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RADIO DETECTION OF COSMIC RAY AIR SHOWERS WITH LOPES[*]

P.G. ISAR[a,p], W.D. APEL[a], J.C. ARTEAGA[b,n], T. ASCH[c], L. BAEHREN[d], K. BEKK[a],
M. BERTAINA[e], P.L. BIERMANN[f], J. BLUEMER[a,b], H. BOZDOG[a], I.M. BRANCUS[g],
P. BUCHHOLZ[h], S. BUITINK[d], E. CANTONI[e,i], A. CHIAVASSA[e], K. DAUMILLER[a],
V. DE SOUZA[b,o], P. DOLL[a], R. ENGEL[a], H. FALCKE[d,j], M. FINGER[a], D. FUHRMANN[k],
H. GEMMEKE[c], C. GRUPEN[h], A. HAUNGS[a], D. HECK[a], J.R. HOERANDEL[d], A. HORNEFFER[d],
D. HUBER[b], T. HUEGE[a], K.-H. KAMPERT[k], D. KANG[b], O. KROEMER[c], J. KUIJPERS[d],
S. LAFEBRE[d], K. LINK[b], P. LUCZAK[l], M. LUDWIG[b], H.J. MATHES[a], M. MELISSAS[b],
C. MORELLO[i], S. NEHLS[a], J. OEHLSCHLAEGER[a], N. PALMIERI[b], T. PIEROG[a],
J. RAUTENBERG[k], H. REBEL[a] , M. ROTH[a], C. RUEHLE[c], A. SAFTOIU[g], H. SCHIELER[a],
A. SCHMIDT[c], F.G. SCHROEDER[a], O. SIMA[m], G. TOMA[g], G.C. TRINCHERO[i], A. WEINDL[a],
J. WOEHELE[a], M. WOMMER[a], J. ZABIEROSKI[l], J.A. ZENSUS[f]

[a]Karlsruhe Institute of Technology (KIT) - Campus North, Institut fuer Kernphysik, Germany
[b]Karlsruhe Institute of Technology (KIT) - Campus South, Institut fuer Experimentelle Kernphysik, Germany
[c]Karlsruhe Institute of Technology (KIT) - Campus North, Institut fuer Prozessdatenverarbeitung und Elektronik, Germany
[d]Radboud University Nijmegen, Department of Astrophysics, The Netherlands
[e]Dipartimento di Fisica Generale dell' Universita Torino, Italy
[f]"Max-Planck"-Institut fuer Radioastronomie Bonn, Germany
[g]National Institute of Physics and Nuclear Engineering, Bucharest, Romania
[h]Universitaet Siegen, Fachbereich Physik, Germany
[i]INAF Torino, Istituto di Fisica dello Spazio Interplanetario, Italy
[j]ASTRON, Dwingeloo, The Netherlands
[k] Universitaet Wuppertal, Fachbereich Physik, Germany
[l]Soltan Institute for Nuclear Studies, Lodz, Poland
[m]University of Bucharest, Department of Physics, Bucharest, Romania
[n]now at: Universidad Michoacana, Instituto de Fisica y Matem´aticas, Mexico
[o]now at: Universidade Sao Paulo, Instituto de Fisica de Sao Carlos, Brasil
[p]now at: Institute for Space Sciences, Bucharest, Romania
gina.isar@spacescience.ro

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Abstract. Cosmic ray air showers are high energetic particles coming from the Universe toward the Earth every second. It is well known that they generate electromagnetic waves in the Earth atmosphere detectable on the ground. LOPES is an interferometric array of simple dipole radio

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antennas designed to measure radio signals initiated by cosmic air showers. It is working in coincidence with the particle detector array KASCADE-Grande at Karlsruhe Institute of Technology (KIT), campus North, from where receives the well-reconstructed shower observables. Determination of the emission mechanism is an important issue for LOPES, and here polarization measurements can play an important role. For first hints towards the verification of the radio emission mechanism, a comparison between measured data and an analytical approach is elaborated.

Key words: cosmic ray air showers, radio emission, polarization.

1. INTRODUCTION

When a primary cosmic ray particle of sufficiently high energy coming from the Universe penetrates the Earth's atmosphere it produces by cascading interactions the so-called extended air showers of charge and neutral particles. Various components form the shower body, an avalanche of millions of particles which move coherently through the Earth's atmosphere. Moreover, different detectors have been deployed worldwide to record shower observables [1, 2, 3]. The propagation of dominant component of charged particles (mainly electrons and positrons) is influenced by deflections due to the Earth's magnetic field which effectively creates electric dipoles inducing radio waves detectable on the ground. This synchrotron radiation has been proposed to be dominant in the generation of the radio signals. We speak about "geo-synchrotron effect". The first observations of radio emission from extended air showers goes back to the sixties of the last century, but at that time the effect could not be uniquely established due to the lack of suitable electronic devices [4].

In our days, we have a revival of the study, because of the ability to use for the detection advanced and reliable electronic devises. The LOPES experiment has been designed to prove experimentally the existence of such an air shower phenomenon [5]. It is collocated at the KIT Campus North with the air shower detector array KASCADE-Grande [6]. The particle detector array provides the trigger information with the well reconstructed shower observables, the core location and the direction of the shower incidence, in particular also informing about the primary shower energy in the range of 10^{16}–10^{18} eV. The LOPES experiment is an array of digital antennas (absolutely amplitude calibrated [7]) working in the 40–80 MHz frequency range. In the beginning the main goal was the 'proof-of-principle', and studies of the characteristic features of the radio signal and of the radio emission mechanism. In 2004, the initial measurements were performed with 10 East-West-orientated antennas, lately the array has been extended with 20 more antennas to increase the sensitivity, but in 2006 the set-up has been modified to performing dual-polarization measurements (15 EW, 15 NS) until 2009, and thus recording the more complete information of the radio signal

[8, 9]. Within dual-polarization measurements and corresponding analysis, the intention of this work is to demonstrate that the geomagnetic effect is the dominant mechanism for the radio emission in extended air showers.

1.1. MOTIVATION – WHY POLARIZATION MEASUREMENTS?

If the main mechanism in the generation of the radio emission form cosmic air showers is the geomagnetic effect, the so-called geomagnetic angle must be of influence. The geomagnetic angle is the angle between the direction of the shower incidence and the direction of the Earth magnetic field. According to a Monte Carlo simulation approach of radio emission from air showers [10], the radio emission is expected to be highly linearly polarized, perpendicular to the shower axis and to the Earth magnetic field. Simulations predict radio signal recordable in both polarization directions, EW and NS, and thus having both components equipped in the LOPES setup, the complete radio signal can be measured and fully compared afterwards with the simulations, which verifies directly the nature of the emission mechanism of radio emission from cosmic ray air showers.

2. MEASUREMENTS

As example, in Fig. 1 is shown an air shower event arriving from the North direction (with a zenith angle of 6 degrees) and of high primary energy above 10^{17} eV, the effective energy in radio, which shows detection in both polarization components of the electric field, the EW and NS directions. The signal experiences a complex reconstruction procedure which mainly includes a Fast Fourier Transformation, a filtering in the effective frequency band, corrections for instrumental properties, suppressing of background noise (because of measuring in a working area). Having a digital antenna array, by interferometric cross-correlation a beam into the direction of the air shower incidence given by the KASCADE-Grande is formed. The beam forming is optimized by three shower parameters: azimuth, zenith of incidence and curvature radius of the wave front, and so the pulse height is maximized. Thus, the coherence of the signal is achieved for each polarization component separately, occurring at a similar time. Data from pairs of antennas are multiplied, the resulting values are averaged, and afterwards the square root is taken while preserving the sign. We call it the cross correlation beam (CC-beam). It is fitted with a Gaussian function separately for each polarization component. The resulting values (the height of the Gauss fit) represent the radio observables used further in the analysis.

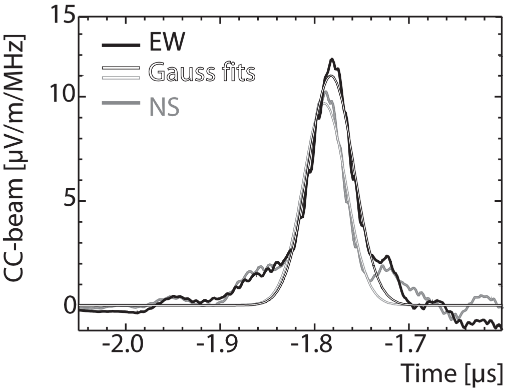

Fig. 1 – An air shower event showing signal in both polarization components.

For selected data of further processing of observed radio emission, air showers of primary energy above 10^{17} eV are preferred, in order to avoid any effects in radio. The triggered air showers (about 2 per min.) by the KASCADE array (10 out of 16 clusters to be fired) are required to have high electron sizes $N_e > 10^5$ and muon numbers $N_{mu} > 10^6$. But, as not every selected air shower event is accompanied by a radio pulse recorded by the LOPES experiment, one has to select reliable events by validating the following aspects: existence of a pulse, coherence of the pulse and position in time of the pulse in all antennas. The KASCADE data-set consists mostly of events with primary energy below 10^{17} eV; consequently, the expected signal strength is relatively low, and the signal-to-noise ratio has large variations, depending on the shower geometry and the core position of the selected events. However, for the present analysis of the radio signal, besides the primary energy above 10^{17} eV, no cut on other shower observables is considered, except zenith angles below 40 degrees and large signal-to-noise ratio above 4. These quality cuts give high accuracy in the reconstruction of the EAS observables.

2.1. A THEORETICAL APPROACH IN COMPARISON WITH MEASURED DATA

In a simplified model the synchrotron radiation produced near the axis of the particle motion is proportional to the cross product $\vec{v} \times \vec{B}$ the Lorentz force, where $\vec{v}$ is the direction of the air shower and $\vec{B}$ the Earth's magnetic field. This vector product reproduces the qualitative results, and can express the expectations of the polarization responses in each component of the *E*-field [8]. The azimuth dependencies emphasize that showers with strongest signals will be registered perpendicular to the Earth magnetic field. It means, the EW polarization component is dominantly detected in the Northern direction and the NS polarization component is expected in the East and West directions. Characteristic features are found in the ratio between the NS and EW projections of the total vector cross product in dependency with azimuth and geomagnetic angles. The aim here is to see whether these feature characteristics are also seen in measured data. We adopt this ratio in order to be independent from common factors (*e.g.* the total signal strength or any additional shower observables). 99 events measured with the dual-polarization antennas, triggered by the particle detector array KASCADE within 90 m radius, are used for this verification. They are ascribed to a primary energy above 10^{17} eV, and have zenith angles between 0–40 degrees, and of large signal-to-noise ratio. Mean values with their root-mean-square of the distributions are shown on a linear scale in Fig. 2. Full circle represents the model applied to the measured shower geometry and open circle represents the measurement. For values larger than 1, the detection of NS polarization direction is dominant. Otherwise, for values below 1, the detection of EW polarization direction is dominant. One can see that there is a relatively good agreement between MODEL and DATA, except for the North and South directions. But, the deviations seen in North and South could be considered as remaining contribution to the radio emission, which could, for example, be associated with the negative charge excess developed in the shower, *i.e.* the number of moving electrons can exceed through the annihilation of the positrons by some 10–20%. It depends on the mass and primary particle energy.

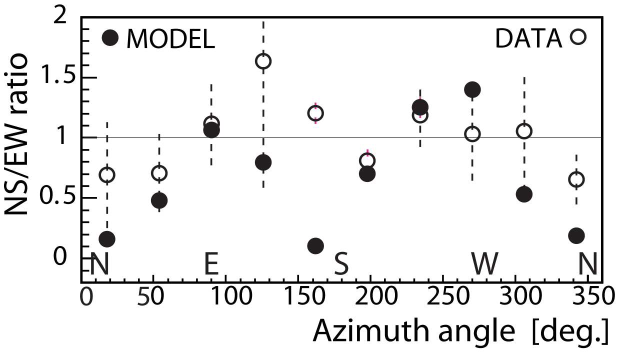

Fig. 2 – Comparison between geomagnetic model (applied to measured shower geometry) and data.

4. CONCLUSIONS

The result gives a strong indication of the geomagnetic origin of the radio emission from air showers as dominant. Still the origin and the quantity of the other non-geomagnetic effect contributing to the radio emission it is not fully clarified yet. Thus, further investigations on both measurements and full detector simulations are considered, in order to verify the radio emission mechanism(s).

Traditional particle detectors, optical telescopes and digital interferometry, all together play an important role in measuring cosmic ray air showers, yielding to separate and complementary results. One objective of LOPES is to pave the way for the use of the radio technique in current and further modern experiments at large scales, like the world largest cosmic ray air shower experiment Pierre Auger Observatory, where the radio technique could help in observing the transition region between the Galactic to Extragalactic sources.

Many other papers describing different relevant aspects of this rapidly growing research field has published in the last years [11–18].

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