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Lateral distribution of the radio signal in extensive air showers measured with LOPES

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ABSTRACT

The antenna array LOPES is set up at the location of the KASCADE-Grande extensive air shower experiment in Karlsruhe, Germany and aims to measure and investigate radio pulses from extensive air showers. The coincident measurements allow us to reconstruct the electric field strength at observation level in dependence of general EAS parameters. In the present work, the lateral distribution of the radio signal in air showers is studied in detail. It is found that the lateral distributions of the electric field strengths in individual EAS can be described by an exponential function. For about 20% of the events a flattening towards the shower axis is observed, preferentially for showers with large inclination angle. The estimated scale parameters R_0, describing the slope of the lateral profiles range between 100 and 200 m. No evidence for a direct correlation of R_0 with shower parameters like azimuth angle, geomagnetic angle, or primary energy can be found. This indicates that the lateral profile is an intrinsic property of the radio emission during the shower development which makes the radio detection technique suitable for large scale applications.

1. Introduction

The traditional method to study extensive air showers (EAS), which are generated by high-energy cosmic rays entering the Earth's atmosphere, is to measure the secondary particles with sufficiently large particle detector arrays. In general, these measurements

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provide only immediate information on the status of the air shower cascade at the particular observation level. This hampers the determination of the properties of the primary inducing the EAS as compared to methods like the observation of Cherenkov and fluorescence light, which also provide information on the longitudinal EAS development, thus providing a more reliable access to the information of interest [1].

In order to reduce the statistical and systematic uncertainties of the detection and reconstruction of EAS, especially with respect to the detection of cosmic particles of highest energies, measuring the radio emission during the shower development is being discusses as a new detection technique. The radio waves can be recorded day and night, and provide a bolometric measure of the electromagnetic shower component. Due to technical restrictions in past times, the radio emission accompanying cosmic ray air showers was a somewhat neglected feature in the past. However, the study of this EAS component has experienced a revival by recent activities, in particular by the LOPES project [2,3]. LOPES as pathfinder for large scale radio detection for the LOFAR project [4] and the Pierre Auger Observatory [5] investigates the correlations of radio data with shower parameters reconstructed by the extensive air shower experiment KASCADE-Grande [6]. Hence, LOPES, which is designed as a digital radio interferometer using large bandwidth and fast data processing, profits from the reconstructed air shower observables of KASCADE-Grande.

The main goal of the investigations in the frame of LOPES is the understanding of the shower radio emission in the primary energy range of 10^{16} eV to 10^{18} eV. Of particular interest is the investigation of the correlation of the measured field strength with main shower parameters. These are the orientation of the shower axis (azimuth angle, zenith angle, and the geomagnetic angle, i.e. the angle between shower axis and geomagnetic field), the position of the observer relative to the shower axis, and the energy and mass (electron and muon number) of the primary particle. Another goal of LOPES (LOPES^{STAR}) is the optimization of the hardware (antenna design and electronics) for a large scale application of the detection technique including a self-trigger mechanism for a stand-alone radio operation [7].

In the present study we investigate in detail the lateral profile of the radio signal as measured by LOPES. Due to a precise amplitude calibration of each individual antenna and the event information from KASCADE-Grande, this is possible on an event-by-event basis with high accuracy. Such investigations are of great interest as the lateral shape defines the optimum grid size for a radio antenna array in a stand-alone mode. Of particular interest is the scale parameter which describes the amount of the signal decrease with distance from the shower axis and the dependence of that parameter on characteristics of the primary particle. In addition, knowing the lateral extension in detail will contribute to the understanding of the emission mechanism of the radio signal as simulations have shown [8], that the lateral shape can be related to important physical quantities such as the primary energy or the mass of the primary.

2. The LOPES experiment

2.1. Experimental setup

LOPES has been set-up as prototype station of the LOFAR project to verify the detection of radio emission from air showers. The basic idea is to use an array of relatively simple, quasi omni-directional dipole antennas. The signals are digitized and sent to a central computer in which the registered waves from the individual antennas are superimposed (software interferometer). With LOPES it is possible to buffer the received data stream for a certain period of time. After a detection of a transient phenomenon like an air shower, a beam in the desired direction can be formed in retrospect. To demonstrate the capability to measure air showers with such antennas, LOPES is situated at the air shower experiment KASCADE-Grande. KASCADE-Grande is an extension of the multi-detector setup KASCADE [9] (KArlsruhe Shower Core and Array DEtector) built in Germany, measuring the charged particles of air showers in the primary energy range of 10^{14} eV to 10^{18} eV with high precision due to the detection of the electromagnetic and the muonic shower component separately with independent detector systems. Hence, on the one hand LOPES profits from the reconstructed air shower observables of KASCADE-Grande, but on the other hand, since radio emission arises from different phases of the EAS development, LOPES is intended to provide complementary information to the particle detector arrays of KASCADE-Grande.

The antenna configuration of LOPES has changed several times in order to study different aspects of the radio emission. With the extension of the antenna field from 10 to 30 east-west orientated antennas in 2005 (LOPES30), the baseline and the low noise amplifier (LNA) performance at the antennas improved. In the configuration used in the analysis described here, LOPES operated 30 short dipole radio antennas. The LOPES antennas, positioned within or close to the original KASCADE array (Fig. 1), operate in the frequency range of 40–80 MHz and are aligned in east-west direction, i.e. they are mainly sensitive to the linear east-west polarized component of the radiation. This layout was in particular chosen to provide the possibility for a detailed investigation of the lateral extension of the radio signal as it has a maximum baseline of approximately 260 m. The read-out window for each antenna is 0.8 ms wide centered around the trigger received from the KASCADE array; the sampling rate is 80 MHz. The logical condition to trigger the LOPES data readout is a high multiplicity of fired particle detector stations of the KASCADE array. This corresponds to primary energies above $\approx 10^{16}$ eV; which are detected with a rate of $\approx$2/min.

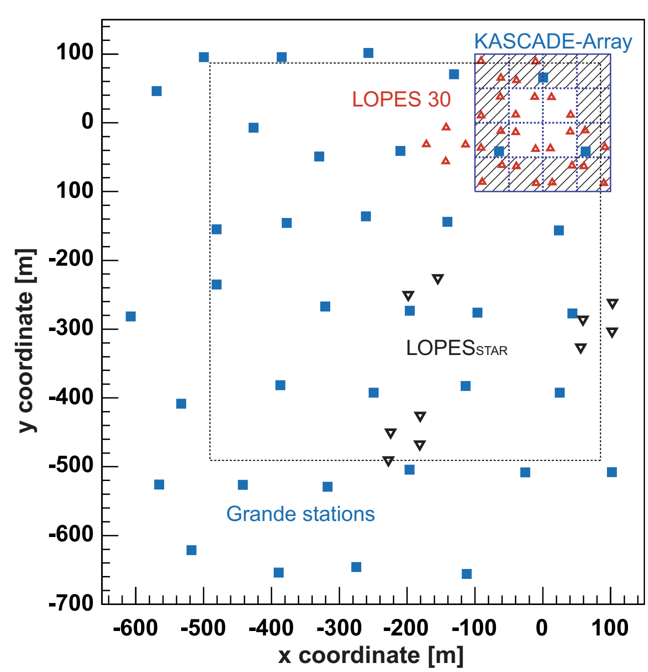

Fig. 1. Sketch of the KASCADE-Grande – LOPES experiments: The squared 16 clusters (12 with muon counters) of the KASCADE field array, the distribution of the 37 stations of the Grande array, the location of the 30 LOPES radio antennas, and the positions of the 10 newly developed LOPES^{STAR} antennas. The dotted line shows the area used for the present analysis.