A Joint Characterization of Galactic and Extragalactic Neutrino Fluxes

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RWTH Aachen University

TeVPA 2026

Josh Veitch-Michaelis, IceCube/NSF

THE HISTORY OF

Neutrino Astronomy in Antarctica

Extragalactic & Galactic Neutrinos

1988
TELESCOPE IN THE ICE
ENVISIONED

2000
AMANDA
COMPLETED

2001
ATMOSPHERIC NEUTRINOS
DETECTED

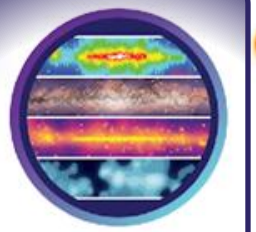
2011
ICECUBE
COMPLETED

2013
ASTROPHYSICAL NEUTRINOS
DISCOVERED

2018
BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED

2021
GLASHOW RESONANCE
NEUTRINO IDENTIFIED

2022
ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED

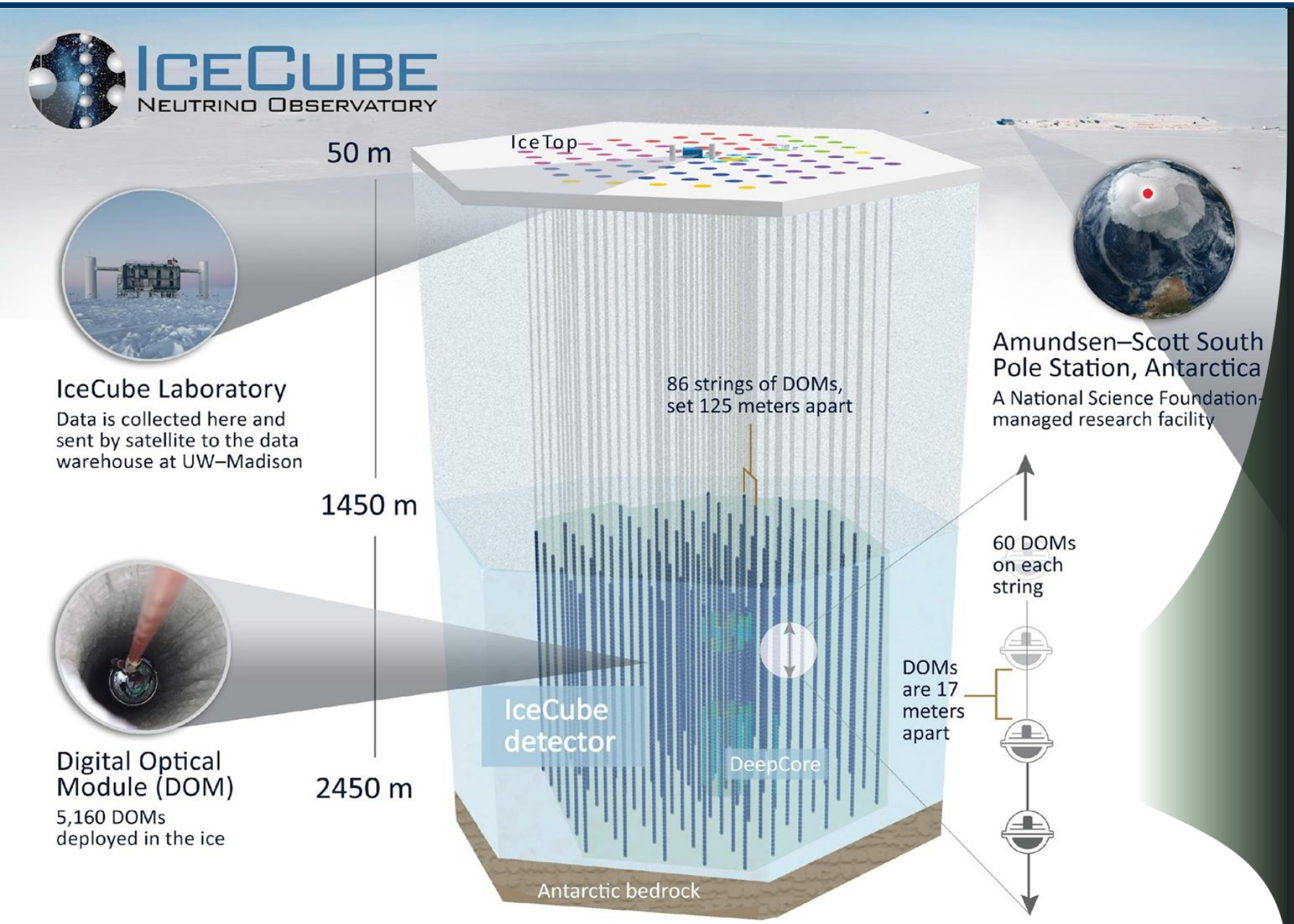


2023
MILKY WAY
NEUTRINO EMISSION IDENTIFIED

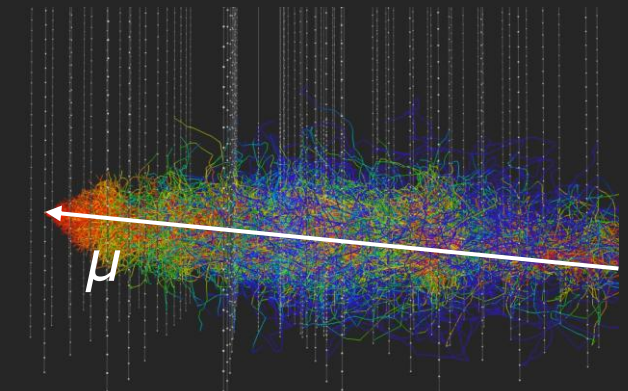
2024
ASTROPHYSICAL TAU NEUTRINOS
IDENTIFIED

NSF | IceCube Neutrino Observatory

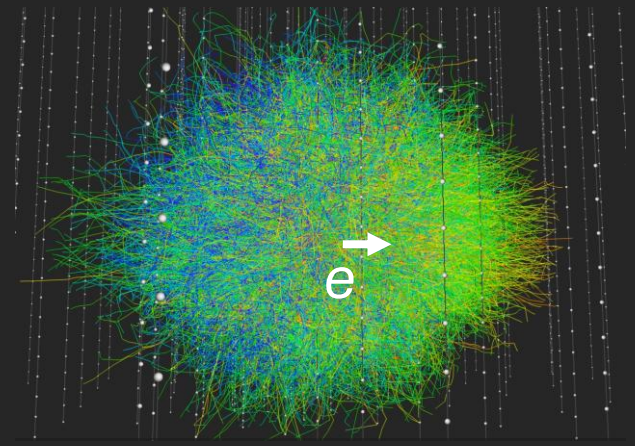
The IceCube Neutrino Observatory



Relativistic, charged particles in the ice produce Cherenkov light:



Tracks: 0.2° - 1° resolution



Cascades: 5° - 15° resolution

Extragalactic and Galactic Neutrinos

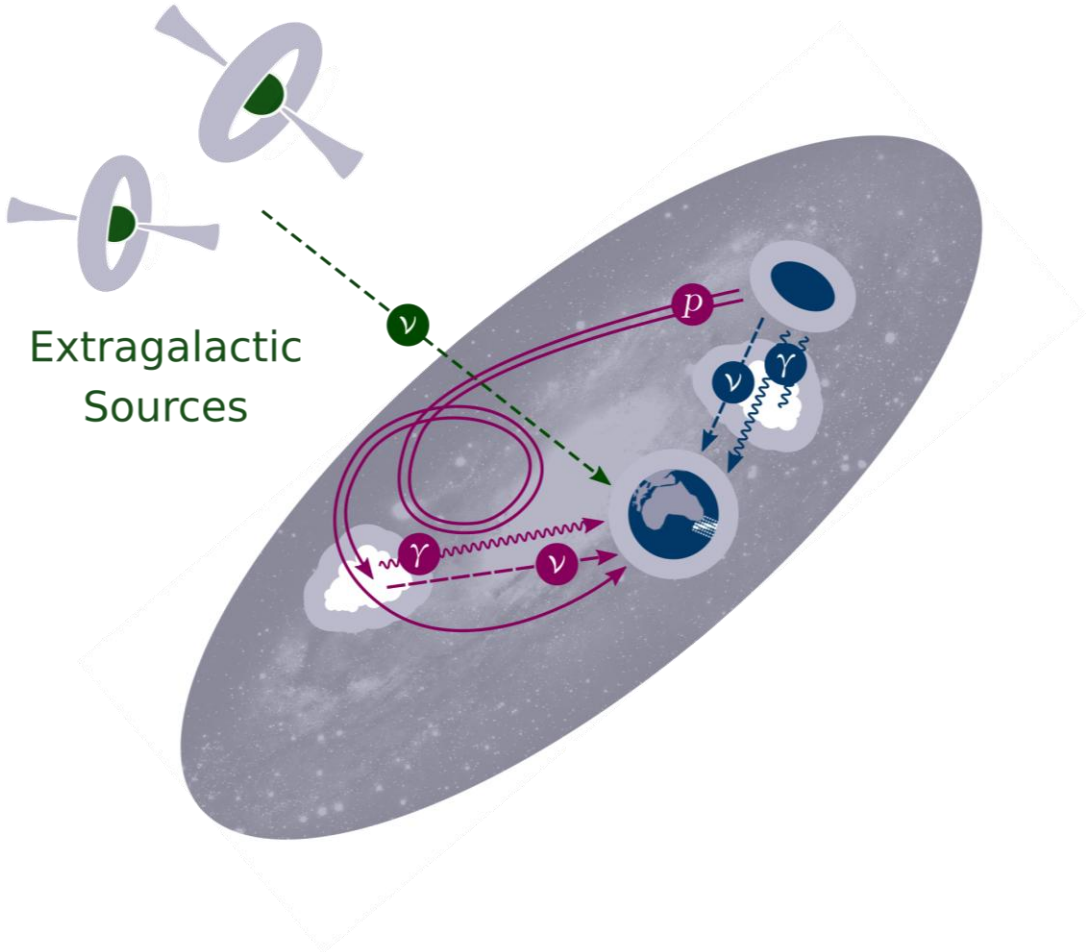
Extragalactic Neutrinos

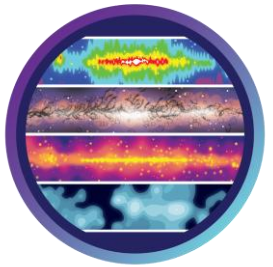
- Two source candidates identified
- Dominant source population unknown

Energy Spectrum:

- >30 TeV: Single power law
- Below: evidence for structure

PRL 136, 121002 (2026)





Galactic Neutrinos

Galactic Neutrinos are a New Background!

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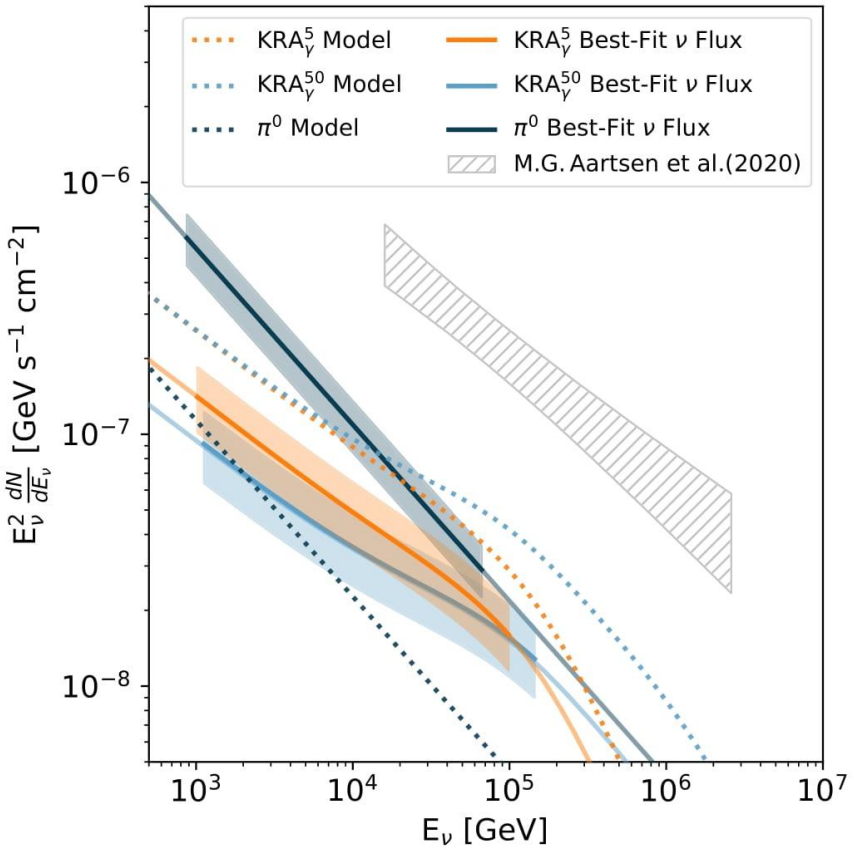
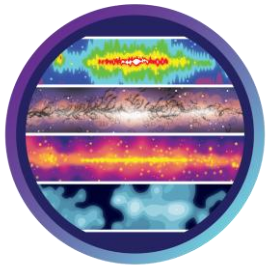
PRL 136, 121002 (2026)



Science 380,1338 (2023)

Analysis Goal #1:
Measure the extragalactic neutrino spectrum while considering the galactic contribution!



Galactic Neutrinos

- Tested different emission models
- Evidence at 4.5σ
- Recent analyses >5σ

Galactic Diffuse Emission

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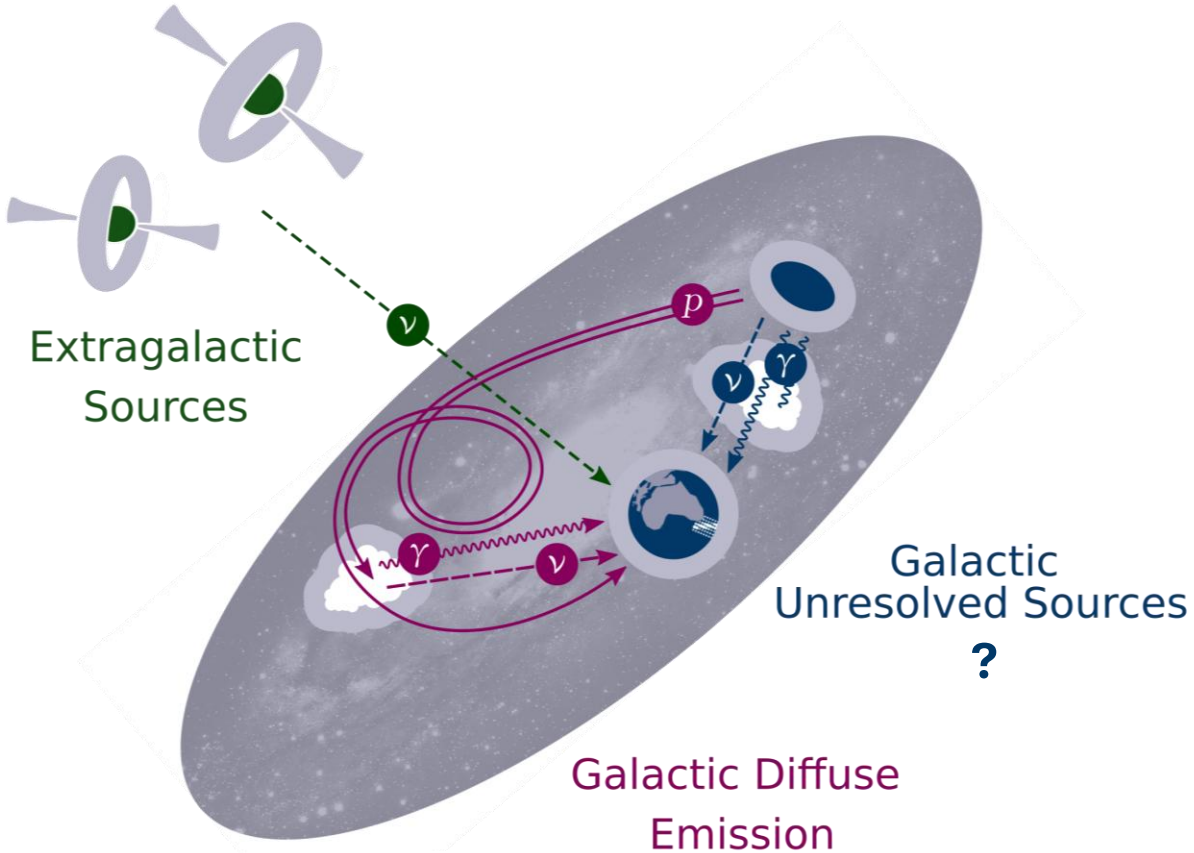


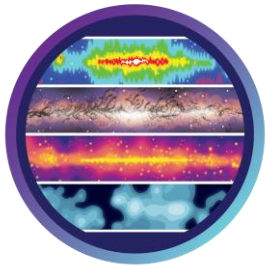
Galactic Diffuse Emission

$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^{+(-)} \rightarrow \mu^{+(-)} + \nu_\mu(\bar{\nu}_\mu)$$

$$\searrow$$

$$e^{+(-)} + \nu_e(\bar{\nu}_e) + \bar{\nu}_\mu(\nu_\mu)$$



Galactic Neutrinos

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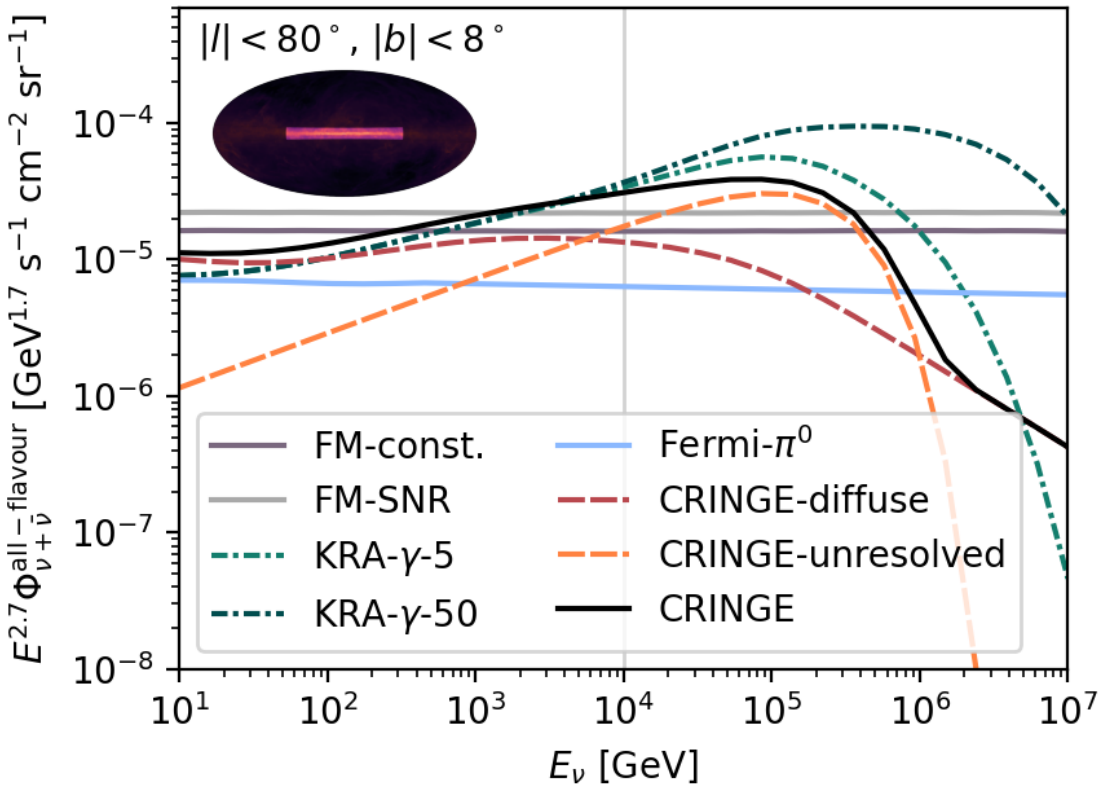
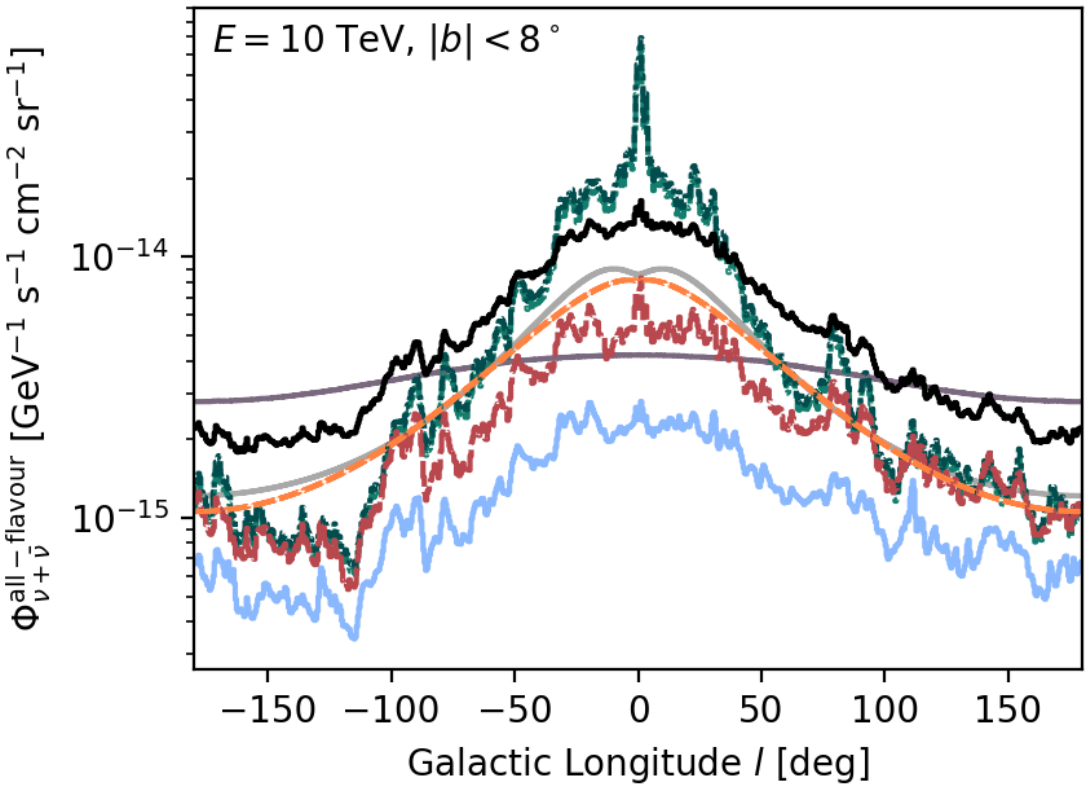
Diffuse Emission:

- CR + ISM → pions

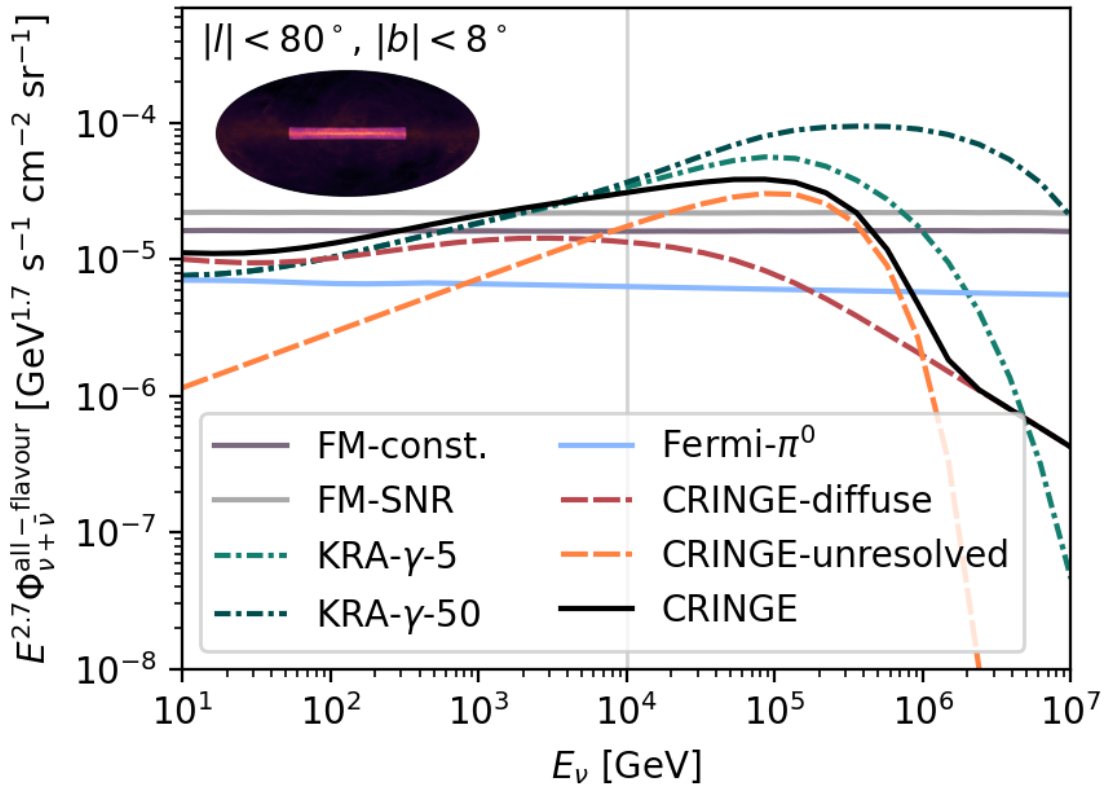
- Additional emission at/near accelerators?

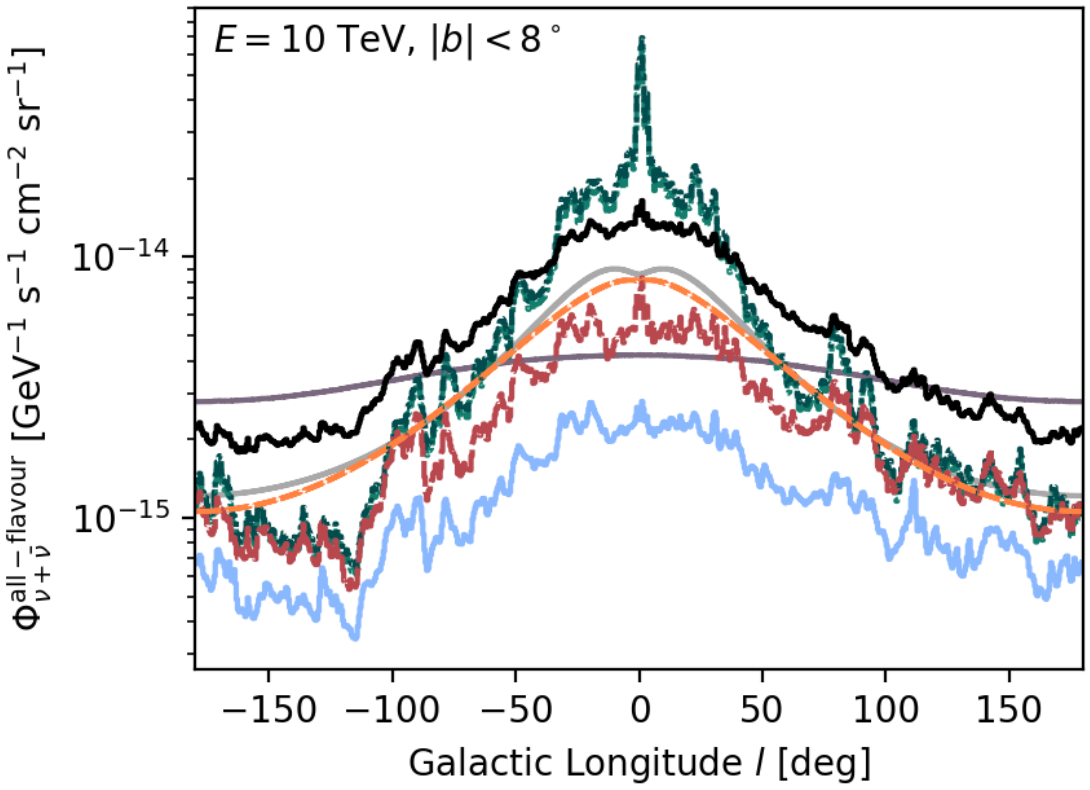
Models for Galactic Diffuse Emission





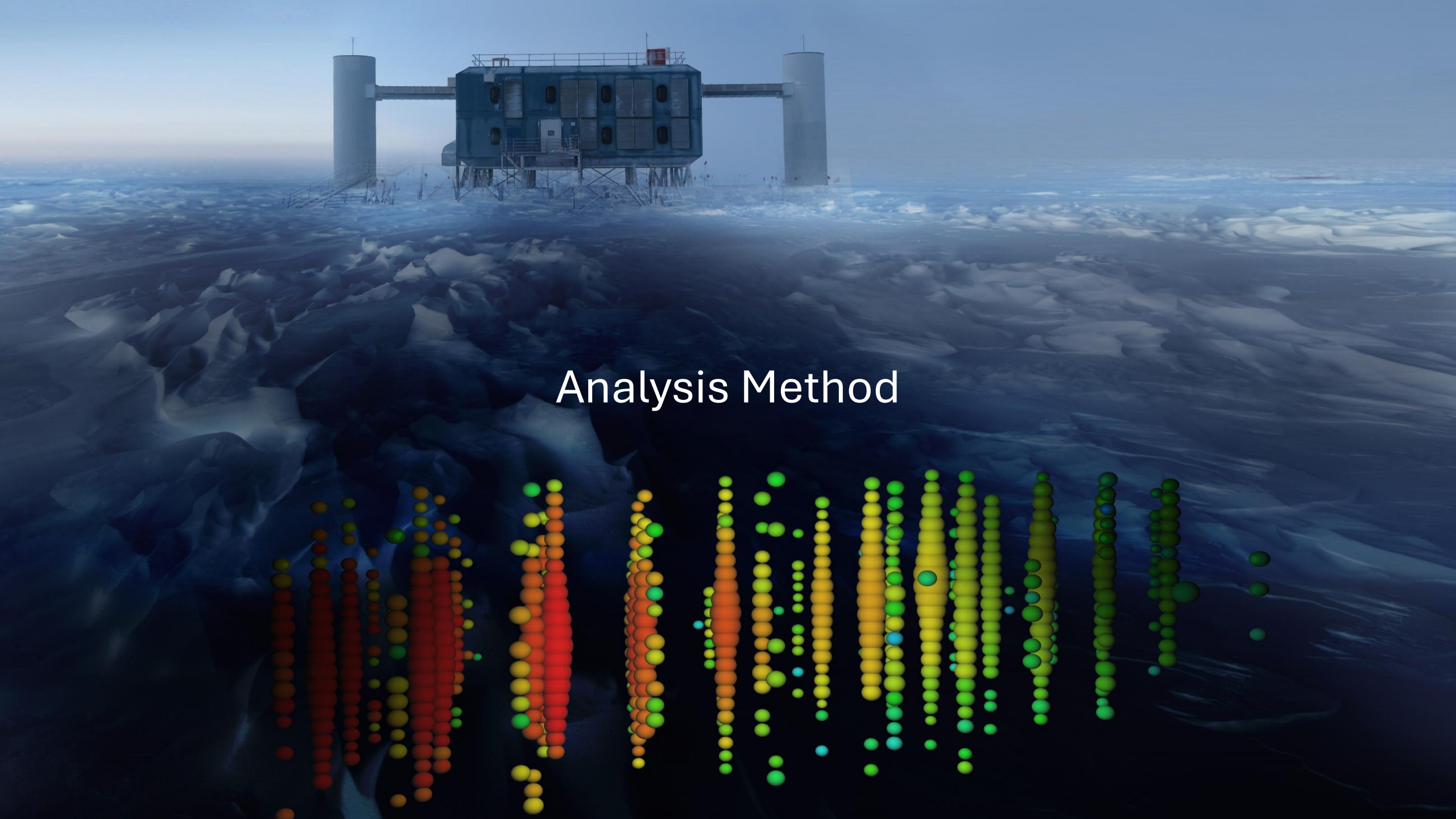
Models for Galactic Diffuse Emission





Analysis Goal #2:
Test different models & learn about the strength & structure of galactic neutrino emission!

Analysis Method



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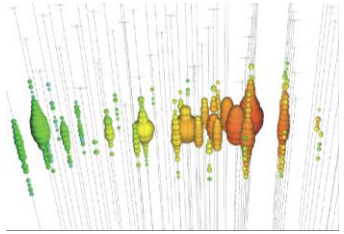
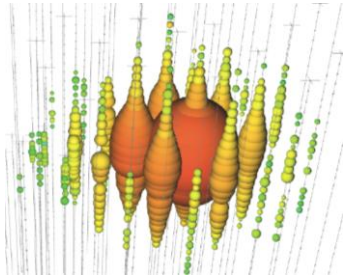
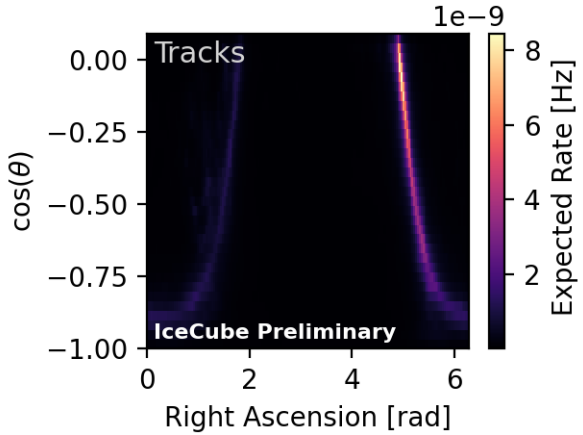
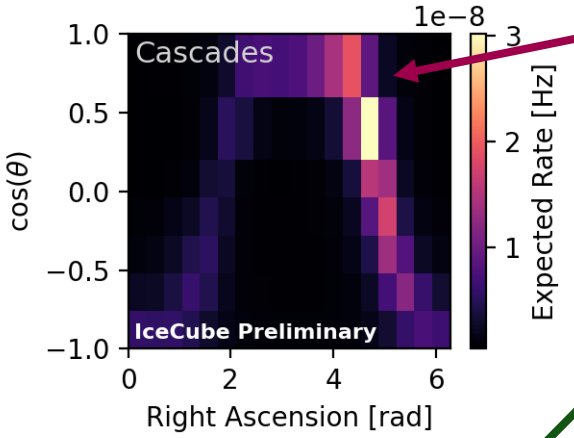




Tracks & **Cascades**

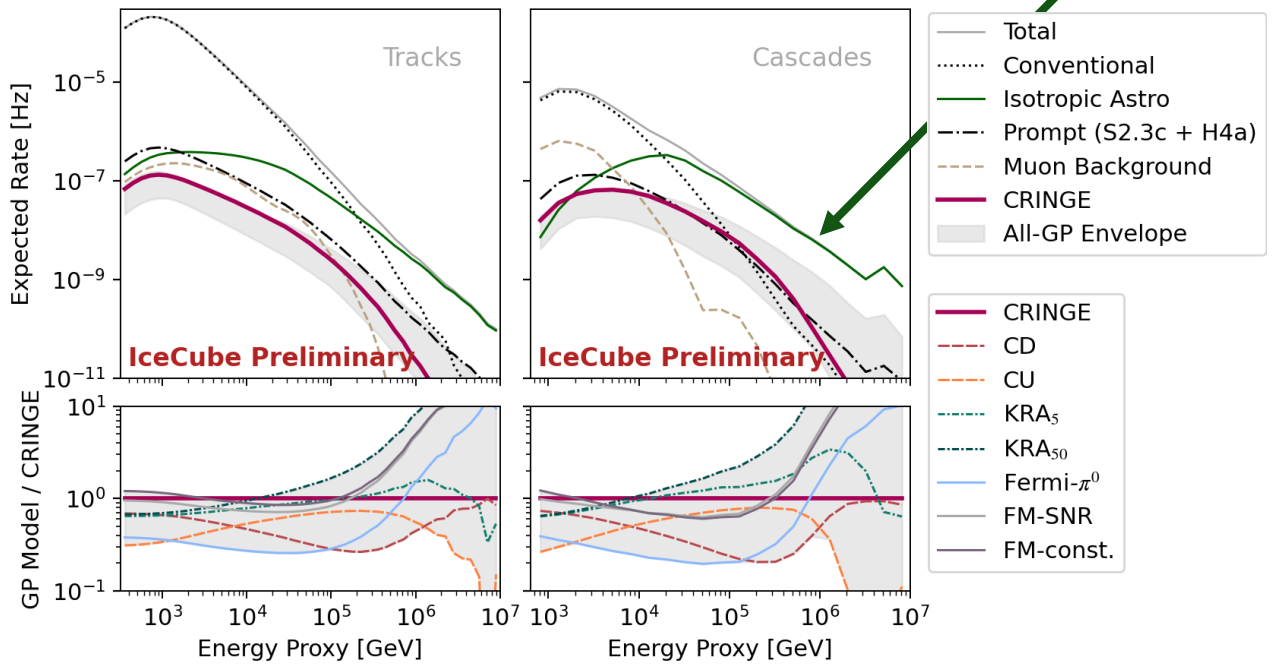
- Forward-folding likelihood fit
- Data & MC are binned in 3 dimensions:
- Energy, zenith, equatorial right ascension
- Parameterization of systematic uncertainties
- Simulation-based signal & background description





Galactic flux signature (spatial)

Extragalactic flux signature (spectral)



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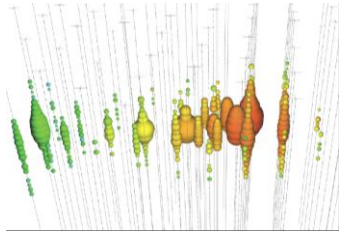

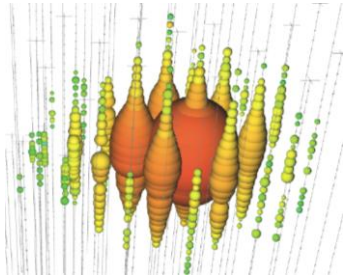

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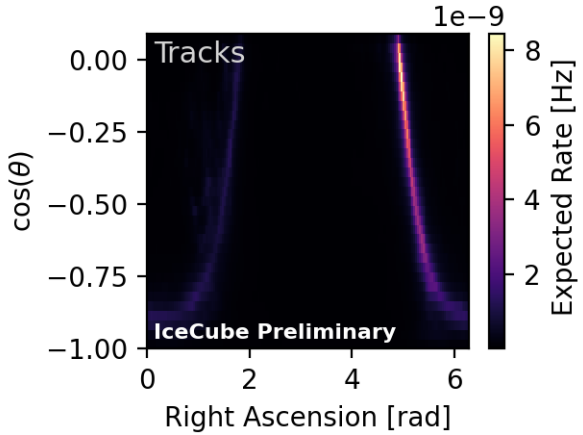

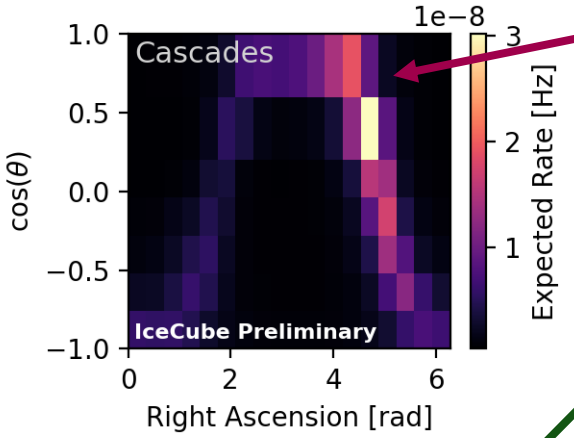

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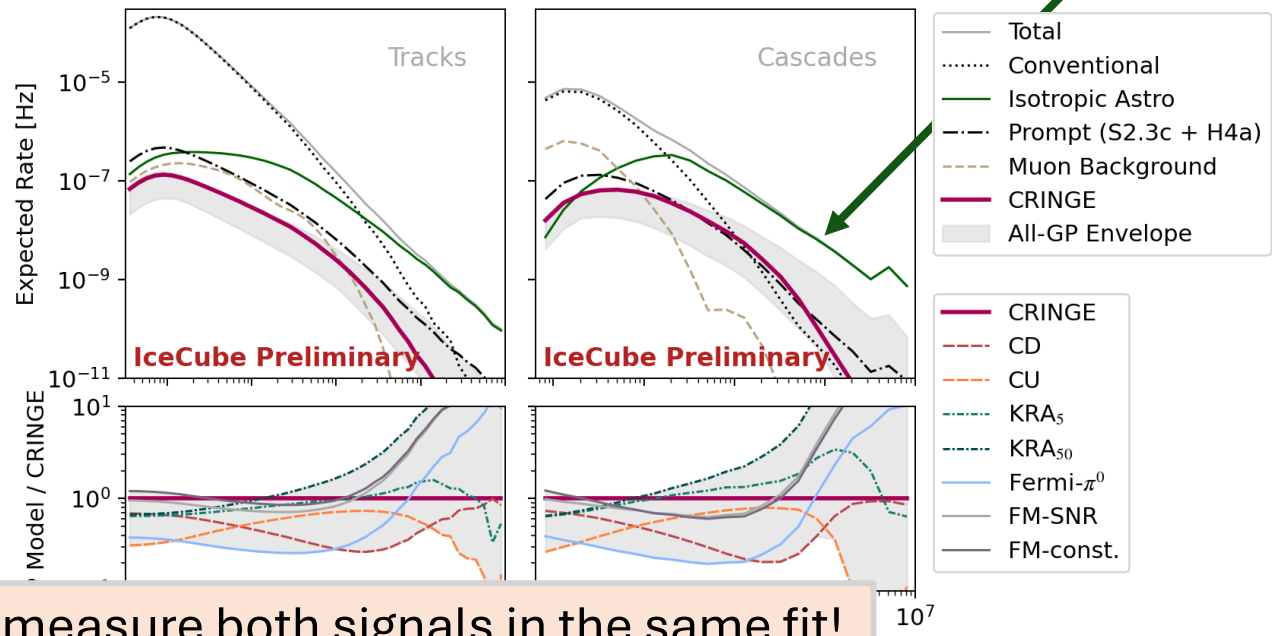
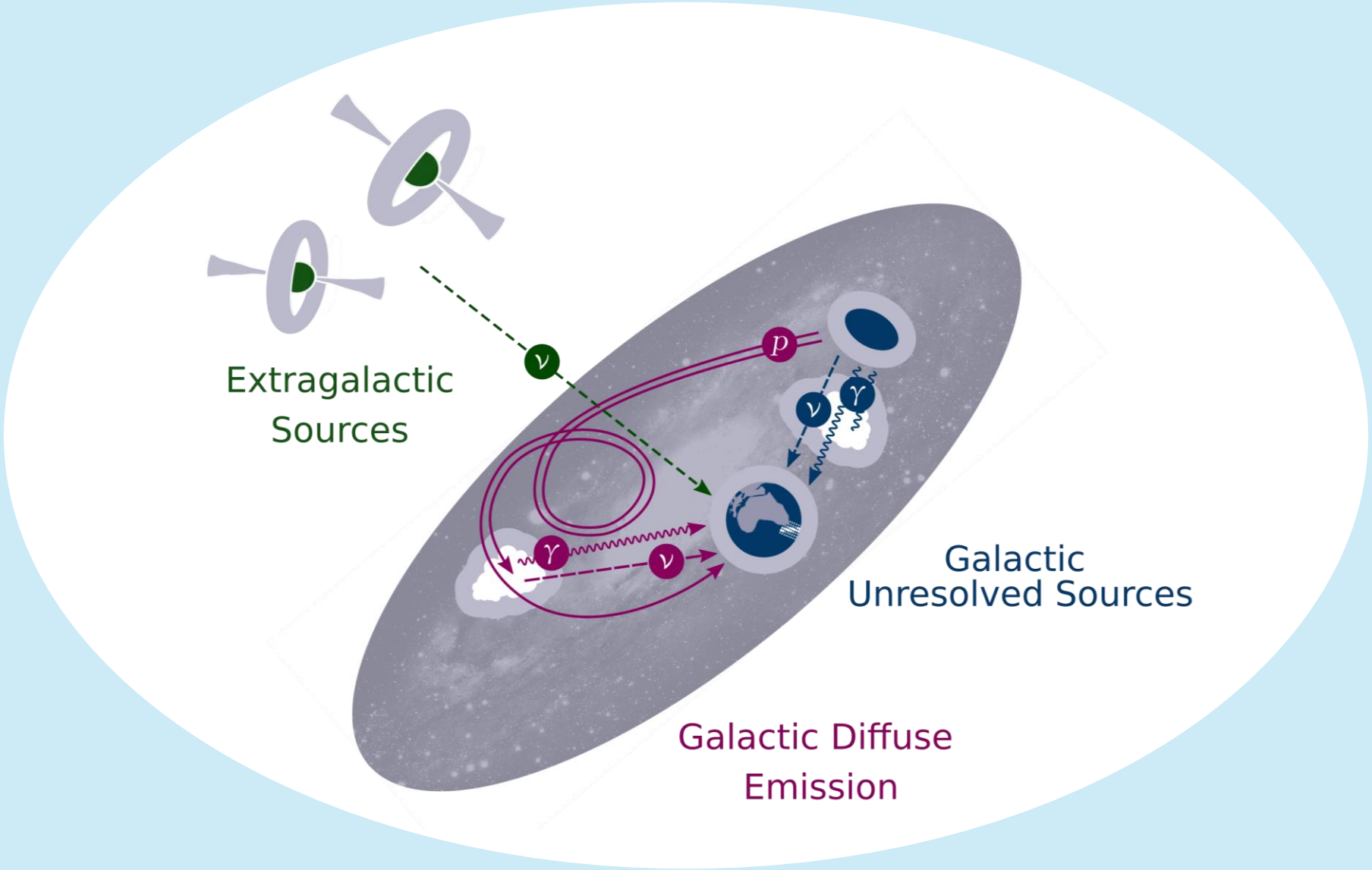


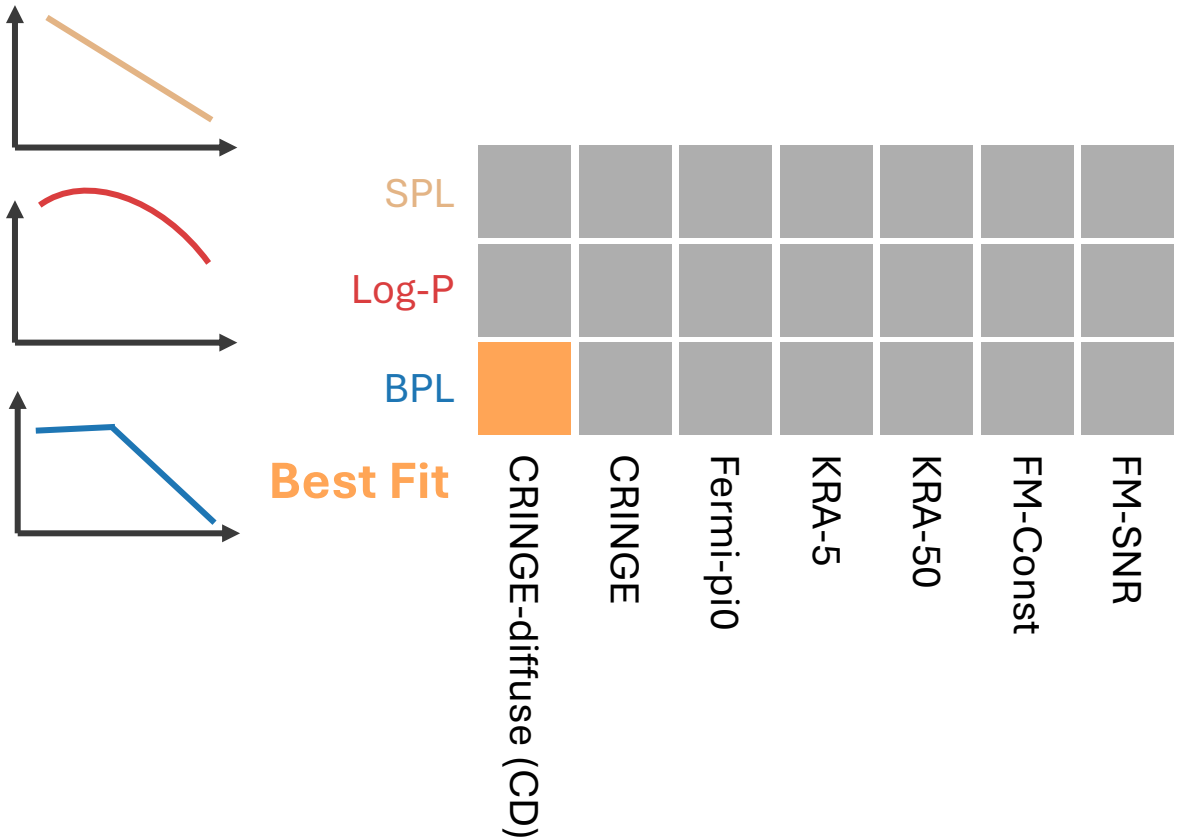
We can measure both signals in the same fit!

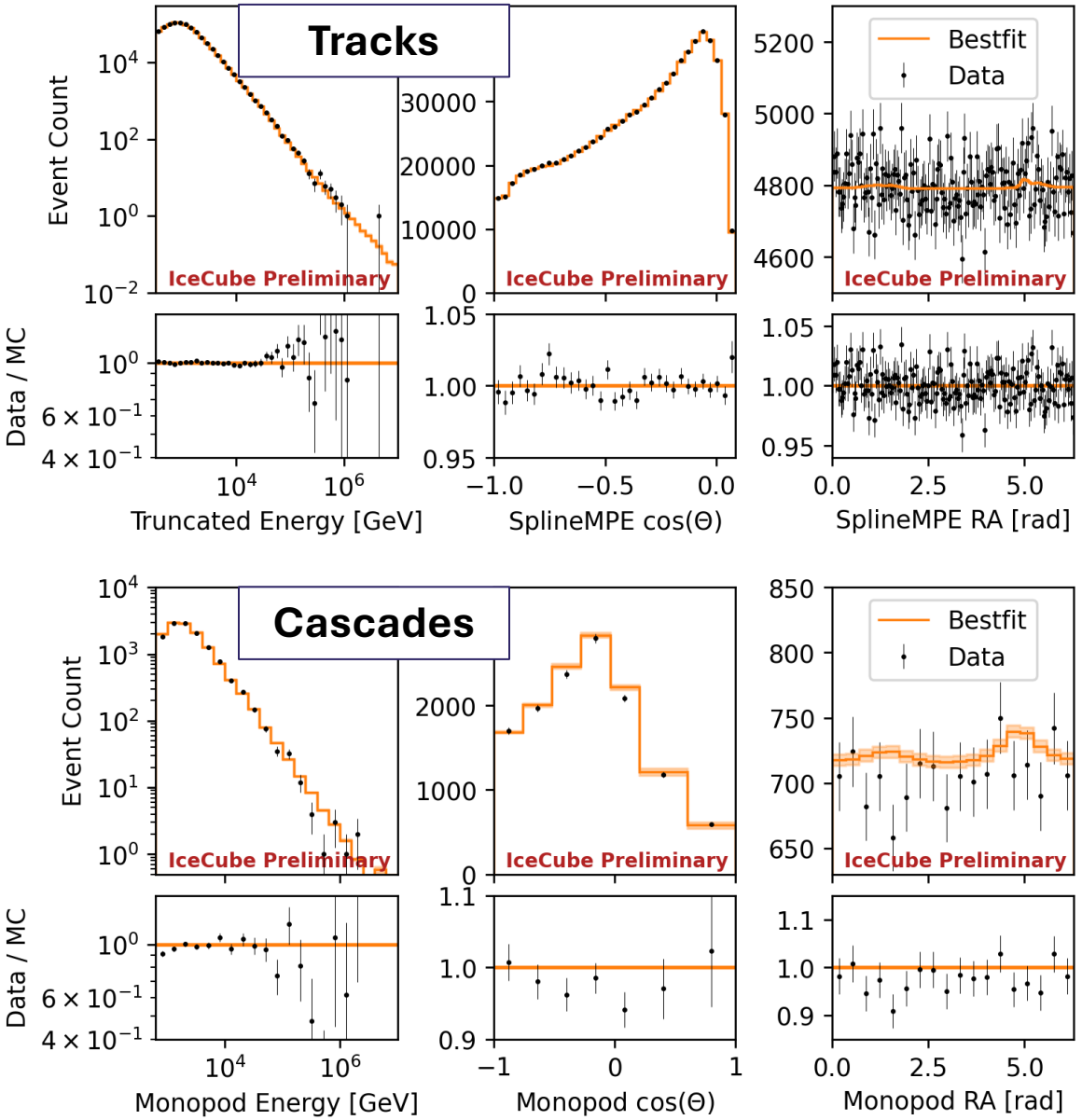
Fit Results: Best Fit



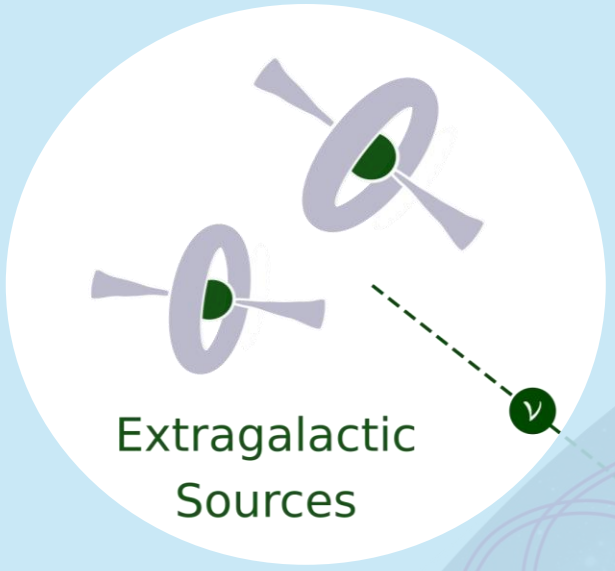
Fit Results: Best Fit

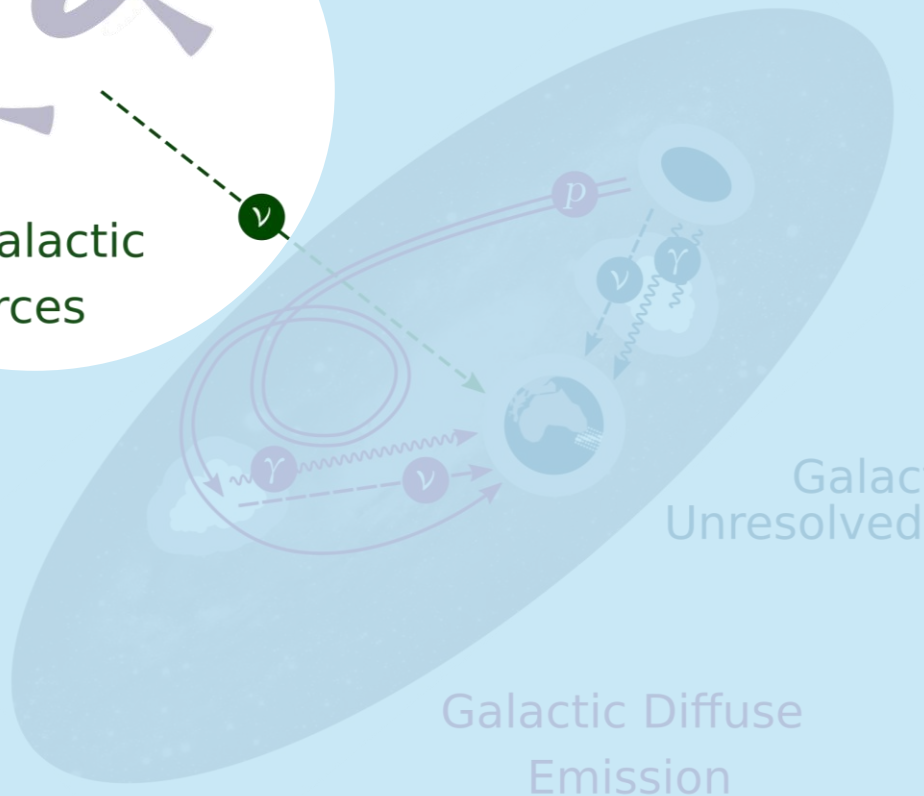
- Two signals with several hypotheses each
- Best fit is a broken power law + diffuse part of the CRINGE model (CD)

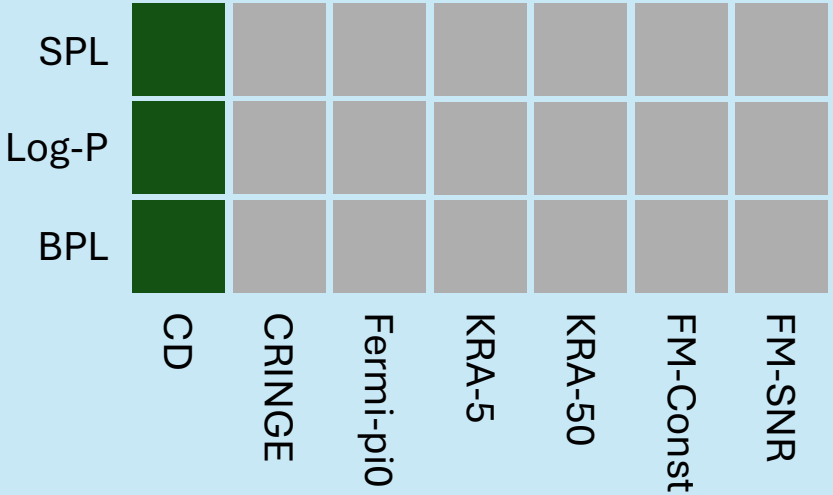




Fit Results: Extragalactic Flux







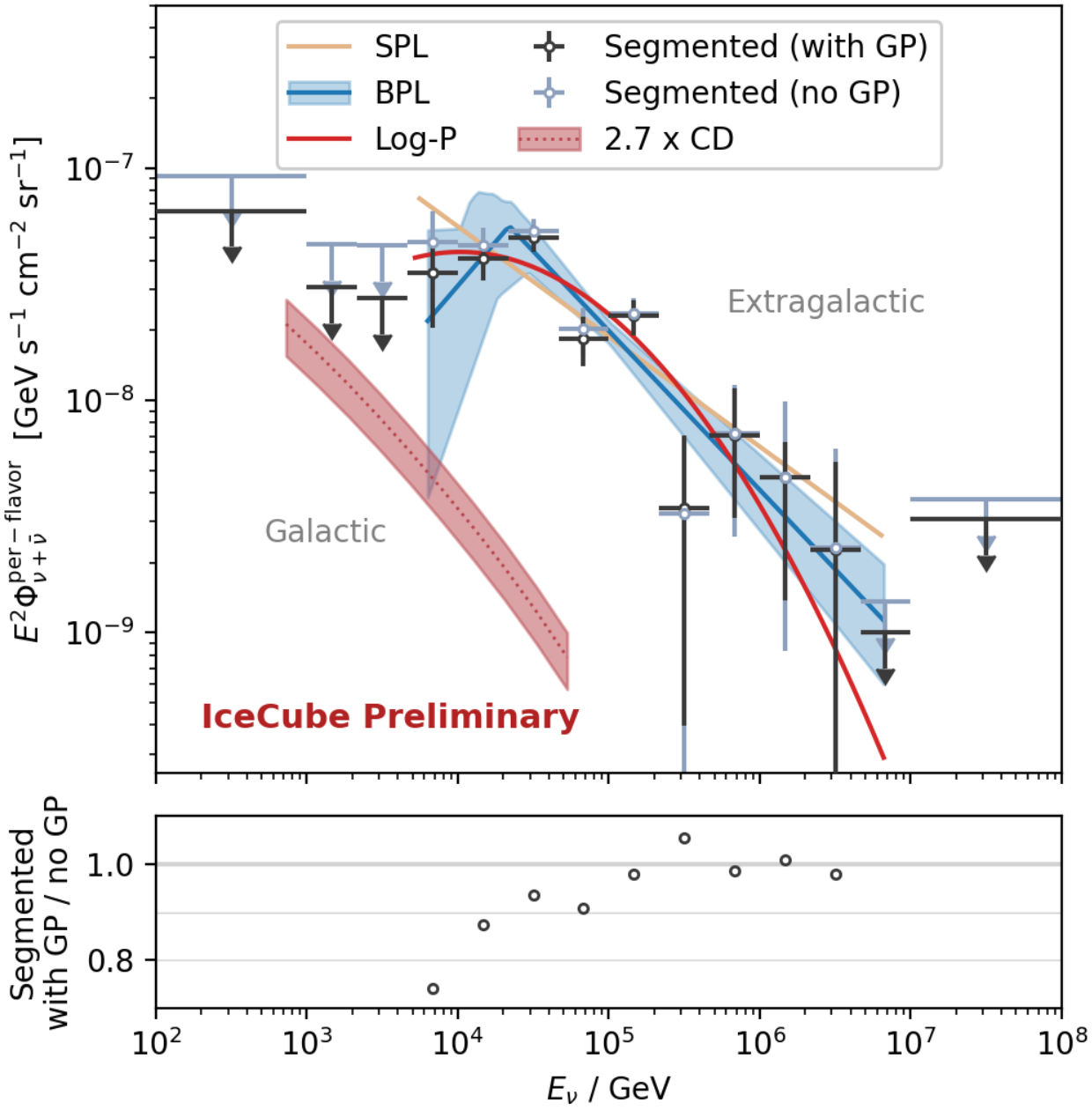
Fit Results: Extragalactic Flux

Preference for Structure:

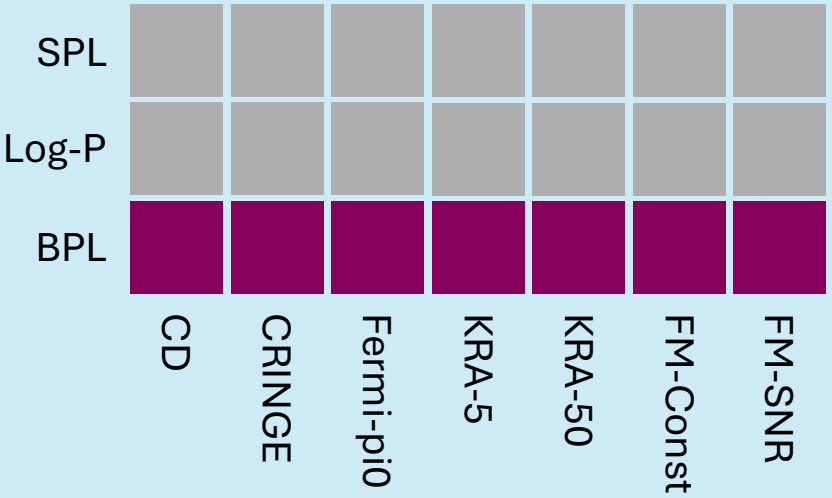
- BPL > SPL: **5.7σ**
- LogP > SPL: **5.4σ**
- Segmented model also exhibits this structure (regardless of GP inclusion)
- Consistent with precursor analysis (PRL 136, 121002 (2026))

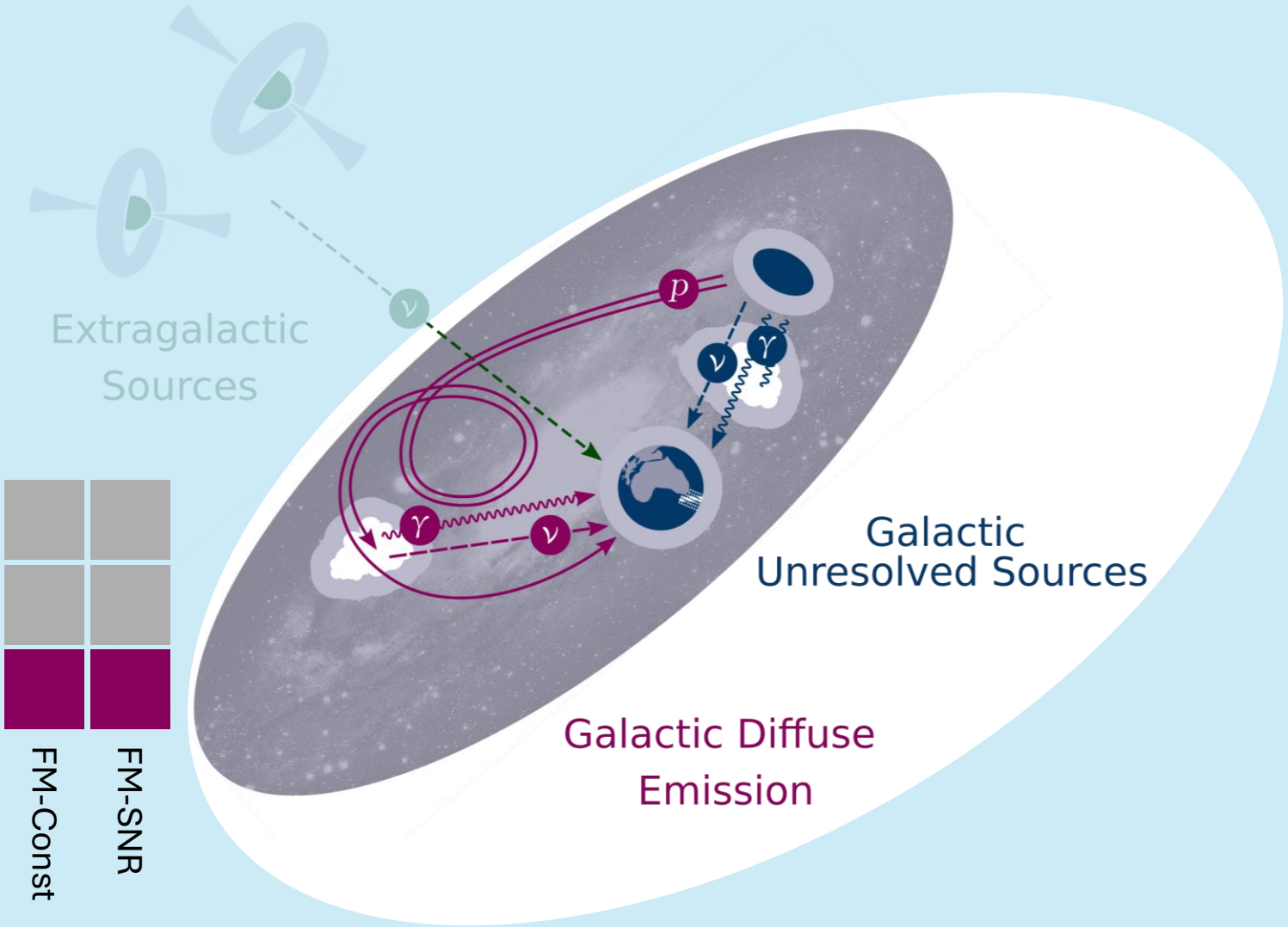
Changes driving the significance:

- Inclusion of more track data
- New ice model improves angular resolution
- More cascade zenith bins
- Galactic plane component



Fit Results: Galactic Flux

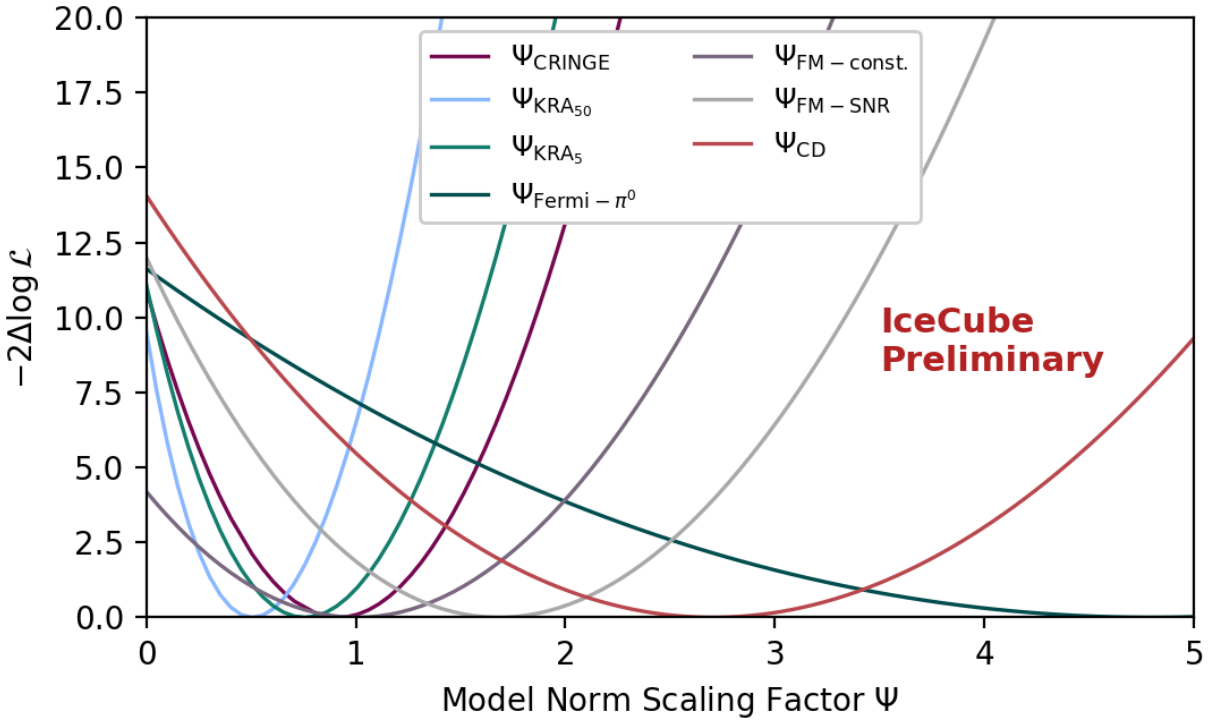




Fit Results: Extragalactic Flux

Best-fit Model CD: **3.7σ**
Post-trial significance: **3.3σ**

Model	Significance σ	Scaling Factor Ψ
Fermi-π^0	3.4	4.8 +/-1.5
KRA-γ 50	3.1	0.5 +0.19/-0.18
KRA-γ 5	3.3	0.76 +0.25/-0.24
CRINGE	3.3	0.9 + 0.3/-0.3
CRINGE-diffuse	**3.7**	**2.7 + 0.8/-0.8**
FM-Const	2.0	1 +0.5/-0.5
FM-SNR	3.4	1.7 +0.6/-0.5



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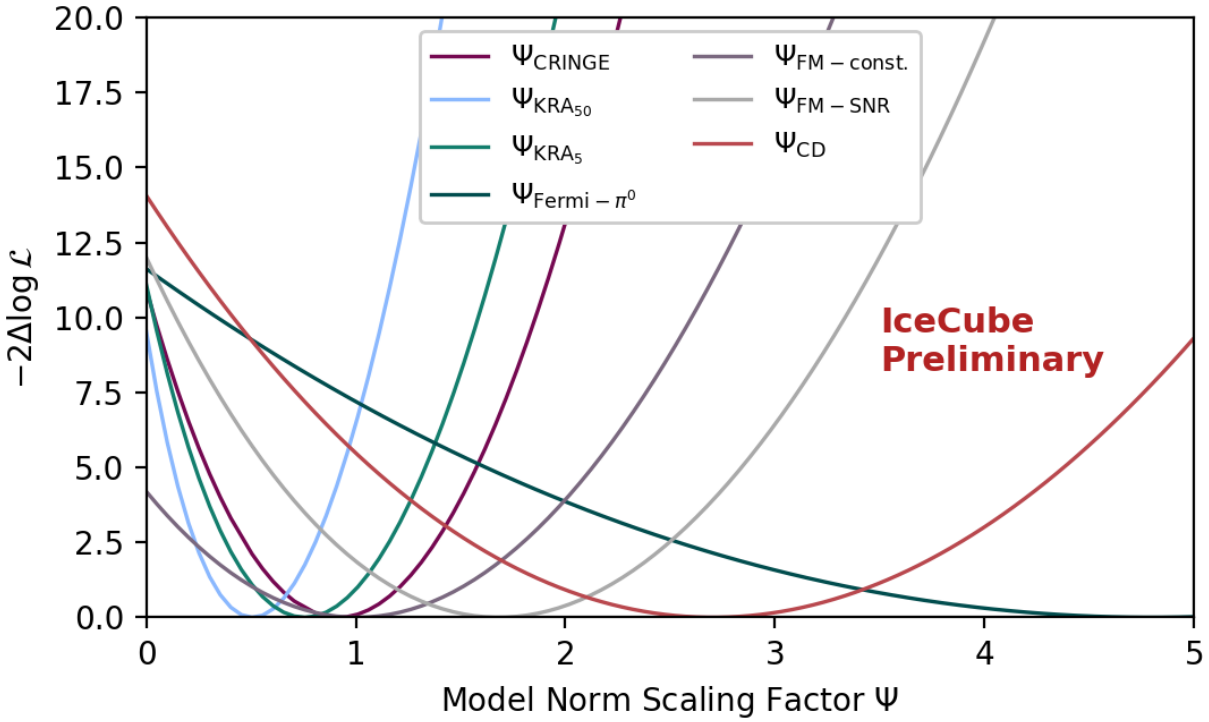
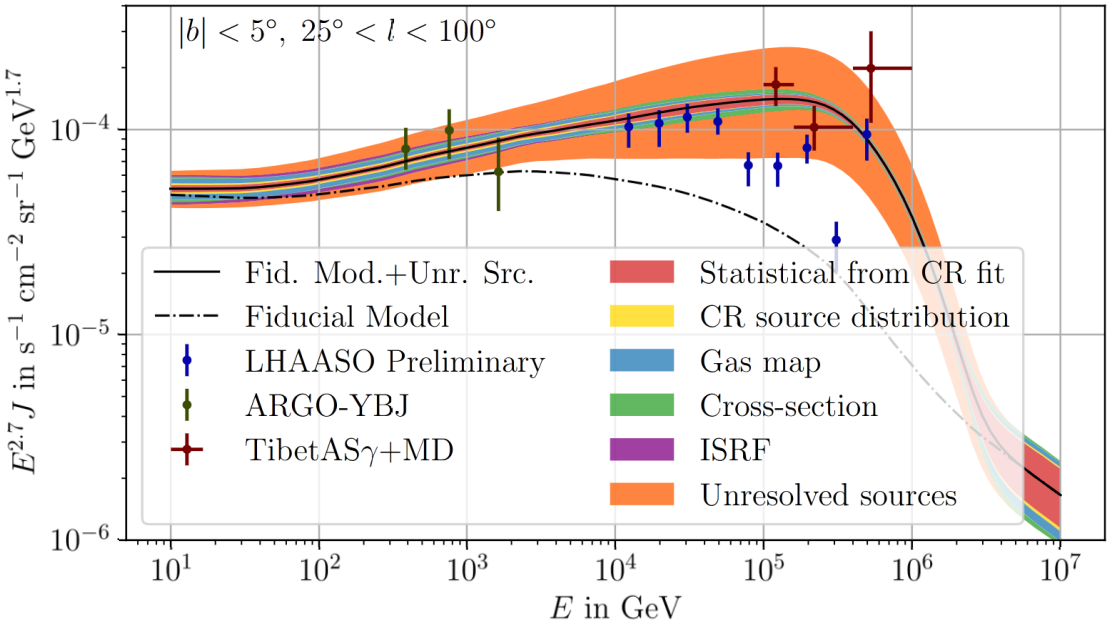


Consistent with previous IceCube analyses, which used data-driven background estimation!

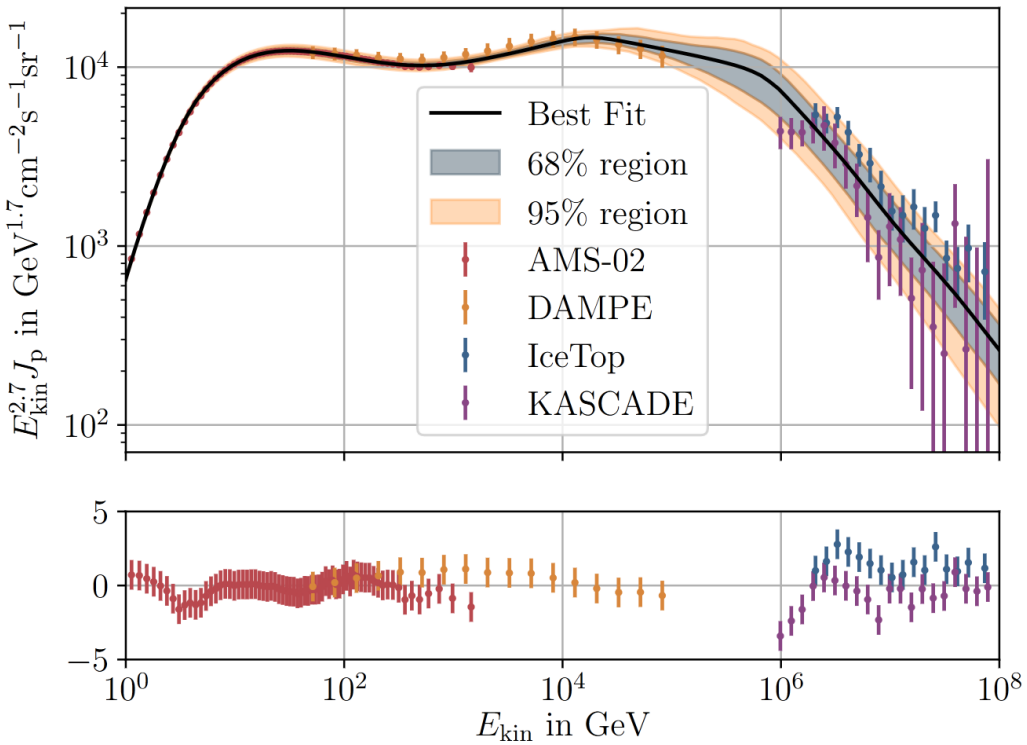
Multimessengers in the Galaxy?

Gamma Rays



ApJ **949**, 16 (2023)

Cosmic Rays



ApJ **949**, 16 (2023)

Model	Significance σ	Scaling Factor Ψ
CRINGE	3.3	0.9 + 0.3/-0.3
CRINGE-diffuse	**3.7**	**2.7 + 0.8/-0.8**

→ **~1**: γ, ν, & CR flux scales are consistent

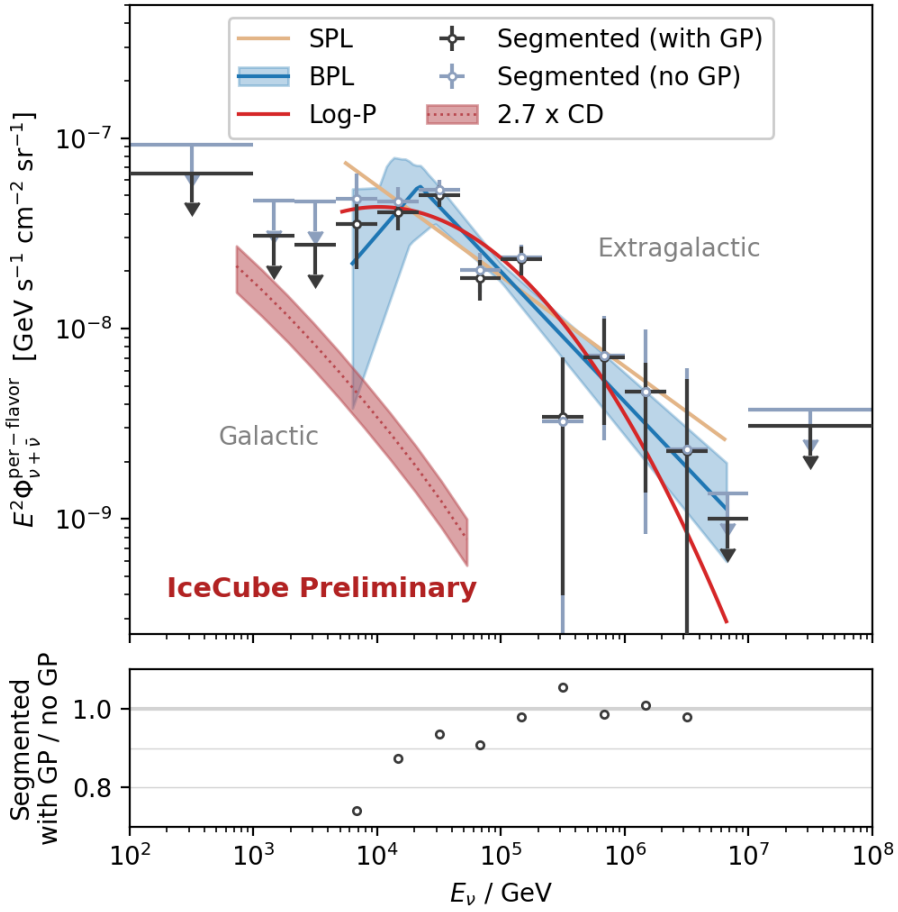
→ $\Psi_{CD} = 1$ (just the diffuse part) is in tension with the main result (2.3σ)

→ There is „space“ for unresolved sources

Summary

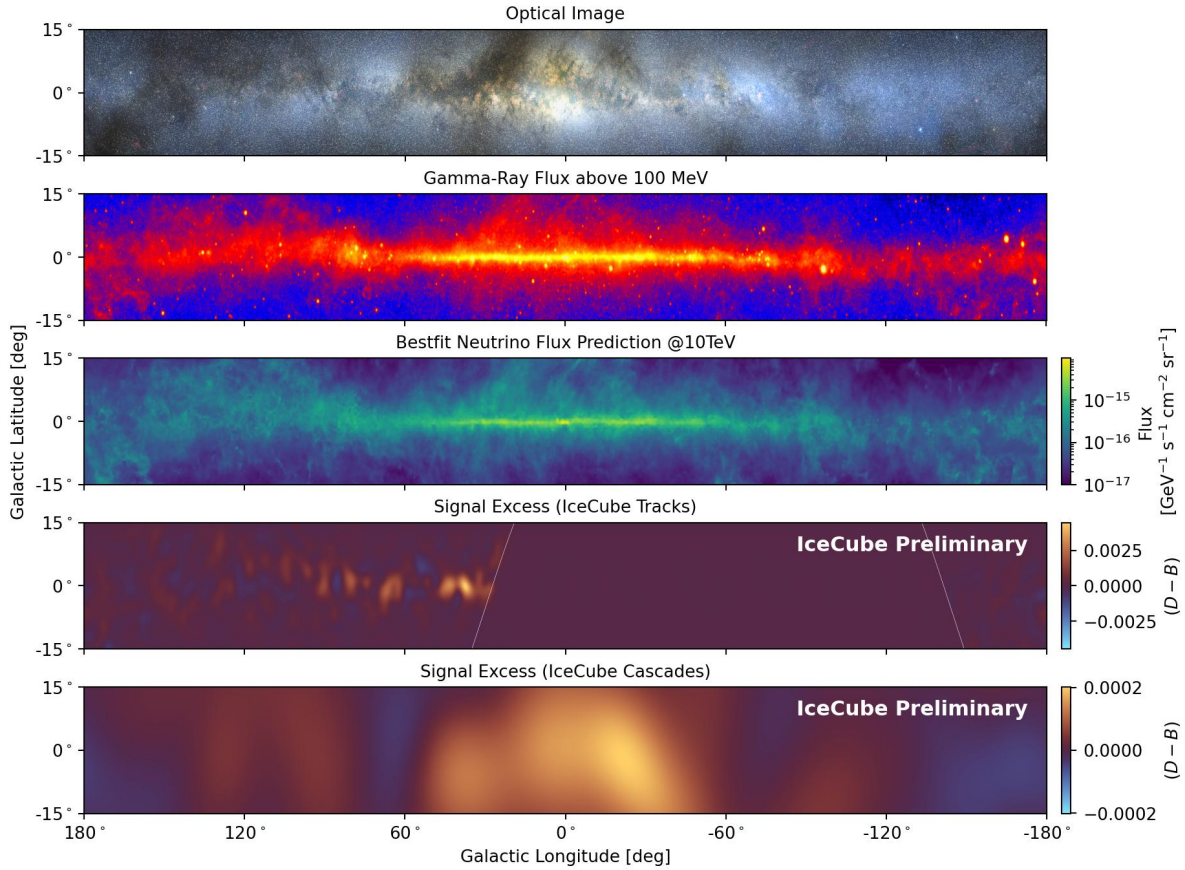
Extragalactic

- Structure below ~40 TeV observed with >5σ
- Measurement now explicitly includes GP background



Galactic

- Different analysis method and consistent with results from previous IceCube Analyses
- Consistent multimessenger picture in the Galaxy
- Contribution from unresolved neutrino sources is possible



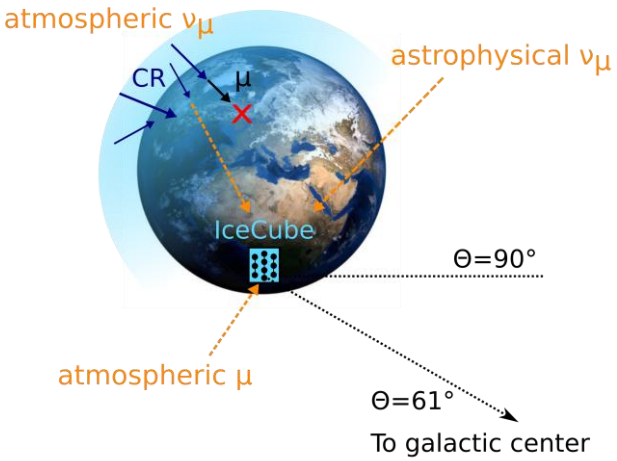
** As of October 2025

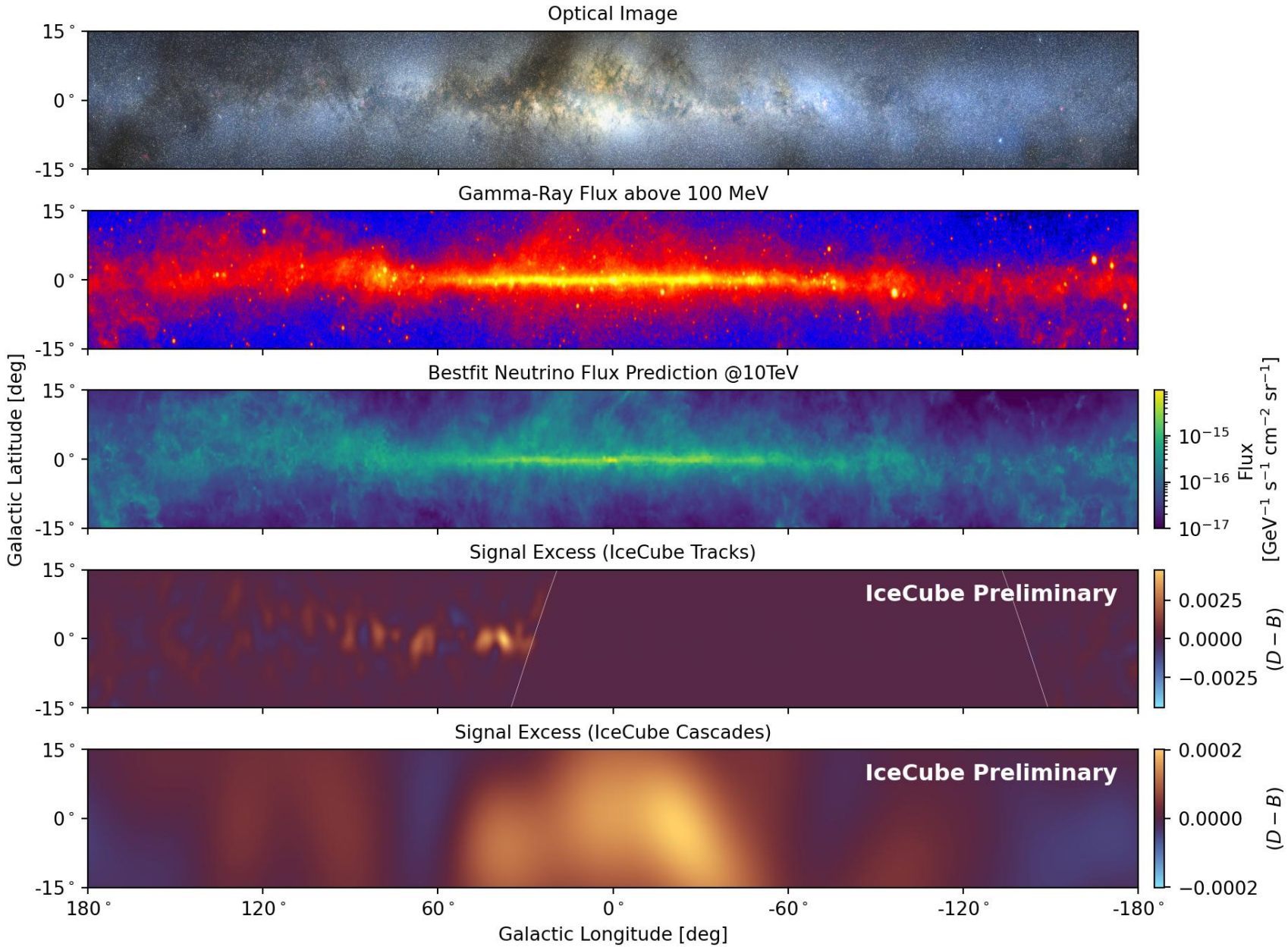
Backup

Visualizing the Neutrino Excess from the Galactic Plane

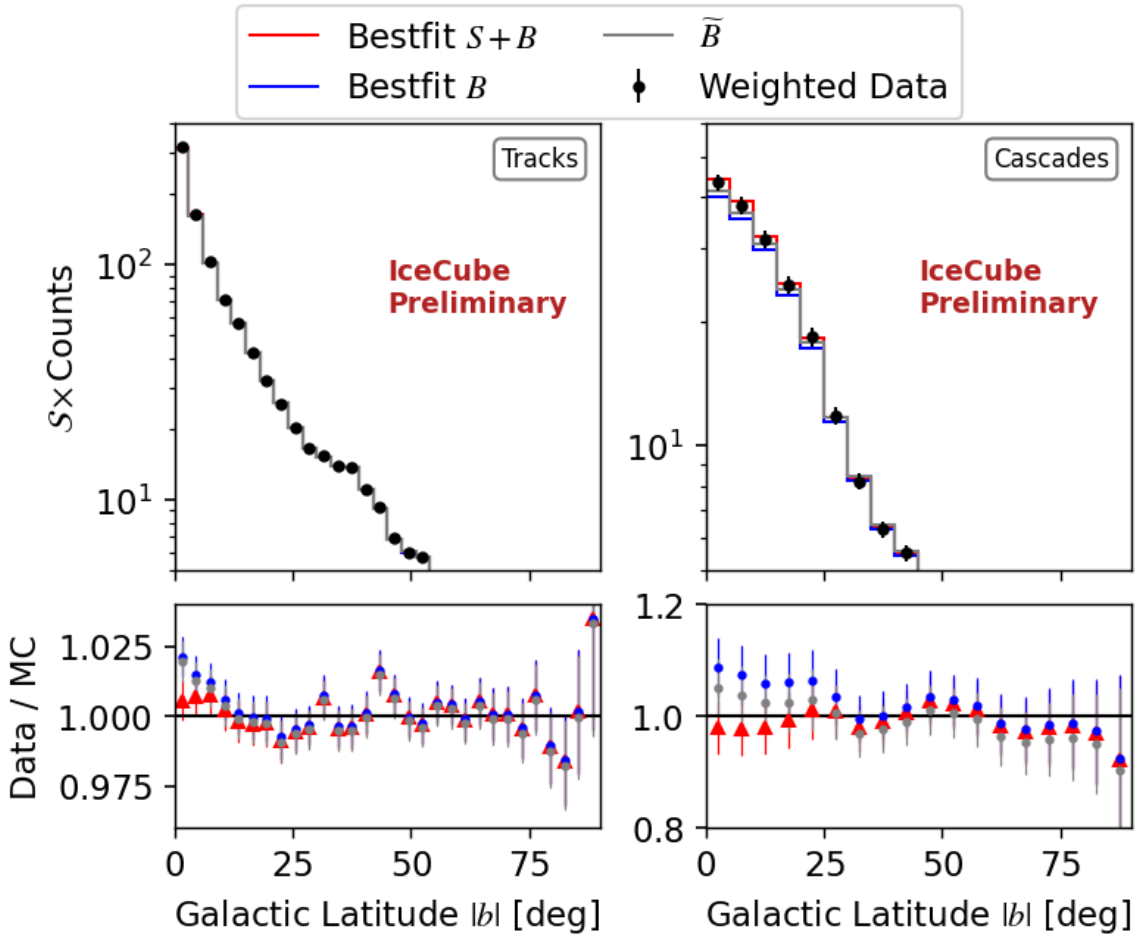
Galactic Plane Excess

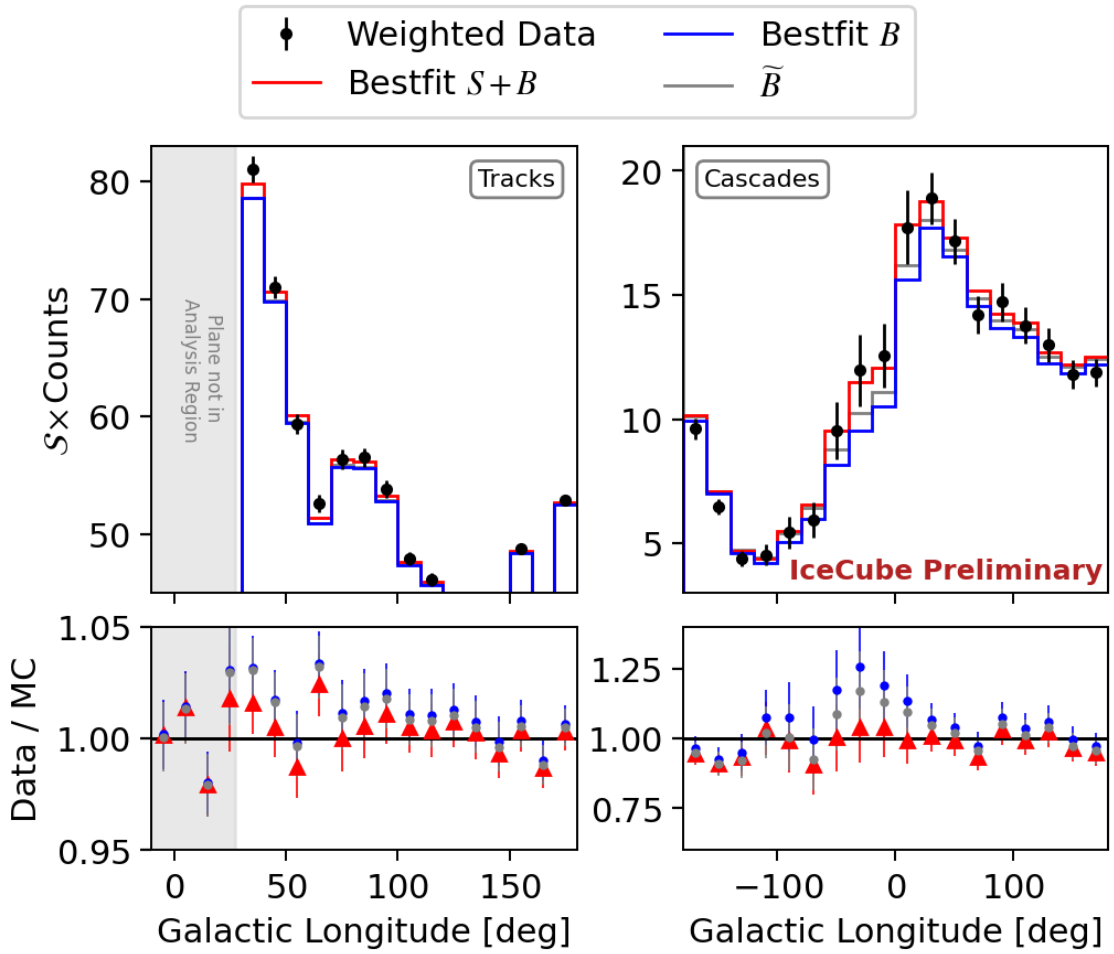
- Subtract fitted backgrounds *B* from data *D*
- Transform analysis binning to GP coordinates
- Weight with signalness: *S*/(*S*+*B*)
- Smoothing with avg. bin size



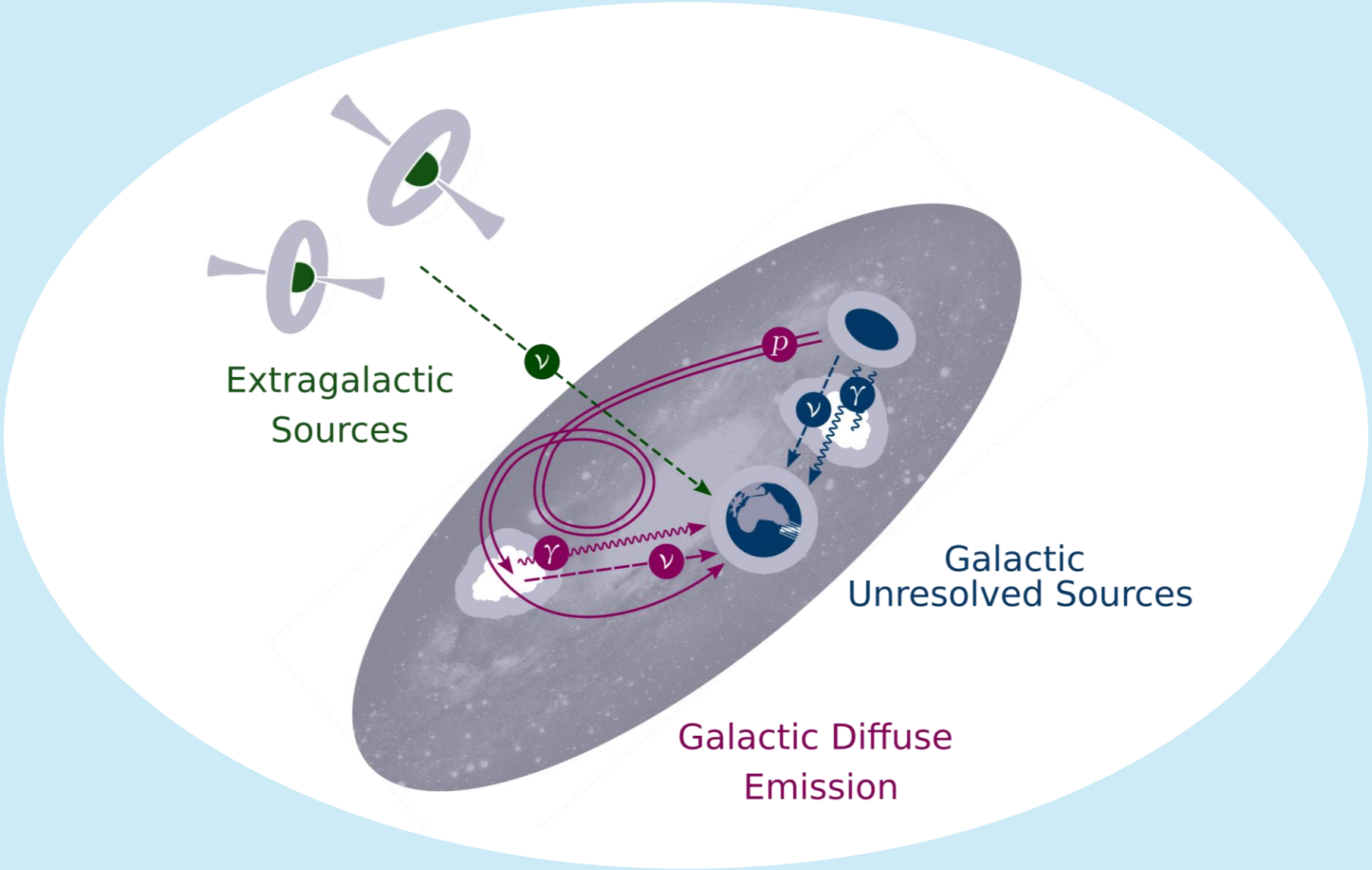


Signal Visualization: Galactic Latitude and Longitude

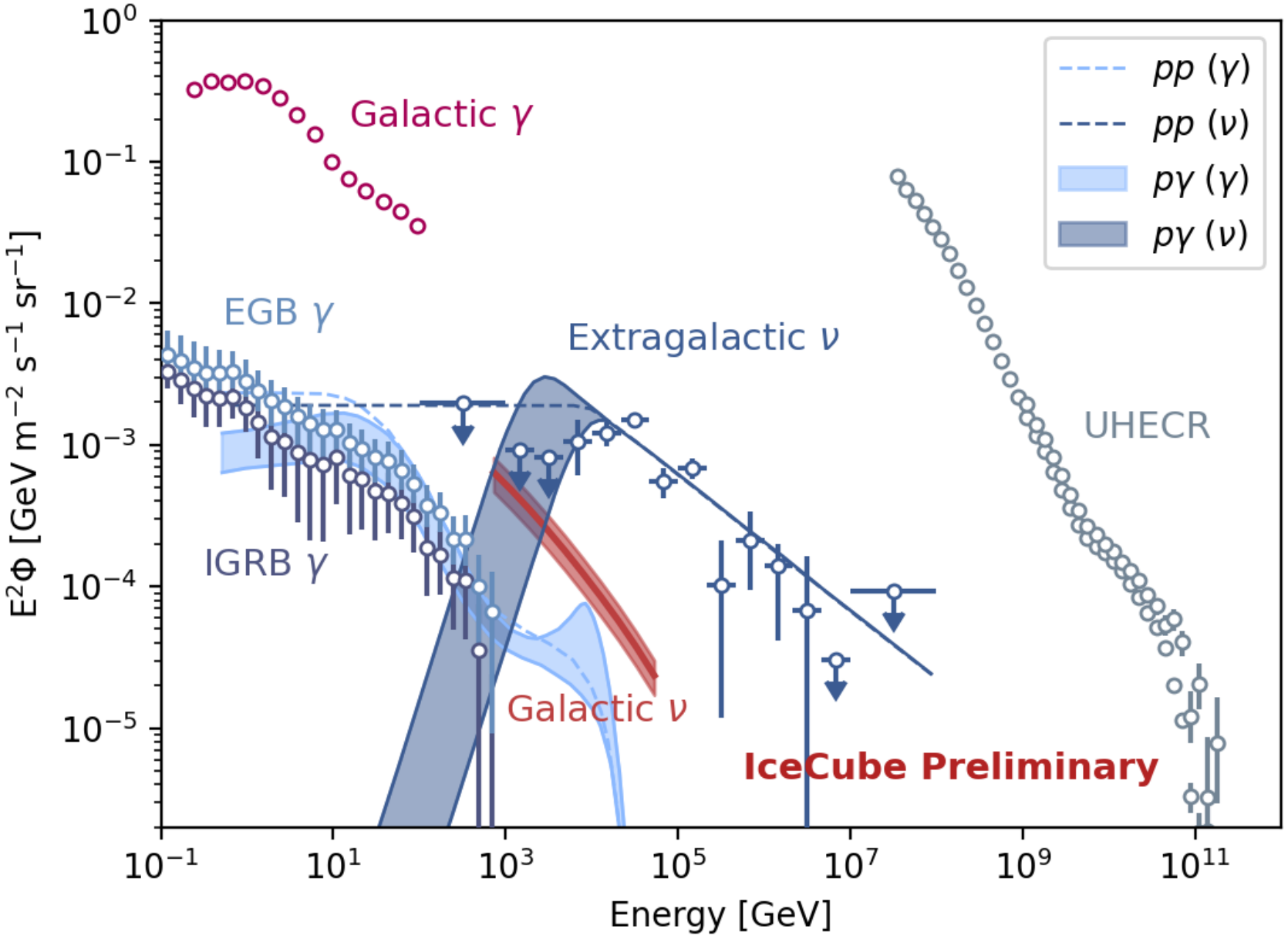




The Multimessenger Picture



Are Extragalactic Sources Gamma-Ray Obscured?



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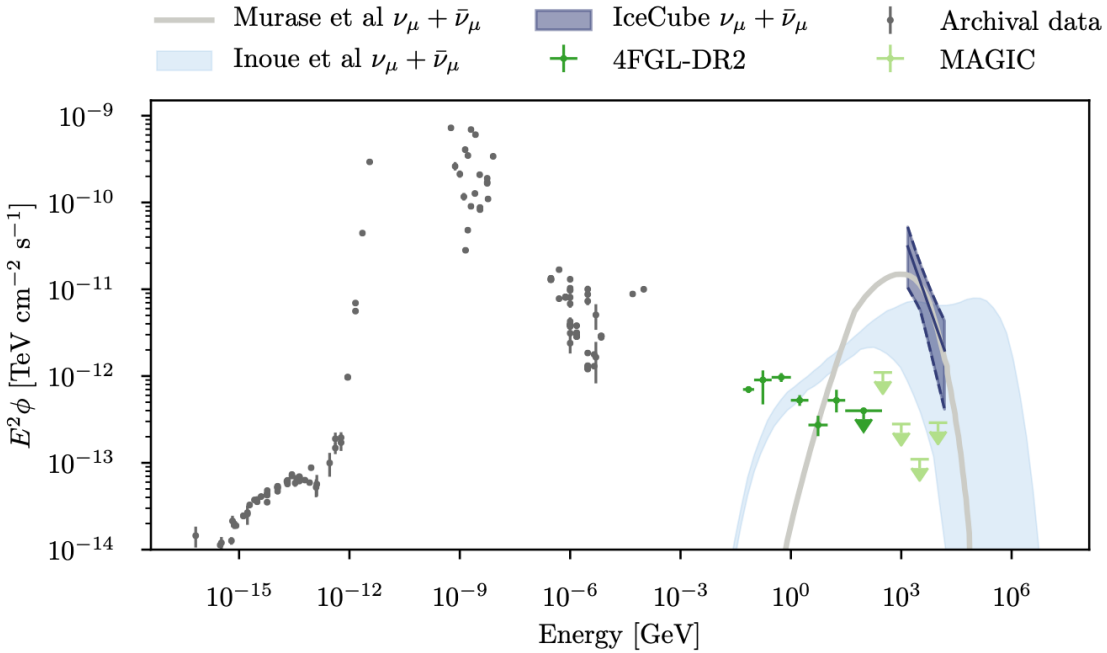
$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^{+(-)} \rightarrow \mu^{+(-)} + \nu_\mu(\bar{\nu}_\mu)$$
$$\searrow$$
$$e^{+(-)} + \nu_e(\bar{\nu}_e) + \bar{\nu}_\mu(\nu_\mu)$$



Science 378,538 (2022)

ASTROPHYSICAL NEUTRINOS
DISCOVERED
2013

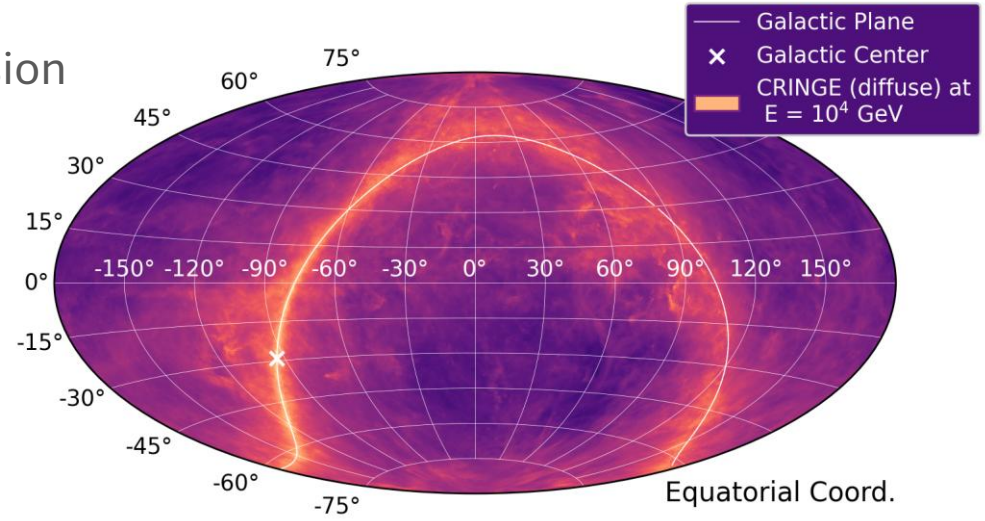
→ Gamma-ray emission in both sources is less than expected from the neutrino flux!

Models for Galactic Diffuse Emission

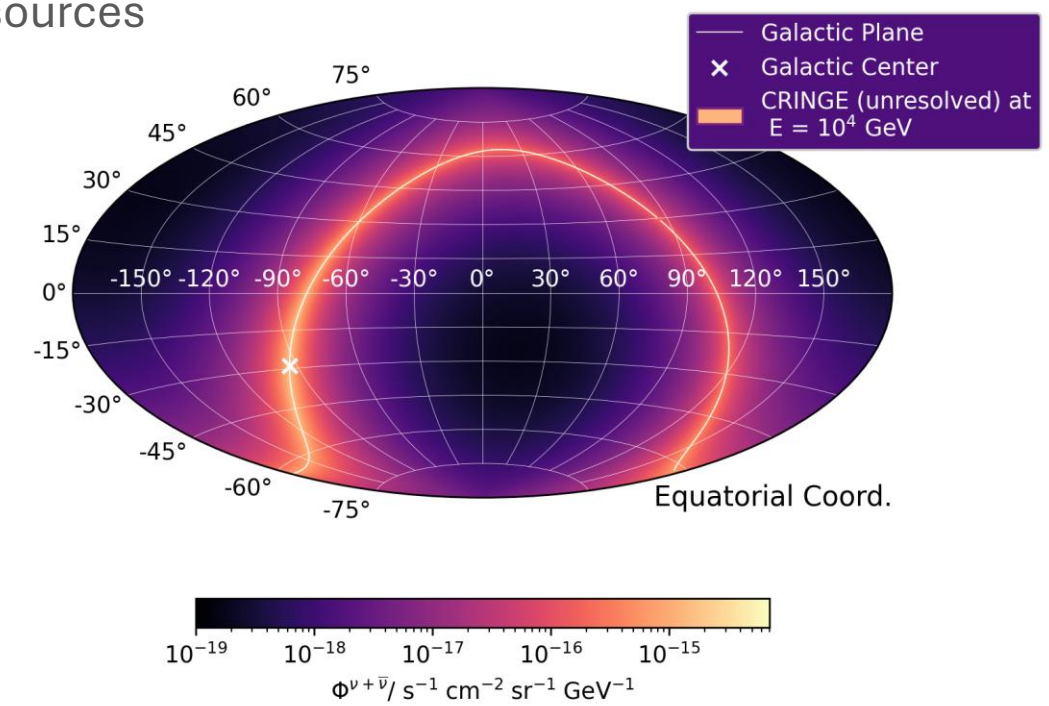
Solve CR transport equation & line-of-sight integral towards Earth

- **Fermi-π^0**
- **KRA-γ-5 (50)**
- **CRINGE:**
  - **diffuse**: emission from CR-gas interaction, fitted to local CR spectra
  - **unresolved** sources: follows SNR distribution
- **Fang&Murase:** built for this analysis, disk filled with homogeneous gas, single powerlaw
  - **Const**: constant emission everywhere
  - **SNR**: emission follows SNR distribution

Diffuse emission template →



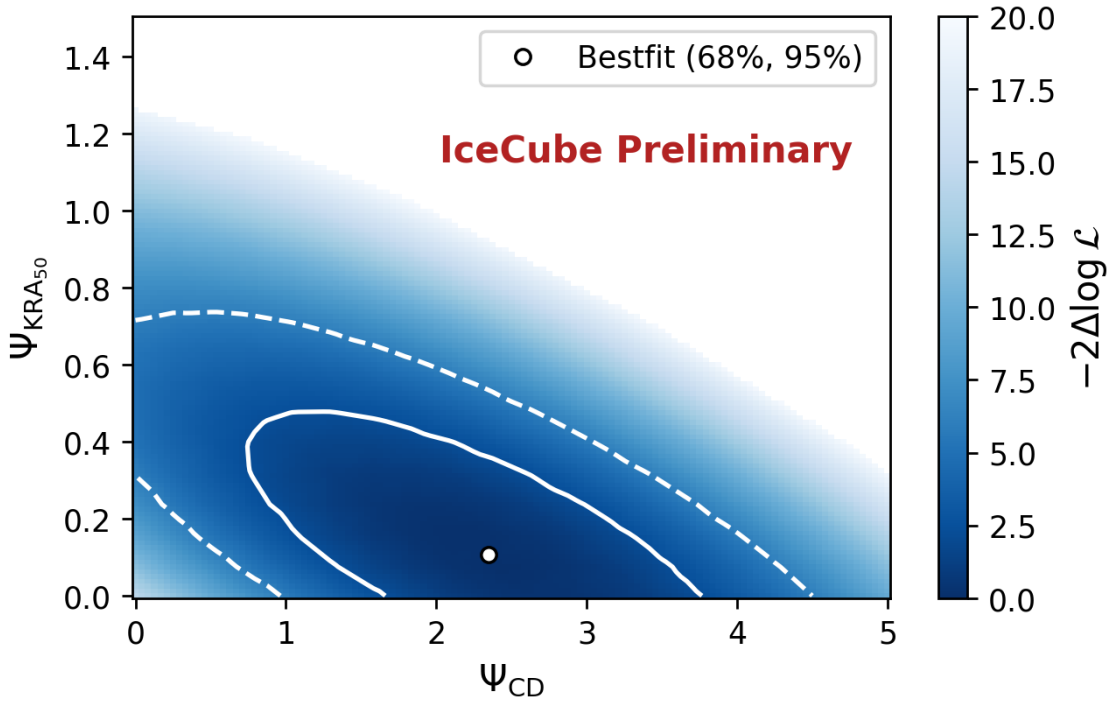
Unresolved sources template →

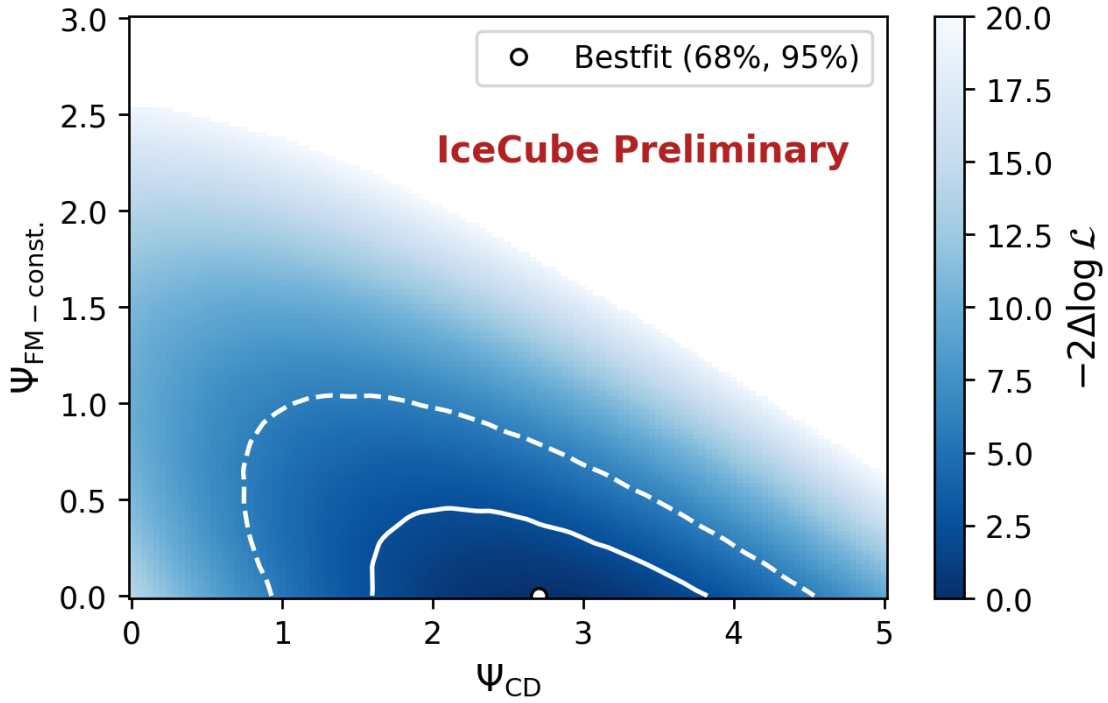


Model Differentiation?

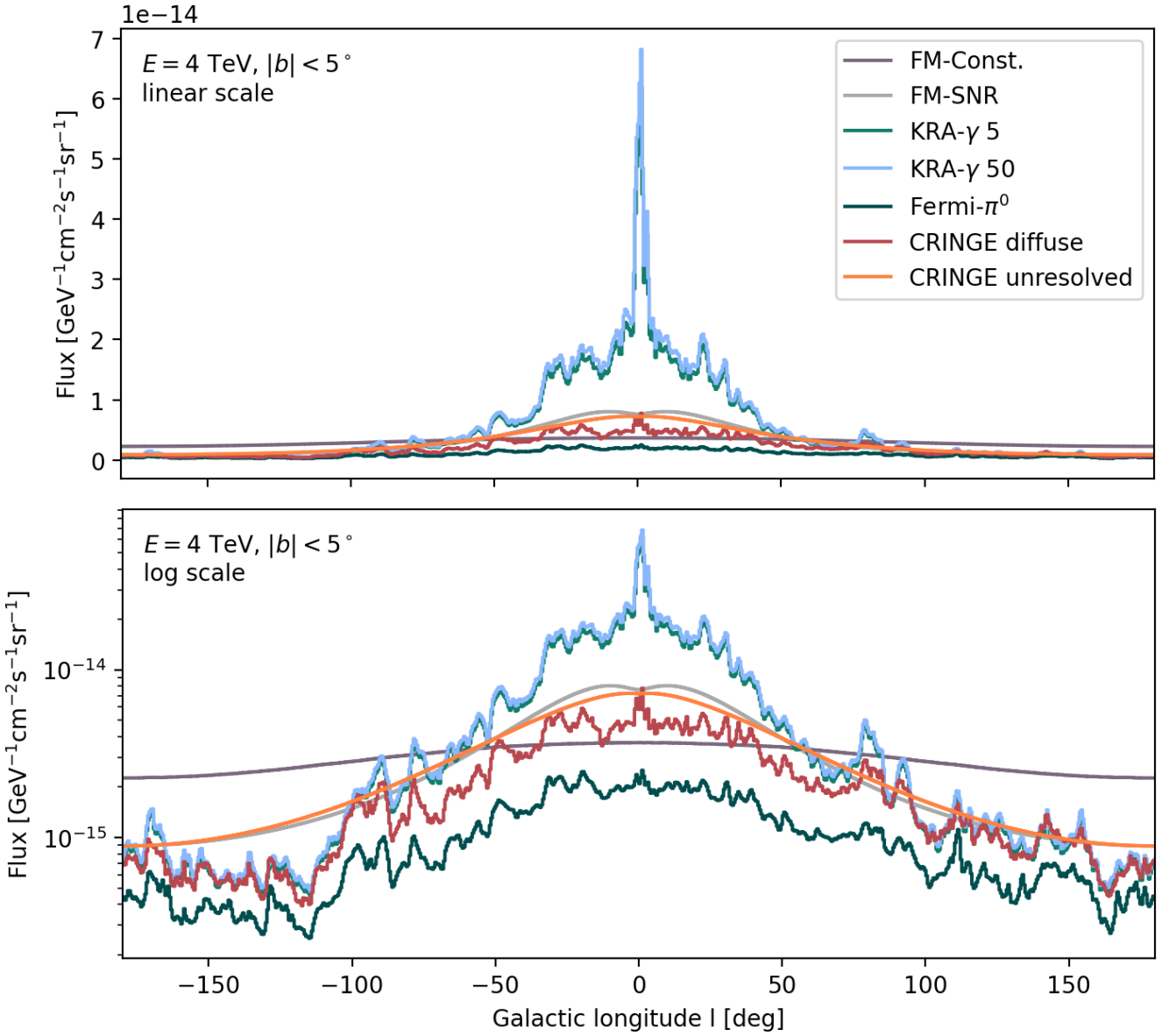
- Fit two galactic plane models at the same time (Ψ_1, Ψ_2)
- Fit can freely mix both models
- 3.1σ preference for CD above FM-Const
- No other significant preferences, model separation not yet possible except rejection of the most basic construction

The galactic plane is not just a homogeneously „neutrino-glowing“ disk

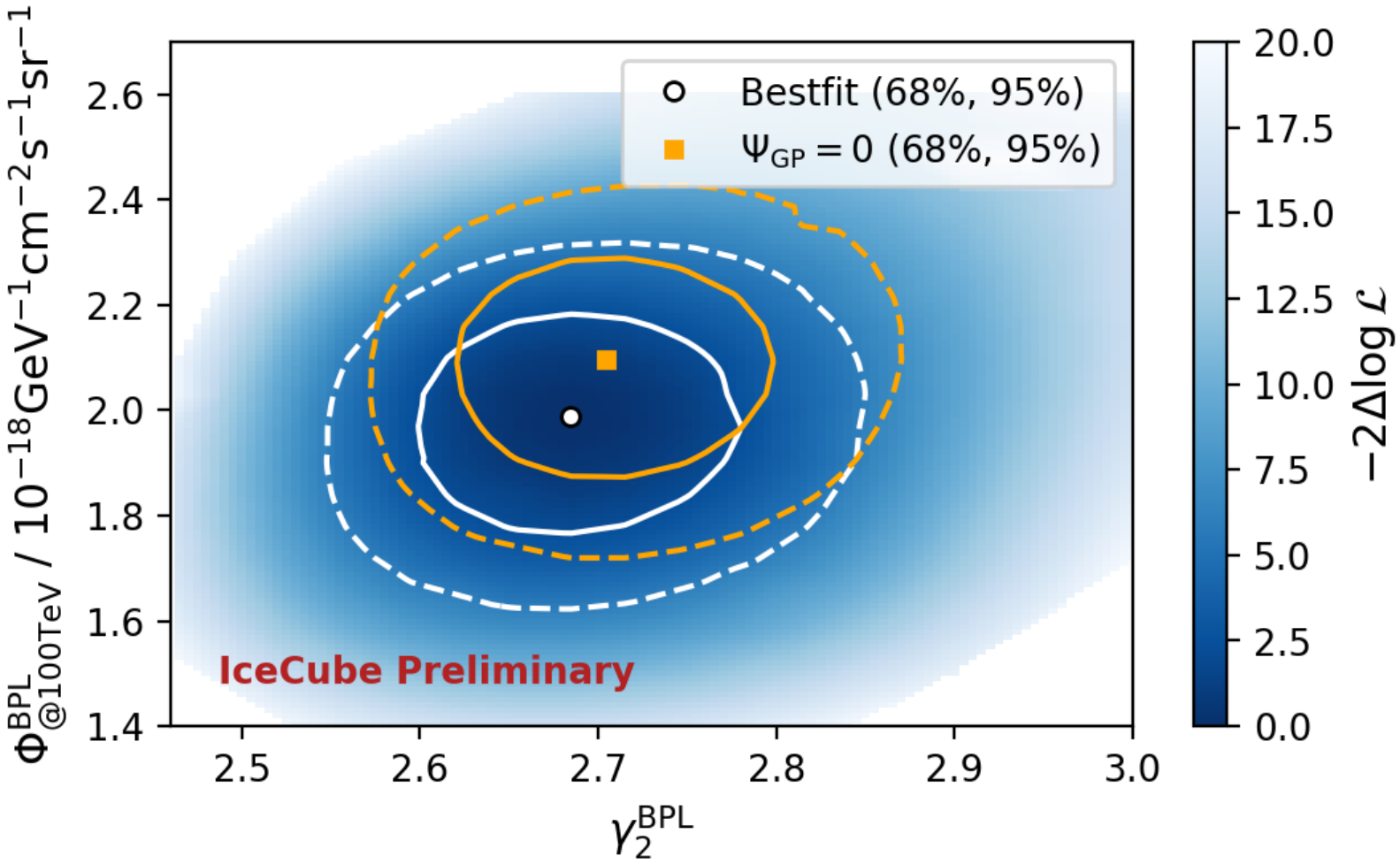




Scales of Flux Predictions



Effect of GP on the >40 TeV Extragalactic Spectrum



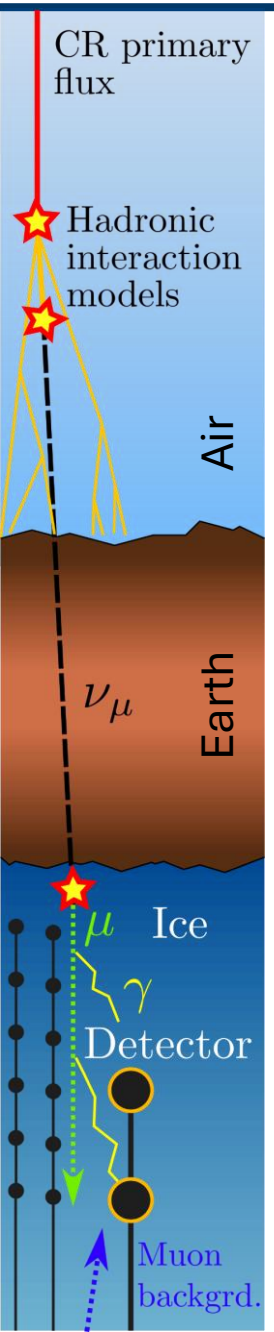
Comparison to Previous Analyses

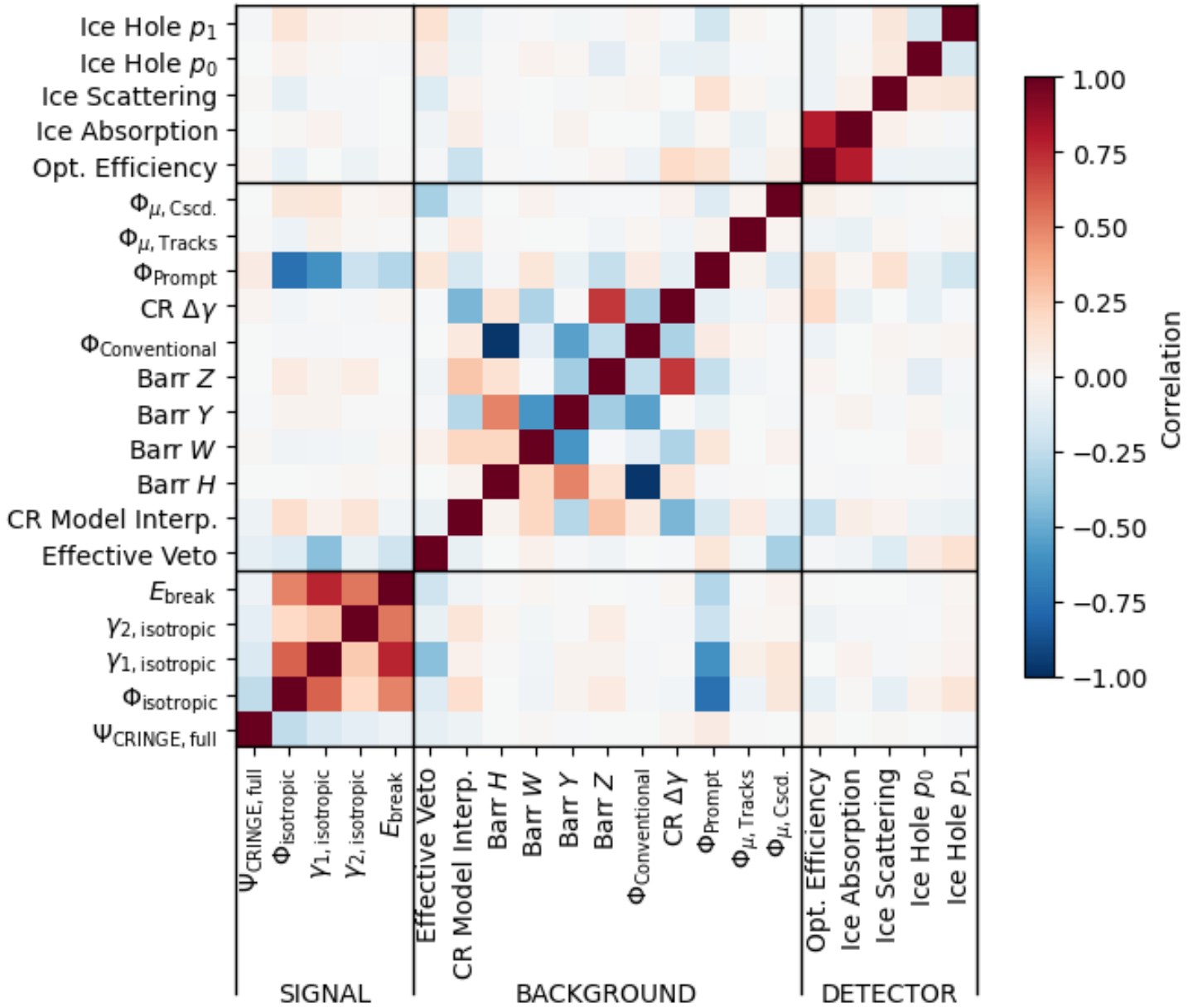
Parameter	SPL	BPL	Log-P	Segmented
ϕ_0	$1.88^{+0.10}_{-0.09}$	$2.0^{+0.12}_{-0.14}$	$2.3^{+0.15}_{-0.14}$	–
$\gamma_{\rm SPL}$	$2.47^{+0.023}_{-0.027}$	–	–	–
γ_1	–	$1.2^{+0.4}_{-0.7}$	–	–
γ_2	–	$2.68^{+0.06}_{-0.06}$	–	–
$E_{\rm break}$	–	22 ± 5 TeV	–	–
$\alpha_{\rm LP}$	–	–	$2.54^{+0.05}_{-0.04}$	–
$\beta_{\rm LP}$	–	–	$0.28^{+0.08}_{-0.06}$	–
$\Psi_{\rm CRINGE\text{-}diffuse}$	2.6 ± 0.8	2.7 ± 0.8	2.6 ± 0.8	$2.7^{+0.7}_{-0.5}$

	Astrophysical model			
Analysis	SPL $[\phi_0(\Lambda)^{-\gamma}]$	SPE $[\phi_0(\Lambda)^{-\gamma} e^{(-E_\nu/E_{\rm cutoff})}]$	BPL $[\phi_{0,\rm broken}(E_\nu/E_{\rm break})^{-\gamma_{\rm BPL}}]$	LP $[\phi_0(\Lambda)^{-\alpha_{\rm LP}-\beta_{\rm LP}\log_{10}(\Lambda)}]$
MESE	$\phi_0 = 2.13^{+0.18}_{-0.17}$ $\gamma = 2.55^{+0.04}_{-0.04}$	$\phi_0 = 3.98^{+1.14}_{-1.32}$ $\gamma = 2.16^{+0.23}_{-0.16}$ $\log_{10}(E_{\rm cutoff}/{\rm GeV}) = 5.40^{+0.51}_{-0.23}$	$\phi_0 = 2.28^{+0.22}_{-0.20}$ $\gamma_1 = 1.72^{+0.26}_{-0.35}$ $\gamma_2 = 2.84^{+0.11}_{-0.09}$ $\log_{10}(E_{\rm break}/{\rm GeV}) = 4.52^{+0.11}_{-0.09}$	$\phi_0 = 2.58^{+0.26}_{-0.26}$ $\alpha_{\rm LP} = 2.67^{+0.13}_{-0.06}$ $\beta_{\rm LP} = 0.36^{+0.10}_{-0.08}$
		$-2\Delta \ln \mathcal{L} = 1.8$	$-2\Delta \ln \mathcal{L} = 27.3$	$-2\Delta \ln \mathcal{L} = 18.8$
CF	$\phi_0 = 1.80^{+0.13}_{-0.16}$ $\gamma = 2.52^{+0.04}_{-0.04}$	$\phi_0 = 2.20^{+0.30}_{-0.25}$ $\gamma = 2.39^{+0.08}_{-0.08}$ $\log_{10}(E_{\rm cutoff}/{\rm GeV}) = 6.15^{+0.37}_{-0.24}$	$\phi_0 = 1.77^{+0.15}_{-0.11}$ $\gamma_1 = 1.31^{+0.50}_{-1.21}$ $\gamma_2 = 2.74^{+0.06}_{-0.07}$ $\log_{10}(E_{\rm break}/{\rm GeV}) = 4.39^{+0.09}_{-0.08}$	$\phi_0 = 2.13^{+0.16}_{-0.19}$ $\alpha_{\rm LP} = 2.57^{+0.06}_{-0.05}$ $\beta_{\rm LP} = 0.23^{+0.10}_{-0.07}$
		$-2\Delta \ln \mathcal{L} = 7.5$	$-2\Delta \ln \mathcal{L} = 24.7$	$-2\Delta \ln \mathcal{L} = 16.4$

PRL 136, 121002 (2026)

Fit Parameters





THE HISTORY OF

Neutrino Astronomy in Antarctica

But First:

1988
TELESCOPE IN THE ICE
ENVISIONED

2000
AMANDA
COMPLETED

2001
ATMOSPHERIC NEUTRINOS
DETECTED

2011
ICECUBE
COMPLETED

2013
ASTROPHYSICAL NEUTRINOS
DISCOVERED

2018
BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED

2021
GLASHOW RESONANCE
NEUTRINO IDENTIFIED

2022
ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED

2023
MILKY WAY
NEUTRINO EMISSION IDENTIFIED

2024
ASTROPHYSICAL TAU NEUTRINOS
IDENTIFIED

NSF | IceCube Neutrino Observatory