Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 949–952

30TH INTERNATIONAL COSMIC RAY CONFERENCE
ICRC'07 Mérida, México

Cosmic Ray Tau Neutrino Telescope (CRTNT) Prototype Experiment at Yangbajing

HE HUIHAI[1], BAI YUNXIANG[1], CAO CHENGFANG[1], CAO ZHEN[1], HUANG MING-HUEY A.[2], LIN GUEY-LIN[3], LIU JIALI[1], LIU TSUNG CHE[3], XIAO GANG[1], ZHA MIN[1], ZHANG SHOUSHAN[1], ZHANG YONG[1]
[1]*Institute of High Energy Physics, CAS, Beijing 100049*
[2]*Department of Energy and Resources, National United University, Miao-Li, Taiwan 36003*
[3]*Institute of Physics, National Chiao-Tung University, Hsinchu 300*
hhh@ihep.ac.cn

Abstract: Cosmic Ray Tau Neutrino Telescope (CRTNT) is designed to detect tau lepton showers initiated from Earth-skimming tau neutrinos. A potential site is located at Mt. Balikun, Xinjiang, China. Two CRTNT prototype telescopes are installed at Yangbajing, Tibet (4300m a.s.l.) near the ARGO-YBJ RPC carpet detector, for coincident observation of cosmic ray showers above 10^{14} eV. Detector status and operational results are reported in this paper.

Introduction

Cosmic Rays Tau Neutrino Telescope (CRTNT) project [1] uses the well developed fluorescence/Cerenkov light technique to detect extensive air showers. Its main physics goals are to search for Earth-skimming tau neutrinos from active galactic nuclei (AGN) and to measure sub-EeV (10^{17}-10^{18}eV) cosmic rays. A potential site for observing tau neutrinos is located at Mt. Balikun, Xinjiang, China (1600m a. s. l.), where the weather and environment permits a duty cycle of about 15% for air shower observation using fluorescence/Cerenkov light technique. A Full MC simulation on this site shows that 7.6 AGN and 0.3 GZK tau-neutrino events are expected per year with the background of about 1 event [2, 3]. Two prototype telescopes have been constructed and mounted at the Yangbajing Cosmic Ray Observatory (4300m a. s. l.) near the ARGO-YBJ experiment [4] site. This setup is used for debugging the telescopes and coincident measurement of cosmic ray showers for composition around knee region. In May, 2007, the first set of events in coincidence with the ARGO-YBJ experiment was observed. Here we report the status of the experiment and operational results.

Detector design

The telescope collects UV light (>300nm) using a 5m^2 spherical Aluminized mirror (radius of curvature of 4730±20mm) with reflectivity greater than 82%. Signals are recorded by a cluster of 16x16 photo-multiplier tubes (PMT) at the focal plane. 40mm hexagonal Photonis PMTs with a typical quantum efficiency of 28% above 300nm are used. The pixel size is about $1^o\times1^o$ forming a total field of view (FOV) of $14^o\times16^o$. The whole system including on-line status monitoring is hosted in a standard shipping container with a dimension of 2.5m×2.3m×3m. The container is mounted on a standard dump-truck frame with a hydraulic lift that allows the container to be tilted in any elevation angles from 0 to 60 degrees. Changing the configuration of the telescope array for different observations can be easily made by this portable design.

Signal features

Detailed MC simulations [3, 4] show that scattered Cerenkov light dominates signals in tau neutrino search where air showers are populated around 10PeV, while fluorescence light dominates signals in sub-EeV cosmic ray air showers obser-

vation. Fluorescence signals can be as small as several photo-electrons (pe) spread out in a duration of about 6 micro-seconds [3], while Cerenkov signals produce typically very large (thousands of pes) but narrow (5-10ns) signals [4].
The prototype detector is designed to cover such a large dynamic range of signals and to handle such a wide range of variation of pulse widths, i.e. from few pes to 4000 pes in amplitudes and from several nanoseconds to six microseconds in signal widths. A 50MHz 12-bit-equivelent Flash Analog-to-Digital Converter (FADC) is used for each channel and a dynamic pulse expansion/shaping circuit is designed to meet those requirements.

Gain Balance and Pulse Shaping

PMTs are grouped into 4×4 sub-clusters that are attached by an integrated high voltage (HV) power distribution and readout electronics including pulse shaping/expansion, gain variable amplifying (VGA), high/low gain splitting, flash A/D conversion and single channel trigger forming. PMTs in a sub-cluster are selected to have similar gains and supplied with slightly different HV to obtain gain uniformity. According to a daily measurement of UV-light from a LED mounted at the mirror center, gains are adjusted by programmable VGA to compensate the difference between channels. A non-uniformity of gains less than 5% is expected between channels throughout the cluster. The non-uniformity of UV LED light smeared by Teflon films in the area of the cluster is measured to be less than 5%.
Analog signals from PMTs with narrow width (e.g. Cerenkov light signals) are filtered for suppressing noises in both low and high frequency domains and shaped in order to meet the FADC sampling duration (20ns under the working frequency of 50MHz).

Digitization and dynamic range

Analog signals from PMTs are digitized on Digital Board (DB, one for each sub-cluster) by a 10-bit FADC, which has a linear range (with linearity better than 2%) of about two decades of the input amplitude. To cover the dynamic range of greater than three decades of amplitudes, the signal from the PMT is fed into two channels with high (×32) and low (×4) gain amplifiers each followed by one FADC. The digital data from the FADCs are analyzed online by a Field Programmable Gate Array (FPGA, each serves 4 channels). If a signal saturates the high gain channel FADC, the FPGA automatically switches to use the low gain channel FADC data, vice versa. This provides almost same resolutions for both small and large signals.

Trigger and the data acquisition system

Air shower trigger is formed in a history, i.e. the coincidence time window, of 6 microseconds (300 FADC timing bins) at three levels:
1. Single channel trigger: Digitized data is fed into a pipeline with a length of 5 histories in the FPGA and scanned with a running window with a programmable width, 8 bins is currently set for the prototype, corresponding to a typical width of shaped Cerenkov light signal. To find the mean and the standard deviation σ of pedestal during a history, sums of counts over windows surrounding the maximum that probably contains shower signal are removed. Any channel with the sum of FADC greater than 4σ above the pedestal is considered as a signal in this channel. The threshold of 4σ is on-line adjustable.
2. Telescope trigger: A FPGA on trigger board (TB) collects single channel triggers from all 16 DBs and finds specific pre-stored patterns using triggered tubes in a 6x6 running box throughout the cluster. Once a pattern is recognized, a telescope trigger is latched. For trigger on shower Cerenkov light, each pattern consists of one PMT in the center and surrounded by 6 adjacent tubes. With the 4σ single channel threshold, noise trigger rate is less than 10^{-6}Hz.
3. Event trigger: A coincidence of the two telescopes makes an event trigger in stereo mode.
The event trigger is distributed to all FPGAs on DBs, and then data in three histories (including the previous, current and post history, in case a signal spans in two histories) is fed into a data First-In-First-Out (FIFO) buffer attached to each channel on DB. The data FIFO is two-event long which enables the system almost dead time free.
An online embedded computer TS7200 polls data buffers and reads data through its PC104 bus when data is there. A Global Positioning System (GPS) based clock is used to record the event time with an accuracy of 1 microsecond.
Synchronization between PMT signals is crucial for shower reconstruction. It is achieved by distributing a single clock to all electronics units in

all telescopes through fibers. The timing accuracy equals to one FADC timing bin of 20ns.

Sky background and Telescope pointing

During the observation period of February, 2007, one telescope was setup at elevation angle about 60^o to observe the sky night background. Tens of well known bright stars were seen by the telescope, as shown in Fig.1. By analyzing the relative time of stars in each PMT FOV, the telescope pointing direction was calibrated as azimuth 226^o and zenith 32^o.

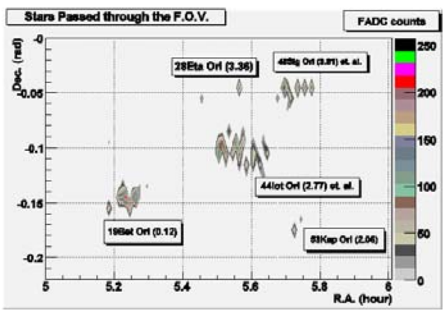

Figure 1: The sky-map of background excess (in FADC counts) as stars pass the FOV.

Cosmic Ray Observation

Two prototype telescopes, shown in diamonds in Fig.2, were installed at the ARGO-YBJ experiment site at about 59m and 60m to the center of the carpet array of RPC detectors. During the observation period of May, 2007, the first set of air shower events were observed with No. 1 telescope in monocular mode. 45 events are coincident with the ARGO-YBJ experiment by GPS timing within $\pm 1\mu s$. Their shower core positions, reconstructed from ARGO-YBJ data, are shown in circles in Fig.2.

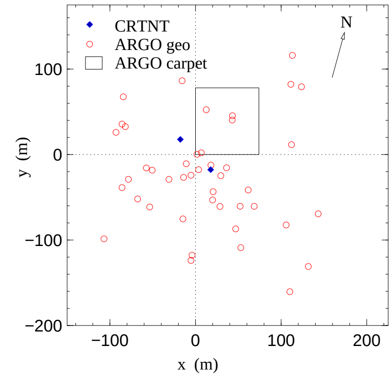

Figure 2: Shower core positions distribution

As an example, an image on the CRTNT cluster is shown in Fig.3 with FADC traces measured by two channels together. The ARGO-YBJ measurement of the same event is shown in Fig.4.

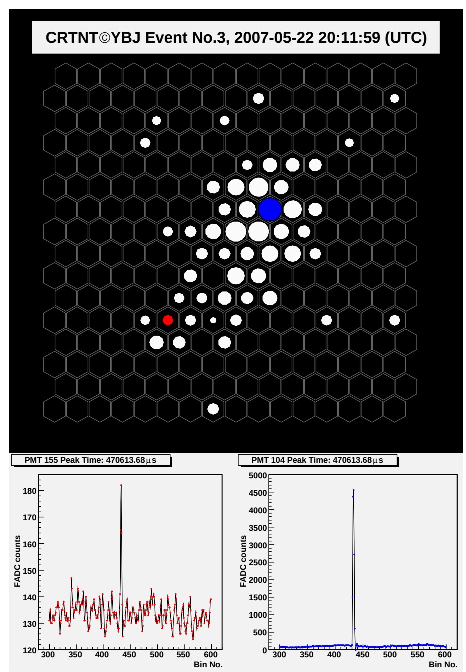

Figure 3: An example of CRTNT and ARGO-YBJ coincident event. Top panel shows the triggered pattern in PMT cluster. FADC histories of two firing tubes, marked with blue and red, are shown at bottom two panels

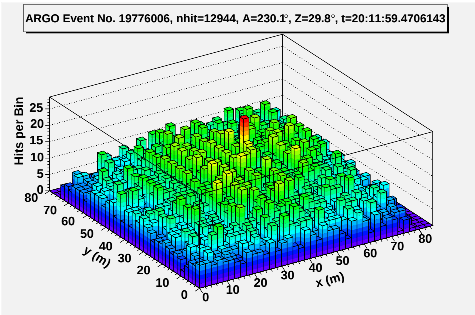

Figure 4: Hit map of the ARGO-YBJ carper array for the same event shown in Fig.3

According to shower arrival direction reconstructed from ARGO-YBJ data, events distribute in the FOV of the CRTNT telescope are shown in Fig.5. If the brightest tube indicates the shower maximum direction, then the space angle between shower maximum direction (according to CRTNT) and shower arrival direction (according to ARGO-YBJ) is approximately 3 degrees, close to the expected values of sub-PeV showers.

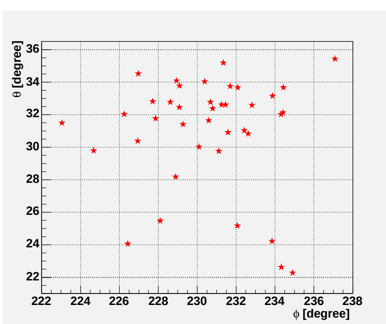

Figure 5: Direction map of coincident events

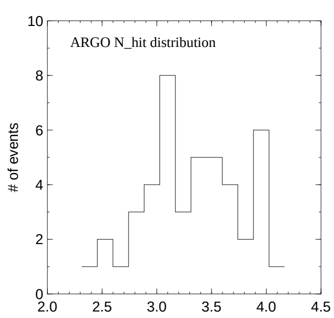

Figure 6: N_hit distribution of coincident events

The ARGO-YBJ data also provides a measure of shower size at the ground in terms of N_{hit}, corresponding to recorded number of particles in showers. The distribution of matched events, in Fig.6, indicates that shower mode energy is about 50TeV.

Conclusions

The CRTNT prototype telescopes are tested at the ARGO-YBJ experiment site, Tibet. All 7 subsystems are working properly to the required specifications, including full remote operation and status monitoring (the observation in May was done in IHEP, Beijing). Night sky background is measured and used as calibration of telescope pointing accuracy. Cosmic ray air showers are measured in coincidence with ARGO-YBJ within $\pm 1\mu s$. Shower reconstruction is undergoing towards extracting more shower parameters, especially longitudinal development information in a stereo-hybrid mode. Further modifications in design of telescopes are undergoing to make the hardware more robust and easy to debug/maintain. More trigger patterns will be added and tested for the neutrino observation.

Acknowledgements

This work is supported by the Chinese Academy of Sciences (O529110S13) and the Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, CAS.

We are very grateful to the ARGO-YBJ Collaboration for the authorization to use the data of ARGO-YBJ experiment.

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