Status and first results of the Tunka Radio Extension

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Tunka-Rex is a new radio detector for extensive air showers from cosmic rays, built in 2012 as an extension to Tunka-133. The latter is a non-imaging air-Cherenkov detector, located near lake Baikal, Siberia. With its 25 radio antennas, Tunka-Rex extends over 1 km^2 with a spacing of 200 m and therefore is expected to be sensitive to an primary energy range of 10^{17}-10^{18} eV. Using Trigger and DAQ from Tunka-133, this setup allows for a hybrid analysis with the air-Cherenkov and radio technique combined. The main goal of Tunka-Rex is to investigate the achievable precision in reconstruction of energy and composition of the primary cosmic rays by cross-calibrating to the well understood air-Cherenkov detector. An early analysis proves the detection of air-shower events with dependencies on energy and incoming direction as expected from a dominant geomagnetic emission mechanism.

Keywords: Tunka-Rex, Tunka, Radio, Antenna

1. Introduction

Over 100 years after their discovery, many questions about cosmic rays remain open. To tackle them, new detection techniques have to be investigated, which open new perspectives on cosmic rays or contribute to next generation super-hybrid detectors.

A promising candidate for that is the radio detection. An array of radio antennas is used to detect the radio pulse of a cosmic ray air shower. The

emission mechanism for this pulse is predominantly the time variation of a geomagnetically induced transverse current in the shower front.[1] Another contribution, for most incoming directions subdominant, comes from the Askaryan effect, via the time variation of the net charge in the shower.[2] Experiments like LOPES[3] proved that air shower of primaries above 10^{17} eV can be detected with an angular precision of $< 1°$. The next step now is to develop reconstruction methods for high level shower parameters with competitive precision - especially for the depth of the shower maximum X_{max}, the most important parameter for the reconstruction of the primary mass composition of high energy cosmic rays.
For this purpose, the Tunka Radio Extension (Tunka-Rex) was built. It is an extension to Tunka-133,[4] an non-imaging air-Cherenkov detector in Siberia, close to Lake Baikal. Tunka-133 is sensitive to an energy range of about 10^{16}-10^{18} eV. The Tunka-Rex antennas are connected to the Tunka-133 DAQ and are read out together with the PMTs for the Tunka-133 triggered events. This automatically provides hybrid measurements with the radio and the air-Cherenkov detector and allows us to use the established air-Cherenkov detector for cross-calibration.
For triggering, the Tunka-133 PMT array is grouped in 19 clusters with 7 spatially compact PMTs. If 3 or more PMTs pass a threshold in coincidence, the whole cluster is read out, i.e. 7 PMTs and one antenna. Coincidental cluster triggers have to be combined offline to events.

2. The detector setup of Tunka-Rex

The first stage of Tunka-Rex was deployed in 2012 and consisted of 20 antenna stations, of which 18 took data from Oct. 2012 to April 2013. In Sep. 2013 the array will be completed to 25 antenna stations with a spacing of about 200 m (fig. 1).

Each station consists of 2 channels, which are independent antennas, aligned perpendicular to each other and 45° rotated to the NS and EW axis. With additional information on the incoming direction, the electrical field vector $\vec{E}$ can be reconstructed with the two channels. The incoming direction is approximated by the shower axis and reconstructed from the pulse timing in different stations. As antenna we use an active version of the SALLA[5] (fig. 1), which is economic, rugged and has little dependence on ground conditions, but on its downside has a relatively low gain. Its active part is a 24 dB low noise amplifier directly connected to the antenna arcs. The LNA is connected to a filter amplifier, which filters the signal to the design band of 30-80 MHz and amplifies it by another 32 dB. On

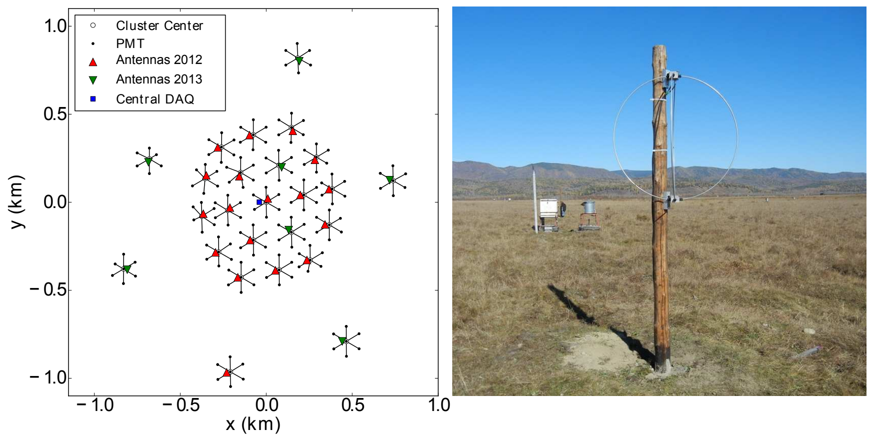

Fig. 1. **left**:Map of Tunka-133 and the Tunka-Rex antenna layout.**right**:A Tunka-Rex antenna with the Tunka-133 cluster center and central PMT in the back.

each trigger of a cluster a 5 μs trace of the corresponding antennas station is digitized by FADCs with 200 MHz sampling rate and 12 bit depth and send to the central DAQ.

To reconstruct $\vec{E}$ from the measurements, the detector response of the analog chain has to be known. It consists of the antenna gain pattern and the electronics response. The antenna gain pattern is currently taken from a NEC2[6] simulation. In 2013 also a calibration with a reference source was performed for several solid angles. It will be used for future analyses to normalize the directivity of the simulation. The analog electronics response was measured with a network analyzer. For more information on the deconvolution of signal and detector response and its impact on the reconstruction see ref.[7]

3. Performance of Tunka-Rex in the first season

After the deployment of Tunka-Rex in Oct. 2012, 18 antenna stations were taking data until April 2013, when Tunka-133 was shut down for maintenance. About 400 h of measurement time were accumulated during moonless nights with good weather, when the air-Cherenkov detector is able to operate.

As a first step we performed a relative simple reconstruction. After the inversion of the electronics response we cut digitally to our design band, 30-80 MHz and remove narrow band interferences.

With this enhanced signal trace from multiple antenna stations, $\vec{E}$ and the shower axis are reconstructed recursively. If the amplitude of $\vec{E}$ passes a signal-to-noise (SNR) cut, we use the timing of the pulses to reconstruct the shower axis, at the moment with a simple plane shower front model. Furthermore, to qualify as an air-shower event, we require to have at least 3 antenna stations with an SNR (amplitude^2/noise^2) of $\vec{E}_{rec}$ of at least 6. Finally, the direction reconstruction from Tunka-133 and Tunka-Rex have to agree within 5° to exclude a few events where background pulses pass the SNR cut.

With this analysis, we found a total of 131 events above 10^{17} eV in the first season. 49 vertical ones, with zenith angles $\theta < 50°$ and 82 horizontal ones, with larger zenith angles. Tunka-133 provides a full reconstruction, including energy and X_{max}, only for the vertical events, but still gives a trigger and geometry reconstruction for the horizontal events. In fig. 2 left the distribution of the events on the sky is shown. As several other experiments,[3,9,10] we observe a north-south asymmetry, with diminishing event rate close to the magnetic field direction, as expected from a geomagnetic emission mechanism. There are 89 events from the northern half and 42 from the southern half of the sky.

For the vertical events, for which an energy reconstruction from Tunka-133 is available, we can show the sensitivity of Tunka-Rex to the primary energy. Therefore we fit a Lateral Distribution Function (LDF) to the reconstructed amplitudes. As a first approach, we chose an exponential function for the

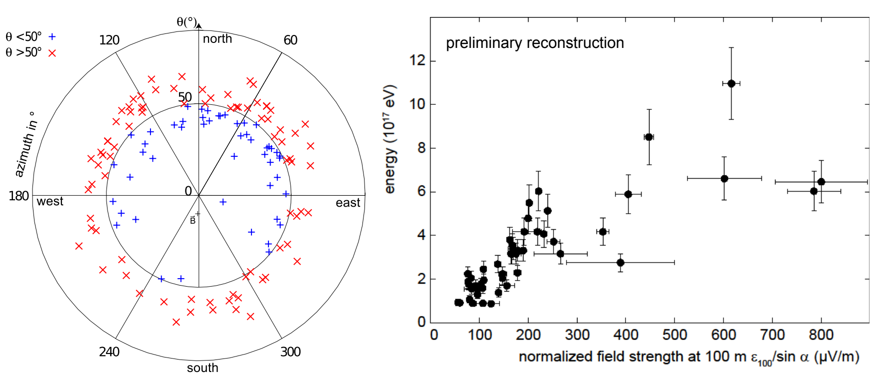

Fig. 2. **right**:Correlation of the reconstructed amplitude of the electric field at 100 m distance to the shower core with the reconstructed energy of Tunka-133. **left**:Event distribution of the preliminary analysis of Tunka-Rex on the sky and the magnetic field direction. Note the asymmetry between north and south sky, as expected from a geomagnetic emission mechanism.

LDF, since it is an established and simple choice. For the uncertainty of the amplitude, a formula from LOPES[8] was used. In agreement with other radio experiments[3,9,10] the reconstructed amplitude at 100 m with this method correlates with the energy, here reconstructed by Tunka-133 (fig. 2 right). Next steps include the investigation of the sensitivity of the slope parameter from the exponential LDF to X_{max} and the development of more sophisticated reconstruction methods.

4. Conclusion

Tunka-Rex started its operation in Oct. 2012 and successfully ran in its first season. More than 100 detected events could already be found in a preliminary analysis. In agreement with other experiments, an NS-asymmetry in the event distribution on the sky and a correlation of the reconstructed amplitude at 100 m with the energy has been observed. These observations prove the principal functionality of Tunka-Rex. Therefore we are confident, that Tunka-Rex can be used to compare the radio and air-Cherenkov reconstructions to measure the sensitivity of the radio technique to the energy up to 15% and X_{max} up to 28 g/cm^2.[4] Furthermore, our measurements can be compared to simulations and other experiments, e.g. to give input for the theoretical description of the radio emission from air showers.

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