The performance of the LHAASO-KM2A tested by the cosmic-ray Moon shadow

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Abstract:

The performance of the half array of the KM2A, including the pointing error, angular resolution, long-term stability and absolute energy scale of the primary cosmic-ray particles, are tested through the observation of the characteristics of the cosmic ray Moon shadow, which includes the position displacement, shape, deficit, and their variation with the time and energy. In particular, the pointing errors for showers from different declinations are discussed in this work.

1. The LHAASO-KM2A

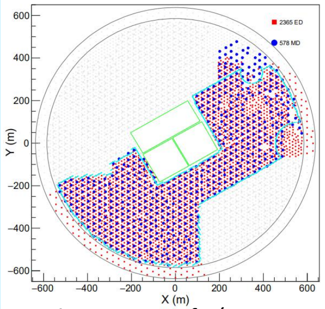

Fig.1 Layout of 1/2 KM2A.

The LHAASO is a new-generation complex EAS array being constructed in China (100.01° E, 29.35° N). And the half of KM2A in it includes 2365 electromagnetic particle detectors(EDs) and 578 muon detectors(MDs)[1]. It has been successfully operated from November 2019 to December 2020.The average duty cycle is higher than 90%. The simulation data, mainly protons, are generated where the energy is from 1 TeV to10 PeV and the zenith angle is sampled from 0° to 70°.

2. Data analysis

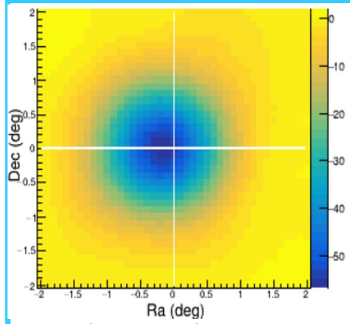

Fig.2 significance map of the Moon shadow.

Data selection:

(1) $\triangle\theta_{sun\&moon}>5°$

(2)Zenith angle<50°

Nine N_{fit} data groups (the number of fired EDs after filtering out the noise) is divided according to the reconstructed energy. The background is estimated by the direct integral method[2]. The satistical significance is calculated by the Li&Ma's formula(9)[3] with taking into account the angular resolution. The position and shape information of the Moon shadow is obtained by 1D projection of the signal events and gaussian fitting.

3. Array performance

3.1 Pointing accuracy

The Earth's magnetic field near the north-south direction will not make the Moon shadow move in the north-south direction, so the position of Moon shadow in the north-south direction can represents the pointing accuracy[4, 5]. The pointing accuray for different Nfit, zenith angles and declinations is investigated in Fig. 3. The pointing error is 0.02° ± 0.01°, and it is same for different zenith angles and the sources on different declination bands.

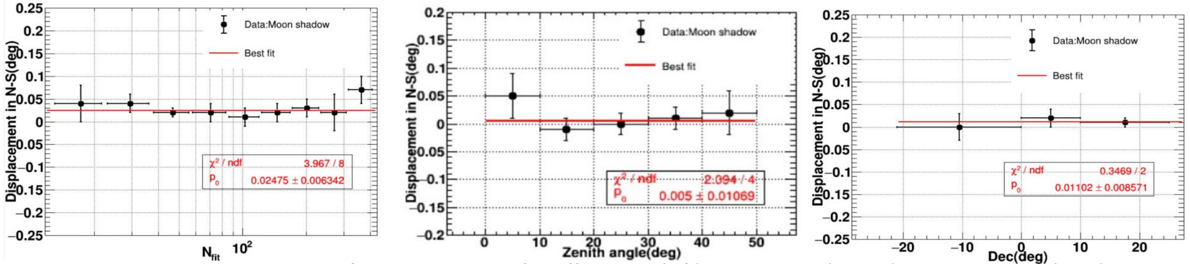

Fig.3 The N-S direction displacement of the Moon shadow for different N_{fit} (left), zenith angles(middle), and Declinations(right).

3.2 Angular resolution

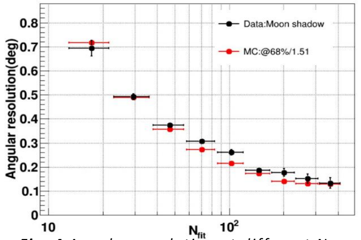

Fig. 4 Angular resolution at different N_{fit} obtained from the observation and simulation.

According to the results[5], the angular resolution can be approximately calculated by the RMS of the Moon shadow in the N-S direction:

$$RMS = \sigma\sqrt{1+\left(\frac{R_{Moon}}{2\sigma}\right)^2}$$

where R_{Moon} and σ are Moon radius and the angular resolution. The result is shown in Fig4. It is in agreement with the angular resolution obtained by the simulation.

3.3 Absolute energy scale

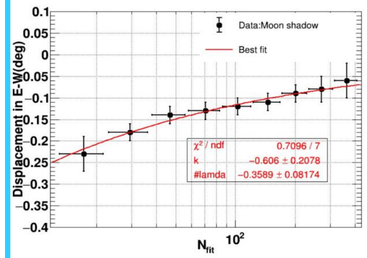

Fig. 5 The displacement of the Moon shadow for different Nfit along the E-W direction.

In Fig.5, As N_{fit} increases, the displacements of the Moon shadow in E-W direction decrease . We use kN_{fit}^{λ} to fit this change and get $(0.60\pm0.19)N_{fit}^{(0.36\pm0.08)}$. More research on the absolute energy scale will be carried out in the future.

3.4 Long-term stability

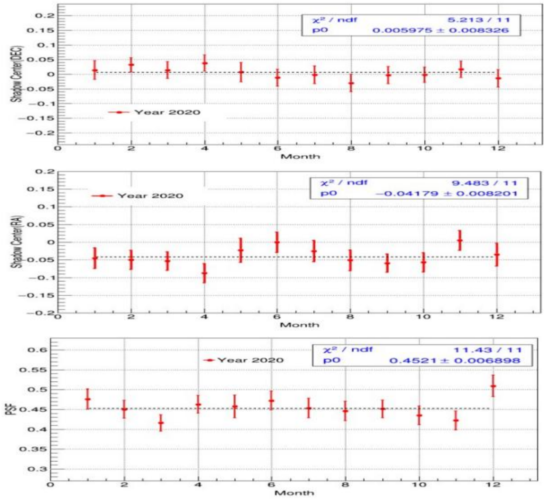

Fig.6 The variation of the declinations, the right ascensions, and the angular resolution of Moon shadow with month.

In order to explore the long-term stability of the array, we monitored the position and angular resolution of the Moon shadow every month. The results are summarized in Fig.6. We can see that the data is stable for different months within the error range of nearly 1σ.

4. Conclusion

The performance of the half of KM2A is tested by the Moon shadow. The pointing error is 0.02° ± 0.01°. The angular resolution from the Moon shadow is in agreement with that from the simulation. The relationship between the displacement of the Moon shadow along the E-W direction and N_{fit} is also calculated to satisfy $((0.60 \pm 0.19)N_{fit}^{(0.36\pm0.08)}$. Through monitoring the position of the Moon shadow, and the angular resolution variance as time goes by, we find the detector is very stable. Besides, we find that the accuracy of the detector for the position of the source on different declination bands is the same. In the future, the simulation of the Moon shadow will be involved and the absolute energy scale of the primary particle will be investigated.

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