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D. Barret, F. Casoli, T. Contini, G. Lagache, A. Lecavelier, and L. Pagani (eds)

UPGRADE OF THE CODALEMA EAS RADIO-DETECTION EXPERIMENT

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

Abstract. In order to improve the performances of the EAS radio-measurements, the CODALEMA experiment has been upgraded. The detection array has been widened and new type of antennas and particle detectors are used. First results and new possibilities given by this new configuration will be presented.

1 Introduction

Inspired by the idea of extensive air showers (EAS) radio-detection suggested in the 60's (Askar'yan 1962, Allan 1971), the CODALEMA objective is to study cosmic ray air showers through the detection of the radiated electric fields. Multiple electromagnetic mechanisms (charge excess, geomagnetic processes) contribute to generate the transient field. The expected signal is a fast and tenuous pulse (of the order of hundreds of nanoseconds and about ten microvolts), corresponding to a large band radio frequency spectrum (roughly from 1 to 100 MHz).

Up to now, CODALEMA used spiral log-periodic antennas used in the 24-82 MHz frequency band. Especially, a 612 m line of 7 antennas in the East-West direction was deployed to study electric field evolution. In order to correlate the radio signals measured by the antennas with the particles of the shower detected by 4 scintillator based detectors, the experiment was triggered out by coincidences between the 4 particle detectors. 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 and angular windows between radio wave and particle fronts. CODALEMA demonstrates the feasibility of this cosmic rays radio-detection method for energies above 10^{16} eV. Several EAS electric field characteristics have been measured for the first time, such as lateral extends and impact parameter dependences (Ardouin 2006).

2 Upgrade of CODALEMA

To improve the CODALEMA performances, the existing North-South antenna line has been increased up to 473 m setting up 7 new antennas based on short actives dipoles (see fig. 1). These new detectors have been developed with the following main requirements: large frequency bandwidth (from 100 kHz to 100 MHz), small dimensions, high sensitivity, poor directivity and low cost. These specifications are fulfilled in the design of a short active dipole antenna associated with a high-performance linear ASIC amplifier (Ardouin 2006 b). Because the short dipole antenna is a resonant device, its gain is not constant but increases near its own resonance frequency. In order to get a flat response in the frequency band of interest, the constant gain is obtained by means of a high input impedance amplifier. Figure 2 shows the simulated dipole gains versus the elevation angle for frequencies from 1 MHz to 70 MHz and for both perpendicular directions: E-plane (parallel to the antenna) and H-plane (perpendicular to the antenna). The dipole antenna directivity is 120° in the H-plane and 90° in the E-plane.

The performances of the trigger have been enhanced with the use of 5 new scintillator stations. The new layout increases the energy detection threshold up to 2.10^{15} eV. Thanks to the change of the scintillator

[1] SUBATECH IN2P3-CNRS/Université de Nantes/Ecole des Mines de Nantes France
[2] LESIA, Observatoire de Paris-Meudon France - Station de Radioastronomie de Nançay France - LAL, IN2P3-CNRS/Université de PaRe: ris Sud Orsay France - LPSC, IN2P3-CNRS/UJF/INPG Grenoble France - ESEO, Angers France - LAOB, INSU-CNRS Besançon France - LPCE, SDU-CNRS Université d'Orléans France

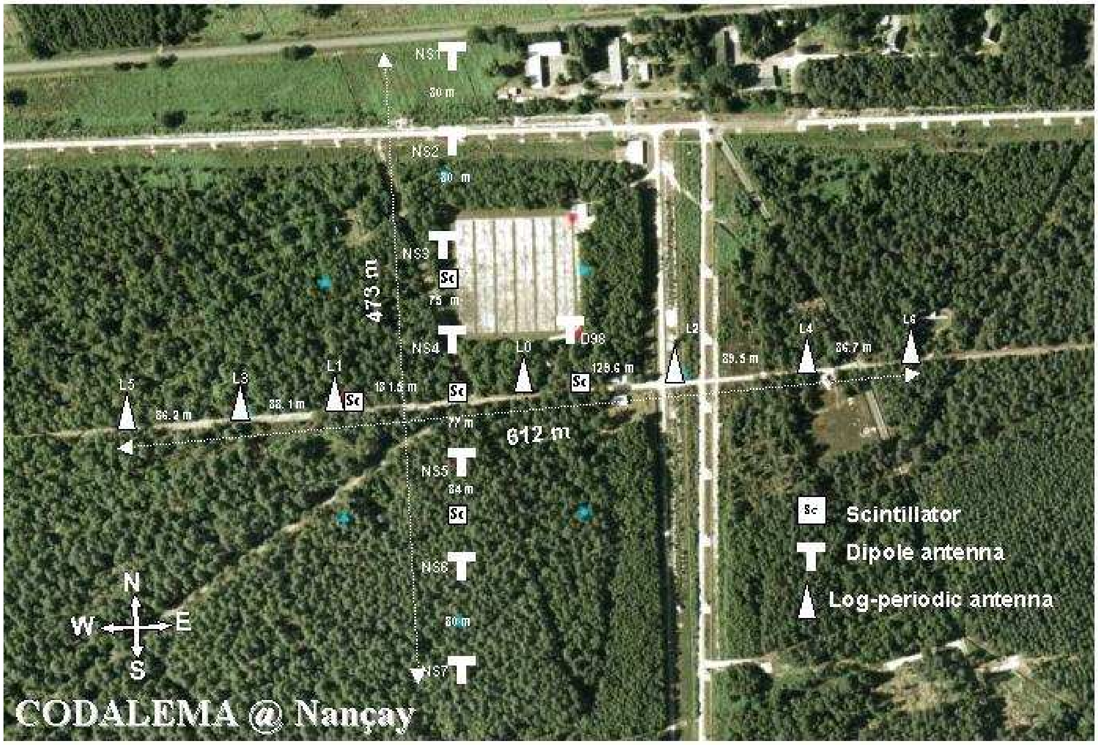

Fig. 1. The new cross-shaped configuration of the CODALEMA experiment at Nançay. To compare the detection performances, the East-West axis is equipped of circular polarized antennas (spiral log-periodic) when the North-South axis is equipped with linear polarized antennas (new dipoles).

performance (Ultra 2006), the estimations of the shower core locations and the number of electrons in the shower at ground level have been improved by an event-by-event analysis. These parameters will be used to estimate the primary's energy, in order to be correlated to the electric field amplitude of the radio signal. The acquisition system has also been improved using new waveform digitizers (MATACQ ADCs, 12 bit, 1 GS/s, 2.5 μs recording time) (Breton 2005). This results in a more accurate measurement for the smallest signals with a larger frequency bandwidth (1-100 MHz) than given by the previous 8 bit ADC. Moreover, the larger accessible ADC dynamics avoids also signal saturations due to the strong irregular radio transmitters.

3 First results

Preliminary resul of CODALEMA with the new line of dipoles show enhanced performances in EAS radio detection. A typical EAS radio event detected with the dipoles is displayed on fig. 3. With these linearly polarized antennas only one polarization of electric field can be measured. In a first analysis, both electric field amplitudes and profiles provided by the dipoles and log-periodic antennas offer similar characteristics.

The electric field dependence versus the distance to the shower axis (in the shower coordinate system), deduced from a high-multiplicity event (8 tagged antennas), is presented in fig. 4. This electric field profile of an EAS event is well described by a decreasing exponential law, in agreement with the synthesis given by Allan (Allan 1971) and recent developments made by Huege and Falcke (Huege 2005). The shower core position can be also estimated by using both distributions on North-South axis (7 antennas) and East-West axis (7 antennas).

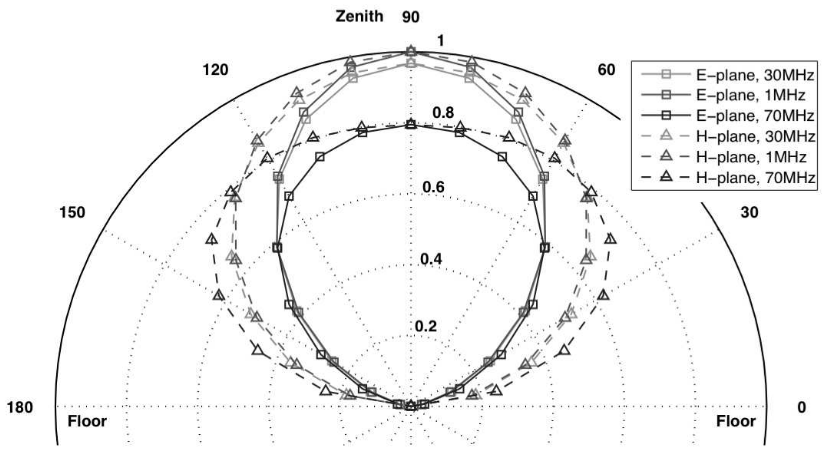

Fig. 2. Gain pattern of our active dipole simulated with the EZNEC software. The displayed gain is not a power but a normalized voltage since the dipole is loaded by a high input impedance.

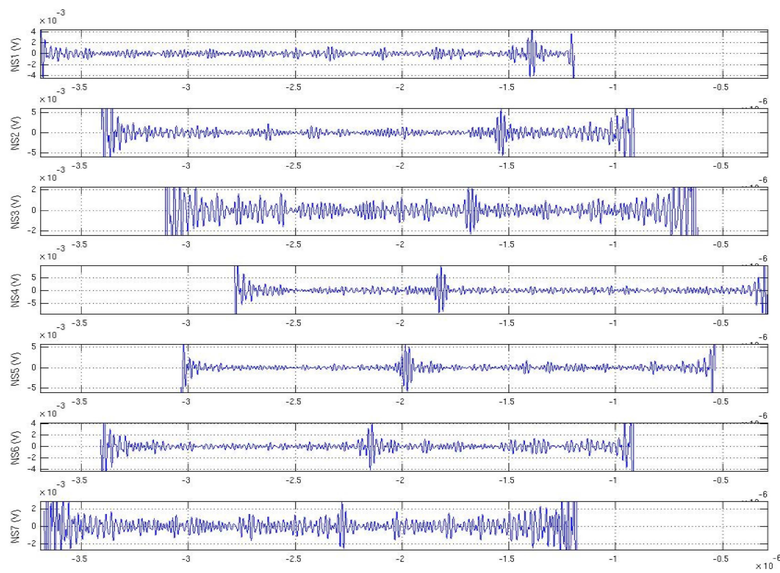

Fig. 3. Typical EAS event measured with the dipole line (voltage in volts versus time in seconds). Oscillations on the sides are artefacts due to the numerical filtering in the 37-70 MHz bandwidth.

4 Outlooks

The extend of the antenna array with the use of several new devices enhance the CODALEMA performances. Based on the quality of the results obtained from these first measurements, additional upgrades are still in progress: replacement of all the log-periodic antennas by the dipoles and increase of the number of particle detectors (up to 13 scintillators). Energy calibration provided by the particle detectors will allow a more detailed understanding both of the radio signal and of the shower development. For instance, the study of the electric field polarization effects and correlations with the geomagnetic angle of the shower will be possible. In a next step, the full horizontal components of the electric field will be studied with a set-up of active dipoles crossed perpendicularly. Currently, the use of dipoles in a stand-alone mode is also studied. In this frame, all the antennas will be fully independent from each others allowing to exploit this detection method over very

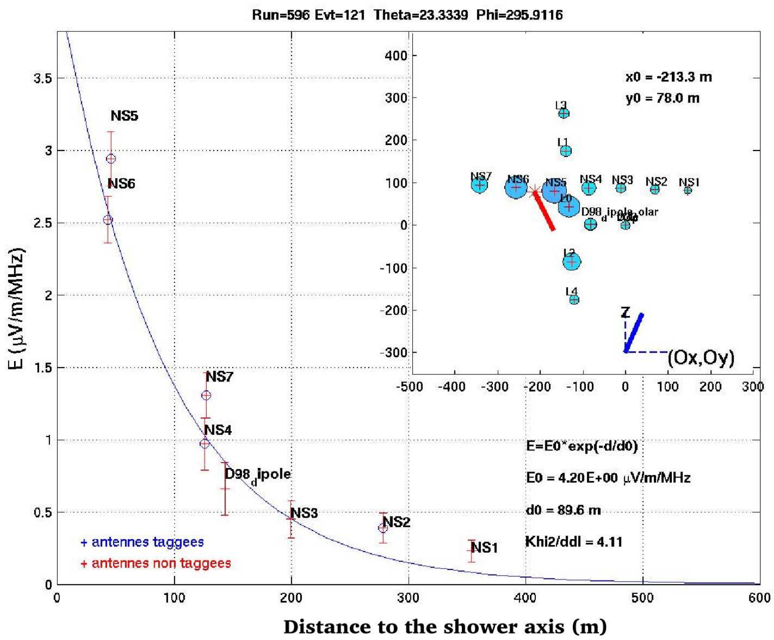

Fig. 4. EAS electric field amplitude distribution versus distance to the shower axis. An additional dipole (D98) is located 40 m apart the East-West line. The inset displays the topology of the field at ground with the reconstructed direction and core location of the shower.

large arrays. First prototypes of autonomous stations will be tested at the Pierre Auger Observatory at autumn 2006.

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