Performances of the LHAASO-KM2A engineering array

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Abstract: An engineering array for the LHAASO-KM2A, which consists of 42 detector units and fully overlaps the ARGO-YBJ experiment, was set up at the Yangbajing cosmic ray observatory and has been in stable operation since Oct. 2010. A telescope consisting of 2 scintillation detectors is used to continuously monitor the stability of a detector unit. The resulting performances of the KM2A electromagnetic particle detector prototypes fully meet the requirements. Through hybrid observation of cosmic ray showers with the ARGO-YBJ experiment, the performances of the engineering array are tested and the results are consistent with expectation. The long term stability of the array is also presented.

Keywords: LHAASO, KM2A, engineering array, electromagnetic particle detector

1 Introduction

The Large High Altitude Air Shower Observatory (LHAASO) project focuses mainly on the study of sub-TeV-1Pev gamma ray astronomy and 5Tev-1Eev cosmic ray physics by using a compound detector array distributed in one square kilometer [1]. It consists of 1 km^2extensive air shower array （KM2A） with 40,000 m^2 muon detectors, 90,000 m^2 water Cherenkov detector array, 5,000 m^2 shower core detector array and a wide-angle air Cherenkov/fluorescence telescope array. As the major array of LHAASO, KM2A [2] is comprised of 5137 electromagnetic particle detectors (EDs) [3] and 1161 muon detectors (MDs) [4]. An engineering array of 1% size of KM2A was built at the Yangbajing cosmic ray observatory (4300m a. s. l.) and has been in operation since October 2010 to test the validity of the design and to study the performances of the detector units and the array.

2 Experiment setup

A KM2A ED (1m×1m) consists of 4×4 plastic scintillation tiles (25cm×25cm×2cm each) packed in an aluminum box [Fig. 1].

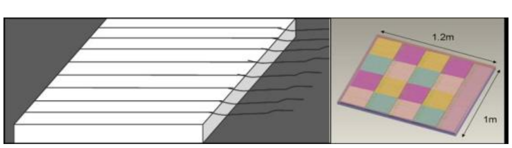

Figure 1.Schematic of an ED tile (left) and an ED (right).

Eight wavelength-shifting fibers (BCF92) of 1.5 mm in diameter and 30 cm long in each tile collect the scintillation lights generated by charged particles. One end of each BCF92 fiber is coated with aluminum layer to reflect the photons, while the other end is coupled to a single-cladding optical fiber (BCD98) of 180 cm long. A photomultiplier tube (PMT, XP2012B) collects the photons from the 128 fibers. Signals from each PMT are transferred through coaxial cables of 45 m long to a so-called local station, where the front-end electronics (FEE) discriminate the signals according to a preset threshold. Once a single channel trigger is generated, the trigger time is recorded by a FPGA-based TDC with a resolution of 1.56 ns and a jitter lower than 0.78ns, while the signal charge is measured by a shaping and peak-finding system based on FADCs with a resolution of 20% at 1 pC and 1% above 5 pC. With a high/low gain design for each channel, a dynamic range of 3.5 orders of magnitude is achieved for signal charge measurement. A trigger board collects the single channel trigger information and calculates the hit multiplicity in a time window of 400 ns. If the hit multiplicity exceeds 5, an event trigger will be generated and broadcasted to the FEEs, on the receiving of which the time and charge of all hits in a time window of ±5 microseconds are saved in a FPGA buffer for the data acquisition system to read. The event trigger time is recorded by a GPS-based event timing system with an accuracy of about 20 ns. A detailed description of the electronics and data acquisition system can be found in

[5].

For the KM2A engineering array, a total sum of 42 detector units are uniformly distributed in the central carpet of the ARGO-YBJ array [引ARGO] with the same spacing (15 m) as the one proposed for KM2A. The engineering array fully overlaps with the ARGO-YBJ carpet, covering a total area of about 75m×75m [Fig.2].

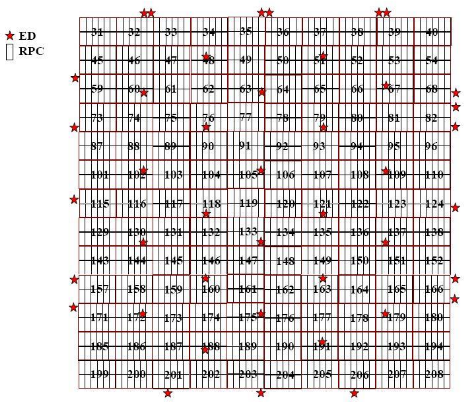

Figure 2.Sketch map of the KM2A engineering array in the ARGO-YBJ array. Each red star represents a detector unit.

3 Performances of the KM2A engineering array

A telescope consisting of 2 scintillation detectors (25cm×25cm×4cm each) was constructed to calibrate the single particle spectrum, detection efficiency, time resolution and offset of each detector unit. About 20 p.e. are emitted from photocathode of each PMT in case of single particle. Each tile has good amplitude uniformity with non-uniformity less than 5%. The time resolution is better than 2 ns, as designed. The single particle spectrum of each detector was measured both in Beijing and at Yangbajing. A slight difference due to transportation and different environment can be seen from Fig.3. The large difference among detector units comes mainly from the different PMT gains at the same high voltage. The high voltage of each PMT is then adjusted accordingly to achieve a uniform response from each channel.

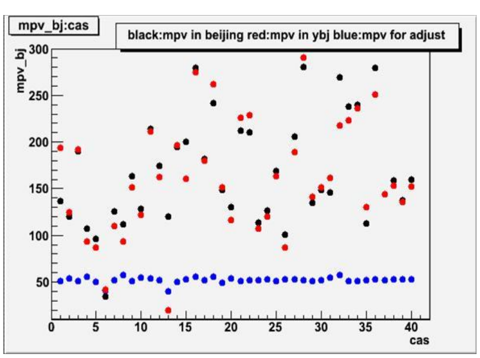

Figure 3.Mean amplitudes of all detector units in case of single particle measured in Beijing (black), at Yangbajing (red) and after high voltage adjustment (blue).

We measure the single channel counting rate of each channel while changing its trigger threshold. Fig.4 shows an example. The trigger threshold for each channel is set to 25% of the MPV of the single particle spectrum. The resulting detection efficiency is higher than 95% and single rate is lower than 1 kHz.

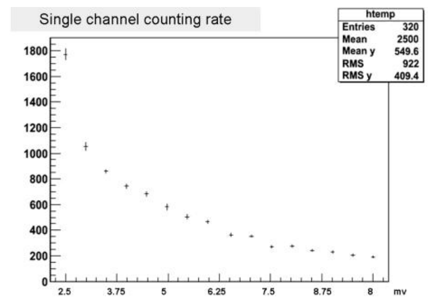

Figure 4.Single channel counting rate vs. threshold value.

3.1 Trigger rate

The KM2A engineering array started data taking in October 2010. The trigger rate is about 48Hz with an event trigger threshold of >4 hits as shown in Figure 5.

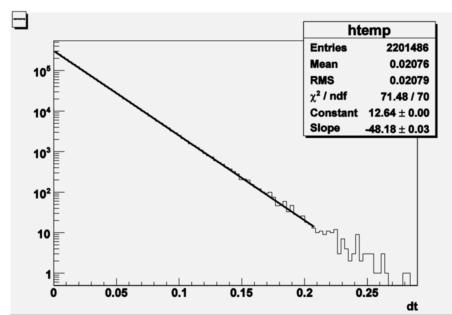

Figure 5.Distribution of event time intervals.

Each day about 1.5 GB data are generated and transferred to Beijing. More than 95% shower events of the KM2A engineering array match with the events of ARGO-YBJ in a time window of ±500 ns. Figure 6 shows an example shower front observed by ARGO-YBJ and the KM2A engineering array.

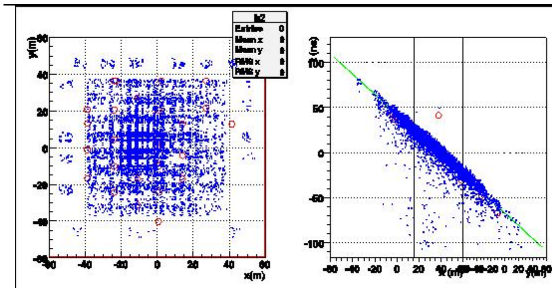

Figure 6.An example shower front observed by ARGO-YBJ (blue) and the KM2A engineering array (red). The green line in the right shows the shower plane reconstructed by the engineering array data.

Since the engineering array fully overlaps with the ARGO-YBJ central carpet, the event rates of the engineering array under different event trigger thresholds can be estimated by using the ARGO-YBJ data. The measured and estimated event rates are consistent as shown in Fig.7.

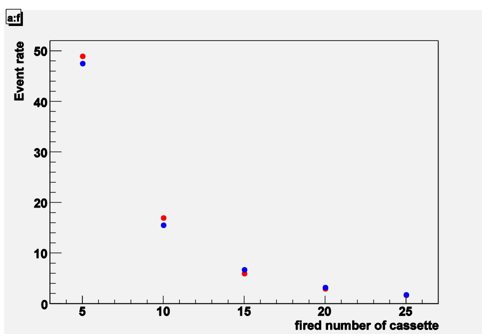

Figure 7.The measured trigger rates vs. event trigger threshold (blue) is consistent with that estimated by the ARGO-YBJ data (red).

3.2 Data reconstruction

The primary direction is reconstructed by using a planar fit to the time profile measured by the engineering array with the hit time corrected according to the calibrated time offset. Figure 8 shows the distribution of the incident zenith angle and the distribution of the incident azimuth angle as obtained from the data of the KM2A engineering array and ARGO-YBJ matched event.

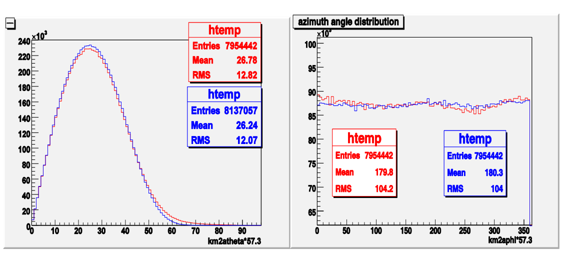

Figure 8.Comparison of the zenith angle and the azimuth angle distributions measured by the KM2A engineering array (red) and ARGO-YBJ(blue).

3.3 Angular resolution

Figure 9 shows the distribution of space angle between the shower directions independently measured by the engineering array and ARGO-YBJ for events with more than 20 hits in the engineering array and ARGO-YBJ reconstructed core location of 10 m to the center of the array.

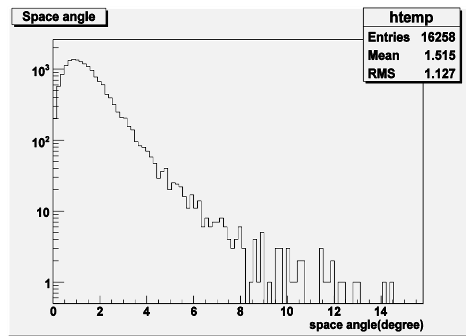

Figure 9.Distribution of space angles between the shower directions measured by the KM2A engineering array and the ARGO-YBJ experiment.

The angular resolution of the engineering array is estimated by:

$$\sigma_{km2a} = \sqrt{\sigma_{spatial}^2 - \sigma_{ARGO}^2}$$

Where σ_{km2a} is the angular resolution of the KM2A engineering array; $\sigma_{spatial}$ is the resolution of the space angle; σ_{km2a} is the angular resolution of the ARGO.

Table 1 shows the angular resolution of the engineering array in different hit ranges. For KM2A the expected angular resolution should be better than that of the engineering array in the same hit range since the fired detectors are expected to be distribute in a large area. This is consistent with Monte Carlo simulation results [6]. It should be mentioned that the above formula is correct only when the pointing errors of both arrays are negligible.

Km2a nhit	ARGO nhit	Shower Energy	Angular resolution(in degree)
>5	1904	13Tev	2.0
>10	3466	35Tev	1.4
>15	5039	50Tev	1.2
>20	6610	100Tev	1.1
>25	8176	140Tev	1.0

>30	9684	180Tev	0.9

Table 1.Angular resolution of the KM2A engineering array

3.4 Long term stability

The engineering array has been continuously operated for about 6 months. The long term stability of the detector performances is studied. From 6 months' data, we study three parameters: event rate, single muon charge and time resolution. The monitoring of the three parameters allows us to monitor the status of the detector. Figure 10 shows the long term stability of the event rate.

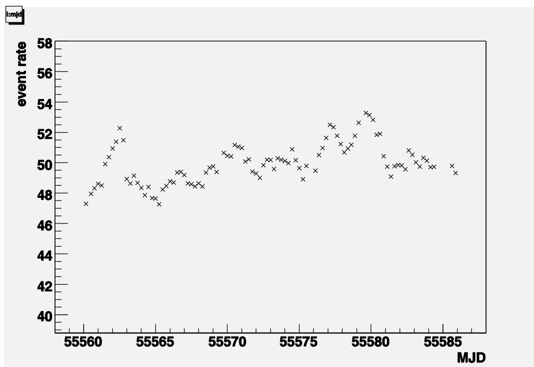

Figure 10.the event rate vs. MJD time for the KM2A engineering array.

From the pre-trigger part of the QADC, we get the single muon average charge. The data was analyzed offline. The long term stability of the single muon average charge is shown in Figure 11. Through monitoring the single muon average charge, we can monitor the relative gain (PMT+electronic) of all the detectors.

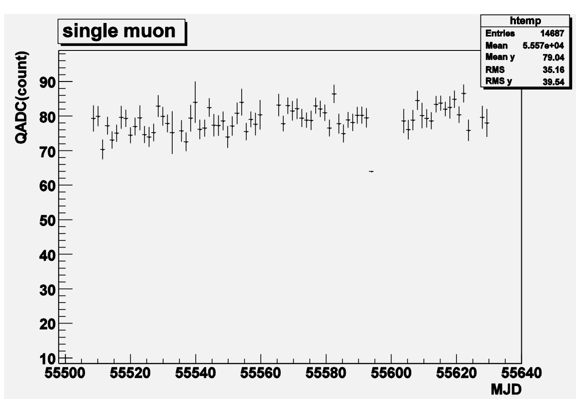

Figure 11.the amplitude of the single muon vs. MJD time for one cassette.

The telescope consisting of two small scintillation detectors is used to monitor the long term stability of the time resolution of one cassette. The RMS /mean of the time resolution is less than 2%.

4 Conclusion

An engineering array with 1% size of the LHAASO-KM2A is set up in the Yangbajing cosmic ray observatory fully overlapping with ARGO-YBJ. The performances of the array are studied through hybrid observation of cosmic ray showers with ARGO-YBJ. The results meet the design requirements. Under the high altitude environment, the engineering array has been stably running for about 6 months, helpful to the design and optimization of the full array of LHAASO-KM2A.

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