

Cosmic ray energy spectrum and composition measurements from the GRAPES-3 experiment: Latest results

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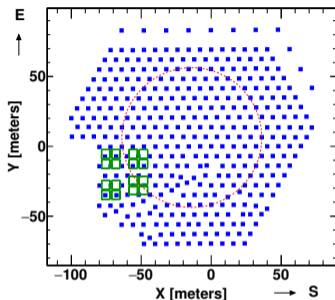
Selection quality cuts and data summary

Analysis

Preliminary results

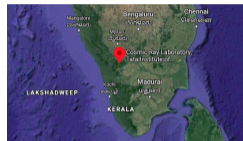
Summary

GRAPES-3 experiment



Location:

- Ooty, south India
- 11.4° N, 76.7° E
- 2200 m a.s.l.



- 400 plastic scintillation detectors (1 m^2 each) cover an area of 25,000 m^2 .
- Large tracking muon telescope of area 560 m^2 .
- **Fiducial area = 7850 m^2 .**
- Fraction of detector area covered is 2%.
- Energy range: 1 TeV – 10 PeV.

MC simulations, Experimental data and Selection quality cuts

- MC simulation data used for analysis:

- CORSIKA v7.69
- QGSJET-II-04/FLUKA as high/low-energy hadronic interaction model.
- H, He, N, Al and Fe
- $E = 1$ TeV to 10 PeV
- $E^{-2.5}$ spectral slope
- $\theta = 0^\circ$ to 45°
- 1.2×10^8 showers for each element

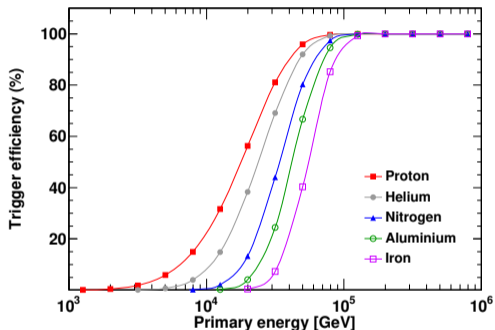
- Data used for analysis:

- 32 months (1 January 2014 to 31 August 2016)
- Live time ≈ 926 days
- Number of showers after quality cuts: 3.2×10^7 from 2.5×10^9 .

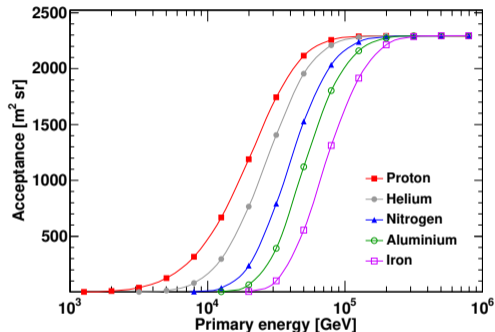
- Selection quality cuts:

- Successful arrival direction reconstruction
- Successful shower parameters (core, shower size and age) reconstruction
- Reconstructed cores restricted within the fiducial area.
- $0.2 < \text{age parameter (s)} \leq 1.8$.
- $\theta < 18^\circ$.
- Shower size (N_e) $> 10^4$ (trigger efficiency $> 90\%$).

Trigger efficiency and Acceptance

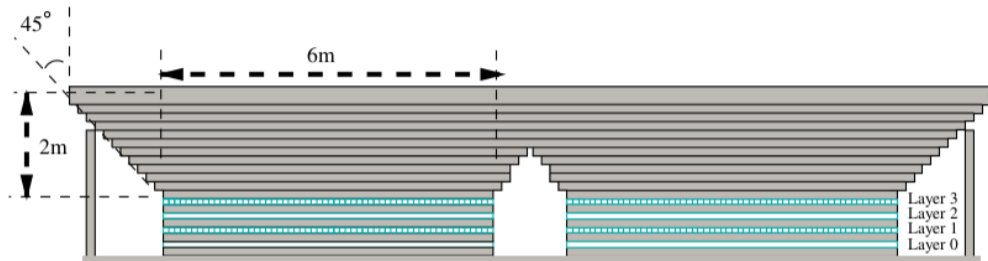


- Trigger efficiency:
 - Proton: >90% at 50 TeV
 - Iron: >90% at 100 TeV

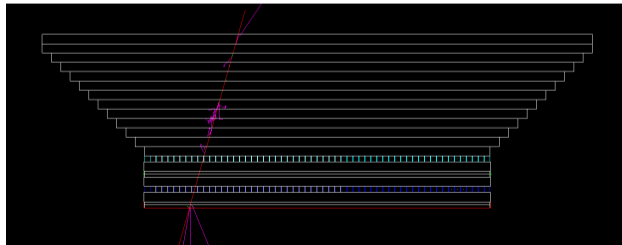


- Acceptance:
 - $\theta < 18^\circ$
 - $\approx 2300 m^2 sr$ at 100% efficiency

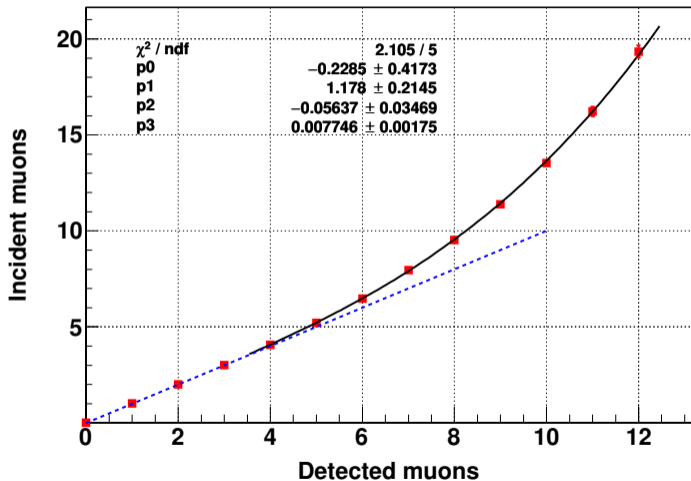
GRAPES-3 muon telescope



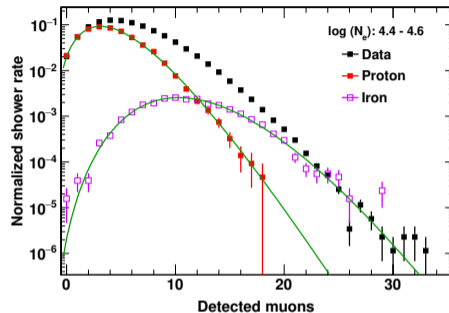
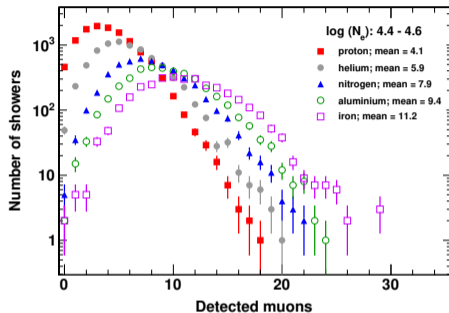
- 3712 PRCs
- 16 Modules
- 4 orthogonal layers of PRCs
- $\text{Sec}(\theta)$ GeV.



Correction to saturation of muon module



Muon Multiplicity distributions (MMDs)

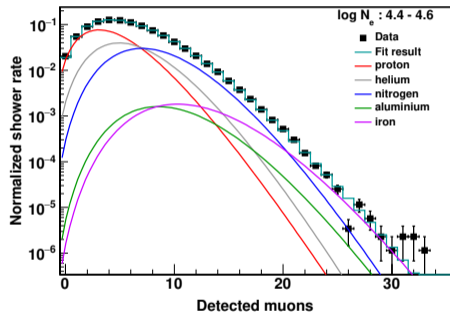


- MMDs fitted with negative binomial distribution (NBD).

$$NBD(x; r, m) = \frac{\Gamma(x+r)}{\Gamma(x+1)\Gamma(r)} \left(\frac{r}{r+m}\right)^r \left(\frac{m}{r+m}\right)^x \quad (1)$$

- where m is the mean value and r is a measure of the standard deviation of the MMD.
- The muon multiplicity distribution (MMD) is sensitive to the composition of the PCR's.

Extracting composition

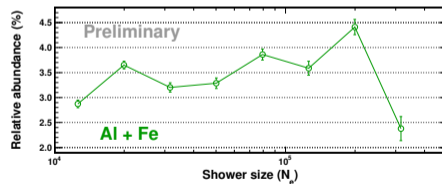
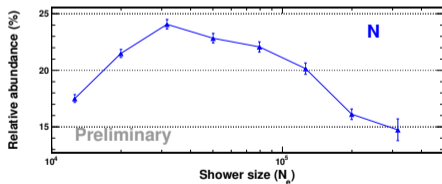
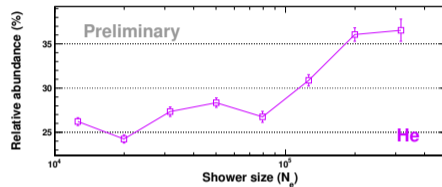
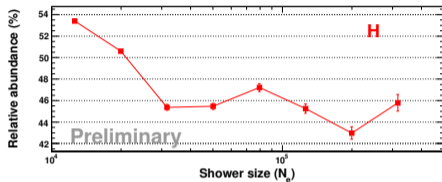


- Composition Al/Fe = 0.8.
- Relative abundance of each nuclei is measured by fitting normalized MMD of each simulated nuclei with observed MMD by minimizing χ^2 (using TMinuit).

$$\chi^2 = \sum_i \frac{(d_i - \sum_j a_j n_{ji})^2}{\epsilon_i^2} \quad (2)$$

where a_j is relative abundance of j^{th} element.

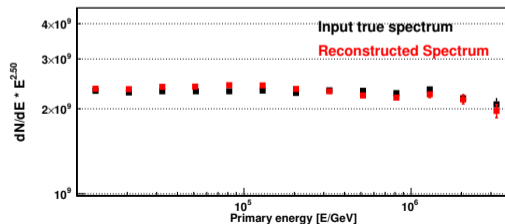
Composition

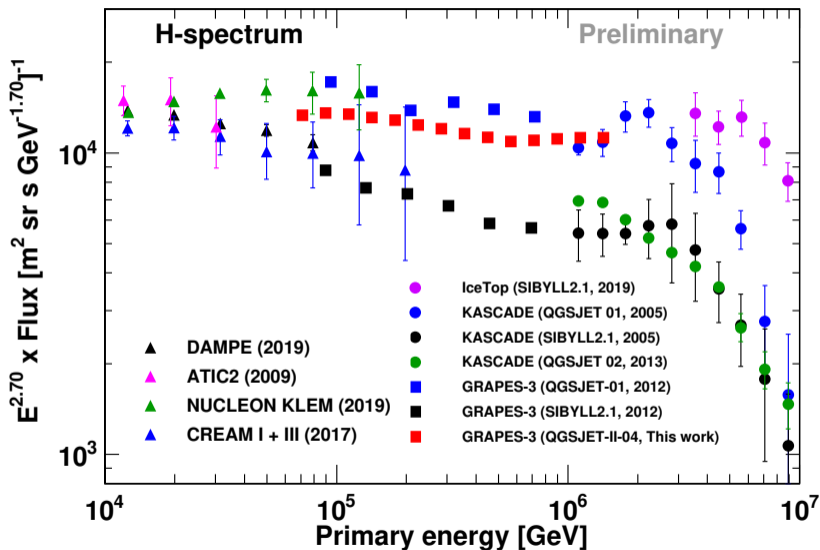


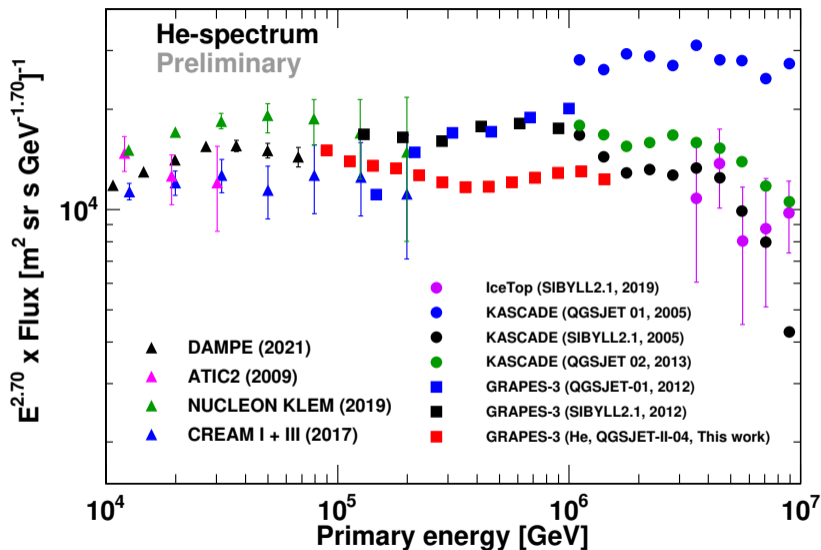
Elemental spectrum

- Energy distribution of simulated primaries is studied for a given shower size bin.
- In the shower size range of interest (trigger efficiency > 90%), the energy distribution can be approximated to Gaussian on log scale.
- With the help of Gaussian random number generator, the distribution of energy is generated for a given shower size.
- The differential cosmic-ray spectrum (dI/dE) is obtained as follows:

$$\frac{dI}{dE} = \frac{1}{T_{obs}} \left(\frac{N}{\Delta E \cdot A} \right)_i \quad (3)$$







Summary

- The trigger efficiency is $>90\%$ at 50 TeV, 55 TeV, 60 TeV, 80 TeV and 100 TeV for H, He, N, Al and Fe, respectively. The acceptance is increased to $2300 \text{ m}^2 \text{ sr}$ at 100% efficiency for $\theta < 18^\circ$.
- Normalized MMD of each simulated primary is fitted with NBD. Relative abundance of each simulated primary is measured by minimizing the χ^2 of normalized MMD function of each simulated primary with normalized observed MMD using TMinuit package.
- The flux of proton spectrum is consistent with CREAM I + III and NUCLEON KLEM (within error) at lower energy and consistent with KASCADE (QGSJET-01) at higher energy.
- The Helium spectrum is also consistent with CREAM I + III and NUCLEON KLEM (within error) at lower energy.

Date and time (Berlin) of ZOOM-Meeting : 13 July 2021-18:00.

Thank you