Detection of Extensive Air Showers with the self-triggered TREND radio array

Tianshan Radio Experiment for Neutrinos Detection

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35th International Cosmic Ray Conference - ICRC2017
July 15th, 2017
Bexco, Busan, Korea
TREND setup

- Proposed in 2008 by: O. Martineau (Paris), V. Niess (Clermont) Wu Xiang Ping (Beijing), P. Lautridou, D. Ardouin (Nantes, France)
- Goal: establish autonomous radio detection of air showers
- Location: 21cmA radio interferometer (Ulastai, Xinjiang)

50 antennas
50 m spacing
~ 1.5 km²
TREND setup

DAQ periods:
- EW orientation 2011-2012
- NS orientation 2013

~2.10^8 events recorded for EW

@ DAQ room: on the fly digitization (200MS/s+8bits) +T0 if >6-8σ above noise (up to ~200Hz/ant) +record if 4+antennas in causal coincidence

<2km optical fiber

21cmA pod

Ampli (64 dB) + filter (50-100MHz)

<300m coaxial cable

Single polar antenna

One postdoc lost in the field

Ex. of recorded antenna trace 1024 samples

<300m coaxial cable
TREND data analysis

Offline noise rejection cuts:
(based on EAS radio signal expectations)
pulse duration, multiplicity, trigger pattern at
ground, valid direction reconstruction, wavefront,
direction & time correlation between events

→ from \(~2.10^8\) events to 574 EAS candidates
for 316 DAQ days
→ background transient events ultra-dominant
even at the radio-quiet TREND site

DAQ= Data AcQuisition
EAS=Extensive Air Shower
The 574 EAS candidates angular distribution: overdensity of events with $\theta > 60^\circ$ coming from North, as expected for EAS (radio signal $\uparrow$ if EAS $\perp B_{\text{geo}}$) → indicating candidates are likely to be real EAS

How to check quantitatively if these candidates are EAS? → expected angle distribution for EAS detected by TREND?

How many EAS were actually expected? → efficiency of TREND to detect EAS?

Simulate air shower events and propagate them into TREND DAQ + offline analysis (« end-to-end » simulation)
TREND end-to-end simulation

- **simulation of EAS** (random core & direction) with their radio electric field using ZHAIREs

- **simulation of voltage** at each antenna output from each electric field using NEC2

- **insertion** of simulated events in real data files
  randomisation of insertion time;
  propagate voltages through DAQ electronic chain: frequency filter, gain,
  digitization, noise addition (from real data), trigger

- **analysis** of these files with standard TREND offline program
  number of simulated events selected within real data → computation of
  effective surface for each EAS θ,ϕ,E, and aperture (m².sr) for each E
TREND gain calibration

Need to calibrate TREND gain (antennas and time variations)
→ can be dragged from the recorded voltage $\langle V_{DAQ}^2 \rangle$, with $\langle V_{sky}^2 \rangle$ and $\langle V_{ground}^2 \rangle$ expectations:

\[
\langle V_{DAQ}^2 \rangle = G_{tot}^2 (\langle V_{sky}^2 \rangle + \langle V_{ground}^2 \rangle)
\]

\[
\langle V_{ground}^2 \rangle = k_B \langle G_{ant} T_{ground} \rangle_{4\pi} \Delta v R_L
\]

kB boltzmann constant
Black body $T_{ground}=290$ K
$R_L$(Load)=112.5 Ohm

\[
\langle V_{sky}^2 \rangle = \frac{R_L}{2} \int_{\Delta\nu} \int_{4\pi} B_v(\theta, \varphi, v) A_{eff}(\theta', \varphi', v) \sin \theta d\theta d\varphi dv
\]

$\langle V_{sky}^2 \rangle$ received by antenna as a function of antenna instantaneous field of view (Local Sideral Time)

- sky brightness $B(\theta, \phi, \nu)$ with LFMap
- antenna effective area $A_{eff}(\theta', \phi', \nu)$ computation with NEC2

→ Computation of gain $G_{tot}$ from noise level monitoring, each 20 min
TREND gain calibration

For purpose of illustration only:

Gain unique value adjusted to fit mean recorded voltage on 1 day for 1 ant. Only a scale of Gtot is necessary to get a peak to peak match & \(| \text{model} - \text{data} \| < 10\% \)

→ validation of model

BUT:
other measurements indicate additional noise of 0% to 20%
→ Gain possible bias of 20%
→ Gain uncertainty = \([\text{Gtot}/1.2, \text{Gtot}]\)
TREND end-to-end simulation

**Data subset:**
- Period 6 of DAQ
- Runs 3562 to 3733
- Feb. 23\(^{th}\) to June 19\(^{th}\) 2012
- 80 DAQ days
- Nselected real events = 205

**Simulation set:**
- proton EAS
- \([5e16, 8e16, 1e17, 2e17, 3e17, 5e17, 7e17, 1e18, 3e18]\) eV (up to ~10 K simulated EAS per energy)
- Nselected simulated events leads to effective surface:

\[
S_{eff}(\theta, \varphi, E) = S_{draw}(\theta, \varphi, E) \frac{N_{set}(\theta, \varphi, E)}{N_{draw}(\theta, \varphi, E)}
\]

DAQ= Data AcQuisition
EAS=Extensive Air Shower
Aperture of TREND: \[ A_p(E) = \int_{2\pi} S_{eff}(\theta, \varphi, E) \cos \theta \sin \theta \, d\theta \, d\varphi \]

real TREND antenna & DAQ state + offline analysis

« ideal » offline analysis (do not cut air showers)

« ideal » TREND antenna & DAQ (100% of time working)
TREND expected events

Expected number of events in $\Delta t = 80$ DAQ days:

$$N_{expected} = \int_{\Delta E} A p(E) F(E) dE \Delta t$$

$F(E) =$ cosmic ray flux $[\text{GeV/m}^2\text{sr/s}]$

- $[159, 240]$ for real TREND antenna & DAQ state + offline analysis
- $[370, 561]$ for «ideal» offline analysis (do not cut air showers)
- $[2188, 3279]$ for «ideal» TREND antenna & DAQ (100% of time working)

(uncertainty comes from gain calibration bias of 0% to 20%)

Effective number of events in the subdata set = 205

→ satisfying modelisation of EAS radio emission + TREND response
Partial agreement between data and simulation distributions shows that TREND has indeed detected air shower events.

Excess in data indicates noise contamination of ~30% for Gtot/1.2 case.
TREND efficiency

Simulated events
Random (θ,φ)
Random core position
Random t

5+ antenna triggers

Instantaneous antenna + DAQ status

Offline EAS selection

«ideal» detector:
Antenna+DAQ live time = 100%

«ideal» selection:
100% EAS pass cuts

TREND EAS selection

DAQ time: 80 days (02-06/2012)

Preliminary results
To be confirmed with full TRENDS dataset (317 days)

Expected
nb of events:
2188 to 3279

Expected
nb of events:
370 to 561

Expected
nb of events:
159 to 240

ε_{det} ∼ 17%

ε_{tot} ∼ 7%

ε_{sel} ∼ 43%
Conclusion and 'to do'

Conclusion

- TREND system well understood
- Autonomous radio detection EAS goal reached first time ever
- Detector efficiency 17% and EAS selection efficiency 43%
- Noise contamination ~30%
- Promising for future neutrinos experiments such as GRAND (see [NU039] & [CRI187], this conference)

To do

- Compute efficiencies also with iron EAS & for the whole DAQ period
- Submit a publication on the results