# Estimating the Galactic Neutrino Flux

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# Neutrinos tracers of hadronic interactions

# Galactic Neutrino source component

$$\phi_{\nu,total} = \boxed{\phi_{\nu,\ source}} + \phi_{\nu,\ propagation}$$

## simulated gamma-ray source populations:

1. **Model I: All different type of gamma ray sources** by Steppa et al. 2020[1]

- Luminosities and radii sampled from power-law distributions fitted to HGPS data

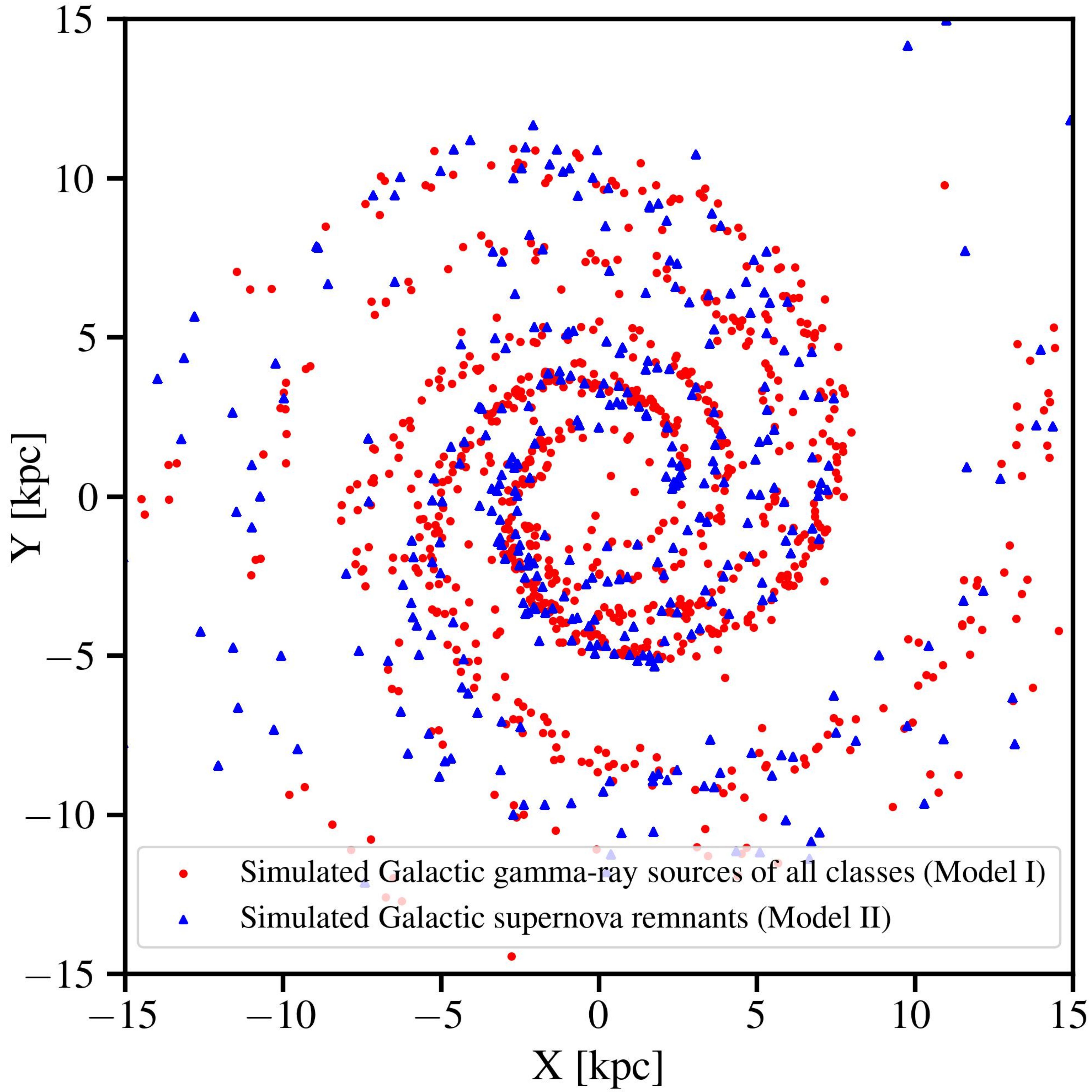
**Maximum source contribution**

2. **Model II: Hadronic component of Galactic Supernova Remnants** by Batzofin et al. 2024[2]

- Parameter space producing the most realisations within the limits of the HGPS sample includes: cosmic-ray spectral index, electron-to-proton ratio, acceleration efficiency, and the Sedov-Taylor phase duration

**Minimum source contribution**

Two models have been optimised to HGPS data and follow the same matter distribution as in Steiman-Cameron et al. (four-arm spiral pattern in the Galactic plane)



# Gamma ray to neutrino conversion

HGPS $\gamma$-ray flux and neutrino flux associated to HGPS (Batzofin et al 2021)

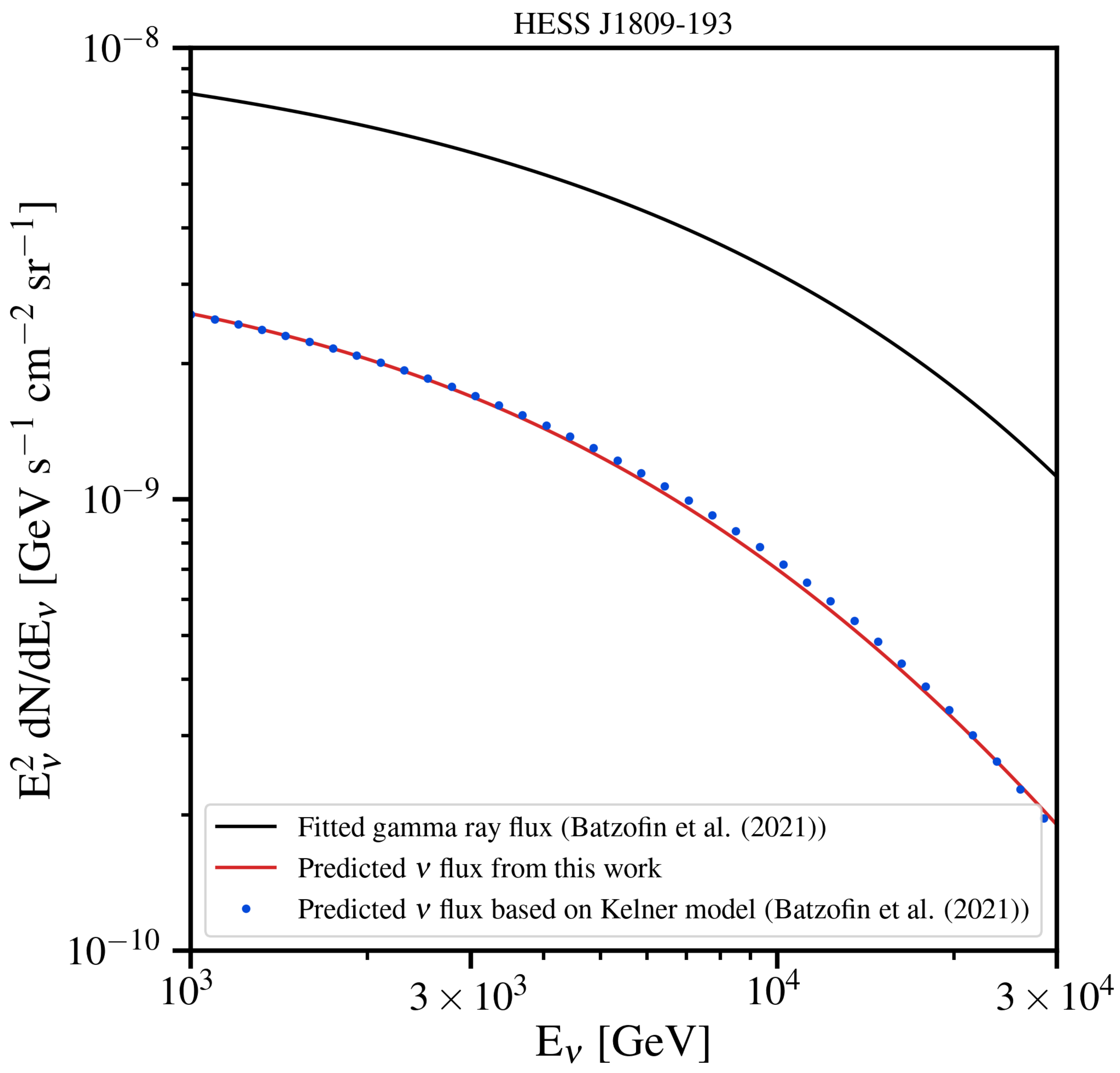
↓

Normalised simulated $\gamma$-ray flux to HGPS $\gamma$-ray flux

↓

Applied the normalisation factor to neutrino flux associated to HGPS (Batzofin et al 2021)

**Example for a single source**




- Assumptions:

  Negligible absorption effects

  Neutrino flavour as $\nu_\mu, \nu_\tau, \nu_e$ = 1 : 1 : 1 (direct consequence of neutrino oscillations)

# Galactic Neutrino propagation component

$$\phi_{\nu,total} = \phi_{\nu,\ sources} + \boxed{\phi_{\nu,\ propagation}}$$

$$\varphi_{\nu,\mathrm{diffuse}}\left(E_\nu, \hat{n}_\nu\right) = \frac{1}{3}\sum_{l=e,\mu,\tau}\left[\int_{E_\nu}^{\infty} dE \frac{d\sigma_l\left(E, E_\nu\right)}{dE_\nu}\int_0^{\infty} dl \varphi_{CR}\left(E, r_\odot + l\hat{n}_\nu\right) n_{\mathrm{H}}\left(r_\odot + l\hat{n}_\nu\right)\right]$$

Differential inelastic cross section of pp interaction
(taken from *Kelner et al(2006))*

Cosmic-ray energy and spatial distribution

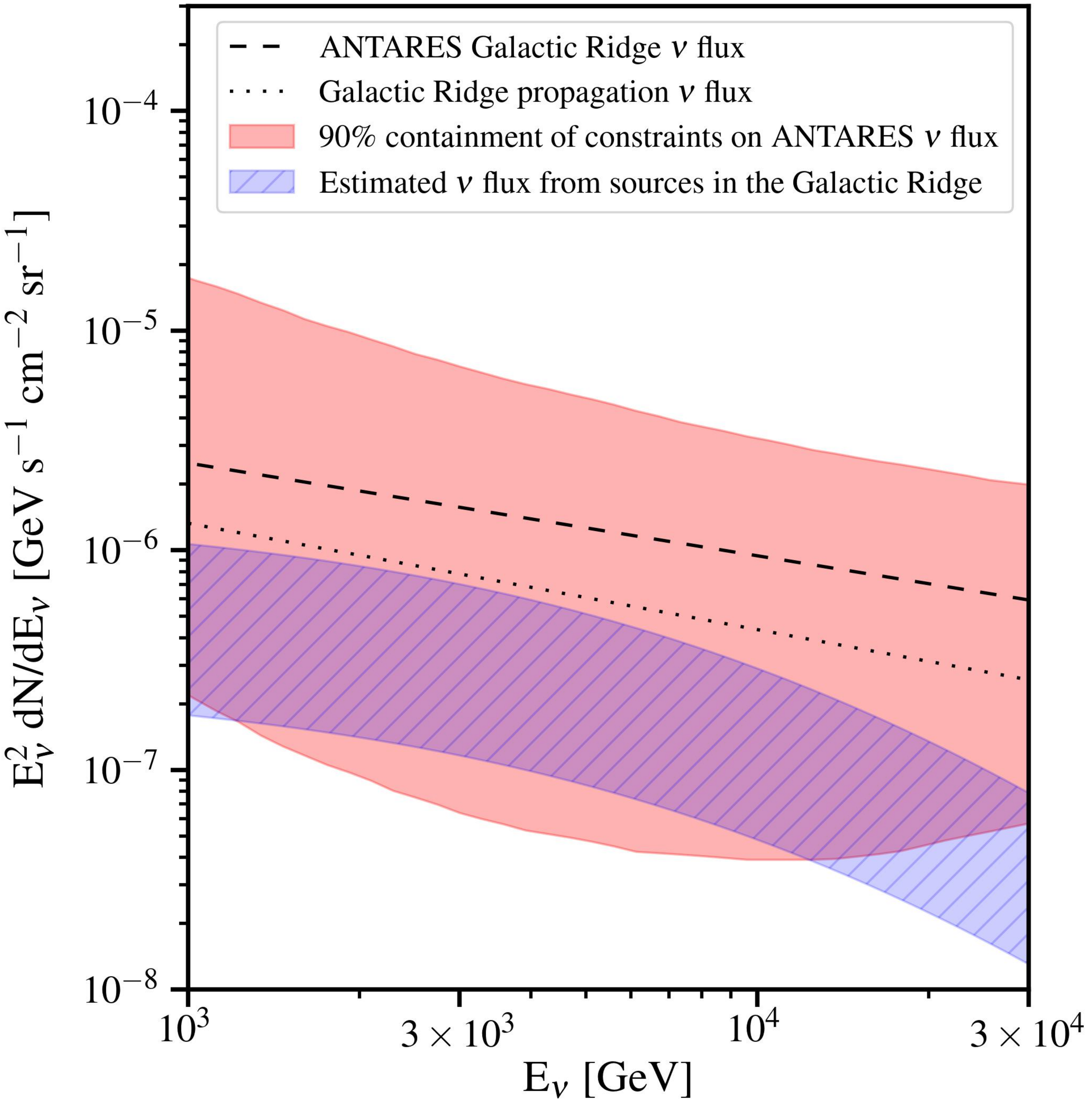
Assuming homogeneous and uniform source distribution → **minimum case**

Gas distribution in the Galaxy (taken from T. Shibata et al 2011 ApJ 727 38)

# Galactic Neutrino in Galactic ridge
# $(-30^\circ < l < 30^\circ, -2^\circ < b < 2^\circ)$

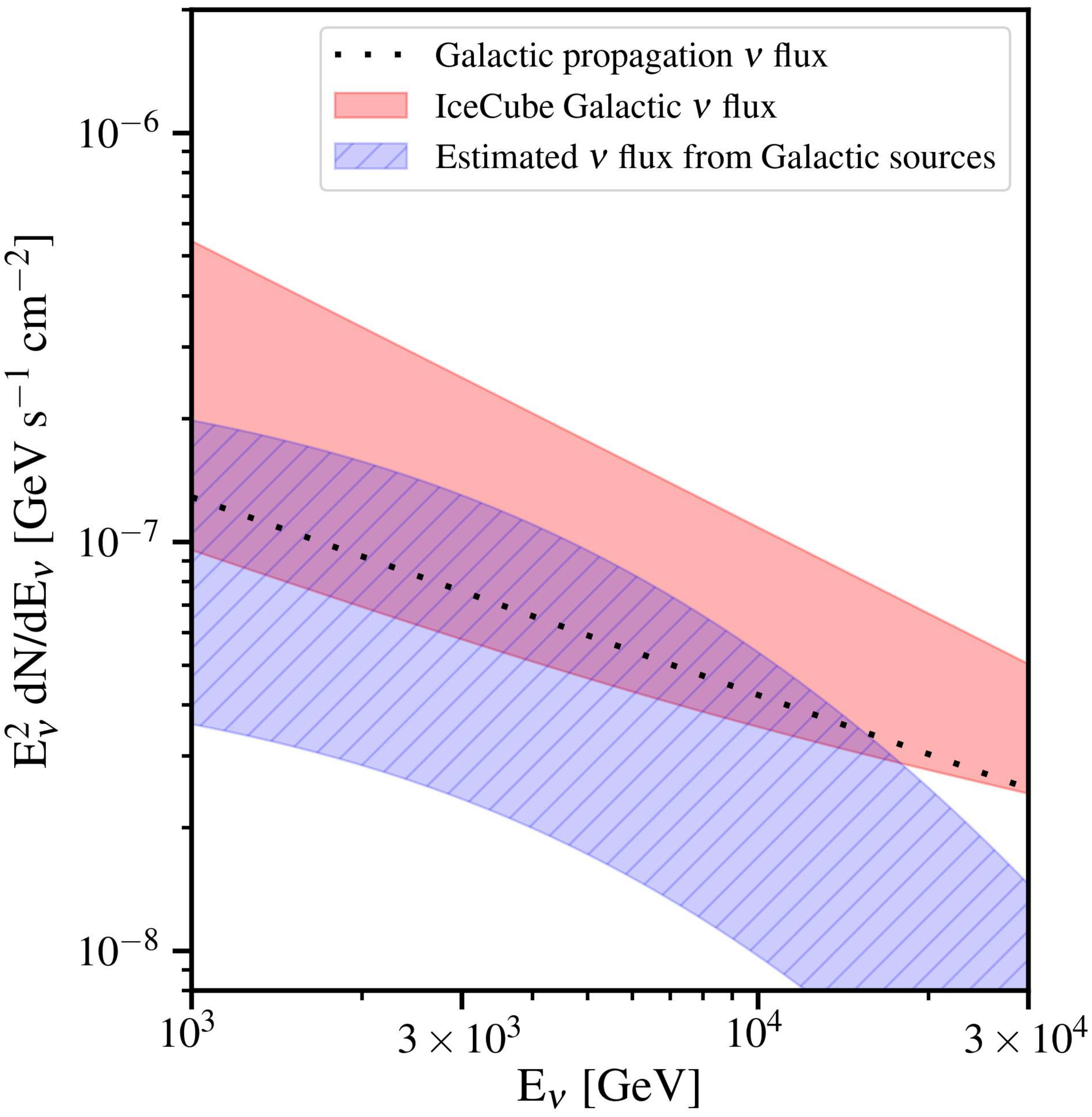
- Less than an order of magnitude between minimum and maximum source contribution

- Minimum propagation model already larger than the source contribution could even explain the data with no sources at all



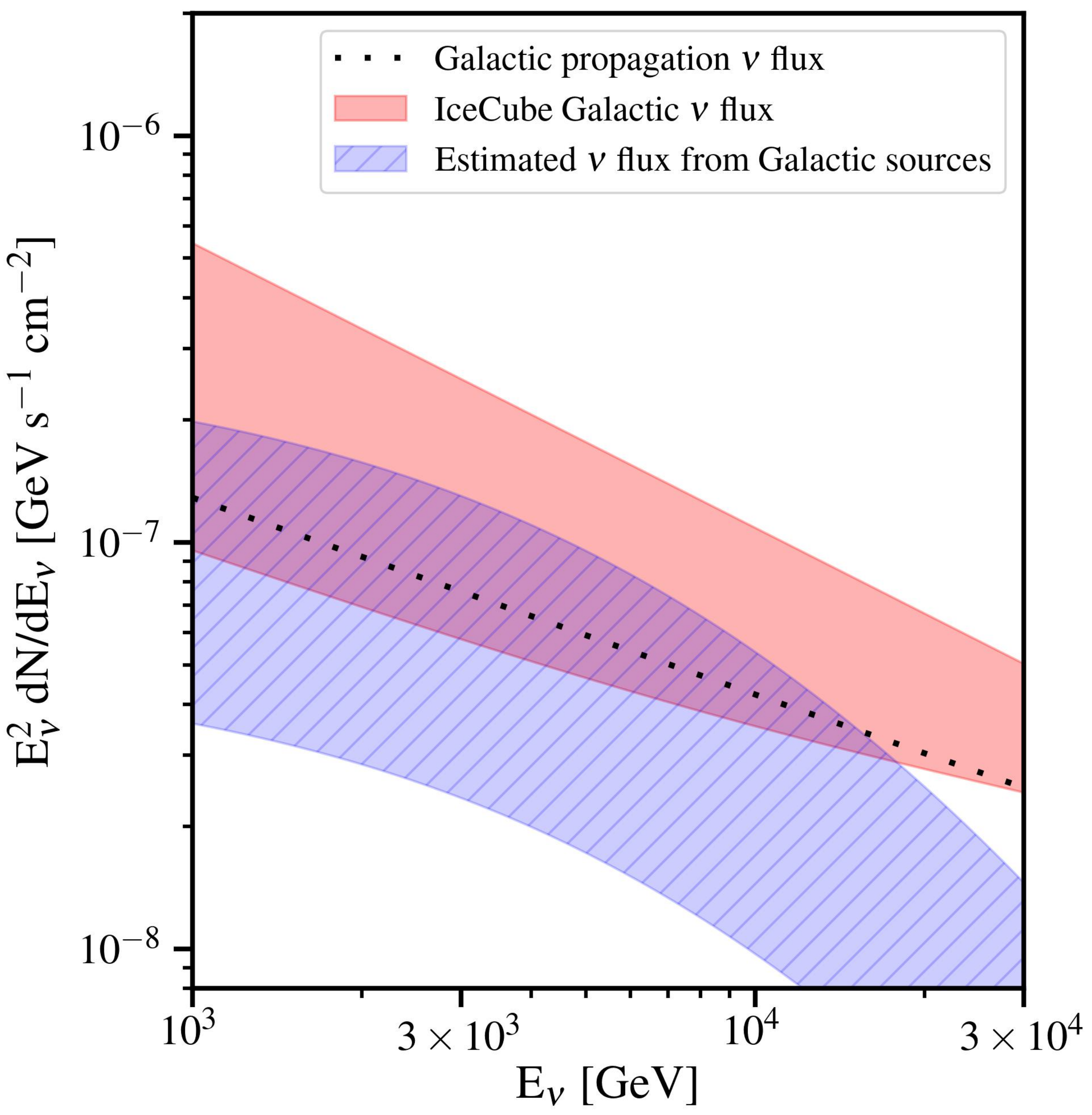
# Galactic Neutrino (full sky)

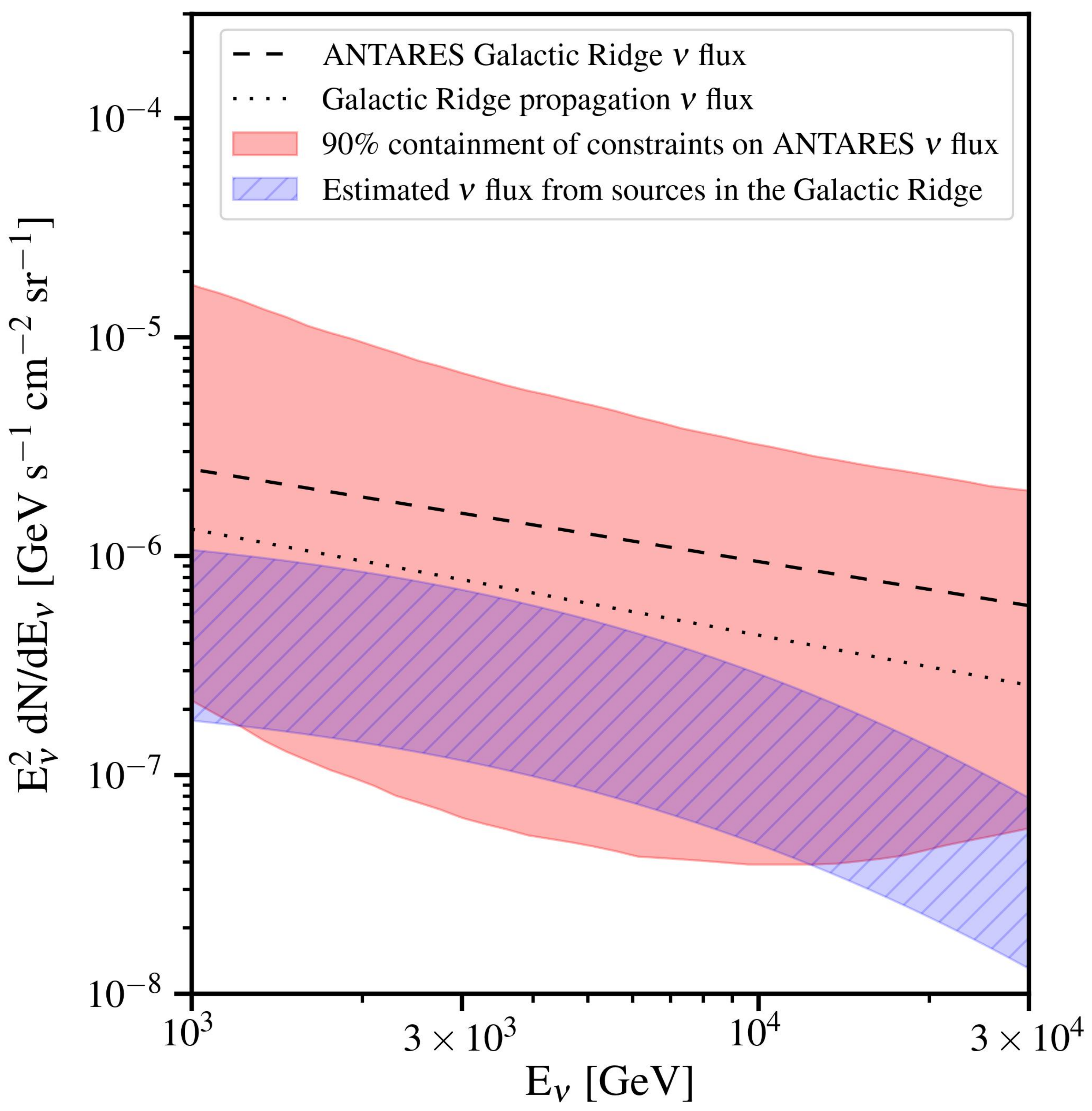
- Red band = IceCube best-fit normalisations for three Galactic templates.
- Source contribution and propagation component on comparable level
- Yet, no necessity for enhancements in the propagation model



# Conclusion

- Our maximum source contribution is modest; even the minimum plus propagation already approaches the data
- Uncertainties in both the available neutrino data and the underlying models → Future detectors like KM3NeT and IceCube-Gen2 will provide more precise data, hence stronger model constraints



# Thank you for your attention

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# Backup slides

- Model I: Luminosities and radii: Independently sampled from power-law distributions fitted to HGPS observations.
- Model II: The simulated sources in these populations were confronted to HPGS sources to identify the region of the parameter space producing the most realisations within the limits of the HGPS sample. The results are constrained by both the total number of sources and the maximum energy, ensuring that the maximum energy at SNRs is compatible with values estimated at individual SNRs. The maximum energy of protons was estimated using the Bell description based on the maximum non-resonant hybrid growth rate

Table 4: Optimal parameter set producing 97% of simulations consistent with HGPS observations.

| Parameter | Symbol | Value |
|---|---|---|
| Cosmic-ray spectral index (momentum space) | $\alpha$ | 4.2 |
| Electron-to-proton ratio | $K_{\mathrm{ep}}$ | $10^{-5}$ |
| Acceleration efficiency | $\eta$ | 9% |
| Sedov–Taylor phase duration | $T_{\mathrm{ST}}$ | 20 kyr |

$$\alpha = \frac{\frac{1}{N_{\mathrm{pop}}} \sum_{j=1}^{N_{\mathrm{pop}}} \sum_{s=1}^{n_j} \int_{1\ \mathrm{TeV}}^{100\ \mathrm{TeV}} \phi_{\gamma,js}^{\mathrm{sim}}(E)\, dE}{\sum_{k=1}^{N_{\mathrm{obs}}} \int_{1\ \mathrm{TeV}}^{100\ \mathrm{TeV}} \phi_{\gamma,k}^{\mathrm{H.E.S.S.}}(E)\, dE},$$

- Measured ν-flux = mix of propagation + unresolved sources (relative share unknown due to low stats & poor angular resolution)
- The interpretation of the Galactic neutrino flux inevitably relies on the vast dataset of gamma-ray data available on the Galactic plane. The gamma-ray/neutrino connection has been intensively studied to interpret the IceCube and ANTARES measurements, following different approaches:
  - One approach uses direct measurements of gamma rays to derive neutrino fluxes, either for the diffuse gamma-ray emission, e.g. with Fermi-LAT, or by integrating over the fluxes of measured gamma-ray sources in the TeV to PeV range
  - Alternatively, gamma-ray data are used to tune the modeling of the propagation component or to constrain the modeling of populations of individual source types, which are then used to determine their cumulative neutrino flux including unresolved sources

One of the most com mon methods :

$$E_\gamma \varphi_\gamma \left(E_\gamma\right) \approx e^{\frac{-d}{\lambda_{\gamma\gamma}}} \frac{1}{3} \sum_{\nu_l} E_\nu \varphi_{\nu_l} \left(E_\nu\right)$$

where the exponential describes gamma absorption (d is the distance to the source, $\lambda_{\gamma\gamma}(E)$ is the gamma-ray interaction length).

The gamma-ray energy can be simply approximated as $E_\gamma \approx 2E_\nu$. Since we only consider Galactic sources, we assume that the absorption of gamma-rays is negligible so:

$$\varphi_{\nu_\mu}(E_{\nu_\mu}) \approx 2\varphi_\gamma(2E_{\nu_\mu})$$

M. Ahlers, K. Murase, Probing the galactic origin of the icecube excess with gamma rays, Physical Review D 90 (2014) 023010.