RECENT RESULTS FROM THE LOPES EXPERIMENT

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The radio emission of extensive air showers is investigated with the LOPES experiment. Latest results are discussed.

Keywords: astroparticle physics; cosmic rays; air showers; radio emission; LOPES.

1. Introduction

Air showers are induced by high-energy cosmic rays impinging on the atmosphere. Objective of LOPES, a LOFAR prototype station is to register radio emission from air showers and establish an independent measurement technique to observe air showers at energies exceeding 10^{16} eV. LOPES had demonstrated that radio emission from air showers can be detected even in an environment with relatively strong radio frequency interference (RFI).[1]

The LOPES experiment registers radio signals in the frequency range from 40 to 80 MHz.[2] In this band are few strong man made radio transmitters only, the emission from air showers is still strong (it decreases with frequency), and background emission from the Galactic plane is still low. An active short dipole has been chosen as antenna. An inverted V-shaped dipole is positioned about 1/4 of the shortest wavelength above an aluminum ground plate. In this way a broad directional beam pattern is obtained. LOPES comprises 30 antennas[3] located on site of the KASCADE-Grande experiment.[4,5] The LOPES data acquisition is triggered by large air showers registered with KASCADE-Grande. The latter measures the showers simultaneously to LOPES and delivers precise information on the shower parameters, such as shower energy as well as position and inclination of the shower axis. All antennas, including the complete analog electronics chain, have been individually calibrated with a reference radio source.[6]

2. Lateral Distribution

The lateral distribution of the measured radio signals has been investigated in detail.[7] A function of the form $\epsilon = \epsilon_0 \exp(-R/R_0)$ has been fitted to the measured field strength as a function of the distance to the shower axis R. The measured field strength as a function of the distance to the shower axis is presented in Fig. 1 (*left*) for a typical event. The characteristic length R_0 for this example is of order of 100 m.

The investigations reveal that there are different types of air showers. Most of them have a lateral distribution which is characterized by a constant $R_0 \approx 100$ to 200 m, like the example shown in Fig. 1 (*left*). On the other hand, there are few showers with relatively flat lateral distributions and corresponding values for R_0 as high as 1000 m or 1200 m. A closer look

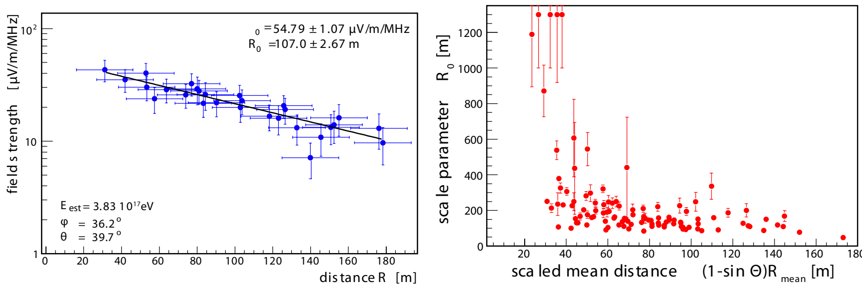

Fig. 1. *Left*: Measured field strength as a function of the distance to shower axis for an individual shower.[7] *Right*: Scale parameter R_0 as a function of the zenith angle times the mean distance to the shower axis.[7]

indicates that the steepness of the fall-off R_0 depends on the mean distance to the shower axis R_{mean} and the zenith angle of the showers θ. The reconstructed scale parameter R_0 is plotted as a function of the relation $(1 - \sin\theta)R_{mean}$ in Fig. 1 (*right*). A correlation between the two quantities can be recognized. Large values for R_0 are obtained for showers with large zenith angles and a small average distance between the shower axis the antennas. But since not all events with small R_{mean} show a flattening — the reason is still unclear and further investigations with larger statistics are required.

3. Polarization

The radio emission generated by the geo-synchrotron mechanism is expected to be highly linearly polarized. The signal is usually present in both polarization components (E-W and N-S). The signal strength depends on the geomagnetic angle and thus, on the shower azimuth and zenith angles.[8] The emission is expected to be polarized perpendicular to the shower axis and the direction of the geomagnetic field. The polarization characteristics can be described by a unit polarization vector $\vec{v} \times \vec{B}$, where $\vec{v}$ is the direction of the shower axis and $\vec{B}$ the direction of the Earth magnetic field.[9]

The 30 LOPES antennas are now set up such that 15 register the east-west component and 15 antennas measure the north-south component of the electric field. Investigations of the measured signals for different polarization directions show that the showers with the strongest signals are registered perpendicular to the Earth magnetic field: from northern directions in east-west polarization direction and from west and east for the north-south polarized signal.[9] To confirm the $\vec{v} \times \vec{B}$ behavior of the polarized signals

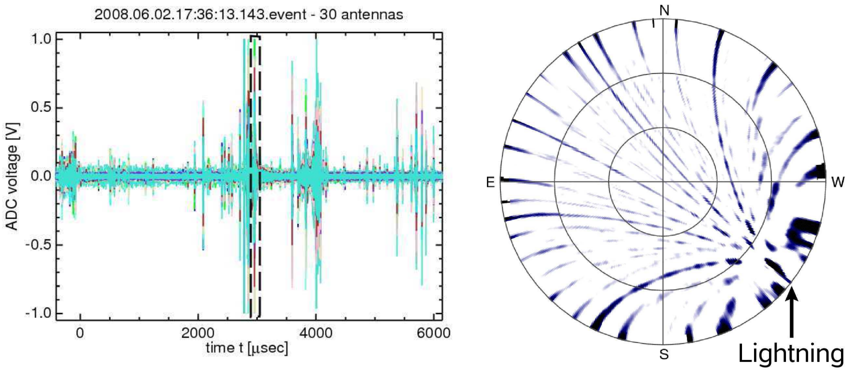

Fig. 2. *Left*: Example of the measured antenna signal as a function of time for a thunderstorm event.[10] *Right*: Sky map of the thunderstorm event shown on the left.

the ratio of the amplitudes of the cross-correlated beams in east-west and north-south polarization was investigated.[9] The observed $\vec{v} \times \vec{B}$ behavior of the measured data is a strong indication for a geomagnetic origin of the radio emission in air showers.

4. Thunderstorm Events

The measured field strength of the radio emission of air showers depends on the (static) electric fields in the atmosphere. The electric fields inside thunderstorm clouds, in particular within the convective region can reach peak values up to 100 kV/m. This leads to additional forces on the electrons and positrons in the air showers and, consequently, to an acceleration and deceleration of parts of the electromagnetic shower component (electrons and positrons, depending on the direction of the electric field). In turn, this yields to an amplification or reduction of the radio emission of air showers during thunderstorms. Such a behavior has been observed with LOPES.[11] To obtain reliable information about the detected air showers from the observations of radio emission requires to monitor the electric field in the atmosphere and to record the signatures of thunderstorms. Therefore, the signals form air showers during thunderstorms are studied in detail.[10]

As an example, the antenna signal as a function of time measured during a thunderstorm is shown in Fig. 2 (*left*). A signal from an air shower is expected at the zero point of the time axis with an amplitude less than 0.1 V. Strong additional signals caused by lightning can be recognized. The dashed lines mark a region with strong lightning signals, which is used to calculate a sky-map of the cross-correlated beam. The result is presented in Fig. 2 (*right*). The map shows the whole sky with the zenith in the center and the horizon at the border. A strong signal is visible in south-western direction, marking the discharge region of the lightning. The signal extends to the horizon. This indicates that a cloud-ground discharge has been registered (and not a cloud-cloud discharge). The grating lobes of the antenna array extend over the whole sky.

At present, studies are under way to detect a possible distortion of an event due to thunderstorm conditions directly from the measured data.[10] The idea is to find a possible deviation of the polarization characteristics from the theoretically expected behavior. Such an indication would point towards a change in the emission process.

5. Outlook

The investigations of radio signals from air showers with LOPES are the basis for the application of these technique in large-scale experiments.[12] The next step is to utilize the radio detection technique in large arrays, comprising several hundreds of antennas as in LOFAR[13] and the Pierre Auger Observatory (AERA).[14] For AERA new antenna designs and FPGA-based hardware for a self trigger algorithm are developed within the LOPES$^{\mathrm{STAR}}$ sub-project.[15–17]

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