



Observation of radio signals from air showers at the Pierre Auger Observatory

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ABSTRACT

Radio detection of cosmic ray induced air showers has been demonstrated in dedicated setups in the past. Currently, radio detector setups are being tested at the Pierre Auger Observatory, in Malargüe, Argentina, for the detection of ultra high energy cosmic rays.

These efforts have been rewarded with promising results. Radio signals from air showers have been measured in coincidence with the Auger surface detector array.

One of the current data sets consists of 313 triggered radio events in coincidence with the surface detector of the observatory. These events have been used to make first analyses, which focus on the lateral distribution function of the radio signals and on the reconstruction of the arrival direction of cosmic rays. Furthermore, the radio background data have been studied. A periodic variation corresponding to the apparent motion of the galactic center has been observed.

New, stand-alone, radio detectors have been developed and the next phase of testing at the Auger Observatory has started in May 2008. The aim is to show that an independent radio detector at the Auger Observatory with an area of about 20 km² is feasible.

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1. Introduction

Charged particles in extensive air showers emit coherent geosynchrotron radiation at radio frequencies [1]. This radiation can be measured with simple radio antennas, as was demonstrated first by Jelley in 1965 [2]. Recently, improved technology has led to a revival of this technique. Radio detectors, like LOPES [3] and CODALEMA [4], produce promising results at energies up to about 10¹⁷ eV. This article discusses the construction and testing of a new setup of radio detectors at the Pierre Auger Observatory for ultra high energy cosmic rays (UHECR, $E > 10^{18}$ eV), in Argentina [5,7]. The Pierre Auger Observatory is a hybrid detector system with a surface detector (SD) and a fluorescence detector (FD) to measure extensive air showers. However, the fluorescence technique can only be used during dark, cloudless nights, whereas radio detection has a duty cycle of almost 100%. Because this hybrid detector observes cosmic rays at the highest energies, it is a very good site to test radio detectors constructed to study air showers with energies of more than 1 EeV.

2. Setup

One of the test sites [6] for radio detection of air showers is located in the western part of the observatory. Here, a sea container provides electricity and internet access. Furthermore, within the array an extra baseline particle detector is deployed to lower the energy threshold of the SD for detection of local showers. In this way, events detected with the radio antennas can be compared to showers measured with the SD. The GPS timestamps of the events recorded by the SD and the radio setup are used to look for coincidences.

The radio detection setup consists of three dual antennas, positioned in a triangle and separated by 100 m, with low noise amplifiers that are sensitive in the 30–80 MHz band (two log periodic dipole antennas [9] and one LOFAR antenna [10], see Fig. 1). The measured signals are filtered, amplified and then digitized using 400 MHz 12 bits ADCs. During the first phase of testing, the digitizers were externally triggered by two scintillator panels that are approximately 10 m apart from each other, and the distance to the nearest SD tank is about 500 m.

3. Results

After one year of taking data with three antennas, 313 cosmic ray events have been measured in coincidence with the SD.

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Fig. 1. Left: an LPDA antenna; right: a LOFAR antenna.

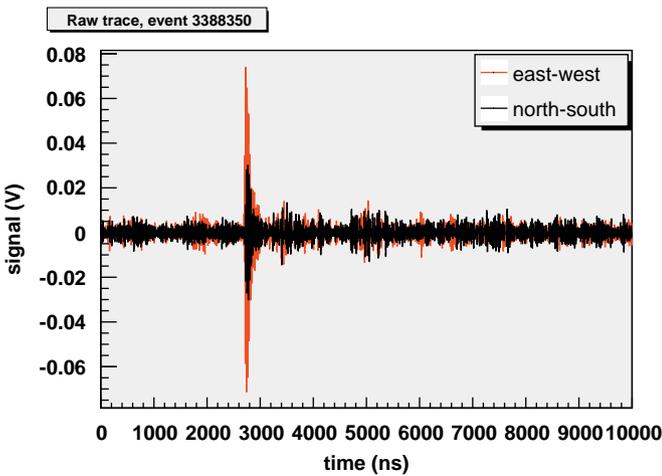


Fig. 2. A radio event in coincidence with the SD.

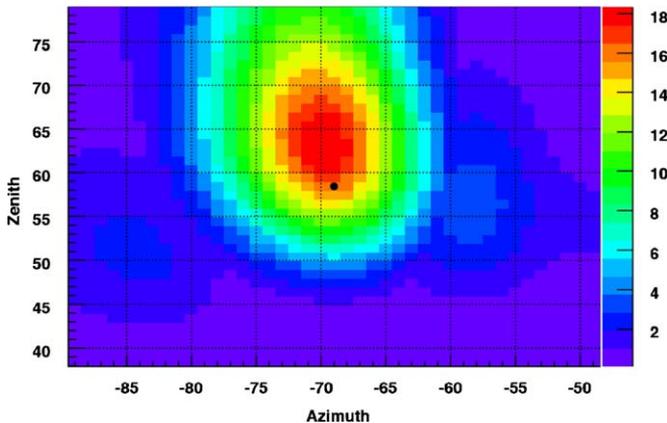


Fig. 3. The reconstructed arrival direction of an event. Here, the black dot depicts the arrival direction reconstructed with the SD, the contours show the radio signal strength as a function of arrival direction.

A typical event is shown in Fig. 2. When we detect a clear radio signal in all three antennas, we can determine the arrival direction of the cosmic ray from the differences in signal arrival time between the three antennas. This is shown for one event in Fig. 3. Here, the arrival direction determined by the SD is depicted with the black dot. The colors indicate the signal strength in the radio antennas as a function of zenith and azimuth angle. The fact that

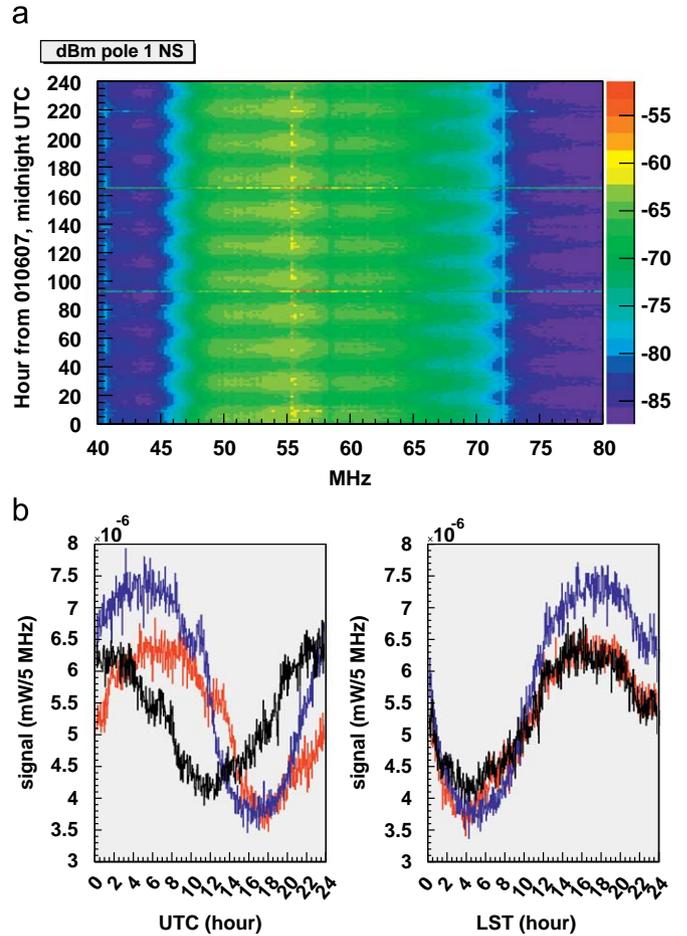


Fig. 4. Top: the dynamic spectrum of the radio background. The false color displays the power in dBM/250 kHz; bottom: the background as a function of local sidereal time. Here, on the left, the signal is plotted as a function of UTC, for three different days in May, June and July. On the right the same signal is plotted, but now as a function of the local sidereal time.

we already get a 5° accuracy with three antennas, that are only 100 m apart, is a very promising result. Furthermore, the last part of the radio traces is used to study the radio background. When we plot this background between 50 and 70 MHz as a function of time, we clearly see a periodic structure (top part of Fig. 4). The period of this variation corresponds to a sidereal day. When we plot the average radio background as a function of local sidereal time, we see a maximum when the galactic center is overhead (bottom part of Fig. 4). This is a clear indication that our setup is sensitive to the galactic background and that the noise is dominated by galactic radio background radiation. The galactic radio background can be used to correct for gain differences for the different antenna types we use. After this correction, we plot the signal strength as a function of distance from the shower core for events seen in three antennas. The location of the shower core (as well as other shower parameters like energy and arrival direction) are obtained from the reconstruction of the SD data. From the radio events we try to obtain a lateral distribution function. An example is shown in the top plot of Fig. 5. In this figure, the signal strength is taken to be the maximum of the cosmic radio pulse (after subtraction of a mean value for the background noise). An uncertainty of 50 m on the distance from the shower core is assumed, which is due to the uncertainty of the SD reconstruction.

When we look at all events measured in coincidence with the SD, we can plot the strength of the signals for each antenna as

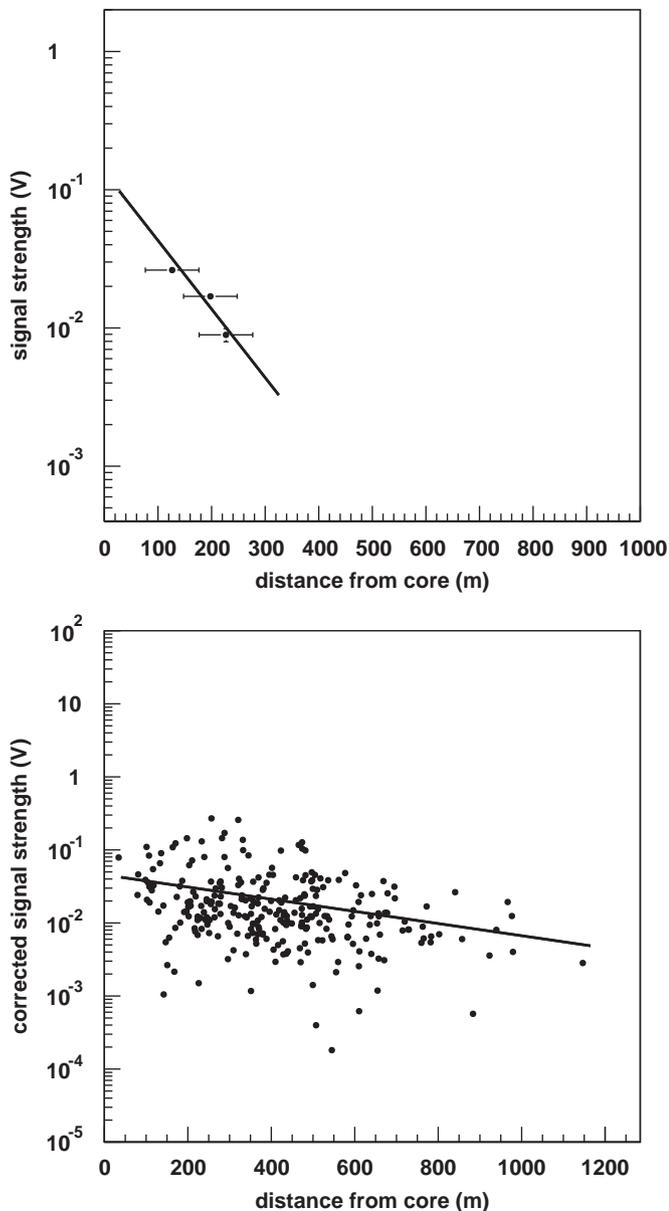


Fig. 5. Top: lateral distribution of a single event measured in three antennas. Horizontal errors are correlated; bottom: lateral distribution of all events in coincidence with the SD for one antenna. The lines are to guide the eye, the data are represented with dots.

function of the distance to the shower core. But we need to correct the signal strength for some shower parameters like primary energy and arrival direction (see [1]). After this correction the signal strength is plotted in Fig. 5 without any error bar.

Another thing that can be studied is the arrival direction of the air showers recorded in the radio antennas. We see that events with a radio signal larger than 5 mV (which is well above the noise level) are predominantly coming from the south. This is in agreement with results presented by Revenu in this conference [8].

4. MAXIMA: Multi Antenna eXperiment in Malargüe Argentina

The next phase of testing has started in May 2008. New, stand-alone detectors have been constructed, see Fig. 6. We use a new



Fig. 6. A new 'black spider' LPDA antenna on the left and a MAXIMA station on the right.

type of 'black spider' LPDA antenna that has been developed by RWTH Aachen. The stations are solar-powered and communicate with a central computer through a wireless ethernet. The scintillator panels are no longer used to provide an external trigger. These stations, as well as the three antennas that were used for the first phase of testing, have new digitizers and run in self-trigger mode. Three trigger levels have been introduced. The first level trigger is implemented in the FPGA of the digitizer and is based on a few parameters that describe the radio pulse shape. These parameters (like threshold, pulsewidth, number of pulses in a certain time interval, etc.) can be set by the user. Next, there is a second level trigger which consists of a signal over background check after a digital filter that is applied to the time trace. Finally, the third level trigger is made at the central computer. It looks for coincidences between different antennas. It can be set to only get data from individual stations when, for example, at least two of them have triggered simultaneously.

Apart from triggering on radio pulses, the stations trigger once every 10 s to measure the radio background. In this way, the stations also monitor the environmental background noise.

5. Conclusions and outlook

The first phase of testing of a new radio detector setup for cosmic rays at the Pierre Auger Observatory has finished. We have measured over 300 cosmic radio events in coincidence with the SD. The data analysis of these events is ongoing and we have also entered the next phase of testing. Here, we focus on the self-triggering of the radio antennas. The aim is to show that an independent radio detector at the Pierre Auger Observatory with an area of about 20 km² is feasible.

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