Tunka-Rex: a Radio Extension of the Tunka Experiment

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Abstract. Tunka-Rex, the Tunka radio extension, is an array of about 20 antennas currently under construction, which covers an area of 1 km². Tunka-Rex measures the radio emission of cosmic-ray air showers above 10¹⁶ eV. It is triggered by the photomultipliers of the Tunka-133 experiment which simultaneously measure the Cherenkov light emitted by the same air showers. The radio-Cherenkov-hybrid measurements thus offer a unique opportunity for a cross-calibration of both detection methods. The main goal of Tunka-Rex is to determine the precision of the radio reconstruction for the energy and the atmospheric depth of the shower maximum, Xmax, and thus to experimentally test theoretical predictions that the radio precision can be similar to the precision of air-Cherenkov and fluorescence measurements. At the same time, Tunka-Rex can demonstrate that radio measurements can be performed on a large area for a relatively cheap price, since the antennas will be connected to the already existing Tunka DAQ. Finally, radio-antenna arrays have the perspective to increase the effective observation time compared to air-Cherenkov and fluorescence detectors by an order of magnitude, since radio measurements are possible under almost any atmospheric and light conditions.

1. Introduction

Revealing the sources of the cosmic rays with energies above 10¹⁷ eV requires measuring their properties with sufficient accuracy and statistics. This exceeds the possibilities of current air-shower observatories. With a fixed available area, the detection of secondary air-shower particles at ground provides the highest statistics, but unfortunately not the highest accuracy, since the energy and mass of the primary particle can be reconstructed only with large uncertainties. On the other hand, the most accurate methods for extensive air showers, the detection of air-fluorescence and air-Cherenkov light, are limited to dark moonless nights, and thus deliver...
Figure 1. Map of the Tunka-133 array: already existing photomultipliers for the detection of air-Cherenkov light (circles), and planned positions of the Tunka-Rex antennas (triangles).

only low statistics (see references [1], [2] for reviews). The radio technique for air-shower measurements offers the opportunity to combine both advantages: high statistics, since radio measurements can be performed under almost any atmospheric conditions (except very close thunderstorms [3]), and high accuracy, since the principle limitation is the same as for the established air-fluorescence and air-Cherenkov techniques, because also the radio emission is mainly caused by the electrons and positrons in the air shower. Yet, it has to be shown experimentally that radio measurements can provide a competitive precision in practice.

Already in the 1960’s many experiments demonstrated that the arrival direction and energy can be determined from radio measurements (see reference [4] for a review). However, these historic experiments have been limited by the simple analog electronics and insufficient computing power available at that time. While nowadays sophisticated digital electronics allows for data conditioning, e.g., to suppress radio background. Consequently, the radio technique experienced a revival about 10 years ago. Digital radio-antenna arrays like CODALEMA [5] or LOPES [6], [7] successfully measured air-showers in coincidence with particle-detector arrays. LOPES recently demonstrated experimentally that the radio emission is sensitive to the longitudinal shower development [8], which allows to statistically determine the cosmic-ray composition. While the precision of LOPES is limited by the high level of human-made radio background, simulations indicate that at sites with lower background the precision could be comparable to the established air-fluorescence and air-Cherenkov techniques [9] [10]. Consequently, Tunka-Rex as a next-generation radio-array is built at the radio-quiet site of the Tunka experiment [11].
Figure 2. Tunka-Rex prototype antenna SALLA connected to the data-acquisition of one Tunka cluster (white box) close to one of the photomultiplier detectors.

2. Tunka-Rex

Tunka-Rex, the Tunka Radio extension, will start autumn 2012 as an array of 20 radio stations. It is installed within the Tunka-133 array which measures the air-Cherenkov light emitted by air-showers with 133 non-imaging photomultipliers on an area of 1 km$^2$ (figure 1). Tunka-Rex is based on the experience gained with other radio arrays, in particular LOPES and AERA [12], and thus copies several successful design decisions, e.g., a beacon for time calibration [13]. Each Tunka-Rex station consists two orthogonally aligned antennas, which allows to study the polarization of the radio signal, and to reconstruct the electrical field vector. The frequency range of Tunka-Rex is 30 – 80 MHz, and the antenna spacing is about 200 m, which is significantly larger than at LOPES, but similar to the AERA spacing. In addition, the Offline analysis software [14] of the Pierre Auger Observatory [15] is used for the Tunka-Rex analysis, too.

However, in two important aspects Tunka-Rex is different and unique. As first radio-array it will be based on the cheap and simple SALLA antenna type [16], and as first radio-array it is operated jointly with an air-Cherenkov detector. Since the Tunka-Rex radio detectors are connected to the same digital data acquisition as the Tunka-133 photomultipliers, Tunka-Rex can easily be triggered by Tunka-133 to perform coincident measurements of the same air showers. This enables a cross-calibration of radio and air-Cherenkov measurements aiming for an optimization of the radio reconstruction for the energy and the atmospheric depth of the shower maximum, $X_{\text{max}}$.

The joint operation of a Tunka-Rex antenna with the Tunka-133 photomultiplier detectors has been successfully demonstrated with a prototype antenna installed in summer 2009 (figure 2) [11], [17], [18]. About 70 candidate events have been found where a radio pulse has been detected simultaneously with the Cherenkov light of the air shower, and a careful study has been performed to exclude that the radio pulses were only interferences from Tunka-133. Thus, we expect several 100 Tunka-Rex radio events per year at energies above $10^{16}$ eV. The analysis of these events will aim at the following main physics and technical goals of Tunka-Rex:
• Determine the radio reconstruction precision for the energy and $X_{\text{max}}$ by a cross-calibration with Tunka-133, which itself has an energy precision of about 15%, and a $X_{\text{max}}$ precision of about 25 g/cm$^2$ [19].

• Improve the understanding of the air-shower radio emission. For example, we will study the lateral distribution up-to distances of 1 km, and compare the results to theoretical predictions, e.g., REAS simulations [20], [21], and the model described in Ref. [22].

• Demonstrate that the radio technique is competitive to the established techniques not only in precision, but also in terms of costs. In particular, the joint operation of antennas with other detectors, can make radio an economic and effective add-on to any air-shower observatory. Therefore, we will not only test the joint operation with Tunka-133, but also the joint operation with HiSCORE [23], [24] prototype stations deployed at the Tunka site.

3. Conclusion

Tunka-Rex can show whether the radio emission of air showers can indeed be exploited for a feasible, additional detection technique, which would combine the advantages of the established techniques, i.e. a high duty cycle and a relatively high precision at the same time. With this research, Tunka-Rex is complementary to other next-generation radio arrays, like AERA, which allows to check results by different experiments. If successful, Tunks-Rex may enhance the effective observation time of Tunka by an order of magnitude - especially for the interesting energy range above $10^{17}$ eV.

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