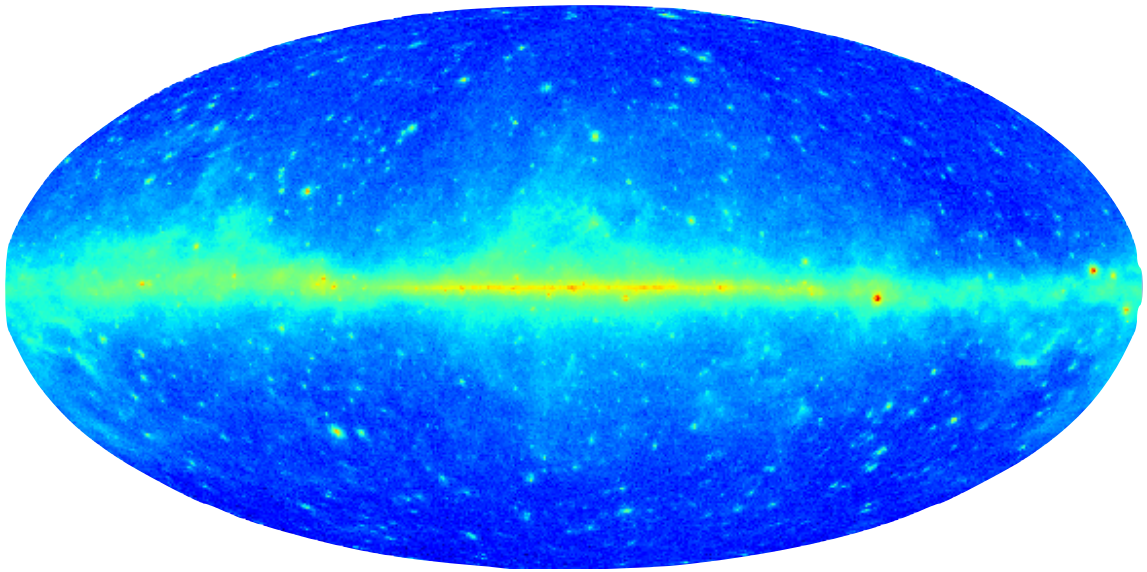
Gamma-ray Constraints on Decaying Dark Matter and Implications for IceCube

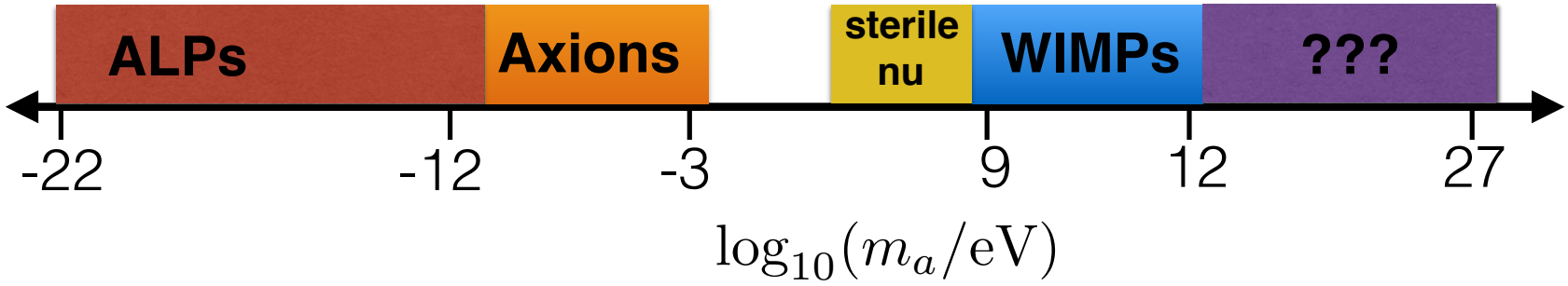


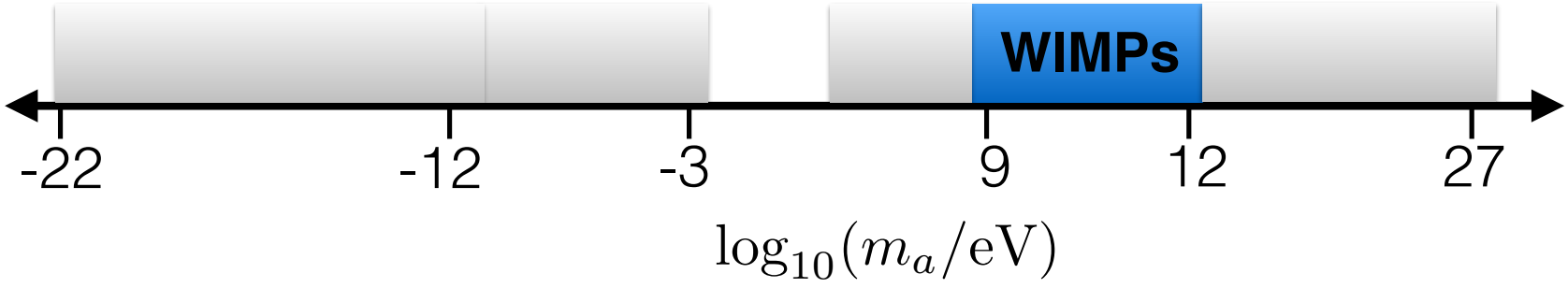
Ben Safdi

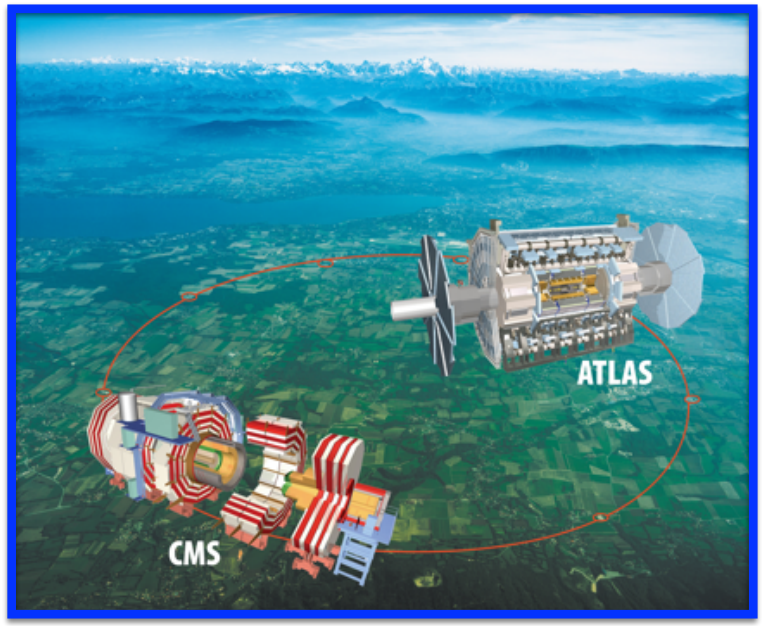
Massachusetts Institute of Technology

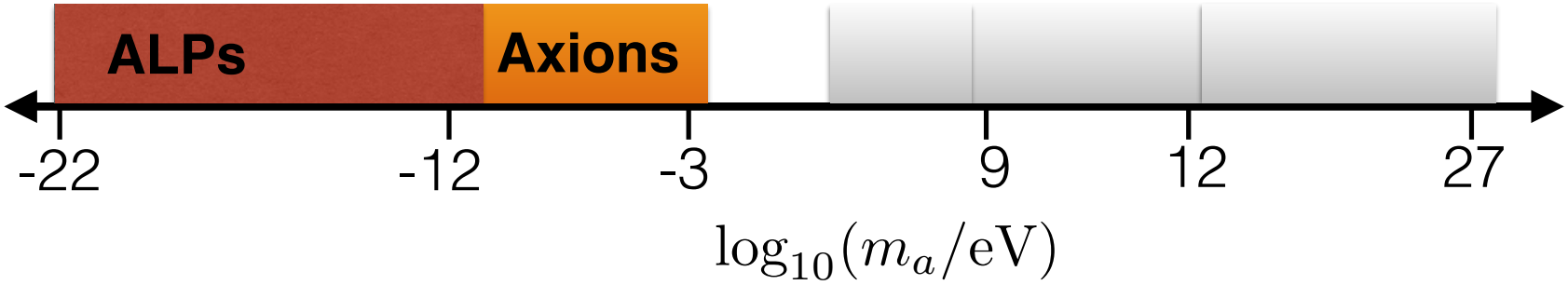
T. Cohen, K. Murase, N. Rodd, **B.S.**, Y. Soreq [1612.05638]

About 50 orders of magnitude in particle DM mass!



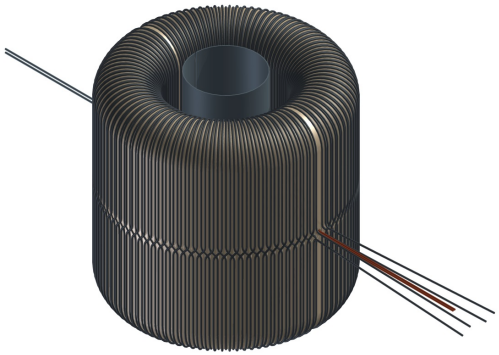

WIMPs
-22
-12
-3
9
12
27
$\log_{10}(m_a/\mathrm{eV})$


ATLAS
CMS



From Theory...

- **Phys. Rev. Lett.**, 117, 141801 (2016): Yoni Kahn, **B.S.**, Jesse Thaler

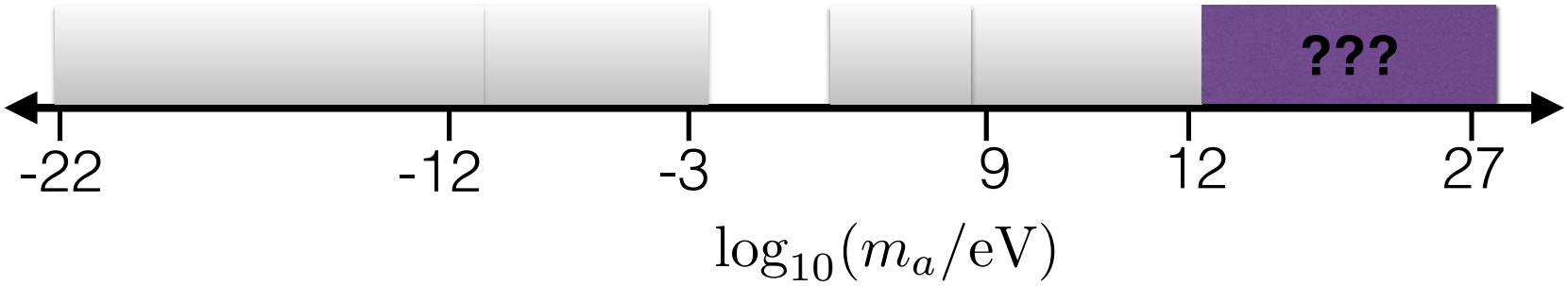


- Ultimate goal: Detect axion dark matter from GUT-scale solution to strong-CP problem

...to Experiment

- ABRACADABRA-10 cm

- The team: J. Conrad, J. Formaggio, S. Heine, J. Minervini, J. Ouellet, K. Perez, A. Radovinsky, D. Winklehner, L. Winslow, . . .
- Funded by the NSF, data soon!

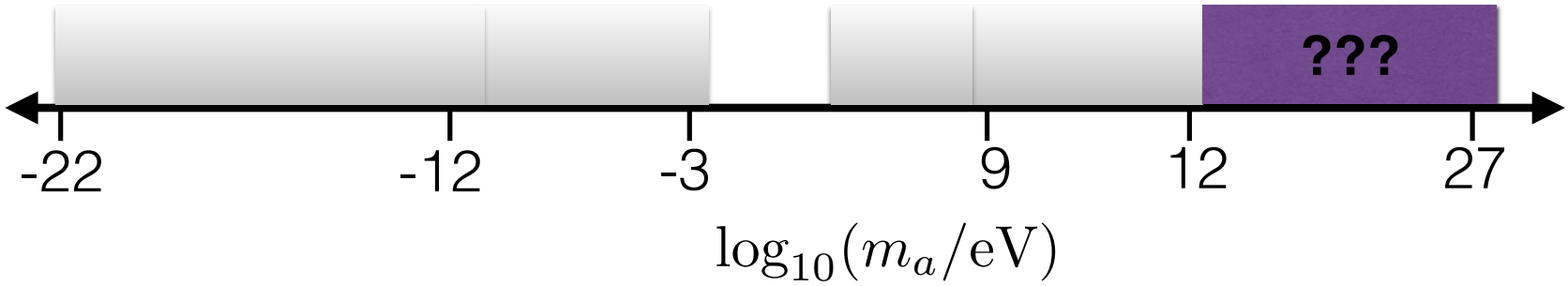


Fermi

Fermi (NASA)

IceCube

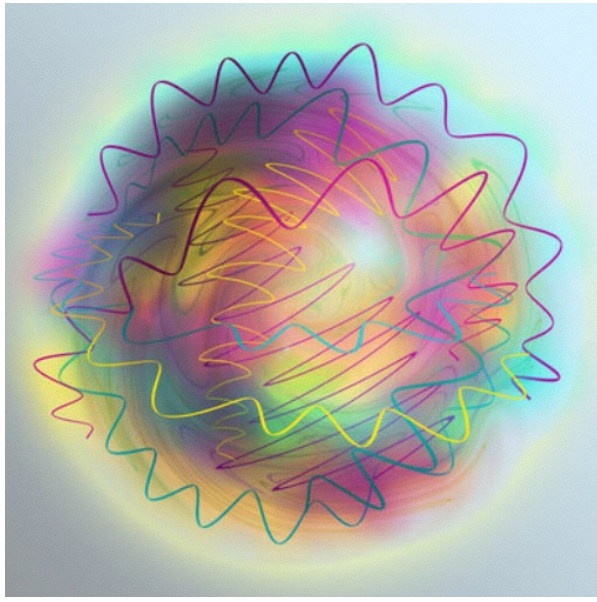
Heavy Dark-matter Example: Glueball



- Hidden $SU(N')$ coupled to SM: $\Lambda \sim 10^{16} - 10^{18}$ GeV
- Ex: $SU(3)$ and pure glue, $\Lambda_{\text{QCD'}} \sim 100$ TeV

$$\mathcal{L} \supset \frac{\lambda'}{\Lambda^2} G'_{\mu\nu} G'^{\mu\nu} |H|^2$$

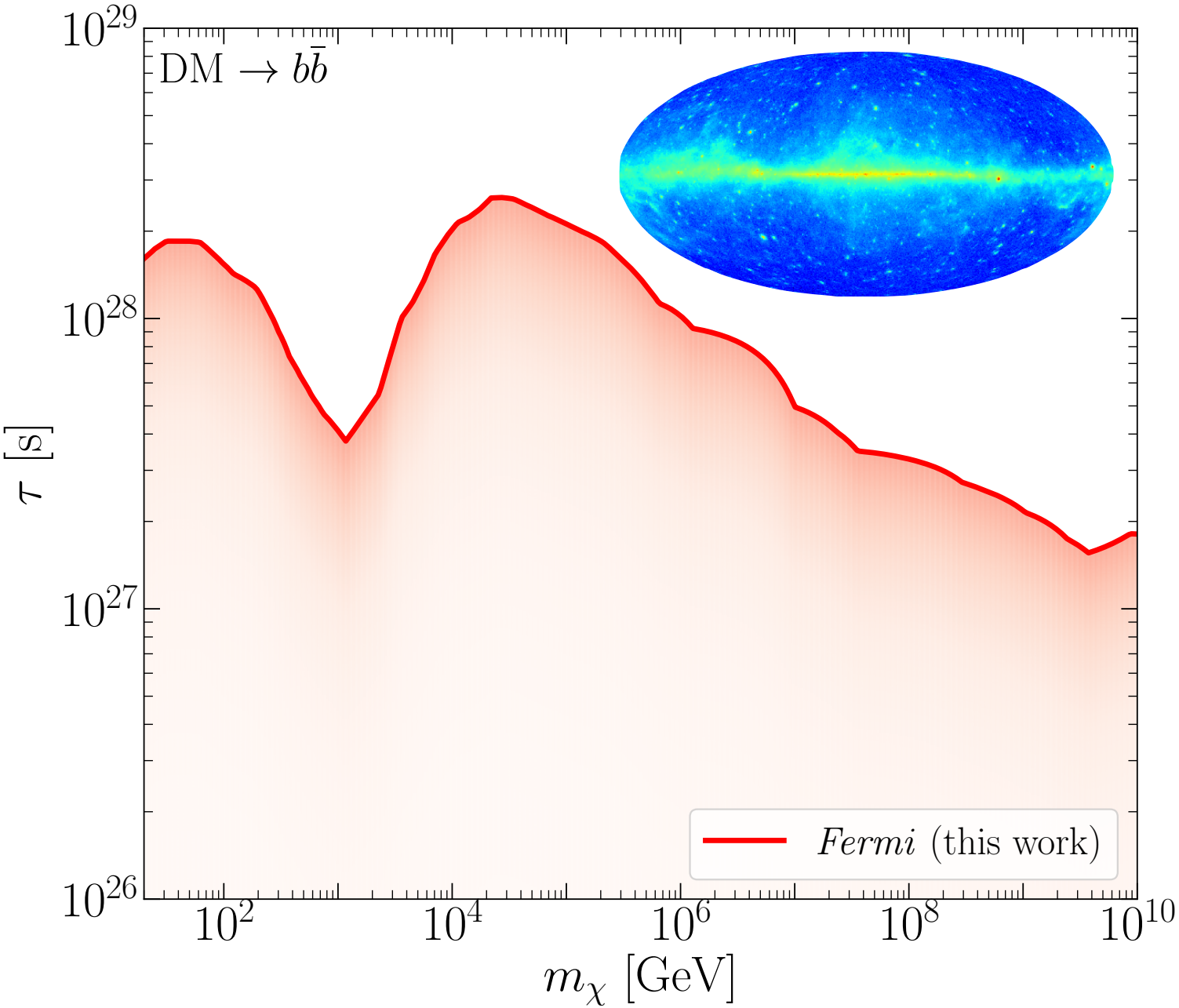
$$\to \lambda' \frac{\Lambda^3_{\text{QCD'}}}{\Lambda^2} \phi_{G'} |H|^2$$



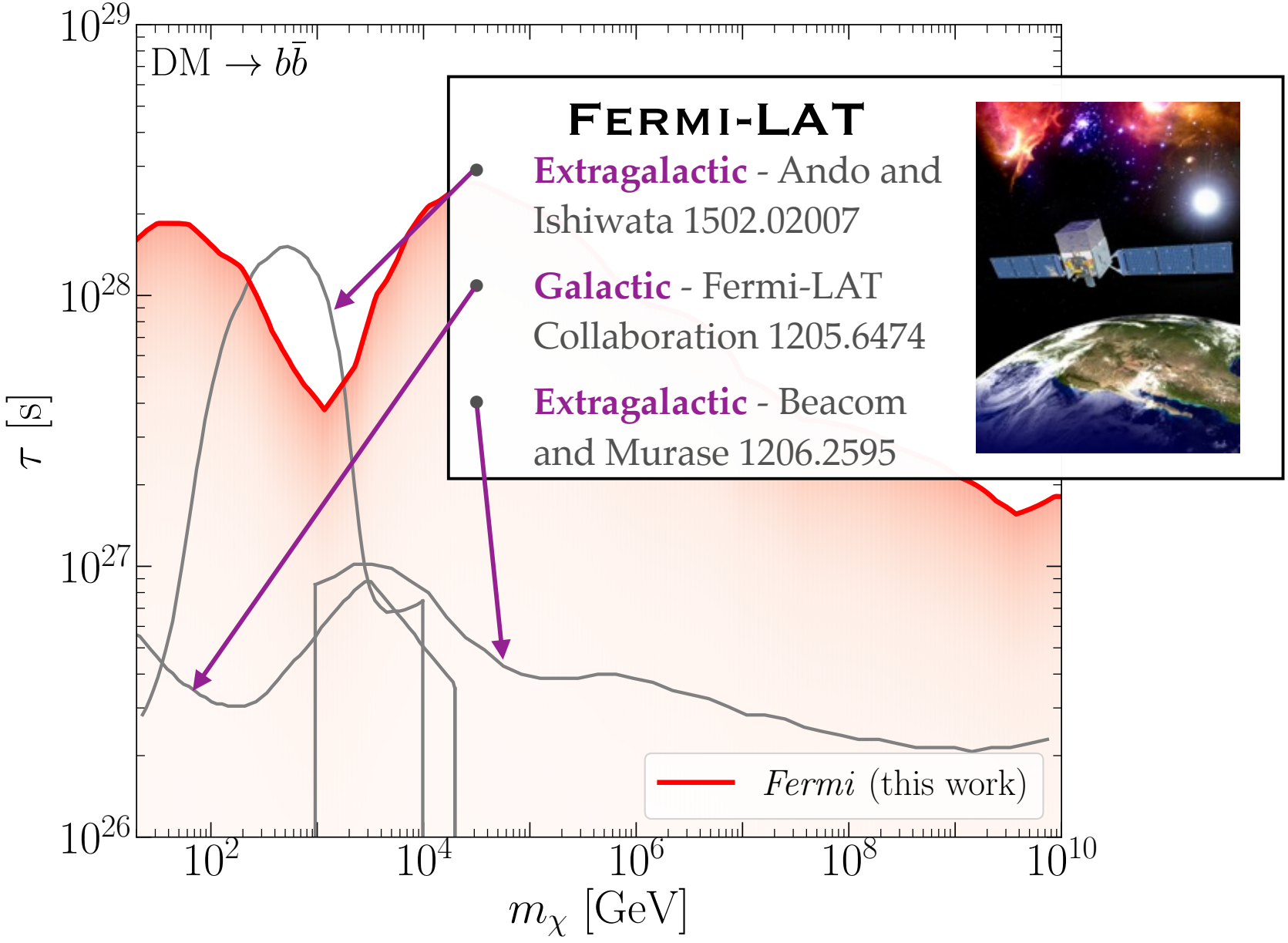
- Slow decay to SM:

$$\tau \approx 5 \times 10^{27}\ \text{s} \left(\frac{3}{N'}\frac{1}{4\pi\lambda'}\right)^2 \left(\frac{\Lambda}{m_{\text{pl}}}\right)^4 \left(\frac{100\ \text{TeV}}{\Lambda_{\text{QCD'}}}\right)^5$$

Looking ahead: our limit on the DM lifetime



Comparison to previous limits



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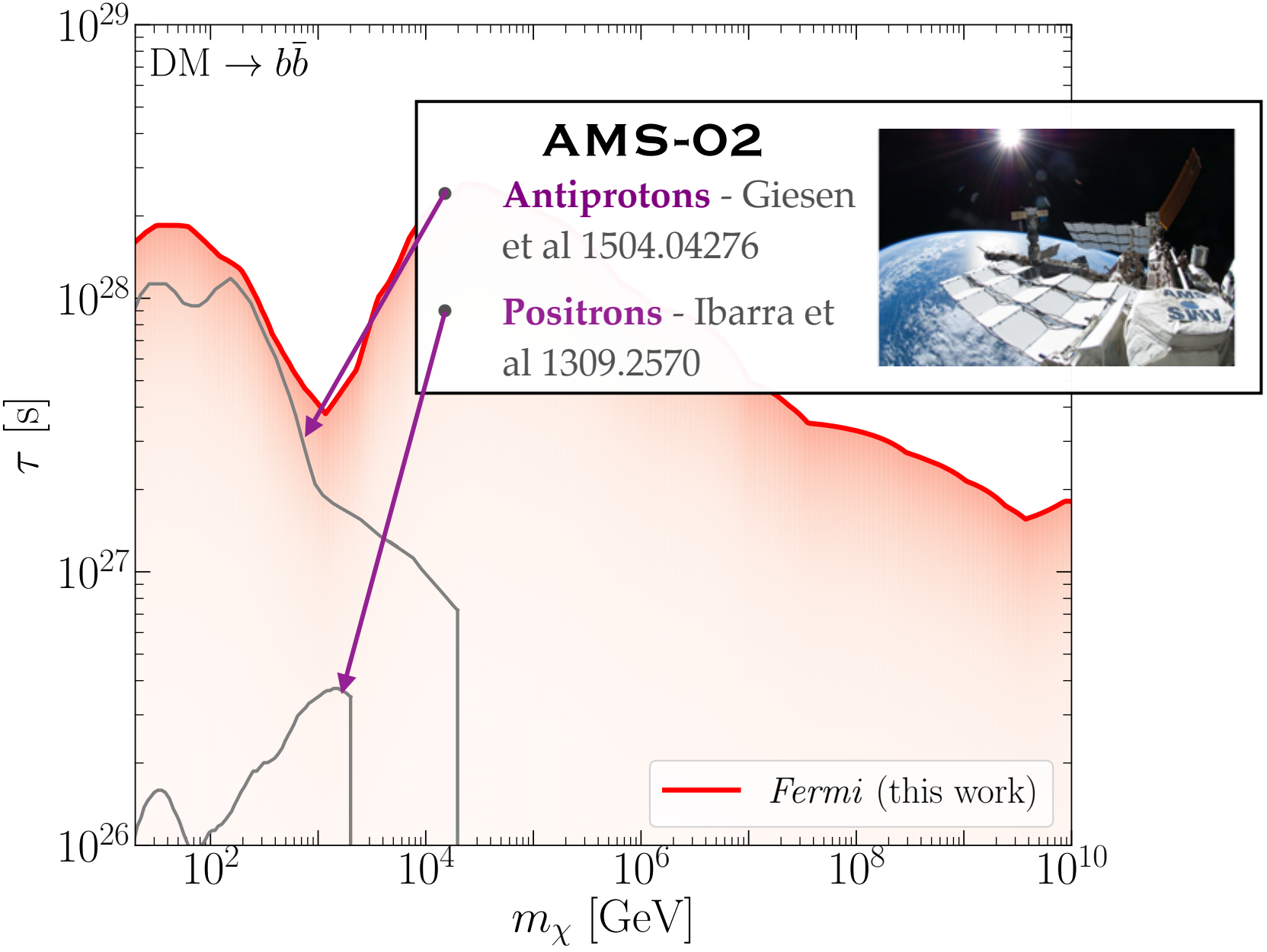

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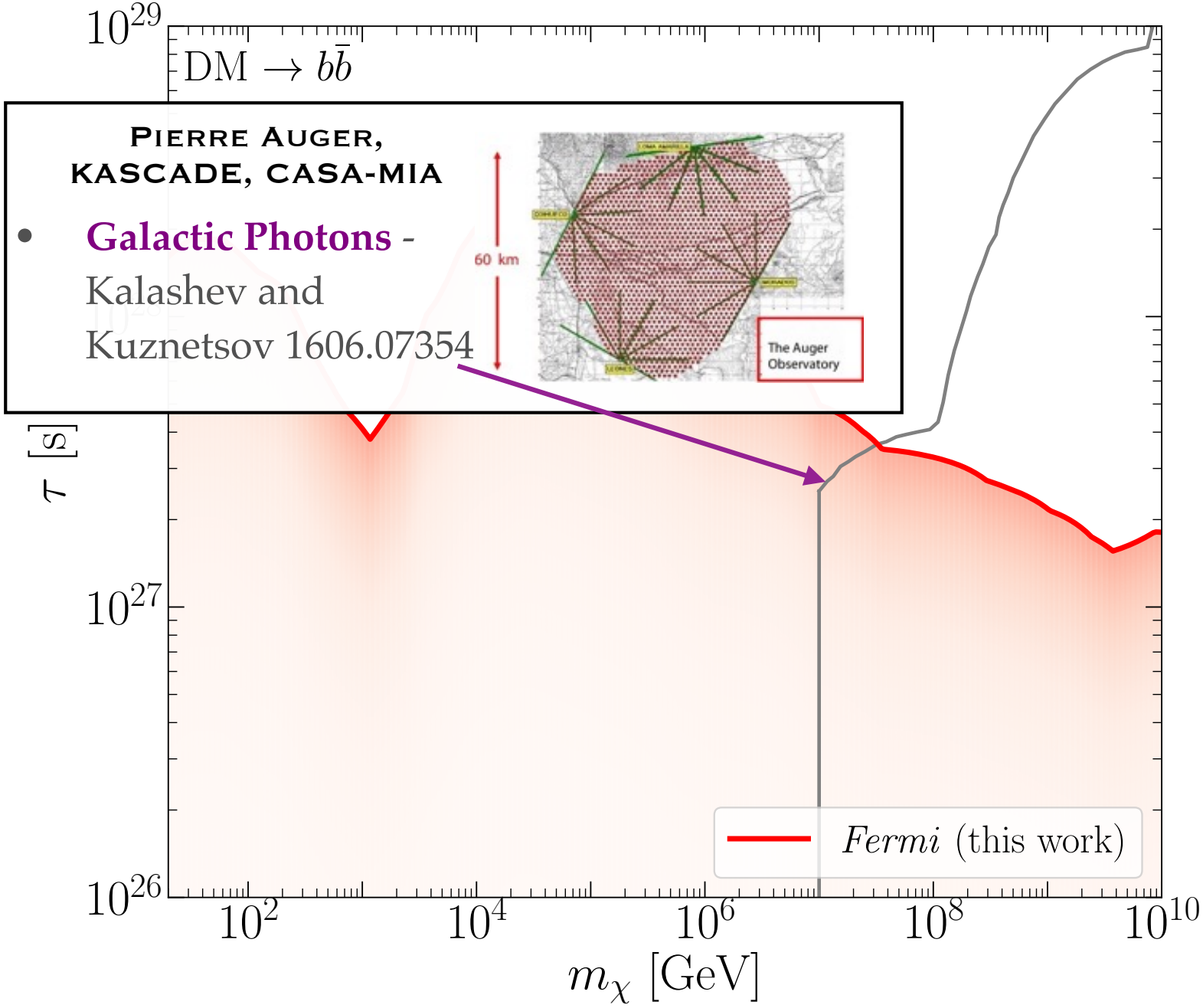
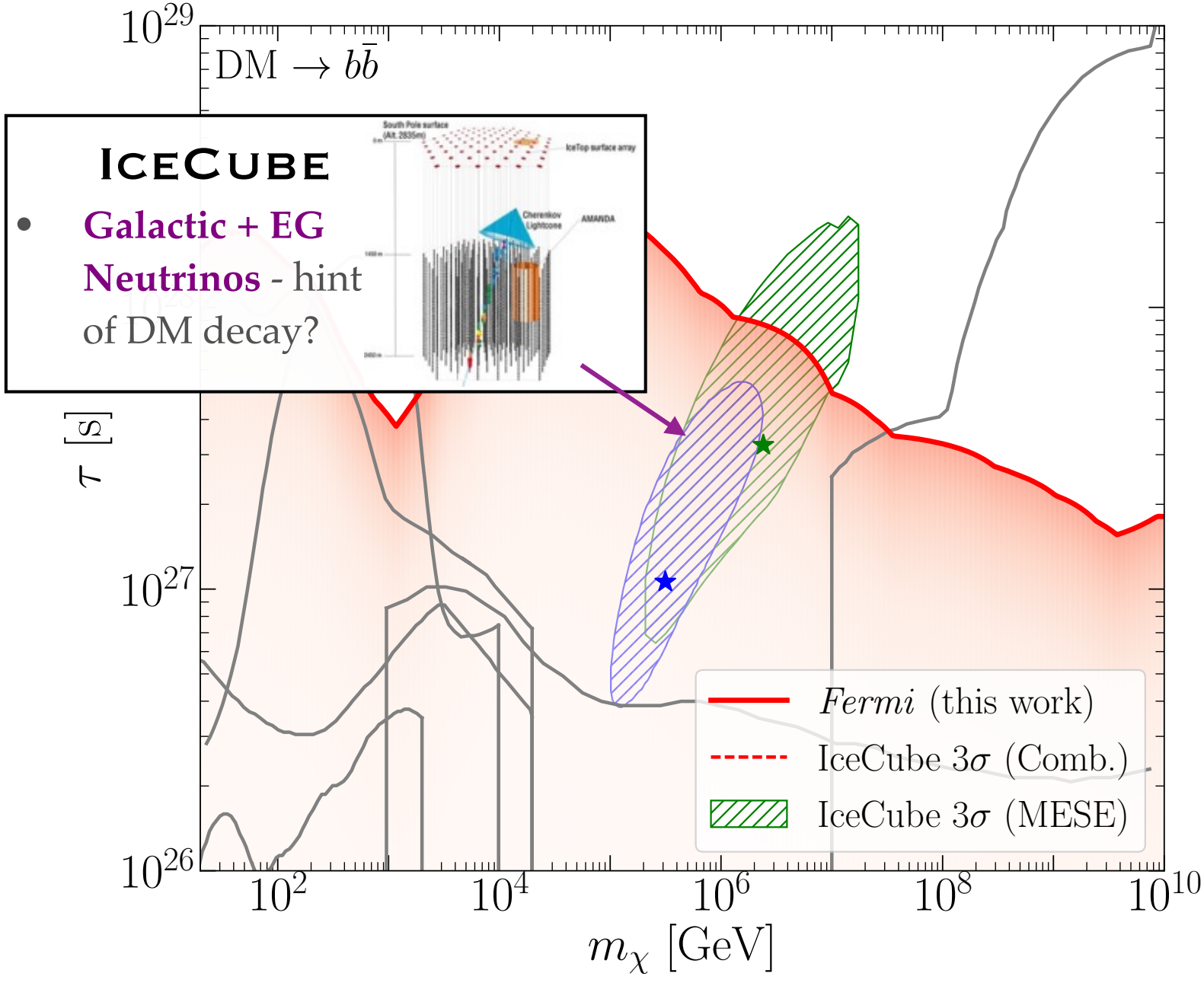
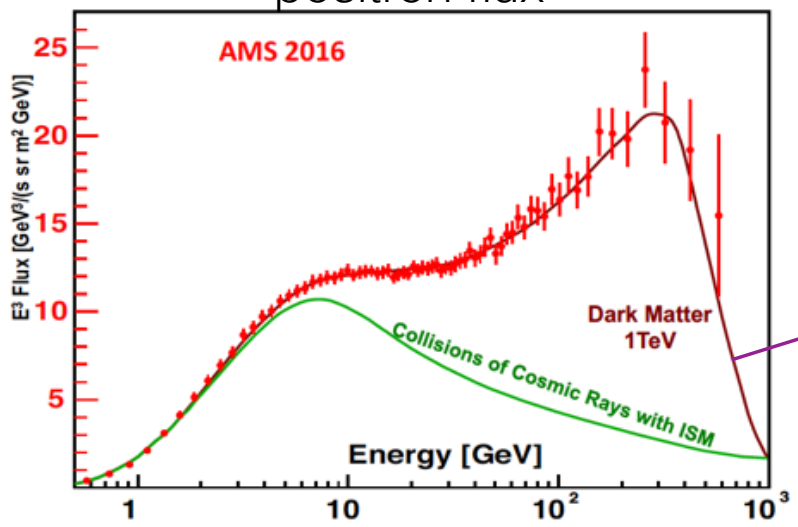


Has IceCube detected decaying DM?

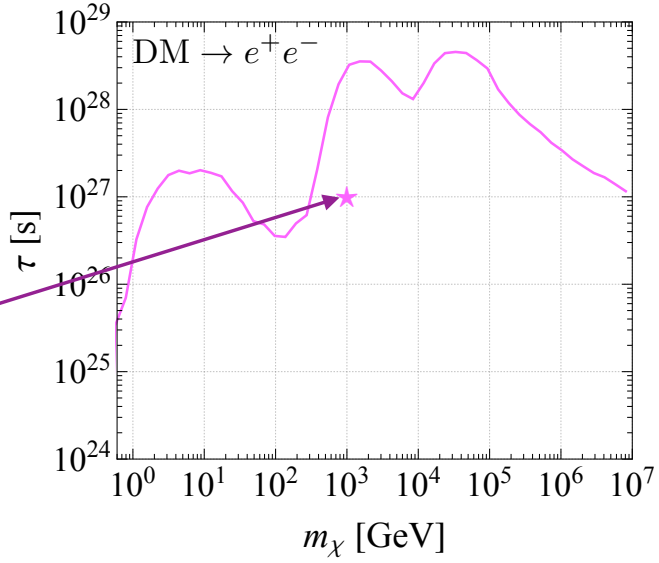


AMS-02 positron excess likely not from decaying DM

positron flux



https://cds.cern.ch/record/2238506

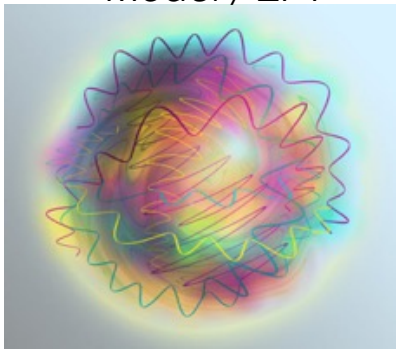


- AMS-02 positron flux appears to have excess and break
- Excess could arise from pulsars, decaying DM, . . .
- Decaying DM appears in strong tension with *Fermi* data

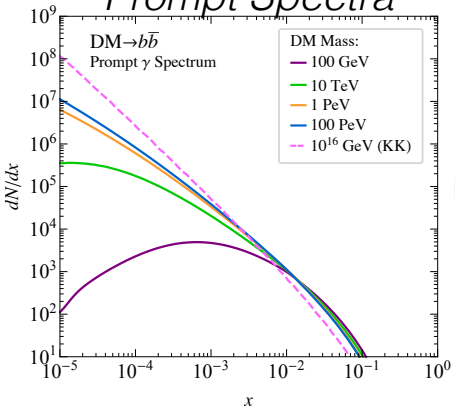
Decaying DM search proceeds in two steps:

- 1. Given a decaying DM model, how do we predict gamma-ray flux at Earth?

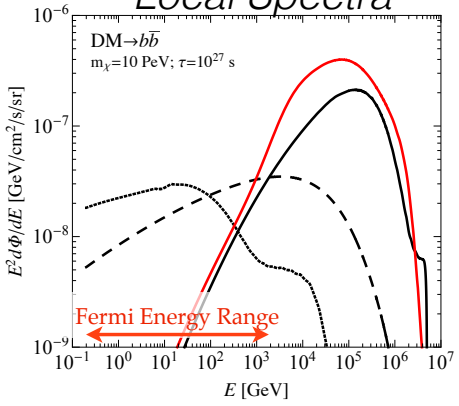
Model / EFT



Prompt Spectra



Local Spectra



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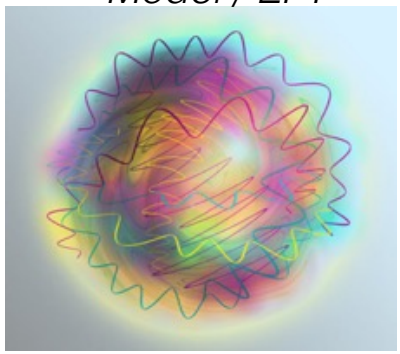
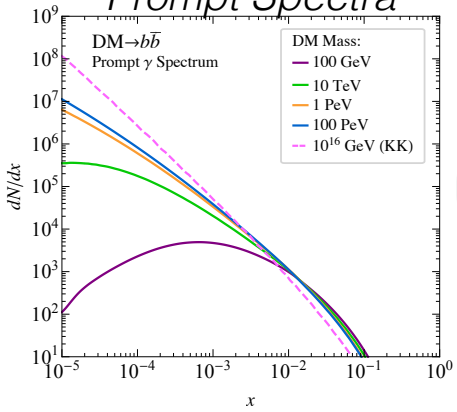
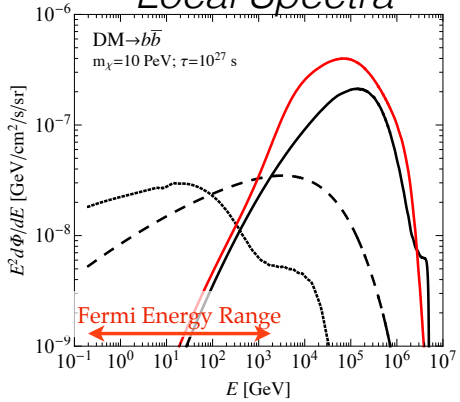


Prompt Spectra

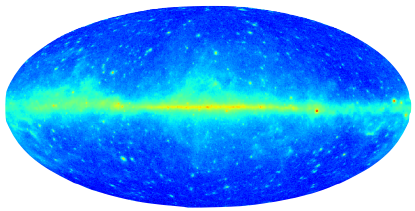


Local Spectra

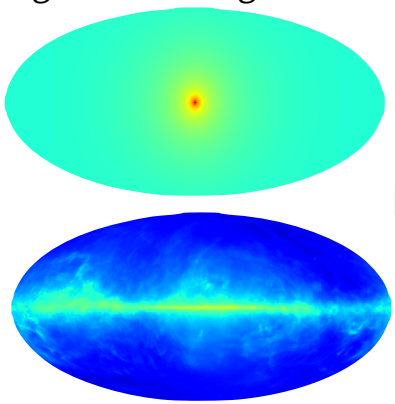


- 2. How do we search for that flux in *Fermi* data?

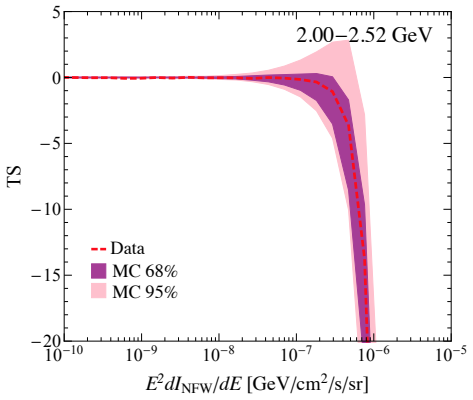
Fermi Data



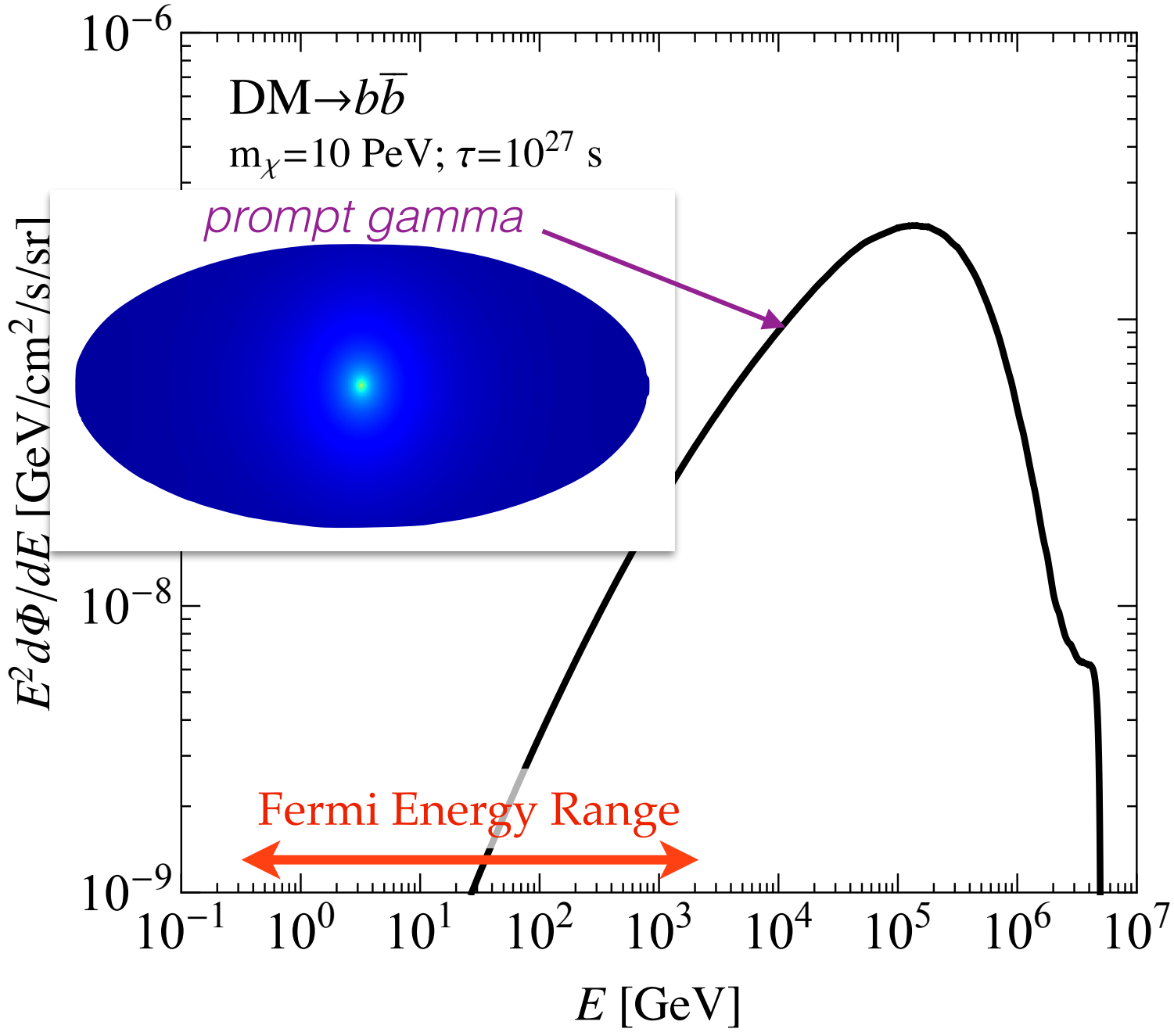
Background + Signal Templates



Likelihood Profiles



Step 1: computing the local spectra (γ's)



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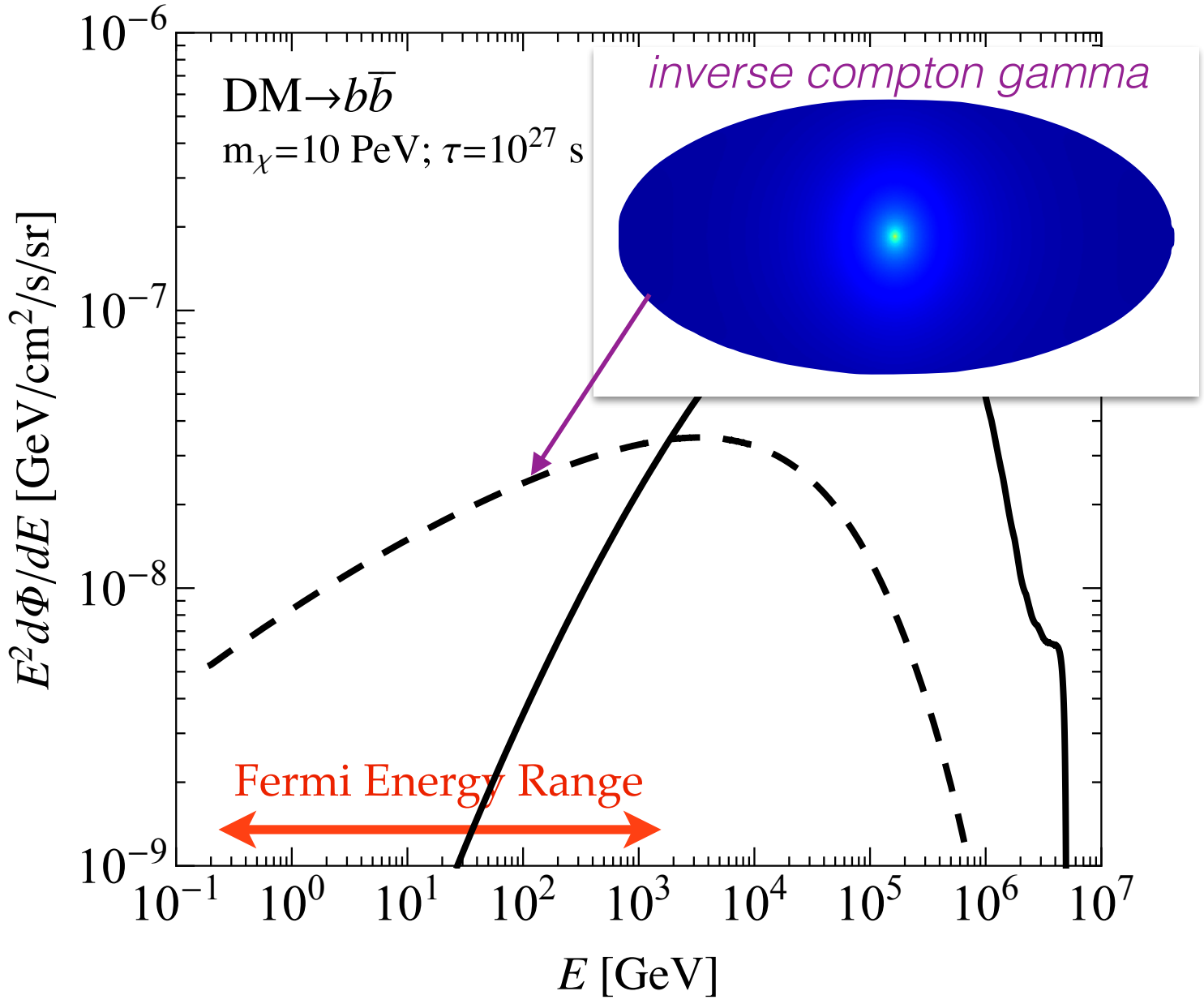

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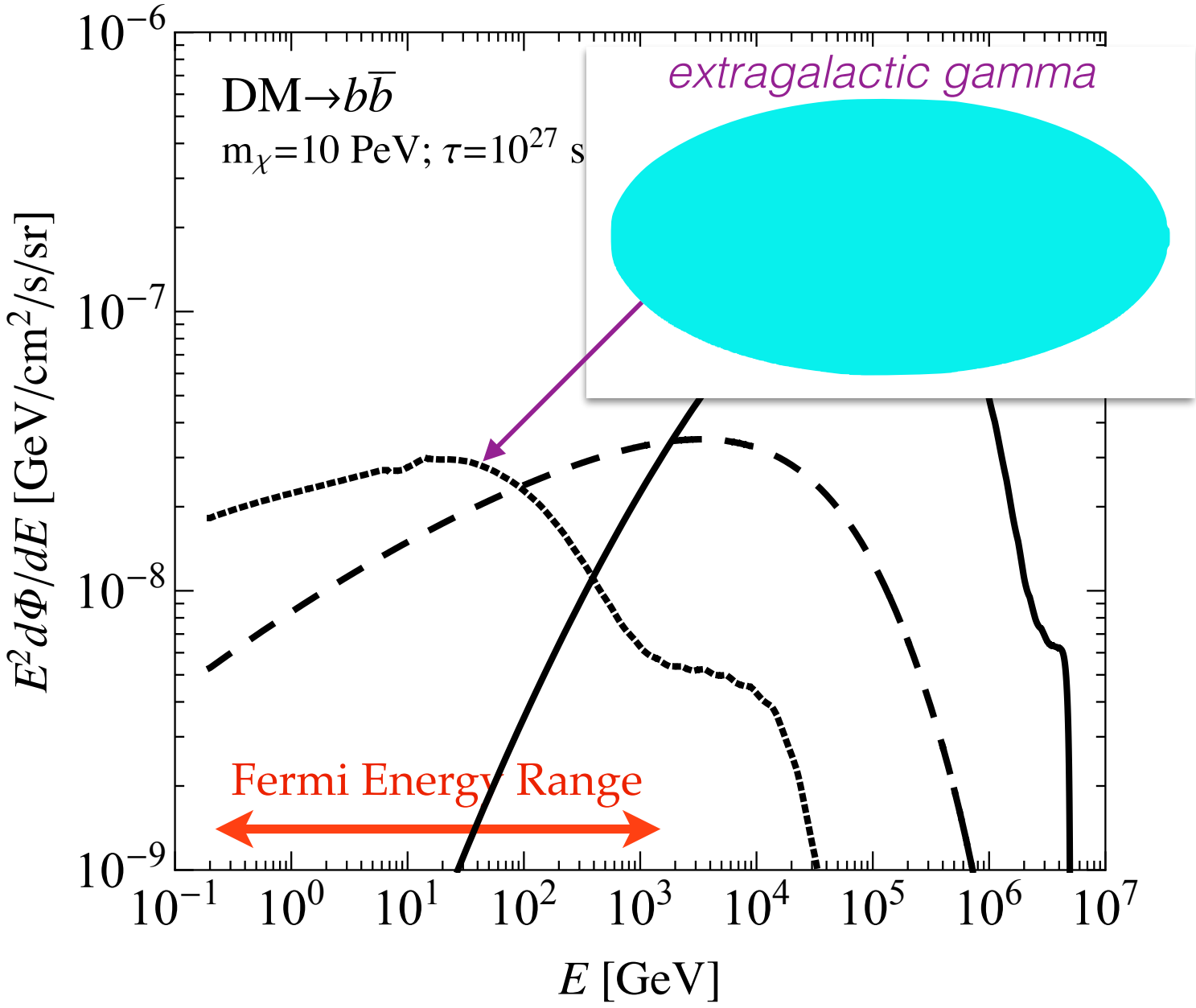
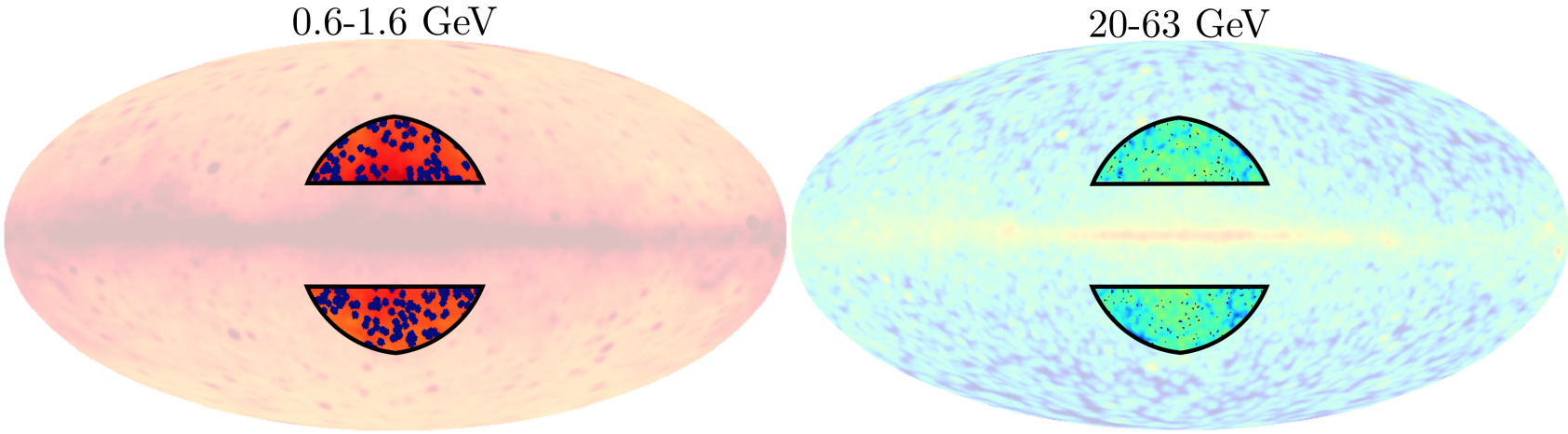


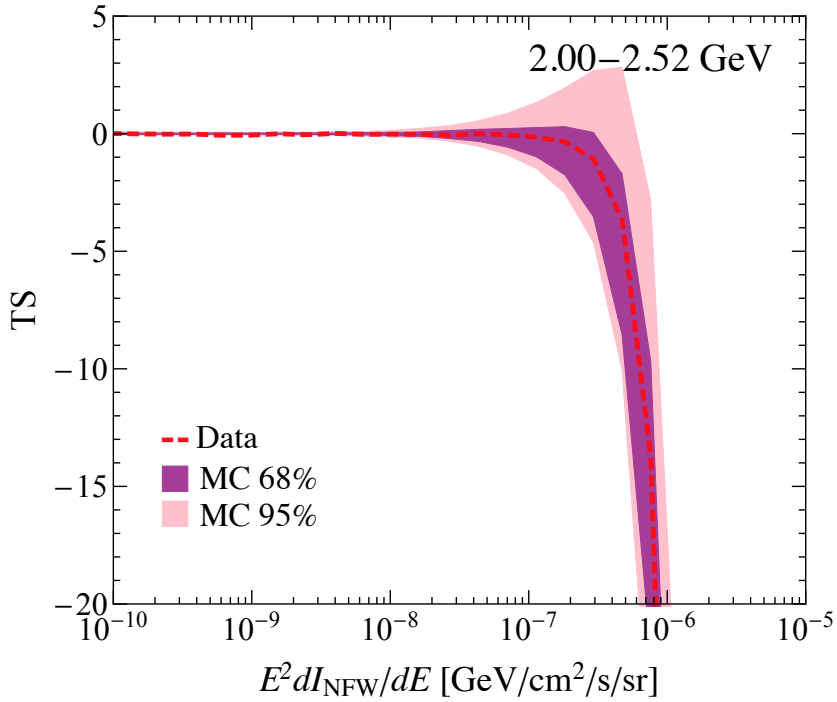
Step 2: *Fermi* data selection

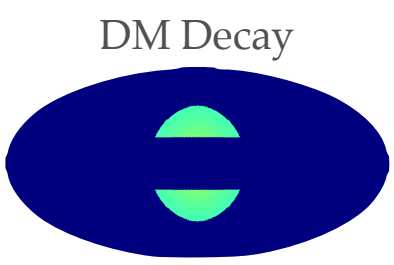


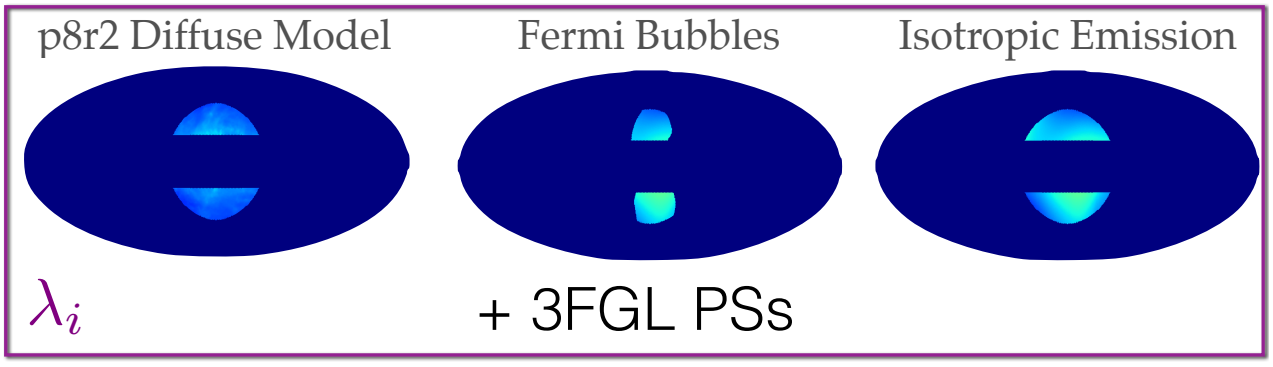
- 40 log-spaced bins between 200 MeV - 2 TeV
- 423 weeks Pass 8 UltracleanVeto BestPSF events
- mask: top 300 3FGL PSs, $|b| \leq 20^\circ$, $r > 45^\circ$

Step 2: Pre-compute likelihood profiles

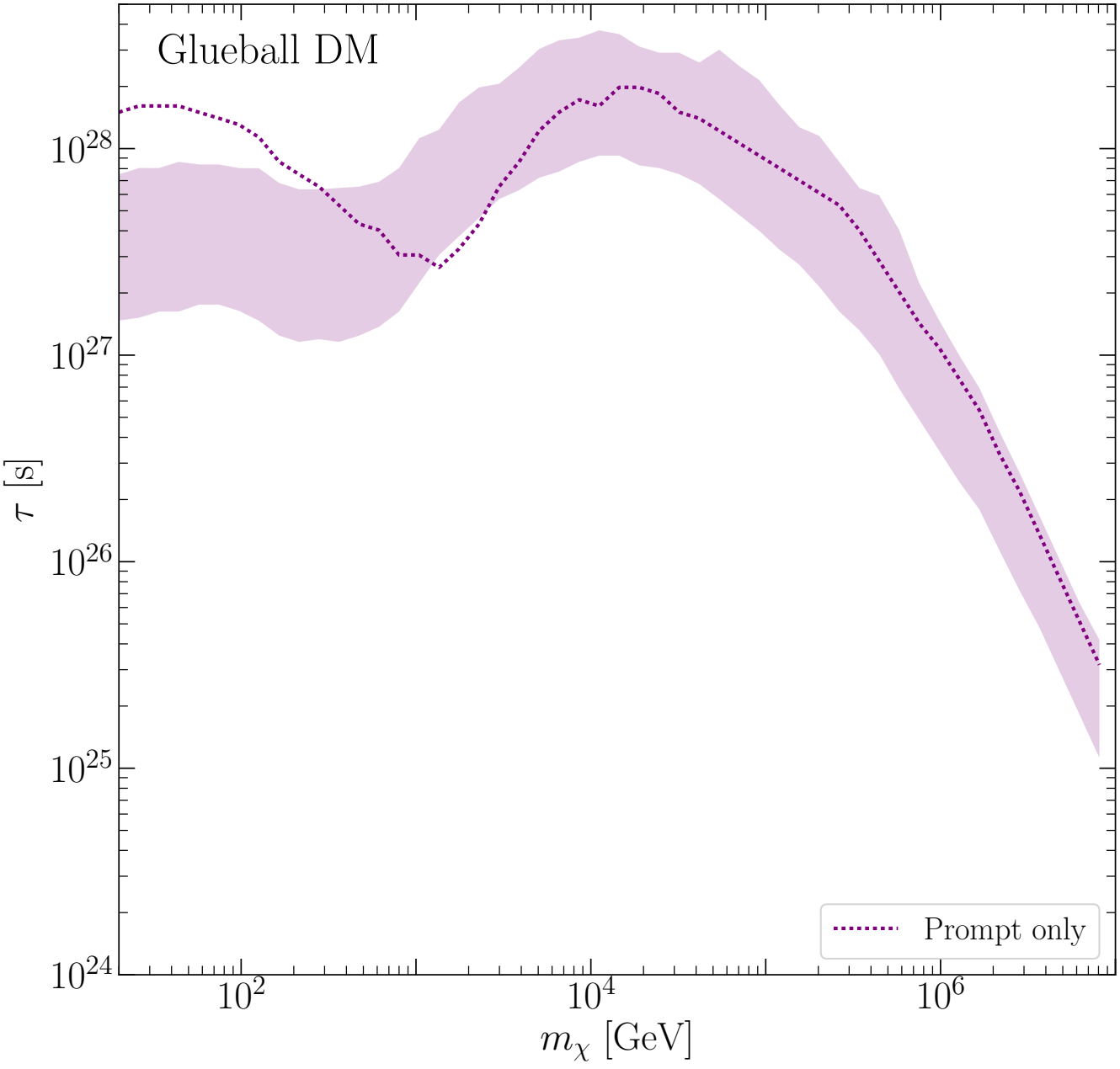
- 2-d intensity $\{I_{\text{EG-DM}}, I_{\text{Gal-DM}}\}$ profiles in 40 energy bins



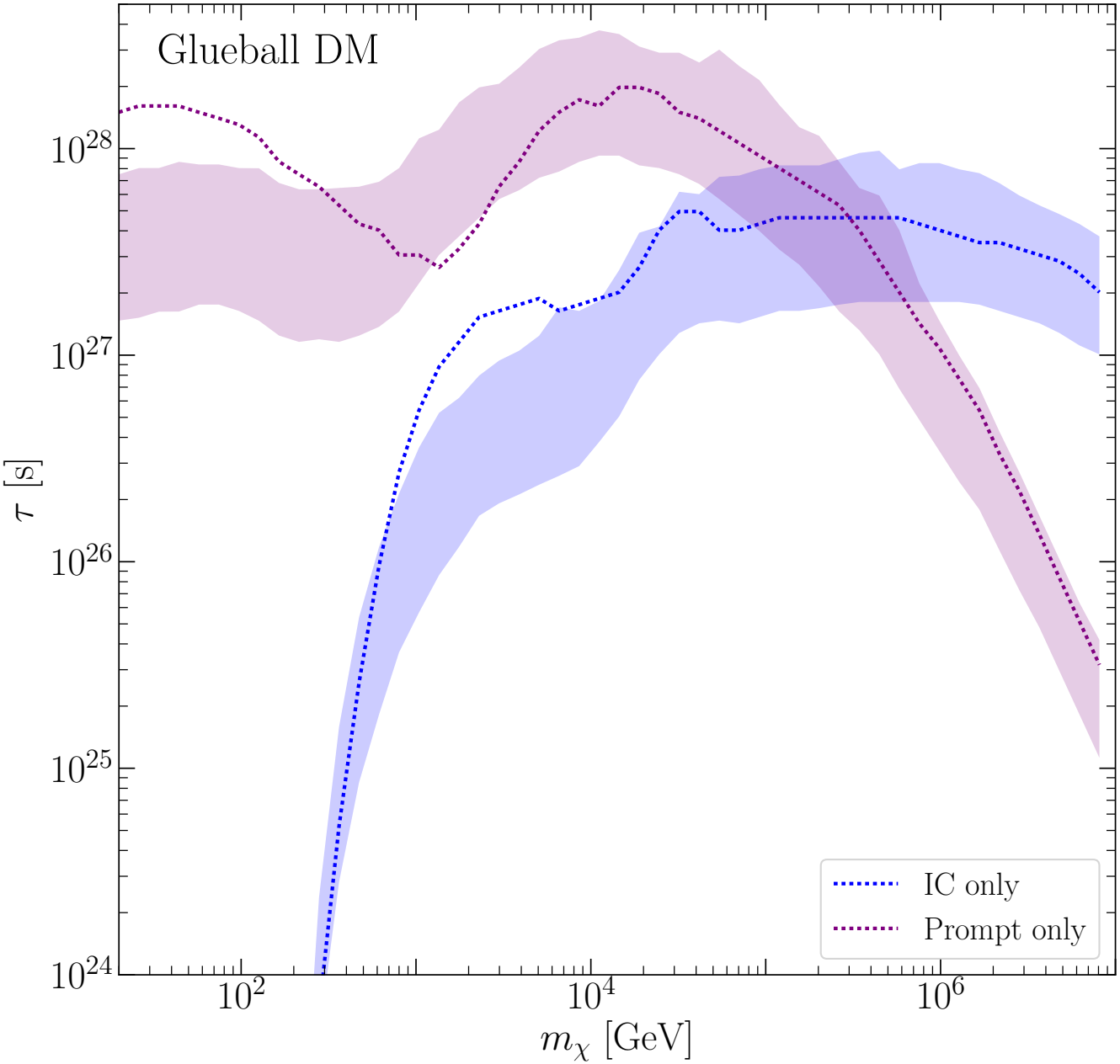




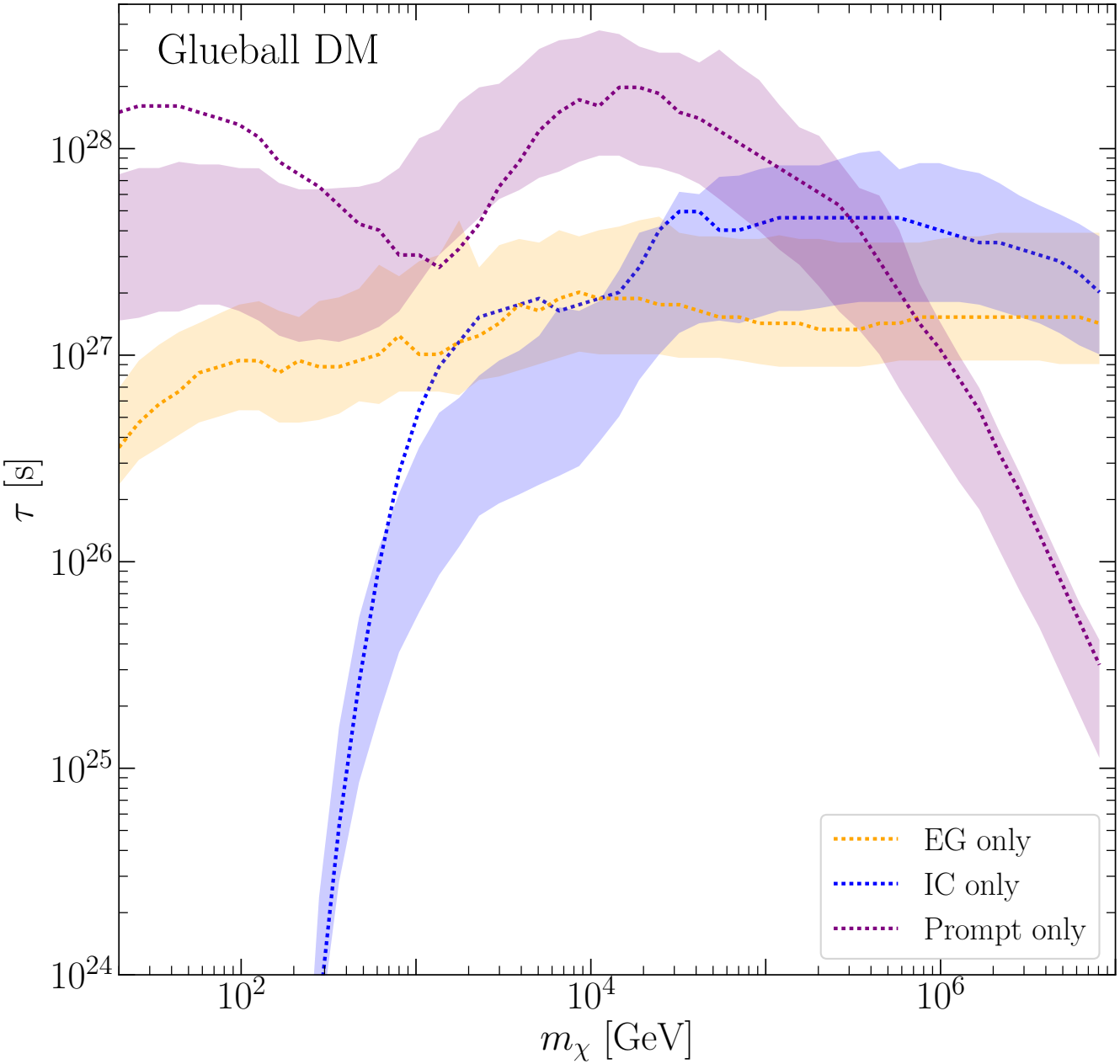
Limit: prompt only



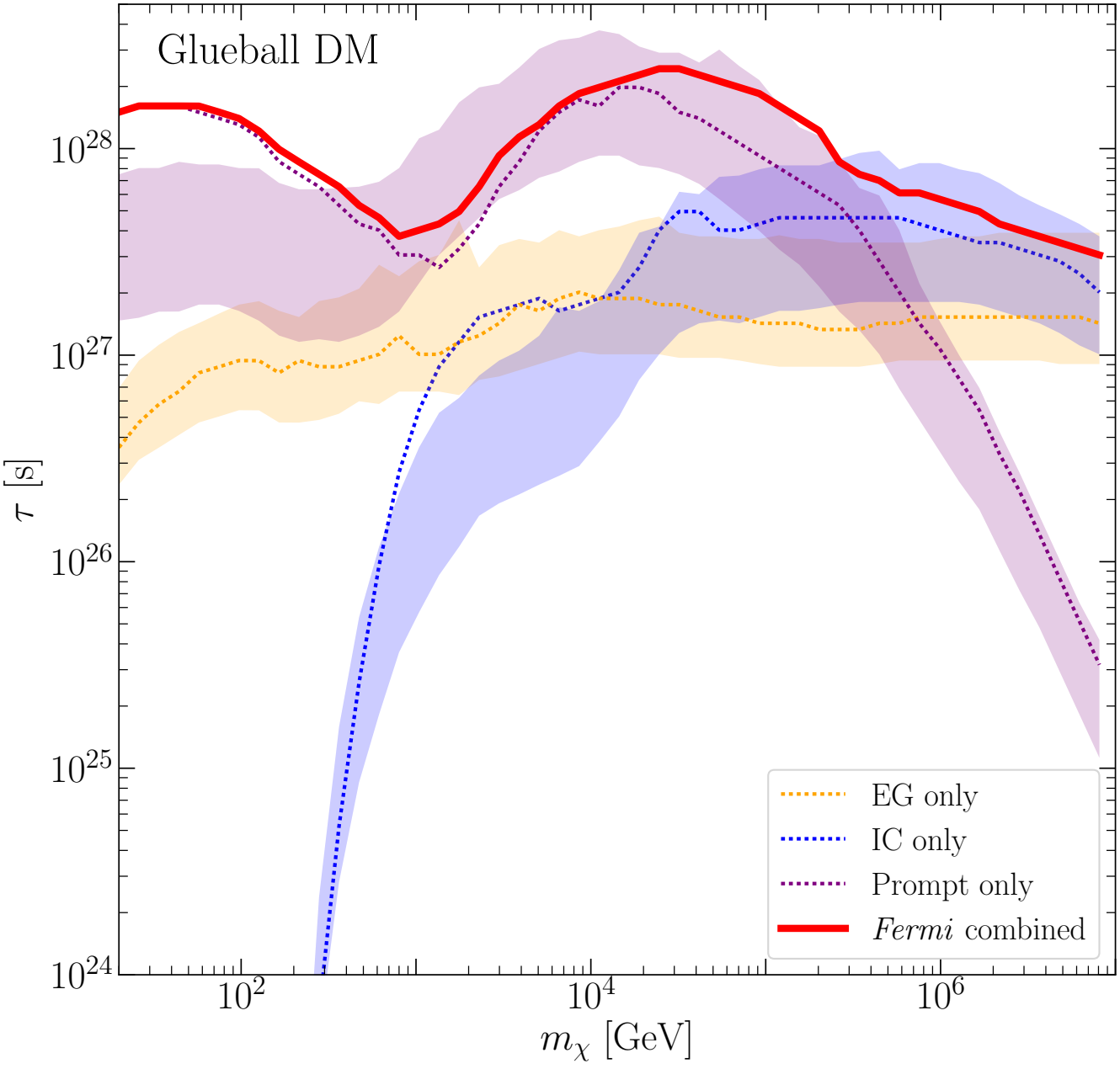
Limit: inverse compton only



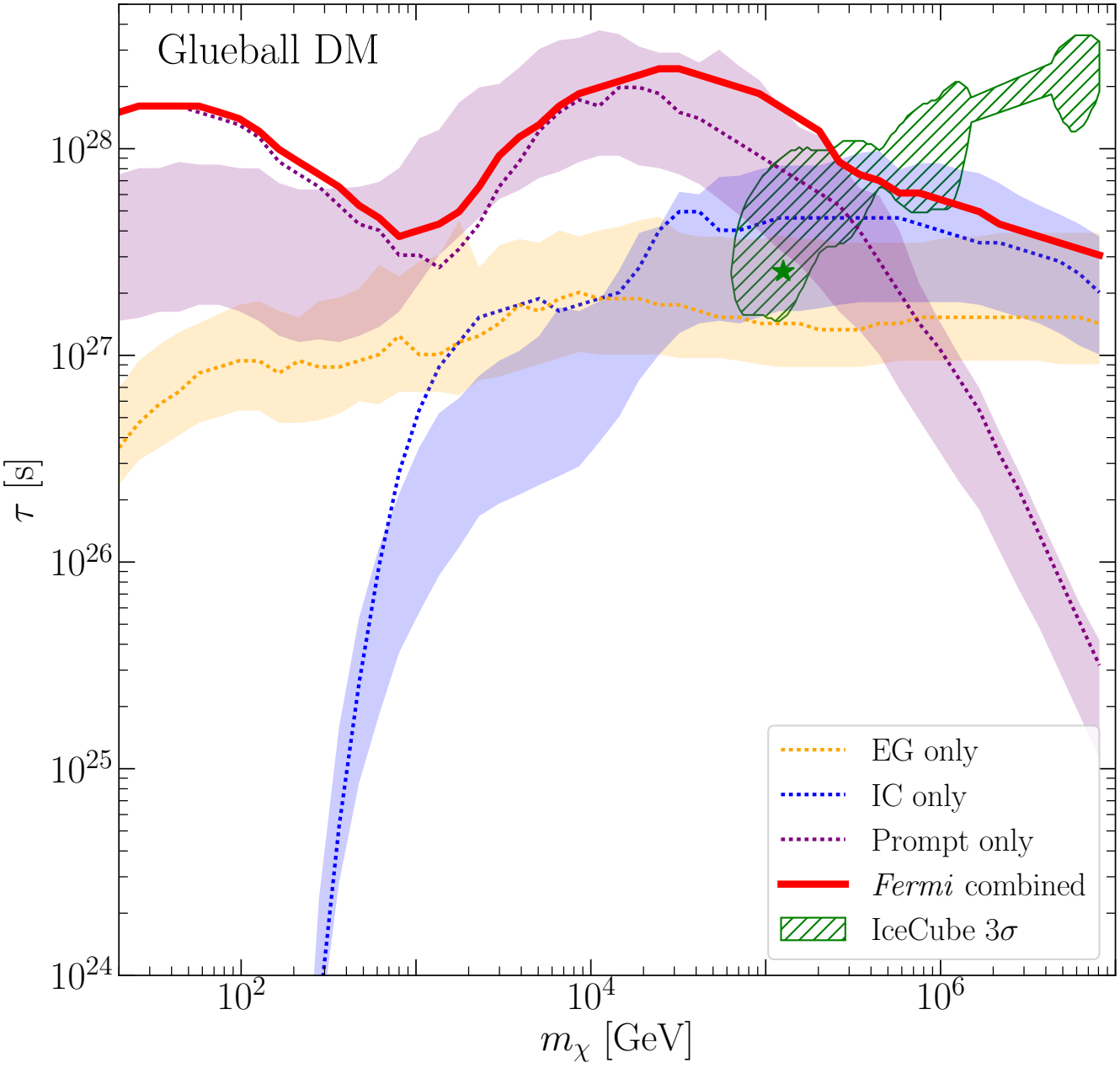
Limit: extragalactic only



Limit: combined



Limit: comparison to IceCube region



Data and code available

- http://hdl.handle.net/1721.1/105550: 2-d likelihood profiles in all energy bins + limits on final states

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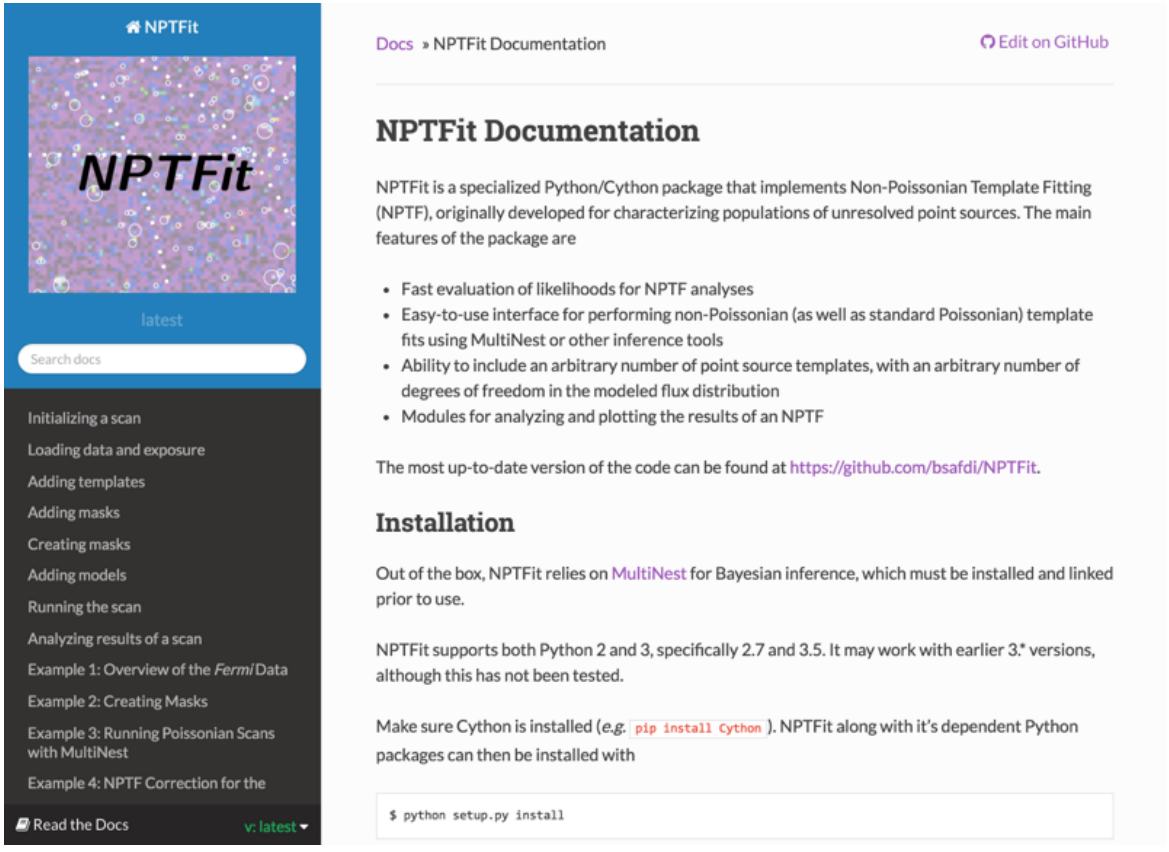
- https://github.com/bsafdi/NPTFit: S. M.-Sharma, N. Rodd, **B.S.**, 1612.03173. Open-source code for performing template analysis



Summary

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- Many systematic tests performed.
- DM decay may be only probe of decoupled hidden sectors
- Sensitivity is improvable (CTA, HAWC, KM3NeT, . . .)

Questions?

Backup

Step 2: Poissonian template fit

- Model parameters: $\theta = \{\psi_{\mathrm{DM}}, \lambda_{nuisance}\}$ ($\psi_{\mathrm{DM}} = \{m_{\mathrm{DM}}, \tau\}$)

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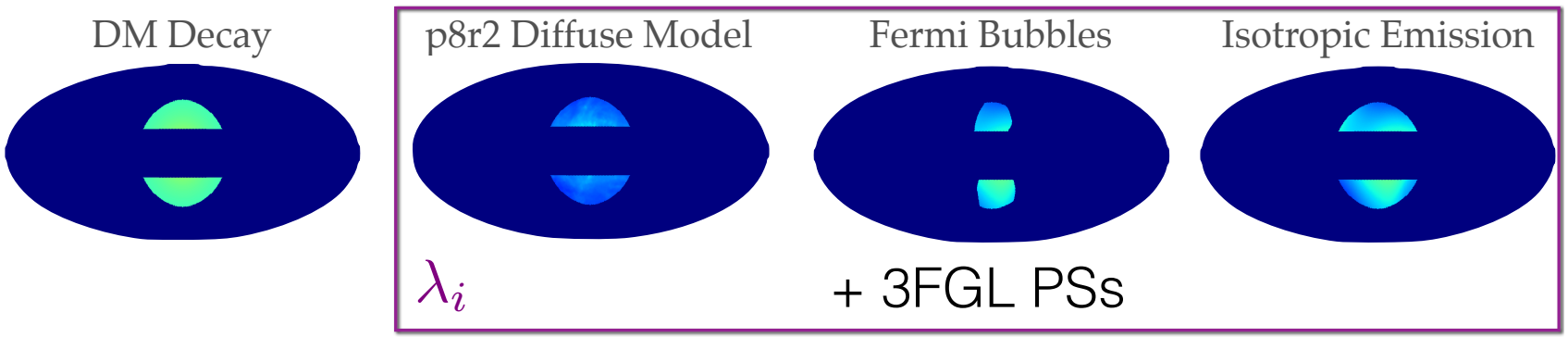
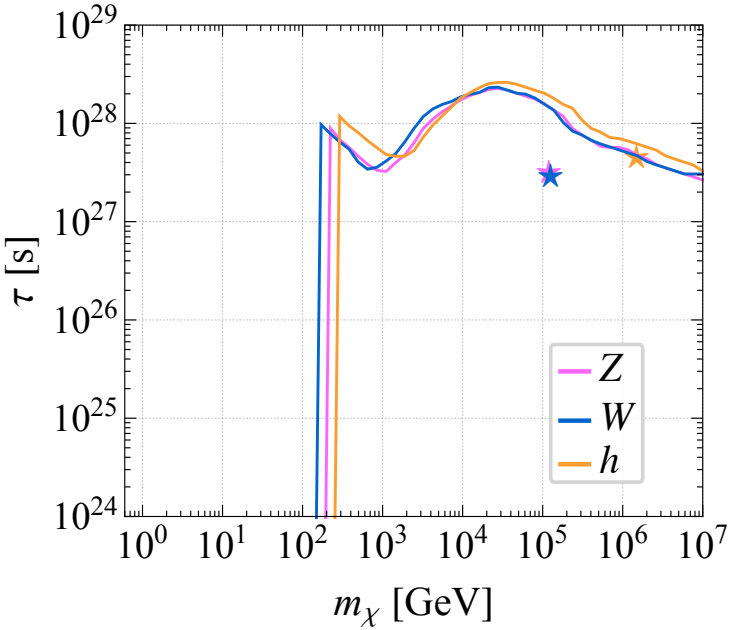
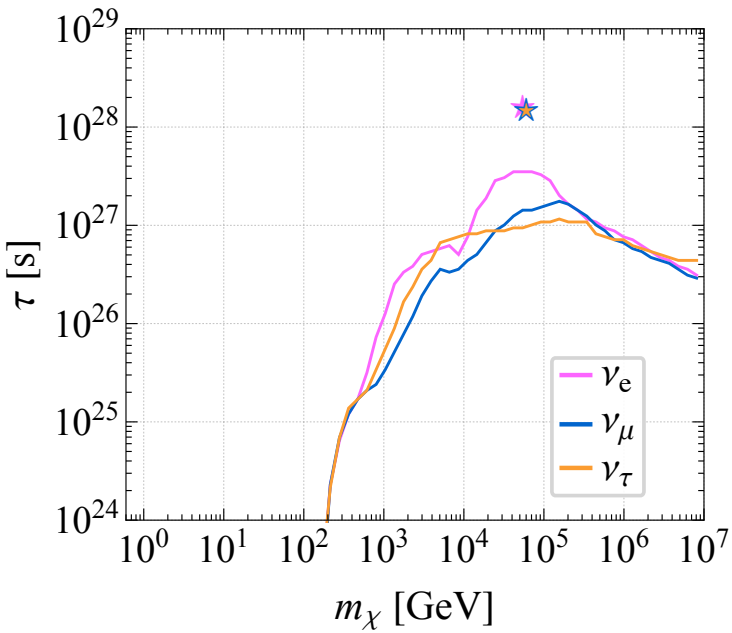
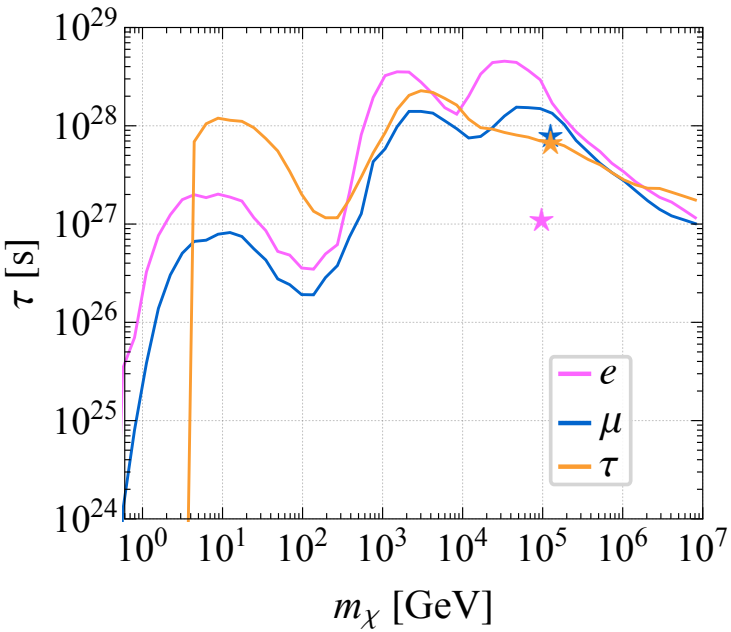
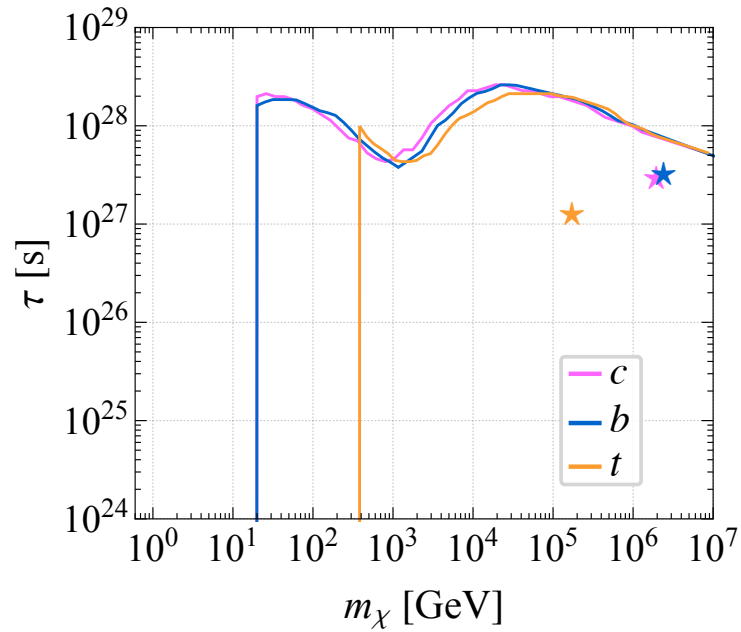


Limit: multiple channels

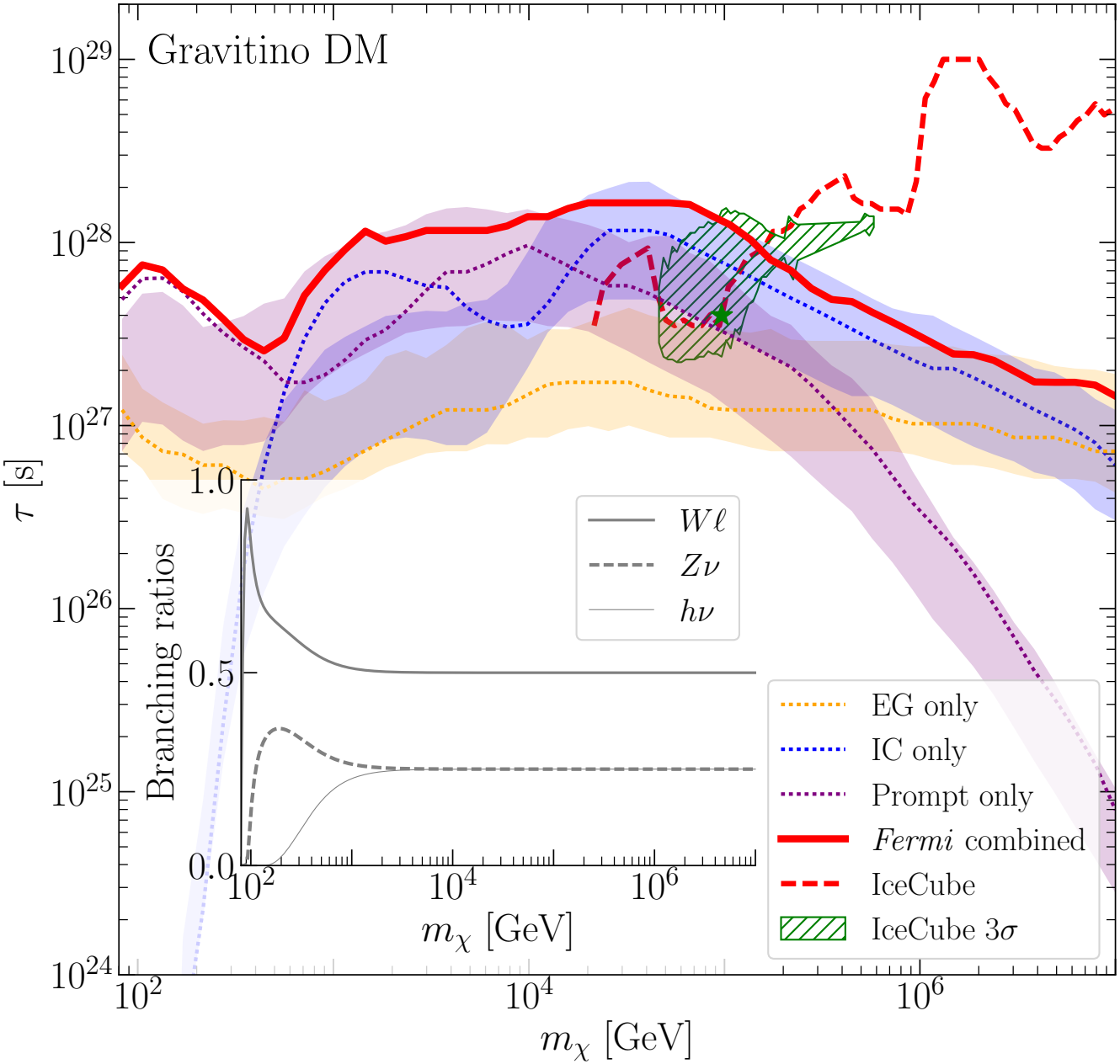




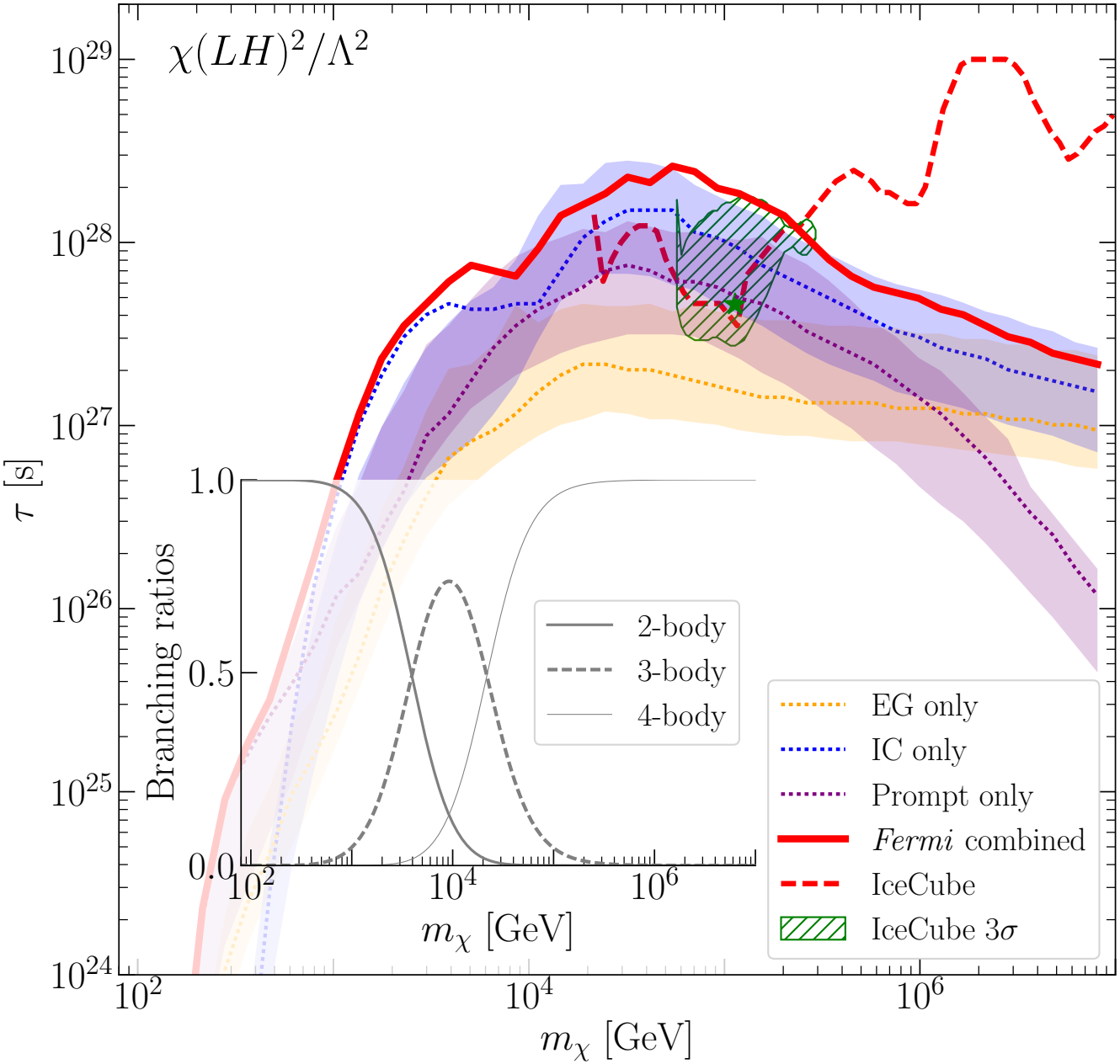




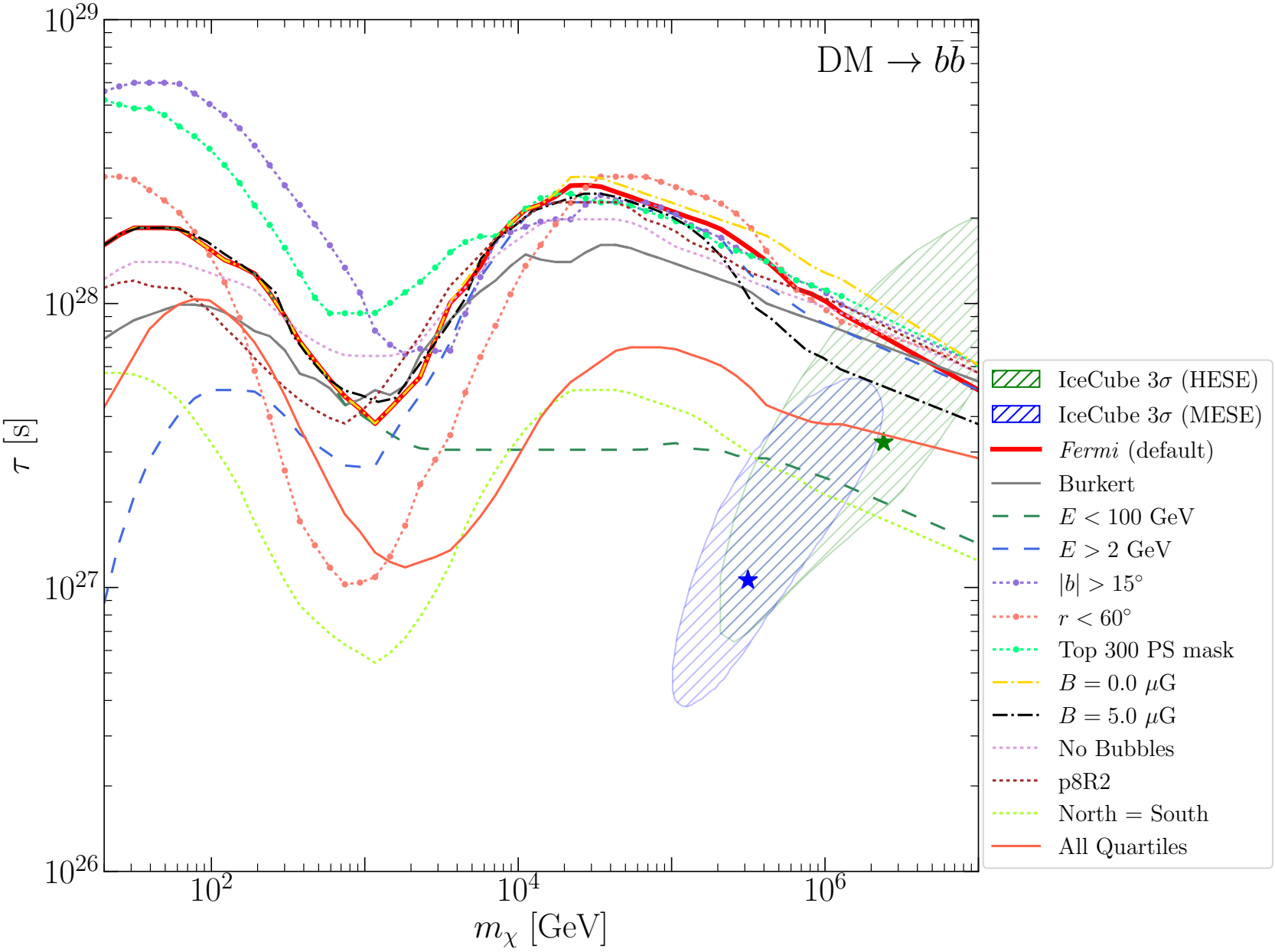
Limit: gravitino DM



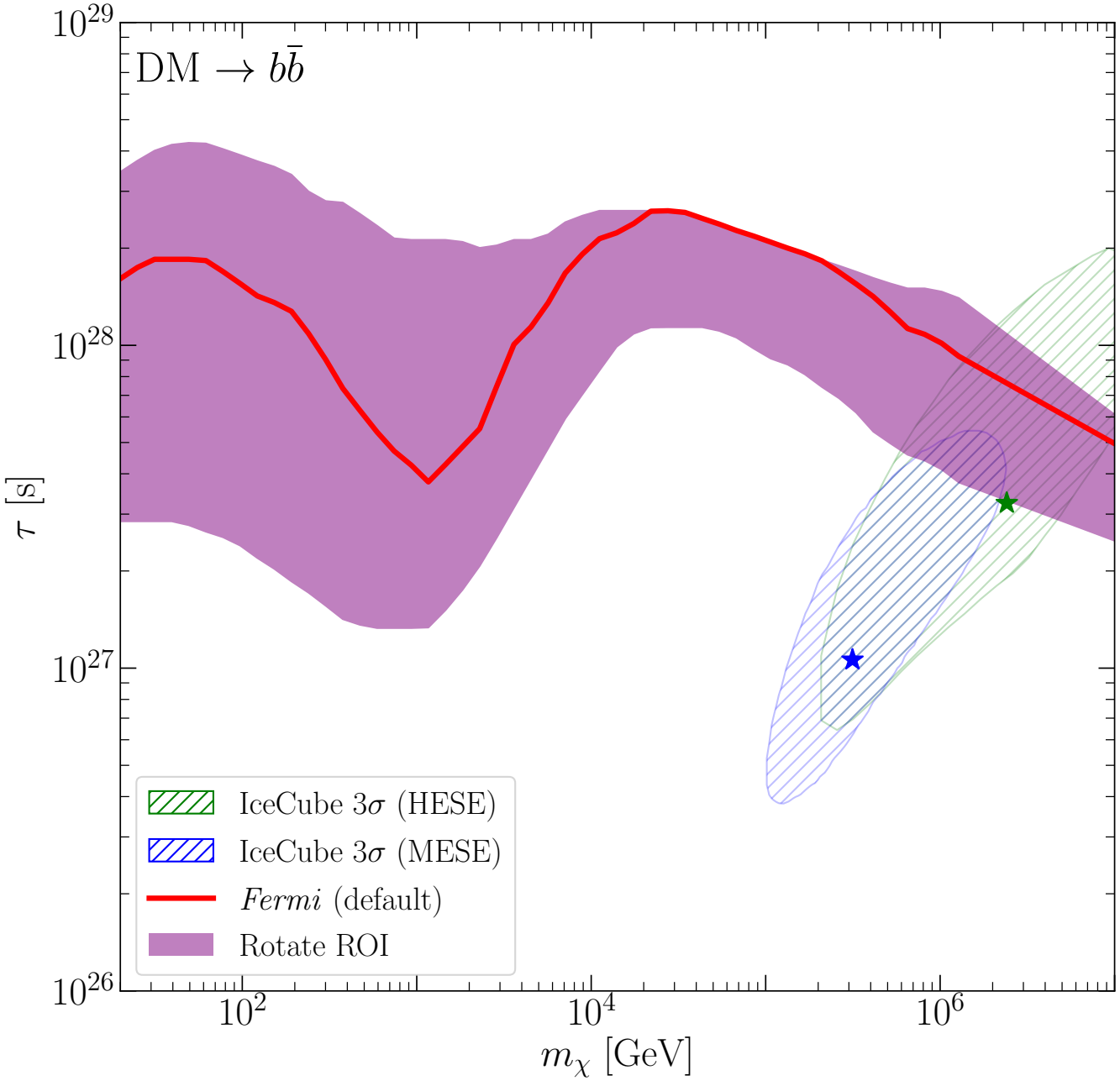
Limit: LHLH


$\chi(LH)^2/\Lambda^2$
10^{29}
10^{28}
10^{27}
10^{26}
10^{25}
10^{24}
τ [s]
10^2
10^4
10^6
m_χ [GeV]
Branching ratios
1.0
0.5
0.0
2-body
3-body
4-body
EG only
IC only
Prompt only
Fermi combined
IceCube
IceCube 3σ

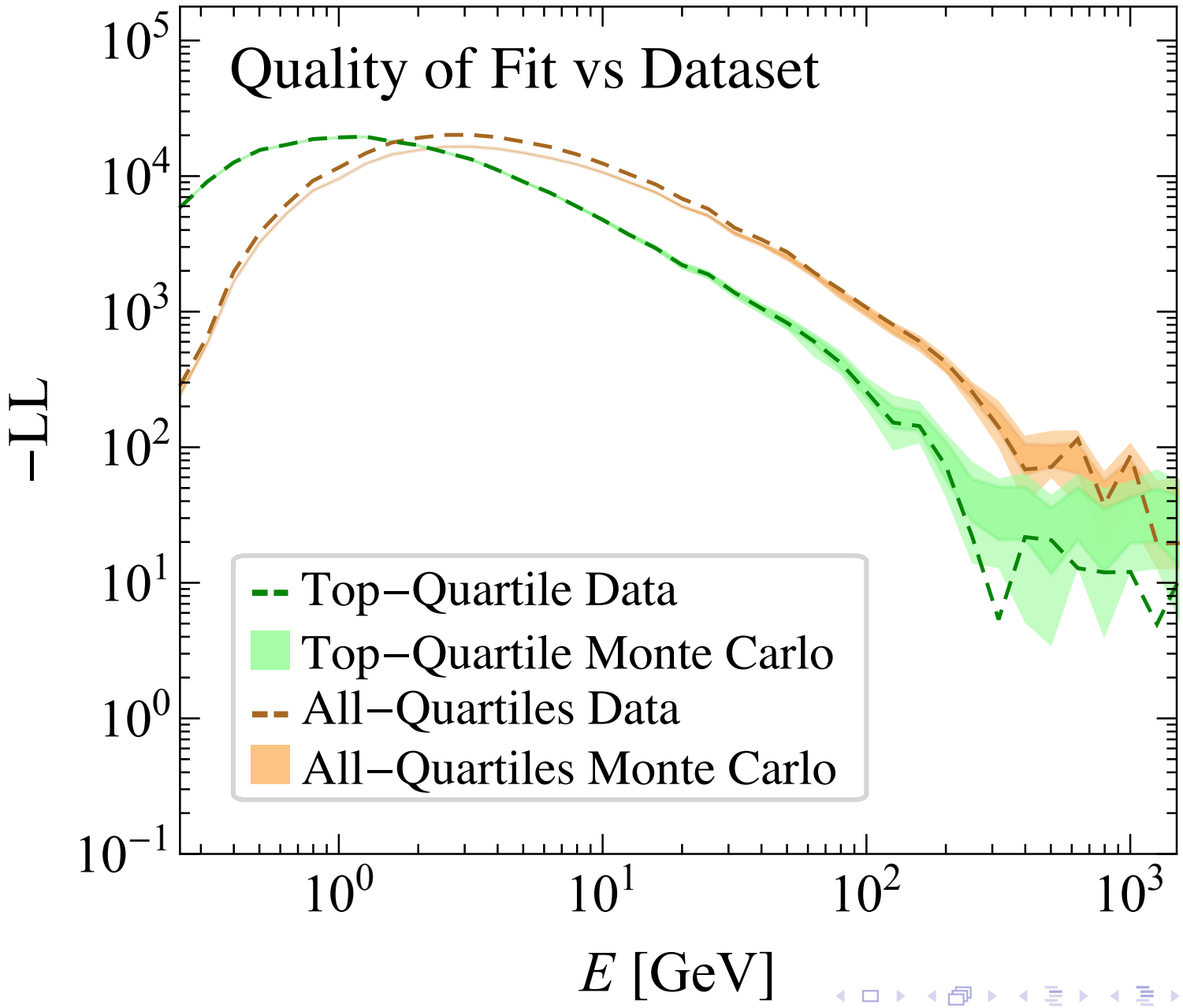
Systematics Summary



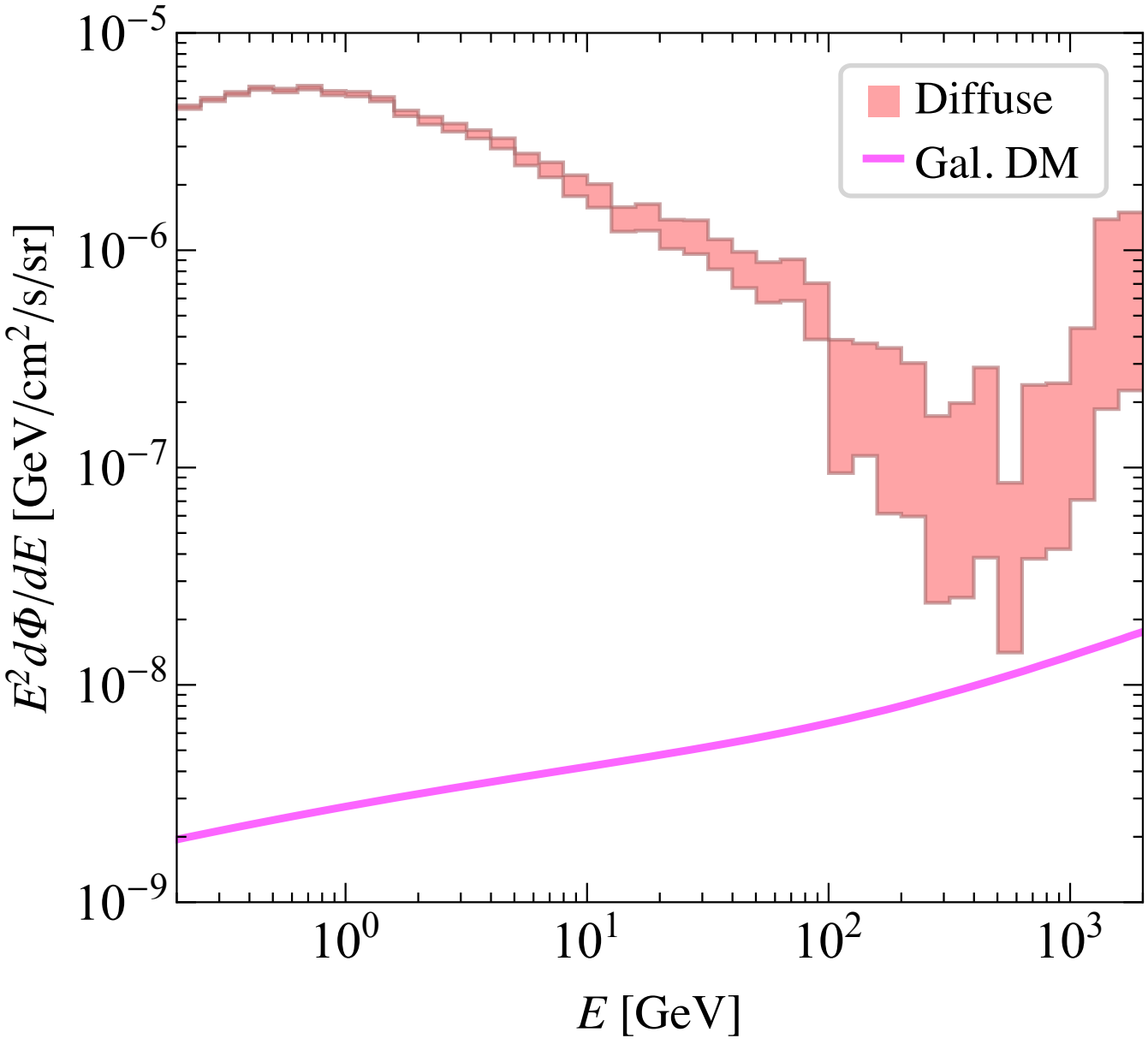
Rotate the region of interest about plane



Overall quality of fit



Signal vs background (1 PeV $b\bar{b}$)



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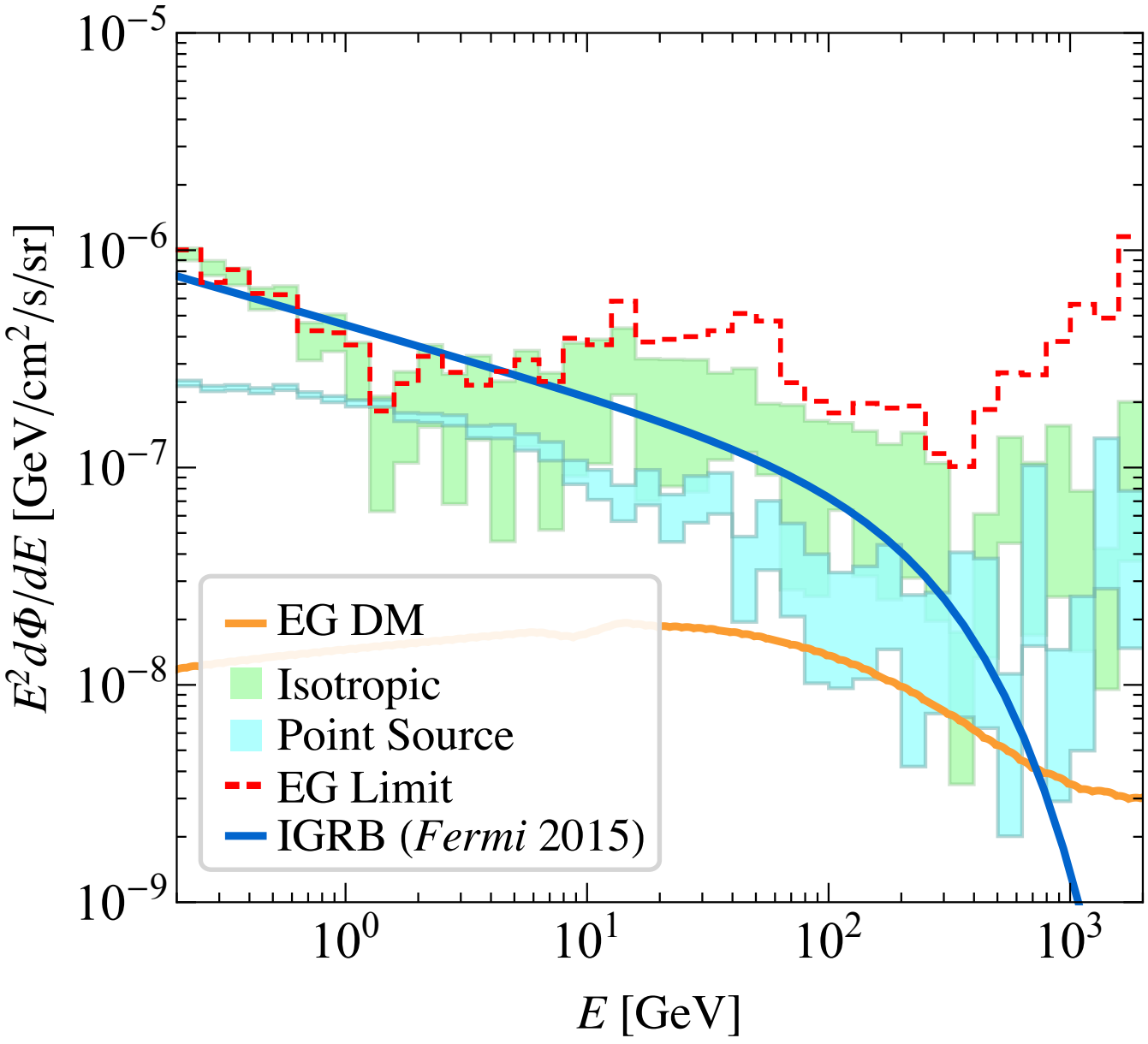
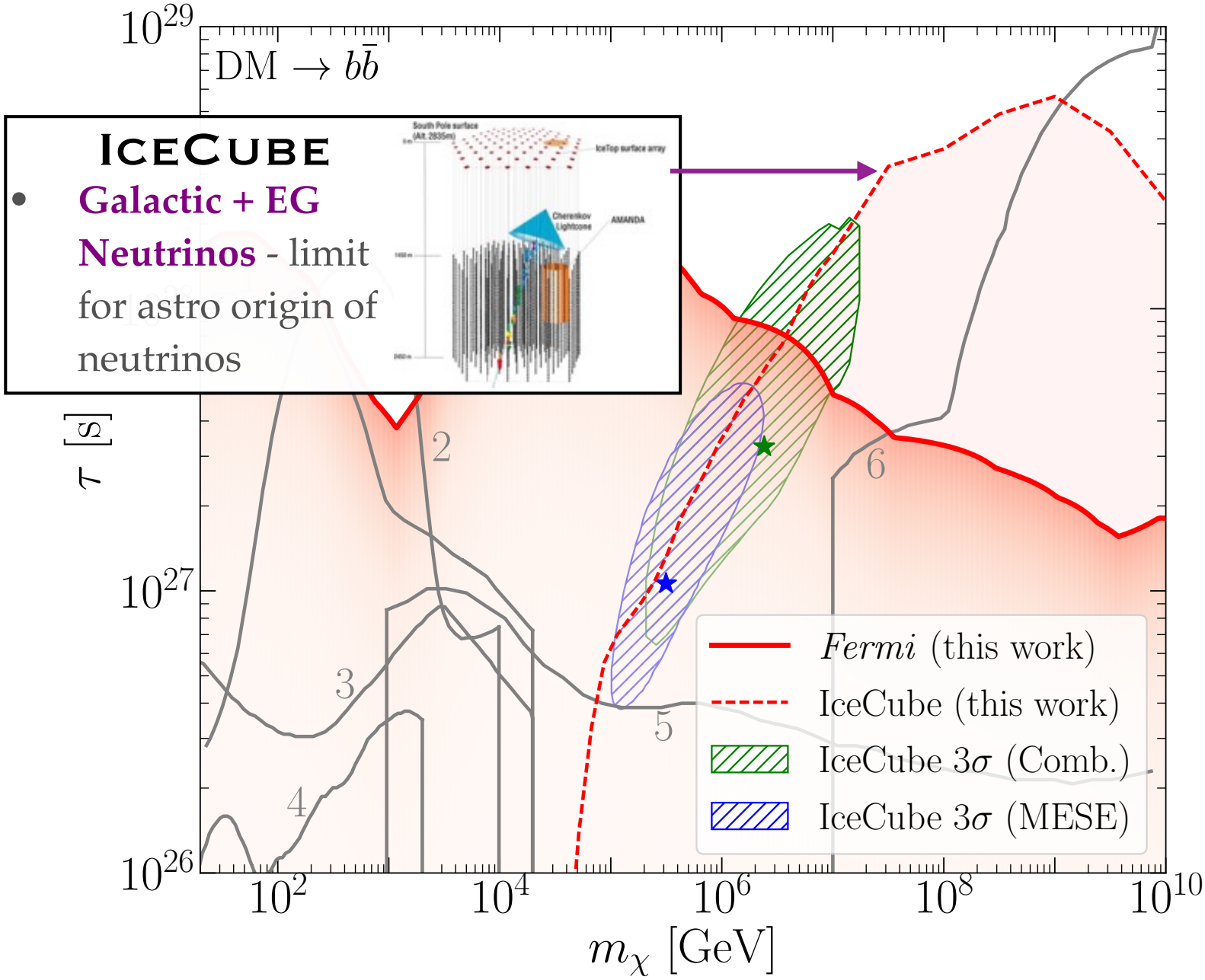
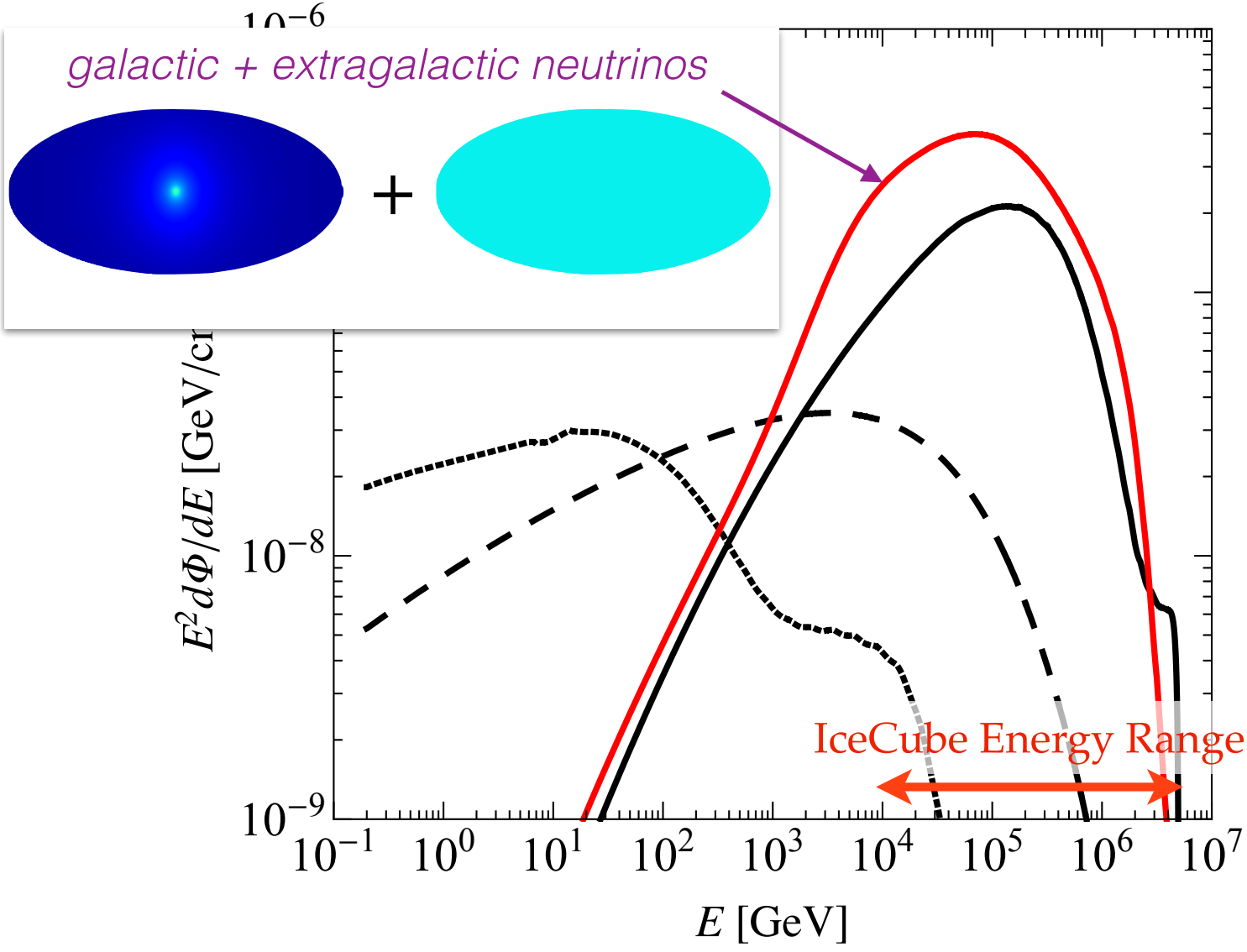


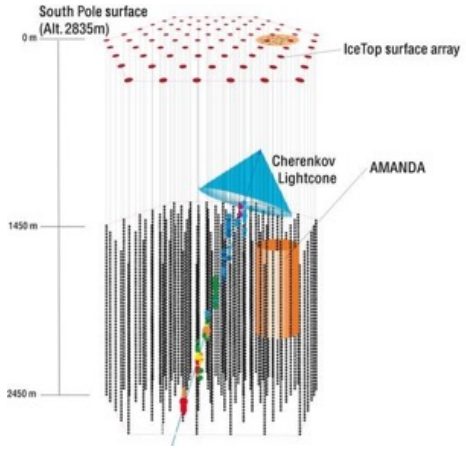
If not, what constraint does IceCube set?

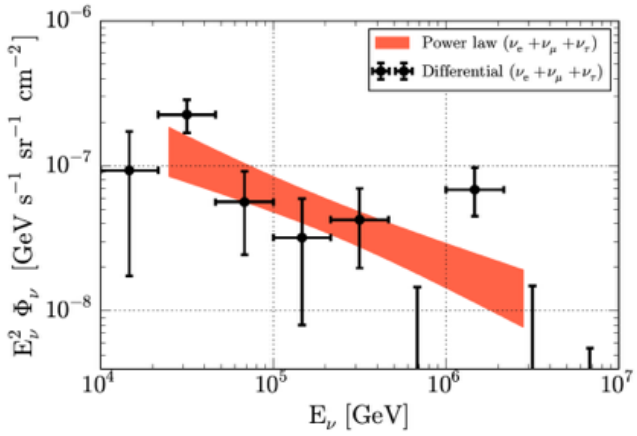


Step 1: computing the local spectra (ν's)



IceCube has detected astrophysical neutrinos





Spectrum from The IceCube Collaboration 1507.03991
Determined via a combined maximum-likelihood analysis of six different IceCube analyses
See: http://icecube.wisc.edu/science/data/combined-fit

$$\frac{dN}{dE} \sim E^{-2.50\pm0.09}$$

- Overall normalization of signal consistent with expectation from Waxman and Bahcall (hep-ph/9807282) for Universal origin of ν's and ultrahigh-energy cosmic rays

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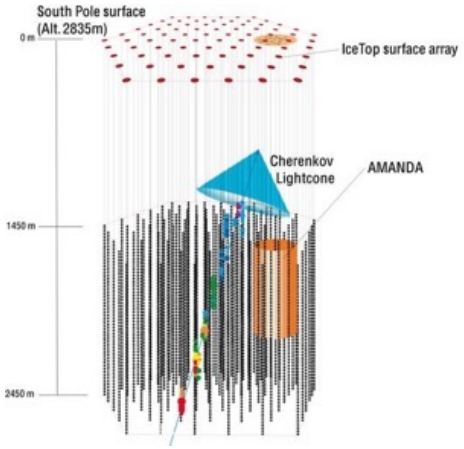

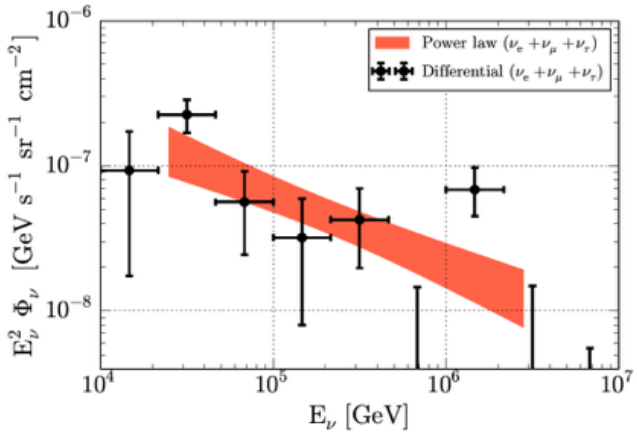

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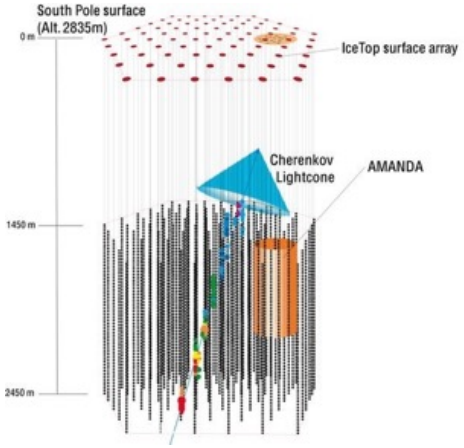

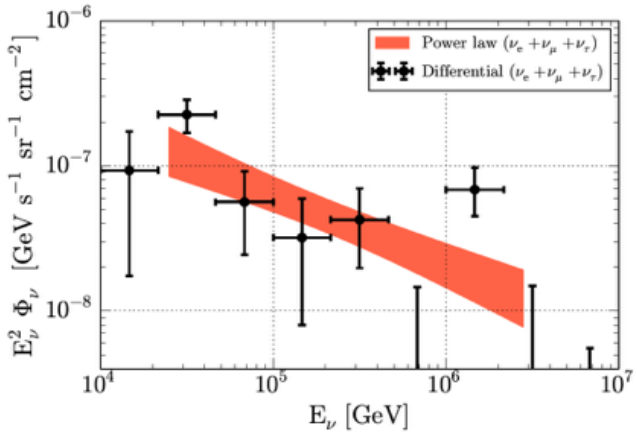

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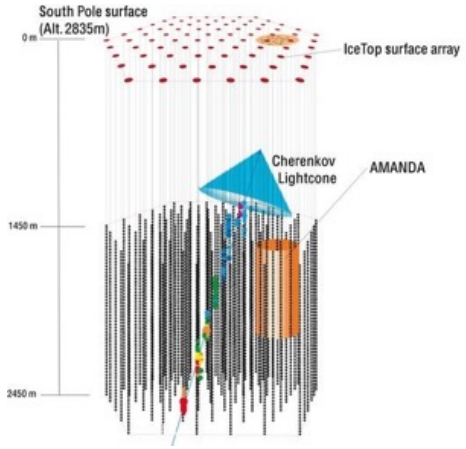

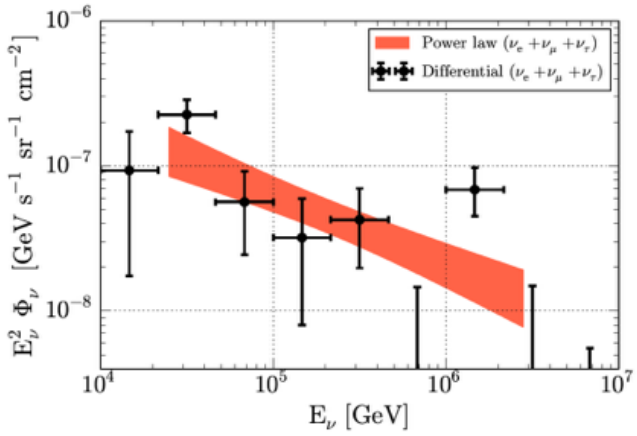

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  - pp in radio galaxies: promising, but gamma-ray variability may suggest $p\gamma$? (in progress)

Limit: what goes into glueball model?