Exponentially Light Dark Matter from Coannihilation

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Cargèse

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Coannihilation in a simple model

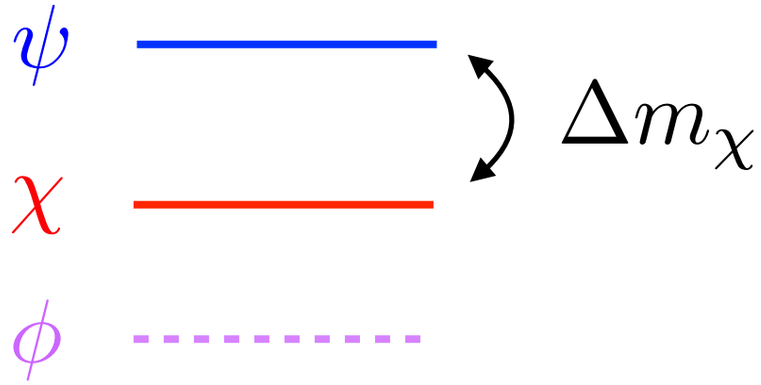
$$\mathcal{L} \supset -\frac{m_\phi^2}{2}\phi^2 - \frac{m_\psi}{2}\psi^2 - \frac{y}{2}\phi\psi^2$$

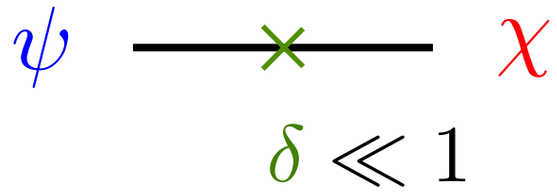
ψ ——————

ϕ - - - - - - - - -

Coannihilation in a simple model

$$\mathcal{L} \supset -\frac{m_\phi^2}{2}\phi^2 - \frac{m_\psi}{2}\psi^2 - \frac{y}{2}\phi\psi^2 - \frac{m_\chi}{2}\chi^2 - \delta m_\chi \chi\psi$$





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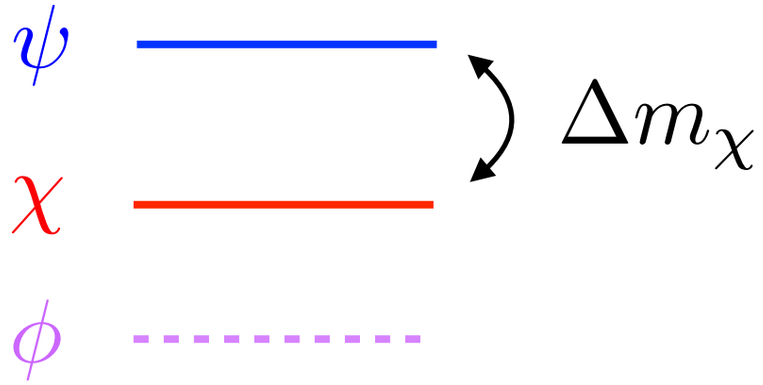
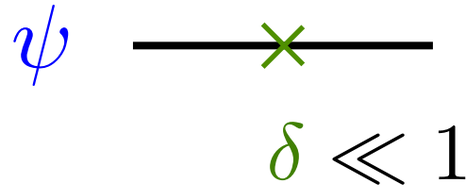
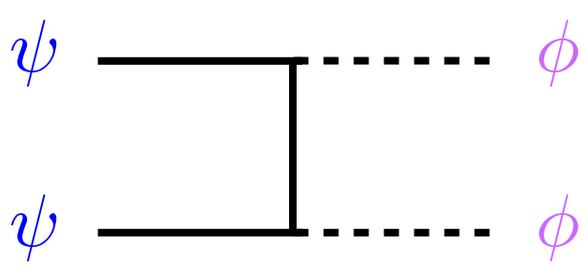
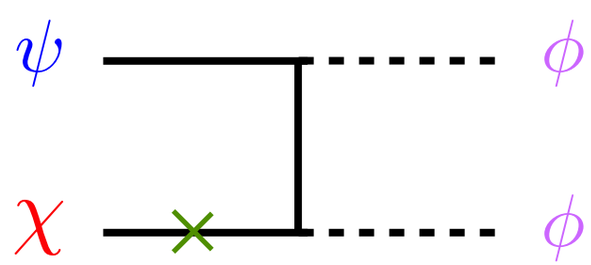




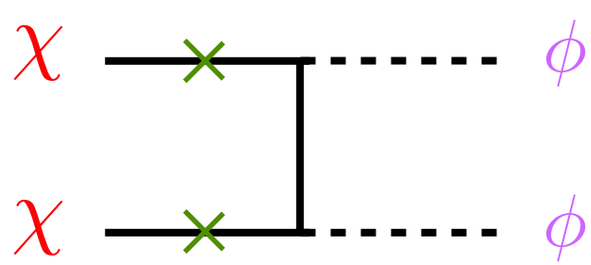
$\delta \ll 1$



$\langle \sigma_{\rm eff} v \rangle \propto \; e^{-2\Delta x_f}$



$\delta^2 e^{-\Delta x_f}$



δ^4

Coannihilation in a simple model

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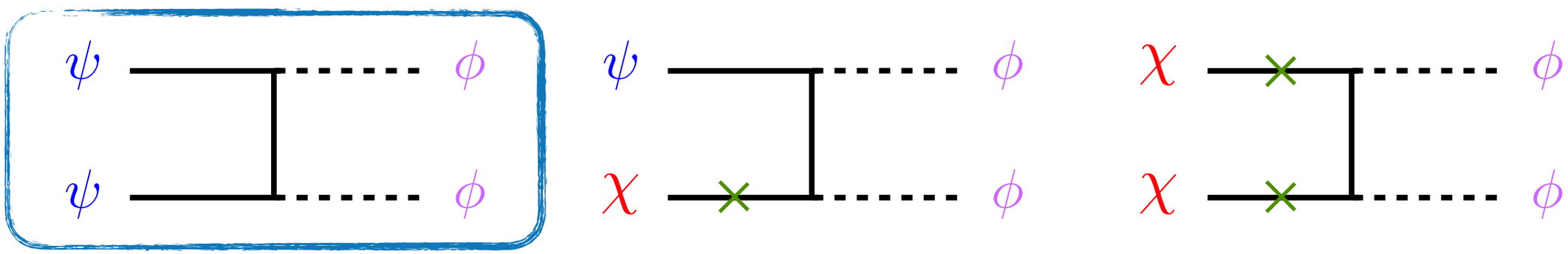
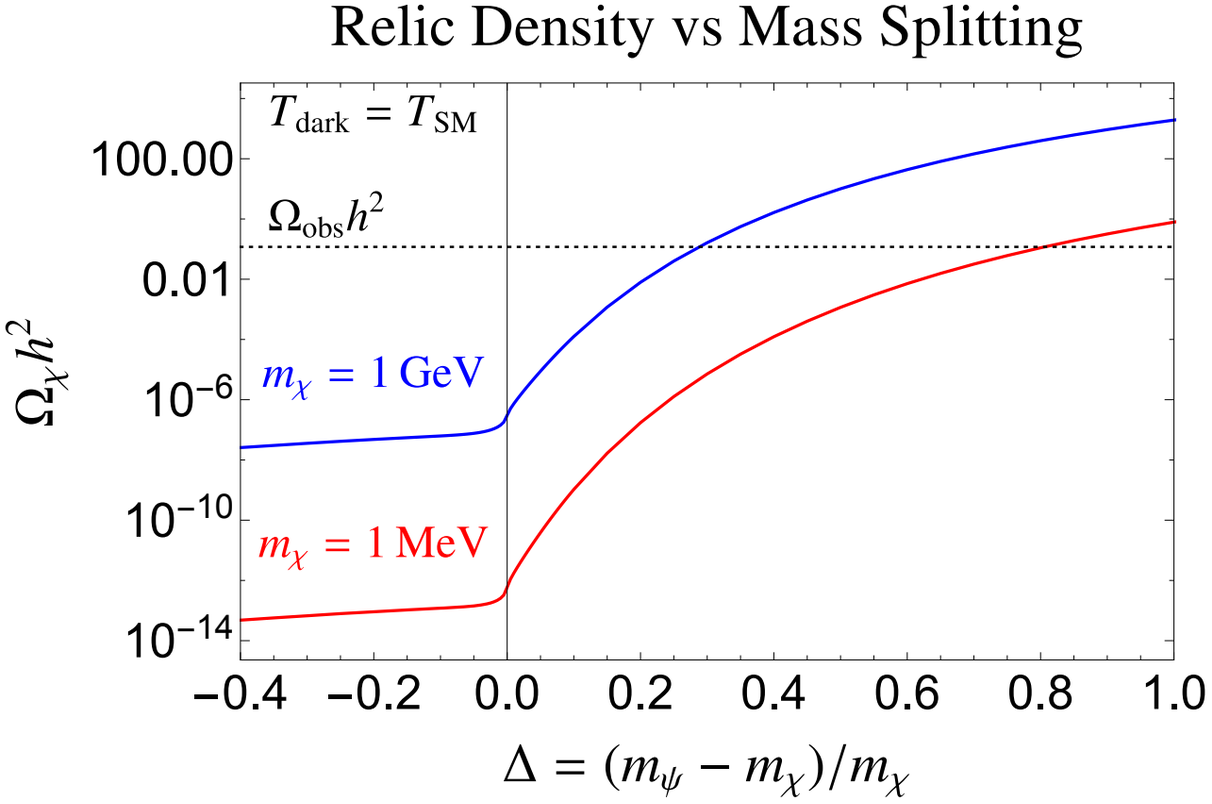
Sterile coannihilation: $\delta^2 \ll e^{-\Delta x_f}$



$\langle \sigma_{\rm eff} v \rangle \propto e^{-2\Delta x_f}$ $\quad \delta^2 e^{-\Delta x_f}$ $\quad \delta^4$

Sterile **coannihilation:**

$$\Omega_{\rm DM} h^2 \sim \frac{1}{T_{\rm EQ} M_{Pl} \left\langle \sigma_{\rm eff} v \right\rangle} \sim \frac{1}{T_{\rm EQ} M_{Pl}} \frac{e^{2\Delta x_f}}{\sigma_{\psi\psi}}$$



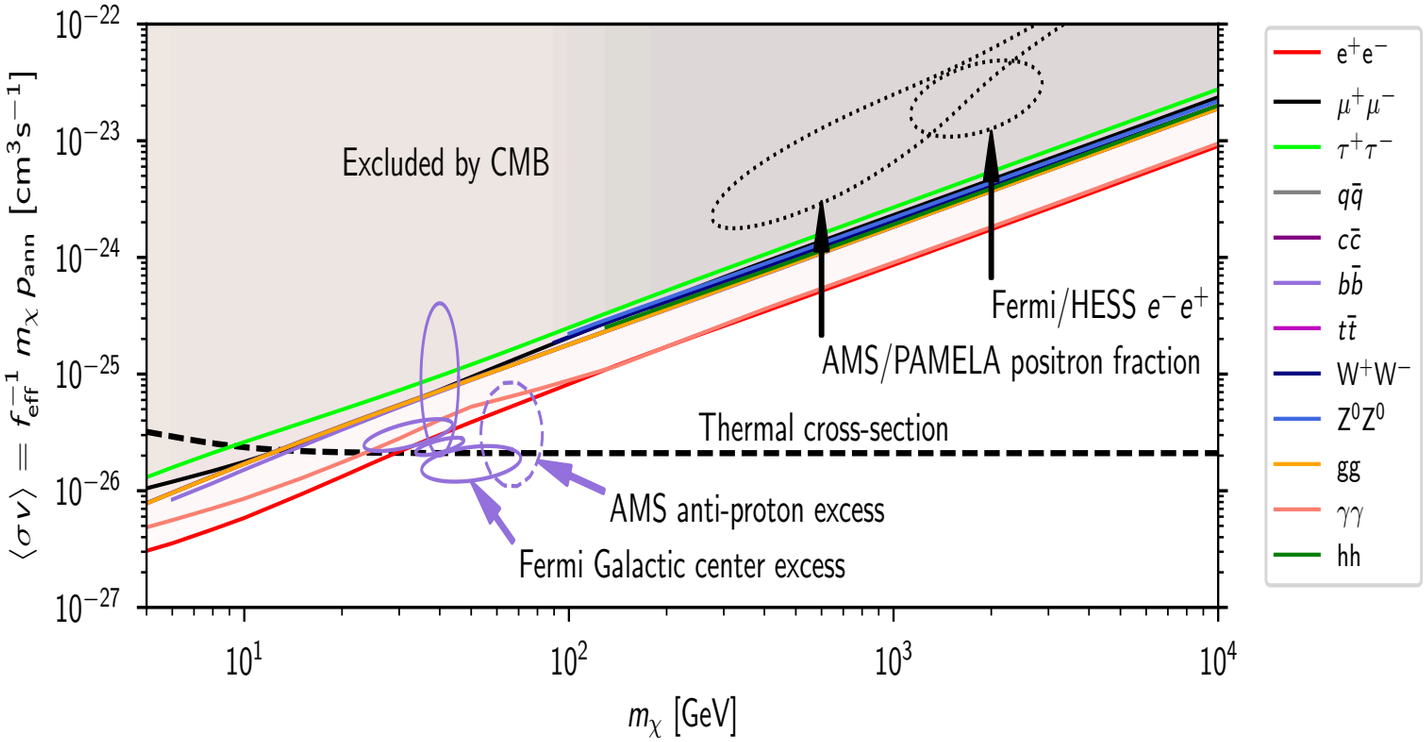
$$m_\chi \sim e^{-\Delta x_f} \sqrt{T_{\rm EQ} M_{Pl}}$$

Exponentially lighter than the weak scale

CMB

Planck collaboration, 2018

Excluded



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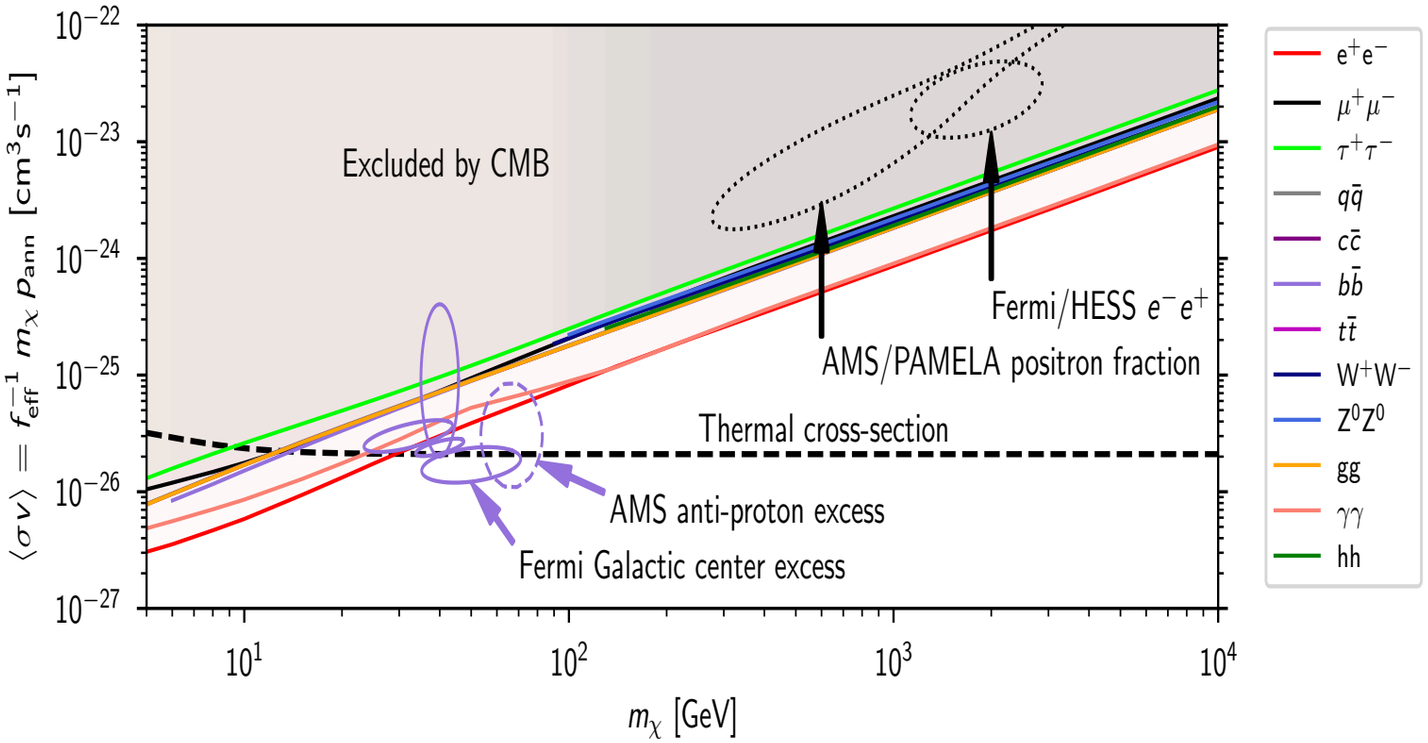
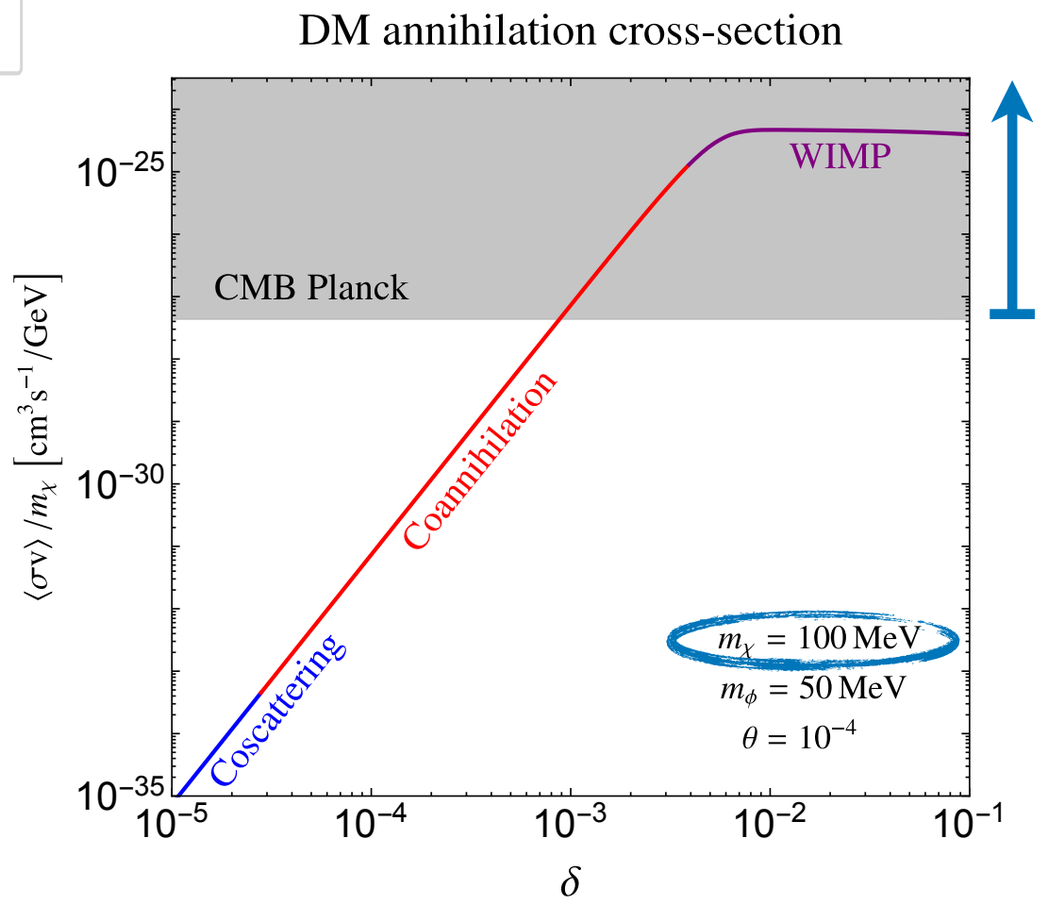


Naturally avoids the CMB bound for sub-GeV DM

***Sterile* coannihilation:** the relic density is insensitive to the DM coupling



Sterile coannihilation realizations

Annihilation to SM particles

Annihilation to Dark Sector (DS) particles

Sterile coannihilation realizations

Annihilation to SM particles

Annihilation to Dark Sector (DS) particles

Need coupling to radiation

$$T_{\rm DM} \sim a^{-1}$$

1. Introduce dark light degrees of freedom
   $\mathrm{T}_{\rm dark} \neq \mathrm{T}_{\rm SM}$

2. Couple the Dark Sector to the SM
   $\mathrm{T}_{\rm dark} = \mathrm{T}_{\rm SM}$

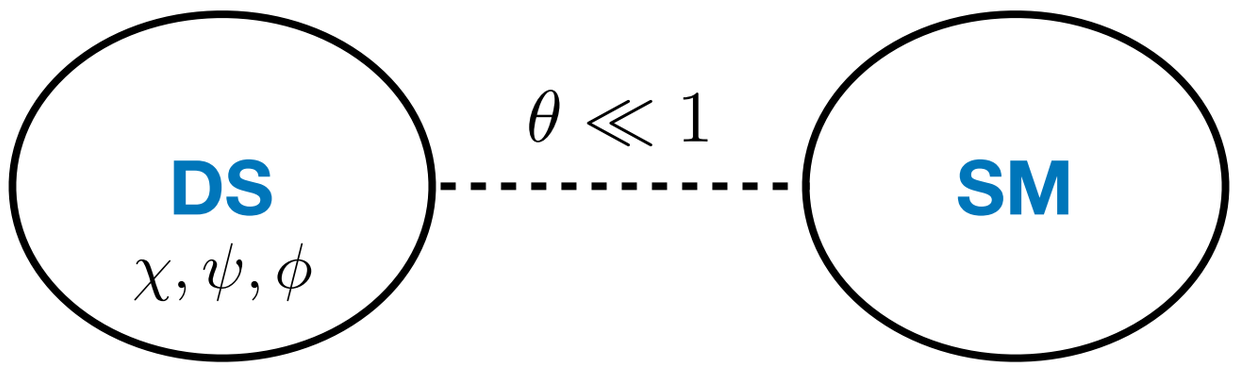
Backup

Coupling to the SM: Higgs portal

$$V \supset -\frac{m_H^2}{2} + \frac{\lambda}{4}|H|^4 + \frac{\mu_\phi^2}{2}\phi^2 + \frac{\lambda_\phi}{4!}\phi^4 + a_\phi \phi |H|^2$$

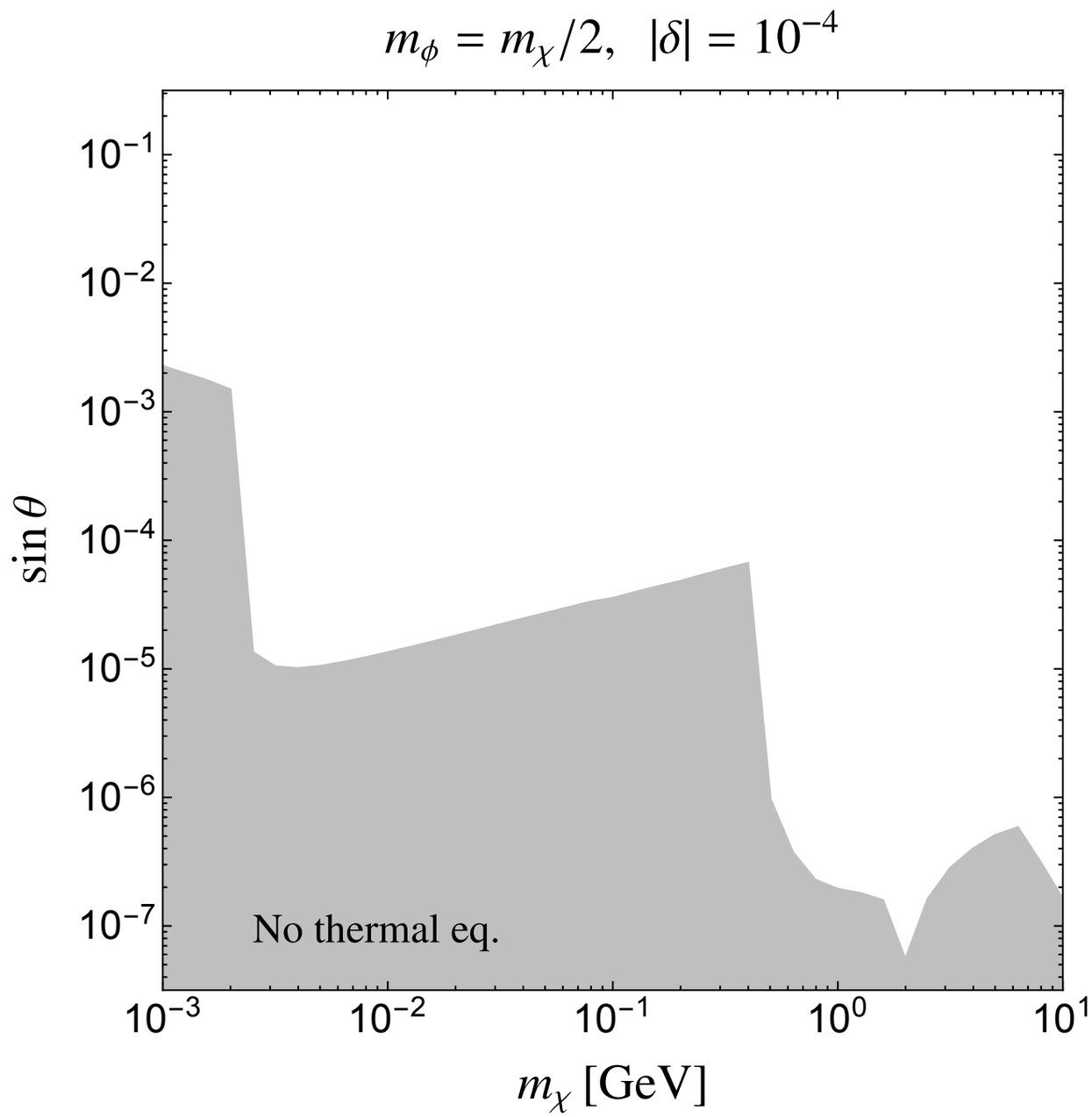
The DM scalar mixes with the SM Higgs

$$\tan 2\theta = \frac{4 a_\phi v}{\lambda v^2 - \lambda_\phi v_\phi^2 - 2\mu_\phi^2}$$



Higgs portal phenomenology

- Require DS and SM equilibrium at DM freeze-out



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- Require DS and SM equilibrium at DM freeze-out
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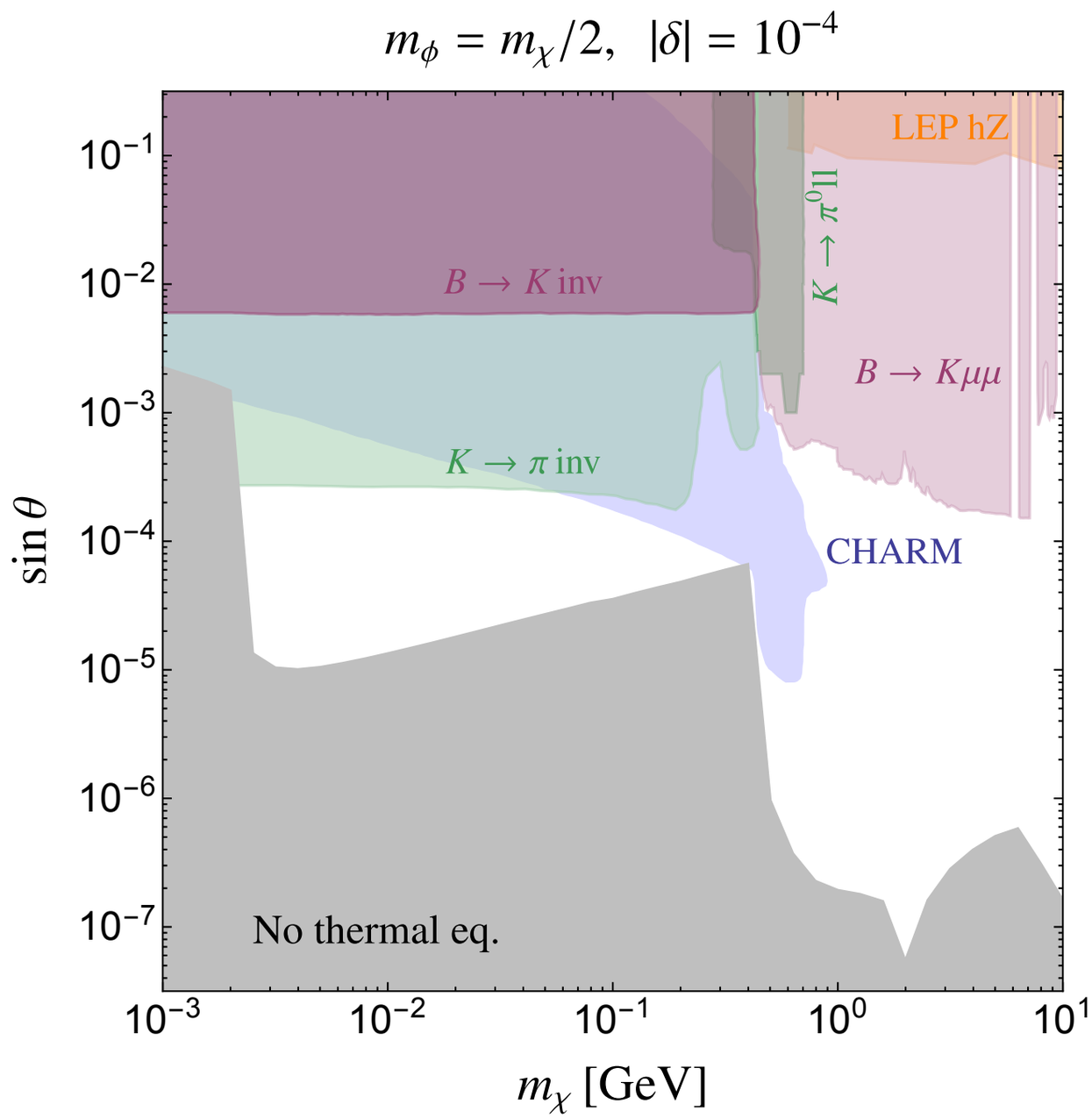
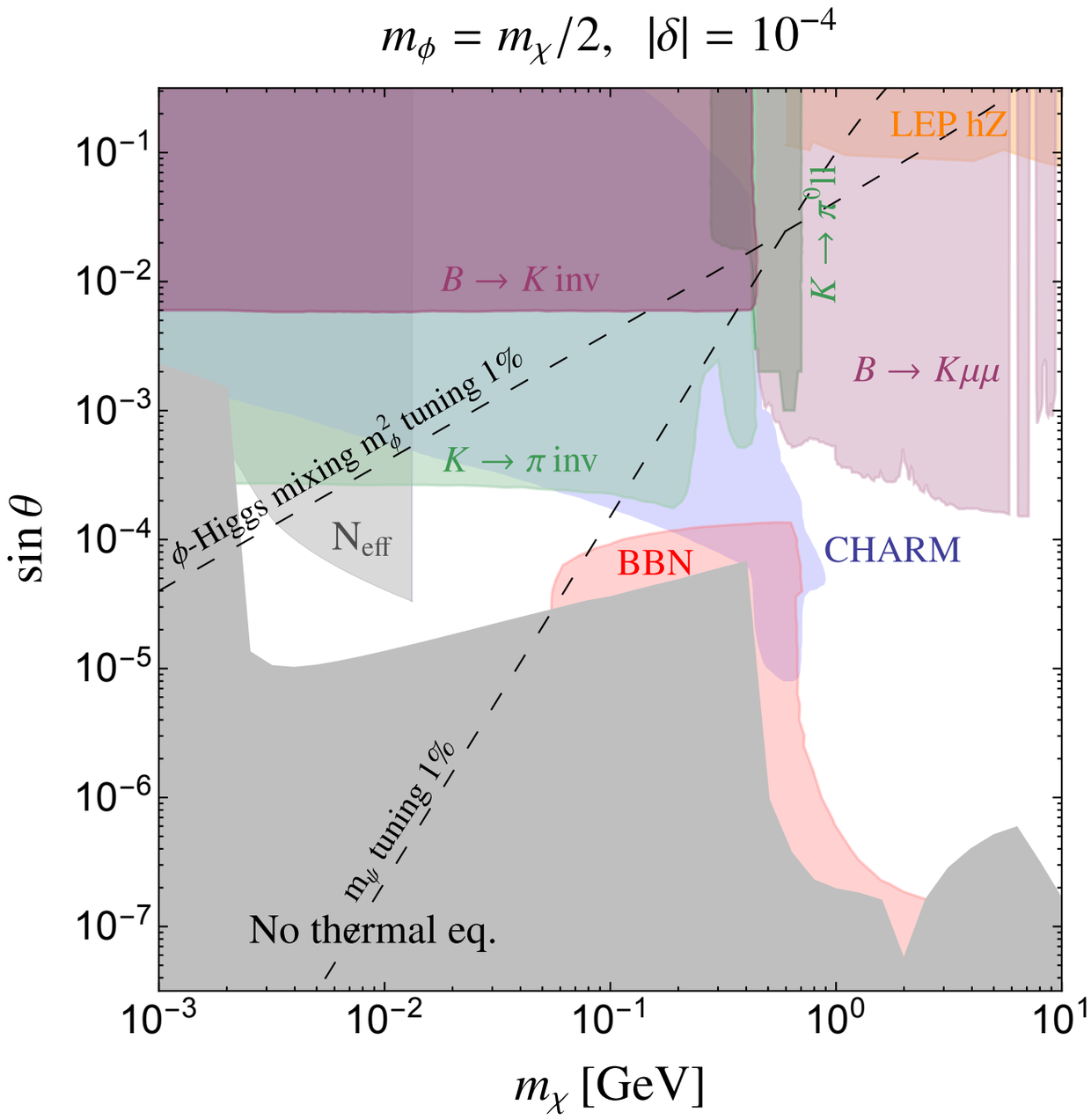


Higgs portal phenomenology

- Require DS and SM equilibrium at DM freeze-out
- Constraints from meson decays on the ϕ-Higgs mixing
- CMB constraints on light degrees of freedom ($N_{\rm eff}$)
- BBN constraints on late ψ decay



Higgs portal phenomenology

- Future experiments looking for long-lived ϕ can probe new parameter space