Radio detection of Cosmic Rays at the Pierre Auger Observatory

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When a cosmic ray enters the Earth's atmosphere, an avalanche of (charged) particles is created, which is called an air shower. Charged particles passing through the Earth's magnetic field emit electromagnetic radiation that can be detected by ground-based dipole antennas. The southern site of the Pierre Auger Observatory, located in Argentina, provides an excellent environment for testing various prototype radio detectors for cosmic-ray studies. The first results of prototype radio detectors will be discussed. The events obtained will be used to characterize the radio signal of air showers. The results of this initial phase provide an important milestone on the path to an engineering array of several tens square kilometers.

Keywords: Cosmic Rays; Air Shower; Radio Detection; Pierre Auger Observatory.

1. Introduction

The air shower created from interactions in the atmosphere initiated by a cosmic-ray particle emits electromagnetic radiation. Already since the late 1960s, synchrotron radiation in the Earth's magnetic field is known to be the dominant component of this EM-radiation [1]. As this radiation is emitted coherently, the amount of radiation depends roughly linearly on the number of particles in the air shower, and thus on the primary energy. This radiation can be measured at ground level using simple antennas, as was demonstrated first by Jelley in 1965 [2]. These pioneering efforts continued in the early 1970s, however, the state of the electronics did not permit proper measurements. Furthermore, shower to shower fluctuations were identified as a possible problem, whereas a good simulation program was
not available. With modern electronics, the measurement of EM-radiation emitted by the shower can be done in a sophisticated way. The revival of radio detection of air showers is evident from a number of recent papers, e.g. by the Lopes [3] and Codalema [4] collaborations, which use particle detectors to identify air showers and to trigger the antenna readout. We continue this development at the Pierre Auger Observatory, with the goal to understand this mechanism at the highest energies, and, afterwards to use this technique to obtain complementary information on the showers, as obtained by only the surface detector array.

2. Setup

At the southern site of the Pierre Auger Observatory [5], near Malargüe in Argentina several antenna-based air-shower detectors have been set up. The Pierre Auger collaboration operates the world’s leading detector system for the observation of the highest energy cosmic rays. Therefore, this observatory is particularly suited for an R&D program to develop radio detection beyond energies of 1 EeV [6]. As the aim is to understand radio detection at the highest energies and to develop a stand-alone radio detector several approaches are taken.

Wireless setups in which different antenna types are used without any external triggers are aimed toward understanding the problems of running a radio detector as an independent and stand-alone cosmic-ray measuring device. An example of such a setup is shown in the left part of Fig. 1.

![Fig. 1. Left: A standalone antenna setup near the center of the Pierre Auger Observatory. Right: LPDA antenna used to obtain the results presented here.](image)

A setup in which three antennas are connected by signal cables to a central place 100 m away, where the data are filtered, amplified, digitized,
and stored onto a central PC is shown in the right part of Fig. 1. The trigger is created from the coincidence between signals originating from two scintillator detectors of 0.5 m$^2$ each. Offline, the data are correlated with those from the Auger Surface Detector (SD) using GPS time-stamps. The results presented below originate from this setup, using well known Log Periodic Dipole Antennas (LPDAs) and Low Noise Amplifiers (LNAs) [7] as shown in the right part of Fig. 1.

3. The Sensitivity of the setup

Fig. 2 shows the average noise level in the 50 to 55 MHz band as function of the local sidereal time for one of the LPDA’s used in this setup. A clear structure is seen for the noise in both the North-South and the East-West arms. The time of maximum noise emission corresponds to the passing of the Galactic center overhead. It is clear that the setup is sensitive to the Galactic background noise. Furthermore, the amplitude of the noise variation is a substantial fraction of the total signal. Therefore, the background noise level created by the readout electronics and external sources, is comparable to the Galactic background levels.

4. Measurement of high-energy cosmic rays

Signals originating from air showers produced by high-energy cosmic rays have been seen by the 3 antennas in the cabled setup. Here we will discuss
one of the most energetic events in more detail, which was measured to have an energy of 2.1 EeV, and a zenith angle of 58 degrees. The azimuthal angle was -69 degrees from the east; i.e. the ray was coming almost from the south. The distance of the shower to our antenna setup is approximately 300 meters. The envelope of the antenna data of this event in the 50-70 MHz band can be seen in Fig. 3, which clearly shows an enhancement of the measured signal in both polarization directions of all three antennas. From detailed Monte Carlo simulations, based on the geosynchrotron model [8] one expects that the signal strength in the North-South arm is only 50% of that in the East-West arm, which is confirmed by our measurement. At this moment, we do not have an absolute calibration of the complete electronics chain, thus we cannot compare the absolute pulse heights.

We have used the antenna data to extract angular information of this event, independently of the SD information. As we only have 3 antennas, the assumption was made that the radio signal arrives in a plane perpendicular to the shower direction. The data of the individual traces is then shifted in time to accommodate different arrival times in the antennas. Afterwards, the resulting traces are multiplied to a single result of which the maximum is used as a discriminating parameter. The result is seen in Fig. 4, which shows good agreement with the measurement from the Auger SD. In general, the angular resolution obtained from these radio measurements is about 5
degrees, which can easily be improved by increasing the antenna baseline (currently only 100 m) and increasing the total number of antennas.

5. Conclusion and outlook

Five events which show clear signals in 3 antennas have been analyzed. One of which was shown above. More events have a clear signal in at least a single antenna. The measurements also provide detailed information on background conditions. This information will be used in the development of a stand-alone radio detector of cosmic rays.

References

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