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INNOVATIVE DETECTION OF ULTRA HIGH ENERGY COSMIC RAYS INDUCED AIR SHOWERS*

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Abstract. Ultra high energy charged particles reach Earth continuously, with many probably coming from far outside our Milky Way. We can discern them through the ionization they produce in air, through a very fast flash in the air, through radio emission. Only using a super-hybrid detection array the ultra high energy cosmic ray particles are best measured.

Key words: cosmic rays, air showers, radio emission, detection techniques.

1. INTRODUCTION

Ultra high energy cosmic rays are the most (mysterious) energetic and rarest particles ever observed. They strike the Earth's atmosphere continuously, producing avalanches of atmospheric air showers made of billions of secondary particles. However, questions like: '*From where do they come from? How do they survive to reach ground at such enormous energies? What can we learn from them*?' are widely addressed by many scientists.

Cosmic rays were first discovered by Victor F. Hess in 1912 using balloon flights [1]. Later, in 1936, V. F. H. obtained the Nobel Prize in Physics 'on his discovery on cosmic radiation'.

Extensive Air Showers (EAS) were discovered in the 1930's by French physicist Pierre V. Auger [2]. The EAS are since then used in indirect cosmic ray measurements, while direct measurements involve balloons and space shuttles for looking at the primary particles before they interact with the Earth's atmosphere.

1.1. FROM PUZZLE TO MYSTERY

While for the human made particle accelerators it is a puzzle to discern the deepest structure of the Universe, for the Ultra High Energy Cosmic Ray Physics it

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is a mystery to point back to their sources. Moreover, the so far estimated energies of cosmic ray induced air showers observed with experiments at ground are far beyond the human reached energies. Nevertheless,

• *High energy cosmic rays are observed*. Indeed cosmic ray induced air showers are measured with a maximum reached energy of about 10^{20} eV at the Pierre Auger Observatory (Auger South in Argentina [3]). See Fig. 1.

• *Cosmic rays reach breath-taking energies*. If the 10-milion GeV range is a puzzle, than the 100-bilion GeV range is a mystery [4].

• *How can cosmic accelerators boost particles to these energies?* Here we have candidates from Galactic and Extragalactic regions. The shock waves of supernovae explosions are the candidates of galactic sources, while the black holes, gamma ray births and active galactic nuclei are the candidates of extragalactic sources.

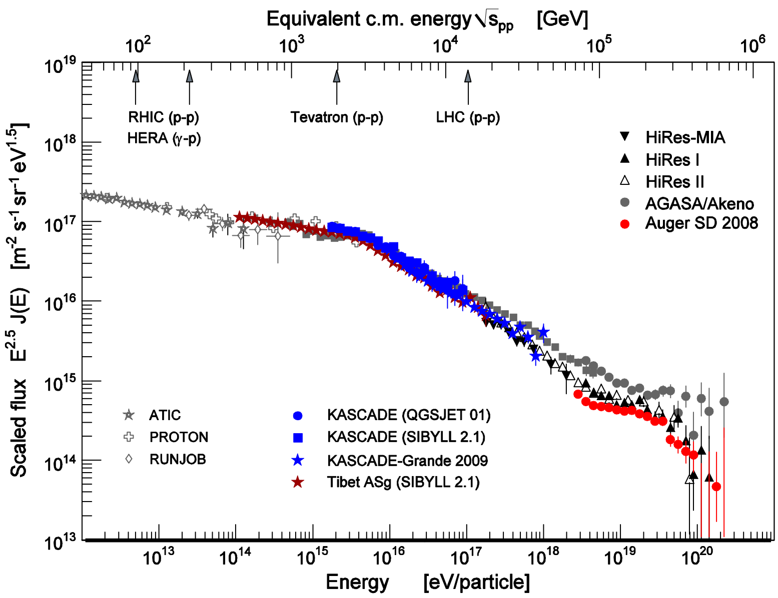

Fig. 1 – Energy spectrum of cosmic rays [3].

2. MOTIVATION

To measure the extreme energies of cosmic particles large detection areas with multiple detection techniques are required in order to learn more from the developed EAS. Here, the Pierre Auger Observatory is a worldwide cosmic ray experiment example, which involves currently three different types of detectors: surface, fluorescence and radio. Radio detection of ultra high energy cosmic ray induced air showers is an innovative method used at air shower measurements. The new technique is applied at the following experiments (among others):

• LOPES (LOFAR Prototype Station), the-proof-of-principle [5], is co-located at the KASCADE-Grande array in Karlsruhe, Germany. The LOPES experiment is an air shower radio detector array at the Karlsruhe Institute of Technology (KIT), Campus North, Germany [6]. It receives trigger from both original KASCADE and the extended KASCADE-Grande, with well-reconstructed air shower information, like: estimated primary energy, shower size (muons, electrons). In Fig. 2 a LOPES event example is shown, recorded in both polarization directions of the electric field, East-West (EW) and North-South (NS).

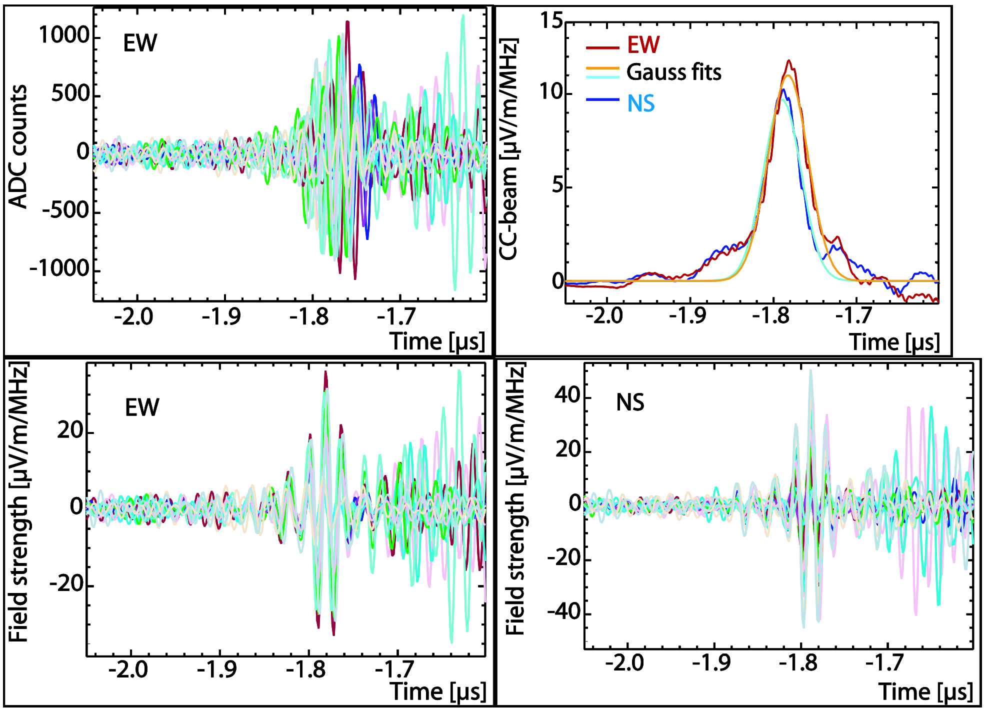

Fig. 2 – Event example seen in radio, coming from the North, of about 10^{18} eV. From left to right: upper level, first panel – raw data, second panel – the quantified pulse height for each polarization fitted with a Gaussian function. Lower level, first panel – reconstructed radio signals seen in the EW polarization channels, second panel – signal seen in the NS channels.

• AERA (Auger Engineering Radio array) at the super-hybrid Pierre Auger cosmic ray Observatory in Malargue, Argentina [7]. The question which may rise here is: Why radio? Because it has 100% duty cycle, relatively low cost, direction accuracy, sensitive to energy and mass of the primary. The radio detection technique is applicable at large scales (e.g. Auger, LOFAR), with potential for developing self-triggering antennas (*e.g.* LOPES^{STAR}), in order to no longer depends on an external source trigger with EAS information.

The radio signal is highly linearly polarized, conform to Monte Carlo simulation studies [8]. Signal is dependent on air shower observables, like, size, energy, direction [9].

3. RADIO EMISSION

The radio emission from ultra high energy cosmic ray air showers is highly linearly polarized in the direction of the shower axis and of the Earth's magnetic field. The radio signal is present in both polarization directions of the electric field, EW and NS. In Fig. 3 is shown the dependence of the pulse height (the cross-correlation beam, CC_{beam}, recorded with the LOPES experiment) on the azimuth and geomagnetic angle respectively, *i.e.* the angle between the shower axis and the

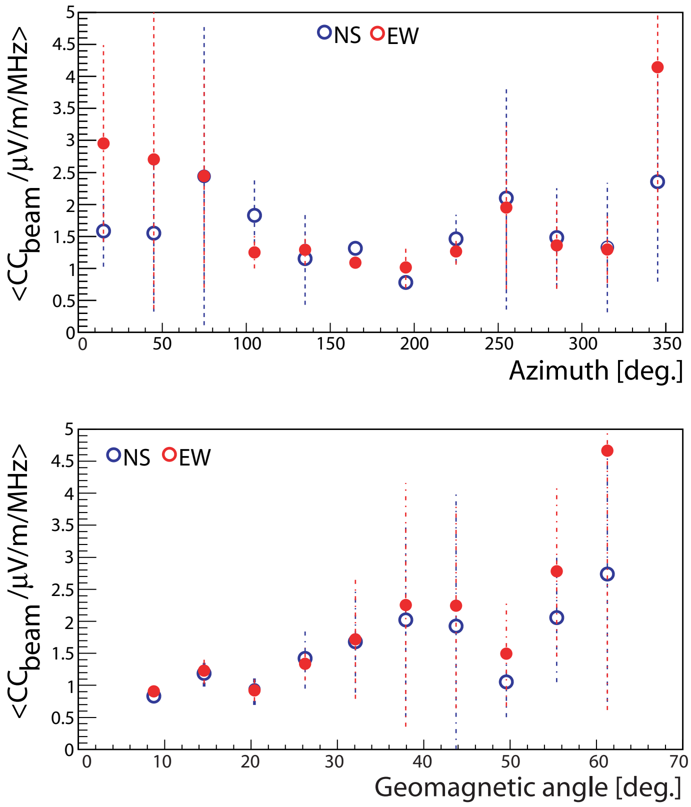

Fig. 3 – Correlation of the measured data with azimuth and geomagnetic angles. The error bars show the root mean square (rms) of the distribution inside the bin. Binned data of 99 KASCADE showers are displayed [6].

Earth's magnetic field, which emphasize the geomagnetic effect of the radio emission. Thus, in the NS polarization direction showers coming from East and West are recorded, while in the EW polarization direction showers coming from the North and South. Moreover, theoretical studies are also involved in comparison with measurements to verify the radio emission mechanism. They stress that another contribution may join the main geomagnetic effect of the radio emission, the so-called negative charge excess developed in the shower, which has more to do with showers coming from the North and South hemispheres recorded in the NS polarization direction [10].

4. SUMMARY & OUTLOOK

The radio detection technique opens a new window of observations to ultra high energy cosmic rays coming from the not yet all known cosmic ray sources.

The world largest cosmic ray experiment, the Pierre Auger Observatory, involves three different methods used at shower observations at the same time, and same location: radio emission, fluorescence, particles. This makes it a super-hybrid experiment, which is one of the seven priority projects in the European roadmap of Astroparticle Physics. Nevertheless, large arrays deployed with innovative detection techniques are needed for a next generation experiment at large scale (*i.e.* "going large, looking large"). And here the radio technique plays an important role, because it helps in gaining complementary information on the air shower properties at highest energies.

Several other papers describing different relevant aspects of this rapidly growing research field has published in the last years [11–14].

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