Nuclear Instruments and Methods in Physics Research A 604 (2009) S1–S8

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Air shower measurements with the LOPES radio antenna array

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A R T I C L E I N F O

Available online 19 March 2009

Keywords:
Radio emission
Air showers
Ultra-high energy cosmic rays

A B S T R A C T

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. Since radio waves suffer very little attenuation, radio measurements allow the detection of very distant or highly inclined showers. These waves can be recorded day and night, and provide a bolometric measure of the leptonic shower component. LOPES is designed as a digital radio interferometer using high bandwidths and fast data processing and profits from the reconstructed air shower observables of KASCADE-Grande. The LOPES antennas are absolutely amplitude calibrated allowing to reconstruct the electric field strength which can be compared with predictions from detailed Monte-Carlo simulations. We report about the analysis of correlations present in the radio signals measured by the LOPES 30 antenna array. Additionally, LOPES operates antennas of a different type (LOPES$^{\mathrm{STAR}}$) which are optimized for an application at the Pierre Auger Observatory. Status, recent results of the data analysis and further perspectives of LOPES and the possible large scale application of this new detection technique are discussed.

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

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doi:10.1016/j.nima.2009.03.033

measurements provide only immediate information on the status of the air shower cascade on the particular observation level. This hampers the determination of the properties of the EAS inducing primary as compared to methods like the observation of Cherenkov and fluorescence light, which provide also some information on the longitudinal EAS development, thus enabling a more reliable access to the intended information [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, there is a current methodical discussion on new detection techniques. Due to technical restrictions in past times the radio emission accompanying cosmic ray air showers was a somewhat neglected EAS feature. For a review on the early investigations of the radio emission in EAS in the 1960s see Ref. [2]. However, the study of this EAS component has experienced a revival by recent activities, in particular by the LOPES project, and the CODALEMA experiment in France [3].

The main goal of the investigations in Karlsruhe in the frame of LOPES is the understanding of the shower radio emission in the primary energy range of 10^{16}–10^{18} eV. I.e., to investigate in detail the correlation of the measured field strength with the shower parameters, in particular the orientation of the shower axis (geomagnetic angle, azimuth angle, zenith angle), the position of the observer (lateral extension and polarization of the radio signal), and the energy and mass (electron and muon number) of the primary particle. Another goal of LOPES 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 [4].

Finally, within the frame of LOPES a detailed Monte-Carlo simulation program package is developed. The emission mechanism utilized in the REAS code (see Ref. [5] and references therein) is embedded in the scheme of coherent geosynchrotron radiation. Progress in theory and simulation of the radio emission in air showers is described in a further contribution to this conference [6].

The present contribution sketches briefly recent results of the LOPES project [7] obtained by analyzing the correlations of radio data with shower parameters reconstructed by KASCADE (KArlsruhe Shower Core and Array DEtector)-Grande [8,9]. Hence, LOPES, which is designed as digital radio interferometer using large bandwidths and fast data processing, profits from the reconstructed air shower observables of KASCADE-Grande.

2. General layout, calibration, and data processing

2.1. General layout

The basic idea of the LOPES (= LOFAR prototype station) project was to build an array of relatively simple, quasi-omnidirectional dipole antennas, where the received waves are digitized and sent to a central computer. This combines the advantages of low-gain antennas, such as the large field of view, with those of high-gain antennas, like the high sensitivity and good background suppression. With LOPES it is possible to store the received data stream for a certain period of time, i.e. 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 built-up at the air shower experiment KASCADE-Grande [8]. KASCADE-Grande is an extension of the multi-detector setup KASCADE [9] built in Germany, measuring the charged particles of air showers in the primary energy range of 100 TeV to 1 EeV 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 also provides complementary information and helps to understand the observables measured with the particle detector arrays of KASCADE-Grande.

In the current (2007 and 2008) status LOPES [10] operate 30 short dipole radio antennas (LOPES 30) and 10 logarithmic periodic dipole antennas (LOPES^{STAR}). The latter operate in both polarization directions each (i.e. 20 channels), and are used for the development of a radio self-trigger system (see Ref. [4]).

The LOPES 30 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 sensitive to the linear east–west polarized component of the radiation only, which can be easily changed into the opposite polarization by turning the antennas. The layout provides the possibility for, e.g. a detailed investigation of the lateral extension of the radio signal as LOPES 30 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 shape of the antenna and their metal ground screen gives the highest sensitivity to the zenith and half sensitivity to a zenith angle of 45°, almost independent on the azimuth angle. The logical condition for the LOPES-trigger is a high multiplicity of fired stations of the KASCADE-Grande arrays. This corresponds to primary energies above $\approx 10^{16}$ eV; such showers are detected at a rate of ≈ 2 per minute.

2.2. Amplitude calibration

Each single LOPES 30 radio antenna is absolute amplitude calibrated at its location inside the KASCADE-Array (end-to-end calibration) using a commercial reference antenna [11] of known

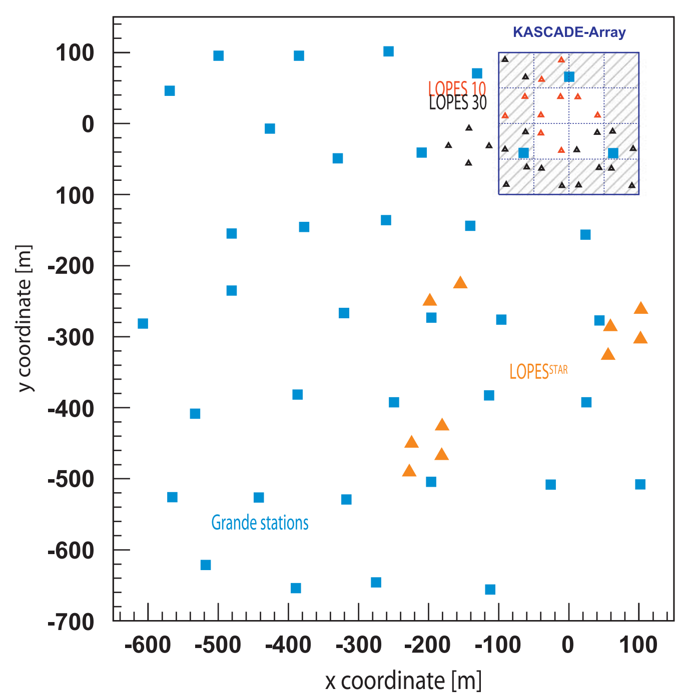

Fig. 1. Sketch of the KASCADE-Grande—LOPES experiments: the 16 clusters (12 with muon counters) of the KASCADE field array, the distribution of the 37 stations of the Grande array are shown. The location of the 30 LOPES radio antennas is also displayed as well as the positions of the 10 newly developed LOPES^{STAR} antennas.