Characterizing the Isotropic Diffuse γ-ray Flux (10 – 300 TeV) by the GRAPES-3 Experiment

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Introduction

- Origin and acceleration mechanism of ultra-high energy cosmic rays (UHECRs) is still an open problem in astrophysics.
- Enormously difficult to detect directly due to extreme low flux (≤ 1 particle km^{-2} yr^{-1}).
- However, while propagating, UHECRs interact with CMB radiation and undergo cascading.
- The final outcome is the diffuse and isotropic flux of ultra-high energy γ-rays (UHE, ~ 100 TeV).
- A significant information can be extracted out by studying these isotropic UHE γ-rays.
- GRAPES-3 experiment is capable of searching for multi-TeV γ-ray sources.

GRAPES-3 experiment

- GRAPES-3 (**G**amma **R**ay **A**stronomy at **P**eV **E**nergie**S** phase-**3**) is an extensive air shower (EAS) array experiment.
- **Location:** Ooty, India (11.4° N, 76.7° E, 2200 m asl).
- 400 plastic scintillator detectors (each $1 m^2$ area) spread over 25000 m^2 and a large area tracking muon telescope of 560 m^2 area. [1, 2, 3]
- It records $\sim 3 \times 10^6$ EAS per day in the energy range 1TeV-10PeV.

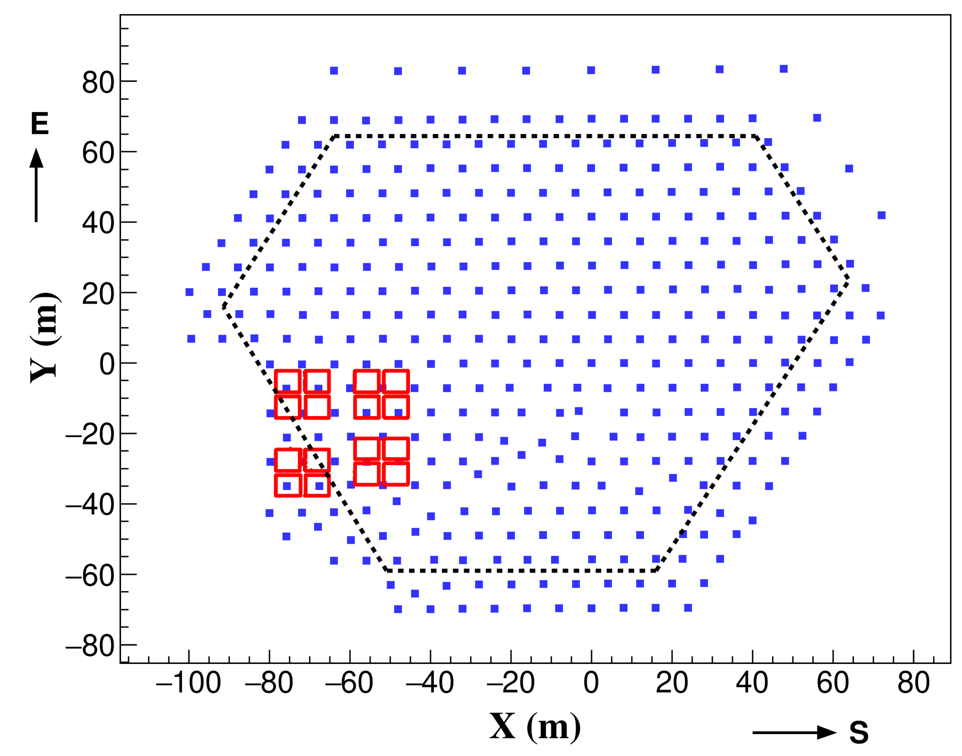

Figure 1: GRAPES-3 array consisting of scintilator detectors (blue) and muon telescope (red). The dashed line represents fiducial area.

Data Selection & Gamma Simulation

- Data observed by the GRAPES-3 for the year 2014 is used for the analysis.
- Quality cuts to select events:
  1. Reconstructed cores must lie inside the fiducial area.
  2. Age restricted to $0.12 \leq s \leq 1.8$.
  3. Zenith angle < 25°.
- CORSIKA (v7.4001) simulation for the γ primary is performed.
- Hadronic interaction models: SIBYLL 2.1 and FLUKA 2011.
- Energy range: 5 TeV - 10 PeV with differential spectrum of E$^{-2.7}$.
- Shower parameters are reconstructed for radial bins of 5 m from the muon telescope center.
- Geant4 simulation is performed for muon detectors to count observed muon tracks.

Distinction between cosmic ray & γ-ray shower

- γ-ray showers contain less muons compared to hadronic showers.
- Showers with zero muon content are selected as gamma-like (muon-poor) showers.
- Gamma selection and cosmic ray rejection efficiency is calculated for each radial bin of 5m from the muon telescope center and $logN_e$ of interval 0.2.
- Gamma Selection efficiency (ϵ_γ) = $\frac{N_{mu-poor}}{N_{total}}$.
- Cosmic ray rejection efficiency = 1 - ϵ_γ

Gamma Selection Efficiency

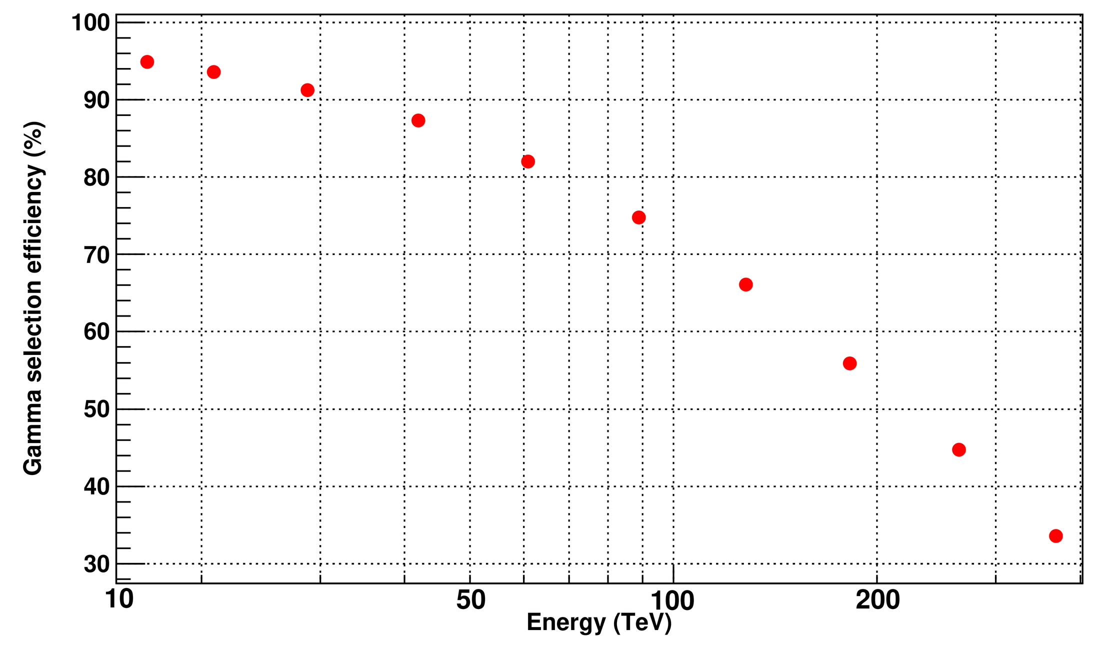

Figure 2: Variation of selection efficiency with energy.

CRs Rejection Efficiency

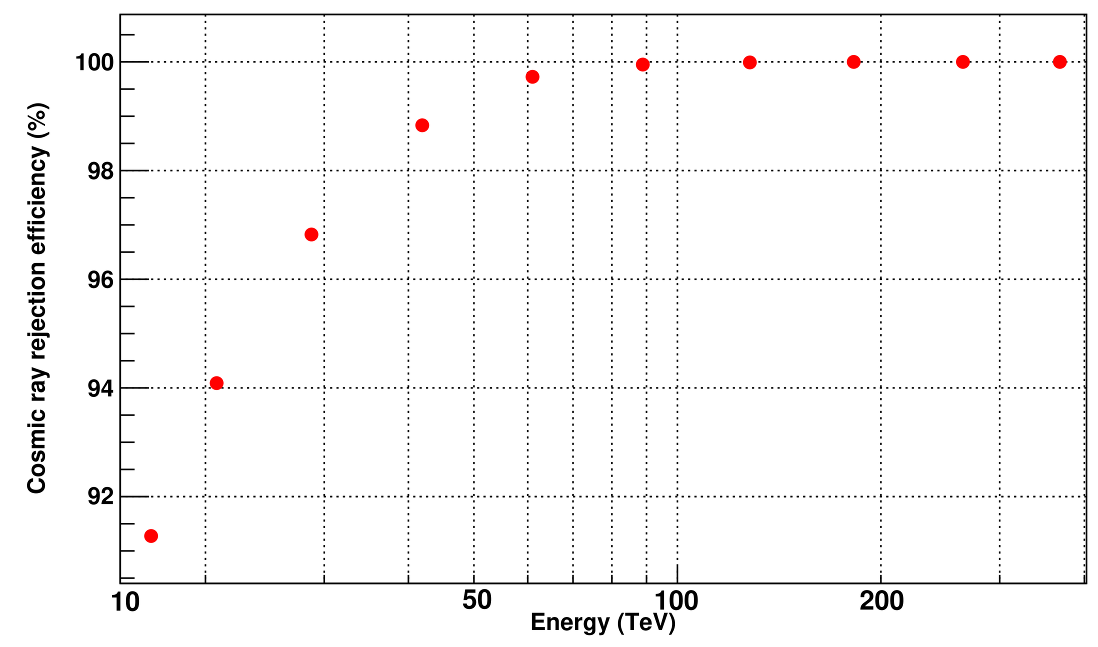

Figure 3: Variation of rejection efficiency with energy.

Upper Limit on Isotropic Diffuse Gamma-Rays Flux

- Upper limit is given by [4]:

$$I_\gamma / I_{CR} \leq \frac{N^{\mu=0}_{90\% C.L.}}{N_{tot}} \frac{1}{\epsilon_\gamma} \frac{1}{1 - n_{chance}} \quad (1)$$

where $N^{\mu=0}_{90\% C.L.}$ is the 90% C.L. upper limit on muon poor showers assuming Poisson distribution, N_{tot} is the total number of showers, ϵ_γ is the selection efficiency, and n_{chance} is the average number of chance muons.

- Integral flux is calculated at different threshold values of $logN_e$ at a radial distance of 30 m from the center of the muon telescope.

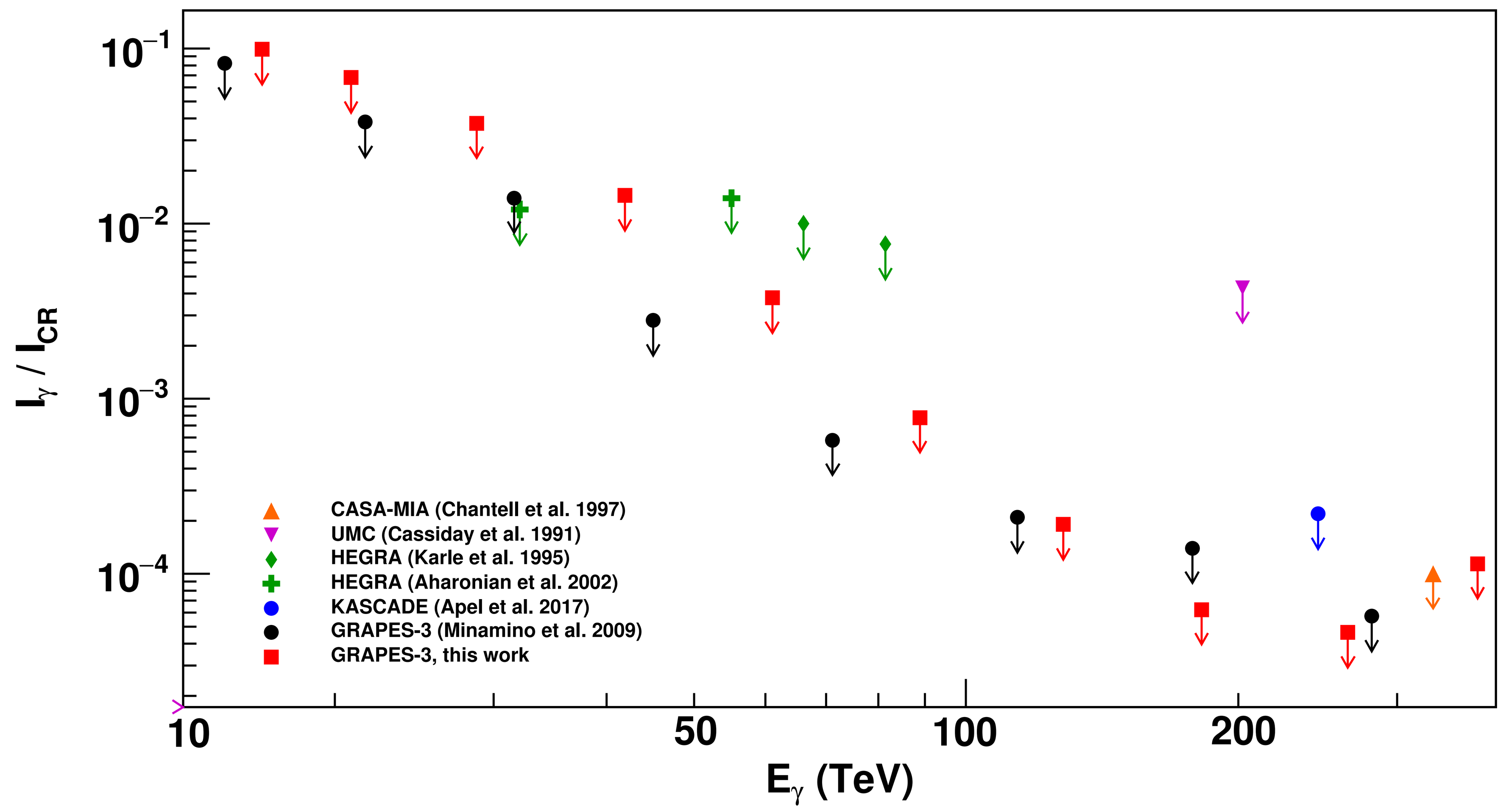

Figure 4: Upper limit measurements of the fraction of γ-rays to cosmic rays compared with upper limits given by other groups.

References

[1] S. K. Gupta et al., *Nucl. Instrum. Meth.* **A 540** (2005) 311.
[2] P. K. Mohanty et al., *Astropart. Phys.* **31** (2009) 24.
[3] Y. Hayashi et al., *Nucl. Instrum. Meth.* **A 545** (2005) 643.
[4] M. Minamino et al., *Proc. 31st ICRC (Lodz)* (2009) 1723.