Probing freeze-in via invisible Higgs decay

Based on arXiv: 2409.XXXXX (In progress)

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Motivation

- **Explore Low Reheating Temperature Scenarios:** The absence of evidence imposing a high reheating temperature in the early Universe motivates the investigation of scenarios with low reheating temperatures;
- **Exploring the Light Dark Matter Region:** It is a region that has not been fully explored in previous studies, especially in the context of low reheating temperatures;
- **Exploring the Invisible Higgs Decay Window:** If the dark matter is light enough, the Higgs boson could decay invisibly into a pair of dark matter particles;

All Equations

Model

We assume that a scalar DM candidate S couples with SM particles via the Higgs portal, with the Lagrangian

$$\mathscr{L}_s = \left(\partial_\mu S\right)^2 + \frac{m_s^2}{2} S^2 + \frac{\lambda_{hs}}{2} H^\dagger H S^2 \,. \qquad (1)$$

Number density

The evolution of DM number density n is given by the Boltzmann equation,

$$\dot{n}_S + 3Hn_S = 2\Gamma(f\bar{f} \to SS) - 2\Gamma(SS \to f\bar{f})\,, \qquad (2)$$

where the factor 2 takes into account 2 particles.

Hadronic contribution

Winkler's approach

Decay and Detection of a Light Scalar Boson Mixing with the Higgs

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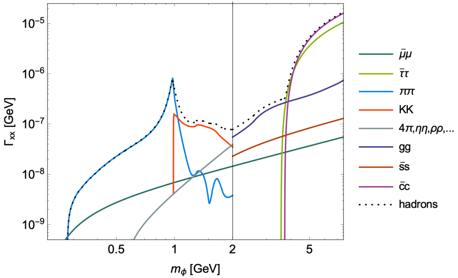

Dmitry's approach

Scalar decay into pions via Higgs portal

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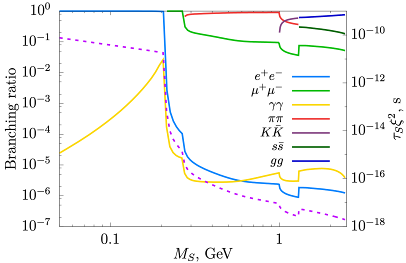
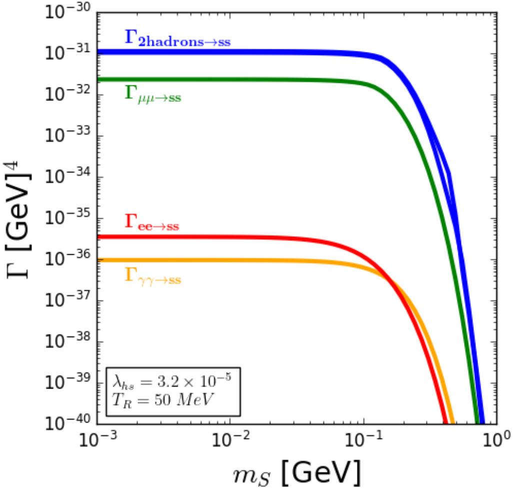
(Dated: July 23, 2024)

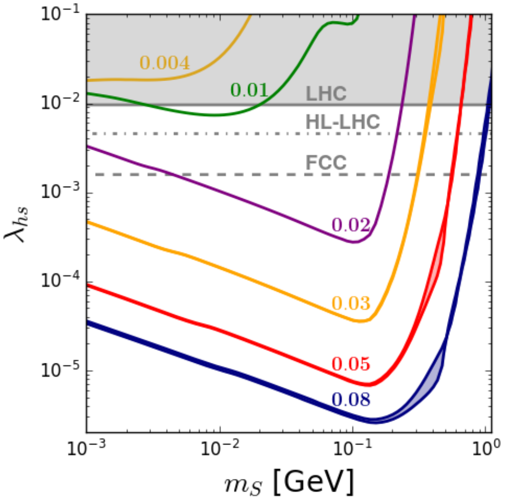


Contributions



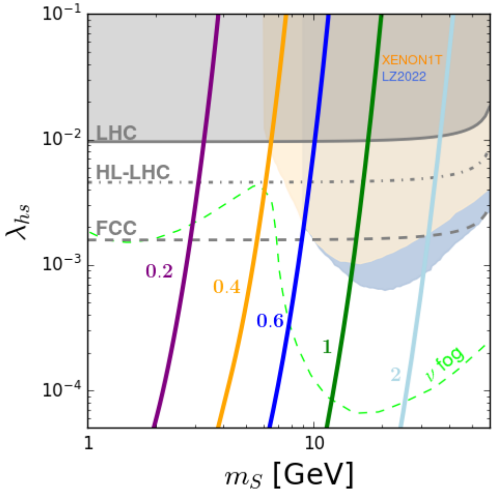
Light dark matter

$$BR_{\rm inv}^{\rm LHC} < 0.1\,,$$
$$BR_{\rm inv}^{\rm HL\text{-}LHC} < 0.025\,,$$
$$BR_{\rm inv}^{\rm FCC} < 0.003$$



Heavy dark matter

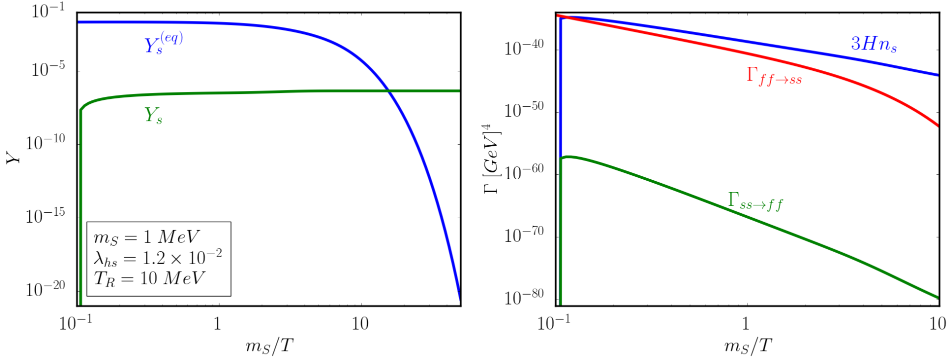
$$BR_{\text{inv}}^{\text{LHC}} < 0.1\,,$$
$$BR_{\text{inv}}^{\text{HL-LHC}} < 0.025\,,$$
$$BR_{\text{inv}}^{\text{FCC}} < 0.003$$



Thermalization

Thermalization conditions:

$$Y_S(T) = Y_S^{(\mathrm{eq})}(T) \quad \text{and/or} \quad \Gamma_{ff\to ss}(T) = \Gamma_{ss\to ff}(T) \quad \text{for some } T\,. \tag{3}$$



Thank you for listening !

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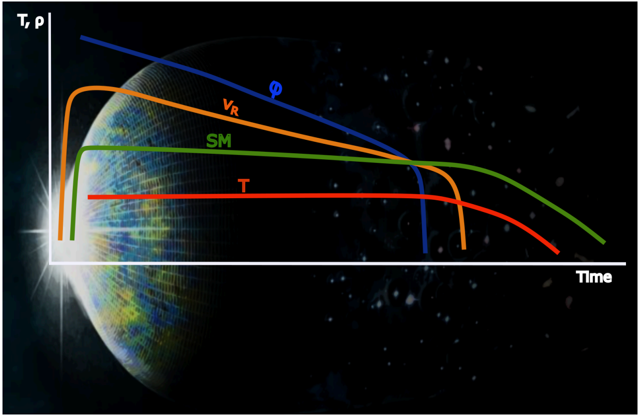
BackUp!

Cosmological History (following: arXiv:2402.04743)



Number density

The evolution of DM number density n is given by the Boltzmann equation,

$$\dot{n}_S + 3Hn_S = 2\Gamma(f\bar{f} \to SS) - 2\Gamma(SS \to f\bar{f})\,, \tag{4}$$

where the factor 2 takes into account 2 particles.

Rate of interaction

The Γ for the process $f\bar{f} \to SS$ is defined as

$$\Gamma(f\bar{f} \to SS) = \langle \sigma v_r \rangle \, n_f^{(\mathrm{eq})2} \tag{5}$$

$$= \frac{T}{32\pi^4} \int_{\max(4m_f^2, 4m_S^2)} ds \sigma_{f\bar{f} \to SS} (s - 4m_f^2) \sqrt{s} K_1 \left(\frac{\sqrt{s}}{T} \right). \tag{6}$$

Boltzmann Equation

To make the Boltzmann equation more manageable, it is useful to express it in terms of $Y_s \equiv n_s/s$,

$$\frac{dY_s}{dx} = 2\sqrt{\frac{8\pi^2 M_{\rm Pl}^2}{45}}\frac{g_*^{1/2} m_s}{x^2}\sum_{X=\rm SM}\langle\sigma_{X\bar{X}\to ss}v\rangle Y_X^{(\rm eq)2}\times\left[1-\left(\frac{Y_s}{Y_s^{(\rm eq)}}\right)^2\right], \tag{7}$$

where the initial condition is $Y_s\left(\frac{m_s}{T_R}\right) = 0$.

Hadronic contribution

If we assume:

- $f(p_1)f(p_2) = f(p_3)f(p_4) = e^{-(E_1+E_2)/T}$
- $|\mathcal{M}_{2\text{SM}\to 2\text{DM}}|^2 = |\mathcal{M}_{2\text{DM}\to 2\text{SM}}|^2$
- $|\mathcal{M}_{ss\to ff}|^2 = |\mathcal{M}_{ss\to h}|^2 \frac{1}{(s-m_h^2)^2} |\mathcal{M}_{h\to ff}|^2$

We obtain

$$\Gamma_{ff\to ss} = \Gamma_{ss\to ff} = \frac{\lambda_{hs}^2 v^2 T}{2^6 \pi^4 m_h^4} \times \int_{4m_s^2}^{\infty} ds \sqrt{s} \sqrt{s - 4m_s^2} K_1\left(\frac{\sqrt{s}}{T}\right) \times \Gamma_h(m_h = \sqrt{s}) \,. \tag{8}$$