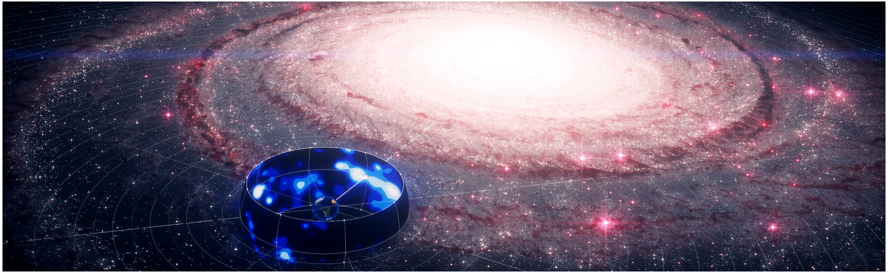
Characterising the Galactic Neutrino Emission with IceCube

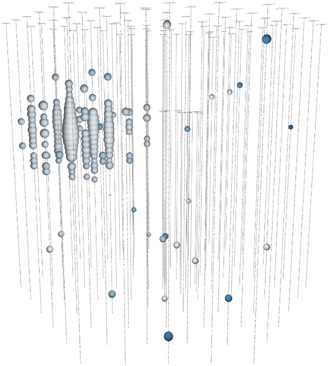
Tendo
Japan
August 30 - September 4, 2026

2026-08-31 — Ludwig Neste*, Mirco Hünnefeld and Chad Finley
on behalf of the IceCube Collaboration



Stockholm University

Using all-sky cascades



4.5σ observation of GP neutrinos (2023)[1]:

- New Machine Learning based event selection improved cascade effective area $\sim \times 20$
- Neutrino emission template fitted to flux normalization

$\rightarrow$ GP flux contributes $\sim 10\,\%$ to astrophysical flux

[1] DOI: 10.1126/science.adc9818

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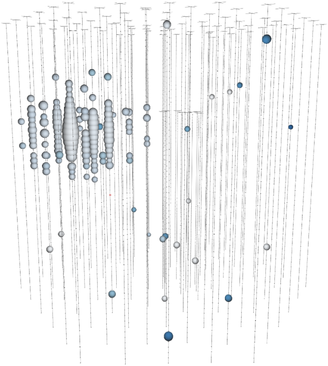

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5.7σ observation of GP neutrinos (2025):

- Combined track & cascades with improved reconstruction
- Now on the arXiv:2607.25966

⇒ Cascades still the driving part

Joint Galactic and Extragalactic Neutrinos (TeVPA 2026):

- Joint fit of Galactic and Extragalactic neutrinos
- Please go to Philipp Fürst's talk on Tuesday in the Nu3 session

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Template Fitting

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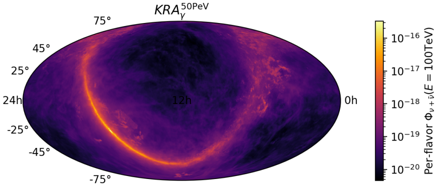
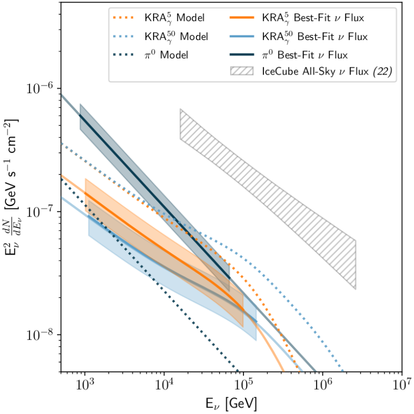
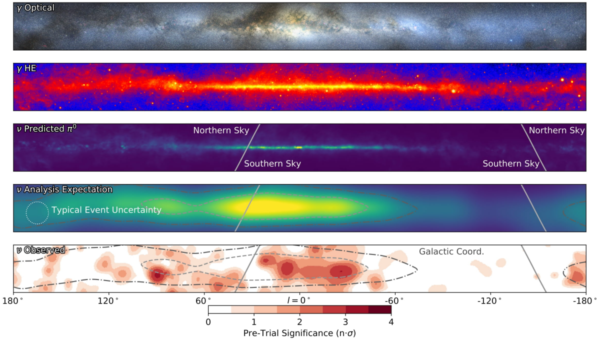
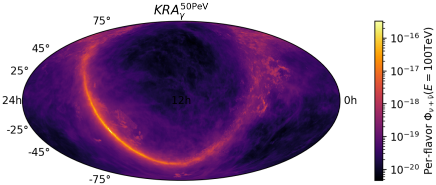
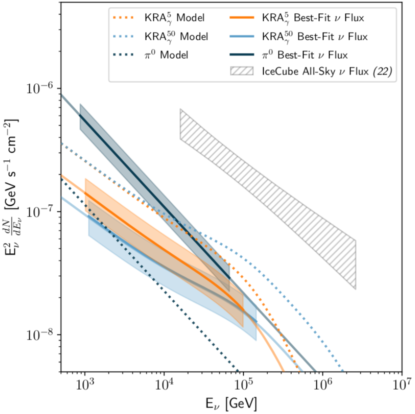


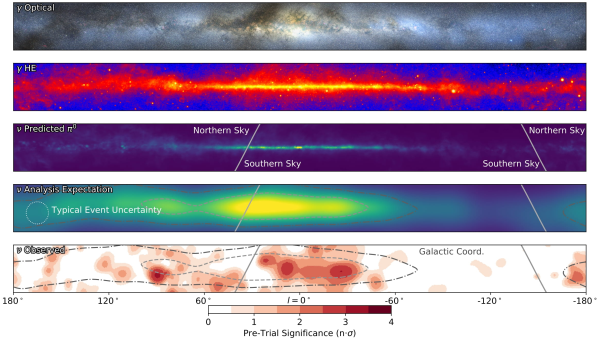




- Use models (e.g. $\pi^0, \mathrm{KRA}_\gamma^{50\mathrm{PeV}}, \mathrm{KRA}_\gamma^{5\mathrm{PeV}}$)
- Fit scale factor relative to predicted flux
- **Assume spatial** distribution of ν flux
- **Assume energy** distribution of ν flux







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$\Rightarrow$ Depends on the chosen template

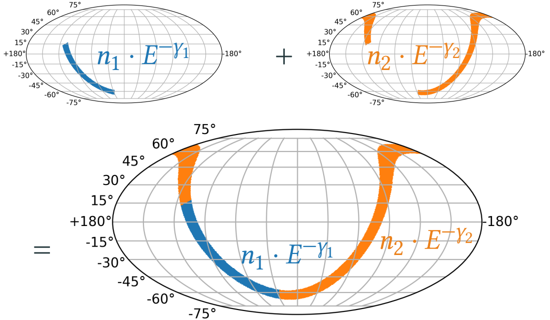
New Analysis Method: Segmented Templates

Unbinned maximum likelihood fit with data-driven background:

$$\mathcal{L}(\gamma, n_s) = \prod_{i=1}^{N} \left[\frac{n_s}{N} S_i(\gamma) + \frac{N - n_s}{N} B_i \right]$$

Segmented Template Analysis

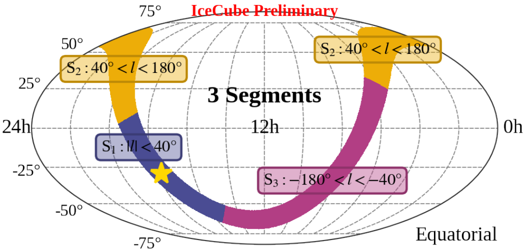
$$n_s S_i(\gamma) \rightarrow n_1 S_i^1(\gamma_1) + n_2 S_i^2(\gamma_2) + \cdots + n_M S_i^M(\gamma_M)$$



New Features

- Assume uniform emission in each segment
- Fit flux normalization n_k
- **Fit spectral index γ_k**
- 2 fit parameters per segment

Tested Segmentation Schemes



- One choice of division is called "segmentation scheme"
- Segments along Galactic longitude
- Constant latitude
- No emission outside the Galactic Plane

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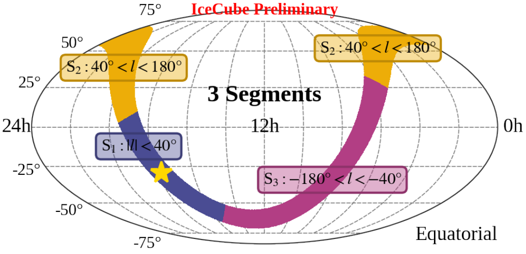

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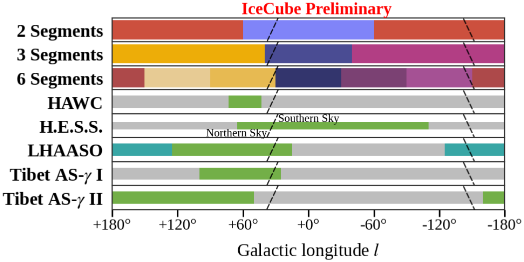
- 8 tested schemes
- 3 generic divisions

→ Tightening inner Galaxy

- 5 align with Galactic observations from TeV γ-ray instruments

→ Fit the unobserved region also as one segment (gray)



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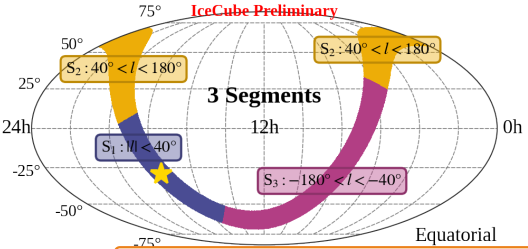

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Today:

Closer look at the Galactic Ridge and comparison to LHAASO

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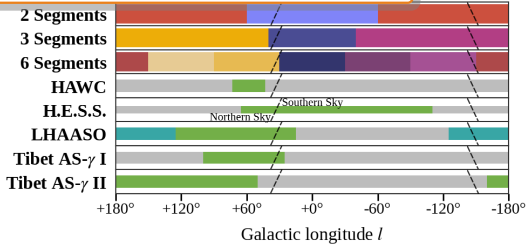
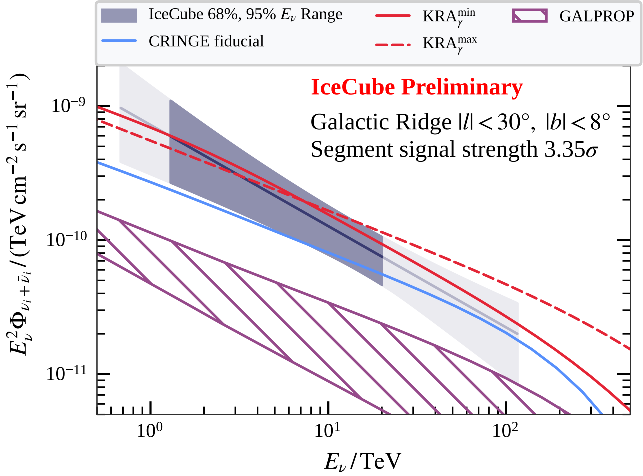
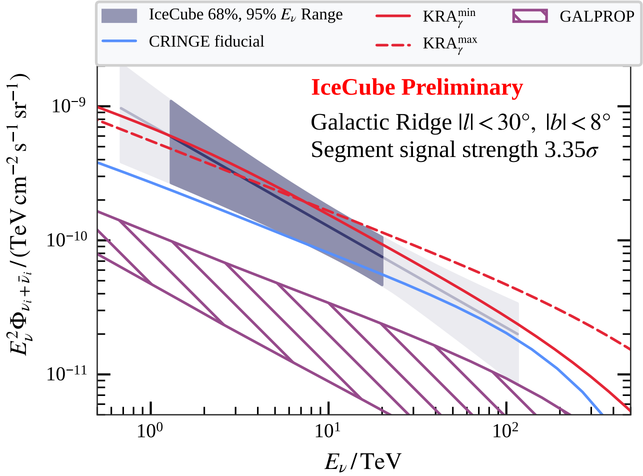




←Model prediction in the Galactic Ridge

- Reminder: We use uniform emission
- 68% confidence region
- Constructed with Feldman-Cousins
- Systematics included
- 68%, 95% energy range
- Models: `doi:10/rmrq`, `doi:10/rmrr`, `doi:10/rmrs`



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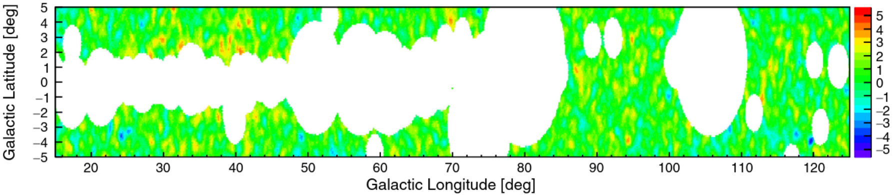
68% profiled confidence intervals, known systematics included:

$$\gamma = 2.76^{+0.18}_{-0.15} \qquad E_\nu^2 \Phi^{5\mathrm{TeV}}_{\nu_i+\bar{\nu}_i} = 21.4^{+6.8}_{-6.1} 10^{-11} \mathrm{TeV}/(\mathrm{cm}^2\,\mathrm{s\,sr})^{-1}$$

Driven by statistical uncertainties: e.g. $\gamma^{\mathrm{stat.-only}} = 2.76^{+0.14}_{-0.12}$

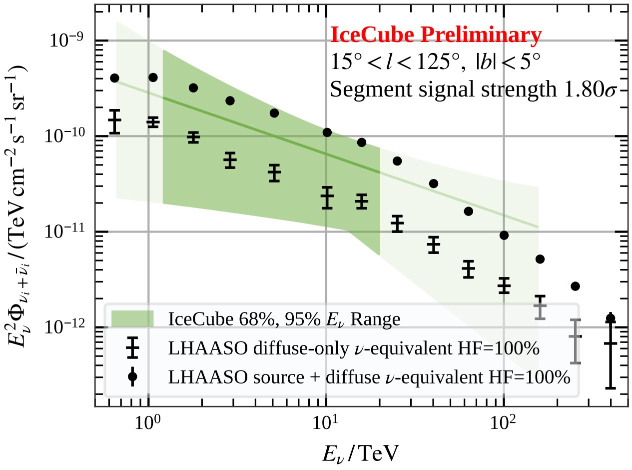
Comparison to TeV γ-rays



LHAASO's significance map after masking LHAASO and TeVCat sources (PRL 2025, `doi:10/rmqs`)

- γ-ray instruments estimate diffuse flux by masking *known* sources
- No Galactic ν-sources discovered so far
- LHAASO provides unmasked fluxes as well

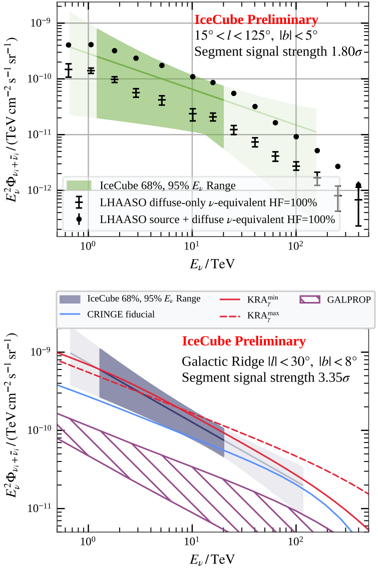
Birdview of LHAASO (from english.ihep.cas.cn/lhaaso)



- Local signal strength: 1.8σ
- Converted LHAASO fluxes assuming 100% hadronic origin of γ-rays
- $E_\nu^2 \frac{\mathrm{d}N_{\nu_i}}{\mathrm{d}E_\nu} = {}^1\!/_2 E_\gamma^2 \frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}$ and $E_\gamma = 2E_\nu$
- IceCube flux is compatible with both diffuse-only and total γ-ray emission
- Best-fit is between diffuse-only and total γ-ray flux

Conclusions and Outlook

- New method for a model independent analysis of IceCube GP data
- 10 years of all-sky cascades
- First IC measurement of the ν spectral index in the inner galaxy
- Uncertainties still driven by statistical uncertainty



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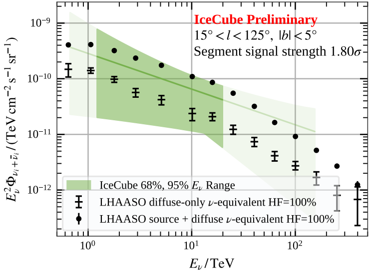
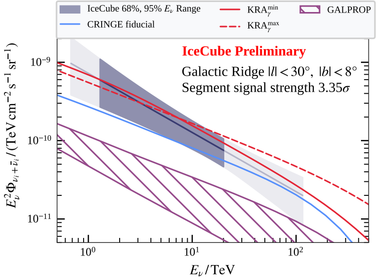
- $\mathrm{KRA}_\gamma^{\mathrm{min}}$ is closest to our best fit in the inner Galaxy
- Compatible with LHAASO's diffuse results
- With the first discovered ν-source, we can actually start to *measure* things





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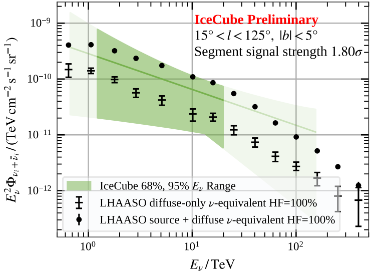
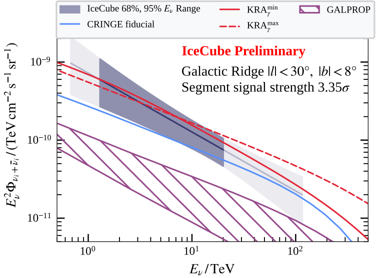
Thanks for listening!





Backup

Expected Significance

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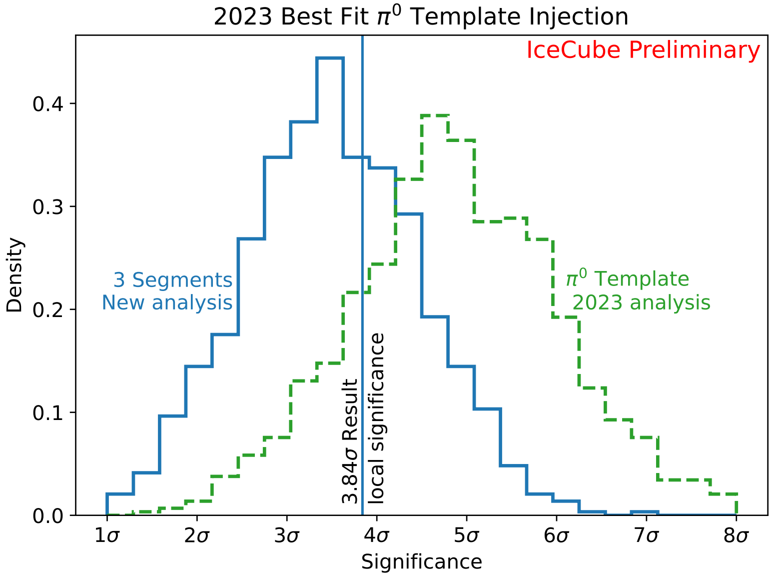
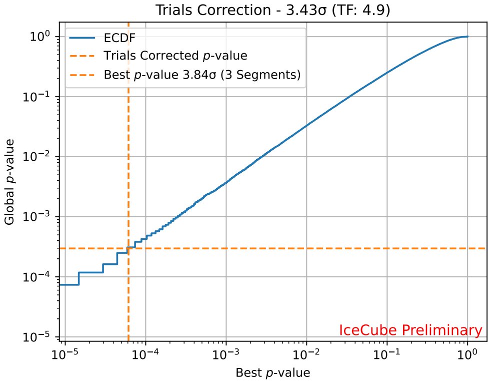
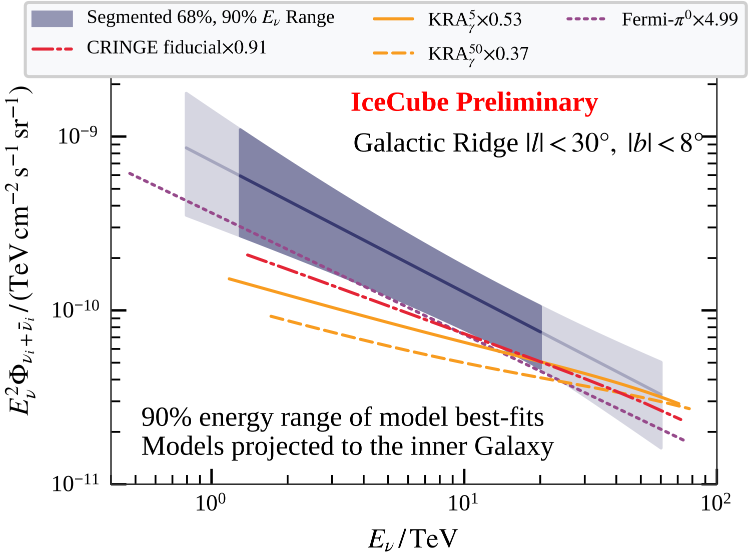


Scheme	Significance	n_s
2-segments	3.81 σ	643
3-segments	3.84 σ	643
6-segments	3.58 σ	808
H.E.S.S.	3.06 σ	569
HAWC	3.01 σ	664
LHAASO-KM2A	2.73 σ	371
Tibet AS γ I	2.96 σ	660
Tibet AS γ II	2.98 σ	626
Trials-corrected	3.43 σ	



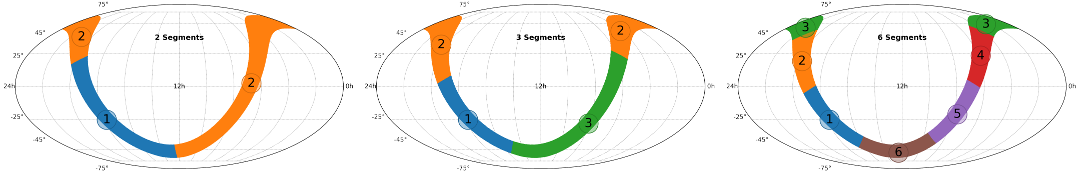
p-values **are not** the focus of the analysis, rather a model-independent measurement.

Comparison to Template Fits

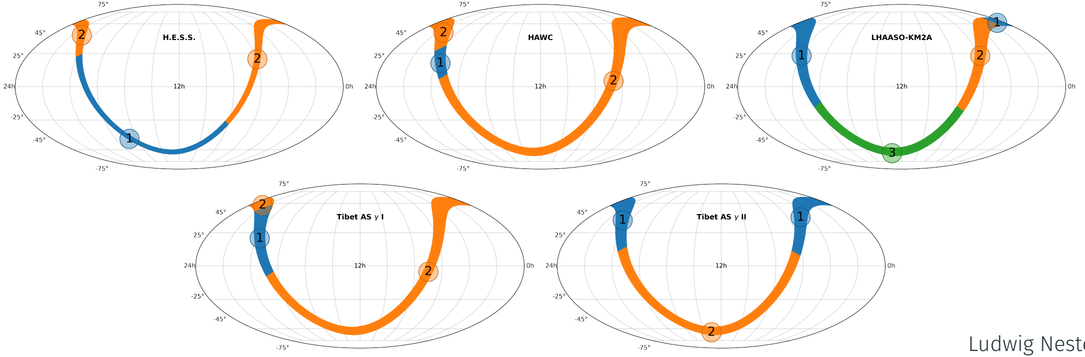


- Models scaled by best fit factors of the 5.7σ analysis (arXiv:2607.25966)
- Here: Only best fit template scale shown, uncertainties omitted

Generic segmentation schemes:



Aligning with γ ray GP measurements:



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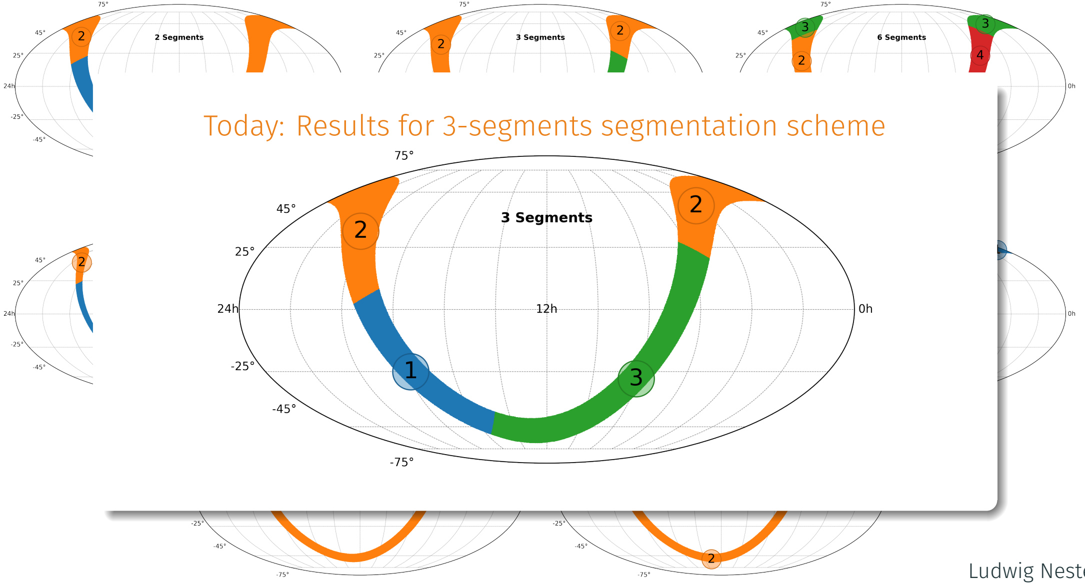
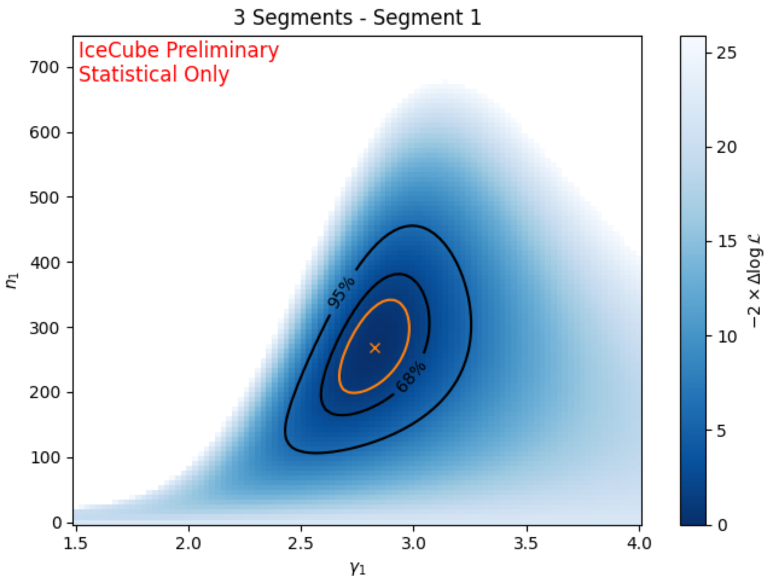
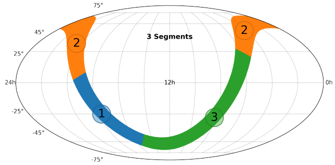


Result: Inner Galaxy





- Region: $-40^\circ < l < 40^\circ,\ |b| < 8^\circ$
- Likelihood contours assume Wilks' theorem
- $\gamma_{\text{Wilks}} = 2.83^{+0.14}_{-0.12}$
- With systematics and Feldman-Cousins treatment: $\gamma_{\text{FC}} = 2.83^{+0.15}_{-0.18}$

$$E_\nu^2 \Phi_{\nu_i+\bar{\nu}_i}(E_\nu = 5\text{TeV}) = 19.1^{+5.0}_{-5.6} 10^{-11} \text{TeV}/(\text{cm}^2 \text{ s sr})^{-1}$$

Result: Outer Galaxy

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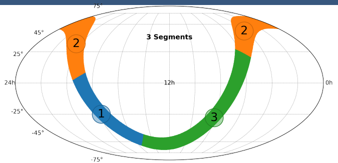
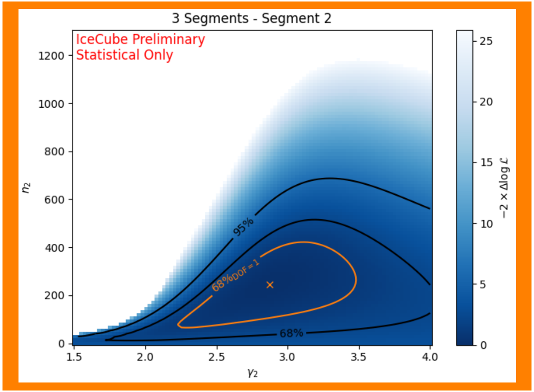
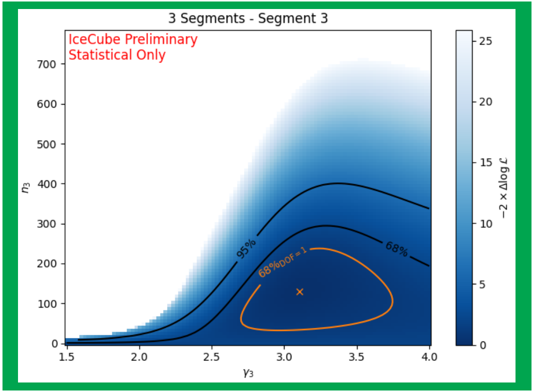


Still non-zero flux in the outer galaxy, larger uncertainty on γ





$$40^\circ < l < 180^\circ\text{: } \gamma = 2.93^{+0.81}_{-0.71}$$

$$E_\nu^2 \Phi_{\nu_i+\bar{\nu}_i}^{E_\nu=5\mathrm{TeV}} = 5.1^{+3.9}_{-3.9} 10^{-11} \mathrm{TeV}/(\mathrm{cm}^2\ \mathrm{s\ sr}\ )^{-1}$$

$$-180^\circ < l < -40^\circ\text{: } \gamma > 2.81$$

$$E_\nu^2 \Phi_{\nu_i+\bar{\nu}_i}^{E_\nu=5\mathrm{TeV}} = 3.5^{+4.4}_{-2.8} 10^{-11} \mathrm{TeV}/(\mathrm{cm}^2\ \mathrm{s\ sr}\ )^{-1}$$

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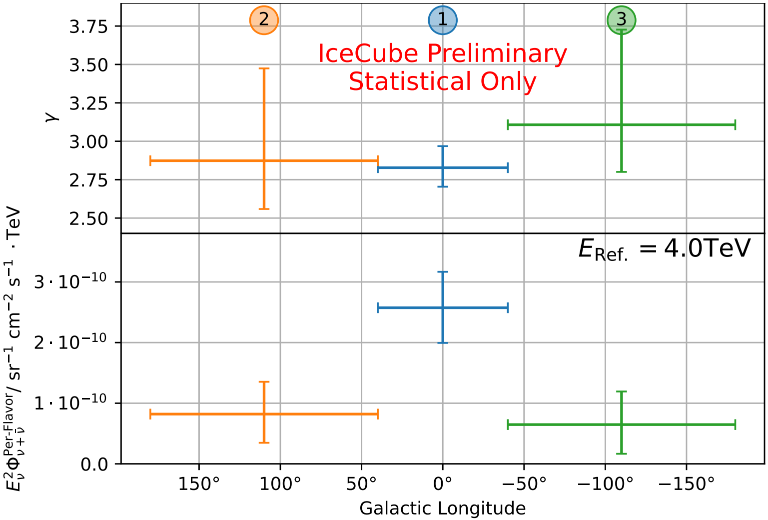
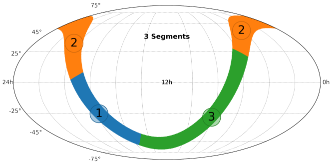
Compact way of visualizing the result:





- Higher emission from the galactic center
- 68% 1D intervals assuming Wilks' theorem
- Flux @4 TeV per steradian