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AUTONOMOUS RADIODETECTION OF HIGH ENERGY COSMIC RAYS AT THE PIERRE AUGER OBSERVATORY

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Abstract. The RAuger experiment is a test prototype of autonomous station for radiodetection that has been deployed on the southern site of the Pierre Auger Observatory. We report in this paper first radio detection of high energy cosmic rays with fully autonomous and self triggered cluster of antennas in coincidence with the Auger surface detector. The experimental setup and results are discussed.

1 Introduction

As a complement to other techniques, like particle detector array or fluorescence telescope, radiodetection of UHECR is a new detection method that could enable both an increase of the statistic and a reduction of systematic uncertainties on the determination of the air shower properties. Radiodetection aims to detect the electric field emitted by an air shower developping in the atmosphere. This electric field propagates through the atmosphere and can be detected over large distance by using an antenna in the radio frequency domain. This offers a bolometric measurement of the air shower, in a way quite similar to the fluorescence technique, with a sensitivity to a large volume of detection. Thus it enables to probe the history of the shower development so that important information on both the nature and the energy of the primary particle can potentially be accessed from the radio signal properties (Huege *et al* 2007, Meyer-Vernet *et al* 2007, Scholten *et al* 2008).

Experimental measurements were first attempted in the 60's, see (Allan 1971) for a complete review. Despite a validated observation in 1965 (Jelley *et al* 1965), experiments had to face difficulties of reproducibility and the technique was quickly abandoned to the profit of other methods that appeared more promising at that time. Recently, the growing interest in UHECR together with technical developments, in particular on fast ADC, gave a new impulse to this technique that is beeing re-investigated on modern experiments such as LOPES (Falcke *et al* 2005) in Germany and CODALEMA (Ardouin *et al* 2005) in France. Successful results obtained by those collaborations, both working in the 10^{17} eV energy range, motivates the transposition of the radio detection technique at higher energy.

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Increasing by one order of magnitude the observed energy supposes new experimental constraints to be taken into account. The antenna array should be deployed over a large area, typically 10 km^2, which prohibits the use of cables between detectors and a central acquisition building as it is the case on both CODALEMA and LOPES experiments. Antennas should be mounted on fully autonomous stations that should provide power supply, accurate dating system as well as embedded electronic. In order to define an experimental strategy, a radiodetection R&D program on the southern site of the Pierre Auger Observatory was initiated in 2006 in a collective effort by the Auger, CODALEMA and LOPES groups.

One major item of the R&D program is the trigger system of such an autonomous detector. Indeed, on experiments like CODALEMA or LOPES, the antenna array is triggered by an associated particle detector array. This should not be feasible on a large array of antennas and a trigger based on the radio signal itself has to be achieved. The most advanced approach toward such a radio trigger was probably done by the CODALEMA collaboration that validated the autonomous detection and reconstruction of arrival direction of

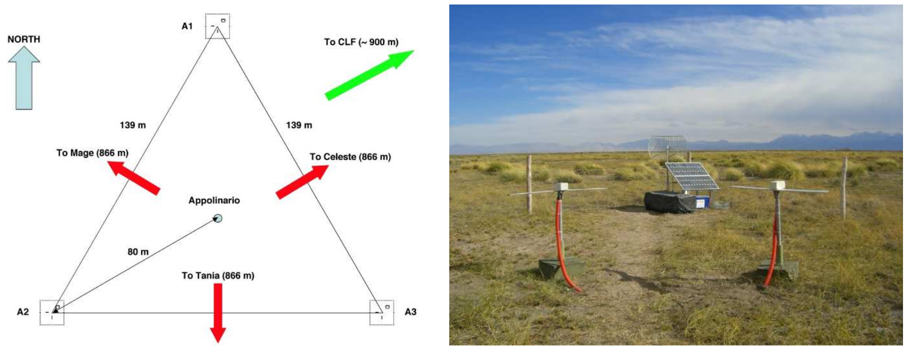

Fig. 1. Left : Global setup of the RAuger experiment. The 3 stations, namely A1, A2 and A3, are arround the additionnal tank named Appolinario at the center of an elementary triangle of the Auger surface detector (not on the figure). The Central PC is at the CLF, 900 m away. **Right**: Detail of one of the 3 radio stations. The 2 short active dipoles (EW and NS) are at the foreground. The electronic box, solar panels and the WIFI antenna for data transmission are just behind.

fast radio transients during a first operation phase (Ardouin *et al* 2005). Unfortunately, they could not firmly confirm at that time the CR origin of those transients.

The first phase of the R&D program started by the end of the year 2006 and is currently ending. During this phase, the CODALEMA collaboration in association with the Auger group developed an experimental prototype called RAuger for Radio at Auger to investigate the feasibility of a fully autonomous radio station and to perform in situ background measurements to qualify the southern site on a radio point of view.

3 Experimental Setup

The prototype has been deployed at the centre of one elementary triangle of the Auger surface detector array. One additional Cerenkov water tank was also installed in the centre of that triangle to locally lower the energy threshold of the Auger array. The RAuger experiment is made up of 3 fully autonomous radio detectors surrounding that additional tank as shown on fig 1 (left). The radio array pitch is 139 m and each station is at 80 m from the additional water tank.

The electric field is measured using two short active dipoles from the CODALEMA experiment on each radio station, see fig 1 (right). Those antennas are composed of two aluminium slats of 0.6 m length and 0.1 m width. Antennas are parallel to the ground, 1 m above and oriented one in the North-South (NS) direction and the other in the East-West (EW) direction to measure independently the corresponding polarization of the electric field. The antenna has good performances in the 80 kHz-230 MHz band and is coupled with a low-noise high input impedance amplifier with a constant gain in this wide frequency domain. The performances of the system are presented in (Charrier 2007) and (Revenu 2007).

The technicality of the device lies in the nature of the trigger system. The antenna sensitivity to fast transients is hardly compatible with the fast electronic activity of the station. The electromagnetic compatibility of various components of the radio station becomes a crucial issue that requires to pay a special care to connectivity, shielding and ground loops. The EW polarization channel is divided in 2 parts, one is directed to the ADC, the other to a 50-70 MHz bandpass analogue filter to trigger the acquisition. This particular frequency band was chosen for its low radio activity that ensures a good signal to noise ratio. The filtered signal is compared to an adjustable threshold. When that threshold is passed over, both signals, EW and NS polarization, are digitized in full frequency band on 8 bits ADC with a sampling rate of 500 MS/s for a 5 μs duration waveform.

The embedded electronic uses the Unified Board from Auger tanks with its GPS timing system that enables a dating of the events with a 10 ns accuracy. It masters the local data streams and sends it by a WiFi link to

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a Central PC installed at the Central Laser Facility (CLF), 900 m away. From that Central PC, the collected data are finally sent to the Auger building in Malargue, Argentina and brought back to the laboratory via a usual ethernet link. The acquisition is frozen until data transmission has been acknowledged by the central PC. This leads to an acquisition dead time of approximately 2.7 s mainly due to the time transfer via serial ports of the Unified Board. RAuger is installed since November 2006 and is running in a quite stable mode since July 2007. The analysis presented here is performed on data taken between July 2007 and May 2008 corresponding to 318 days.

4 Detection in coincidence with Auger

The trigger rate of the system depends on many effects that are not fully understood yet. Among them, thunderstorms and stormy weather have been identified as playing an important role. Radio signals attributed to thunderstorm present very long duration and contain a massive amount of energy that can lead to the saturation of the ADC channel. Those particular features make them easily recognizable from the type of radio signal one can expect from an air shower.

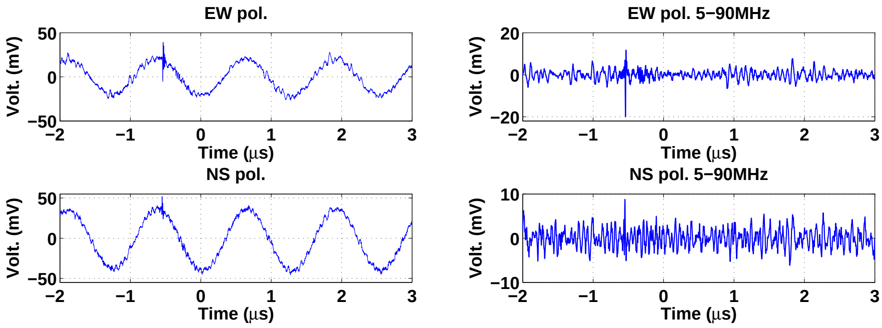

Fig. 2. Left : Illustration of one air shower detected with radio in coincidence with Auger surface detector. The measured voltages are ploted versus time for both polarizations, EW top and NS bottom, in full frequency bandwidth (from some 100KHz to 100MHz). The fast transients superimposed to radio background are clearly visible on both polarizations. The sinewave is due to LV19, a local radio station emitting at 790 KHz at Malargue. **Right**: The same event is displayed but signals have been numerically filtered in the 5-90 MHz frequency band. Most of the radio background has been removed with that very large filter. Our system enables to use very low frequency bands.

During periods of stormy weather, many events have detected in coincidence by the 3 radio stations. We have been able to triangulate the arrival directions of those events and in this way to confirm that the system enables good reconstruction. Unfortunately, none of those 3 fold events were identified as resulting from an air shower as they did not present time coincidence with the Auger surface detector. This lack of three fold event can be charged on both, the high dead time of the system and hardware failures that occurred occasionnaly on radio stations. As a test prototype, the station doesn't have the robustness one would expect from a dedicated instrument. Those aspects should be easily improved in a next generation of radio station.

To identify cosmic ray events in coincidence, we are searching for time coincidences between Auger events and our radio events in a 1 μs window. The shower plane and the core are given by the Auger reconstruction. The fortuitous events rate is very small, of the order of 10^{-11} s^{-1} , due to the small trigger rate of the antennas (the saturation corresponds to 0.37 events/s) and the small number of Auger events falling closer than 1 km (axis distance) from Appolinario (around 1.6 events/day). Integrated over a period of 318 days, the expected number of random coincidences is of the order of 10^{-4} so that the association of our coincidences with actual Auger events is unambiguous. The total number of coincidences with Auger is 25 in the considered period with energies ranging from 0.2 to 8 EeV.

Illustrative signals measured on one radio station for a 0.9 EeV event are given fig 3. The fast transients associated with the air shower is clearly visible in full frequency band, superimposed to the radio-background, on both polarizations. Depending mainly on ionospheric conditions, it is possible to use frequency down to 5 MHz with a good signal to noise ratio as shown fig 3 (right). It should be notice that the lowest usable

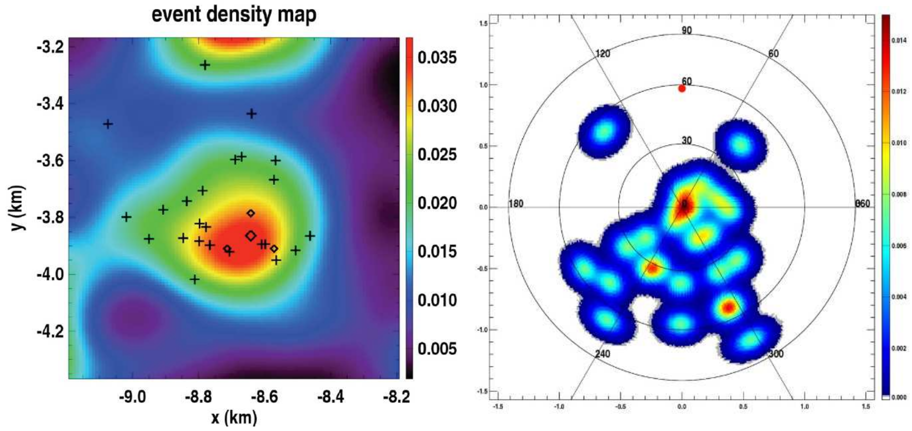

Fig. 3. Left :Event ground density map around Appolinario, computed from the Auger event list and smoothed by a 100 m width Gaussian. The Auger events with a radio counterpart are indicated by the black crosses. Appolinario is the largest diamond at the center and the 3 radio stations are the small one around. **Right**: Sky map in local coordinates of the radio events seen in coincidence with Auger SD and smoothed by a 10^o Gaussian beam. The zenith is at the center, North at the top, East on the right. 80% of the events are coming from the South while the Auger SD events skymap is uniform in azimuth. The red dot towards the north at θ 60^o is the location of the geomagnetic field.

frequency is an important parameter as it has an influence upon the ability to detect distant air showers and to recover the original waveform of the radio signal. This lowest usuable frequency should be considered for a future antenna array. The polarization measurement is also an interesting aspect as the ratio of the EW to the NS component should help a better understanding of the emission processes at work inside the air shower.

Fig. 4 left shows that the ground distribution of the 25 radiodetected events follows well the Auger SD event density map around Appolinario. This is not the case for the angular distributions. The azimuthal distribution of the radio events is not uniform as compared to that of the Auger SD events as it is visible on fig 4 right. It is found that 80 % (20/25) of the radio events are coming from the South as one should expect considering the direction of the geomagnetic vector in Argentina.

5 Conclusion

Measurements shows that the southern site of the Pierre Auger Observatory is very well suited for radiodetection. The low radio activity enable the use of very low frequency band down to 5 MHz depending on background conditions. The trigger based on the radio signal has been validated for the first time by the detection of air showers in coincidence with the Auger surface detector. The arrival direction of those events indicates a North-South asymmetry although the poor statistic and the weakness of this test prototype does not allow any quantitative conclusion. The prototype is not maintained anymore and should be replaced soon by a new generation of autonomous stations.

References

Huege T., Ulrich R., Engel R., Astropart. Phys. 27 (2007) 392

Meyer-Vernet N., Lecacheux A., Ardouin D., Astronomy & Astrophysics 480 1 (2008) 15-25

Scholten O., Werner K. and Rusydi F., Astropart. Phys. 29 (2008) 94

Allan H.R. , J.G. Wilson & S.A. Wouthuysen Eds, Progress in elementary particle and cosmic ray physics (1971) 169

Jelley J. V. *et al*, Nature 205 (1965) 237

Falcke H. *et al*, Nature 435 (2005) 313

Ardouin D. *et al*, Nucl. Instrum. Meth. A 555 (2005) 148

Charrier D. and the CODALEMA collaboration, Nucl. Instrum. Meth. A 572 (2007) 481

Revenu B. and the CODALEMA collaboration, proc. of the 30th Int. Cosmic Ray Conf. (2007).