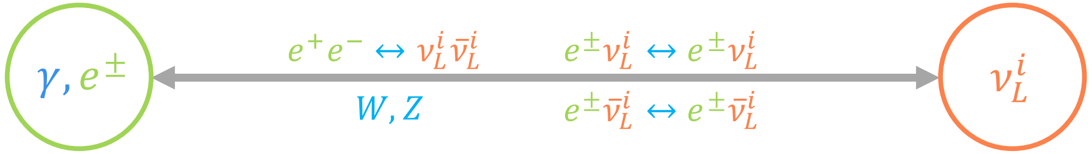
Cosmological implications of gauged $U(1)_{B-L}$ on ΔN_{eff} in the CMB and BBN

(2308.07955)

Haidar Esseili* & Graham Kribs

Cosmological Implications of Gauged $U(1)_{B-L}$ on ΔN_{eff} in the CMB & BBN

At $T \sim 10$ MeV



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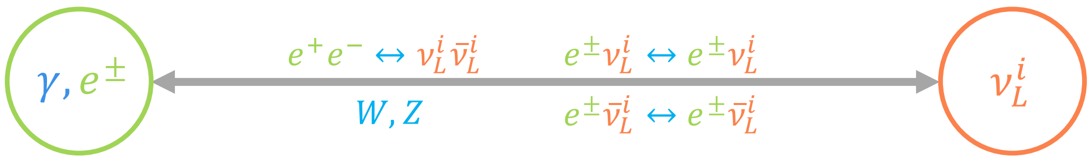

$$\frac{dT_\gamma}{dt} = -\frac{4H\rho_\gamma + 3H\left(\rho_e + p_e\right) + \frac{\delta\rho_{\nu_e}}{\delta t} + 2\frac{\delta\rho_{\nu_\mu}}{\delta t}}{\frac{\partial\rho_\gamma}{\partial T_\gamma} + \frac{\partial\rho_e}{\partial T_\gamma}}$$

$$\frac{dT_\nu}{dt} = \frac{-12H\rho_\nu + \frac{\delta\rho_{\nu_e}}{\delta t} + 2\frac{\delta\rho_{\nu_\mu}}{\delta t}}{3\,\frac{\partial\rho_\nu}{\partial T_\nu}}$$

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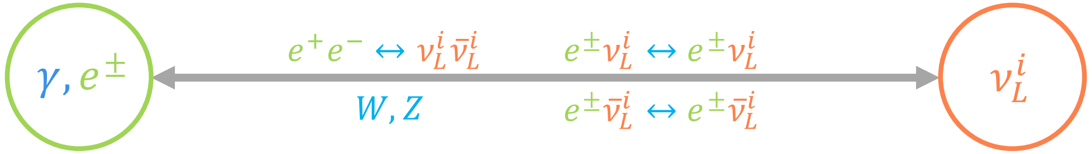

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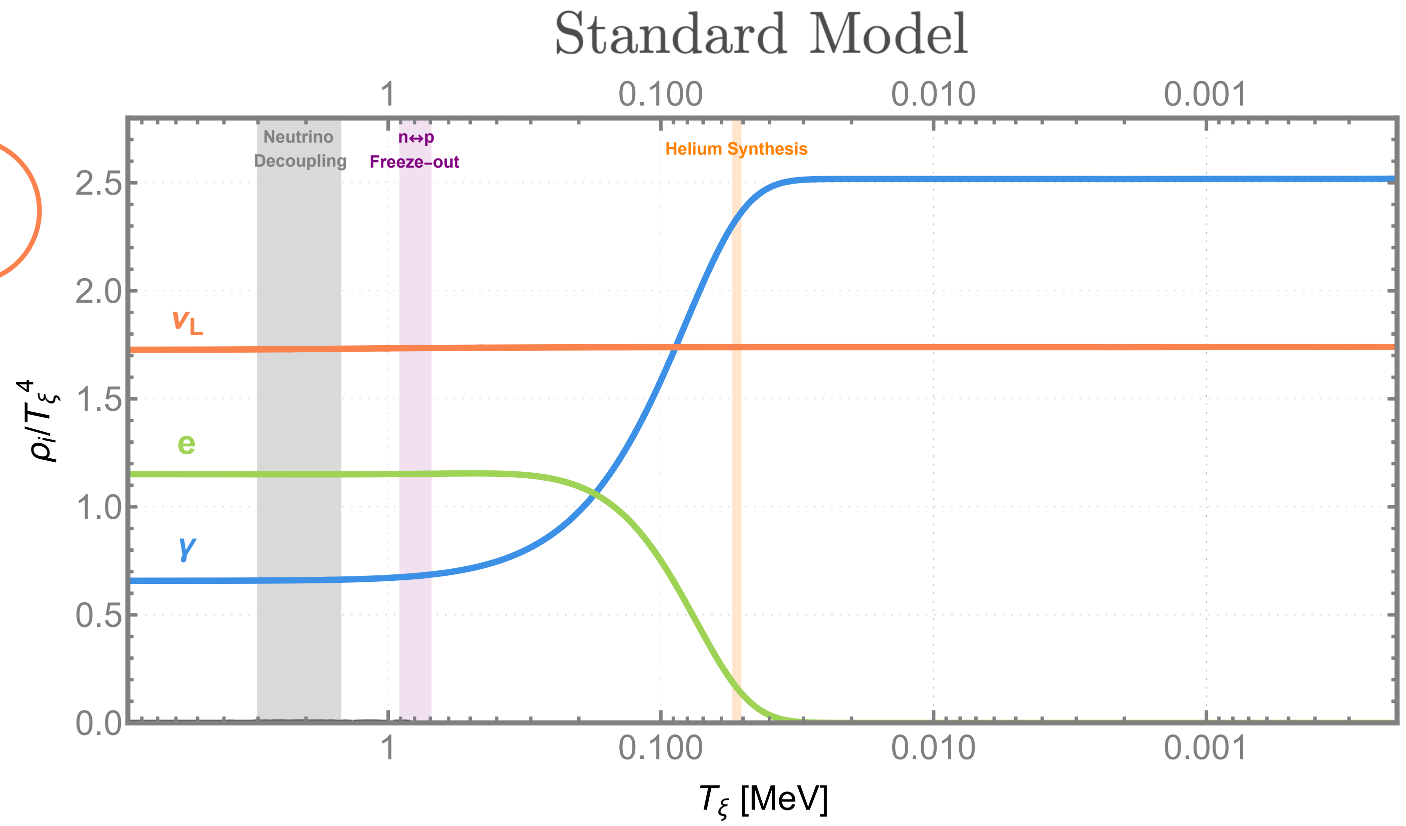
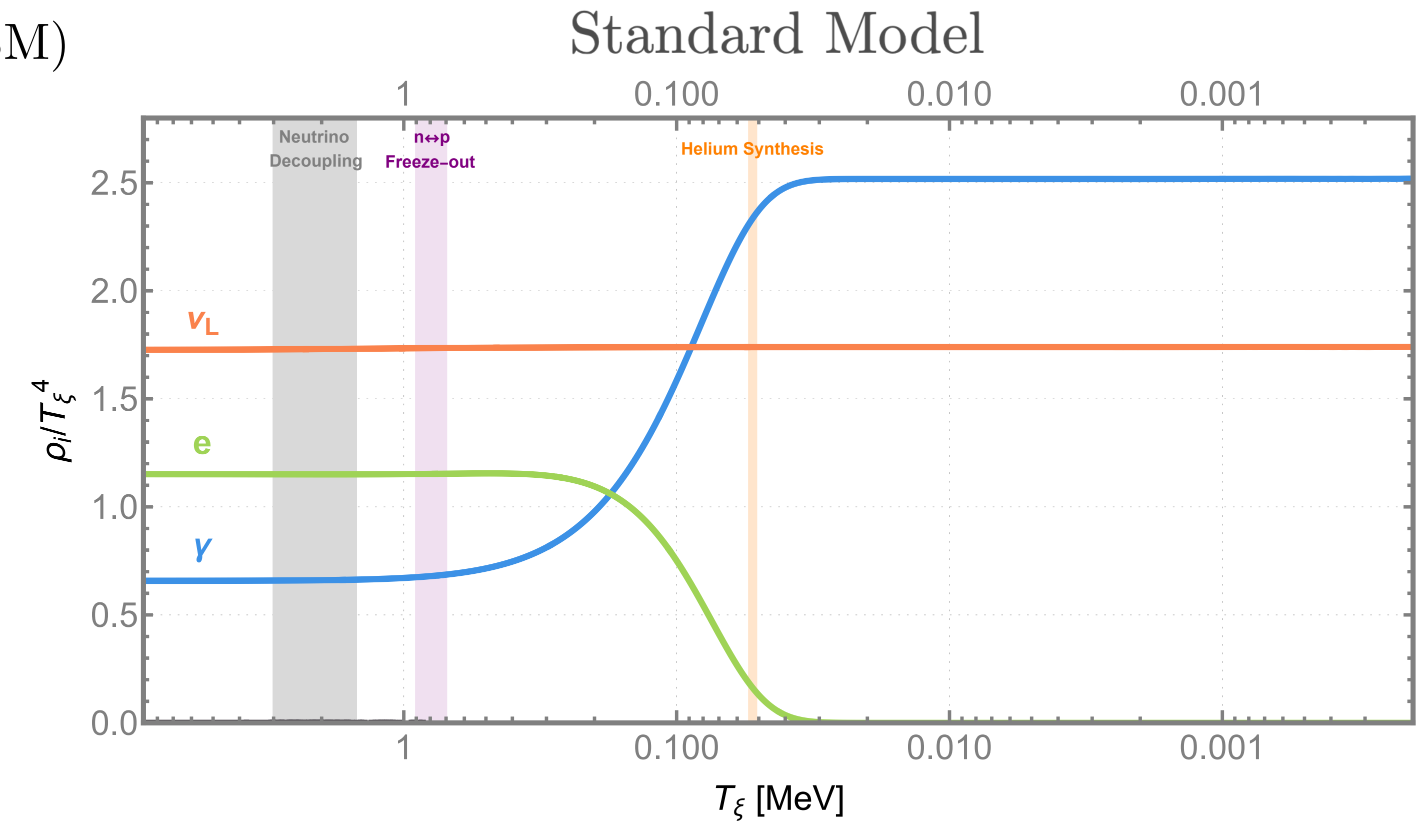


Cosmological Implications of Gauged $U(1)_{B-L}$ on ΔN_{eff} in the CMB & BBN

$$N_{\text{eff}} \equiv \frac{8}{7}\left(\frac{11}{4}\right)^{4/3}\left(\frac{\rho_{\text{rad}}-\rho_\gamma}{\rho_\gamma}\right) = 3.045\ (\text{SM})$$

$$\approx 4.4\,(\rho_\nu/\rho_\gamma)$$



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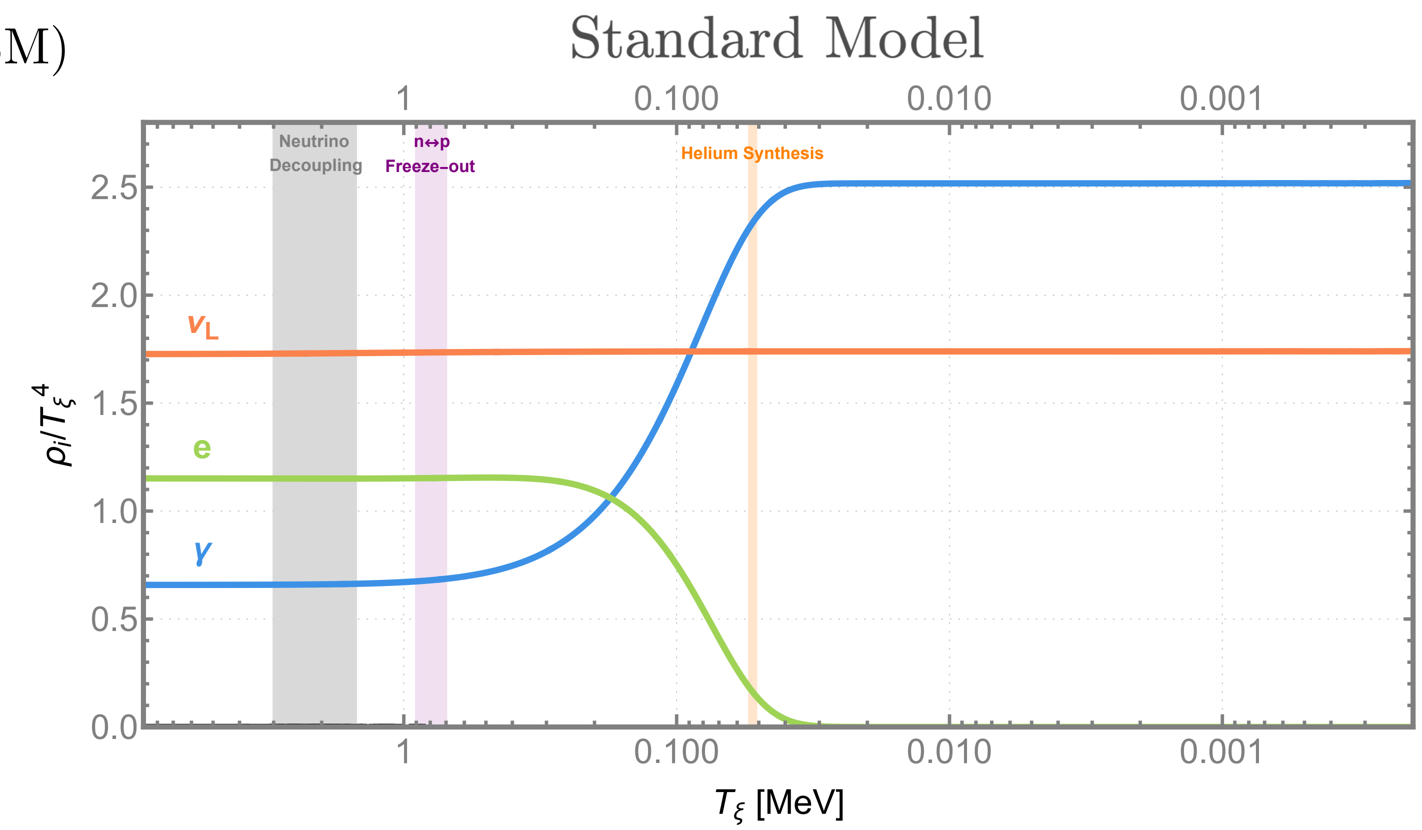
Current:

$$N_{\rm eff}\big|^{\rm PCP18}_{+Y_p} = 2.99^{+0.43}_{-0.40}$$ Planck 1807.06209



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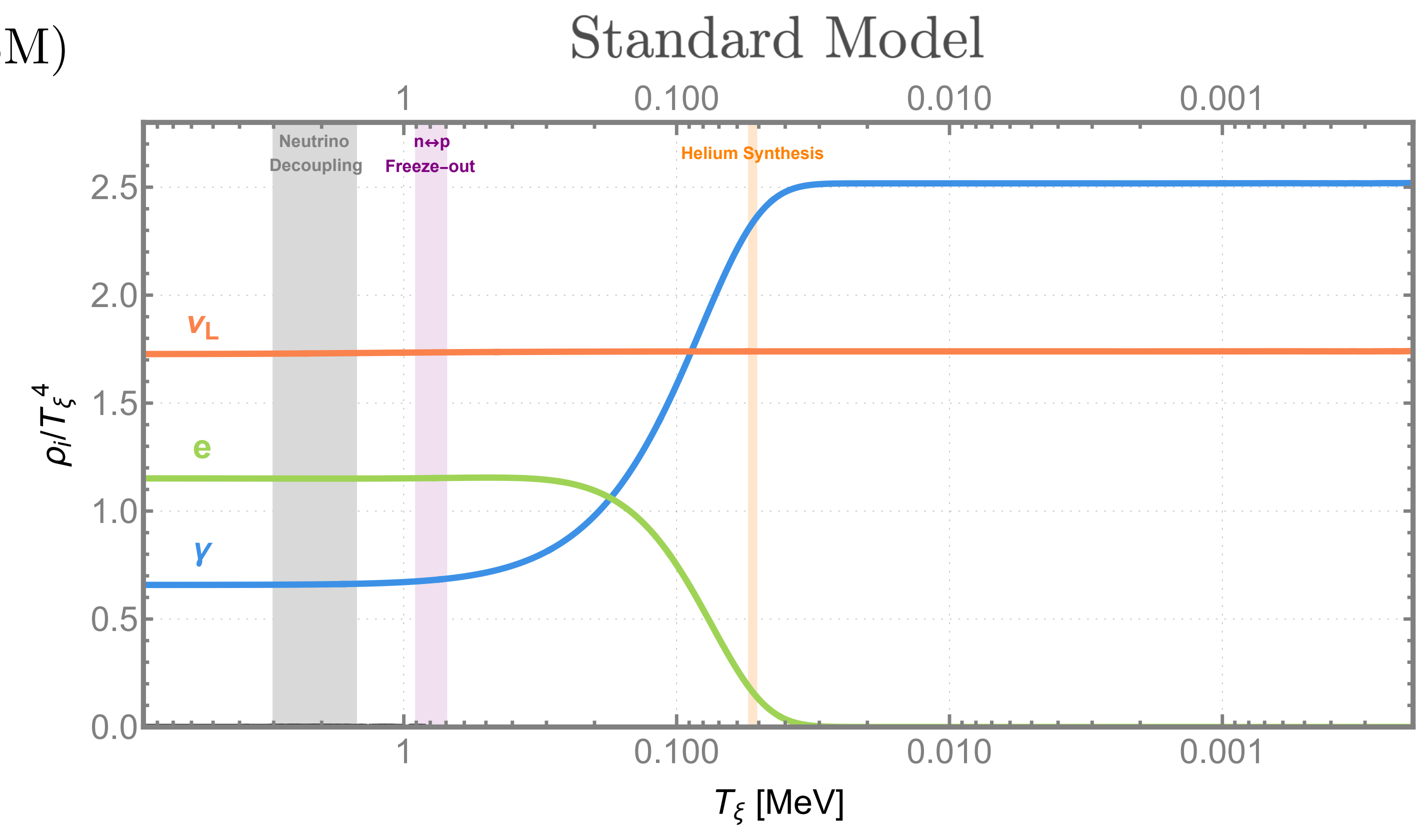
Future:

Simons Observatory	1808.07445	$\pm\,0.055$
CMB-S4	1907.04473	$\pm\,0.06$
CMB-HD	1906.10134	$\pm\,0.014$



Cosmological Implications of Gauged $U(1)_{B-L}$ on ΔN_{eff} in the CMB & BBN

$$\mathcal{L} = -g_X X_\mu j^\mu_{B-L}$$

$$(B-L)_f = \begin{cases} +1/3 & Q_L,\ u_R,\ d_R \\ -1 & L,\ e_R,\ \nu_R \end{cases}$$

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$$\mathcal{L} = (D_\mu \phi_X)^\dagger D^\mu \phi_X - \lambda \left(\phi_X^\dagger \phi_X + \frac{v_X^2}{2} \right)^2$$

$$D_\mu = \partial_\mu - i g_X q_X X_\mu$$

Expand around the vev
$\phi_X = (h_X + v_X)/\sqrt{2}$
Generates m_X & m_{h_X}

We work in the limit
$m_X \ll m_{h_X}$
h_X doesn't participate
in the dynamics

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Neutrino Masses →

Dirac Case
mass via $y_D^{ij} \bar{L}_i H^\dagger \nu_{R,j}$
ν_R participates
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Neutrino Masses

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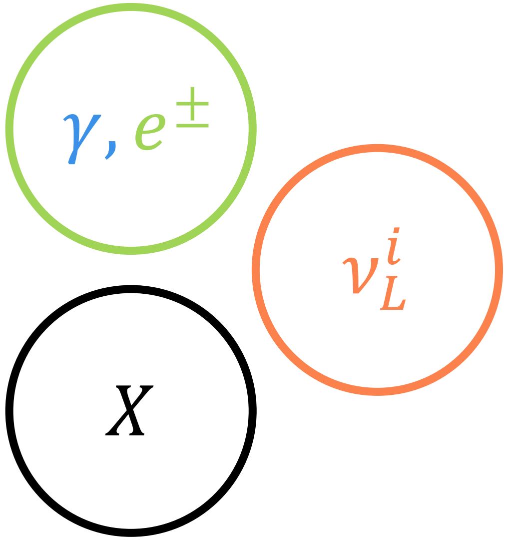
mass via $y_D^{ij} \bar{L}_i H^\dagger \nu_{R,j}$
ν_R participates
in the dynamics

Majorana Case
mass via $\frac{y_M^{ij}}{2} \nu^c_{R,i} \nu^c_{R,i} \phi^\dagger_X$
take $m_{\nu_R} > 20$ GeV
ν_R doesn't participates
in the dynamics

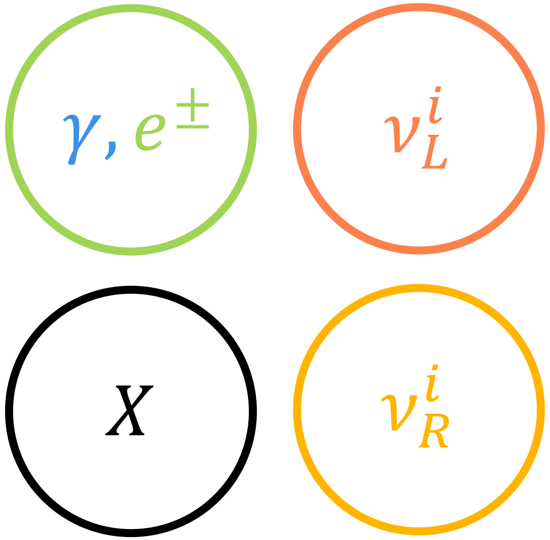
Majorana Case:



m_X

g_X

Dirac Case:



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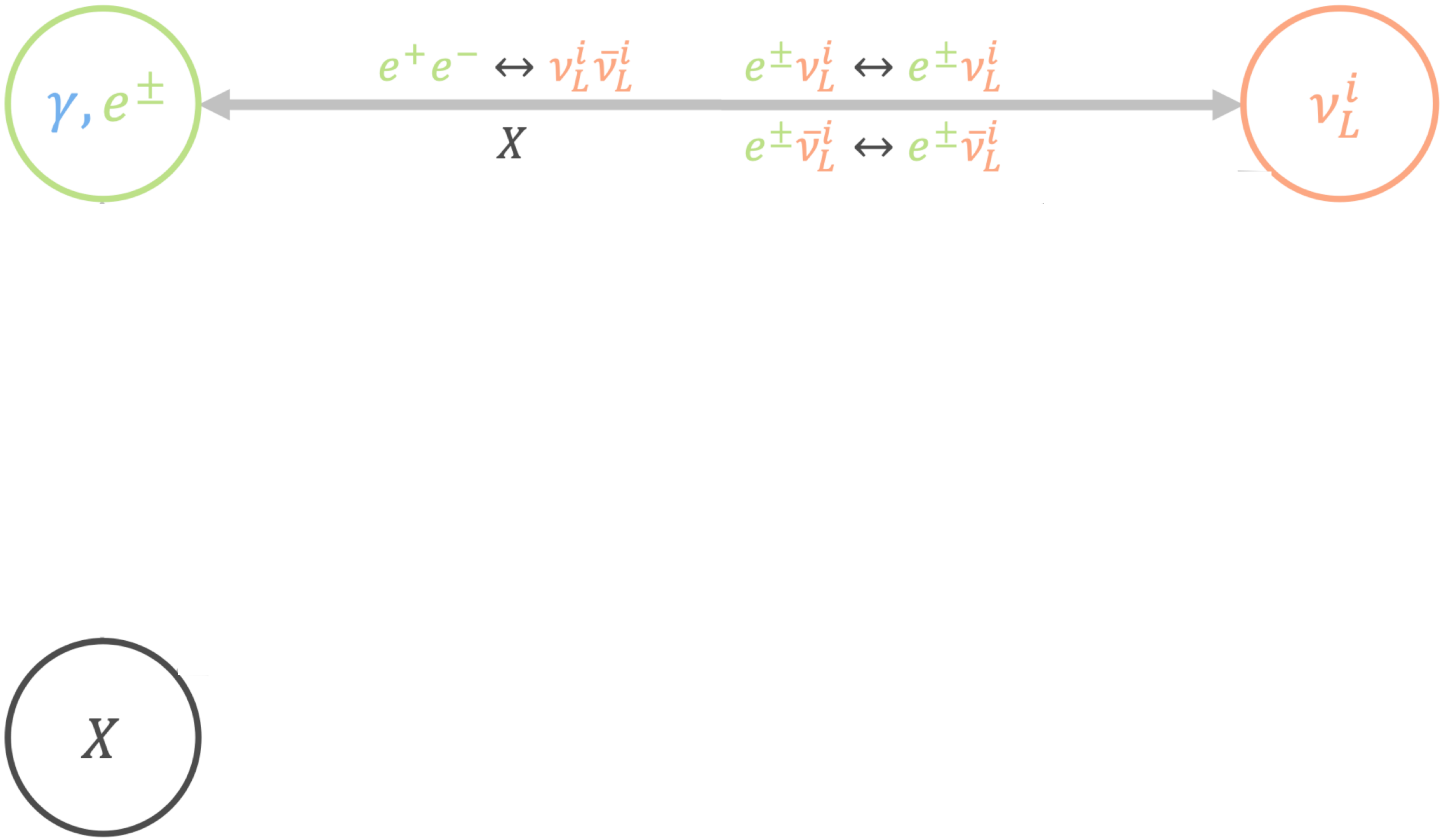

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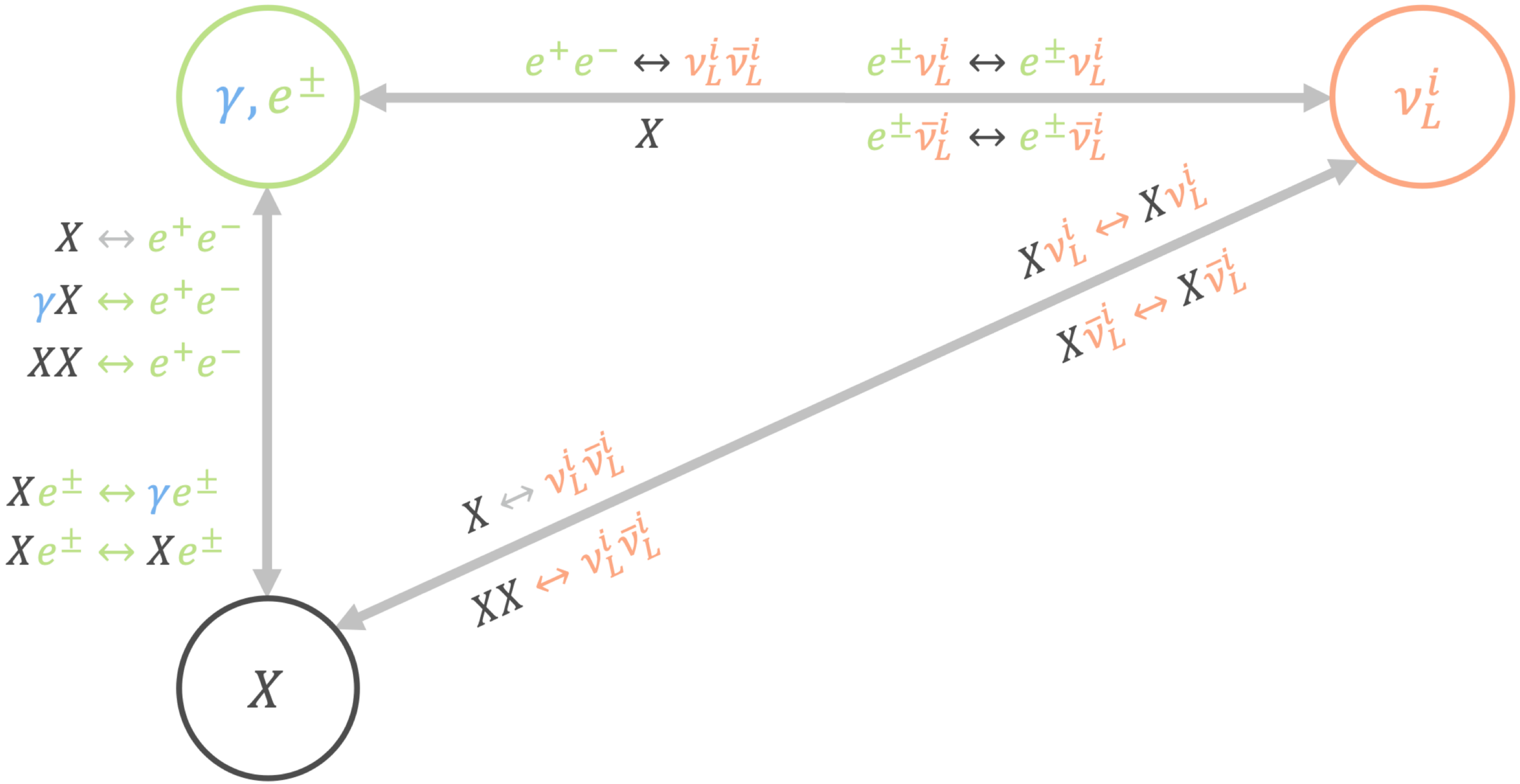

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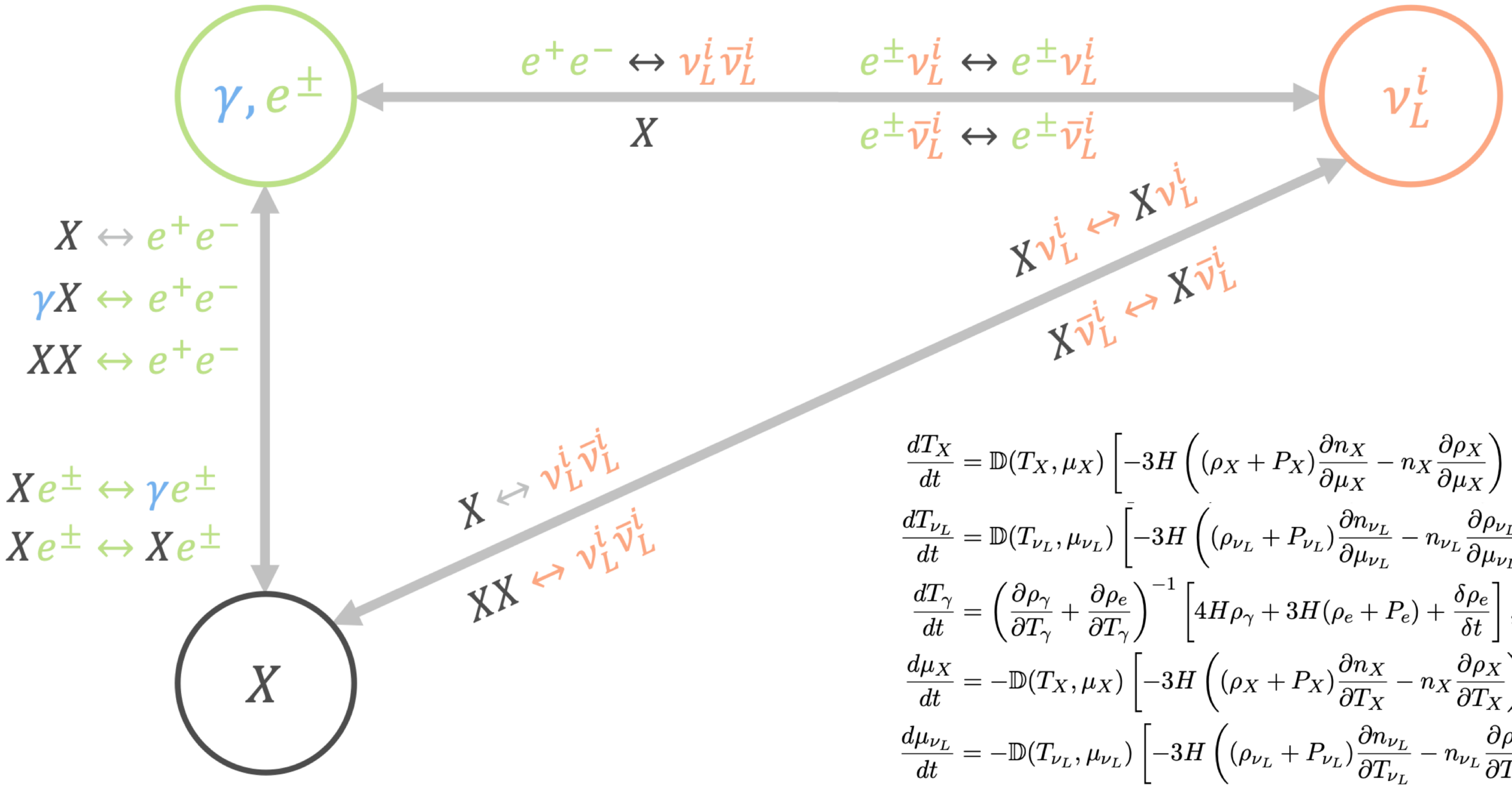

$$\frac{dT_X}{dt} = \mathbb{D}(T_X, \mu_X)\left[-3H\left((\rho_X + P_X)\frac{\partial n_X}{\partial \mu_X} - n_X \frac{\partial \rho_X}{\partial \mu_X}\right) + \frac{\partial n_X}{\partial \mu_X}\frac{\delta \rho_X}{\delta t} - \frac{\partial \rho_X}{\partial \mu_X}\frac{\delta n_X}{\delta t}\right],$$

$$\frac{dT_{\nu_L}}{dt} = \mathbb{D}(T_{\nu_L}, \mu_{\nu_L})\left[-3H\left((\rho_{\nu_L} + P_{\nu_L})\frac{\partial n_{\nu_L}}{\partial \mu_{\nu_L}} - n_{\nu_L} \frac{\partial \rho_{\nu_L}}{\partial \mu_{\nu_L}}\right) + \frac{\partial n_{\nu_L}}{\partial \mu_{\nu_L}}\frac{\delta \rho_{\nu_L}}{\delta t} - \frac{\partial \rho_{\nu_L}}{\partial \mu_{\nu_L}}\frac{\delta n_{\nu_L}}{\delta t}\right],$$

$$\frac{dT_\gamma}{dt} = \left(\frac{\partial \rho_\gamma}{\partial T_\gamma} + \frac{\partial \rho_e}{\partial T_\gamma}\right)^{-1}\left[4H\rho_\gamma + 3H(\rho_e + P_e) + \frac{\delta \rho_e}{\delta t}\right],$$

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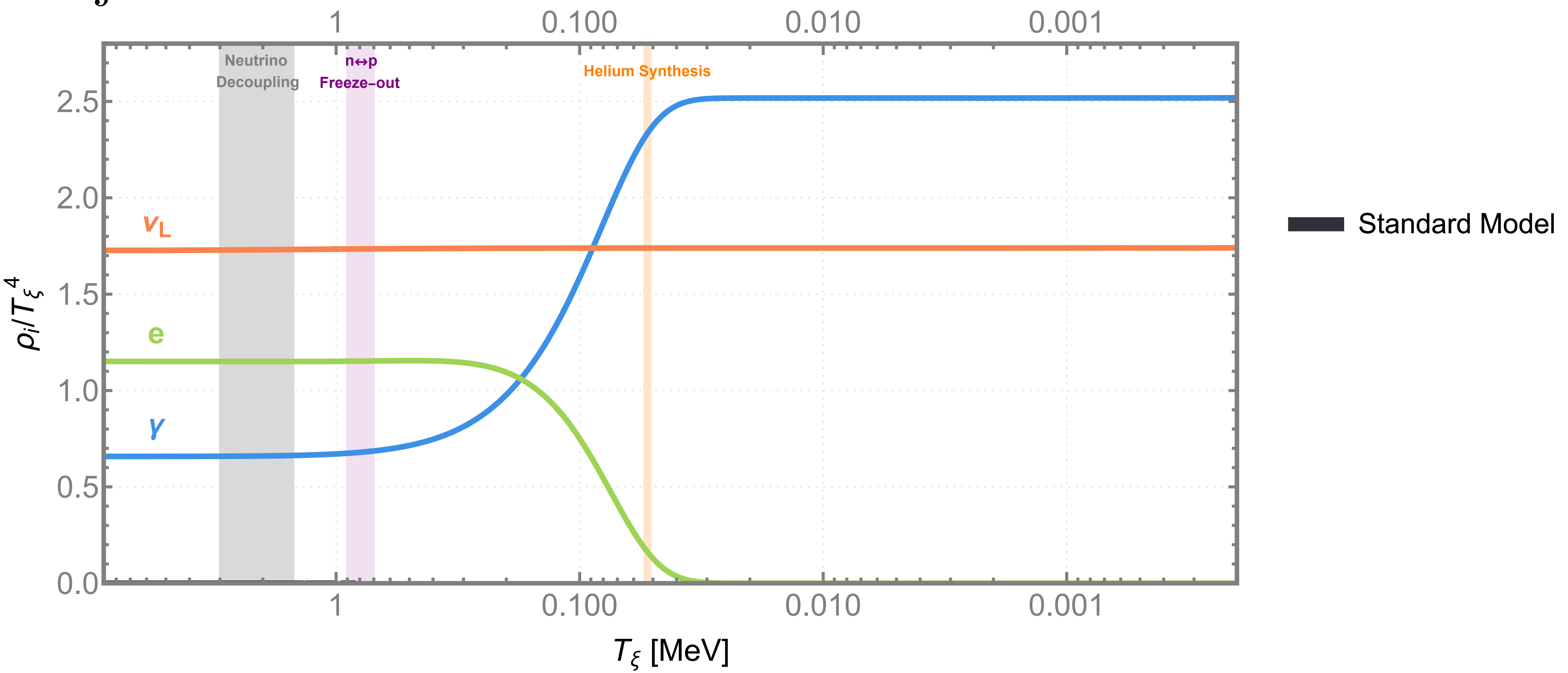

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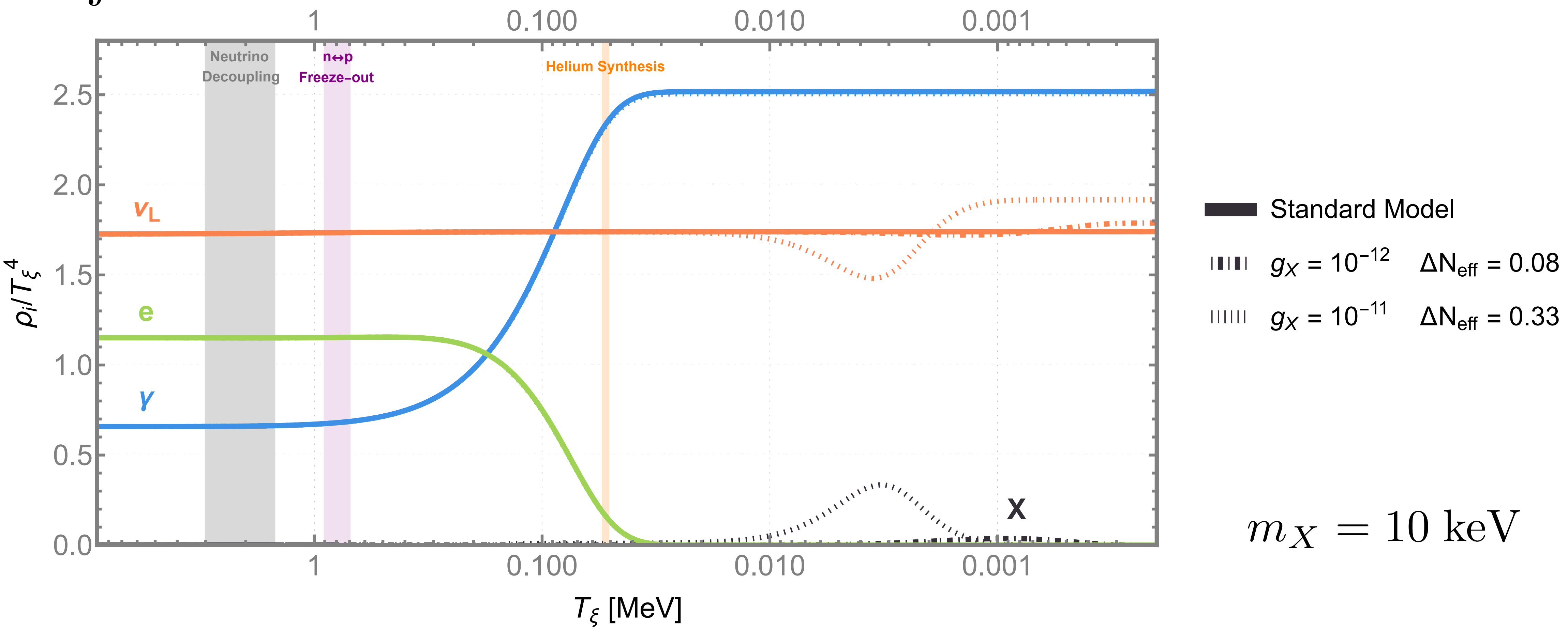

$$m_X = 10 \text{ keV}$$

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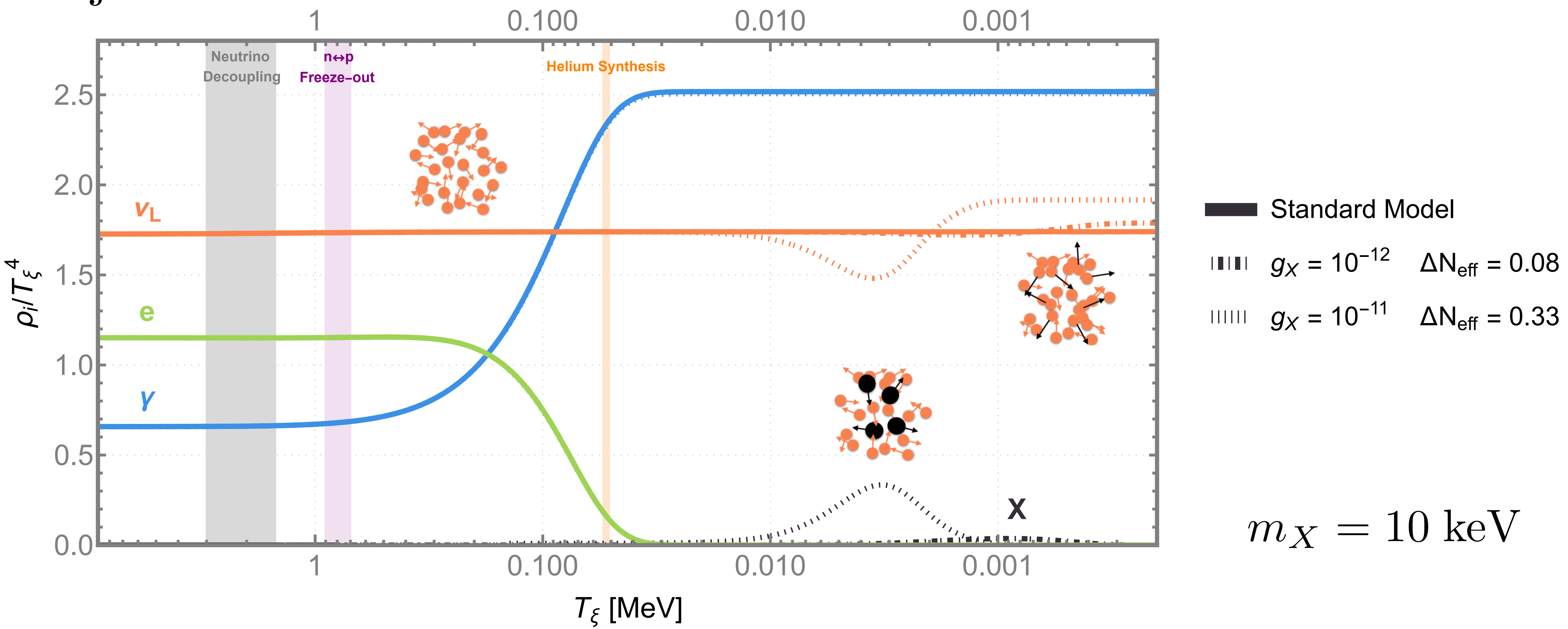

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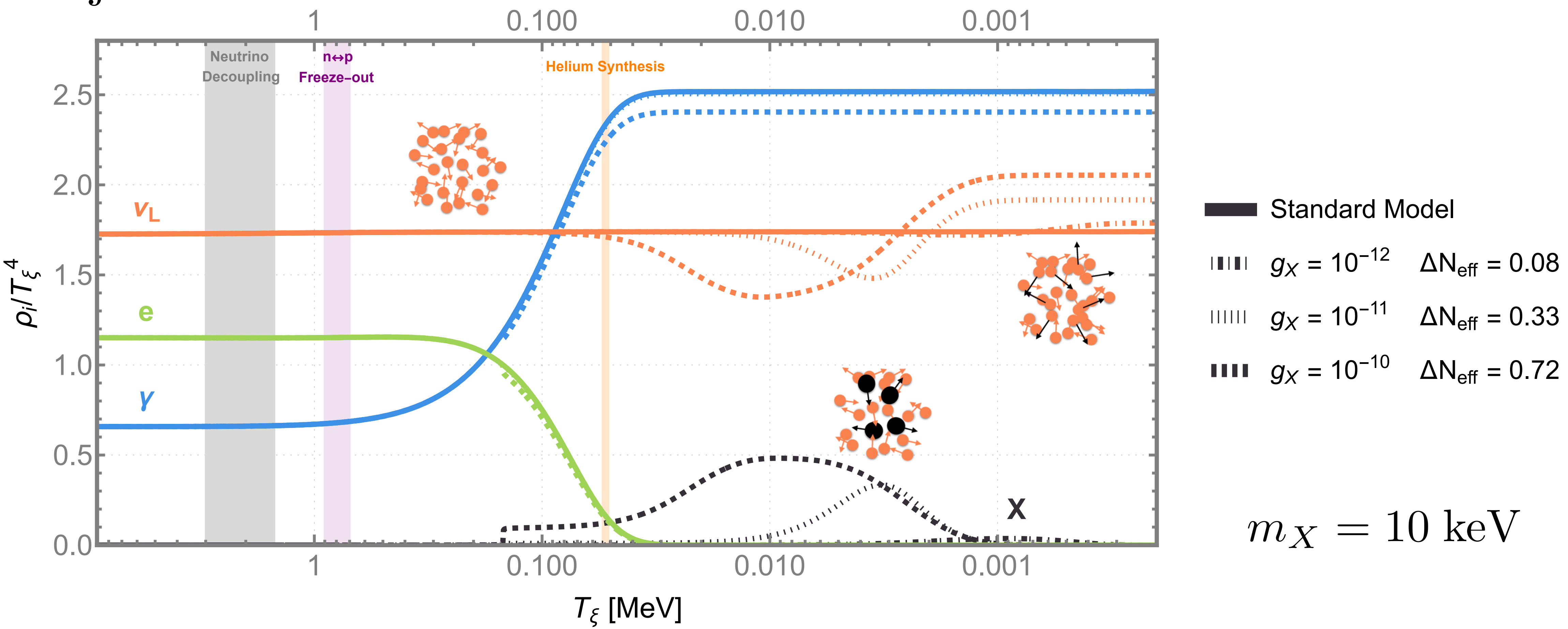

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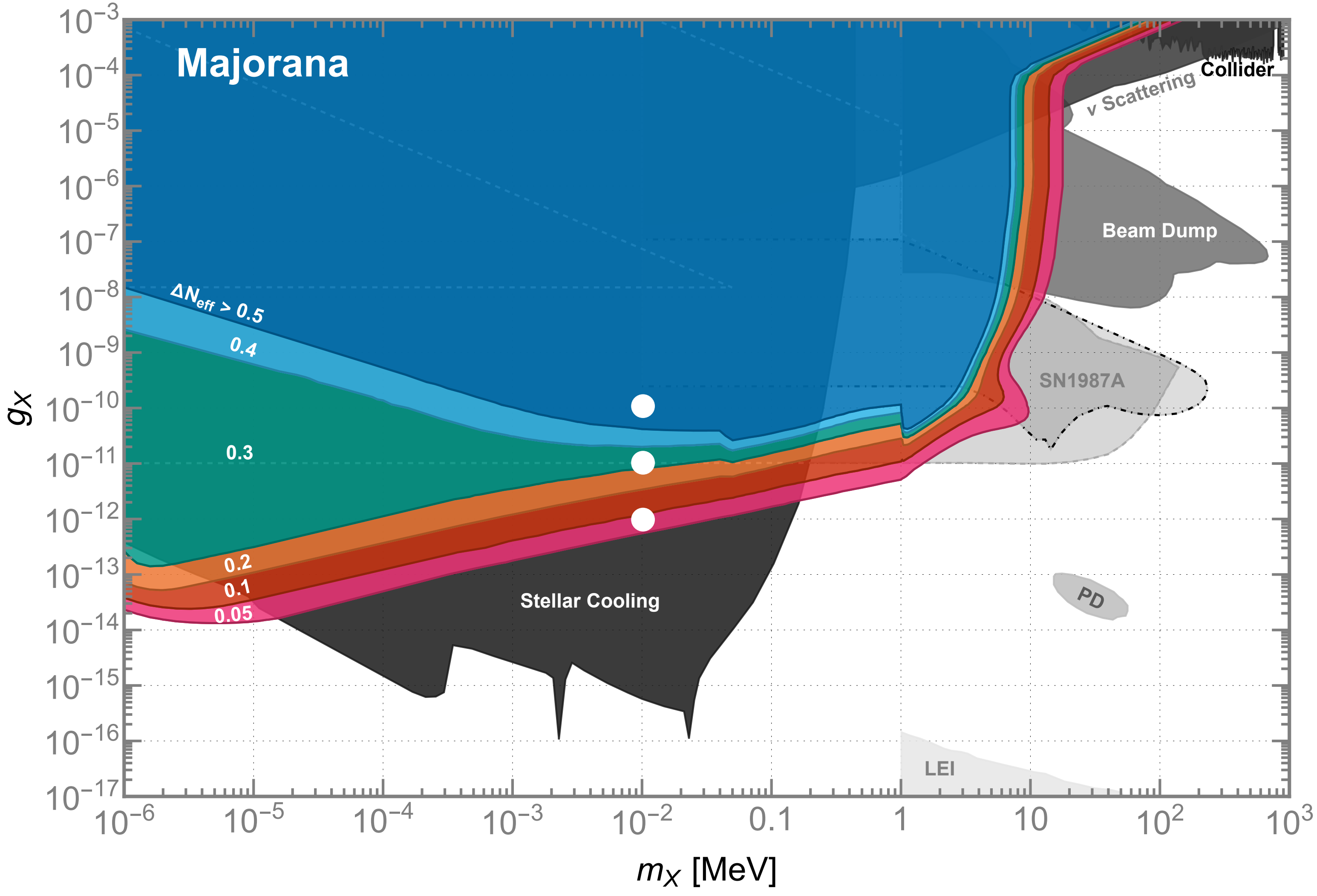
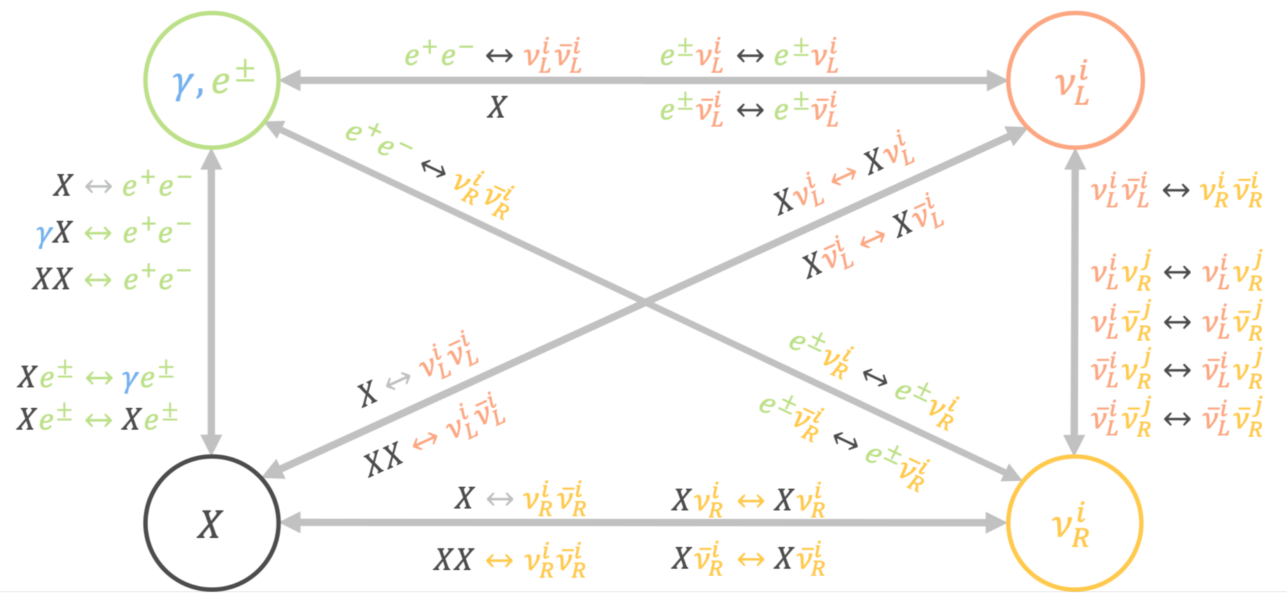


Dirac Case:



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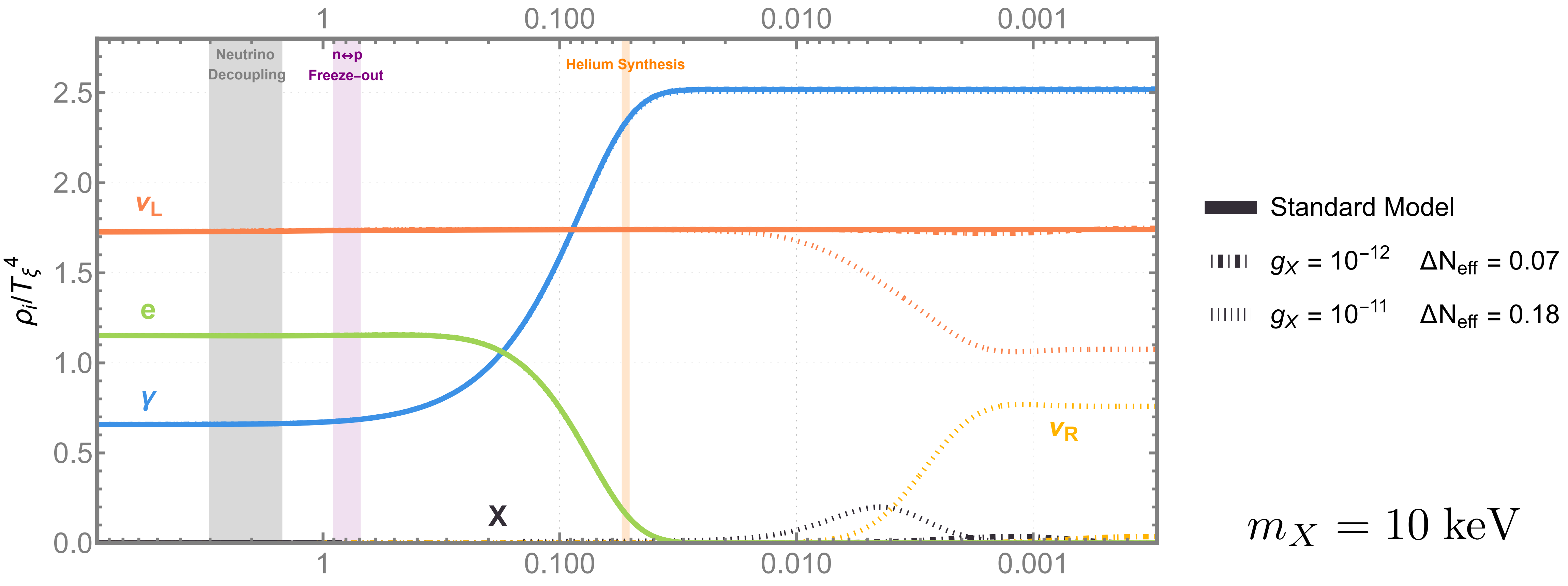
Dirac Case:



$$m_X = 10\ \text{keV}$$

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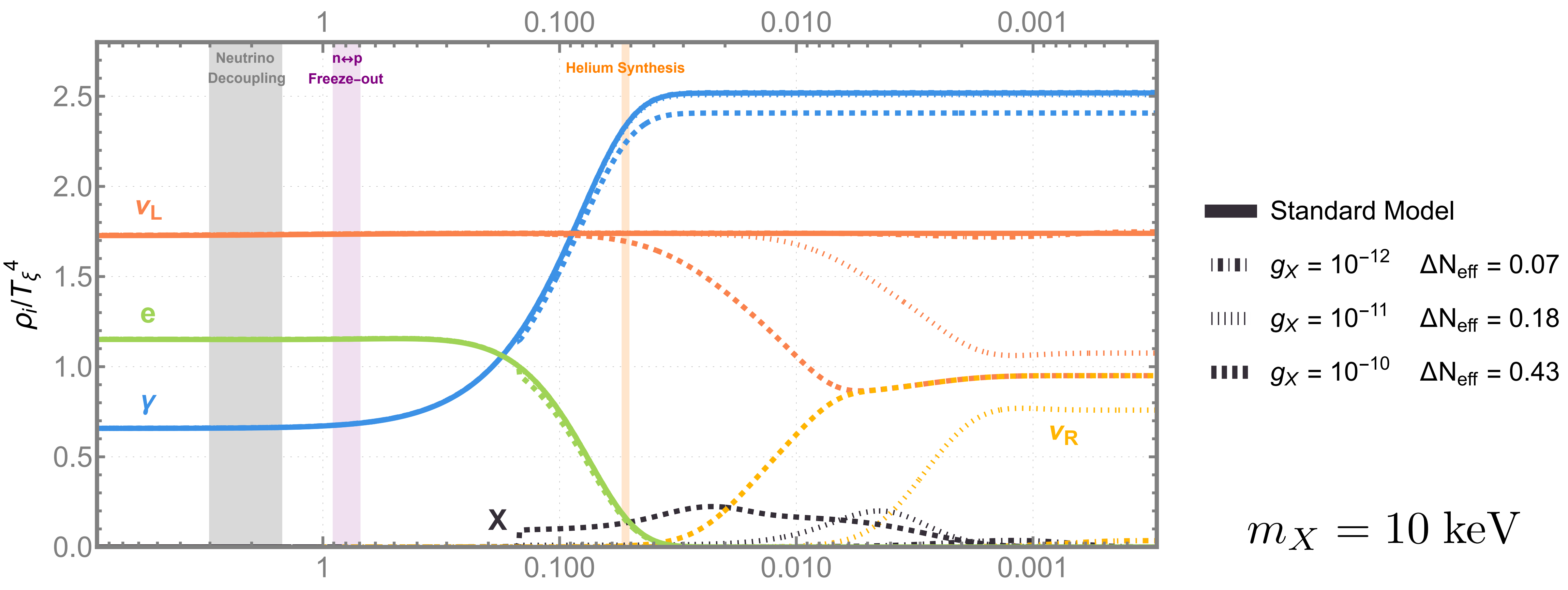

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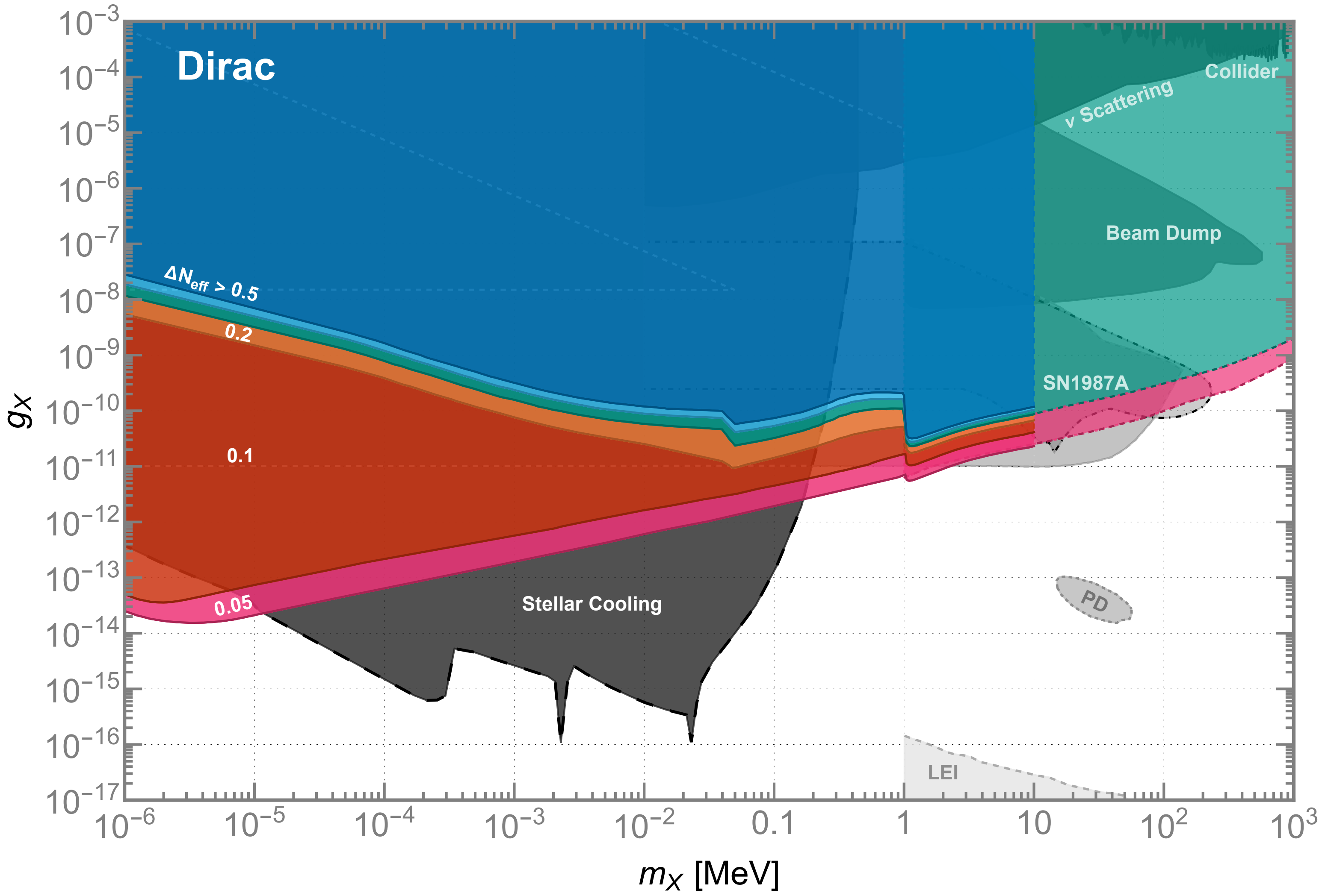

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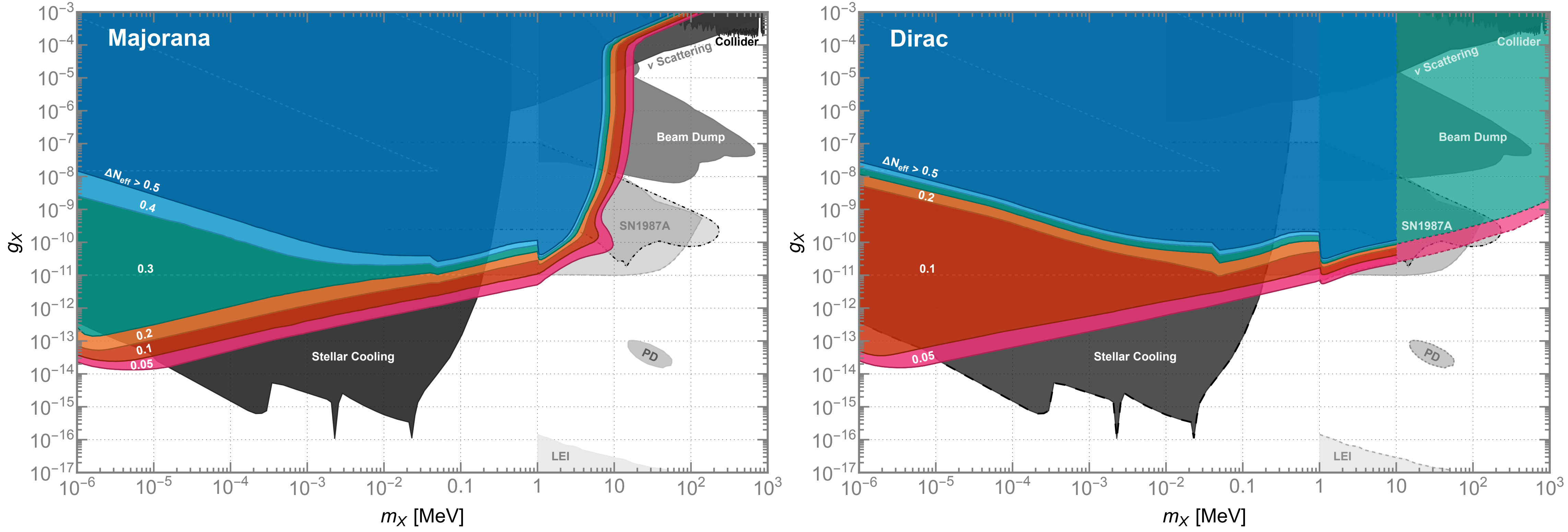

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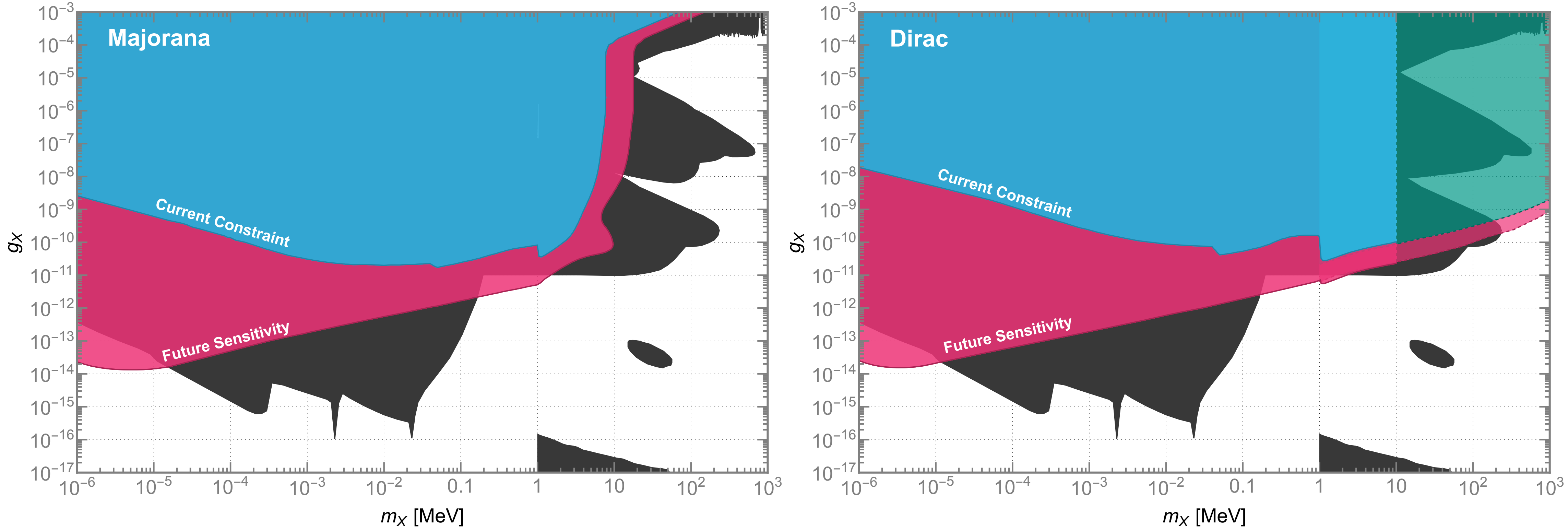


Additional Material

Cosmological Implications of Gauged $U(1)_{B-L}$ on ΔN_{eff} in the CMB & BBN

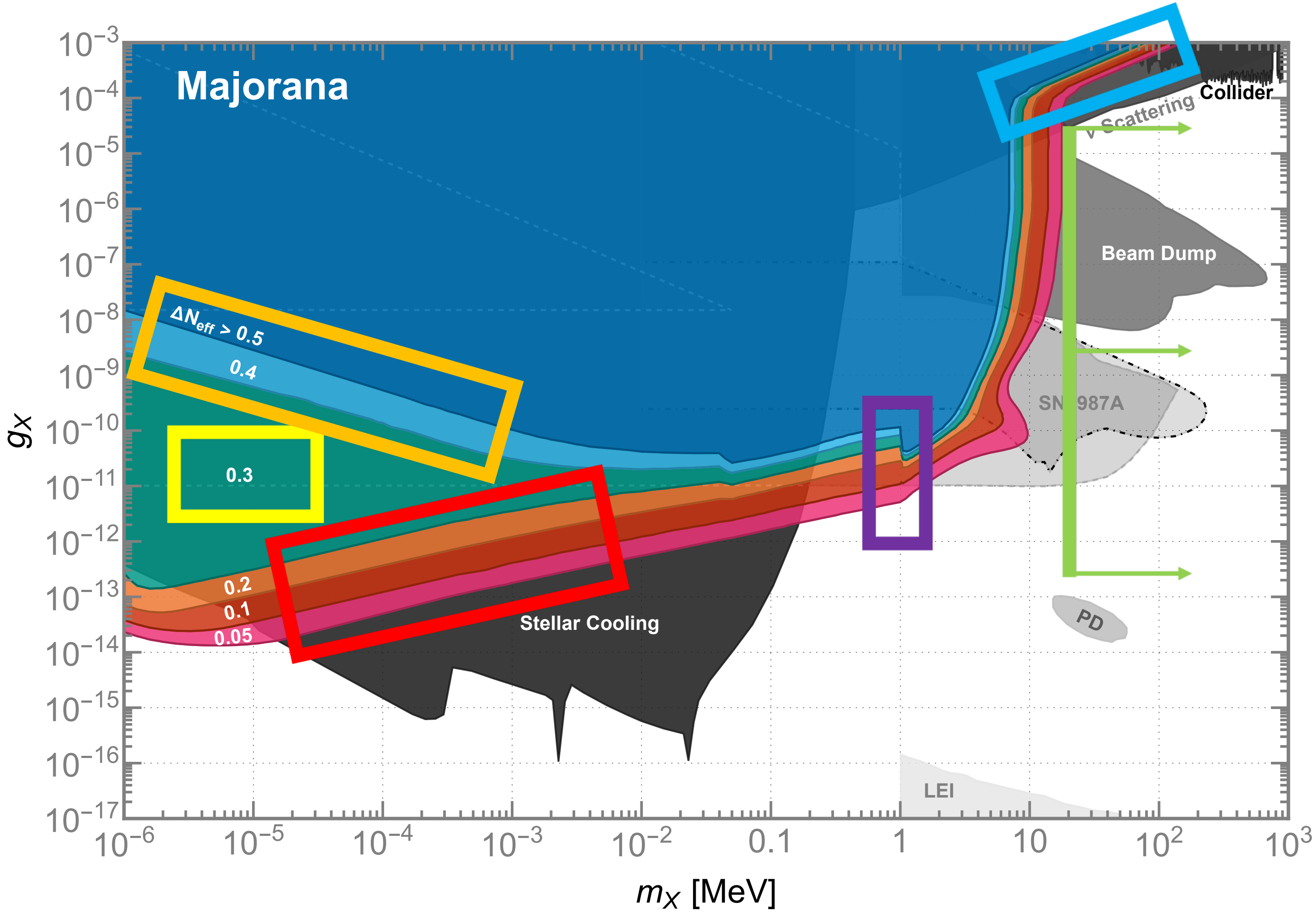
Finite temperature effects are important

X and neutrinos Thermalized, but

$$e^+e^- \leftrightarrow \gamma X$$

not efficient.

X and neutrinos thermalize if $\frac{\Gamma}{H} \sim 1$ at $T \sim m_X$ for smaller m_X, Hubble is smaller



$$e^+e^- \overset{X}{\leftrightarrow} \nu_L^i\bar{\nu}_L^i$$

comparable to

$$e^+e^- \underset{W,Z}{\leftrightarrow} \nu_L^i\bar{\nu}_L^i$$

around neutrino decoupling.

Decay back to SM before neutrino decoupling.

$$X \to e^+e^-$$

$$X \to \nu_L^i\bar{\nu}_L^i$$

$$X \to e^+e^-$$

kinematically accessible

Y_p

$n+\nu_e \leftrightarrow p+e^-$, $n+e^+ \leftrightarrow p+\bar{\nu}_e$, and $n \leftrightarrow p+e^-+\bar{\nu}_e$