Energy spectrum and composition measurements of cosmic rays from GRAPES-3 experiment

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(on behalf of GRAPES-3 Collaboration)

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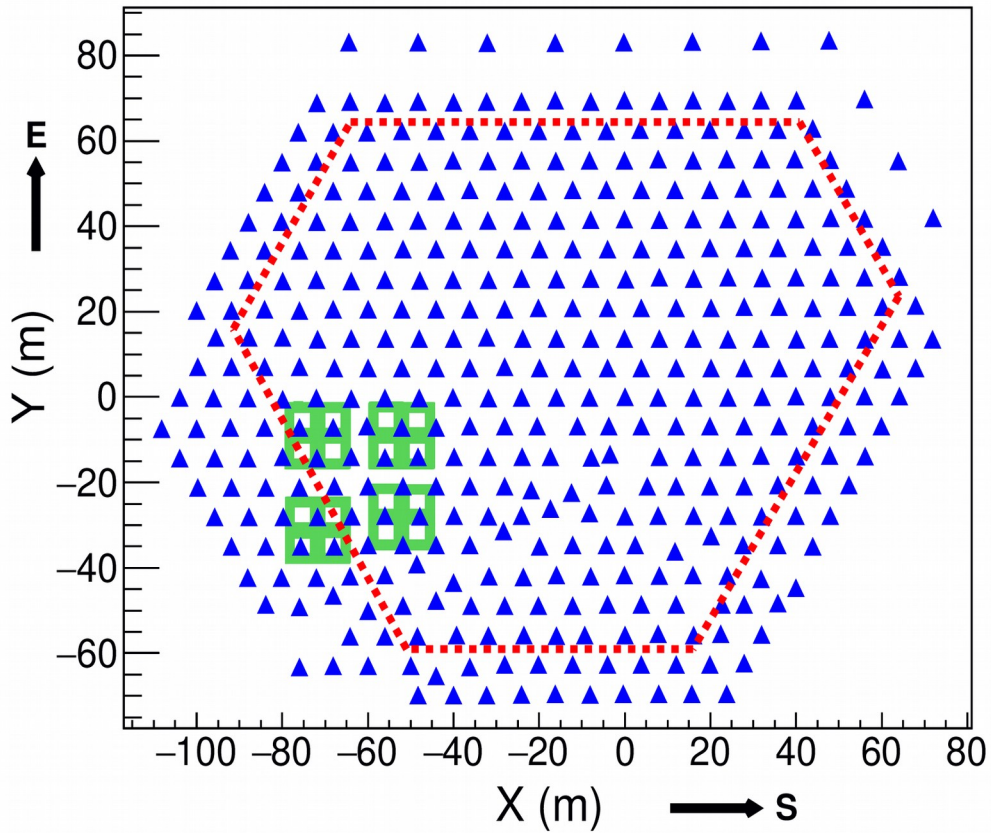
Outline

- Introduction to GRAPES-3 EAS array
- Array trigger efficiency and acceptance
- Energy calibration
- Cosmic rays energy spectrum
- Summary

GRAPES-3 EAS Array

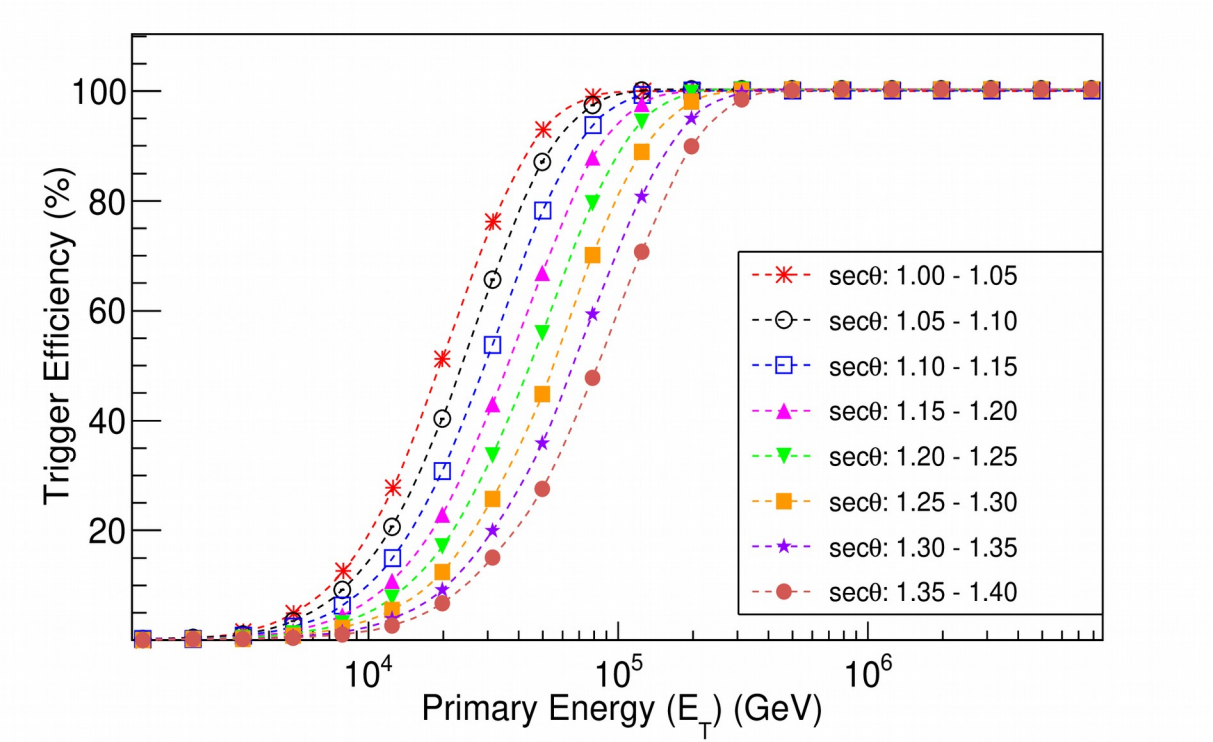


- Located at Ooty, India (11.4° N, 76.7° E, 2.2 km a.s.l.).
- 400 plastic scintillation detectors (1 m^2 each) covers an area of 25,000 m^2.
- Large tracking muon telescope of area 560 m^2.
- Fiducial area = 14560 m^2.
- Fraction of array covered is 2%, Energy range: 1 TeV – 10 PeV.

Simulation

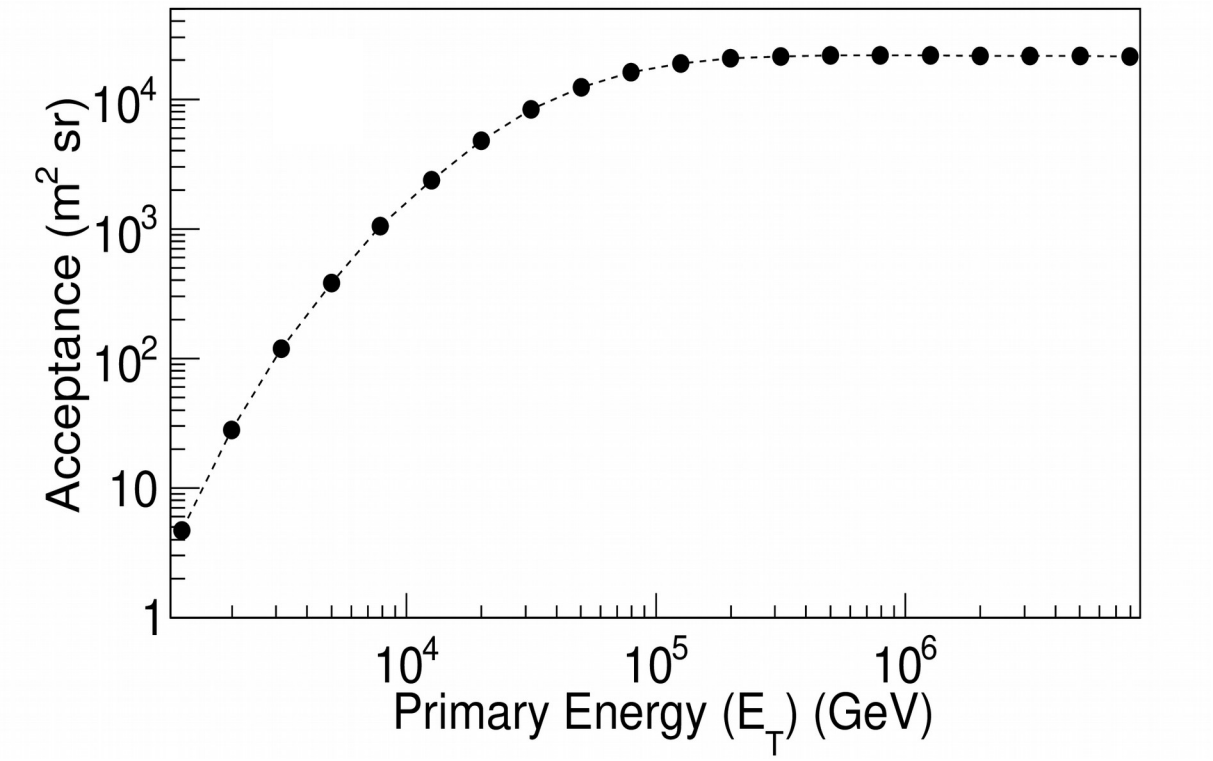
- Proton initiated EAS
- CORSIKA (v 7.69) with SIBYLL-2.3c and FLUKA
- 1.2 x 10^9 EAS
- Energy range: 1 TeV to 10 PeV.
- Zenith range: 0° to 60°.

Trigger efficiency



- For $1.0 \leq \sec\theta < 1.05$, the trigger efficiency increases from 0.1% at 1 TeV to 95% at 50 TeV.

Acceptance



- For $1.0 \leq \sec\theta < 1.4$, the acceptance is 5 m^2 sr at 1 TeV and increases upto 22000 m^2 sr at 750 TeV.

Energy-size relation

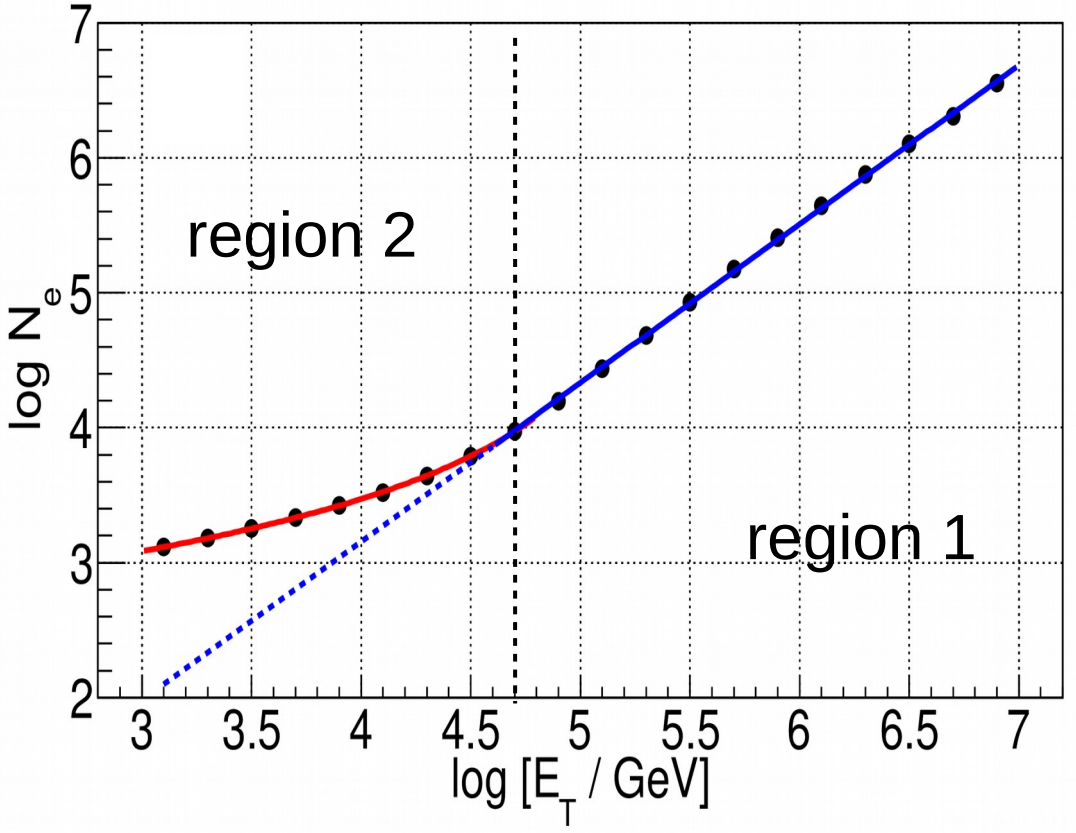
- Region 1:

$$logN_e = \frac{logE_T - A}{\alpha_1}$$

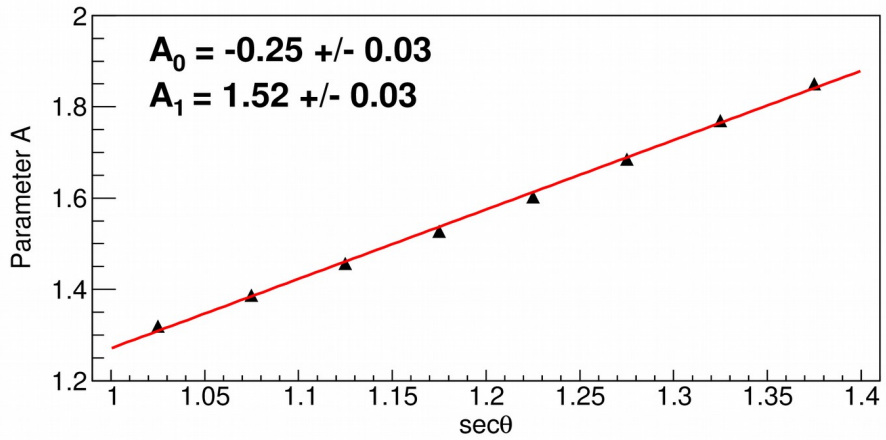
- Region 2:

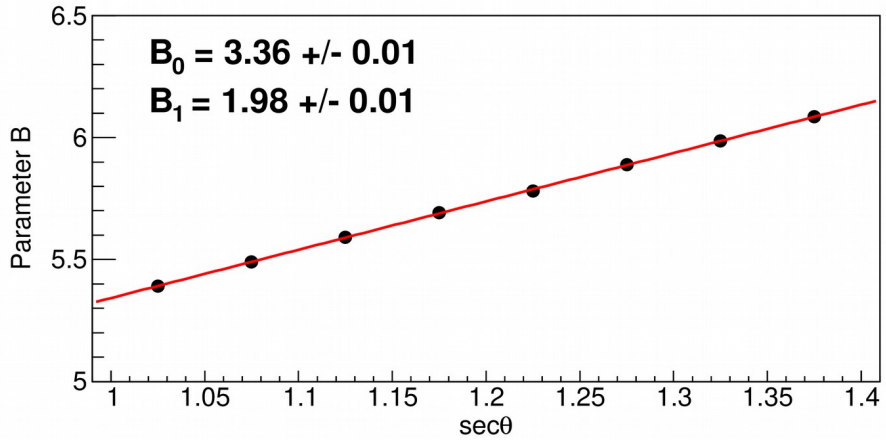
$$logN_e = \frac{1}{\alpha_2} \ln\left(\frac{B - logE_T}{C}\right)$$

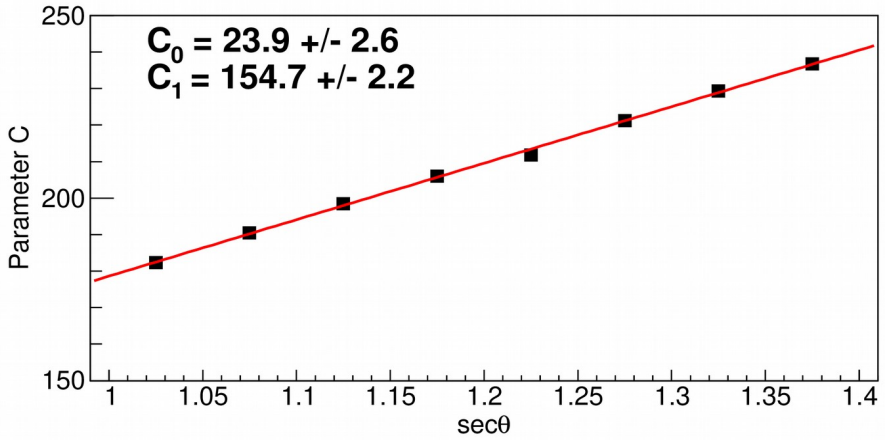
where $\alpha_1 = 0.85$ and $\alpha_2 = -1.405$, A, B and C are fit parameters.



Sec θ correction by parameterization







$$A = A_0 + A_1 \sec\theta$$
$$B = B_0 + B_1 \sec\theta$$
$$C = C_0 + C_1 \sec\theta$$

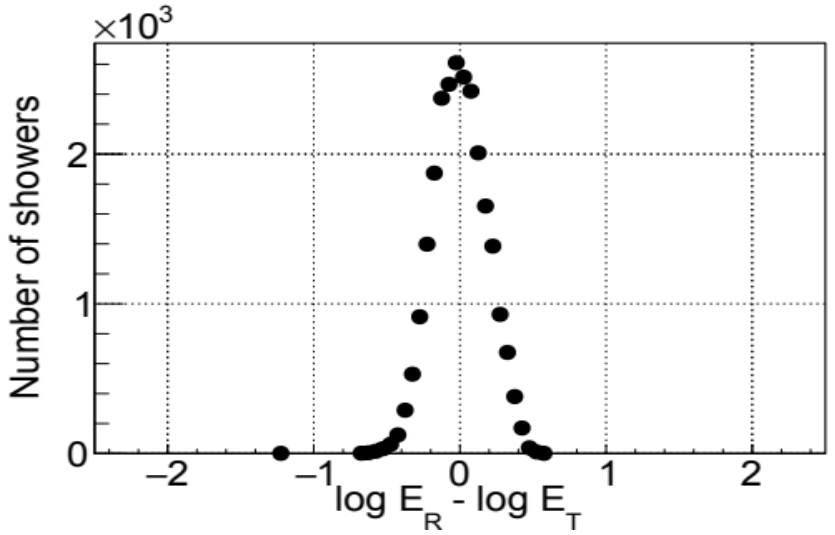
Reconstructed energy

- Region 1:

$$logE_R = A + \alpha_1 logN_e$$

- Region 2:

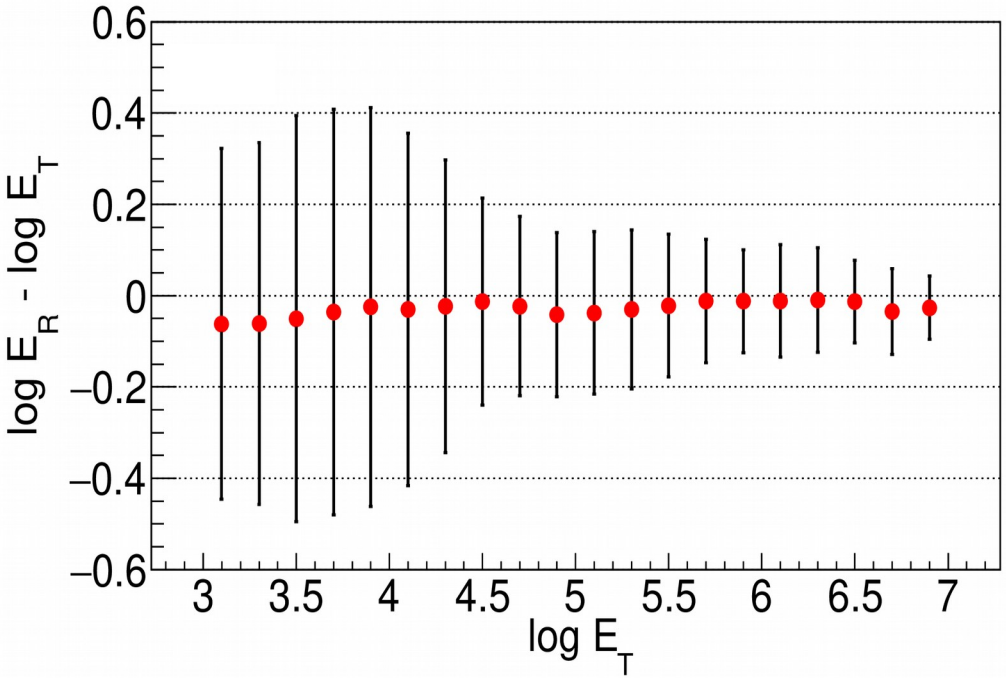
$$logE_R = B - C\exp(\alpha_2 logN_e)$$

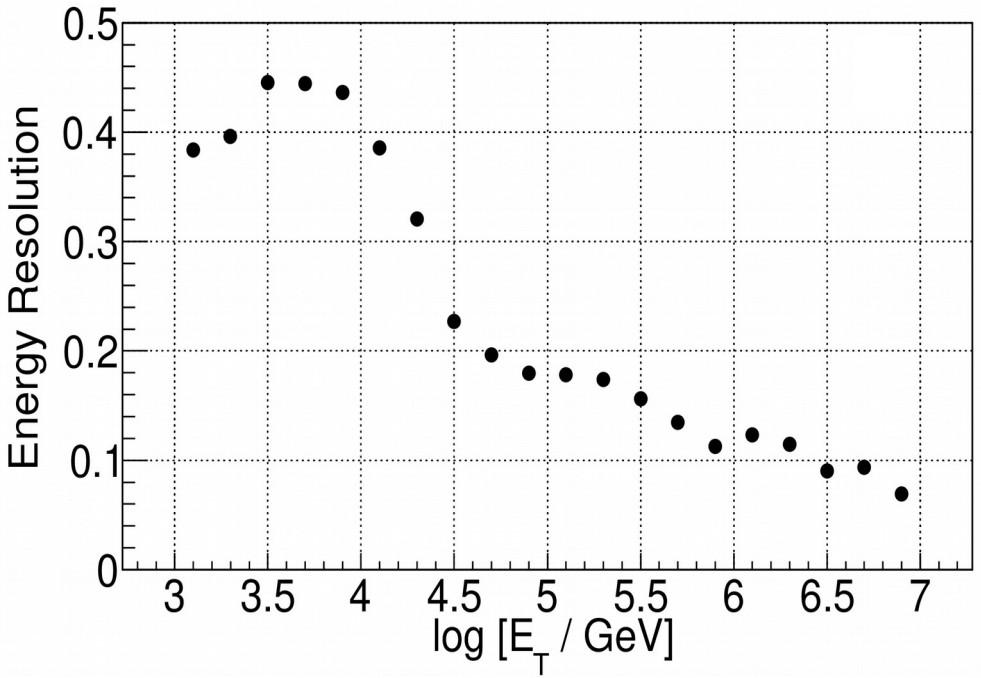


- The systematic uncertainty and energy resolution is calculated via the distribution of $\log E_R - \log E_T$.

  systematic uncertainty = Median of distribution
  energy resolution = FWHM / 2.354.

Systematic uncertainties and energy resolution





- Systematic uncertainties are within 8%. Error bars represent energy resolution.
- Energy resolution is 45% at 5 TeV and 8% at 10 PeV.

Data Selection

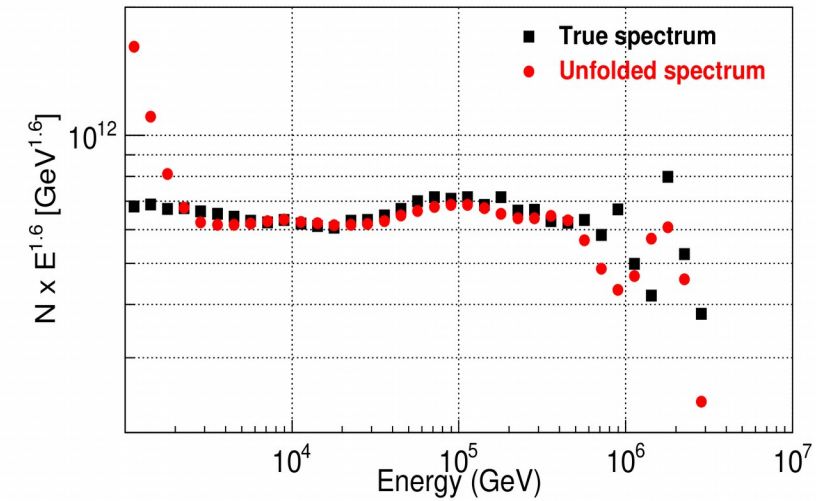
- 1 January - 31 December 2014.
- Live time ~ 318.5 days.
- EAS recorded during live time is 9.7×10^8.

- Quality cuts
  - Only those EAS were selected for the analysis which satisfied reconstruction quality criteria.
  - Reconstructed cores must lie within the fiducial area.
  - $0.5 <$ reconstructed age parameter (s) ≤ 1.7.
  - $\theta < 25^\circ$ ($1.0 \leq \sec\theta < 1.1$).

- EAS remaining after applying all the cuts are 2.3×10^8.

Preliminary cosmic rays spectrum

- Assuming all particles to be proton.
- Iterative bayesian unfolding method is used.
- Good agreement between unfolding distribution and true distribution in the energy range 5 TeV to 150 TeV.



- E > 150 TeV, the spectrum is formed directly from the observed reconstructed energy distribution.

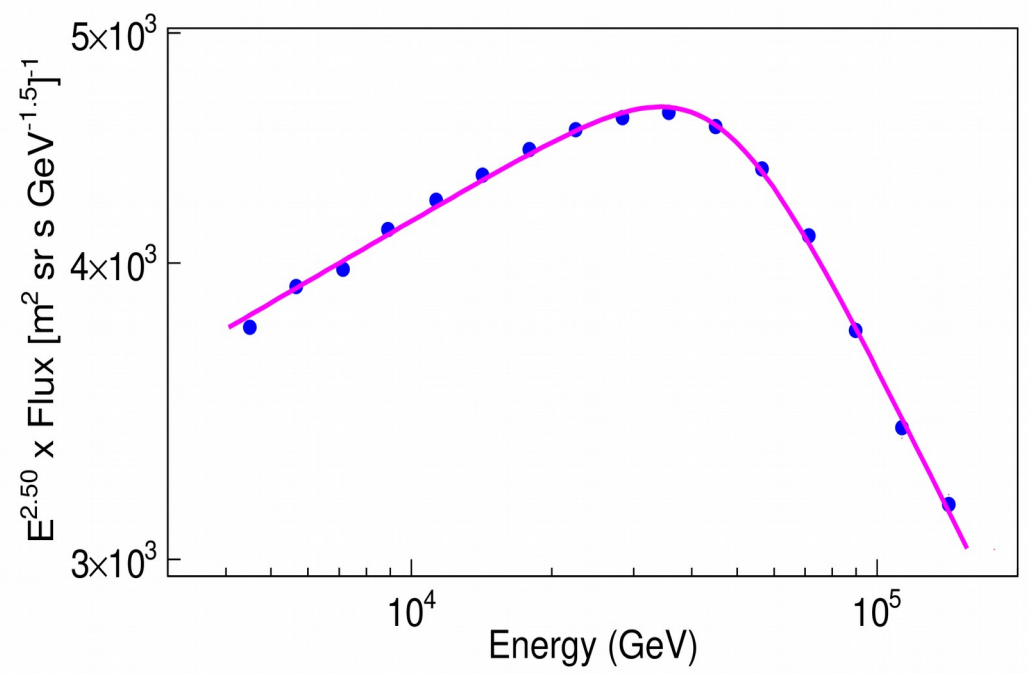
Low energy spectrum

- **Broken power law (5 TeV – 150 TeV)**

  $\gamma_1 = -2.386 \pm 0.002$

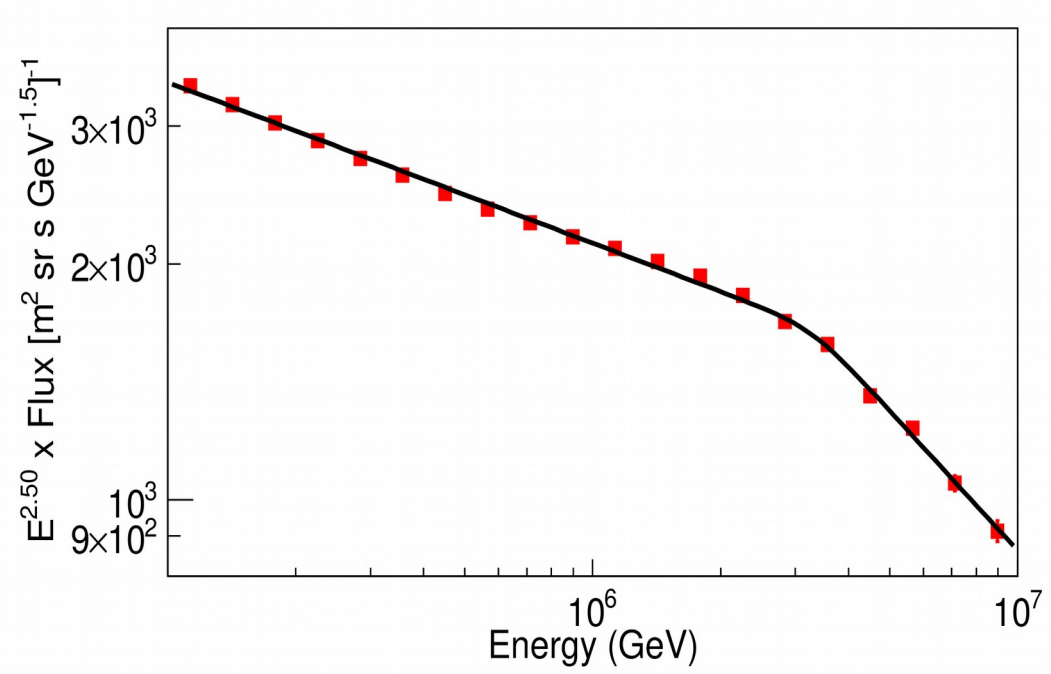
  $\gamma_2 = -2.898 \pm 0.004$

  $E_{break} = 45.4 \pm 0.3$ TeV



High energy spectrum

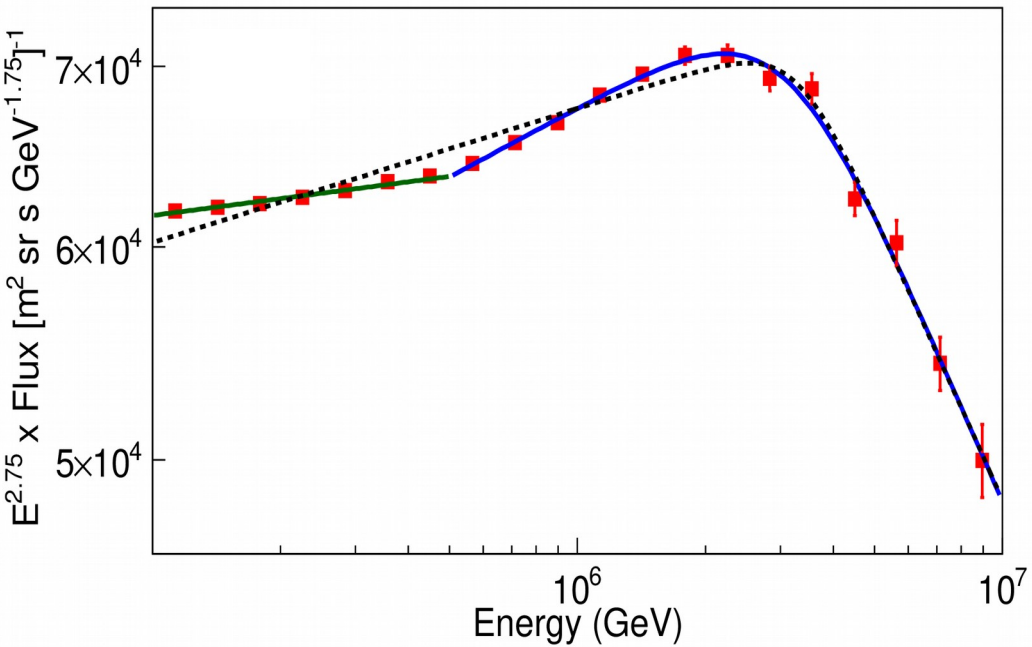
- **Broken power law (100 TeV – 10 PeV)**
  - $\gamma_1 = -2.705 \pm 0.004$
  - $\gamma_2 = -3.092 \pm 0.066$
  - **Knee = 3.3 ± 0.3 PeV**



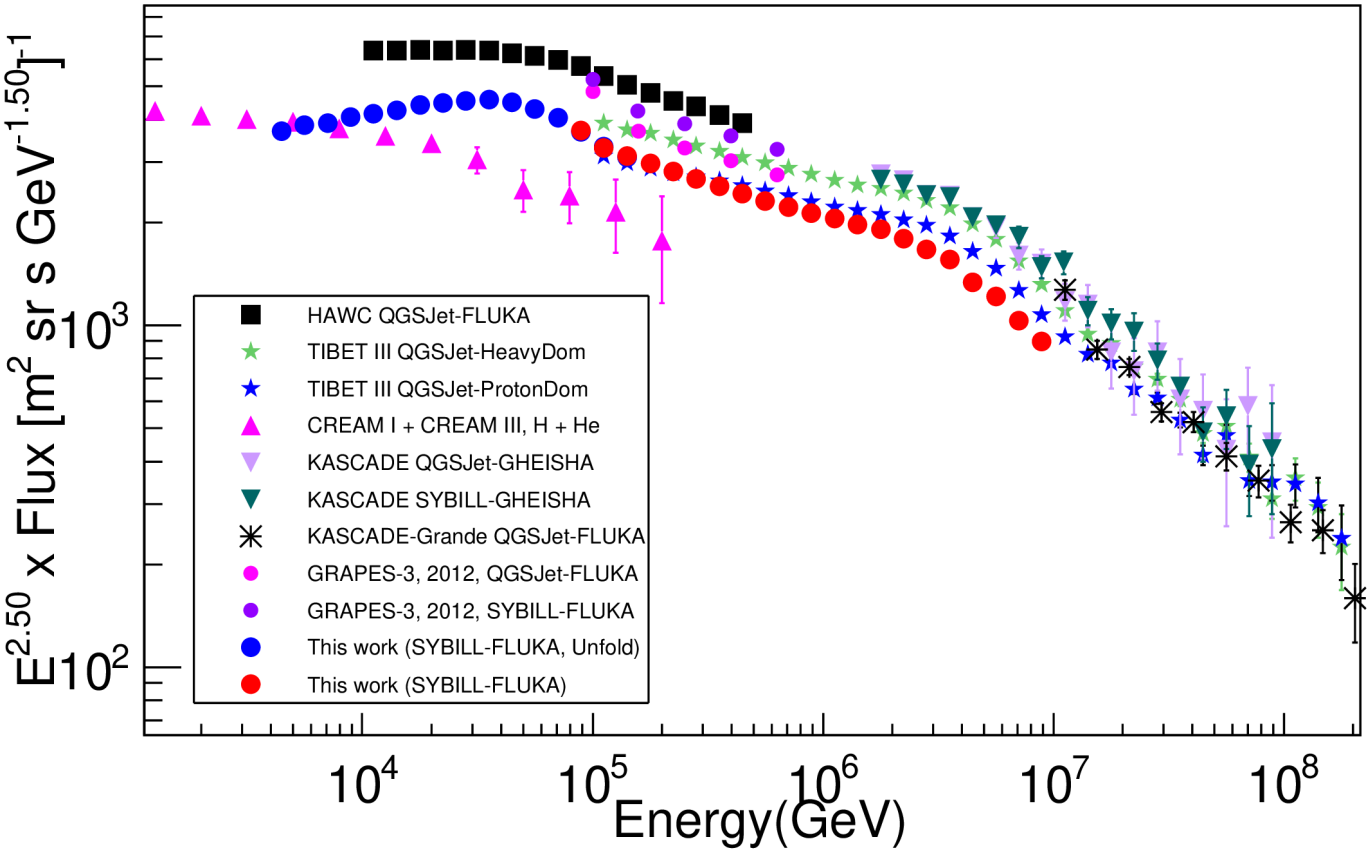
High energy spectrum

- **Power law (100 TeV – 500 TeV)**
  $\Gamma = -2.729 \pm 0.001$

- **Broken power law (500 TeV – 10 PeV)**
  $\gamma_1 = -2.664 \pm 0.007$
  $\gamma_2 = -3.116 \pm 0.064$
  Knee = 3.1 ± 0.3 PeV

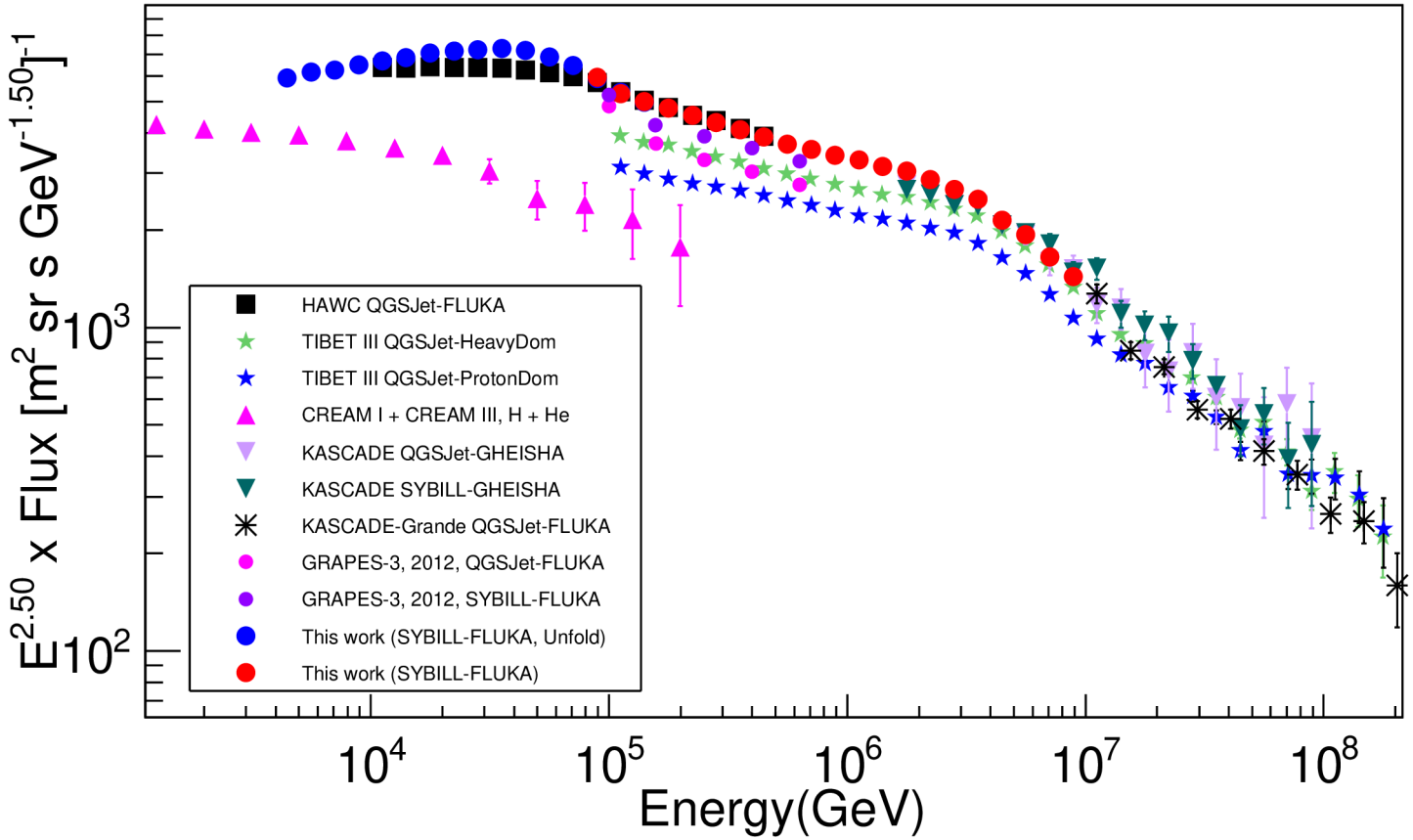


Energy spectrum



- Flux of low energy spectrum is scaled by 1.48 to match with the high energy spectrum.

Energy spectrum



- Flux is further scaled by 1.6 to match with the KASCADE all particle spectrum.

Summary

- Total acceptance for the GRAPES-3 EAS array is measured to be 5 m^2 sr at 1 TeV and increases upto 22000 m^2 sr at 750 TeV.
- Energy size relation is calculated for proton initiated showers for different sec bins and then corrected by parameterization.
- Low energy spectrum is measured by unfolding and shows an energy break at 45.4 TeV.
- Signature of a fine structure near the knee.

Thank You