Energy Dependence of Cosmic Ray Anisotropy Using IceTop Detector

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Introduction

In this work, we are studying the energy dependence in the arrival directions of cosmic rays, as detected by the IceTop air shower array over ten years. IceTop is a dedicated cosmic ray detector located at the South Pole. IceTop is able to detect cosmic rays from 100 TeV to 1 EeV. In this work, we are using ten years of cosmic ray data collected by IceTop from 2012-2021. One- and two-dimensional skymaps were produced to measure the amplitude, location, and significance of the anisotropy for each energy band.

Simulation

To understand the quality cuts needed for this work, we compared a sample data set from IceTop to Monte Carlo simulations. Figure 1 shows the data to MC comparison for the zenith distribution of detected cosmic ray events by IceTop.

The energy distribution dependence on the number of stations triggered by the detected events was also investigated. Events that triggered at least 3 but less than 8 stations were selected for the low energy skymap with a median energy of 0.41 PeV. While events that triggered 8 or more stations were selected for the high energy skymap with a median energy of 1.8 PeV. Figure 2 provides the energy distribution for proton and iron primary cosmic ray particles for low and high energy skymaps.

Figure 3 shows the median energy across different zenith-angle bins. From figure 3 we determined that we would apply a quality cut to exclude events with zenith angles greater than 60 degrees to ensure consistent median energy across our skymaps.

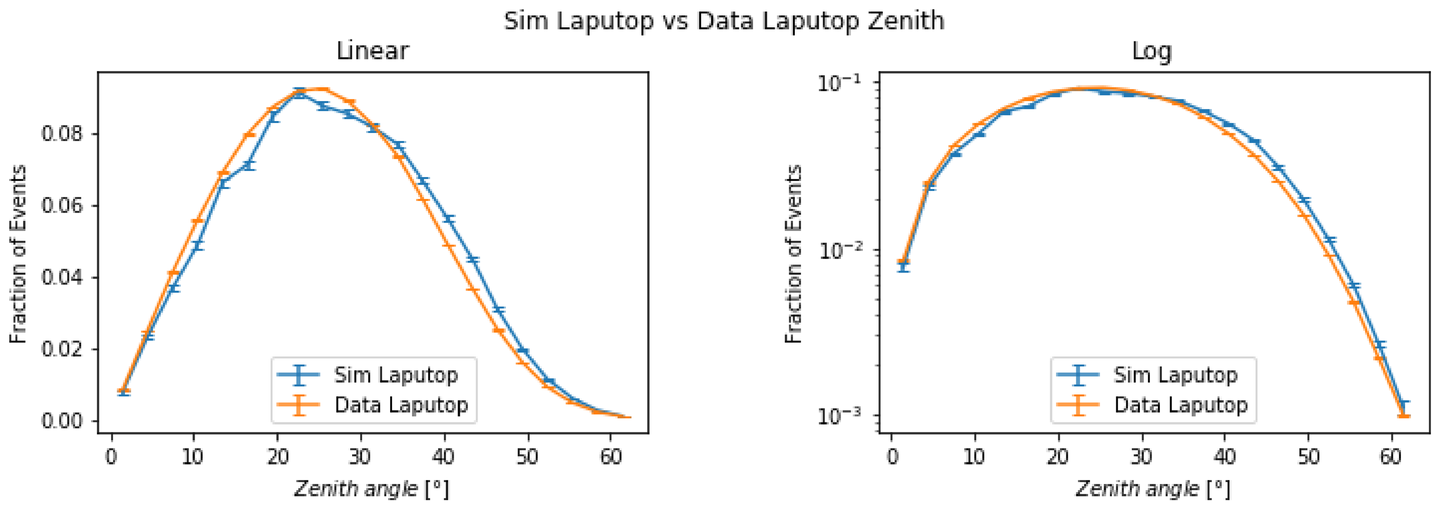

Figure 1: Graphs of the fraction of the events compared to the zenith angle for the MC simulation and the burnsample data.

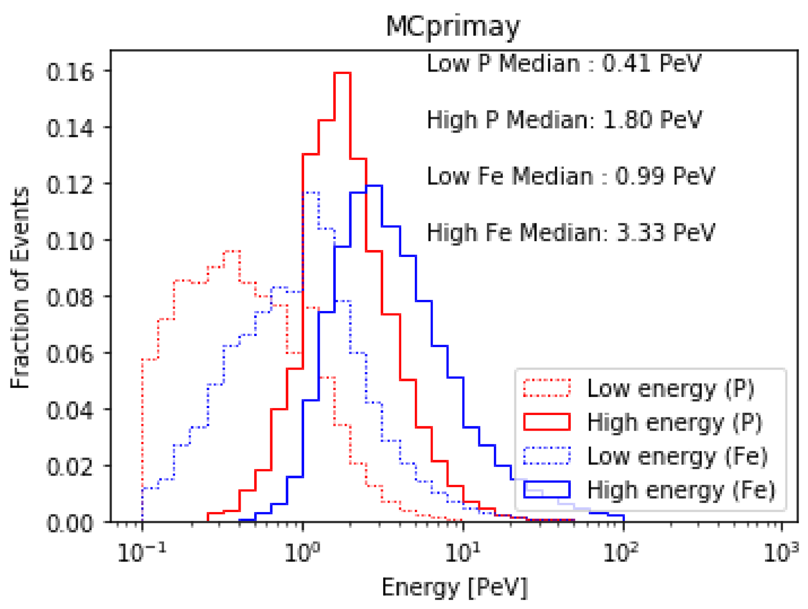

Figure 2: Distribution of the iron and proton events over the energy divided into high energy and low energy bins.

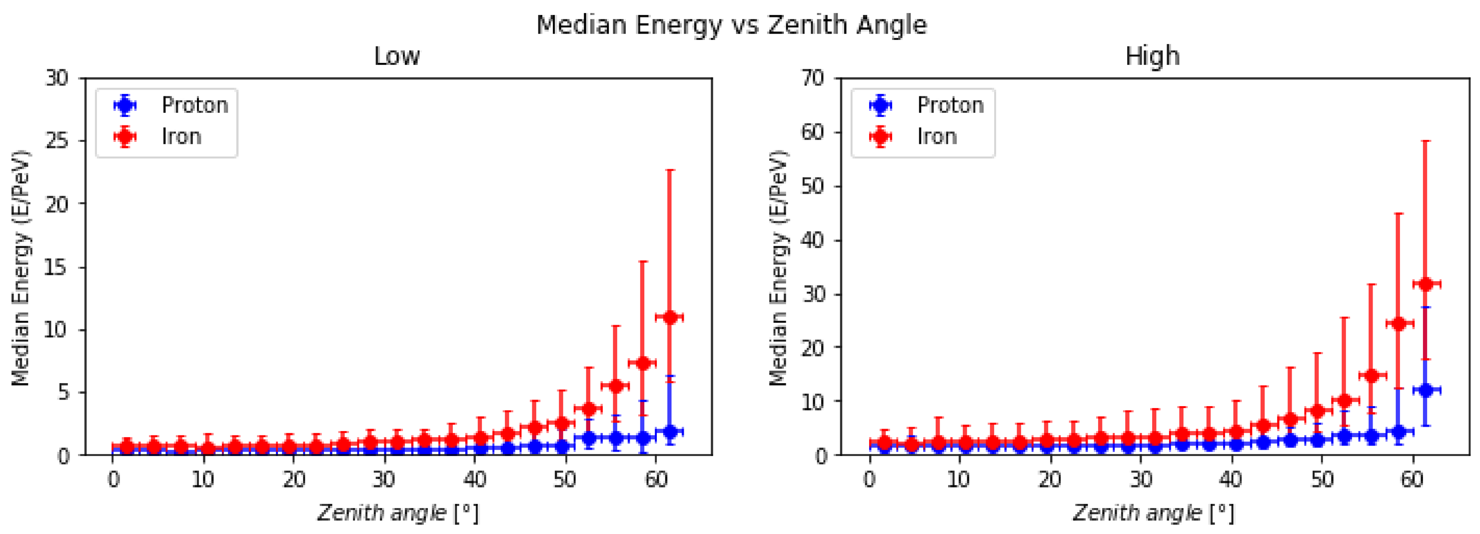

Figure 3: Graphs of the median energy at the zenith angle using the MC simulation data.

Anisotropy Analysis

After applying the quality cuts and studying the station selection needed to study the cosmic ray anisotropy energy dependence, we produced the two-dimensional and one-dimensional anisotropy skymaps using the iteration method [1].

Figures 4 shows the two-dimensional skymaps and their corresponding one-dimensional projection for both low and high energy. The one-dimensional projection allows us to quantify the anisotropy amplitude and phase. A Gaussian function was determined to fit the data sets.

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

We were also able to see the solar dipole for the first time using IceTop as shown in Figure 5.

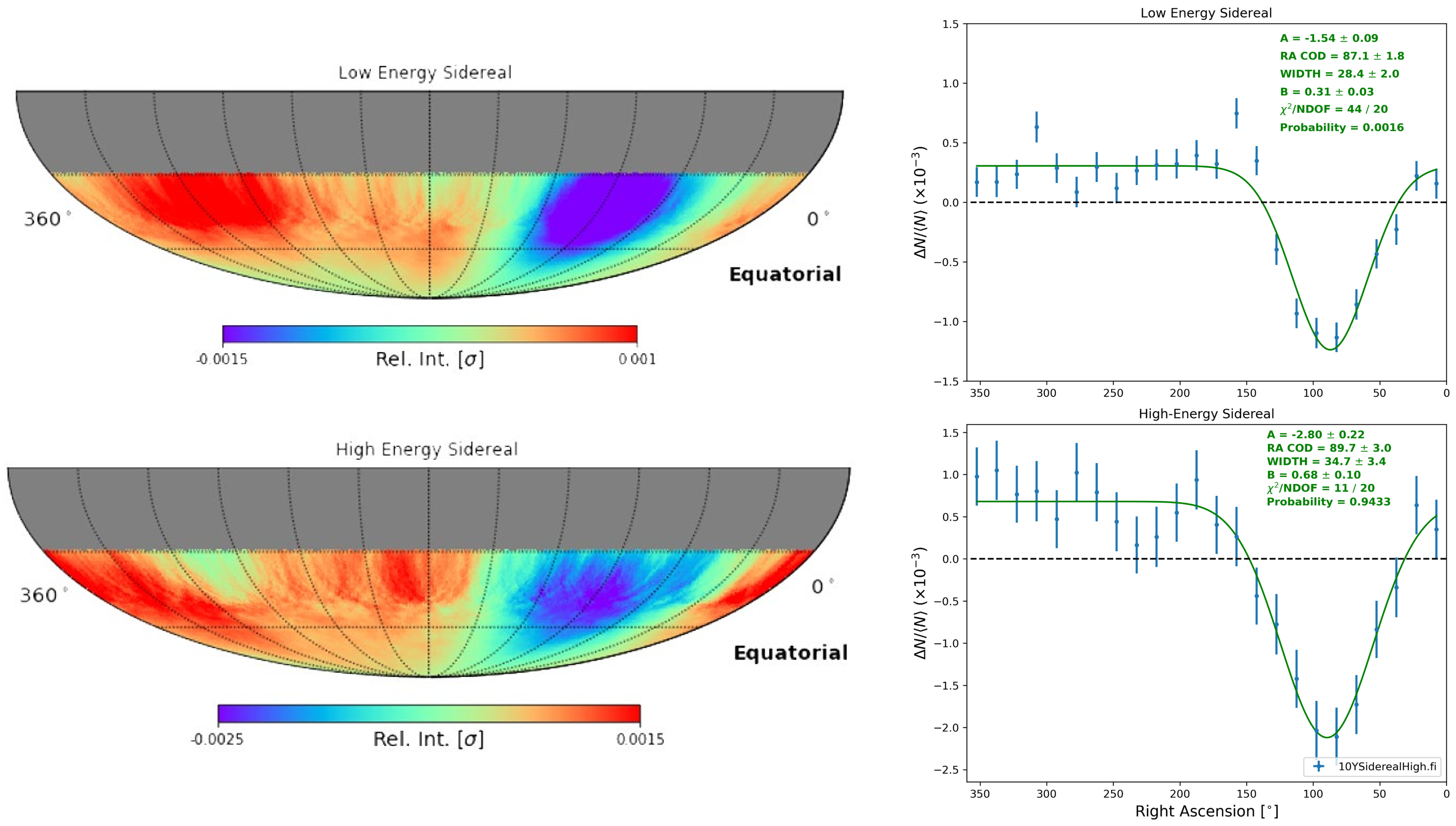

Figure 4: These 2D skymaps and their associated 1D projections show the high energy and low energy structures. The 1D projections have a Gaussian fit applied.

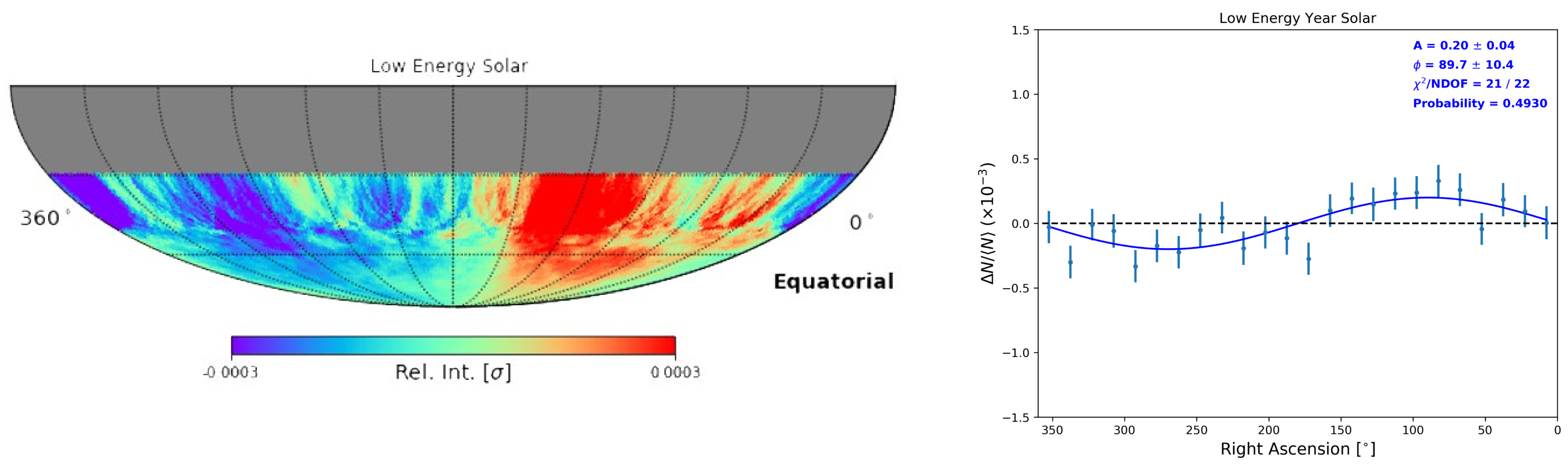

Figure 5: This 2D skymap and its associated 1D projection shows the solar dipole. The 1D projection has a first harmonic fit applied.

Conclusion

In this work, we produced an analysis of cosmic ray anisotropy as detected by IceTop across two energy bands, one centered at 0.41 PeV and the other at 1.8 PeV. We determined the depth, size, location, and significance of a large-scale deficit. We compared our results to the previous work published by IceTop [2] and found that the location, size, and depth of the large-scale deficit across both energy bands and the overall anisotropy was consistent.

We also detected the solar dipole for the first time using IceTop with our low energy data set. Our next step is integrating an estimation of the systematic error to ensure that our fits and parameter values are reasonable.

References:

[1] https://arxiv.org/abs/1601.07877

[2] Aartsen, M. G. et al. "Observation Of Cosmic-Ray Anisotropy With The Icetop Air Shower Array." The Astrophysical Journal 765, no. 1 (2013): 55.