the electric field amplitude to the shower axis distance with the 2 parameters (E_0, d_0) fit $E = E_0 . \exp(-d/d_0)$. Figure 7 displays one of the most energetic event measured by CODALEMA. This event is unfortunately not “internal”; despite that, we can estimate with confidence its energy because the position of the shower core (evaluated by radio) allows to constrain the fit. For this event, E_0 is 3.2mV/m and d_0 =135 m. Response of the 12 dipoles simultaneous tagged are corrected for the antenna and amplifier gains. The energy is evaluated at 2.10^{18} eV.

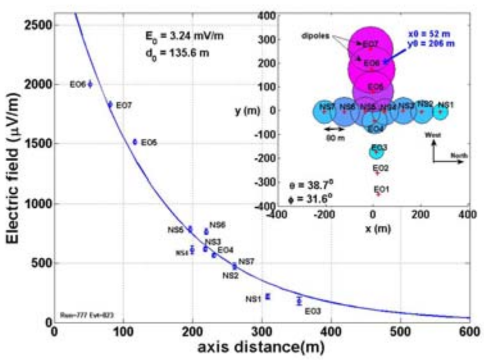

Figure 7: EAS electric field amplitude versus distance to the shower axis for the higher energetic event. The inset displays the topology of the ground field with the reconstructed direction and core location of the shower.

However, we need at least 5 antennas tagged to be able to fit the E profile. We do not have enough “internal event” data to seek a correlation between the value of E_0 and the estimated energy of the primary cosmic ray.

Conclusion

The first results of the CODALEMA experiment with the new set-up (using only active dipoles) confirm the field characteristics from our previous measurement [2, 3]. The measurement of showers arrival time and direction coincidence is clearly seen. Moreover the addition of a dense network of particle detectors makes possible the shower measurement and the correlation of the measured energy with radio observables. We measure the CODALEMA radio-detection efficiency threshold at 9.10^{16} eV (100% efficiency is expected at 10^{18} eV). On the other hand, the new result is the apparent depletion of the number of radio-detected events for south directions, which seems consistent with the decreasing of the electric field geosynchrotron contribution at small α. This dependence in α doesn’t call into questions the cosmic rays radio-detection capacities. Indeed we can suppose that the Coulombian emission processes, presently believed to be less important will be dominant close to the terrestrial magnetic field direction. I.e. for a given radio detector the energy threshold should be higher for the South arrival direction. Improved statistics for “internal events” and an experimental study of the signal polarization will allow confirming this assumption. Moreover the exponential dependence of the electric fields to the shower axis distance is also observed and should make possible to establish the correlation between the energy of the primary cosmic ray with the electric field amplitude. We will increase at the end of the year the size of the array at Nançay by addition of autonomous antenna stations. The CODALEMA collaboration also explores the radio detection beyond 10^{18} eV in collaboration with the AUGER radio R&D group.

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