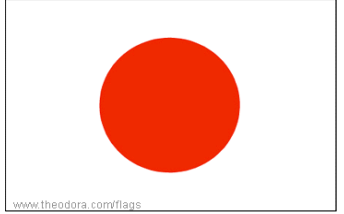
Highlights from the GRAPES-3 experiment

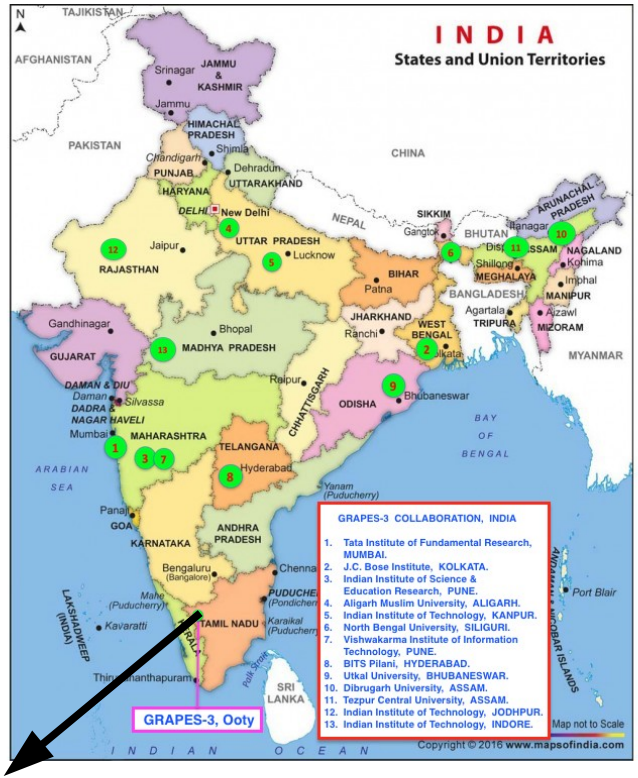
Pravata Mohanty for the GRAPES-3 collaboration

Tata Institute of Fundamental Research, India

37th ICRC, Berlin, Germany (online), 12-23 July 2021

The GRAPES-3 Collaboration





GRAPES-3 experiment, Ooty

1. Tata Institute of Fundamental Research, Mumbai, India
2. Osaka City University, Osaka, Japan
3. Aichi Institute of Technology, Aichi, Japan
4. J.C. Bose Institute, Kolkata, India
5. Indian Institute of Science & Edu. Res. Pune, India
6. Chubu University, Kasugai, Aichi, Japan
7. Hiroshima City University, Hiroshima, Japan
8. Aligarh Muslim University, Aligarh, India
9. Indian Institute of Technology, Kanpur, India
10. North Bengal University, Siliguri, India
11. Vishwakarma Inst. of Information Tech., Pune, India
12. Kochi University, Kochi, Japan
13. BITS Pilani, Hyderabad, India
14. Utkal University, Bhubaneswar, India
15. Dibrugarh University, Dibrugarh, India
16. Nagoya University, Nagoya, Japan
17. Tezpur Central University, Tezpur, India
18. Indian Institute of Technology, Jodhpur, India
19. Indian Institute of Technology, Indore, India
20. Institute for Cosmic Ray Research, Tokyo U., Japan

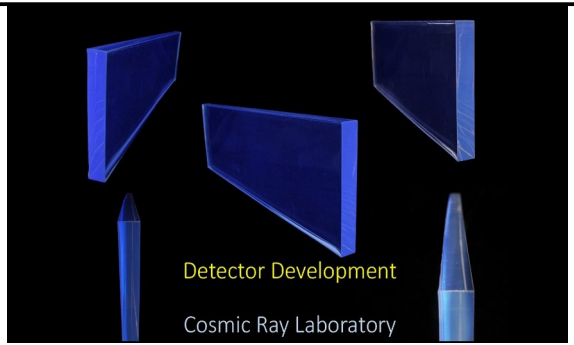
List of contributions from GRAPES-3 to ICRC 2021

- F. Varsi et al., PoS(ICRC2021)388: Recent measurements of the cosmic ray energy spectrum and composition from the GRAPES-3 experiment.
- M. Chakraborty et al., PoS(ICRC2021)393: Large-scale cosmic ray anisotropy measured by the GRAPES-3 experiment.
- M. Chakraborty et al., PoS(ICRC2021)394: Vetoing the high energy showers in the GRAPES-3 experiment whose cores lie outside the array.
- A. Chandra et al., PoS(ICRC2021)396: An extensive study for correcting the nonlinear particle density measured by GRAPES-3 scintillator detectors.
- D. Pattanaik et al., PoS(ICRC2021)391: Measurement of the improved angular resolution of GRAPES-3 EAS array by the observation of the Moon shadow.
- D. Pattanaik et al., PoS(ICRC2021)870: Search for gamma rays above 30 TeV from the Crab Nebula with the GRAPES-3 experiment.
- B. Pant et al., PoS(ICRC2021)871: Characterizing the isotropic diffuse gamma-ray flux (10-300 TeV) by the GRAPES-3 experiment.
- M. Zuberi et al., PoS(ICRC2021)390: Zenith angle dependence of pressure effect in GRAPES-3 muon telescope.
- H. Kojima et al., PoS(ICRC2021)1303: High-resolution two-dimensional map of the solar-time anisotropy obtained by the GRAPES-3 large-area muon telescope.
- B. Hariharan et al., PoS(ICRC2021)378.The azimuthal distribution of thunderstorm events recorded by the GRAPES-3 experiment.
- A. Jain et al., PoS(ICRC2021)257: An Advanced Triggerless Data Acquisition System for GRAPES-3 Muon Detector.
- B. Hariharan et al., PoS(ICRC2021) 379: Measurement of large angle muon flux in GRAPES-3 experiment using triggerless DAQ system.
- M. Zuberi et al., (PoS(ICRC2021)389: A study of the Moon shadow by using GRAPES-3 muon telescope – M. Zuberi

GRAPES-3 experiment in Ooty, India (altitude 2200m)

- 400 plastic scintillator detectors of 1 m^2 area each with 8 m separation spread over 25000 m^2
- 560 m^2 area muon telescope consiting 3712 proportional counters (6m x 0.1m x 0.1m)
- Scintillator detectors measure particle density and relative arrival time in EAS
- Energy sensitivity of the aray is in TeV-PeV range.

GRAPES-3 scintillator development

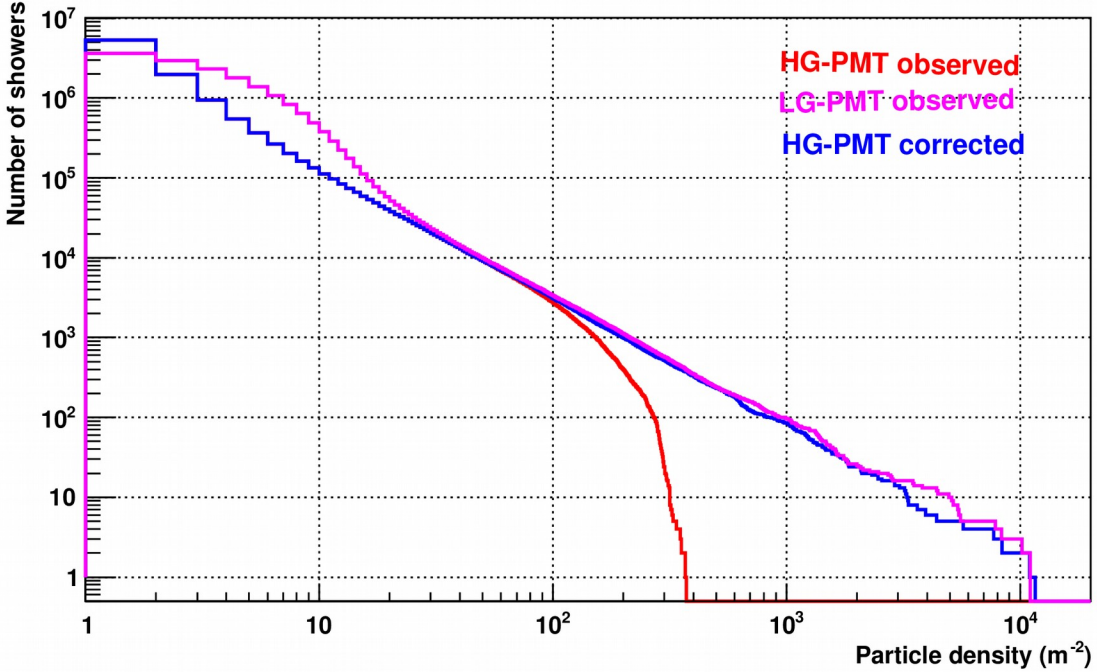


An in-house developed compact Monte Carlo code G3sim accurately predicts the responses of scintillator detectors
P.K. Mohanty et al., Rev. Sci. Instr. 83 043301 (2012).

Extended particle density measurements

A. Chandra et al., PoS (ICRC2021)396

25% of scintillator detectors in the GRAPES-3 array are instrumented with two PMTs to increase the dynamic range of particle density measurements taking data since 2017.



Non-linearity correction enhances particle density measurements of single PMT detectors from 100-200 to over 5000 m^{-2}

GRAPES-3 Muon Telescope

Inside view of Muon Telescope

16 (35 m^2 each) modules

58 PRCs x 4 Layers @ module

3712 total PRCs

560 m^2 total area

13x13 directions (2.3sr) view

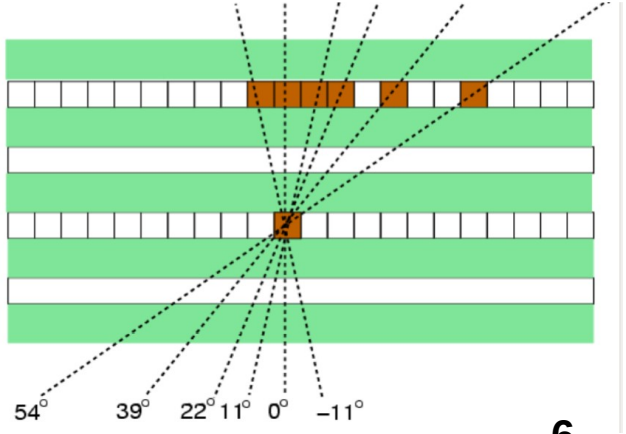
Energy threshold=1 GeV sec(theta)

4 billion muons per day

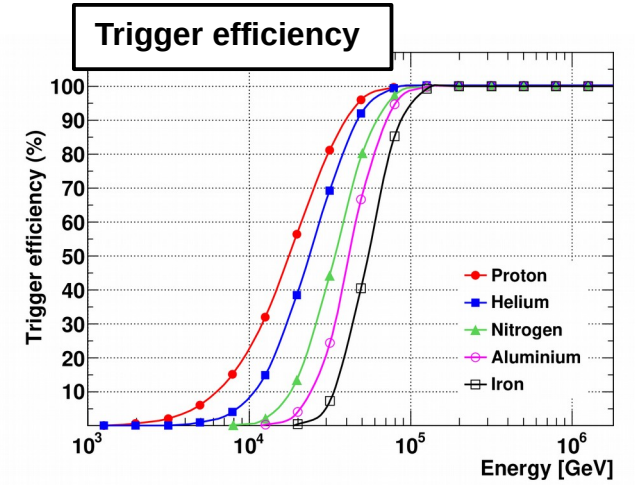
Sensitivity: 10^{-3} per minute

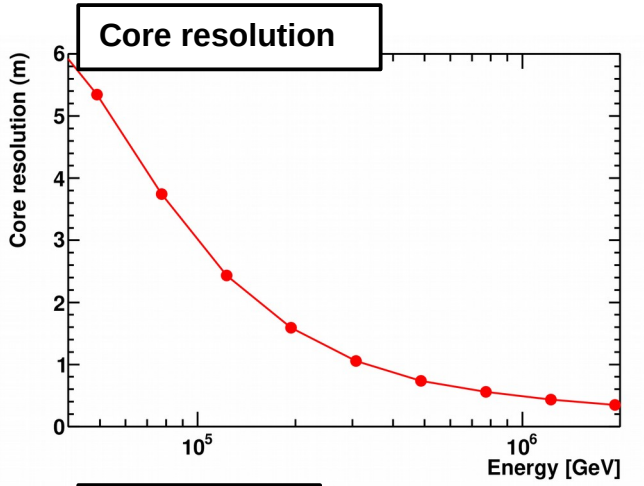
Cutoff rigidity: 14-32 GV

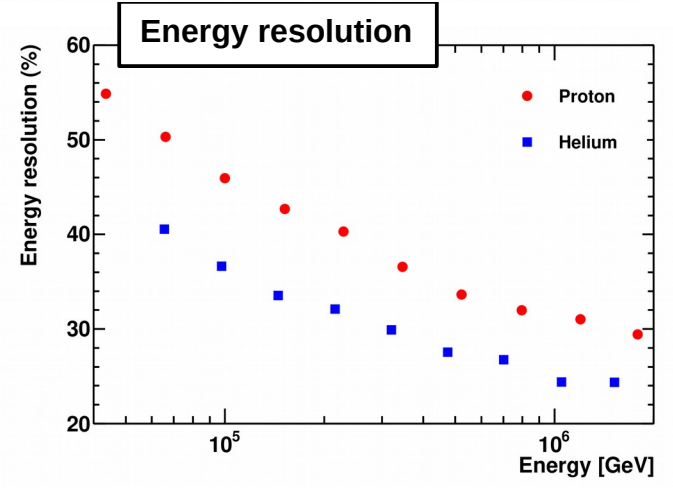
Median rigidity: 65-140 GV

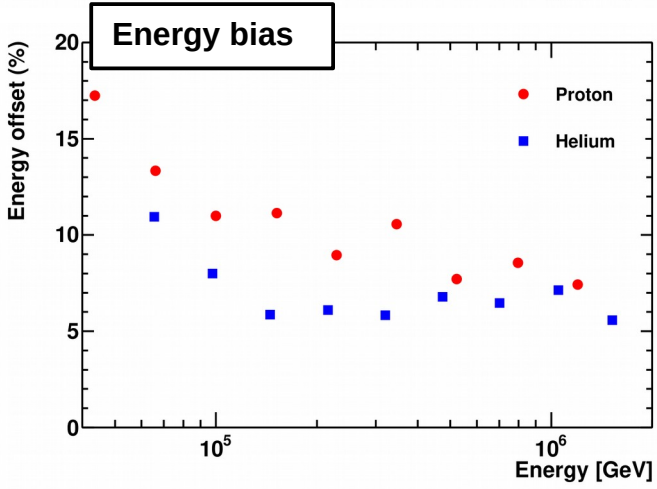


GRAPES-3 scintillator array response to primary CRs

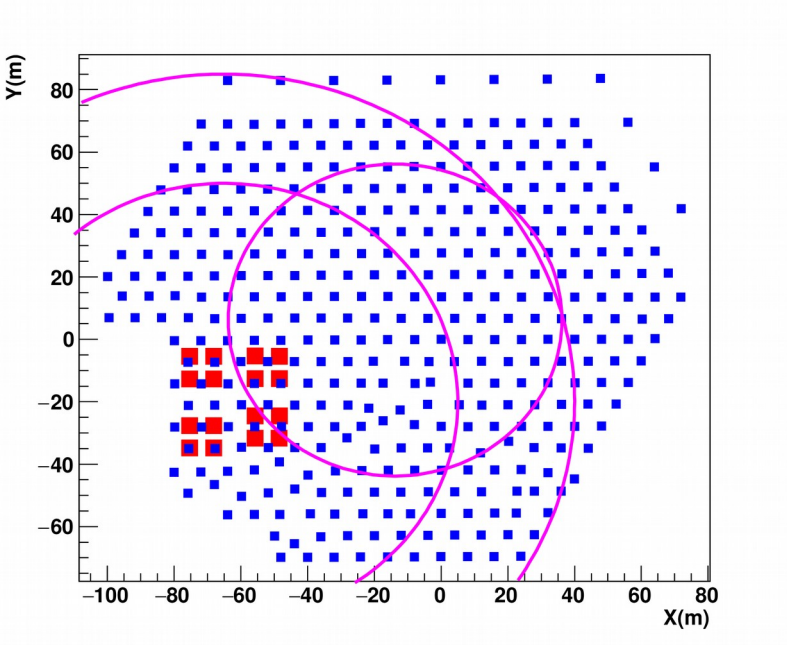


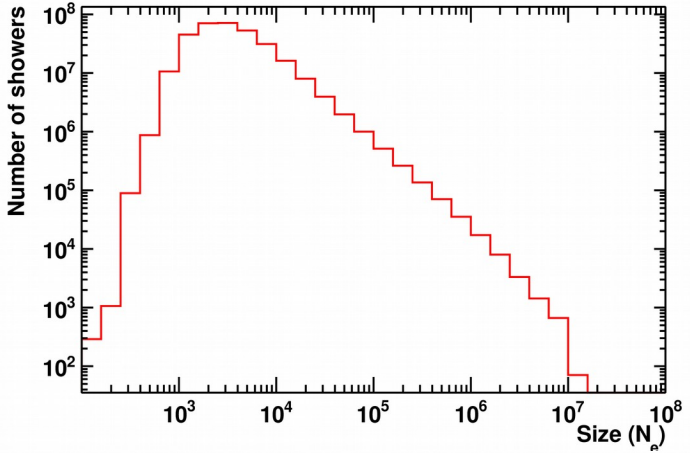


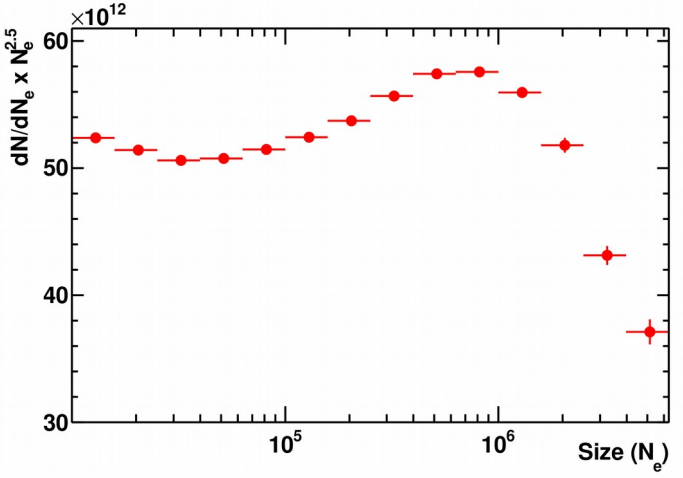




Shower selection for CR energy spectrum and composition

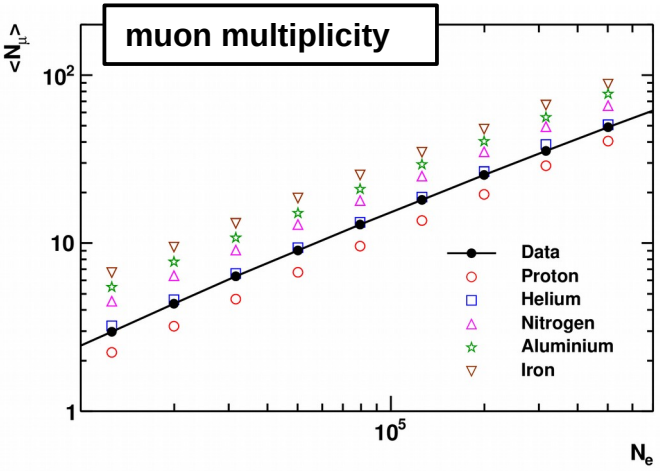


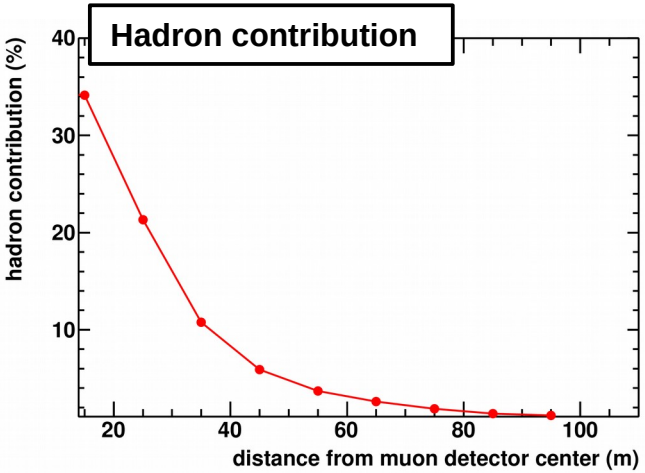




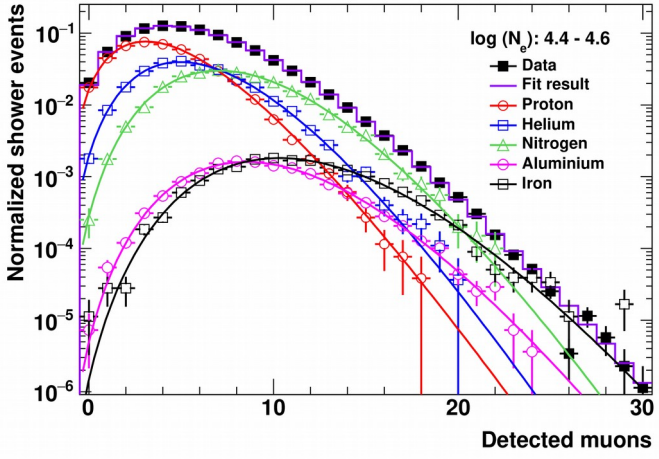
- 32 months data used (926 days live time)
- Zenith angle < 18^{o}
- Showers selected within 50 m from center of the array which reduced contaminations of showers landing outside the array < 1%.
- Number of showers after quality cuts = 3.2 x 10^{7} (1.5%)

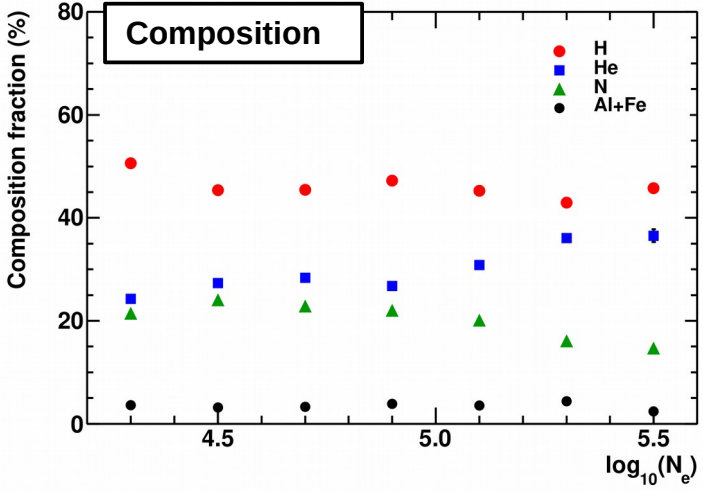
Muon multiplicity distribution and mass composition



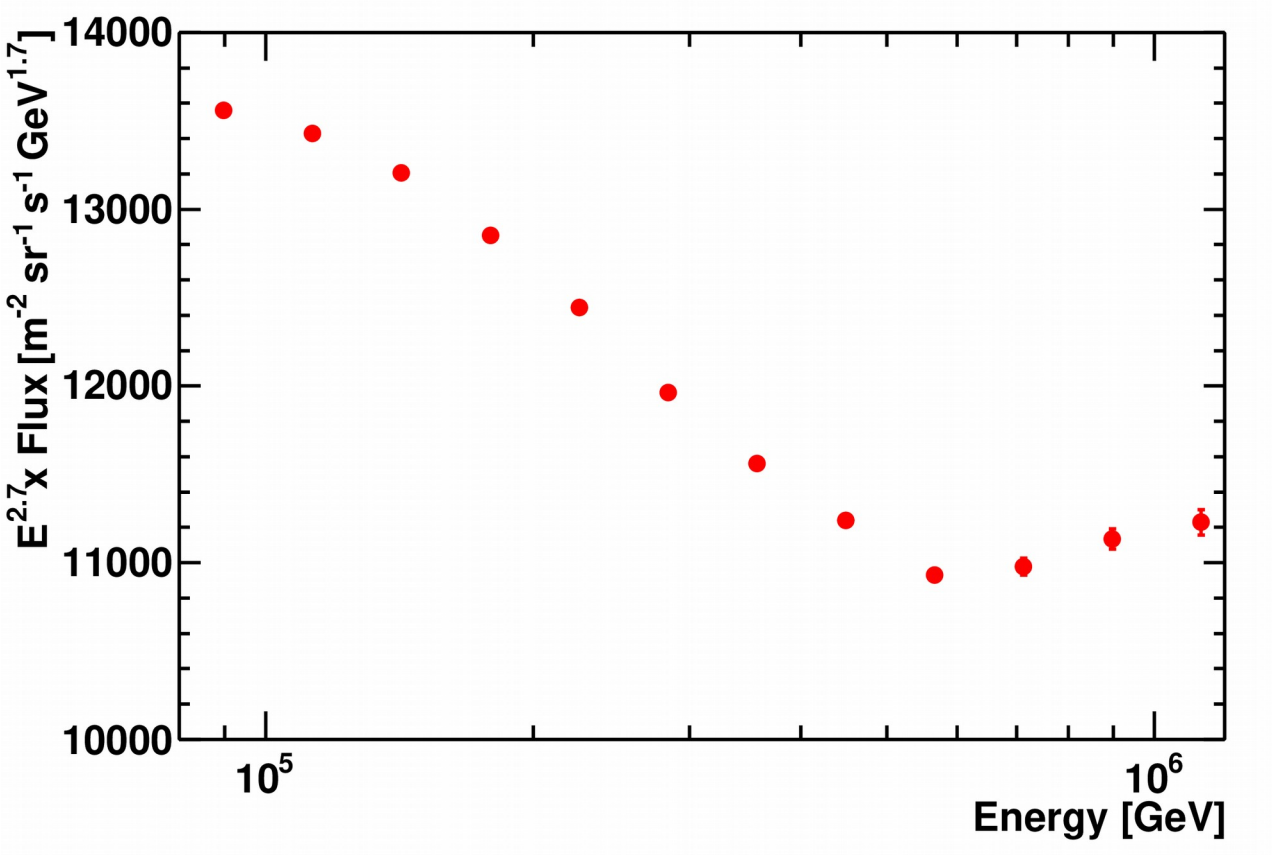


Air shower simulation performed using CORSIKA post LHC QGSJETII-04 hadronic interaction model

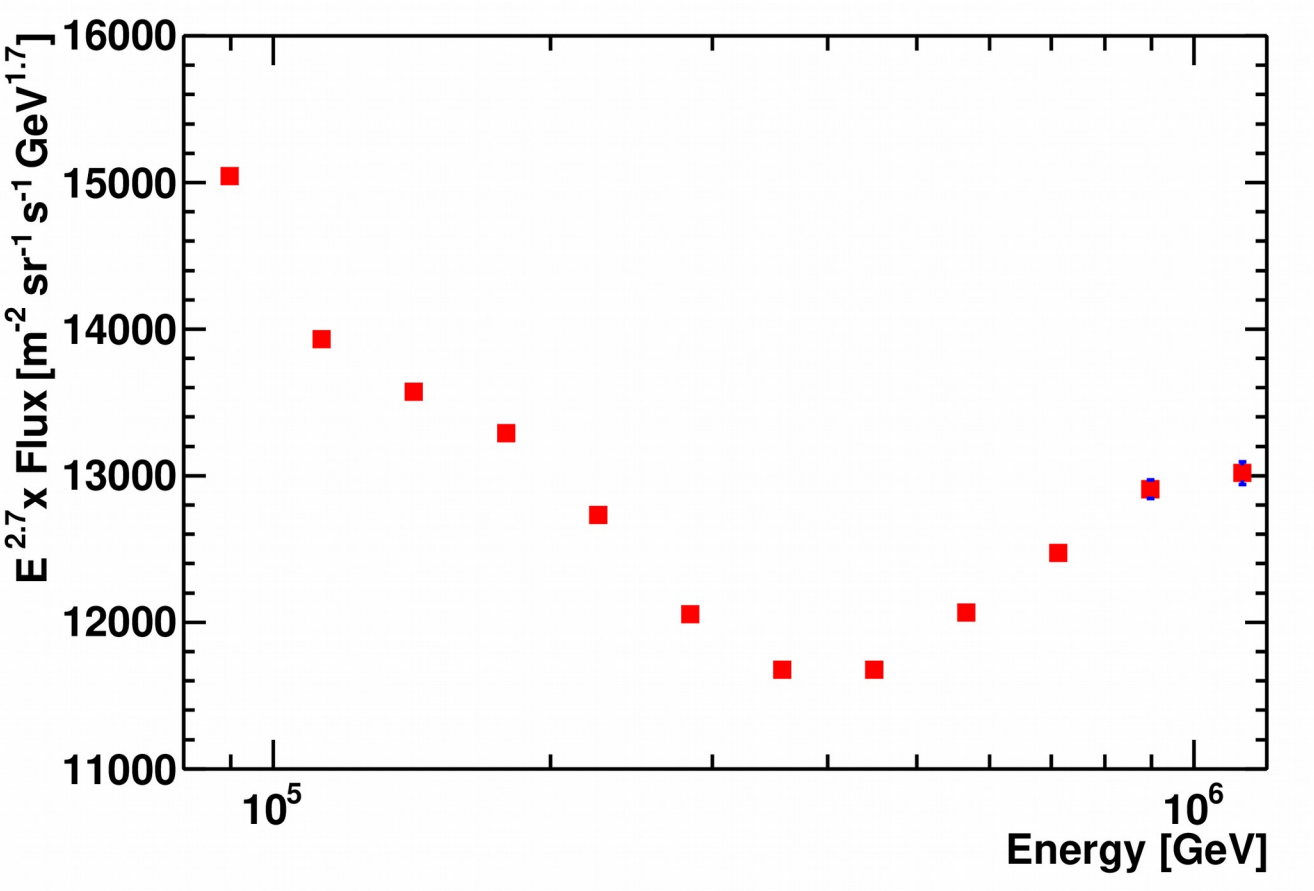




GRAPES-3 Proton spectrum results

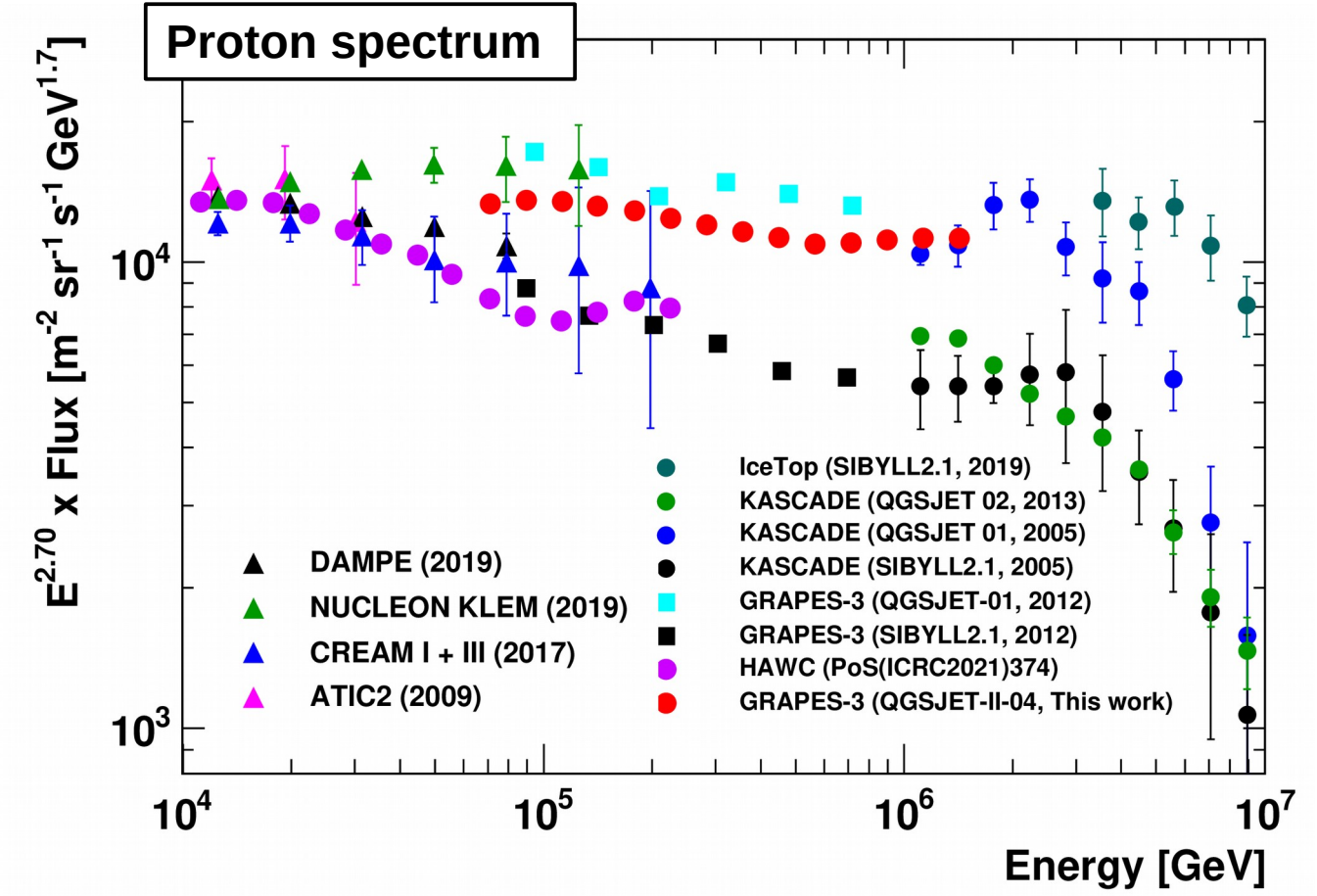


GRAPES-3 Helium spectrum results



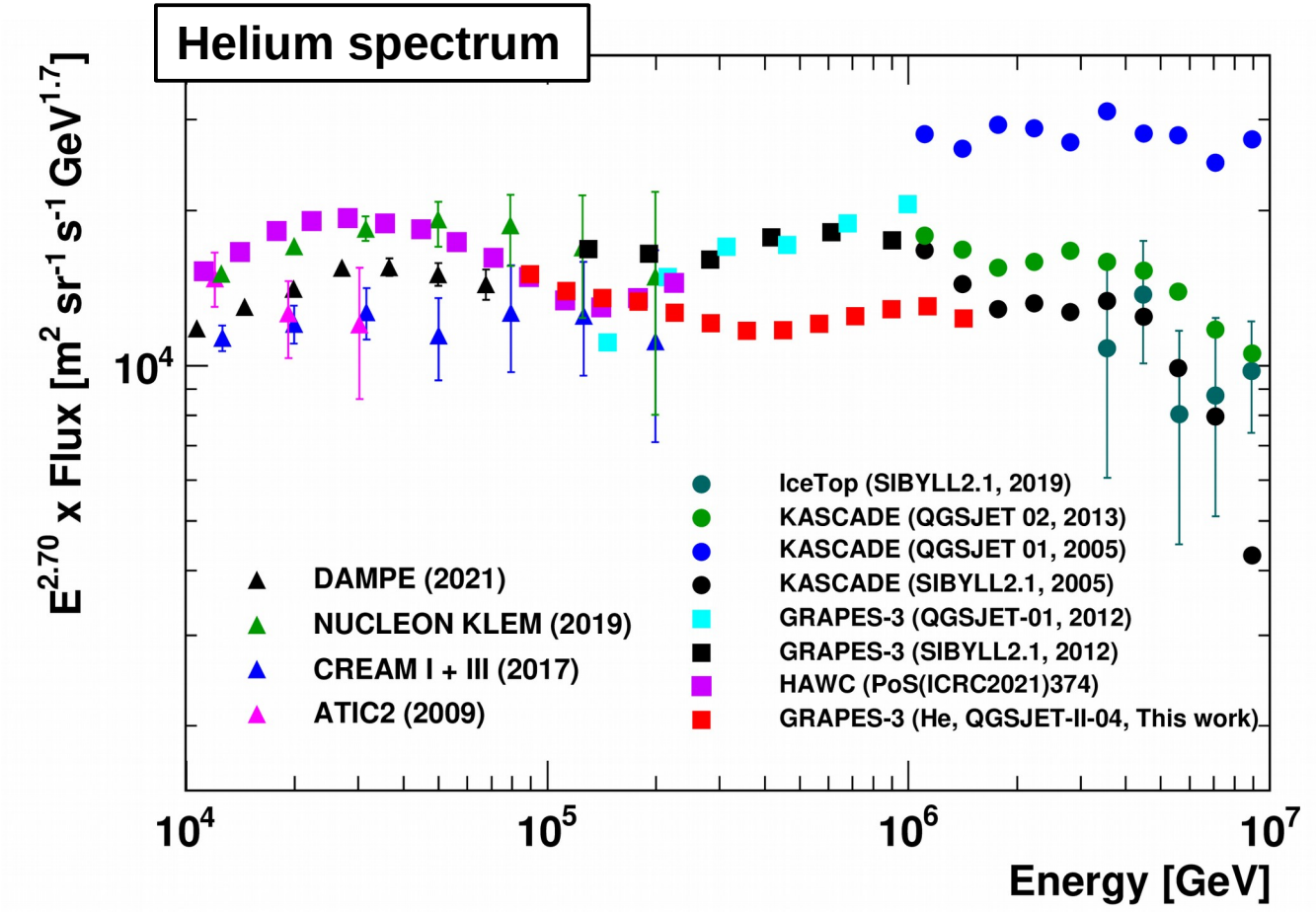
Connecting to direct/indirect measurements

F. Varsi et al., PoS (ICRC2021)388



Connecting to direct/indirect measurements

F. Varsi et al., PoS (ICRC2021)388

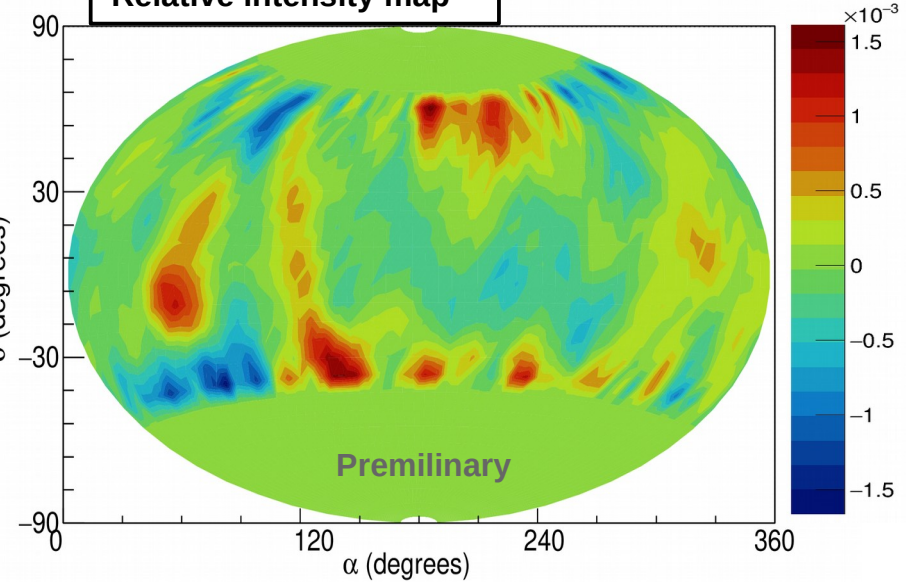


GRAPES-3 cosmic ray anisotropy

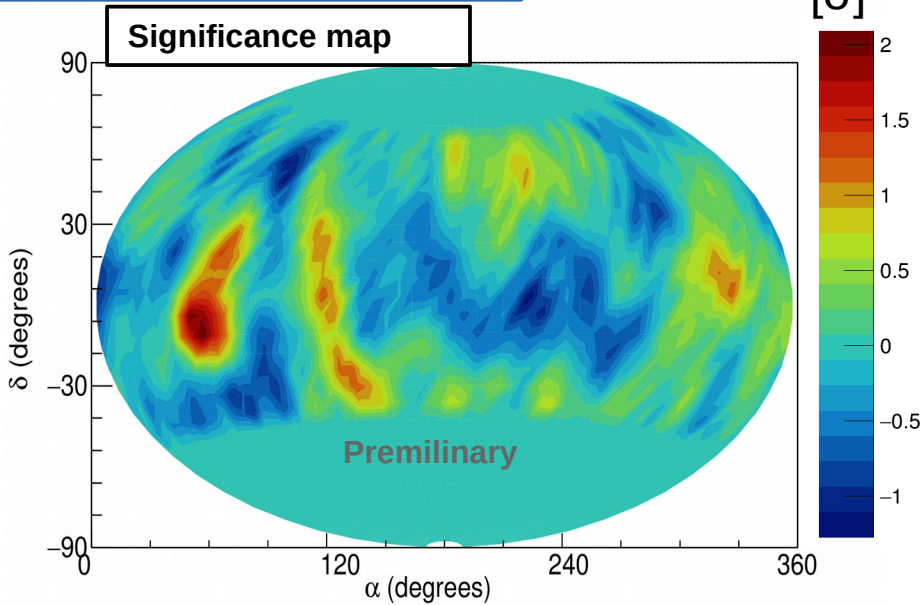
M. Chakraborty et al., PoS (ICRC2021) 391

- 3 years of data used with total 2.5 x 10^9 events
- Median energy ~28 TeV
- Scrambling method used to extract anisotropy
- Several small scale structures observed with a prominent one at 50-80^o RA
- Also faint large scale deficit observed at 130-260^o RA

Relative intensity map



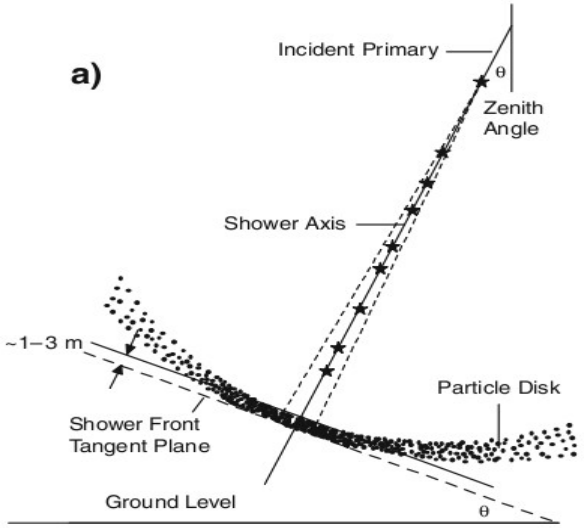
Significance map

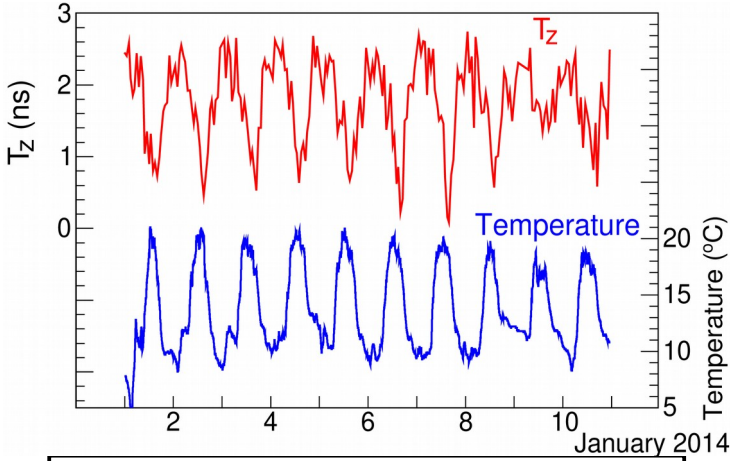


Shower front curvature

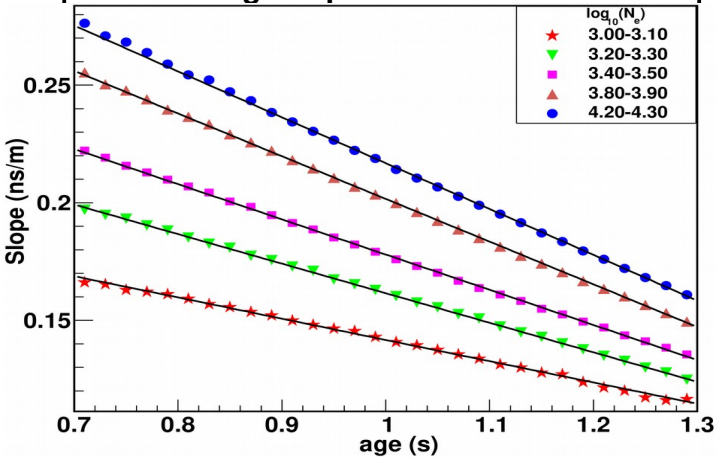
V.B. Jhansi et al., JCAP07 (2020) 024

- Propagation delay from detector in the field to TDC in the control room through 230m co-axial cable is observed to be dependent on ambient temperature.
- A method developed to measure this time offset on hourly basis from the EAS data



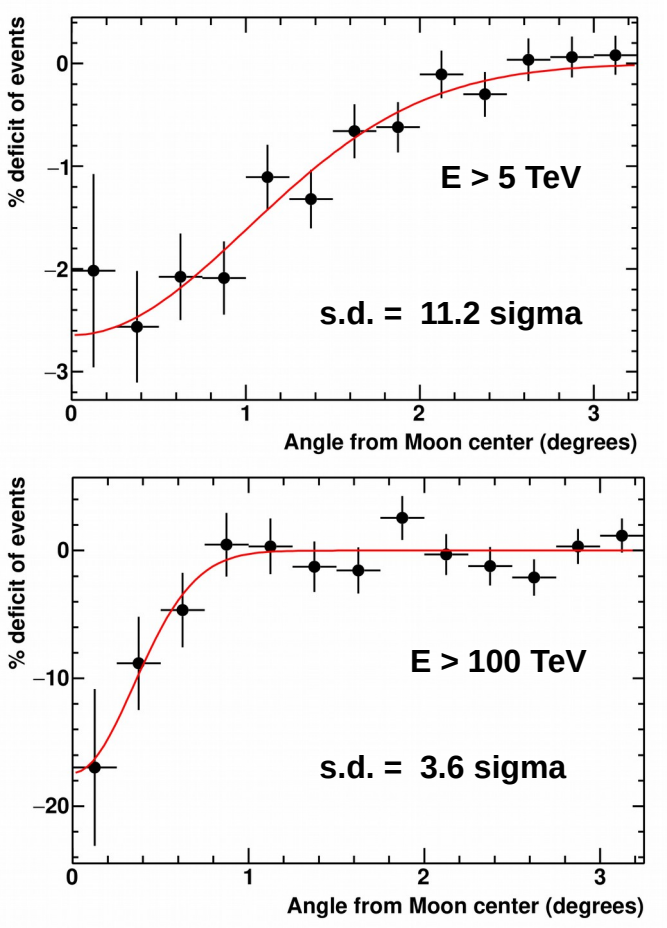


Size and age depedence of curvature

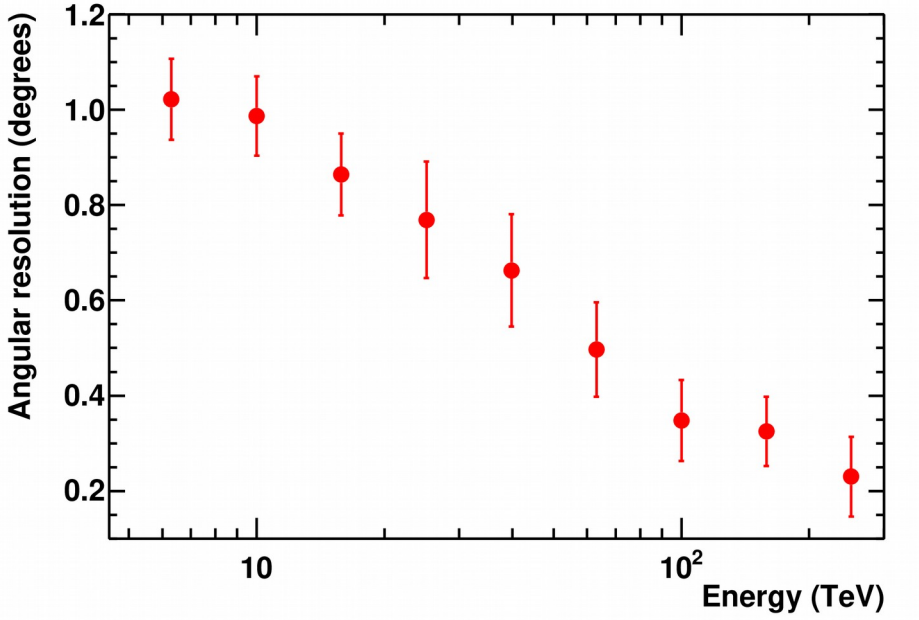


Moon shadow results

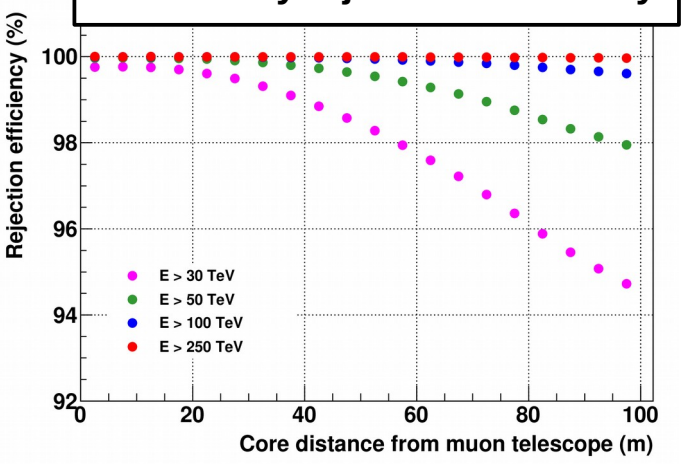
D. Pattanaik et al., PoS (ICRC2021)391



Angular resolution by Moon shadow with 3 years of data

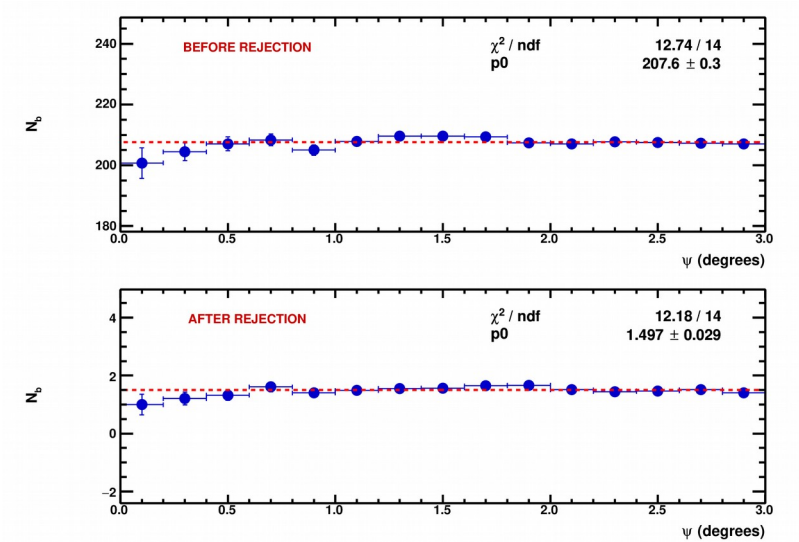


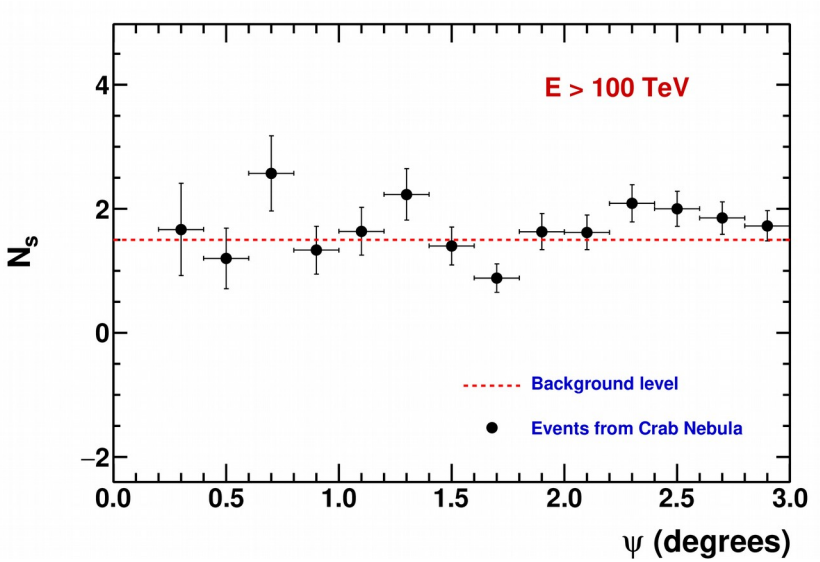
Cosmic ray rejection efficiency



D. Pattanaik et al., PoS (ICRC2021)870

Gamma ray search from Crab nebula





GRAPES-3 isotropic diffuse gamma ray results

B.P. Pant et al., PoS(ICRC2021)871

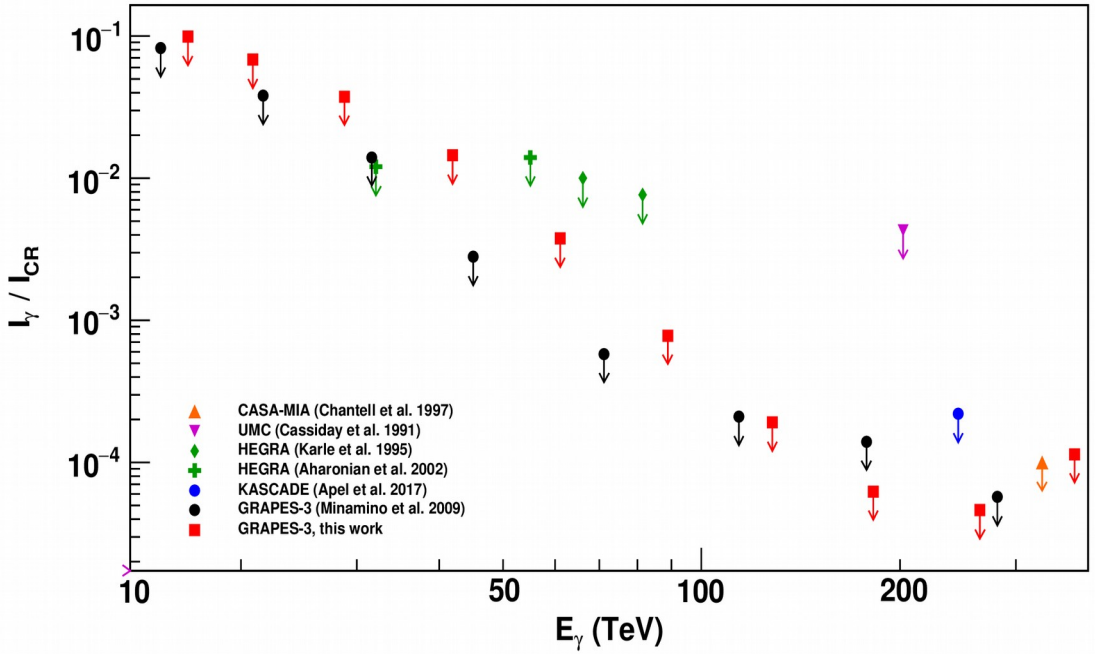
Interaction of UHECRs with CMB radiation via:

- Pion photoproduction
$p + \gamma_{CMB} \rightarrow p + \pi^0$

- Bethe-Heitler pair production
$p + \gamma_{CMB} \rightarrow p + e^+ + e^-$

- Secondaries further interact with CMB radiation and undergo EM cascading.

- Final outcome is diffuse and isotropic flux of ultra-high-energy γ-rays ~ 100 TeV

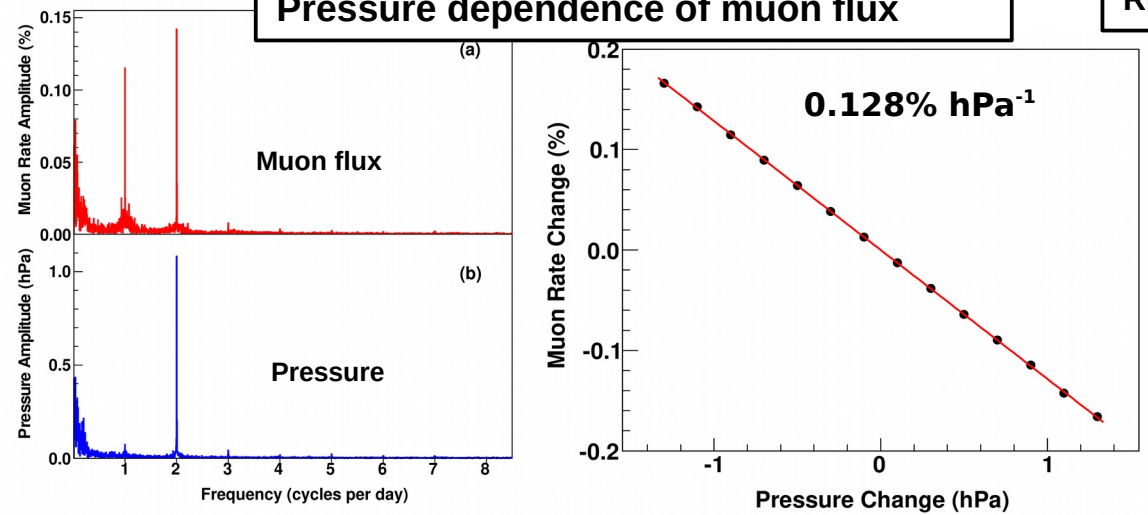


In this analysis, air showers with zero muons were selected as gamma-like events

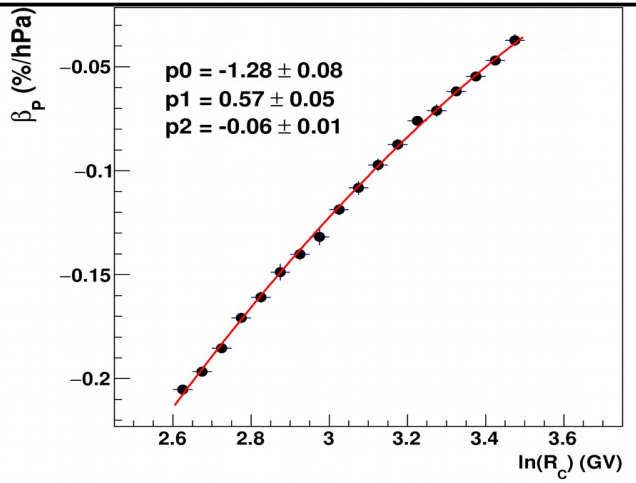
Atmospheric corrections of muon flux

M. Zuberi, PoS(ICRC2021)390

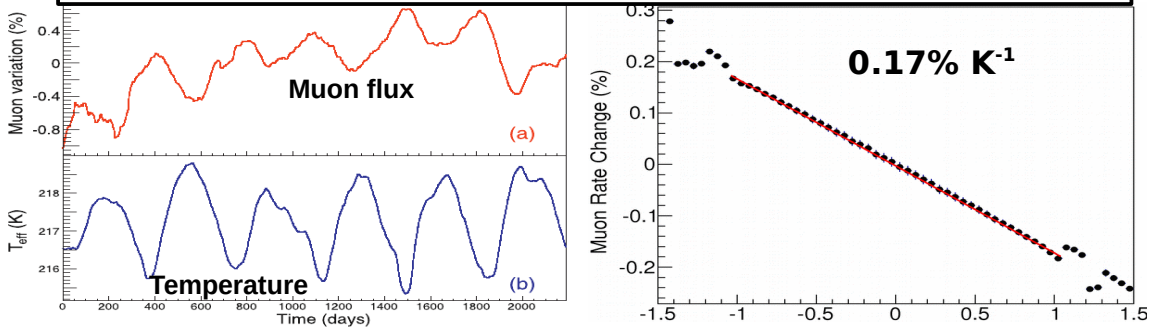
Pressure dependence of muon flux



Rigidity dependence of pressure coefficient



Atmospheric temperature dependence of muon flux

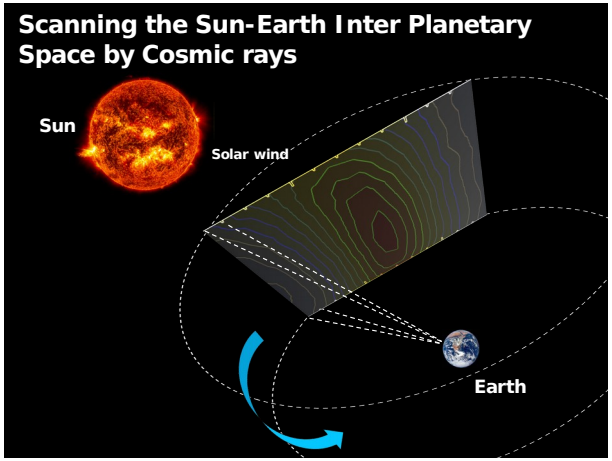


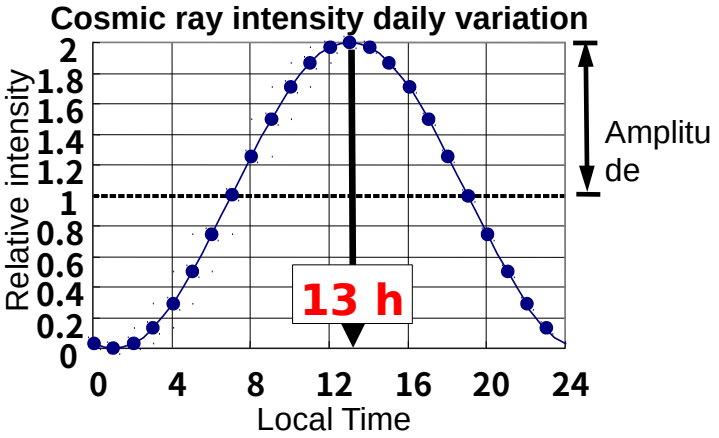
Pressure results:
P.K. Mohanty et al., Astropart. Phys. 79 (2016) 23-30.

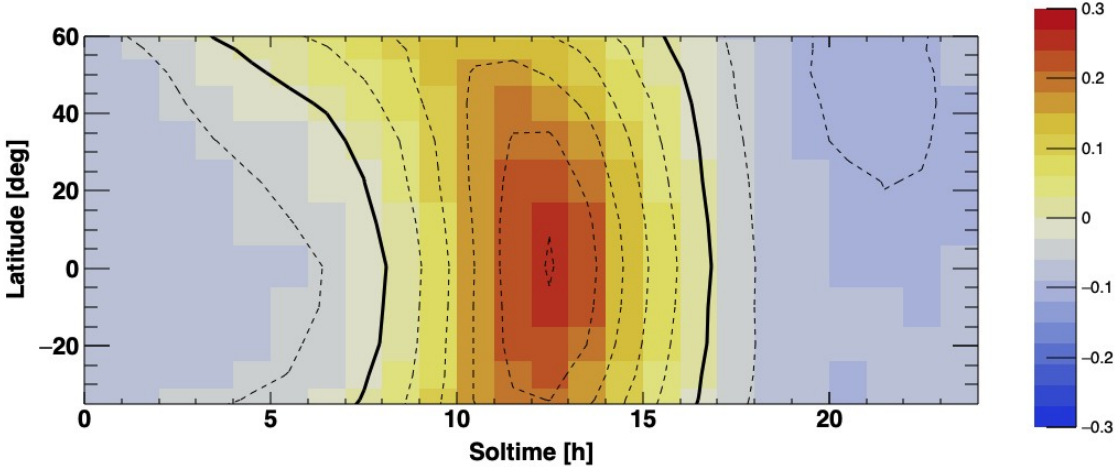
Temperature results:
K.P. Arunbabu et al., Astropart. Phys. 94 (2017) 22-28.

GRAPES-3 solar anisotropy results

H. Kojima et al., PoS (ICRC2021) 1301



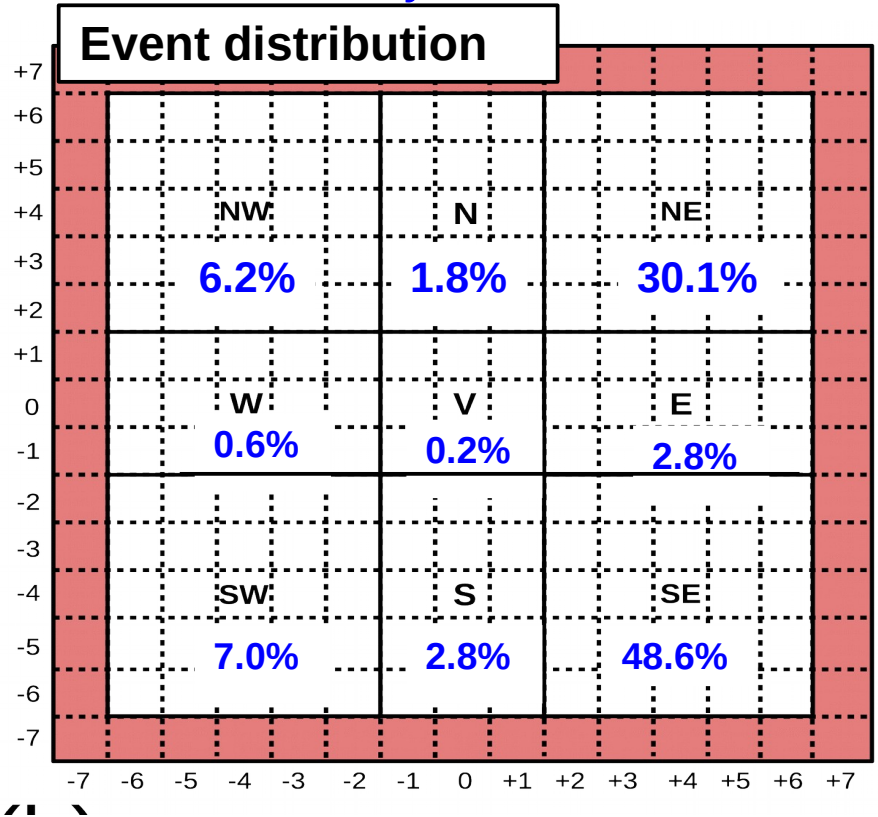


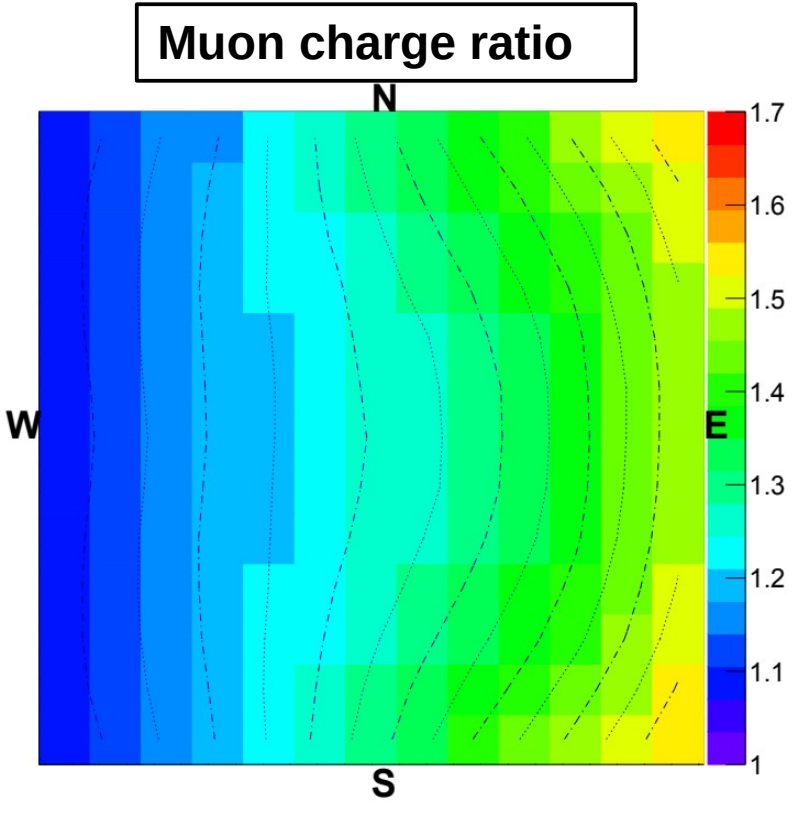


Thunderstorm investigations

B. Hariharan et al., PoS (ICRC2021)378

Total 487 thunderstorm events associated with variation of muon intensity were recorded by GRAPES-3 since installation of electric field mills in 2011.





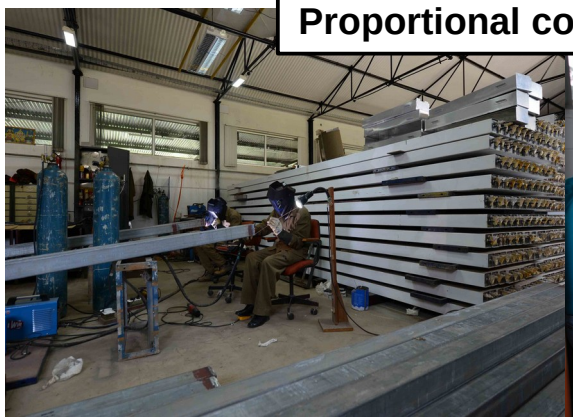
Upgrade of GRAPES-3 in next 2-3 years

1. Scintillator array will be doubled
2. Muon telescope will be doubled

To increase sensitivity for

1. CR composition below < 100 TeV
2. PeV gamma ray sources
3. 70% larger sky coverage for solar and atmospheric studies

Proportional counter fabrication

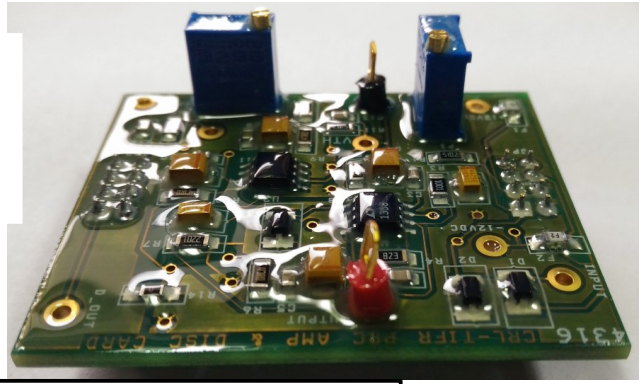


Electronics development for muon telescope

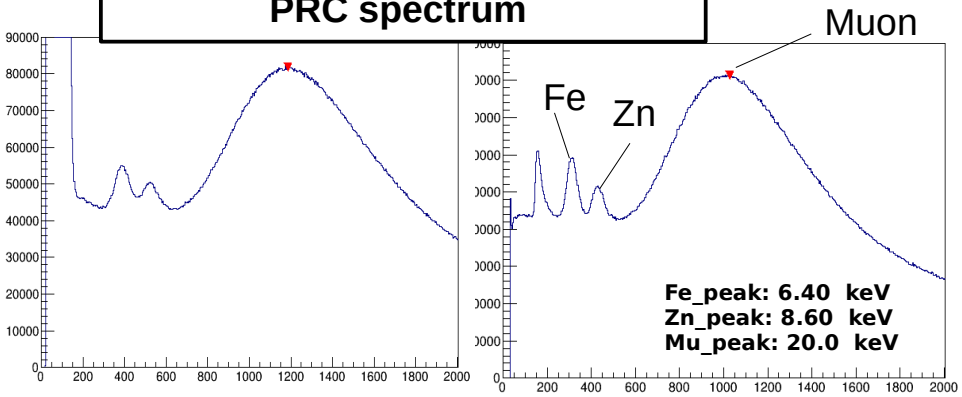
A. Jain et al., PoS (ICRC2021)257

Discriminator-amplifier for PRC

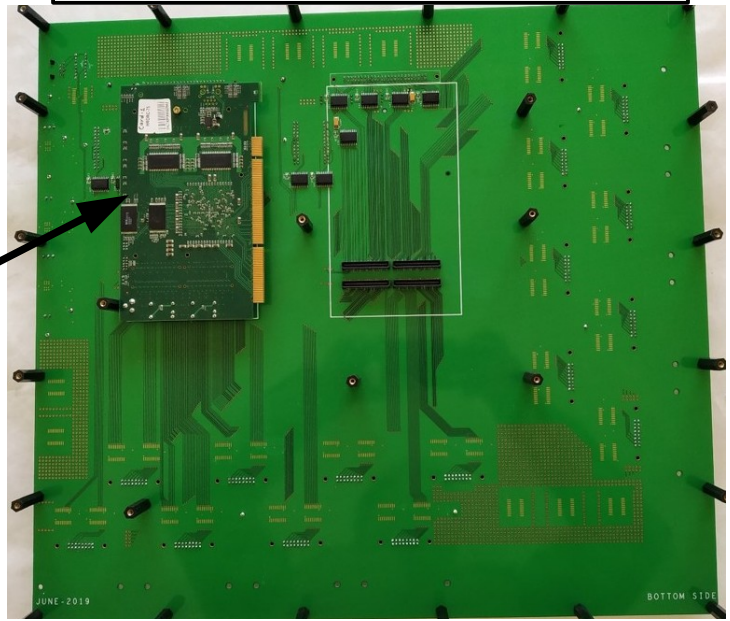
- Low noise
- Low power budget
- Cost effective



PRC spectrum



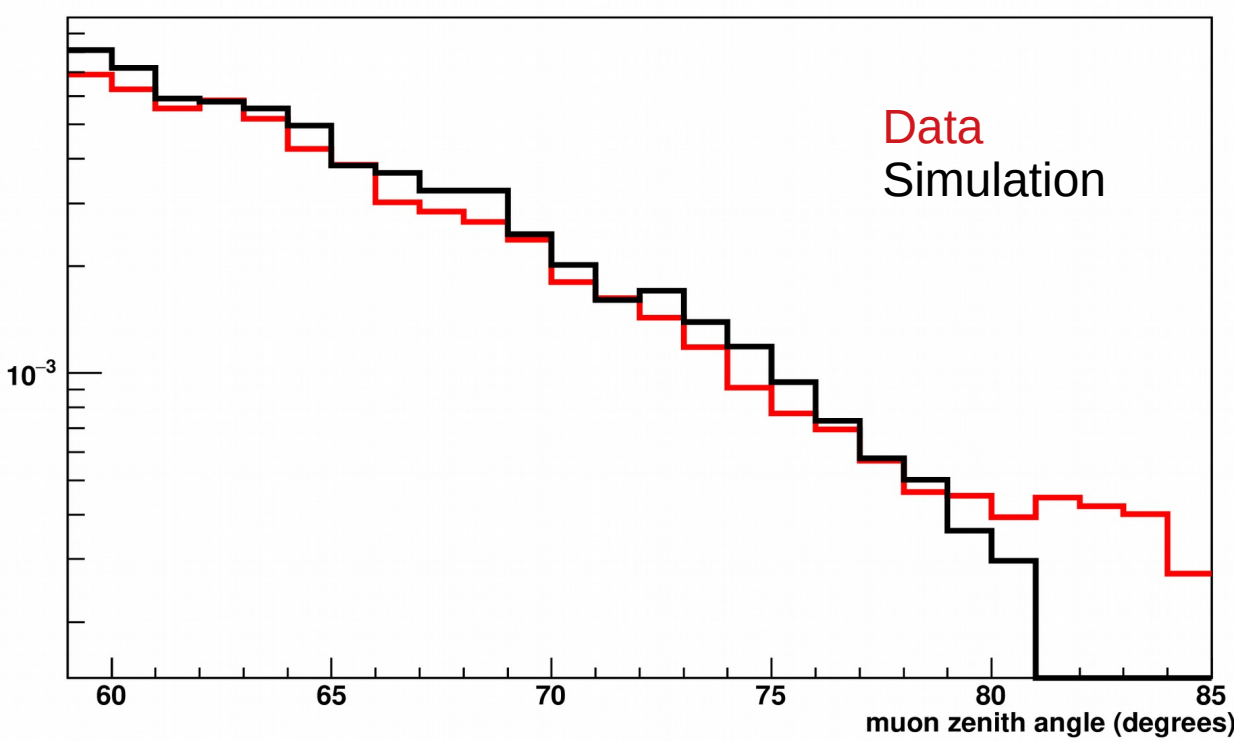
FPGA based DAQ electronics



- Small deadtime of ~0.001% as compared 15% of the legacy DAQ.
- Compact and low power consumption
- Taking data from 4 muon modules

Large angle muons with new DAQ

B. Hariharan, PoS(ICRC2021)379



Summary

- GRAPES-3 is a versatile experimental setup for studies of cosmic ray, gamma ray, solar and atmospheric phenomena.
- Muon multiplicity distributions is a sensitive parameter for composition
- Cosmic ray energy spectrum and composition results connects with direct and indirect measurements are reported.
- Dependence of shower front curvature on shower age and size observed. Angular resolution valiated through moon shadow method presented.
- High rejection of cosmic ray background through muon component presented. More analysis required for detection for multi-TeV gamma ray sources.
- Solar diurnal anisotropy is mapped to show the spatial variation
- Upgrade of the GRAPES-3 array is in progress.

We welcome new participation in GRAPES-3 experiment

Thank you