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Study for correlation between neutrons detected by Electron and Neutron Detector Array (ENDA) and soil humidity

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The electron and neutron detector (EN-detector) can detect the thermal neutrons produced by hadronic components in the secondary particles of cosmic rays. According to our previous paper about the performance of EN-detectors in Yangbajing, Tibet, during the period from August 2019 to January 2020, the number of detected neutrons in rain season is significantly ($\sim$ 10%) lower than that in periods of dry season. In order to further study the correlation between the detector performance and humidity in soil, five soil moisture meters have been installed at different depths inside ENDA-16-HZS in August 2020. By analyzing the data in September 2020, it is demonstrated that both counting rate of EN-detector and neutrons in triggered events are negatively correlated with humidity.

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1. Introduction

The cosmic ray energy spectrum spans over more than 14 decades from about 10^6 eV to beyond 10^{20} eV. In particular, high energy hadrons, which constitute the EAS (extensive air shower) skeleton, may carry important information for multi-parameter studies, since some hadronic observable, primarily the hadron number and electron number correlation, depend on the nature of the particle inducing the EAS [1][2]. Thus, the detection of high energy hadrons, aiming to improve the discrimination power in these analyses, is highly worthwhile. Avoiding the use of huge, expensive hadron calorimeters, a way using thermal neutrons, the so called PRISMA project (PRImary Spectrum Measurement Array), was brought out in [3]. Now, the project starts to with LHAASO, called LHAASO-ENDA. Thermal neutrons are generated abundantly from hadrons on the ground, up to 2 orders of magnitude more than parent hadrons [4]. This idea led to the development of the EN-detector (electron and neutron detector). The EN-detectors, relatively simple, compact and cheap, can be easily deployed in an EAS array to record simultaneously thermal neutrons and the charged particles in the EAS front [2].

In a previous study [5] with the END-16-YBJ, we find that the number of neutrons recorded by the detector array varies in different time periods, lower number of detected neutrons in rainy season than that in dry season. So There are five soil moisture meters which are used to monitor the humidity in the soil near the EN-detectors were installed inside ENDA-16-HZS in August of 2020. With them, we explored the effect of humidity on the performance of the EN- detector.

2. Experimental Setup

The EN-detector is based on a special phosphor that is made in Russia, which is a granulated alloy of inorganic ZnS(Ag) scintillator added with natural B_2O_3 with the ^{10}B isotope about 20%. The ^{10}B captures thermal neutron via the reaction:

$$^{10}B{+}n \to ^7 Li^*(0.84MeV){+}\alpha(1.47MeV) \to ^7 Li{+}\alpha{+}\gamma(0.478MeV),\ Q = 2.310MeV, 93.7\%$$
$$\to ^7 Li(1.01MeV) + \alpha(1.78MeV),\ Q = 2.790MeV, 6.3\%$$

with cross section of 3980 barn. The phosphor is deposited in silicone rubber in the form of a thin one-grain layer. The scintillating compound grains are of 0.3 - 0.8 mm in size. The effective thickness of the scintillator layer is 50 mg/cm^2. Light yield of the scintillator is $\sim 160,000$ photons per neutron capture.

The EN-detectors were assembled and tested in a laboratory at Hebei Normal University, and then they are installed at LHAASO in Haizishan (HZS) Sichuan (4400m a.s.l.). The array is shown in figure 1, where the left plot is the location of the array inside LHAASO. In the right plot, the green squares are electron detectors (ED) and the black circles are EN-detectors, They are named ENDA-16-HZS, distributed by 4×4 , with distance about of 5m between adjacent detectors. The array uses a 32-channels, 14-bit, 50MS/s FADC, which records the counting rate of every detector and the trigger events in the array[6]. In August 2020, five soil moisture meters (WKT-SH1920) were installed at a distance of about 1.4m from the detector No.8. Their probes are buried in the soil and distributed vertically (figure 2 left), where the probe of No.1 soil moisture meter is uppermost, 0.2m from the ground, and the probe of No.5 is downmost, 2m underground (figure 2 right).

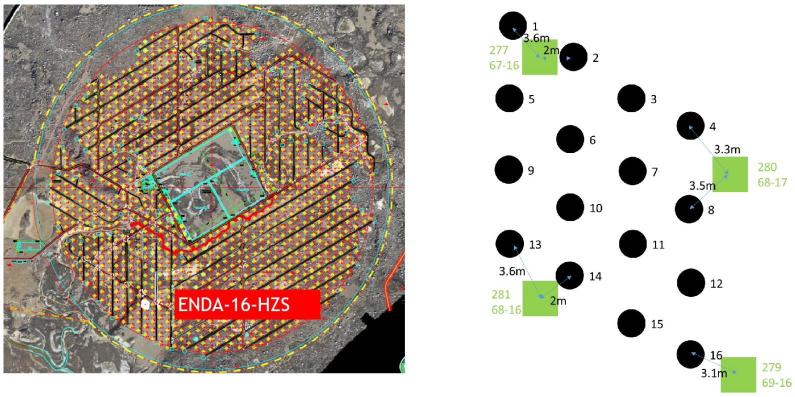

Figure 1: left: Location of ENDA-16-HZS inside the LHAASO. right: Configuration of ENDA-16-HZS. Black circles are EN-detectors; Green squares are EDs.

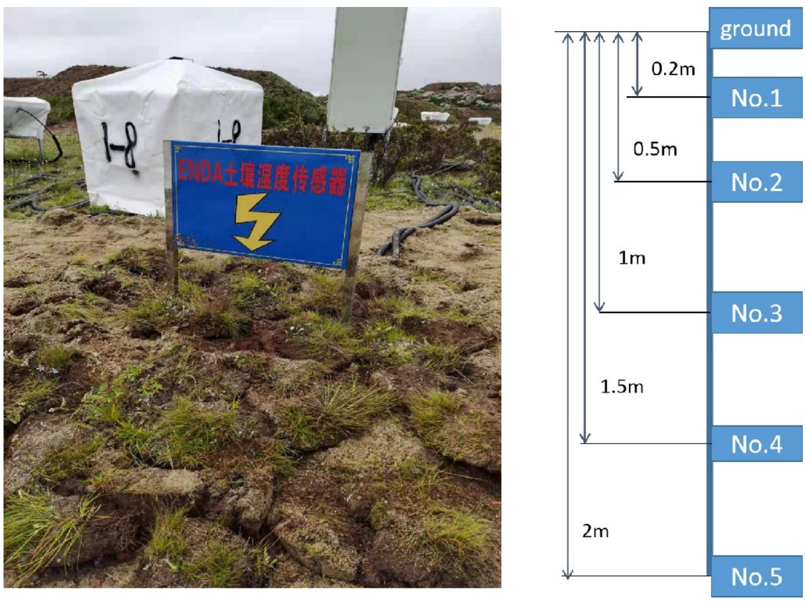

Figure 2: Configuration of soil moisture meters.

3. Result

The rain mainly occurred in September 2020, and only the humidity of No.1 and No.2, changed significantly during rainfall. Some detectors are affected by lightning and their work was not stable, so we select the detector 4, 5, 7, 8, 9, 10, 11 and 14 for the analysis. Counting rate of one detector is smoothed in 20-minute time window. It didn't rain on September 4, so the counting rate of that day is used as the standard , rate of which is denoted as R_b. The relative difference of detector's counting rate is,

$$\delta = \frac{R_n - R_b}{R_n} \times 100\%$$

Where δ is the relative difference value of the count rate, R_n is the counting rate. Figure 3 shows that linear fitting of profile of δ in each detector versus humidity of the No.1 soil moisture meter and the fitting parameters is listed in Table 1. Figure 4 is the linear fitting of profile of δ

in each detector versus humidity of No.2 soil moisture meter and the fitting parameters is listed in Table 2. Results indicate that counting rate is negatively correlated to humidity in soil.

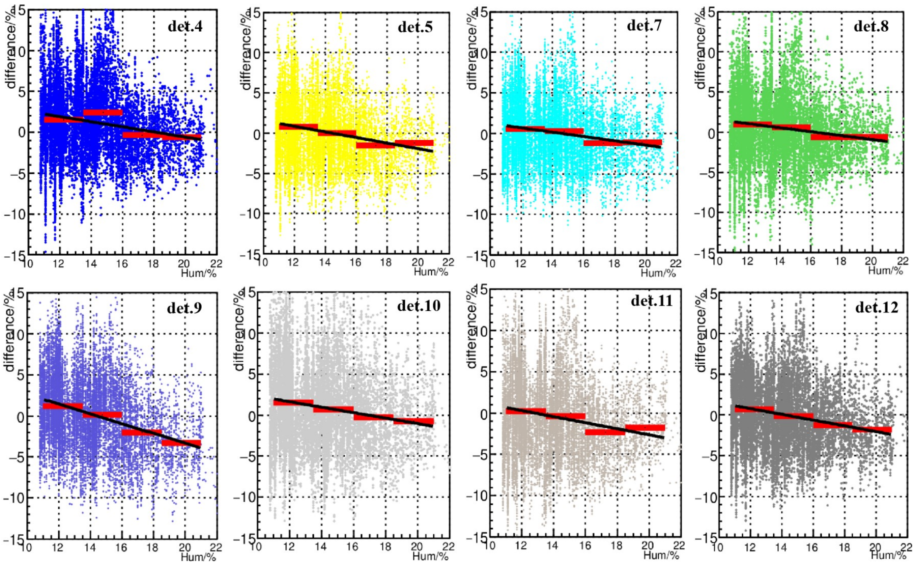

Figure 3: linear fitting of profile of δ vs humidity of No.1 soil moisture meter

Table 1: The fitting parameters of Figure3

detector number	4	5	7	8	9	10	11	14
p0	5.68	5.02	3.90	4.02	8.57	5.64	4.69	5.02
p1	-0.31	-0.35	-0.27	-0.25	-0.60	-0.33	-0.37	-0.35

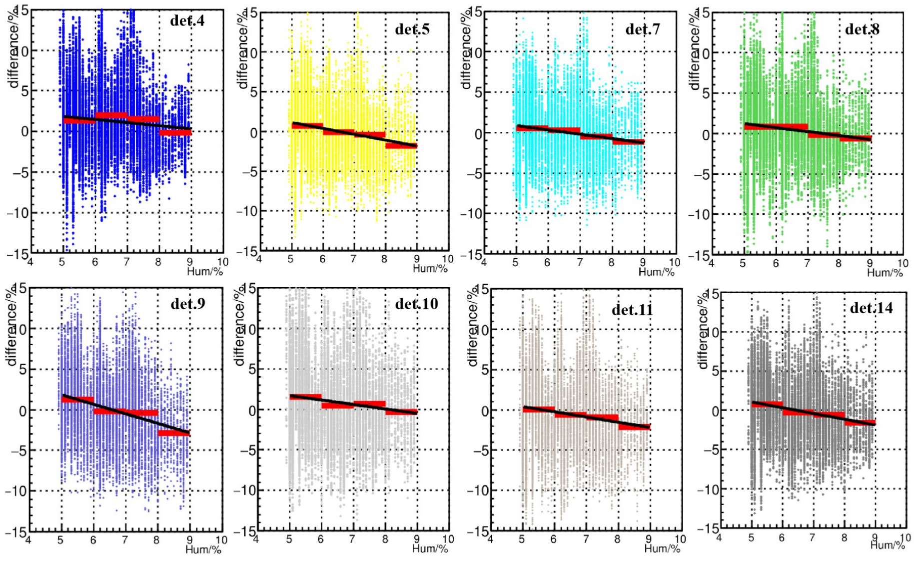

Figure 4: linear fitting of profile of δ vs humidity of No.2 soil moisture meter

Table 2: The fitting parameters of Figure4

detector number	4	5	7	8	9	10	11	14
p0	3.77	4.82	3.54	3.69	7.70	4.45	3.62	4.72
p1	-0.38	-0.74	-0.54	-0.50	-1.17	-0.55	-0.65	-0.73

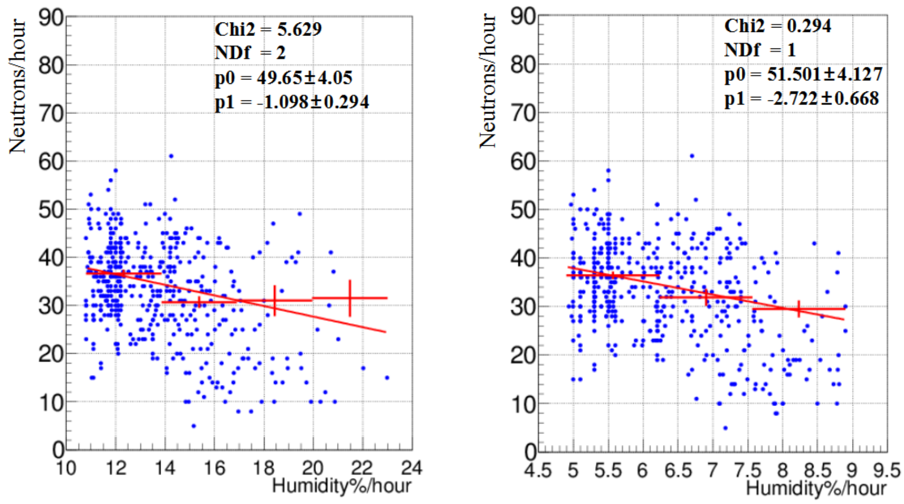

Figure 5: the linear fitting of of scattering plot of neutrons per hour vs humidity in soil

Meanwhile, the correlation between the number of neutrons in the trigger events and humidity in soil is also studied. The total number of neutrons in the trigger events recorded by the eight EN-detectors in every hour was counted in this month. As shown in figure 5, the left plot is the linear fitting of scattering plot of neutrons per hour vs humidity of No.1 soil moisture meter, and the right plot is the one corrected with the No.2 soil moisture meter. With the increase of humidity, the number of neutrons in the trigger events also reduces.

4. Conclusion

The ENDA-16-HZS is operating stably. By analyzing the data in September 2020, it is confirmed that when rainfall occurs, the humidity of soil vary differently in different depth, the count rate of EN-detector is got influence and it also affects the neutrons in the trigger events. We plan to get more data during the rainy season in 2021, so that to quantify the correlation parameters which are beneficial for correcting neutrons detected in EAS events and reducing systematic uncertainties in the energy spectrum unfolding for different primary cosmic ray components.

5. Acknowledgments

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