First detection of extensive air showers by the TREND self-triggering radio experiment

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Abstract: The Tianshan Radio Experiment for Neutrino Detection (TREND) is a sino-french collaboration (CNRS/IN2P3 and Chinese Academy of Science) aiming at building an autonomous antenna array for the detection of high energy Extensive Air Showers (EAS) on the site of the 21CMA radio observatory. The project has been running for 2 years already, and is now composed of 50 antennas, covering a total area of 1.1km². The autonomous detection and identification of EAS was achieved by TREND on a prototype array, and confirmed by the observation of coincidences between the self-triggered antenna array and an independent EAS detection by 3 additional particle detectors. This is an important milestone for TREND, and more generally, for the maturation of the EAS radiodetection technique. Here we introduce the present status of the TREND experiment. In a long term perspective, TREND is designed to use both radiodetection intrinsic characteristics and the additional target provided by the mountains surrounding the experiment site to test the feasibility of radiodetecting high energy tau neutrinos.

Keywords: Cosmic rays, Neutrino, Radiodetection, Extensive Air Shower

1 Introduction

One of the major experimental challenges in cosmic rays physics is the detection of ultra high energy cosmic rays (UHECRs). In this energy range ($>10^{18}$ eV), the very low flux makes very large detection surface or volume necessary in order to acquire statistically significant results [1]. Results obtained by the Pierre Auger Observatory indicate the relevance of hybrid detection system deployed over large surfaces [2]. Complementary detection techniques to the usual particle detectors or fluorescence telescopes are under investigation in order to improve the efficiency and reduce the cost of such giant-sized experiments. One of the most promising is the radiodetection technique.

Charged particles created during the development of an extensive air shower (EAS) generate a coherent emission detectable at radio frequencies (< 200 MHz). This radio emission was first predicted by Askar'yan in the 60s [3], but experimental applications failed to prove radiodetection efficiency because of technical difficulties. Nevertheless, the radiodetection technique shows interesting potentialities for UHECRs studies, since the detector unit is a basic cheap radio antenna easy to deploy on large surface, and its duty cycle is theoretically 100%. Rebirth of research on radiodetection occurred in the 2000's thanks to experiments like CODALEMA in France and LOPES in Germany, which successfully detected EAS radio emissions by using an antenna array triggered by particle detectors [4], [5]. Besides this proof of feasibility, these experiments were able to put in evidence the geomagnetic mechanism in the EAS radio signal generation process or shower energy estimation from the radio signal (correlated with the particle detector estimation) [6], [7].

Radiodetection is today mature enough to be implemented on a large scale self-triggering setup in order to estimate the potential of the technique as a stand-alone detector. The Tianshan Radio Experiment for Neutrino Detection (TREND), initiated in 2009, proposes to deploy an autonomous antenna array in the Ulastai valley (Tianshan mountains, Xinjiang autonomous province, People Republic of China). Besides the exceptional quality of the electromagnetic environment (due to its remote location at high altitude, ~2.650 meters a.s.l), the TREND site is surrounded by high mountains (up to 5000 meters a.s.l) and therefore offers a perfect location to study nearly horizontal EAS induced by high energy neutrinos with an Earth-skimming trajectory. The specific problematic of UHE neutrino detection by the TREND setup is detailed in a another proceeding of this conference [8].

2 The TREND experiment

2.1 Description

The TREND experiment is located on the site of the 21CM Array (21CMA) experiment, a giant radio interferometer built in 2005 for the study of the epoch of reionization. 21CMA uses 10287 log-periodic antennas grouped on 80 pods, deployed along two arms of ~4 kilometers each and oriented along the North-South and East-West directions. Each pod is connected through an optical fiber to a acquisition room, where its signal is continuously recorded in parallel by dedicated 8-bits ADCs working at a sampling frequency of 200 MHz.

The driving idea of the TREND experiment is to use the pre-existing infrastructures of the 21CMA (such as the power, optical fibers or electronics and computers) for setting up in parallel of the radiotelescope a independent array of antennas dedicated to radiodetection. Each TREND antenna is equipped with its dedicated electronic board allowing a signal amplification of 64 dB and a signal filtering in the 50–100 MHz frequency bandwidth. It is connected through a 21CMA pod to the acquisition room. The digitalization of each antenna signal is performed in parallel by 8-bits ADC (200 MHz) placed in the acquisition room with a signal depth of 5 µs, only in case an electromagnetic transient is present. The trigger for signal recording occurs when a sample value exceeds a threshold set as a multiple of σ, the instantaneous noise level at the ADC level.

Between 2009 and today, the TREND experiment has gone through 3 different experimental set-up:

- In January 2009, a prototype of 6 log-periodic antennas was deployed along the East-West arm. This set-up was used to validate with success the concept of using the 21CMA setup for EAS radiodetection. Radio environment at the Ulastai site was also tested, showing remarkable results as notably a high sensitivity of the antennas to the galactic signal variation, mostly induced by the crossing of the antenna field of view by the galactic plane.

- In January 2010, a new array of 15 antennas was deployed at the intersection of the 21CMA arms. This set-up of the TREND experiment was designed to define a selection procedure of EAS radio candidates which will be describe in the next part. In addition to the antennas, a setup of 3 scintillators, working independently of the antenna array, was added to the TREND setup. Offline coincidences between scintillators and radio events selected as EAS candidates permitted a confirmation of the autonomous identification of cosmic ray radiodetected events by the antenna array only [9].

- In January 2011, 50 antennas were deployed along the East-West arm of the 21CMA, on a total distance of 3 kilometers with an average step between 2 antennas of 150 meters (figure 1). The scintillator array is still operational at the west extremity of the array. New antennas, inspired by the design of the CODALEMA "butterfly" antenna, are now used instead of the 21CMA regular log-periodic antenna which are especially design to point in a particular direction of the sky. The new antennas have a small directivity, which fit better to the needs of radiodetection of cosmic rays induced EAS.

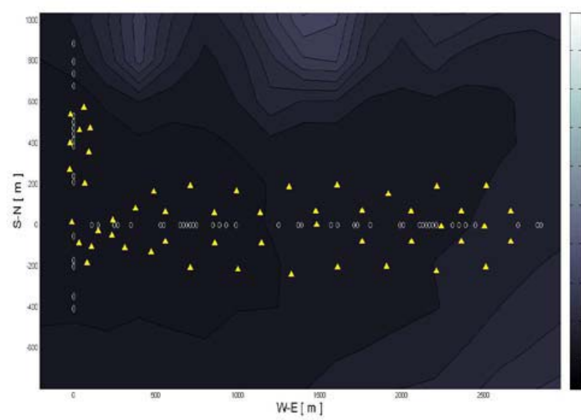

Figure 1. TREND present experiment. Each of the 50 antennas (triangle) are associated to a 21CMA pod (diamond). The 3 scintillators, located at the extreme West part of the array, are represented with stars.

2.2 Noise rejection & EAS identification

Here we detail the procedure of selection of cosmic rays events. Since the antenna signals are recorded in parallel, the first step for data analysis is to look for the coincidences between the detectors. This is simply performed by verifying that consecutive triggers on different antennas are compatible with the propagation of an electromagnetic wave. Indeed, trigger time t on antennas i and j are causally linked if they respect the condition :

$$\left| t_i - t_j \right| \leq \frac{d_{ij}}{c} . T$$

d_{ij} being the distance between the antennas, c the velocity of light, and T a safety factor taking into account the TREND time resolution (T=1.1 is usually used in the analysis). The trigger time corresponds to the position of the maximum of the signal, and is corrected of the delay induced by the signal propagation in the coaxial cable and in the optical fiber. If four or more antennas are found to be causally linked, we consider that these detectors have detected a electromagnetic event in coincidence and then define it as a radio event. Time differences between antennas are then precisely estimated using a cross-correlation procedure [7]. Arrival directions of radio events can be easily reconstructed by triangulation, using the time difference between triggered antennas. This reconstruction is performed for both hypothesis of a plane electromagnetic wave (distant sources) or a spherical electromagnetic wave (close sources). Estimations of the reconstruction performances performed with the 2009 TREND setup yield a angular resolution of 1.5° for plane reconstruction and a resolution of 2 meters on source position using spherical reconstruction, for a source located inside the array.

As the TREND experiment is working in a radio standalone mode, any source of radio emission could potentially trigger the antenna array. Defining an efficient procedure of noise rejection able to discriminate EAS radio event from the radio background is a key issue for a self-triggering radiodetection experiment. It this respect, it's important to stress that the average background level is extremely quiet at Ulastai, and all the radio sources are very well localized both in space (fixed sources) and in time (temporary moving sources such as car, plane, train). The main source of radio noise for TREND has been identified as a close by electric power line, which punctually generates bursts of electromagnetic transients. It induces a temporary increase of the trigger rate on the antennas located close to the power line. The time difference between consecutive coincidences during these burst periods exhibits typical features, with a repetition delay equal to a multiple of 10 ms, a clear signature of the 50 Hz power line. Identification and rejection of the radio noise coming from this identified source can be easily performed, and its efficiency can reach 80% of the total detected coincidences during burst periods. Note that this background treatment induces a decrease of the global duty cycle of the experiment.

After the rejection of the main radio noise sources, the procedure of identification of EAS events is applied to the radio data, following different steps :

- As the electric signal induced by an EAS and the one emitted by ground source present different features, notably on the signal length, a signal waveform analysis is performed to reject all the measured signals with a time-over-threshold duration bigger than several hundreds of nanoseconds (typically 400 ns).

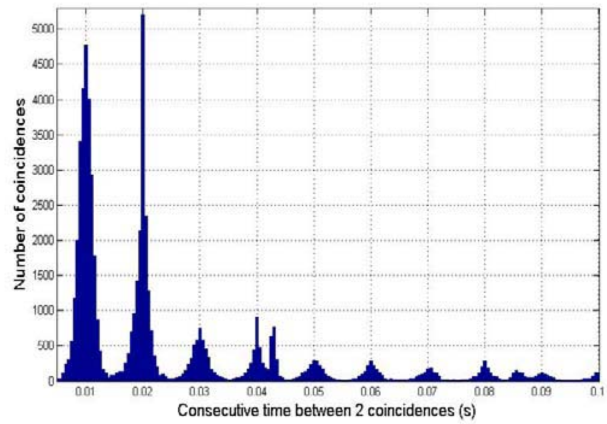

Figure 2. Distribution of the difference time between consecutive coincidences measured by TREND during a power line burst period. Peaks can be identified every 10 ms, corresponding to 50 Hz frequency of the power line.

- The overwhelming majority of the radio background events is generated by human sources located at ground level, most of the reconstructed arrival direction point close to the horizon. In order to limit the contamination of our cosmic candidates search with background events, we select only radio events with a reconstructed zenithal angle lower than 65° for the dedicated cosmic rays EAS study. Note that this particular cut is only temporary since horizontal showers cannot be study in that case.

- It has been established by previous experiments that the signal amplitude lateral profile of a EAS radiodetected event decreases exponentially when moving away to the shower axis [9]. Background events present a different lateral profile with amplitude scaling as R^{-1}, R being the wavefront curvature radius. Close sources will therefore generate quickly decreasing signals associated with a spherical wavefront, far sources will generate an almost constant signal associated with a plane wavefront. This amplitude criterion could a powerful tool to discriminate EAS, nevertheless, it requires a accurate sampling of the electric field to be use efficiently. Due to the reduced extension of the previous TREND setups, this cut was not applied in the EAS identification procedure. However, it will be use in the data analysis of the 50 antennas array.

3 Validation of the identification procedure

3.1 Scintillator array characteristics

Each of the 3 scintillators deployed in January 2010 are composed of a 0.5 m x0.5 m x2 cm plastic layer associated with a photomultiplier. The PMT signal is transmitted through an optical transmitter working in the 20 – 200

MHz frequency bandwidth to the acquisition room where the digitalization is performed by dedicated 8-bits ADCs working at a sampling frequency of 200 MHz. In a similar way to the TREND antennas, the scintillator signal is recorded only if a transient is identified following the trigger condition define previously. In case of 3-fold coincidence between the scintillators, an estimation of the shower arrival direction is performed by triangulation assuming a plane wavefront.

A sample of data of 19 live days, measured during 2010 with the 15 antennas array is presented here. It contains 620 3-folds coincidences with a detection rate of ~4 events/hour. The arrival direction distribution in both azimuth and zenith angle are presented in the figure 3. They follow the behavior expected for an operational scintillator array.

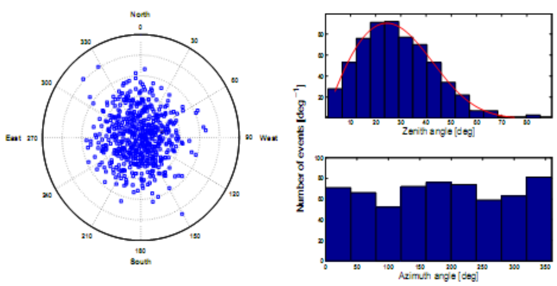

Figure 3. Left: repartition of the direction of arrival for the 620 3-fold events recorded with the scintillator array. Right: distribution of zenith and azimuth angles for the same data by bins of 6 and 40 ◦ respectively. The zenithal angle distribution is fitted by to the expected zenith distribution for a scintillator array in sinθ.cosθ [9].

3.2 Hybrid events

On this same data sample of 19 days, 3 EAS radio candidates, selected following the previously detailed identification procedure were found to be in coincidence with 3-scintillators events, and 2 with 2-scintillators events.

For the 3 hybrid events with a 3-fold scintillator event, a reconstruction of the arrival direction can be performed with the antenna array data and with the scintillator data independently. These independent reconstructions exhibit an excellent agreement within uncertainties (Table 1). For the 2 hybrid events with 2 scintillators, an independent reconstruction of the shower arrival direction by the scintillator array is impossible. Nevertheless, the trigger times measured on the particle detectors are consistent with the expected time deduced from the arrival direction of the electromagnetic wave reconstructed with the antenna arrays.

These results permitted to prove the relevance of the criterion used in the EAS identification procedure as radio candidates actually selected are identified as EAS cosmic rays. It is therefore establish that the TREND self-triggering experiment is so clearly able to detect and identify EAS. This result confirms that the radiodetection technique can be used as a stand-alone detector for high energies cosmic rays studies at least in favorable electromagnetic background conditions.

Table 1. Reconstructed zenith and azimuth angles for the 3 hybrid events detected with the TREND setup

	Radio antennas		Scintillators	
	Θ (°)	φ(°)	Θ (°)	φ(°)
A	52±1	195±2	49±3	191±4
B	61±3	359±2	67±5	3±4
C	42±1	55±4	36±3	56±5

4 Conclusion

The two first setup of the TREND experiment (6 and 10 antennas arrays) perfectly fulfilled their objectives by proving the viability of deploying a radiodetection experiment on the 21CMA site, and by proposing and validating an identification method for EAS. These results have made possible a major extension of the setup to a 50 antennas array in January 2011. Data recorded with this setup are actually under analysis. Upgrades on electronics and antenna design are scheduled for 2012 in order to allow TREND to study the high energy neutrino radiodetection.

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