

# To $\nu$ or Not to $\nu$

*That is the interaction*

## Subhajit Ghosh

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Weinberg Institute  
Department of Physics



The University of Texas at Austin

# Φαινó 2026

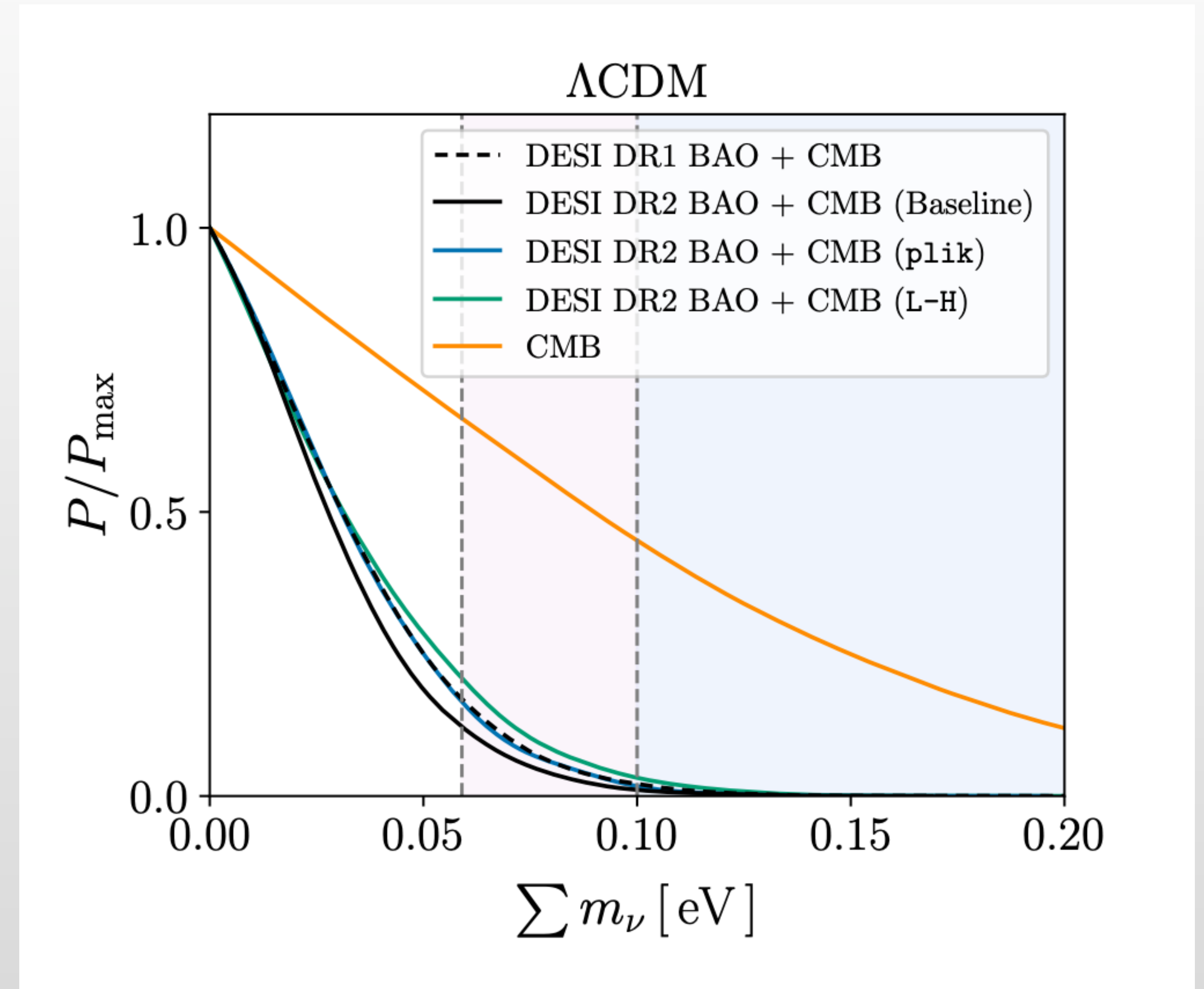
# Probing Neutrinos via cosmology

Neutrino mass

$$\sum m_\nu < 0.0642 \text{ eV} \quad (95\% \text{ C.L.})$$

Planck + ACT + DESI

$$\nu \text{ Oscillation: } \sum m_\nu > 0.059 \text{ eV}$$



# $H_0$ tension

Early Universe (CMB)

Late Universe

$$H_0 = 67.24 \pm 0.35$$

← Tension  $> 5\sigma$  →

$$H_0 = 73.18 \pm 0.88 \text{ km/s/Mpc}$$

Planck + ACT + SPT

arXiv:2506.20707

SH0ES Collaboration

arXiv:2509.01667

$$H_0 = 70.39 \pm 1.22 \text{ (stat)} \pm 1.33 \text{ (sys)} \pm 0.70 \text{ (}\sigma\text{SN)}$$

CCHP Collaboration

arXiv:2408.06153

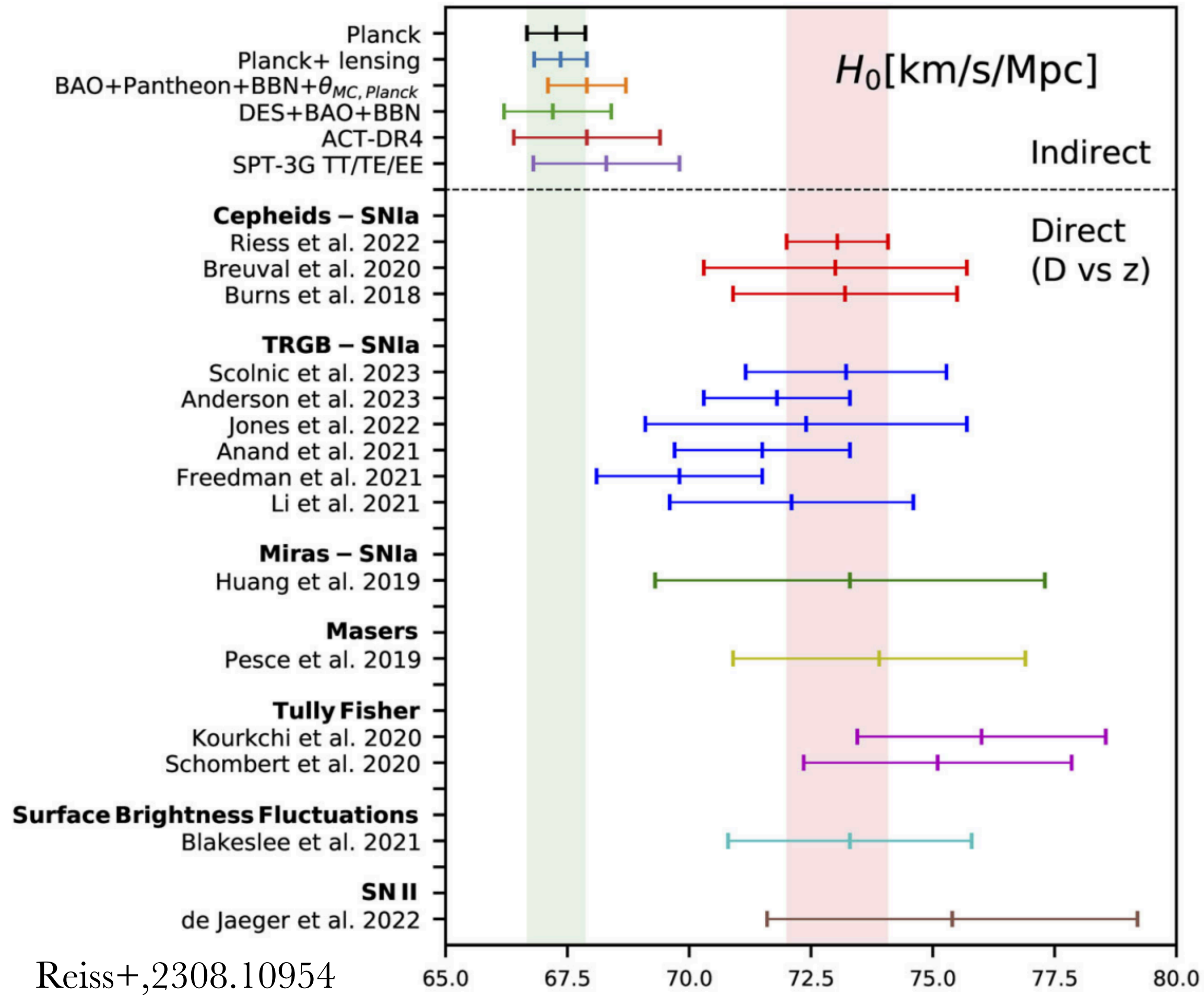
# $H_0$ tension

Early Universe

$$H_0 =$$

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verse

38 km/s/Mpc

laboration

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$$1.33 \text{ (sys)} \pm 0.70 \text{ (}\sigma\text{SN)}$$

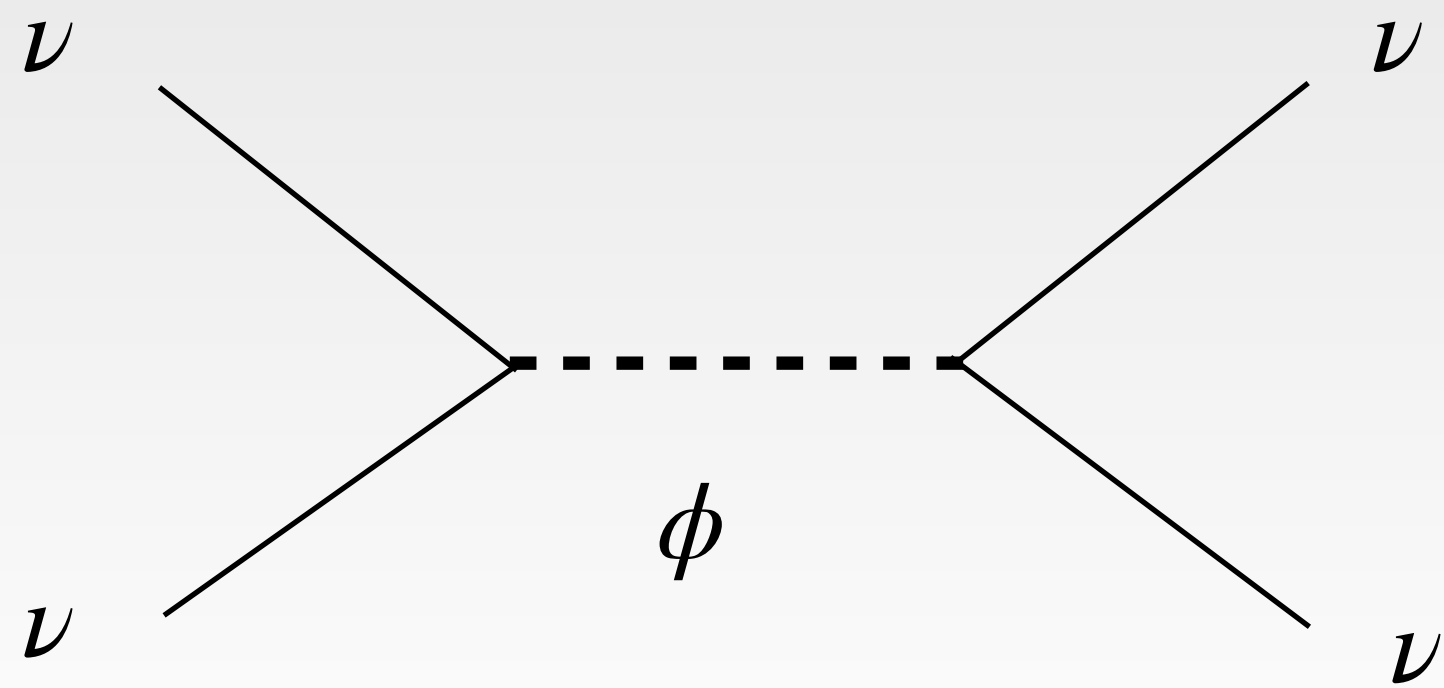
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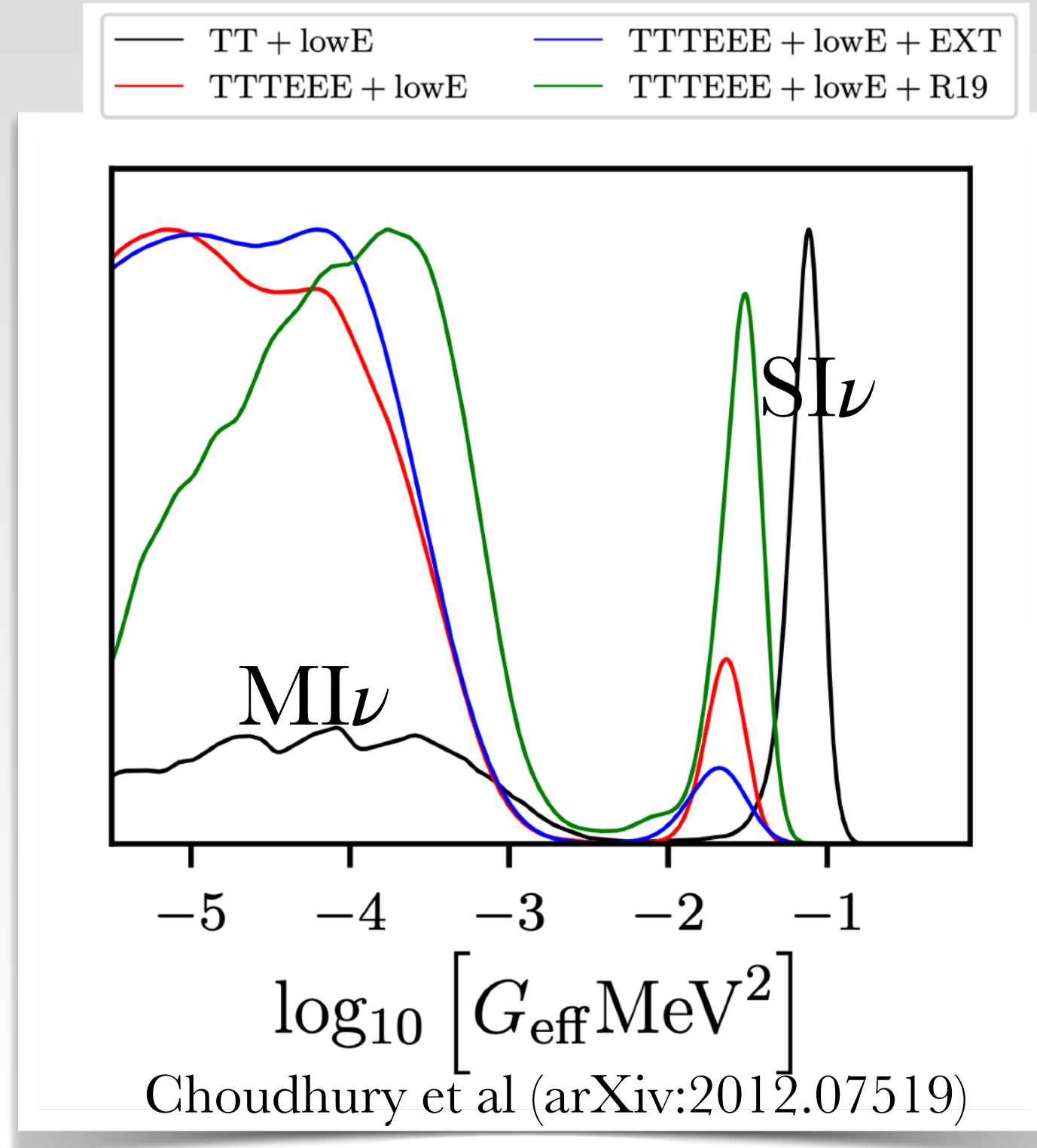
Reiss+,2308.10954

# Neutrino self-interaction to the rescue (?)

$$\mathcal{L}_{\text{int}} \supset \frac{1}{2} g_{ij} \bar{\nu}_i \nu_j \phi + \frac{1}{2} m_\phi^2 \phi^2, \quad g_{ij} = g \delta_{ij}$$



+ t, u channel

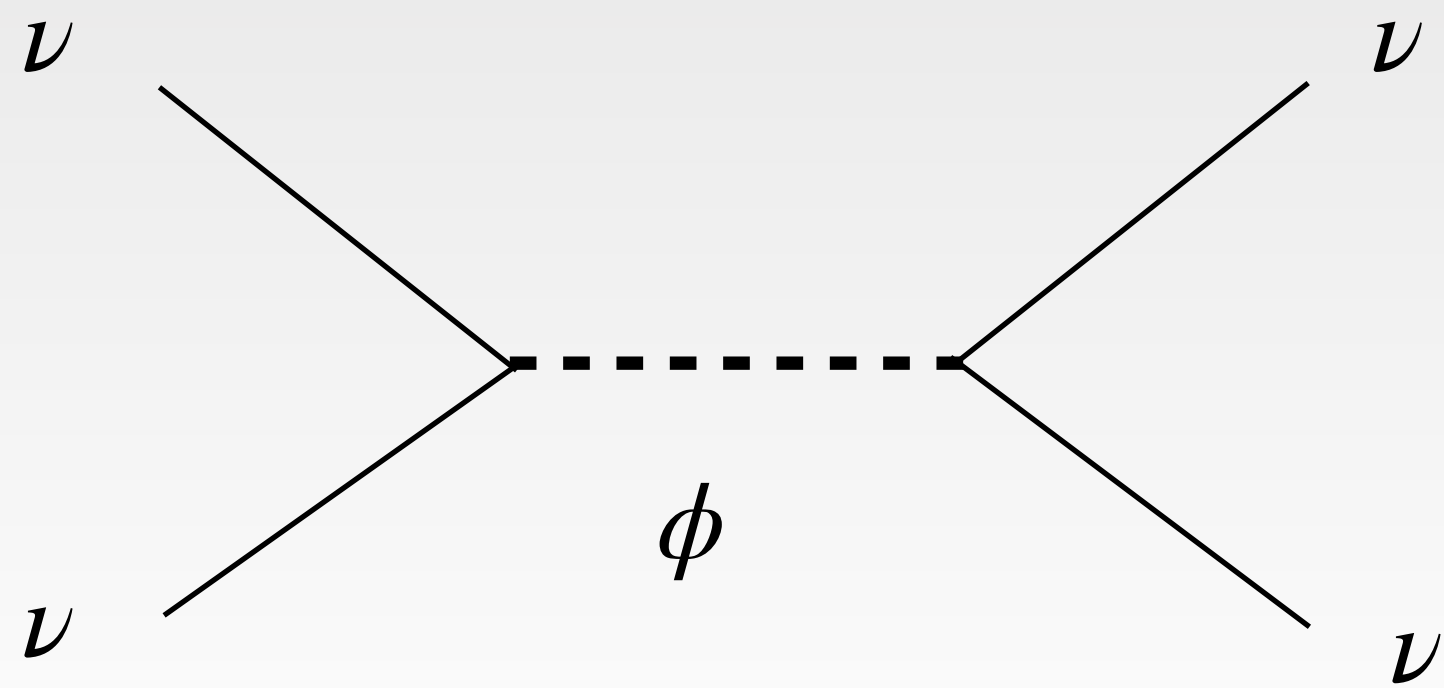


Scattering rate:  $\Gamma_\nu = G_{\text{eff}}^2 T_\nu^5$

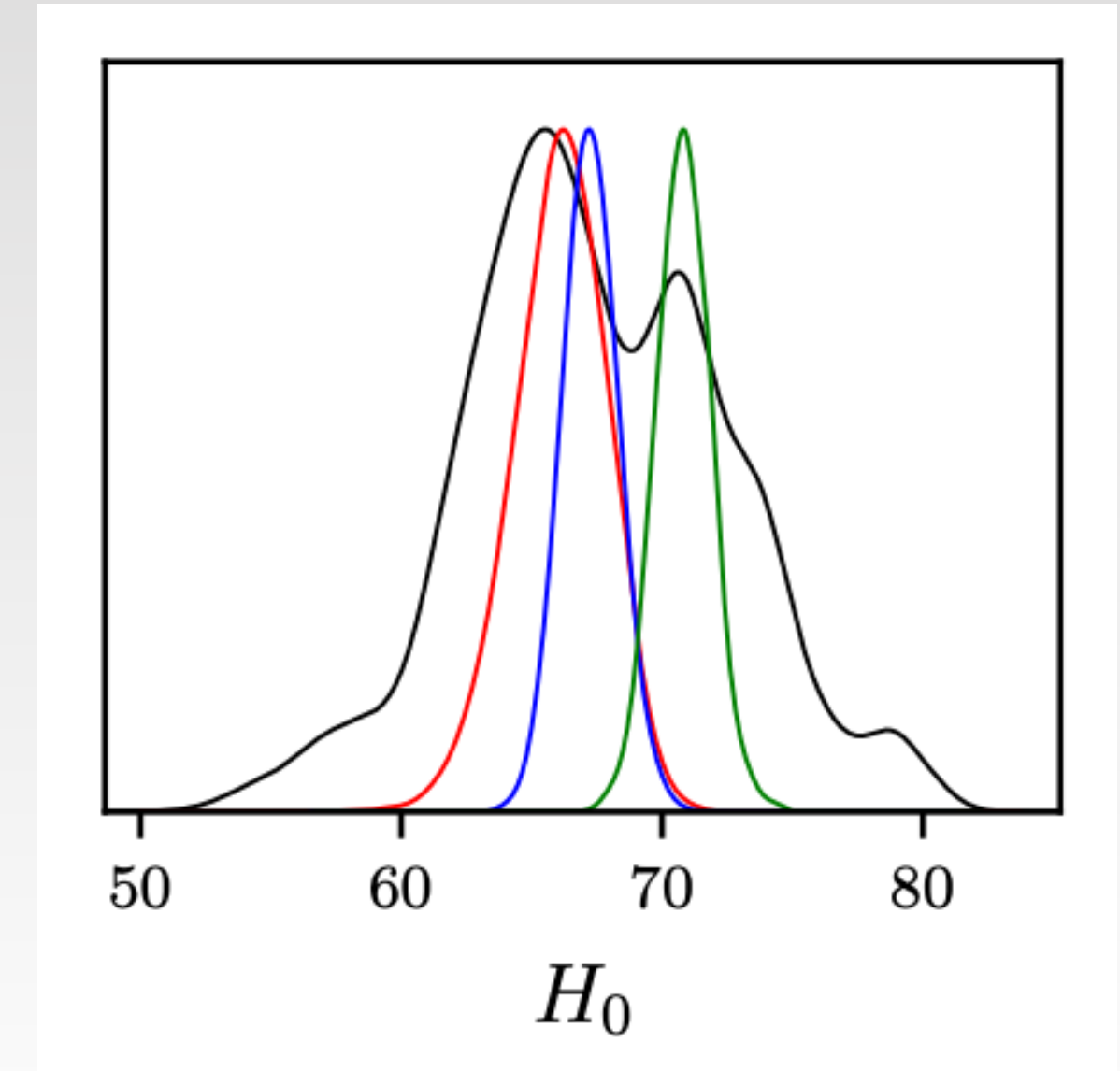
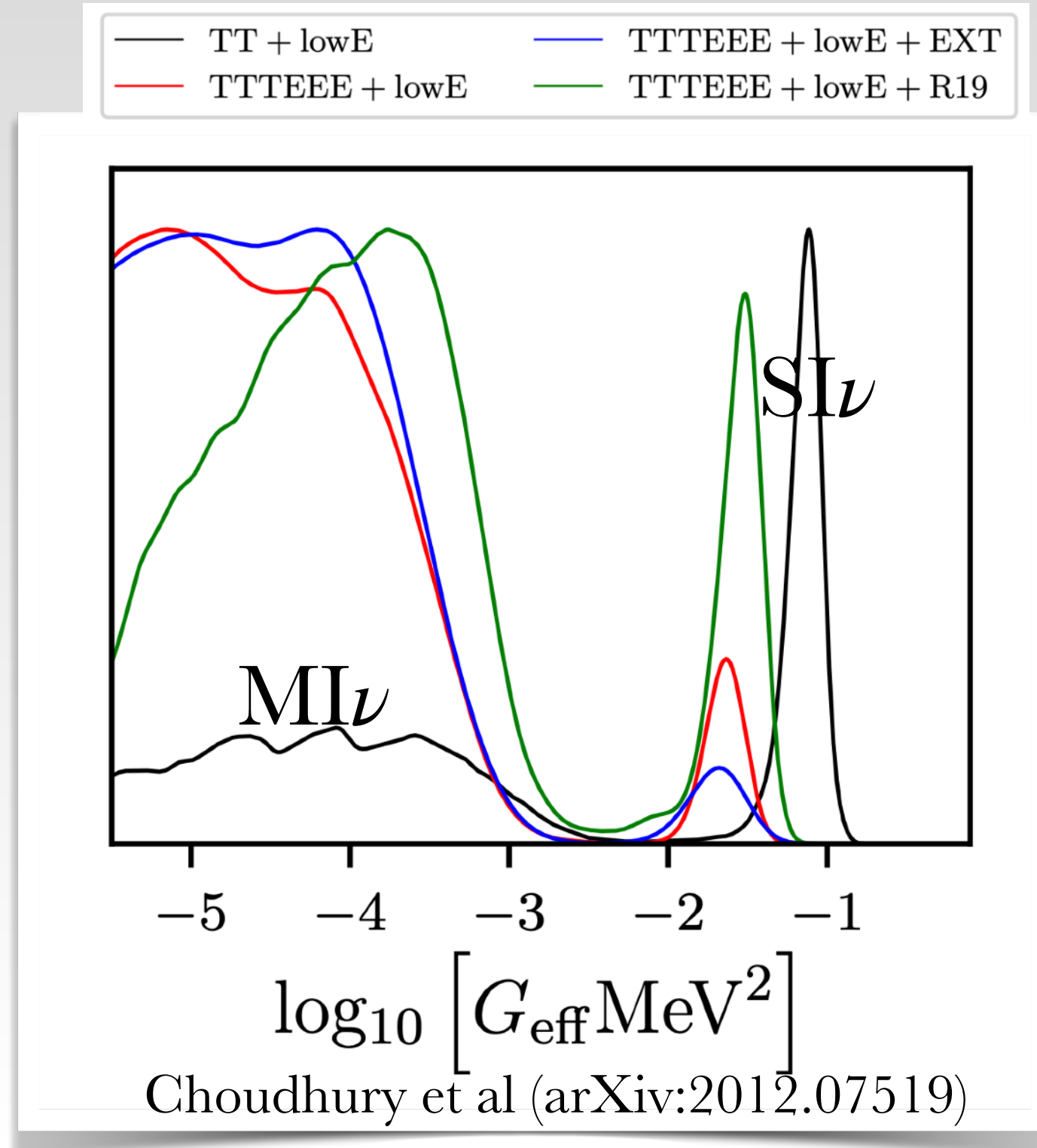
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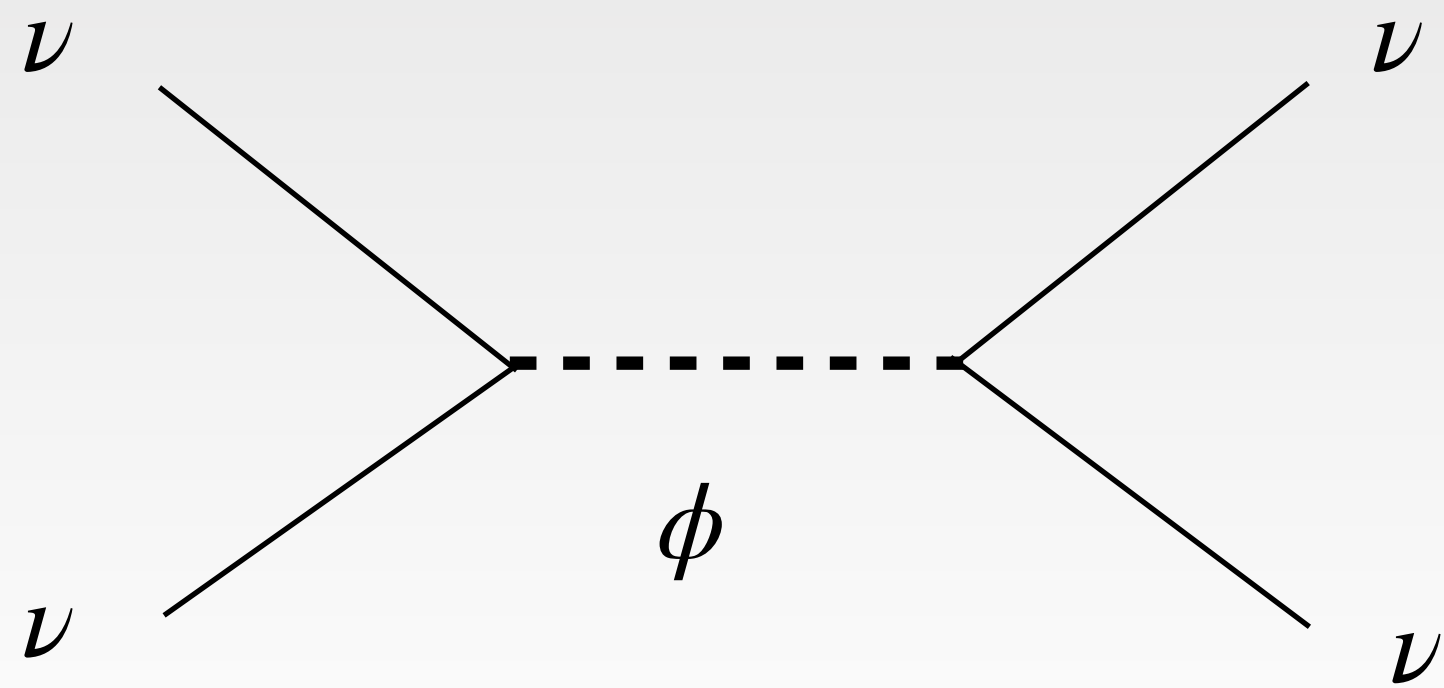


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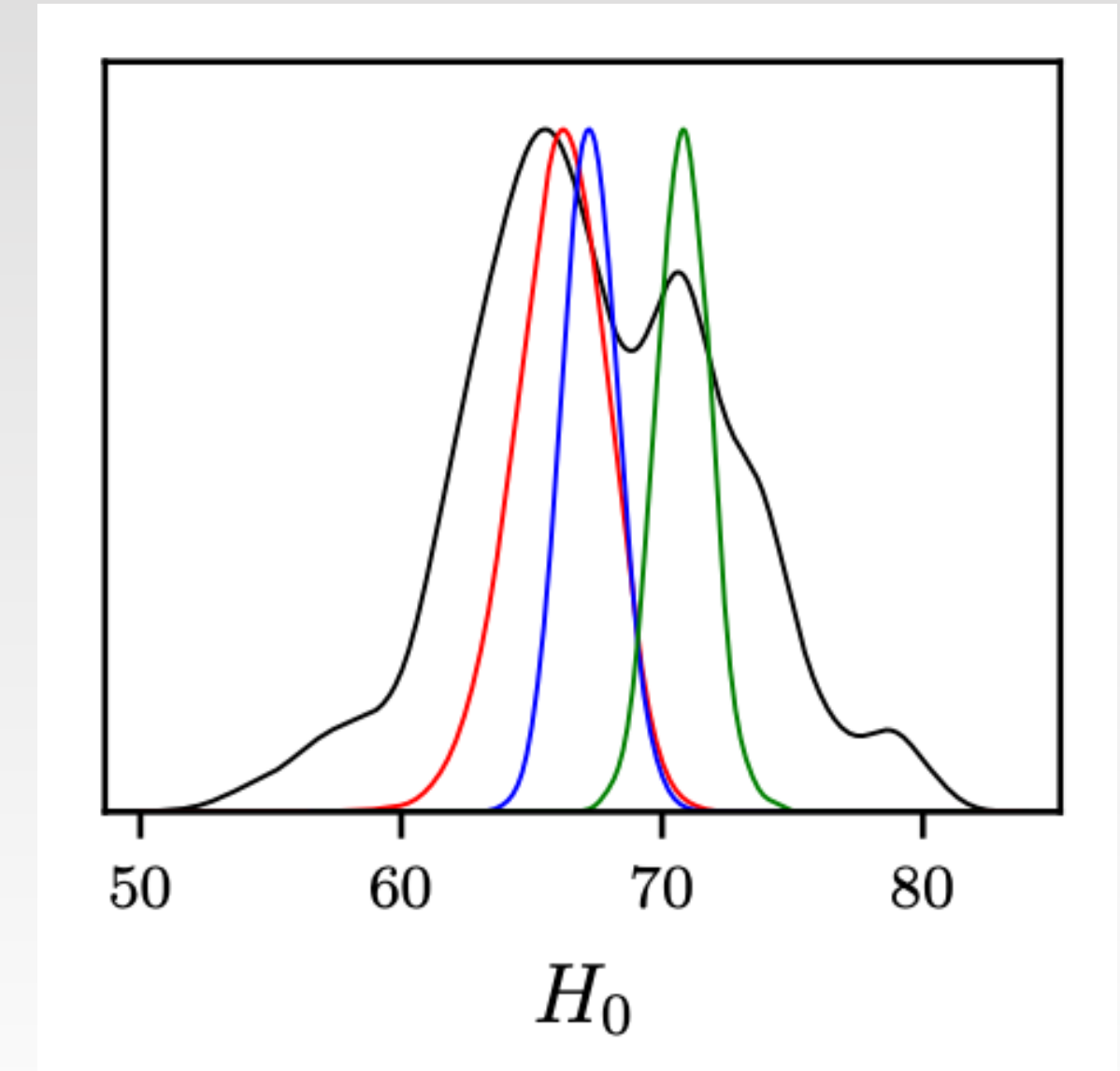
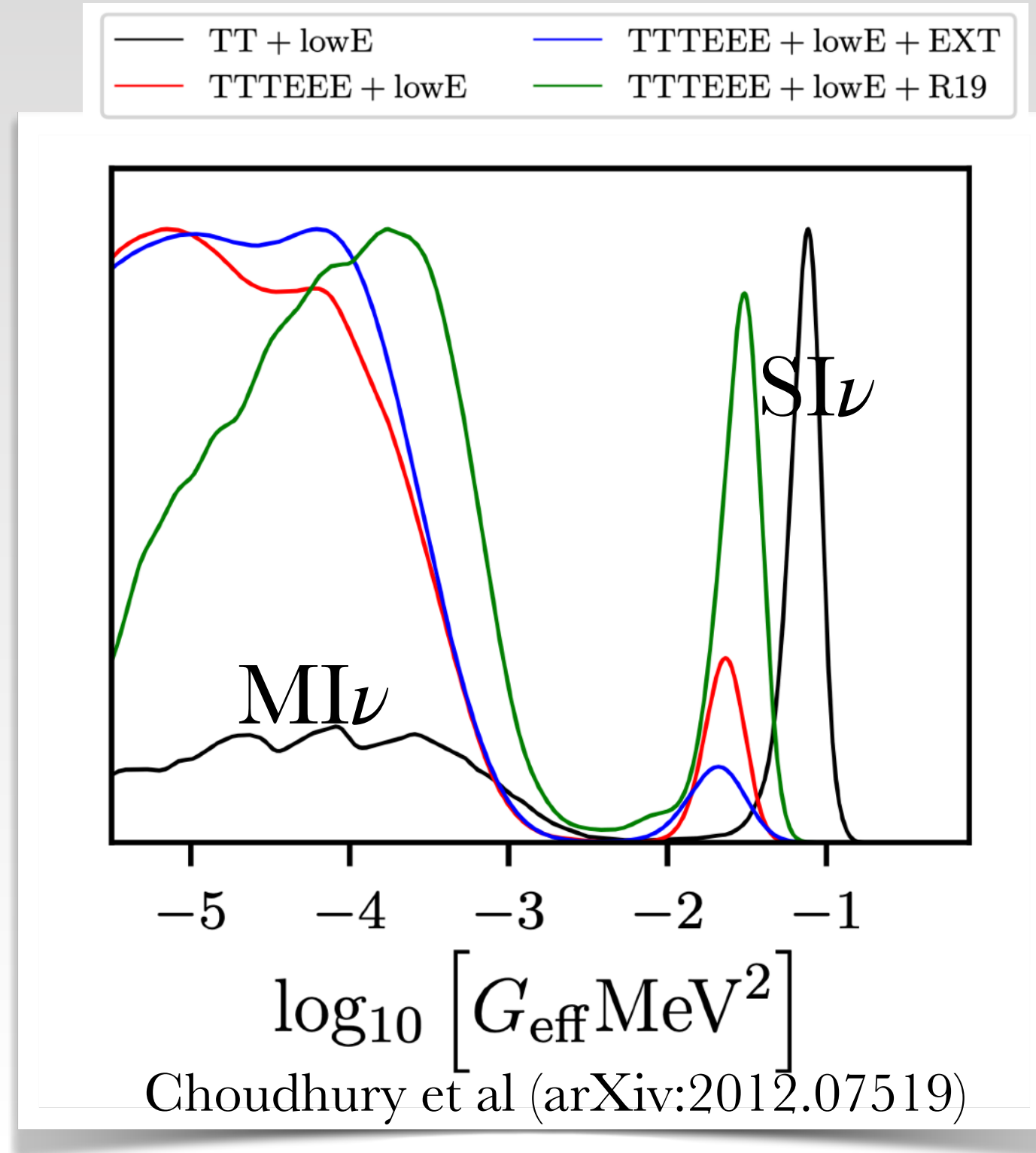
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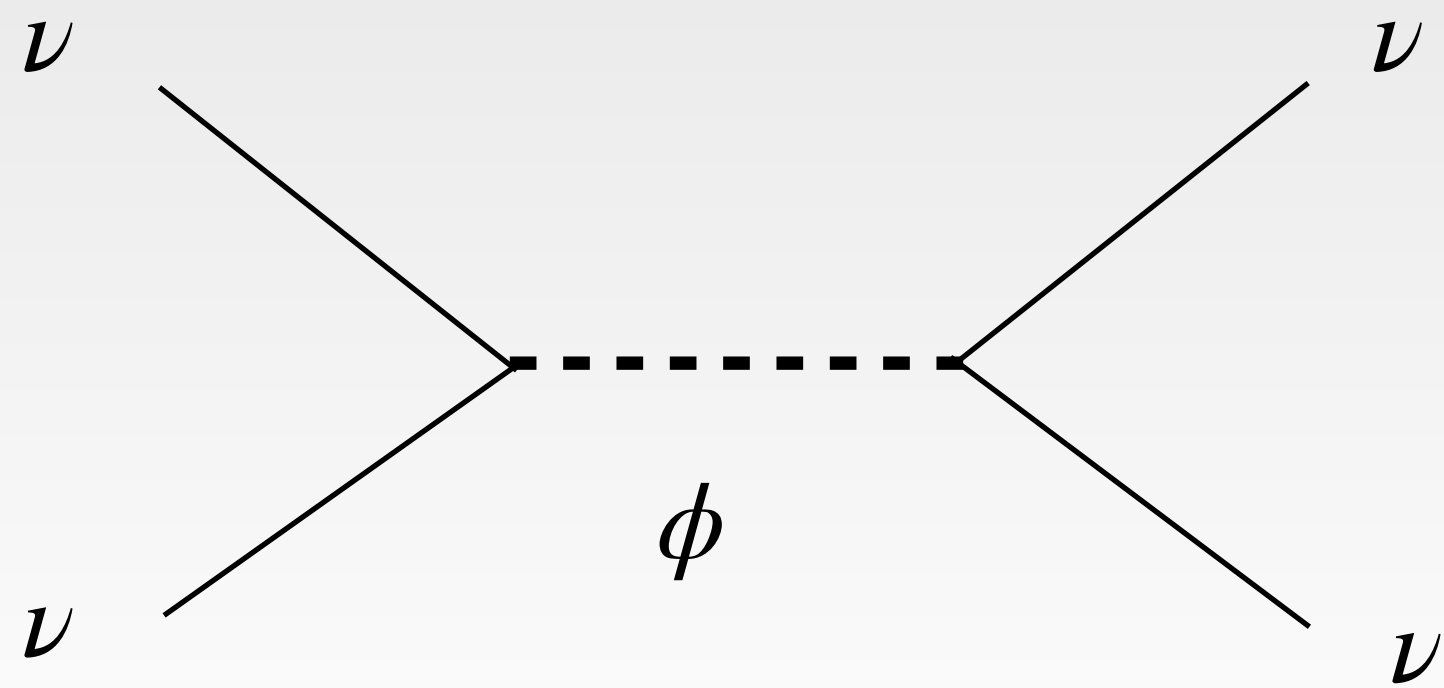
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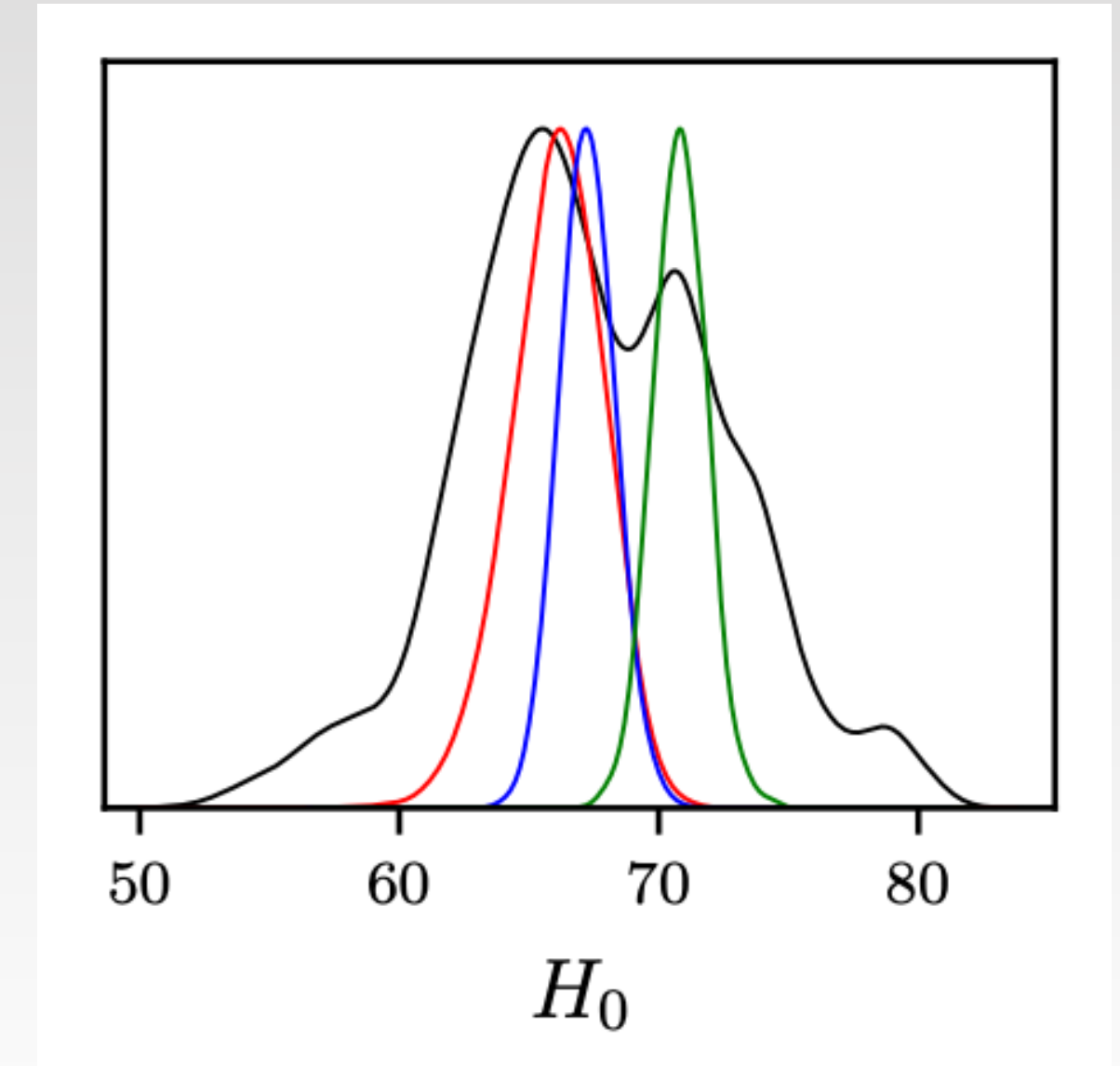
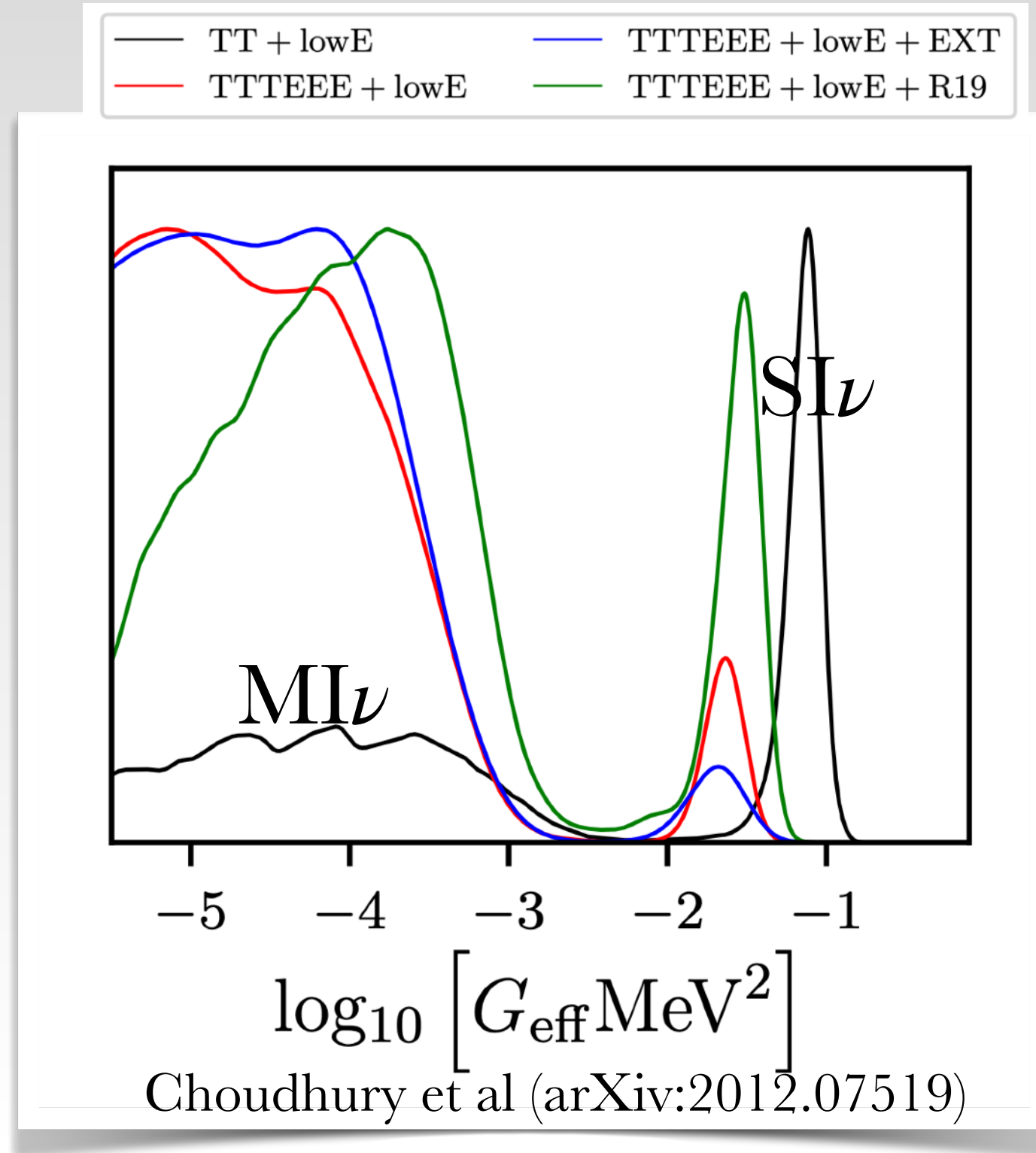
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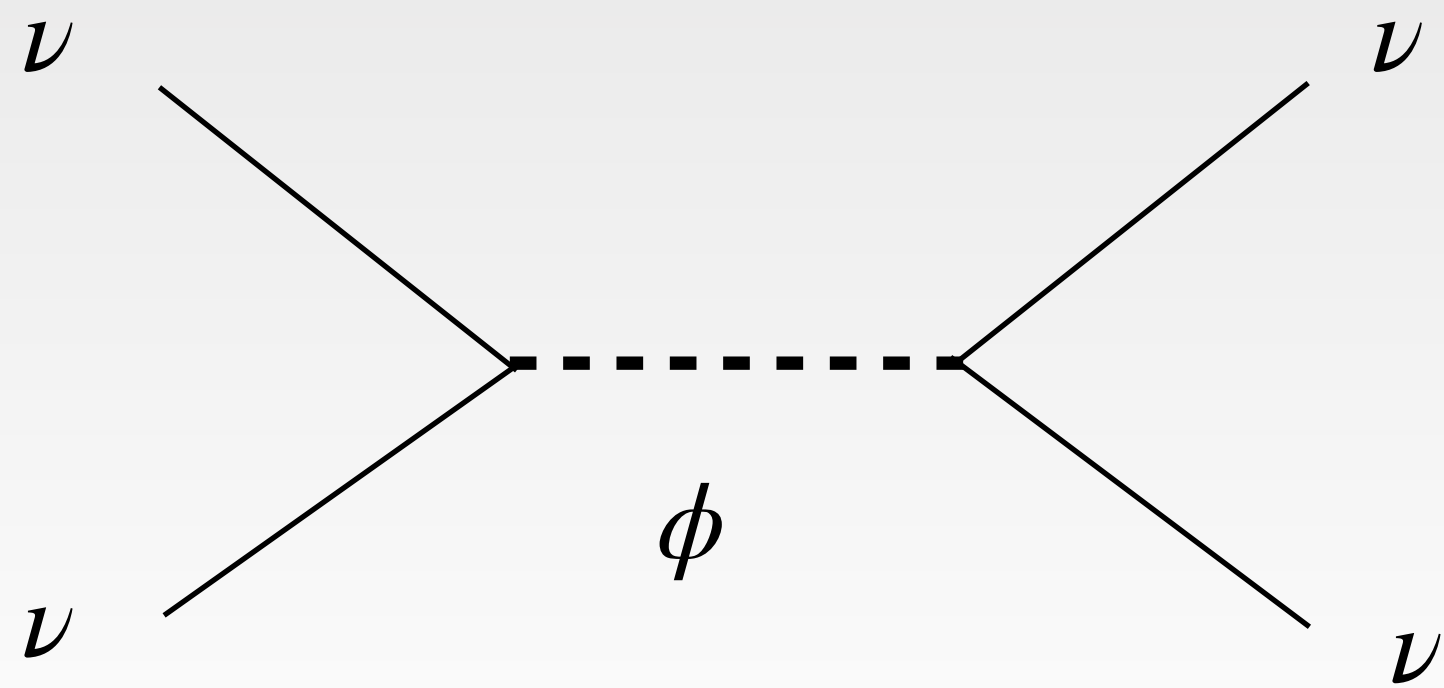
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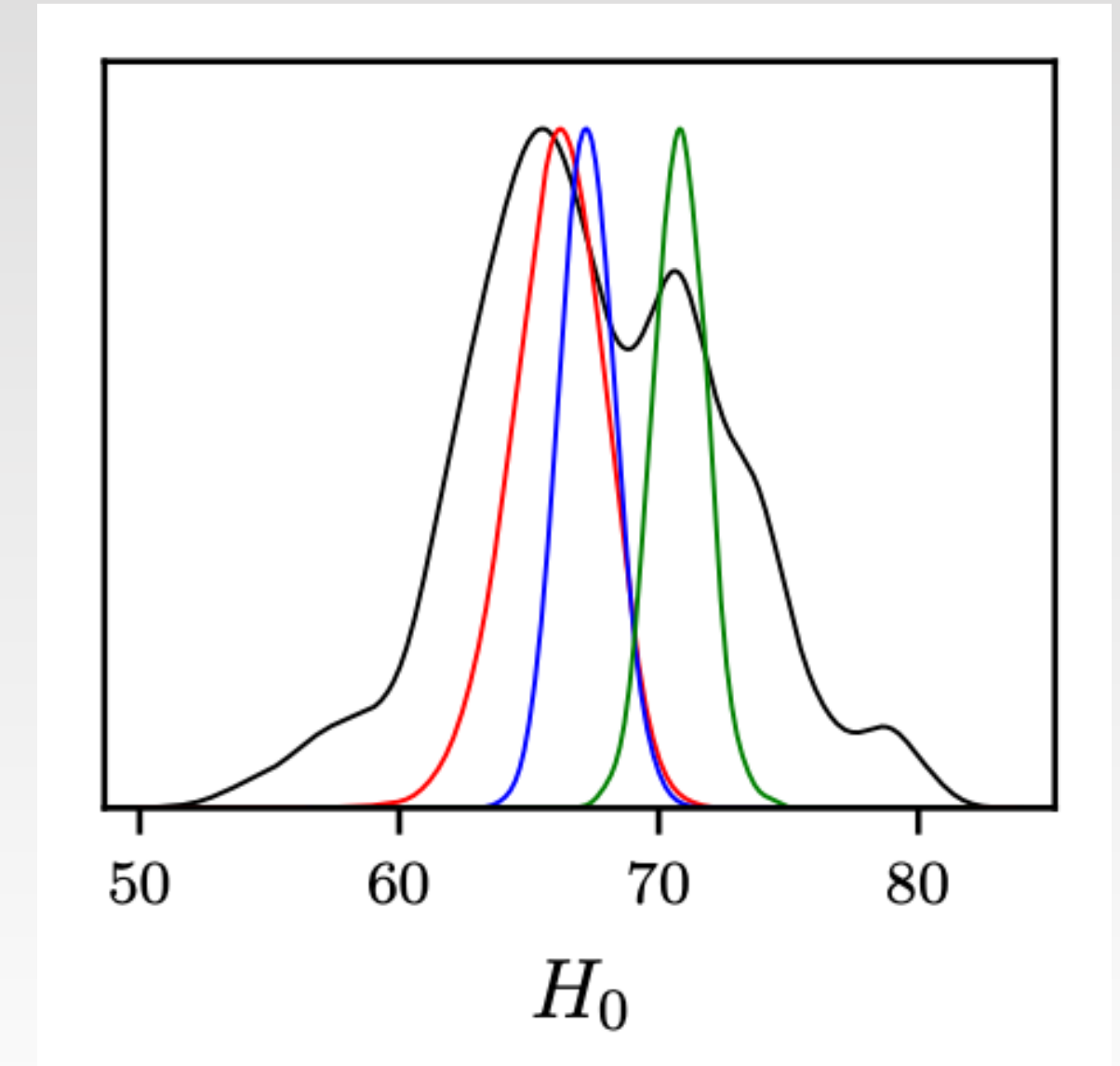
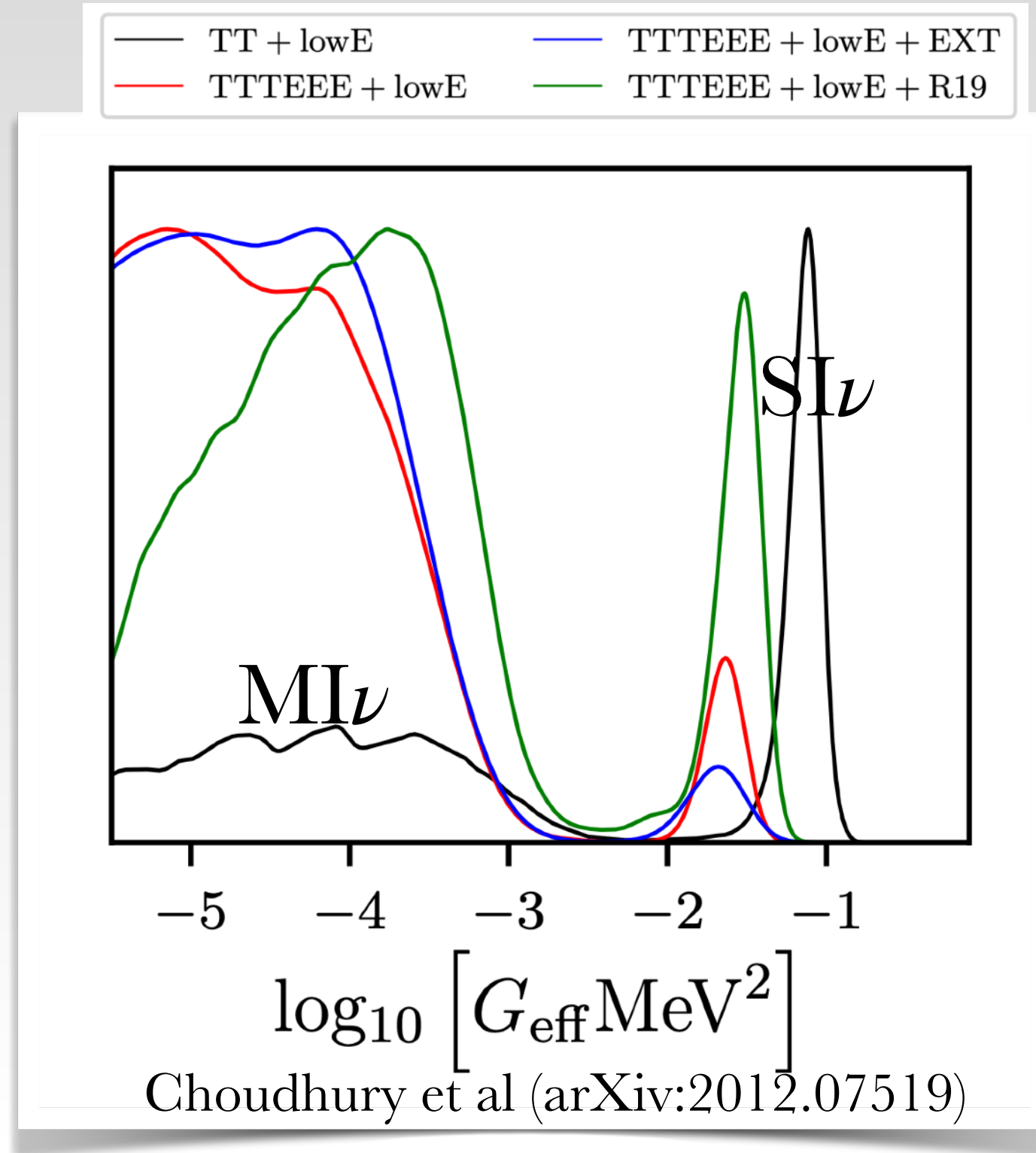
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ACT Collaboration, arXiv:2503.14454

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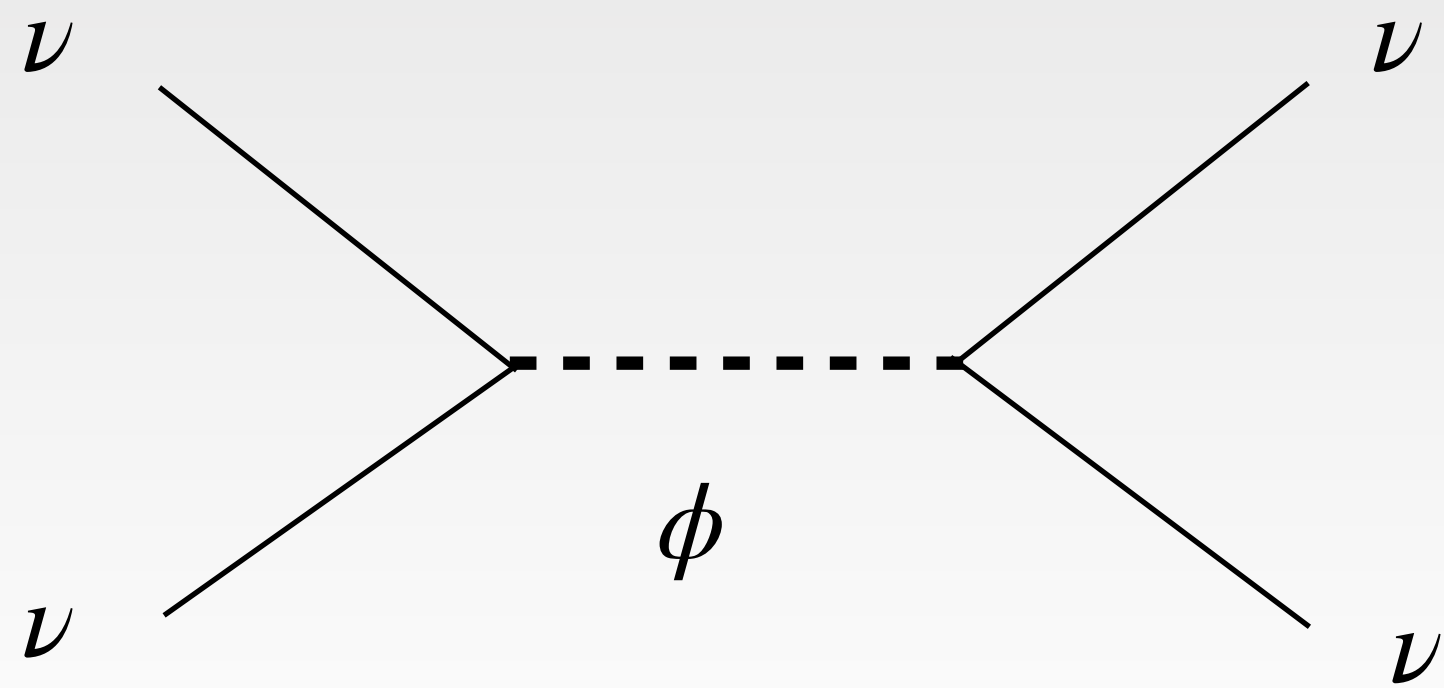
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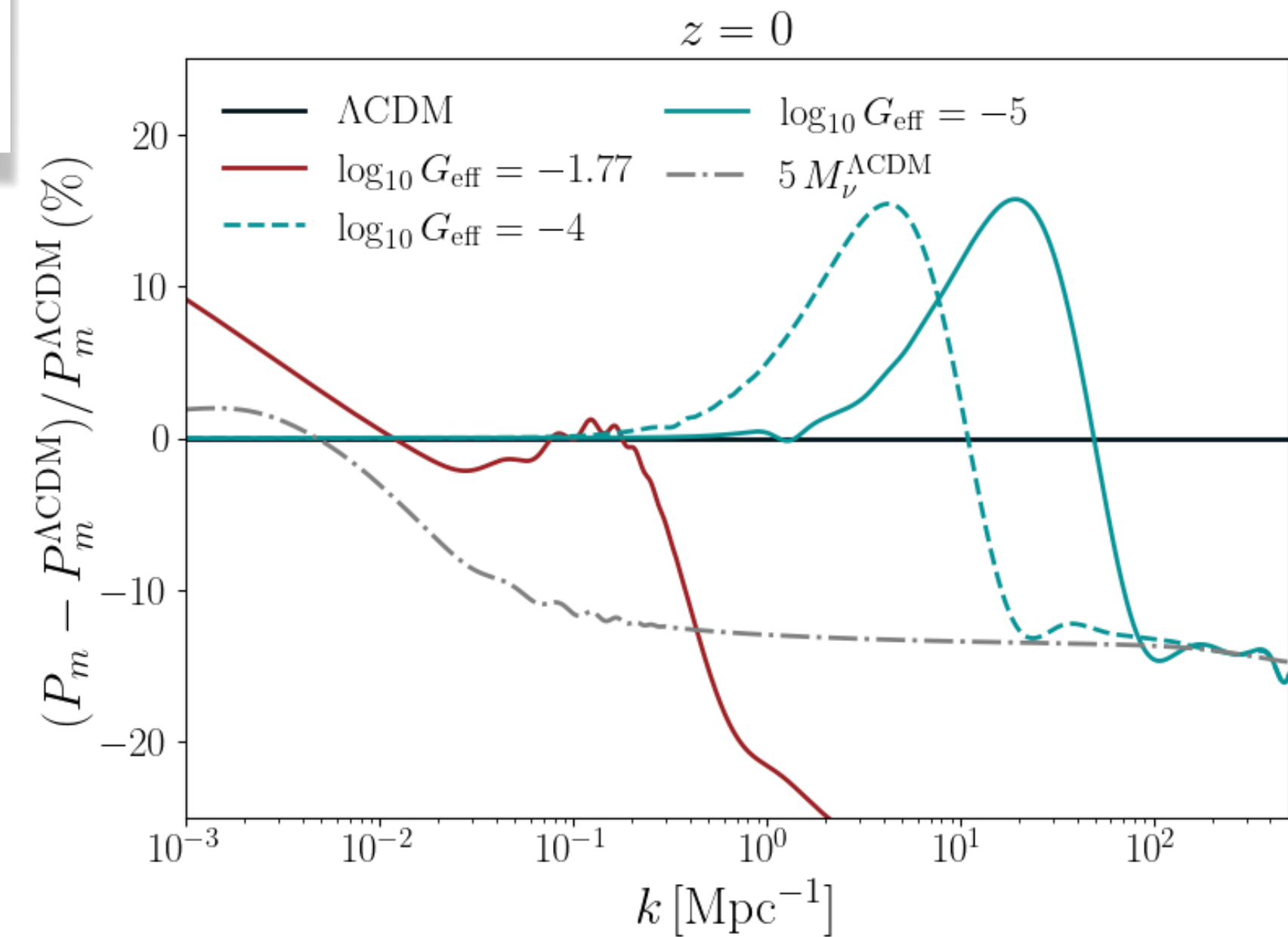
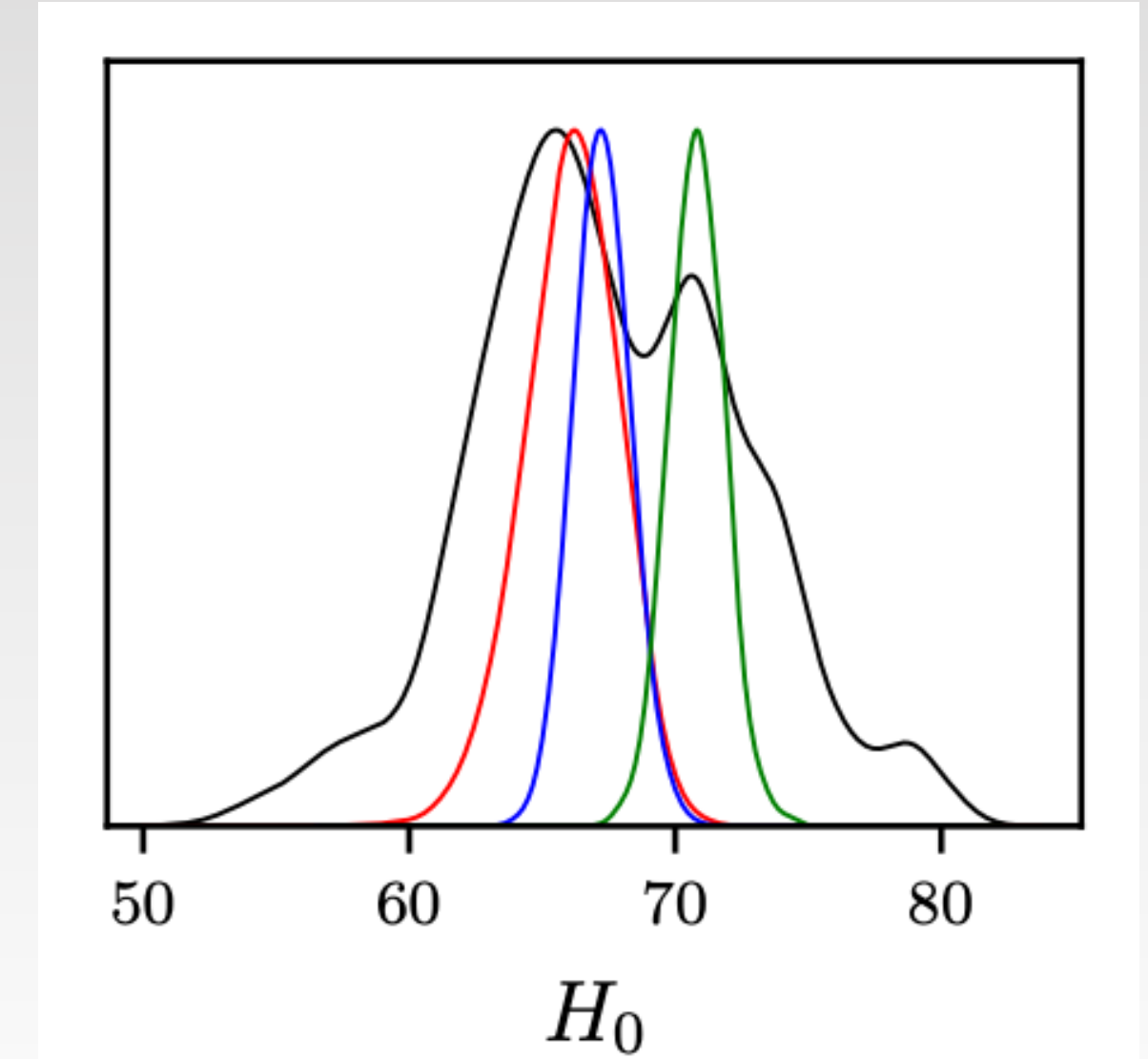
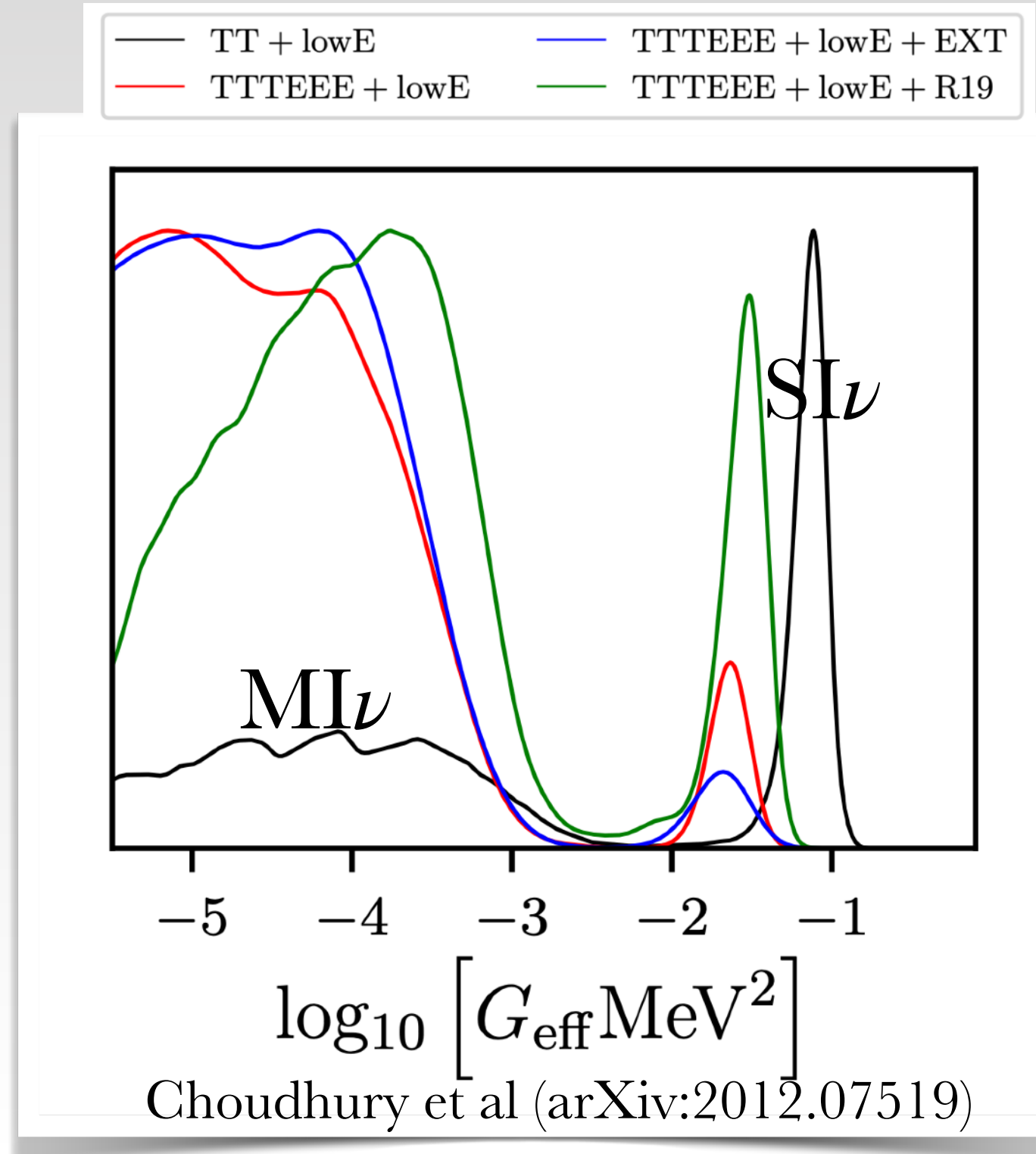
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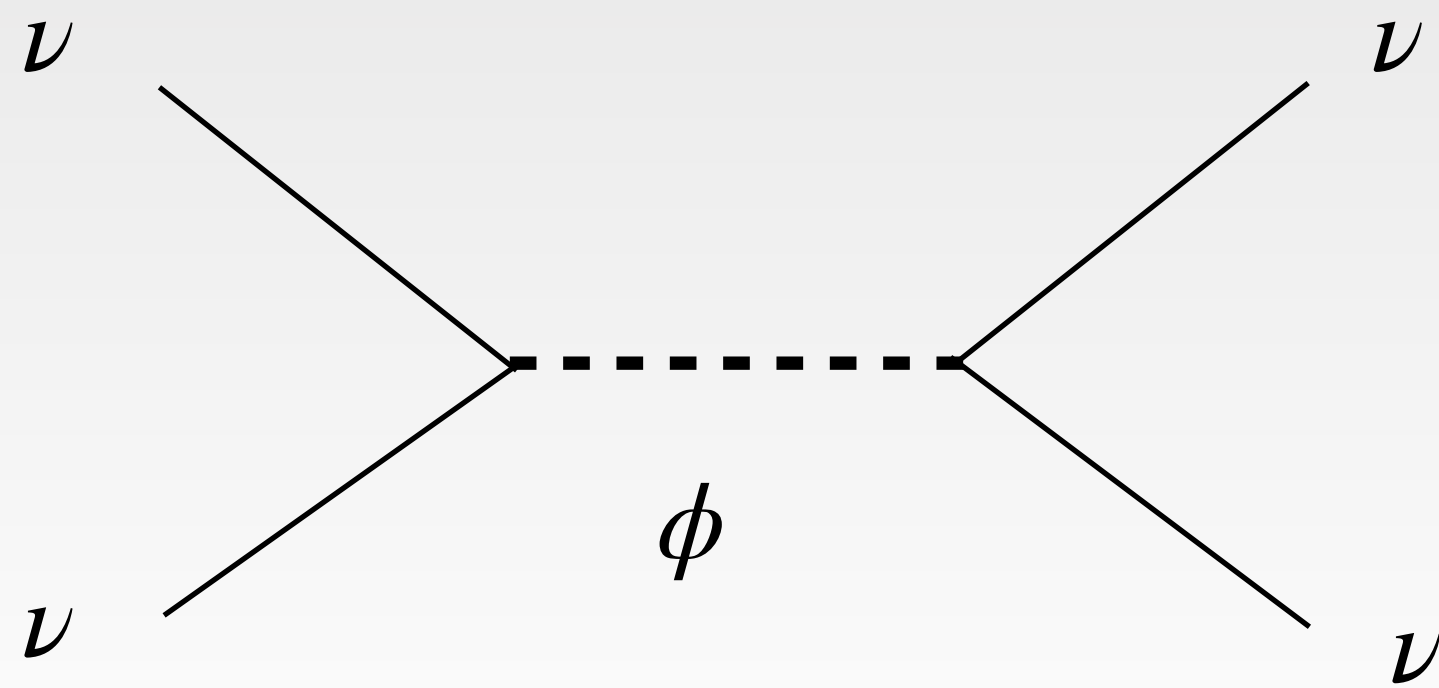
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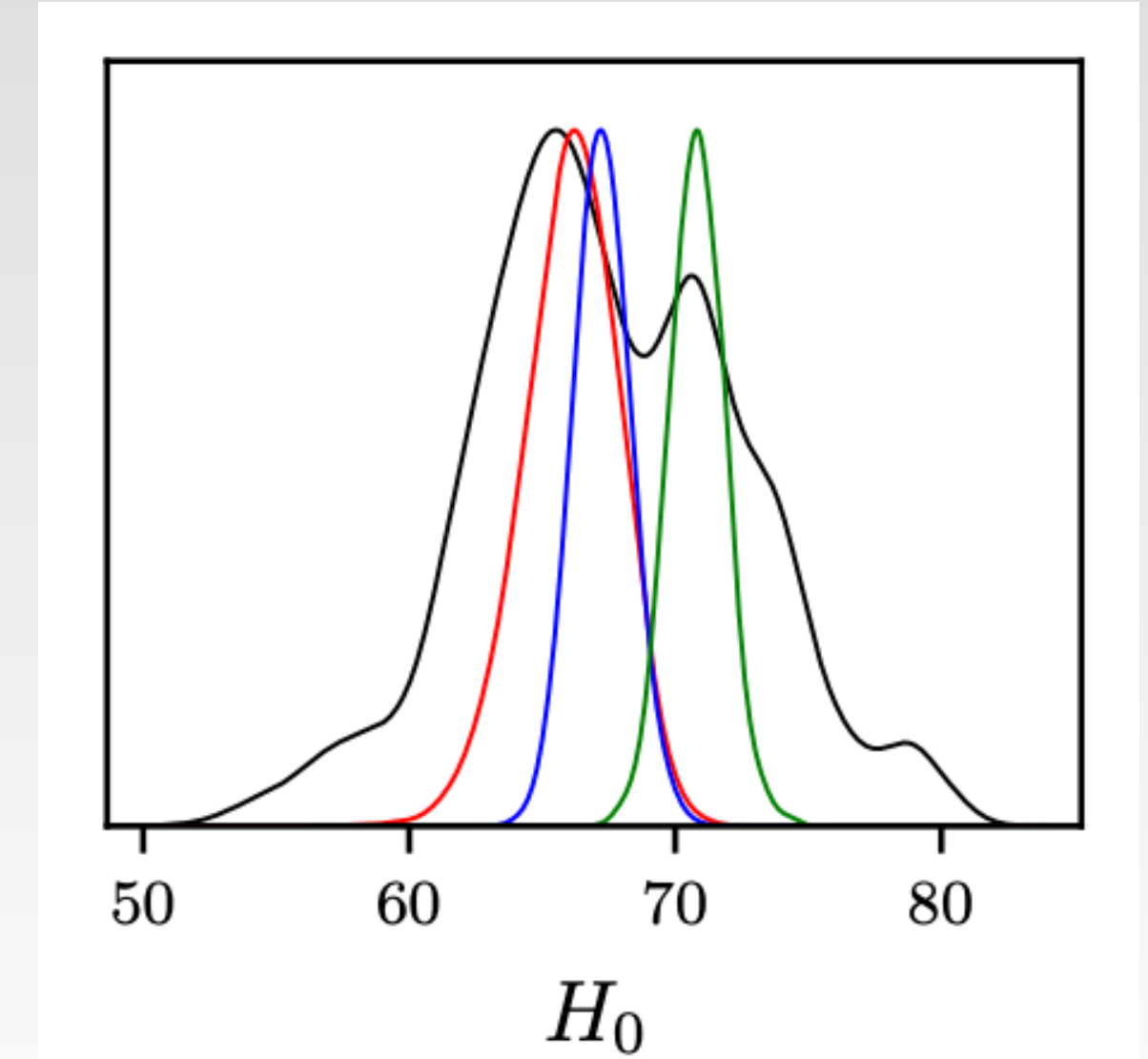
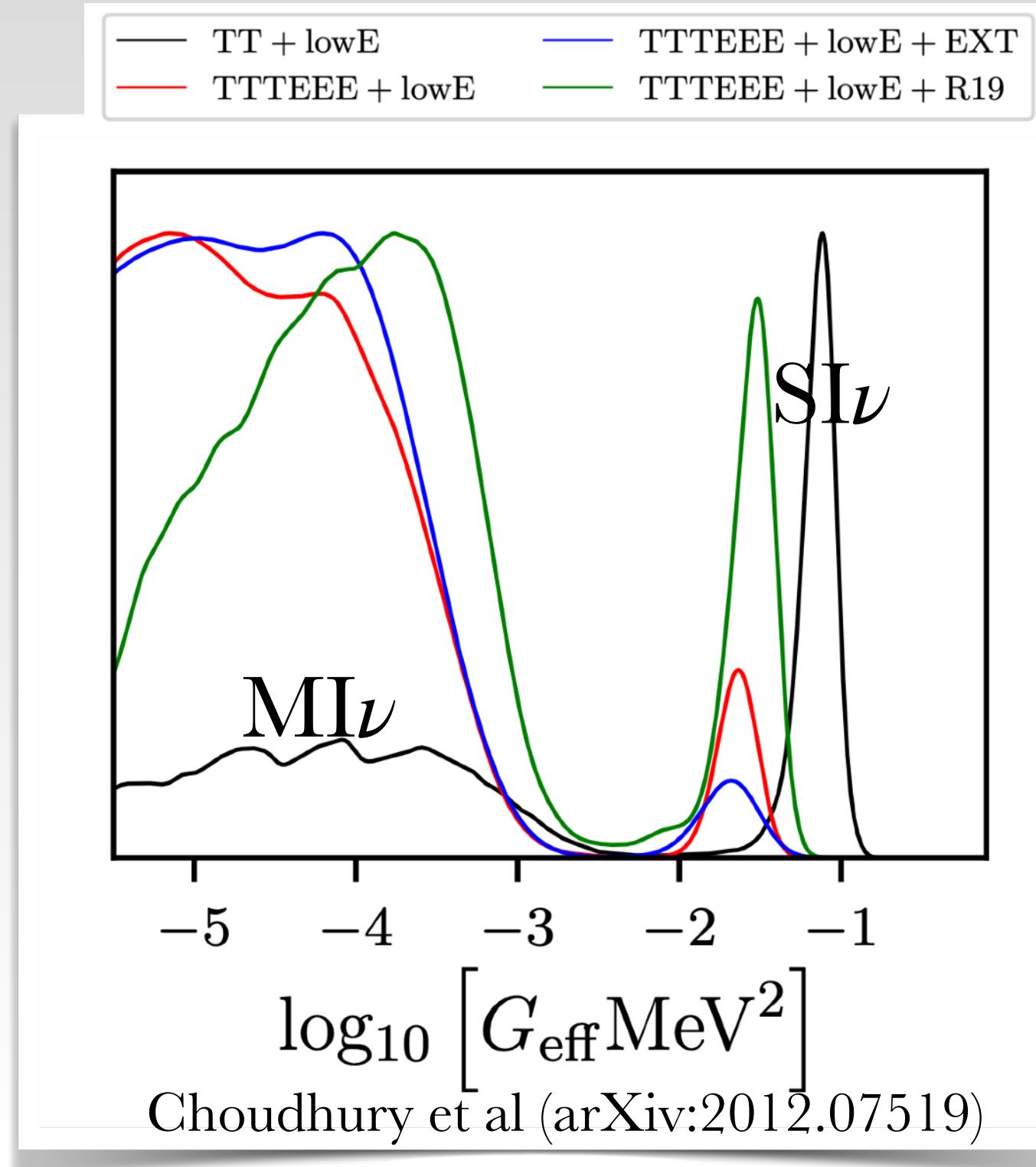
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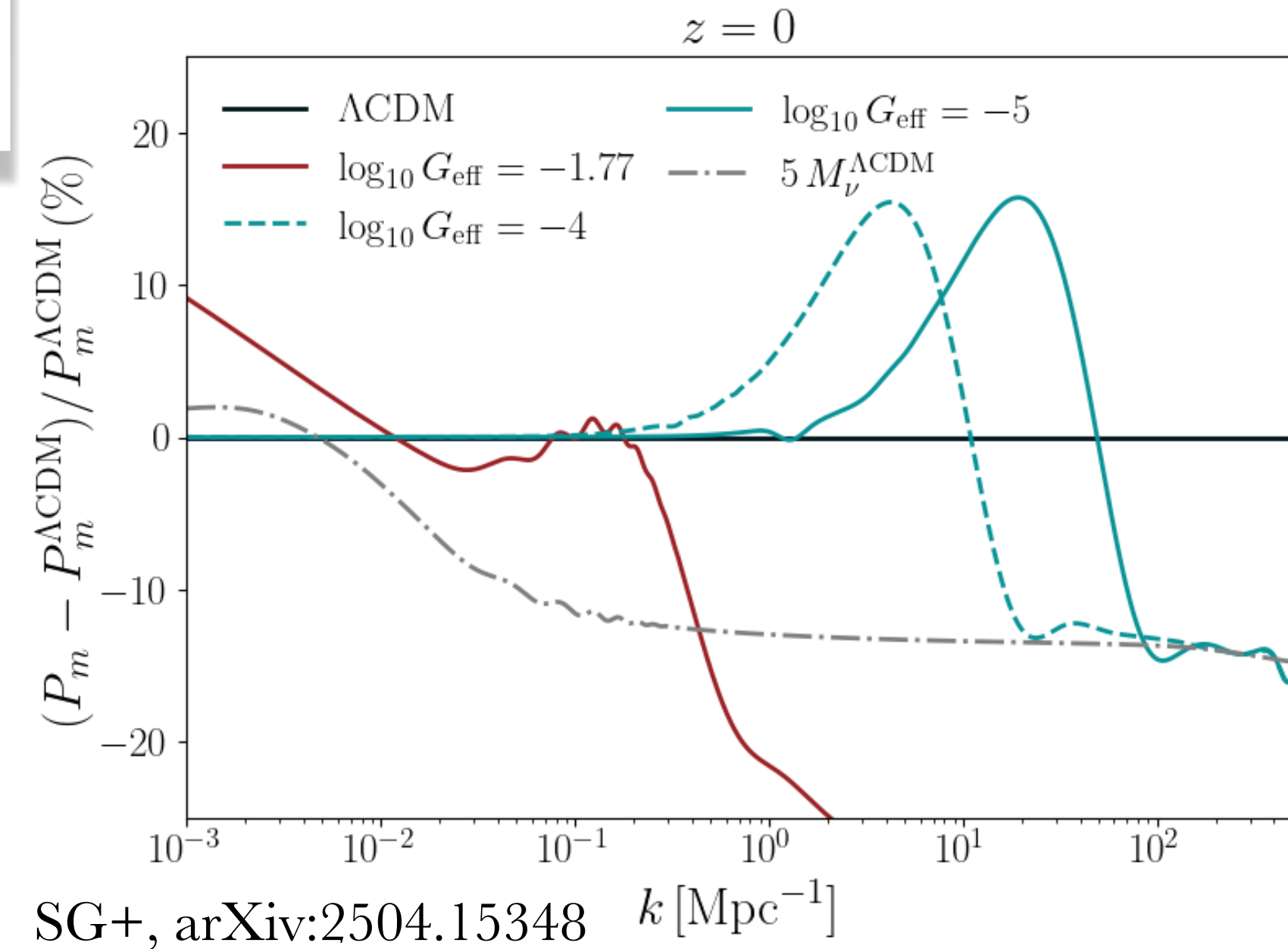
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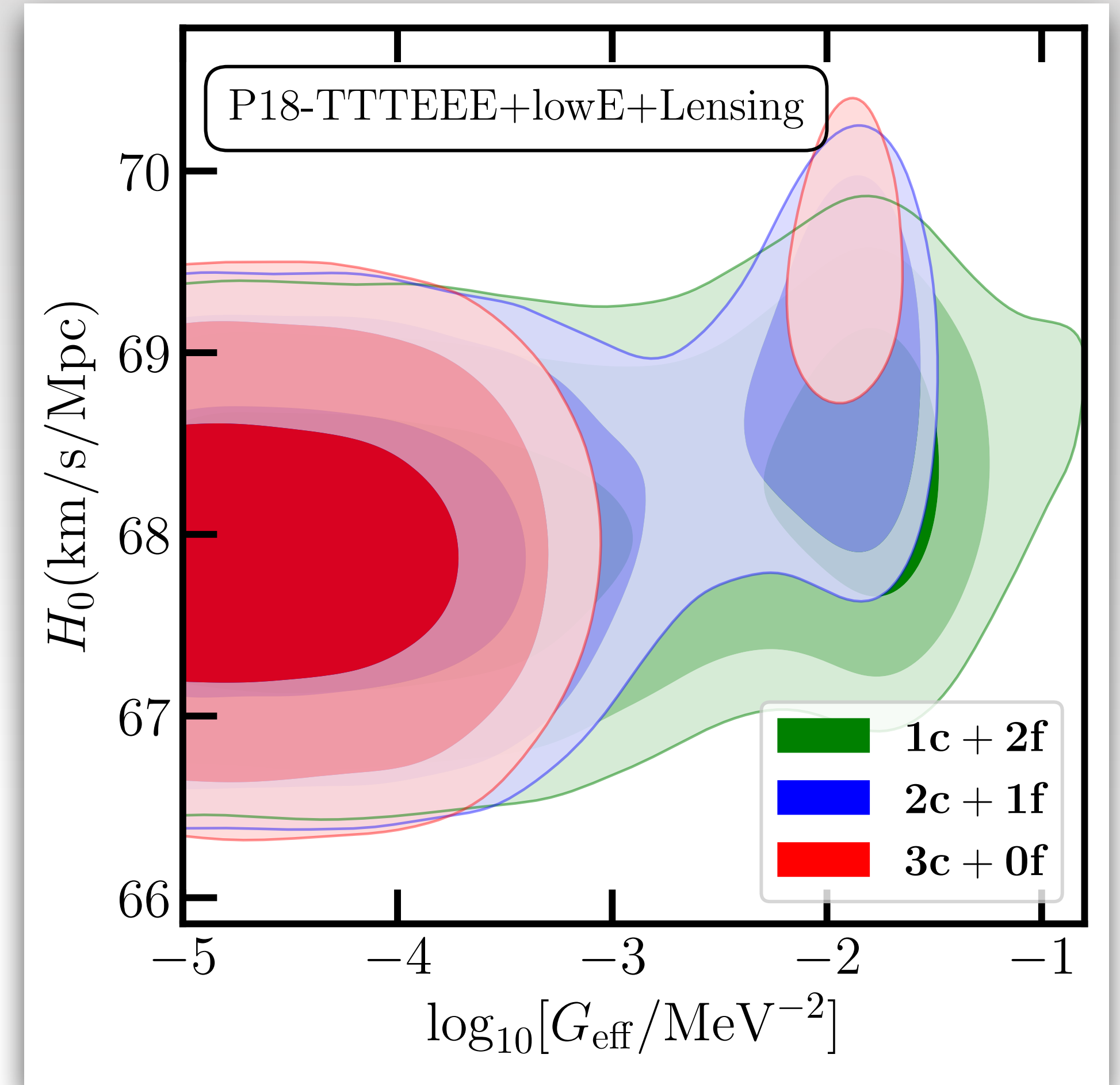
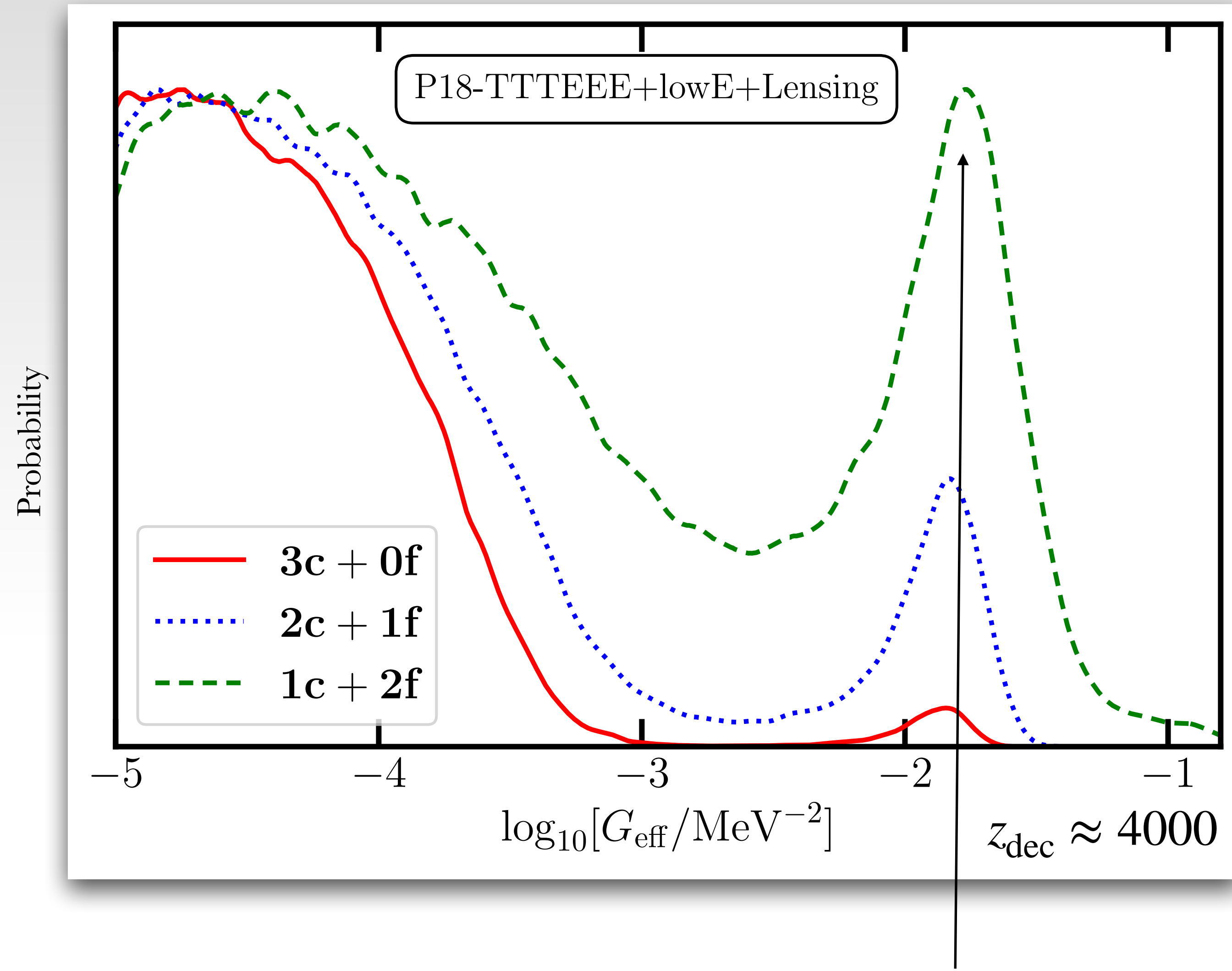
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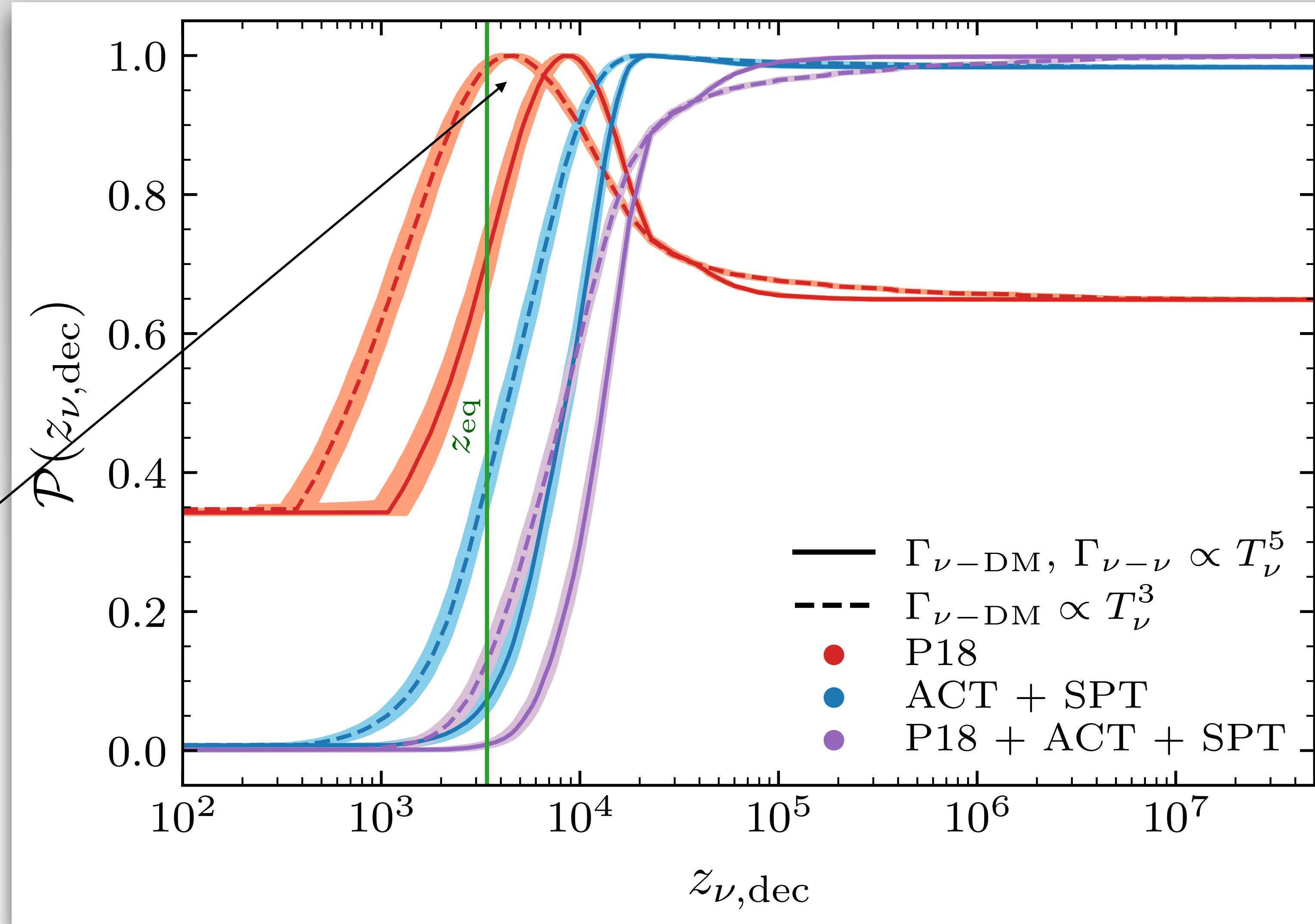
# Strong flavor specific interaction preferred by CMB



Hint of strong interaction flavor-specific scenario

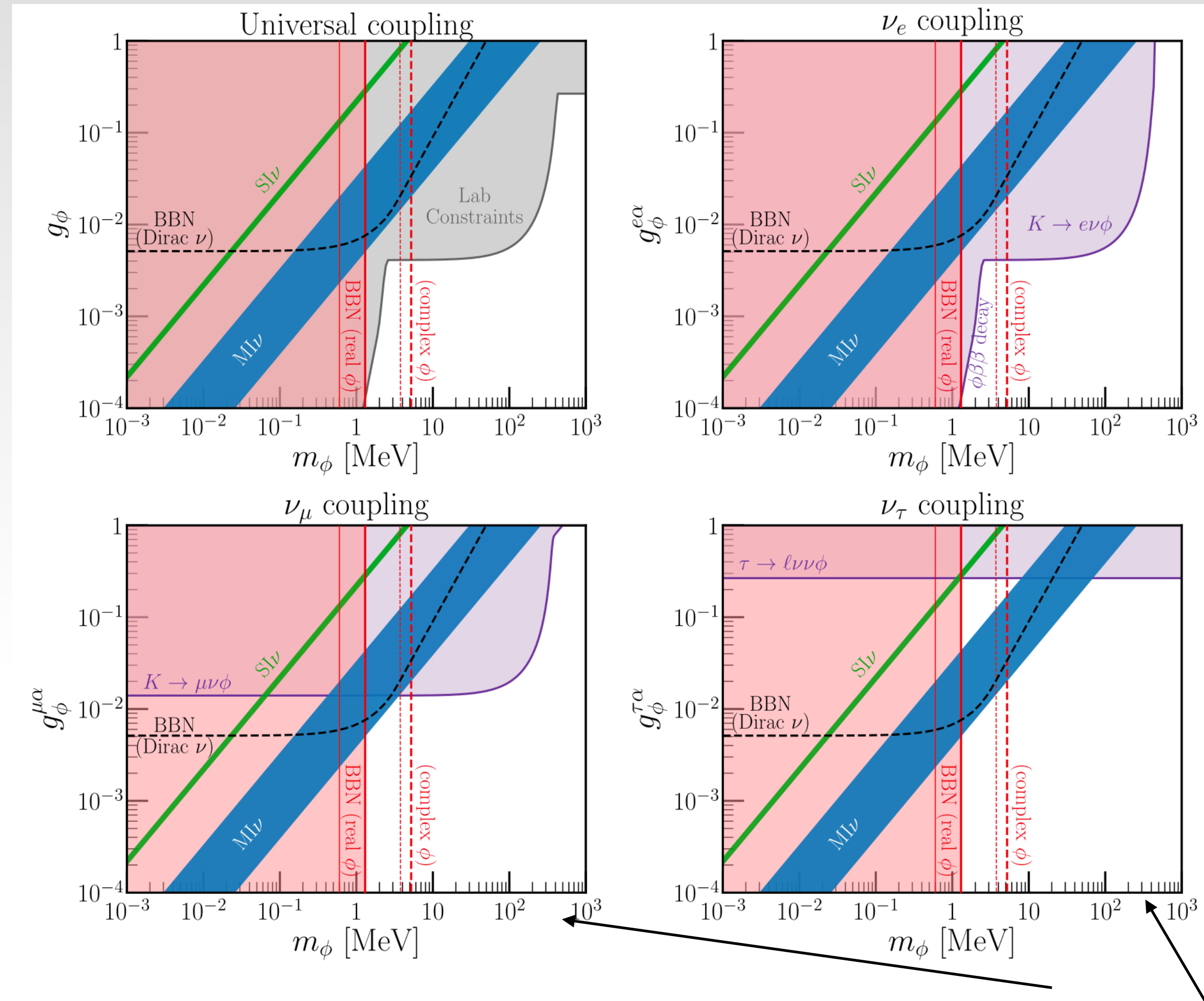
# Constraints on 1-Neutrino decoupling (other 2 freestreaming) from **only** phase-shift

Slight preference for finite decoupling  $z_{\text{dec}}$  around equality



# Strong Laboratory & BBN constraint for Neutrino self-interaction

Flavor - Universal coupling is strongly ruled out by laboratory constraints



Blinov et. al., 1905.02727

Lyu et. al., 2004.10868

Constraints are comparatively weaker for coupling with  $\nu_\mu$  and  $\nu_\tau$

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# Trinity of neutrino cosmology

$$\sum m_\nu < 0.0642 \text{ eV (cosmo)}$$

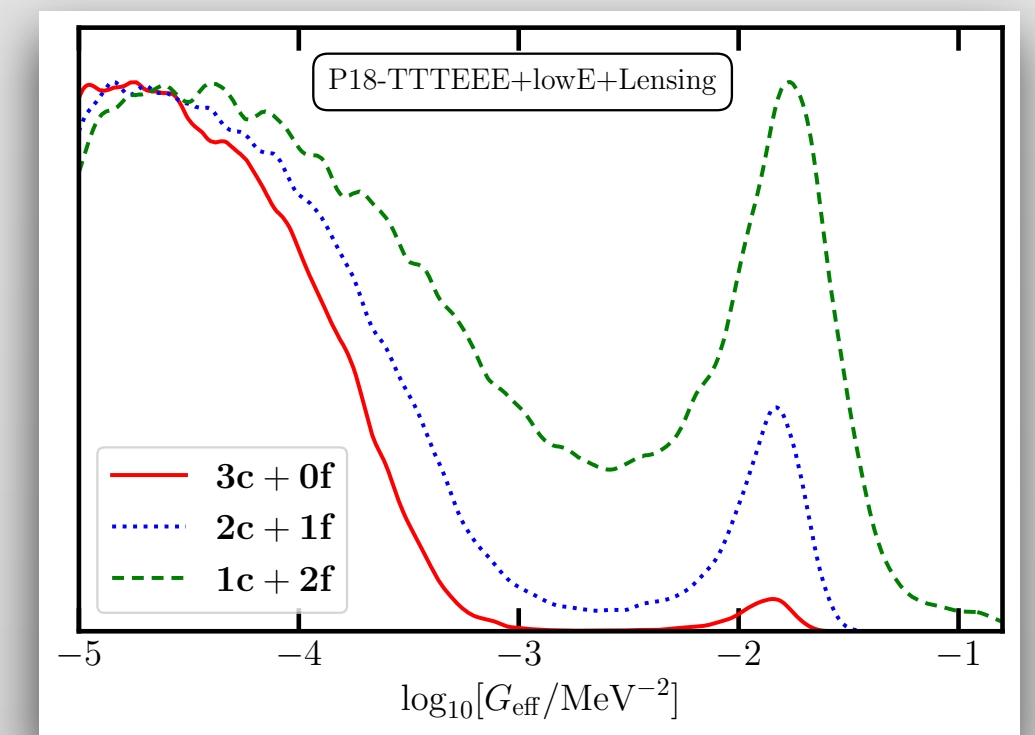
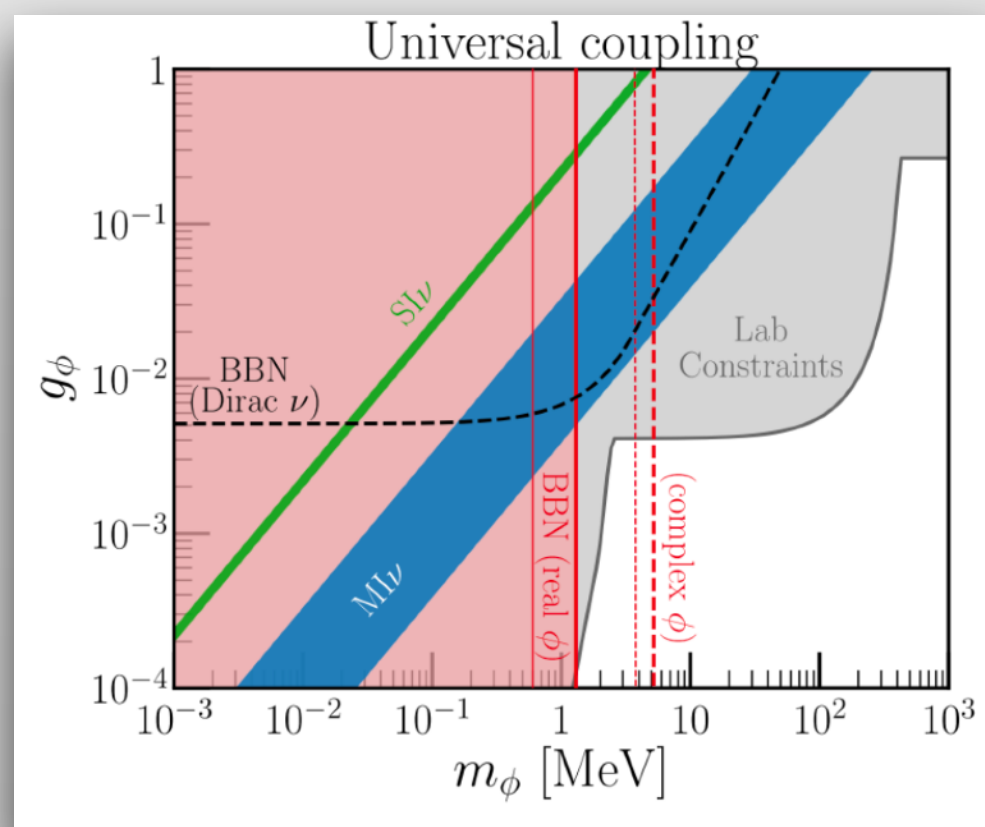
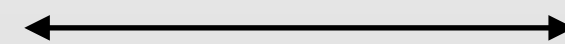
$$\sum m_\nu > 0.059 \text{ eV (NH)}$$

Strong neutrino mass bound



Strong constraints from laboratory & BBN

Accommodate flavor-specific self-interaction? (SI mode)



# Trinity of neutrino/DR cosmology

Reduce the neutrino contribution to  $N_{\text{eff}}$  and add massless DR

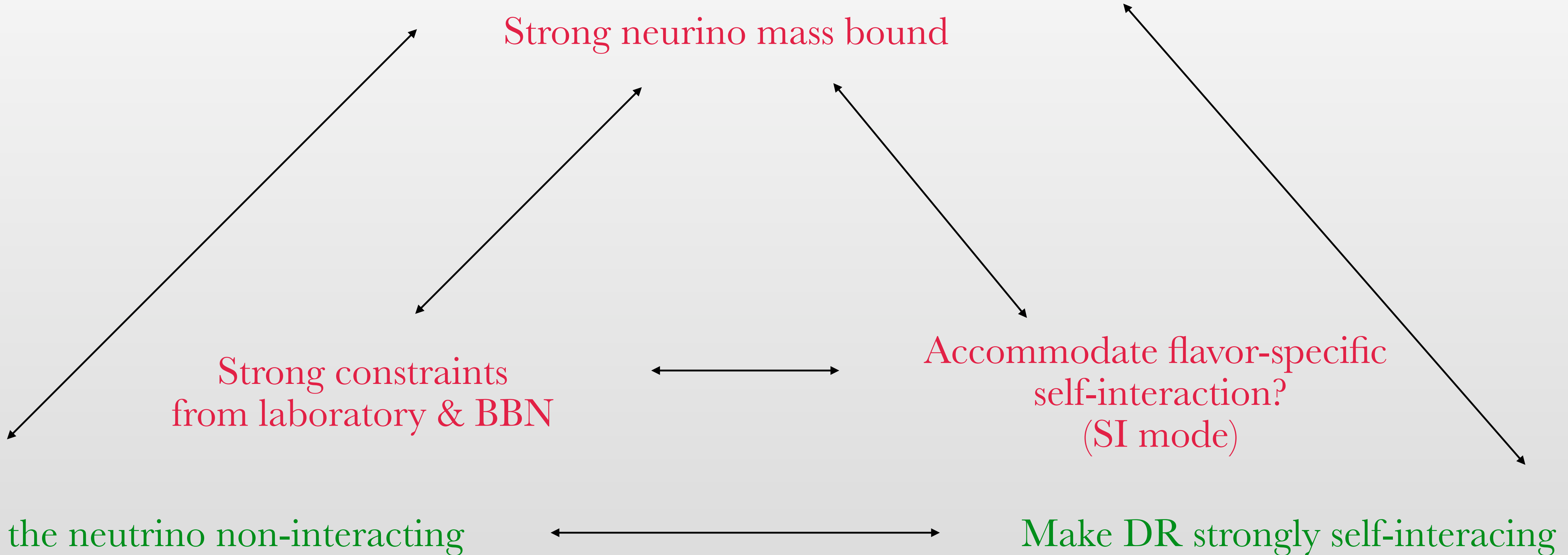
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Neutrino and DR having same abundance and free-streaming properties are indistinguishable in cosmology

# Resonant conversion of $\nu \rightarrow \chi$ (DR)

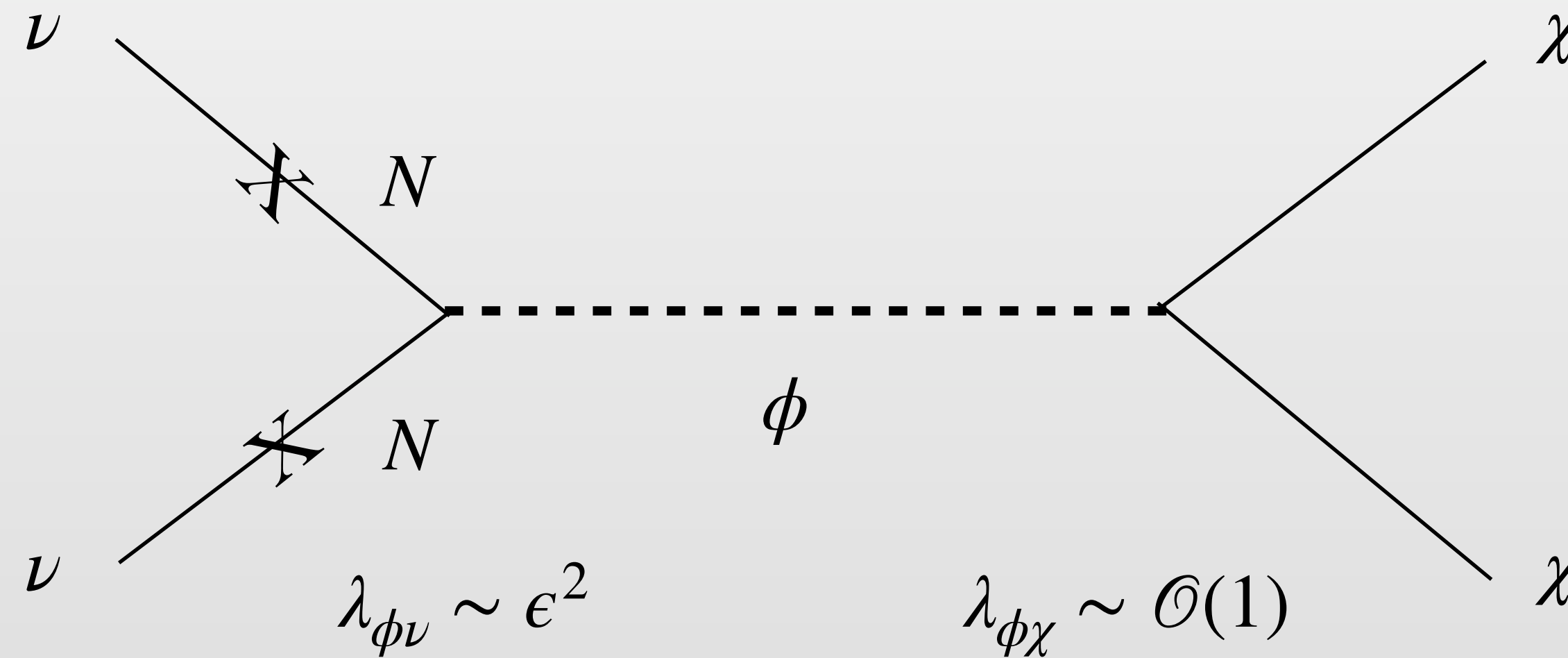
Anirban Das, P. S. Bhupal Dev, Christina Gao, **SG**, Taegyun Kim: *PRL* 136 (2026) 13, 131003 ([2506.08085](#))

$$\Delta\mathcal{L} = \left( y^{\alpha i} L_{\alpha} N_i^c H - \frac{1}{2} M_N^{ii} N_i^c N_i^c + h.c. \right) - \frac{1}{2} \lambda_{\phi N} \phi N^c N^c - \frac{1}{2} \lambda_{\phi\chi} \phi \chi^2.$$

Similar models:

Farzan+, arXiv:1510.02201

Escudero+, arXiv:2211.01729



$$m_{\phi} \approx [10^{-1} - 10^{-3}] \text{ MeV}$$

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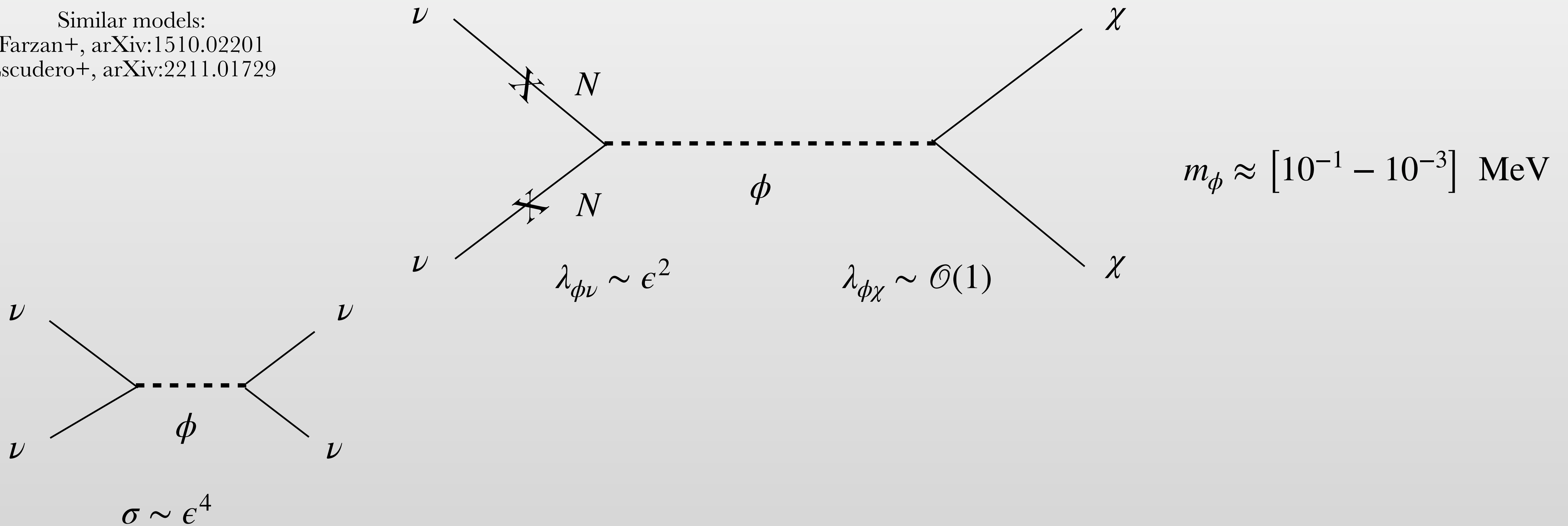
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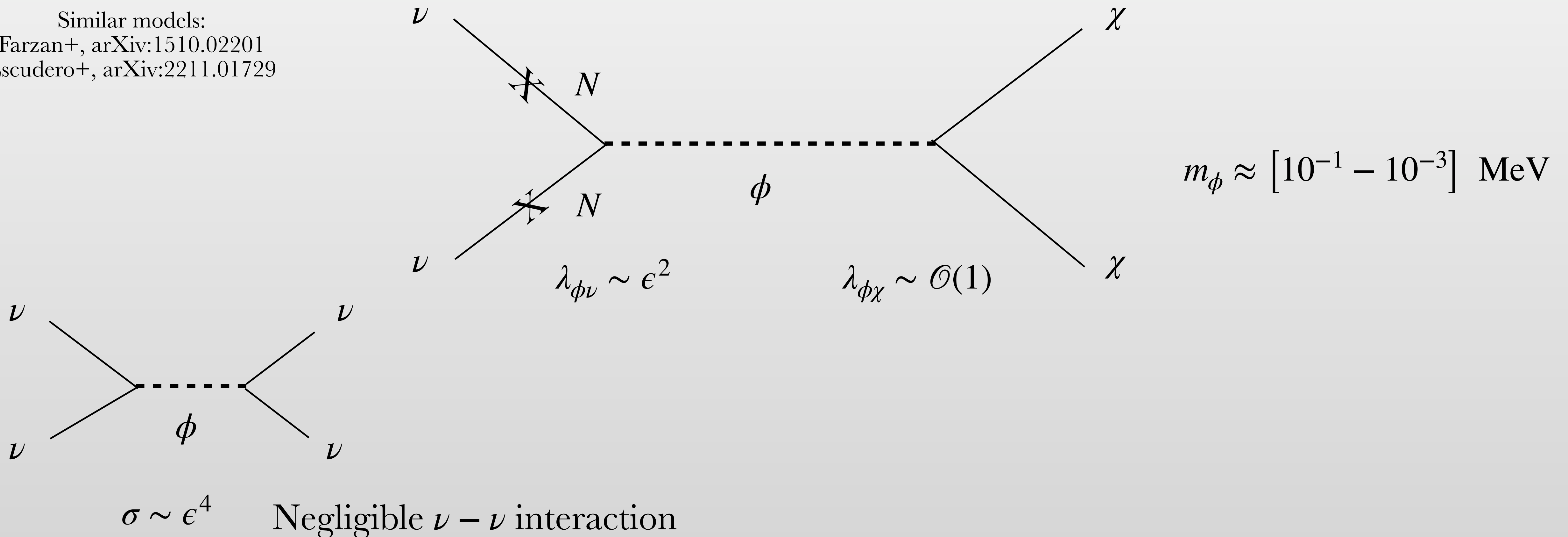
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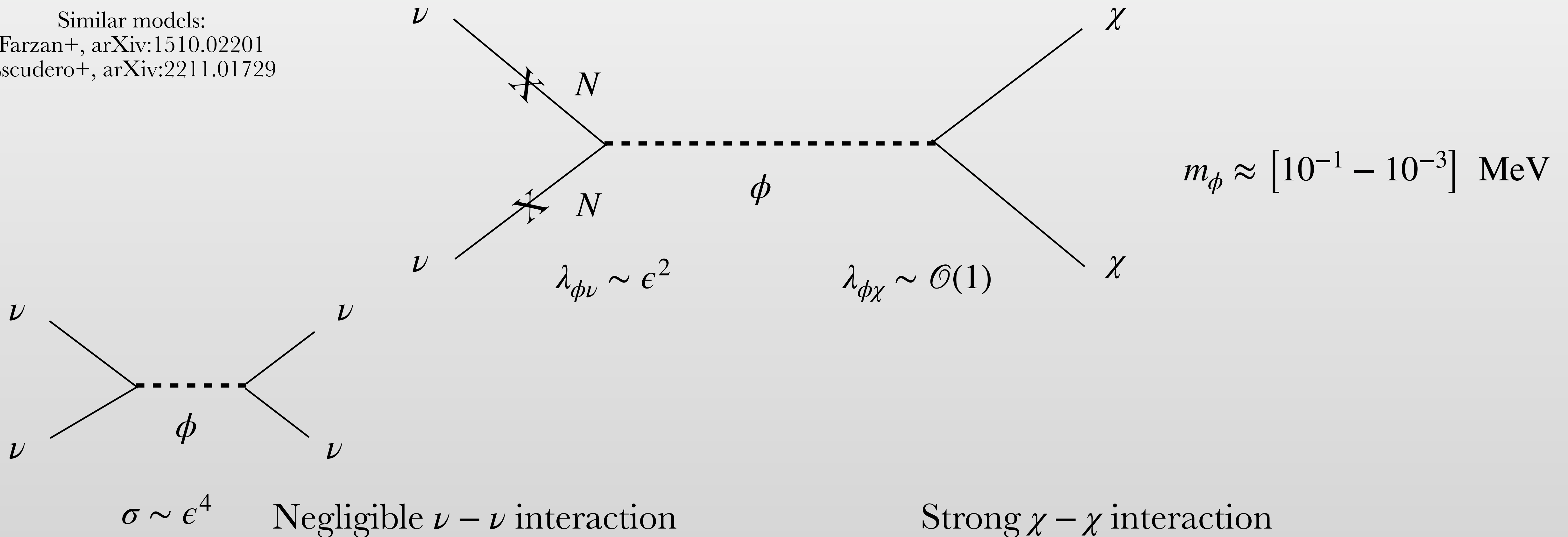
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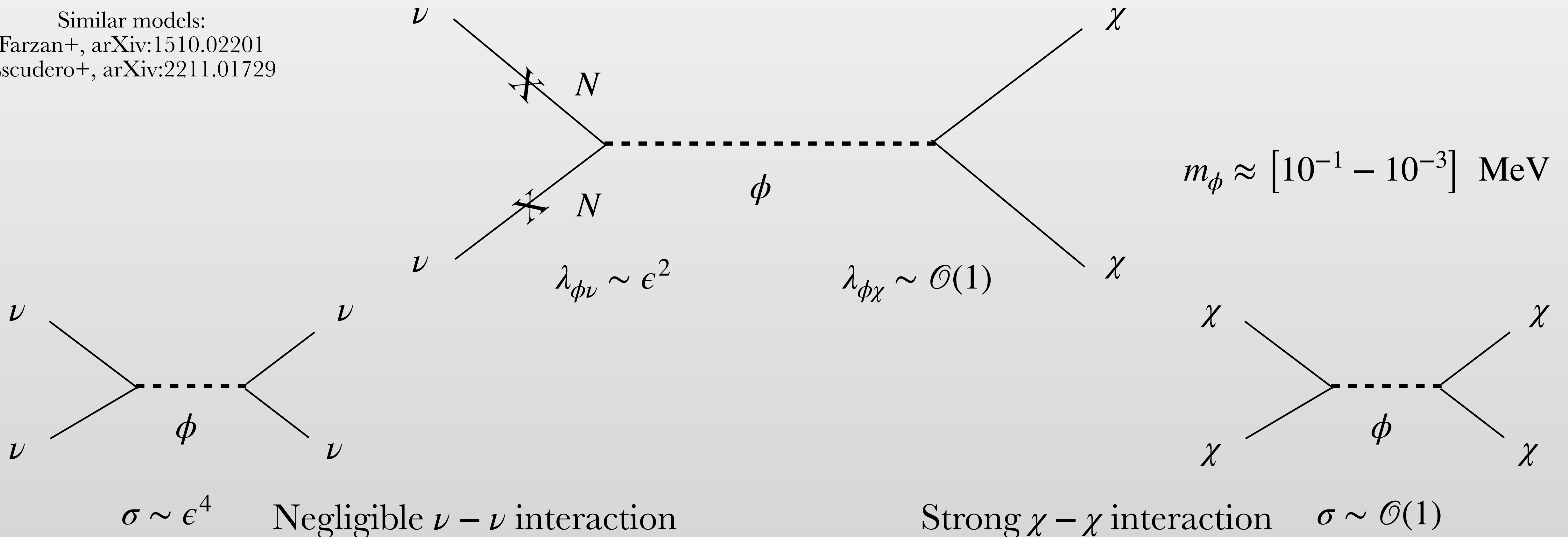
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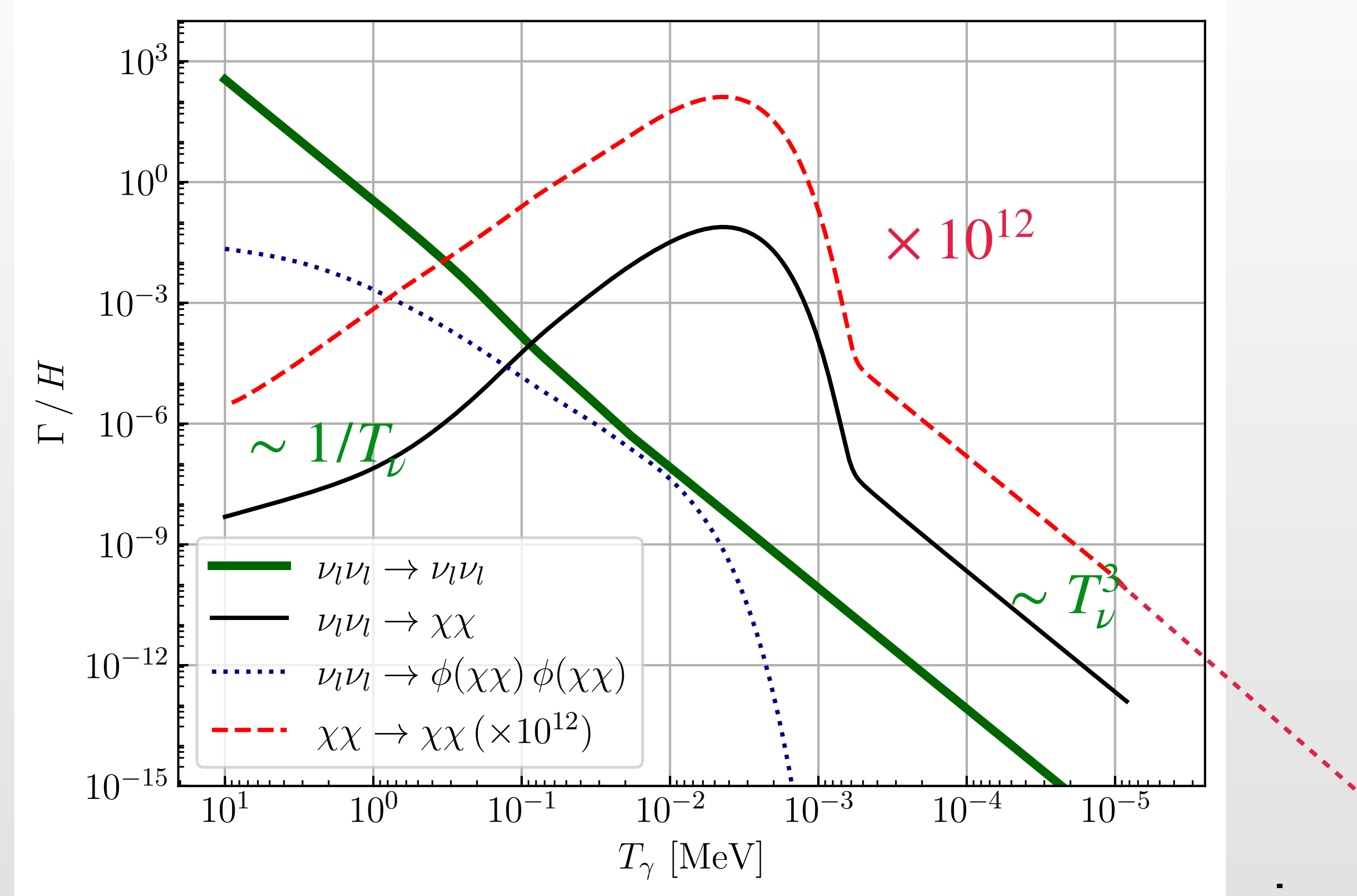
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( $N_\nu^{\text{eff}} = 3$ )

BBN

Free streaming  $\nu$  + self-interacting  $\chi$

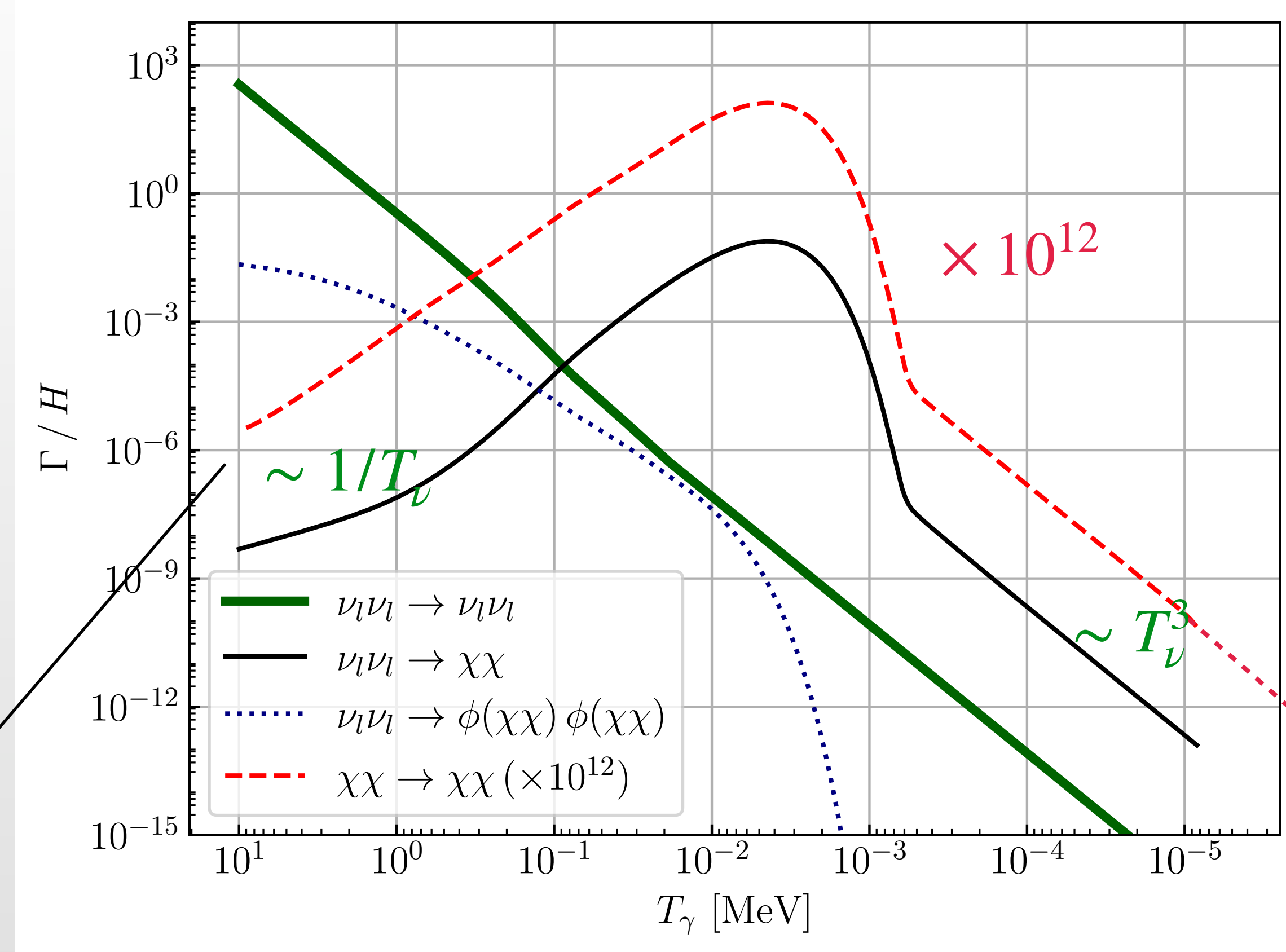
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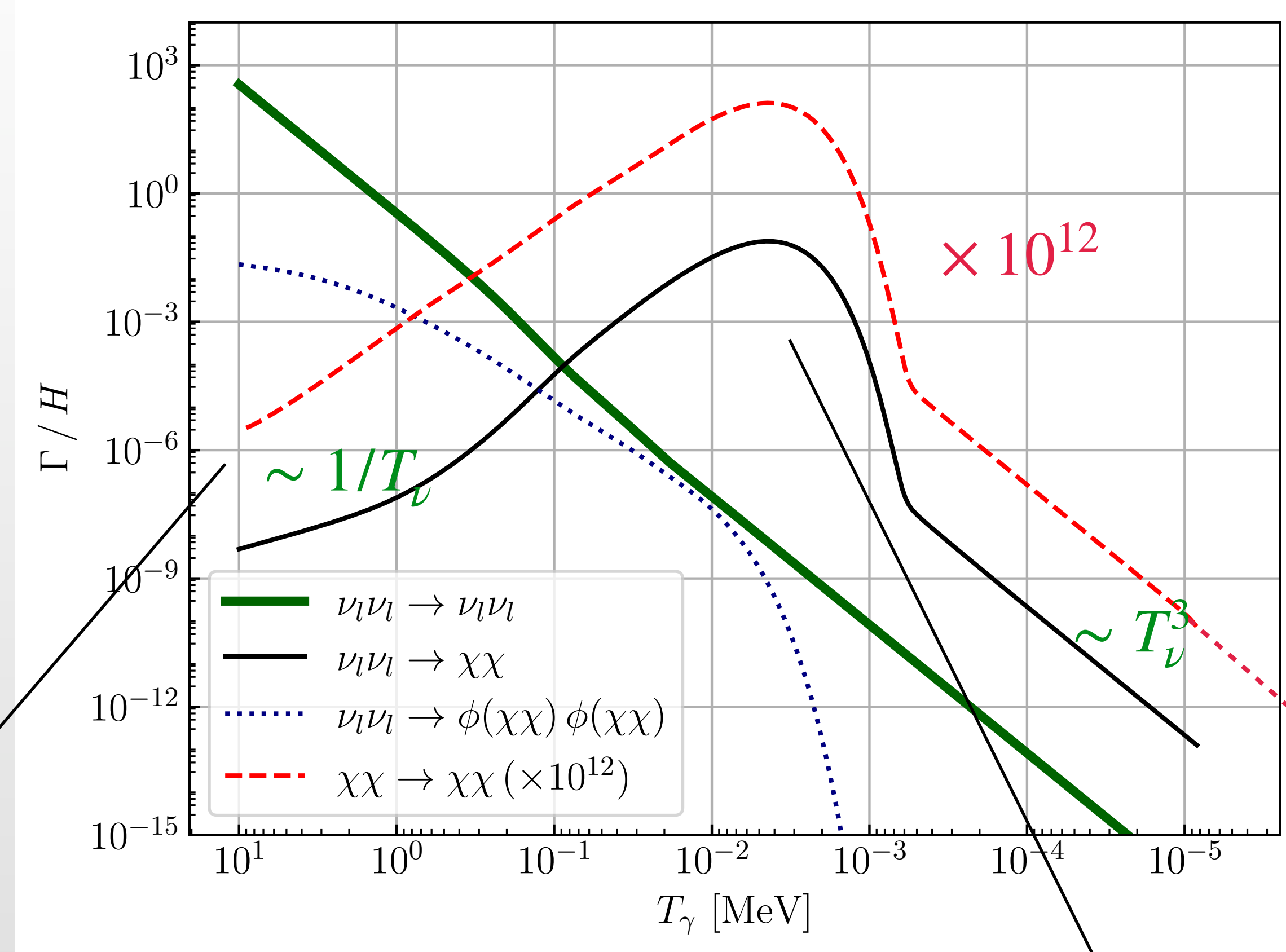
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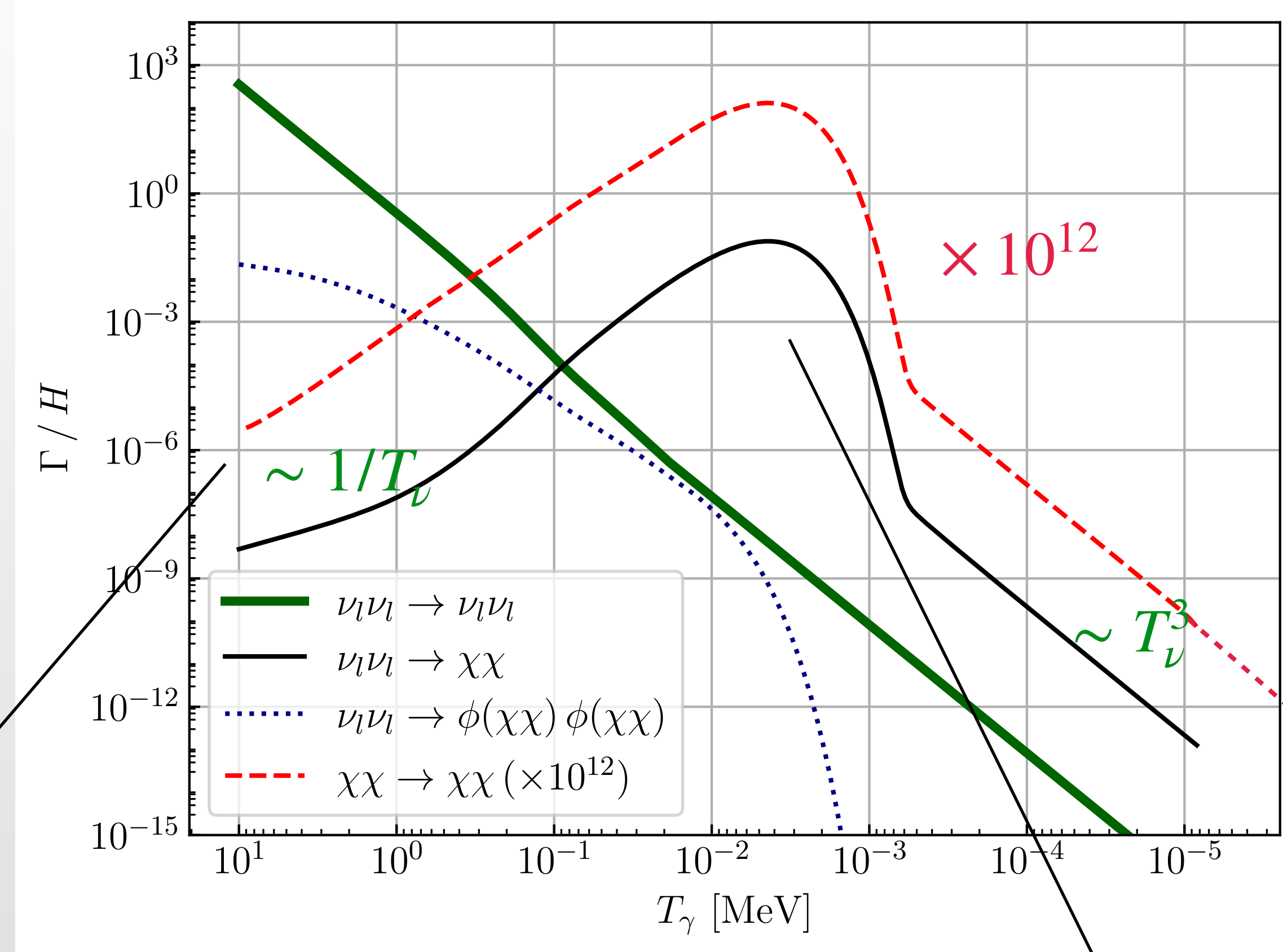
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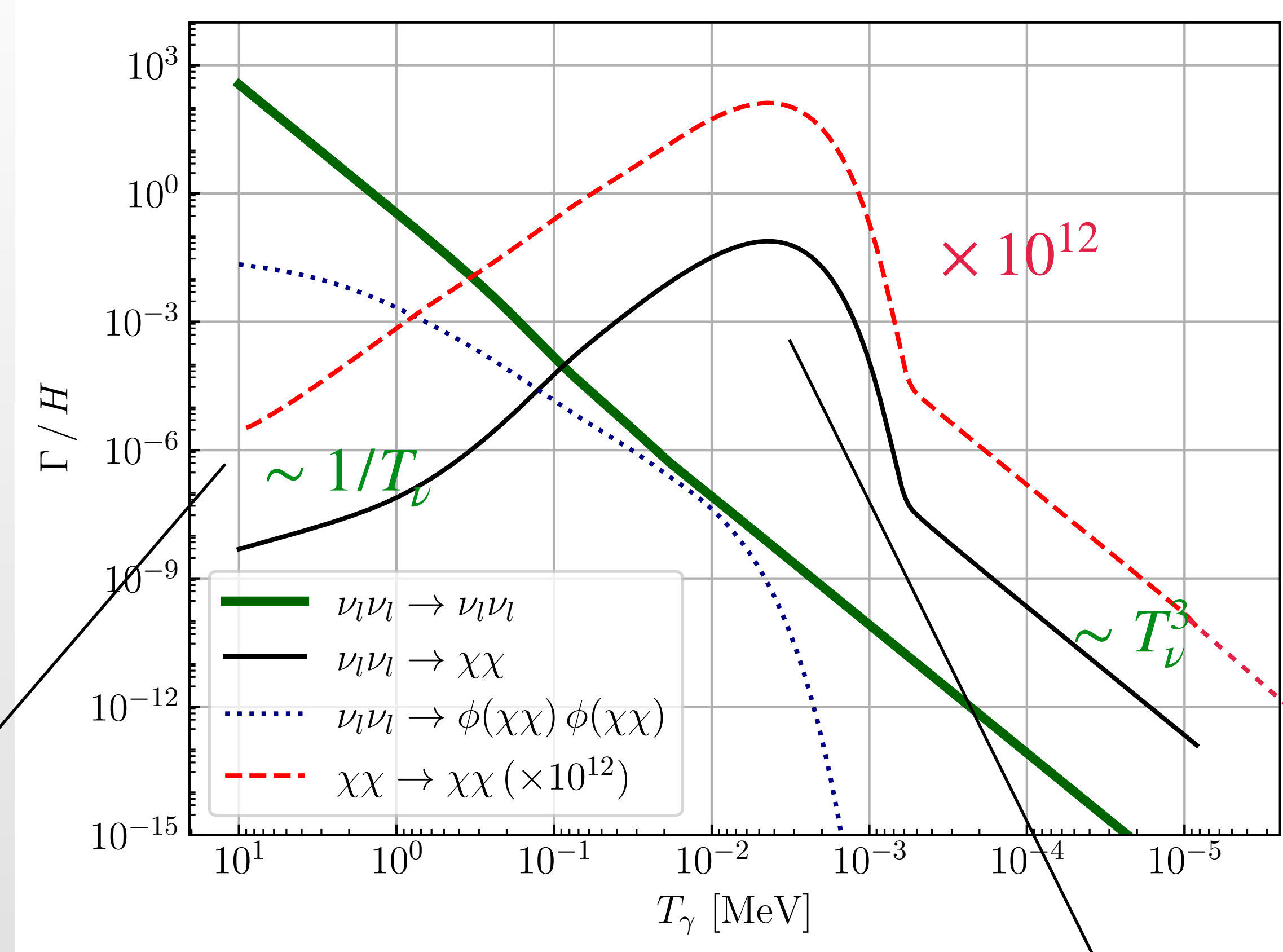
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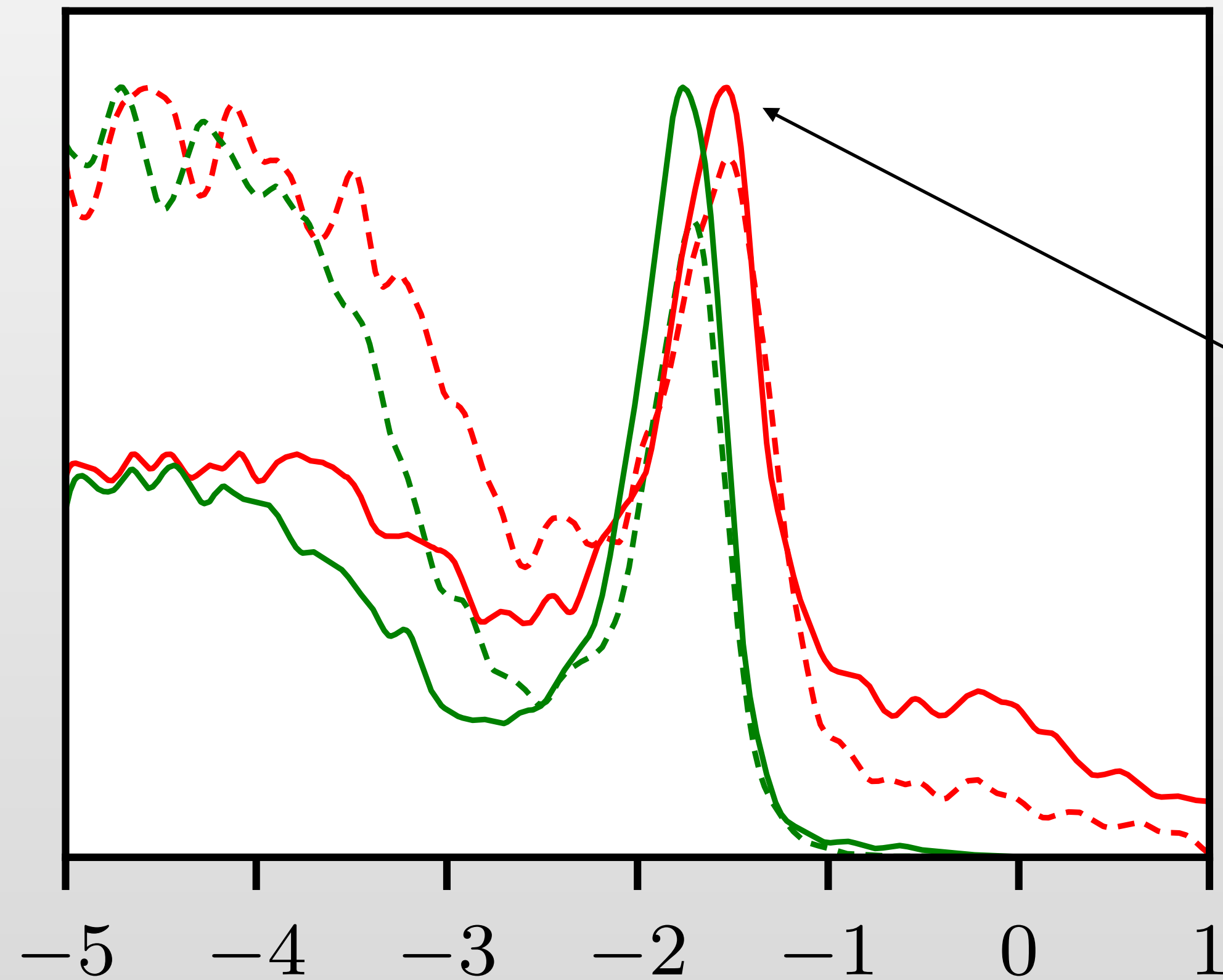
Similar cosmology to flavor-specific interactions

# Preference for DR Self-interaction

- Planck :  $0.75N_\chi + 2.25N_\nu$
- Planck :  $1.2N_\chi + 1.8N_\nu$
- Planck + DESI :  $0.75N_\chi + 2.25N_\nu$
- Planck + DESI :  $1.2N_\chi + 1.8N_\nu$

$$N_{\text{eff}}^\nu = N_{\text{eff}}^{\text{SM}} \frac{3}{3 + N_{\text{ds}}}$$

$$N_\chi, N_\nu = \begin{cases} 0.75, 2.25 & : N_{\text{ds}} = 1 \\ 1.20, 1.80 & : N_{\text{ds}} = 2 \end{cases}$$



This cosmology is marginally preferred over  $\Lambda$ CDM  
w/ Planck18 + DESI

$\log 10[G_{\text{eff}} \text{MeV}^2]$

# Two mechanisms to relax neutrino mass

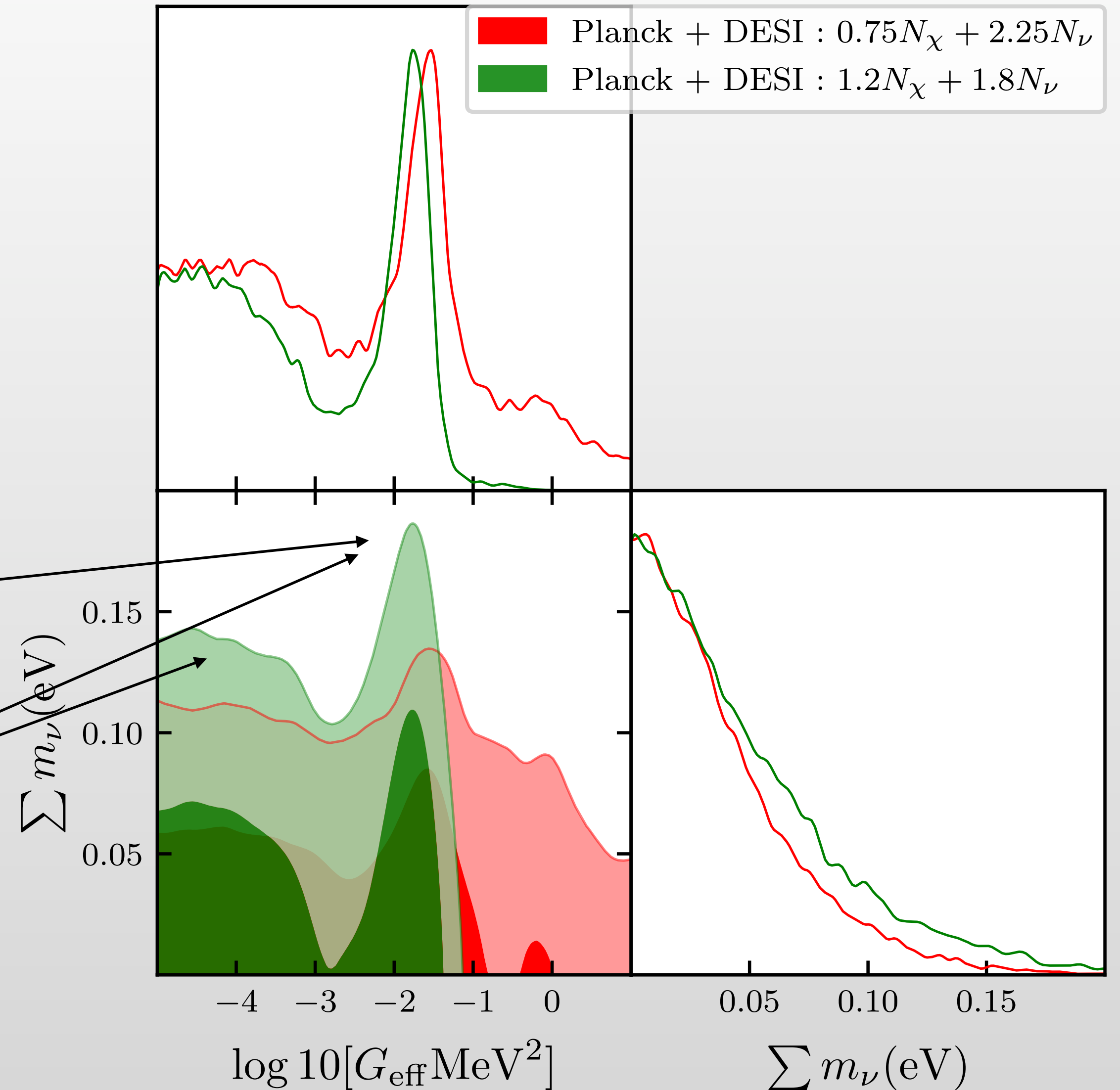
Anirban Das, P. S. Bhupal Dev, Christina Gao,  
**SG**, Taegyun Kim: arXiv: [2506.08085](https://arxiv.org/abs/2506.08085)

$$N_{\text{eff}}^{\nu} = N_{\text{eff}}^{\text{SM}} \frac{3}{3 + N_{\text{ds}}}$$

$$N_{\chi}, N_{\nu} = \begin{cases} 0.75, 2.25 & : N_{\text{ds}} = 1 \\ 1.20, 1.80 & : N_{\text{ds}} = 2 \end{cases}$$

Additional relaxation due to indirect effects  
 from self-interacting  $\chi$

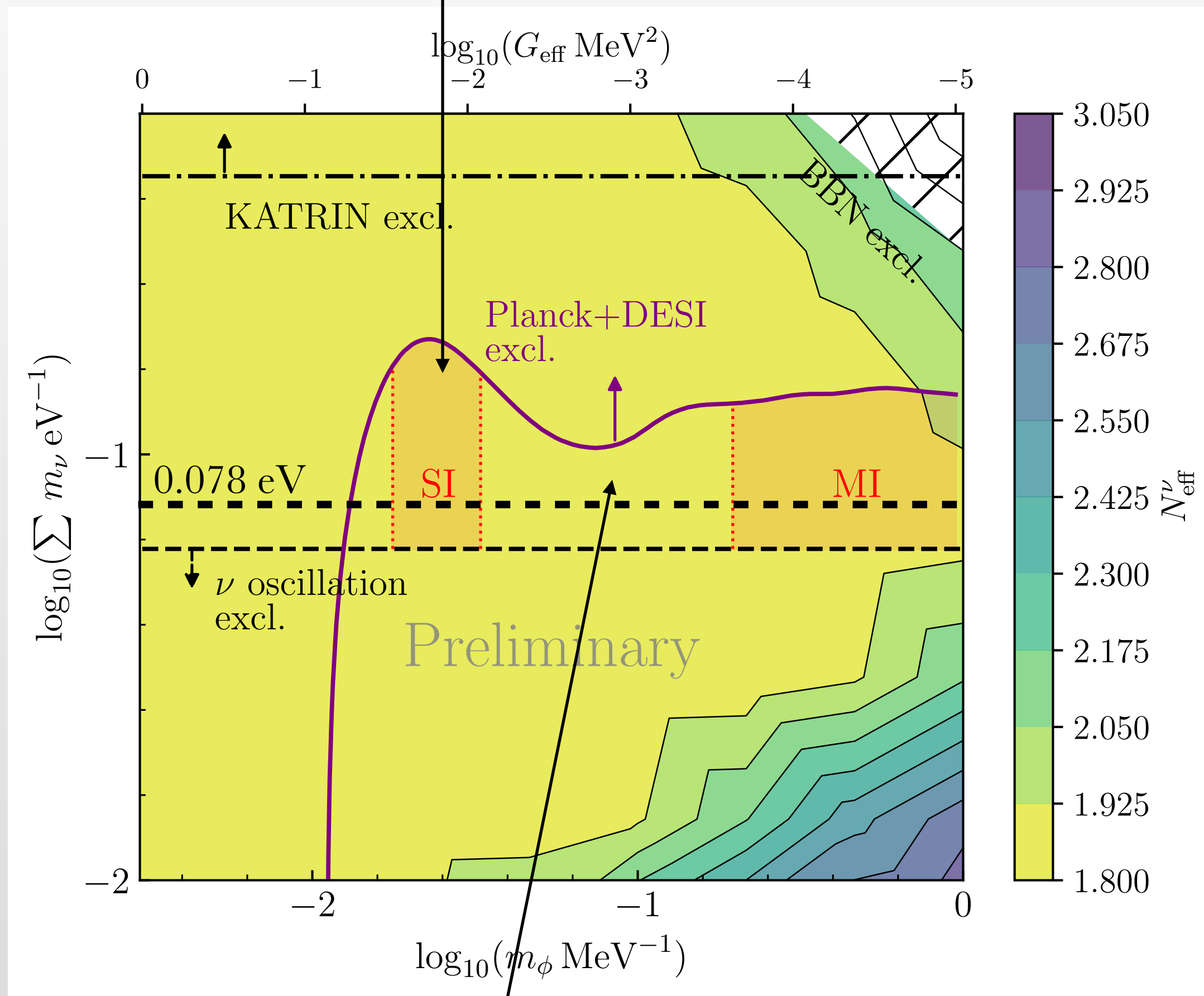
$$\sum m_{\nu} < 0.078 \text{ eV} \left( 1 + \frac{N_{\text{ds}}}{3} \right) \text{ [95 \% C.L.]}$$



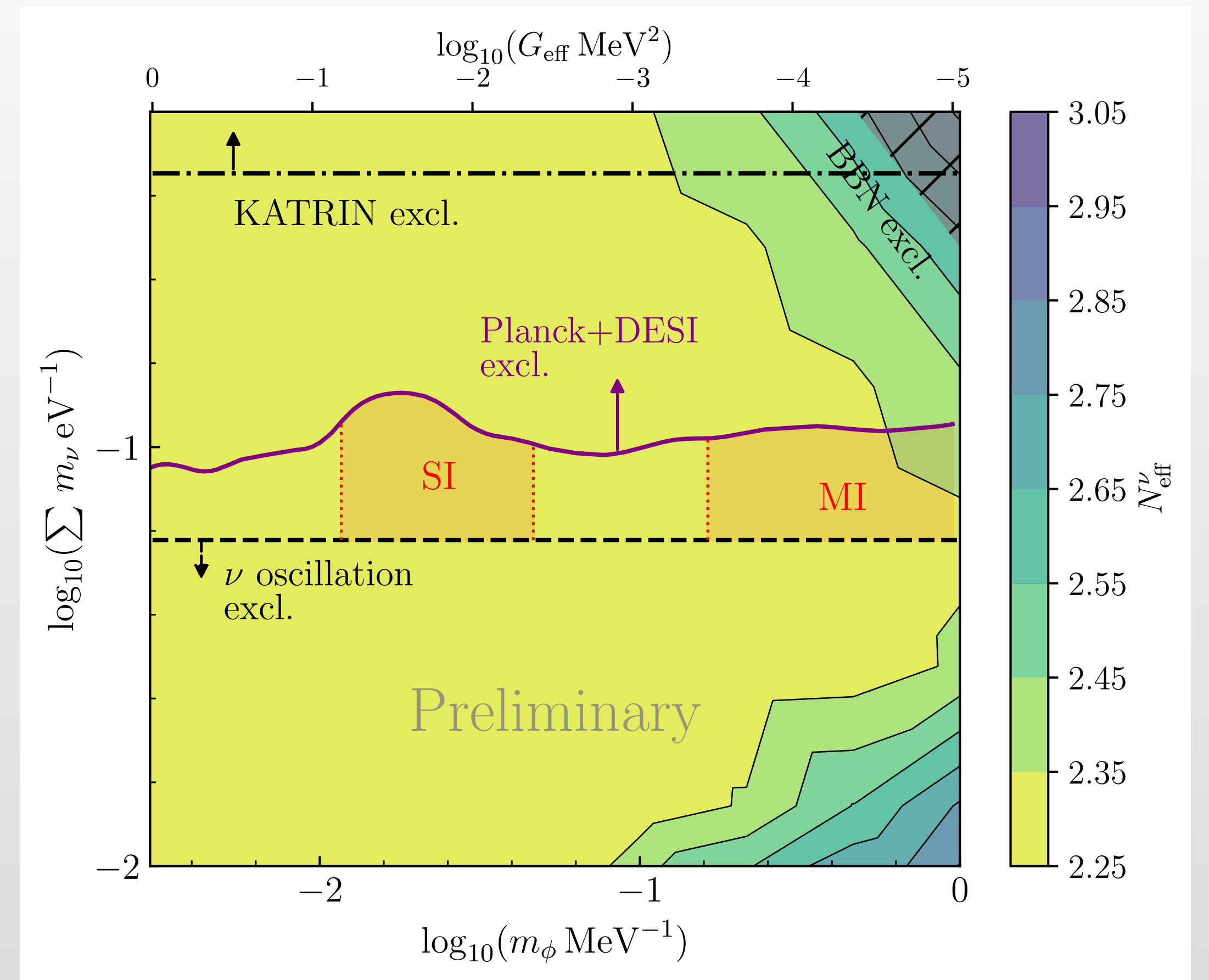
Universe wants to be here (cosmologically)

# Parameter space

$N_{\text{ds}} = 2$



$N_{\text{ds}} = 1$



Relaxation on mass bound

$g_{\nu\phi}$  is too small to be probed in meson decays

# Conclusion

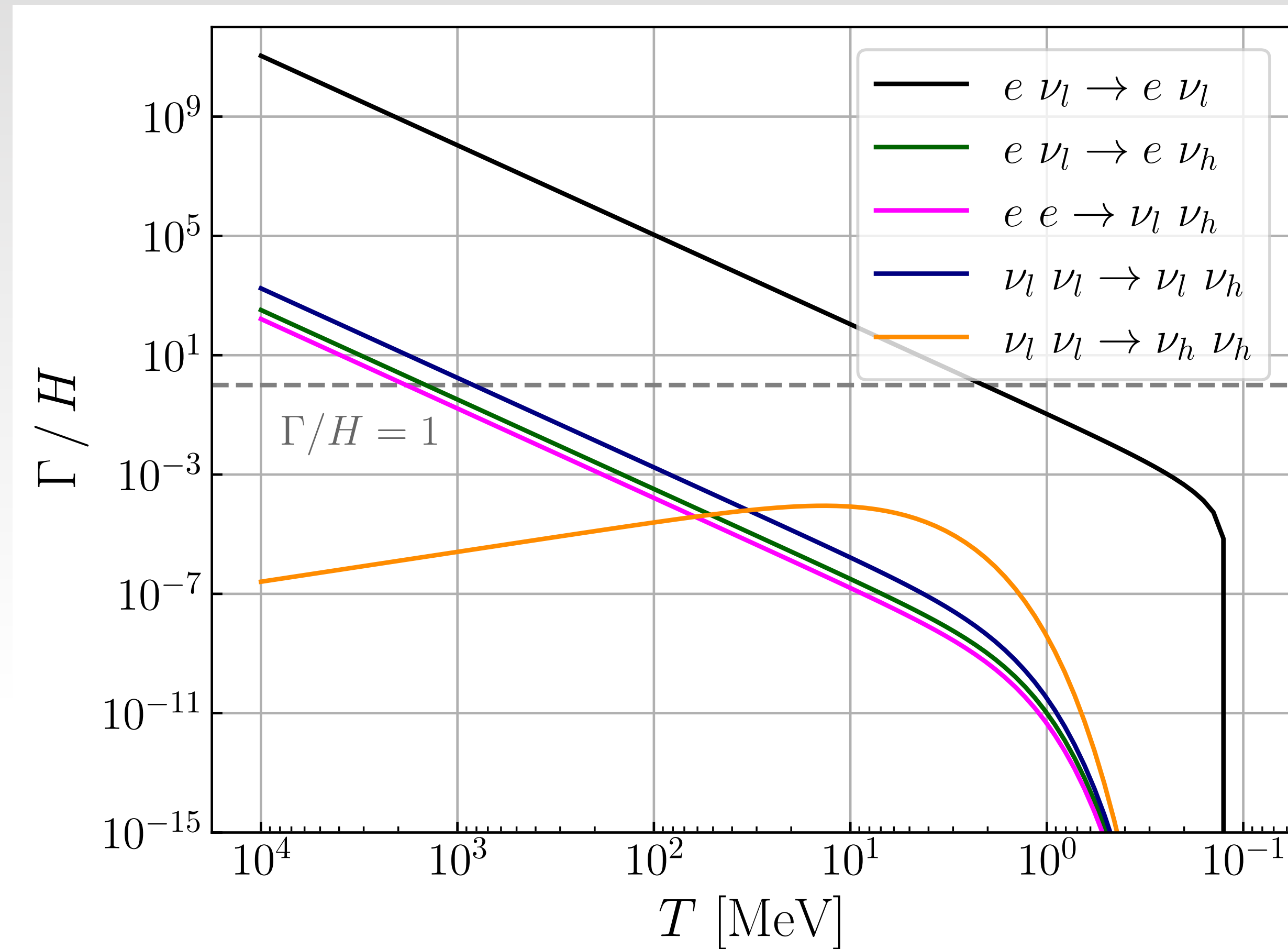
Strong neutrino interaction cosmology can be realized in a collider & BBN safe way

Additionally, the neutrino mass bound is significantly relaxed

Modified phase-shift induces a shift in  $\theta_s$  that increases the value  $H_0$  from CMB

# Post-credit Conclusion

# Low reheating Temperature



HNL ( $N$ ) can be produced in the early universe and give rise to large  $\Delta N_{\text{eff}}$   
 can be prevented by having a **low reheating temperature  $T_{\text{rh}} \lesssim 1$  GeV**

# Parameter constraints ( $1\sigma$ )

Parameters	Planck			
	$0.75N_\chi + 2.25N_\nu$		$1.2N_\chi + 1.8N_\nu$	
	MI	SI	MI	SI
$10^2\omega_b$	$2.23 \pm 0.02$	$2.24 \pm 0.02$	$2.23 \pm 0.02$	$2.24 \pm 0.02$
$\omega_c$	$0.120 \pm 0.001$	$0.120 \pm 0.001$	$0.120 \pm 0.001$	$0.121 \pm 0.001$
$H_0$ [km/s/Mpc]	$67.1^{+1}_{-0.6}$	$67.5^{+1}_{-0.7}$	$67.0^{+1}_{-0.6}$	$67.6^{+1}_{-0.6}$
$\log(10^{10}A_s)$	$3.05 \pm 0.02$	$3.03 \pm 0.02$	$3.05 \pm 0.02$	$3.02 \pm 0.02$
$n_s$	$0.963^{+0.005}_{-0.004}$	$0.957^{+0.005}_{-0.005}$	$0.962^{+0.005}_{-0.005}$	$0.953 \pm 0.005$
$\tau_{\text{reio}}$	$0.055 \pm 0.008$	$0.055^{+0.007}_{-0.008}$	$0.055 \pm 0.008$	$0.055^{+0.007}_{-0.008}$
$\sigma_8$	$0.809^{+0.02}_{-0.007}$	$0.809^{+0.02}_{-0.008}$	$0.809^{+0.02}_{-0.007}$	$0.810^{+0.02}_{-0.008}$
$\log_{10}(G_{\text{eff}}\text{MeV}^2)$	$< -3.34$	$< -1.23$	$< -3.48$	$-1.7^{+0.3}_{-0.2}$
$\sum m_\nu$ [eV]	$< 0.126$	$< 0.121$	$< 0.159$	$< 0.157$
$\Omega_m$	$0.319^{+0.008}_{-0.02}$	$0.316^{+0.008}_{-0.01}$	$0.320^{+0.008}_{-0.02}$	$0.315^{+0.008}_{-0.02}$

Parameters	Planck + DESI			
	$0.75N_\chi + 2.25N_\nu$		$1.2N_\chi + 1.8N_\nu$	
	MI	SI	MI	SI
$10^2\omega_b$	$2.25 \pm 0.01$	$2.25 \pm 0.01$	$2.25 \pm 0.01$	$2.25 \pm 0.01$
$\omega_c$	$0.1185 \pm 0.0009$	$0.1191 \pm 0.0009$	$0.1185 \pm 0.0009$	$0.119 \pm 0.001$
$H_0$ [km/s/Mpc]	$68.4^{+0.5}_{-0.4}$	$68.6 \pm 0.5$	$68.4 \pm 0.4$	$68.6 \pm 0.5$
$\log(10^{10}A_s)$	$3.05 \pm 0.02$	$3.03 \pm 0.02$	$3.05 \pm 0.02$	$3.03 \pm 0.02$
$n_s$	$0.967 \pm 0.004$	$0.959^{+0.006}_{-0.004}$	$0.967^{+0.005}_{-0.004}$	$0.957^{+0.005}_{-0.004}$
$\tau_{\text{reio}}$	$0.058 \pm 0.008$	$0.057 \pm 0.007$	$0.058^{+0.007}_{-0.008}$	$0.057^{+0.007}_{-0.008}$
$\sigma_8$	$0.817^{+0.008}_{-0.007}$	$0.815^{+0.01}_{-0.008}$	$0.818^{+0.008}_{-0.007}$	$0.819^{+0.01}_{-0.007}$
$\log_{10}(G_{\text{eff}}\text{MeV}^2)$	$< -3.28$	$-1.3^{+0.3}_{-0.9}$	$< -3.44$	$-1.7^{+0.3}_{-0.2}$
$\sum m_\nu$ [eV]	$< 0.0471$	$< 0.0518$	$< 0.0575$	$< 0.0667$
$\Omega_m$	$0.302 \pm 0.006$	$0.302^{+0.005}_{-0.006}$	$0.302^{+0.005}_{-0.006}$	$0.302 \pm 0.006$