Correlation of High-Energy Neutrinos with *Fermi*-LAT Diffuse Galactic Emission

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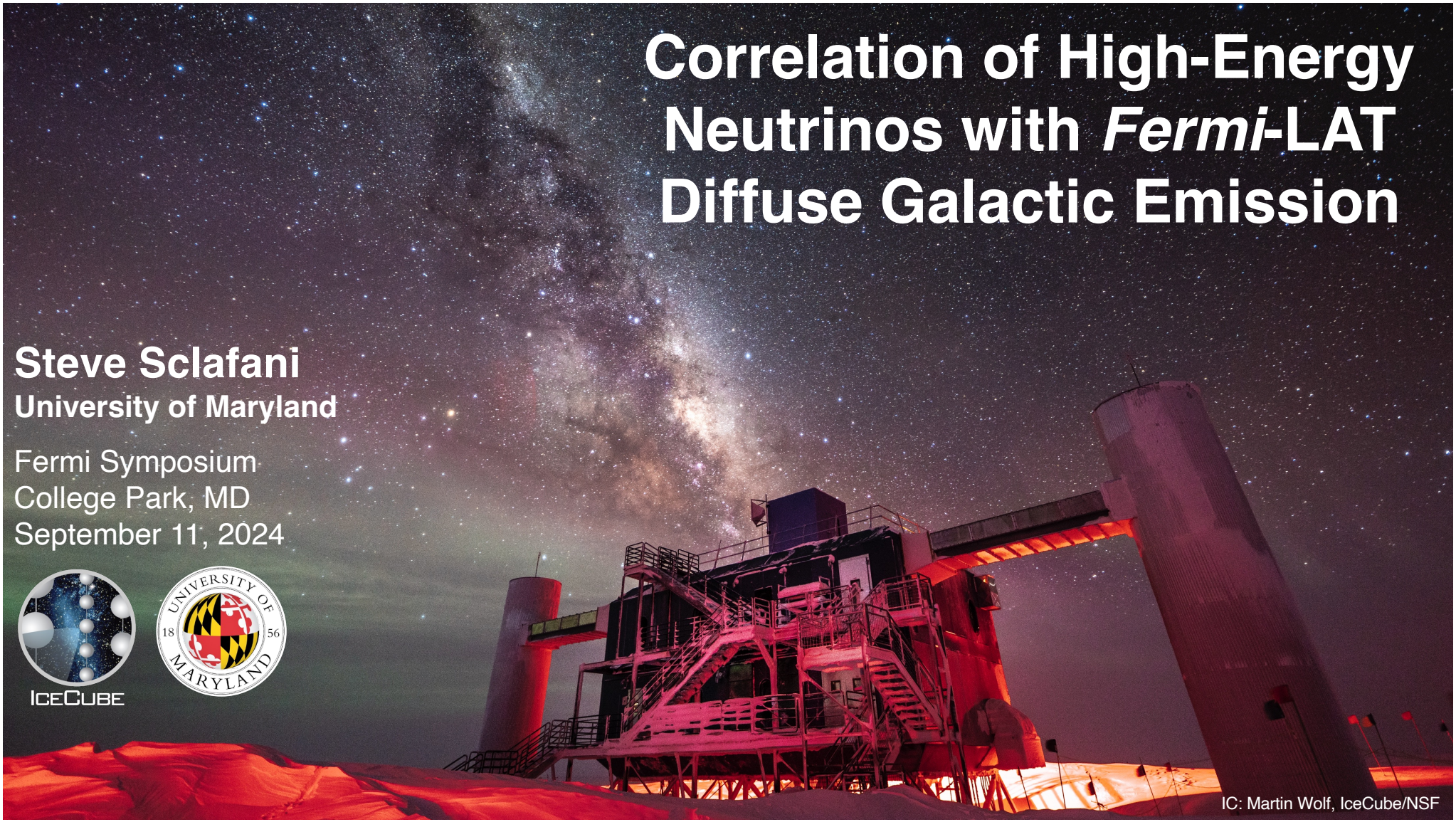
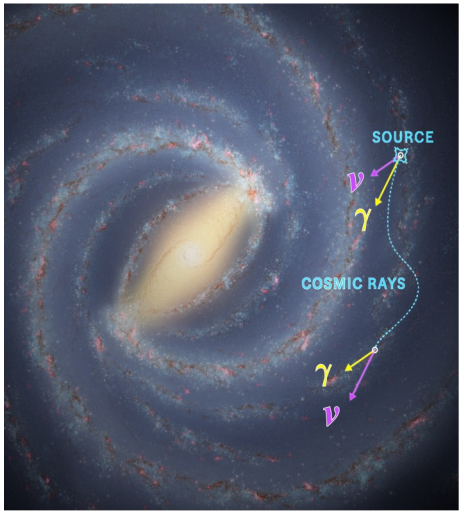
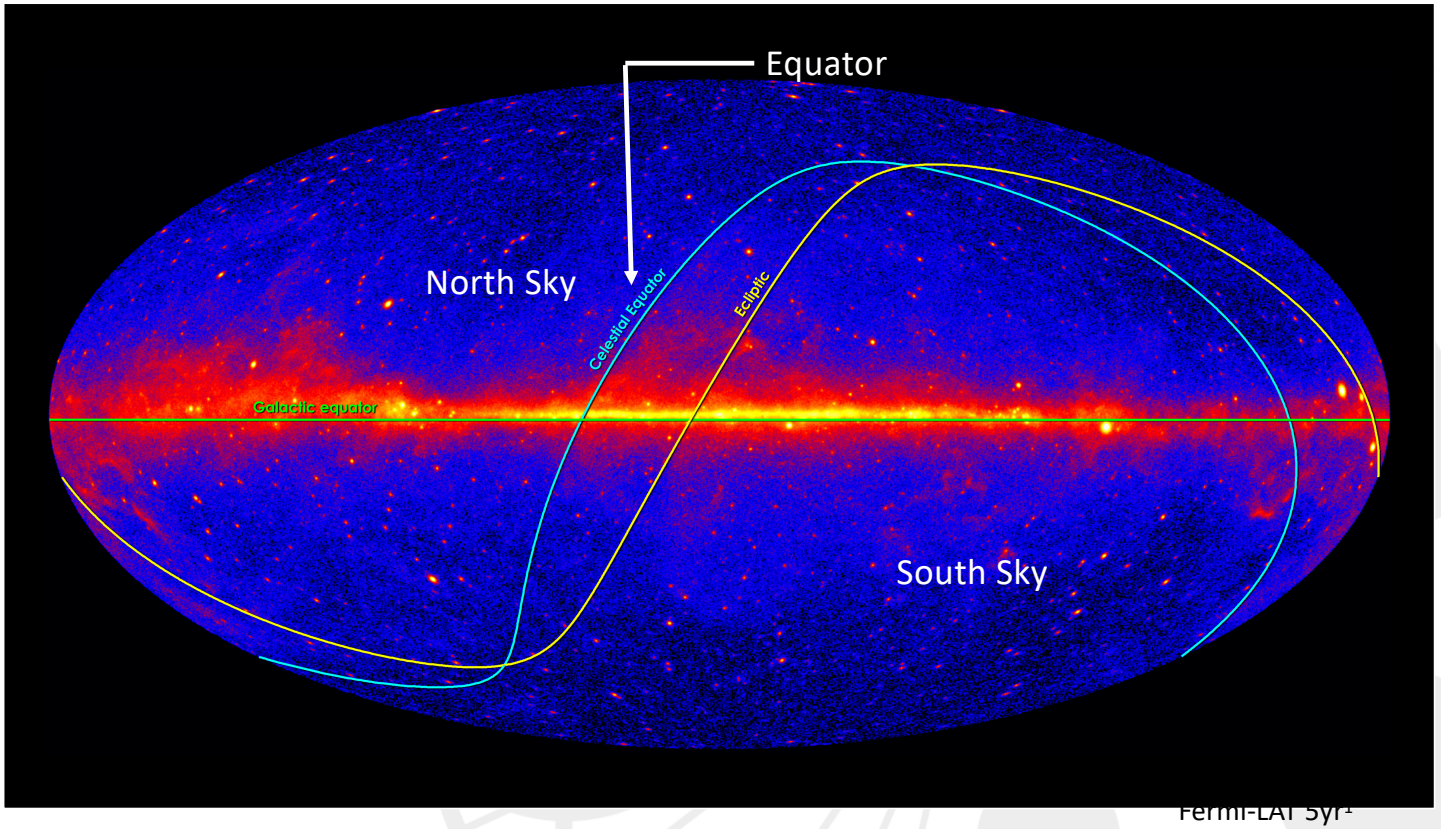


Gamma Ray Sky

- Gamma-ray sky dominated by Galactic Plane
- Diffuse Galactic emission: From CR interactions with matter



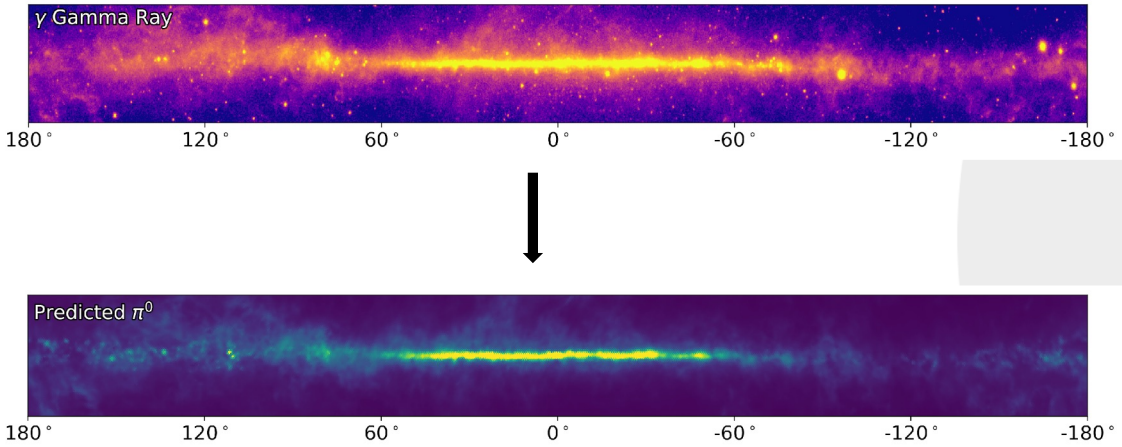


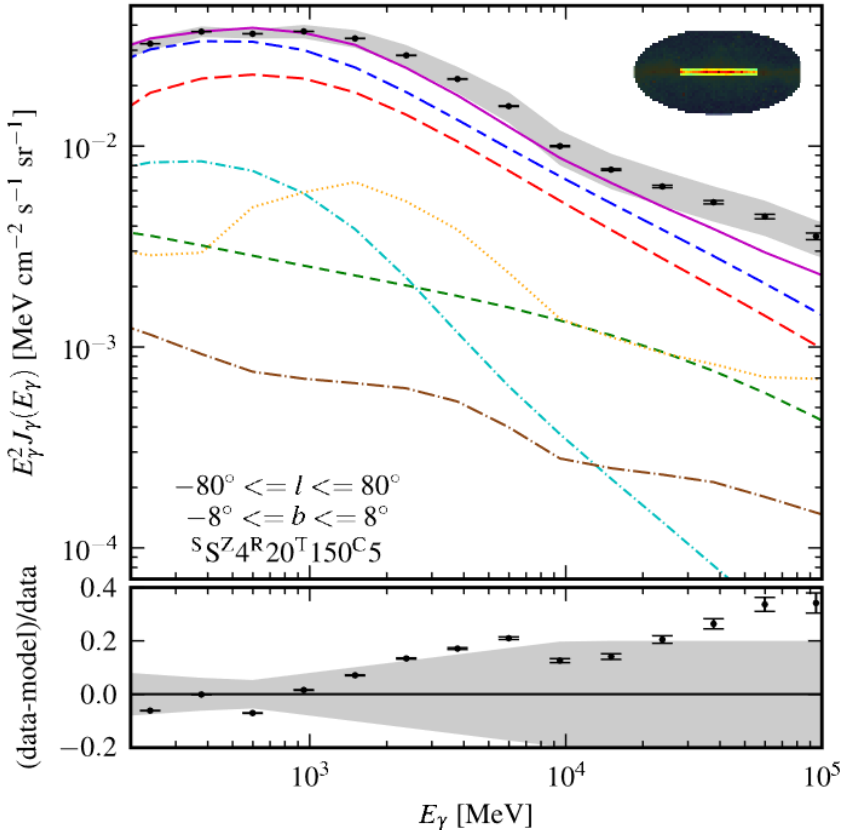
Fermi-LAT 5yr[1]

1. NASA/DOE/*Fermi* LAT Collaboration: https://svs.gsfc.nasa.gov/11342

Diffuse Galactic Emission

- Diffuse Galactic Emission (DGE) from CR interactions with Milky Way gas
- *Fermi*-LAT measurement in 2012
- Fit DGE based on models and measurements of CR, gas, sources
- DGE at high energies mostly pion decay following an $E^{-2.7}$ spectrum
- Expected Neutrino Counterpart



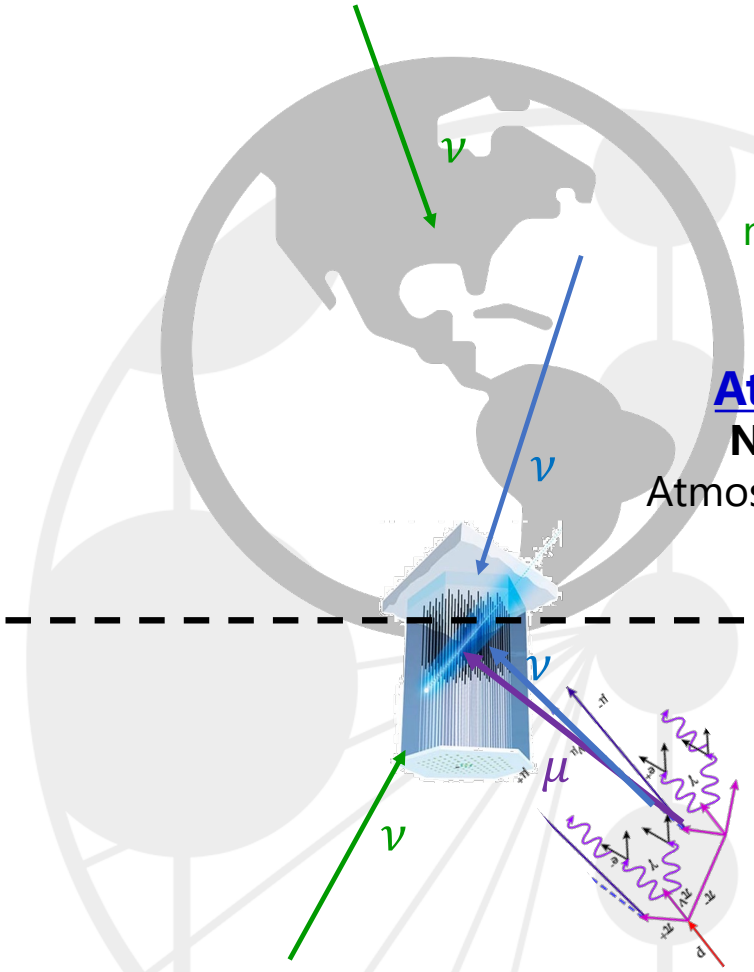


- - Total Diffuse Galactic Emission
-- Total including sources and iso. background
- - Pion Decay
- - IC
- . Bremsstrahlung

1. Ackermann et al. *The Astrophysical Journal* 750, no. 1 (April 2012): 3. https://doi.org/10.1088/0004-637X/750/1/3.

Diffuse Galactic Neutrinos

- Expect neutrino counterpart
- **Why is it difficult to detect in neutrinos?**
  - IceCube optimal sensitivity for point sources in the northern sky
    - Reduced atmospheric muon background
    - Clustering of signal like events detectable over background
- Galactic plane is:
  - Extended
  - Largely southern sky
  - Softer spectrum
- Challenging region to probe for IceCube



Astrophysics: astrophysical neutrinos arriving isotropically

Atmospherics
Northern Sky
Atmospheric Neutrinos

Southern Sky
Atmospheric Muons
+
Atmospheric Neutrinos

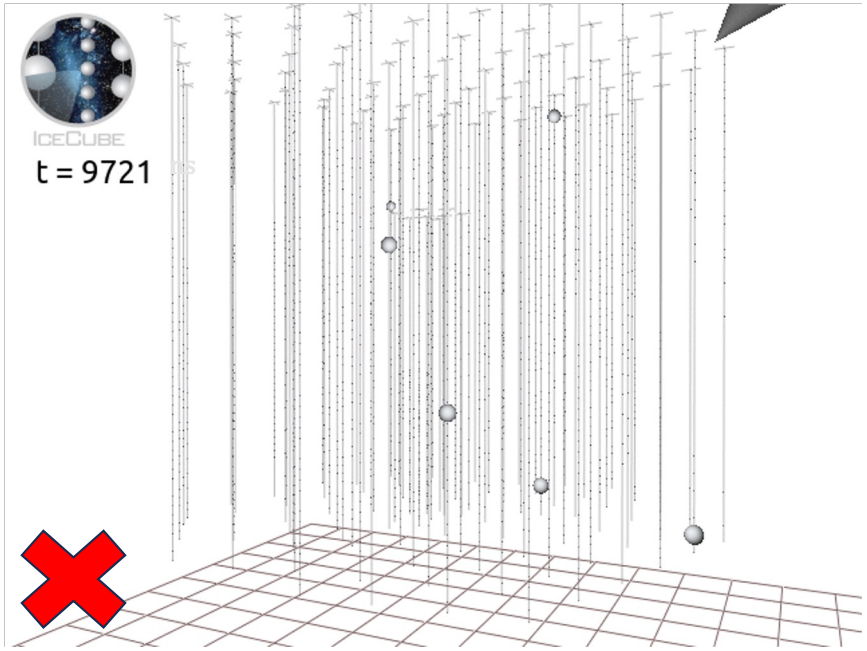
1. NASA/DOE/Fermi LAT Collaboration: https://svs.gsfc.nasa.gov/11342

Starting Cascade Events

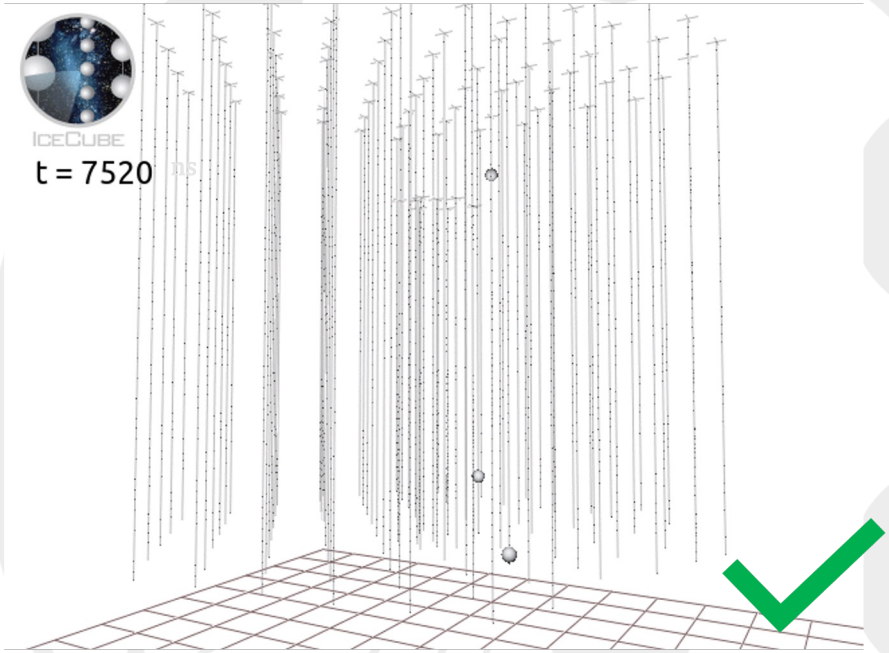
Track: $\nu_\mu + N \rightarrow \mu + X$
(mostly)

Cascade: $\nu_{e/\tau} + N \rightarrow e/\tau + X$
$\nu_x + N \rightarrow \nu_x + X$

Good Pointing (0.5°)
Large Southern Sky Atmospheric Muon Background

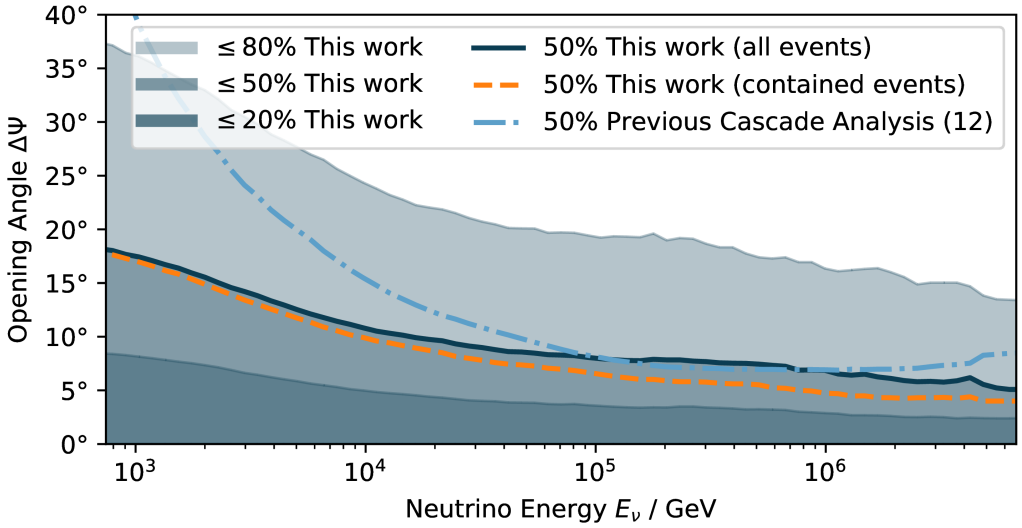


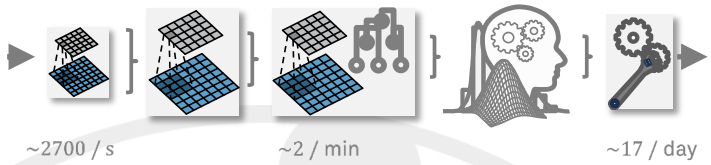
Poor Pointing (10°)
Reduced Atmospheric Background

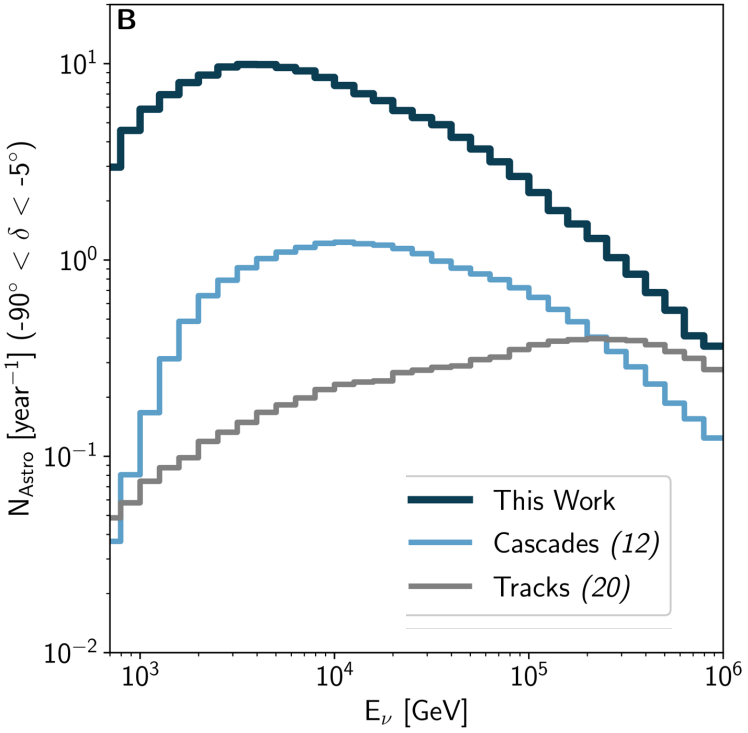


New Cascade Event Sample

- 10 years of cascade-like events
  - 60,000 events
  - 30x more events than previous cascade selection
- Improved angular resolution
- **3-4x Sensitivity**





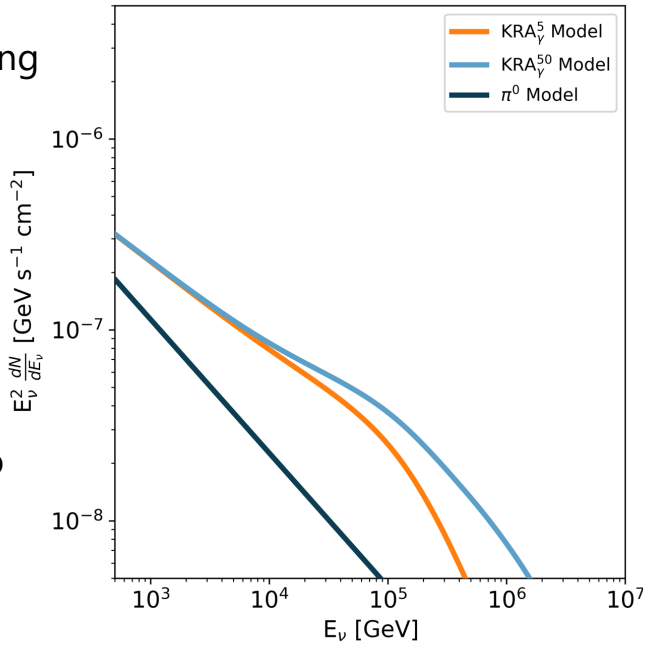


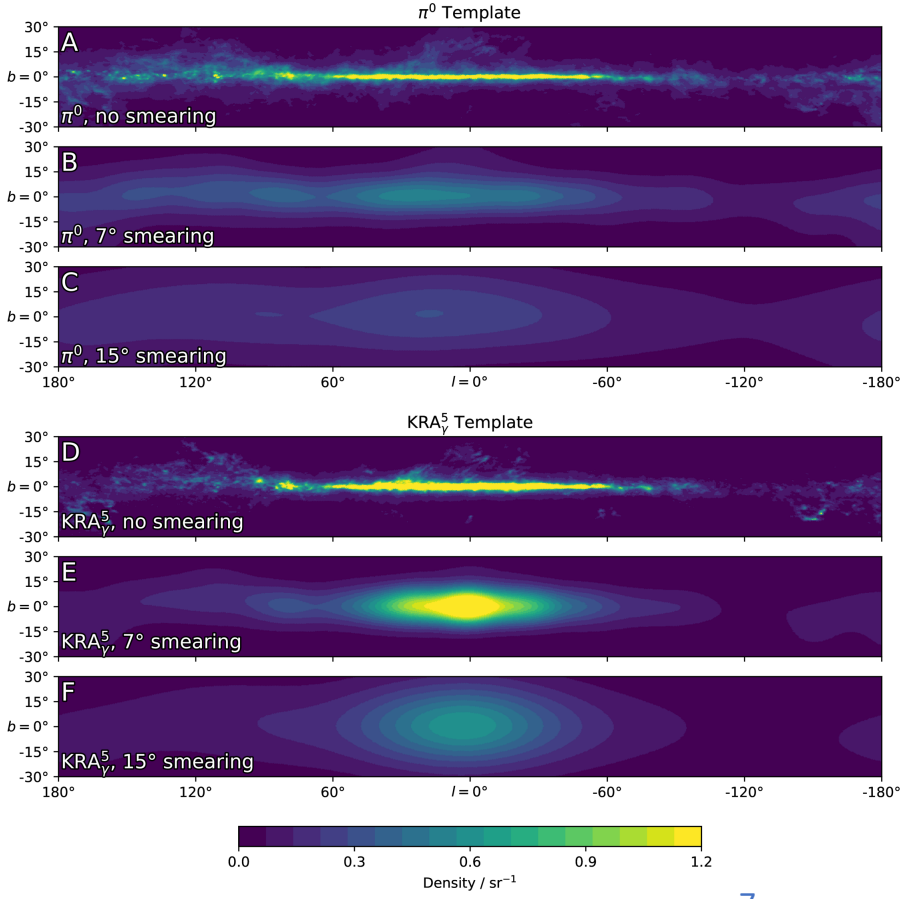
IceCube Collaboration*†*Science* **380**,6652 1338-1343(2023).DOI:10.1126/science.adc9818
IceCube Collaboration, M. Huennefeld et al. PoS ICRC2021 (2021) 1065

Models of Galactic Emission

- <u>(3) diffuse models as spatial / spectral templates</u>

- Spatial Template accounting for neutrino event uncertainty
- (1) *Fermi* π^0
- (2) KRAγ
- Fixed spectrum
- Fit for flux normalization
- Compare with pseudo experiments using data to model background



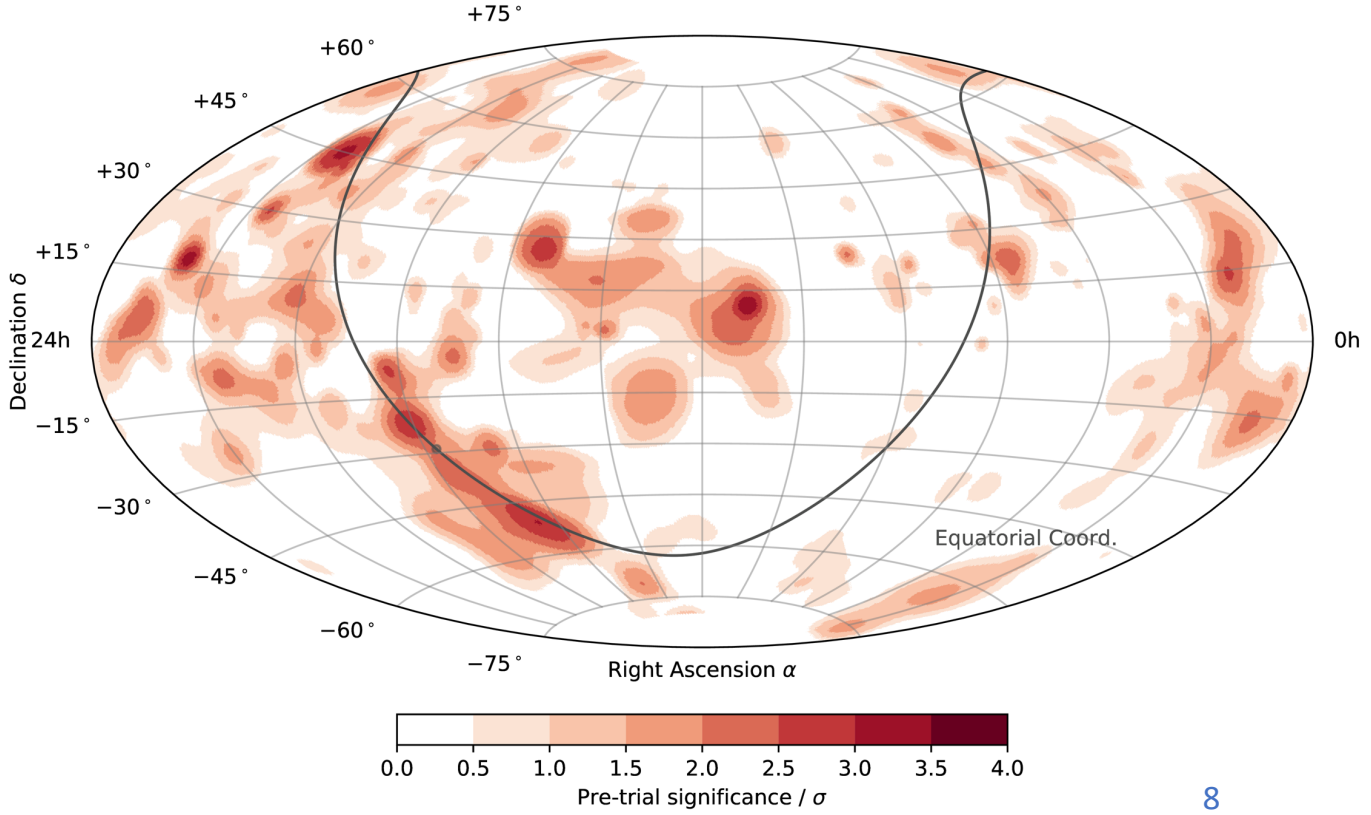


1. Ackermann et al. *The Astrophysical Journal* 750, no. 1 (April 2012): 3. https://doi.org/10.1088/0004-637X/750/1/3.
2. Gaggero et al *The Astrophysical Journal* 815, no. 2 (December 2015): L25. https://doi.org/10.1088/2041-8205/815/2/L25.

Results

- **This work has identified High-Energy neutrinos from the Milky Way galaxy for the first time**
  - Global significance of 4.5σ
- Skymap no individually significant points but clustering along plane

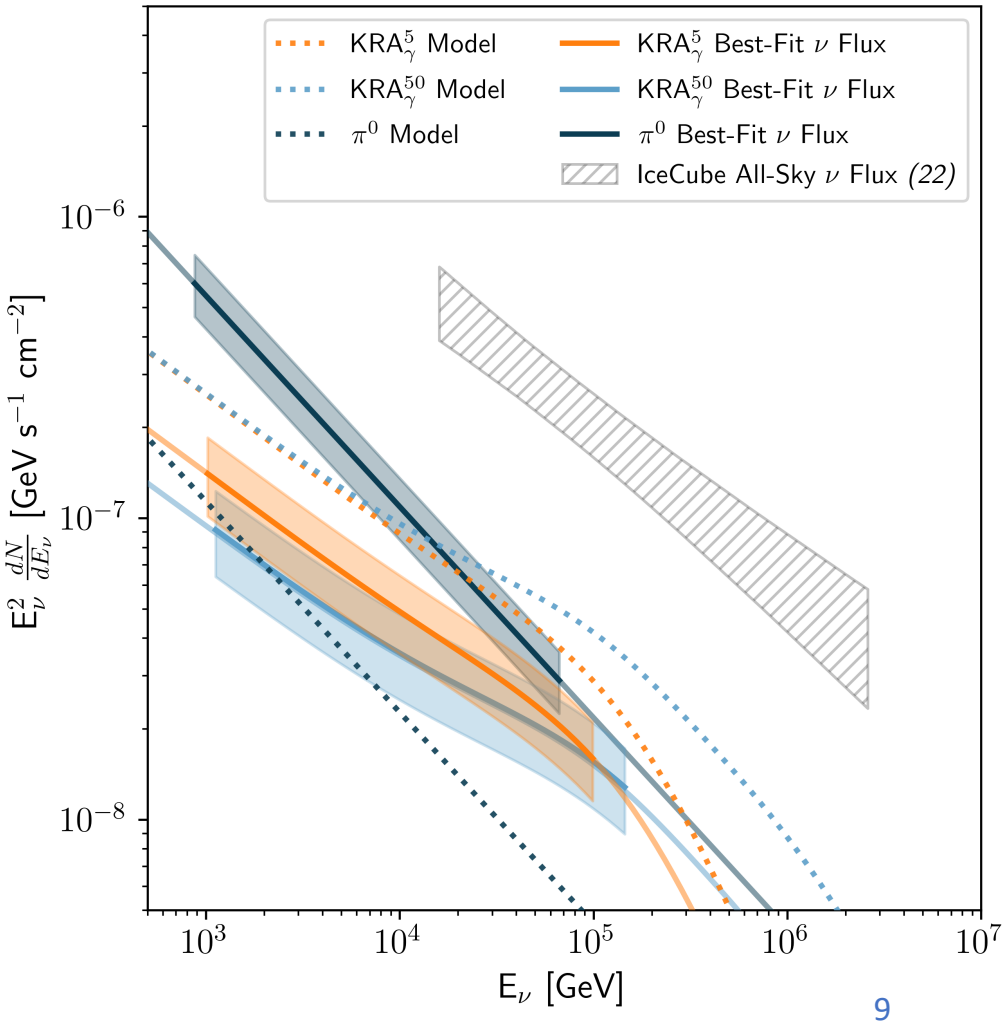
Diffuse Galactic plane analyses	Flux sensitivity Φ	p-value	Best-fitting flux Φ
π^0	5.98	1.26×10^{-6} (4.71σ)	$21.8\ ^{+5.3}_{-4.9}$
$\mathrm{KRA}^{5}_{\gamma}$	$0.16\times$MF	6.13×10^{-6} (4.37σ)	$0.55^{+0.18}_{-0.15}\times$MF
$\mathrm{KRA}^{50}_{\gamma}$	$0.11\times$MF	3.72×10^{-5} (3.96σ)	$0.37^{+0.13}_{-0.11}\times$MF



The IceCube Collabortaion *Science* 380, 6652 (June 2023)

Diffuse Galactic Flux

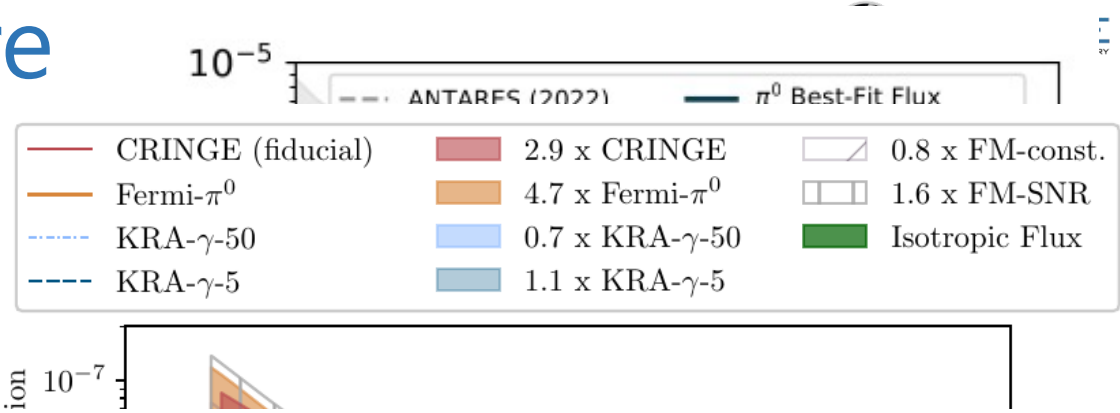
- ~10% of extragalactic flux
- ~5x emission predicted from just extending *Fermi*-LAT pion decay to higher energies, converting γ to ν
  - Source contamination
  - 12-year-old *Fermi*-LAT data
  - Newer models have higher energy data but combine IC + Brems. + pions
- Can be explained by a difference in spectra or emission region



The IceCube Collabortaion *Science* 380, 6652 (June 2023)

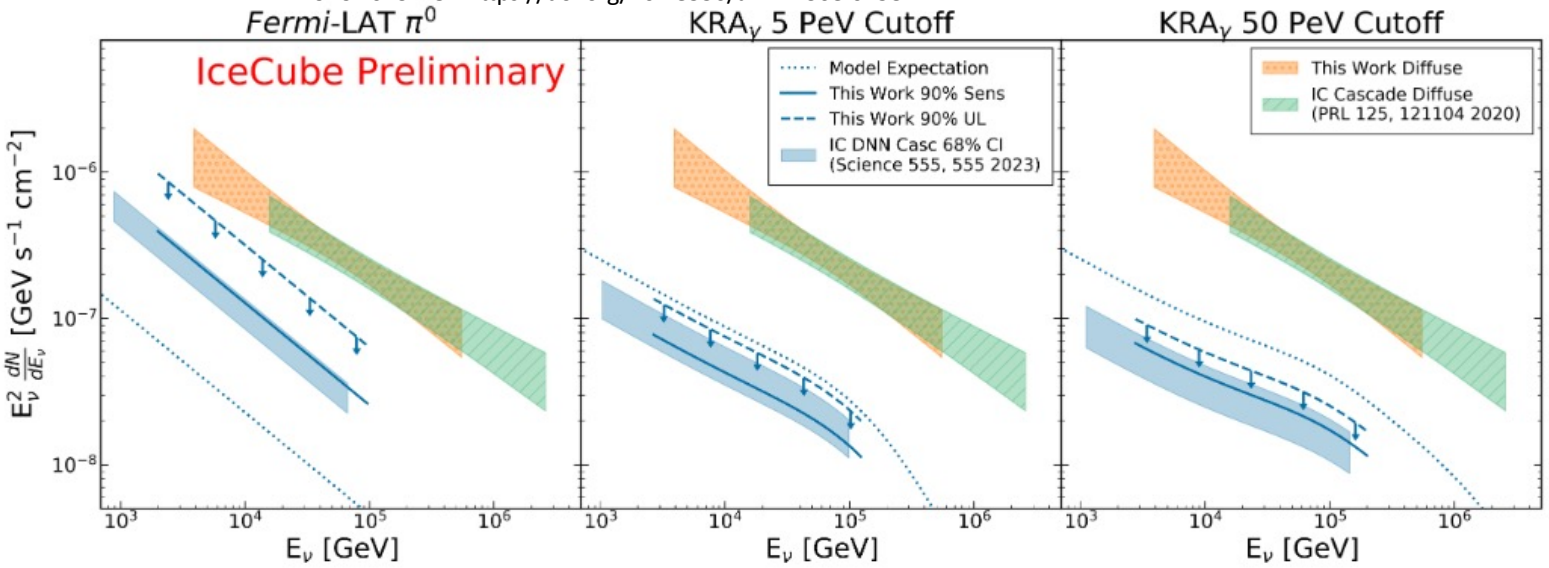
A Consistent Picture

- Consistent picture in other datasets /detectors:
- Next Step: Combine all IceCube data[1]
- Incorporate newer models



Starting Tracks

ICRC 2023 DOI: https://doi.org/10.48550/arXiv.2308.04582

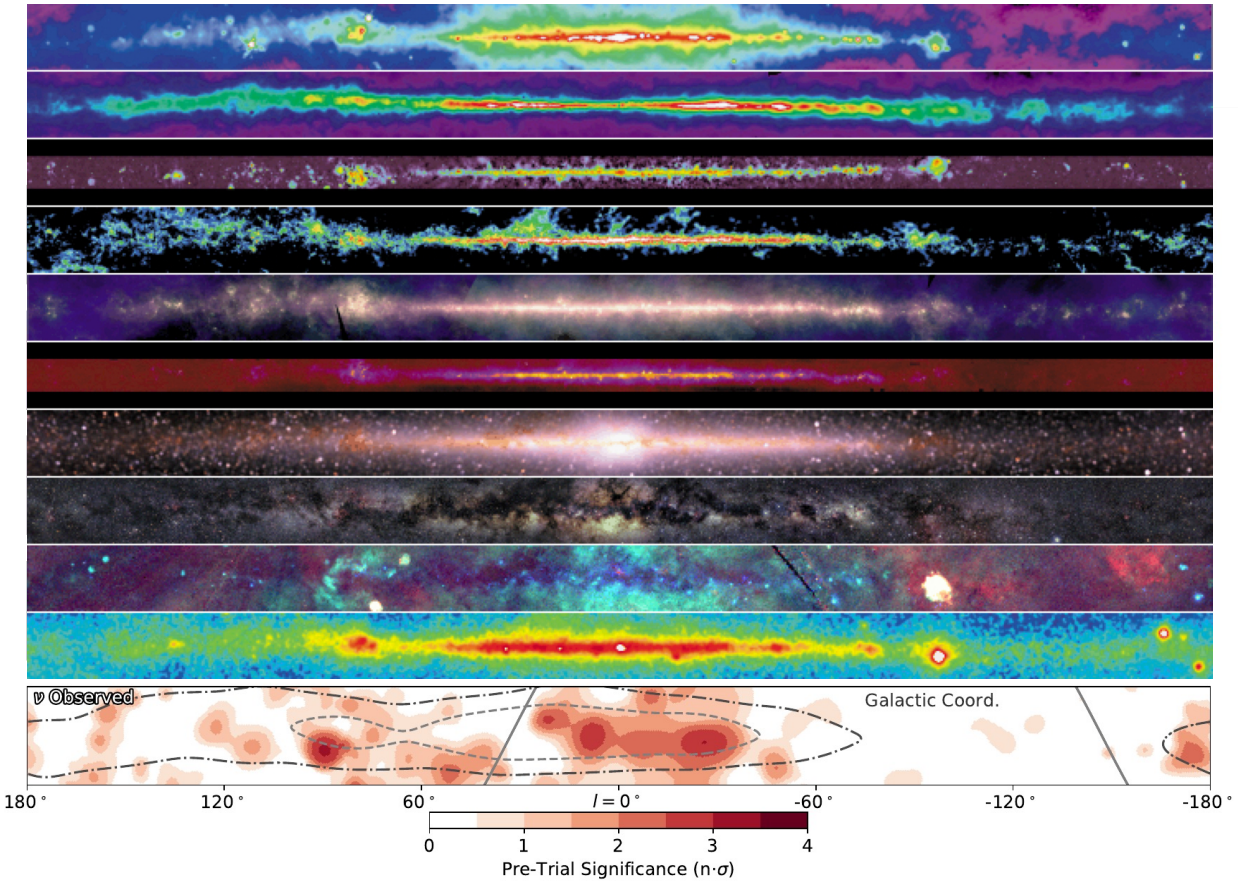


1. ICRC 2023 DOI: https://doi.org/10.22323/1.444.1010

ICRC 2023 DOI: https://doi.org/10.22323/1.444.1046

Conclusion

- Observation Galactic Plane in Neutrinos made possible by leveraging *Fermi*-LAT data
- Need newer models for emission
- Future of Diffuse Galactic Emission measurements including neutrinos




Thank You!
Questions?