Observation of Cosmic Ray Anisotropy with GRAPES-3 Experiment

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(on behalf of P.K. Mohanty)

GRAPES-3 Collaboration

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Outline

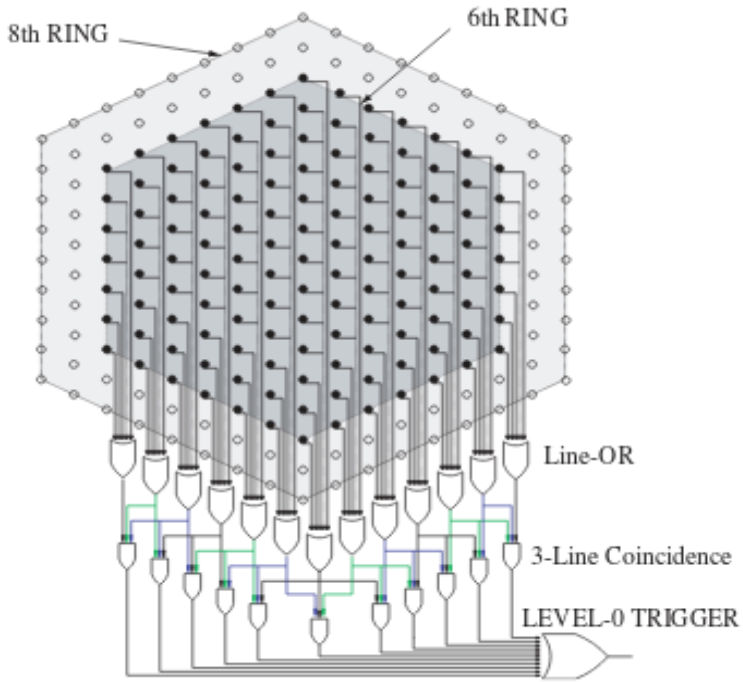
GRAPES-3 Experiment

- Located at Ooty, India (11.4° N, 76.7° E and 2.2 km msl)
- EAS array: 400 plastic scintillation detectors (1 m^2 each) total area of 25,000 m^2
- Muon telescope: 3712 PRCs arranged in 16 modules total area of 560 m^2

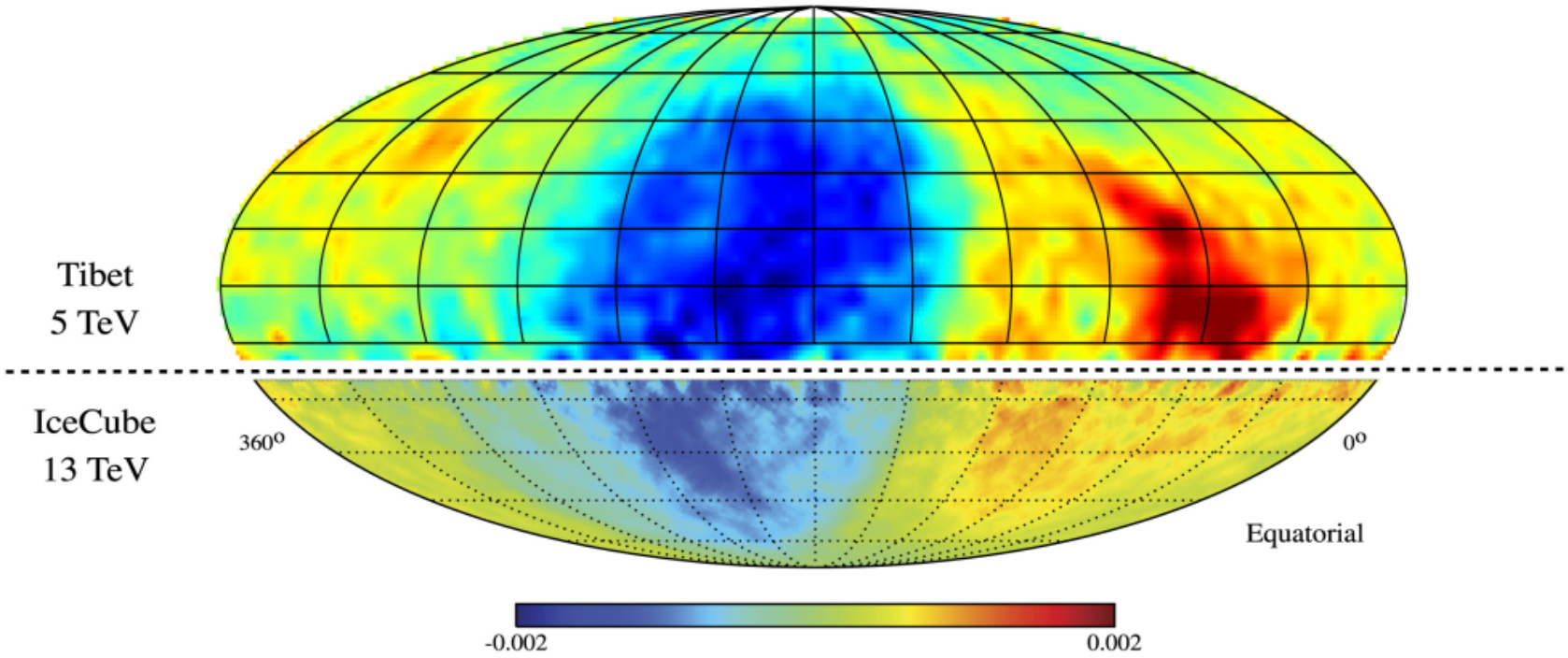
Air Shower Trigger

Two level trigger system :

- Level 0 :
  -> OR of detectors in each line
  -> Coincidence of three consecutive lines
- Level 1 : Minimum 10 detectors out of central core region
- Trigger Rate : $\sim$42 Hz
  (3.6 million EAS/day)
- Energy Range :
  few TeV to $\sim$10 PeV

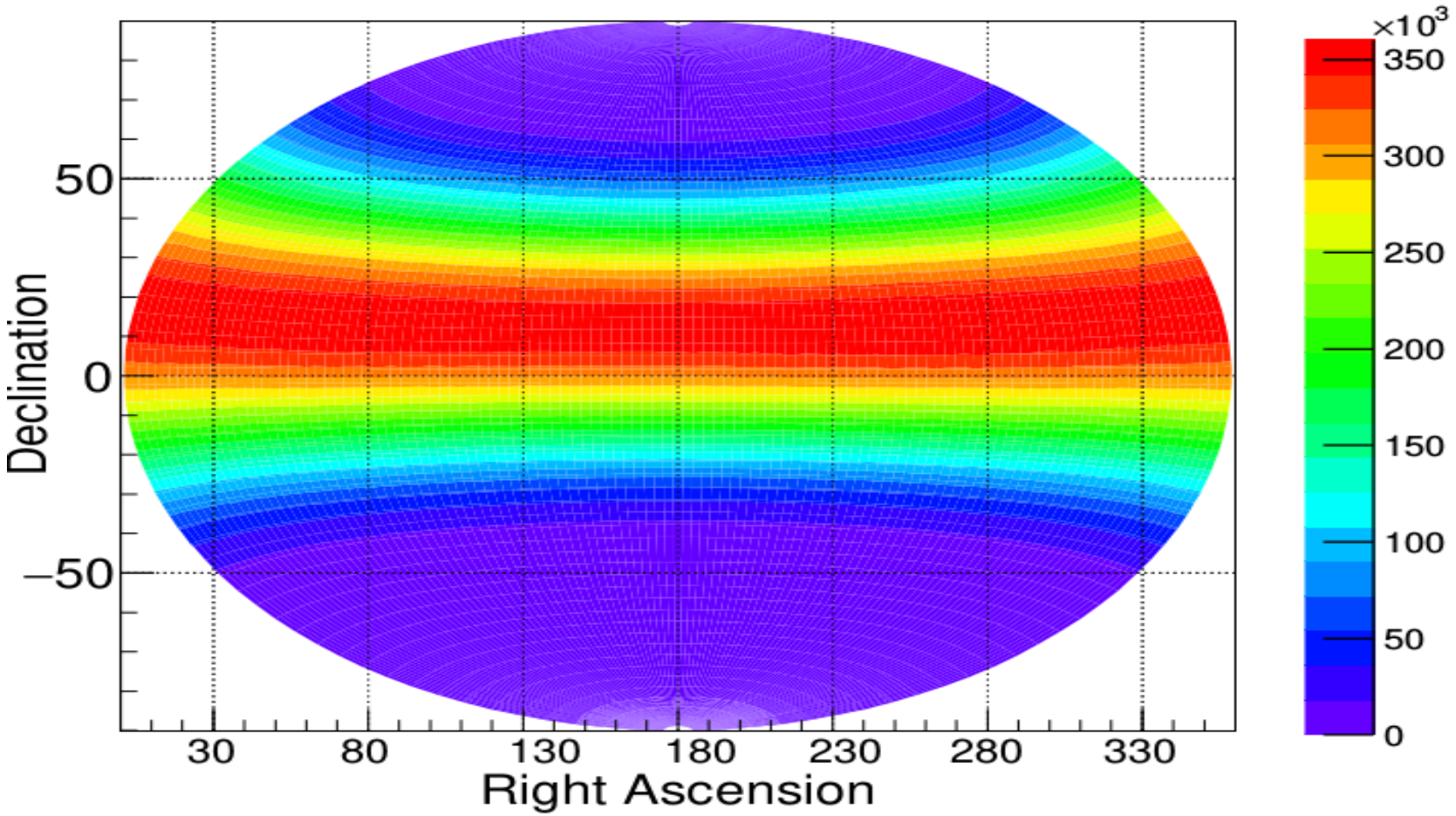


Cosmic Ray Anisotropy



* *Prog. Part. Nucl. Phys. 94 (2017) 184*

Sky coverage of GRAPES–3



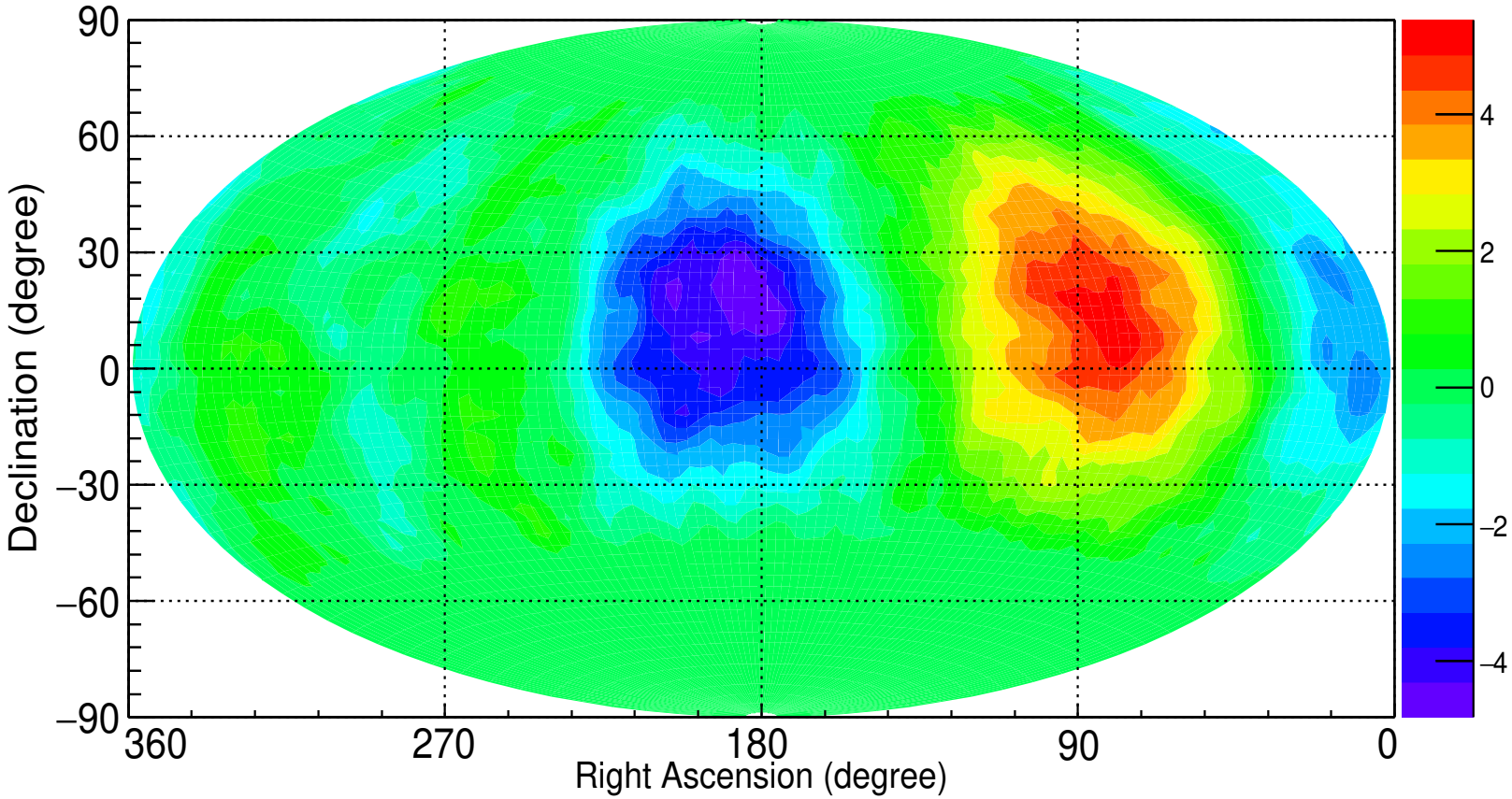
Data Selection

- Data used: 2000–2006
- Selection cut: Only when full day data is available
- Live Time: $\sim$1377 days ($\sim$54%)
- Total Showers: $\sim$2 billions
- Median Energy: 15 TeV

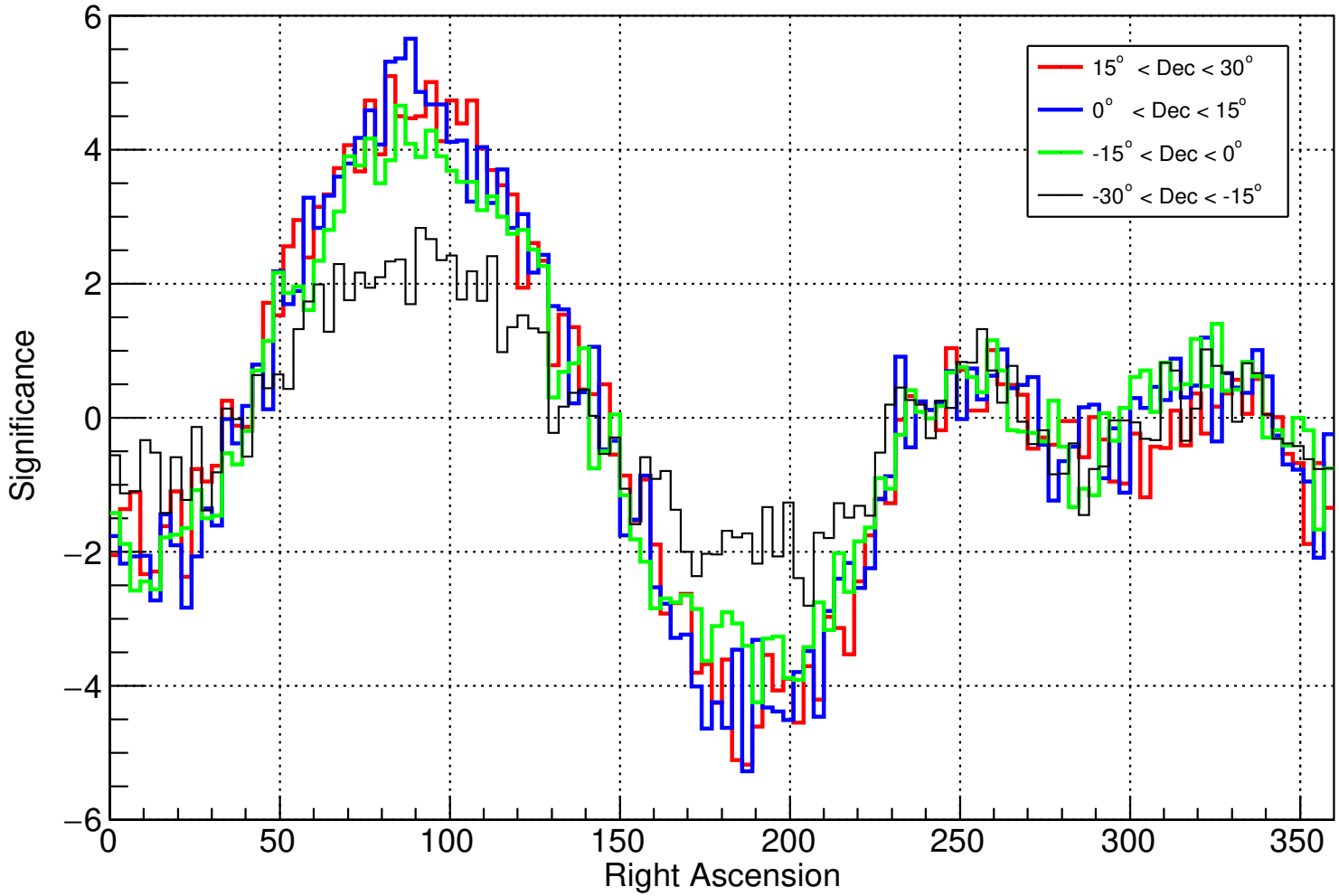
Analysis Method

- For each shower, zenith (θ) and azimuthal (ϕ) angles are determined by using a conical fit to the relative arrival times of shower particles.
- Some of the shower parameters namely core location, age and size are obtained by fitting NKG function.
- For each shower, θ and ϕ are converted into right ascension (α) and declination (δ).
- α and δ are binned into $3^o \times 3^o$ cells.
- Each cell is normalized with the average by its respective declination band.
- A dummy cosmic ray distribution is calculated by shuffling the real data event times.
- Anisotropy is calculated by subtracting from real cosmic ray distribution with the dummy one and then the significance is calculated by using Li–Ma formula.

Anisotropy Significance Map



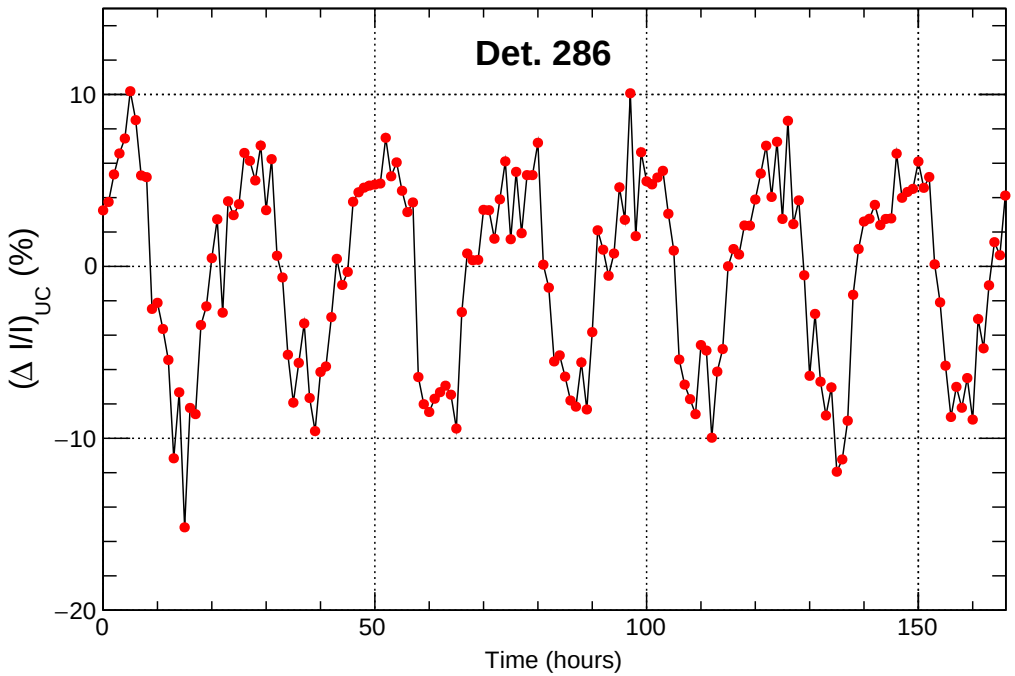
Anisotropy in different Declination Bands



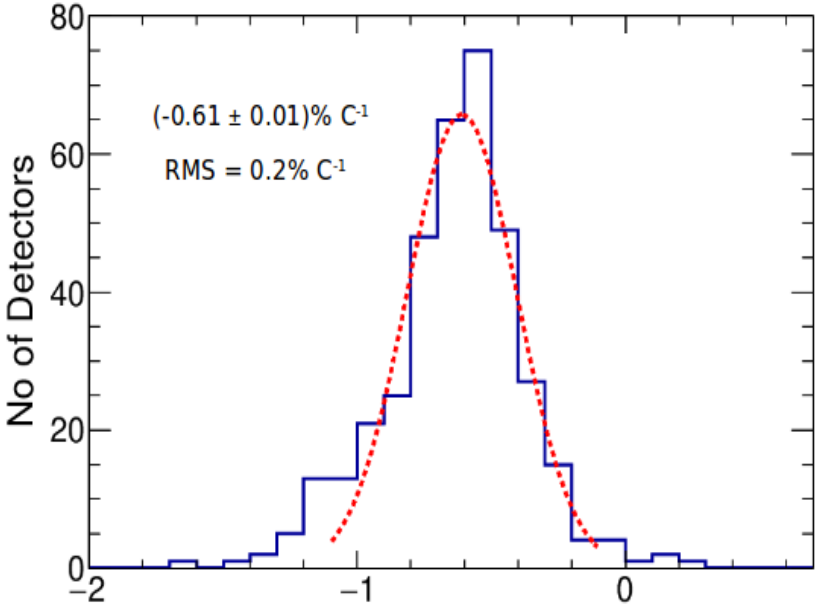
Recent Improvements in Air Shower Parameters

Atmospheric Effect Corrections

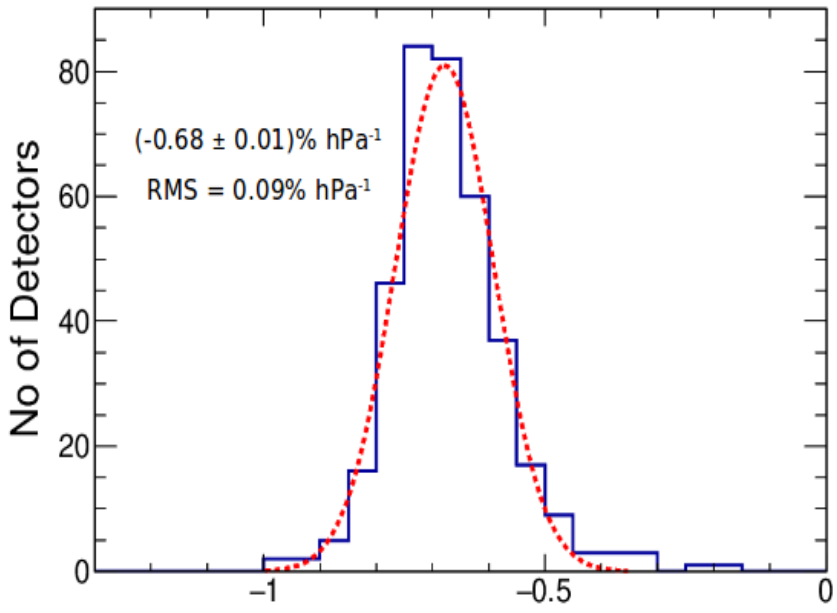
- Particle densities observed by plastic scintillation detectors show periodic variations.
- These variations are found to have correlation with temperature and atmospheric pressure.



Atmospheric Effect Corrections

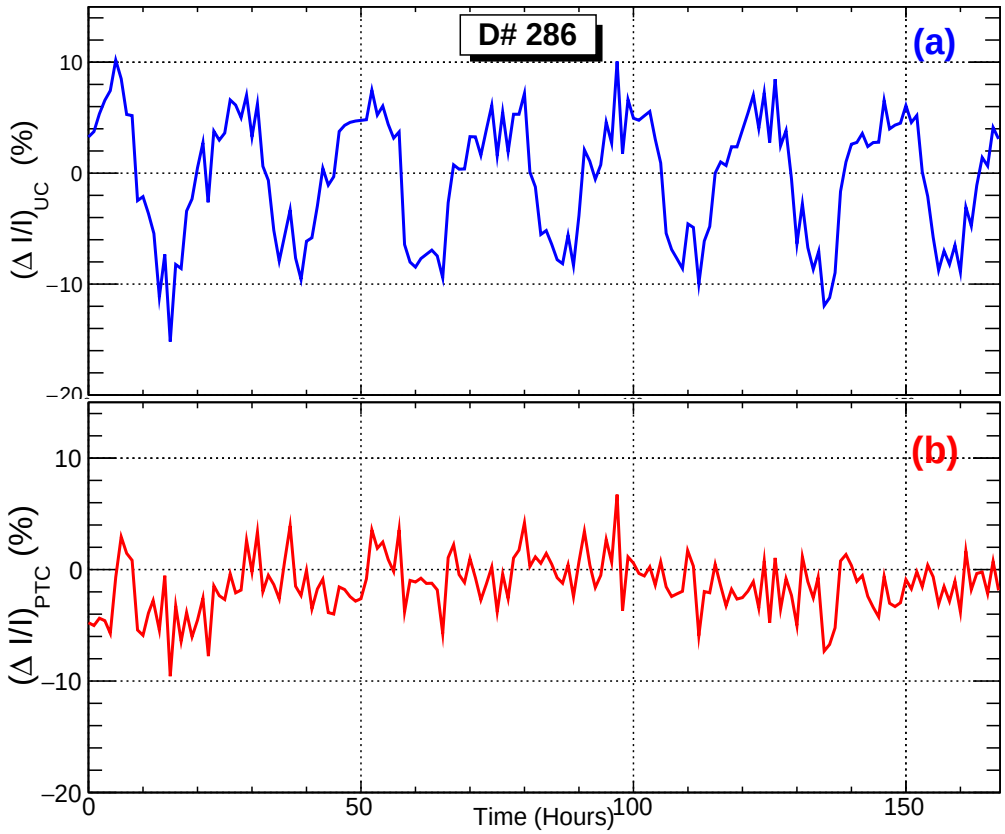


Temperature Coefficient Distribution



Pressure Coefficient Distribution

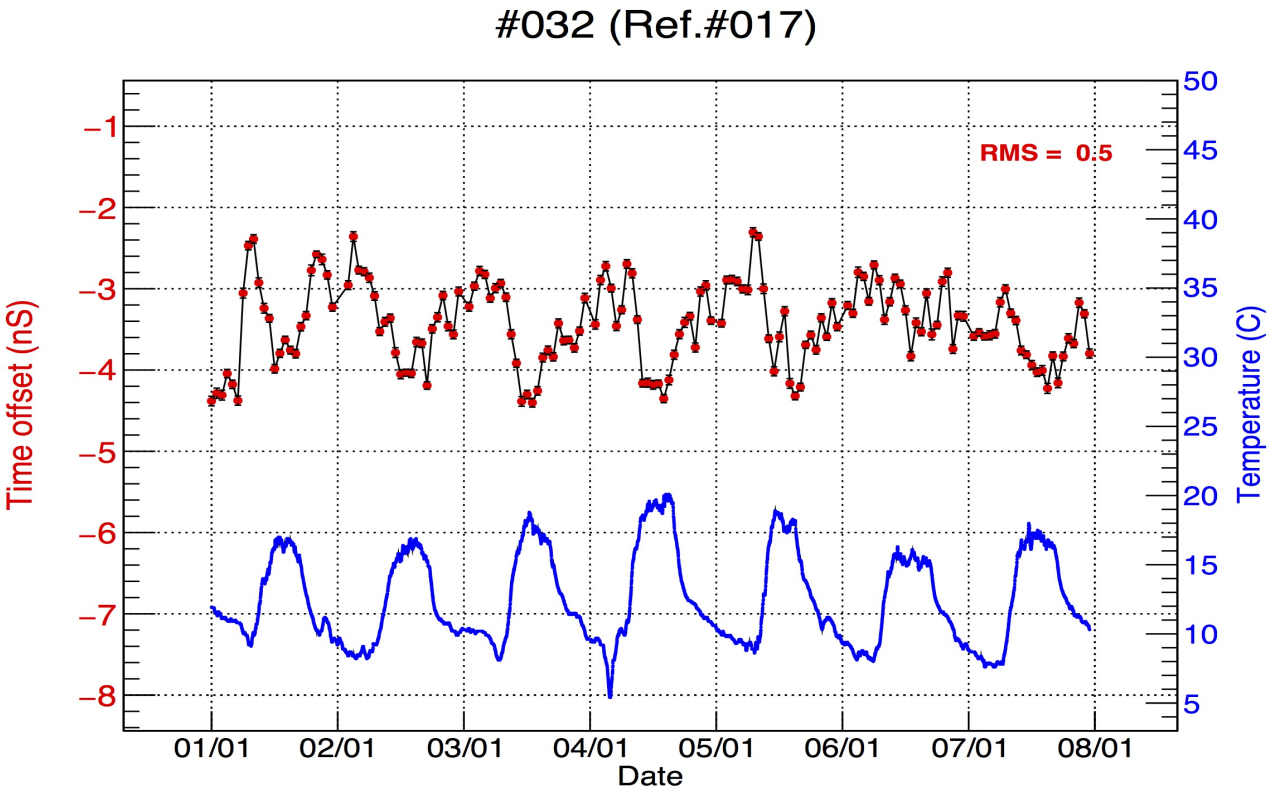
Atmospheric Effect Corrections



Atmospheric effects corrected particle density for Det. 286.

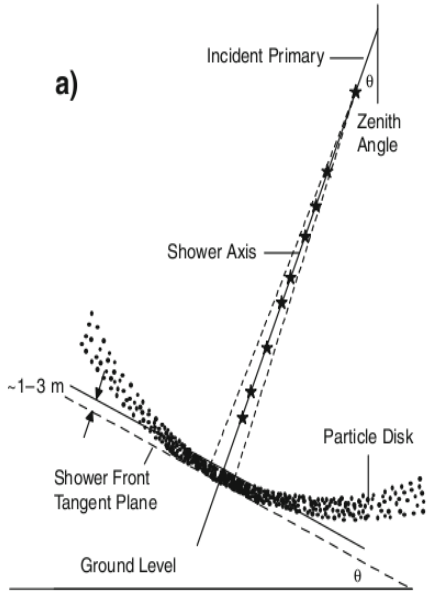
Timing Measurements

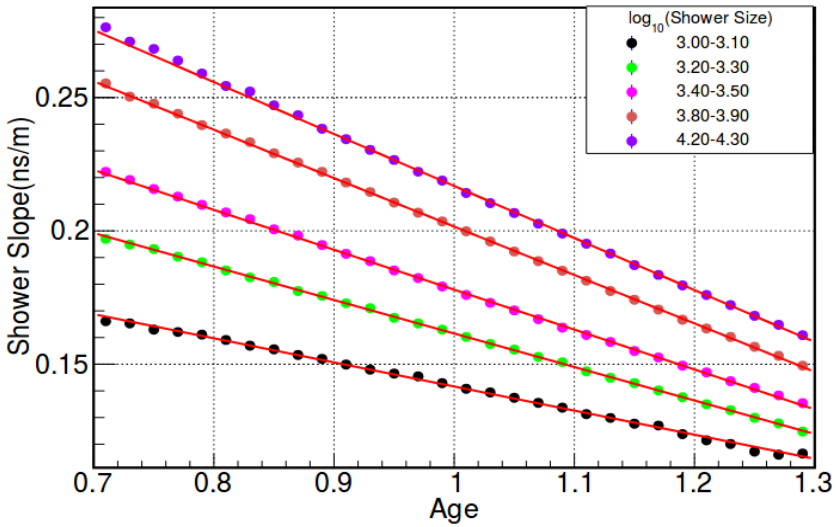
- Since 2013, better TDCs (32–channel HPTDC) are used to record the relative arrival time of showers.
- Hourly time offsets are measured by using Random Walk Method.

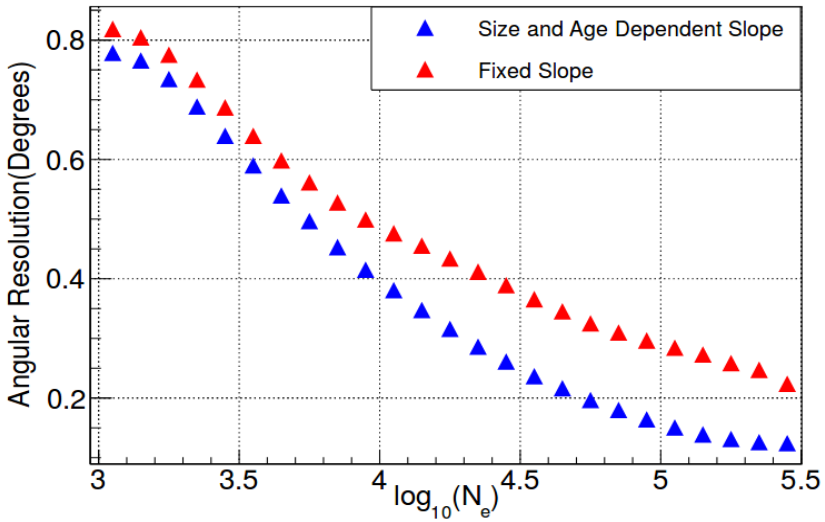


Angular Resolution Improvement

- Shower front curvature shows the dependence over shower size and age.
- After applying curvature corrections, angular resolution (AR) improved by $\sim$50 % for $log_{10}(N_e) > 4.0$.
- At present, AR is 0.8^o at $\sim$ 4 TeV and 0.1^o at $\sim$ 500 TeV.







Summary

- Anisotropy measurements with GRAPES–3 data are consistent with results reported by Tibet and IceCube.
- A better understanding of detectors performance has improved the angular resolution by $\geqslant$ factor of 2.
- With these improvements we hope to obtained precise measurements of anisotropy overlapping both northern and southern hemispheres.

Angular Resolution

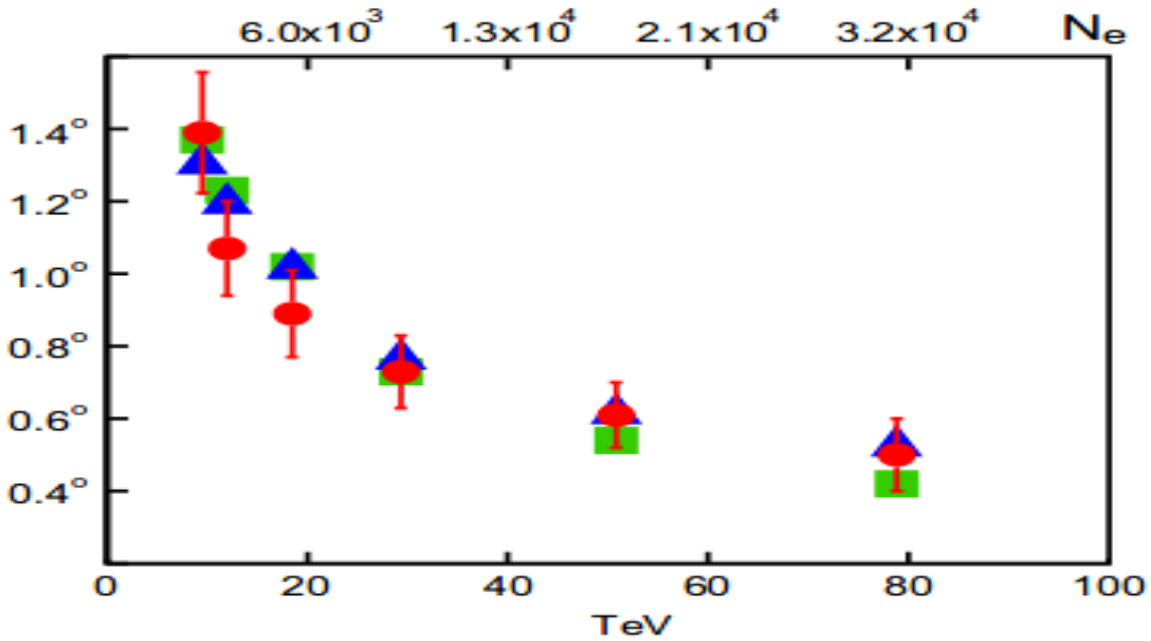


Fig. 16. Variation of angular resolution with primary energy (TeV) by three methods, (a) even–odd, filled squares (■), (b) left–right, filled triangles (▲), (c) Moon shadow, filled circles (●). Shower size N_e is shown at top along secondary x-axis.