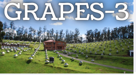

Angular resolution and pointing accuracy of the GRAPES-3 experiment obtained by Moon shadow observation

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On behalf of the **GRAPES-3** collaboration

XXV DAE-BRNS High Energy Physics Symposium 2022
12 - 16 December, 2022
IISER Mohali

Motivation : VHE Gamma ray astronomy

⇒ Very High Energy (E > 50 TeV) gamma rays travel undeflected directly from the source region, which can be detected by the ground based large air shower array experiment.

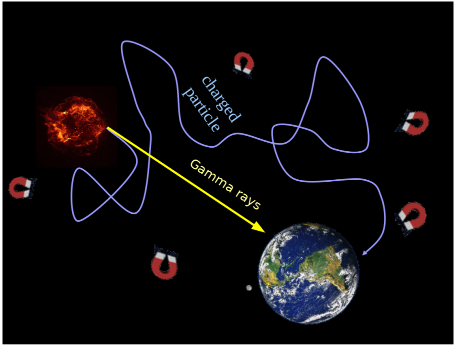


Figure: Illustration of gamma ray propagation from the source.

Challenges:

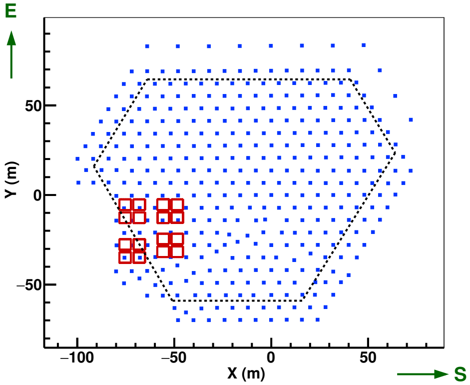
- Extremely small flux of gamma rays from the sources.
- Overwhelming cosmic ray background.

Tools required:

1. Excellent angular resolution.
2. Effective rejection of background cosmic rays.

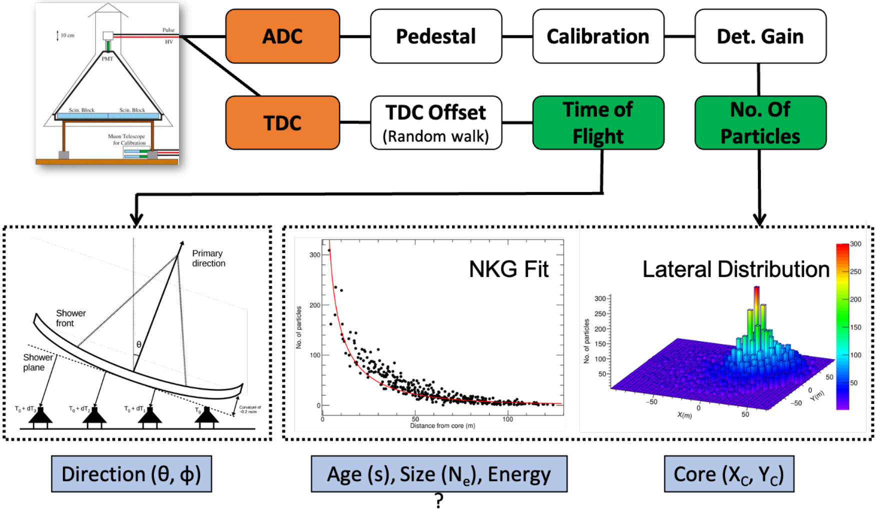
The GRAPES-3 experiment

GRAPES-3 stands for **G**amma **R**ay **A**stronomy at **P**eV **E**nergie**S** phase-**3**.

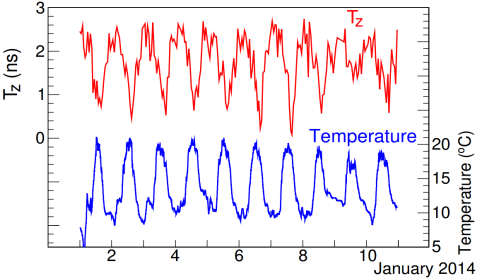


- Dense array of scintillator detectors with 8 m inter-detector separation.
- Records $\sim 3\times10^6$ air showers/day in TeV-PeV energy range.

Air shower reconstruction

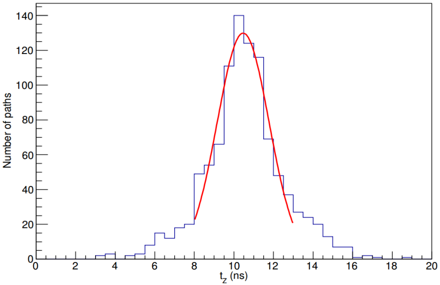


Precision measurement of time offset (T_Z)



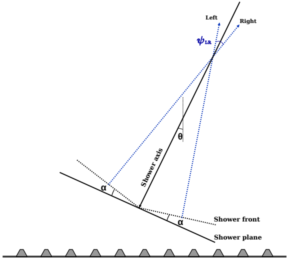
- Time offset (T_Z) = Delay in the measurements of arrival time.
- T_Z varries with temperature.

- Air shower data used based on random walk method to calculate hourly variation of T_Z.

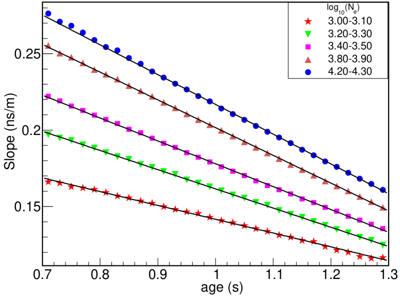


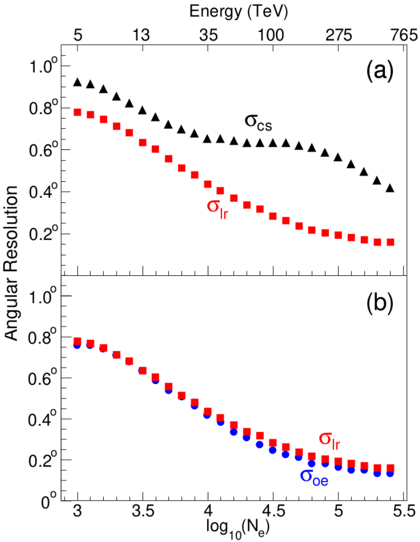
Shower front curvature

Shower front:



Dependance on size and age:





[*V. B. Jhansi et al., JCAP 2020 (07), 024*]

Data selection

- Data period: **1 January, 2014 - 31 December, 2016**
- 2.98×10^9 events recorded.

Quality cuts:

- Events with good quality NKG fit.
- Showers with core inside the fiducial area.
- Shower age between [0.2, 1.8].
- Zenith angle (θ) below 40°.

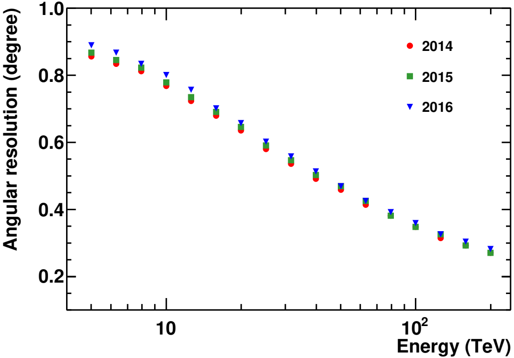
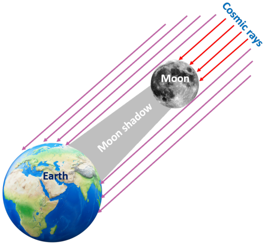


Figure: The angular resolution using Left-Right method for 2014, 2015 and 2016.

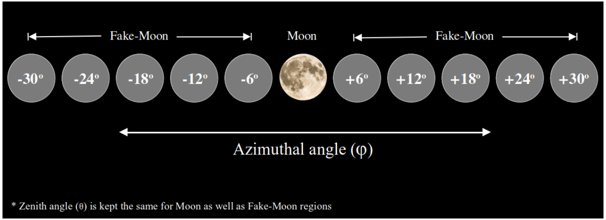
$\Rightarrow 1.65 \times 10^9$ events remained after the quality cuts.

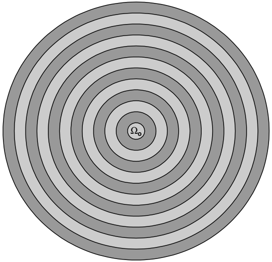
Analysis method

Moon shadow:



Background selection:





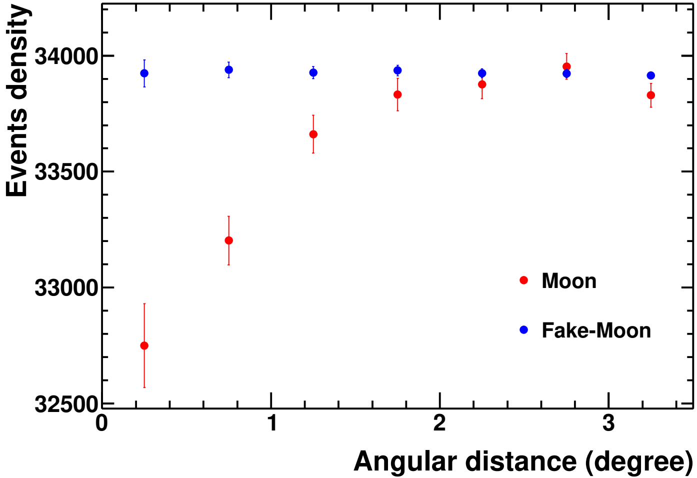
- A circular region of angular radius 3.5° from the center of the Moon was selected.
- The region was then divided into 14 annular bins of equal bin width i.e. 0.25°.
- The central bin is comparable to the size of the Moon (angular radius = ∼0.26°).

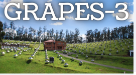
Analysis method

- Event density in each annuar bin is given by,

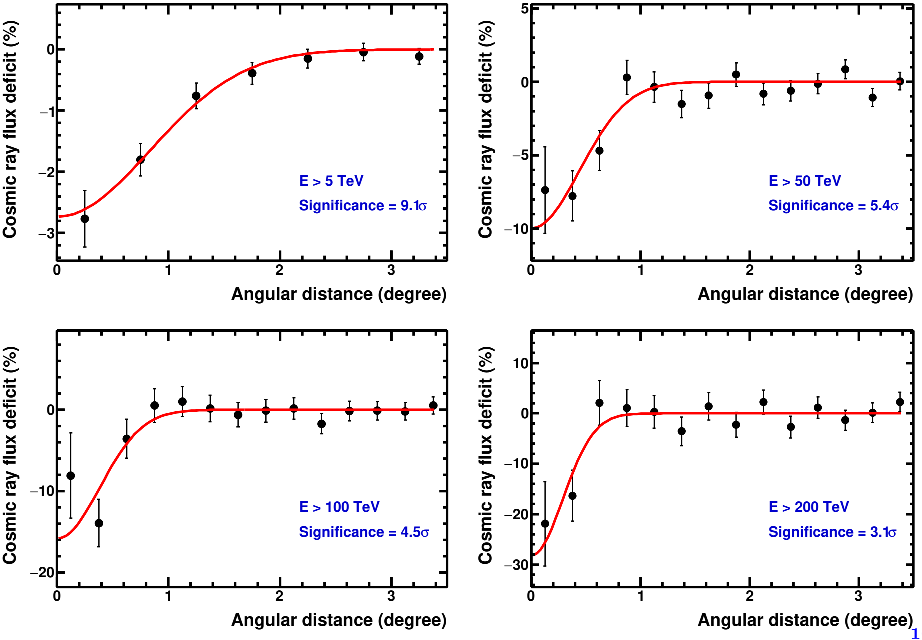
$$Event\ density\ (N_{\Omega_i}) = \frac{N_i}{\Omega_i} \times \Omega_\circ$$

N_i = Observed events in i^{th} annular bin.
Ω_i = Solid angle of the i^{th} annular bin.
$\Omega_\circ$ = Solid angle of the central bin

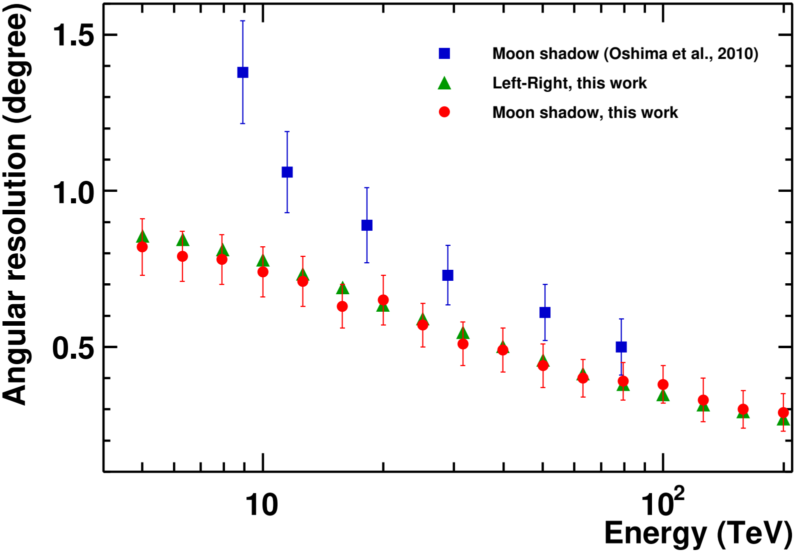




Results : Cosmic ray flux deficit

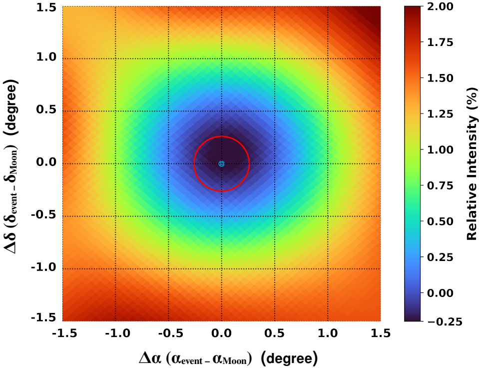


Results: Angular resolution



[D. Pattanaik et al., Phys. Rev. D, 106, 022009 (2022)]

Results : Pointing accuracy

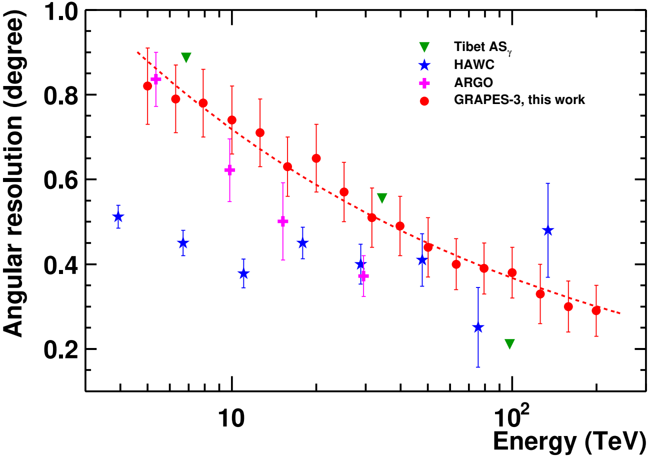


- $\Delta\delta = \delta_{event} - \delta_{Moon}$
  $\Delta\alpha = \alpha_{event} - \alpha_{Moon}$
- HEALPix map between $\Delta\delta$ and $\Delta\alpha$ generated.
- Location of the maximum deficit determines the pointng accuracy.

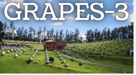
Pointing accuracy

- Pointing accuracy along $\alpha = 0.032^\circ \pm 0.004^\circ$
- Pointing accuracy along $\delta = 0.09^\circ \pm 0.003^\circ$

Summary



- Despite being located at 2200 meter, GRAPES-3 angular resolution is comparable to other experiments located at twice the altitude.



Summary and outlook

✓ Shower front curvature dependance on shower size and age was studied.

✓ Significant improvements in the angular resolution (**$0.44^\circ \pm 0.07^\circ$ at $E >$ 50 TeV and $0.29^\circ \pm 0.06^\circ$ at $E >$ 200 TeV**) have been achieved after curvature correction.

✓ From the Moon shadow analysis, pointing accuracy was calculated to be **$0.032^\circ \pm 0.004^\circ$** along Right ascension and **$0.09^\circ \pm 0.003^\circ$** along Declination.

✓ Muon telescope helps to distinguish between cosmic rays and gamma rays based on the muon multiplicity.

Excellent angular resolution and small pointing accuracy combined with the muon measurement can help detecting the multi-TeV gamma ray sources.


THANK YOU