Measurement of the improved angular resolution of GRAPES-3 EAS array by the observation of the Moon shadow

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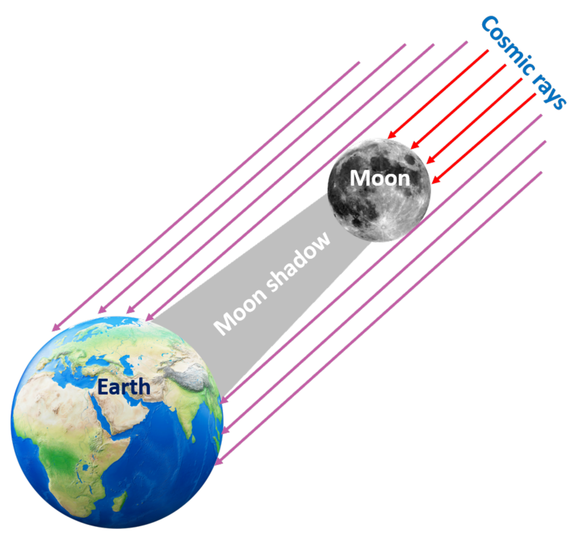
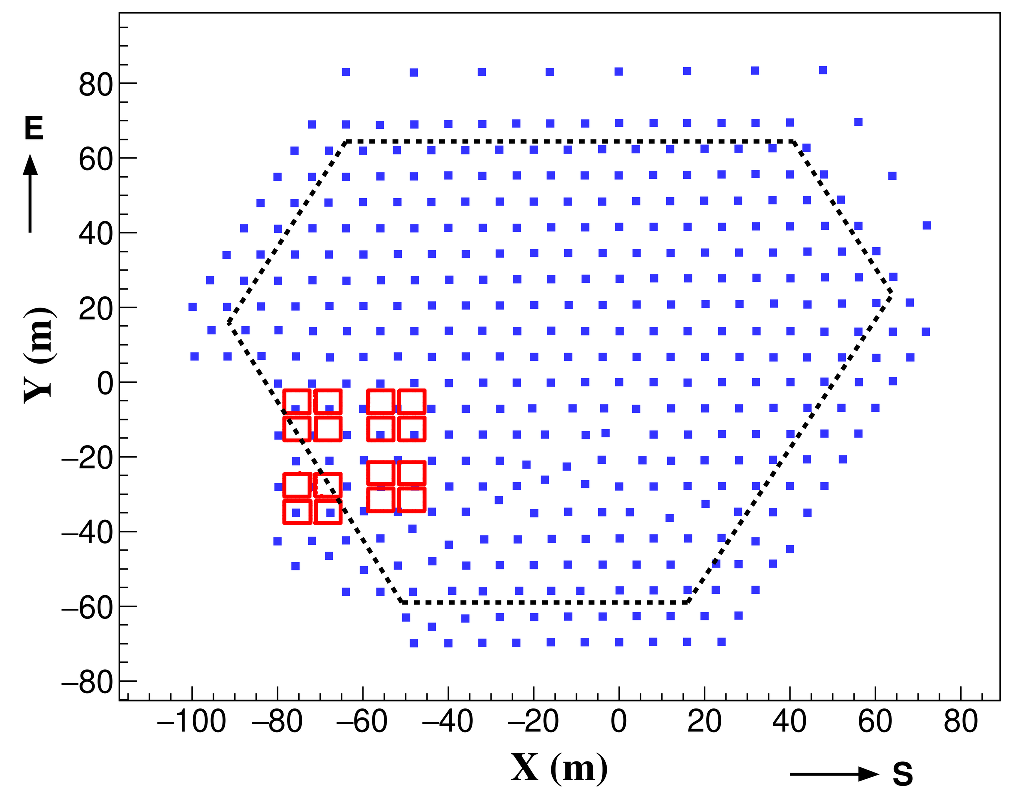
Introduction

- One of the primary objectives of the GRAPES-3 experiment is to search for the cosmic ray sources.
- Cosmic ray sources can be detected by detecting the γ-rays travelling from the sources.
- An excellent angular resolution is required to detect the tiny flux of γ-rays.
- Absolute angular resolution can be obtained by observing the shadow of the Moon.



GRAPES-3 experiment

- GRAPES-3 (Gamma Ray Astronomy at PeV EnergieS phase-3) is an Extensive Air-shower (EAS) array experiment ($11.4°N$, $76.7°E$, $2200\ m\ asl$).
- Scintillator array [2]: 400 (1 m^2 each) detectors (■) covering an area of 25000 m^2.
- Muon telescope [3] (□): 560 m^2 area.
- The dashed line represents the fiducial area.
- Measures cosmic rays & γ-rays at TeV-PeV energies.



Data selection

The particle densities recorded in the scintillator detector are used to fit the lateral density profile of the air shower with the well-known Nishimura-Kamata-Greisen (NKG) function.

- 3 years of data used (January 1, 2014 to December 31, 2016).
- Successful NKG Fit events.
- Shower cores should be within fiducial area.
- Age parameter between 0.2-1.8.
- Zenith angle below 45°

References

[1] G. W. Clark, Phys. Rev. 108, 450 (1957).

[2] S.K. Gupta et al., Nucl. Instr. Meth. A 540 (2005) 311-323.

[3] Y. Hayashi et al., Nucl. Instr. Meth. Phys. A 545 (2005) 643-657.

Background study

- Total 6 fake-Moon regions were combined.
- Each fake-Moon position is at 10° offset from the Moon successively .
- The relative deficit is then calculated by,

$$\frac{\Delta N_i}{\langle N \rangle} = \frac{N_i^{on} - \langle N_i^{off} \rangle}{\langle N_i^{off} \rangle}$$

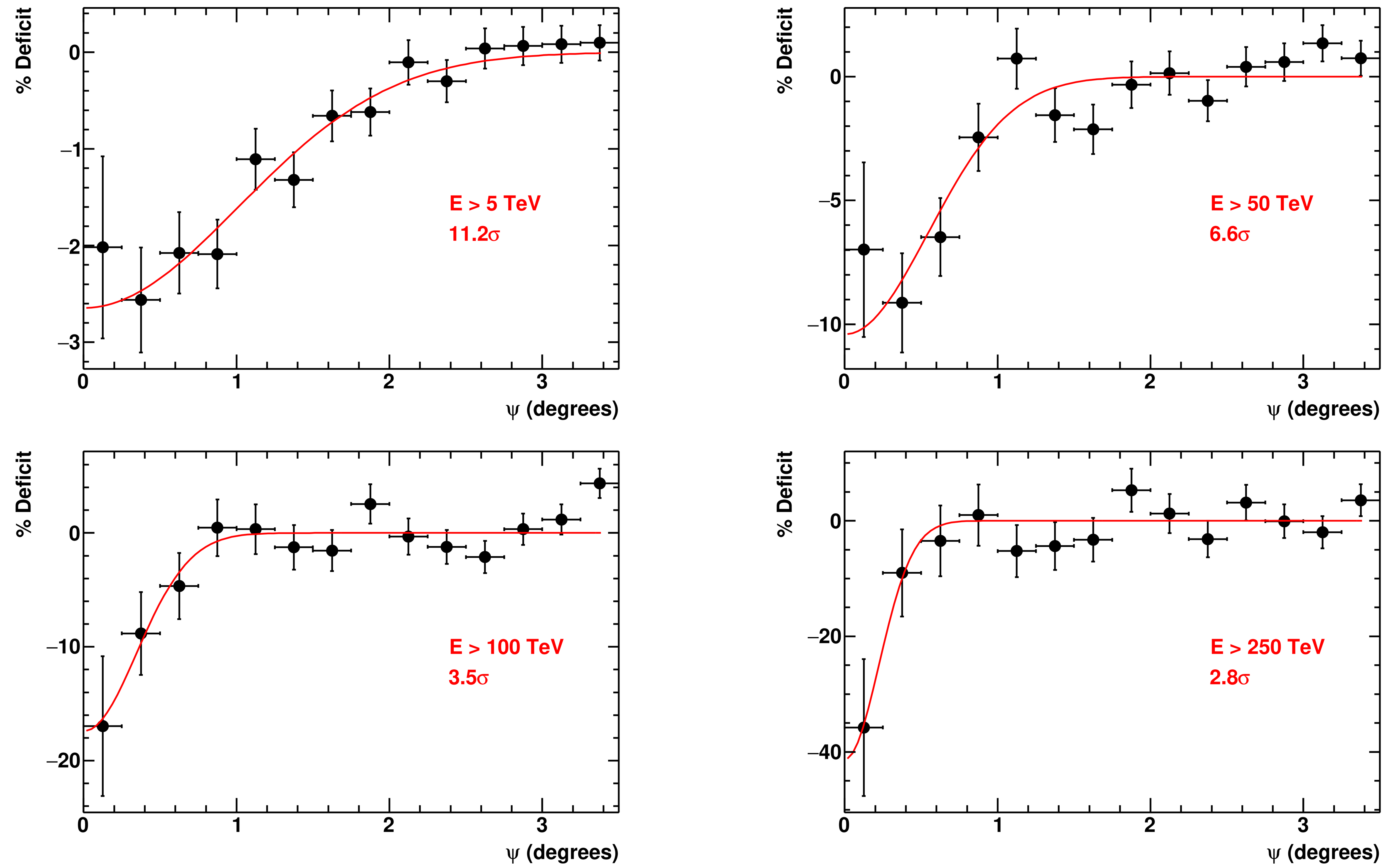
where, N_i^{on}, is the Number of events along Moon in the i^{th} bin. $\langle N_i^{off} \rangle$ is the avg. number of events from fake-Moon positions.

- The relative deficit profiles is then fitted with a Gaussian function given by,

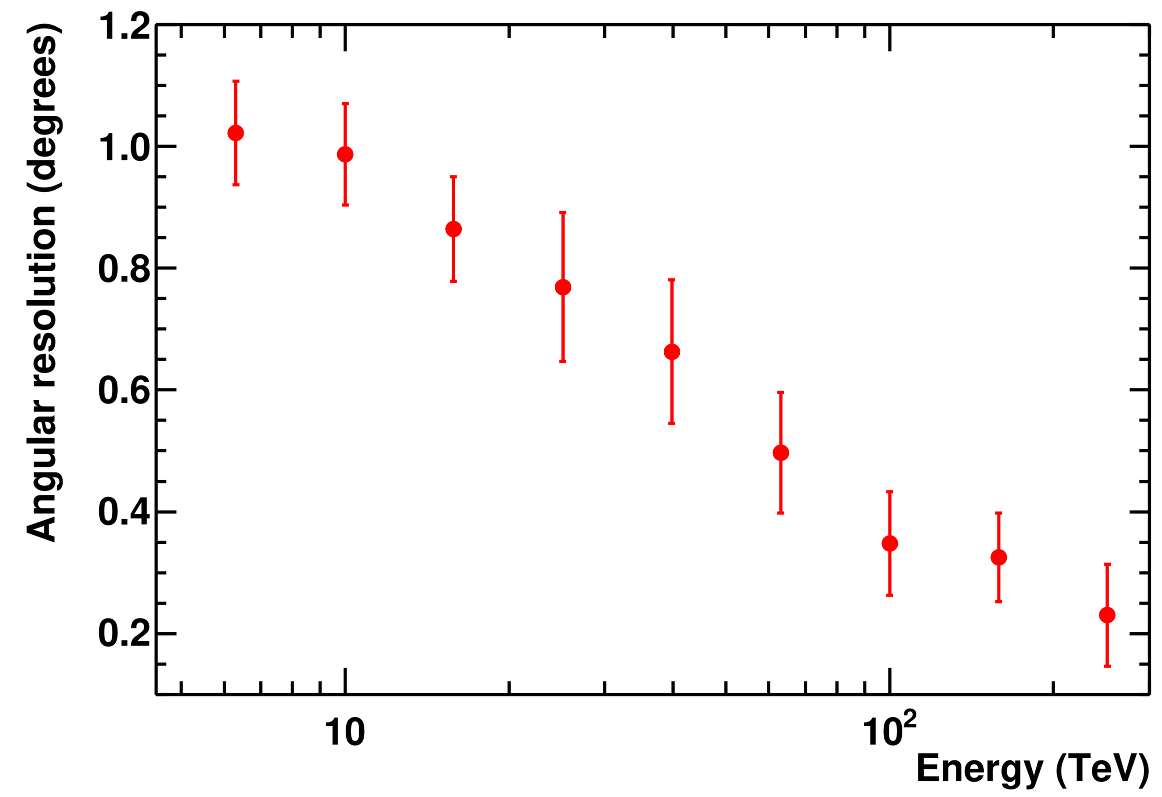
$$N(\psi) = N_0 \frac{\psi_M^2}{2\sigma_\psi} e^{-\frac{\psi^2}{2\sigma_\psi^2}}$$

where, σ_ψ is the angular resolution and ψ is the incident angle from the direction of the Moon.

Cosmic ray shadow of the Moon



Angular Resolution



Summary of the fit

Energy	Angular resolution	Maximum deficit (%)	S
$\geq$ 5 TeV	1.01° ±0.08°	2.5 ± 0.5	11.2σ
$\geq$ 10 TeV	0.98° ±0.08°	3.0 ± 0.6	11.3σ
$\geq$ 20 TeV	0.88° ±0.09°	4.0 ± 1.6	8.5σ
$\geq$ 50 TeV	0.54° ±0.09°	10 ± 2.0	6.6σ
$\geq$ 80 TeV	0.37° ±0.06°	15 ± 5.1	5.0σ
$\geq$ 100 TeV	0.35° ±0.08°	19 ± 6.1	3.5σ
$\geq$ 250 TeV	0.23° ±0.08°	40 ± 12	2.8σ

S = Significance of detection

Summary and Conclusion

- The angular resolution of the GRAPES-3 array has been obtained to be ~1° above 5 TeV with > 11.2σ.
- The angular resolution further improves with increase in energy.
- Better angular resolution at higher energies will help us to search for point sources of γ-rays.
- With this result, we have attempted to detect the multi-TeV γ-rays from the Crab Nebula.