Analysis of the Diffuse Astrophysical Flux from the Galactic Plane with 12.1 Years of IceCube Starting Tracks, Throughgoing Tracks and Cascades

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Introduction

IceCube is a cubic-kilometer neutrino detector located at the South Pole. IceCube has previously detected neutrino emission from the Galactic plane at the 4.5σ significance level compared to a background-only hypothesis, testing three models of Galactic diffuse emission: Fermi-LAT π^0 [1], KRA_γ^5 and KRA_γ^{50} [2]. This analysis will better characterize Galactic neutrino emission.

Event Selections

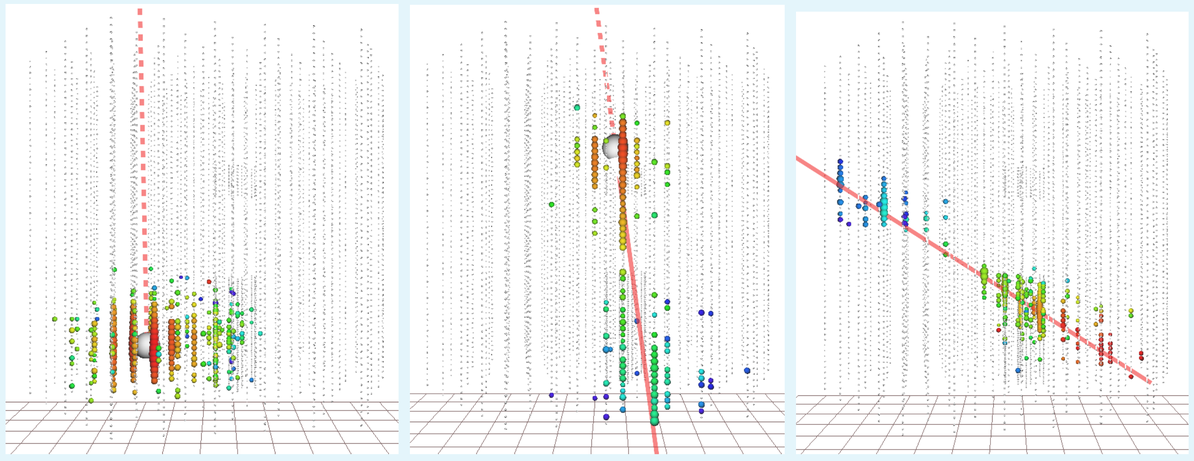


Figure 1: Final level Monte Carlo event displays for each selection. Red (blue) is the earliest (latest) light detected for the event. A dashed (solid) red line denotes the true trajectory of a neutrino (muon), and a large gray sphere denotes the true interaction vertex of a neutrino. Left: A DNN Cascades 18 TeV charged current ν_e cascade event from the southern sky. Middle: An ESTES 22 TeV charged current $\bar{\nu_\mu}$ starting track event from the southern sky. Right: A Northern Tracks 77 TeV charged current ν_μ throughgoing track event from the northern sky.

This analysis combines three event selections targeting different event morphologies:

1. Deep Neural Network (DNN) Cascades: Targets cascade events for great energy resolution. An isotropic astrophysical measurement is currently underway parallel to this analysis [3].
2. Enhanced Starting Track Event Selection (ESTES): Targets starting track events for good angular and energy resolution. Previously used for a 10.3 year isotropic astrophysical flux measurement [4].
3. Northern Tracks: Targets throughgoing events from the northern sky for great angular resolution. Previously used for a 9.5 year isotropic astrophysical flux measurement [5]. The energy reconstruction has been improved [6].

Analysis Method

This analysis will measure ν emission from the Galactic Plane using generic spatial and spectral modeling to allow for a more robust characterization of the energy spectrum and spatial distribution.

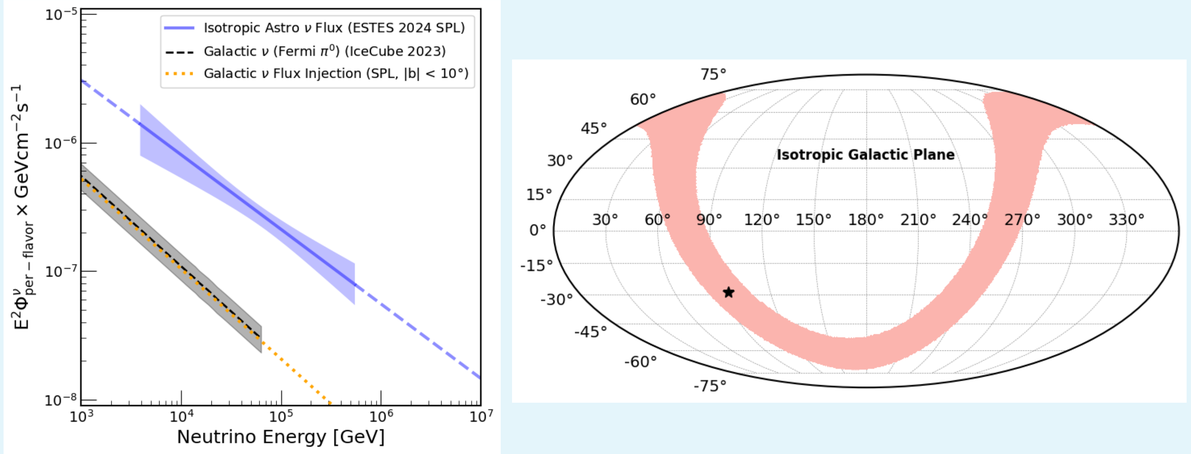
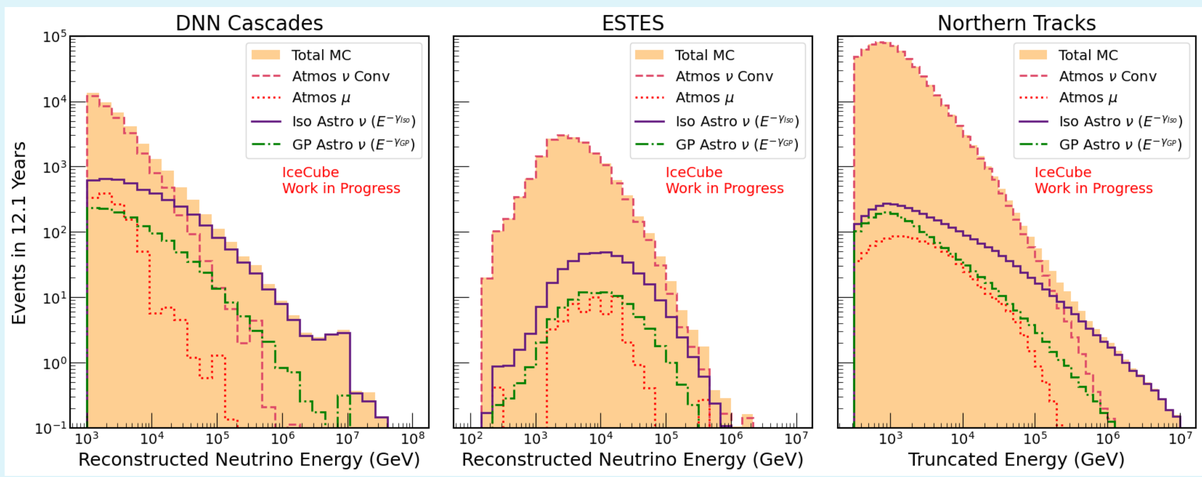


Figure 2: Left: Energy scaled, all sky, per-flavor neutrino flux plot. The blue line / shaded band is the 10.3 year ESTES measurement of the isotropic astrophysical flux [4]. The dashed gray line / shaded band are the best fit Galactic neutrino flux using the Fermi-π^0 template from the 2023 IceCube Science result using DNN Cascades [7]. The dotted orange line is injected to the Galactic plane band shown in the right panel to test this analysis's sensitivity. Right: A sky map illustrating a band ($|b| < 10°$) surrounding the Galactic plane with a star at the Galactic center.

The analysis will also measure the isotropic astrophysical ν flux as has been done in previous measurements [4, 5]. Measuring both fluxes simultaneously will allow for the best understanding of the astrophysical ν flux down to 1 TeV.



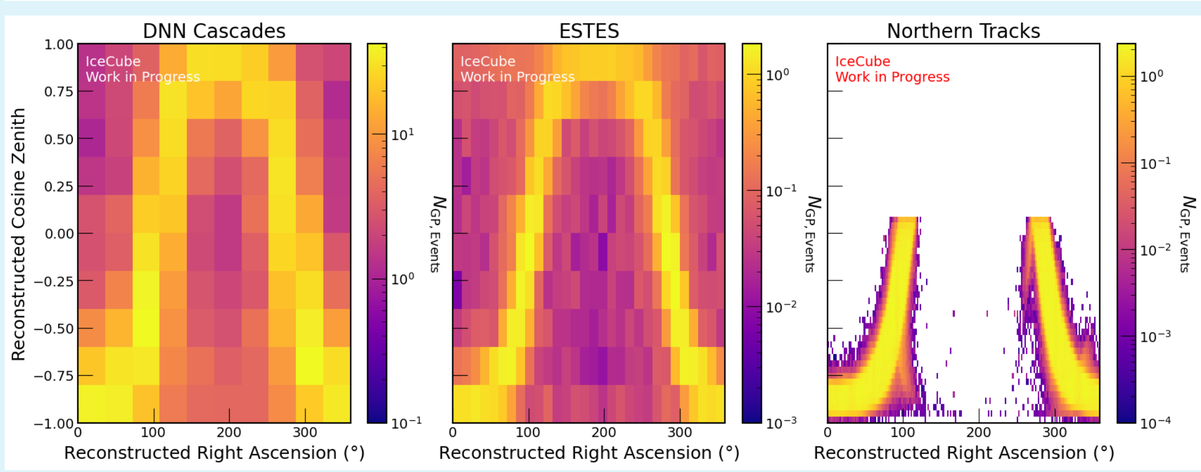


Figure 3: The Monte Carlo (MC) is weighted using pre-fit parameters based on earlier measurements and baseline values. Top: The reconstructed energy distributions for the 3 selections. Bottom: The reconstructed cosine zenith vs reconstructed right ascension distributions for the 3 selections. The color axes denote the number of Galactic Plane neutrinos in each bin.

Sensitivity

The analysis uses a forward-folding binned likelihood fit in three dimensions: N energy bins, M cosine zenith bins and O right ascension bins. The likelihood of observing k events when expecting λ events is modeled using a Poisson probability. The test statistic is the negative log-likelihood ratio comparing the likelihood at parameters Θ to the maximum likelihood at $\hat{\Theta}$:

$$\mathcal{L}(\lambda|k) = \Pi_{i=1}^{N\cdot M\cdot O}\left(\frac{e^{-\lambda_i}\lambda^k}{k!}\right),\ \mathcal{TS}(\Theta) = -2\log\left(\frac{\mathcal{L}(\lambda(\Theta)|k)}{\mathcal{L}(\lambda(\hat{\Theta})|k)}\right). \quad (1)$$

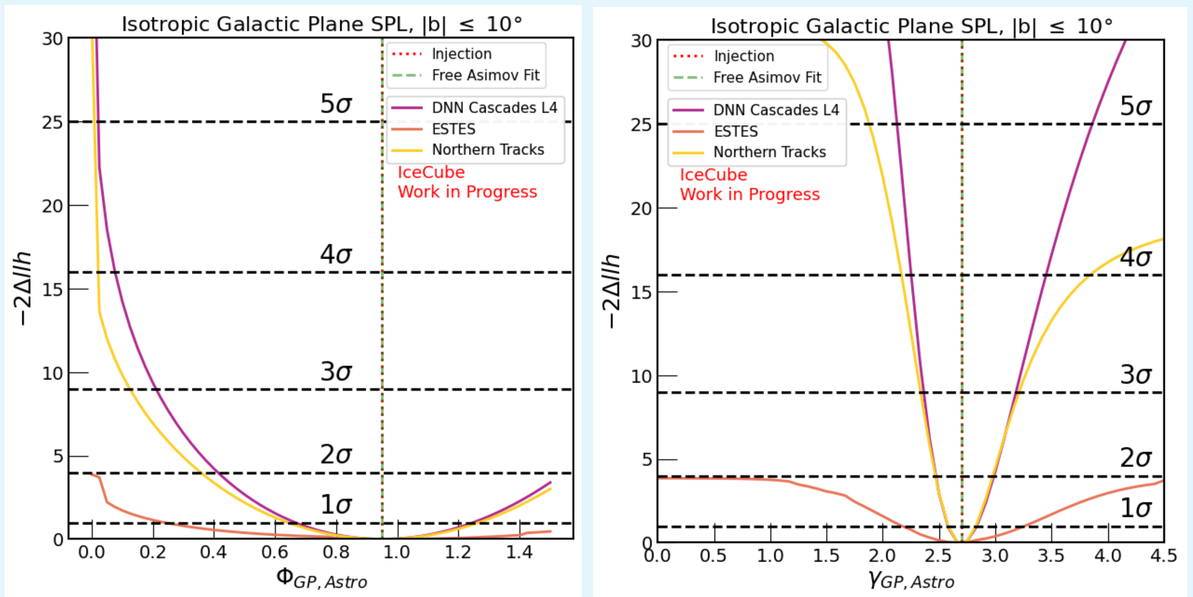


Figure 4: One dimensional log likelihood scans for the normalization (left) and spectral index (right) of a single power law flux injected from the Galactic Plane box. The confidence lines are presented using Wilks' theorem.

Conclusion

This analysis is sensitive to characterizing the spatial and spectral features of Galactic plane neutrino emission using generic modeling to allow for robust measurements. Simultaneously measuring the isotropic astrophysical ν spectrum will allow this analysis to improve our understanding of the astrophysical ν flux down to 1 TeV.

References

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[2] D. Gaggero, D. Grasso, A. Marinelli, A. Urbano, and M. Valli *The Astrophysical Journal Letters* **815** no. 2, (Dec, 2015) L25.
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[4] **IceCube** Collaboration, R. Abbasi *et al. Phys. Rev. D* **110** (Jul, 2024) 022001.
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[7] **IceCube** Collaboration, R. Abbasi *et al. Science* **380** no. 6652, (2023) 1338–1343.