Results of the CODALEMA 2006-2007 measurement campaign

Les données collectées depuis novembre 2006 dans la nouvelle configuration de CODALEMA (comprenant des antennes dipolaires et de nouveaux détecteurs de particules) sont actuellement en cours d'analyse. Ces modifications ont permis de calculer l'efficacité de radio-détection en fonction de l'énergie des gerbes et de mettre en évidence le rôle prépondérant de l'effet géomagnétique dans l'émission radio. Une analyse préliminaire concernant les profils de champ électrique indique aussi une corrélation forte entre l'énergie de la gerbe et le champ radio-électrique.

In 2006 several important modifications of CODALEMA have opened the possibility of simultaneous measurements of the particle and radio characteristics ([1] and other contributions to this report). This upgrade has lead to deduce the radio detection efficiency in function of the energy of the shower and to demonstrate the role of the geomagnetic field in the radio emission processes [2].

The results have been deduced from a sample of events corresponding to 104 effective days of data acquisition, composed of 15029 internal events (the 5 central particle detectors flagged, with 1 having the maximum signal). Among these events, 101 coincidences between the radio and the particles were identified using criteria in arrival time and in direction. Fig. 1 shows the energy distribution measured for the both detectors, indicating an energy threshold around 10^{15} eV for the particle detection and around 10^{17} eV for the radio detection.

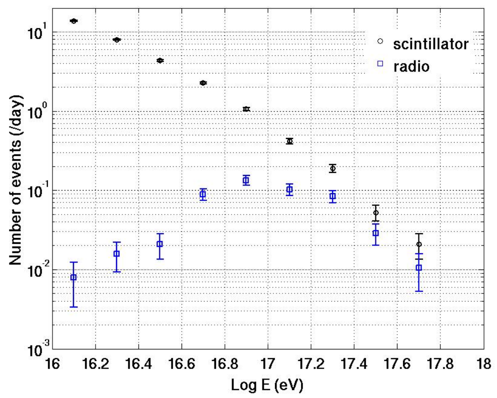

Fig. 1: Energy distribution of "internal" events measured by the ground particle detector array (black circles) and seen in coincidence by the antenna array (blue squares).

Because of the low number of events available we do not establish the detection efficiency at higher energy, nevertheless we should expect a full efficiency around 10^{18} eV with one single East-West polarization.

Fig. 2 exhibits a sky map of the arrival direction of the radio events, which shows a pronounced asymmetry between the North and South sectors, while the distribution of the scintillator events is approximately uniform in azimuth, reflecting the uniformity of the cosmic ray distribution. The South to North ratio of the events is approximately 15%. This South deficit is not observed using an autonomous radio trigger, i.e., when statistics is not dominated by cosmic rays. The interpretation of this effect is that the showers coming from North and South do not generate radio signal in a symmetric way. An obvious candidate for a symmetry breaking of the generation of the electric field is the geomagnetic field, oriented in Nançay at 27° to the South from the zenith. The Lorentz force acting on the charged particles in the shower causes the electric field emission from the cosmic air showers. This electric field magnitude should follow the variations of the vector cross product VxB, where V is the velocity of the shower particle and B the geomagnetic field. With this hypothesis, the predicted sky map is very similar to the sky map recorded by the antenna. Improved statistics for "internal events" and an experimental study of the signal polarization will enable confirming this assumption.

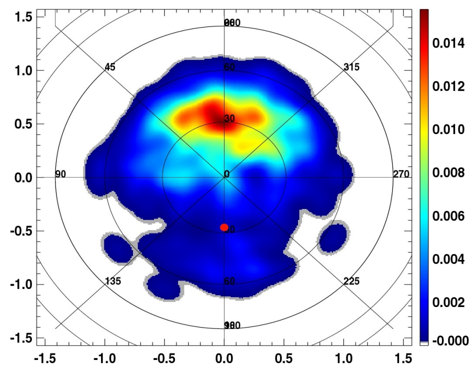

Fig. 2: Sky map of observed radio events (10 degrees Gaussian-smoothed map). The zenith is at the centre, East is at 270°, West at 90°. The direction of the geomagnetic field in Nançay is indicated by the red dot.

The last aspect, which is certainly one of the keys to the success of the technique, is related to the correlation with the energy. Although this analysis is still regarded as preliminary, for the "golden events" in the 37-84 MHz frequency band, a satisfactory dependence for the electric field amplitude to the shower axis distance was obtained using the formula $E = E_0 \exp(-d/d_0)$ which allows to deduce E_0 after fitting the parameters (Fig. 3).

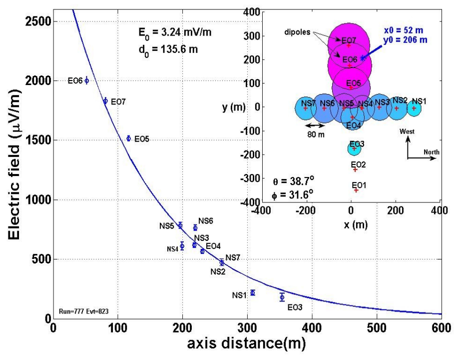

Fig. 3: EAS electric field amplitude versus distance to the shower axis for the higher energy event. The inset displays the topology of the ground field with the reconstructed direction and core location of the shower.

This should make possible to establish the correlation between the energy of the primary cosmic ray deduced from the particle analysis and the electric field amplitude (Fig. 4) using E_0 as a calorimetric estimator of the energy of the shower. First investigations seem to indicate that $E_0 \sim \sin\alpha . \cos\theta . E_p^{1.1}$, where α is the so-called "geomagnetic angle" existing between the arrival direction of the shower and the geomagnetic field direction, and E_P the primary particle energy estimation. With the assumption that the number of particles in the shower follows $N \sim E_p^{0.9}$, this relation becomes $E_0 \sim \sin\alpha . \cos\theta . N_p^{0.99}$, suggesting that the radio-emission could be coherent in the used frequency band.

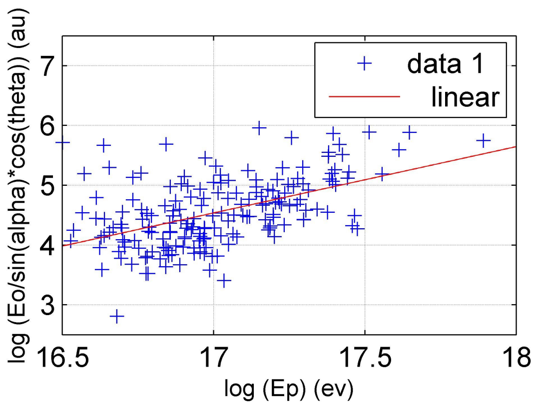

Fig. 3: Correlation between the energy E_P of the shower, deduced from the particle detector, and the radio estimator of the energy E_0.

Dans sa nouvelle configuration, l'expérience CODALEMA permet la mesure simultanée des caractéristiques radio (grâce aux dipôles), et particules (grâce aux scintillateurs) des gerbes cosmiques. Cela a permis de mettre en évidence un déficit d'évènements dans la direction du champ magnétique terrestre qui pourrait être attribué à un effet géomagnétique prépondérant dans les mécanismes d'émission radio. Une dépendance exponentielle du champ électrique à la distance à la gerbe est également observée et permet d'établir une corrélation entre l'énergie du primaire et la l'amplitude du champ électrique.

[1] D. Lebrun et al, 30th Int. Cosmic Ray Conf. ICRC'07, Mérida, Mexico (2007).
[2] O. Ravel and the CODALEMA collaboration, 2007, Proceedings of the XXXth ICRC, Merida, Mexico