LOPES – Detecting Radio Emission from Cosmic Ray Air Showers

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Abstract

Radio pulses from air showers were measured during the late 1960ies in the frequency range from 2 MHz to 520 MHz. Mainly due to difficulties with radio interference these measurements ceased in the late 1970ies. LOFAR (**Lo**w **F**requency **Ar**ray) is a new digital radio interferometer under development. Due to its fully digital nature it will be able to filter out interference and form beams even after a transient event like an air shower has been detected. To test this new technology and demonstrate its ability to measure air showers we are building a **LO**FAR **P**rototyp**e** **S**tation (LOPES) for the frequency range of 40 to 80 MHz at the site of KASCADE-Grande in Karlsruhe/Germany. The 10 antennas of the first phase of LOPES are now set up and four are taking data in coincidence with KASCADE-Grande.

1. Introduction

A standard method to observe cosmic rays is to measure the secondary particles of an air shower with an array of particle detectors on the ground. Very useful information for the determination of primary particle energy and type can be obtained by additionally observing the air shower as it evolves. So far this is only done by observing optical emission like Cherenkov or fluorescence light. This requires dark, clear and moonless nights and thus limits the available efficiency to about 10%.

Measuring radio emission from air showers might be an alternative method for such observations, providing a much better efficiency. This becomes particularly relevant since a new generation of digital radio telescopes – designed primarily for astronomical purposes – promises a new way of measuring air showers.

2. Radio Properties of EAS

Radio emission from cosmic ray air showers were discovered for the first time by Jelly [5] at 44 MHz. The results were soon verified and in the late 1960's

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emission from 2 MHz up to 520 MHz were found. In the following years these activities ceased due to difficulty with radio interference, uncertainty about the interpretation of the results, and the success of other methods.

The radio properties of extensive air showers are summarized in an excellent review by Allan [1]. The main result of this review can be summarized by an approximate formula for the received voltage:

$$\epsilon_\nu = 20\left(\frac{\mathrm{E_p}}{10^{17}\mathrm{eV}}\right)\sin\alpha\cos\theta\exp\left(\frac{-\mathrm{R}}{\mathrm{R_0}(\nu,\theta)}\right)\left[\frac{\mu\mathrm{V}}{\mathrm{m\,MHz}}\right] \quad (1)$$

Here $\mathrm{E_p}$ is the primary particle energy, α is the angle to the geomagnetic field, θ is the zenith angle, R is the distance to the shower center, $\mathrm{R_0}$ is around 110 m at 55 MHz, and ν is the observing frequency. The spectral form of the radio emission seems to be valid in the range $2 < \nu < 520$ MHz but in general is fairly uncertain. Recent results suggest that the emission may be geosynchrotron emission (see [2] and [4]).

3. LOFAR and LOPES

LOFAR is a new attempt to revitalize astrophysical research at 10-200 MHz with the means of modern information technology. The basic idea of LOFAR is to build a large array of 100 stations of 100 omnidirectional dipole antennas in which the received waves are digitized and sent to a central super-cluster of computers.

A new feature is the possibility to store the entire data stream for a certain period of time. If one detects a transient phenomenon one can then retrospectively form a beam in the desired direction. LOFAR therefore combines the advantages of a low-gain antenna (large field of view) and a high-gain antenna (high sensitivity and background suppression). This makes it an ideal tool to study radio emission from cosmic ray air showers. With its range of baselines between 10 m and 400 km LOFAR will be capable to detect air showers from $> 2\cdot 10^{14}$ eV to $\sim 10^{20}$ eV.

To test the technology of LOFAR and demonstrate its capability to measure air showers we are building LOPES at the site of KASCADE-Grande in Karlsruhe/Germany (see [3]). The data from a well tested air shower experiment not only allows us to calibrate the radio data with other air shower parameters, it also provides us with starting points for the air shower reconstruction, simplifying the development process. This will enable us to clarify the nature and properties of radio emission from air showers and provide an energy calibration for future radio air shower experiments. Also, LOPES will provide KASCADE-Grande with valuable additional information about the air shower, as the radio data and the particle data come from different stages in the evolution of a shower.

4. The Hardware of LOPES

The first stage of LOPES consists of 10 antennas. This will be extended to an improved system with 100 antennas in the second stage. LOPES will be

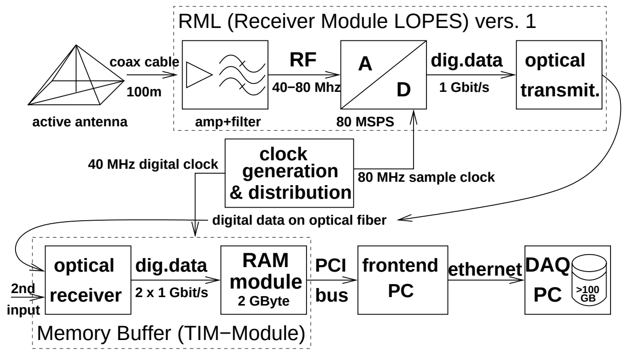

Fig. 1. Left: Outline of the hardware of the first LOPES stage. Right: One of the LOPES antennas at the KASCADE-Grande site.

sensitive to cosmic rays from 10^{15} to 10^{17}eV. It operates in the frequency range of 40–80 MHz, because in this range there are only few strong radio transmitters (the FM band is avoided) and the radio emission from air showers are strong compared to the sky noise.

As basic element the short dipole antennas, developed for LOFAR by ASTRON, are used. The radio frequency signal is sampled without the use of a local oscillator inside the receiver module (see Figure 1). The necessary dynamic range to detect weak pulses while not saturating the ADC with radio interference is achieved by using 12-bit ADCs. In the first stage the ADCs work at 80 MHz, allowing 2nd Nyquist sampling of the signal. The sample clock for the ADCs is generated on a central clock module and is then distributed to all A/D-boards. This allows us to combine the data from all antennas as a phased array and thus enhance the sensitivity. The digital data is transferred via fiber optics to a memory module on a front-end PC. The module can store up to six seconds of data for two channels in a digital ring buffer. After a trigger signal is received the data is read out and sent to a central DAQ-PC, where it can be analyzed online or stored on hard disk. The specialized hardware (active antenna, A/D-electronics, memory module and clock distribution) was developed at ASTRON in Dwingeloo.

5. Status and First Results

The first stage of LOPES is nearly complete. The system and ten antennas are set up at the KASCADE-Grande site at the positions shown in Figure 2 (left panel). At the time of writing four of the antennas are taking air shower data.

A preliminary analysis of the first data has already been performed. Some candidates for air shower radio pulses have been identified. In Figure 2 (right panel) one of those candidates is plotted. The origin of the x-axis is the arrival time of the trigger. The three lines are the block-averaged power of the radio signal normalized to give the same noise level. We show the raw data from one antenna, the same data after filtering radio interference in frequency space, and

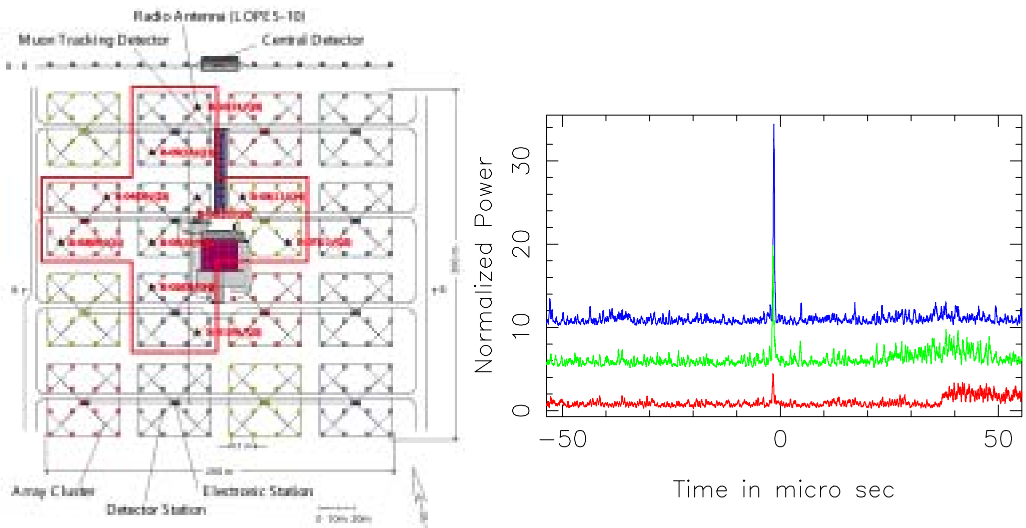

Fig. 2. Left: Layout of the first 10 LOPES antennas at KASCADE-Grande. Right: Average power of an air shower radio pulse candidate normalized to the background noise. Bottom: raw data; Middle (offset +5): after filtering of narrow band interference; Top (offset +10): after beam forming of four antennas.

the data of four filtered datasets after combining and beam forming. The jump in noise at $+37\,\mu$sec originates in triggered electronics of KASCADE-Grande.

6. Outlook

Currently we are working on the data analysis and an improved system for the second stage, which is scheduled to be implemented in early 2004. Possible improvements are full Nyquist sampling of the 80 MHz, A/D conversion at the antenna, better noise performance, and lower production costs.

The same technology can be applied to other forthcoming digital radio telescopes like LOFAR and the SKA, providing additional detection area for high energy cosmic rays. In the long run a digital radio telescope could even form the northern part of the Pierre Auger Project.

7. Acknowledgments

LOPES is supported by the German Federal Ministry of Education and Research, under grant No. 05 CS1ERA/1 (Verbundforschung Astroteilchenphysik).

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