X-ray: NASA/CXC/SAO/J. Drake et al. IR: NASA/JPL-Caltech/Spitzer; Image Processing: NASA/CXC/SAO/N. Wolk

Searching for Galactic PeVatrons with ICEMAN

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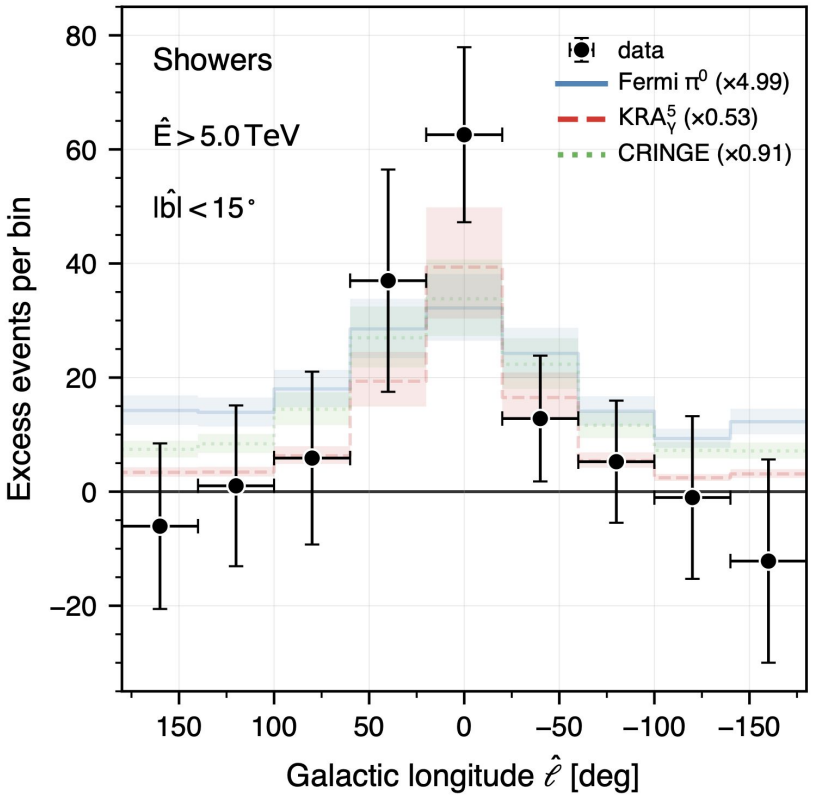
On behalf of the IceCube Collaboration

TeVPA 2026

Galactic neutrino emission

- The Galactic neutrino flux has been observed at 5.7σ
- Excess of events toward the inner Galaxy
- Potentially consists of two components
  - Emission from the Galactic cosmic-ray sea
  - Emission from cosmic-ray interactions within individual accelerators

https://arxiv.org/abs/2607.25966



Disentangling the origin of the Galactic neutrino flux

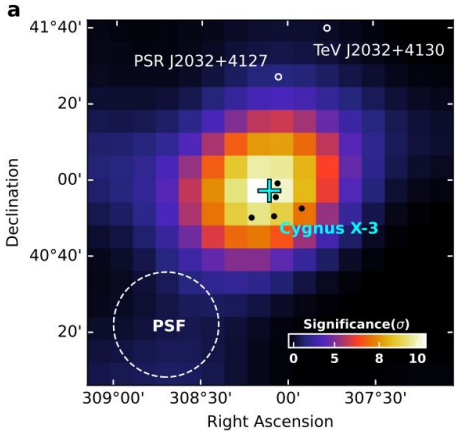
1. Direct search for individual accelerators [This work]
2. Fit source populations and diffuse [Upcoming work]

- In both cases, need multi-messenger driven approach
- γ-rays are tracers of hadronic and leptonic processes
    - Proton-proton, proton-γ interactions
    - Inverse-compton scattering, Synchrotron radiation, Bremsstrahlung radiation

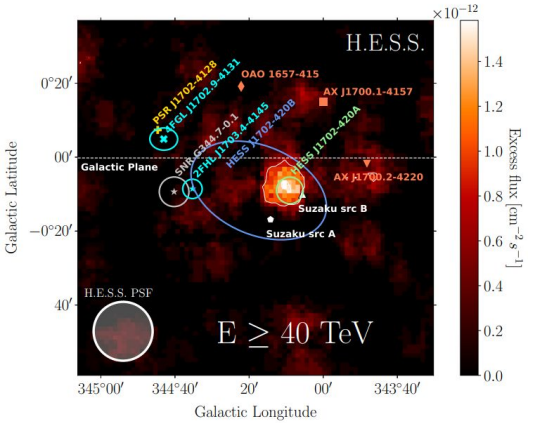
Galactic PeVatron candidates

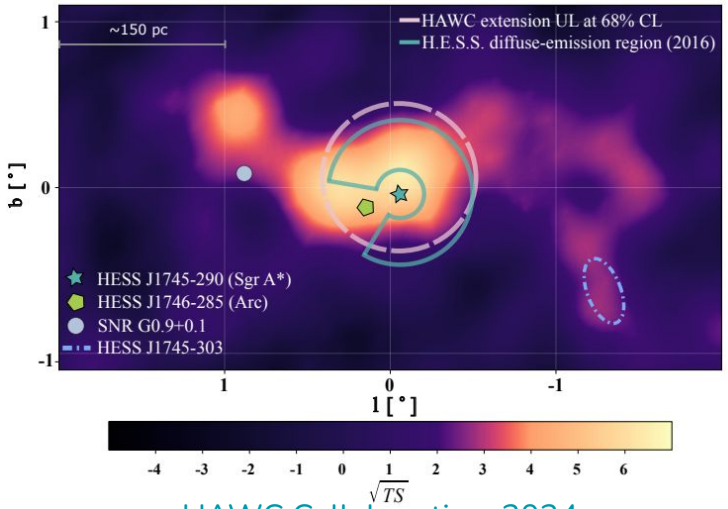
- 49 γ-ray sources with emission exceeding 100 TeV
- At >100 TeV energies, inverse compton scattering is the main method of leptonic γ-ray production
  - Cross section is greatly suppressed following the Klein-Nishina formula
- Notable candidates
  - Cygnus X-3, HESS J1702-420A, Galactic center

LHAASO Collaboration, 2026



H.E.S.S. Collaboration, 2021

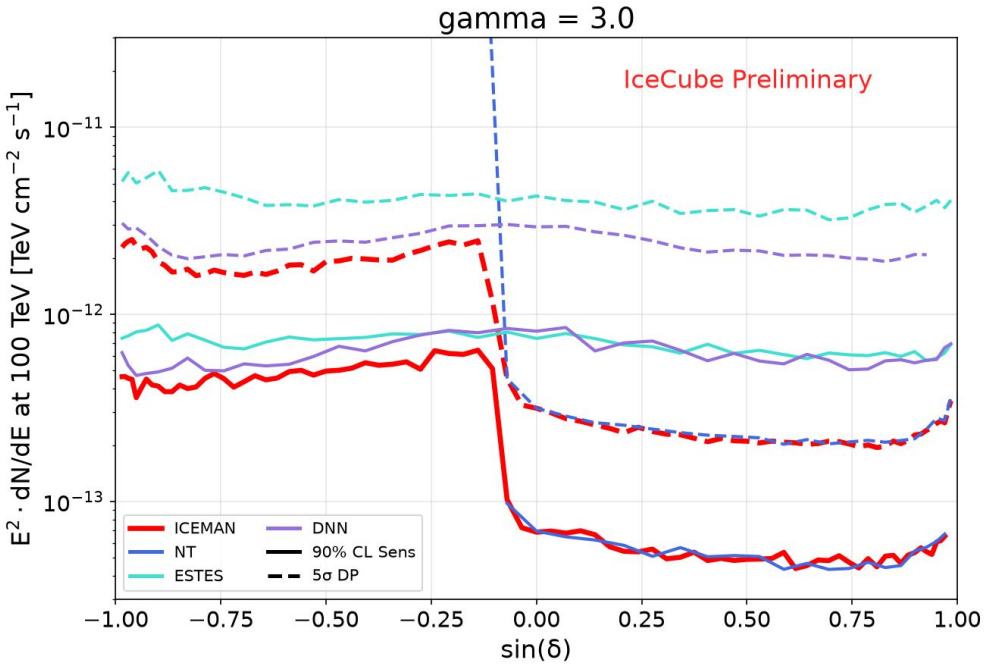




HAWC Collaboration, 2024

ICEMAN dataset

- ICEMAN - IceCubE Multi-flavor Astrophysical Neutrino dataset
  - 13 years of through-going muon tracks
  - 12 years of in-ice particle showers
  - 12 years of starting muon tracks
- In-ice particle shower dataset
  - Improved reconstruction
  - Improved ice modeling
  - Improved point spread function estimator

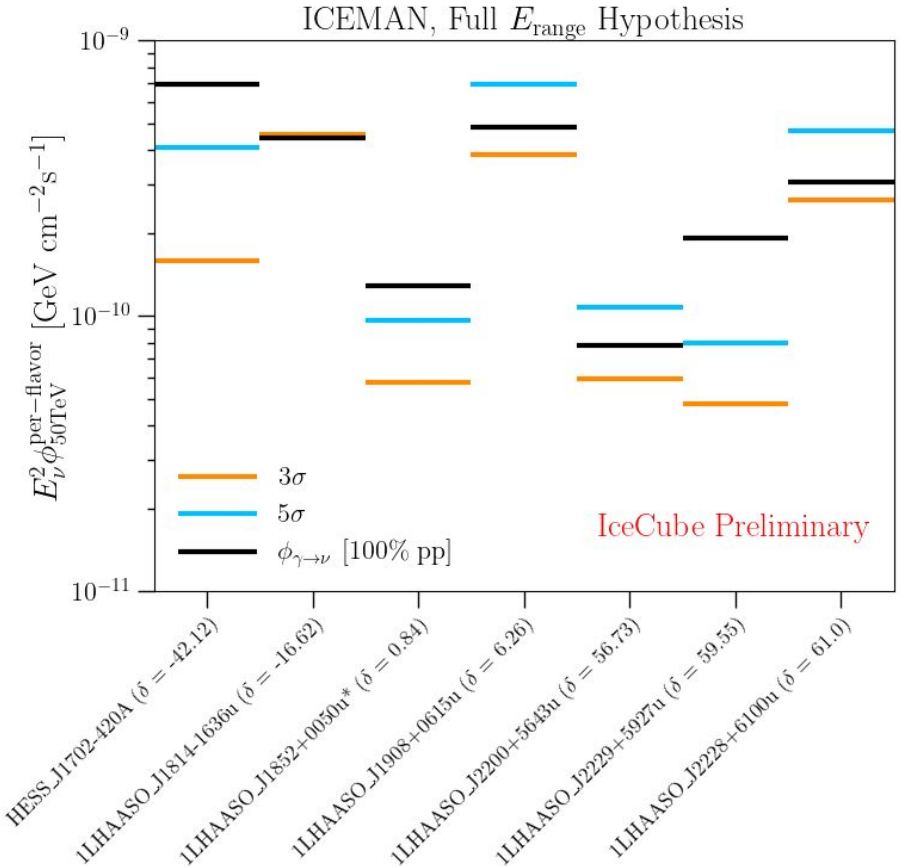


Individual source selection

- Filter out PWN, Pulsars, and sources deemed leptonic in literature
- Remove sources with expected neutrino emission below 3σ threshold
  - Expected neutrino emission assumes 100% proton-proton

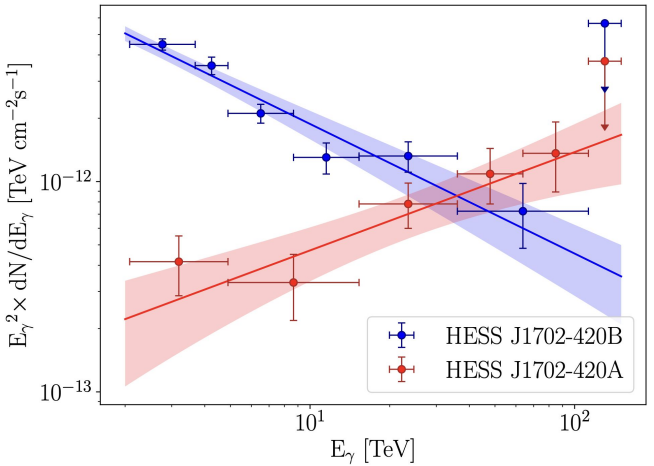
$$E_\nu^2 \frac{dN_\nu}{dE_\nu}\bigg|_{\text{per-flavor}} \approx \frac{\chi}{2}\left(E_\gamma^2 \frac{dN_\gamma}{dE_\gamma}\bigg|_{E_\gamma = 2E_\nu}\right)$$

- No significant excess observed

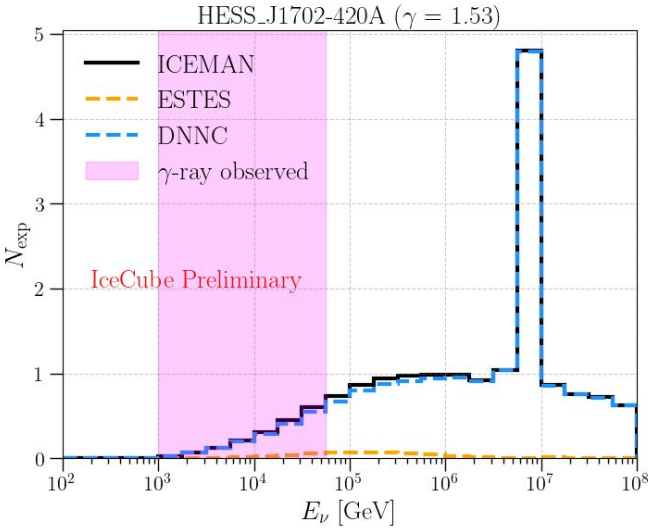


HESS J1702-420A

https://arxiv.org/abs/2106.06405



- Southern sky source observed by H.E.S.S.
  - Spectral index of 1.53 up to E_γ = 100 TeV with no signs of a cutoff
- Unique opportunity to place limit on hadronic energy cutoff
  - Non-detection of Glashow beam from HESS J1702-420A provides constraints



Cygnus region

- Complex region along one of the Milky Way's galactic spiral arms
  - Contains Cygnus OB2, Cygnus X-3, γ-cygni, etc.
- HAWC reports 2.13° extended Cygnus Cocoon, while LHAASO reports 6° Cygnus Bubble
- Numerous PeV photons observed in the region by LHAASO

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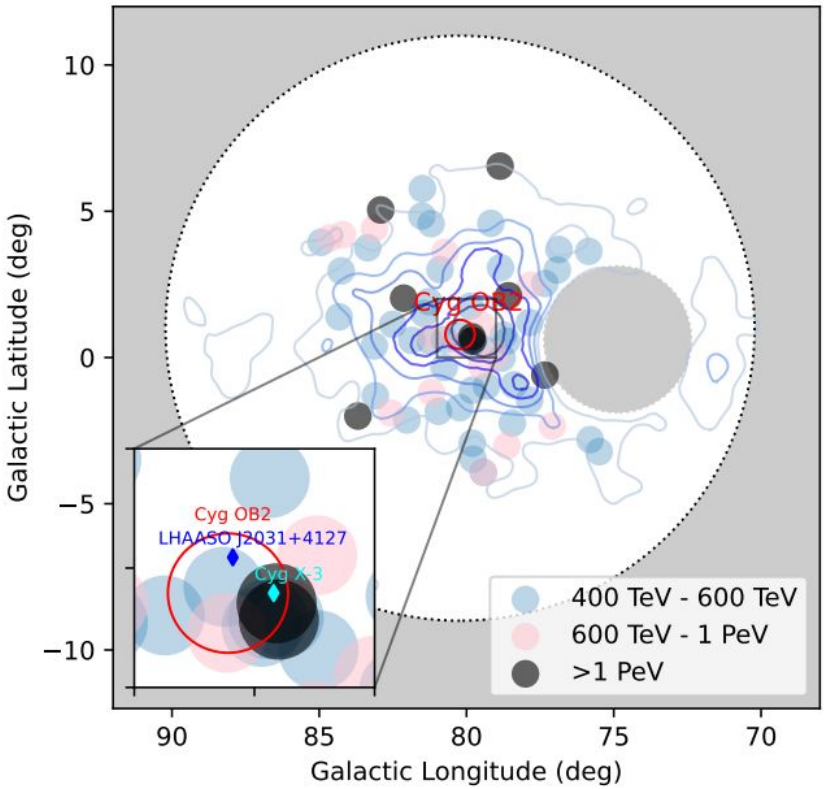
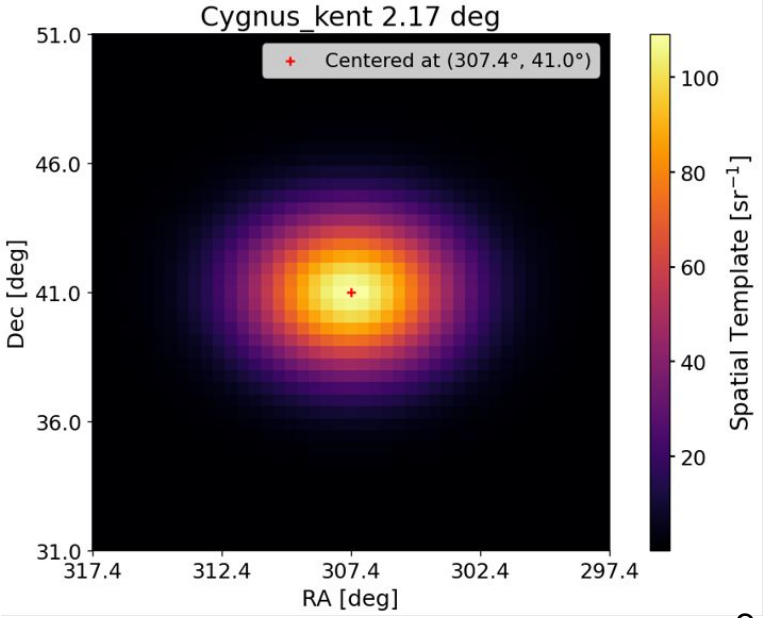


Cygnus analysis method

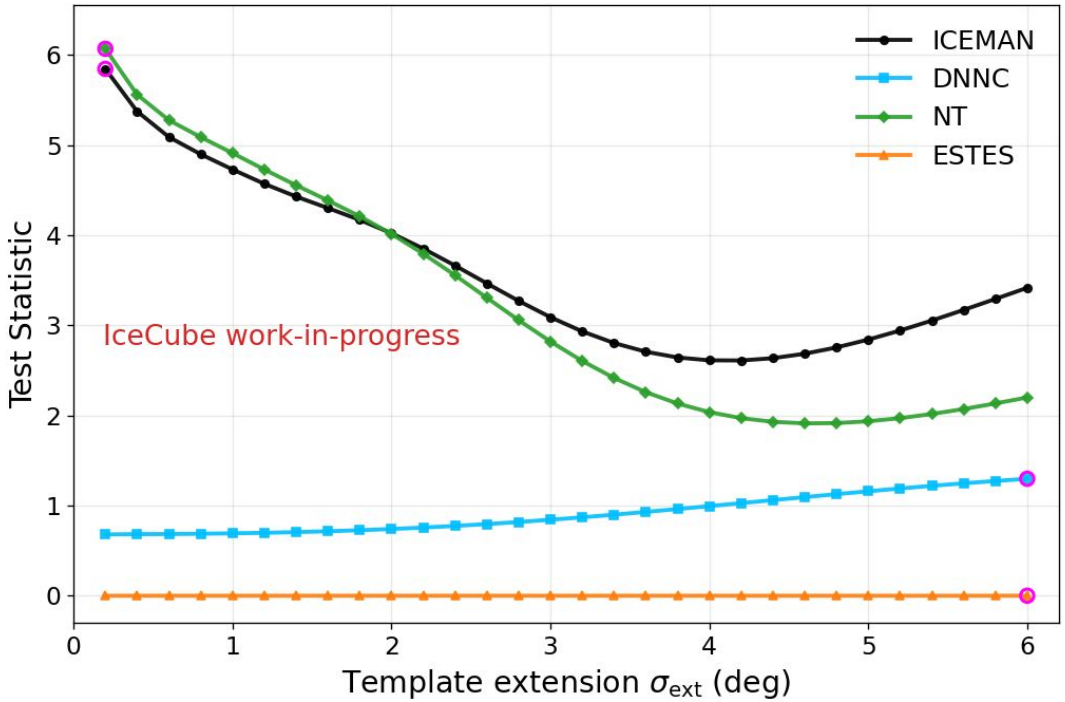
$$f(x;\sigma) = \begin{cases} \dfrac{\kappa}{4\pi} \cdot \dfrac{2\exp\left[\kappa(\cos x - 1)\right]}{1 - \exp(-2\kappa)} & \text{if } \sigma > \sigma_{\min} \\ \dfrac{1}{2\pi\sigma^2} \exp\left(-\dfrac{x^2}{2\sigma^2}\right) & \text{if } \sigma \leq \sigma_{\min} \end{cases}$$

- Neutrino spatial morphology unknown
- Scan extension parameter σ from 0.2° to 6°
- Spectral shape is fixed to a log-parabola as reported by LHAASO
- Fit 2 parameters: Normalization and extension



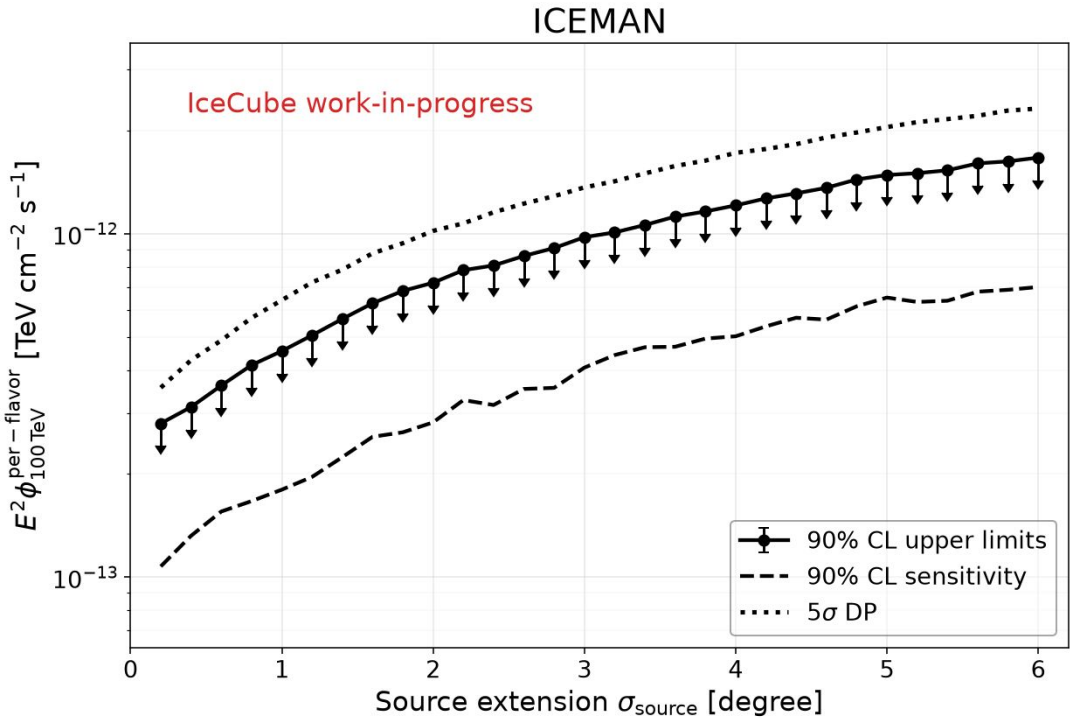
Cygnus search results

- Pre-trial: 2.47σ at 0.2° extension
- Through-going muons drive the TS at all extensions



Cygnus upper limits

- LHAASO measures a flux of 3.63×10^{-13} $TeV cm^{-2} s^{-1}$ @ 100 TeV
- A significantly γ-ray obscured hadronic source is ruled out assuming proton-proton interactions
  - Hadronic fraction is limited to <2 assuming HAWC extension of 2.13°



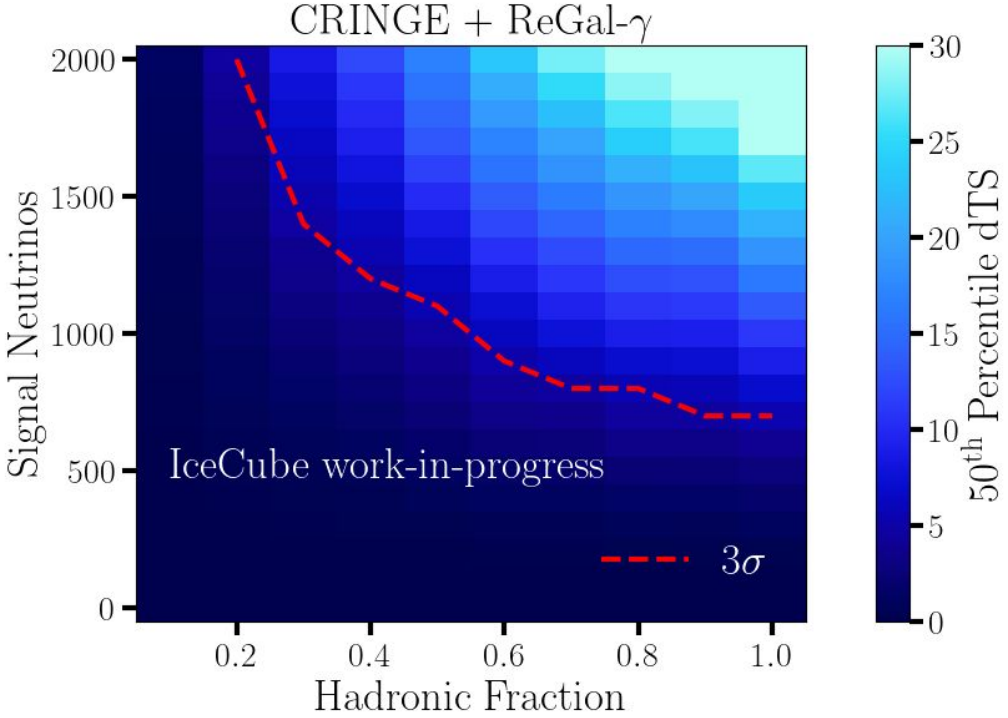
On-going and future works

- Individual Galactic neutrino sources remain elusive, however, can study source populations
- ReGal-γ: A neutrino source template made from resolved Galactic γ-ray sources
  - Uses sources observed by Fermi-LAT, H.E.S.S., HAWC, and LHAASO
  - PWN, Pulsars, and extragalactic sources are filtered out
  - Source catalogs are then applied in discrete energy ranges
  - To convert from γ-ray to neutrino, assume an average hadronic fraction

$$E_\nu^2 \frac{dN_\nu}{dE_\nu}\bigg|_{\text{per-flavor}} \approx \frac{\chi}{2}\left(E_\gamma^2 \frac{dN_\gamma}{dE_\gamma}\bigg|_{E_\gamma = 2E_\nu}\right)$$

Differentiating Galactic source and Galactic diffuse emission

- Null hypothesis is that Galactic neutrino emission is purely diffuse
- For context, while a 1:1 comparison is not possible, the ICEMAN Galactic Plane analysis yielded 1124 signal neutrinos using CRINGE with unresolved sources template



Summary

- Showed the PS sensitivity of the ICEMAN dataset
- Presented first results of the Galactic PeVatron analyses performed using the ICEMAN dataset
  - Stay tuned for more unblinded results!
- No significant excess observed at all tested extensions for the Cygnus Cocoon region
  - Best-fit extension is 0.2° driven by through-going muon tracks
  - Upper limits constrain hadronic fraction assuming HAWC extension to <2
- Presented upcoming analysis on differentiating Galactic source vs. Galactic diffuse emission

Backup

Cygnus SED from different gamma-ray observations