GRAPES-3 Experiment at Ooty

Pravata Mohanty

TIFR, Mumbai

email: pkm@tifr.res.in

(for the GRAPES-3 collaboration)

International Conference on High Energy Particle & Astroparticle Physics (ICHEPAP2023)
Saha Institute of Nuclear Physics, Kolkata, December 11-15, 2023

The GRAPES-3 Collaboration

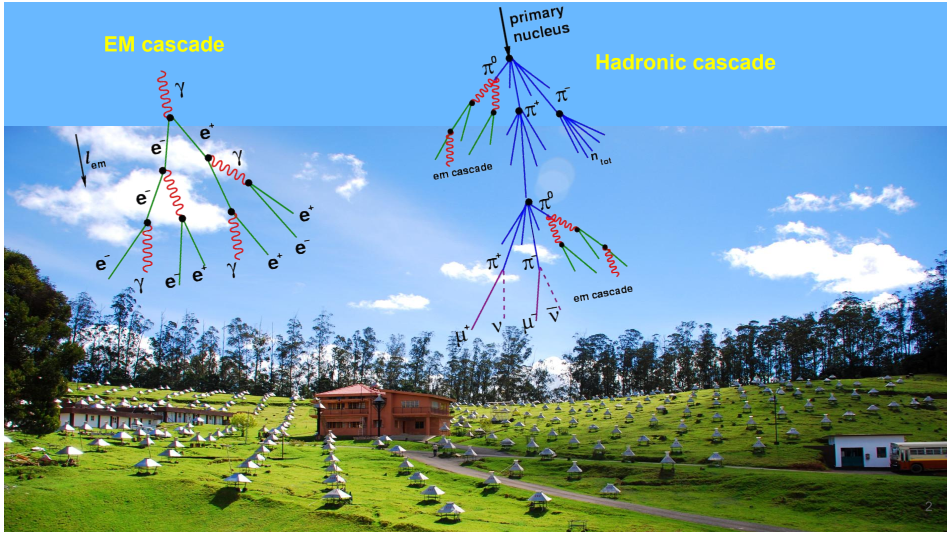
GRAPES-3 is located in Ooty, India

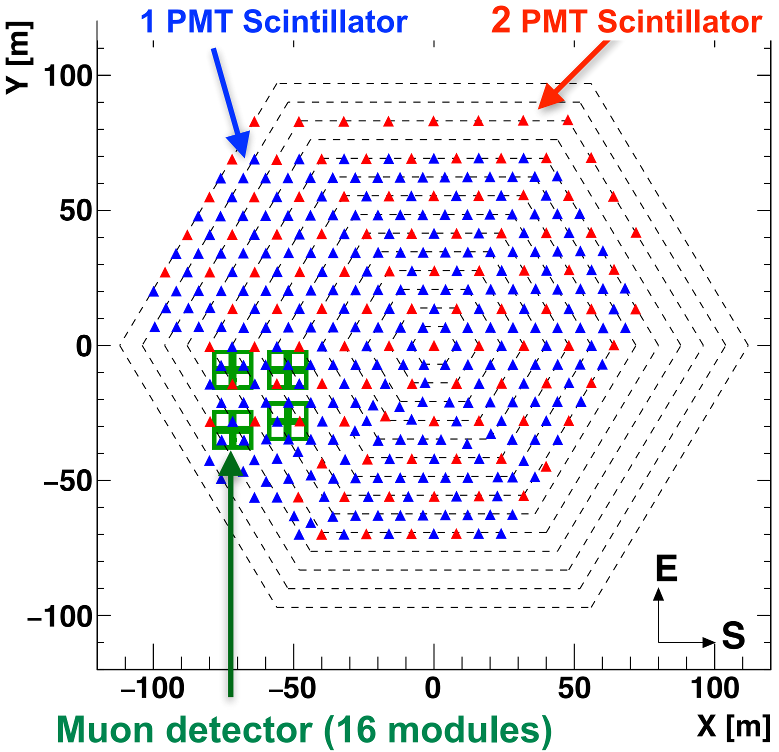
11.4° N lat., 76.7°E lon., 2200 m alt.

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. Utkal University, Bhubaneswar, India
14. Dibrugarh University, Dibrugarh, India
15. Nagoya University, Nagoya, Japan
16. Tezpur Central University, Tezpur, India
17. Indian Institute of Technology, Jodhpur, India
18. Indian Institute of Technology, Indore, India
19. Institute for Cosmic Ray Research, Tokyo U., Japan
20. Amity University, Noida, India
21. Institute of physics, Bhubaneswar, India

GRAPES-3 experiment at Ooty, India, altitude: 2200m

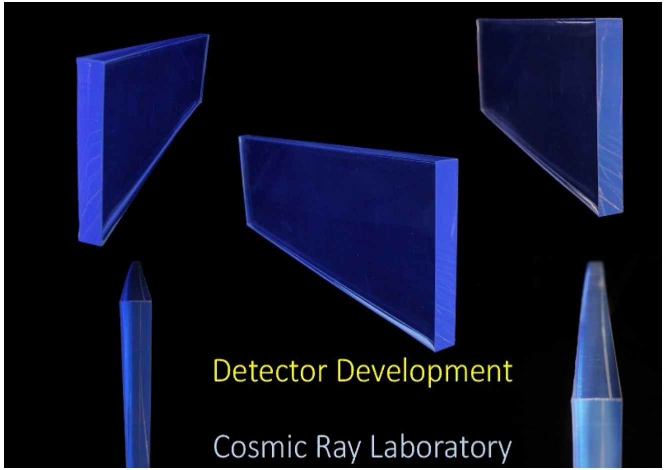
- 400 plastic scintillator detectors (1 m^2 area) with 8 m inter-separation spread over 25,000m^2
- 560 m^2 muon detector consisting 3712 proportional counters (6m x 0.1m x 0.1m).
- 3 x 10^6 EAS events per day in TeV- PeV range with median energy of 15 TeV.

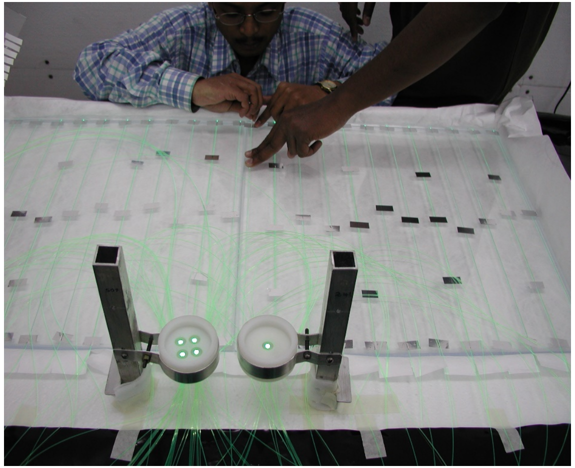


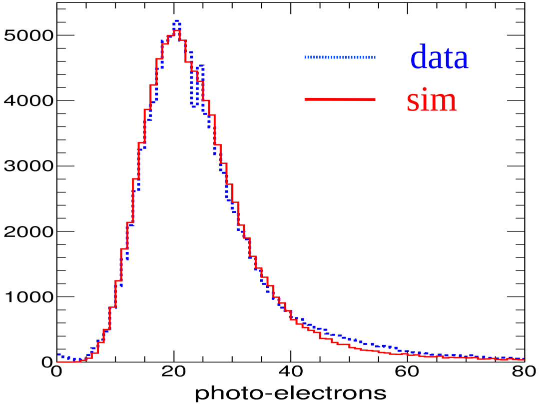


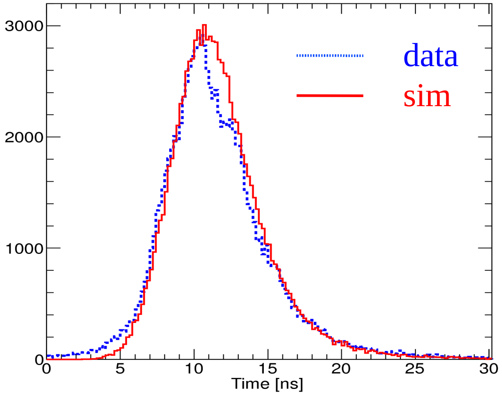
- Scintillator detectors measure density and arrival times of EAS particles
- 25% of scintillators instrumented with 2 PMTs for extended density measurements over 10000 m^{-2}

Development and fabrication of plastic scintillators at GRAPES-3









Plastic Scintillator development:

Decay Time= 1.6 ns Light Output = 85% Bicron (54% anthracene)

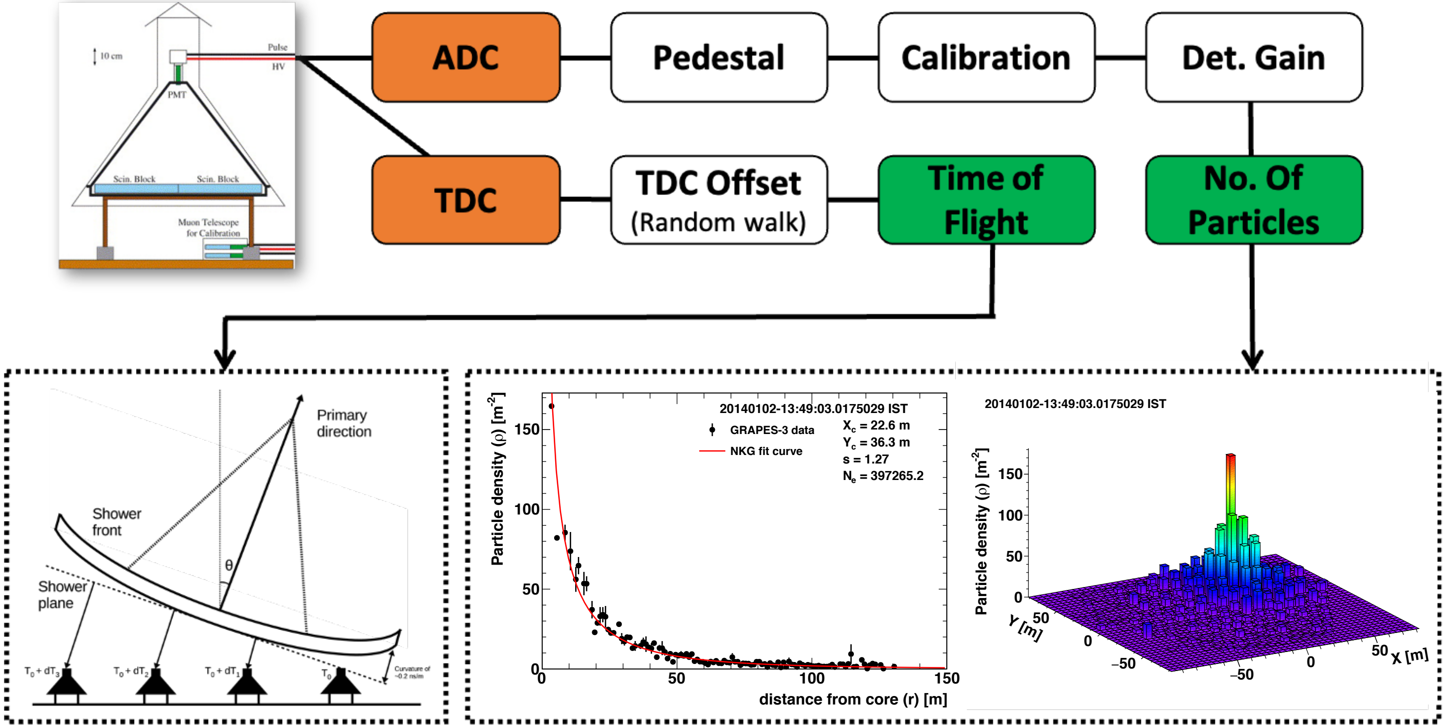
Timing 25% faster Atten. Length λ= 100cm Cost ~30% of Bicron

Max Size 100cmX100cm Total > 2000

CERN, Osaka, IUAC Delhi, Bose, VECC, BARC, ECIL, Utkal U. Dayalbag, IISER Pune

In-house developed simulation code G3sim. P.K. Mohanty et al., Rev. Sci. Instrum. 83 (2012) 043301.

Shower reconstruction and parameters

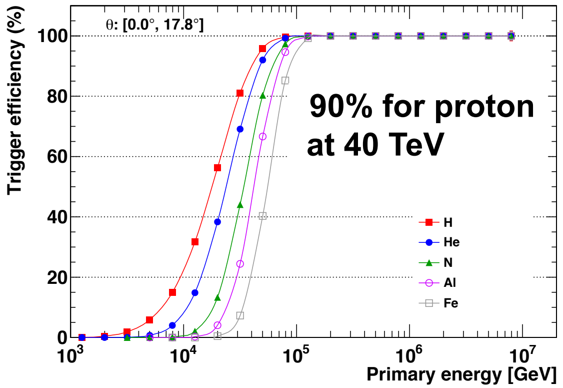


Direction (θ, ϕ)

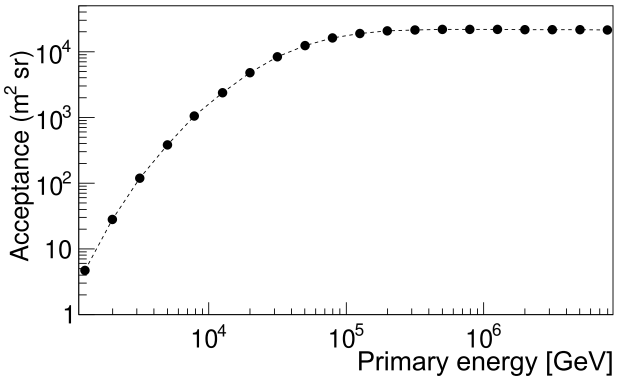
Core location (Xc, Yc), Age (s), Size (Ne) -> Energy

Performances of the scintillator array (through MC)

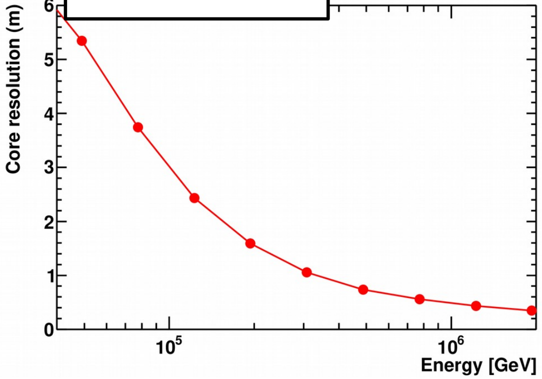
Trigger efficiency



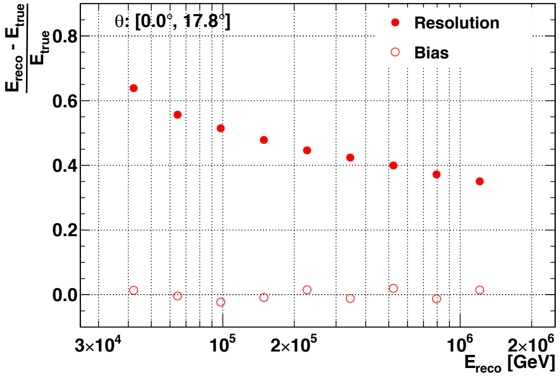
Acceptance for proton



Core resolution

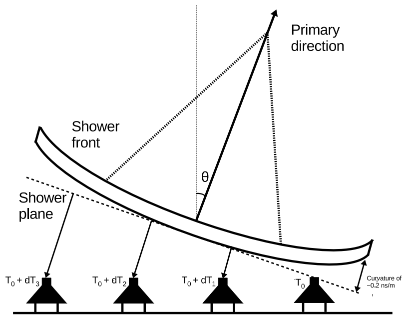


Energy resolution and bias

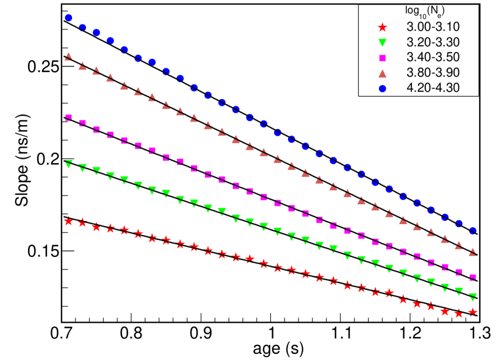


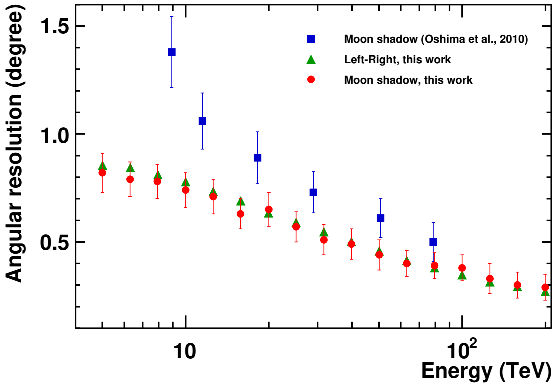
Performances of the scintillator array (angular resolution)

Shower front curvature

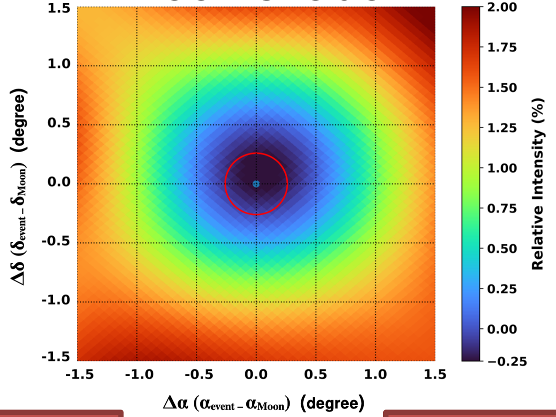


Dependence of slope on size and age:

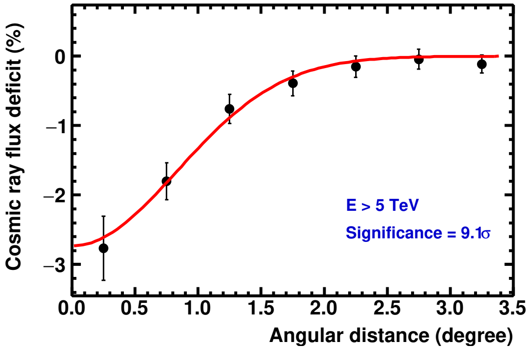


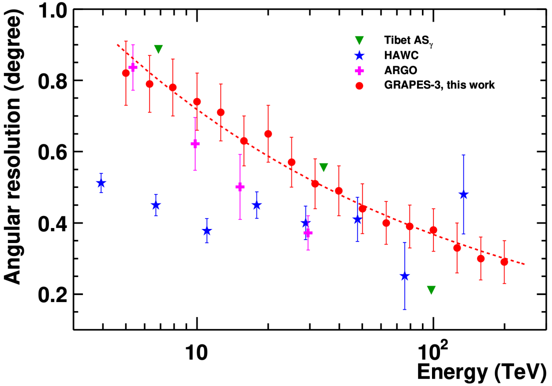


Moon shadow



Moon shadow





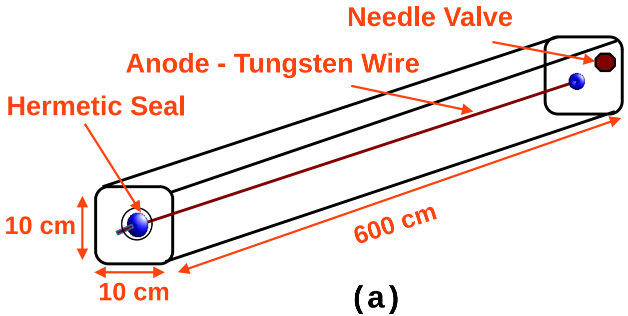
V.B. Jhansi et al., JCAP 07 (2020) 024

D. Pattanaik et al., PRD 106 (2022) 022009

GRAPES-3 muon detector (560 m^2)

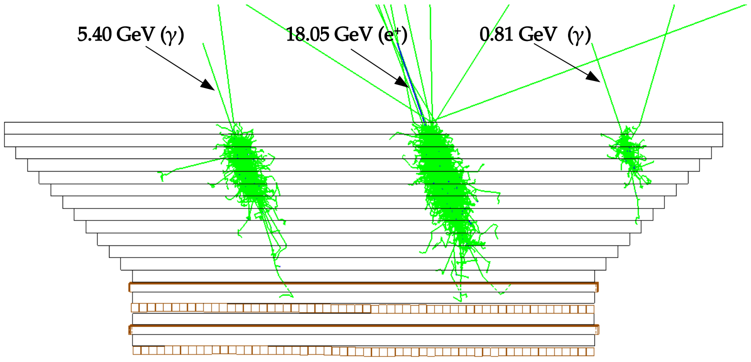
- Muon detector consists of 16 modules of 35 m^2 area each.
- Threshold of muons = 1 GeV
- Muons recorded associated with each EAS trigger, also with self trigger or individual muons for measurement of muon flux.
- Self triggered muons are recorded in 169 directional bins with 4^o resolution. Muons recorded per day ~4 billions.

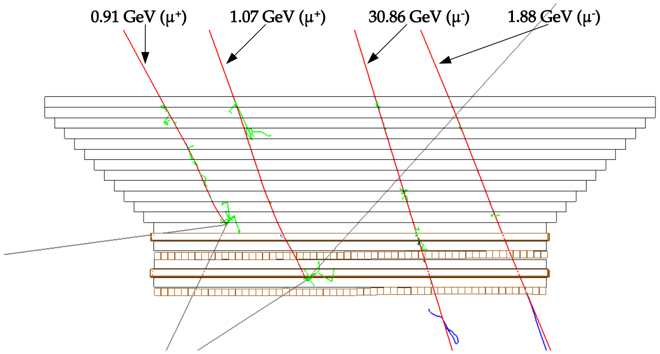
proportional counter



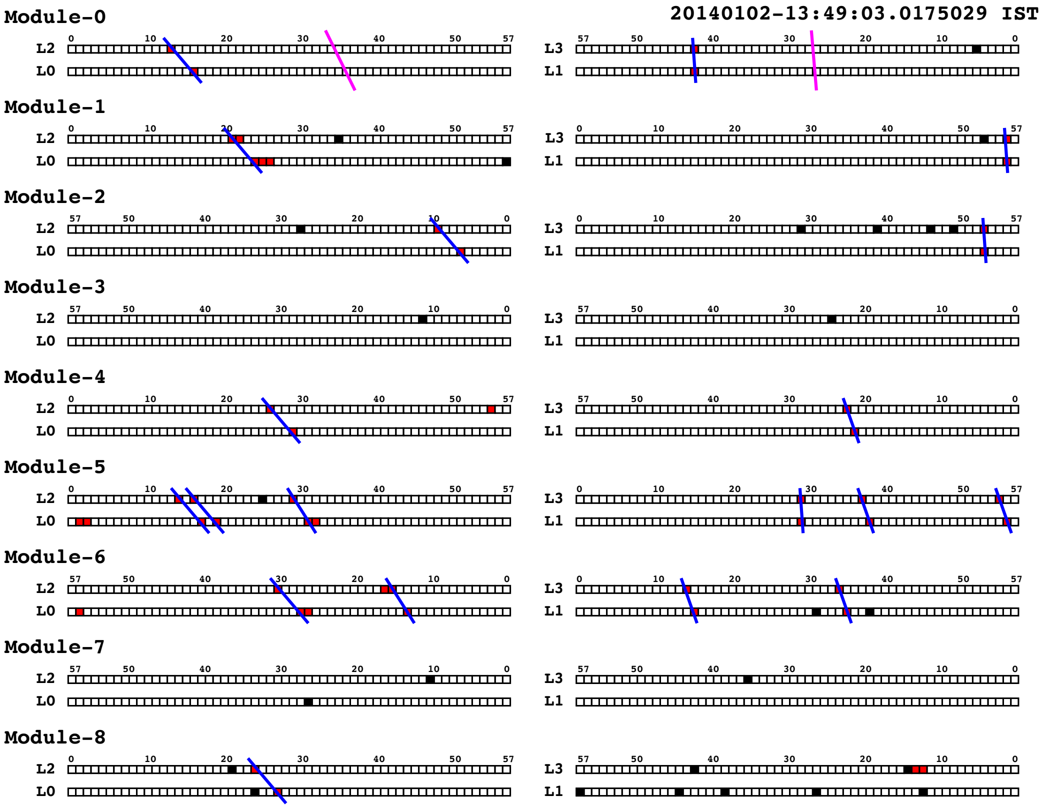
(a)

Geant4 response of a muon module





Tracking of muons in shower event



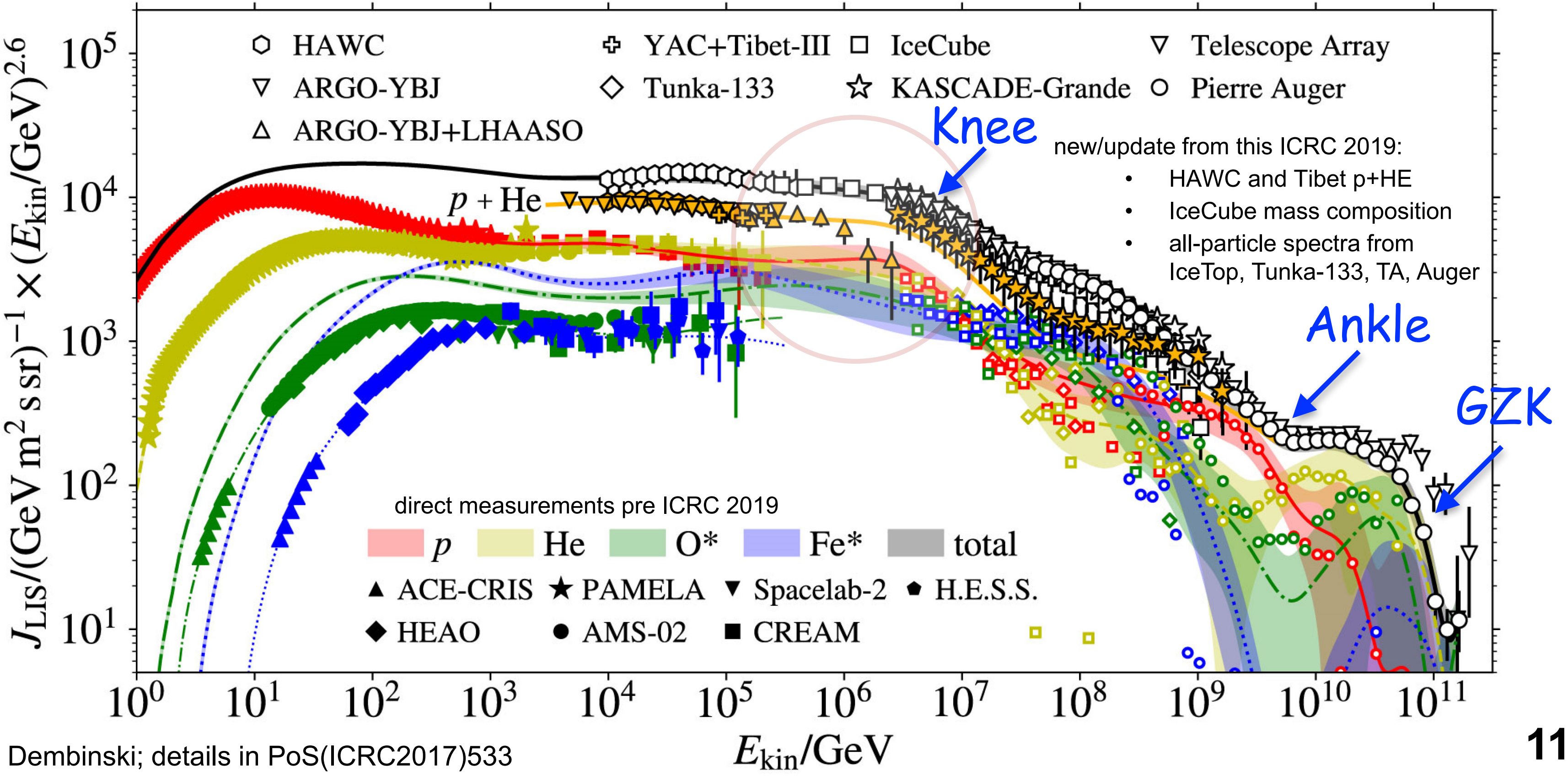
550 gm cm^{-2} of concrete absorber. Threshold for muons = 1 GeV x sec(theta).

Scientific objectives of GRAPES-3

- Cosmic ray energy spectrum and composition over 10 TeV - 100 PeV
- Cosmic ray anisotropy at TeV-PeV energies
- Point and diffuse gamma ray sources at PeV energies
- Space weather and heliospheric phenomena
- Particle acceleration in thunderstorm electric fields

Global Spline Fit (Composition and Energy Spectrum)

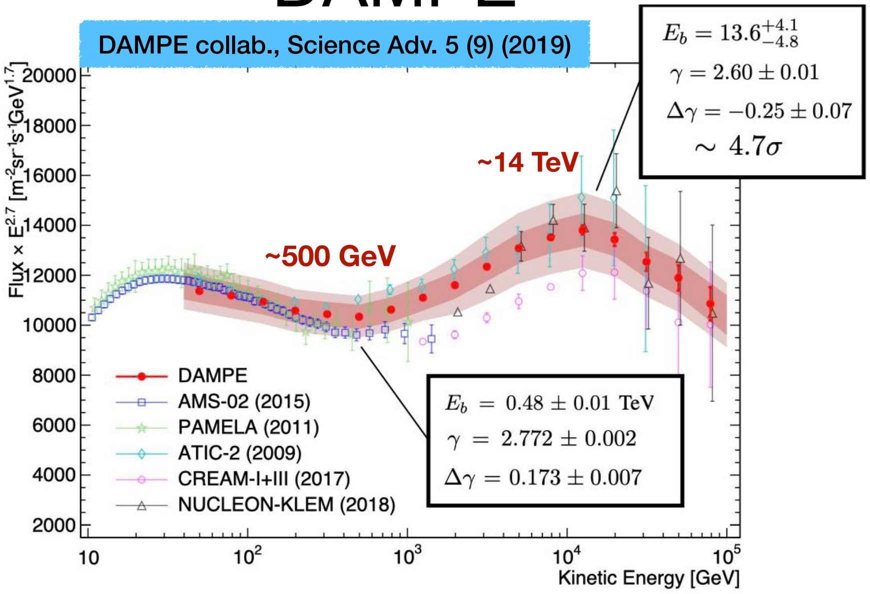
Fit of spectra *within experimental uncertainties*, allowing for constant shift in energy scales



plot by H. Dembinski; details in PoS(ICRC2017)533

Does proton spectrum follow single power law (with known spectral index of -2.7) below the Knee ? Answer is NO.

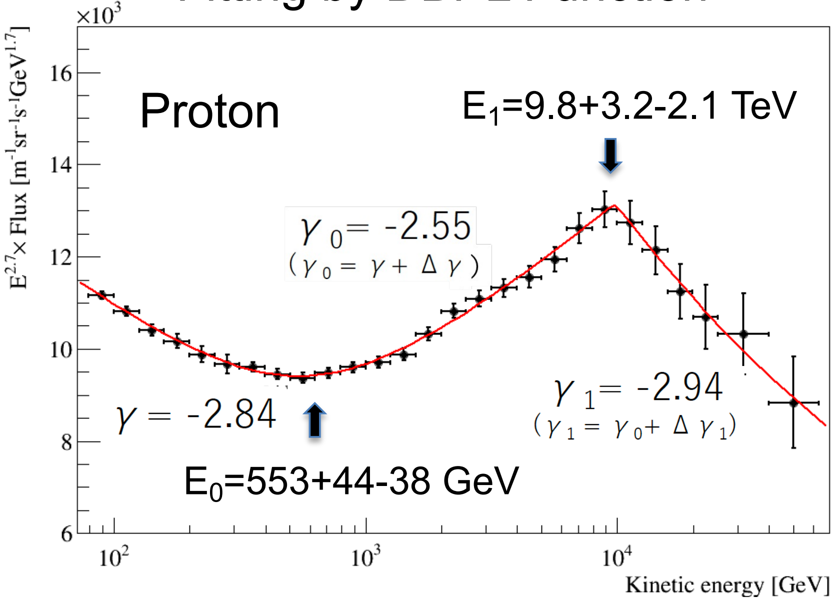
DAMPE



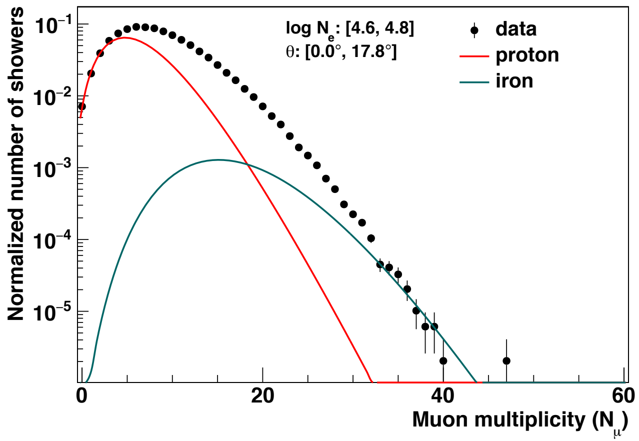
- Confirms hardening at ~ 500 GeV
- Detection of softening at ~14 TeV with high significance

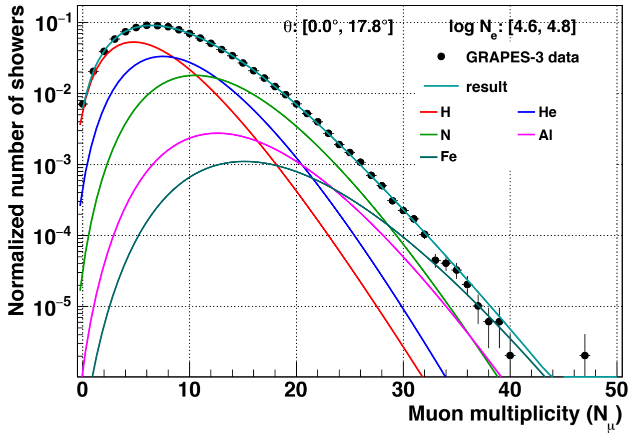
CALET

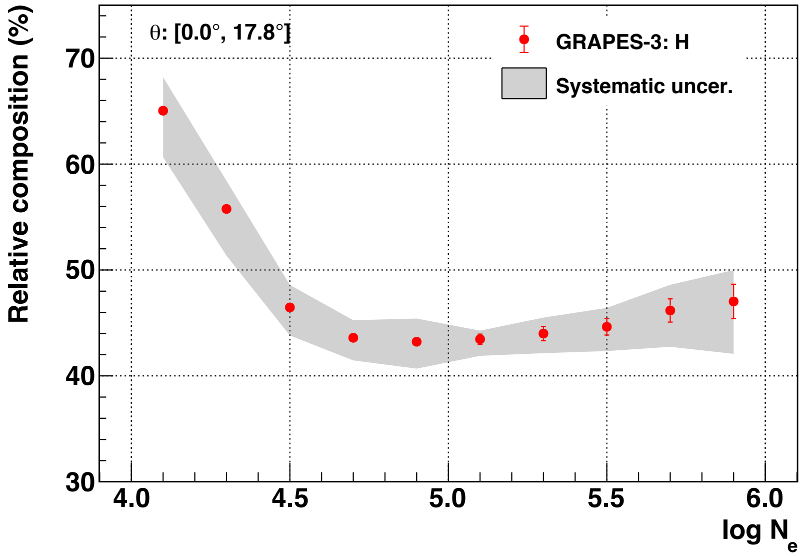
Fitting by DBPL Function



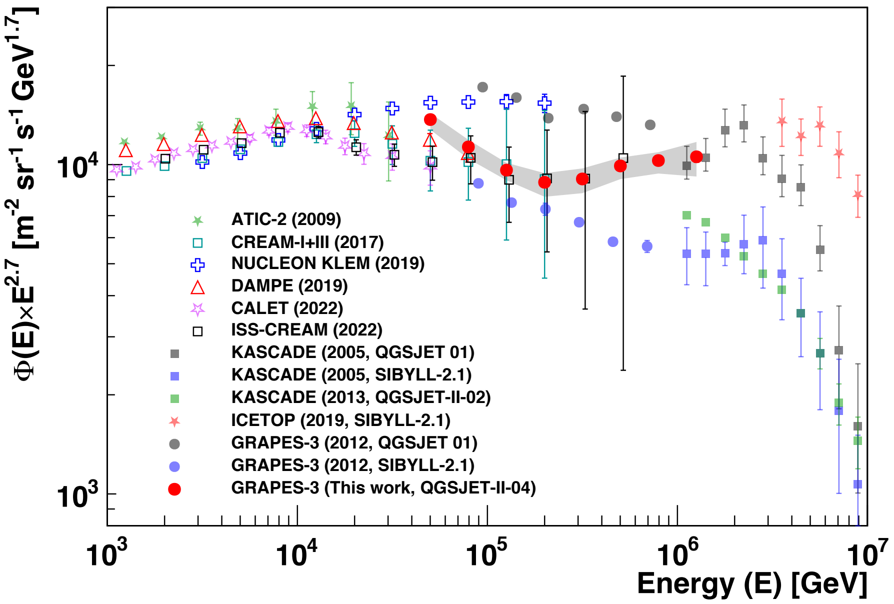
Extraction of composition using muon component

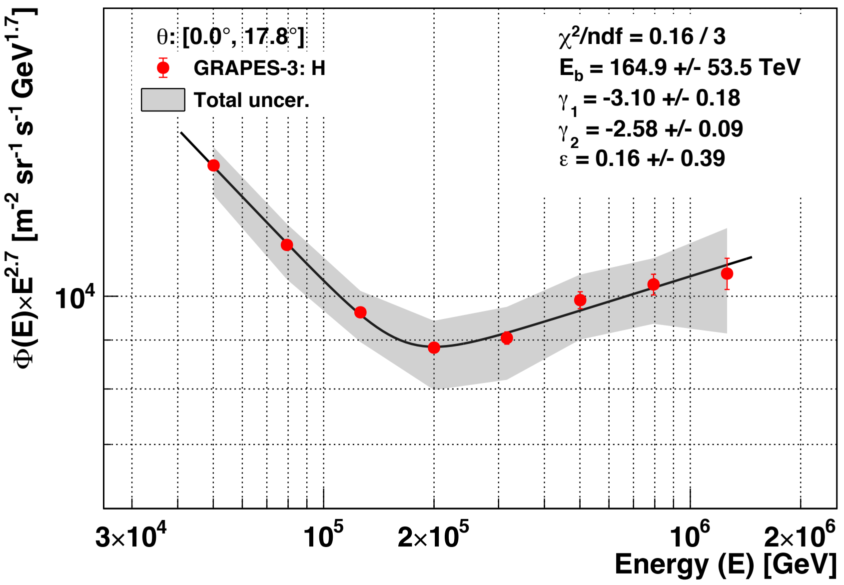






GRAPES-3 proton spectrum measurement from 50 TeV to 1.3 PeV

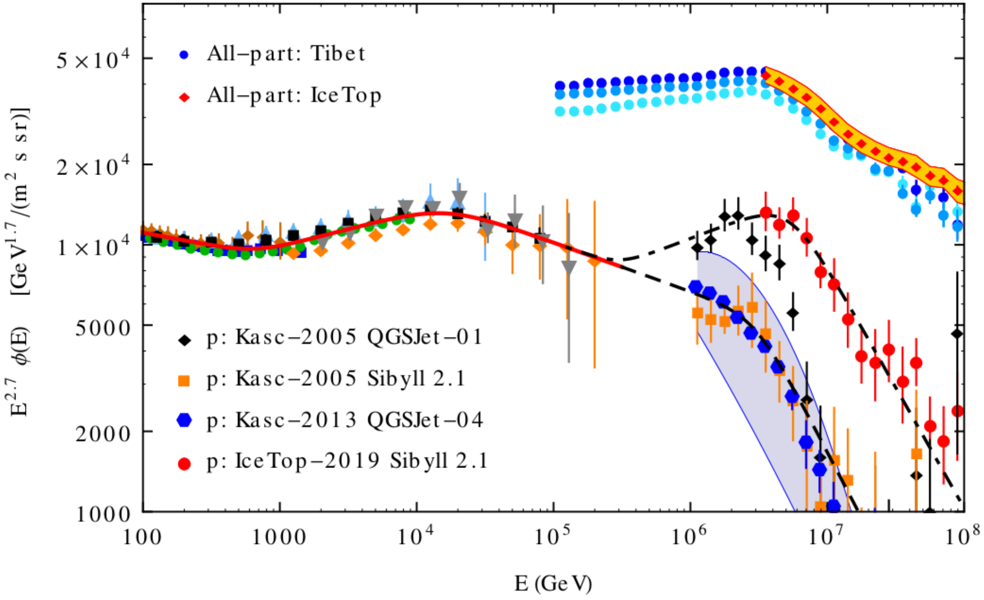


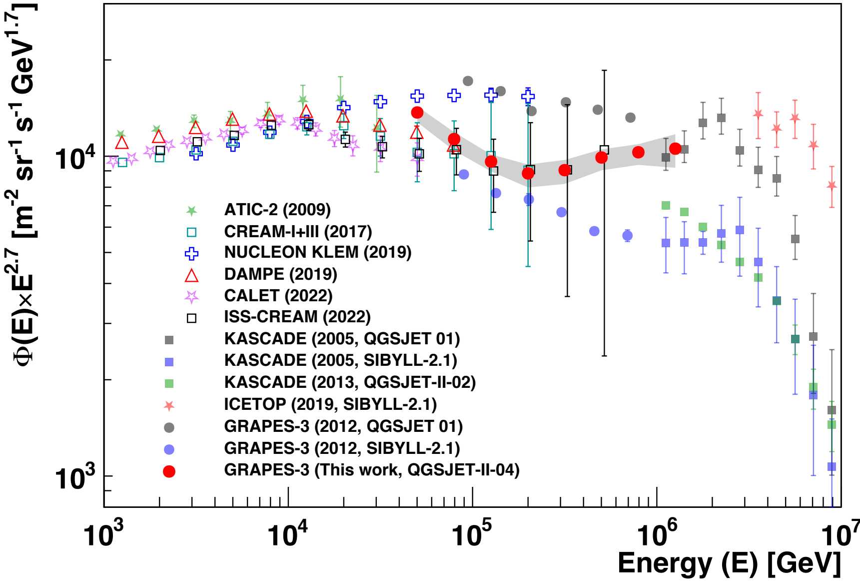


The observed spectral hardening by GRAPES-3 ~165 TeV against the long-held belief of single power-law description of the spectrum below the Knee

Spectral hardening in proton spectrum

P. Lipari and S. Vernetto, Astropart. Phys. 120, 102441 (2020)



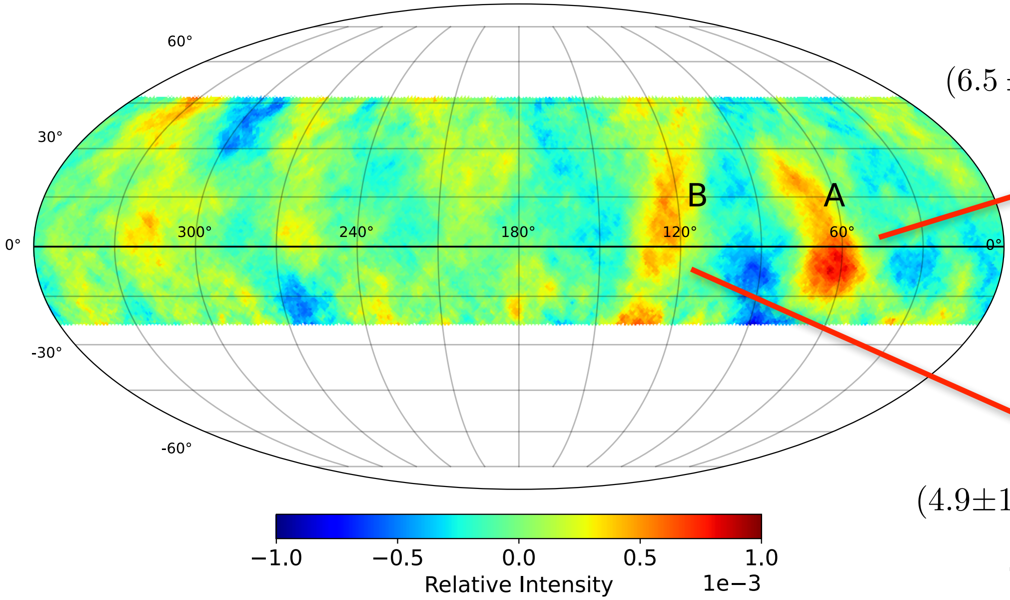


May require complex models, such as those where multiple classes of sources with different rigidity cutoffs contribute to the flux.

Cosmic ray anisotropy results

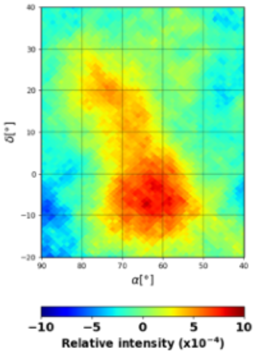
PhD work of M. Chakraborty

Analysis is performed using 3.7 billion cosmic ray events spanning 4 years at median energy of 16 TeV. Time scrambling method is used for background map generation.



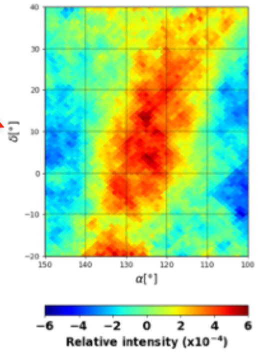
$(6.5 \pm 1.3) \times 10^{-4}$

6.8σ



$(4.9 \pm 1.4) \times 10^{-4}$

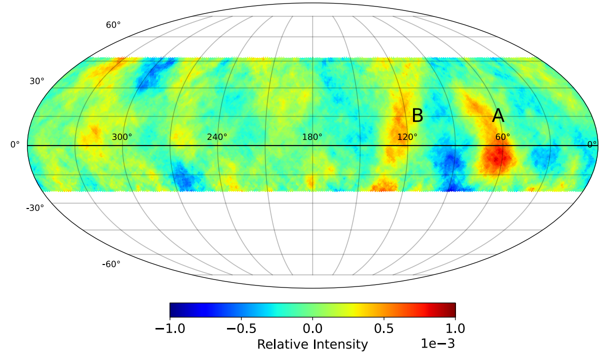
4.7σ



Accepted in ApJ

Comparison with other experiments

GRAPES-3



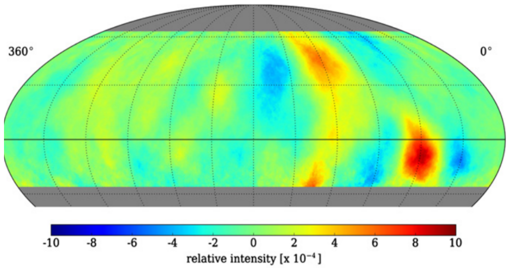
	Region A ($\times 10^{-4}$)	Region B ($\times 10^{-4}$)
ARGO-YBJ	10.0	5.0
HAWC	$(8.5 \pm 0.6 \pm 0.8)$	$(5.2 \pm 0.6 \pm 0.7)$
GRAPES-3	$(8.9 \pm 2.1 \pm 0.3)$	$(5.6 \pm 1.8 \pm 0.1)$

Table 1. The **peak relative intensities** of regions A and B as reported by ARGO-YBJ, HAWC and GRAPES-3

Origin of the anisotropy is not known.Various models proposed.

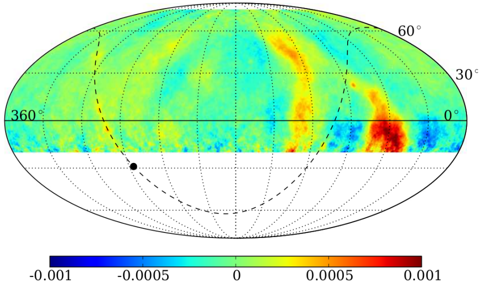
1. Supernova explosion that gave rise to Geminga pulsar
2. Turbulent magnetic field within CR scattering length
3. Decay of quark matters in pulsars

HAWC



(a) HAWC

ARGO-YBJ



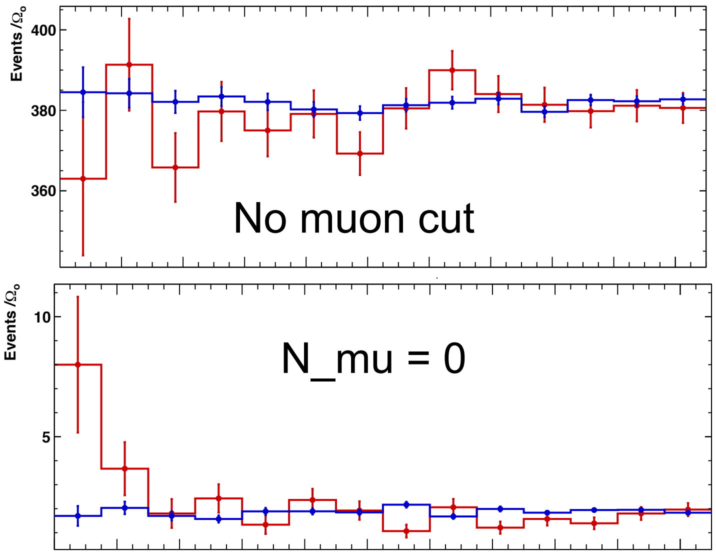
(b) ARGO-YBJ

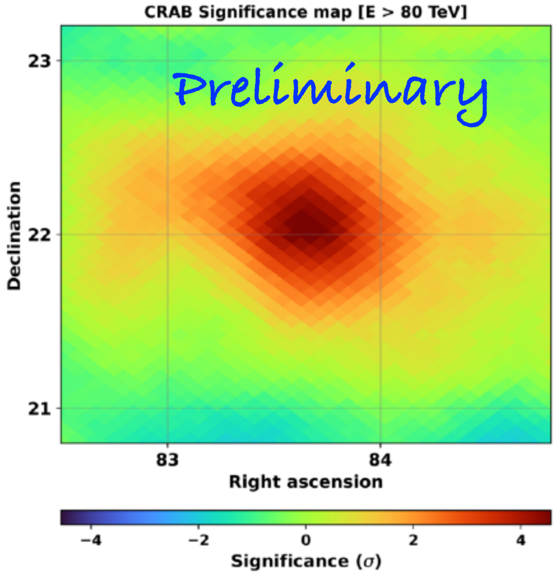
gamma ray source search at multi-TeV energies

PhD work of D. Pattanaik

CR background rejection > 99.5% using muons in shower

Crab detection > 80 TeV with 9 years of observation





The near-equatorial location of GRAPES-3 and nearly 100% duty cycle would allow it to observe many point gamma ray sources including from the Galactic plane

Upgrade of the GRAPES-3 experiment

1. Upgrade of muon detector from 560 m^2 to 1130 m^2
2. Upgrade of scintillator array to 3.5 times larger area

Scientific objectives:

1. To enhance sensitivity for gamma ray observation

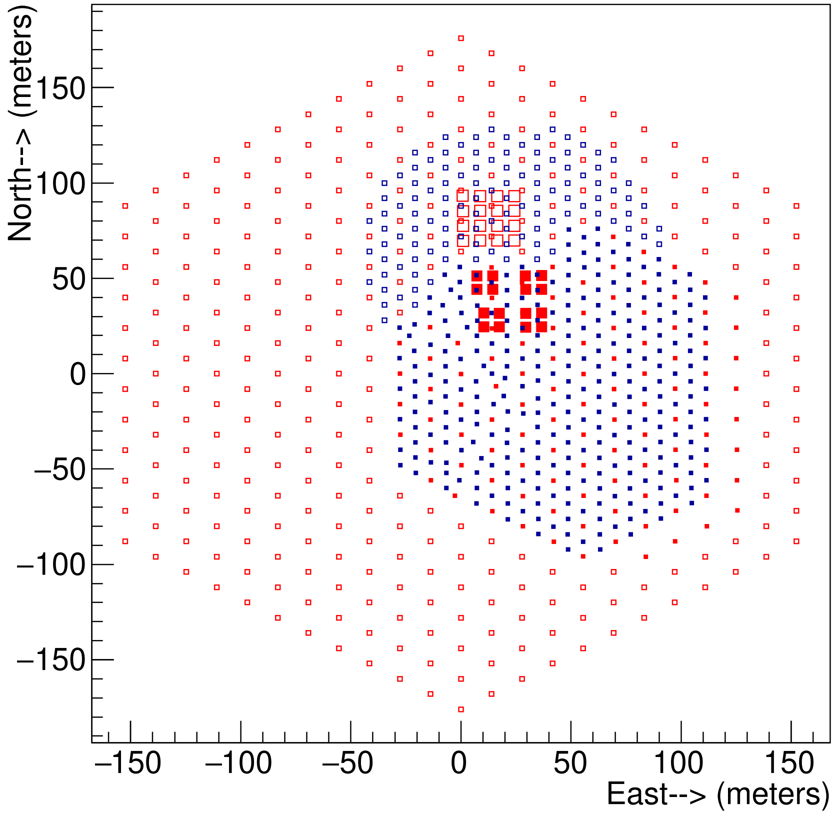
   Expected 5 sigma detection of Crab Nebula in 1 yea observation for E > 100 TeV

2. To enhance cosmic ray composition measurements

   - Good separation of mass in 10-100 TeV range

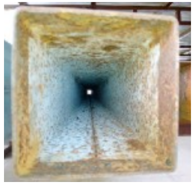
   - Measurements beyond the Knee (up to 100 PeV)

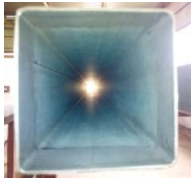
3. To enhance solar & atmospheric studies
   New muon detector has 70% more sky coverage



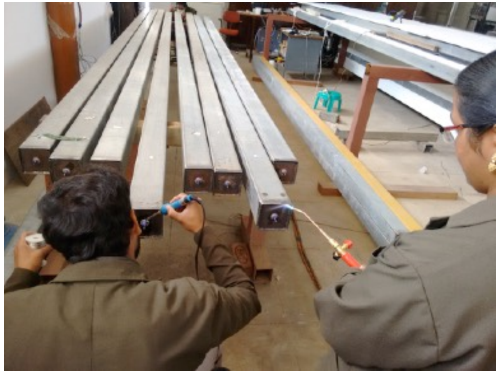
Proportional counter fabrication at GRAPES-3. ~4000 successfully made.

Rust removal

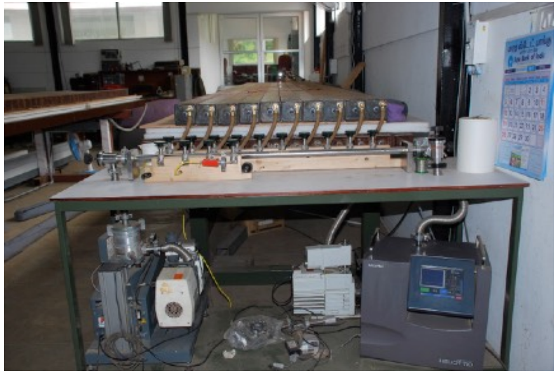




Hermetic seal fixing



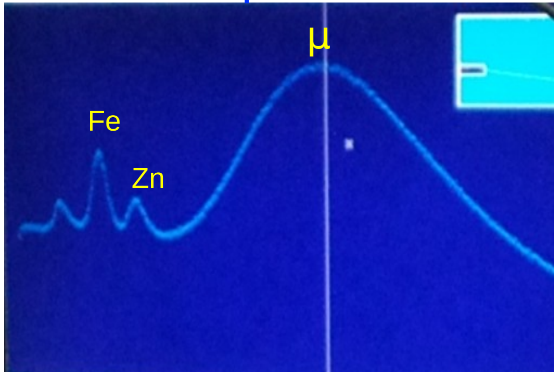
Evacuation



P10 gas filling

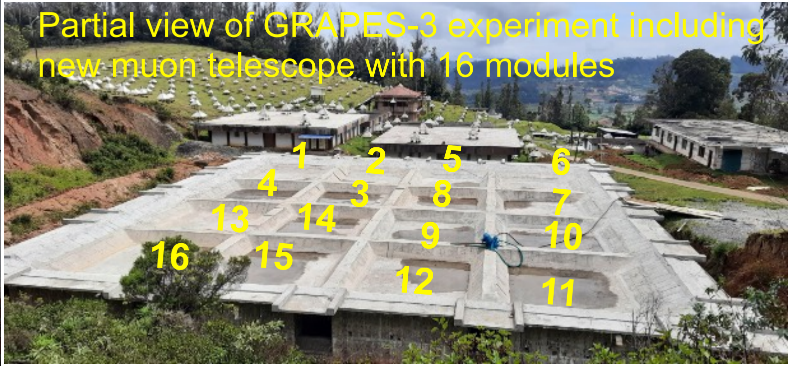
Long term test

PRC spectrum



Muon detector upgrade (560 m^2 to 1130 m^2)

3776 PRCs needed for new muon detector successfully fabricated in-house



First operated module of new muon detector

Summary

- Compact configuration of scintillator detectors coupled with the mid-altitude location of GRAPES-3 has lead to achieve excellent performances in terms of core, angular and energy, resolution.

- Cosmic ray composition is measured below the Knee and proton spectrum has a good overlap with direct measurements and shows deviation from single power law.

- Observation of cosmic ray anisotropy has been demonstrated from near-equatorial location.

- Near equatorial location of GRAPES-3's is an advantage for gamma ray studies. However it's sensitivity needs to be enhanced.

- Ongoing upgrade of the muon telescope together with scintillator array expansion can provide enhanced sensitivity for cosmic ray composition and gamma ray studies.

THANK YOU