SF2A 2007
J. Bouvier, A. Chalabaev, C. Charbonnel (eds)

ULTRA-HIGH ENERGY COSMIC RAYS DETECTED BY THE RADIODETECTION EXPERIMENT CODALEMA

T. Saugrin[1] and the CODALEMA collaboration[1 2]

Abstract. The radiodetection experiment CODALEMA allows to study cosmic ray air showers on an event-by-event basis through the detection of the radiated electric field. Two major upgrades have been made in September 2006: a new antenna array made up of 14 active dipole antennas, arranged in a cross shape, and 13 new particle detectors providing more accurate information on air showers such as primary cosmic ray energy estimation and core shower position. Radiodetection efficiency versus energy and arrival direction distribution will be discussed.

1 Introduction

The idea of extensive air showers (EAS) radio-detection first appeared in the 60's (Askar'yan 1962, Allan 1971), but in spite of some promising attempts (Weekes 2000), did not succeed to be indispensable facing more usual others techniques, like ground detection.

Today, with the availability of fast electronics, EAS radio detection becomes again an operational technique. Indeed, several experiments, like LOPES in Germany or CODALEMA in France, have already obtained evidence for a radio emission counterpart in atmospheric showers. An accurate study of electromagnetic field characteristics and radiodetection possibilitites is now possible thanks to six months of data taking.

2 Radio electric field creation mechanisms

Among all the particles created by the interaction between primary cosmic particles and Earth's atmosphere, the charged particles, especially electron-positron pairs, lead to the creation of a coherent induced radioelectric field.

Historically, the charge excess mechanism, was the first to be assumed at the origin of induced radioelectric field (Allan 1971). Positrons created in the particle shower interact with atmospheric electrons: a negative charge excess appears, moves across the atmosphere and creates a subsequent electromagnetic field.

This mechanism was at the origin of radiodetection researchs, but negative charge excess is not the only mechanism inducing electromagnetic field. Indeed, geomagnetic mechanisms can also be inferred (Huege 2005). We can distinguish two mechanisms, a dipolar field creation mechanism, and the geosynchrotron radiation. Geomagnetic effects should depend on the angle between the shower axis and the geomagnetic field. Consequently, a suppression of geomagnetic effects is expected if the shower axis is aligned with the geomagnetic field.

At the present time, in spite of a good theorical knowledge of radioelectric field emission processes, we are still unable to know precisely the contribution of each mechanism. It is one of the radiodetection current challenges to determine these different contributions by an experimental way.

[1] SUBATECH IN2P3-CNRS/Universite de Nantes/Ecole des Mines de Nantes

[2] LESIA, Observatoire de Paris-Meudon France - Station de Radioastronomie de Nancay France - LAL, IN2P3-CNRS/Universite Paris Sud Orsay France - LPSC, IN2P3-CNRS/UJF/INPG Grenoble France - ESEO, Angers France - LAOB, INSU-CNRS Besancon France - LPCE, SDU-CNRS Universite d'Orleans France

3 Experimental setup

The radiodetection experiment CODALEMA is located at the radio observatory of Nancay. It works in the frequency band 1 to 100 MHz, corresponding to the expected electric signal duration (of the order of tens to hundreds of nanoseconds with a few microvolts amplitude).

The CODALEMA experiment is a ground detector triggered experiment in order to correlate the measured electric transients with particles detected by a scintillator based detector-array. Currently 13 ground detectors are in operation, and the experiment is triggered by coincidences between the 5 central scintillators. The trigger energy threshold is 2.10^{15} eV. Estimations of the shower core locations and the number of electrons in the shower at ground level are available for internal events (a trigger event is classified as internal if the central station gets the maximum signal). These parameters are used to estimate the primary energy, in order to be correlated with the electric field amplitude of the radio signal.

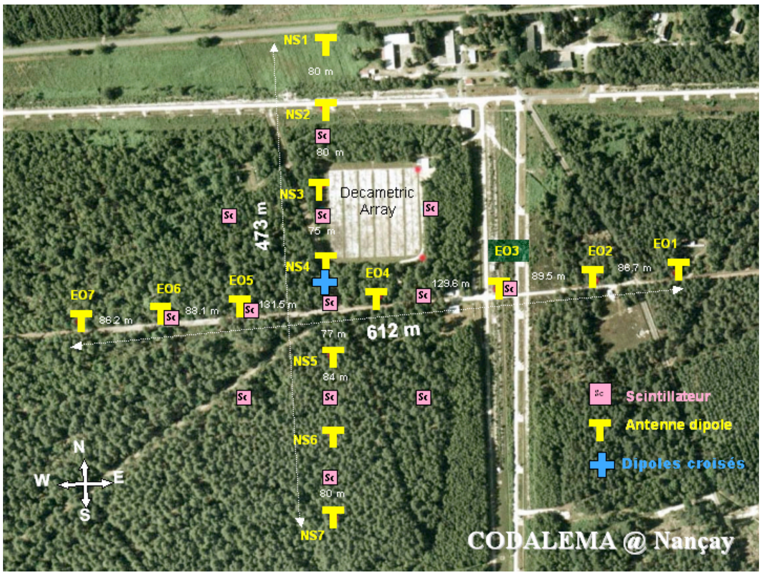

Fig. 1. Configuration of CODALEMA experiment with 2 crossed lines of antennas.

To measure the induced radio electric field, CODALEMA uses 14 dedicated antennas, deployed over 2 lines of 473 and 612 meters in the North-South axis and the East-West axis (Fig. 1). Antennas are short active dipoles with the following characteristics: large frequency bandwith (from 100 kHz to 100 MHz), small dimensions (antenna length 1.20 meters), high sensitivity and poor directivity. These specifications are obtained using a high-performance linear amplifier (ASIC) (Ardouin 2007, Charrier 2007). Data acquisition system uses waveform digitizers (MATACQ ADCs, 12 bits, 1 GS/s, 2.5 microseconds recording time) which allows an accurate measurement for the smallest signals and avoid signal saturation due to the radio transmitters.

The recorded radio signals are identified by an off-line analysis (Ardouin 2005): waveforms are numerically filtered in the 37-70 MHz band, and occurrences of pulses are tagged by setting an amplitude threshold on the signals. If at least 3 antennas detect a radio pulse, the arrival direction of the wave front is determined by triangulation. True EAS events are discriminated from fortuitous events by using selection criteria on arrival time ($<$ 200 nanoseconds) and angular difference ($< 20^o$) between particle impacts and radio wave fronts.

4 Radiodetection efficiency

The present results have been acquired using data measured between December 2006 and May 2007 (Ravel 2007). During this period of 104 effective days of data acquisition, 101 true EAS radio events have been detected by CODALEMA. The number of radio events triggered with the internal criterion is 31. By using EAS radio events correlated with internal trigger events with an estimation of the primary energy, we obtain a first energy distribution of radio detected events. A comparison with the energy distribution of internal events shows that the two distributions converge when energy increases (Fig. 2), while the radio detection efficiency rises with energy (Fig. 3).

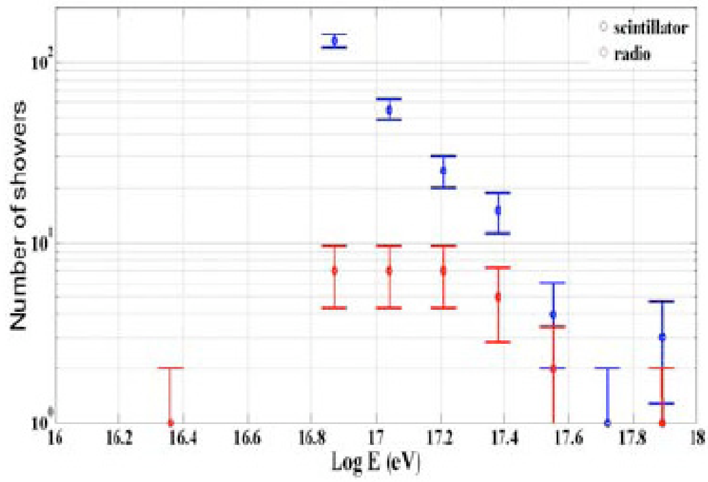

Fig. 2. Energy distributions measured by the scintillators (blue errors bars) and by the antennas (red errors bars).

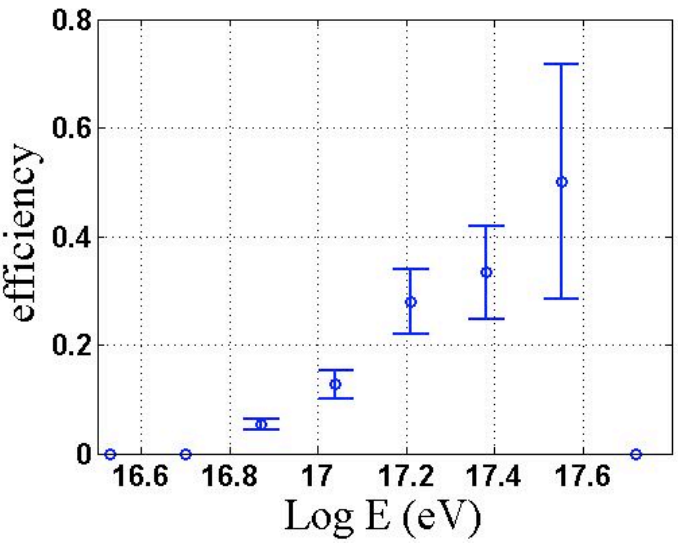

Fig. 3. Radiodetection efficiency versus energy.

We estimate the radio detection energy threshold at 10% at 9.10^{16} eV. The lack of statistics prevents to conclude about the radio efficiency at higher energy, but we can expect an efficiency of 100% above an energy of 10^{18} eV.

5 Geomagnetic effect

The arrival direction distribution of our 101 EAS radio events shows a deficit of events in the South direction. However, the arrival distribution of trigger events is uniform, so the North-South asymmetry only appears with correlated radio events (Fig. 4). A possible explanation of this phenomenon could be related to geomagnetic mechanisms: the closer the arrival direction is with respect to the geomagnetic field, the less geomagnetic effects should occur. The geomagnetic field is oriented at 27^o from the zenith and towards South, then the North-South asymmetry can be explained by a suppression of geomagnetic effects close to the geomagnetic field. The distribution of α (angular difference between the geomagnetic field and the shower arrival direction) corrected by the acceptance of the ground detectors confirms the radio-detection suppression for small angular values below 15^o (Fig. 5). In addition, the energy distribution shows that we detect lower energy showers only for larger values of α (Fig. 6).

This result confirms the importance of geomagnetic mechanisms in the induced radio electric field creation process. Nevertheless, we cannot conclude on the contribution of others creation mechanisms, which could be detectable only at higher energy.

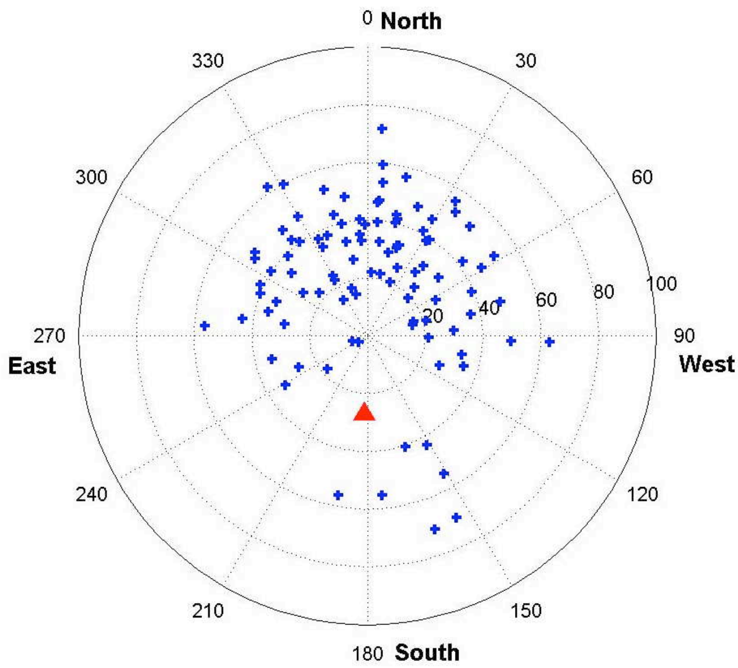

Fig. 4. Skymap of the arrival directions for the 101 EAS radio events. The red triangle represents the geomagnetic field orientation at Nancay.

6 Conclusion

The North-South asymmetry observed by CODALEMA is an important result for a better understanding of the radioelectric field creation process. The estimation of the radiodetection efficiency is a necessary first step for an optimization of the radiodetection technique. The rise of efficiency with energy confirms the interest of using radiodetection for ultra-high energy cosmic ray detection. More statistics appear necessary to confirm this results and go further in the analysis. In order to improve our measurement statistics, we have to increase the size of both antenna and the scintillator arrays. Several upgrades of the CODALEMA experiment are already scheduled, like adding 4 ground detectors in order to double the number of internal events, as well as autonomous antenna stations, easier to deploy over large areas.

In a complementary task, 3 autonomous stations are already in operation at the Pierre Auger Observatory in order to characterize EAS radio counterpart above 10^{18} eV.

References

G.A. Askar'yan, Soviet Physics, J.E.T.P., 14, (2) 441 (1962)

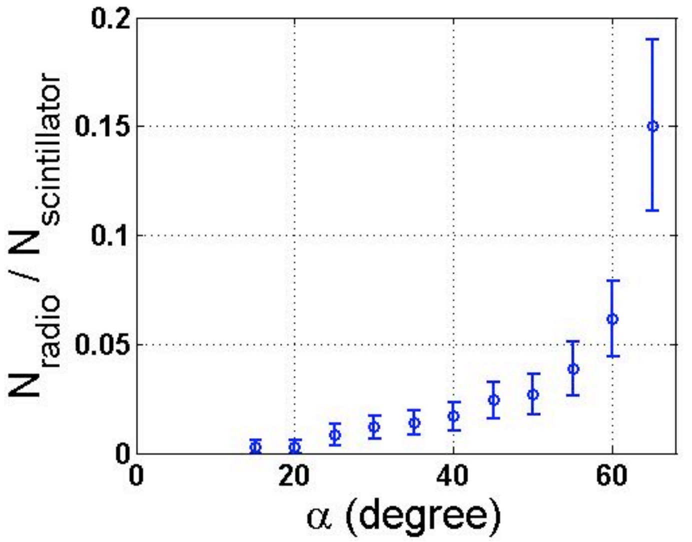

Fig. 5. Distribution of α, angular difference between the geomagnetic field and the shower arrival direction.

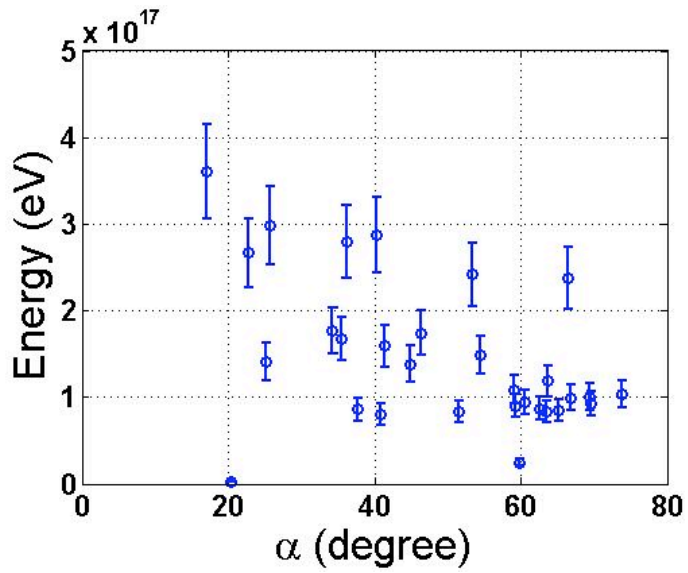

Fig. 6. Primary cosmic ray energy versus α.

H.R. Allan in: Progress in elementary particle and cosmic rays physicsm ed. by J.G.Wilson and S.A. Wouthuysen (North Holland, 1971), p. 169

T.C. Weekes, Proc. of the first int. workshop on "Radiodetection of high Energy Particles", Los Angeles, November 16-18, 2000, AIP Conference Proceedings Vol 579 (2001), 3-13

T. Huege and H. Falcke, Astropar. Phys. 24 (2005) 116-136

D. Ardouin et al., Proc. of the X^{th} Pisa Meeting, Isola d'Elba Italy, Nucl. Inst. and Met. - A572 (2007) 481-482

D. Ardouin et al., Nucl. Inst. and Meth. - A555 (2005) 148-163, astro-ph/0504297

D. Charrier, Proc. of the International Symposium on Antennas and Propagation, 10-15 June 2007, Honolulu, Hawaii

O. Ravel et al., Proc. of the XXX^{th} International Cosmic Ray Conference, 3-11 July 2007, Merida, Mexico