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# Operation of LOPES-30 for Polarization Measurements of the Radio Emission of Cosmic Ray Air Showers

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**Abstract:** The LOPES-30 experiment, located at the site of the air shower experiment KASCADE-Grande at Forschungszentrum Karlsruhe, Germany, is an array of 30 dipole antennas set-up to investigate the pulsed radio emission from cosmic ray air showers in the Earth's atmosphere. After one year of measurements of the East-West polarization by all 30 antennas, recently, the LOPES-30 set-up was re-configured to perform dual-polarization measurements. Half of the antennas have been configured for measurements of the North-South polarization direction. By measuring at the same time both, the E-W and N-S polarization components of the radio emission, the geosynchrotron effect as the dominant emission mechanism in air showers can be verified. The status of the measurements, including the absolute calibration procedure of the antennas as well as a preliminary analysis of dual-polarized event examples are reported.

## Introduction

The $LO$FAR (LOw Frequency ARray) $P$rototyp$E$ $S$tation - $LOPES$ experiment [1] is operating in the 40-80 MHz frequency range. The KASCADE-Grande [2] experiment (an extension of the KArlsruhe Shower Core and Array DEtector KASCADE) provides the trigger information and well-reconstructed parameters of the air shower properties in the energy range from a few PeV to 1 EeV. The LOPES-30 configuration is an extension of the initially installed 10 LOPES antennas (LOPES-10) by the addition of 20 dipole antennas, which have an absolute amplitude calibration providing a larger sensitive area and a large baseline to the radio signal at a single event basis. This provides the possibility for a detailed investigation of the lateral extension of the pulsed radio signal. Moreover, the antenna number is high enough for a new configuration sensitive to both, the East-West and North-South polarization directions.

## The LOPES-POL Configuration

Since end of 2006, LOPES is performing polarization measurements. Half of the 30 antennas are configured for the East-West and North-South polarization measurements respectively, while five of them are configured as dual-polarization antennas at the same place, measuring at the same time both, the N-S and E-W polarization directions. The actual configuration is depicted in Fig.4.

Since December 2006, the LOPES antennas are triggered by the original KASCADE and in addition by the KASCADE-Grande array. Within this new additional trigger source, the LOPES experiment can therefore benefit from the extended detection area making possible the analysis of large events at large distances with a much better accuracy.

## Motivation for Performing Polarization Measurements

For the initial measurements, all 30 antennas of the LOPES experiment were equipped with dipoles in E-W direction, measuring the single polarization of the radio emission only. Recently, for recording the full radio signal, LOPES-30 has been reconfigured to perform dual-polarization measurements.

The radio emission generated by the geosynchrotron mechanism is expected to be highly linearly polarized [3]. As predicted by the sophisticated Monte Carlo simulation for the radio emission, the signal is usually present in both polar-

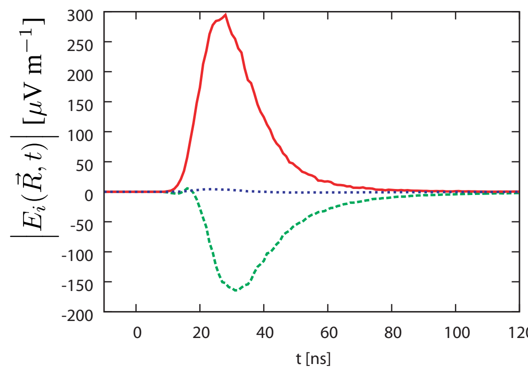


Figure 1: Raw simulated pulses in the individual linear polarization components of a $10^{17}$ eV vertical air shower. The solid line represent the E-W polarization component, dashed line N-S and dotted line the vertical component respectively.

ization components which strengths strongly depends on the position of the observer relative to the incoming air shower. In addition, the polarization is directly related with the shower azimuth for a given zenith angle. Knowledge of these polarization characteristics of the radio emission are mandatory for the interpretation of experimental measurements, which can directly verify the geomagnetic origin of the radio emission from atmospheric air showers.

Fig.1 shows a simulated raw (unlimited-bandwidth) pulse arriving at a distance of 200 m to the N-W from the center of a $10^{17}$ eV vertical shower. The N-S and E-W polarization components are of similar strength and arrive mostly synchronously, as expected for a linearly polarized pulse. For inclined air showers, a vertical polarized component can occur as well.

## Polarization Sensitivity

The array of 30 digital radio antennas have an absolute amplitude calibration in order to estimate the electric field strength of the short radio pulse generated in air showers [4]. To perform the calibration, a commercial calibrated radio source is used as emitter and LOPES antennas are measuring within an artificially triggered event. For a calibration campaign, the reference source is placed

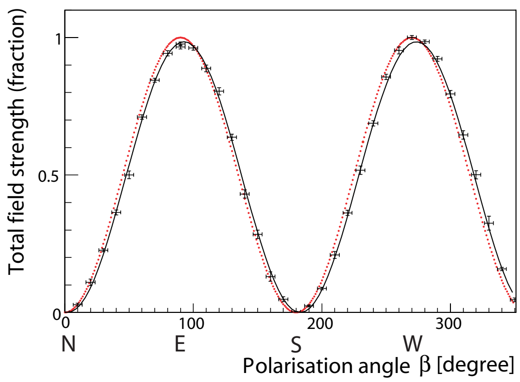


Figure 2: Fraction of the total field strength seen by the linearly polarized LOPES antenna (sensitive to E-W) as a function of the polarization angle $\beta$. Points: experimental data, solid line: data fit by a sin$\beta$-function, dotted line: theoretical sin$\beta$-distribution (normalized to the value at $\beta$=270°).

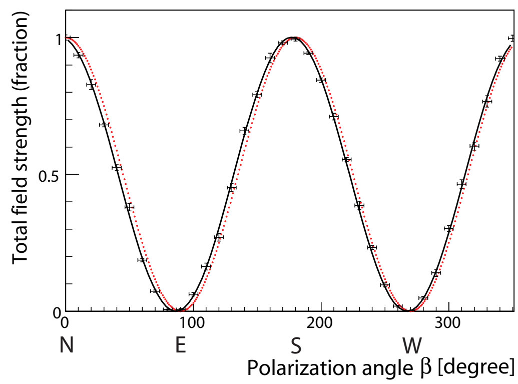


Figure 3: The same as Fig.2, but now for the antenna sensitive to the N-S polarization direction of the radio signal. The dotted curve is normalized to the value at $\beta$=180°.

at 11m above each LOPES antenna. It is a movable biconical reference antenna which is linearly polarized and has a nearly constant directivity near its principal axis.

Fig.2, respectively Fig.3 shows the fraction of the total field strength seen by a linearly dual-polarized LOPES antenna as a function of the angle $\beta$ between the polarization axes of the reference source and the LOPES antenna. Each polarization direction is measured individually during the same campaign varying the polarization angle of the reference antenna in steps of 10 degrees by rotating the reference source in vertical position. The results obtained prove the expected polarization sensitivity (and insensitivity) of both, the E-W and N-S oriented LOPES antennas.

## First Events

As an example, (see Fig.5) we display an event detected by LOPES in the new polarization configuration in December 2006. The KASCADE shower reconstruction results in a primary energy of $E_0 \approx 10^{18}$ eV, a geomagnetic angle (the angle between the shower axis and the Earth magnetic field) of 83°, an azimuth angle of 51° (i.e. coming from North-East), and a zenith angle of 66°. The shower shows clearly signals recorded in both polarization directions. The figure shows the value of the reconstructed CC-beam [5] which describes the average electric field strength for the mean distance from the shower axis.

As another example, (see Fig.6) we display an event detected in December 2006 with a primary energy of $E_0 \approx 3 \cdot 10^{17}$ eV, a geomagnetic angle of 77°, an azimuth angle of 333° (i.e. coming from North, North-West), and a zenith angle of 54°. The shower shows clearly signal recorded only in the E-W polarization direction without a significant signal contribution in the other N-S polarization direction.

These two selected events clearly show the capabilities of the LOPES experiment in recording the radio emission in both, the E-W and N-S polarization components. The new antenna configuration allows a full detection of the pulsed radio signal generated by the cosmic ray air showers in the Earth's atmosphere.

## Conclusions

In its current configuration, the LOPES experiment is performing polarization measurements; measuring at the same time both, the E-W and N-S polar-

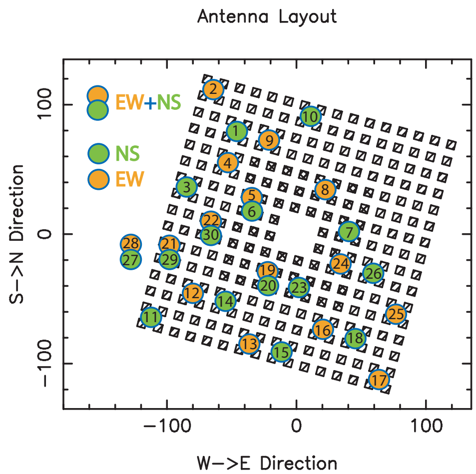


Figure 4: The antenna layout at the KASCADE array. The all antenna setup is divided in 15 E-W and 15 N-S polarized channels. Five antennas are sensitive to both polarization directions at the same time.

ization components allows a much more detailed analysis of the radio events than with the East-West polarized measurements alone.

Providing calibrated data, the LOPES experiment allows a direct comparison with theoretical predictions for the first time. A direct verification of the geosynchrotron effect as the dominant emission mechanism in air showers is possible now.

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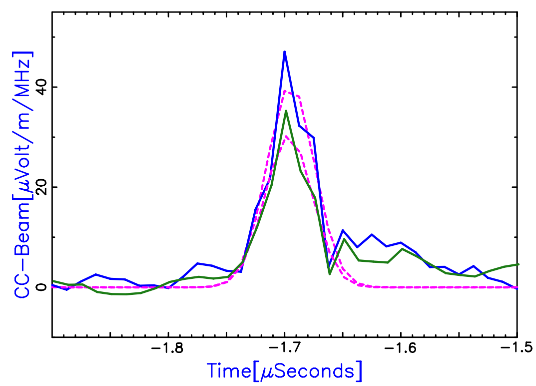


Figure 5: The Cross Correlation(CC)-beams for a dual-polarized event (E-W component: upper signal, N-S component: lower signal) of a primary energy of $10^{18}$ eV coming from North-East. The full lines indicate the CC-beams and the dotted lines the Gaussian fits respectively. One can clearly see very high radio signal recorded in both polarization directions.

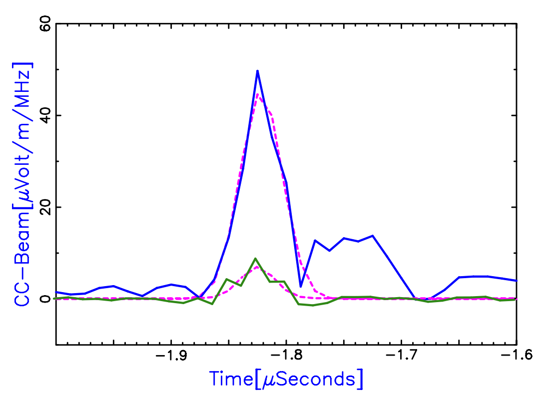


Figure 6: The same Cross Correlation(CC)-beams (see Fig.5) for a dual-polarized event of a primary energy of $3 \cdot 10^{17}$ eV coming from North, North-West. One can cleraly see very high signal recorded in the E-W polarization direction only.