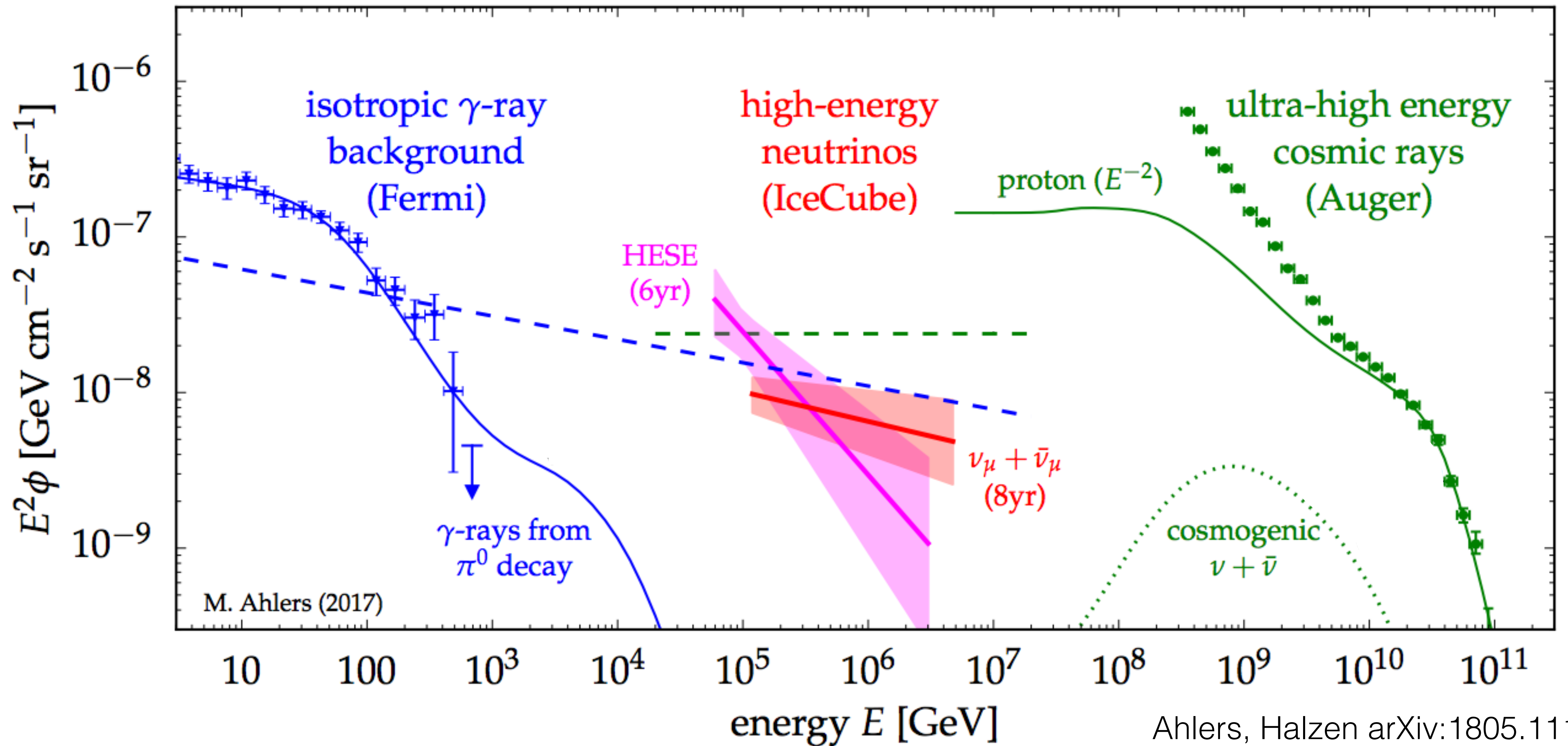


*Multimessenger probes of UHECR
source environments & their connection
to astrophysical neutrinos*

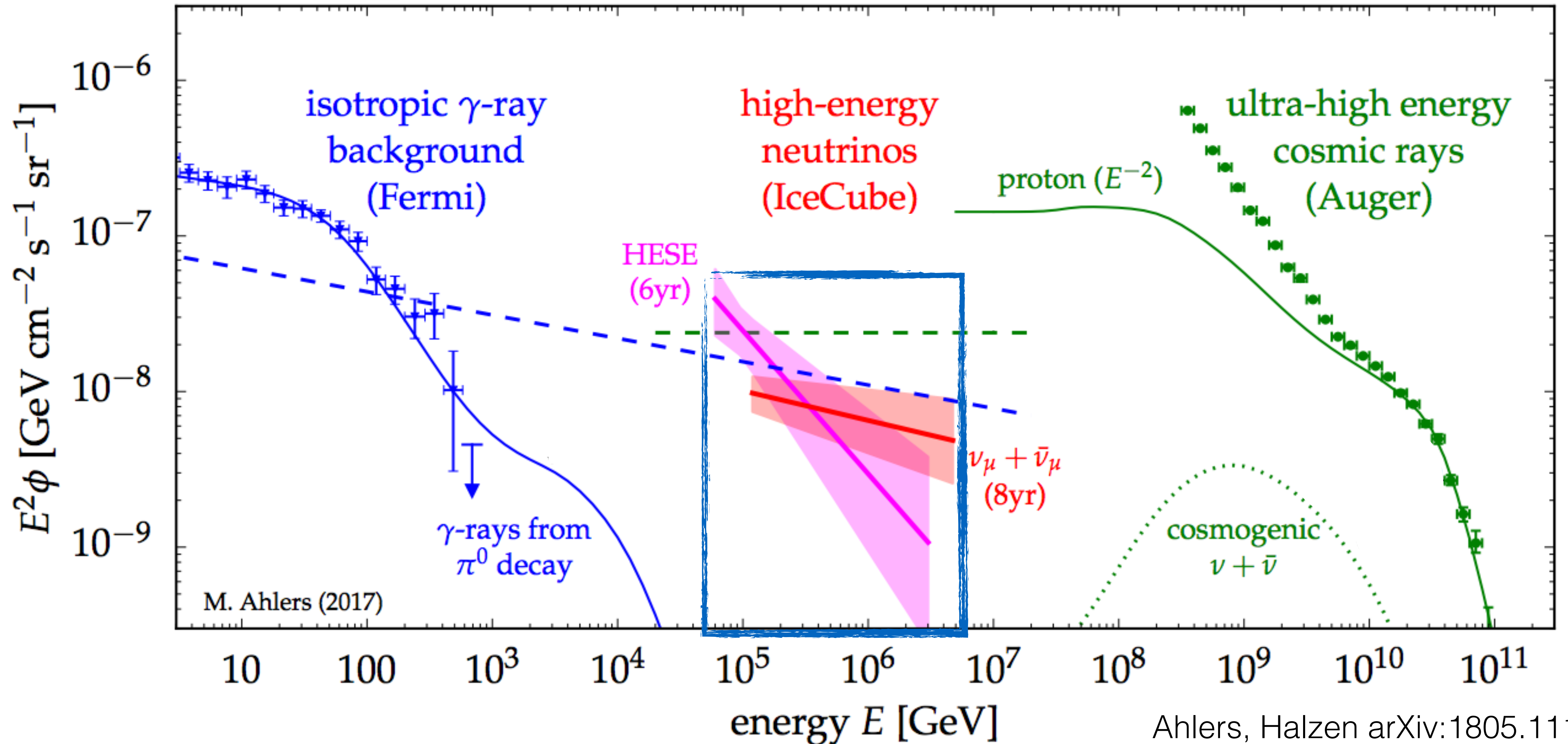
Marco Muzio (Penn State)

Glennys Farrar (NYU), Michael Unger (KIT)



Ahlers, Halzen arXiv:1805.11112

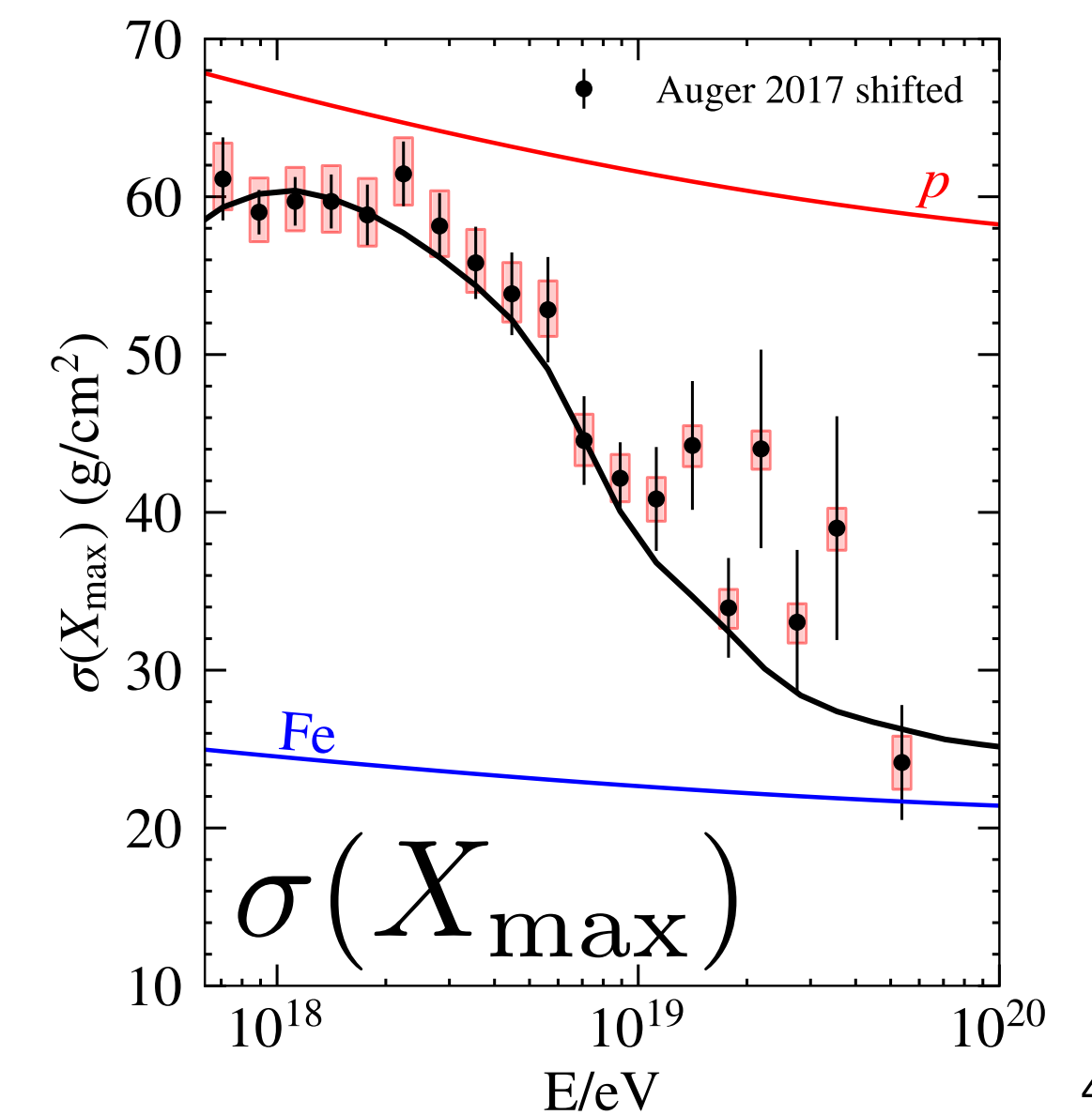
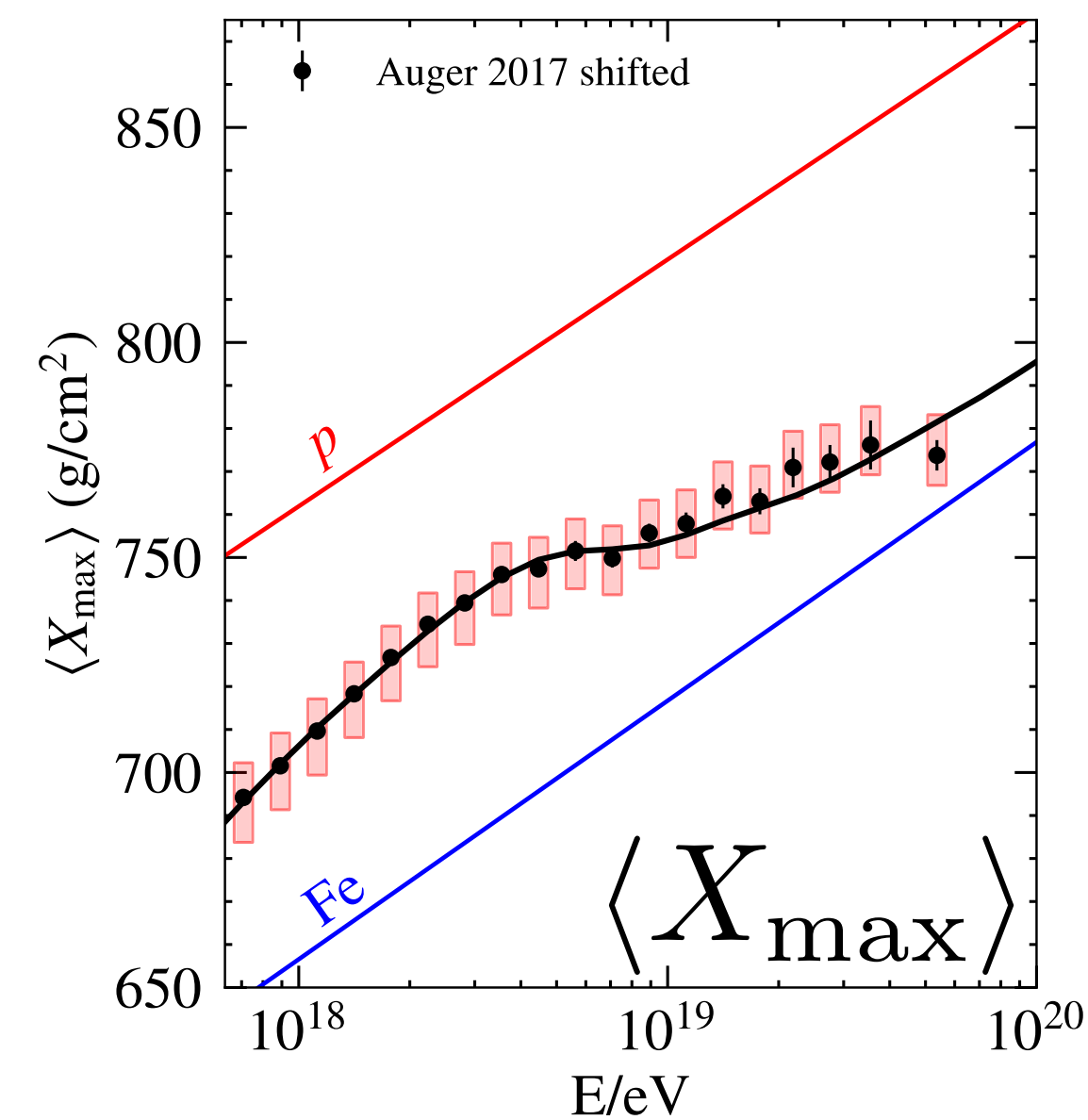
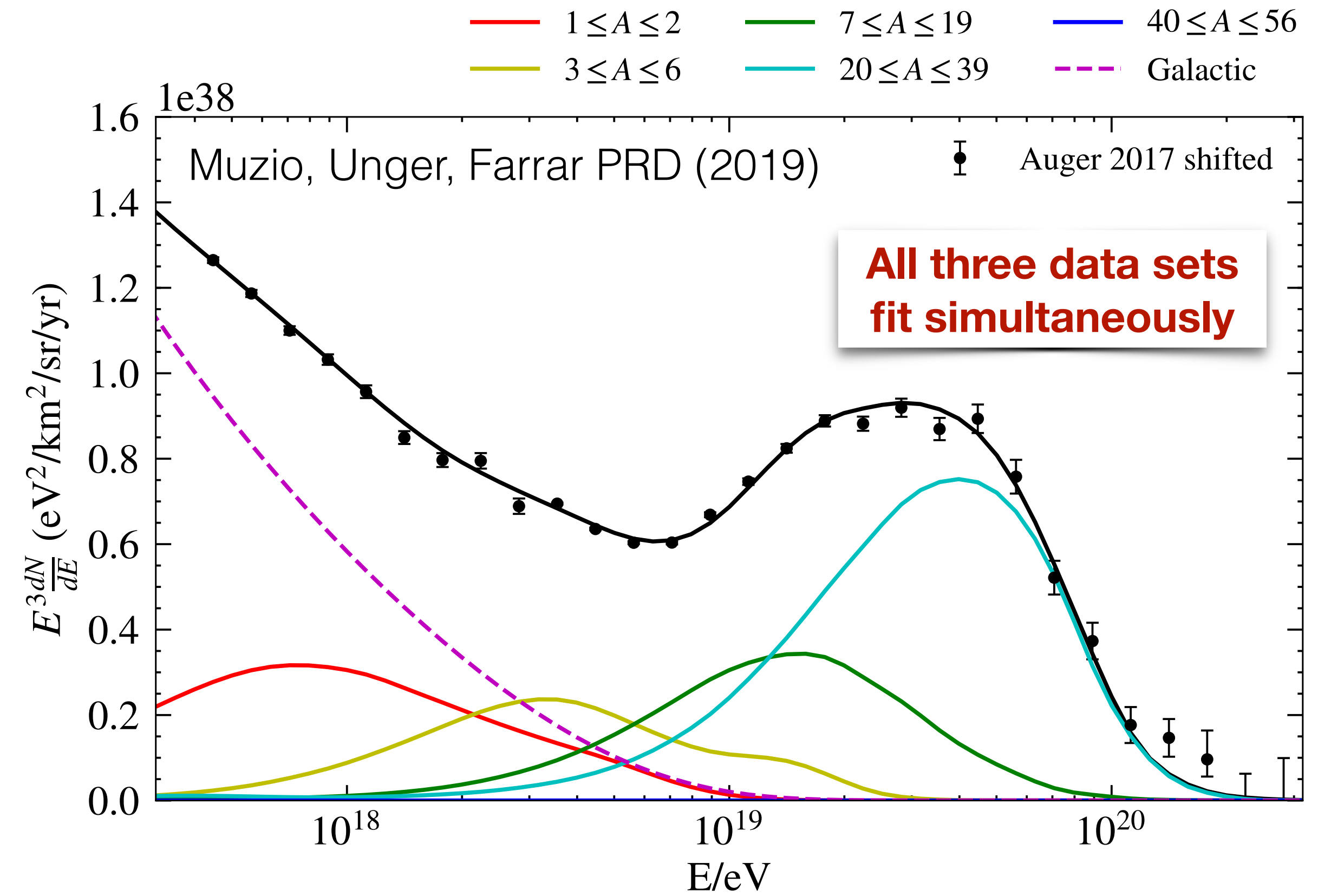
Could astrophysical neutrinos have common origin with UHECRS?



Ahlers, Halzen arXiv:1805.11112

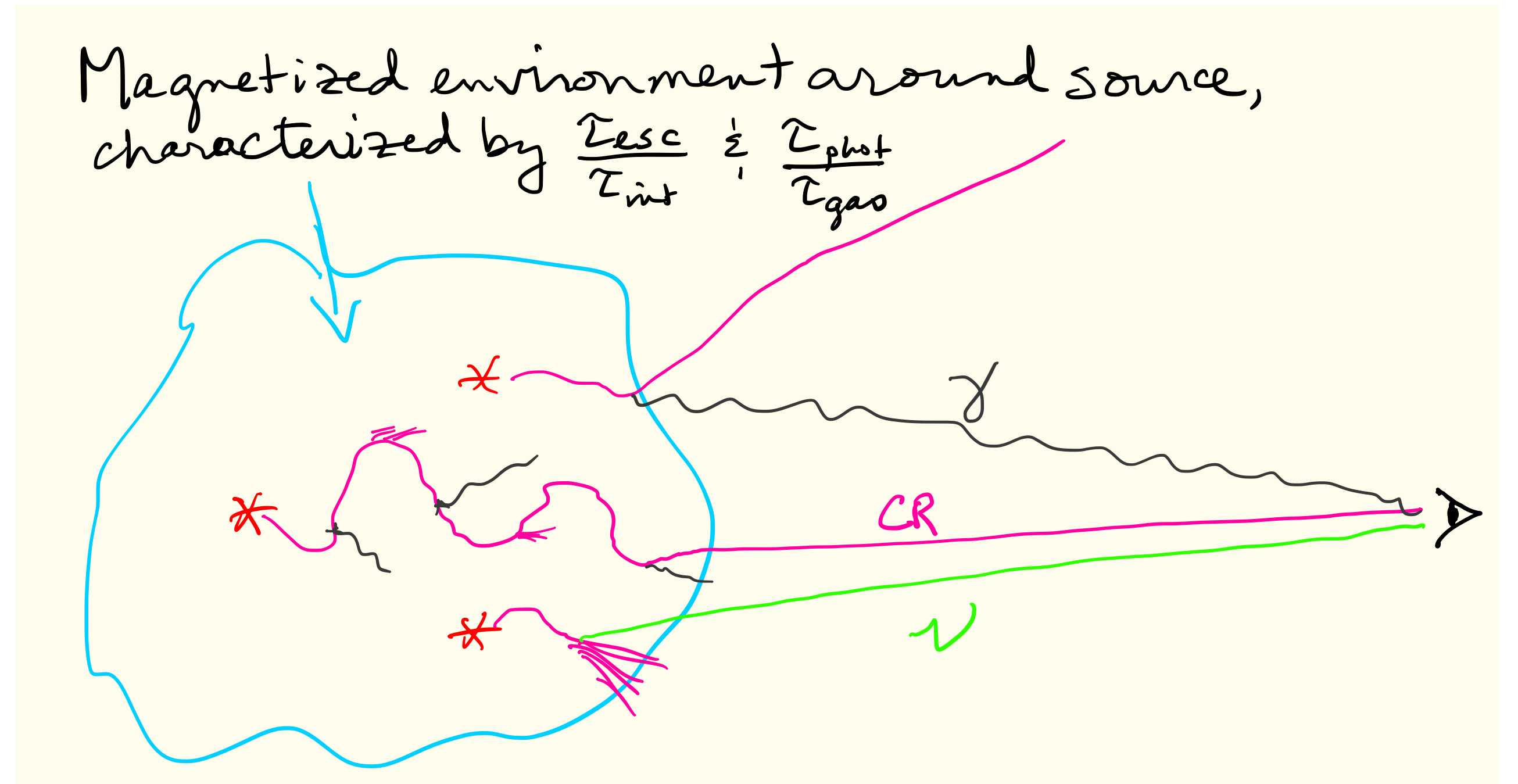
CR Source Model

- Unger-Farrar-Anchordoqui model (UFA, 2015 PRD):
 1. Inject CRs into source environment
 - 2. CRs processed by *photon* interactions**
 3. CRs escape source environment
 4. CRs propagate to Earth
- Accounts for observed spectrum ($> 10^{17.5}$ eV) & composition ($> 10^{17.8}$ eV)



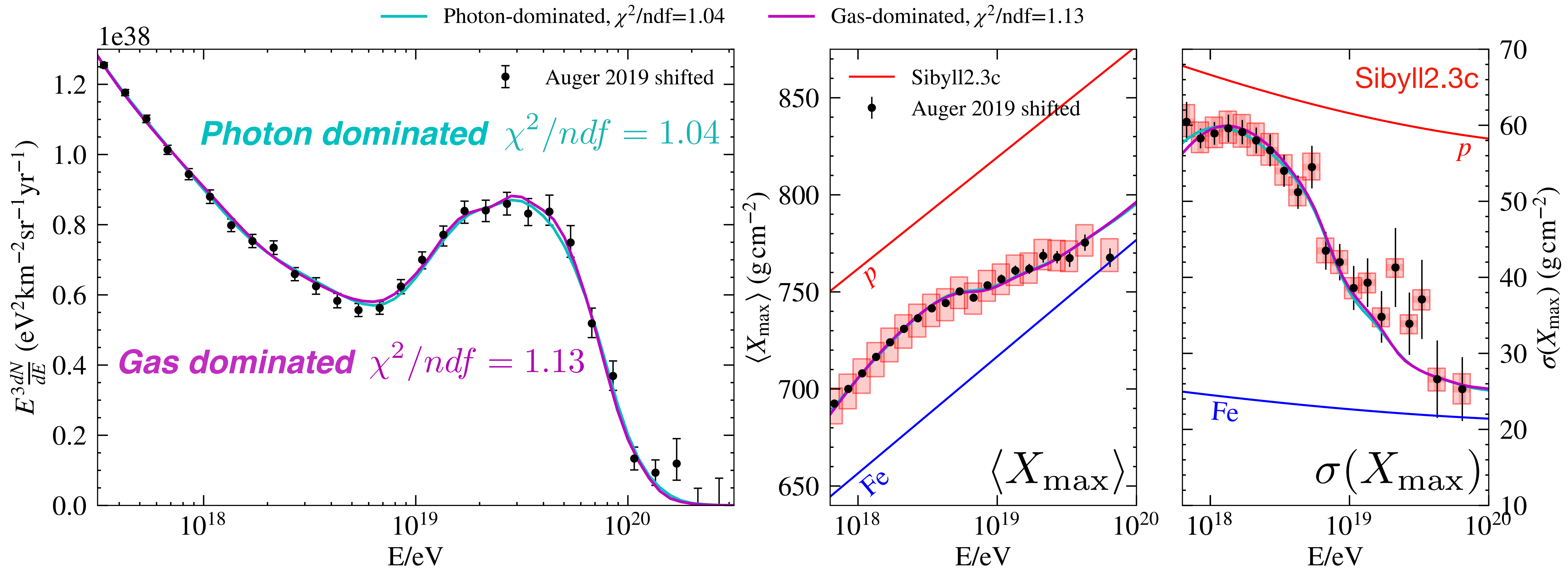
Elaborations to UFA

- **Addition of gas in source** environment (single zone) — hadronic interactions
 - Calculated interaction matrices with CRMC using Sibyll2.3c and EPOS-LHC
- **Realistic rigidity-dependent escape time**, allowing for transition between diffusive, Bohm, & quasi-ballistic propagation regimes and reflecting finite source size



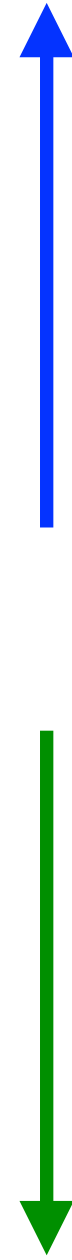
- Model doesn't rely on specific astrophysical model
- Model parameters **(10 EeV Fe-56 as the reference)**
 - Average # interactions (10 EeV ^{56}Fe) $\langle N_{int} \rangle$
 - Ratio of photon-to-gas interactions (10 EeV ^{56}Fe) $\frac{\langle N_{int}^{\gamma} \rangle}{\langle N_{int}^p \rangle}$
- Preferred astrophysical properties constrained by model parameters

Both gas- and photon-dominated sources can give good fits to CR data

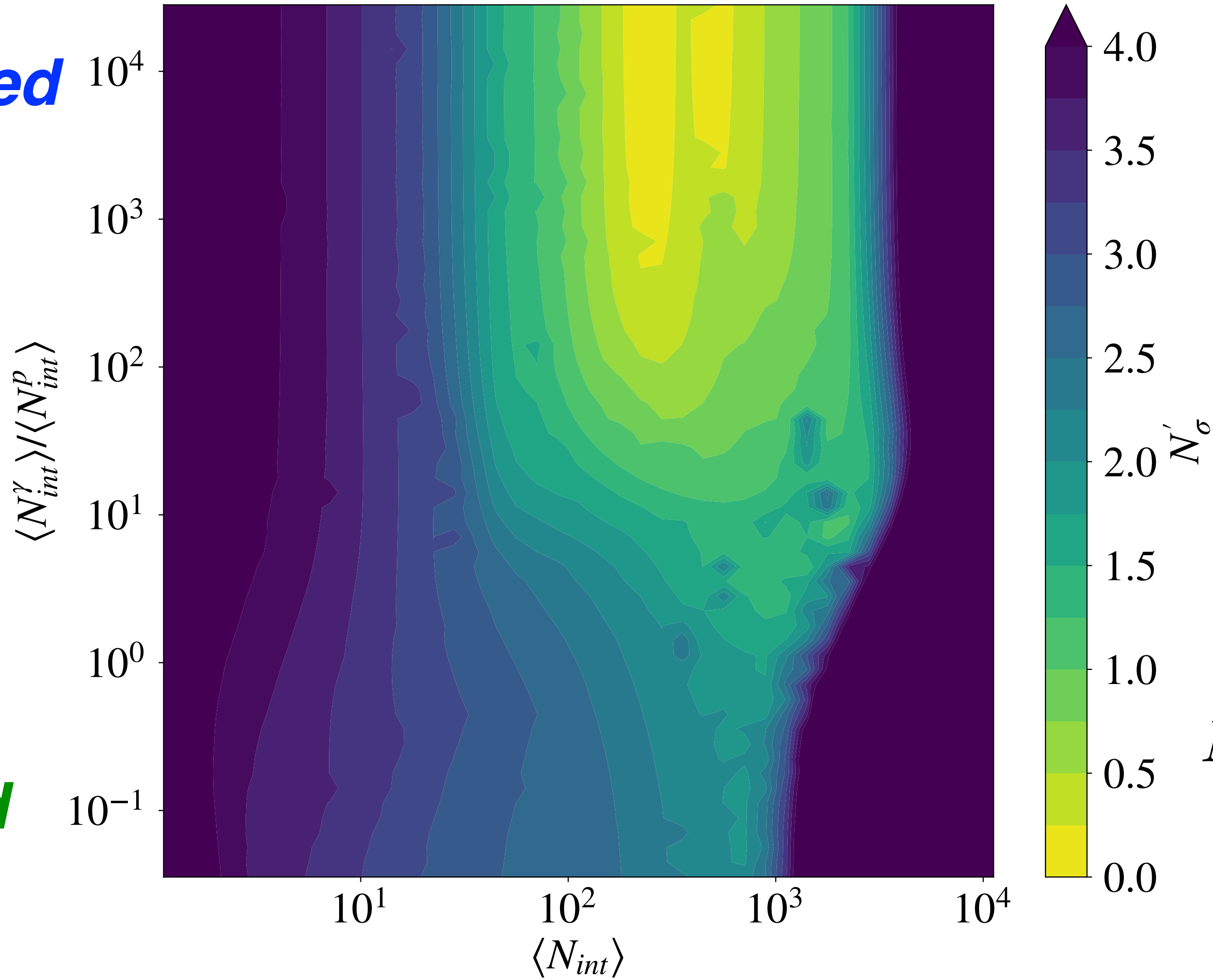


CRs: Slight preference for photon-dominated sources

Photon dominated



Gas dominated

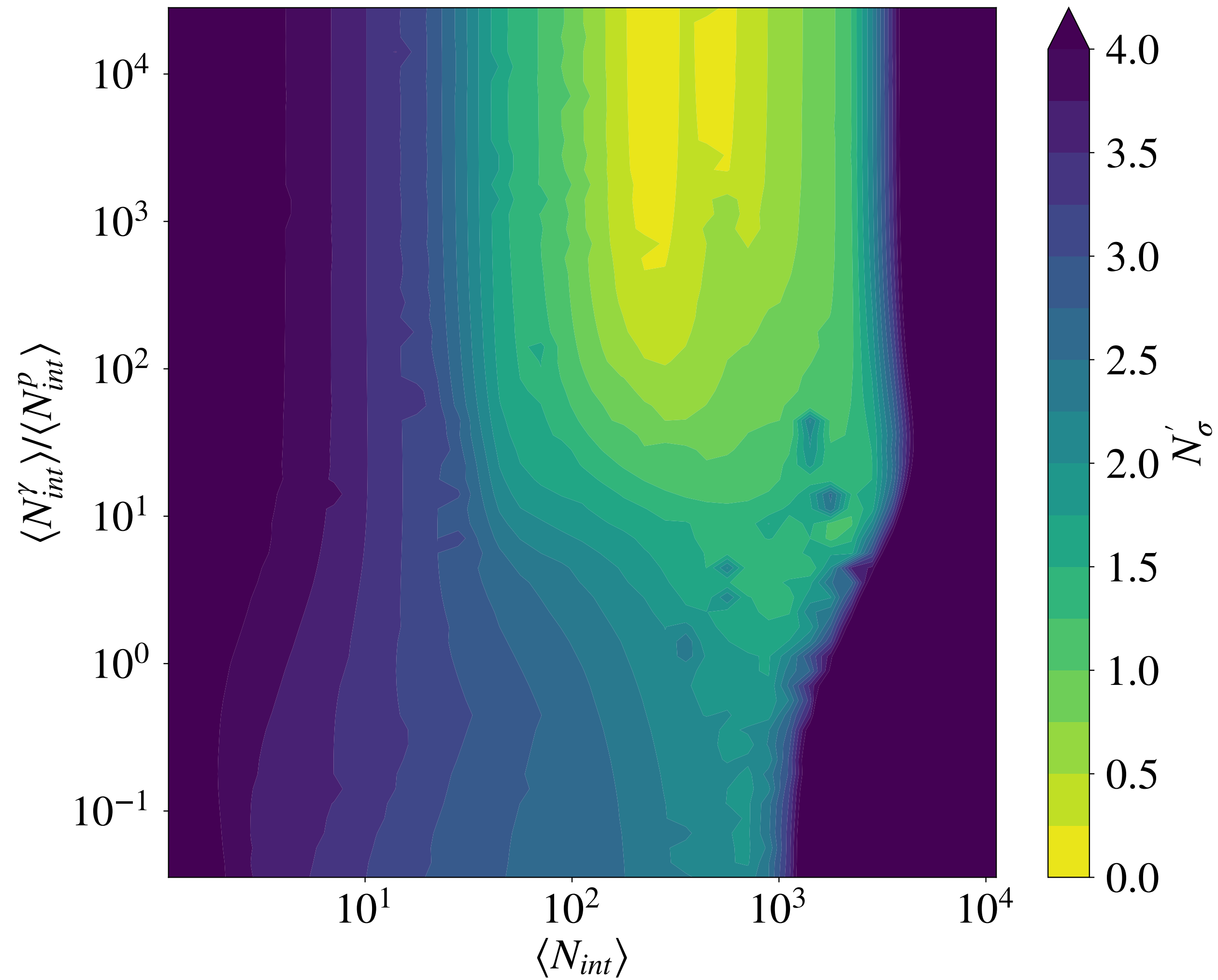


Photon-dominated sources less constrained

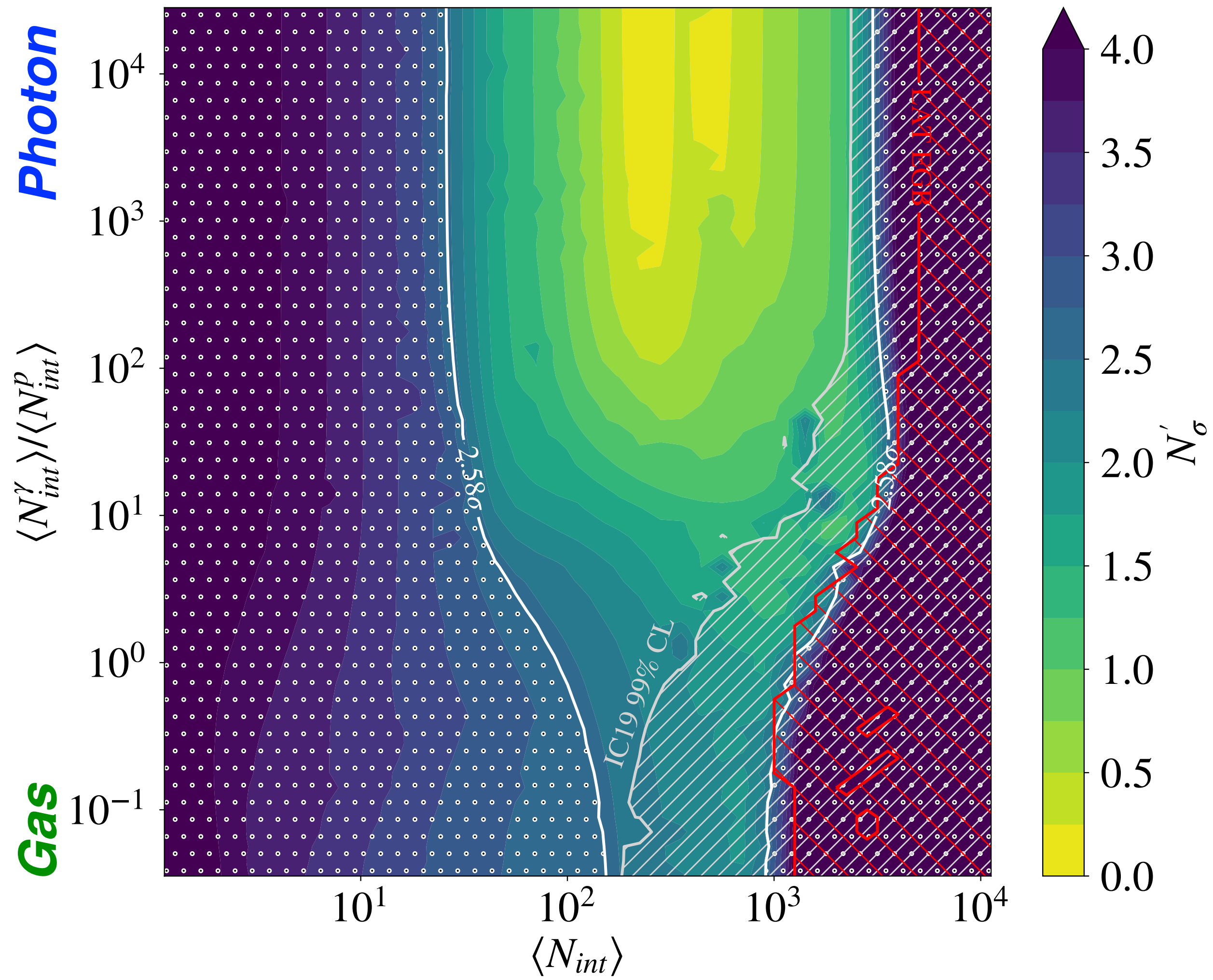
$$N'_{\sigma} = \sqrt{N_{dof} \frac{(\chi^2 - \chi_{min}^2)}{\chi_{min}^2}}$$

Average number of interactions (10 EeV ⁵⁶Fe)

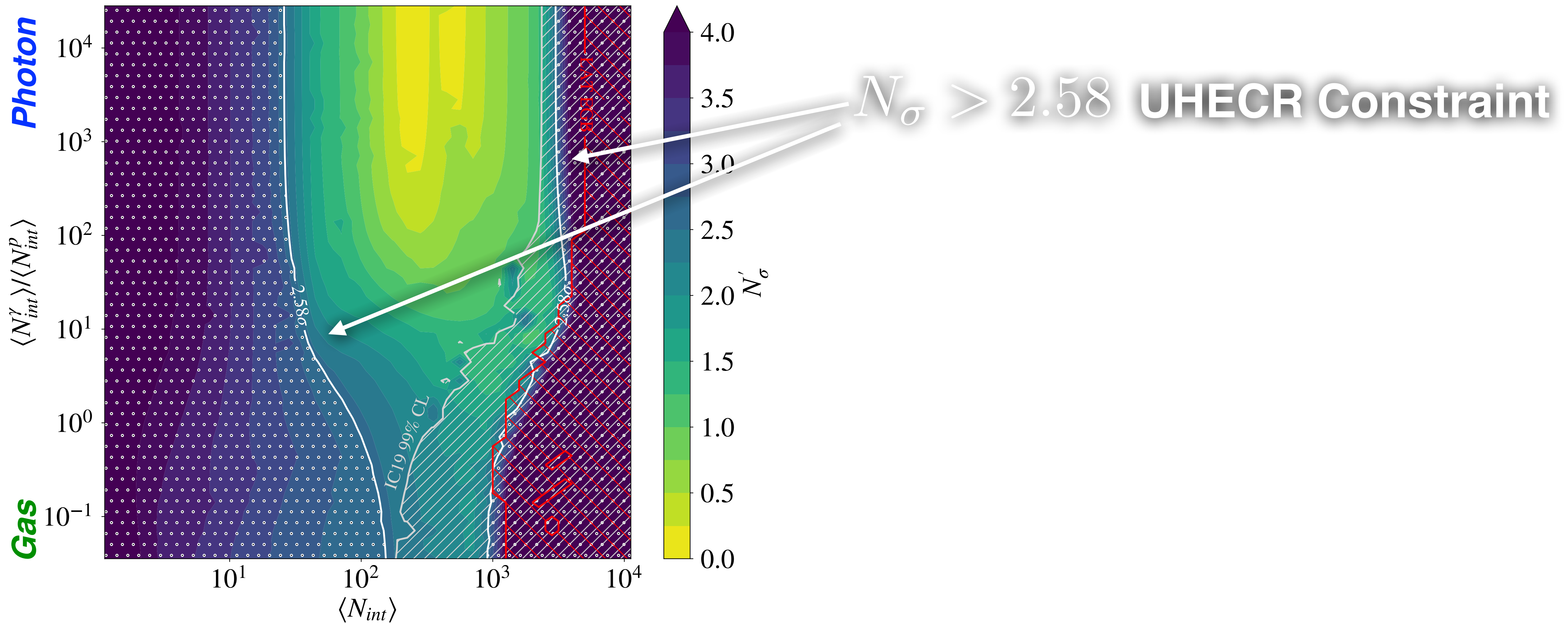
Multimessenger Constraints



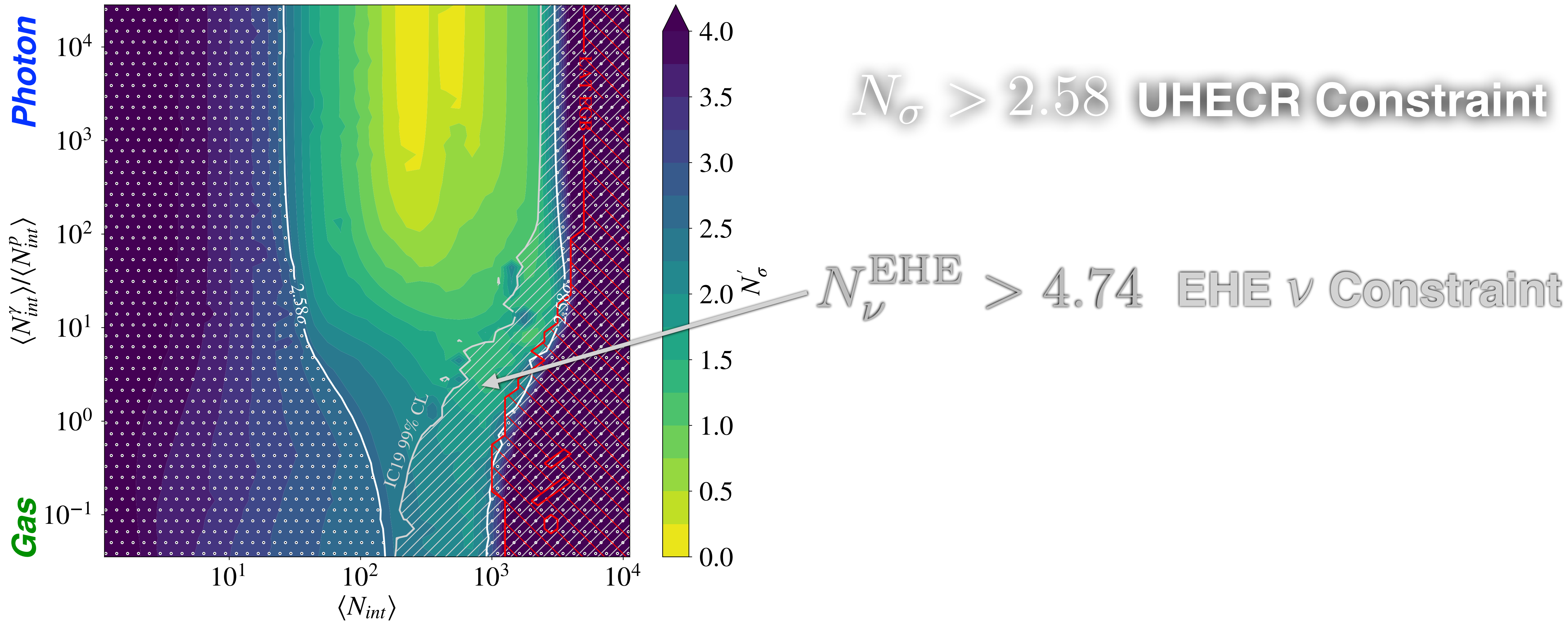
Multimessenger Constraints



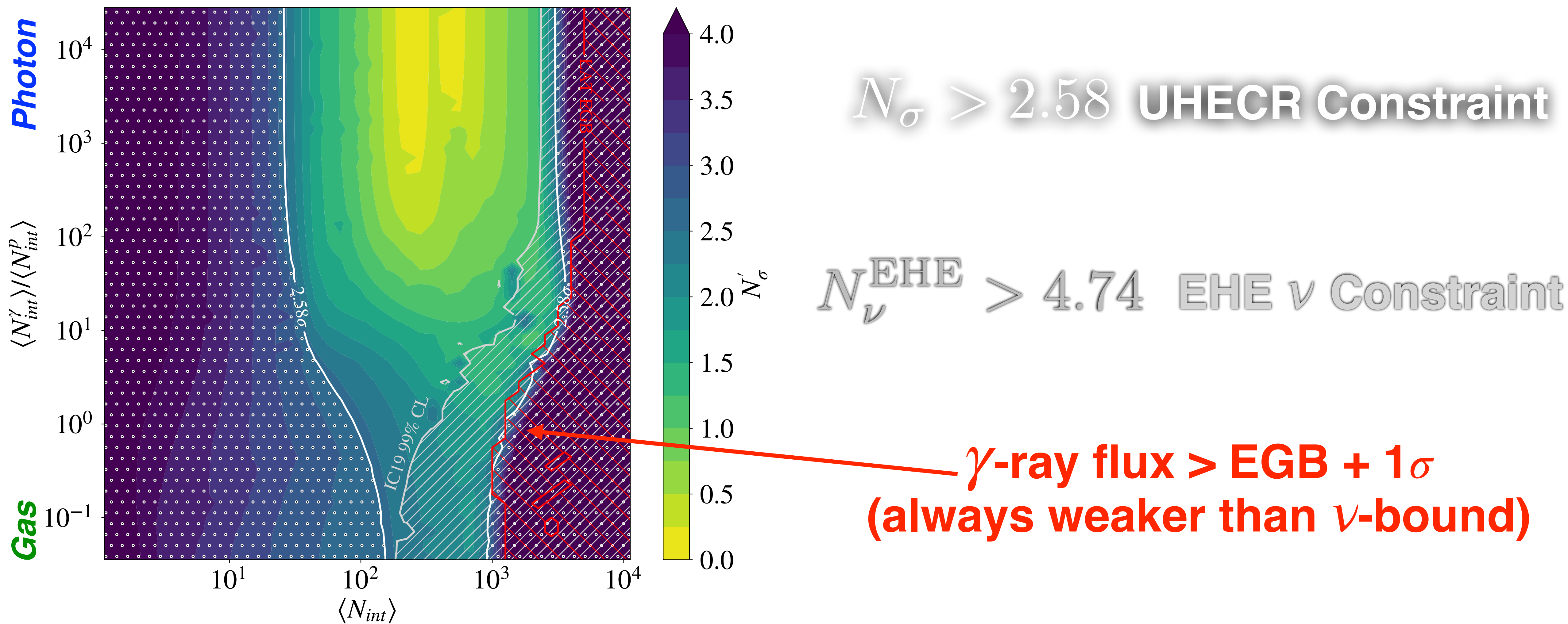
Multimessenger Constraints



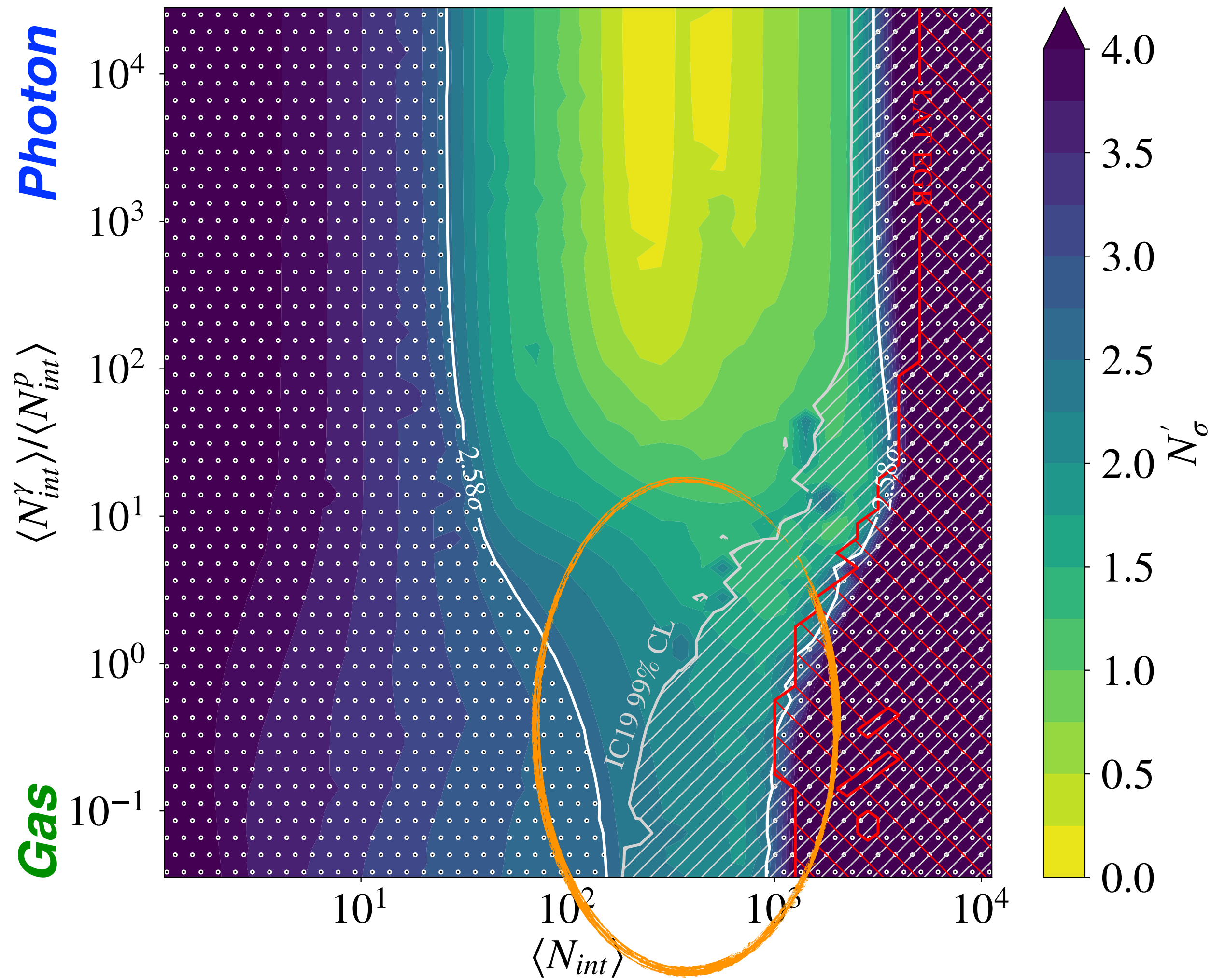
Multimessenger Constraints



Multimessenger Constraints



Multimessenger Constraints

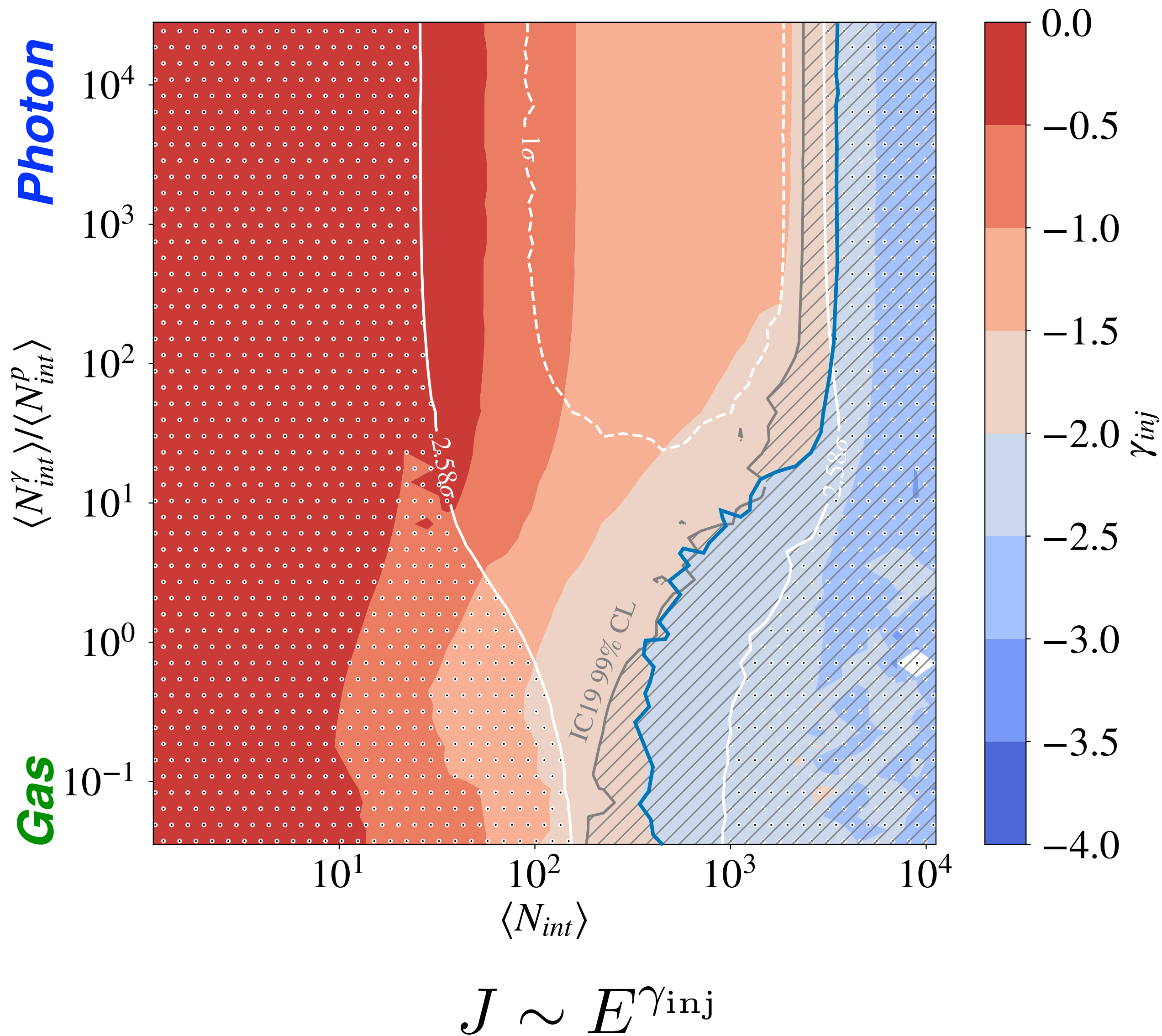


$N_\sigma > 2.58$ UHECR Constraint

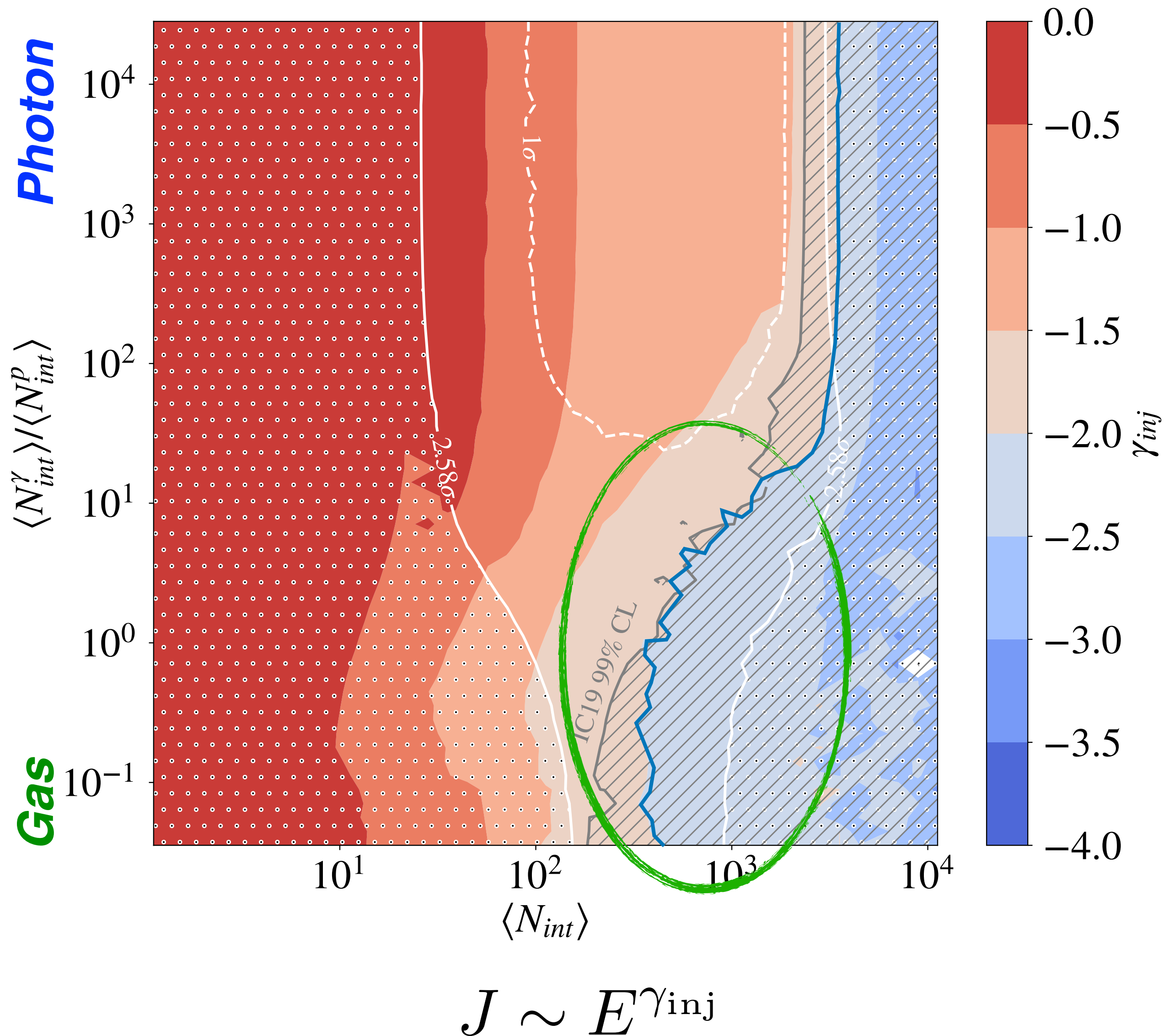
***Gas-dominated sources
in tension with
EHE neutrino constraints***

γ -ray flux $>$ EGB + 1σ
(always weaker than ν -bound)

Spectral Index of UHECR Accelerator



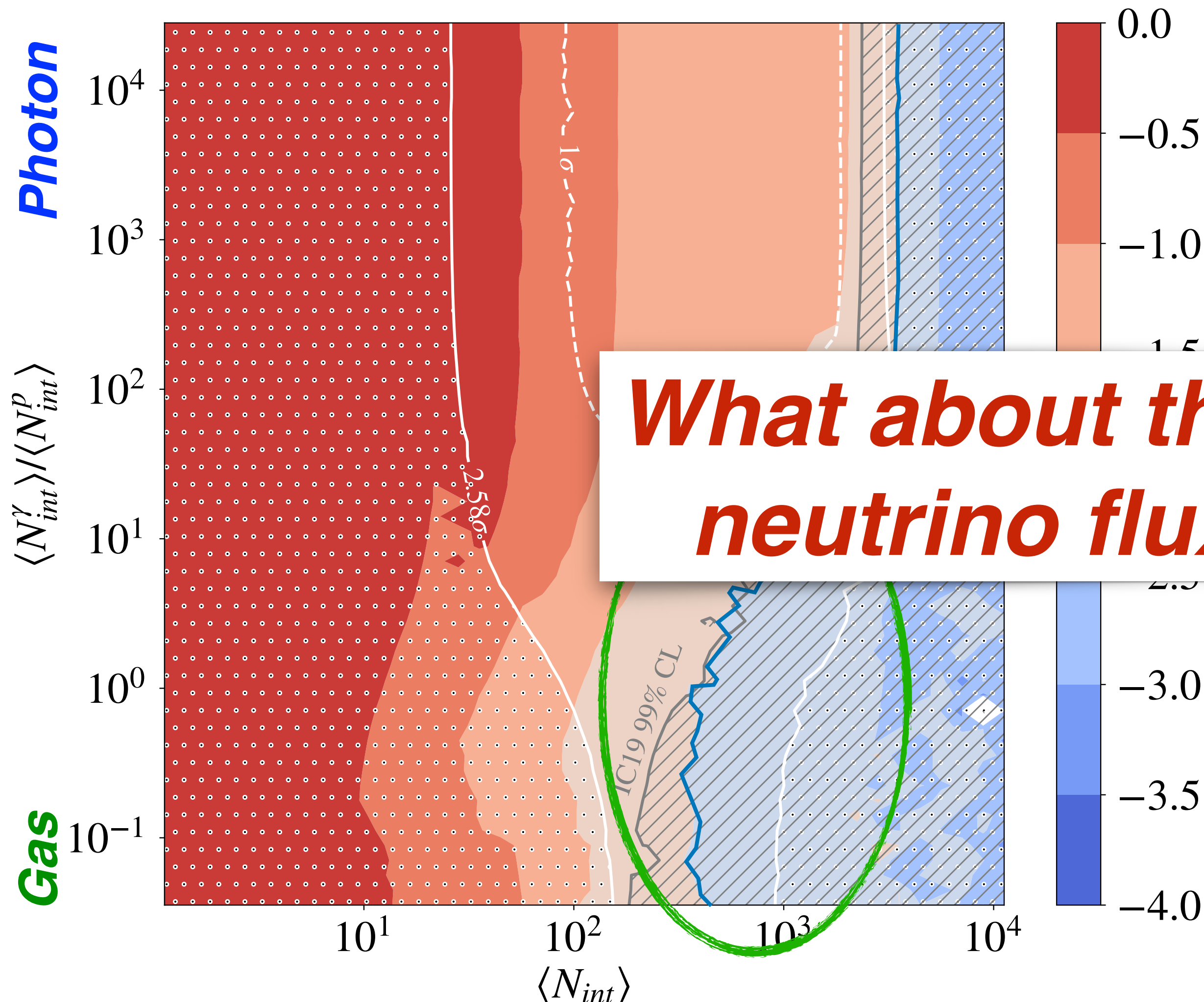
Spectral Index of UHECR Accelerator



***Spectral indices $\sim E^{-2}$
compatible with UHECRS
in tension with EHE
neutrinos***

***Accurate measurement of
neutrino flux in ~ 10 PeV energy
range could exclude E^{-2}***

Spectral Index of UHECR Accelerator



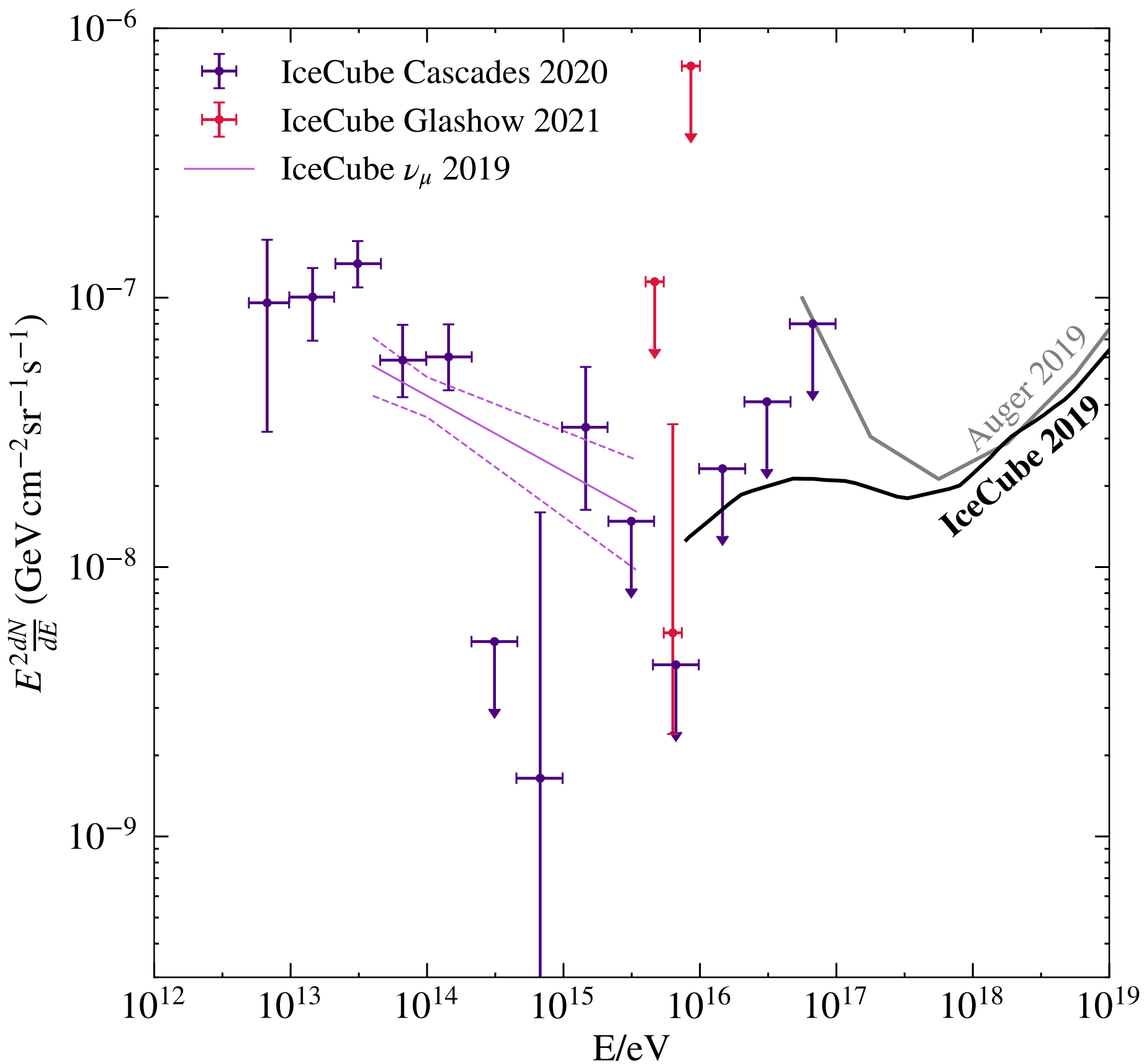
$$J \sim E^{\gamma_{inj}}$$

Spectral indices $\sim E^{-2}$ compatible with UHECRS in tension with EHE neutrinos

What about the astrophysical neutrino flux description?

Accurate measurement of neutrino flux in ~ 10 PeV energy range could exclude E^{-2}

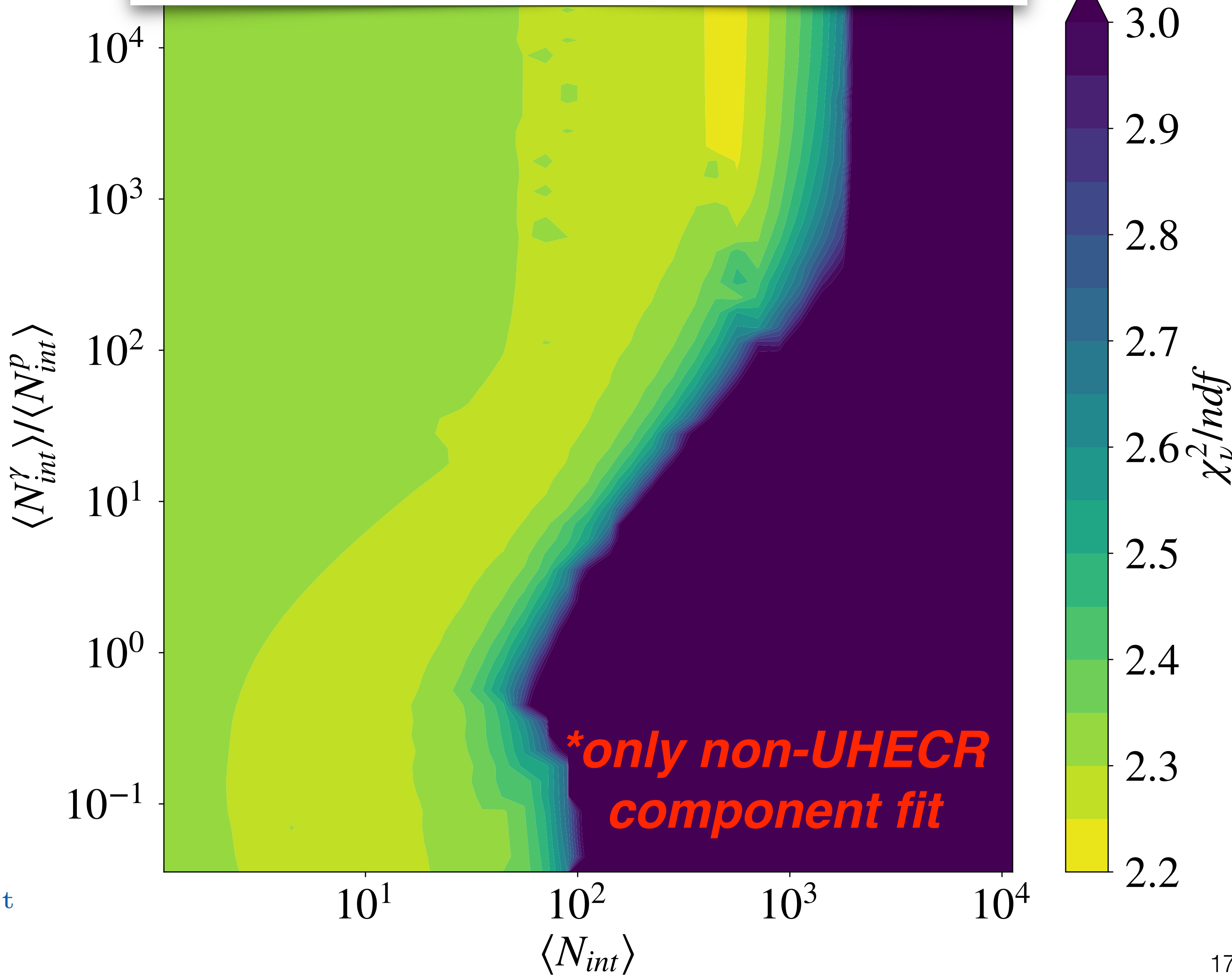
χ^2_ν / ndf to astrophysical neutrinos



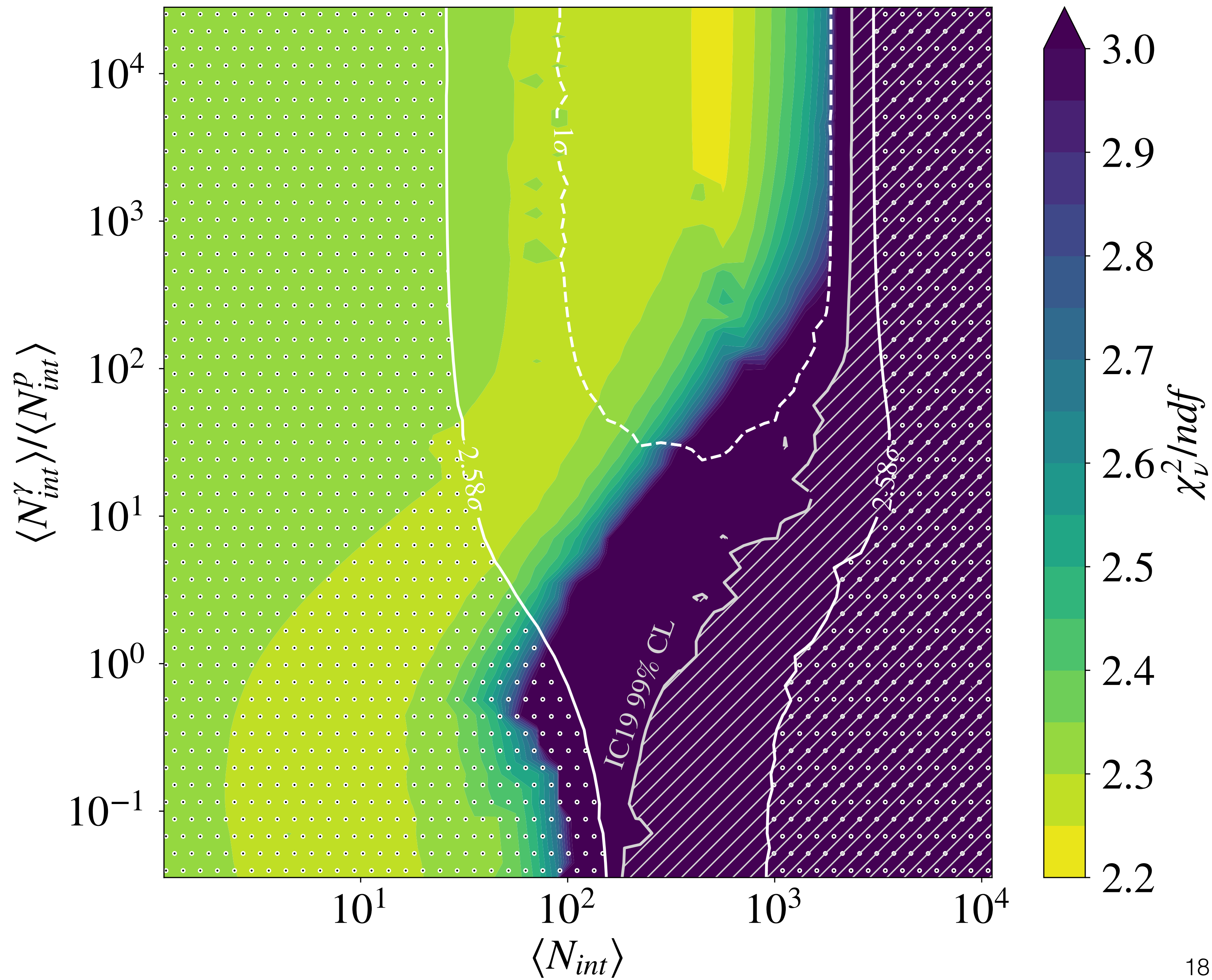
→
High-energy component from UHECRs

←
Fit for low-energy component not from UHECRs

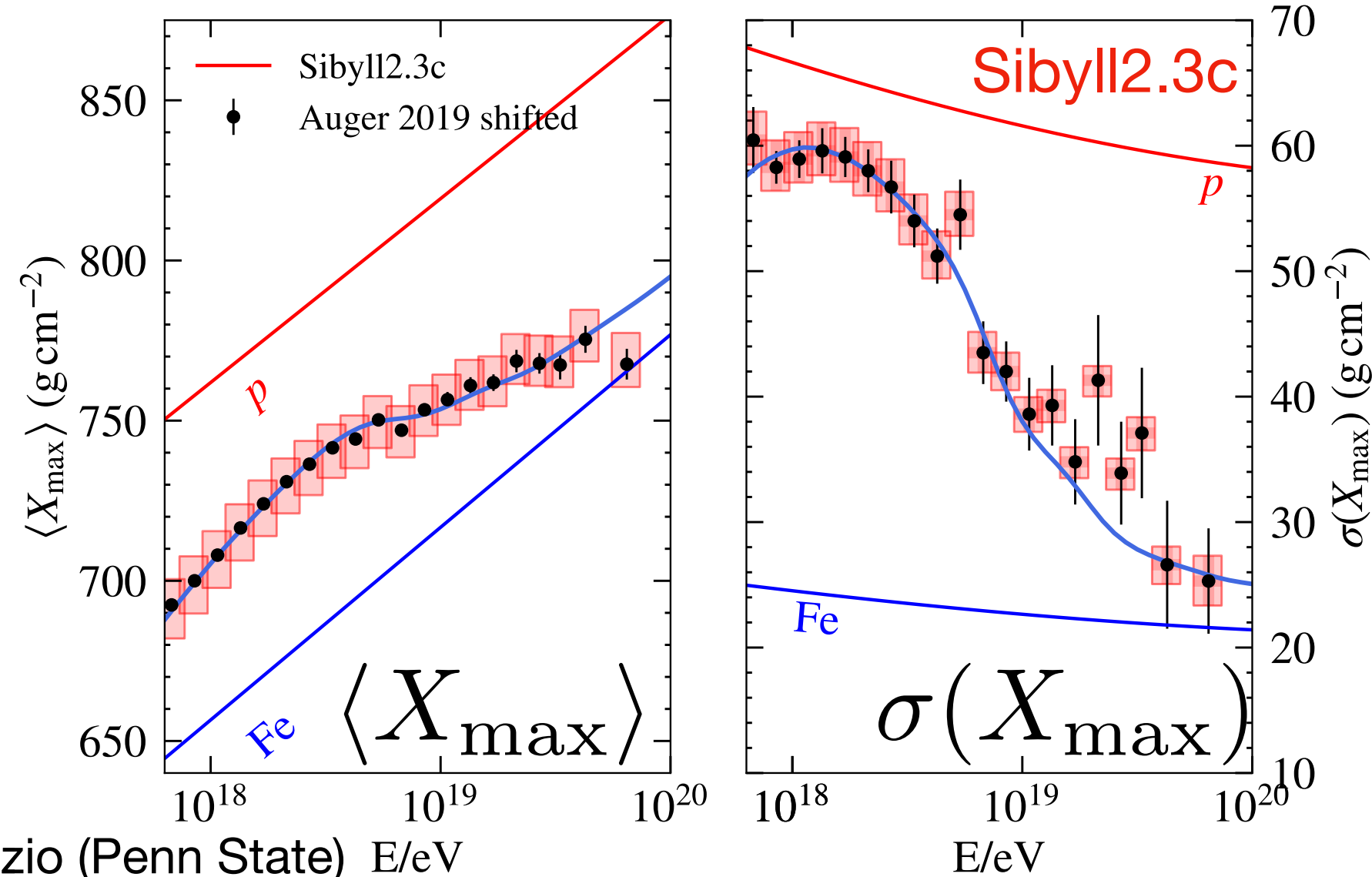
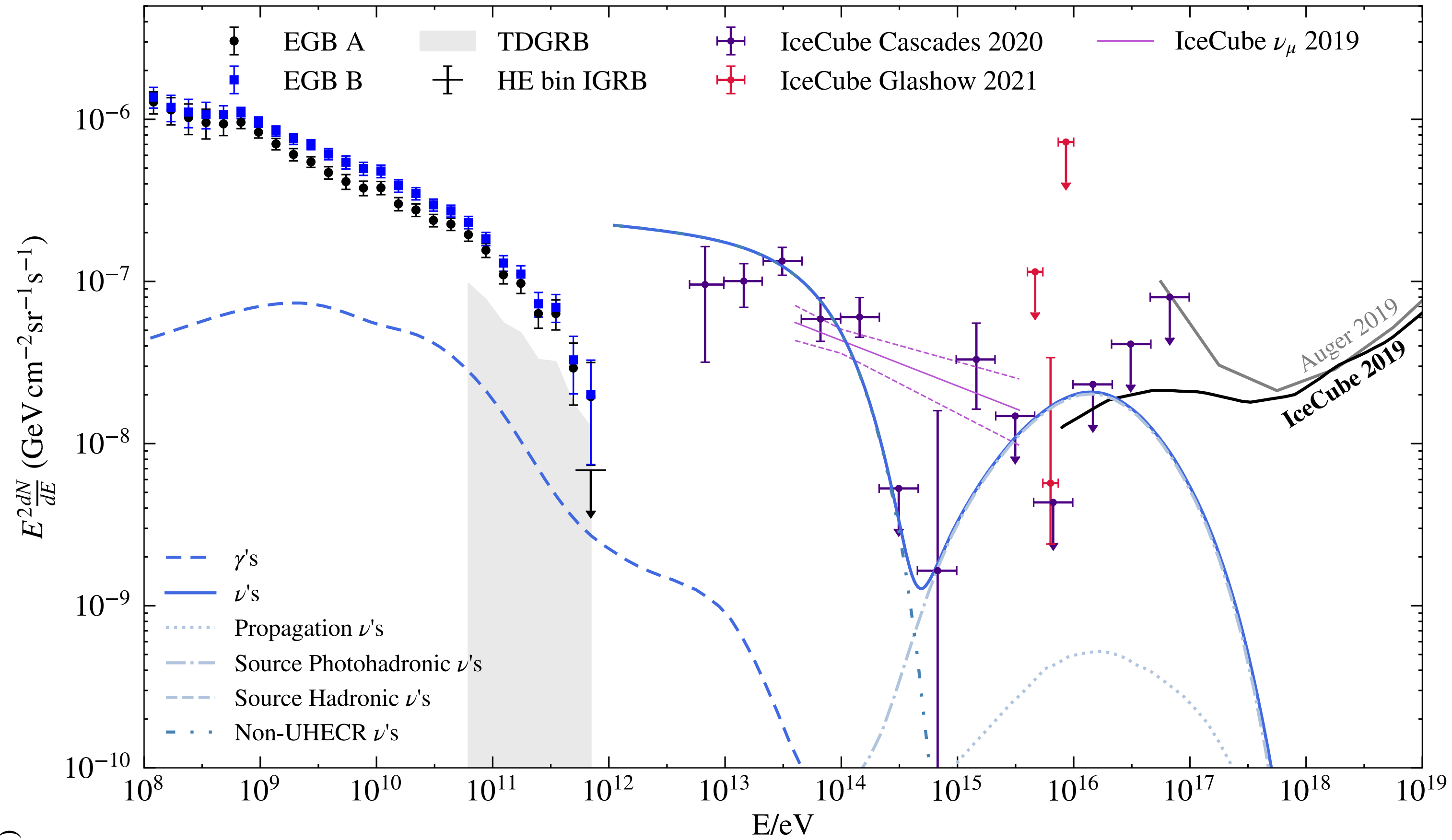
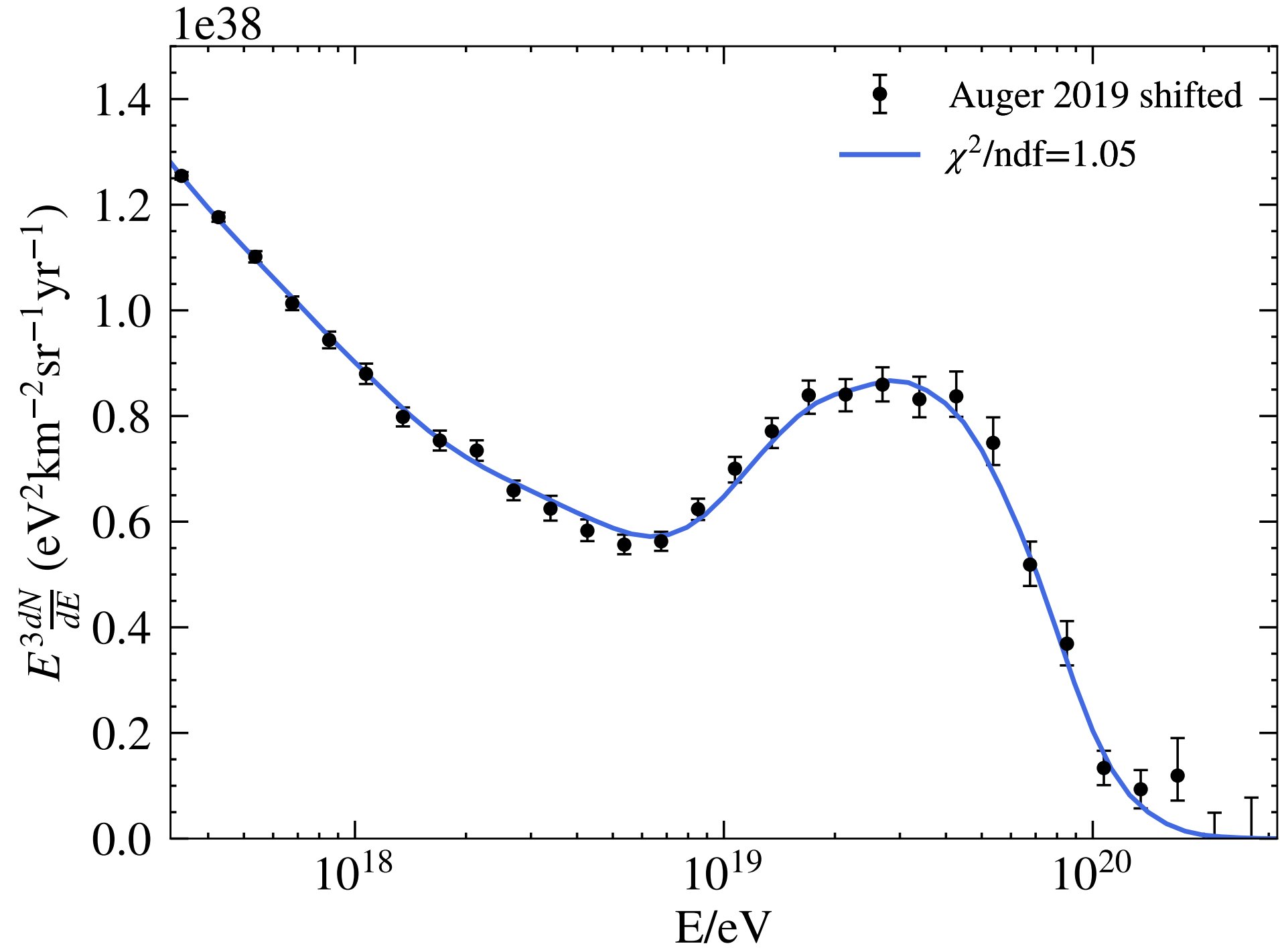
$$\phi_\nu \sim \phi_0 E^\gamma e^{-E/E_{\text{cut}}}$$



Best description of astrophysical neutrino flux corresponds to best-fit UHECR region!



Best Description of Astrophysical Neutrino Flux



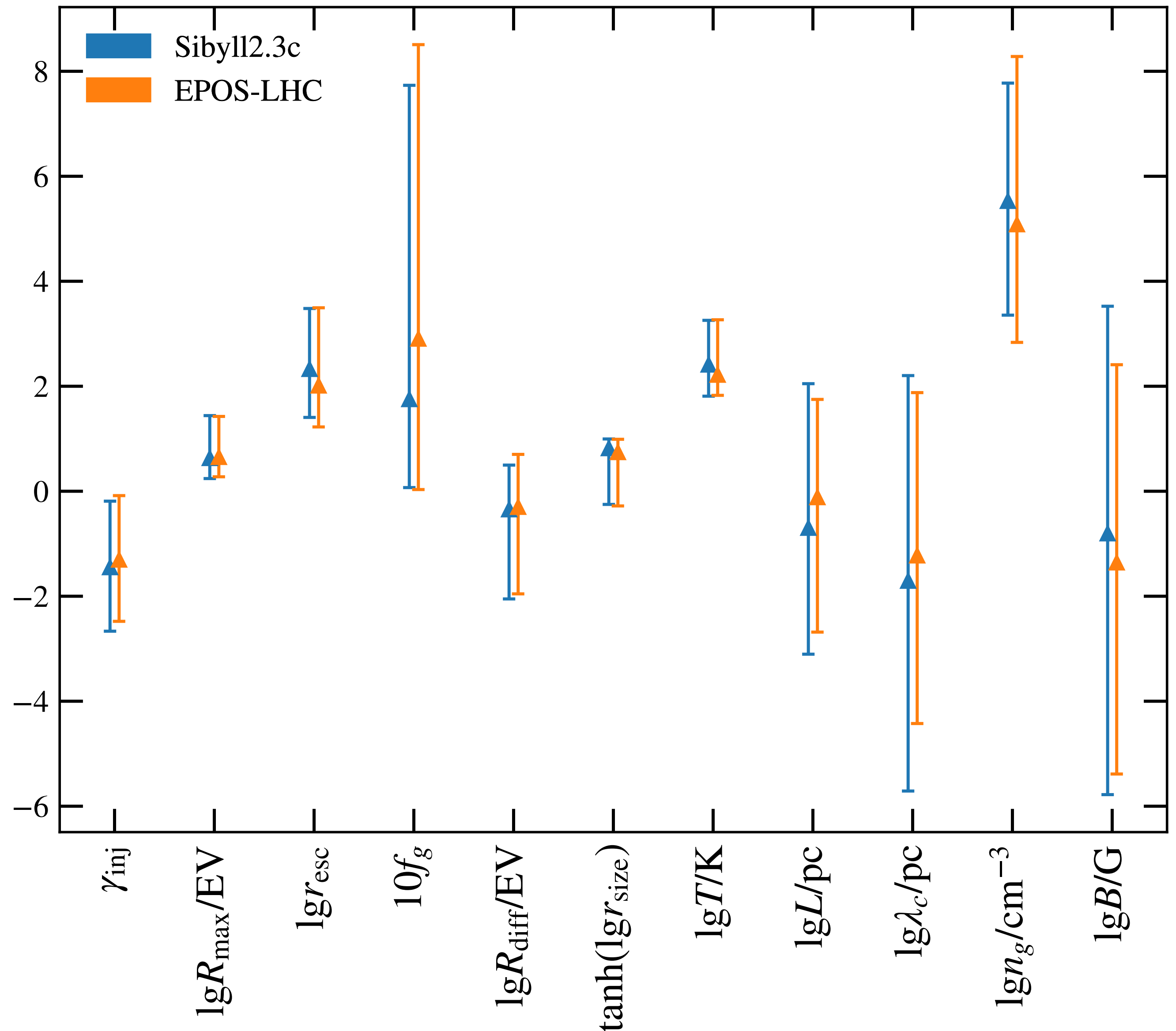
Inferred Source Parameters:

$$\begin{aligned}
 \langle N_{\text{int}} \rangle &= 447 & T_{\text{BB}} &= 8987 \text{ K} & R_{\text{diff}} &= 10^{17.8} \text{ V} \\
 \frac{\langle N_{\text{int}}^\gamma \rangle}{\langle N_{\text{int}}^p \rangle} &= 22387 & \gamma_{\text{inj}} &= -1.16 & L/\lambda_c &= 9.5
 \end{aligned}$$

Narrowing in on Possible Sources

Performed MCMC to find spread of parameter values compatible with data and constraints

Posterior distribution modes and 16th/84th percentiles indicated



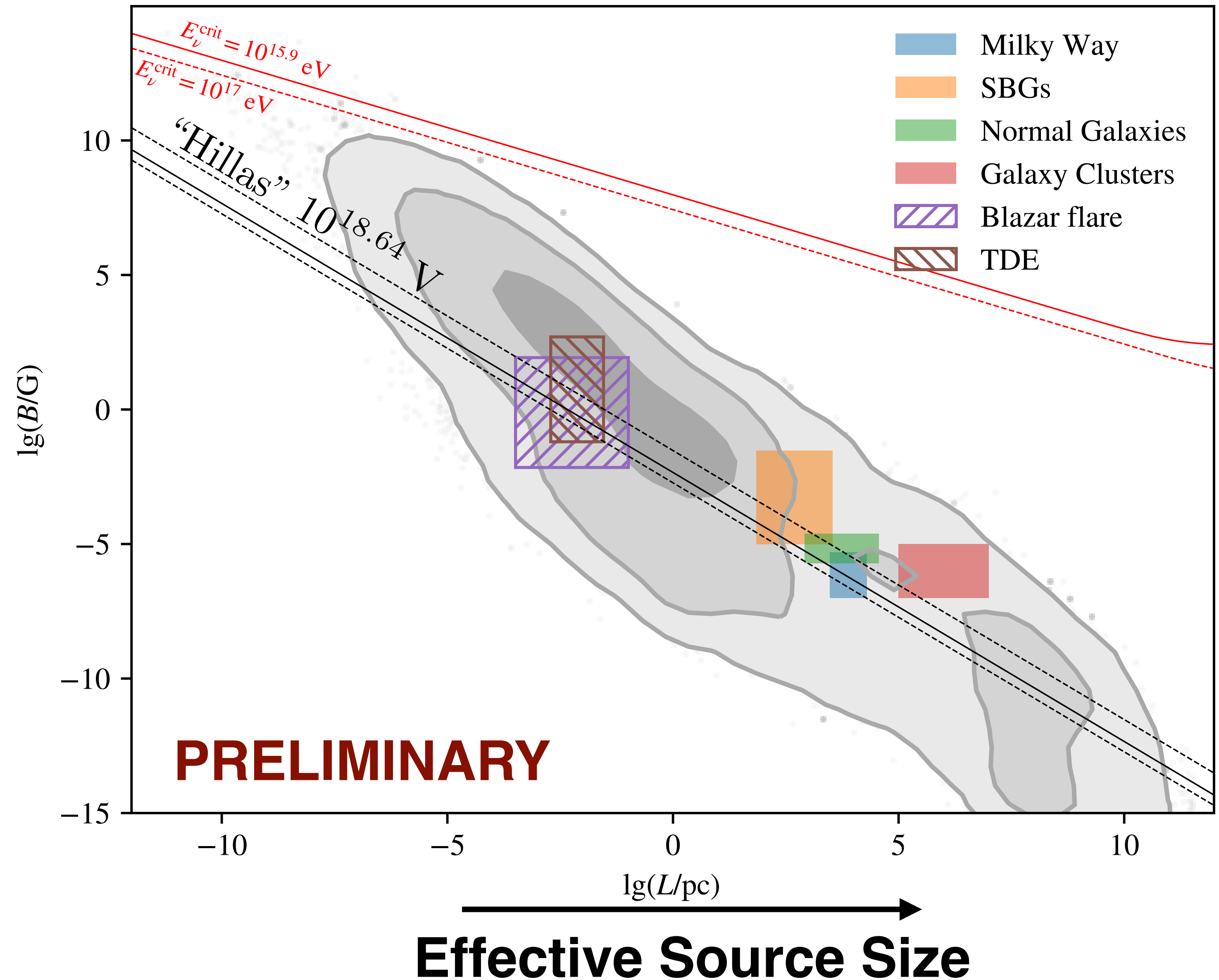
Work in Progress: the Not-Hillas Plot

Posterior distribution
constrains source size L and
magnetic field strength B

Source regions indicated
represent fiducial values
from literature, plot still
being populated

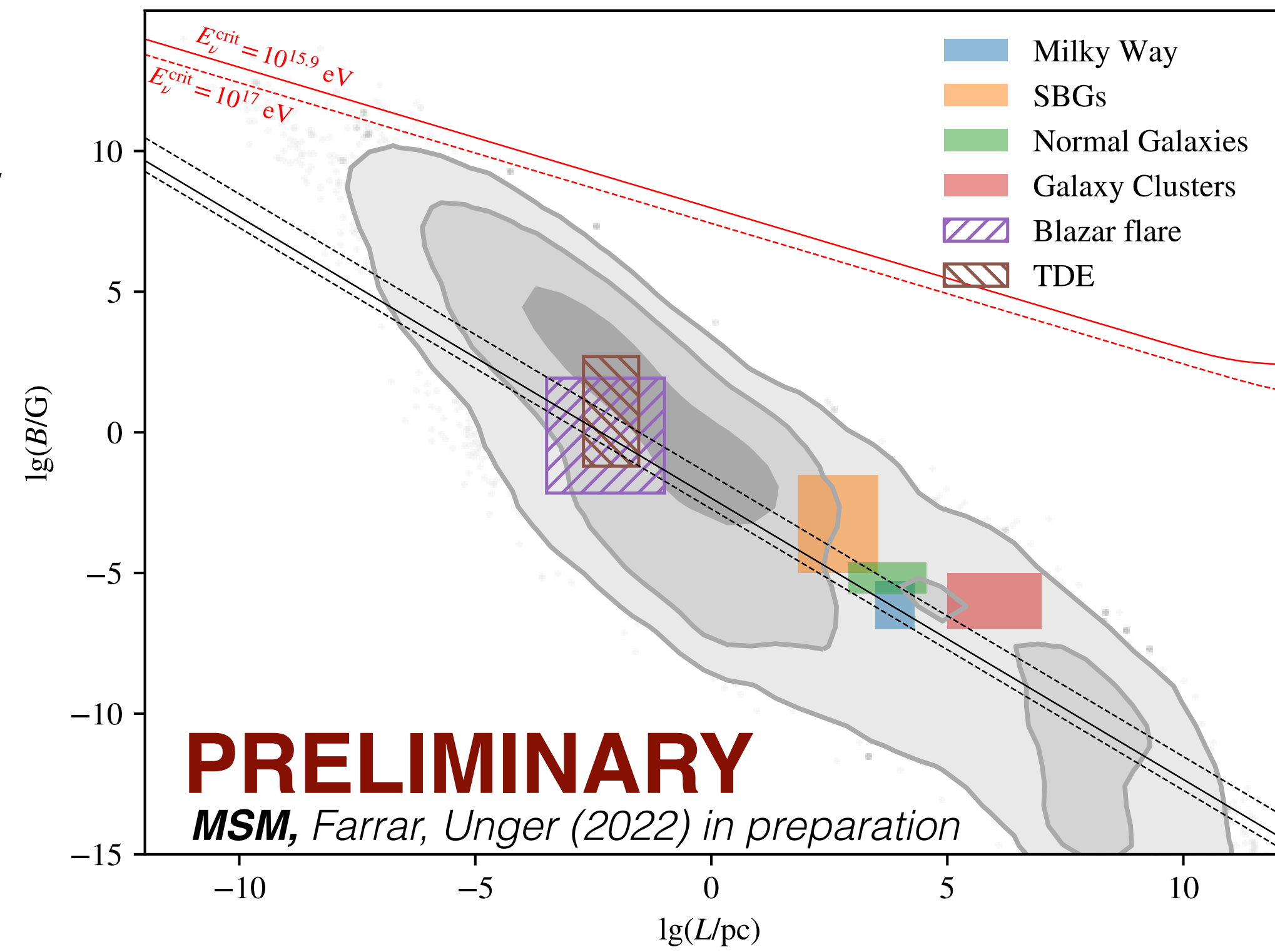
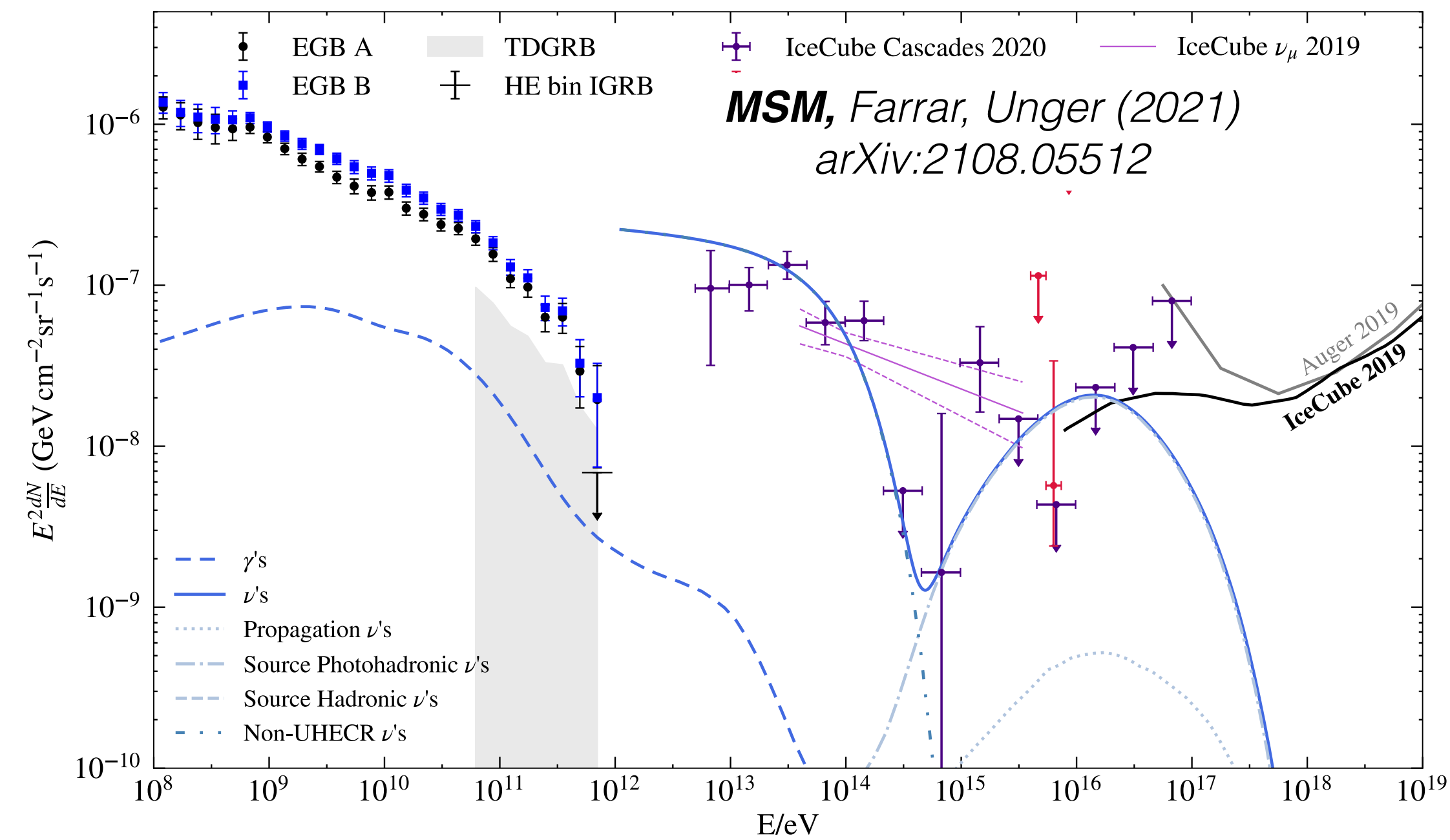
***What known
astrophysical sources lie
in the favored region?***

**Magnetic Field
Strength**



Summary

- **Gas & photon interactions** in source environment can **explain UHECR data**
- **Gas dominated source** environments in **tension with EHE neutrinos**
- **Viability of soft spectral indices** like $\sim E^{-2}$ **determined by** accurate measurement of **neutrino flux at ~ 10 PeV**
- **High energy astrophysical neutrinos** can be **explained by UHECR sources**
- Analysis **constrains astrophysical source properties**, potentially determines preferred source types



A night sky photograph featuring the Milky Way galaxy and a vibrant green aurora borealis. A complex white wireframe structure, resembling a large-scale antenna or sensor array, is superimposed on the scene. The structure consists of numerous thin white lines radiating from a central point, creating a dense, conical shape. The background shows a dark sky with stars and the Milky Way, transitioning to a green aurora near the horizon. In the foreground, a small white structure with a satellite dish and a utility pole are visible.

Thank you!