



Bundesministerium
für Forschung, Technologie
und Raumfahrt



III. Physikalisches
Institut B

RWTHAACHEN
UNIVERSITY

A Joint Characterization of Galactic and Extragalactic Neutrino Fluxes

Philipp Fürst for the IceCube Collaboration

RWTH Aachen University

TeVPA 2026

THE HISTORY OF Neutrino Astronomy *in* Antarctica

Extragalactic & Galactic Neutrinos



ICECUBE
NEUTRINO OBSERVATORY

The IceCube Neutrino Observatory



ICECUBE
NEUTRINO OBSERVATORY

50 m

Ice Top

86 strings of DOMs,
set 125 meters apart

1450 m



IceCube Laboratory
Data is collected here and
sent by satellite to the data
warehouse at UW-Madison



Digital Optical Module (DOM)
5,160 DOMs
deployed in the ice

2450 m

IceCube
detector

DeepCore

Antarctic bedrock

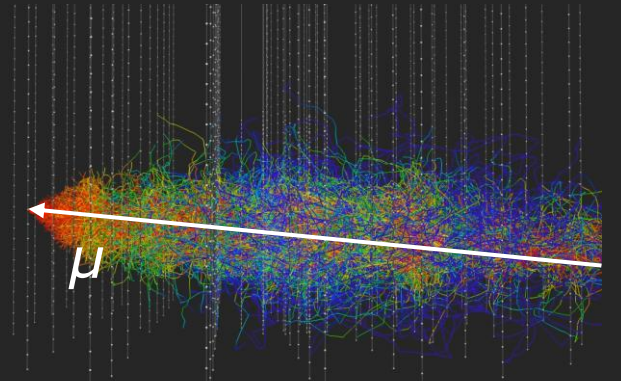
Amundsen-Scott South
Pole Station, Antarctica
A National Science Foundation-
managed research facility

60 DOMs
on each string

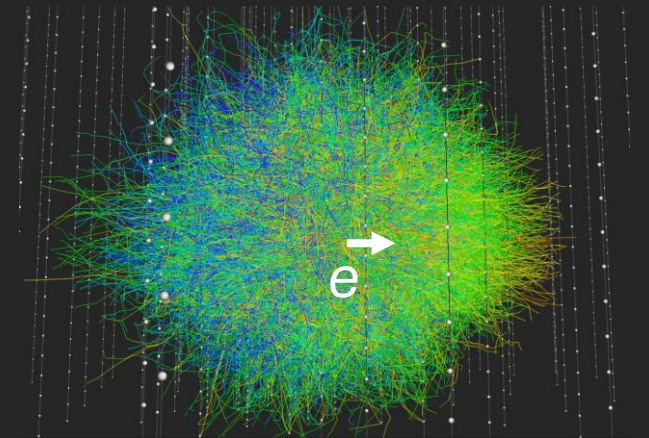
DOMs
are 17
meters
apart



Relativistic, charged particles in
the ice produce Cherenkov light:



Tracks: 0.2° - 1° resolution



Cascades: 5° - 15° resolution

Extragalactic and Galactic Neutrinos



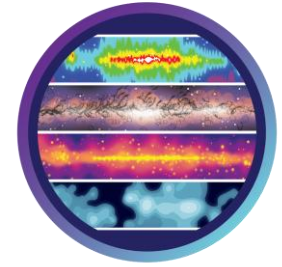
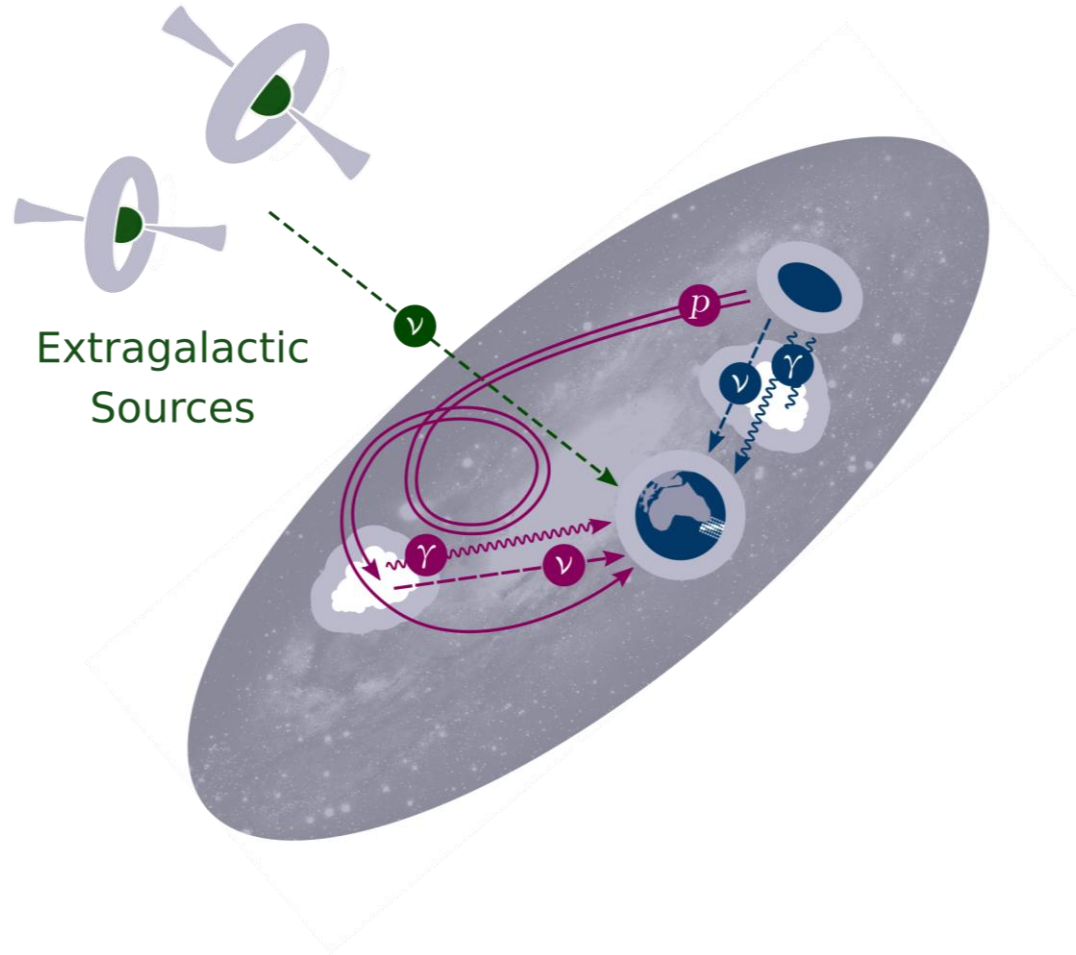
Extragalactic Neutrinos

- 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!



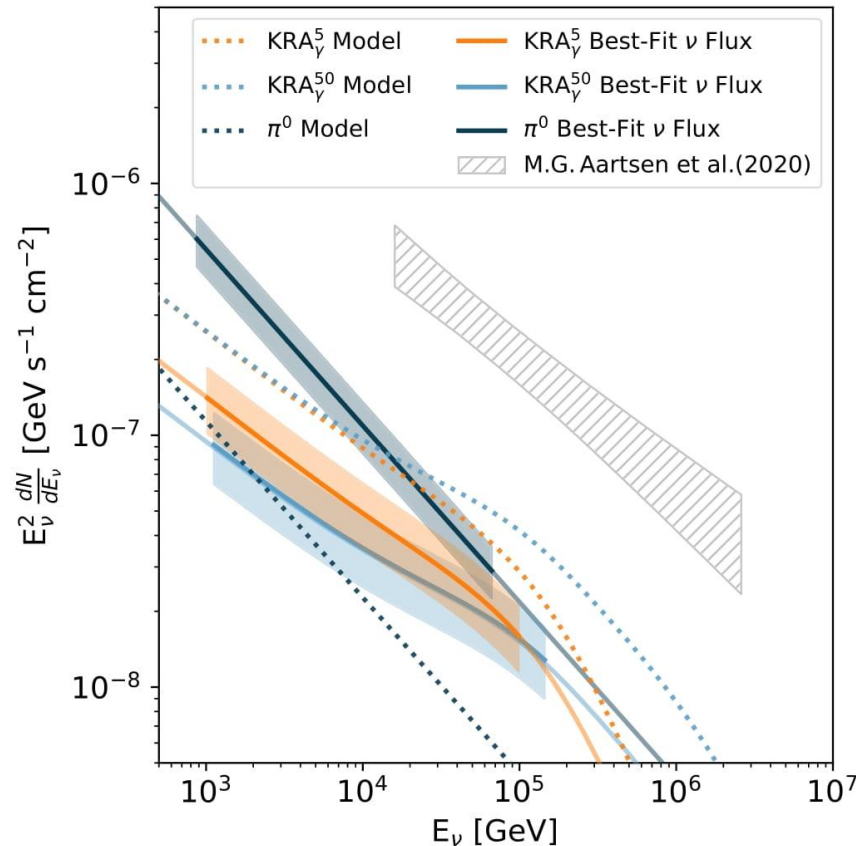
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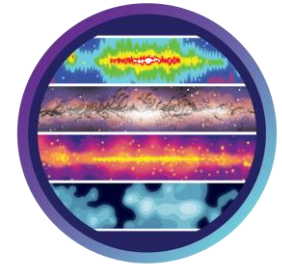
[PRL 136, 121002 \(2026\)](#)



[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 $>5\sigma$

Galactic Diffuse Emission



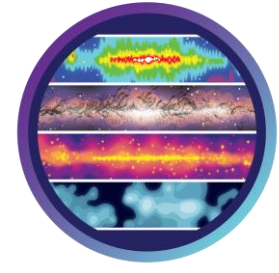
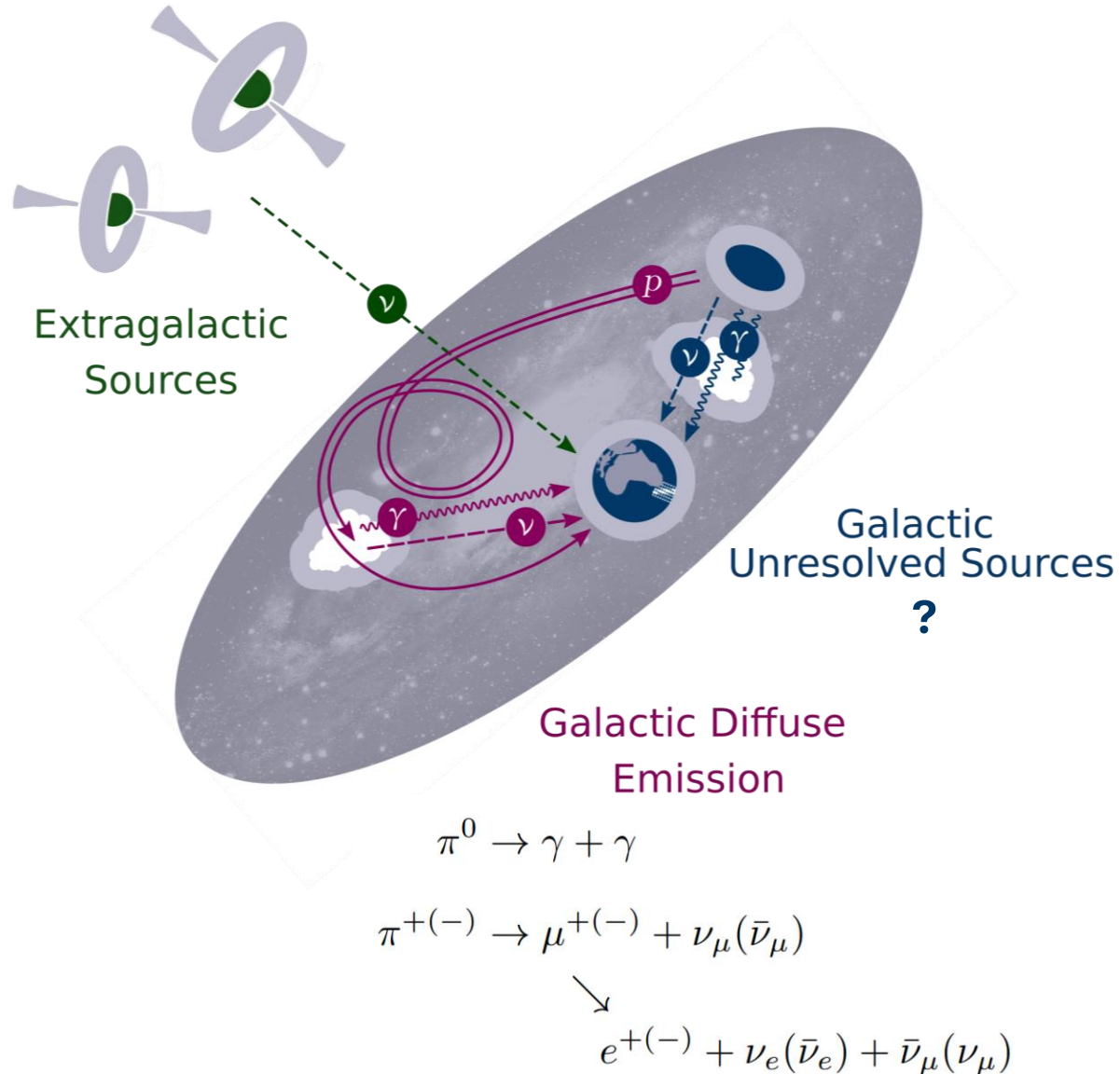
Extragalactic Neutrinos

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- Dominant source population unknown

Energy Spectrum:

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

[PRL 136, 121002 \(2026\)](#)



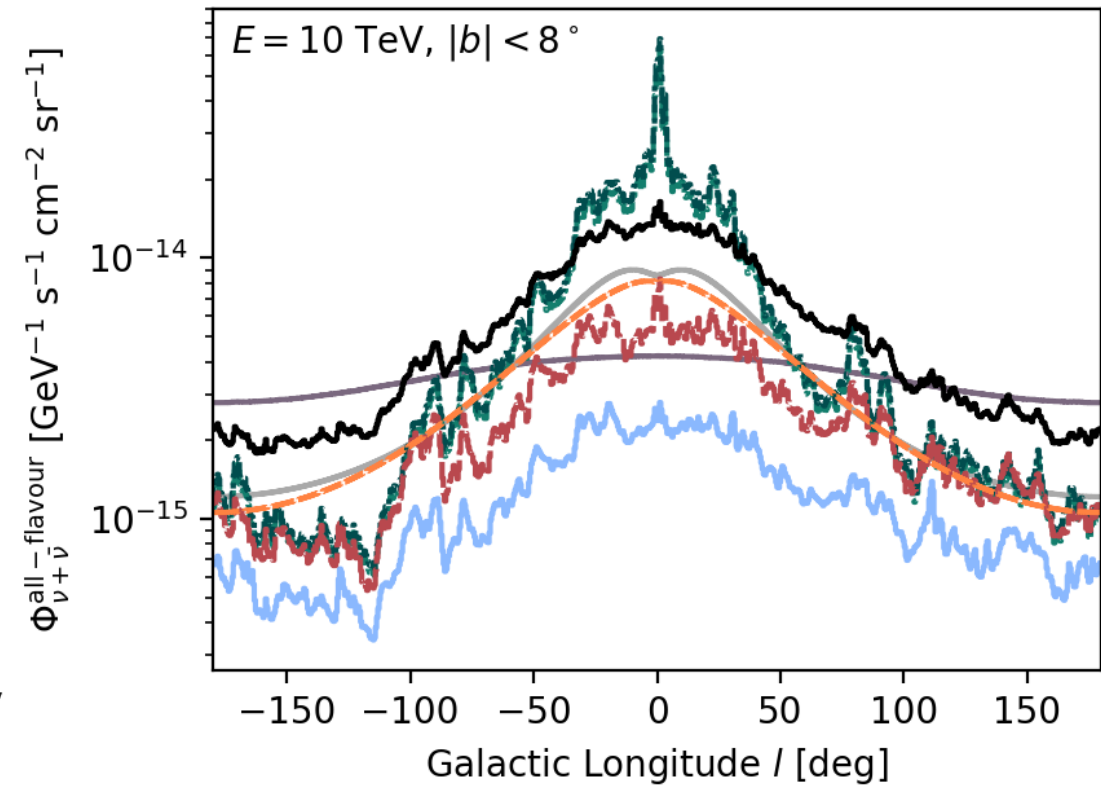
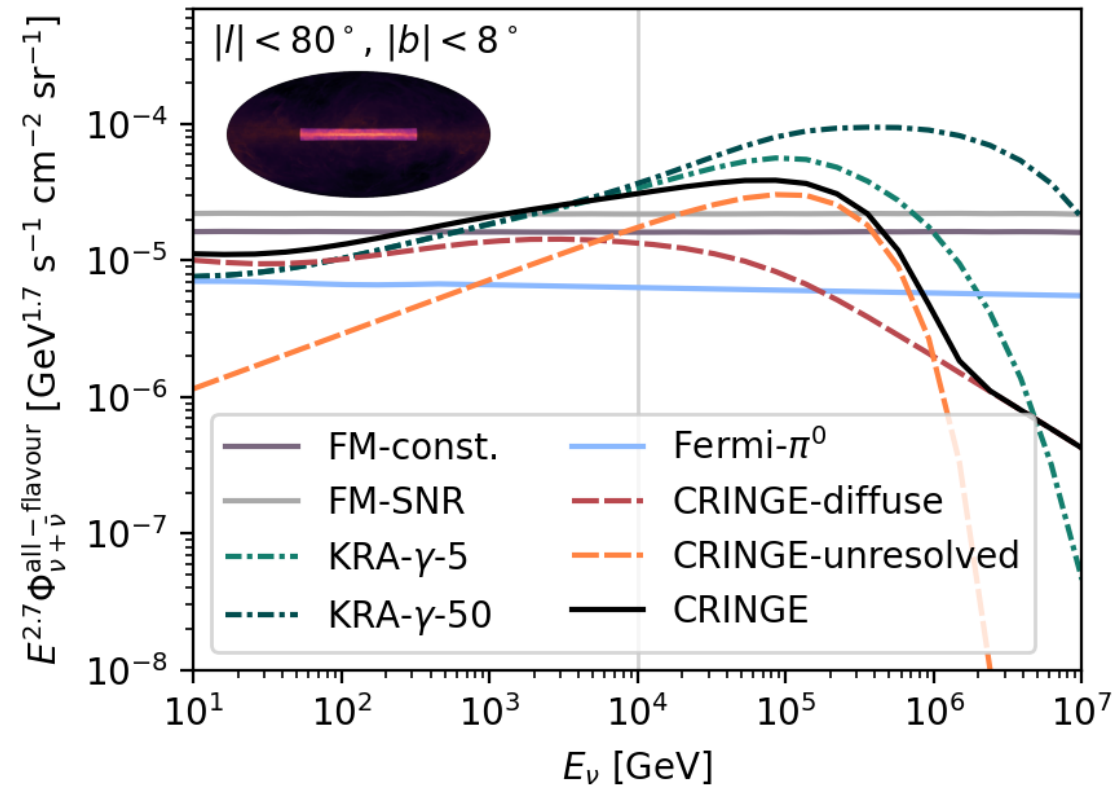
Galactic Neutrinos

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

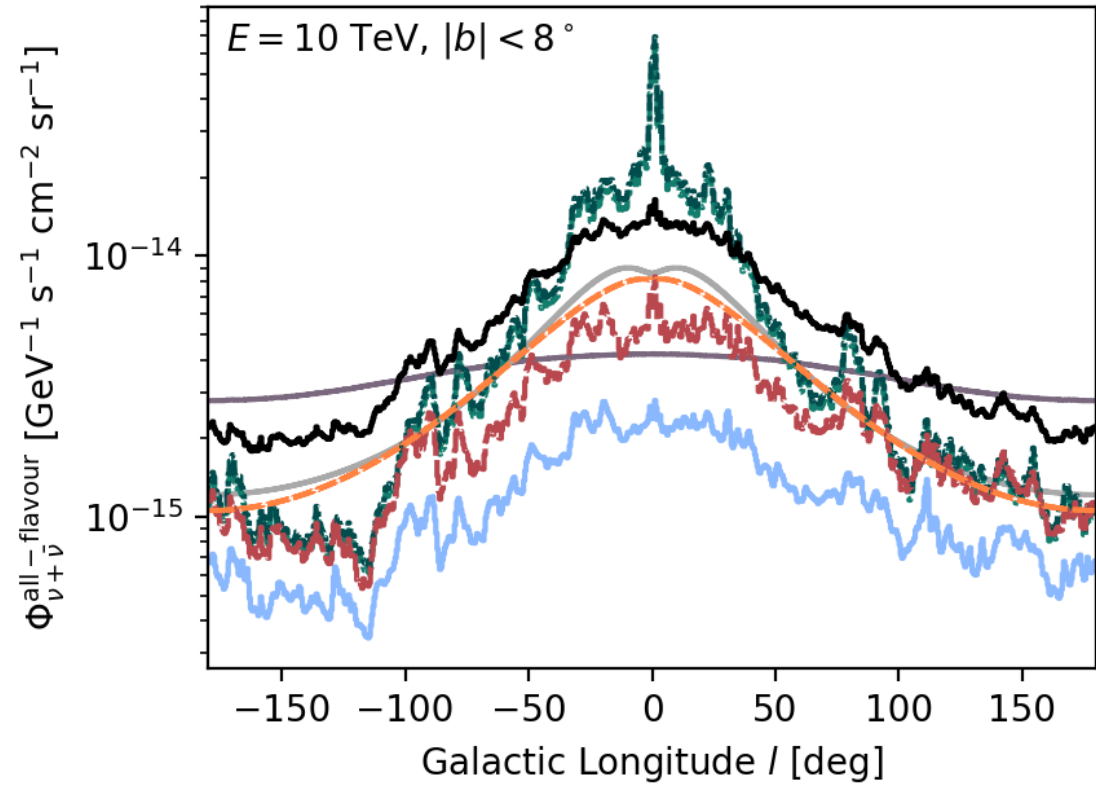
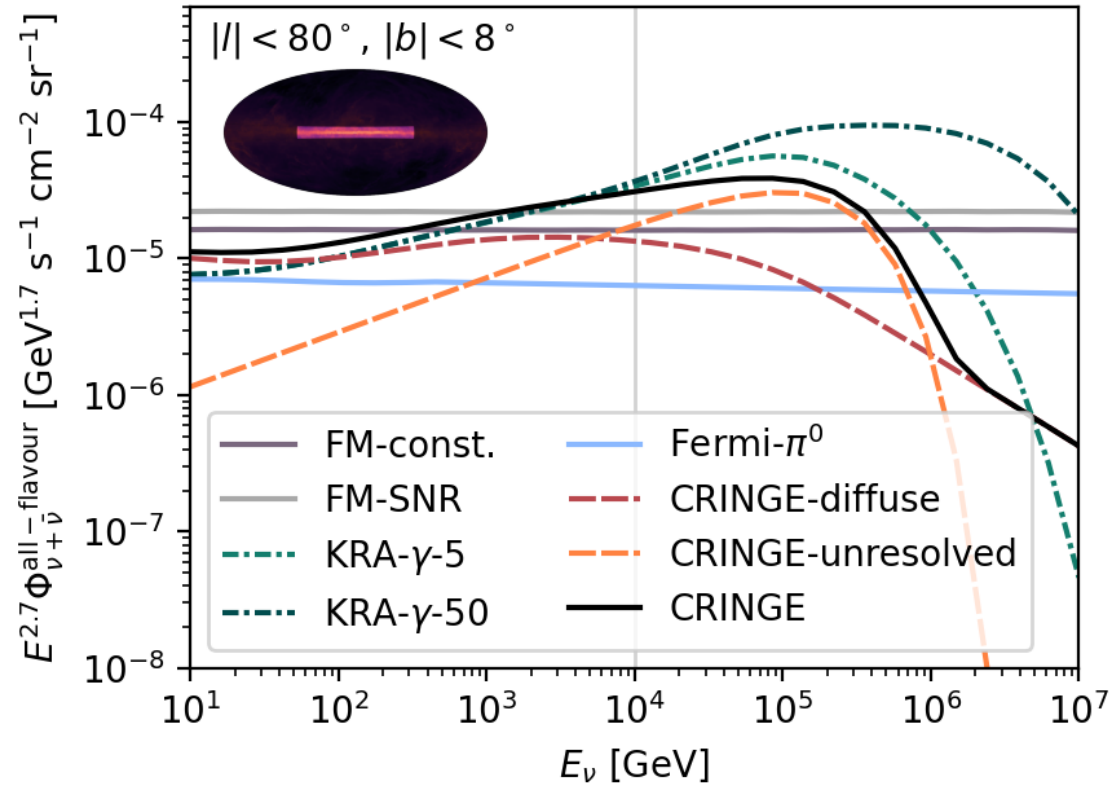
Diffuse Emission:

- CR + ISM $\rightarrow$ pions
- Additional emission at/near accelerators?

Models for Galactic Diffuse Emission

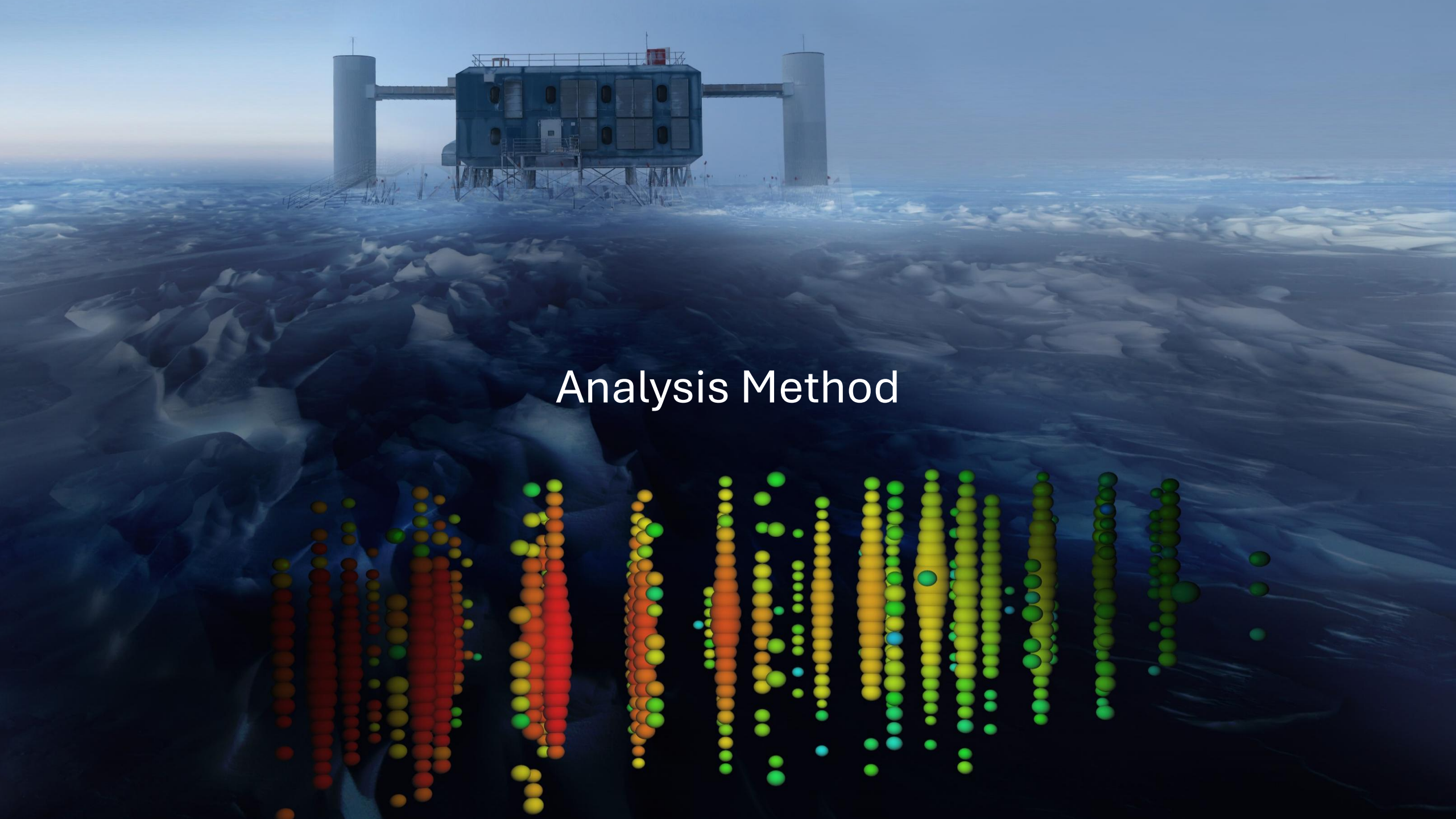


Models for Galactic Diffuse Emission



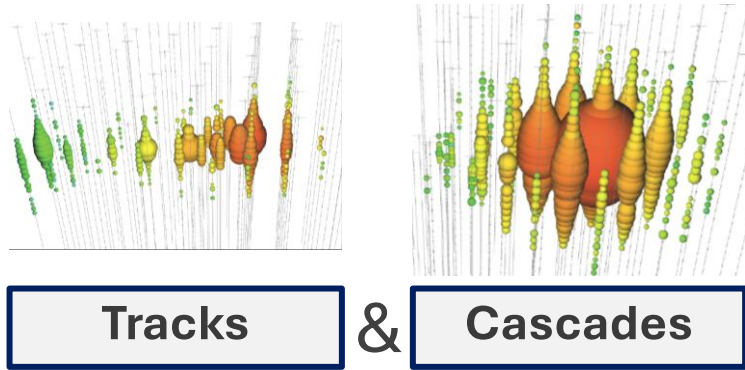
Analysis Goal #2:

Test different models & learn about the strength & structure of galactic neutrino emission!

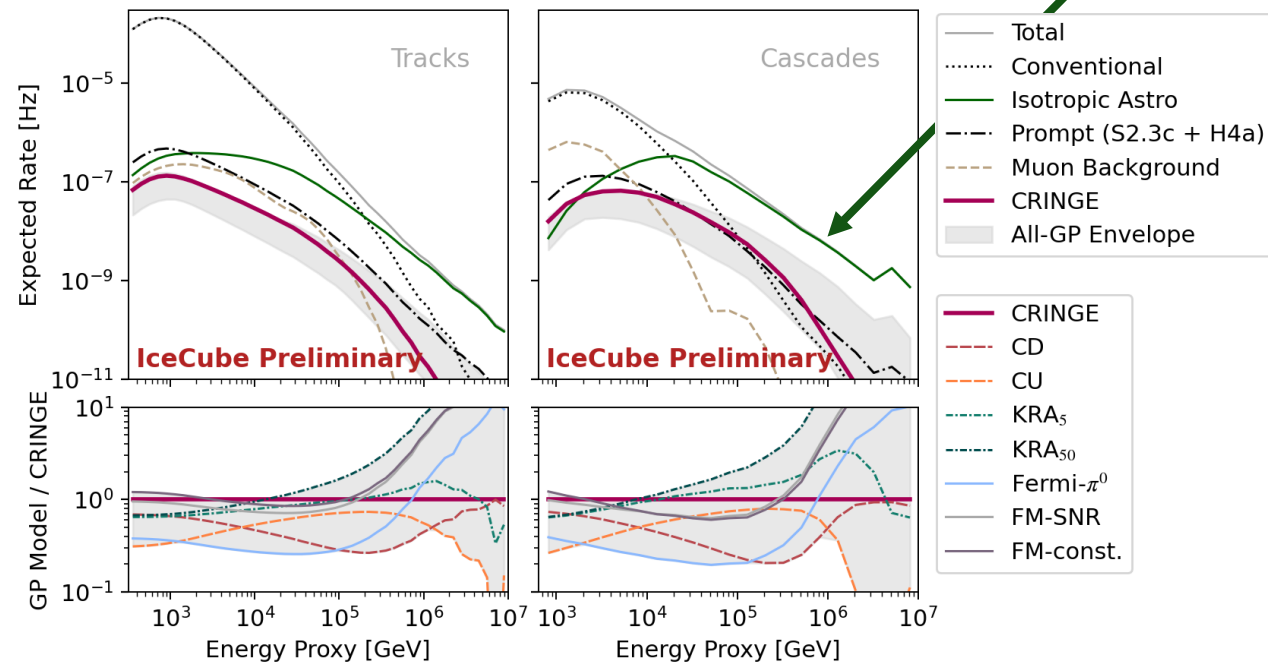
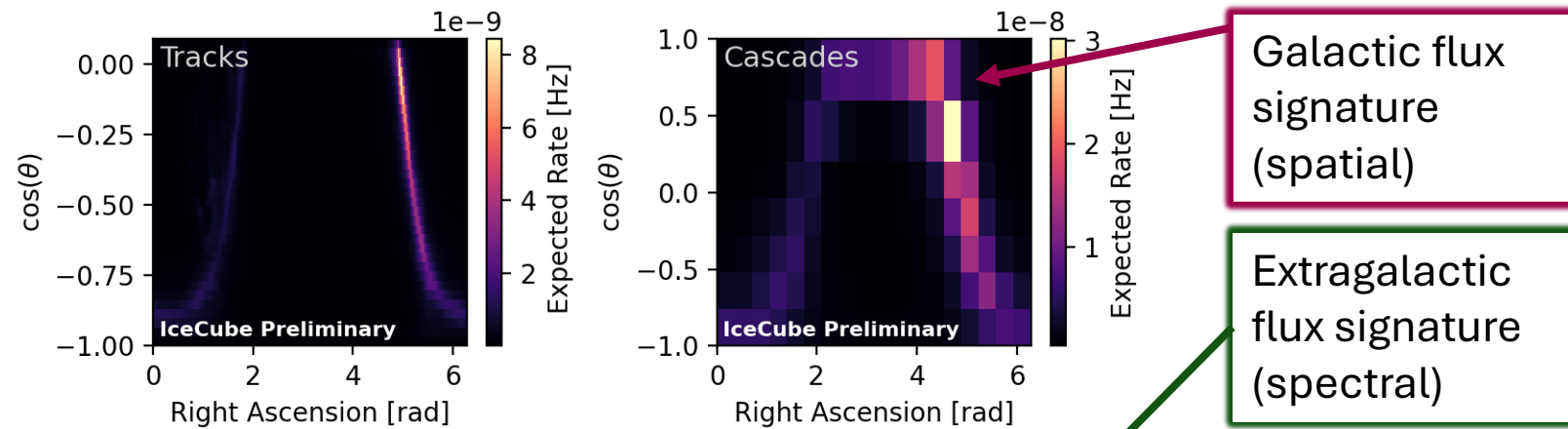
The background of the slide is a photograph of a research station, likely the IceCube Neutrino Observatory, situated on a vast, dark blue ice field under a clear sky. The station consists of a central blue building with several windows and two tall, white cylindrical towers on either side, connected by a horizontal bridge. In the foreground, a large, dark blue ice formation is visible. Overlaid on the bottom half of the image is a 3D molecular model. This model consists of numerous small spheres arranged in vertical columns. The spheres are colored in a gradient: red at the bottom, transitioning through orange and yellow to green at the top. The columns are of varying heights and are slightly offset from each other, creating a sense of depth and structure.

Analysis Method

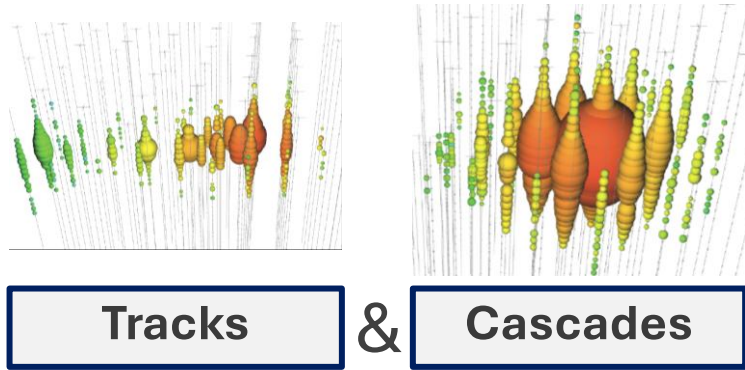
Analysis Method



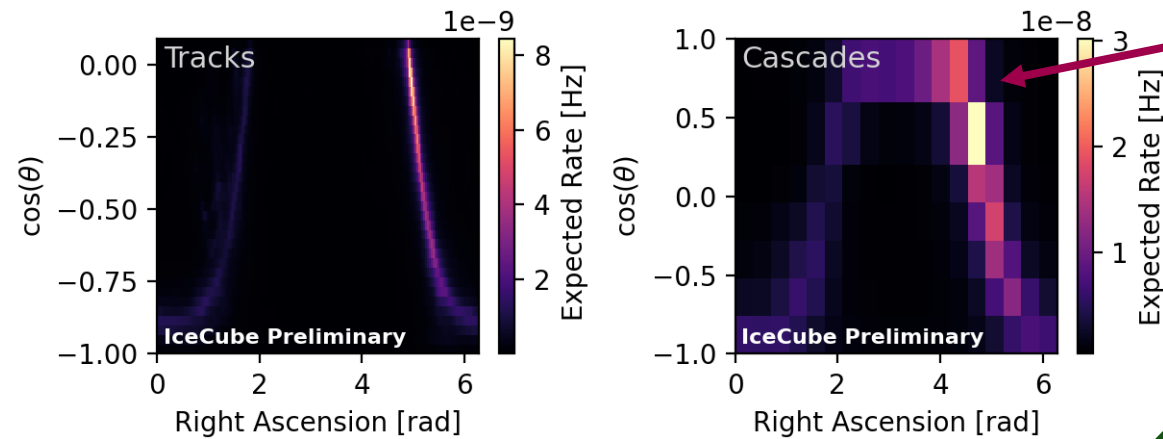
- Forward-folding likelihood fit
- Data & MC are binned in 3 dimensions:
- Energy, zenith, equatorial right ascension
- Parameterization of systematic uncertainties
- Simulation-based signal & background description



Analysis Method

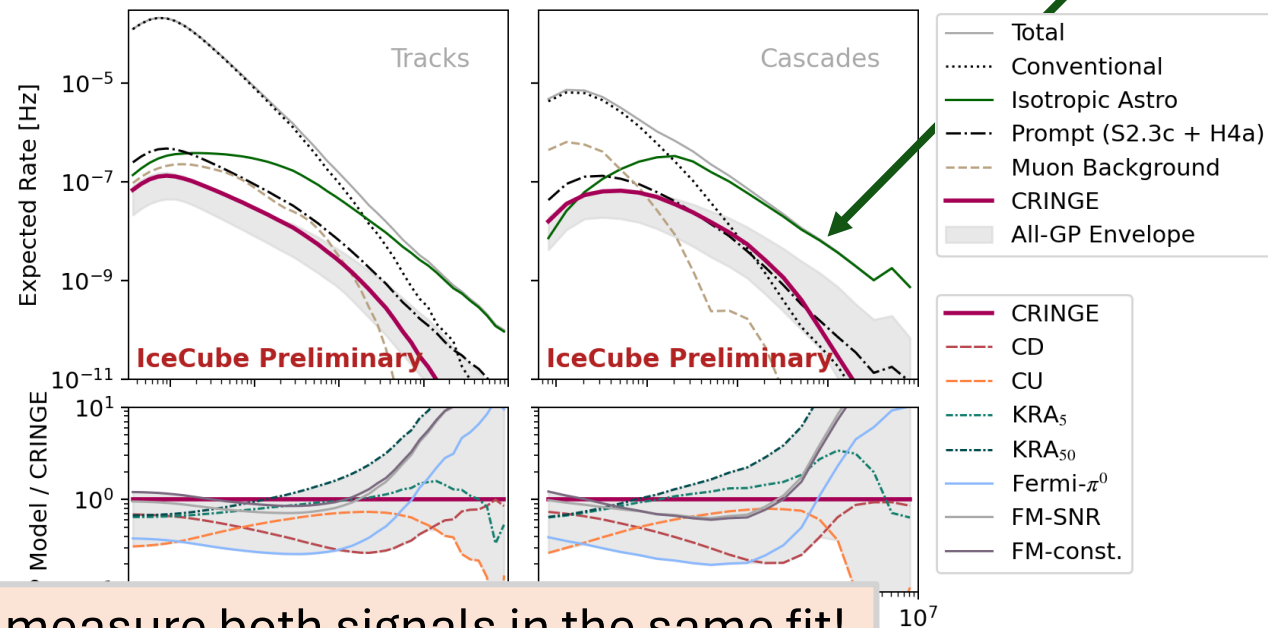


- Forward-folding likelihood fit
- Data & MC are binned in 3 dimensions:
- Energy, zenith, equatorial right ascension
- Parameterization of systematic uncertainties
- Simulation-based signal & background description



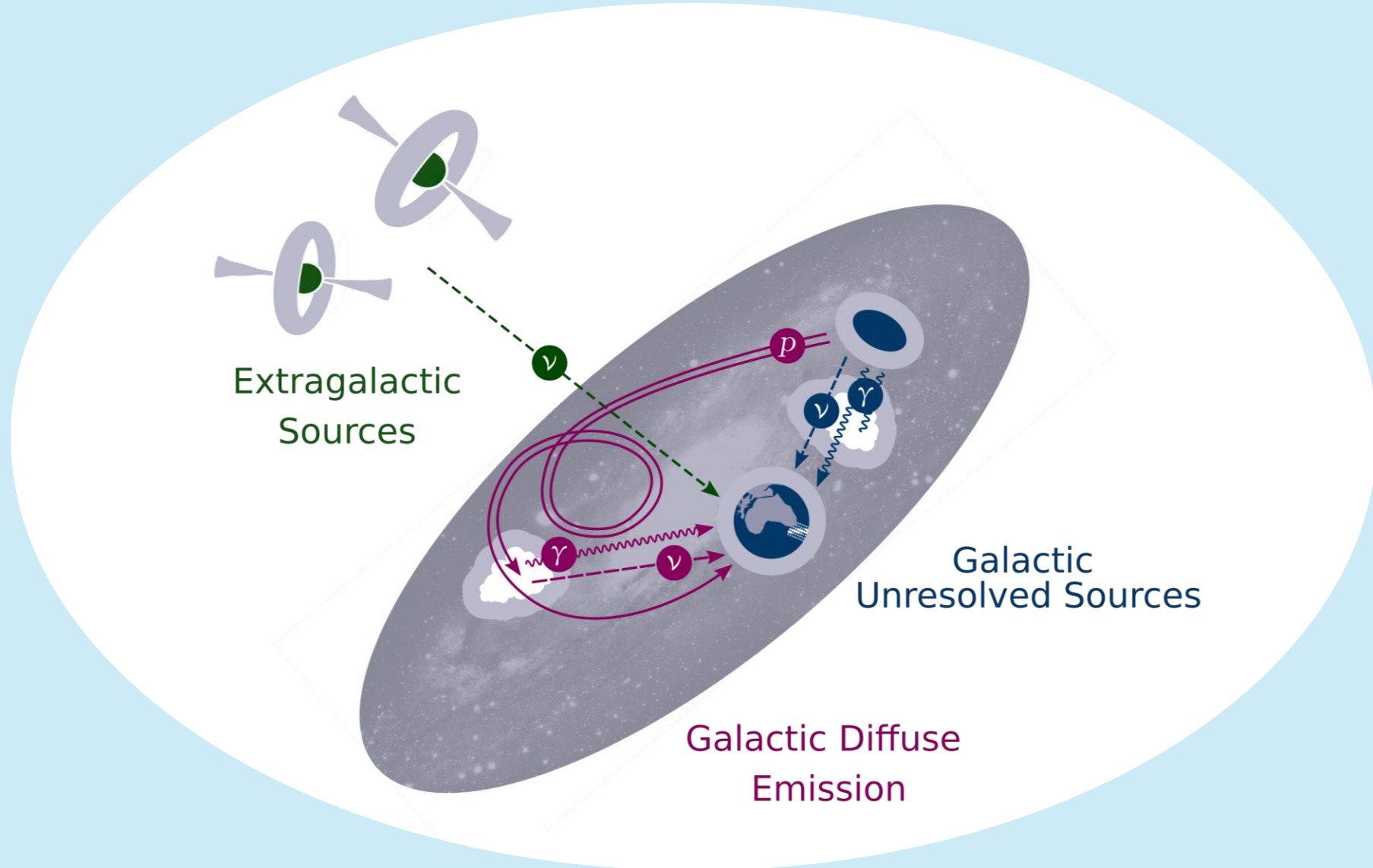
Galactic flux signature (spatial)

Extragalactic flux signature (spectral)



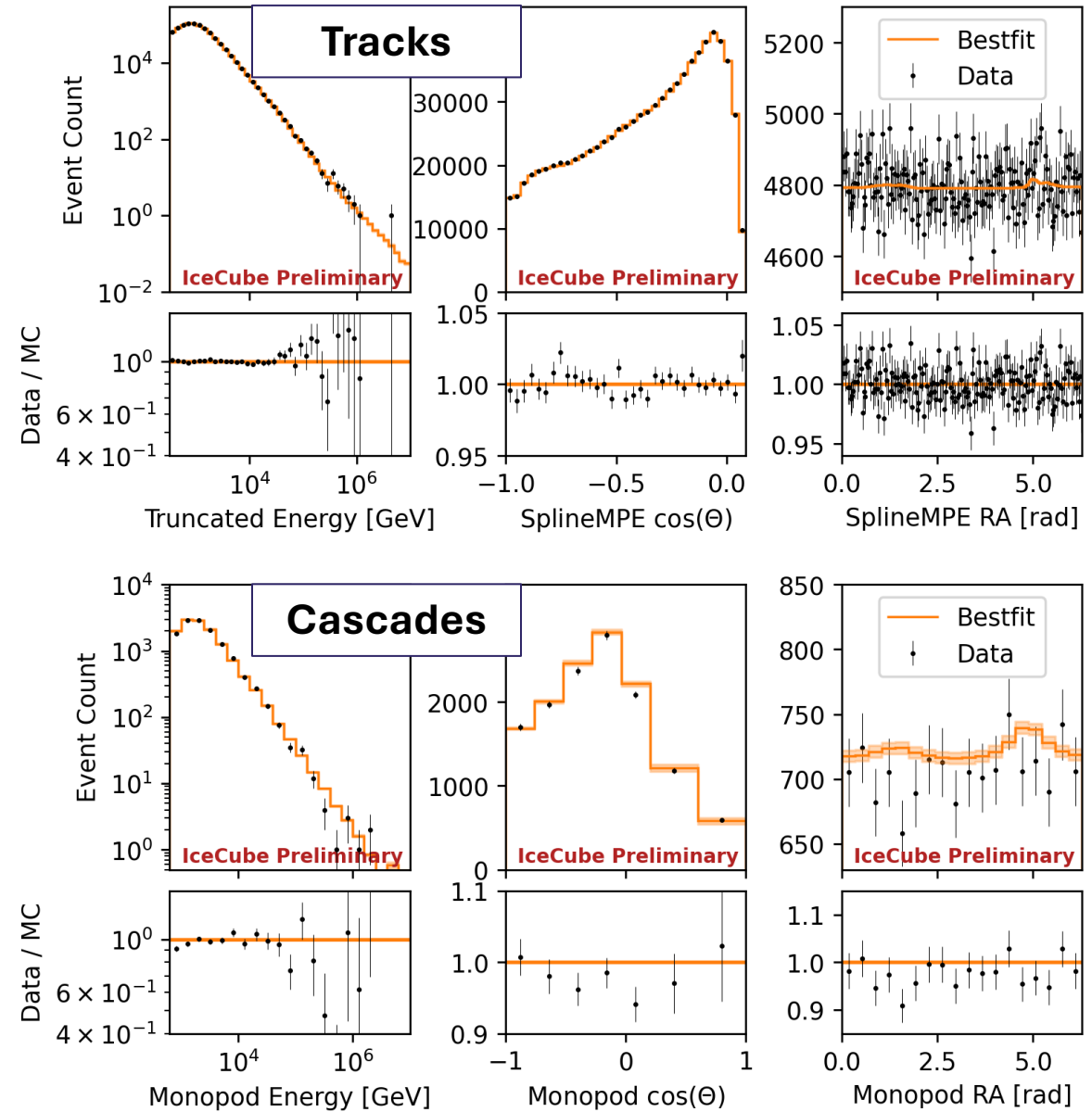
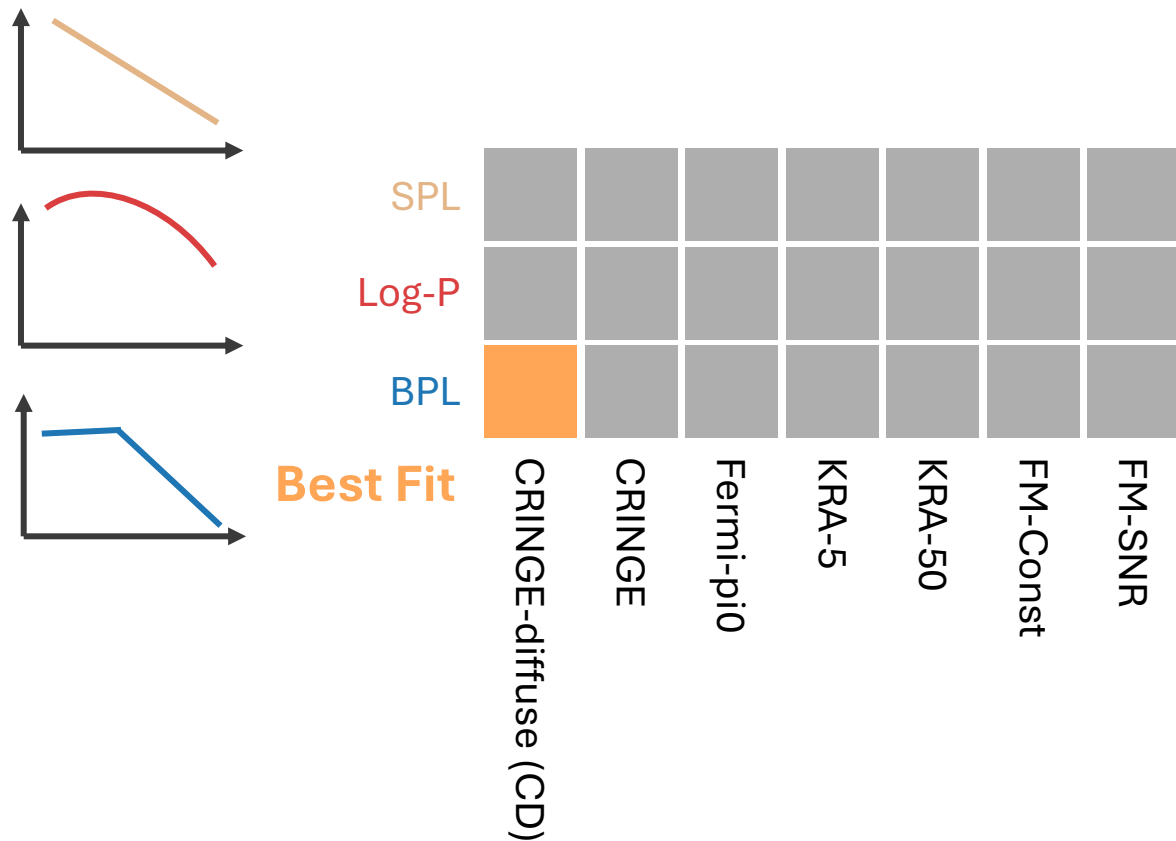
We can measure both signals in the same fit!

Fit Results: Best Fit

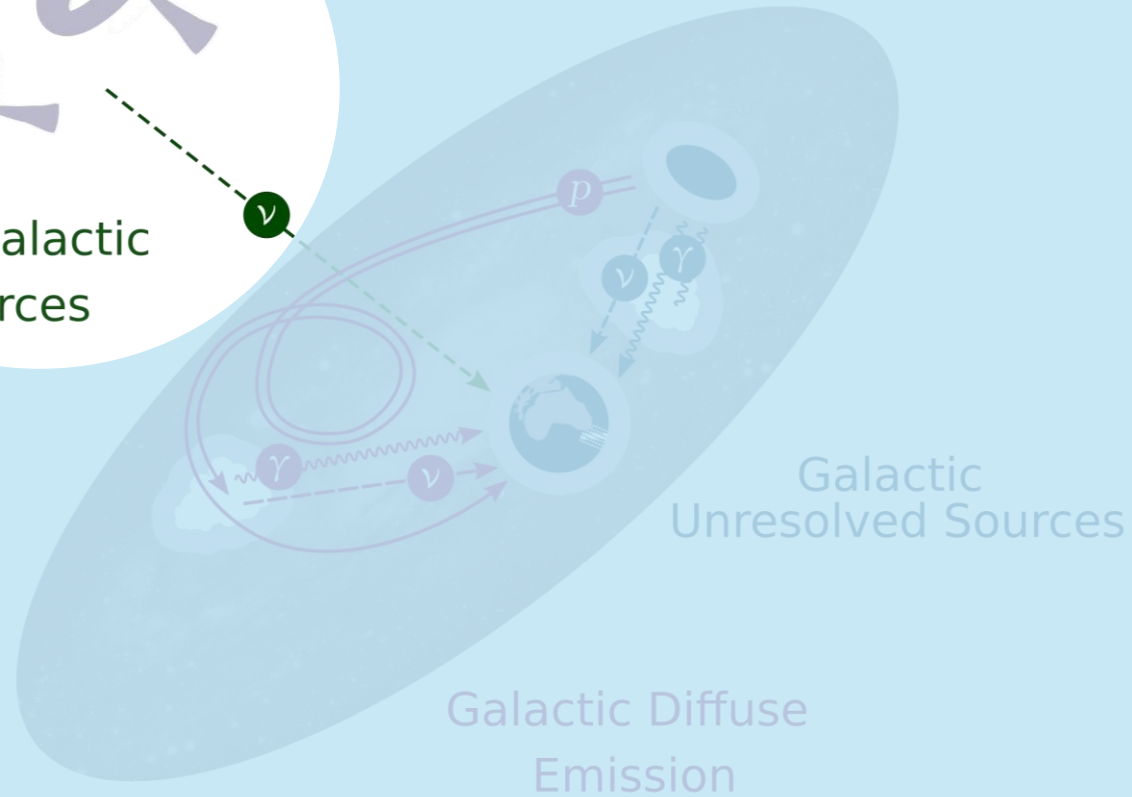
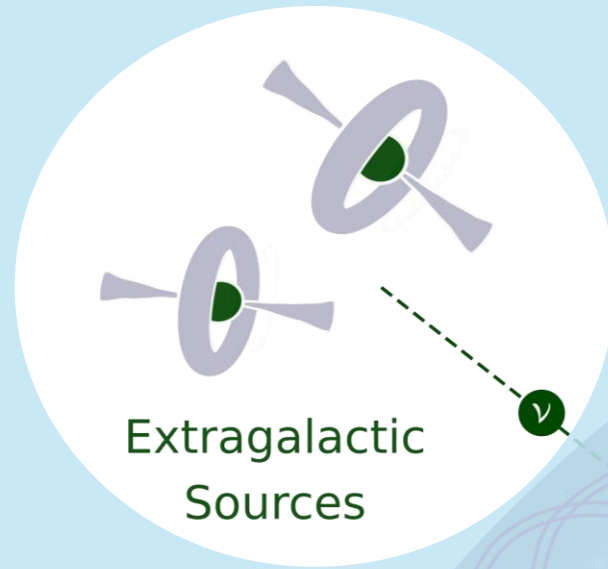


Fit Results: Best Fit

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



Fit Results: Extragalactic Flux



SPL						
Log-P						
BPL						
CD						
CRINGE						
Fermi-p10						
KRA-5						
KRA-50						
FM-Const						
FM-SNR						

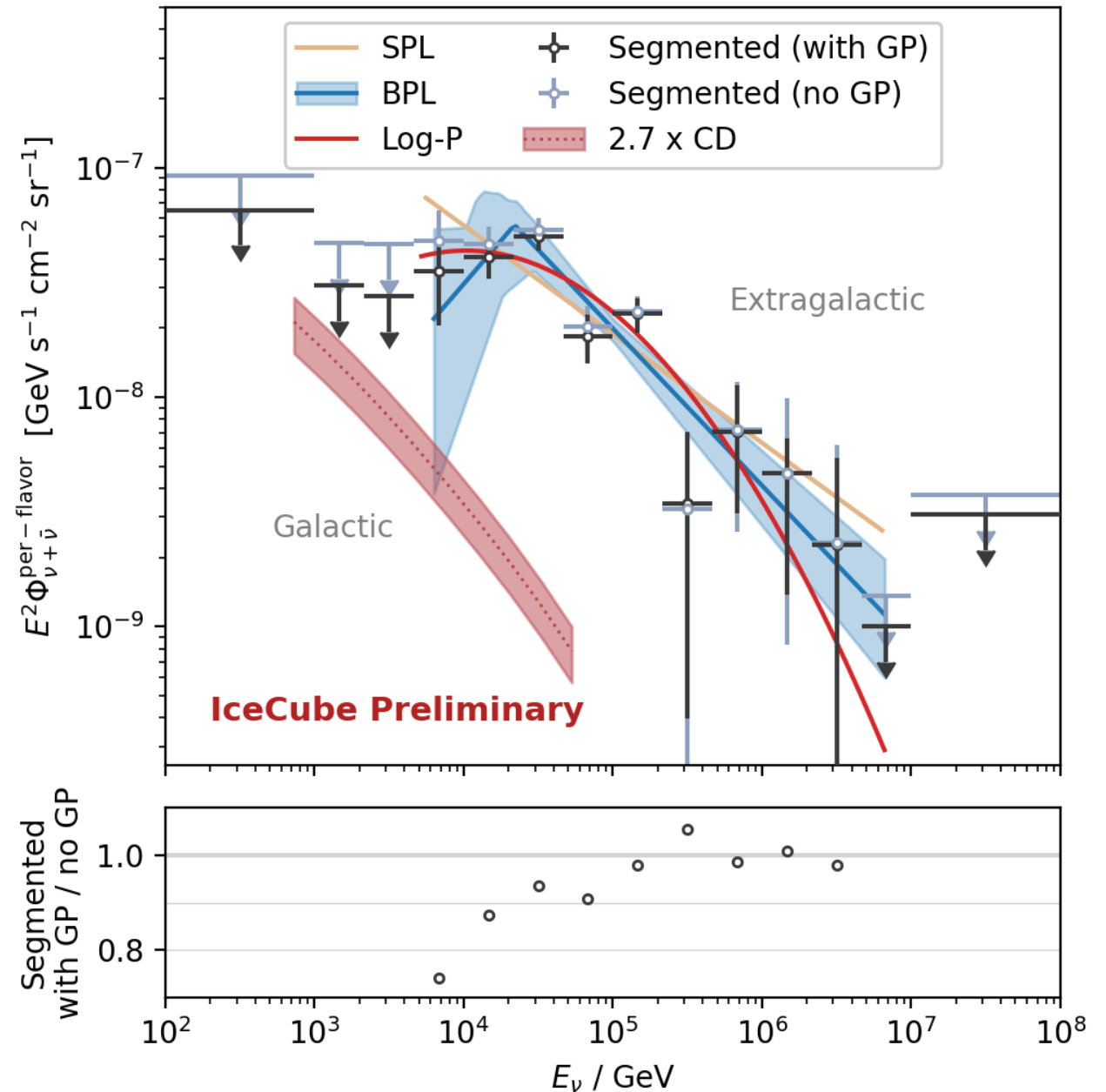
Fit Results: Extragalactic Flux

Preference for Structure:

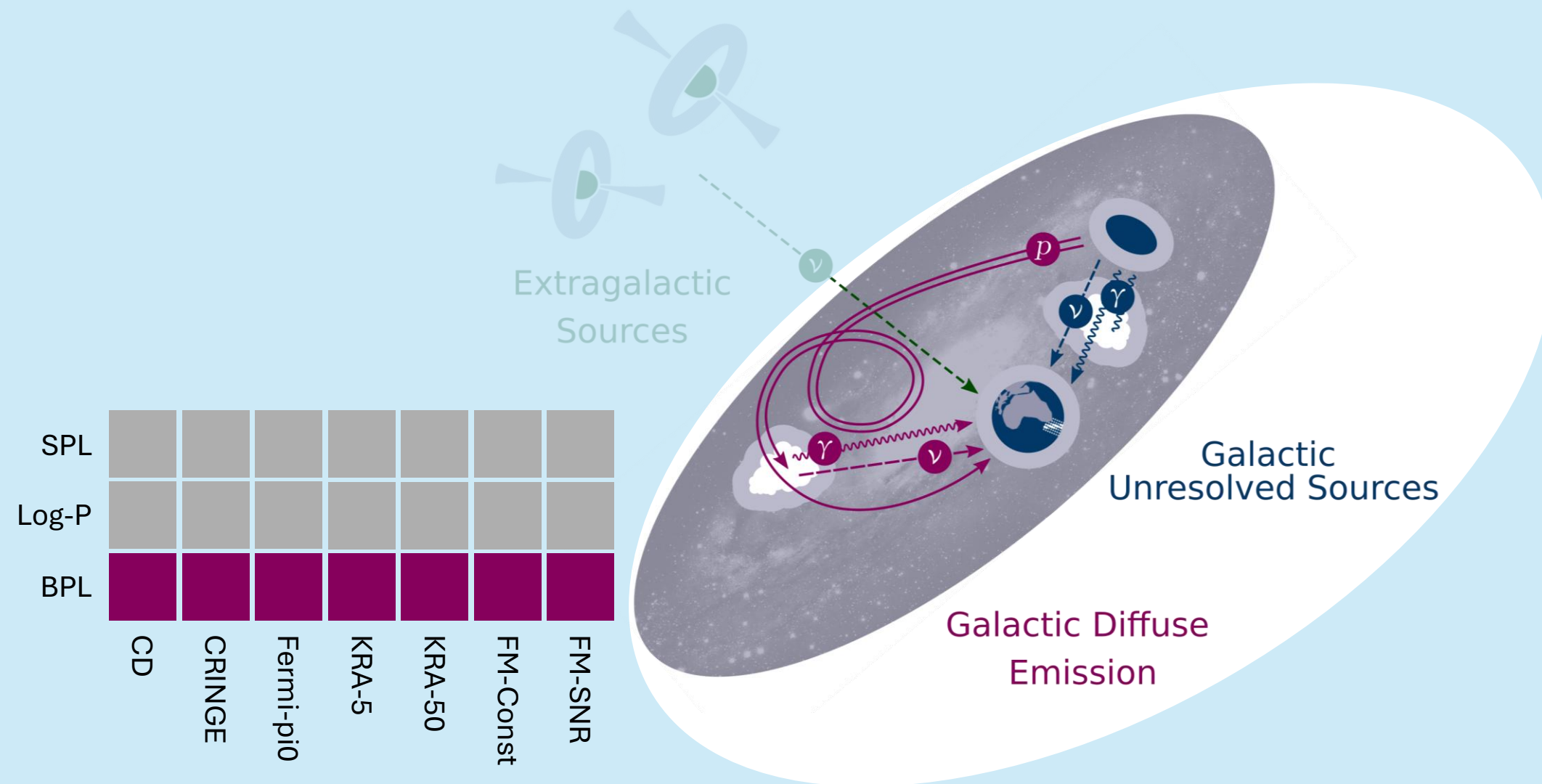
- BPL > SPL: **5.7σ**
- LogP > SPL: **5.4σ**
- Segmented model also exhibits this structure (regardless of GP inclusion)
- Consistent with precursor analysis ([PRL 136, 121002 \(2026\)](#))

Changes driving the significance:

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



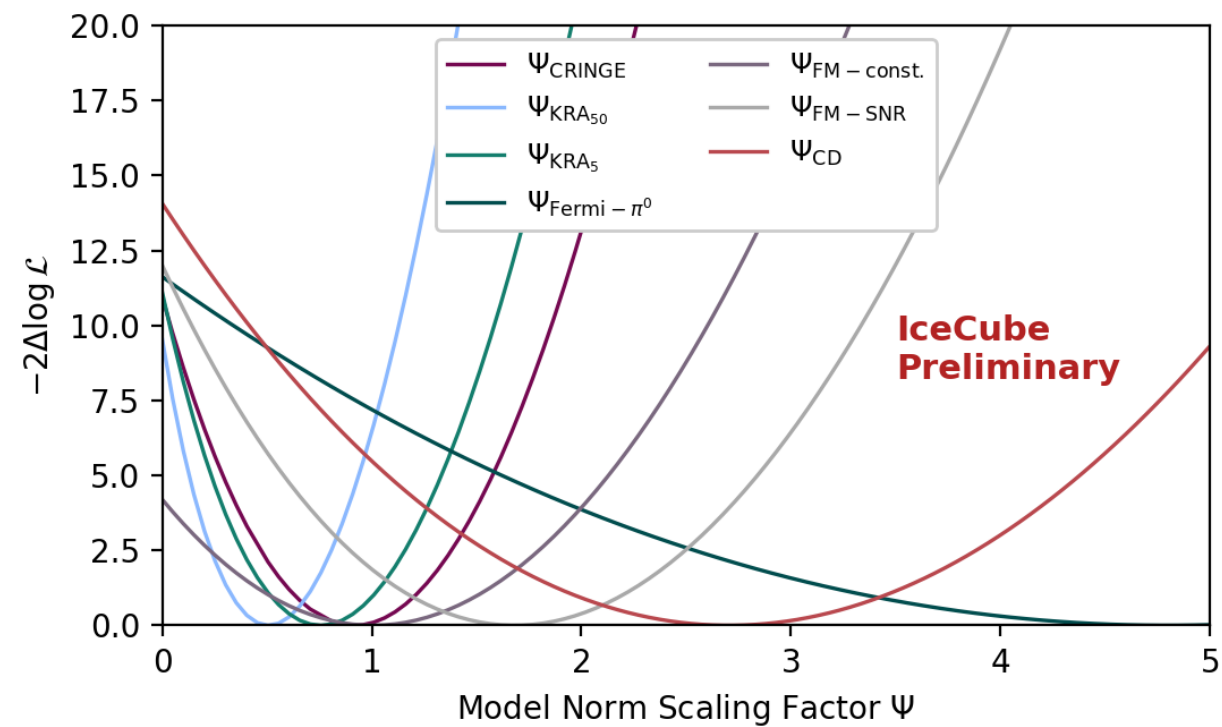
Fit Results: Galactic Flux



Fit Results: Extragalactic Flux

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

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

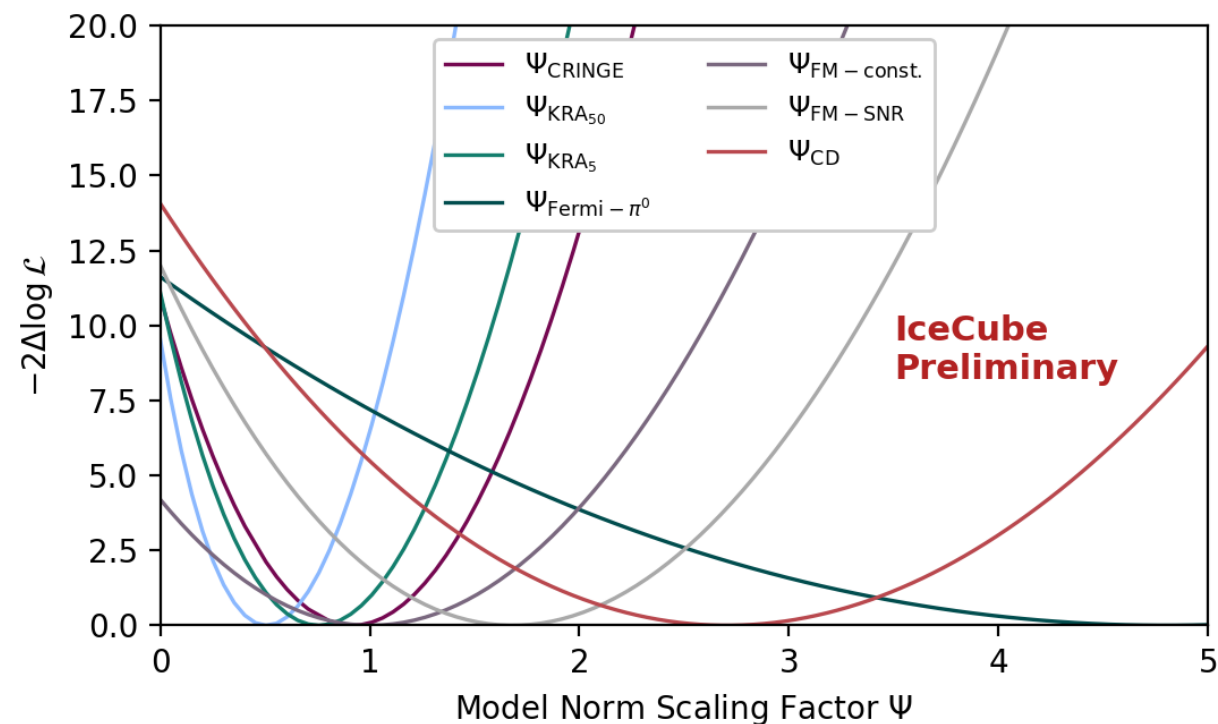


Fit Results: Extragalactic Flux

Best-fit Model CD: **3.7σ**

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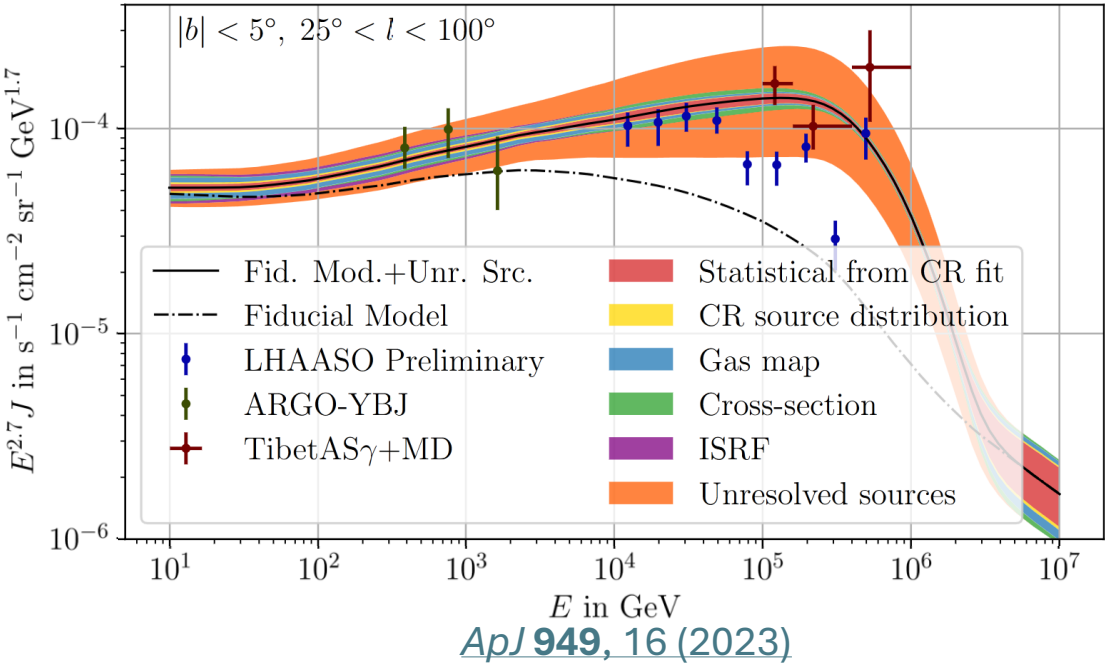
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KRA- γ 5	3.3	0.76 $^{+0.25}_{-0.24}$
CRINGE	3.3	0.9 $^{+0.3}_{-0.3}$
CRINGE-diffuse	3.7	2.7 $^{+0.8}_{-0.8}$
FM-Const	2.0	1 $^{+0.5}_{-0.5}$
FM-SNR	3.4	1.7 $^{+0.6}_{-0.5}$



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

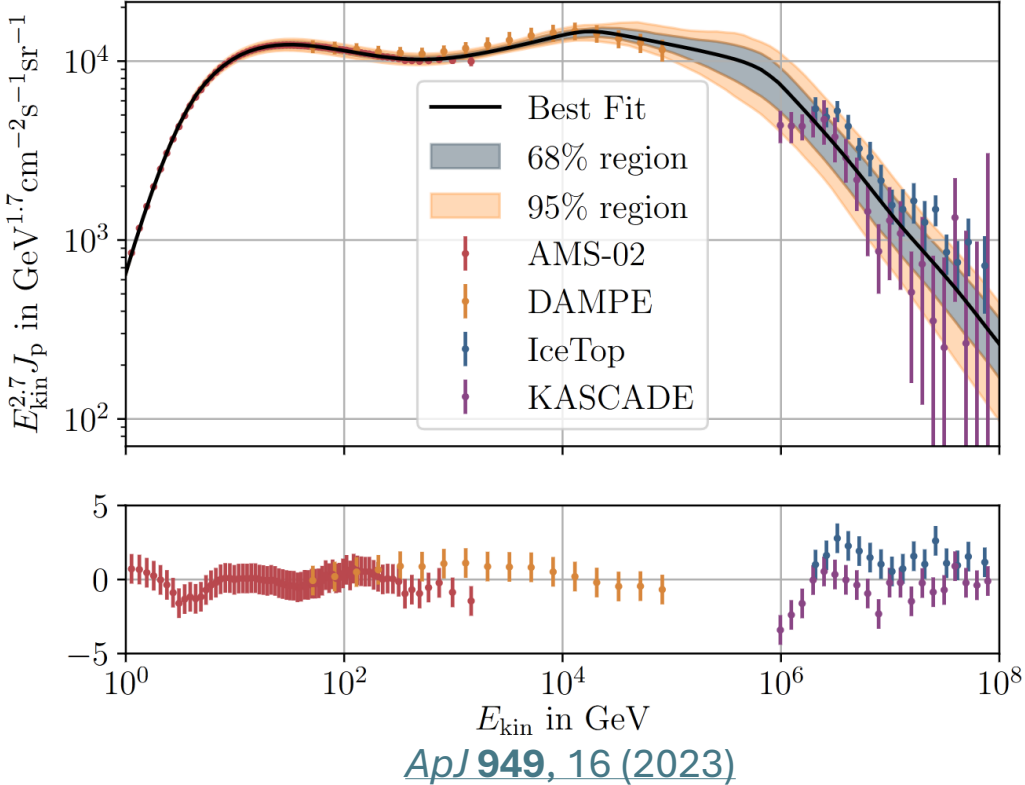
Multimessengers in the Galaxy?

Gamma Rays



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

Cosmic Rays

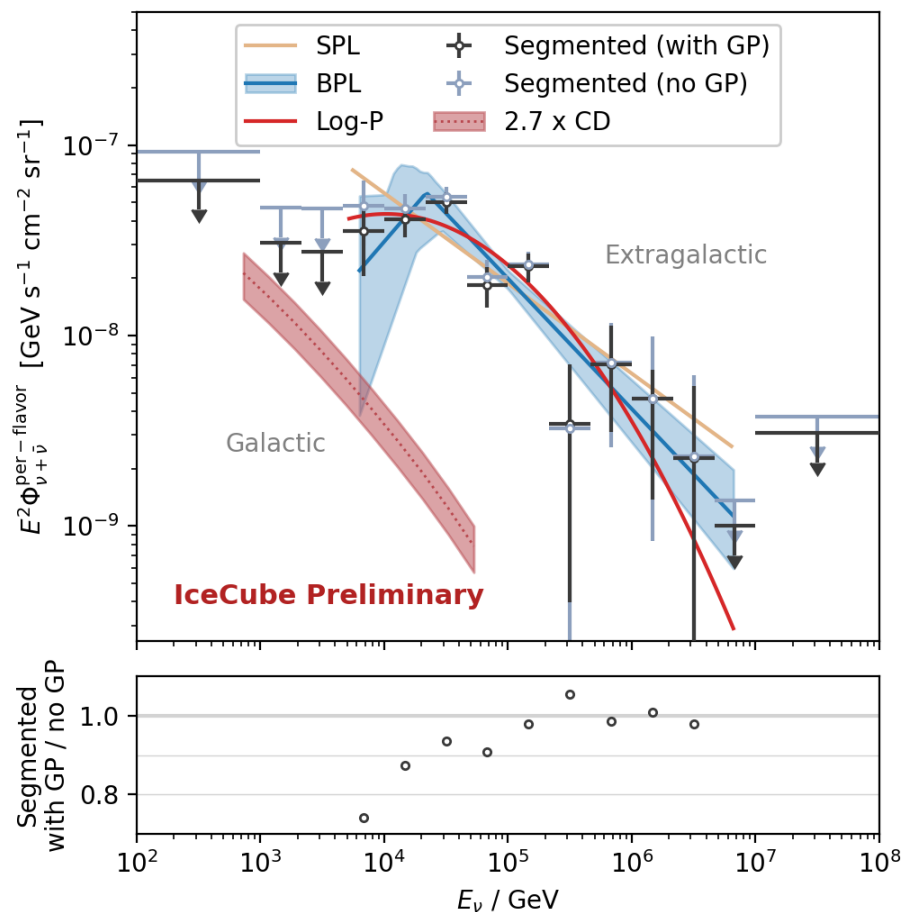


- ~1: γ , ν , & CR flux scales are consistent
- $\Psi_{CD} = 1$ (just the diffuse part) is in tension with the main result (2.3σ)
- There is „space“ for unresolved sources

Summary

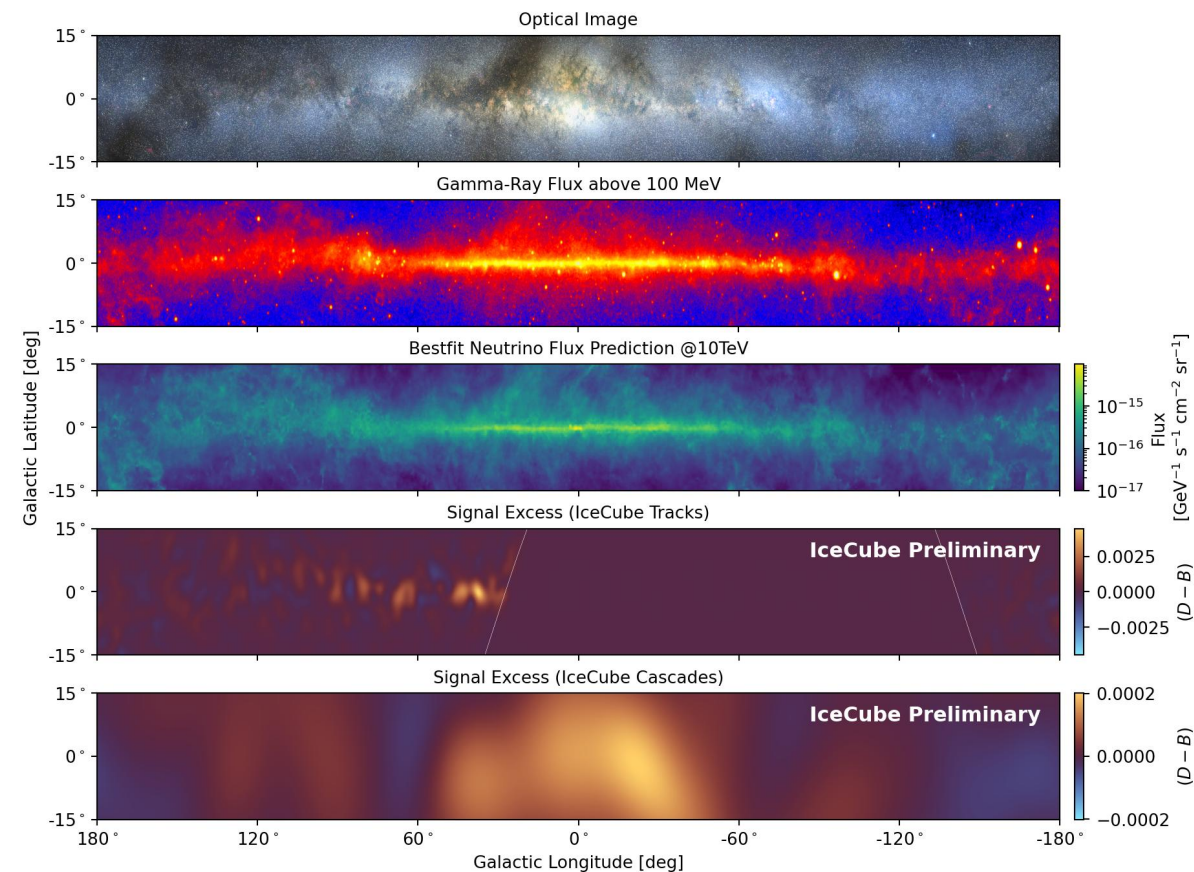
Extragalactic

- Structure below ~ 40 TeV observed with $>5\sigma$
- 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



Thank you for your
Attention!

THE ICECUBE COLLABORATION

AUSTRALIA

University of Adelaide

BELGIUM

UCLouvain
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel

CANADA

Queen's University
Simon Fraser University
University of Alberta-Edmonton

DENMARK

University of Copenhagen

GERMANY

Deutsches Elektronen-Synchrotron
ECAP, Universität Erlangen-Nürnberg
Humboldt-Universität zu Berlin
Karlsruhe Institute of Technology
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität Dortmund
Technische Universität München
Universität Mainz
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Mercer University
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Ohio State University
Pennsylvania State University
South Dakota School of Mines
and Technology
Southern University
and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
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University of Nevada, Las Vegas
University of Rochester
University of Utah
University of Wisconsin-Madison
University of Wisconsin-River Falls
Yale University

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(FWO-Vlaanderen)

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German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)

Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat

The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)



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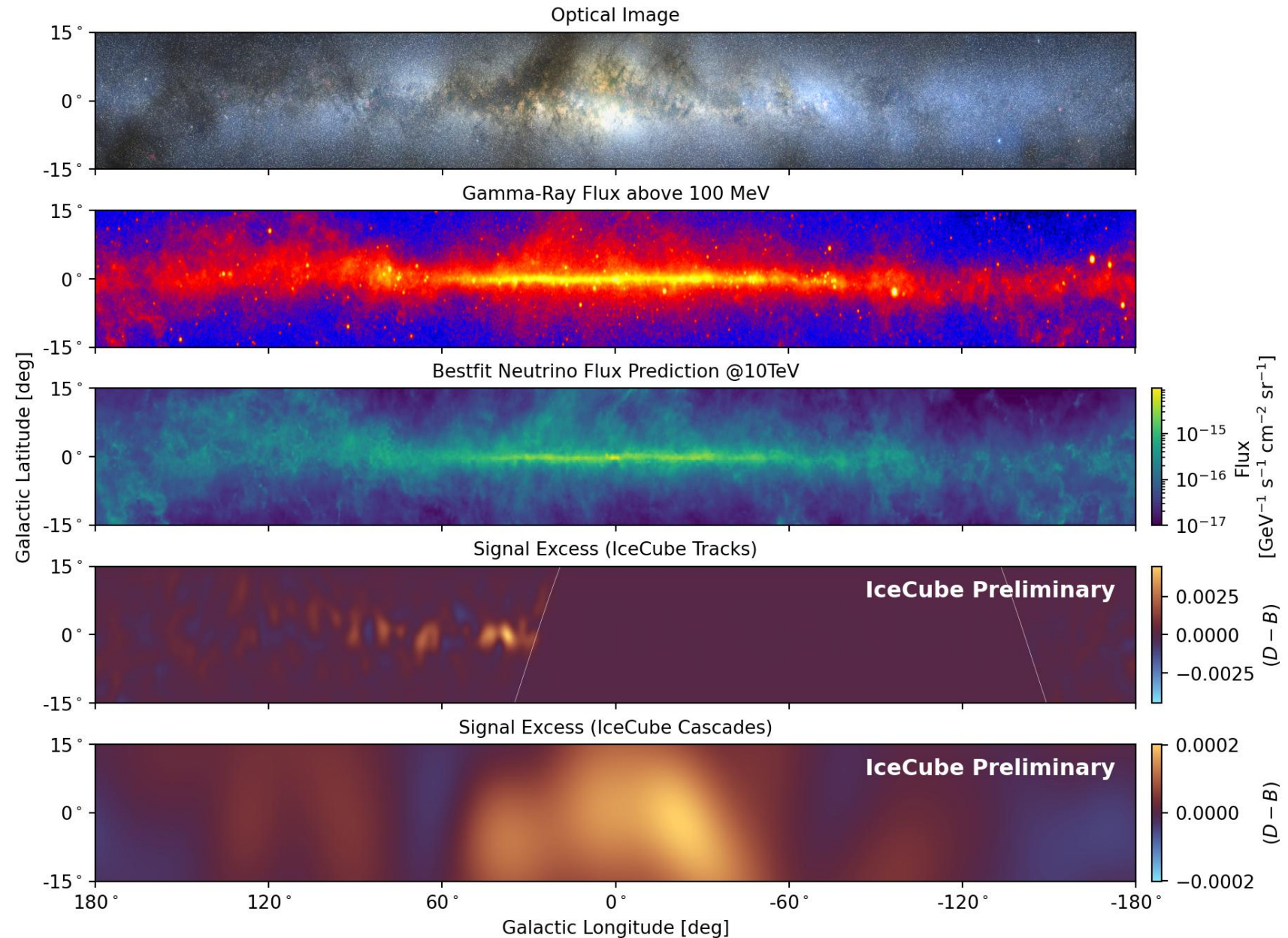
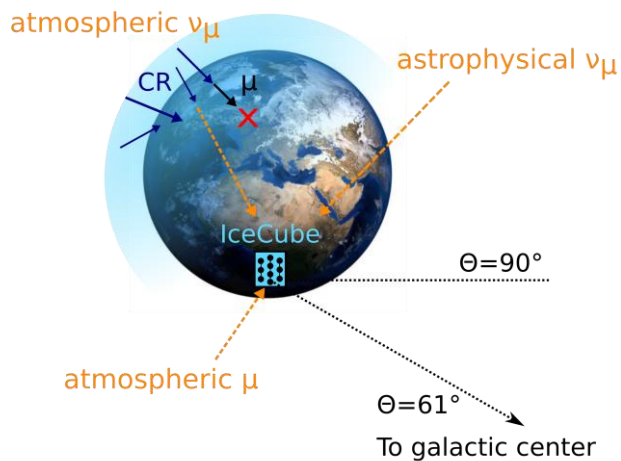
Backup



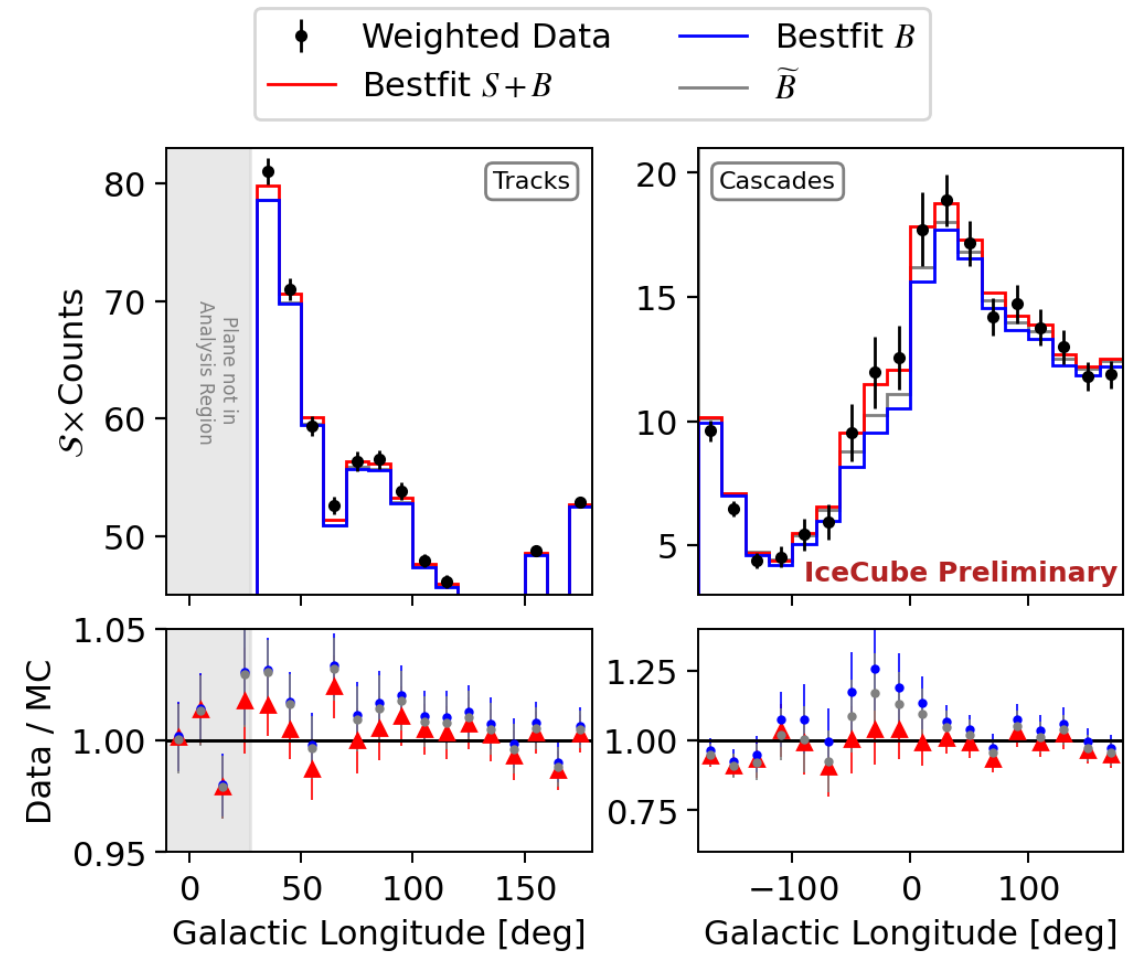
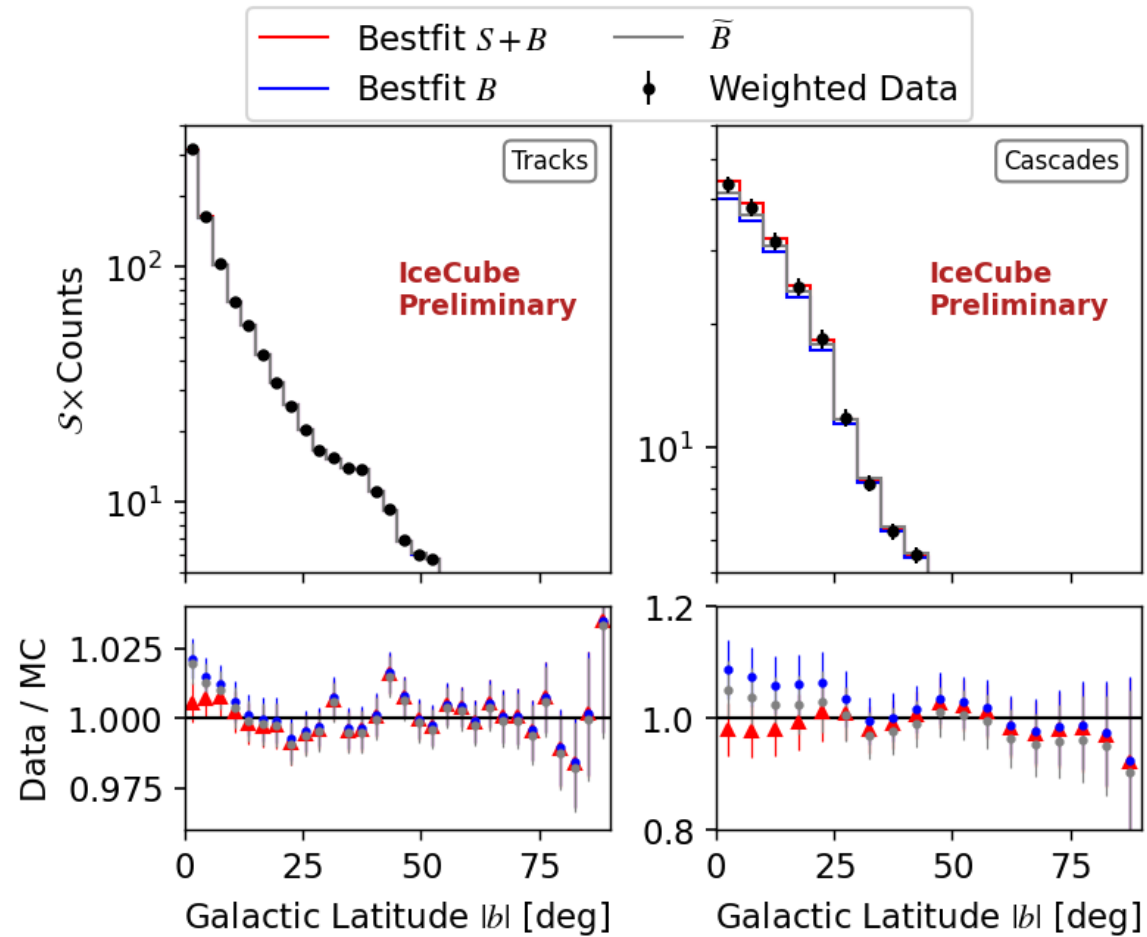
Visualizing the Neutrino Excess from the Galactic Plane

Galactic Plane Excess

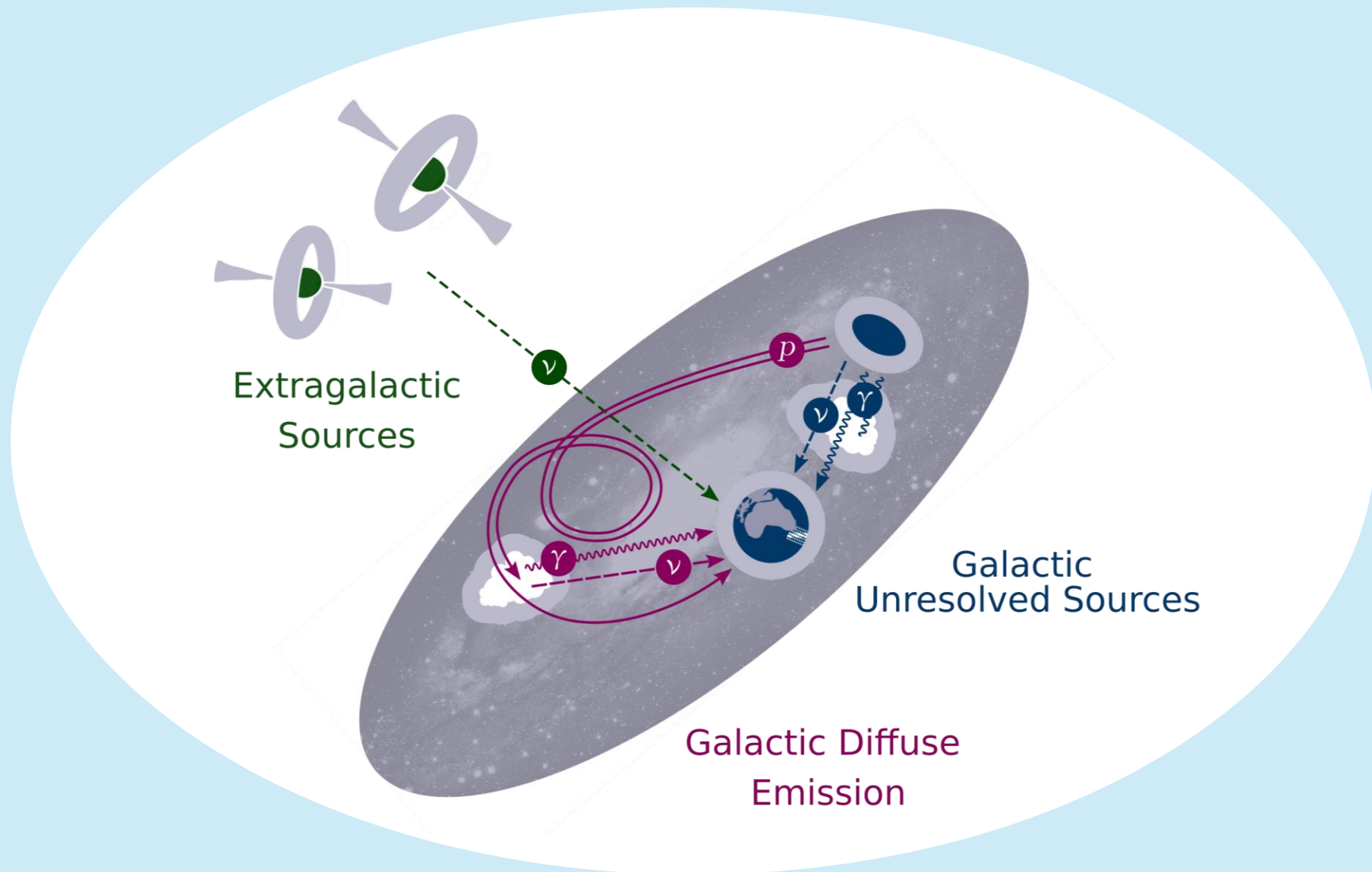
- Subtract fitted backgrounds B from data D
- Transform analysis binning to GP coordinates
- Weight with signalness: $S/(S+B)$
- Smoothing with avg. bin size



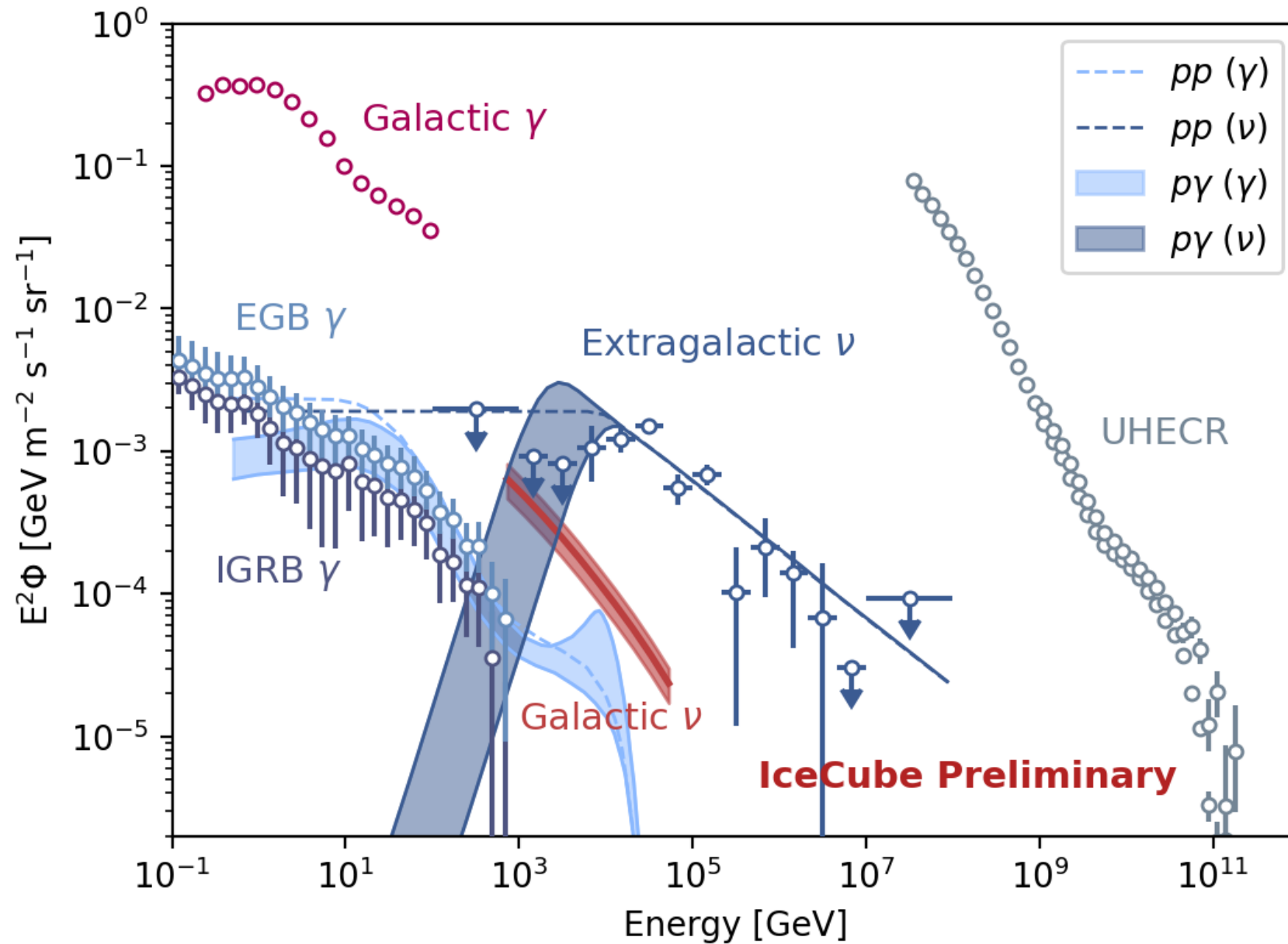
Signal Visualization: Galactic Latitude and Longitude



The Multimessenger Picture



Are Extragalactic Sources Gamma-Ray Obscured?



Are Extragalactic Sources Gamma-Ray Obscured?



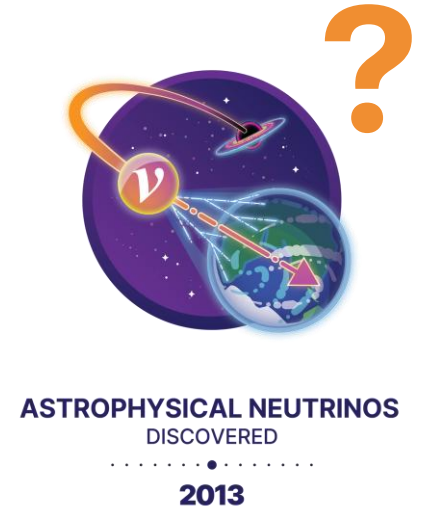
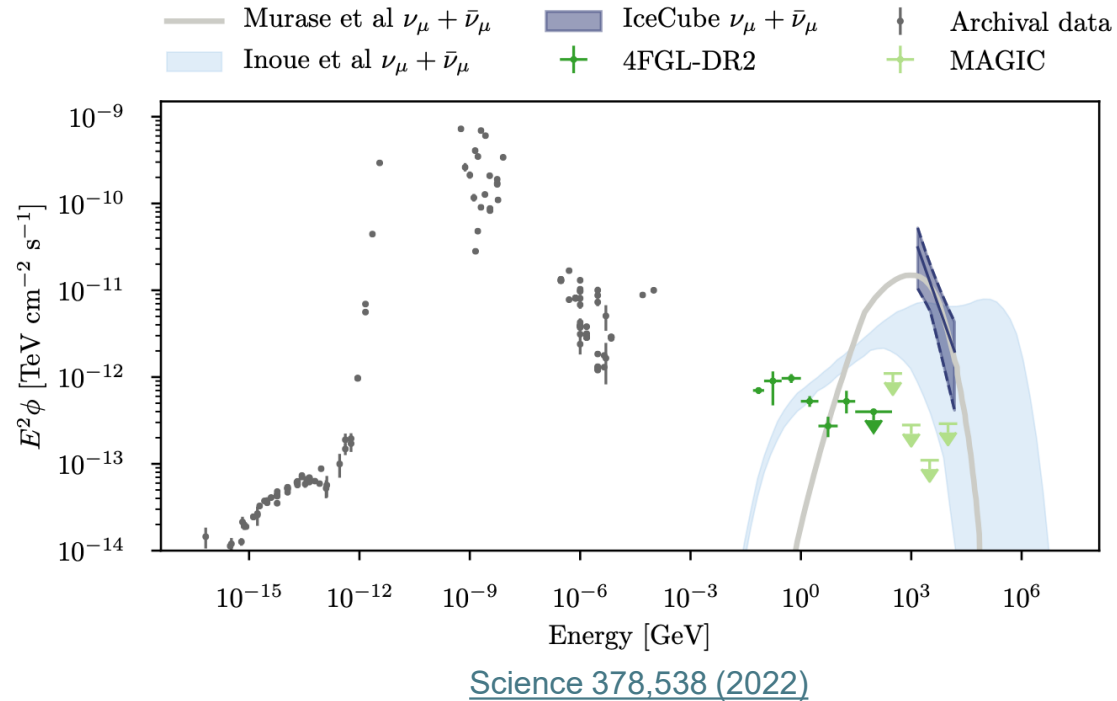
$$\pi^0 \rightarrow \gamma + \gamma$$

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

$$\downarrow$$

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

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

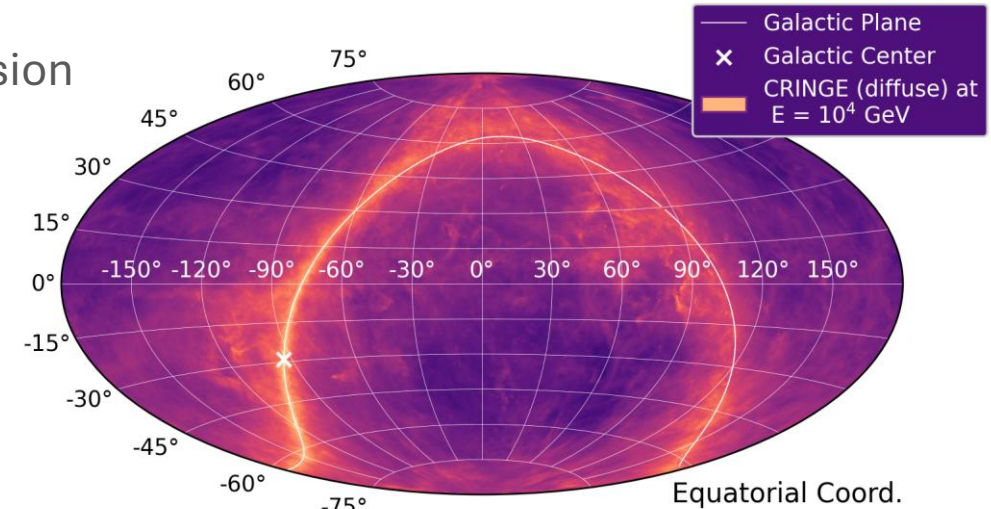


Models for Galactic Diffuse Emission

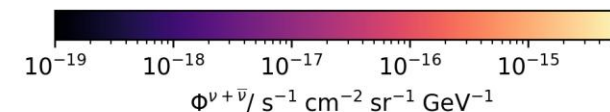
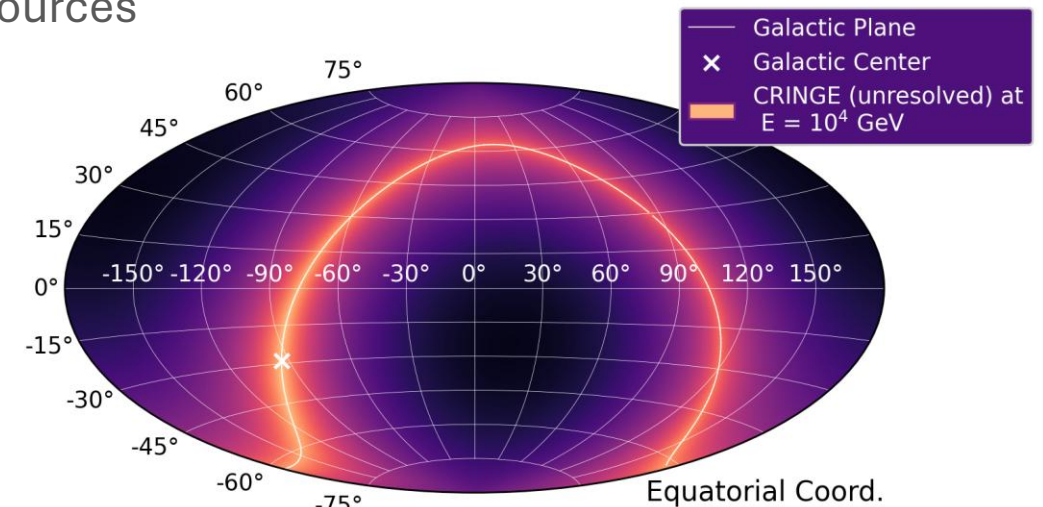
Solve CR transport equation & line-of-sight integral towards Earth

- **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 $\rightarrow$



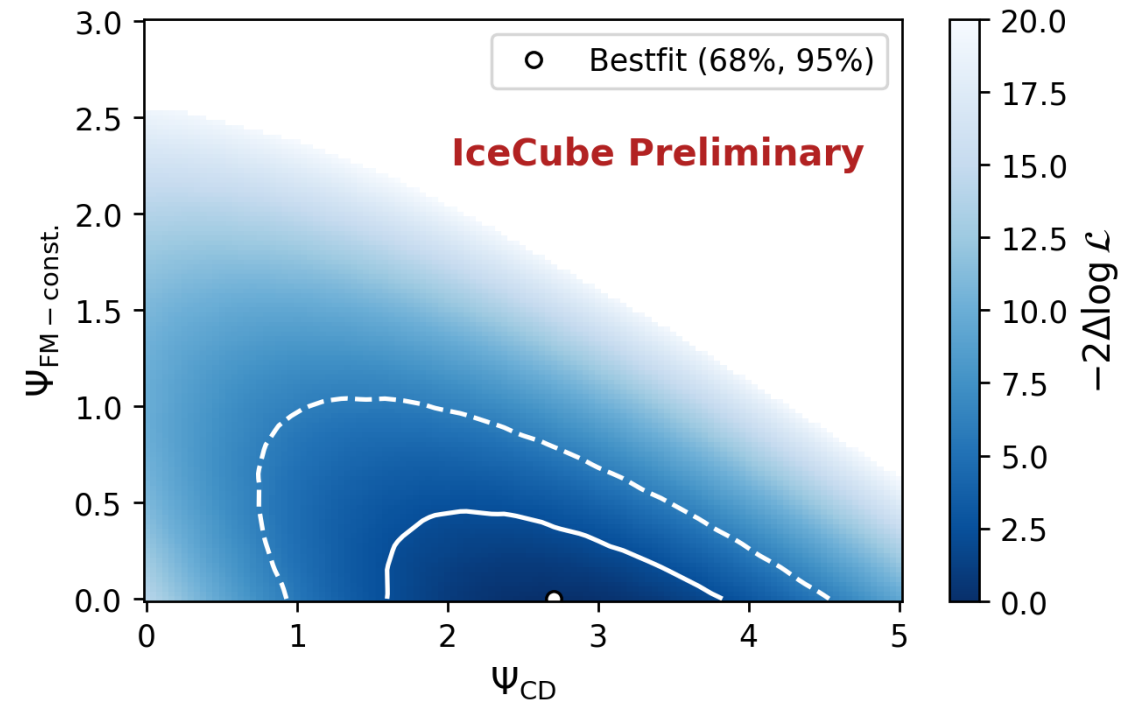
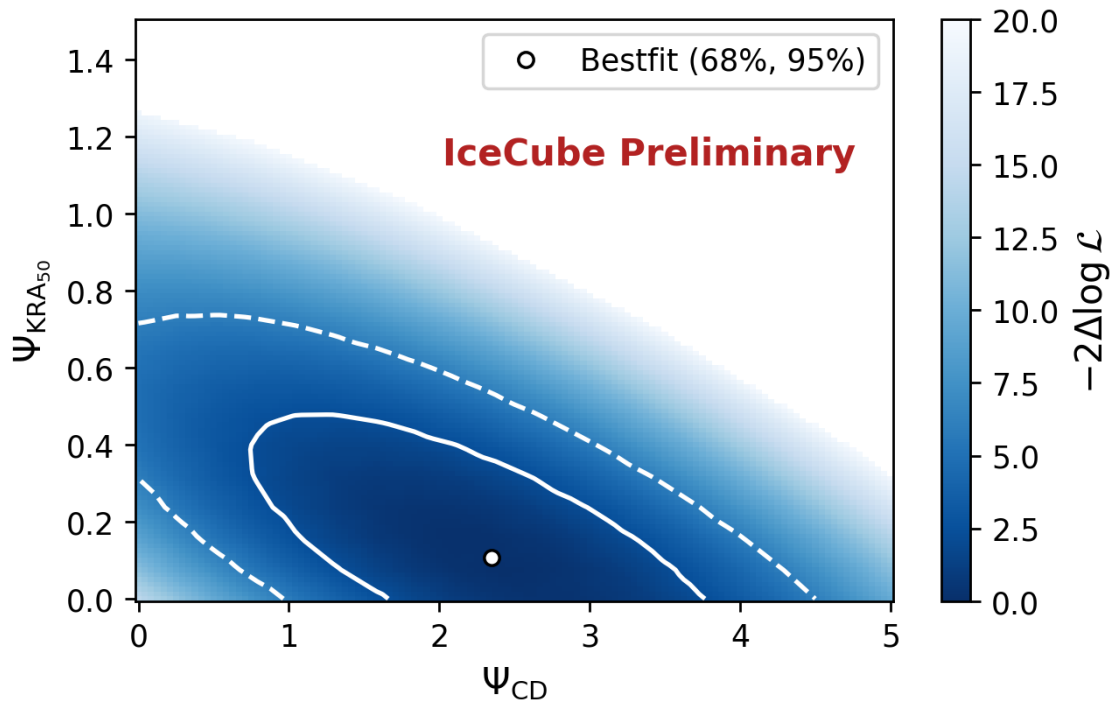
Unresolved sources template $\rightarrow$



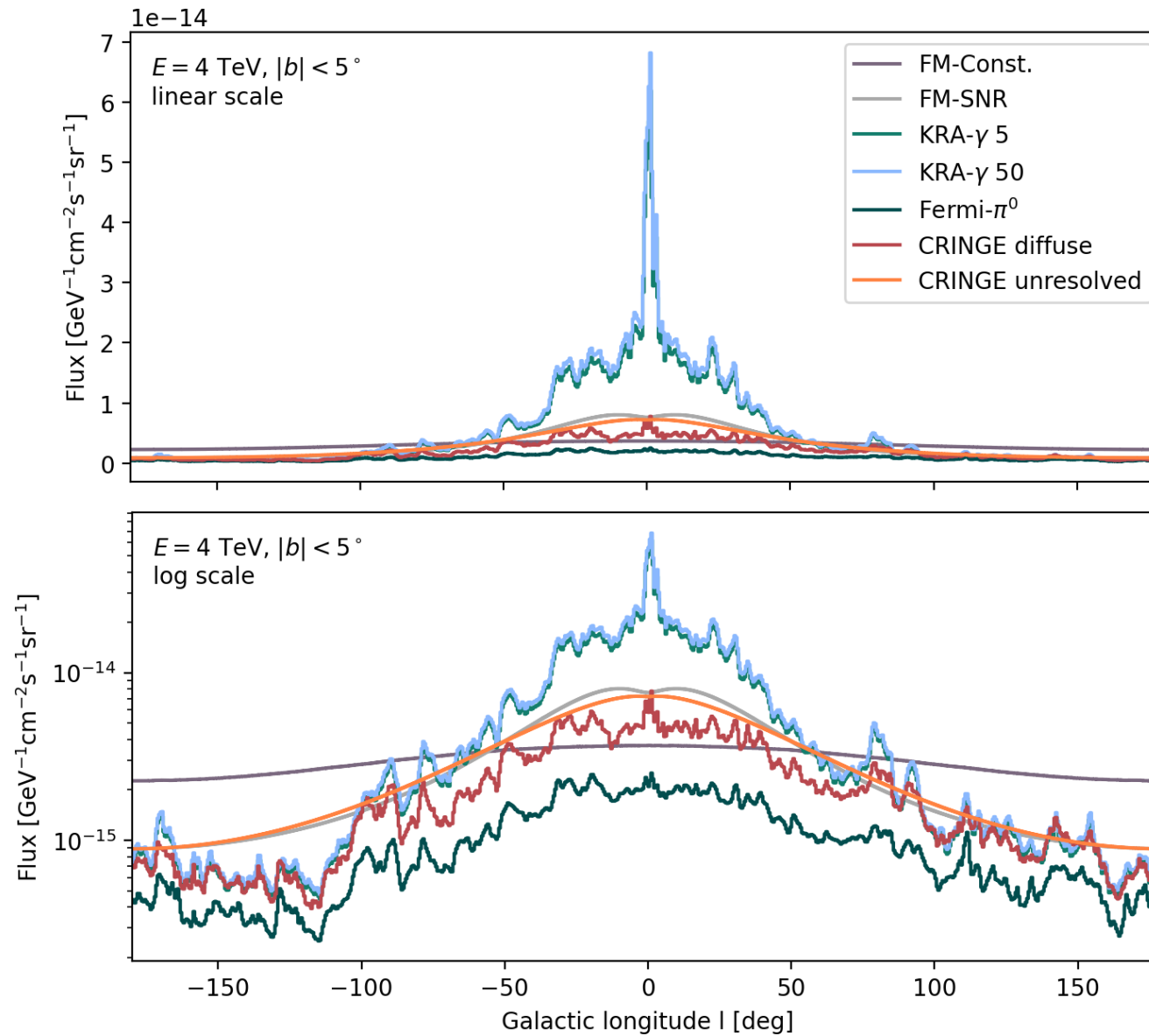
Model Differentiation?

- 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

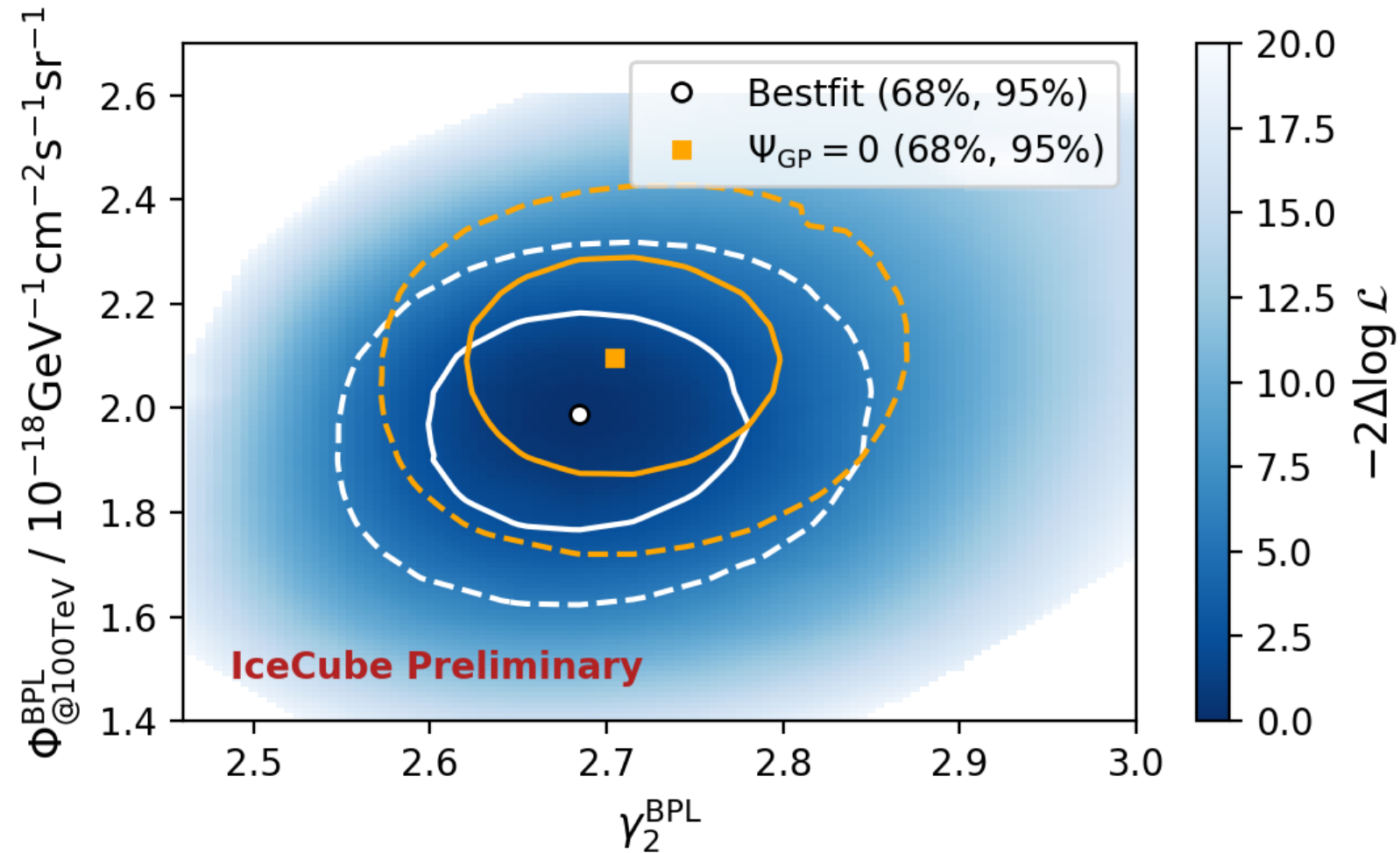
The galactic plane is not just a homogeneously „neutrino-glowing“ disk



Scales of Flux Predictions



Effect of GP on the >40 TeV Extragalactic Spectrum

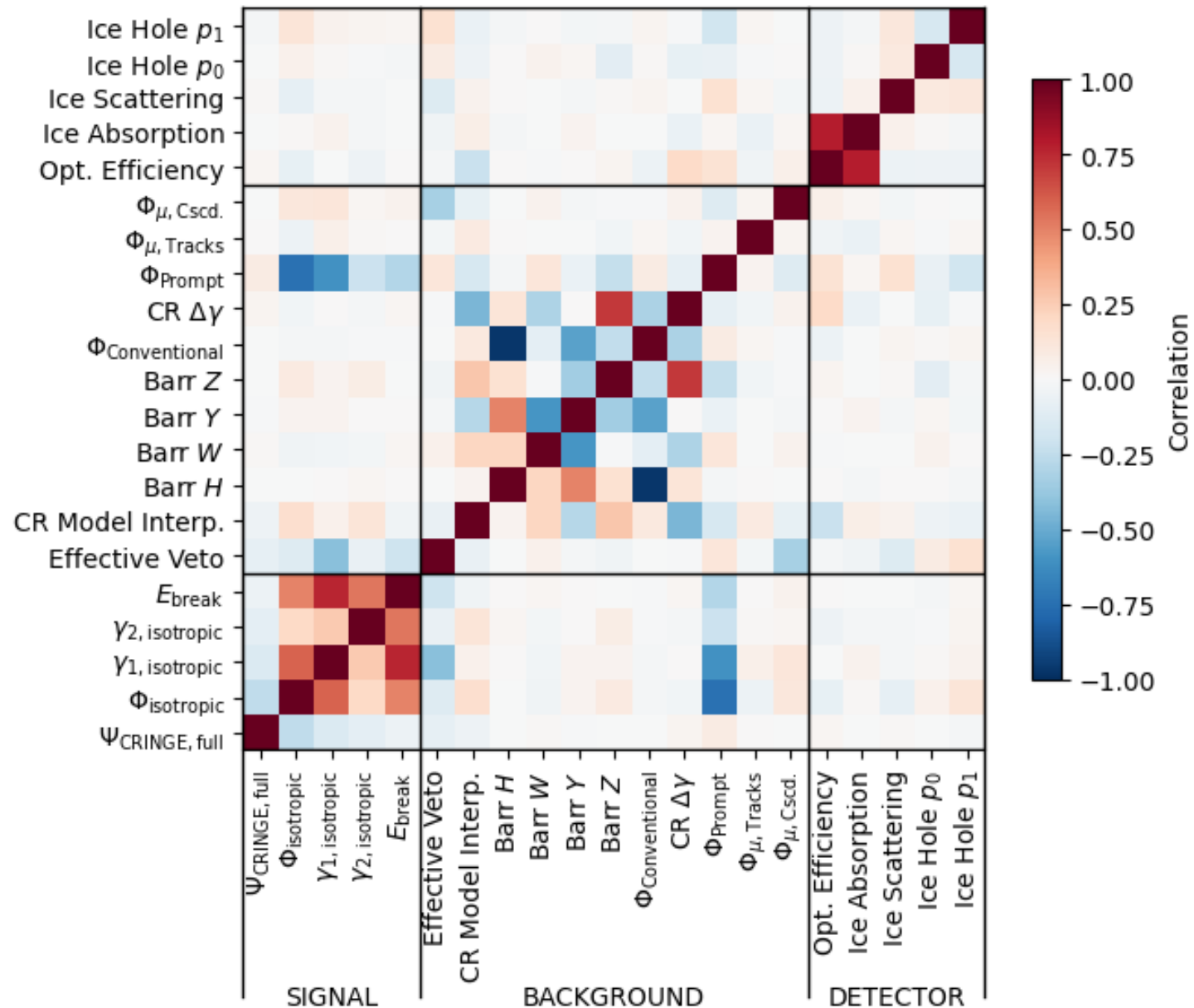
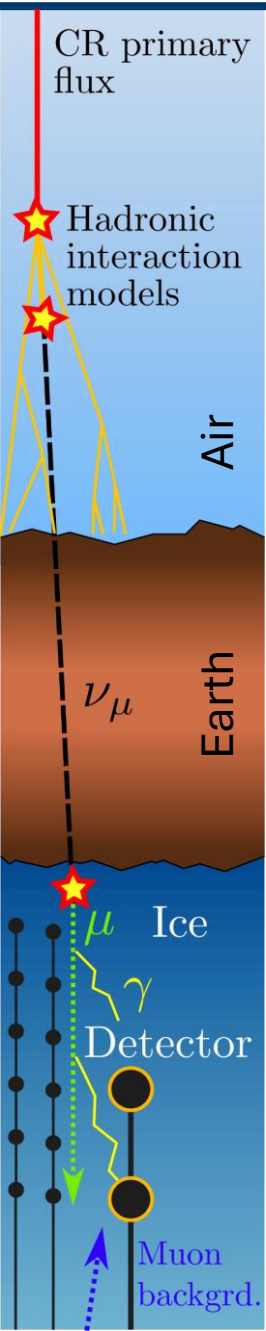


Comparison to Previous Analyses

Parameter	SPL	BPL	Log-P	Segmented
ϕ_0	$1.88^{+0.10}_{-0.09}$	$2.0^{+0.12}_{-0.14}$	$2.3^{+0.15}_{-0.14}$	—
γ_{SPL}	$2.47^{+0.023}_{-0.027}$	—	—	—
γ_1	—	$1.2^{+0.4}_{-0.7}$	—	—
γ_2	—	$2.68^{+0.06}_{-0.06}$	—	—
E_{break}	—	$22 \pm 5 \text{ TeV}$	—	—
α_{LP}	—	—	$2.54^{+0.05}_{-0.04}$	—
β_{LP}	—	—	$0.28^{+0.08}_{-0.06}$	—
$\Psi_{\text{CRINGE-diffuse}}$	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 $[\phi_0(\Lambda)^{-\gamma} e^{(-E_\nu/E_{\text{cutoff}})}]$	BPL $[\phi_{0,\text{broken}}(E_\nu/E_{\text{break}})^{-\gamma_{\text{BPL}}}]$	LP $[\phi_0(\Lambda)^{-\alpha_{\text{LP}}-\beta_{\text{LP}} \log_{10}(\Lambda)}]$
MESE	$\phi_0 = 2.13^{+0.18}_{-0.17}$ $\gamma = 2.55^{+0.04}_{-0.04}$	$\phi_0 = 3.98^{+1.14}_{-1.32}$ $\gamma = 2.16^{+0.23}_{-0.16}$ $\log_{10}(E_{\text{cutoff}}/\text{GeV}) = 5.40^{+0.51}_{-0.23}$ $-2\Delta \ln \mathcal{L} = 1.8$	$\phi_0 = 2.28^{+0.22}_{-0.20}$ $\gamma_1 = 1.72^{+0.26}_{-0.35}$ $\gamma_2 = 2.84^{+0.11}_{-0.09}$ $\log_{10}(E_{\text{break}}/\text{GeV}) = 4.52^{+0.11}_{-0.09}$ $-2\Delta \ln \mathcal{L} = 27.3$	$\phi_0 = 2.58^{+0.26}_{-0.26}$ $\alpha_{\text{LP}} = 2.67^{+0.13}_{-0.06}$ $\beta_{\text{LP}} = 0.36^{+0.10}_{-0.08}$ $-2\Delta \ln \mathcal{L} = 18.8$
CF	$\phi_0 = 1.80^{+0.13}_{-0.16}$ $\gamma = 2.52^{+0.04}_{-0.04}$	$\phi_0 = 2.20^{+0.30}_{-0.25}$ $\gamma = 2.39^{+0.08}_{-0.08}$ $\log_{10}(E_{\text{cutoff}}/\text{GeV}) = 6.15^{+0.37}_{-0.24}$ $-2\Delta \ln \mathcal{L} = 7.5$	$\phi_0 = 1.77^{+0.15}_{-0.11}$ $\gamma_1 = 1.31^{+0.50}_{-1.21}$ $\gamma_2 = 2.74^{+0.06}_{-0.07}$ $\log_{10}(E_{\text{break}}/\text{GeV}) = 4.39^{+0.09}_{-0.08}$ $-2\Delta \ln \mathcal{L} = 24.7$	$\phi_0 = 2.13^{+0.16}_{-0.19}$ $\alpha_{\text{LP}} = 2.57^{+0.06}_{-0.05}$ $\beta_{\text{LP}} = 0.23^{+0.10}_{-0.07}$ $-2\Delta \ln \mathcal{L} = 16.4$

Fit Parameters



THE HISTORY OF Neutrino Astronomy *in* Antarctica

But First:



ICECUBE
NEUTRINO OBSERVATORY