Air Shower Radio Detection with LOPES

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

LOPES COLLABORATION

[a] Institut für Kernphysik, Forschungszentrum Karlsruhe, Germany
[b] Institut für Experimentelle Kernphysik, Universität Karlsruhe, Germany
[c] Inst. Prozessdatenverarbeitung und Elektronik, Forschungszentrum Karlsruhe, Germany
[d] Fachbereich Physik, Universität Wuppertal, Germany
[e] ASTRON, Dwingeloo, The Netherlands
[f] Dipartimento di Fisica Generale dell'Università Torino, Italy
[g] Max-Planck-Institut für Radioastronomie Bonn, Germany
[h] National Institute of Physics and Nuclear Engineering, Bucharest, Romania
[i] Fachbereich Physik, Universität Siegen, Germany
[j] Dept. of Astrophysics, Radboud University Nijmegen, The Netherlands
[k] Istituto di Fisica dello Spazio Interplanetario, INAF, Torino, Italy
[l] Soltan Institute for Nuclear Studies Lodz, Poland

E-mail: `Johannes.Bluemer@ik.fzk.de`

Abstract. LOPES is an array of 30 radio antenna co-located with the KASCADE-Grande extensive air shower detector in Karlsruhe, Germany. It is designed as a digital radio interferometer for the detection of radio emission from extensive air showers. LOPES features high bandwidth and fast data processing. A unique asset is the concurrent operation with KASCADE-Grande. We report about the progress in understanding the radio signals measured by LOPES. In addition, the status and further perspectives of LOPES and the large scale application of this novel detection technique are sketched.

Introduction LOPES (= LOFAR prototype station) is an array of relatively simple, quasi-omnidirectional dipole antennas to detect the radio emission of extensive air showers produced

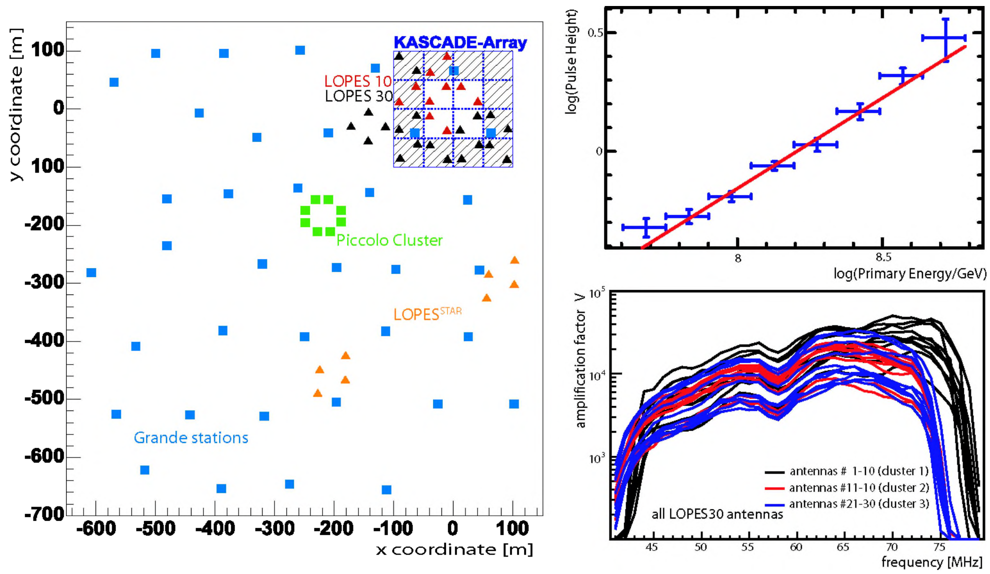

Figure 1. Left: Sketch of the LOPES set-up at the KASCADE-Grande experiment. Upper right: Average radio pulse height of the detected events versus the primary particle energy as reconstructed by KASCADE-Grande. Lower right: Frequency dependent amplification factors for all 30 antennas obtained by the amplitude calibration.

by cosmic ray particles. The radio 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 that one of high-gain antennas, like the high sensitivity and good background suppression. To demonstrate the capability to measure air showers with these antennas, LOPES has been built as an embedded antenna array within the air shower experiment KASCADE-Grande [1]. In this way we exploit the unique opportunity to cross-calibrate the radio emission of air showers in the energy range from 10^{16} eV to 10^{18} eV.

The theoretical foundations and pioneering works had been conducted from the 1960's. The proof-of-principle was achieved in 2005 using a first deployment stage of 10 LOPES antenna (see ref. [2] and references therein). We have now extended the antenna field to 30 stations [3].

Recent theoretical studies [4] of the radio emission in the atmosphere are embedded in the scheme of coherent geo-synchrotron radiation. Here, electron-positron pairs generated in the shower development gyrate in the Earth's magnetic field and emit radio pulses by synchrotron emission. Such simulations lead to expectations of the relevant radio emission in the frequency range from 10 MHz to 500 MHz, which corresponds roughly to the thickness of the shower front. Newest results suggest that by measuring field strength and lateral behavior of the radio emission simultaneously will allow to determine primary energy and mass of the cosmic rays by this technique [5].

We investigate in detail the correlation of the measured field strengths 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. The basic element of the reconstruction is the beam-forming by time shifting, where the data from each pair of antennas is multiplied time-bin by time-bin, the resulting values are averaged, and the square root is taken while preserving the sign. We call this the cross-correlation beam or CC-beam. Although the shape of the resulting pulse (CC-beam) is not really Gaussian, fitting a Gaussian to the smoothed data gives a robust value for the peak strength.

LOPES-10 First measurements during six months of data taking were performed with a set up of 10 antennas. More than 600 showers were detected in the radio domain and basic correlations of the radio signals with shower parameters could be established. In Figure 1 the dependence of the reconstructed radio pulse height with the primary energy of the cosmic particles is depicted. The correlation supports the expectation that the field strength increases linearly with the primary energy of the cosmic rays, i.e. the received energy of the radio signal increases quadratically with the primary energy. The correlation between the reconstructed field strength with the geomagnetic angle suggests a geomagnetic origin of the emission mechanisms. By investigating more distant events an exponential dependence of the signal with the mean distance of the shower axis to the antennas was found [6]. The functional form of this dependence and also the lateral scaling parameter is of high interest for the further development of the radio detection technique. Further interesting features of the radio emission in EAS were investigated by analyzing very inclined showers [7] and events measured during thunderstorms [8].

LOPES-30 The sensitive area of the antenna field has been enlarged using 30 units. Each single antenna has been absolutely calibrated in the amplitude response using a commercial reference antenna [9]. The calibration procedure yields frequency-dependent amplification factors representing the complete system behavior (antenna, cables, electronics) in the environment of the KASCADE-Grande experiment. After one year of measurements using the East-West polarization by all 30 antennas, the LOPES-30 set-up was reconfigured to perform dual-polarization measurements [10]. With the data taken by LOPES-30 it is expected to calibrate the radio emission by air showers in the energy range from 10^{16} eV to 10^{18} eV and to identify the geo-synchrotron effect as the dominant emission mechanism in air showers.

LOPES and the Pierre Auger Experiment LOPES is paving the way for an application of this detection technique in large UHECR experiments, like the Pierre Auger Observatory. We are optimizing the antenna design for an application at Auger, including a self-trigger system, named LOPES$^{\mathrm{STAR}}$ [11]. In parallel to the activities in Karlsruhe, tests are performed at the Auger Southern site, and first radio signals from showers have been detected [12].

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