PROCEEDINGS OF SCIENCE
ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany
37th International Cosmic Ray Conference 12–23 July 2021

# Study of the EN-Detectors Array in Tibet

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To research the "knee" region of cosmic ray energy spectrum, we should clearly discriminate components of cosmic rays at the knee. EN-detectors (Electron-Neutron Detector) can detect both electrons near the shower core and thermal neutrons generated in ground by EAS hadrons. As hadrons are the "skeleton" of EAS and possess the information about the primary, the electron-neutron detector array has the capability of primary components separation and energy measurement. At present, a cluster (16 EN-detectors) is running at the Yangbajing Cosmic Ray Observatory in Tibet to test the performance at high altitude (4300 m above sea level). With a period of stable operation at Yangbajing, we found that the efficiency of thermal neutron detection is affected by environmental water— drier the weather, higher the efficiency. The difference between rain season and dry season could reach the level of 10 percent. Besides, the four EN-detectors at Tibet University(named P-TU) keep running and recorded an increase of counting rate during the Naqu earthquake.

*37th International Cosmic Ray Conference (ICRC 2021)*
*July 12th – 23rd, 2021*
*Online – Berlin, Germany*

*Presenter

## 1. Introduction

The cosmic ray energy spectrum basically obeys a power law. But around $4 \times 10^{15}$ eV, the so-called "knee" region, spectrum index decreases into -3.1 from -2.7. The mechanism of knee region is supposed to related to the origin, acceleration, and propagation of cosmic rays. However, so far, ground-based experiments have yet to give consistent results. Such as KASCADE[1] and Tibet-AS$\gamma$[2], although they confirmed the existence of knee region, The exact power law index, proportion of components, and location of knee region are still ambiguous.

Hadronic components are "skeleton" of EAS[3] and possess information concerning energy and properties of primary particles. Traditional hadron calorimeters could measure incident angle and energy of hadrons, but it is costly and limited by its effective area, so that the statistics of high energy cosmic ray events are very restricted. Hadrons will react with surround materials (such as soil, building, and detectors materials) and produce evaporation neutrons. Those evaporation neutrons are moderated by matter in surrounding environment, and become thermal neutrons, and the total number of thermal neutrons is two or three order of magnitude more than hadrons[4]. In particular, quantity of neutrons is sensitive to primary particles: thermal neutrons generated by light nuclei(such as proton) are one order more than heavy nuclei(such as iron)[5]. So, the thermal neutrons detectors have better performance-cost ratio than hadron calorimeters in composition identification.

With this idea, the PRImary Spectrum Measurement Array (PRISMA) project and the electron-neutron detector(EN-detector) are proposed and developed at Institute for Nuclear Research Russian Academy of Science(INR RAS). EN-detector is capable of simultaneously measuring charged particles and thermal neutrons generated by EAS hadrons[6]. The schematic of an EN-detector is illustrated in Fig.1. To capture thermal neutrons, a new type scintillator based on a compound alloy

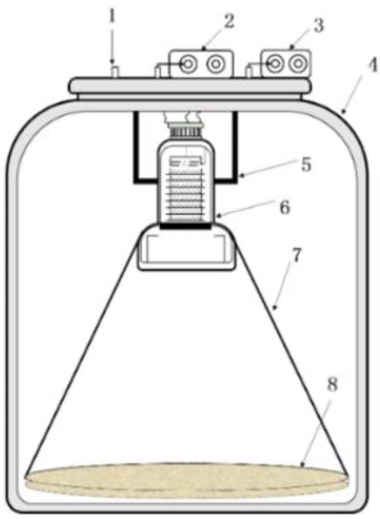



**Figure 1:** Schematic of an EN-detector. 1- HV input port, 2- d8 preamplifier(DIU), 3- d5 preamplifier (UI), 4- black tank, 5- PMT fixed holder, 6-PMT, 7- light collecting cone, 8- scintillator

of ZnS(Ag) and $B_2O_3$(or LiF) is utilized. Our study found that the EAS neutron size spectrum follows a pure power law[8]. And the EN-detector can also study gravitational tidal effect of the Sun-Moon-Earth system[9] and earthquakes[10], which can change thermal neutron flux.

## 2. Experimental Setup

The earlier experimental results of EN-detectors were given by two prototype arrays, one settled on Baksan Neutrino Observatory(1700m about sea level) and another on Moscow Engineering Physics Institute(at sea level)[7]. Then 4 EN-detectors, the so-called PRISMA-YBJ, were placed in ARGO-YBJ experiment hall(4300m about sea level) and simultaneously measure air shower with the ARGO detectors.


(a) PRISMA-16 (b) P-TU

**Figure 2:** (a) PRISMA-16 array in Yangbajing, Tibet. (b)P-TU, 4 detectors on different floor

In these experiments, $^6$Li was used to capture thermal neutrons. When the ARGO experiment had finished, 4 EN-detectors of PRISMA-YBJ were moved to Tibet University, running in the single-particle-mode (recording signals respectively) and renamed to P-TU, shown in Fig.2(b). Later on, 16 EN-detectors using new scintillators with $^{10}$B were built due to high cost and application limitation of $^6$Li. Those new detectors were first installed on the roof of a building at Tibet University[11], then they were moved to Yangbajing Cosmic Ray Observatory in Tibet (4300m above sea level), turning to the so-called PRISMA-16 array, shown in Fig.2(a), starting to take data since December, 2018.

## 3. Data analysis and results

We adopted data recorded by PRISMA-16 array from August 3rd, 2019 to January 12, 2020 for the analysis. We divided those data into 5 periods, listed in Table 1,and selected 25 days, reliable events during each period.

Fig.3(a) shows the distribution of thermal neutrons in these 5 periods. It's obvious that the spectrum obeys a simple power law, which is good agreement with results in PRISMA-YBJ[12] and PRISMA-32[13]. And it is also found that the average number of thermal neutrons increases over

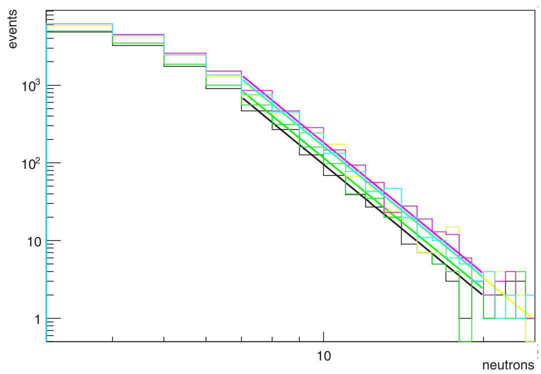
**Table 1:** Periods of running of PRISMA-16

| Period label | Time period | Colors of histograms and fitted lines in Fig.3(a) |
|---|---|---|
| 1 | Aug 03, 2019 – Aug 28, 2019 | Black |
| 2 | Sept 11, 2019 – Oct 06, 2019 | Green |
| 3 | Oct 07, 2019 – Oct 31, 2019 | Blue |
| 4 | Nov 24, 2019 – Dec 18, 2019 | Yellow |
| 5 | Dec 19, 2019 – Jan 12, 2020 | Pink |

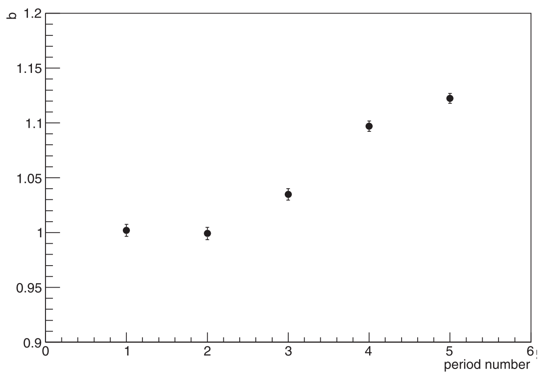
time. The reason could be the transition from the rainy season to the dry season. As water content reduce, the mean free path for neutron absorption increases, therefore the mean number of thermal neutrons increase too. We use function Eq.(1) to describe this "seasonal effect",

$$y = A(\frac{x}{b})^{-r} \quad (1)$$

where $A = 3.8\times10^7$, $r$=5.6, and $b$ are the parameters, which represent the change in the number of thermal neutrons. Fig.3(b) is the fitted parameter $b$ over periods. As shown in plot, the difference between maximum and minimum of b can reach to 11%. More details can be found in [14].




(a)

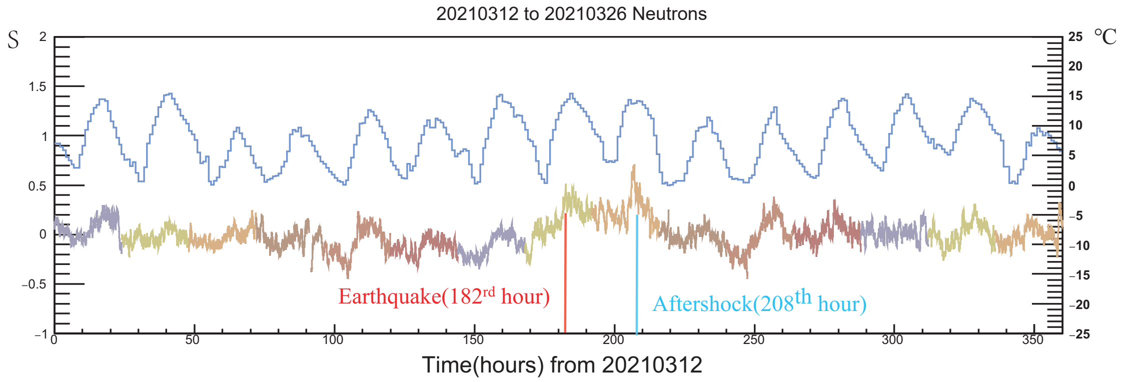



(b)

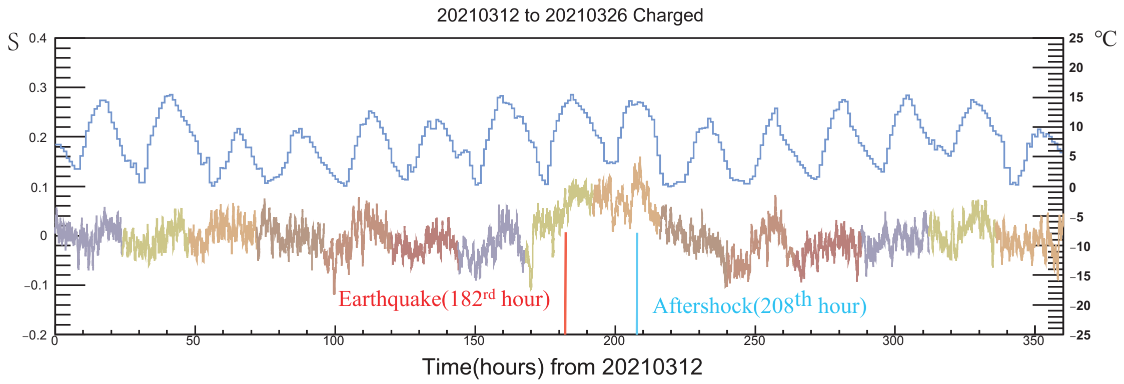
**Figure 3:** (a) Comparison of distributions of thermal neutrons during different periods. (b) Change of fitting parameter $b$ with periods.

Another study given by P-TU in Tibet University revealed a possible relation between neutron and earthquake. On march 19, at 14:11, an earthquake of M6.1 happened in Naqu, Tibet and the epicenter is 295 km from Lhasa. On next day, March 20, at 2:04 am, an aftershock of M3.2 occurred. P-TU were recording the neutron diurnal variation at the time of Naqu earthquake. The results is based on data given by the $3^{rd}$ detector on the $4^{th}$ floor, during 2021.03.12 to 2021.03.26 (7 days before and after March 19).

Fig.4 shows relative variation of neutron and charged particle counting rate, in which S is




(a)




(b)

**Figure 4:** Variation of the counting rate of neutron (a) and charged particle (b) recorded by P-TU during the Naqu earthquake. The upper blue histograms in every frame is variation of hourly averaged temperature in Lhasa. And the colorful graph below is the relative counting rate variation of neutron or charged particle, different color representing different day. At the $182^{th}$ hour the earthquake happened, and the $208^{th}$ hour a strong aftershock happened. A smooth of 30 minutes time span is employed.

defined as

$$S = \frac{N}{\langle N \rangle} - 1 \tag{2}$$

where $N$ is neutron or charged particle counting rate per minute, and $\langle N \rangle$ is their mean value of counting rate during those 15 days, respectively. It can be found that there is an increase at $182^{th}$ hour when the earthquake happened and another increase at $208^{th}$ hour when a strong aftershock happened.

## 4. Summary

PRISMA-16 array composed of 16 novel EN-detectors is placed at high altitude to test a new dimension measurement of EAS from the neutron aspect. The anti-correlation between efficiency of thermal neutron detection and soil moisture is observed. The influence caused by water in soil brings a seasonal effect of 11% difference to yearly counts, but it will be averaged for long-term measurement. P-TU detected possible coincidence between the increasing of neutrons flux and earthquakes. Although the correlation is not very significant, it is worthwhile to operate such detectors to investigate further this topic, and to study other physics topics such as seismology and solar activity.

**Figure 5:** Sand cube(white tank in the front of picture) under construction

As a next step, we proposed a new project named "Sand Cube". Sand cube(shown in Fig.5) is an 1 cubic meter plastic tank filled with sand, on which one detector is mounted. It can lift detectors apart from ground so that reduce the influence caused by water in soil. On other hand, the clean, pure, dry sand in the tank provides a stable environment for thermal neutrons generation. Combined those conditions, the seasonal effect would be minimized. And the well known and uniform ingredient of sand makes simulation easier and more accurate. Hence, the final systematic uncertainties can be reduced substancially.

## Acknowledgments

This work was supported in China by National Natural Science Foundation of China (NSFC) (No. 11963004, 12047575, U2031103, 11905043, U1831208, U1831129), Everest Discipline Construction Plan of Tibet University, and the Science and Technology Department of Sichuan Province (grant number 2021YFSY0031).

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