Freeze-in Dark Matter Through Forbidden Channel in $U(1)_{B-L}$

Sudipta Show

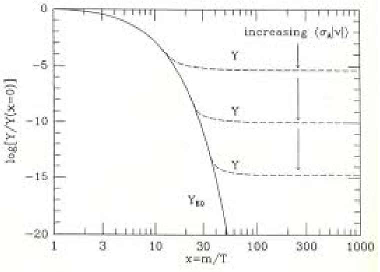
Based on: arXiv:2110.14411

Collaboration with Partha Konar and Rishav Roshan

November 10, 2021

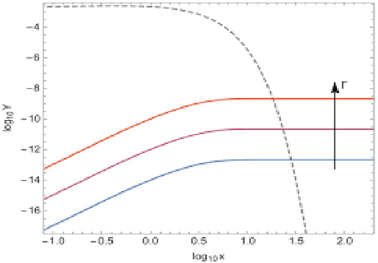
Introduction

WIMP



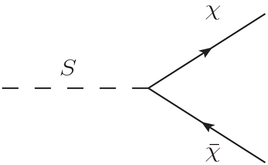
- DM was in thermal equllibrium with the SM particles in the early Universe.
- Freeze out occurs when $\Gamma \simeq H$ and DM abundance remains unchanged.

FIMP



- Interaction of DM with SM is very feeble and never thermalizes with the bath $(\Gamma \ll H)$.
- Produces gradually from the scattering and/or decays of the bath particles.

Thermal effects in Freeze-in



$$\mathcal{L}_{int} = yS\bar{\chi}\chi$$

- So the production of dark matter is possible only if $m_S > 2m_\chi$. Now question is if $m_S < 2m_\chi$, can we produce dark matter ?
- Since S is in thermal equllibrium, it can develop large thermal mass in the early Universe such that $M_S(T) > 2m\chi$.
- Incorporation of thermal mass, can open up the forbidden channel and produce dark matter. It is dubbed as forbidden freeze-in of dark matter.

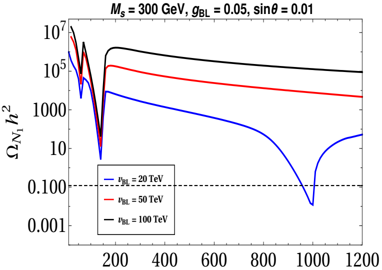
$U(1)_{B-L}$ model

Charges of BSM fields under SM $\times\, U(1)_{B-L} \times \mathbb{Z}_2$

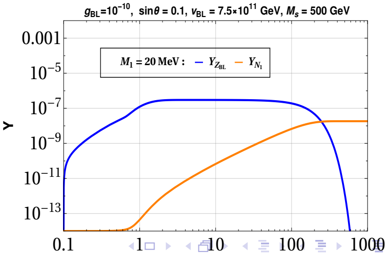
Field	$SU(2)_L \times U(1)_Y$	Y_{BL}	$\mathbb{Z}_2$
N_1	(1, 0)	-1	$-$
N_2, N_3	(1, 0)	-1	$+$
S	(1, 0)	2	$+$

This model can address dark matter, neutrino mass and matter-antimatter asymmetry.

N_1 as WIMP



N_1 as FIMP



- The relevant terms of the Lagrangian for BSM fields

$$\mathcal{L} \supset |D_\mu S|^2 + \sum_{i=1,2,3} \bar{N}_i i\gamma^\mu D_\mu N_i - y_{11}\bar{N}_1^c N_1 S - y_{\alpha\beta}\bar{N}_\alpha^c N_\beta S$$

- After the $B-L$ breaking the masses of the dark scalar, the gauge boson Z_{BL} RHNs

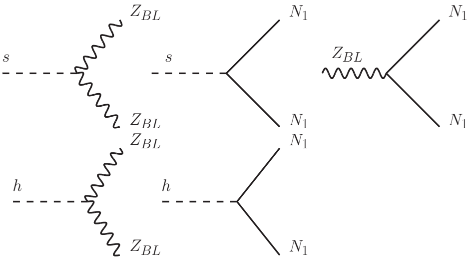
$$m_S^2 = 2\lambda_S v_{BL}^2, \quad M_{Z_{BL}} = 2g_{BL}v_{BL}, \quad M_i = \sqrt{2}\, y_{ii}v_{BL}.$$

- We also assume $y_{22} \simeq y_{33} = y$. The sets of independent parameters for DM phenomenology:

$$\{m_s, M_1, y, v_{BL}, g_{BL}, s_\theta\}.$$

DM phenomenology

Possible production channels of Z_{BL} and the DM (N_1).



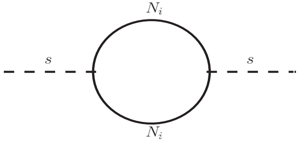
The Boltzmann equations are given by

$$\frac{dY_{Z_{BL}}}{dx} = \frac{1}{Hx}\left[\theta(M_s(m_s/x) - 2M_{Z_{BL}})\,\langle\Gamma_{s\to Z_{BL}Z_{BL}}\rangle\, Y_s^{EQ} - \langle\Gamma_{Z_{BL}\to\ all}\rangle Y_{Z_{BL}}\right], \quad (1)$$

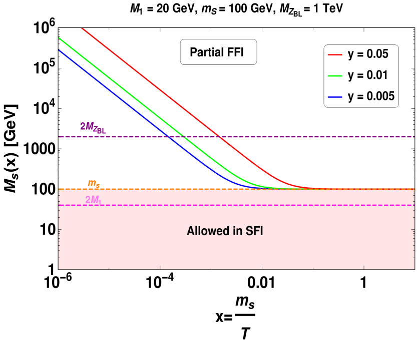
$$\frac{dY_{N_1}}{dx} = \frac{1}{Hx}\left[\langle\Gamma_{Z_{BL}\to N_1 N_1}\rangle Y_{Z_{BL}} + \theta(M_s(m_s/x) - 2M_1)\,\langle\Gamma_{s\to N_1 N_1}\rangle\, Y_s^{EQ}\right], \quad (2)$$

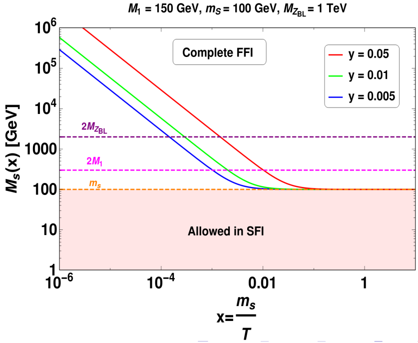
Effects of thermal mass

One-loop diagram dominantly contributes to thermal mass of s.

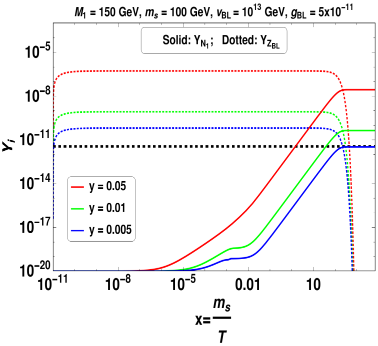


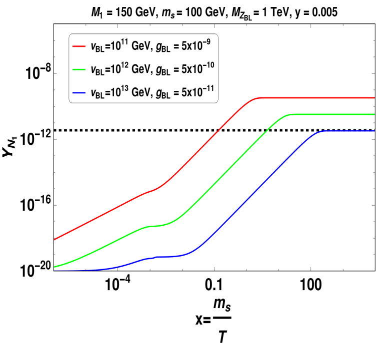
where, $M_s(T) = \sqrt{m_s^2 + \Pi_s^2(T) + \Pi_H^2(T) + \Pi_{Z_{BL}}^2(T) + \Pi_{N_i}^2(T)}$





Decay-Channels	SFI	FFI
$s \to Z_{BL} Z_{BL}$	X	✓
$s \to N_1 N_1$	X	✓
$Z_{BL} \to N_1 N_1$	X	✓





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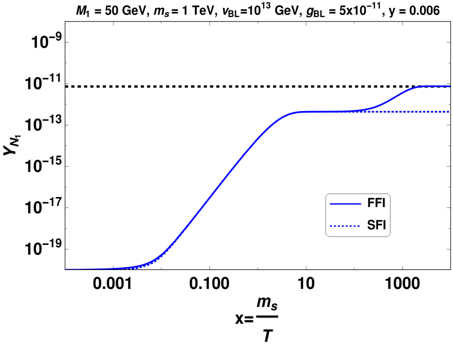

Conclusion

- We study a picture where the forbidden freeze-in production of dark matter occurs in the presence of significant thermal mass.
- We also discuss that production of Z_{BL} in FFI helps to distinguish it from SFI scenario.
- FFI actually enhances the parameter space of dark matter by allowing the disallowed region.

Thank You