Journal of Physics: Conference Series **81** (2007) 012006 doi:10.1088/1742-6596/81/1/012006

Radio Emission in Atmospheric Air Showers: First Measurements with LOPES-30

P G Isar[a,1], S Nehls[a], W D Apel[a], T Asch[b], F Badea[a], L Bähren[c], K Bekk[a], A Bercuci[d], M Bertaina[e], P L Biermann[f], J Blümer[a,g], H Bozdog[a], I M Brancus[d], M Brüggemann[h], P Buchholz[h], S Buitink[i], H Butcher[c], A Chiavassa[e], F Cossavella[g], K Daumiller[a], F Di Pierro[e], P Doll[a], R Engel[a], H Falcke[c,f,i], H Gemmeke[b], P L Ghia[j], R Glasstetter[k], C Grupen[h], A Hakenjos[g], A Haungs[a], D Heck[a], J R Hörandel[g], A Horneffer[i], T Huege[a], K H Kampert[k], Y Kolotaev[h], O Krömer[b], J Kuijpers[i], S Lafebre[i], H J Mathes[a], H J Mayer[a], C Meurer[a], J Milke[a], B Mitrica[d], C Morello[j], G Navarra[e], A Nigl[i], R Obenland[a], J Oehlschläger[a], S Ostapchenko[a], S Over[h], M Petcu[d], J Petrovic[i], T Pierog[a], S Plewnia[a], H Rebel[a], A Risse[l], M Roth[a], H Schieler[a], O Sima[d], K Singh[i], M Stümpert[g], G Toma[d], G C Trinchero[j], H Ulrich[a], J van Buren[a], W Walkowiak[h], A Weindl[a], J Wochele[a], J Zabierowski[l], J A Zensus[f], D Zimmermann[h]

LOPES COLLABORATION

[a] Institut für Kernphysik, Forschungszentrum Karlsruhe, Germany
[b] IPE, Forschungszentrum Karlsruhe, Germany
[c] ASTRON Dwingeloo, The Netherlands
[d] NIPNE Bucharest, Romania
[e] Dpt di Fisica Generale dell'Università Torino, Italy
[f] Max-Planck-Institut für Radioastronomie, Bonn, Germany
[g] Institut für Experimentelle Kernphysik, Uni Karlsruhe, Germany,
[h] Fachbereich Physik, Universität Siegen, Germany
[i] Dpt of Astrophysics, Radboud Uni Nijmegen, The Netherlands
[j] Ist di Fisica dello Spazio Interplanetario INAF, Torino, Italy
[k] Fachbereich Physik, Uni Wuppertal, Germany
[l] Soltan Institute for Nuclear Studies, Lodz, Poland
[1] on leave of absence from Institute of Space Sciences, Bucharest, Romania

E-mail: Gina.Isar@ik.fzk.de

Abstract. When Ultra High Energy Cosmic Rays (UHECR) interact with particles in the Earth's atmosphere, they produce a shower of secondary particles propagating toward the ground. LOPES-30 is an absolutely calibrated array of 30 dipole antennas investigating the radio emission from these showers in detail and clarifying if the technique is useful for large-scale applications. LOPES-30 is co-located and measures in coincidence with the air shower experiment KASCADE-Grande. Status of LOPES-30 and first measurements are presented.

1. Introduction

The LOPES (LOFAR Prototype Station) experiment co-located with the KASCADE-Grande experiment (an extended set-up of the KArlsruhe Shower Core and Array DEtector - KASCADE) at Forschungszentrum Karlsruhe, Germany, measures the radio emission of air showers in the 40 – 80 MHz frequency range. KASCADE-Grande provides the trigger information and well-calibrated parameters of the air shower properties in the energy range from a few PeV to 1 EeV. LOPES-30 with a maximum baseline of approximately 260 m is the extension of the initially installed 10 LOPES antennas (LOPES-10) [1, 2] by the addition of 20 antennas. The antennas now have absolute calibration, and the array provides a larger sampling area to the radio signal of a single event compared with the original LOPES-10 set-up. This provides the possibility for a more detailed investigation of the radio signal on a single air shower basis, in particular of its lateral extension.

2. LOPES-30: First detection of radio pulses from air showers

For the present measurements, all antennas are equipped with dipoles in East-West direction, measuring the single polarization of the radio emission. The radio signal is filtered by a band-pass filter and afterwards digitised with 12-bit ADCs, working with 80 MHz, allowing 2nd Nyquist sampling of the signal. From KASCADE-Grande, LOPES-30 receives a trigger corresponding to approximately 10 PeV primary energy. Under this trigger condition, 819 μs of data from the memory buffer of all antennas are stored on a central DAQ-PC. The main aim in processing the measured LOPES radio raw signals is to reconstruct the radio field strength of the pulse emitted by an individual air shower event. The final observable is the value of the so-called Cross-Correlation beam or CC-beam which combines and averages the data of a set of antennas to achieve the radio pulse height. For a detailed description of the hardware and of the necessary steps for the data processing, see [3, 4]. Selecting good radio events we require a coherent pulse, an expected position of the pulse in time, and an approximately similar pulse shape in all antennas.

Since summer 2005, LOPES-30 is acquiring data, measuring the radio emission in atmospheric air showers and is looking for correlations with shower parameters like arrival direction, primary particle energy, and mass. Each single antenna has an absolute calibration using a commercial reference antenna [5]. The calibration leads to the frequency-dependent amplification factors (see Figure 1, left), representing the amplification of the electronics. These correction factors are applied to the measured signal strength resulting in the true electric field strength which can be compared to the values predicted by simulations. By these calibration procedures variations between different antennas are corrected for. Remaining differences (due to variations in the individual antenna gains) are estimated to be less than 25 %, which provides also a first estimate of a systematic uncertainty in the measurements.

As an example (see Figure 2) we display an event detected by LOPES-30 in December 2005 of a primary energy of $E_0 \approx 1.6 \cdot 10^{17}$ eV, a geomagnetic angle (the angle between the shower axis and the Earth magnetic field) of 36.5°, and a zenith angle of 15°. The event shows clearly the capabilities of LOPES-30: With 30 antennas a very clear and coherent pulse signal can be detected, separated from the radio frequency interference (RFI) noise, and reconstructed. Even more, the whole antenna set-up can be divided in individual clusters of several antennas, and for each of these antennas the signal can be reconstructed. This procedure allows a detailed investigation of the radio emission on the basis of individual events.

3. LOPES-30: Environmental Monitoring by an atmospheric E-field mill

During the LOPES-30 measurements, we put emphasis on monitoring environmental conditions by measuring the static electric field and by recording parameters of nearby weather stations. Atmospheric conditions, in particular E-field variations during thunderstorms, might distort the

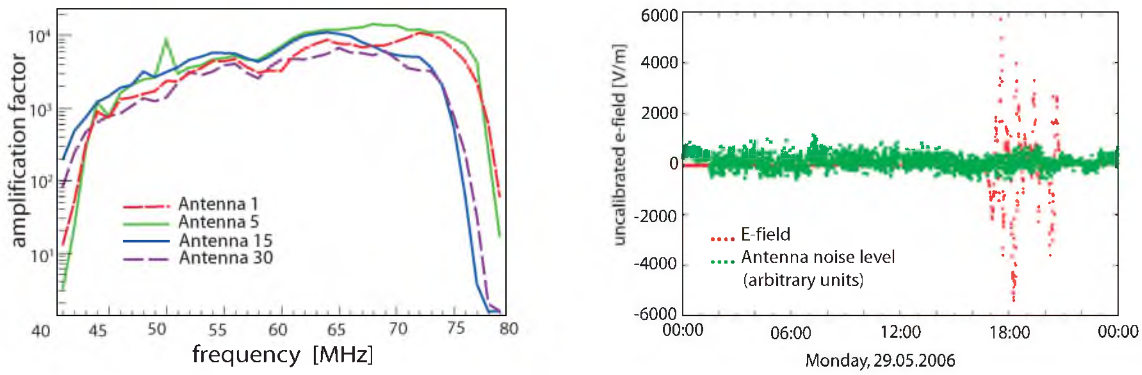

Figure 1. Left: Example for the frequency dependent amplification factors, including full influence of both, individual antenna electronics and environmental conditions. The peak at 50 MHz of antenna 5 is a faulty measurement due to amateur radio activities. Right: Monitoring E-field mill data during a day with a strong thunderstorm at Forschungszentrum Karlsruhe. Shown are the E-field and the relative noise level of the antennas (arbitrary units): no correlation is found. As shown, the atmospheric electric field changes dramatically from fair weather conditions (≈ -160 V/m) to thunderstorm (ca 18h).

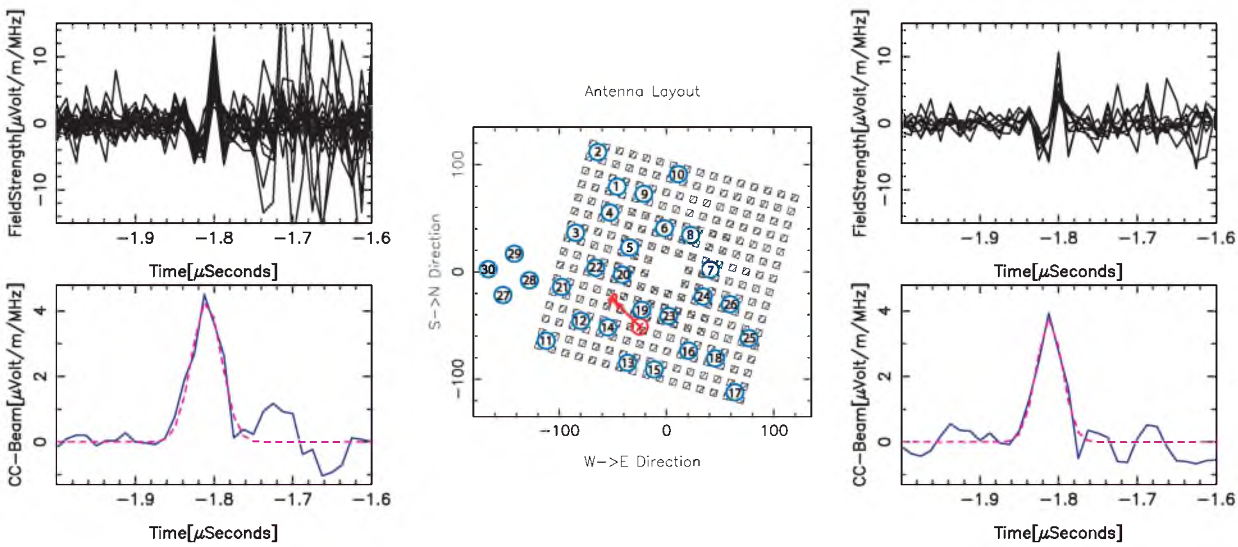

Figure 2. Example of an event registered by LOPES-30. Left: Field Strength of all individual 30 antennas and the result of the Cross Correlation(CC)-beam forming (Full line: CC-beam. Dotted line: Gaussian fit). One can clearly distinguish between the coherent radio pulse at -1.8 μs and the detection of incoherent RFI from KASCADE at -1.7 μs. Middle: Antenna layout at the KASCADE array. The arrow indicates the direction of the incoming cosmic ray shower of this event. Right: The same event reconstructed by using only a selection of antennas (antenna numbers from 1 to 10, see layout) and the resulting signal. For antennas positioned further from the shower core there is a less noise coming from KASCADE (detector stations), and also the resulting CC-beam value is 12.5 % weaker than the value obtained by all antennas.

radio emission during the shower development, and the measurement of the radio pulses [6]. By monitoring the environmental conditions, and comparing them with the antenna noise level as well as with the detected air shower radio signals, correlations can be investigated and corrected for.

The atmospheric electric field is monitored by a so-called field mill. It utilises a reciprocating shutter electrically connected to the ground, placed between the external field and the stationary metal sensor electrodes. This results in a low-frequency voltage proportional to the low-frequency (≤ 10 Hz) electric field. These atmospheric electric field measurements are used for assessing the local rainfall, lightning hazard and thunderstorms research (see Figure 1, right). The data of the field mill get continuously stored at intervals of 1 second in a database, and are investigated for correlations with the LOPES data measurements. As depicted in the right panel of Figure 1, between the E-field and the relative noise level of the antennas (arbitrary units): there is no correlation found.

4. Application of radio air shower detection in large UHECR experiments

One of the main goals of the LOPES project is to pave the way for an application of this "re-discovered" air shower detection technique to large UHECR experiments like LOFAR (LOw Frequency ARray) and the Pierre Auger Observatory. In parallel to the measurements at KASCADE-Grande with LOPES-30, we follow this aim by optimizing the antenna design for such an application. Additionally, the optimum frequency range, depending on the local noise, and an adequate filtering is investigated. All these efforts are part of LOPES$^{\mathrm{STAR}}$ [7], a "Self Triggered Array of Radio detectors for LOPES", where the measuremets will be compared with LOPES-30. The possibilities of a self-triggering antenna system and an online beam forming are also studied setting up a test array at the South part of the Pierre Auger Observatory.

5. Outlook

LOPES continuously takes data in coincidence with KASCADE-Grande. Recently, a number of antennas have been reconfigured for measurements of the North-South polarization direction. Measuring both polarizations of the radio emission will allow to verify the geosynchrotron effect, as the dominant emission process in atmospheric air showers.

Recent theoretical and simulation studies [8, 9], using a sophisticated Monte-Carlo technique, together with the absolute calibration of the antennas, allow us to compare predictions and radio emission measured by LOPES-30.

Monitoring the atmospheric E-field and further environmental conditions allow to investigate the influence of thunderstorms to the measurements.

The radio technique can be applied to existing cosmic ray experiments as well as to large digital radio telescopes like LOFAR and SKA (Square Kilometer Array), providing a large detection area for UHECR. First approaches using the radio technique at the Pierre Auger Observatory and at a first LOFAR station are in progress. Mandatory experience for such applications will be provided by the LOPES-30 measurements.

References

[1] Falcke H et al. - LOPES coll, *Nature 435, 313, 2005*
[2] Haungs A et al. - LOPES coll, *these proceedings*
[3] Horneffer A, *PhD Thesis, Rheinische Friedrich-Wilhelms-Universität Bonn, Germanny 2006, http://nbn-resolving.de/urn:nbn:de:hbz:5N-07819*
[4] Horneffer A et. al - *ARENA Proc. 2005, Int. Journ. Mod. Phys. A 21 Suppl., 168, 2006*
[5] Nehls S et al. - LOPES coll, *ARENA Proc. 2005, Int. Journ. Mod. Phys. A 21 Suppl., 187, 2006*
[6] Buitink S et al. - LOPES coll, *Astronomy and Astrophysics, submitted 2006*
[7] Gemmeke et al. - LOPES coll, *ARENA Proc. 2005, Int. Journ. Mod. Phys. A 21 Suppl., 242, 2006*
[8] Huege T, Ulrich R and Engel R, *these proceedings*
[9] Huege T, Falcke H, *Astroparticle Physics 24, 116, 2005*