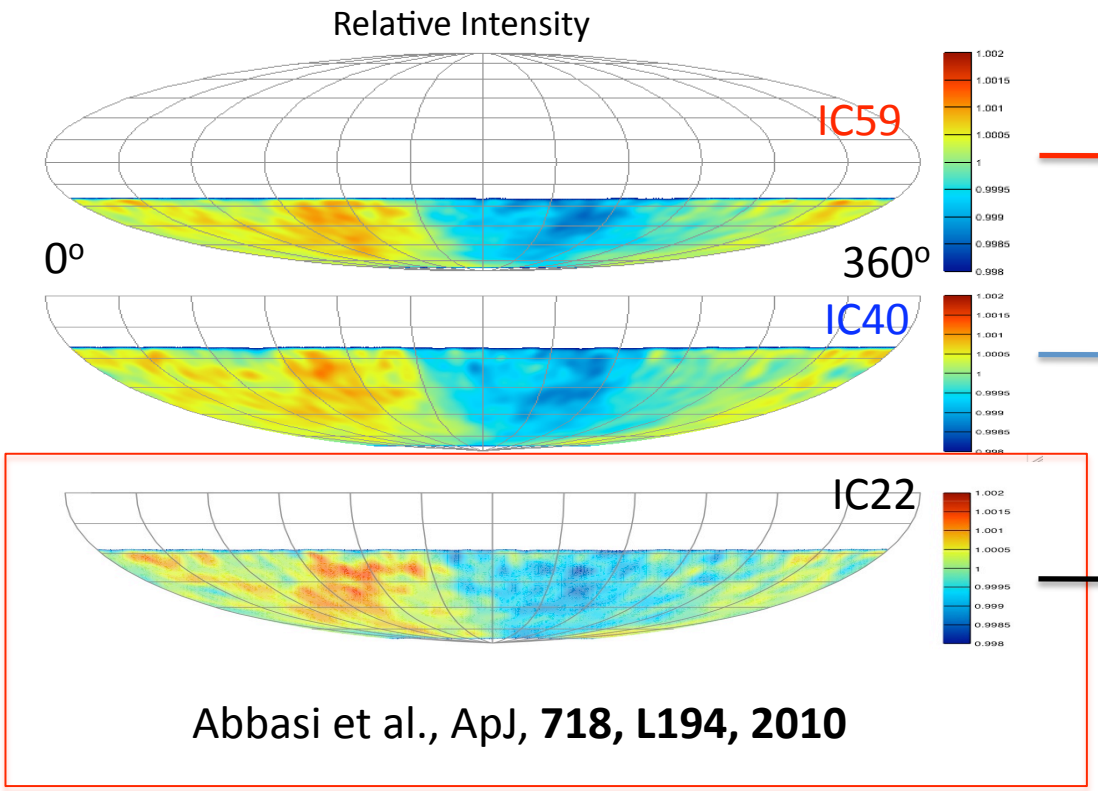
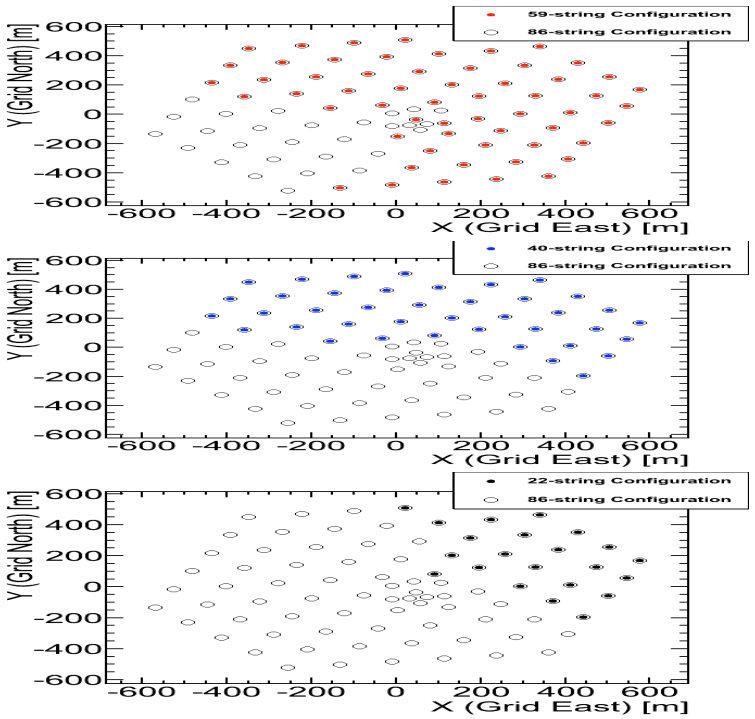
Relative Intensity of Cosmic Rays (IC22, IC40 & IC59)



Abbasi et al., ApJ, **718, L194, 2010**

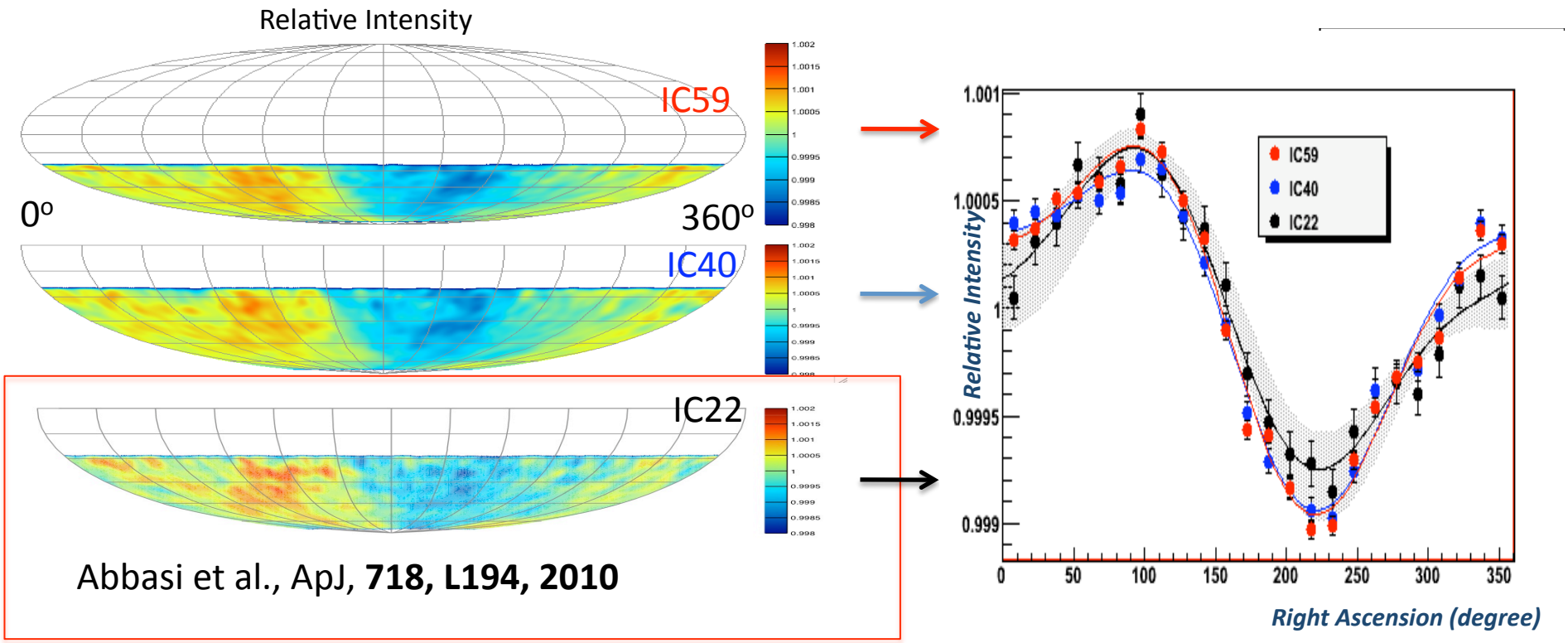


Relative Intensity: $\dfrac{N_i(\alpha,\delta)}{\langle N_i(\delta)\rangle\alpha}$

Relative intensity of the cosmic ray event rate in equatorial coordinates: for each declination belt of width 3°, the
plot shows the number of events relative to the average number of events in the belt.

Year	Rate (Hz)	Livetime (Days)	CR Median Energy (TeV)	Median Angular Resolution	Number of Events
2007-IC22	240	226	20	3°	~4×10^9
2008-IC40	780	324	20	3°	~19×10^9
2009-IC59	1200	324	20	3°	~32×10^9

Relative Intensity of Cosmic Rays (IC22, IC40 & IC59)



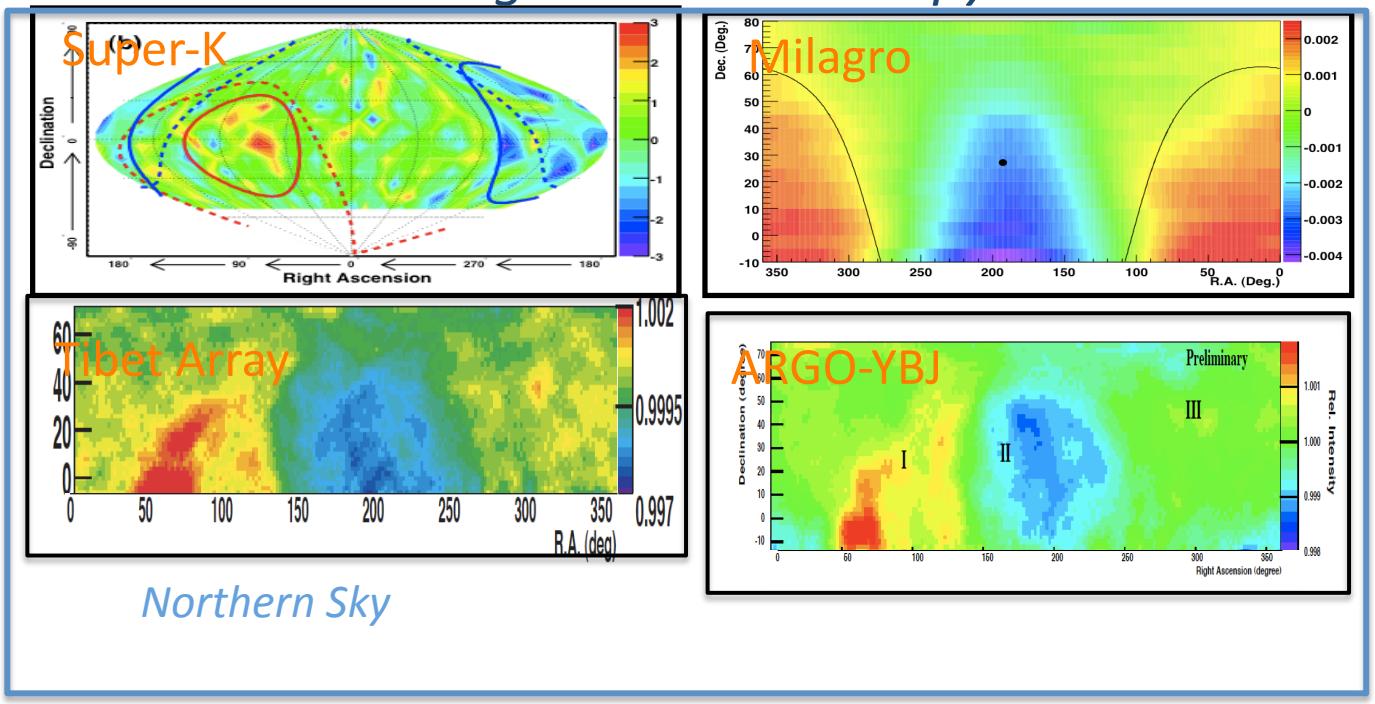
Relative Intensity: $\dfrac{N_i(\alpha,\delta)}{\langle N_i(\delta)\rangle\alpha}$

Relative intensity of the cosmic ray event rate in equatorial coordinates: for each declination belt of width 3°, the plot shows the number of events relative to the average number of events in the belt.

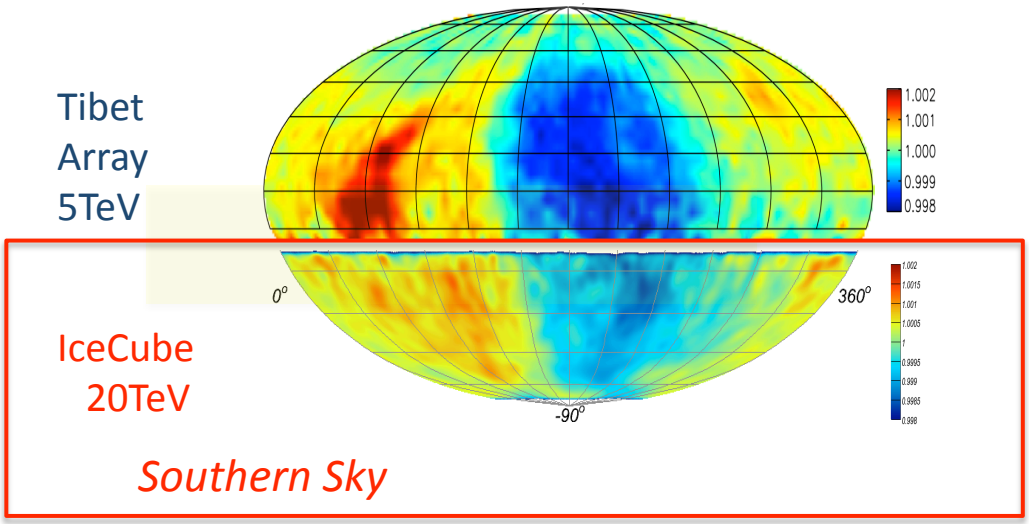
The 1-D projection of the equatorial relative intensity skymap is fitted to a first and second harmonic function of the form

$$\sum_{i=1}^{2} A_i \cos(i(\alpha - \phi_i)) + B$$

Large Scale Anisotropy and Past Results



Northern Sky

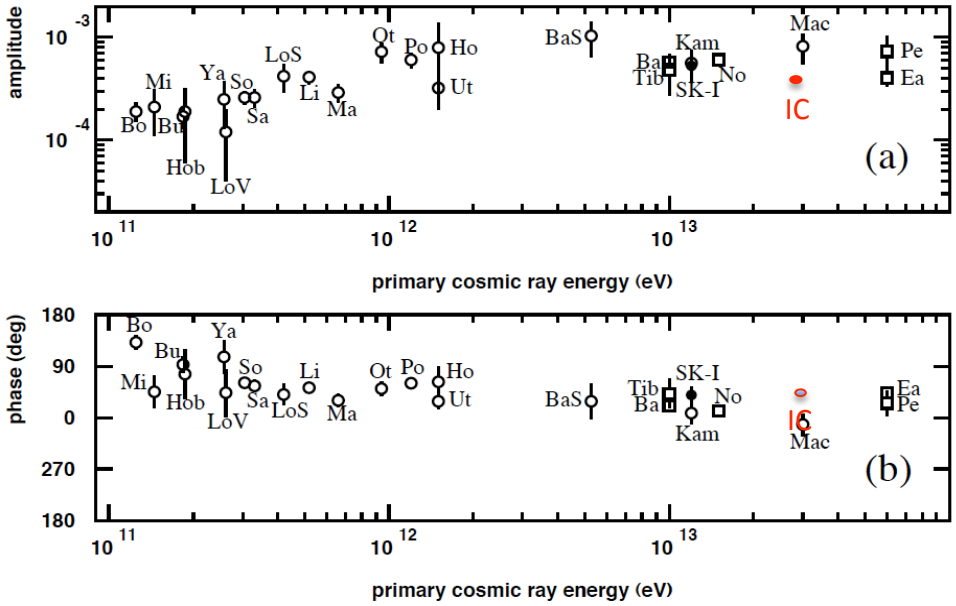


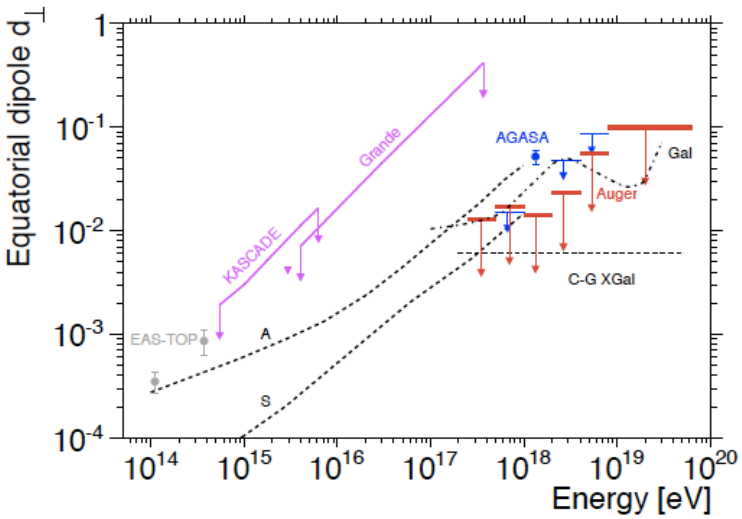
Southern Sky

- IceCube observed a large scale anisotropy at 10^{-3} level for the first time in the Southern Sky.
- *Large Scale Features appear to be a continuation of those observed in the Northern Hemisphere.*

Anisotropy energy dependence with IceCube

Large Scale Anisotropy and Past Results

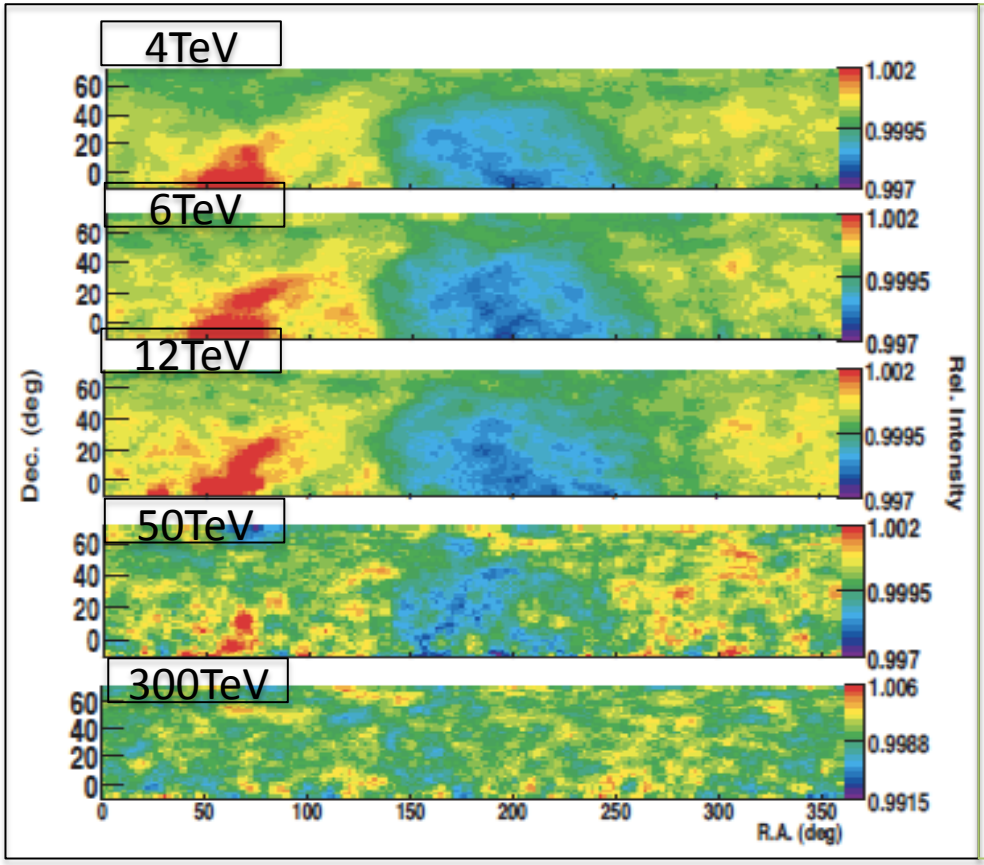




- Amplitude and phase is established experimentally between 10^{11}-10^{14}eV
- *Study of the anisotropy evolution in the energy region >10^{14} eV can provide an insight to the origin and propagation of cosmic rays.*

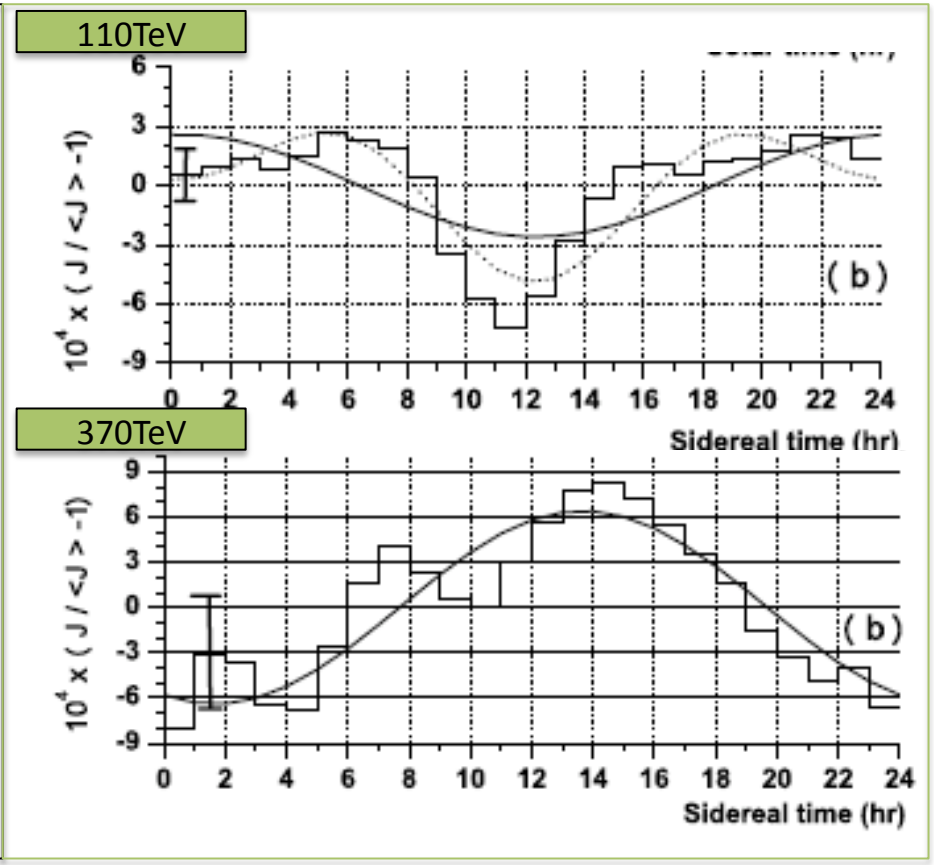
Large Scale Anisotropy and Past Results

Tibet Array



Science314:439-443,2006

EAS-TOP



arXiv:0901.2740

No Coherent Global Picture in the Northern Hemisphere

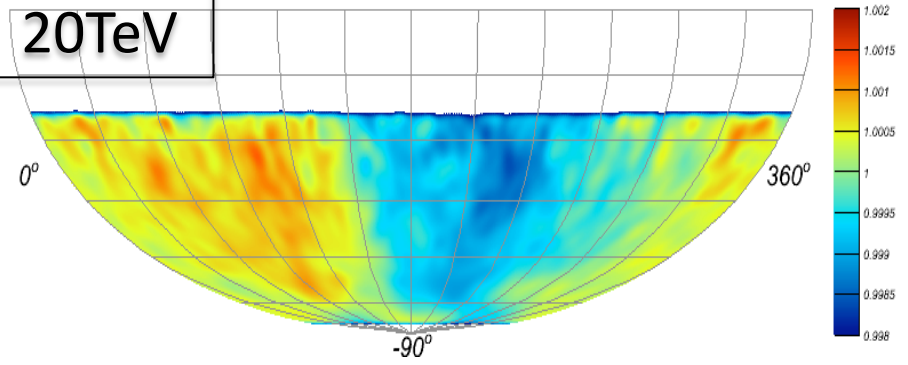
IC59 CR Energy Dependence (20TeV,400TeV)

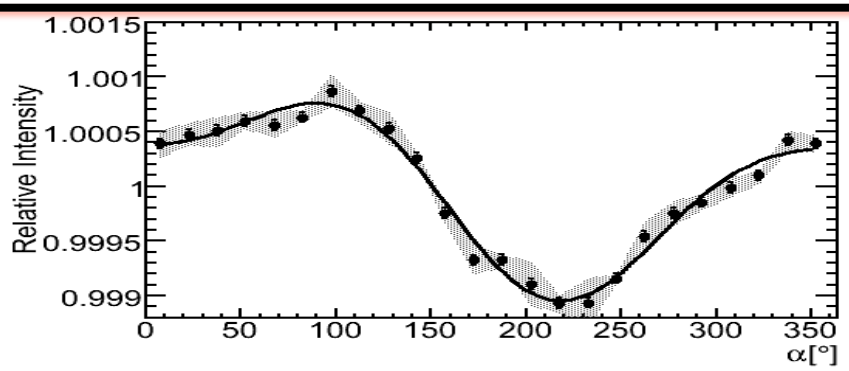
Relative Intensity: $\frac{N_i(\alpha,\delta)}{\langle N_i(\delta)\rangle\alpha}$

equatorial coordinates

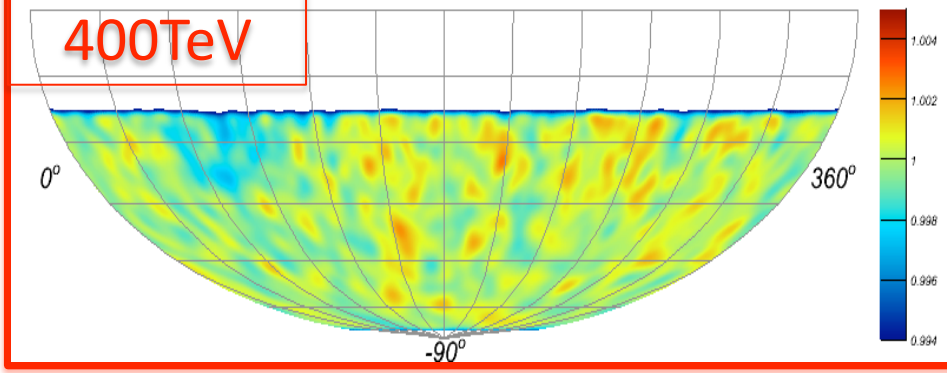
Relative Intensity maps

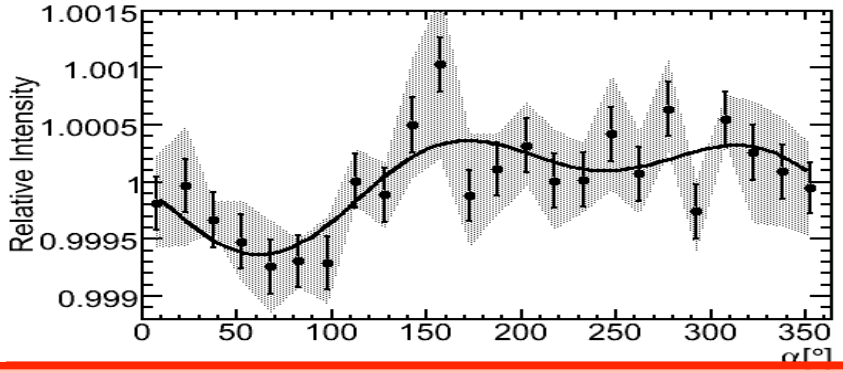
20TeV





400TeV





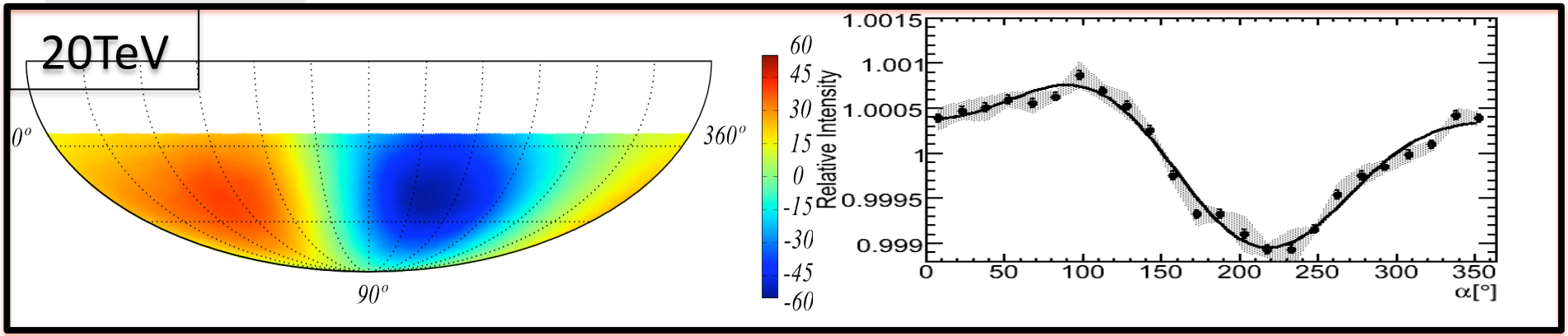
The anisotropy at 400 TeV shows a substantial difference w.r.t that observed at 20 TeV

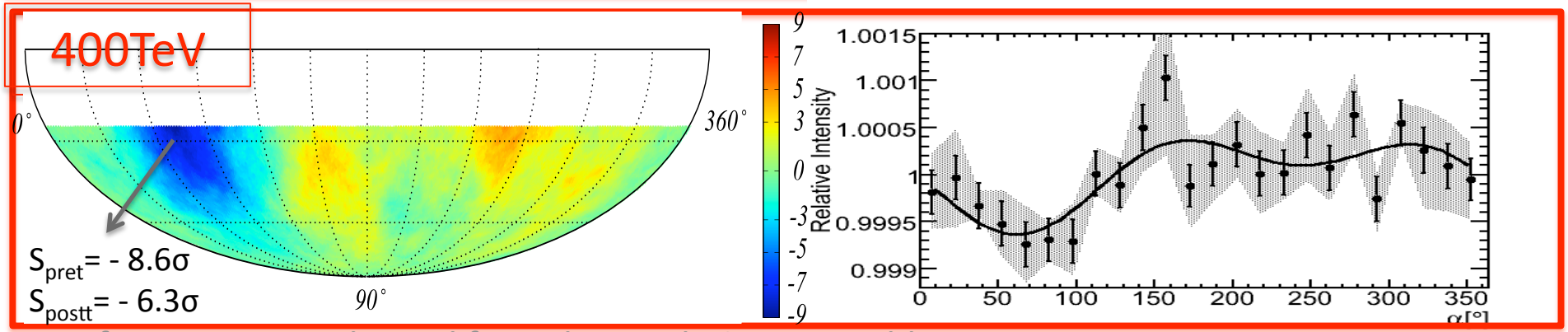
IC59 First Detection of Anisotropy at 400 TeV

Statistical Significance: $$\sqrt{s}\left\{N_{on}\ln\left[\frac{1+\alpha}{\alpha}\left(\frac{N_{on}}{N_{on}+N_{off}}\right)\right]+N_{off}\ln\left[(1-\alpha)\left(\frac{N_{off}}{N_{on}+N_{off}}\right)\right]\right\}^{1/2}$$

equatorial coordinates

Statistical Significance Skymaps

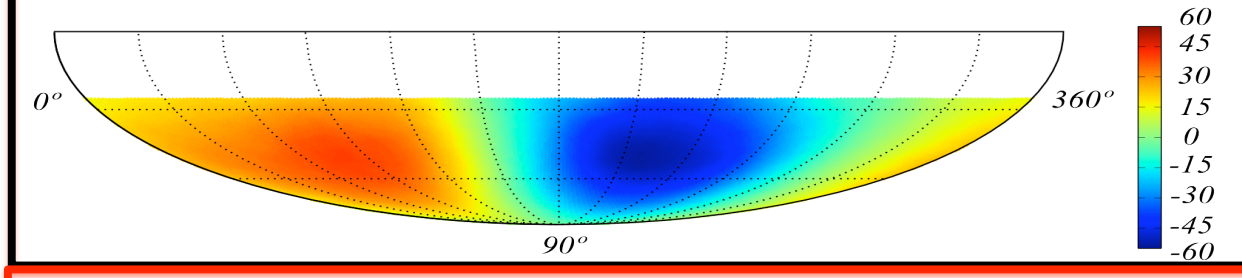




- Reference map is derived from data with time scrambling
- Smoothing is applied to improve the sensitivity to large features
- Scan from 1°-30° in smoothing radius to optimized for the highest significance regions
- Only a deficit at 21° Smoothing, was identified as a significant structure.

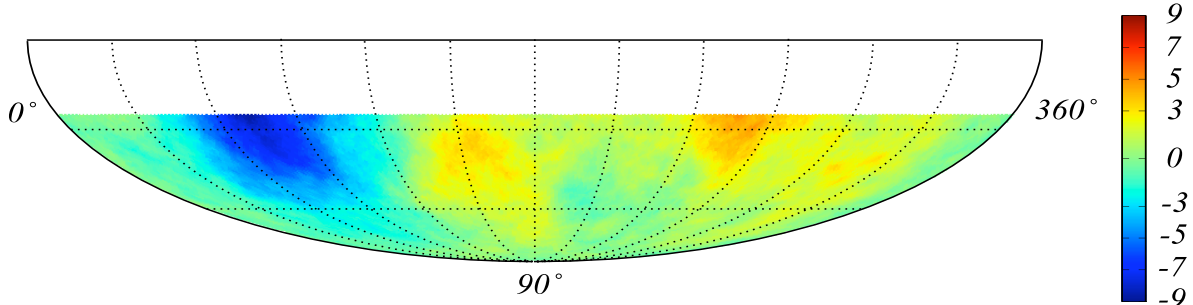
IC59 Anisotropy Energy Dependence (20TeV,400TeV,1PeV)

20 TeV



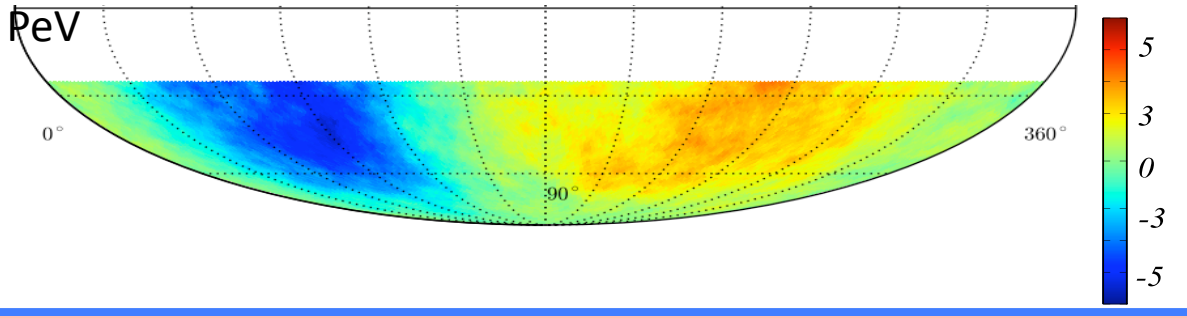
21 Billion events

400 TeV



580 Million events

1 PeV

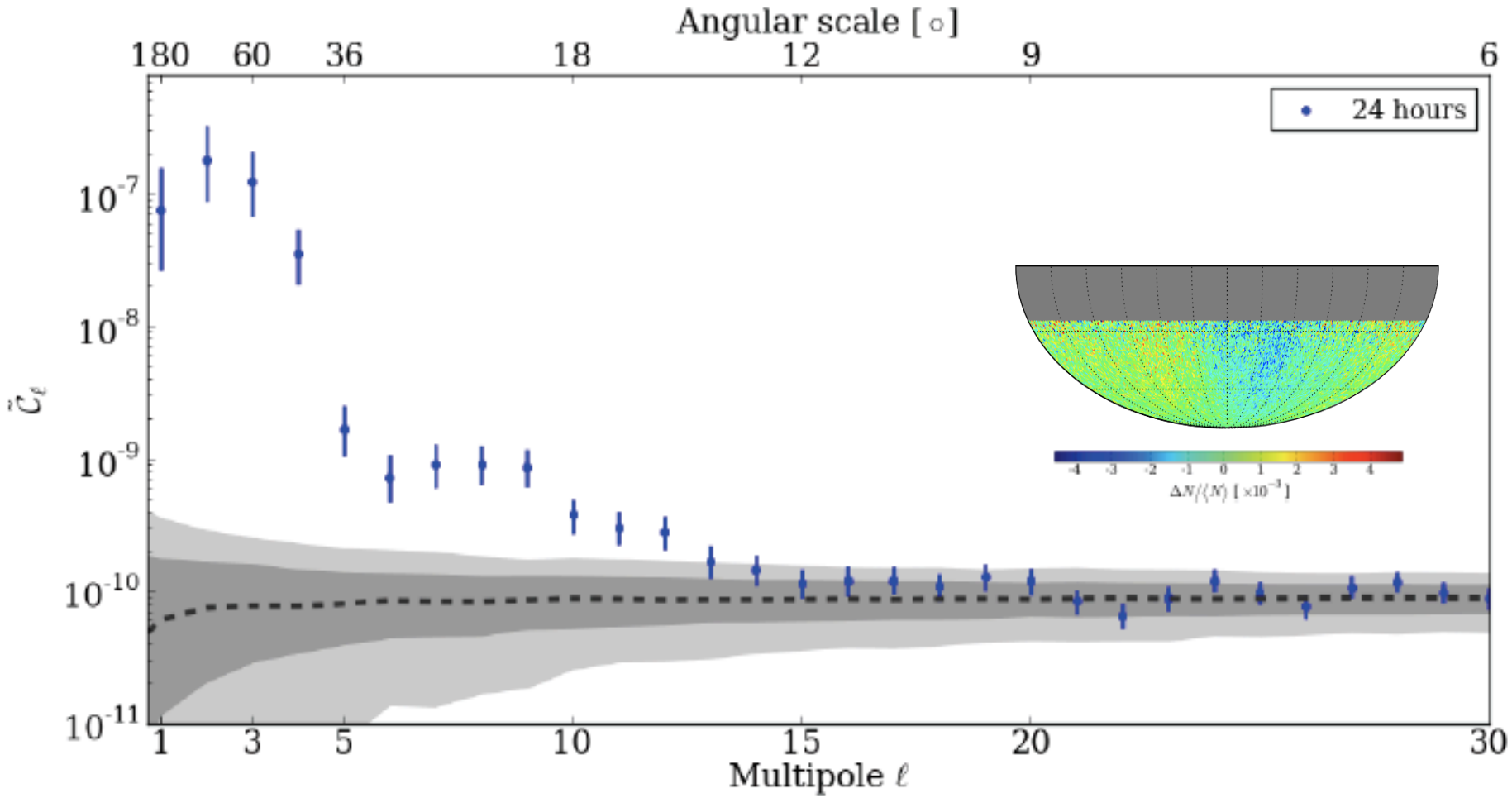


137 Million events

Submitted to APJ

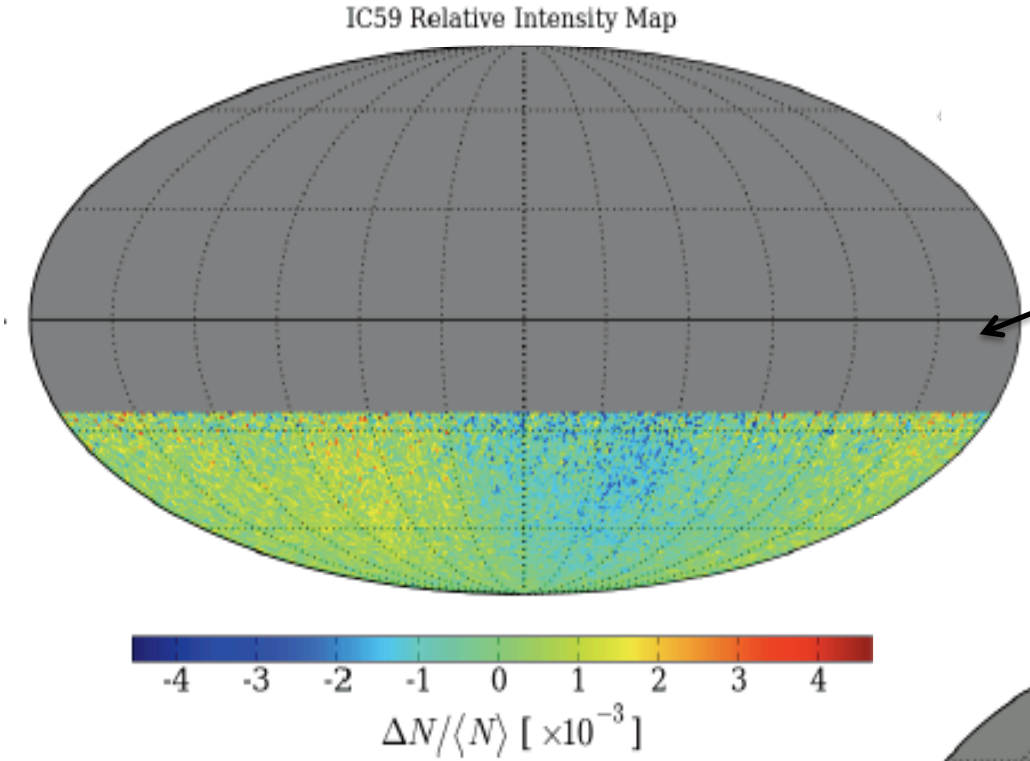
Small scale anisotropy

IceCube-59 Power Spectrum



- Sky map contains correlations at several angular scales
- Gray bands: 68% and 95% bands of simulated isotropic maps

Remove Dipole + Quadrupole

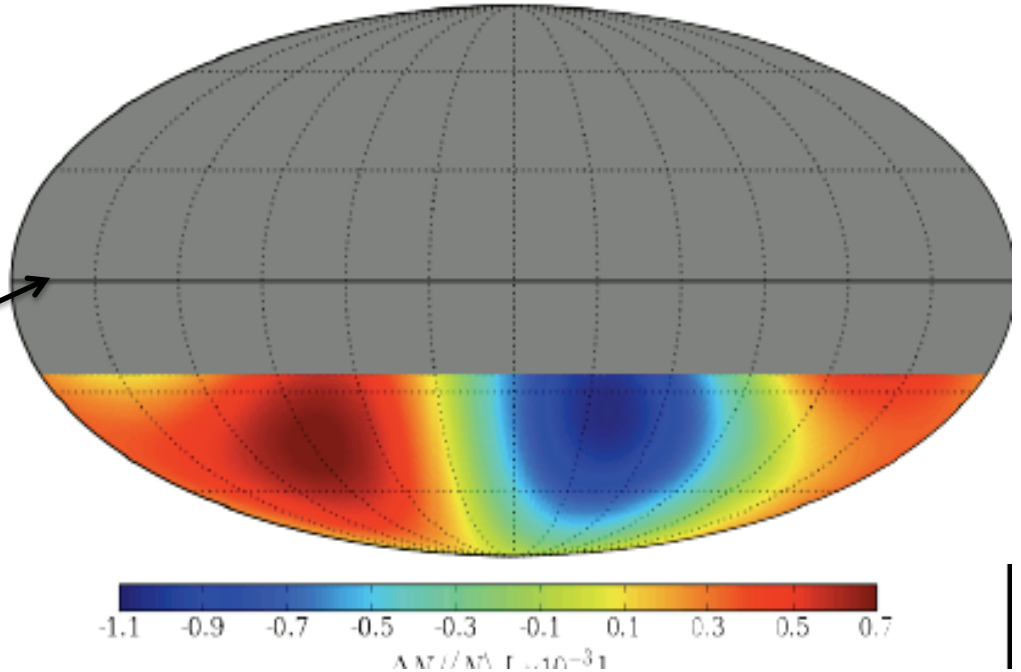


Fit dipole + quadrupole…

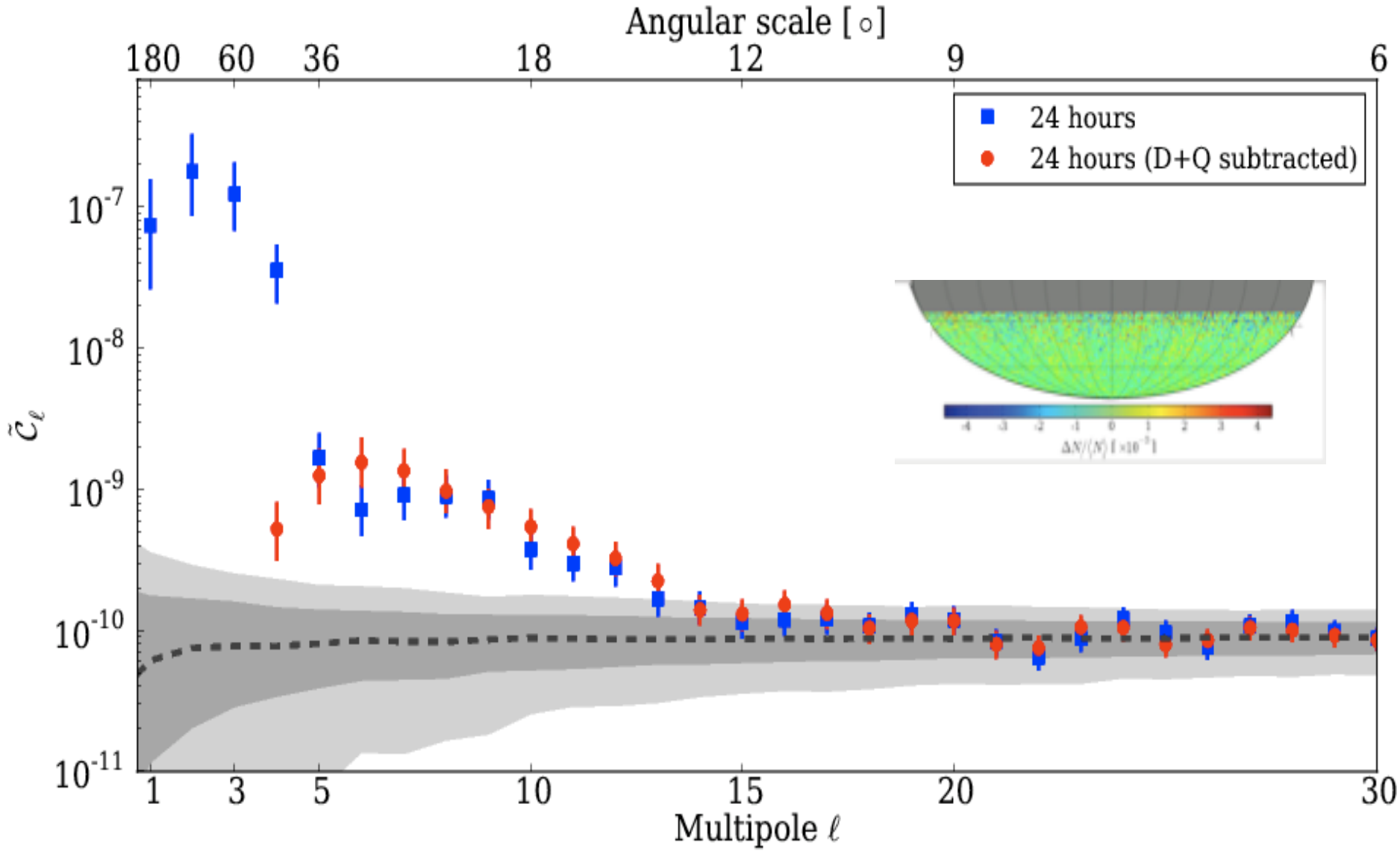
Best fit D+Q moments:

χ^2/ndf = 14743.4 / 14187

Pr(χ^2|ndf) = 0.05%

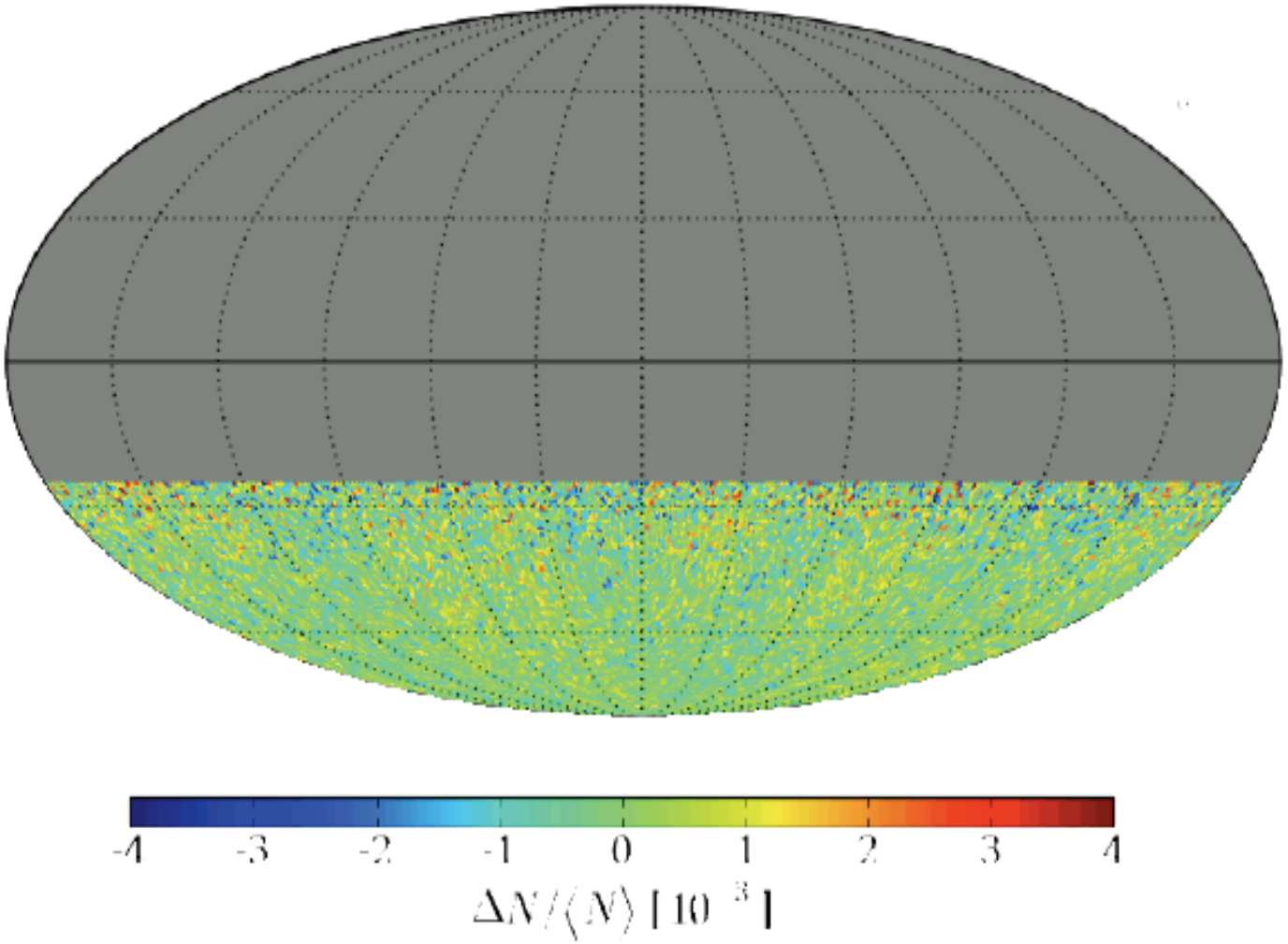


IceCube-59 Power Spectrum



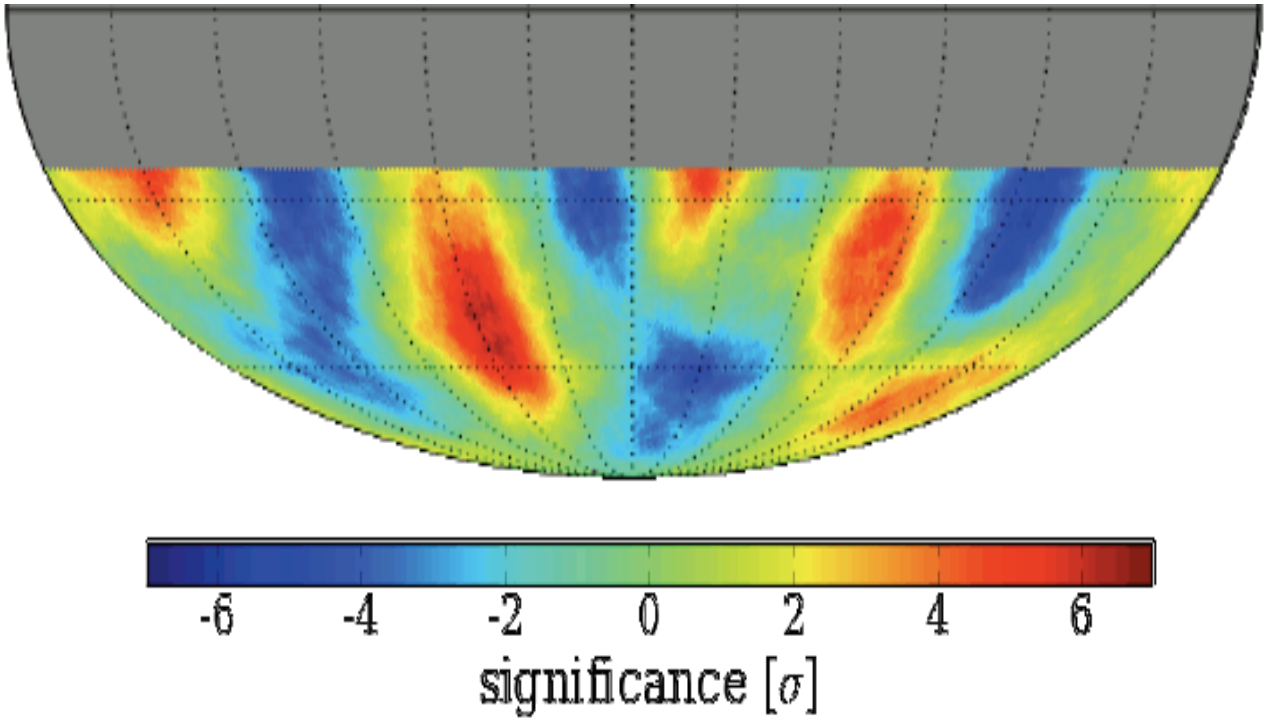
IC59 Residual Map

- Subtract D+Q fit from relative intensity map, and you get this:

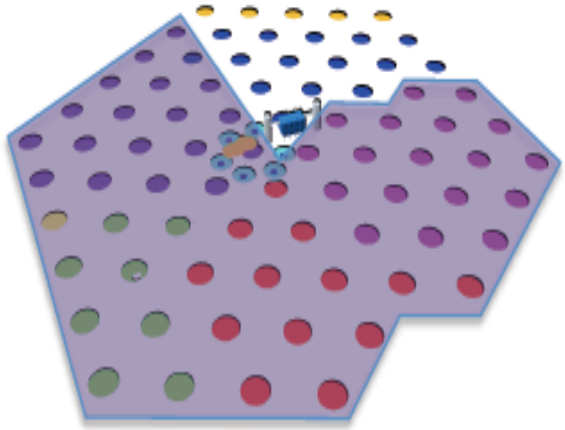


- To see more structure, we have to rebin (or "smooth") the map

IC59 Smoothed Residual Map

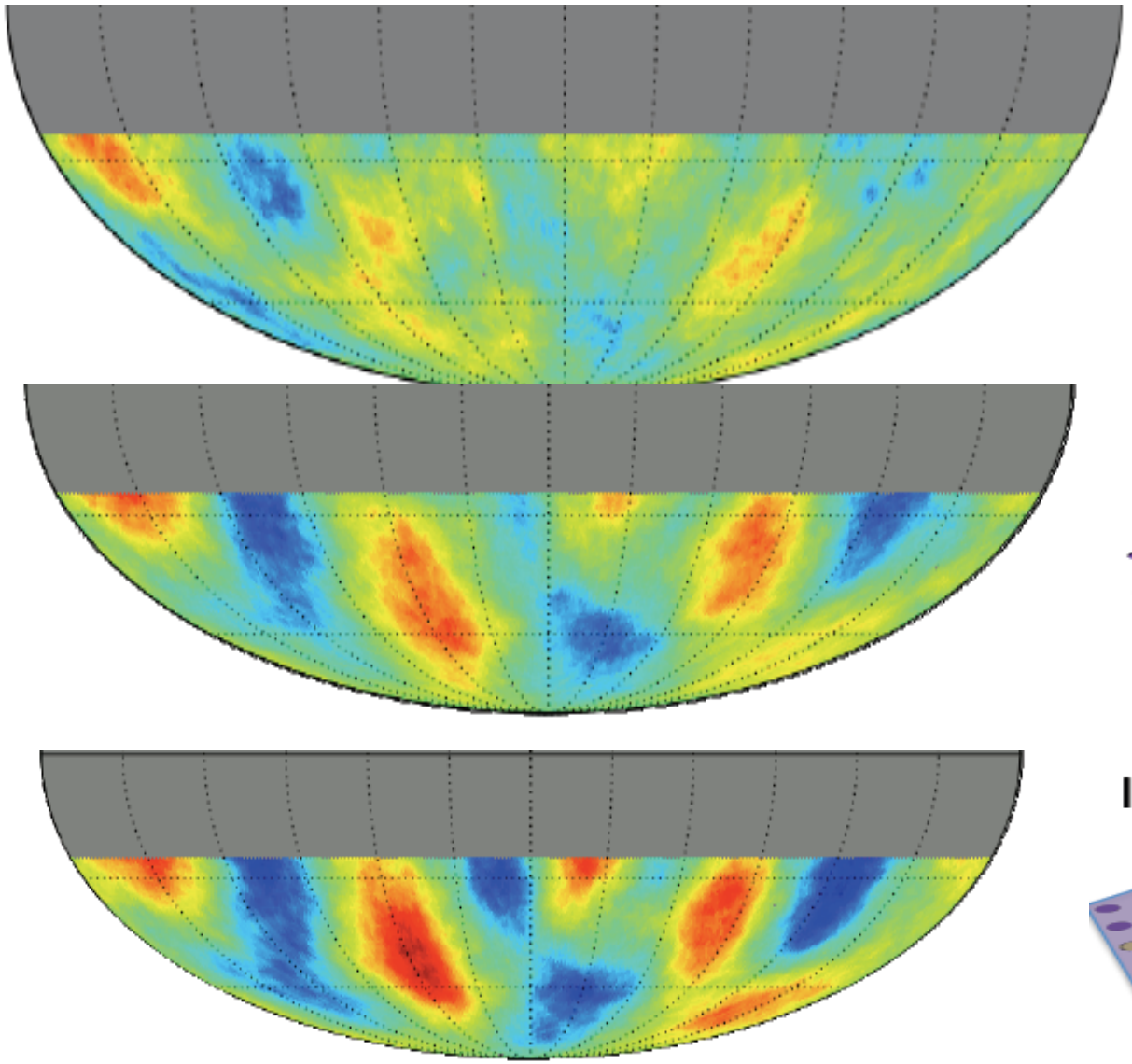


IC59 (2009-2010)

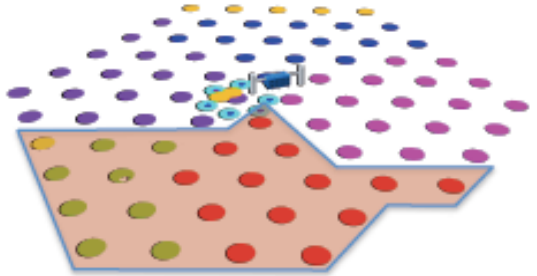


R. Abbasi et al., **ApJ, 740, 16** (2011)

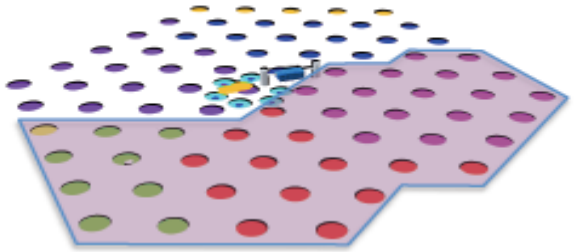
Comparison of IceCube Data Sets



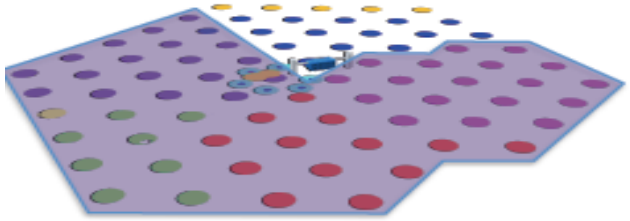
IC22 (2007-2008)



IC40 (2008-2009)

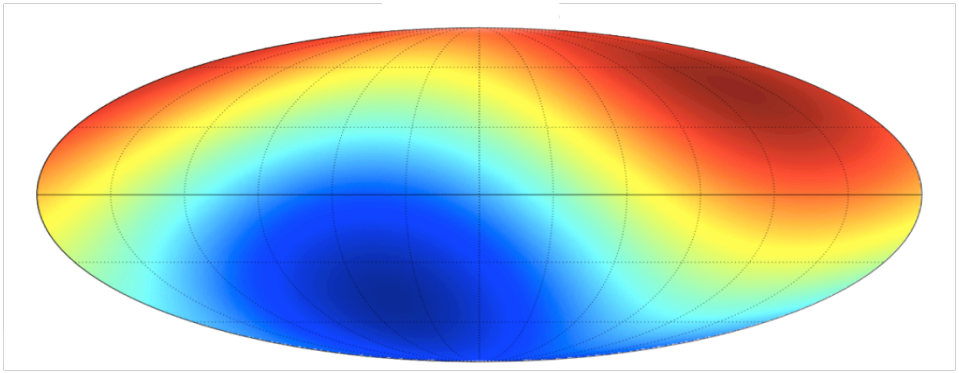


IC59 (2009-2010)

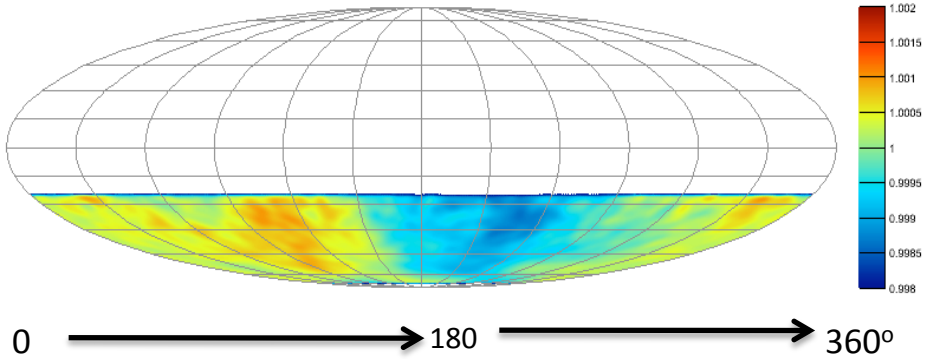


Discussion

Galactic Compton Getting



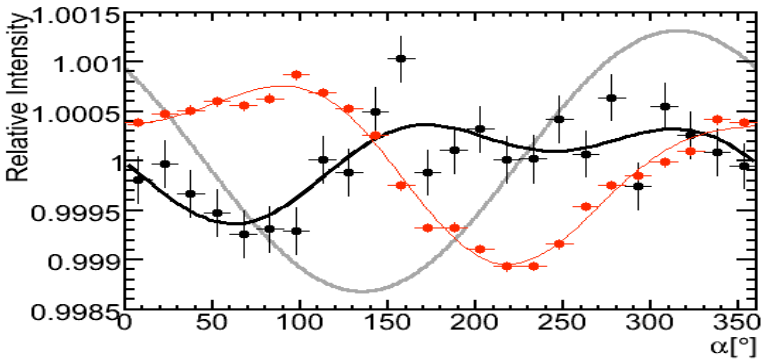
The maximum of the anisotropy is 0.35%, with a maximum at right ascension 315° and declination 48° and a minimum at right ascension 135° and declination - 48°.



$$\frac{\Delta I}{\langle I \rangle} = (\gamma + 2)\ \frac{v}{c}\ \cos\vartheta$$

$\gamma = 2.7$ cosmic ray spectral index

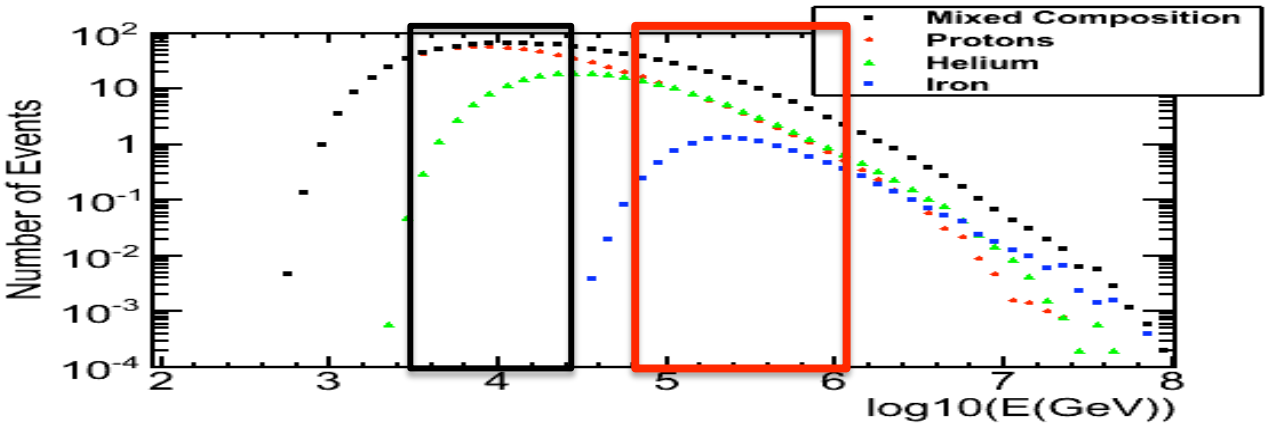
$v = 220$ km/s speed

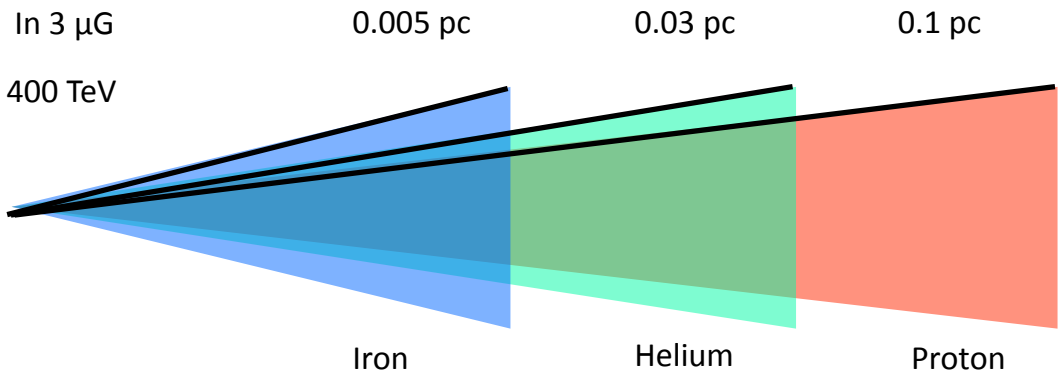


The anisotropy in IceCube data is *not a pure dipole* and does not have the right phase to be explained by the Compton-Getting effect. If the Compton-Getting effect is present in the data, it is overshadowed by a stronger effect.

Composition

$$\frac{R_g^{CR}}{pc} = \frac{1.1 \cdot 10^{-3}}{|Z|}\left(\frac{p_\perp^{CR}}{TeV/c}\right)\left(\frac{\mu G}{B_{IS}}\right)$$





Studying the effect of varying composition with energy on the anisotropy using propagating models.

Summary

- *IceCube data indicate the presence of a significant and persistent anisotropy at large and small angular scales.*
- *IceCube data also indicates the presence of a significant anisotropy >10^{14} eV in the Southern sky.*
- The origin of the anisotropy is unknown:
  - The result is not consistent with the CG assuming the galactic cosmic rays at rest with the galactic center.
  - Improved theoretical description of the diffusion processes of galactic cosmic rays closer to the knee.
  - Interstellar Magnetic field.
  - This anisotropy reveals a new feature of the Galactic cosmic ray distribution, which must be incorporated into theories of the origin and propagation of cosmic rays.