WIν 2021

Dark Matter Phenomenology from Upcoming Neutrino Telescopes

Based on arXiv:2103.01237, JCAP 05 (2021) 054

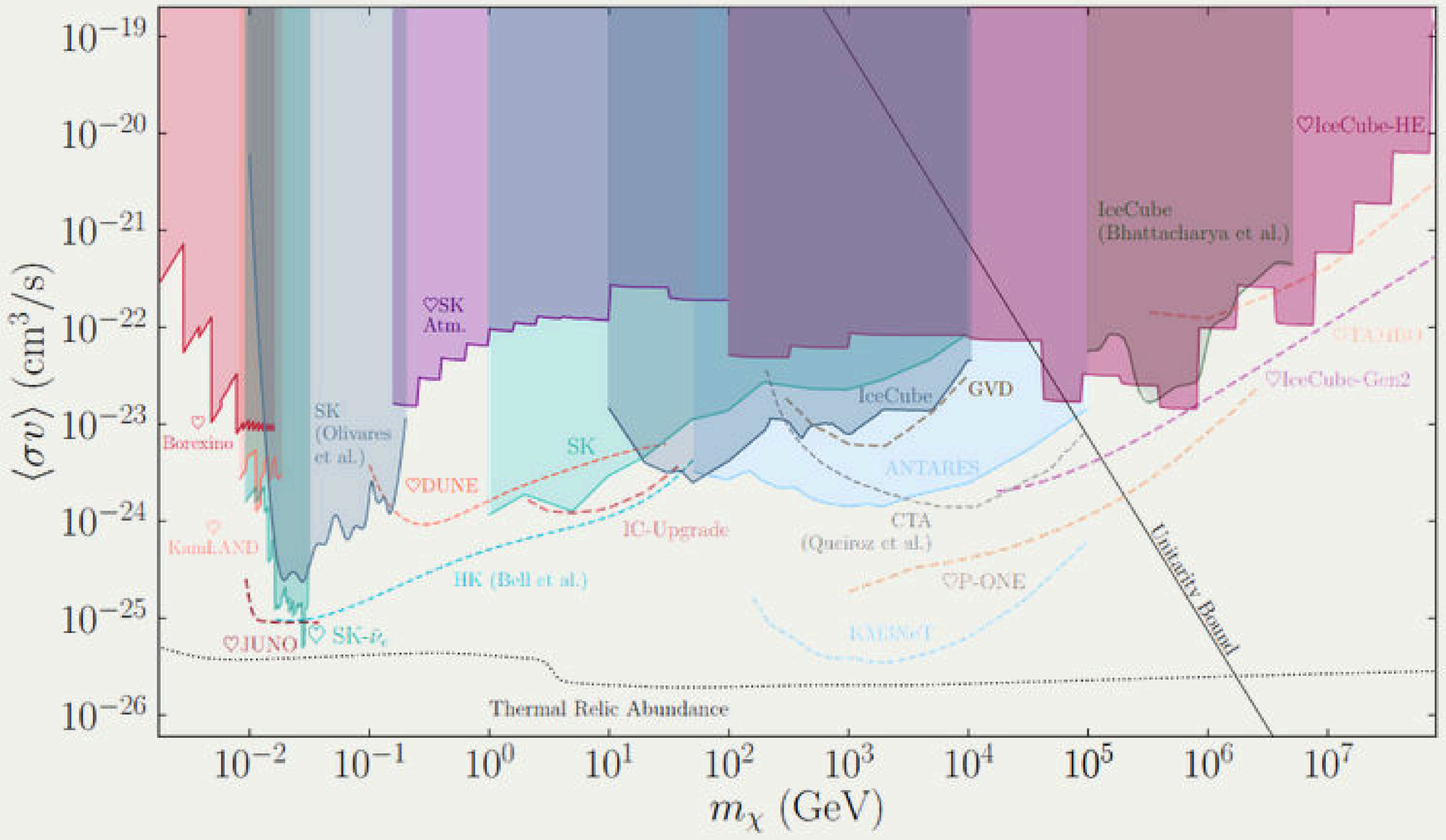
Andrew Cheek

In collaboration with S. Basegmez du Pree, C. Arina, A. Dekker, M. Chianese, S. Ando

Dark Matter Annihilating into neutrinos

WIν 2021

- Dark matter annihilation is central to thermal production.
- In the WIMP mass range, neutrino telescopes are yet to achieve sensitivities to test the thermal relic.
- In the future they will be, our study was to initiate the types of dark matter searches **experiments like KM3NeT** could be doing.

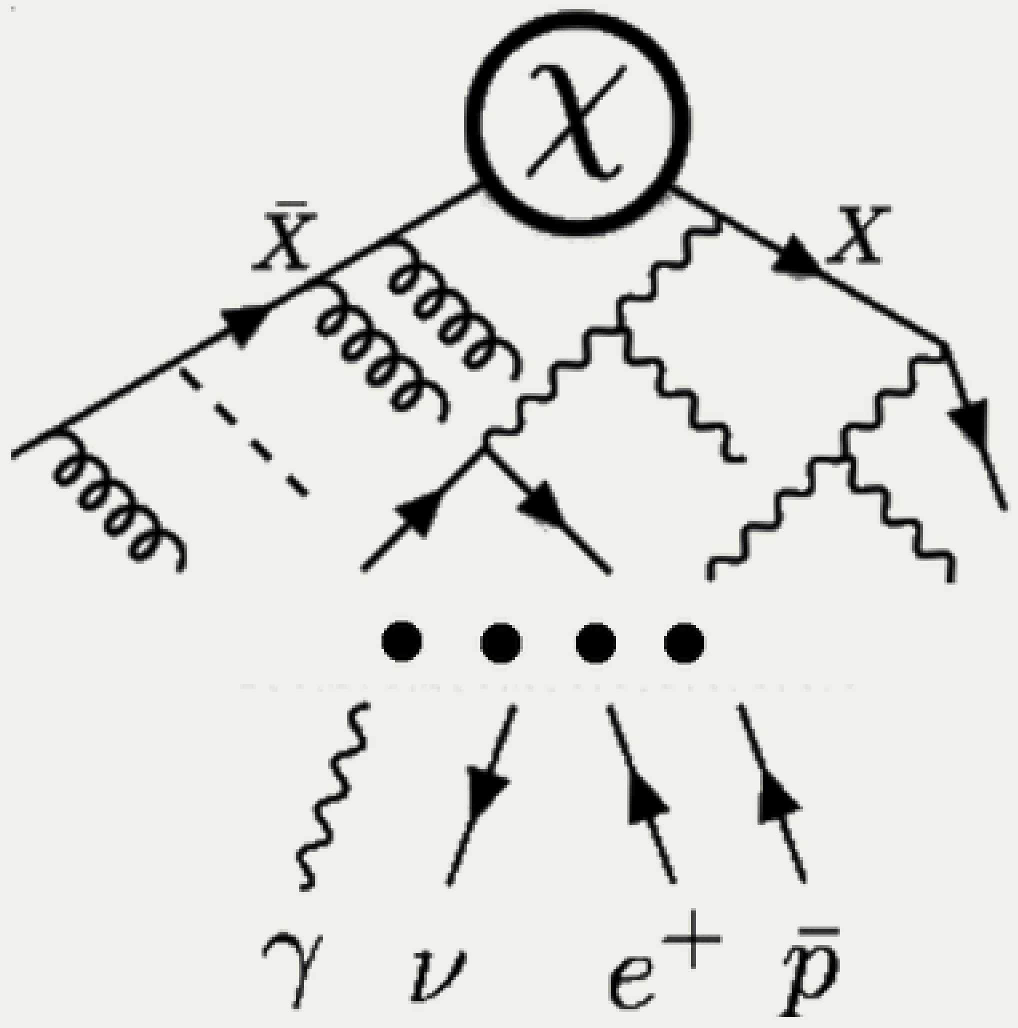


arXiv:1912.09486

WIν 2021

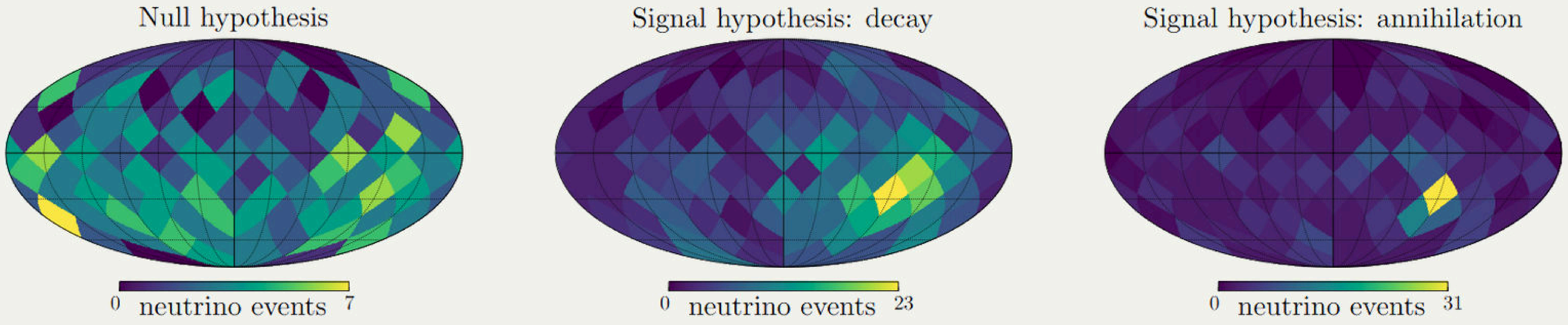
First order connections between dark matter and neutrinos

- Neutrinos have similar characteristics to dark matter (neutral under QCD and EM).
- $m_\nu \neq 0$ means physics beyond the SM.
- Neutrinos are also great messenger particles for telescopes.



Angular Power spectrum (APS)

- We wanted to test a new analysis method which initially was developed to help differentiate between DM and Astrophysical signals JCAP 09 (2020) 007.
- Astrophysical sources are expected to be uniformly distributed across the whole sky.
- DM sources are correlated to the Galactic Centre.
- In this paper we extended collaborators APS analysis from lowering the sensitivity to $m_{\rm DM} = 200\,\text{GeV}$.



Angular Power spectrum (APS) how it works

- We simulate neutrino skymaps with DM signal and expected background, below 100 TeV atmospheric neutrinos is the dominant background.
- Expanding the skymap in spherical harmonics $N_\nu(\theta, \phi) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\theta, \phi)$.
- APS is described by the average expansion coefficient over the sky

$$C'_\ell = \frac{1}{2\ell + 1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2$$

- Since DM signal from GC is the anisotropic source, we normalize $C_\ell = C'_\ell / \mathrm{N}_{\mathrm{tot}}^2$
- Build a χ^2 from C_ℓ.

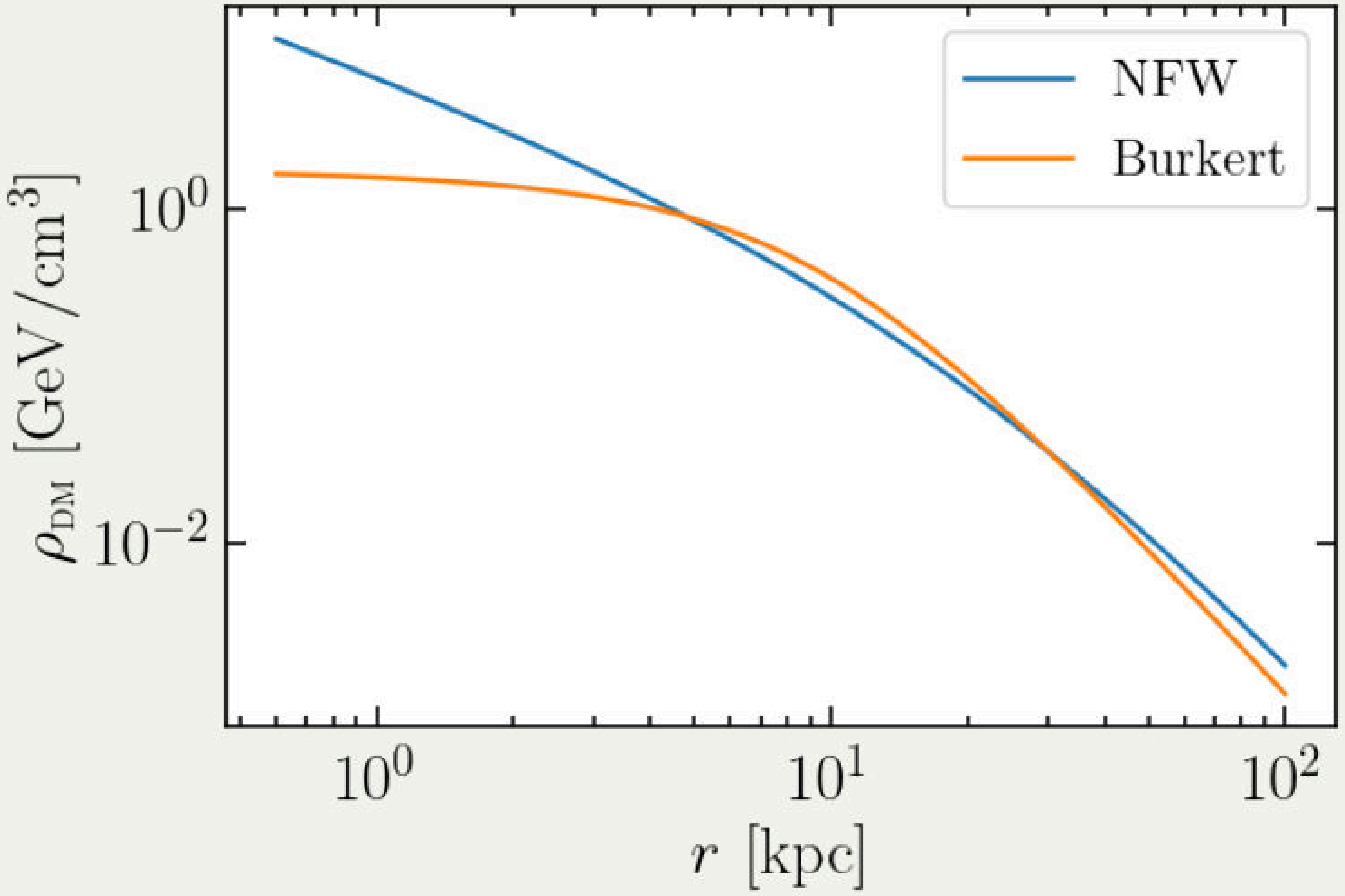
$$\chi^2(C_\ell) = \sum_{\ell\ell'} \left(C_\ell - C_\ell^{\mathrm{mean}}\right) \left(\mathrm{Cov}_{\ell\ell'}\right)^{-1} \left(\mathrm{C}_{\ell'} - \mathrm{C}_{\ell'}^{\mathrm{mean}}\right)$$

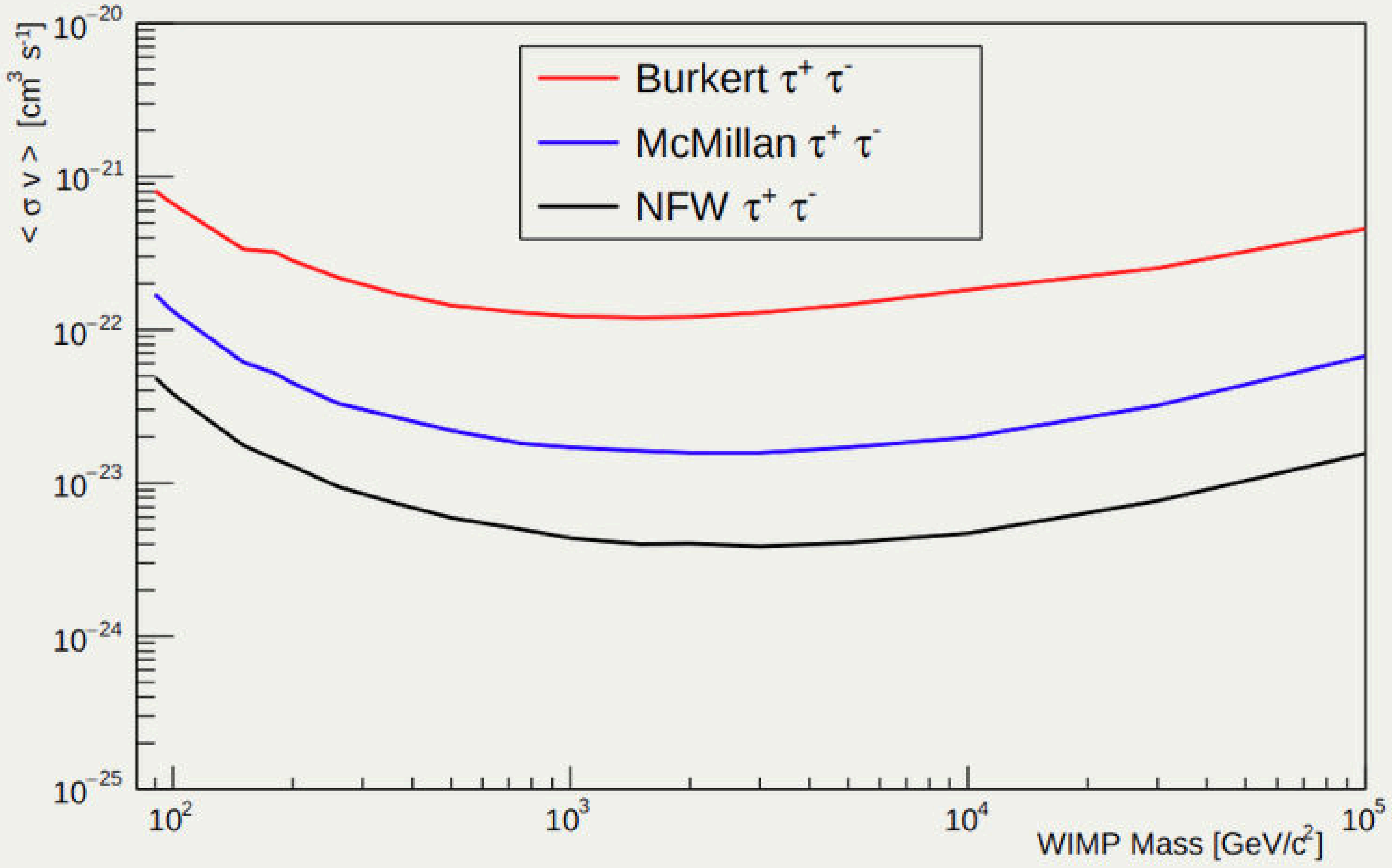
- Which allows us to calculate the p-value

$$p = \int_{\chi^2_{\mathrm{md}}}^{\infty} d\chi^2 P(\chi^2 | \Theta)$$

Galactic DM probes have high levels of uncertainty

- The distribution of DM in our Galaxy is not well known, especially in the Galactic Center.
- Neutrino flux $\Phi_{\nu\bar{\nu}} \propto \rho^2_{\mathrm{DM}}$

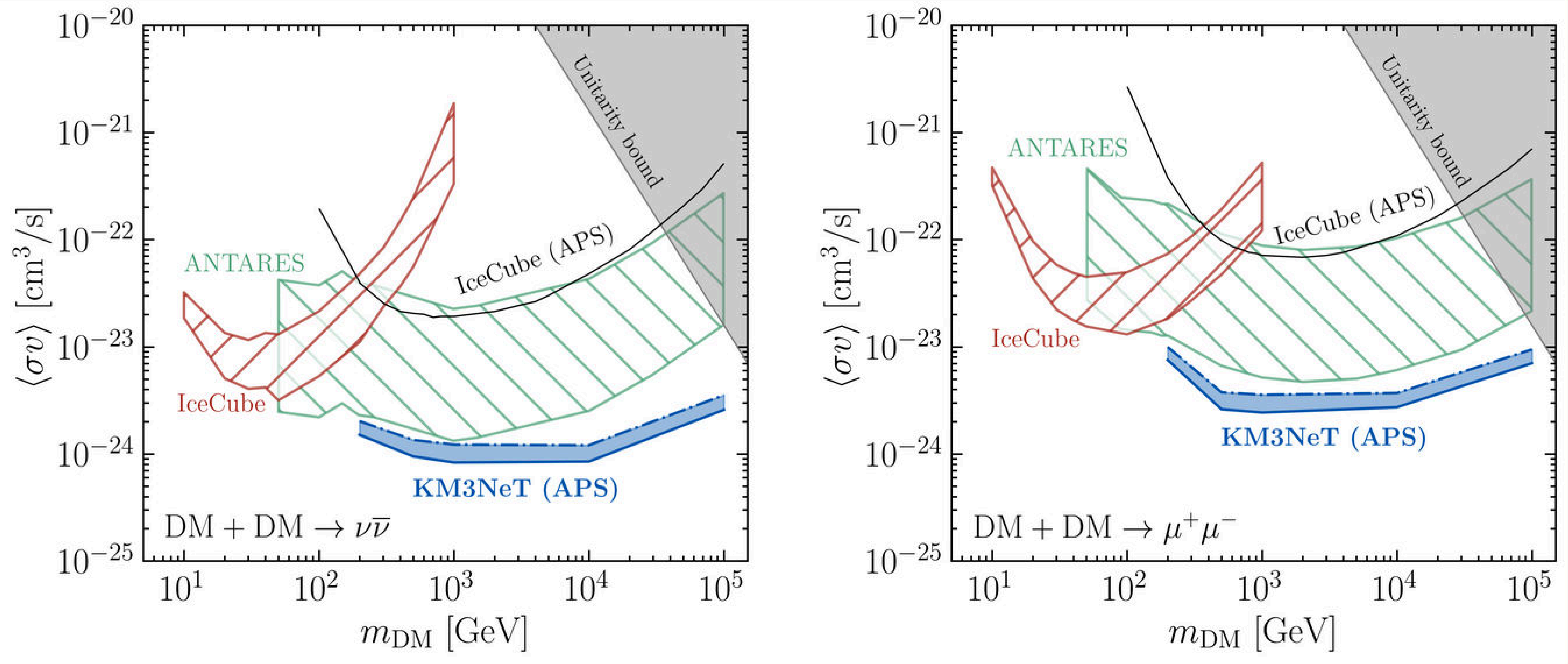




arXiv:1912.05296

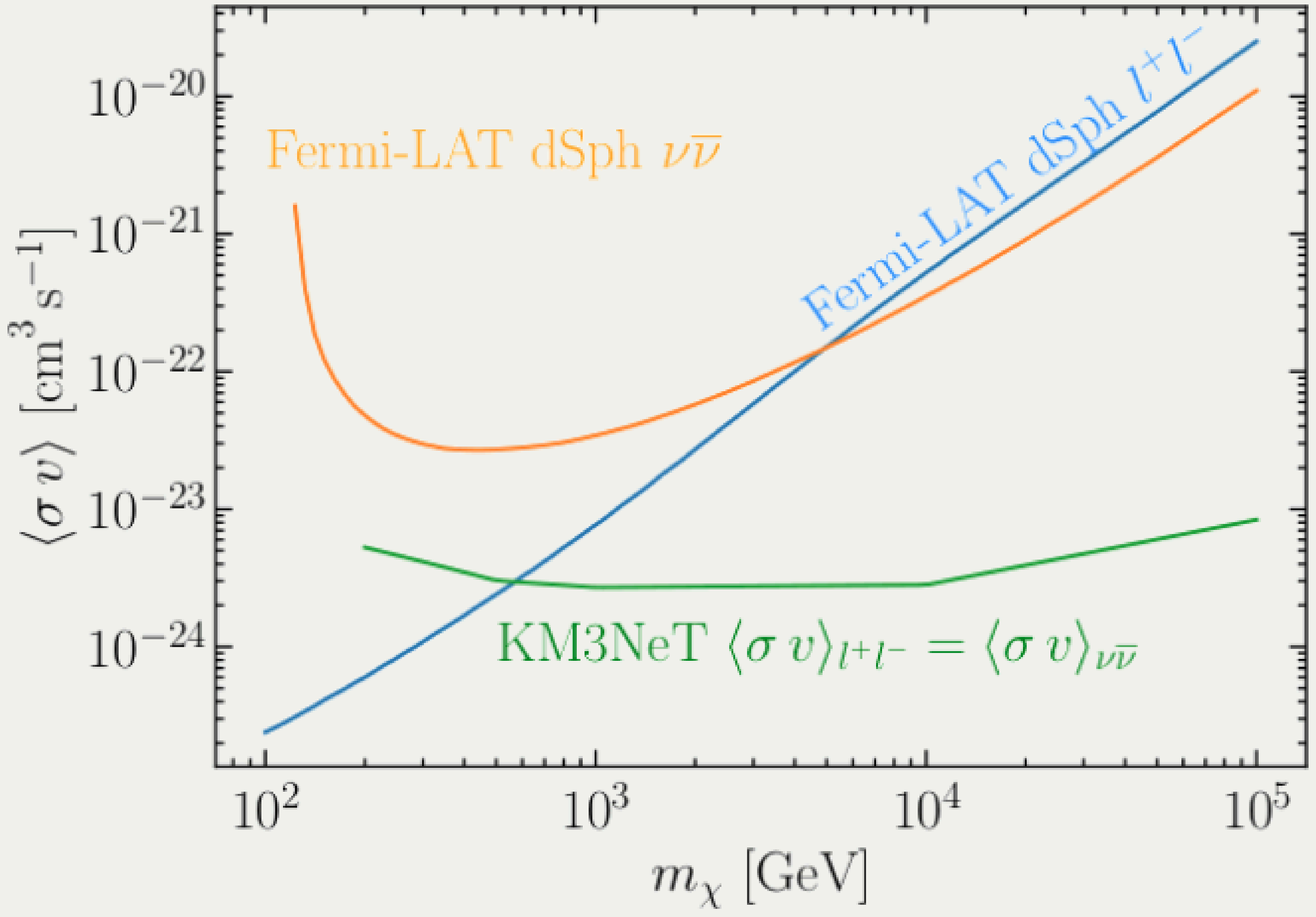
APS reduces the sensitivity to DM halo

- Here are the projections from our analysis (10 years of data taking).
- We see IceCube and ANTARES studies that do not use APS are much more sensitive to the halo distribution.



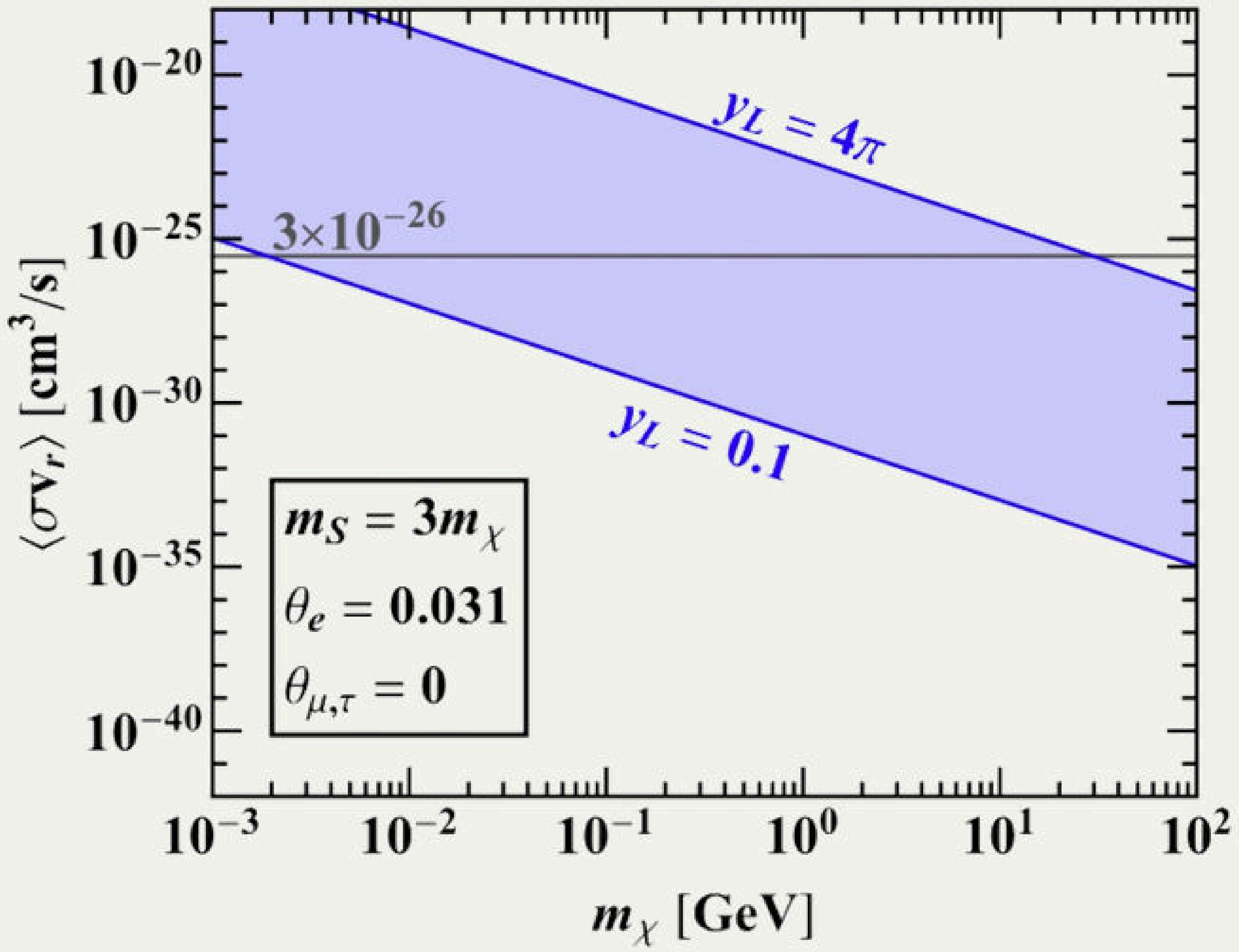
Looking for simple DM model that annihilates primarily into neutrinos

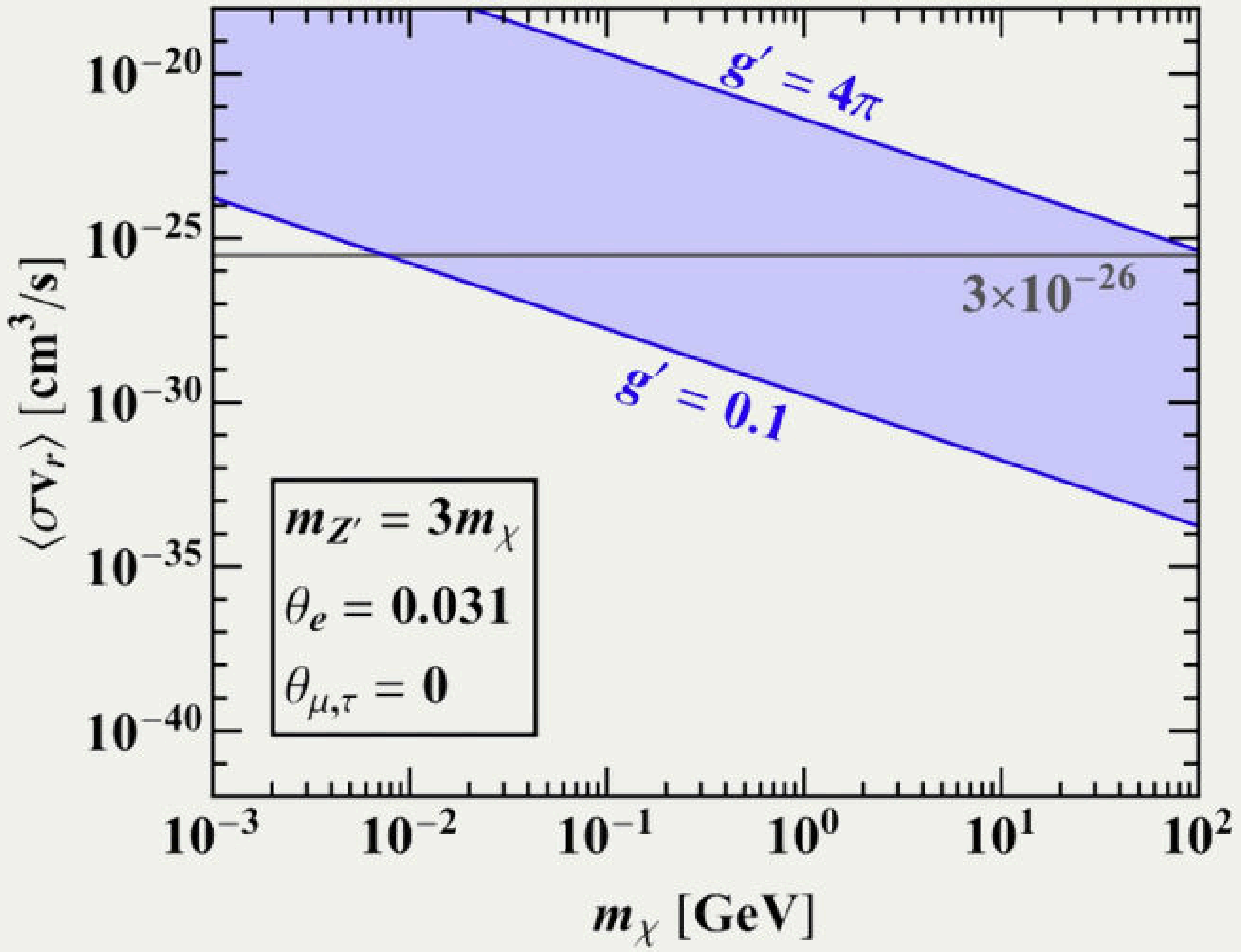
- Its difficult to make a simple DM that annihilates to only neutrinos (when $m_\chi > m_e$) because neutrinos live in the $SU(2)$ doublet L.
- C El Aisati et. al. arXiv:1706.06600 catalogued simple models (1 DM candidate and 1 portal particles).
- Generically you have a charged lepton channel, so γ-ray telescopes will be competing.



Neutrino Portal?

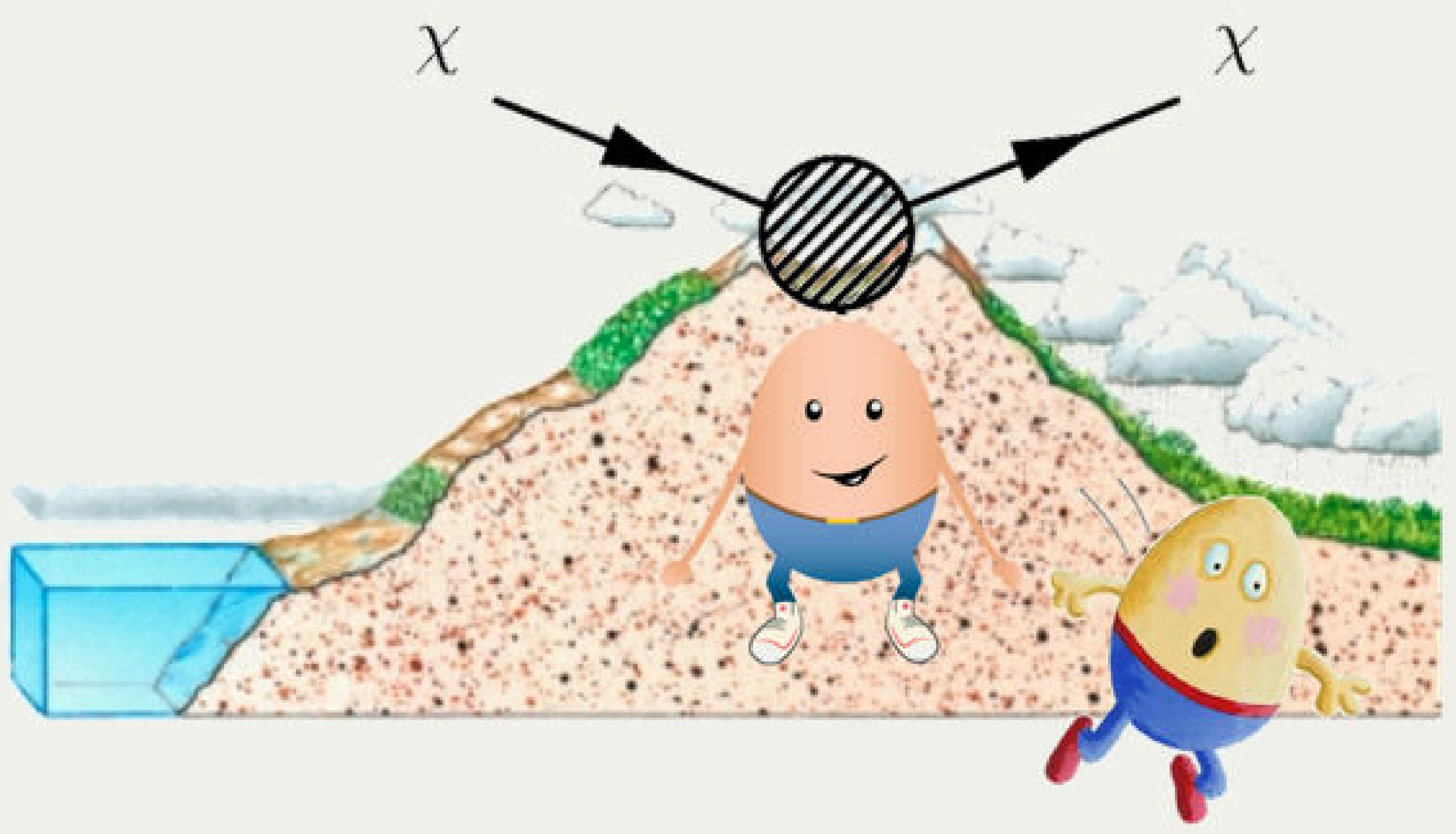
- M. Blennow et. al. arXiv:1903.00006 explored this, via a sterile neutrino portal.
- Constraints on the heavy-active neutrino mixing make it difficult to go above DM masses $\sim 100\,\mathrm{GeV}$ which is what we were interested in.

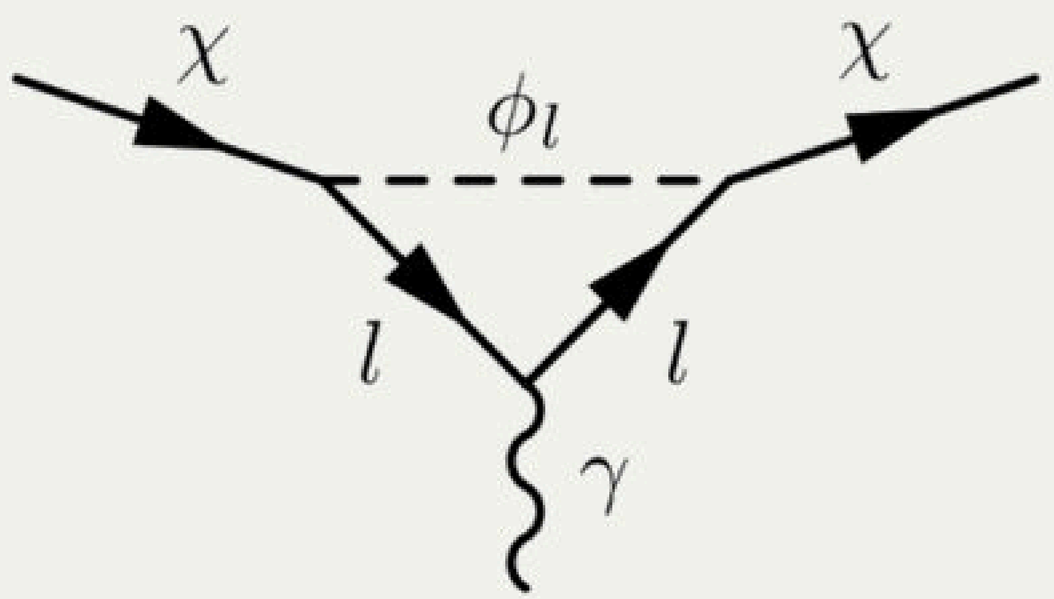


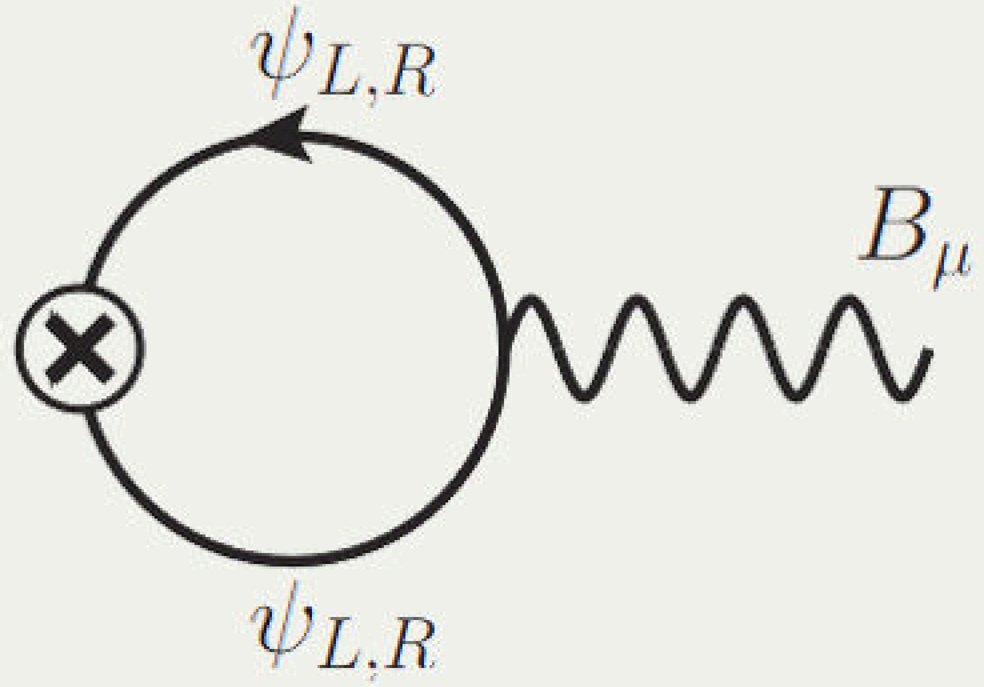


Its difficult to avoid direct dark matter detection

- At the DM masses we are interested in, direct detection often is most constraining.
- Lepto-philic models don't interact at tree-level to quarks or gluons so DD is sometims neglected.



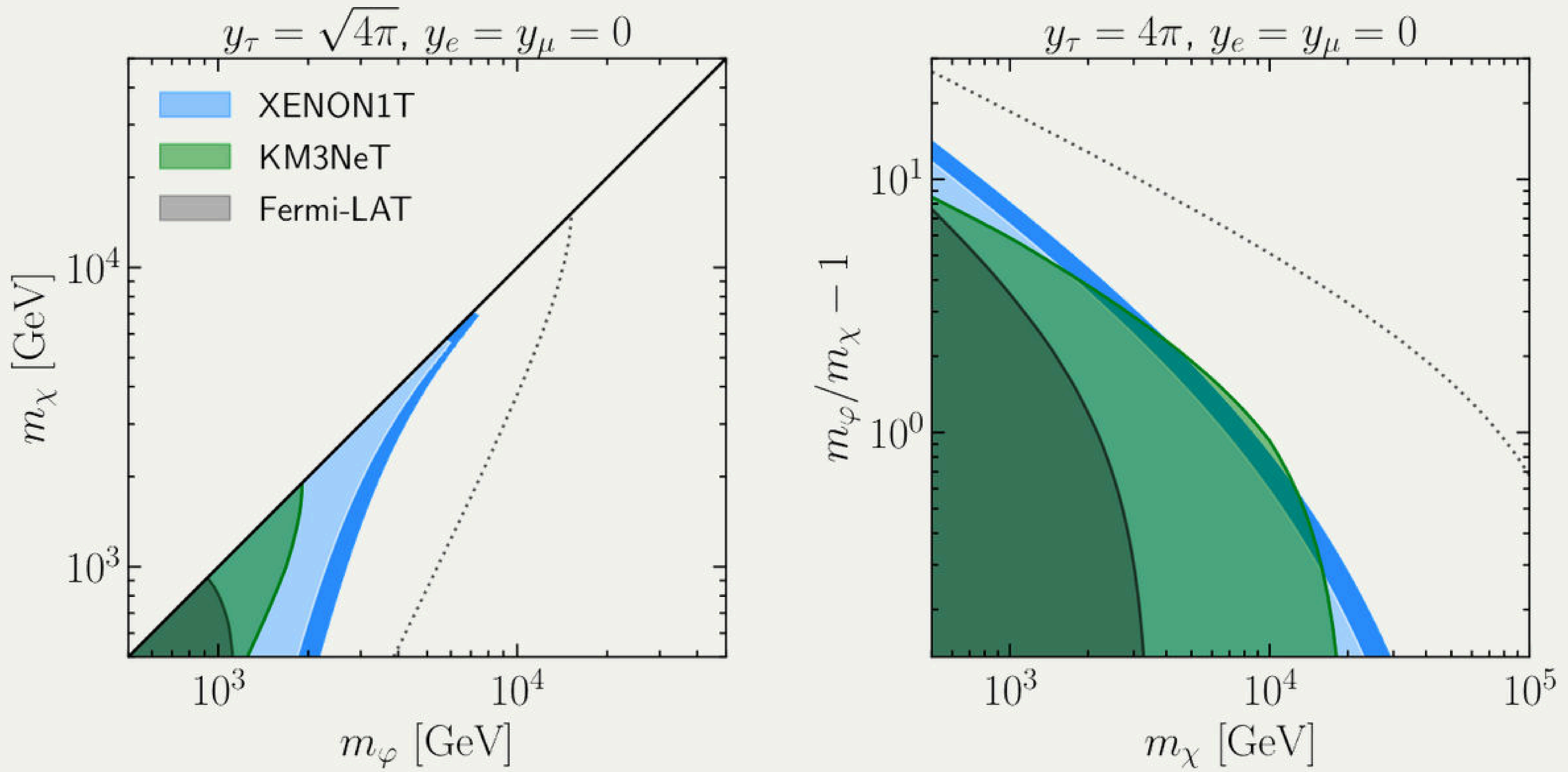




- Loop and radiative corrections mean that a lepto-philic model will be constrained a low energies by baryons.

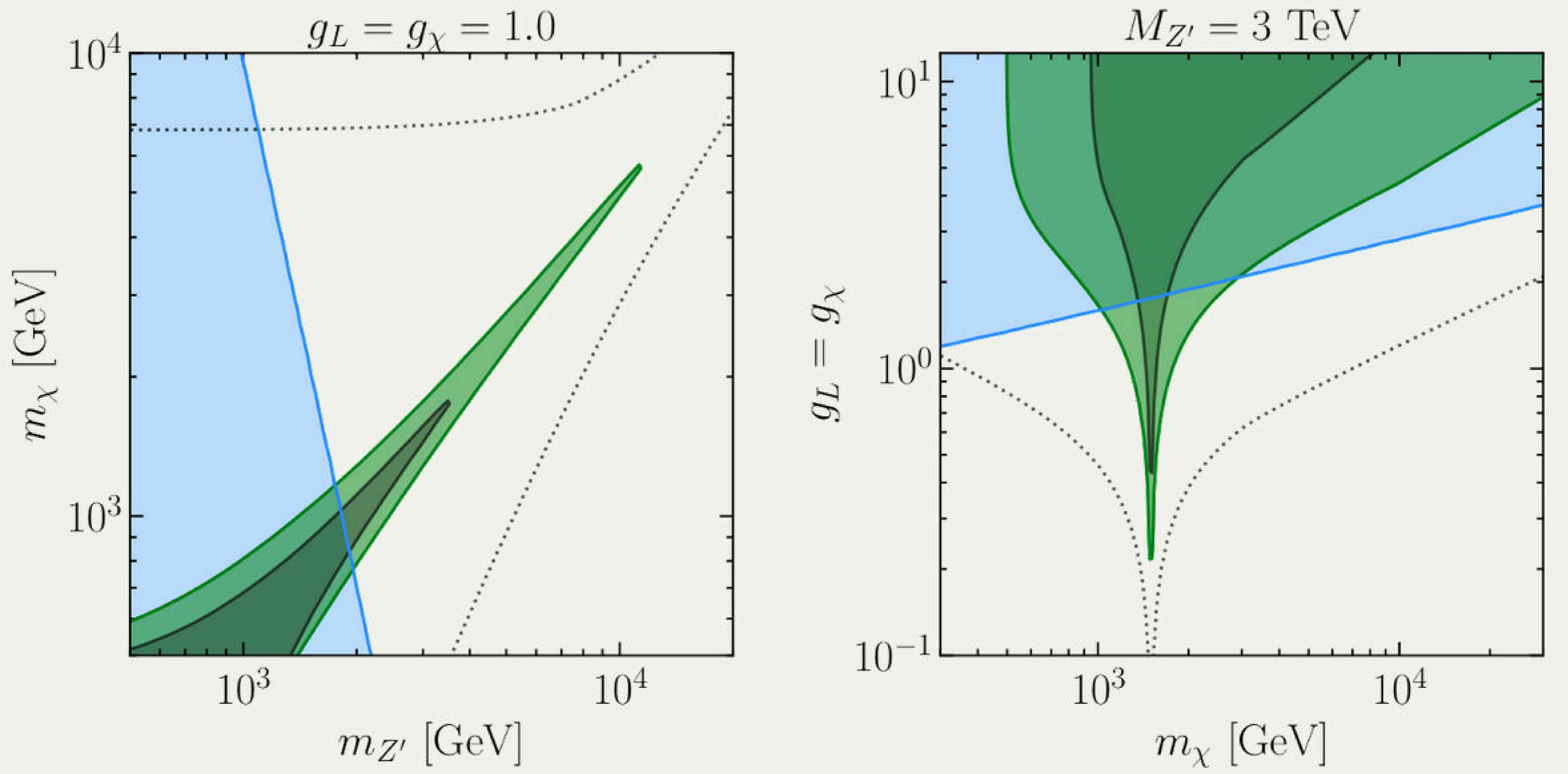
Simple scalar model

- With interaction term $\mathcal{L}^{\varphi} = y_\alpha \bar{\chi} L_\alpha \varphi^\dagger + \text{h.c.}$, leads to $\langle \sigma v \rangle \propto \frac{m_\chi^2}{(m_\chi^2 + m_\varphi^2)^2}$.
- Since $m_\varphi > m_\chi$ is required for DM stability, its difficult to reach higher masses.



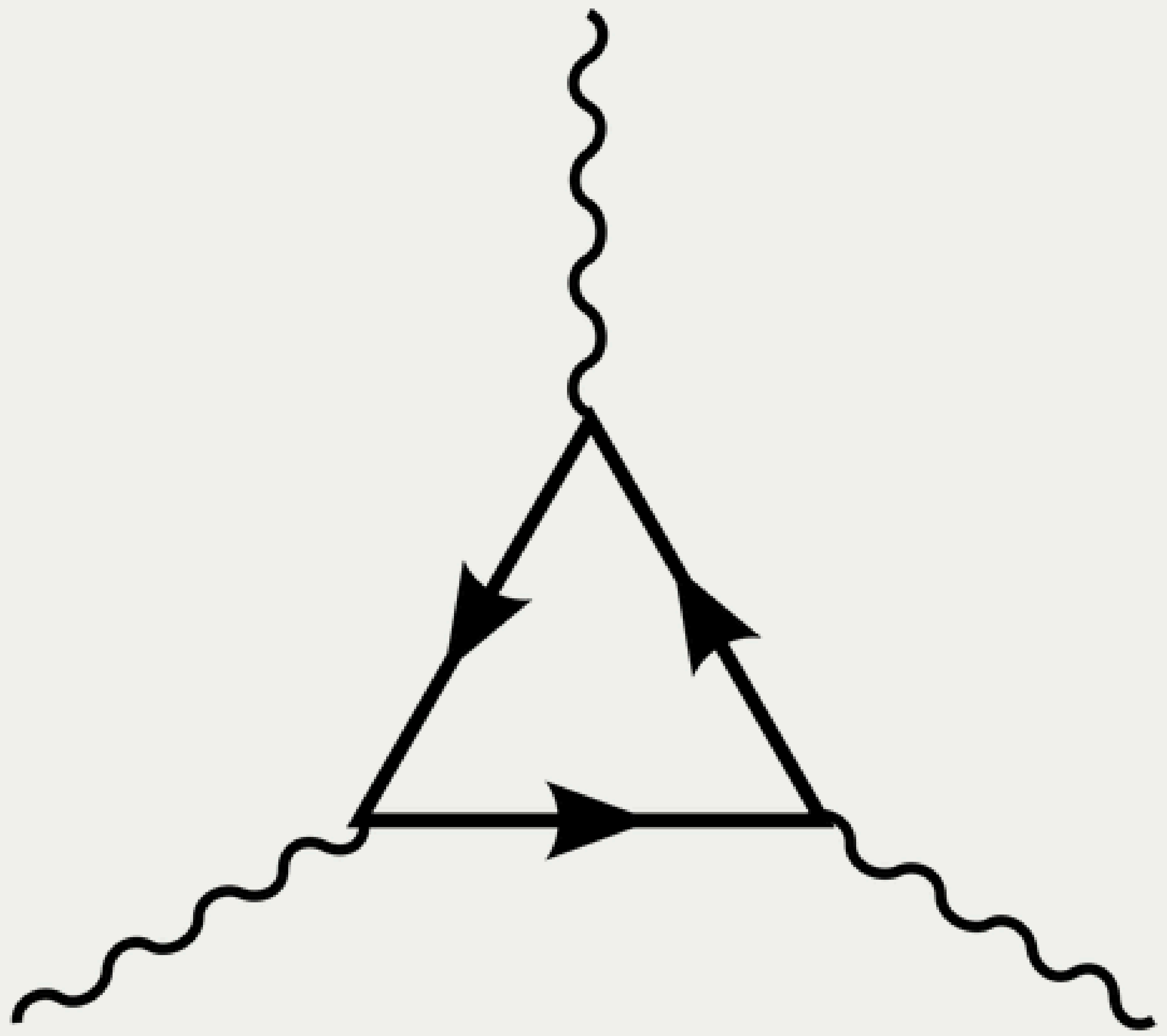
Vector mediated model

- $\mathcal{L}^{Z'} = \bar{\chi}\gamma_\mu(g_\chi^V + g_\chi^A\gamma_5)\chi\, Z'^\mu + \sum_\alpha \bar{l}_\alpha\left[\gamma_\mu(g_{l_\alpha}^V + g_{l_\alpha}^A\gamma_5)\right] l_\alpha Z'^\mu$,
- For s-channel $m_{Z'} > m_\chi \Rightarrow \langle\sigma v\rangle \propto \frac{m_\chi^2}{(4m_\chi^2 - m_{Z'}^2)}$
- Here showing $g_{l_f}^V = g_{l_f}^A \equiv \frac{1}{2} g_{\mathrm{L}}$



Theoretically shaky ground

- Having $g^A \neq 0$ in simplified models have many theoretical constraints.
- Due to the growth of longitudinal part of Z' mediator, perturbative unitarity is violated at high energies arXiv:1510.02110.
- Additionally, anomaly cancellation of a $U(1)$ gauge field restricts the couplings to the SM.

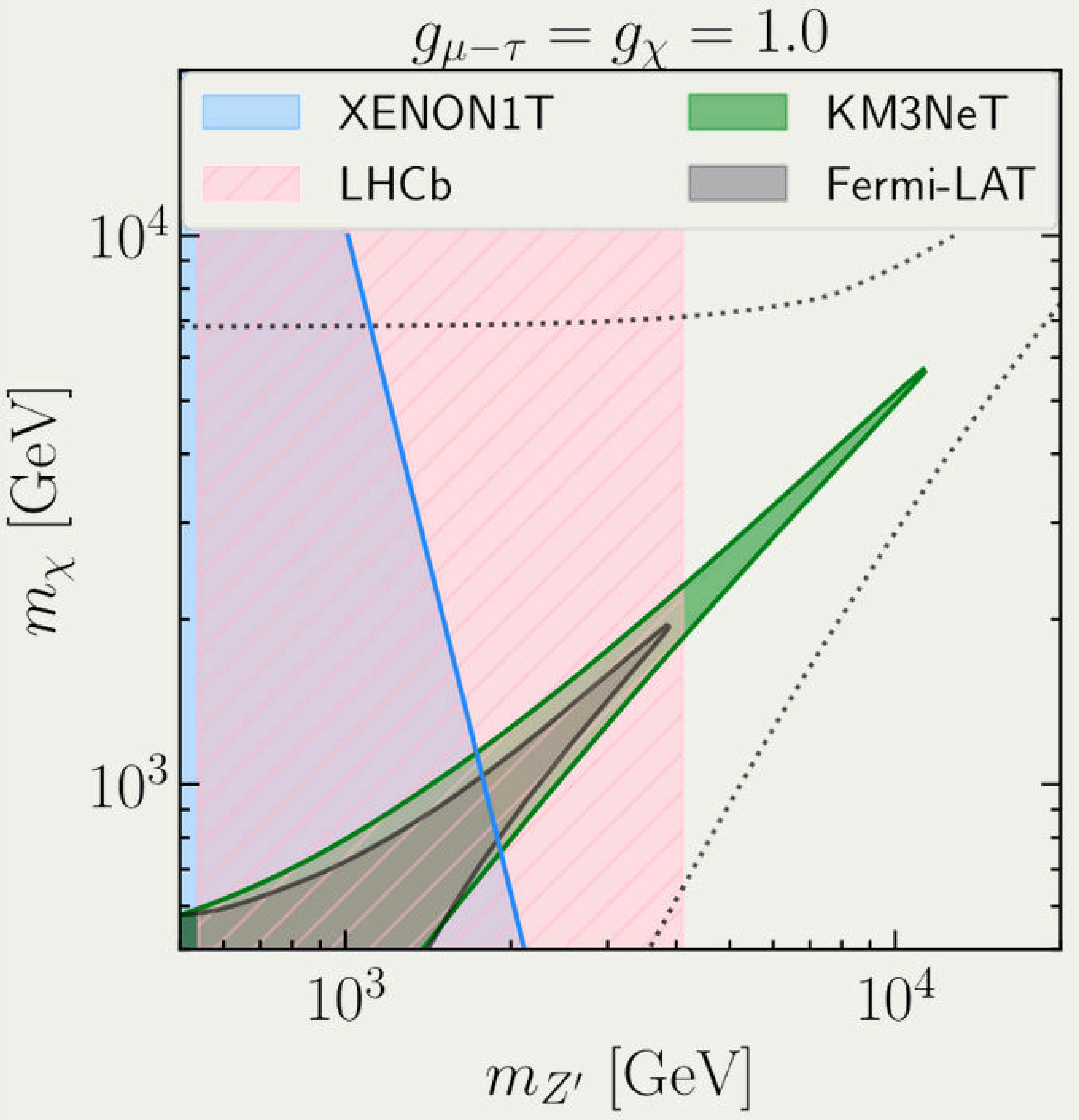


- An anomaly-free $U(1)$ extension is $L_\alpha - L_\beta$
- $L_\mu - L_\tau$ has weaker experimental contraints.
- Additional vector-like Fermions can be added to this model.

WIν 2021

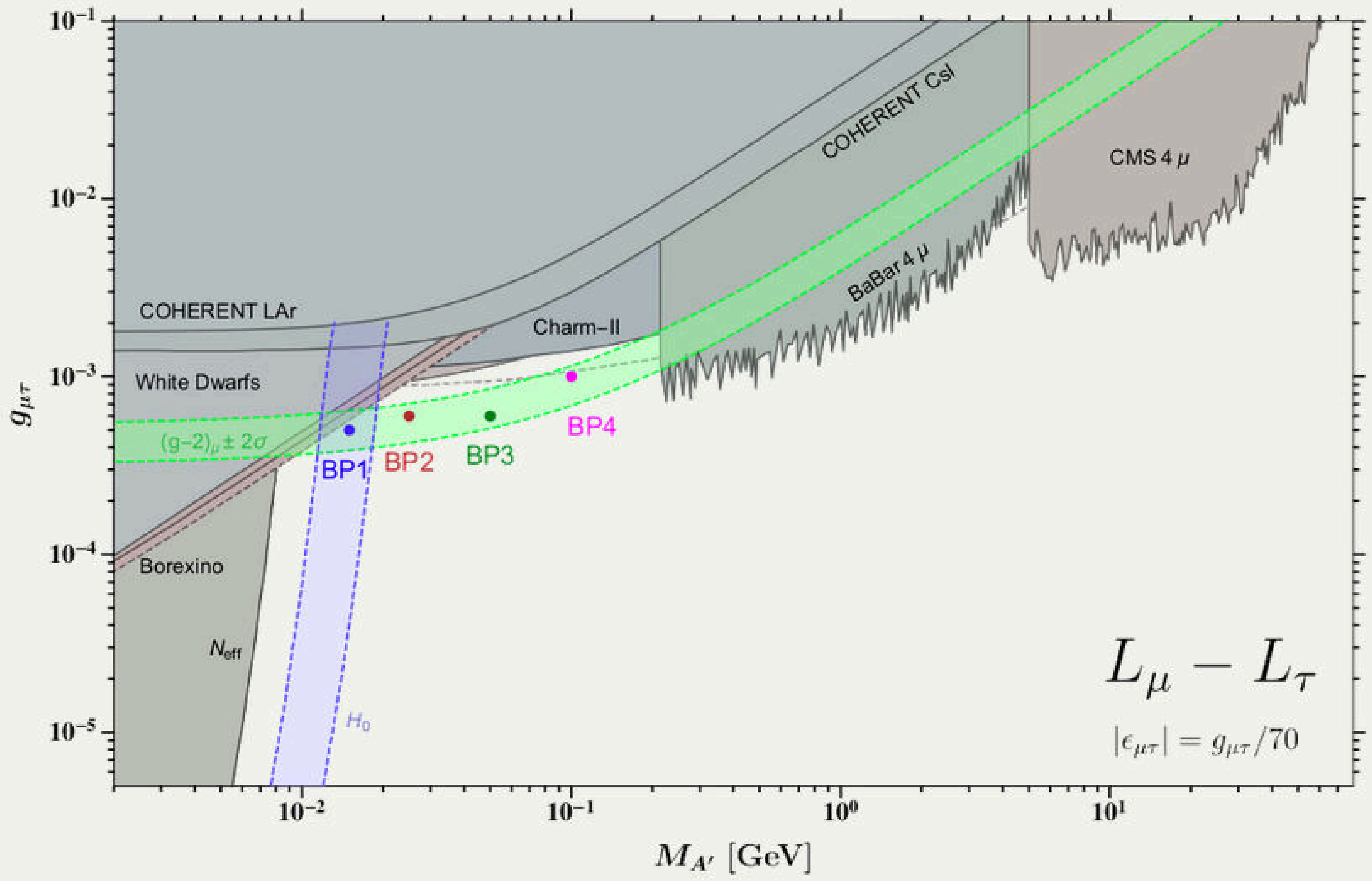
The Anomaly free $U(1)_{L_\mu - L_\tau}$ model

- Anomaly free, potentially there's a connection with flavor anomalies.
- In the $m_Z \sim 100$ GeV region its a similar story to before.
- $g_\mu^V = -g_\tau^V = g_{\mu-\tau}$,
- $g_e^V = g_{l_f}^A = 0$,
- $g_\chi^V \equiv g_\chi$
- and $g_\chi^A = 0.$



Where $U(1)_{L_\mu - L_\tau}$ models shine

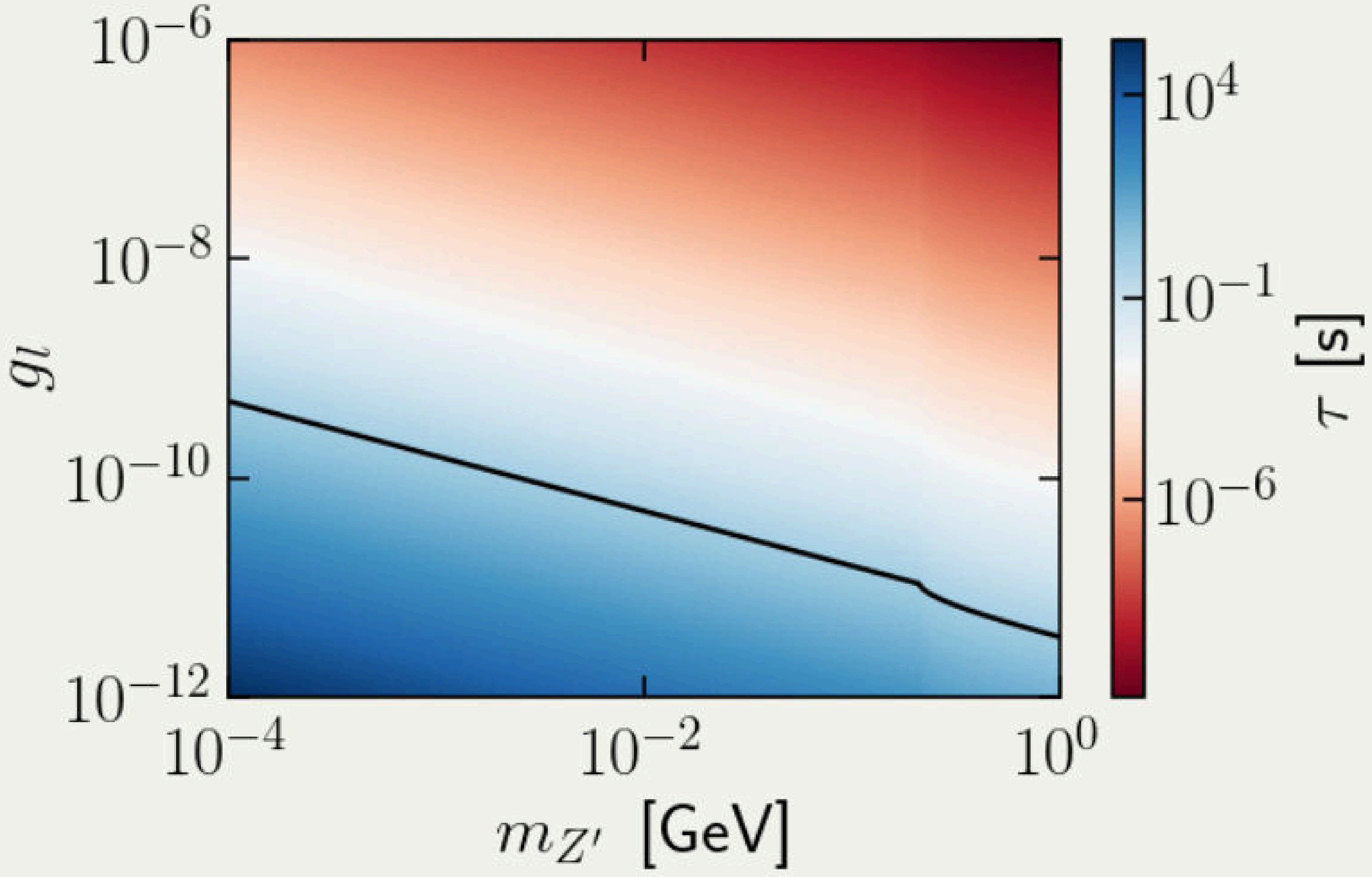
- An explanation of $(g-2)_\mu$ anomaly, no DM required. See D. Amarals asynchronous talk.
- For our purposes ($m_\chi > 200$ GeV), the addition of a DM candidate would be severely constrained by direct detection $\sigma_{DD} \propto m_{Z'}^{-4}$.
- We consider a light mediator $m_{Z'} < m_\chi$ but in a secluded regime $g_{\mu-\tau} \ll g_\chi$.
- So diboson production now allowed.



How low can $g_{\mu-\tau}$ be?

- The life-time of Z' is constrained from below by BBN.

$$\tau_{Z'} = \sum_f \frac{12\pi m_{Z'}^2}{g_{\mu-\tau}^2 \sqrt{m_{Z'}^2 - 4m_f^2}\left(m_{Z'}^2 - m_f^2\right)} \lesssim 1\ \mathrm{s},$$

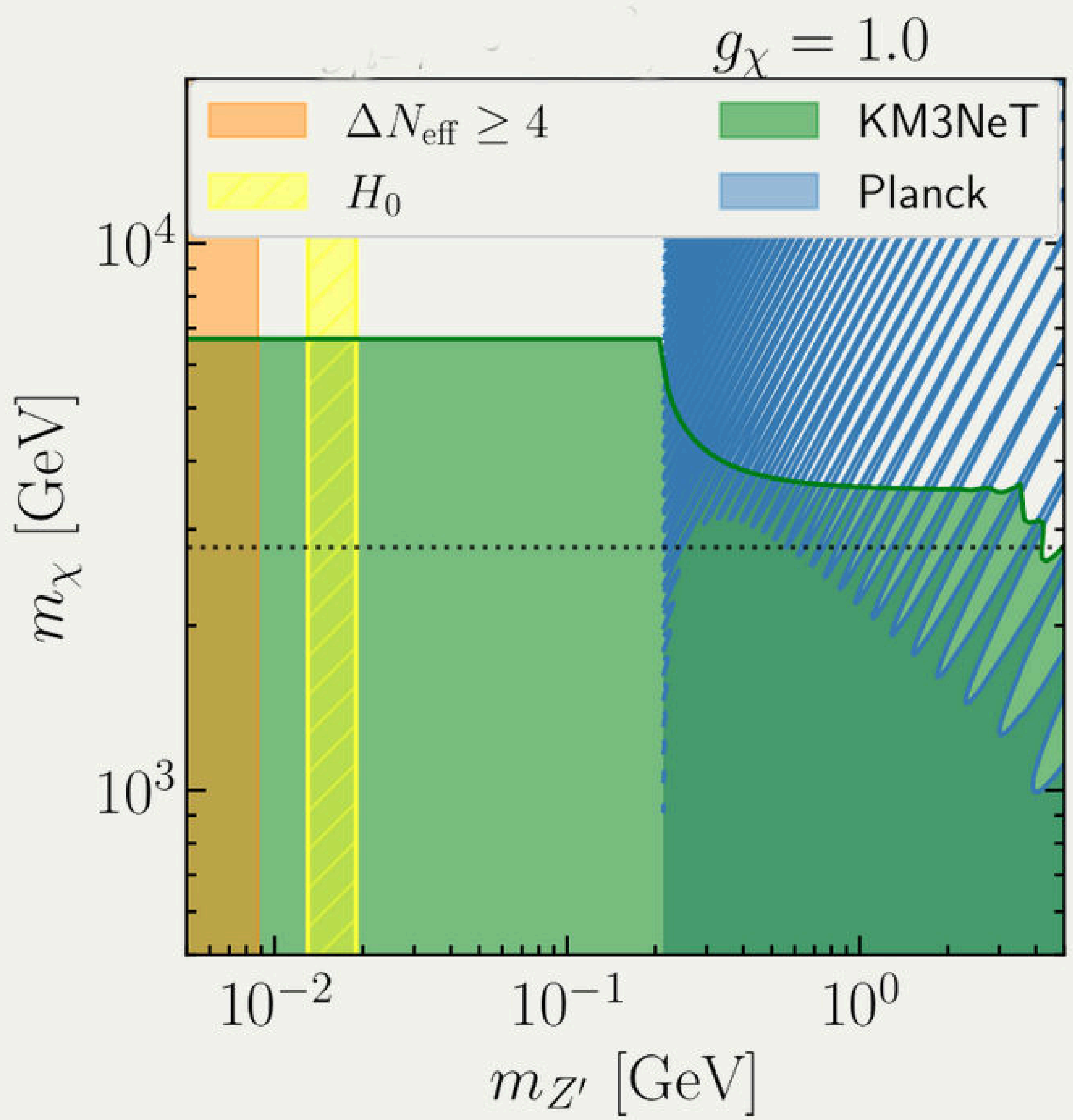


- Which gives us the freedom to choose $g_{\mu-\tau}$ such that direct detection constraints are avoided.

Andrew Cheek

$U(1)_{L_\mu - L_\tau}$ secluded model

- When $m_{Z'} < 2m_\mu$ $\mathrm{Br}_{\nu\bar{\nu}} = 100\,\%$
- Additionally, since $m_{Z'} < m_\chi$ the sommerfeld effect can play a role,



- Since, $S \propto 1/v^2$ and $v_{\mathrm{CMB}} << v_{\mathrm{dSph}} << v_{\mathrm{gal}}$ CMB contraints are stronger than Fermi-LAT.

WIν 2021

Conclusions

- We provided a projection of a KM3NeT-like telescope with a new Angular Power Spectrum analysis.
- APS minimizes uncertainties in the galactic dark matter density.
- We explored simple models for DM and how this analysis fits with the experimental landscape.
- We highlighted the interesting posibility for a secluded $U(1)_{L_\mu - L_\tau}$ model.