Measuring the Radio Emission of Cosmic Ray Air Showers with LOPES

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Abstract

When ultra high energy cosmic rays hit the atmosphere, they produce a shower of millions of secondary particles. Thereby the charged particles in the shower emit a radio pulse whilst deflected in the Earth's magnetic field. LOPES is a digital antenna array measuring these radio pulses in the frequency range from 40 to 80 MHz. It is located at the site of and triggered by the air shower experiment KASCADE-Grande at Forschungszentrum Karlsruhe, Germany. In its present configuration, it consists of 15 east-west-polarized and 15 north-south-polarized, absolutely calibrated short dipole antennas, as well as 10 LPDAs (with two channels each). Furthermore, it serves as a test bench for technological developments, like new antenna types or a radio-based self triggering (LOPES^{STAR}). To achieve a good angular reconstruction and to digitally form a beam into the arrival direction of the shower, it has a precise time calibration.

Key words:
LOPES, Radio Detection, Cosmic Ray Air Shower

1. Introduction and Setup

Cosmic rays are high energy particles (up to more than 10^{20} eV) coming from outside of our solar system. The flux above $\sim 10^{14}$ eV is too low to measure the cosmic rays directly, but they can be measured indirectly: When a high energy cosmic ray hits the atmosphere, it creates an air shower of secondary particles which can be detected on ground by arrays of particle detectors, like KASCADE-Grande at Forschungszentrum Karlsruhe, Germany [1, 2].

A relatively new method to measure cosmic rays at energies above 10^{16} eV consists in the detection of the radio emission of cosmic ray air showers. When the electrons and positrons in the air shower are deflected by the Earth's magnetic field, they emit a coherent radio pulse, which can be detected with antenna arrays like LOPES (fig. 1), [3]. This emission can be explained for example by the geo-synchrotron model implemented in the simulation code REAS2 [4].

LOPES was built as a LOFAR PrototypE Station and is triggered by KASCADE-Grande. Currently the main part consists of 30 inverted V-shape dipole antennas (fig. 2) which measure the radio emission in the band from 40 MHz to 80 MHz. The antennas are absolutely calibrated [5] and oriented in two different directions (east-west and north-south) to study polarization effects [6]. As LOPES is operating in the second Nyquist domain, the full information of the radio signal be-

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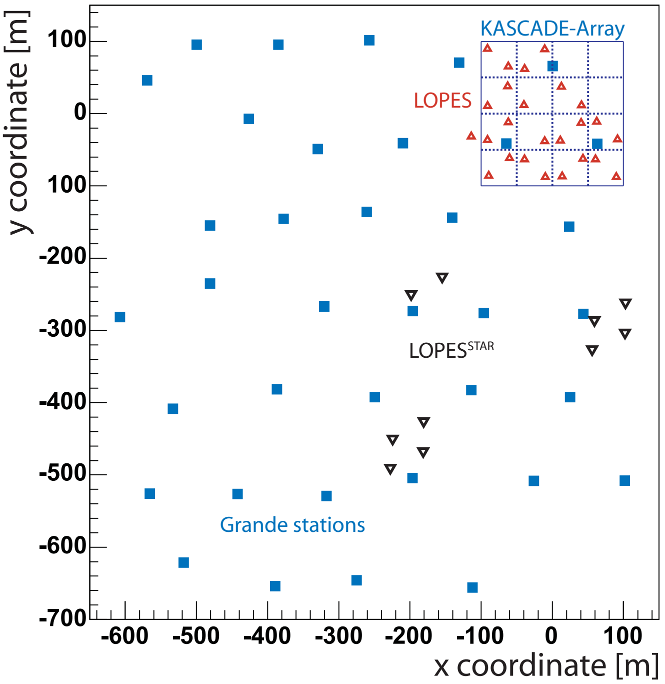

Figure 1: Layout of the LOPES experiment.

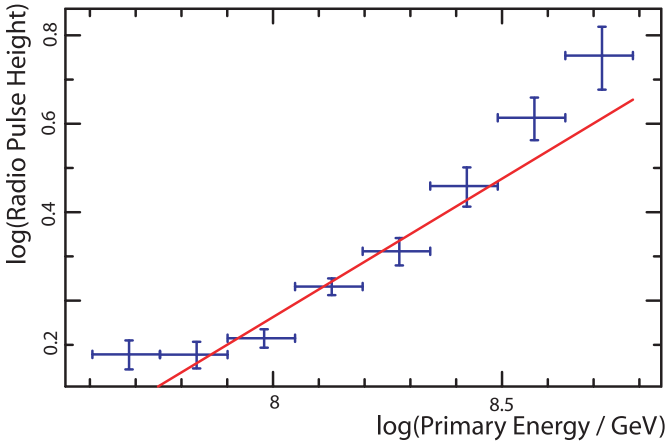

Figure 3: Correlation of the radio pulse height and the cosmic ray energy estimated by KASCADE-Grande [8].

tween 40 MHz and 80 MHz is contained in the data and can be retrieved by up-sampling (i.e. the correct interpolation between the samples) [7].

Because LOPES has a precise time calibration, not only the direction of the cosmic ray air shower can be reconstructed, but it can also be used as a digital interferometer by forming a cross-correlation beam [8]. The timing precision necessary to see the coherence of the radio pulse is about 1 ns. It can be obtained by several calibration methods, including second order effects like correction for the dispersion of the filters and monitoring variations of the electronics delays with time [9].

Furthermore, LOPES serves as a test bench for new technologies. New antenna types for cosmic ray radio detection, like the logarithmic periodic dipole antenna (LPDA) and the short aperiodic loaded loop antenna (SALLA) are tested and a self trigger is developed within the LOPES^{STAR} setup [10].

Figure 2: LOPES inverted V-shape dipole antenna.

2. Results

LOPES has made the proof of principle that radio detection of cosmic rays is indeed possible with a modern, digital antenna array. Several physics results have been obtained, e.g.:

The field strength of the radio pulse is roughly proportional to the energy of the cosmic ray (fig. 3), depends on the geomagnetic angle (angle between the shower axis and the Earth's magnetic field) [8], and is enhanced during thunderstorms [11]. In addition, the polarization of the radio signal depends on the geo-magnetic angle [6].

For most radio events the lateral distribution shows an exponential decrease of the field strength with increasing antenna distance [12]. The electric field spectra of the radio pulses fall off to higher frequencies for all investigated events [13].

Thus, LOPES made the first step to establish radio detection as a complementary method for the measurement of cosmic rays, and yielded useful experience for the next generation of radio arrays.

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