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Coincident air shower events between ARGO-YBJ and PRISMA-YBJ

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Abstract: The ARGO-YBJ experiment at the YangBaJing Laboratory (Tibet, P.R. China, 4300 m a.s.l., $606 g/cm^2$) has been operated for five years since its complete installation in 2007, aiming at the TeV gamma ray astronomy and cosmic ray physics in a wide energy range. The ARGO-YBJ experiment is a full coverage array of Resistive Plate Chambers (RPCs) with the central carpet of $5800m^2$ plus a guard ring resulting in a total active area of $6700m^2$. The PRISMA project is devoted to the detection of thermal neutrons generated by secondary hadrons in extensive air showers(EAS), focusing on the cosmic ray ”knee” physics. Four prototypes of the PRISMA detector have been operated at the YangBaJing site. In January 2013 these detectors (called PRISMA-YBJ) have been installed at the center of the ARGO-YBJ carpet and coincident events between ARGO-YBJ and PRISMA-YBJ have been recorded. It is the first time that the thermal neutron detectors work in coincidence within an EAS array in order to confirm the observation of thermal neutrons really generated from cosmic air showers and study their characteristics in details. Moreover, it is the first detection of air shower thermal neutron at high altitude in the world. This talk presents the analysis of these events.

Keywords: cosmic ray, extensive air shower, thermal neutron, ARGO-YBJ, PRISMA-YBJ

1 Introduction

Cosmic rays were discovered more than 100 years ago and the first detection of extensive air showers was more than 50 years ago, but the origin and acceleration mechanism of cosmic ray is still unknown. To research on cosmic ray with high energy above 100TeV, a ground-based detector array is necessary for low flux at such high energy. Among several kinds of detector arrays built in the world, there are two experiments with unique technology individually: the ARGO-YBJ experiment [1] composed of RPC carpet with full coverage and the PRISMA experiment [2] with thermal neutron detectors. Now the two experiments decide to make a test for hybrid measurement of EAS in order to develop a new technology which opens a new window to the cosmic ray problems, especially the knee region of cosmic rays spectrum.

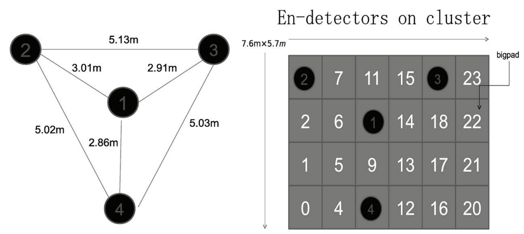

Fig. 1: Configuration of PRISMA-YBJ.

2 Experiments

2.1 The ARGO-YBJ Experiment

The ARGO-YBJ experiment [1] at the YangBaJing Laboratory (Tibet, P.R. China, 4300 m a.s.l., 606 g/cm^2) is currently the only air shower array exploiting the full coverage approach at very high altitude, with the aim of studying the cosmic radiation at an energy threshold of a few hundred GeV. The ARGO-YBJ experiment is made by a single layer of Resistive Plate Chambers (RPCs) [3] housed in a large building (110×100 m^2). The detector has a modular structure: the basic module is a cluster ($7.6\times5.7m^2$), made of 12 RPCs (1.23×2.85 m^2 each). 130 of these clusters are organized in a full coverage carpet of 5800 m^2 with active area of about 93%; this central detector is surrounded by 23 additional clusters with a coverage of $\sim$40% (“guard ring”) to improve the core location reconstruction. The detector installation has been completed in 2007. Each RPC is read via 80 strips (61.8×6.75 cm^2), logically organized in 10 pads of ($61.8\times55.6cm^2$) that are respectively recorded and represent the high granularity pixels of the detector. In addition, the signal of each RPC chamber is picked out by two large size pads ($1.23\times1.39m^2$), called BigPads, in analog read-out mode with a 12 bits Analog-Digit Convertor (ADC). The ARGO RPC carpet is composed of 3120 BigPads. This extends the measurement range of particle density up to 10^4 $particles/m^2$ [4, 5] and the primary cosmic ray energy from some tens of TeV up to several PeV. Therefore, measurement of showers with the BigPads will offer great benefit to research on hadronic interaction and cosmic ray spectrum around the ”knee” region. The event arrival time is measured by a GPS module with precision of 100ns.

2.2 The PRISMA experiment

The idea of a novel type of array for EAS study proposed for the first time in 2001 [6] has been developed in 2008 for the PRISMA (PRImary Spectrum Measurement Array) project [2]. It is based on a simple idea: as the hadrons are the main EAS component forming its skeleton and resulting in all its properties at an observational level, then hadronic component should also be the main component to be measured in experiments. Therefore, we have devel-

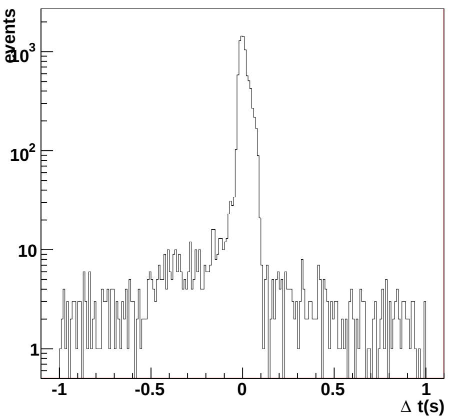

Fig. 2: Time difference distribution between PRISMA-YBJ and ARGO-YBJ.

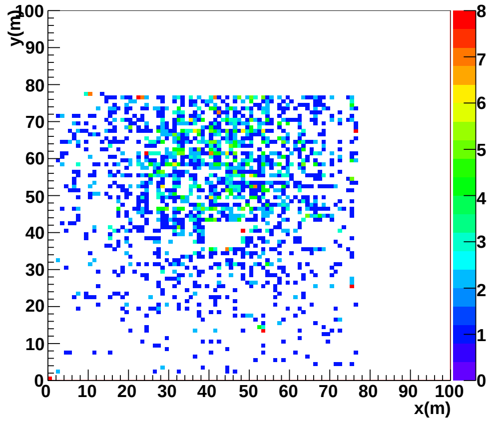

Fig. 3: Core position distribution of the matched events.

oped a novel type of EAS array detector (en- detector) capable to record hadronic component through thermal neutrons detection (n) and electronic component (e) as well [7, 8]. The ProtoPRISMA prototype array consisting of 32 en-detectors is now running in Moscow [9]. It is interesting to compare the data obtained by the same method and by the same detectors at near sea level (ProtoPRISMA) and at high altitude (PRISMA-YBJ). (see presentation of Yuri Stenkin et al. ID 478).

2.3 The PRISMA-YBJ experiment

4 en-detectors similar to that using in ProtoPRISMA (Moscow) were made and installed in Tibet in the ARGO experiment hall. Thin layer ($30mg/cm^2$) of special inorganic scintillator ZnS(Ag) + 6LiF of $0.36m^2$ area is mounted at the bottom of a cylindrical PE 300-l water tank which is used as the detector housing. A 5"-PMT (FEU-200) is mounted on the tank lid. Light reflecting cone made of foiled PE foam of 5-mm thickness is used for better light collection. As a result, we collect 50-100 photoelectrons per neutron capture. All pulses are integrated within $1\mu s$. FADC (ADLINK 12 bit pci slot PCI-9812) is used for pulse shape digitizing (20000 samples with a step of $0.5\mu s$).

The arrangement of the detectors is shown in Fig. 1. The first level trigger is very simple: a coincidence of any 2 from 4 detectors in a time gate of $1\mu s$ starts all FADC's. On-Line program analyses the data and produces second level triggers: M1 in a case of real coincidences, M2 in a case of total energy deposit more than 120 particles and M3 if number of recorded neutrons is more than 10. Under NTF (network timing protocol), timing is taken by the PC which is synchronized every second through the internet time server with precision of some tens of milliseconds. The PRISMA-YBJ array overlaps with the cluster 78 of the ARGO RPC carpet, its center has coordinates (42.9m,58.5m).

3 Data Analysis

ARGO-YBJ and PRISMA-YBJ effectively run together from January 24 to February 6. After removing two test days, the effective run time in coincidence was 11 days. Time difference distribution between PRISMA-YBJ and ARGO-YBJ (Fig.2) indicates that the real matched events between the two arrays are really found in time window $\pm 0.03s$. The distribution is not a good gaussian because the NTF method can only provide timing with precision of some tens of milliseconds. In time window $\pm 0.03s$, 6351 events are selected.

At ARGO-YBJ, the showers are reconstructed to obtain several parameters: core positions are calculated by the weighted mean of the fired bigpad positions - the number of particles in the bigpad being the weight, directions are fitted from timing of the strips, ages (s) and sizes (N_p) are fitted from lateral distribution of particle density (ρ) in the bigpads with power function:

$$\rho = N_p \times r^{s-2} \tag{1}$$

where r is the distance of the bigpad from the shower core. N_p is taken as parameter for shower energy measurement. Fitting range of r is from 1m to 10m. To ensure a good quality of the fit, the number of bigpads in the fitting range in the event was required to be greater than 20, thereby selecting 2626 events. The core position of events in coincidence distributes close to the PRISMA-YBJ position (Fig. 3).

At PRISMA-YBJ, the first pulse in PRISMA-YBJ comes mainly from EAS electrons and is used for energy deposit measurement, while delayed neutron capture pulses are counted within a time gate of 10 ms to give the number of capture neutrons. Linear correlation between electron density detected by ARGO-YBJ bigpads and PRISMA-YBJ in the four detectors is very good (Fig. 4). About thermal neutrons, the following results are obtained:

1. Thermal neutrons coming from EAS are detected with high significance. Background of the PRISMA detector is measured by use of picking up pulse every 1minute online, which is a poisson distribution with a mean value of 0.40 neutrons. The thermal neutron distribution in shower events has a mean value of 0.75 neutrons which is pretty larger than the background one (Fig. 5).

2. Thermal neutrons detected by the four en-detectors are correlated with distance from the shower cores to the center of PRISMA-YBJ. In fact, when the

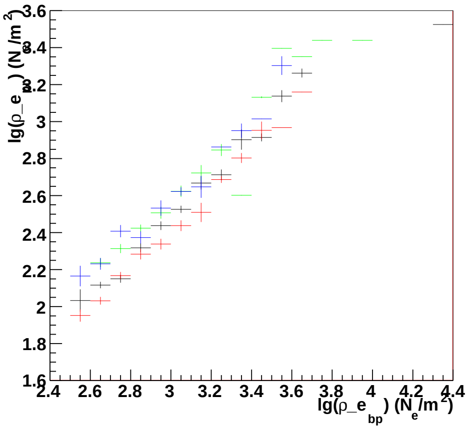

Fig. 4: Correlation between the electron densities measured by the four en-detectors of PRISMA-YBJ (ρ_e_{pr}) and those measured by the four corresponding bigpads of ARGO-YBJ (ρ_e_{bp}): D1(black), D2(red), D3(green) and D4(blue).

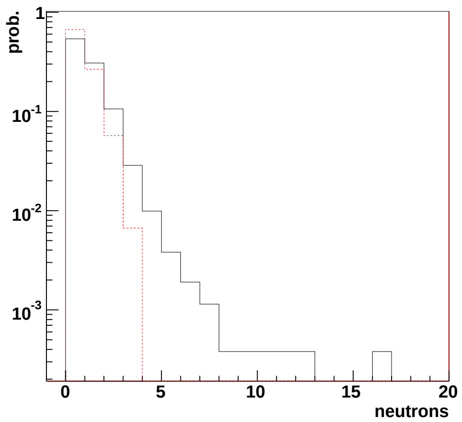

Fig. 5: Thermal neutron normalized distribution of the matched events (black solid line) and background normalized distribution (red dotted line).

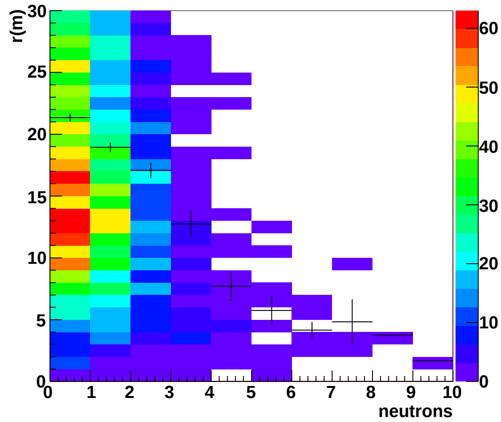

Fig. 6: Correlation between thermal neutrons and distance from the shower cores to the center of PRISMA-YBJ. Colors are number of events, and crosses are profile.

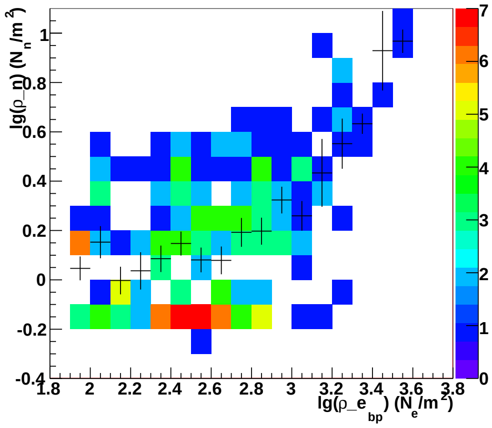

Fig. 7: Correlation between average density of thermal neutrons in the four PRISMA-YBJ detectors and average density of electrons in the four corresponding ARGO-YBJ bigpads. Colors are number of events, and crosses are profile.

shower core is closer to the center of PRISMA-YBJ, PRISMA-YBJ catches more thermal neutrons(Fig. 6). Under the current arrangement, the number of thermal neutrons can reach an average of 3 (5) at a distance of 12m (5m) from the shower core. This information will be important for both design optimization and construction of the neutron detectors, at same time they will help in optimizing the configuration of a large neutron detector array for future experiments.

3. Correlation between average density of thermal neutrons in the four PRISMA-YBJ detectors and average density of electrons in the four corresponding ARGO-YBJ bigpads (Fig. 7) indicates that density of thermal neutrons is 2.6 orders lower than density of electrons.

4. Selecting events with core within 10 m from the center of PRISMA-YBJ, a sample of 308 events is left. For such a sample Fig. 8 shows a quite good correlation of density of thermal neutrons with shower energy, the latter is estimated through the N_p value as resulting from the fit of the lateral distribution with equation (1).

4 Conclusions

The PRISMA-YBJ experiment combines both the ARGO-YBJ technique for full-coverage EAS detection and the PRISMA method for thermal neutrons detection, aiming to establish beyond any doubt the detection of thermal neutrons produced by EAS. The results we got within 11 days of combined operation of the two detectors, confirm the aim has been reached. For the first time, thermal neutron detectors have been operated in coincidence with an EAS array. Moreover, it is the first detection of air shower thermal neutron at high altitude in the world. Thermal neutrons generated from EAS have been measured and their characteristics studied. The lateral distribution of thermal neu-

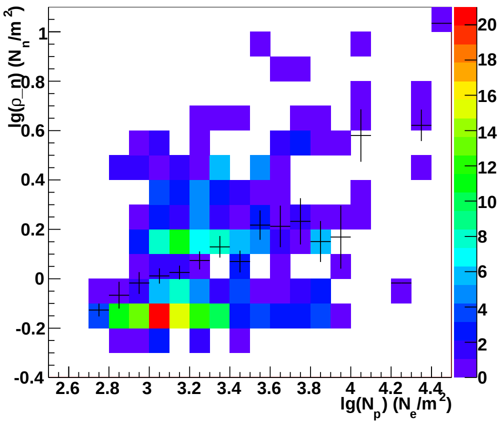

Fig. 8: Correlation between density of thermal neutrons detected by PRSIMA-YBJ and the N_p value (energy estimator) as resulting from the fit of the lateral distribution in ARGO-YBJ with equation (1). Events with core within 10m from the PRISMA-YBJ center have been selected. Colors are number of events, and crosses are profile.

trons in the shower has been measured and the correlation with the shower energy has been proved. Detection of thermal neutrons is an important tool for studying cosmic ray aiming to determine cosmic ray energy and identify elemental composition.

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