Cosmic Ray Anisotropy With Ten Years of Data Collected With IceTop

G. Agrawal[(a)], S. Lehrman[(a)], G. Bratrud[(a)] , J. Summers[(a)], R. Abbasi[(a)], F. McNally[(b)], P. Desiati[(c)], J. Díaz-Vélez[(c)]

[(a)]Loyola University Chicago, [(b)]Mercer University, [(c)]University of Wisconsin-Madison

For the IceCube Collaboration

Introduction

In this study, we examine large-scale cosmic ray anisotropy, or asymmetry in the distribution of arrival directions of cosmic rays, as detected by the IceTop air shower array from 2011 to 2021 across four distinct energy bands, centered at 310 TeV, 1.1 PeV, 2.4 PeV, and 6.6 PeV. IceTop is a dedicated cosmic ray detector located at the South Pole, designed to observe cosmic ray particles with energies from 100 TeV to 1 EeV. The anisotropy is studied and quantified through the production of two-dimensional skymaps of relative intensity and one-dimensional projections of relative intensity versus right ascension using 10% of our dataset.

2D Skymaps

Anisotropy is represented with relative intensity, the deviation from background, which is expected to be isotropically distributed. The relative intensity is calculated using the iteration method [1]. A system of nonlinear equations relating relative intensity, background, and relative detector acceptance is iterated over 20 times to find the best-fit solution. Significance is calculated using the Li & Ma method [2]. Relative intensity and significance is then binned using HEALpx into pixels of approximately $.84^{\circ 2}$ to produce a map in equatorial coordinates. These maps are masked at the 55° declination angle in order to implement a quality cut on zenith angle. Finally, we smooth the map by iterating over every pixel and averaging the values from all neighboring pixels in a 20° radius. This is done because our study is focused on large-scale anisotropy.

Figure 1 below depicts the skymaps produced for each energy band using 10% of our data. A deficit at around 90° persists through all energy levels. As energy increases, the intensity and shape of this deficit changes.

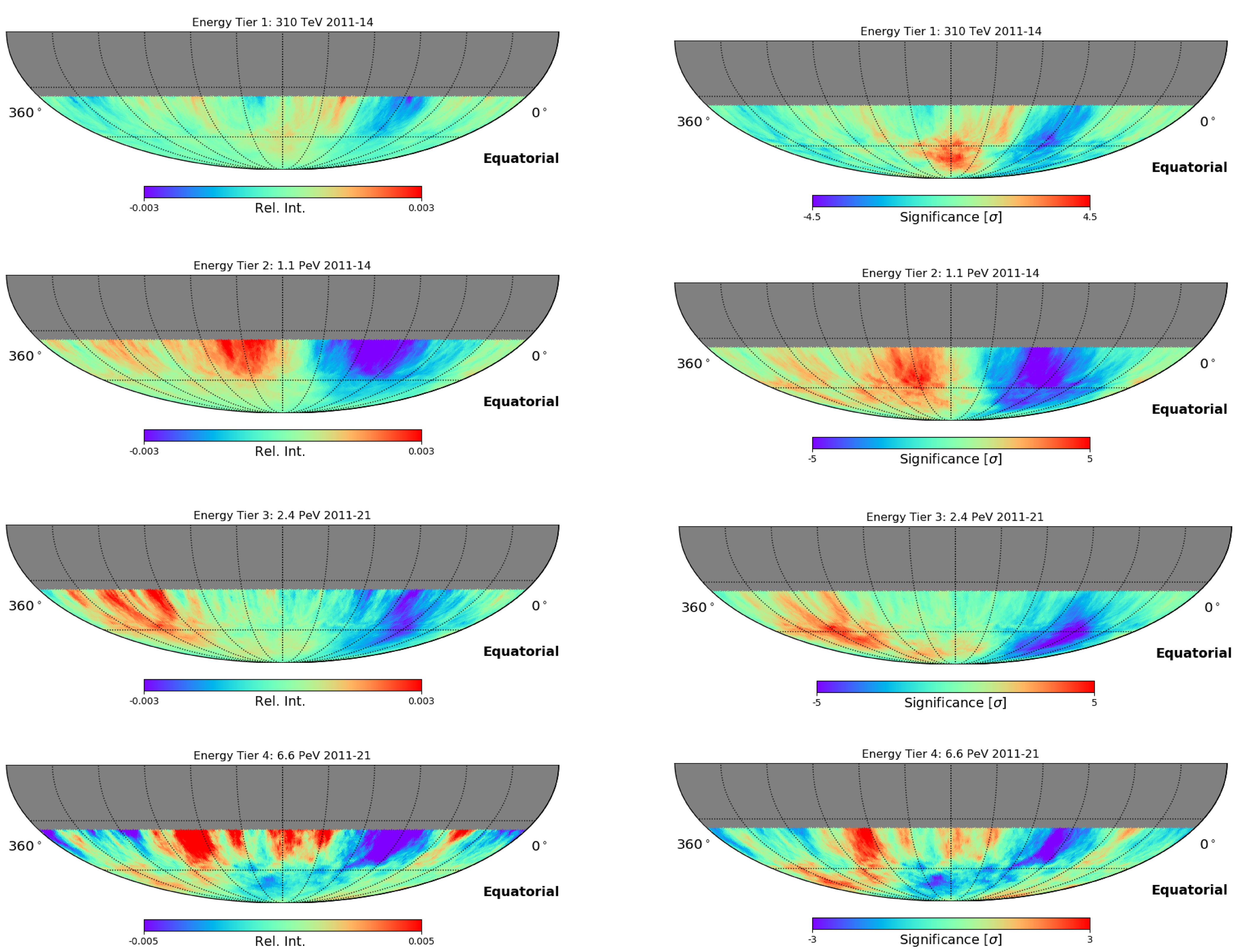

Figure 1: 2D Skymaps showing relative intensity and significance between 0 and 55° declination per energy band.

1D Projections

To quantify important parameters of this deficit, such as location, size, and degree, we project the relative intensity onto right ascension and fit the following Gaussian function:

$$\delta I(\alpha) = Ae^{-\left(\frac{\alpha-\alpha_s}{\sqrt{2}\sigma}\right)^2}$$

In producing these plots, we weigh each declination band to counter the bias introduced by the decrease in event count with greater zenith angle.

Our 1D projections in Figure 2 show the same deficit persisting at approximately 90° across all energy bands that our 2D skymaps depict. Furthermore, we can see that this deficit increases in width from 310 TeV to 1.1 PeV and from 1.1 PeV to 2.4 PeV. Furthermore, while the amplitude of the fitted function is approximately the same, there is greater variability in relative intensity with increased energy.

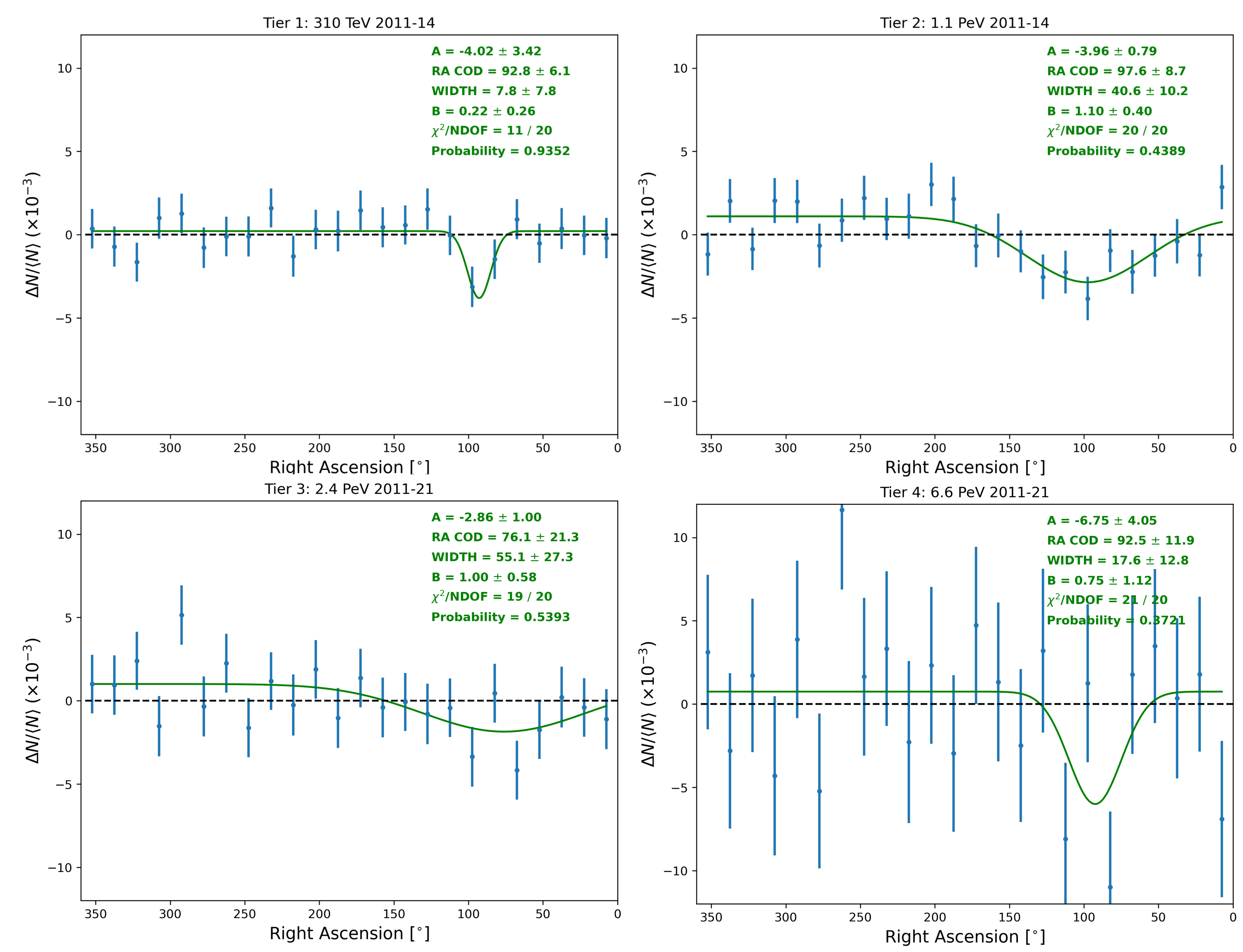

Figure 2: 1D Projections of relative intensity vs right ascension with Gaussian fit per energy band.

Summary and Future Outlook:

In this work, we are studying the large-scale anisotropy energy-dependence. We defined four energy tiers, centered at 310 TeV, 1.1 PeV, 2.4 PeV, and 6.6 PeV. We produced 2D skymaps using 10% of our data that depict a large-scale deficit at approximately 90° that persists across all energy bands, agreeing with previous work [3]. This anisotropy changes in structure as energy increases – for example, the 1D projections indicate an increase in width between 310 TeV and 2.4 PeV. The next steps will be to analyze the complete dataset and estimate our systematic uncertainties.

References:

[1] Ahlers, M. et al. "A New Maximum-likelihood Technique For Reconstructing Cosmic-ray Anisotropy At All Angular Scales." The Astrophysical Journal 823, no. 1(2013):10.
[2] Li, T. and Ma, Y. "Analysis Methods for Results in Gamma-Ray Astronomy." The Astrophysical Journal 272, 317-324
[3] Aartsen, M. G. et al. "Observation Of Cosmic-Ray Anisotropy With The Icetop Air Shower Array." The Astrophysical Journal 765, no. 1 (2013): 55.