A Radio Detector System for Ultra High Energy Cosmic Showers Study

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***Abstract*— A passive Radio Detector System is proposed for Ultra High Energy Cosmic Rays showers and meteors detection. TV emissions, reflected by ionization clouds produced in such events are acquired producing a clearly detectable profile. A Radio Detection station is operating at BNL recording signal samples from a group of three antennas. An offline analysis, here described, allows for event selection and feature extraction. An event rate consistent with the earth rotation 24 hours periodicity could be found. Auxiliary detectors are being built to validate the results obtained so far.**

***Index Terms*— Ultra high energy particle shower, detection, signal processing, meteors.**

I. Introduction

THE nature and origin of Ultra High Energy (UHE) cosmic rays ($E \geq 10^{17}$ eV) are still not understood. Large detector arrays now in operation (e.g. AGASA[1]) and in construction (AUGER[2]) extend the detection capabilities to the energies of 10^{19} eV and beyond. It is now clear that events beyond the GZK (Greisen-Zatsepin-Kuz'min) limit of $10^{19}eV$ can be detected [3]. The interaction of UHE cosmic rays with the atmosphere can also permit the study of exotic physical phenomena, such as extra dimensions and production of mini black-holes [4].

The event rate for such UHE cosmic rays is, however, quite small (1 events per square kilometer per year for $E = 10^{18}eV$). To acquire events at a reasonable rate, conventional scintillating large detector arrays are an expensive option, since a large amount of them should be spread in a large area. It has been suggested that the use of triggered radars and direct radio detection from particle showers could be an alternative technique[5]. The difficulty with this approach is that the proposed systems depends on long ionization lifetime, which may not be the case for UHE shower events.

We explore a technique that employs a bistatic passive CW radar system. Such radar is tuned to the lower VHF frequencies to acquire the signals initially coming from TV stations reflected from the ionization clouds produced by UHE showers and burning meteors in the atmosphere. In the lower VHF range, the TV emissions are more likely to be reflected by these ionization clouds. Due to its larger lifetime, meteors are being used not only for study, but also to help in the experimental setup validation and calibration.

The next section describes the experiment assembled at the Brookhaven National Laboratory which is now acquiring data. The third section presents the offline methodology being used for event selection and feature extraction. The fourth section address the results obtained so far. The last section presents our conclusions and future improvements to the existing system and methodology.

II. The Experimental Setup

The setup proposed is composed of a few radio detection stations. Each station is composed of a set of antennas and data acquisition systems. Two different antenna kinds are being used : Yagi antennas and Log-Periodic Dipole Array antennas. The first one, the Yagi [6] has a broader radiation pattern (around 120 degrees) and operates at a fixed frequency (in our case it was set for 67.26 MHz, the TV channel 4). The second antenna, the LPDA[7], has a much smaller radiation pattern, but, on the other hand, it can operate in a wide frequency range (from 50 to 500 MHz). The setup for data acquisition can be seen in the Figure 1.

The signals from these antennas are preprocessed by computer-controlled radio receivers (PCR-1000[8] from ICOM) which demodulate the reflected signal, down-shifting their frequency to a limited (2.8 KHz) base band signal. In our experiments, one PCR-1000 has been used for the Yagi antenna (performing Continuous Wave - CW - demodulation) operating at 67.26 MHz, while other two PCRs are used for demodulating (also CW) the signal from the LPDA at 67.26 MHz and 55.24 MHz (TV channel 2).

The signal from the three PCRs is then digitized and stored by a computer via a high-acquisition rate soundcard (Delta 1010LT [9] from midiman), which can continuously acquire signal from up to 8 different

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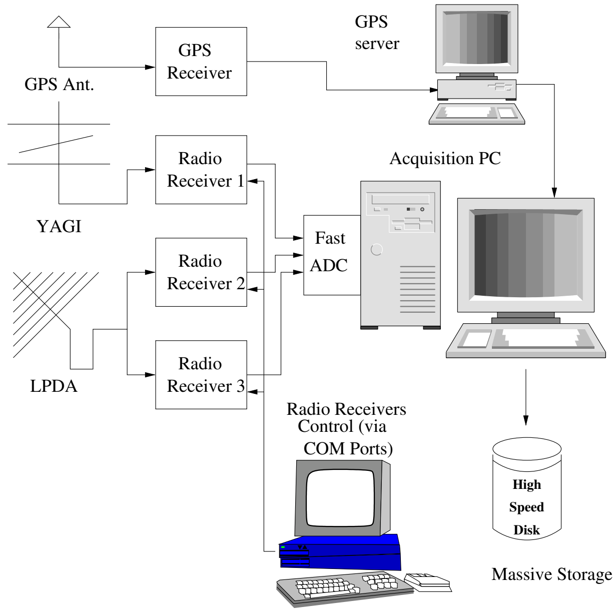

Fig. 1. Setup of the data acquisition system.

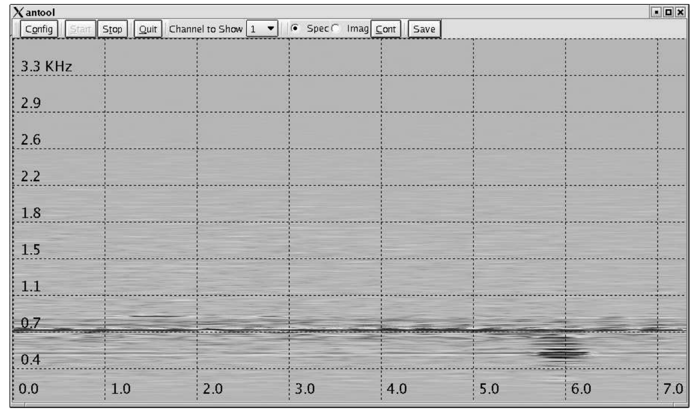

Fig. 2. Meteor event registered by the Radio Detection System in a frequency-time spectrogram.

channels at a rate of 96 KHz. This rate should allow us to identify events occurring in a time scale of 11 μs. The spectrogram of the signal is displayed while data is being recorded, providing a constant monitoring of the acquisition system. Also, the base band signal provided by the PCR-1000 set can be sent to a speaker, allowing a sound characterization of the events.

So far, only one data acquisition station is being used at BNL. Other stations are being assembled to provide data from different locations throughout Long Island and New Jersey. This approach would help in the event position estimative. In order to synchronize data from different sites, a GPS clock is used, allowing for offline data correlation. The GPS clock is obtained via a XXXXX [10] connected to a PC, which serves clock for the data acquisition PCs).

Due to the huge amount of data (a few Giga-Bytes per day per acquisition station), a central RAID disc based system will be daily gathering through the Internet the files temporarily lying in the data acquisition PCs of the remote stations. In a first moment, all data will be recorded. A triggering processing is being envisaged, to select interesting events, discarding samples not related to any interesting source (meteors or UHE cosmic rays).

We are also considering the possibility of using digital radio (GNU Radio [11]) for data acquisition. In such case, very high acquisition rates would be possible (such as 20 MHz), allowing for the identification of very short events in a time frame smaller than 50 ns.

A complete C++ software for data acquisition and time-stamping through the GPS server has been designed [12]. The software runs in a Linux PC with a Pentium IV processor (2.4 GHz). The software uses the fftw[13] library to perform the fast Fourier transform for the online spectrogram display. The Open Sound System library [14] and the Advanced Linux Sound Architecture [15] drivers were used for accessing the Delta 1010LT sound card.

III. Offline Methodology

The system described in the last section has acquired data for some days so far. System calibration and performance measurements have been studied in these occasions, although, some significant data from radio waves scattering by meteors could be found.

Figure 2 displays the online spectrogram (fast Fourier transforms for each 50 samples) of the data acquisition software. The gray tone scale gives the power in dB at each frequency-time point (darker colors meaning higher power values) The vertical axis presents the frequency marks in Kilohertz, whilst the horizontal axis shows the time in seconds.

The quasi constant carrier signal around 700 Hz is the TV station carrier. As can be seen, there is a clear signal (one dark mark) above the noise level around 6 seconds and in the 0.4 to 0.7 KHz range. Due to the long duration of this signal (more than 0.2 s.), it was considered as coming from a meteor.

A quite complex schema has been used for offline analysis. Some signal processing blocks were designed in order to perform the analysis, detection and parameter estimative of the detected events. The block representation is shown in Figure 3, where the interconnection between block is detailed.

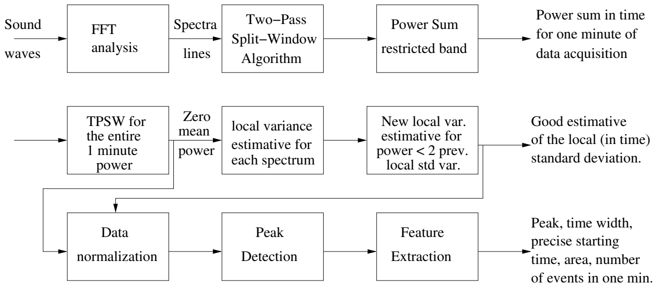

Fig. 3. Block schema of the triggering and classification system adopted for offline analysis.

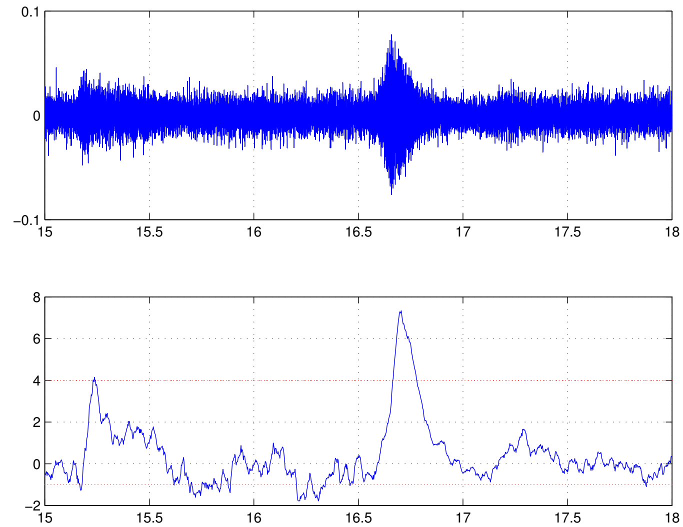

Fig. 4. Signal as acquired by the Radio Detector System (top). Preprocessed power enhances the distinction between signal and background (bottom).

The spectra is performed by the FFT with 2048 points (distributed in the frequency range from 0 to 48 KHz - the sampling frequency used in this first experiment). A huge overlap of 1998 points is being used between spectra in order to profit the maximum from the time resolution provided by the acquisition system. A Hamming window is provided to reduce edge effects between different 2048 sample blocks.

In order to eliminate the background noise during the offline analysis a local mean estimative is subtracted to each one of the spectrum found. This process is performed by the Two-Pass Split-Window (TPSW) algorithm [16], [17]. This method produces spectra samples with reduced noise for those frequency points where no signal was found. Since our events appear in a small frequency range, only the frequencies between 500 and 1700 will be used in the subsequent analysis. This completes the first row in Figure 3.

The power (module of the complex value in a frequency sample) obtained for the frequencies in the range of interest is summed for each time. This produces a vector composed of power measures for each time interval of one spectrum (50 samples of the original sampled signal). This resulting vector of "power in time" is also subtracted by its local mean (obtained again with the TPSW algorithm) in order to produce a signal with a local mean close to 0. Due to variations in the background characteristics, such as the presence or not of clouds, sun, temperature, thunder storms, this "power in time" signal can suffer huge variations which can be wrongly considered as events when a simple peak detection algorithm is applied.

To solve this problem, a local variance (an adaptive calculation considering the last 100 samples of this power) can be used as a normalization factor. Since the local variance can follow important changes in the signal with more than a few samples (eg. a event), the local variance must be calculated in two steps. In the first step, a simple adaptive calculation is performed [18]. A vector stores the "power in time" signal limited to do not overflow 2 local standard deviations (the square root of the local variance). In the cases where the limit is exceeded, the limit value is used. After that, a new local variance is estimated but now using the limited value "power in time" as input. This final local standard deviation is used to normalize the initial "power in time" values. This methodology provides an interesting way for dealing with data, since each power sample is now expressed as a given number of standard deviation from the mean.

IV. Results

Figure 4 shows the performance of this algorithm to enhance the capacity of peak detection algorithms. The top figure is the regular signal in time as it comes from the acquisition system. Two peaks, one around 15.2 sec and another around 16.7 sec can be seen. Although it is easy to see the second one, it would be very difficult to define a threshold to the first one. Many other samples would also satisfy this threshold and, consequently, be considered as new events. The figure below is the preprocessed "power in time". As can be seen, the event before not quite recognizable is now easily spotted with a huge difference with relation to the background.

The classification is performed by a simple two limits algorithm. A signal is considered start of an event if it deviates more than 4 standard deviations from the level 0. An end of event is assigned when the signal goes one local standard deviation below the 0 level. These

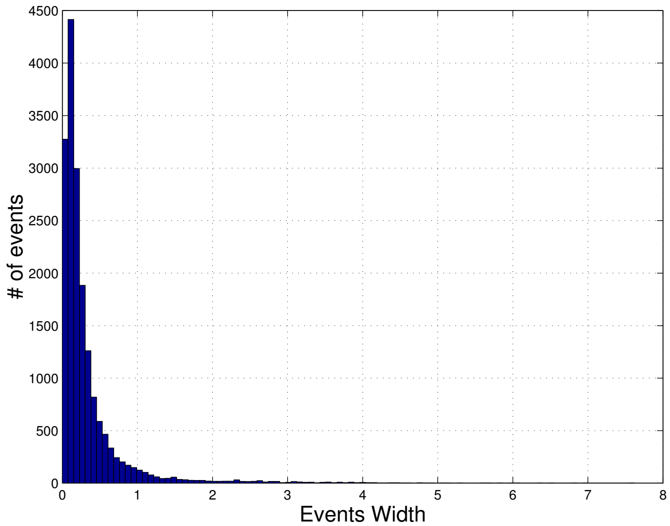

Fig. 5. Time Width for all the event detected in the data set for the period of August 11 to 14.

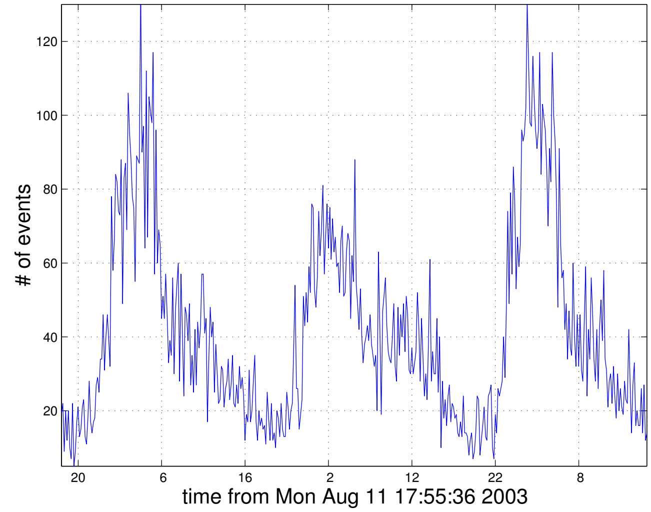

Fig. 6. Event counted during three days of activity. Each point represents a ten minutes acquisition time.

two limits were marked with bold lines in the bottom graphics in Figure 4.

From this, some characteristics of each event can be calculated. For example, the duration width of each event. Figure 5, shows for a three days acquisition period the distribution of the duration for all events found. As can be seen, most of the events detected had a relatively short duration (less than half a second for 83.9% of the events). However, some events had a total duration of more than 8 seconds.

An automatic scheme has been developed to detect the peak values in this normalized power for each event. Also, the exact starting time and the area below the normalized power curve during the whole event are calculated. The counting of the number of meteors (and possible particle shower events) during some fixed time intervals could be also performed.

Figure 6 shows the count number in one of the channels (the Log-Periodic Dipole Array antenna at 55.24 MHz) during 3 consecutive days. The last day was the north-eastern blackout, which turned the acquisition system off at 16:18 p.m. in August, 14. In this picture each point represents the amount of events counted during 10 minutes of acquisition. A 24 hours periodicity is observed and it is consistent with previously readout data [19]. The time shown in the picture is normalized by 24 hours in order to evidentiate the daily hours of more intense radio reflection activity (from around mid-night to the beginning of the morning).

A total of 17880 events was registered during this acquisition period of 70.38 hours, accounting for a mean of 6097 events per day.

V. Conclusions and Future Steps

A Radio Detection System for UHE cosmic showers was discussed. The system can detect signals reflected from TV emissions by ionization clouds produced by meteors and/or Ultra High Energy particle showers interacting with the atmosphere.

The present implementation uses two different antennas in order to evaluate the advantages of each technology. A possible implementation using a higher data acquisition rate ADC is also being studied. The GPS clock used helps by producing a time stamping in order to cross check the system with other techniques (eg: a detection scintillating array).

A data processing schema was designed in order to detect events from the huge amount of data recorded daily (a few GigaBytes). Many different signal processing techniques are used to improve the detectability of the signals. In the near future, this system will be implemented either as an online triggering system during data acquisition or as a zero suppress method to offline eliminate data without important information.

The preliminary results show that the system is sensitive to meteors and possible particle showers. A large amount of data (more than 24 GB) was acquired until now and further analysis are being performed on such data to determinate whether the detection algorithm is correctly selecting events. Also calibration procedures between the radio receivers and the sound card are being performed.

The feature extraction performed allow for further data analysis. One possible envisaged method is the use of clustering algorithms in order to verify the possibility of finding different data subsets with common properties in the events acquired. This could also help selecting better event candidates to be particle showers instead of meteors.

Multiple Radio Detector stations are also envisaged in the Long Island and New Jersey areas to allow for further correlations and event position finding. Other antennas prototypes are also being investigated for event positioning.

In order to confirm particle shower detection and prove the system effectiveness, muon detector arrays will be installed in high schools on Long Island involved in the QuarkNet project [20]. A prototype with a GPS time stamping system is already operating at BNL to validate the Radio Detector System results.

In order to confirm meteor detection, a large apertureXXX video camera connected to a DVD burner was placed close to the antennas. This system is, however, extremely whether dependent and still could not provide interesting results.

A web page has been prepared for announcements of the latest results [21].

Acknowledgments

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