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Electron-Neutron Detector Array (ENDA), Status and Coincidence with the LHAASO Detectors

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Hadrons are the “skeleton” of extensive air shower (EAS). They possess favorable information concerning the cosmic ray components and energy. The electron-neutron detector (EN-detector) can detect both electrons and thermal neutrons generated by EAS hadrons in surrounding matter. The electron-neutron detector array (ENDA) was proposed to add into the LHAASO project to improve its capability of EAS hybrid detection. Up to present 64 EN-detectors have been produced and are running in China. In 2018, a cluster (16 EN-detectors) was installed at Yangbajing (YBJ), Tibet. In 2019, another cluster, so called ENDA-16-HZS, was installed in LHAASO at Haizishan (HZS), Daocheng, Sichuan. Besides, 2 clusters are tested at Hebei Normal University (HNU). ENDA-16-HZS is running and get amount of EAS events at energy above 100 TeV. Moreover, a number of coincident events between ENDA and the LHAASO electron detector (ED) and muon detector (MD) arrays composed the KM2A, as well as Cherenkov detectors WFCTA and WCDA are obtained. The events with cores falling into ENDA are selected. The ED array and ENDA accurately offers the EAS directions and the core positions respectively. Both the lateral distributions of neutrons, electrons and muons and the longitudinal development of atmospheric Cherenkov lights are effectively sampled. A hybrid detection of EAS including thermal neutrons, electrons, muons and Cherenkov lights can provide a strong capability of cosmic nuclei discrimination as well as energy measurement with high resolution. In this talk, the status of the clusters at the different places are summarized, and the preliminary results of coincident events between ENDA and the LHAASO array are presented.

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1. introduction

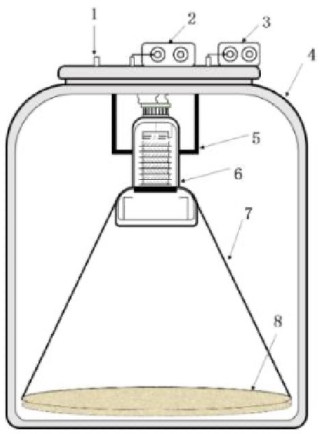
The cosmic ray energy spectrum basically obeys power law. But around $4 \times 10^{15} eV$, there is a steepening of the spectrum, so called "knee", which was discovered by many experiments, e.g., KASCADE[1], Tibet ASγ[2], ARGO/WFCTA[3], etc. In particular, high energy hadrons, which constitute extensive air shower (EAS) skeleton, may carry important information for multi-parameter correlation studies, since some hadronic observables, primarily the hadron number/electron number correlation, depend on the nature of the particle inducing EAS[4][5][6]. Thus, the detection of high energy hadrons, addressed 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 [5]. This idea led to design of the electron-neutron detector (EN-detector) which can record both thermal neutrons and charged particles, developed for the PRISMA project, made of an alloyed mixture of the inorganic scintillator ZnS(Ag) with ^{6}LiF [7][8][9]. The EN-detectors, relatively simple, compact and cheap, can be easily deployed in an EAS array to record charged particles and delayed thermal neutrons in the EAS front.

2. Prototypes of the EN-detector array (ENDA)

In order to check the performance of the EN-detector at a high altitude site, a small array composed of four EN-detectors (PRISMA-YBJ) was installed inside the hall hosting the ARGO-YBJ experiment at the Yangbajing (YBJ) Cosmic Ray Observatory (Tibet, China, 4300 m a.s.l.) [10]. Between ARGO-YBJ and PRISMA-YBJ, the coincident events generated by primary cosmic rays of energies greater than 100 TeV are selected. The correlation of these data confirms the excellent performance of the EN-detector [11]. Now the EN-detector was proposed to add into the LHAASO project to improve its capability of EAS hybrid detection. Under the Chinese-Russian cooperation, up to present 64 EN-detectors have been produced and are running in China. In 2018, a cluster (of 16 EN-detectors) was installed at Yangbajing (YBJ), Tibet. In 2019, another cluster so called ENDA-16-HZS was installed in LHAASO at Haizishan (HZS), Daocheng, Sichuan. Besides, two clusters are under test at Hebei Normal University (HNU).

Because ^{6}Li is expensive and its purchase is limited by governments, we turun to use ^{10}B as a replacement. Although the released energy while capturing neutrons is lower than ^{6}Li, ^{10}B has larger cross section, and it is much easier to be obtained. So a novel type of ZnS(Ag) scintillator alloyed with natural boron compound for thermal neutron capture is developed instead of ZnS(Ag) with ^{6}LiF. Powder of ZnS(Ag) and B_2O_3 alloy is mixed with optical liquid silicon rubber which is easier produced in big size, and also transparent for scintillation lights.

The structure of the EN-detector is illustrated in figure 1. The main component of the detector is a black polyethylene (PE) barrel with a 0.36 m^2 scintillator at the bottom and a 4-inch photomultiplier (PMT type of Beijing Hamamatsu CR-165), at the top. The distance between the scintillator and the PMT is 31 cm. To increase collection of scintillation lights, a tapered reflective layer, made of a 5 mm-thick EVA foam material, is placed inside the barrel.The detector is covered with a white PVC cloth against rain and sunshine. The EN-detector output includes weak and fast signals from charged particles, mainly electrons and positrons, and high, slow and delayed signals from thermal



1- HV input port.
2- d8 preamplifier (DIU).
3- d5 preamplifier (UI).
4- black PE barrel.
5- PMT fixed holder.
6-PMT.
7- light collecting cone.
8- scintillator.

Figure 1: EN-detector schematic diagram

neutron capture. This peculiar characteristic makes EN-detectors well suitable in the framework of EAS experiments. In one EN-detector array, 16 detectors are arranged as a cluster. When an air shower arrives at the cluster, the first pulse is the summed signal generated by many EAS electrons. This signal is used for triggering and energy deposit measurement. The thermal neutron pulses were recorded within 20 ms after triggering. If any 2 of 16 detectors coincided within the window of 1 μs, the flash analog-to-digital converter (FADC) (developed by Sichuan University) will perform the signal sampling. This is the first-level triggering. The online program then analyzed the received input signal and performed the second-level triggering, in a way as follows:
(1) At least 2 detectors produce a first-level triggering, with signals $\geq$ 10 minimum ionizing particles (m.i.p.s);
(2) The total energy deposit power measured is 125 MIPs;
(3) The number of thermal neutrons recorded is $\geq$ 3.
If these 3 conditions are met simultaneously, the full pulse waveform is recorded. In addition, the online program generates a software trigger signal every 5 minutes in order to measure the background thermal neutrons.

In order to check the performance of the new type EN-detectors at a high altitude site, we built a cluster of EN-detectors at Tibet University (TU)(3700 m a.s.l.) [12]. The cluster was moved to YBJ at the end of 2018 to combine with YBJHA [13][14] for further performance test. Distance among adjacent detectors is 5 m and the area of a cluster is 225 m^2. Arrival time of an event is measured by the network timing protocol (NTP) method. NTP is a networking protocol for continuous clock synchronization of computer systems to internet time server. NTP can provide timing with a precision of some 10 ms to Coordinated Universal Time (UTC). Coincident events are obtained between the cluster and YBJHA [15]. The operation results revealed that the detectors are able to detect both EAS electrons and EAS thermal neutrons well at a spacing of 5 m, which is still less than characteristic LDF parameter for EAS hadrons. The efficiency of thermal neutron detection depends on water content in the surrounding matter. The drier the weather, higher is efficiency of thermal neutron detection but we demonstrated that the seasonal effect is of about 10% only. Moreover, long data taking of several years will average this effect making it negligible for EAS study [16].

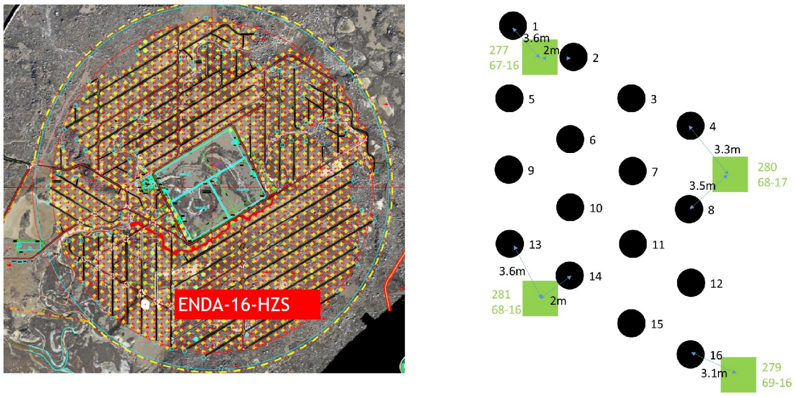


Figure 2: left: The white diamond is location of ENDA inside LHAASO. right: Configuration of ENDA. Black circles are EN-detectors. Green squares are EDs

In 2019, another cluster so called ENDA-16-HZS was installed in Large High Altitude Air Shower Observatory (LHAASO) [18][19][20] at Haizishan (HZS, 4400 m a.s.l.), Daocheng, Sichuan. LHAASO consists of 1.3 km^2 array (KM2A) of electromagnetic particle detectors (EDs) and muon detectors (MDs), water Cherenkov detector array (WCDA) with a total active area of 78,000 m^2 and wide field-of-view air Cherenkov telescopes array (WFCTA) including 18 telescopes. ENDA-16-HZS is located inside the first 1/4 of one km^2 array (KM2A) (figure 2, left plot). The 16 detectors are configured in array of 4×4 in equilateral triangle with side length of 5 m (Figure 2 right plot). Same as LHAASO, ENDA-16-HZS is synchronized to GPS time by using the White Rabbit clock system. ENDA-16-HZS is running normally and get amount of EAS events at energy above 100 TeV. A number of coincident events among ENDA, KM2A and WFCTA are obtained. Figure 3 shows one coincident event, where EDs measures lateral distribution of electrons, MDs measures lateral distribution of muons, three telescopes of WFCTA record atmospheric Cherenkov light images, and ENDA measures both lateral distribution of thermal neutrons and lateral distribution of electrons near the shower core. Lateral distributions of different types of particles of the coincident event is shown in figure 4. Electrons of KM2A-ED are divided by 3 because each ED is covered by a lead used as converter of gamma rays into electron-positron pairs so that it detects electrons higher than ENDA. Further analysis will be done when statistics increases.

3. Summary and Expectation

This talk is addressed to test of the new type EN-detector in the framework of EAS measurements at high altitude. The originality of EN-detector lies in simultaneously recording the EAS charged component and the thermal neutrons generated by high energy hadrons. Two ENDA-16 arrays are running smoothly and the first results of coincidence to YBJHA and LHAASO individually confirm that the array works properly at high altitude.

Up to now, ENDA has totally 66 detectors (ENDA-64 and the other two as backup), including one cluster at YBJ, one at LHAASO, and two tested at Hebei Normal University (HNU), Shijiazhuang, Hebei. ENDA-64 is ready for deploying inside LHAASO in the near future. ENDA-64

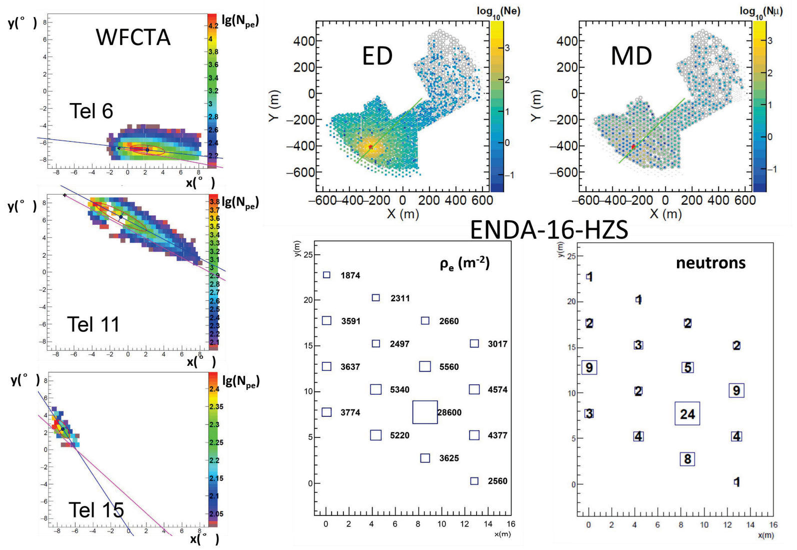


Figure 3: One coincident event between ENDA and LHAASO. In the ED plot, x and y are coordinations of EDs, and z is logarithm of electrons (Ne). In the MD plot, x and y are coordinations of MDs, and z is logarithm of muons (Nμ). In the WFCTA plots, x and y are coordinations of focal plane in the telescope, and z is logarithm of photoelectrons (N$_{pe}$). In two ENDA-16-HZS plots, x and y are coordinations of EN-detectors, and z is electrons density and neutrons respectively.

will have an effective area of 1000 m^2 so as to in one or two years obtain high statistics of data for studying energy spectrum of light components (H and He) [21]. After it, ENDA will be extended to 400 detectors with array area of 10000 m^2 to study energy spectrum of heavy components such as iron.

4. Acknowledgement

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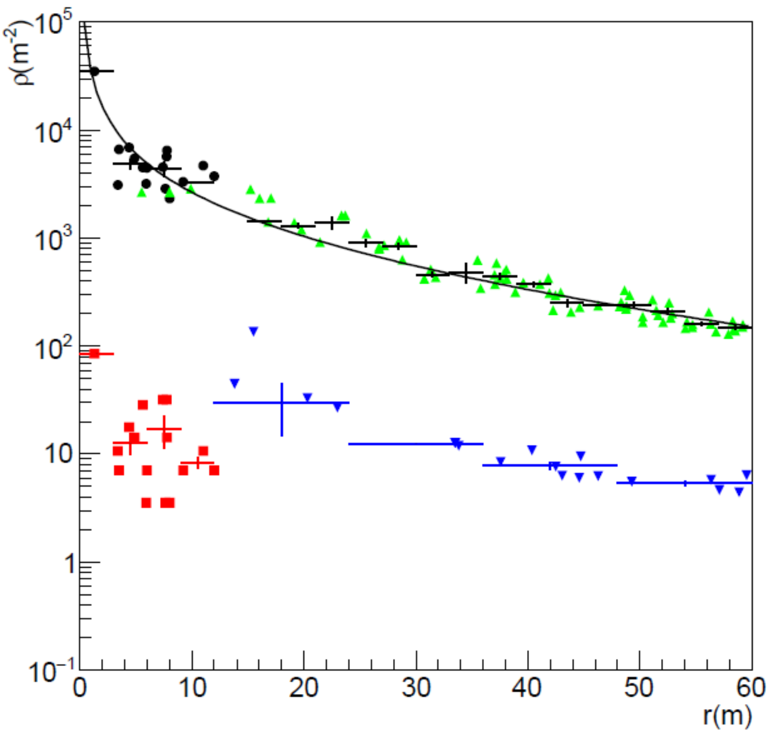

Figure 4: Lateral distribution of the coincident event. Red square: neutrons by ENDA. Blue triangle: muons By KM2A-MD. Black dot: electrons by ENDA. Green triangle: electrons by KM2A-ED. The black line is NKG function fitting.

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