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A Study on the Effect of the Lead Plate on the Shower Front in the prototype array of LHAASO-KM2A

Jia Liu*
Institute of High energy physics
E-mail: jialiu@ihep.ac.cn

Xiangdong Sheng
Institute of High energy physics
E-mail: shengxd@ihep.ac.cn

HongKui Lv
Institute of High energy physics
E-mail: lvhk@ihep.ac.cn

A prototype array for the LHAASO-KM2A, which consists of 39 detector units, was set up at the Yangbajing cosmic ray observatory (4300m a.s.l., Tibet, P.R. China) and has been in stable operation since October 2014. The experiment, which is comparisons with the lead plate on the detector units and no lead plate on the detector units, are presented. In this paper, we present the results on the effect of the lead plate on the shower front.

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*Speaker.

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1. introduction

The Large High Altitude Air Shower Observatory (LHAASO) project plans to build a hybrid extensive air shower (EAS) array in an area of 1 km^2 at an altitude of 4410m a.s.l. in Sichuan province, China, aiming for very high energy gamma ray astronomy and cosmic ray physics around the spectrum of knee[1][2][3]. With a sensitivity of 1% Crab unit, LHAASO will survey the entire northern sky for gamma ray sources with full duty cycle. The spectra of all the sources in its field of view will be measured simultaneously over a wide energy range from 300 GeV to 1 PeV. This will offer a great opportunity for identifying cosmic ray origins among the sources. Equipped also with Cherenkov/fluorescence telescopes and in-filled burst detector array, LHAASO will serve as the most effective detector for energy spectrum measurement of different mass groups of cosmic rays. It consists of 1 km^2 array (KM2A), 90,000 m^2 water Cherenkov detector array (WCDA)[4], 24 wide field Cherenkov telescopes (WFCTA), and 5,000 m^2 shower core detector array(SCDA)(Fig.1). The KM2A is comprised of 5194 electromagnetic particle detectors (EDs) and 1221 muon detectors (MDs)[5]. The KM2A EDs are distributed with a spacing of 15 m in a large area of 1 km^2. Each 0.5cm-thick lead converter will cover one ED in order to increase the number of charged particles by conversion of shower photons and to reduce the time spread of the shower front.

In order to investigate both the ED's performance at high altitude and the effect of lead converter on the shower front, a prototype array, which consists of 39 EDs, was set up at the Yangbajing cosmic ray observatory (4300m a.s.l., Tibet, P.R. China) and has been in stable operation since October 2014. The present paper is a report of the prototype array experiment.

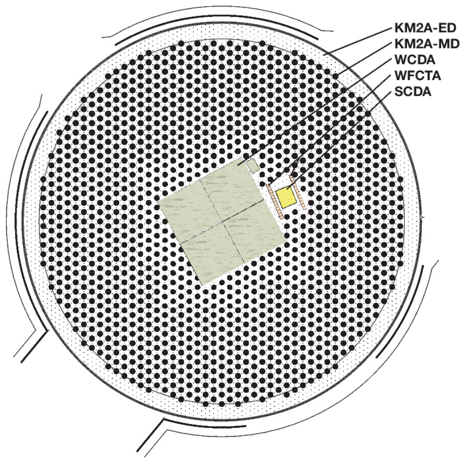

Figure 1: Sketch of LHAASO.

2. The KM2A-ED prototype array

Figure 2 shows a schematic view of an ED (100cm*100cm*2cm) which consists of 4*1 plastic scintillation tiles (100cm*25cm*2cm each). 16 single-cladding wavelength-shifting fibers (BCF92) 1.5mm in diameter and 270cm long are threaded into holes 1.6mm in diameter in each tile to collect scintillation lights generated by charged particles that are interjecting in the tile. Each fiber is threaded two grooves uniformly spaced in 9.375cm. There are 1 m^2 of 0.5cm thickness lead that placed on the plastic scintillation tiles. For each ED, one XP2012B PMT is connected to all ends of the fibers from 4 tiles and used to collect scintillation lights. Each PMT is supplied by a Program controlled high pressure module, thus the high voltage of each PMT can be adjusted independently.

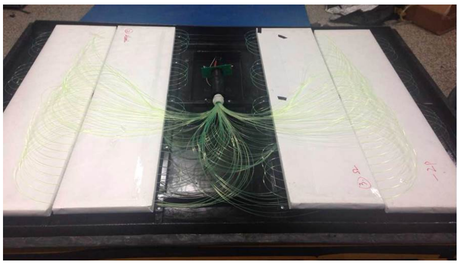

Figure 2: A schematic view of an ED.

For the KM2A prototype array, a total of 39 EDs are uniformly distributed in Yangbajing with the same spacing (15m) as the one proposed for KM2A(Fig3).[5]

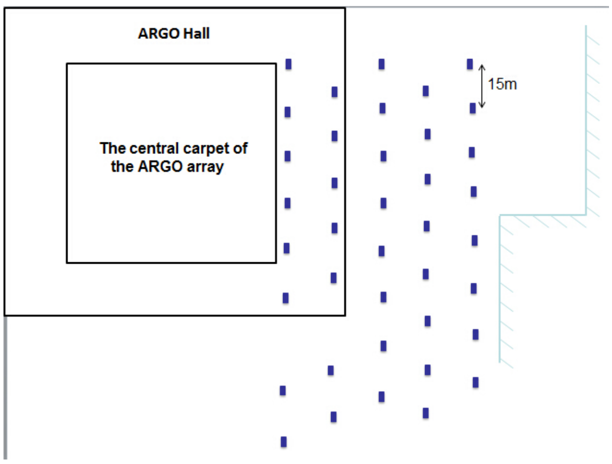

Figure 3: Sketch map of the KM2A prototype array in Yangbajing.

In the prototype array, we are not able to determine the core position; therefore we use a plane as the fitting function. Moreover, the estimated arrival direction is relatively free from the curvature effect because we sample only a small portion of the shower front.

3. Electronics and data acquisition

The front-end electronics (FEE), which follows PMTs of EDs, are installed in the detector housings. The signals from the PMT's Anode and Dynode are transferred to the FEEs via two short cables about 0.5 meters long. The FEEs discriminates the Anode's signals according to a preset threshold. Once a single channel fires, the signalsąŕ charges are measured with a resolution of 25% at 1.28pC and 1% above 5pC by two independent shaping circuits, and then digitalized by a 62.5MHz FADC. A FPGA based TDC with a resolution of 1ns and a jitter lower than 0.5ns is design to measure the arrival of Anode signals. The trigger time is recorded by the White

Rabbit(WR) timing system[6]. At the same time, a peak finding window of 384ns is triggered since the charges of Anode signals are greater than the preset threshold. The charges and time of events are assembled in FPGAs and then transferred to a PC via WR networks.

Data acquisition software is deployed on the PC, connecting to each FEE channel through WR switch. The core tasks of DAQ software are FEE data readout and soft trigger. Each FEE's sends digital data to DAQ system through unreliable UDP protocol, but the percentage of lost packages is monitored by DAQ readout module to ensure the data quality. The digital data stream sends to the soft trigger module. According to the timestamp provided by the WR timing system, the trigger module will calculate the hit multiplicity in a time window of 200ns. If the hit multiplicity exceeds 5, a physical event will be generated, which includes the time and charge of all hits in a time window of +/-5microseconds.

4. Detector Calibration

For each ED, the time resolution, the relative time offsets among the different EDs, detection efficiency and single particle spectrum in case of minimum ionization particles (MIP) are measured by a telescope system. The telescope detectors work in coincidence mode to select MIPs in secondary cosmic rays, which act as the test beam and trigger the whole system. All the detectors are connected to the electronics and data acquisition system described above. The typical detector time resolution measured is about 2ns and the most probable value of the single particle spectrum is approximately 20 photoelectrons. The single channel counting rate of each channel was measured. The final trigger threshold for each channel is set to 1mV. The resulting detection efficiency is higher than 95% and the single rate is about 2 kHz.

5. Effect of 0.5cm lead plate on shower front

The consequences of placing a 0.5cm lead plate on the detector are, qualitatively:(1) absorbtion of low energy electrons and photons which no longer contribute to the time signal;(2) multiplication process of high-energy electrons and photons which produces a signal enhancement. The lead converter thus reduces the temporal fluctuations: the contributions gained are concentrated near the ideal time profile since the high energy particles travel near the shower front while those lost tend to lag far behind. In order to study the effect of the lead on shower front we have taken two experiments.

5.1 The 0.5 cm lead plate on only one detector

In order to guarantee the similarity of the size of shower that triggers the array before and after the lead plate is placed, we place the lead plate on only one detector. The parameter variations of the detector are observed before and after the lead plate is placed.

The charge distribution is shown in Fig.4 for showers before and after the lead was installed. Since the multiplication process of high-energy electrons and photons enhance the signal, a comparison at fixed rate indicates an increasing of mean of charge due to the effect of the lead of 55%,
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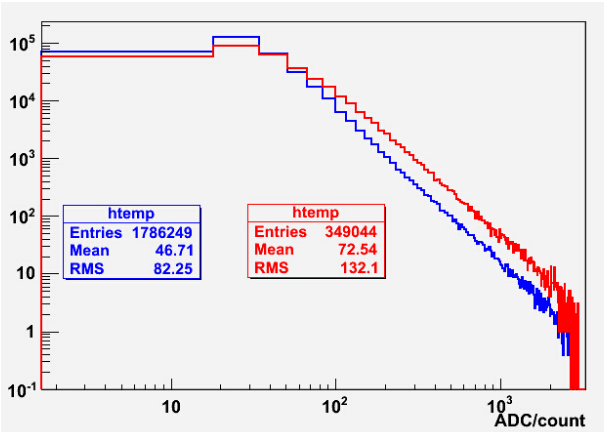

Figure 4: The charge distribution before (blue) and after (red) the lead was placed on the detector.

The distribution of time residuals t = t_i - t_{plane}, exhibits a long tail due to time fluctuations and to the curved profile of the shower front. The width of time residuals distributions is related to the time thickness of the shower front. Since the position of the shower core is not reconstructed, the experimental result concerns a time thickness averaged on different radial distances. Fig.5 show the distribution of time residuals before and after the lead was installed. After the lead was installed on the detector, the time residual of the detector have smaller than before. One reason is more high-energy particles trigger the detector, the another is low energy electrons and photons no longer contribute to the delay time.

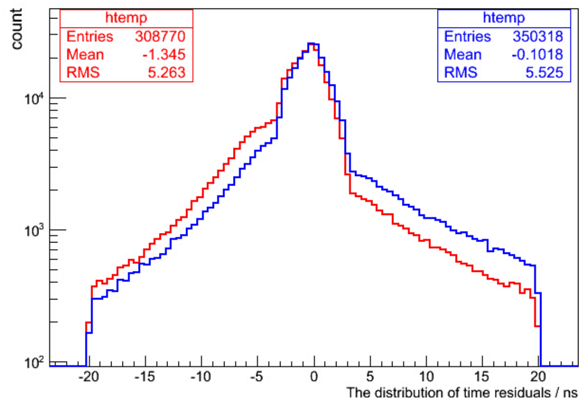

Figure 5: The distribution of time residuals before (blue) and after (red) the lead was placed on the detector.

5.2 The 0.5cm lead plate on all detectors

The prototype array has been used to collect about 8.5^6 shower events without 0.5 cm lead plate and also collect about 8.5^6 shower events with 0.5cm lead plate in October 2014. So we can study the effect of the lead plate on the shower front.

The angular resolution of the prototype array has been estimated by dividing the detectors into two independent sub-arrays and comparing the two reconstructed shower directions. Events with

N total hits have been selected according to the constraint $N_{odd} \simeq N_{even} \simeq N/2$. The even-odd space angle $\triangle\Theta_{eo}$ is shown in Fig.6 for showers reconstructed before and after the lead was placed. The improvement of the angular resolution is a factor∼1.35 for N > 20. We show in Fig.7 the mean of the distribution of $\triangle\Theta_{eo}$ as a function of hit multiplicity for showers reconstructed before and after the lead was placed.

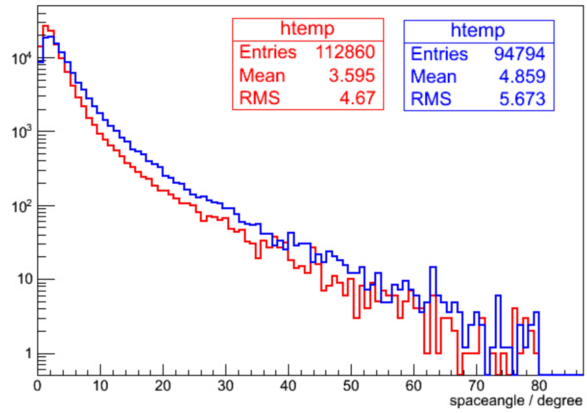

Figure 6: The distribution of the space angle between two sub-arrays before (blue) and after (red) the lead was placed on the detectors.

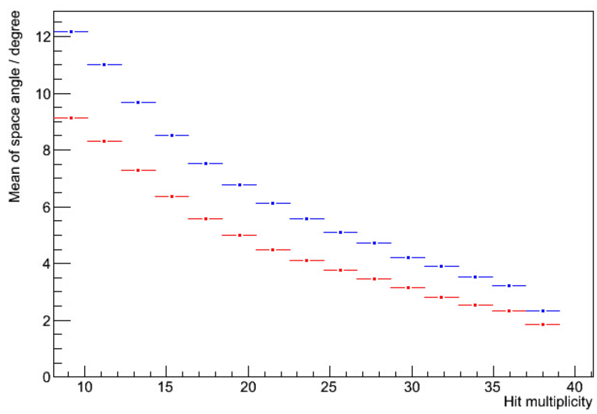

Figure 7: Mean of space angle distribution as a function of hit multiplicity for showers reconstructed before (blue) and after (red) the lead was placed

6. Conclusions

A prototype array, which consists of 39 EDs, was set up at the Yangbajing cosmic ray observatory (4300m a.s.l., Tibet, P.R. China) and has been in stable operation since October 2014. In the paper, the effect of 0.5cm lead plate placed on one ED and placed all EDs has been investigated. An increase 55% of the mean of charge is found. The improvement of the angular resolution depends on the shower density.

Acknowledgements

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