Astroparticle Physics 74 (2016) 79–86

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

Reconstruction of air-shower parameters for large-scale radio detectors using the lateral distribution

D. Kostunin [a,*], P.A. Bezyazeekov [b], R. Hiller [a], F.G. Schröder [a], V. Lenok [b], E. Levinson [b]

[a] Institut für Kernphysik, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[b] Institute of Applied Physics, Irkutsk State University (ISU), Irkutsk, Russia

ARTICLE INFO

Article history:
Received 29 April 2015
Revised 4 September 2015
Accepted 15 October 2015
Available online 22 October 2015

Keywords:
Cosmic rays
Extensive air-showers
Radio detection
Lateral distribution

ABSTRACT

We investigate features of the lateral distribution function (LDF) of the radio signal emitted by cosmic ray air-showers with primary energies $E_{\text{pr}} > 0.1$ EeV and its connection to air-shower parameters such as energy and shower maximum using CoREAS simulations made for the configuration of the Tunka-Rex antenna array. Taking into account all significant contributions to the total radio emission, such as by the geomagnetic effect, the charge excess, and the atmospheric refraction we parameterize the radio LDF. This parameterization is two-dimensional and has several free parameters. The large number of free parameters is not suitable for experiments of sparse arrays operating at low SNR (signal-to-noise ratios). Thus, exploiting symmetries, we decrease the number of free parameters based on the shower geometry and reduce the LDF to a simple one-dimensional function. The remaining parameters can be fit with a small number of points, i.e. as few as the signal from three antennas above detection threshold. Finally, we present a method for the reconstruction of air-shower parameters, in particular, energy and X_{max} (shower maximum), which can be reached with a theoretical accuracy of better than 15% and 30 g/cm^2, respectively.

1. Introduction

The determination of the composition of the primary particles is one of the most interesting and complicated problems of experimental high-energy cosmic ray physics. Imaging instruments, particularly, fluorescence or Čerenkov detectors, detect cosmic ray air showers with high precision, but their duty cycle is only in the order of 10%. On the other hand, detectors with a full duty cycle, such as particle detectors, until now have poor sensitivity to the shower maximum and cannot provide accurate studies of the composition. A candidate to solve this dilemma is the radio detection of cosmic rays. It probably can reach a precision comparable with air-Čerenkov measurements. However, it still has a number of important open issues such as efficiency, systematic uncertainties and precision of the energy and shower maximum reconstruction, all also depending on the detector layout.

In the present paper we perform a detailed theoretical study based on a real large-scale detector layout. We performed about 300 simulations based on the reconstruction of measured high energy Tunka-Rex [1] and Tunka-133 [2] events. To simulate air showers we used CoREAS [3], software integrated in CORSIKA, which implements the end-point formalism for calculating radio emission from air showers. In comparison with previous work made for ideal detectors (see, for example, [4,5]), LOPES [6] and LOFAR [7], our investigations have several important differences. First, we reproduce detected events with small uncertainty, thus, our simulation could be compared with signals measured by Tunka-Rex, which, in turn, features an absolute amplitude calibration. Second, the geometry of the detector matches modern large-scale setups, i.e. the spacing between antennas is about 200 m. Finally, we transform the simulated signals applying the real hardware properties of Tunka-Rex (amplifiers, antennas, etc.), and check the sensitivity of selected antennas. That means, we do a statistical study which gives realistic upper limits for the precision of the reconstruction of air shower properties. “Upper limits” because we do not include noise and the precision will be slightly worse when taking into account realistic background (see Appendix). Therefore, this limit could be reached in the case of large signal-to-noise ratios (SNR).

The complication in describing the radio LDF originates from the interference of two completely different mechanisms of radio emission: emission due to geomagnetic deflection of charged particles, and the Askaryan (also known as charge-excess) effect. Adding these two effects causes an asymmetric two-dimensional lateral distribution function (LDF). There are two obvious approaches to describe this lateral distribution: to use a complex two-dimensional function, or to find some symmetries and rewrite the LDF invariantly. The first

* Corresponding author.
E-mail address: dmitriy.kostunin@kit.edu (D. Kostunin).

http://dx.doi.org/10.1016/j.astropartphys.2015.10.004
0927-6505/