

Secluded Dark Matter in Gauged $B - L$ Model

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Motivation

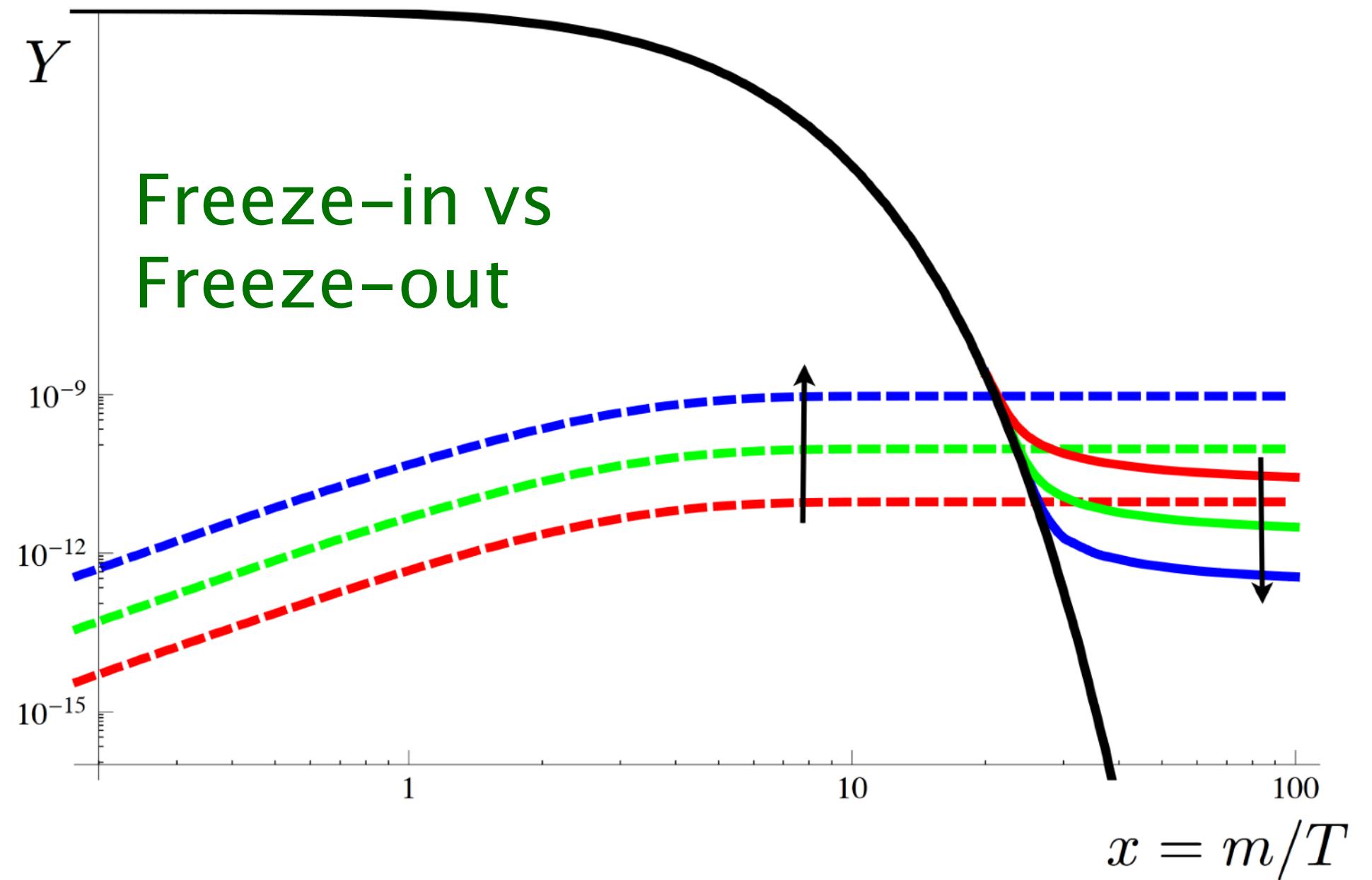
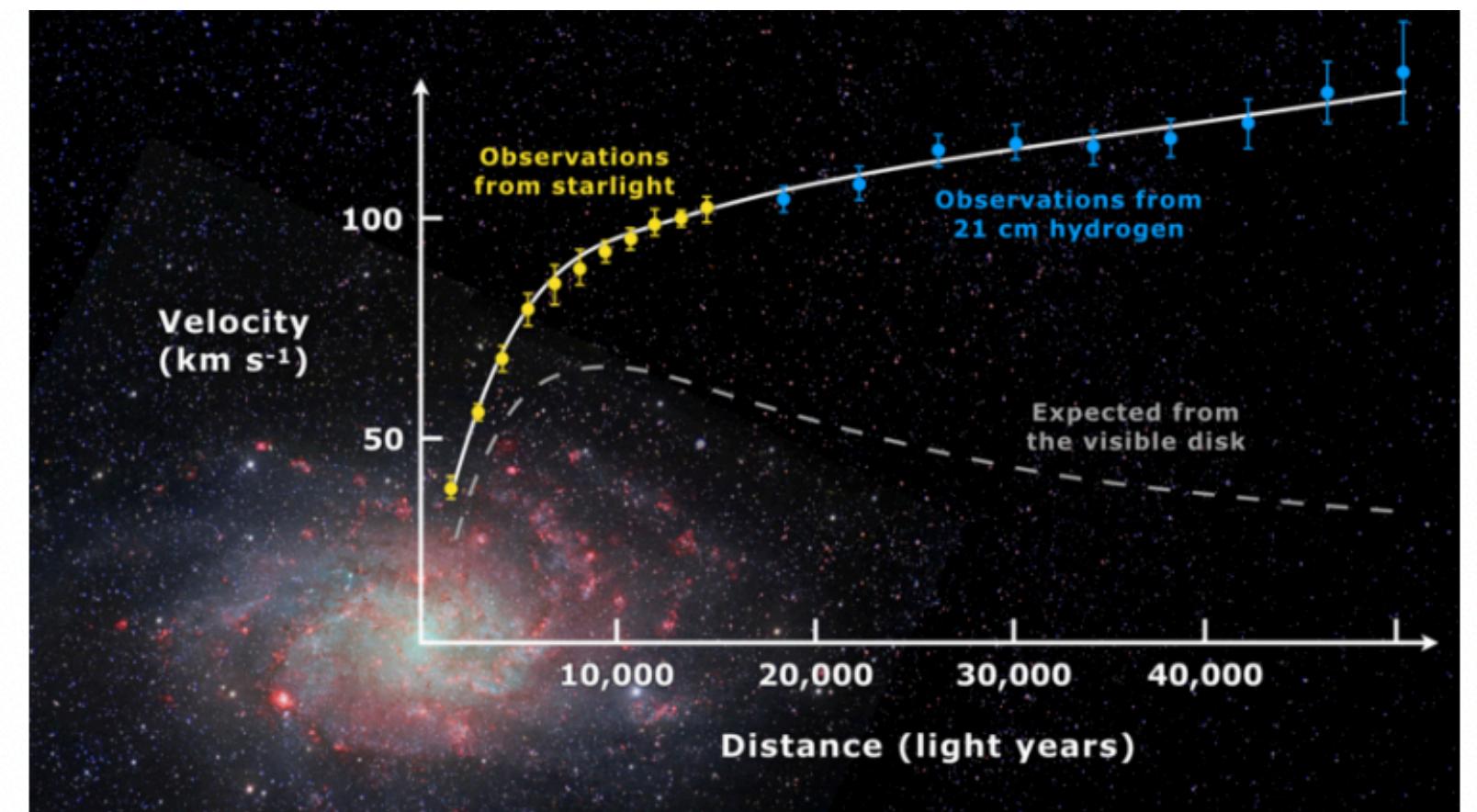
- Evidence of Dark matter: Rotation curves, Bullet cluster, CMB, gravitational lensing..
- No viable DM candidate in Standard Model
- Several hypothesis: WIMPs, FIMPs, SIMPs, Axion etc.

WIMPs : Most popular theory.
No signal although explored by several dedicated experiments

FIMPs:

McDonald(J. hep-ph/0106249), L.J.Hall et al (0911.1120)

- a Feebly Interacting Massive Particles is motivated. Easily evade strong direct detection bound because of tiny coupling with thermal bath
- **Freeze-in mechanism:** production of FIMPs from decay or annihilation of bath particle. Production “freezes-in” when number density of parent particle becomes Boltzmann suppressed
- Decoupled from the thermal bath due to the feeble interaction
- Initial abundance is negligible



Extended $U(1)_{B-L}$ Model

A framework to address the eV scale light neutrino mass and dark matter relic density

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

	h	N	L	Q	u_R	d_R	e_R	S	ϕ_D	χ
Y_{B-L}	0	-1	-1	1/3	1/3	1/3	1	2	1	0
Z_2	1	1	1	1	1	1	1	1	-1	-1

Z_2 symmetry ensure stability of DM

Dark Matter

super-WIMP

$H_1 \rightarrow$ SM Higgs, $H_2 \rightarrow$ BSM Higgs

$Z_{BL} \rightarrow$ BSM gauge boson, $N \rightarrow$ right handed neutrino

$$\mathcal{L}_{DM} = \bar{\chi}(\partial - m_\chi)\chi + (D^\mu \phi_D)^\dagger (D_\mu \phi_D) - \mu_D^2 (\phi_D^\dagger \phi_D) - \lambda_D (\phi_D^\dagger \phi_D)^2$$

$$-\lambda_{Dh} (\phi_D^\dagger \phi_D) (h^\dagger h) - \lambda_{SD} (\phi_D^\dagger \phi_D) (S^\dagger S) - (Y_{D\chi} \bar{\chi} \phi_D N + h.c.) .$$

interaction ϕ_D with visible sector scalars

Portal interaction of χ

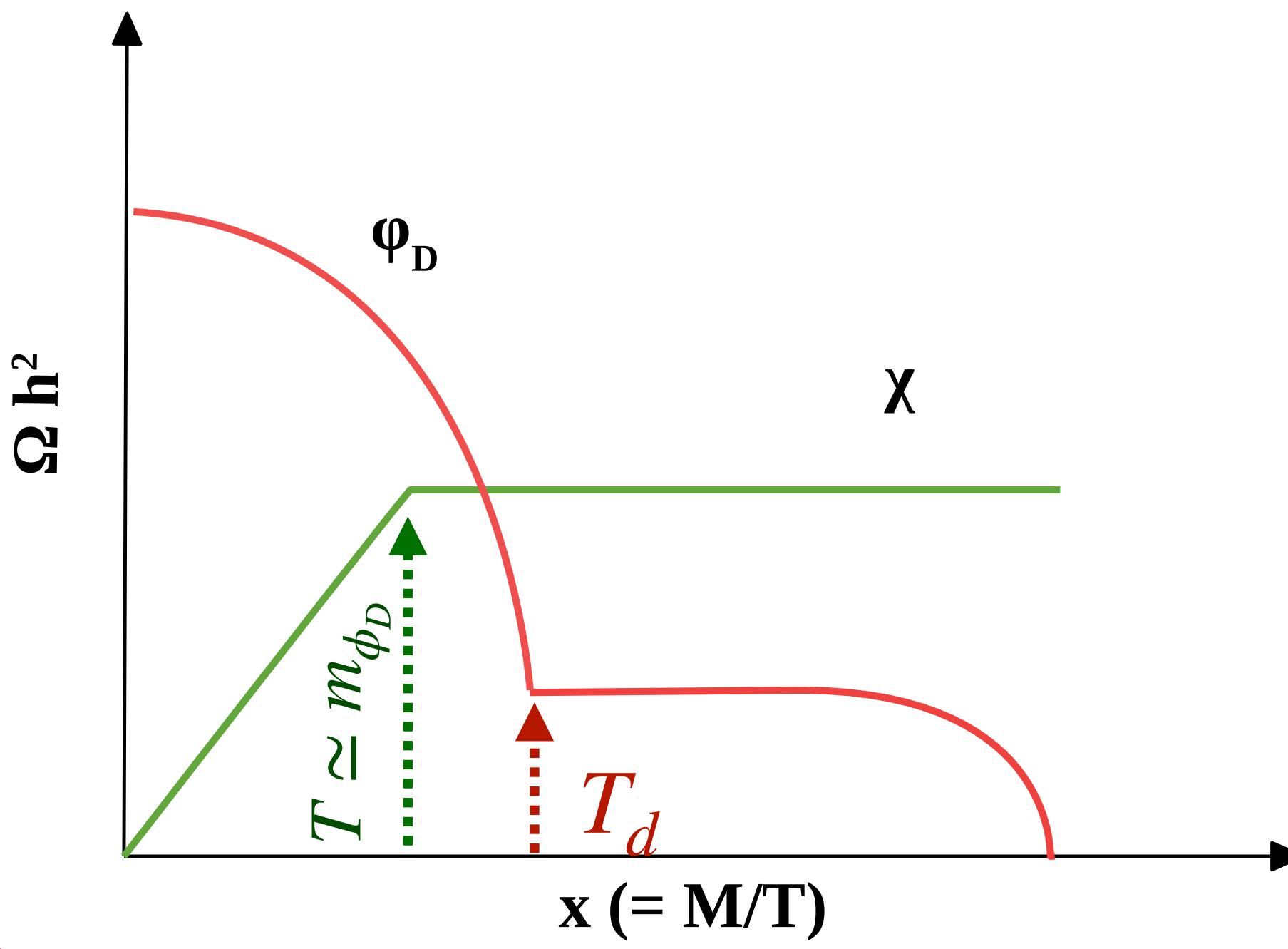
$$Y_{D\chi} = \mathcal{O}(10^{-10})$$

E. Molinaro (1405.1259),
M. Garny (1809.10135)
L. Covi (hep-ph/9905212)
J. L. Feng (hep-ph/0306024)

Freeze-in vs super-WIMP

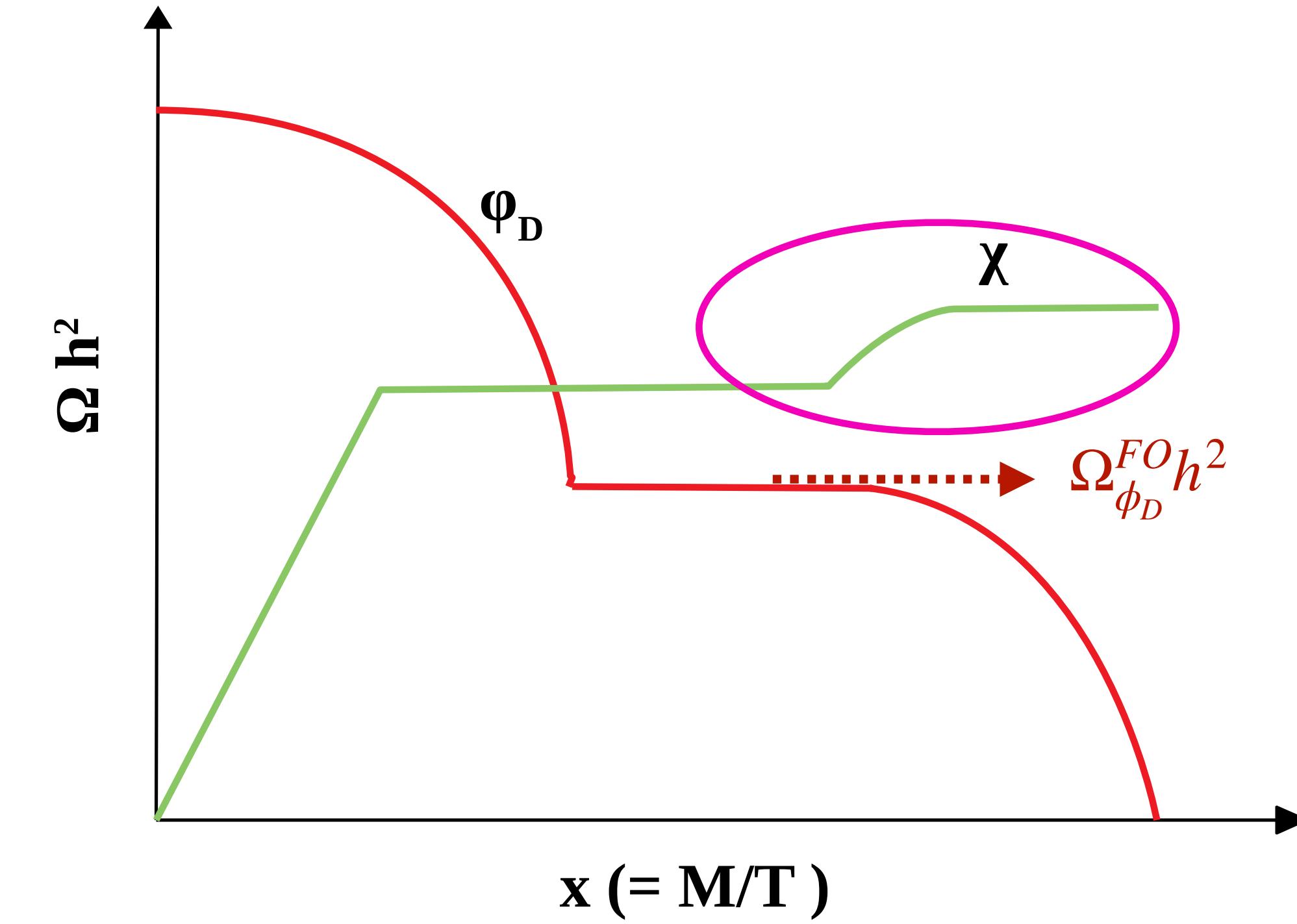
Freeze-in mechanism:

- FIMP χ never attains thermal equilibrium due to tiny portal coupling $Y_{D\chi}$
- produced from the decay and/or annihilation of SM/BSM particles in thermal plasma

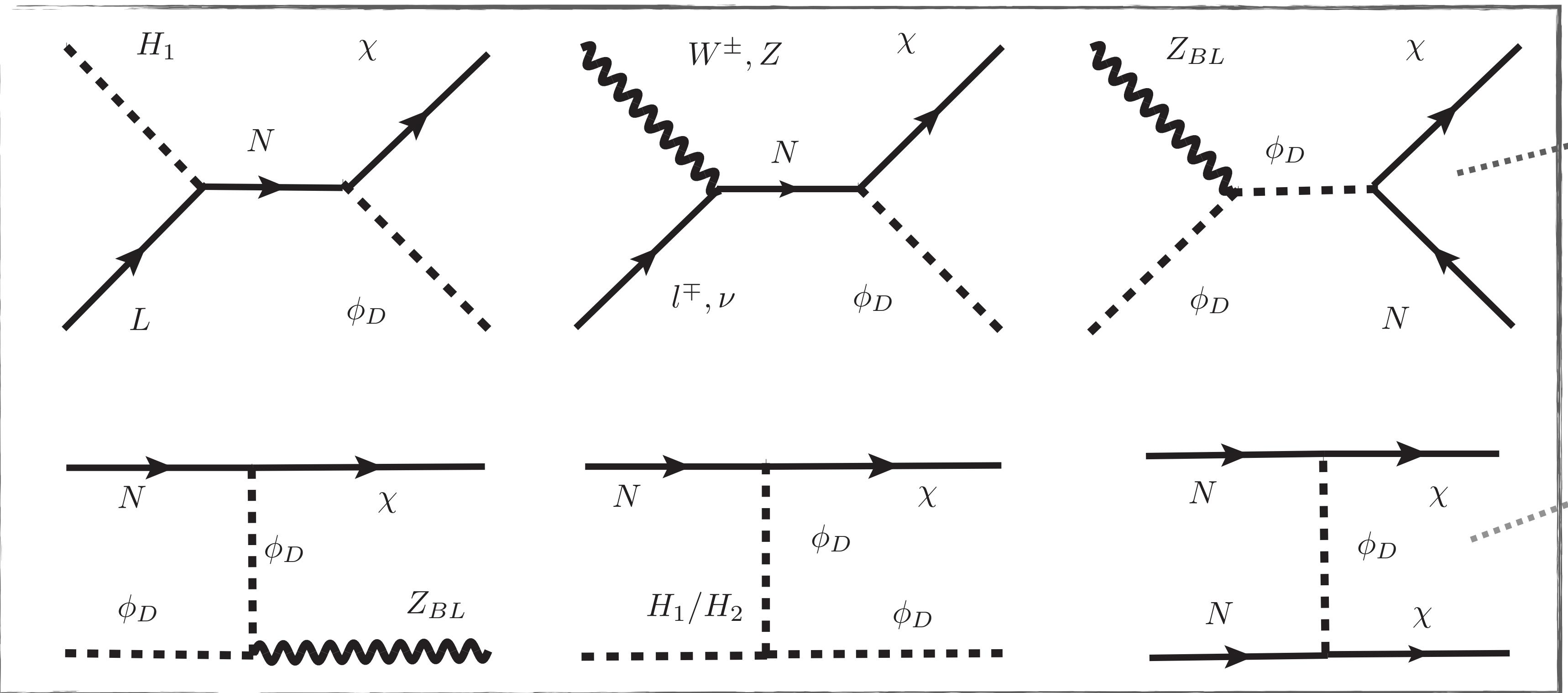


super-WIMP mechanism:

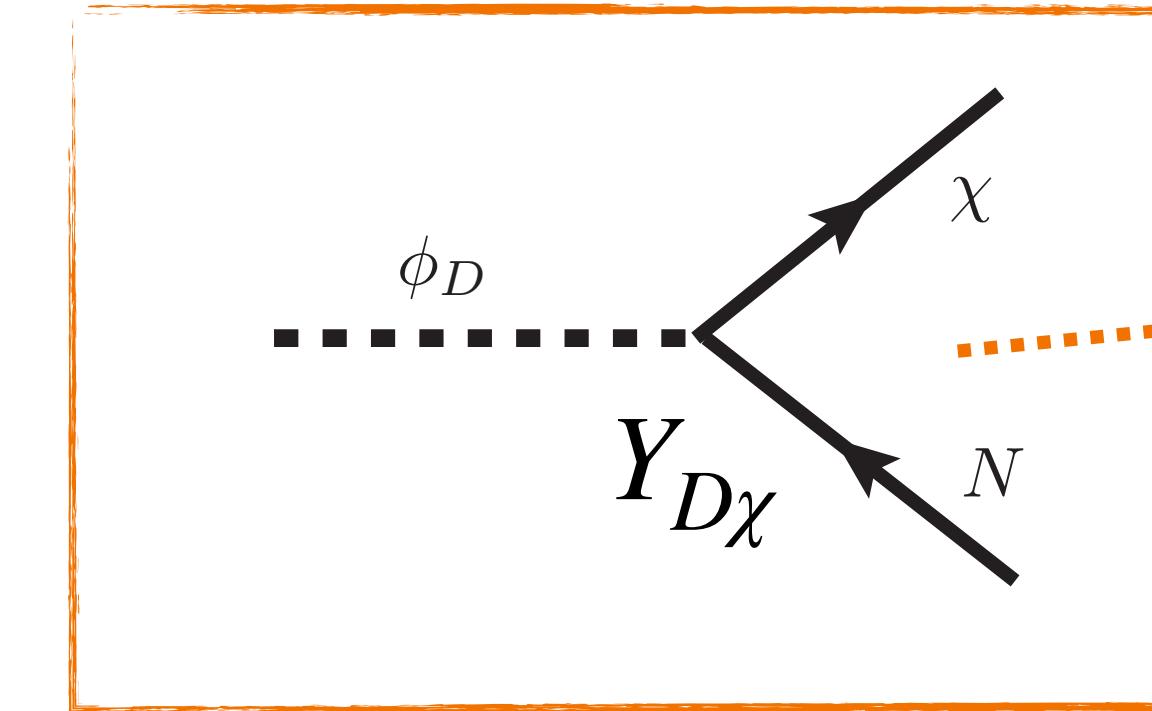
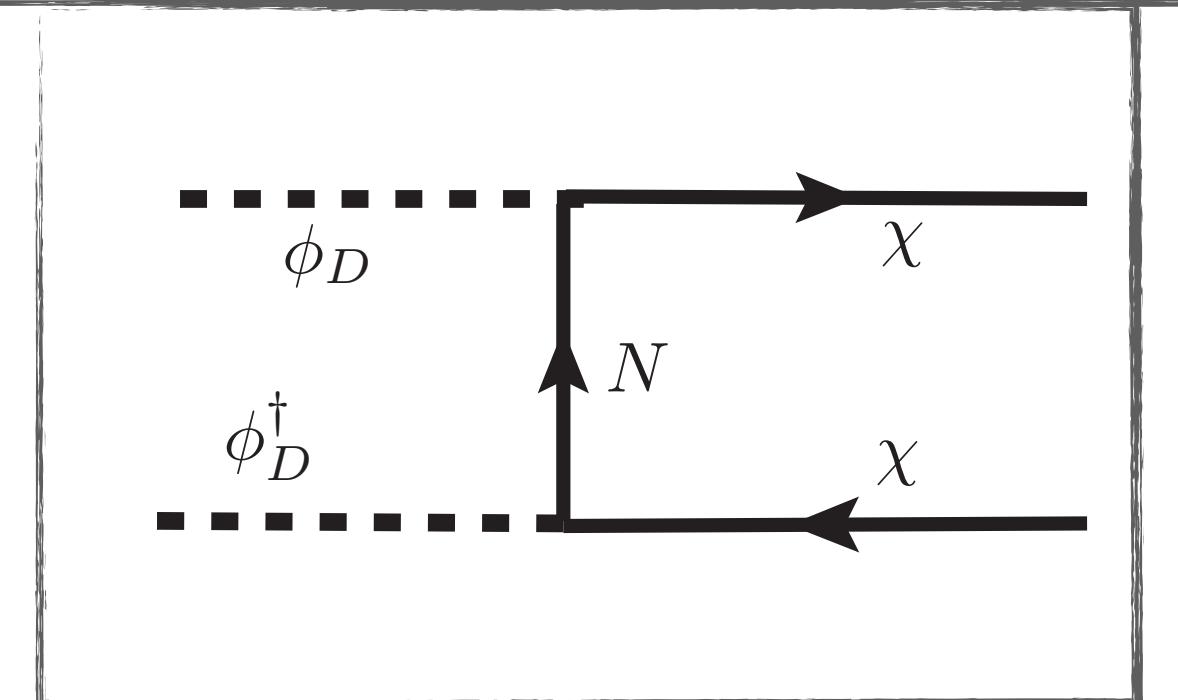
- ϕ_D attains thermal equilibrium due to sizable gauge coupling and interaction with SM/BSM Higgs
- An additional contribution to relic density of χ due to out of equilibrium decay of ϕ_D
- Relatively lower interaction of $\phi_D \rightarrow$
Larger $\Omega_{\phi_D}^{FO} h^2 \rightarrow$ More super-WIMP contribution



Production channels of χ

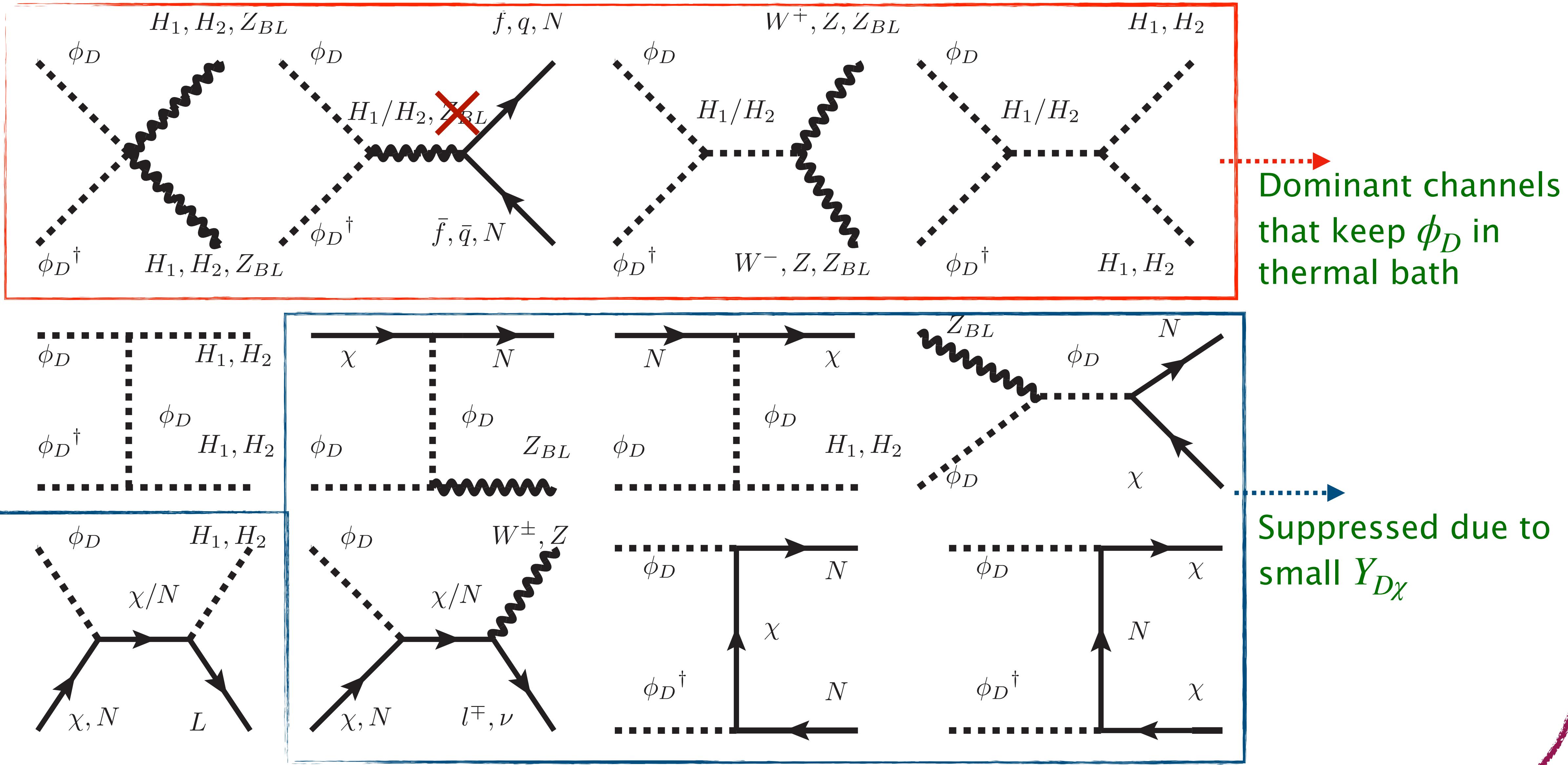


Sub-dominant due to small couplings, heavy propagators, and phase space suppression



Dominant freeze-in
Production

Annihilation channel of ϕ_D



Constraints on $Y_{D\chi}$

Parameters:

$$M_N = 50 \text{ GeV}, M_{H_2} = 500 \text{ GeV}$$

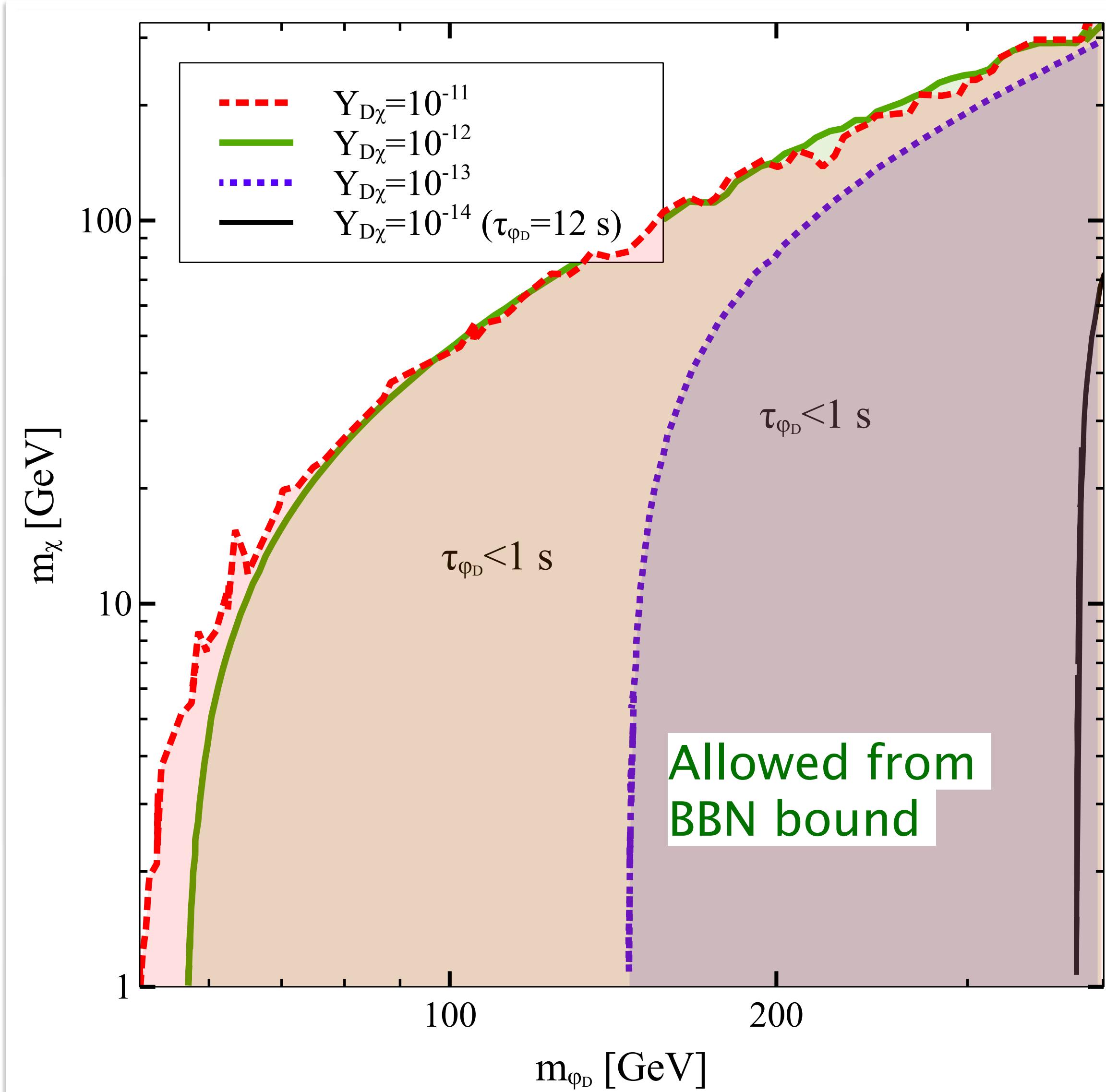
$$M_{Z_{BL}} = 7 \text{ TeV}, v_{BL} = 3.8 \text{ TeV},$$

- Decay of ϕ_D adds relativistic particles to the thermal bath which can alter the standard BBN scenario.
- ϕ_D decay before BBN, $\tau_{\phi_D} < 1 \text{ sec}$

Upper bound on $Y_{D\chi}$ (ϕ_D decays after it freezes-out)

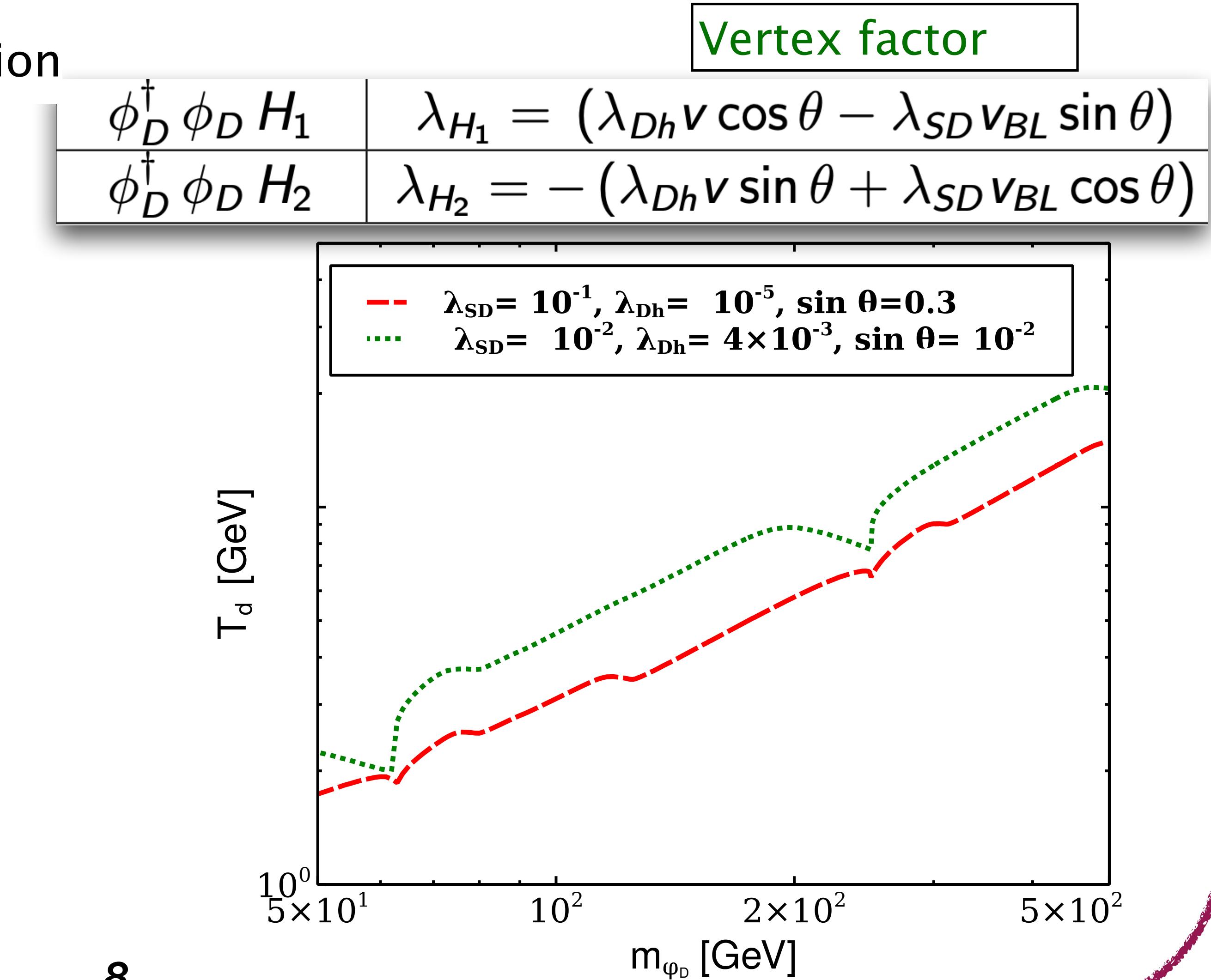
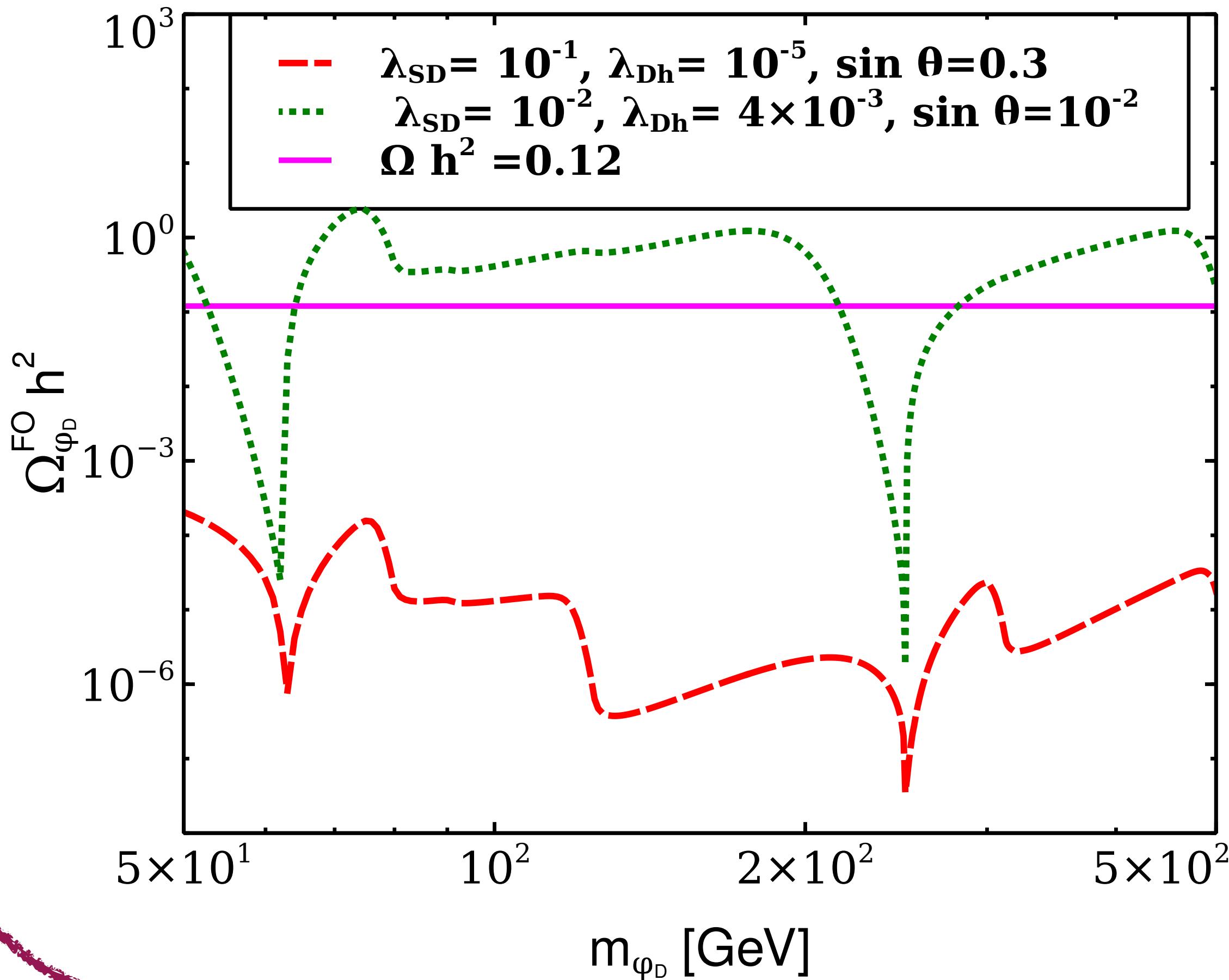
$$\Gamma_{\phi_D \rightarrow \chi N} \leq H(m_{\phi_D}) \rightarrow Y_{D\chi} \leq 10^{-8}$$

for $m_{\phi_D} = 100 \text{ GeV}$



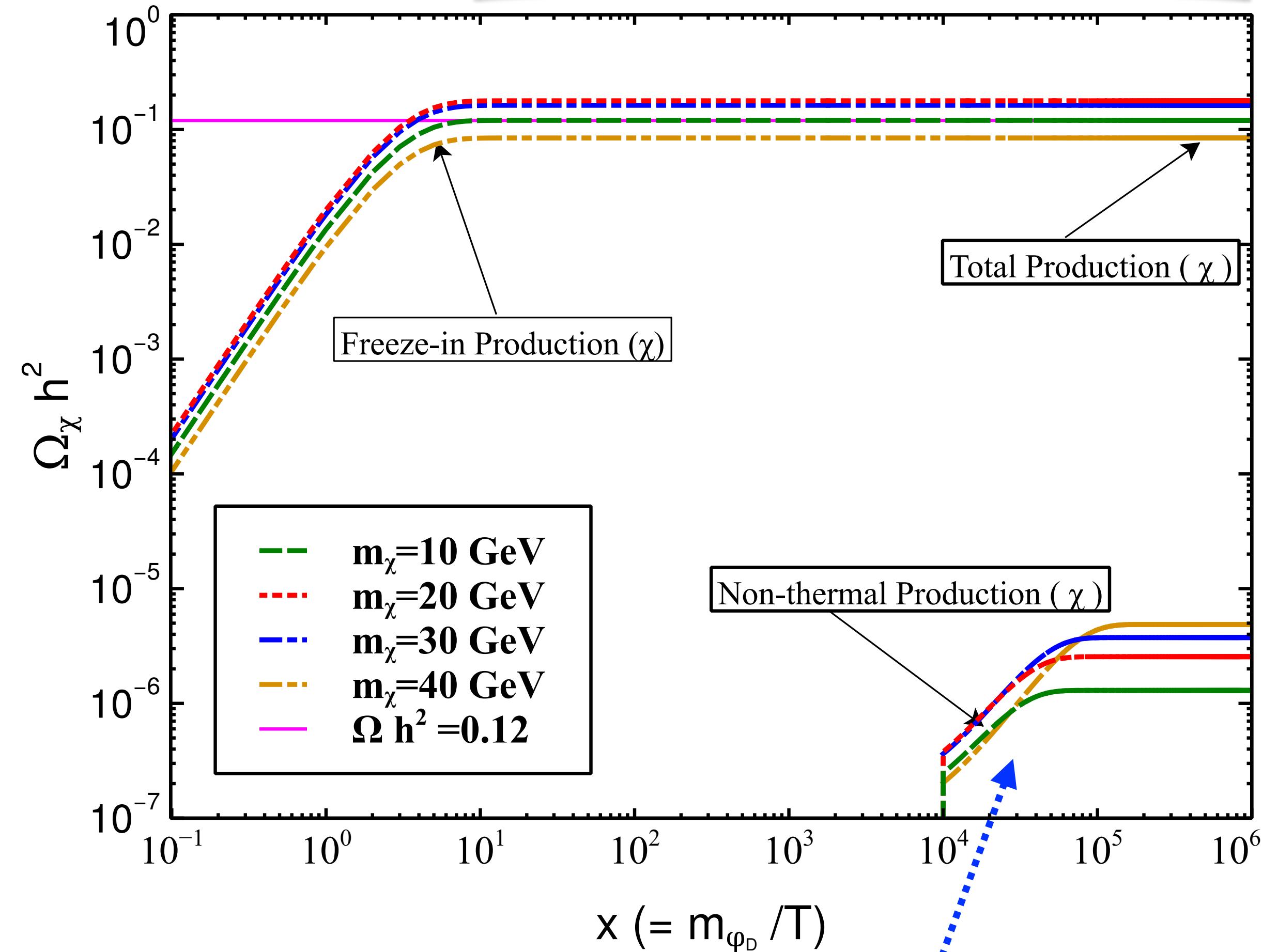
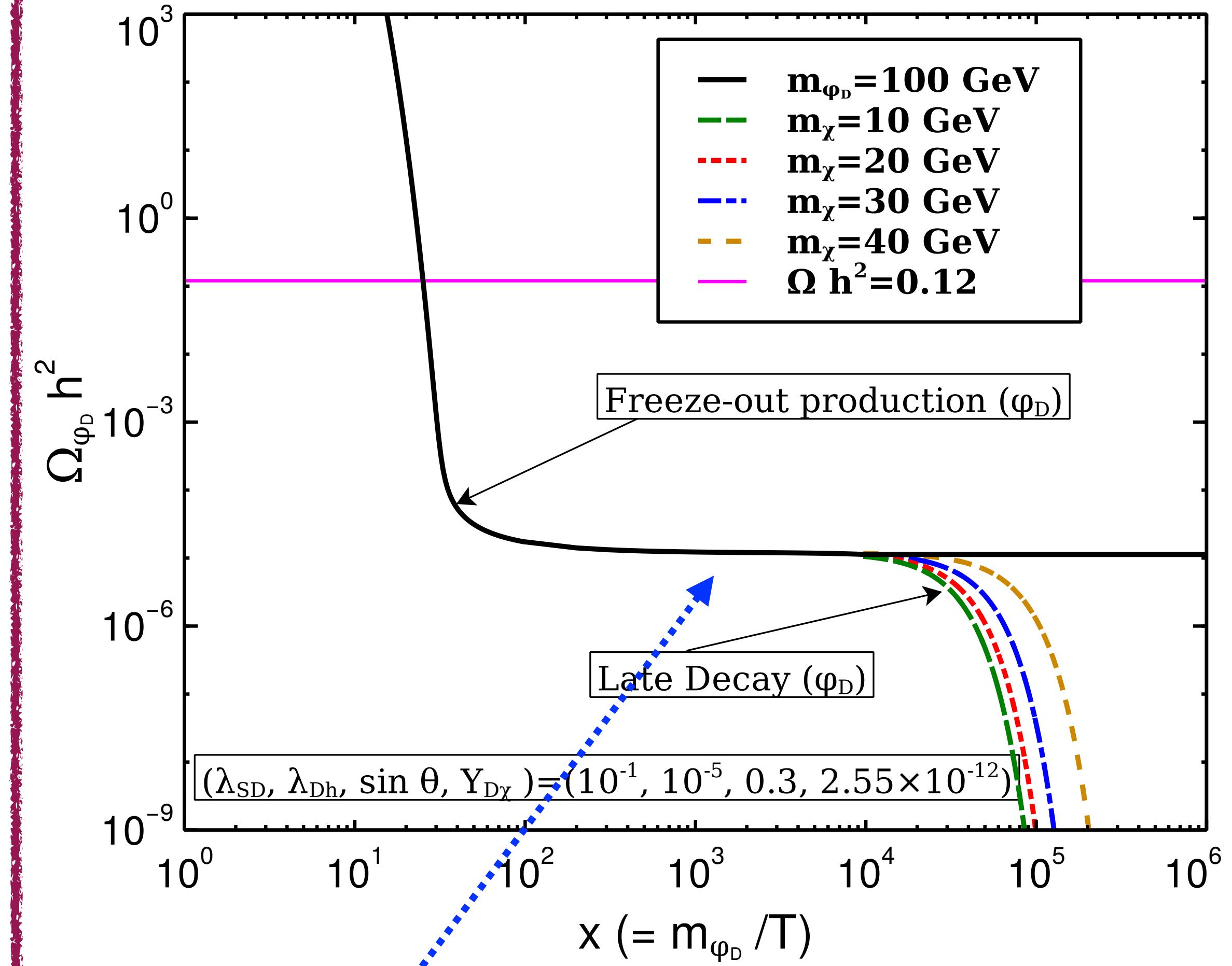
Abundance of ϕ_D

- Freeze-out Abundance of ϕ_D ($\Omega_{\phi_D}^{FO} h^2$): primarily governed by quartic coupling λ_{SD} , λ_{Dh} , and $\sin \theta$ (scalar mixing)
- Larger $\Omega_{\phi_D}^{FO} h^2 \rightarrow$ More super-WIMP contribution



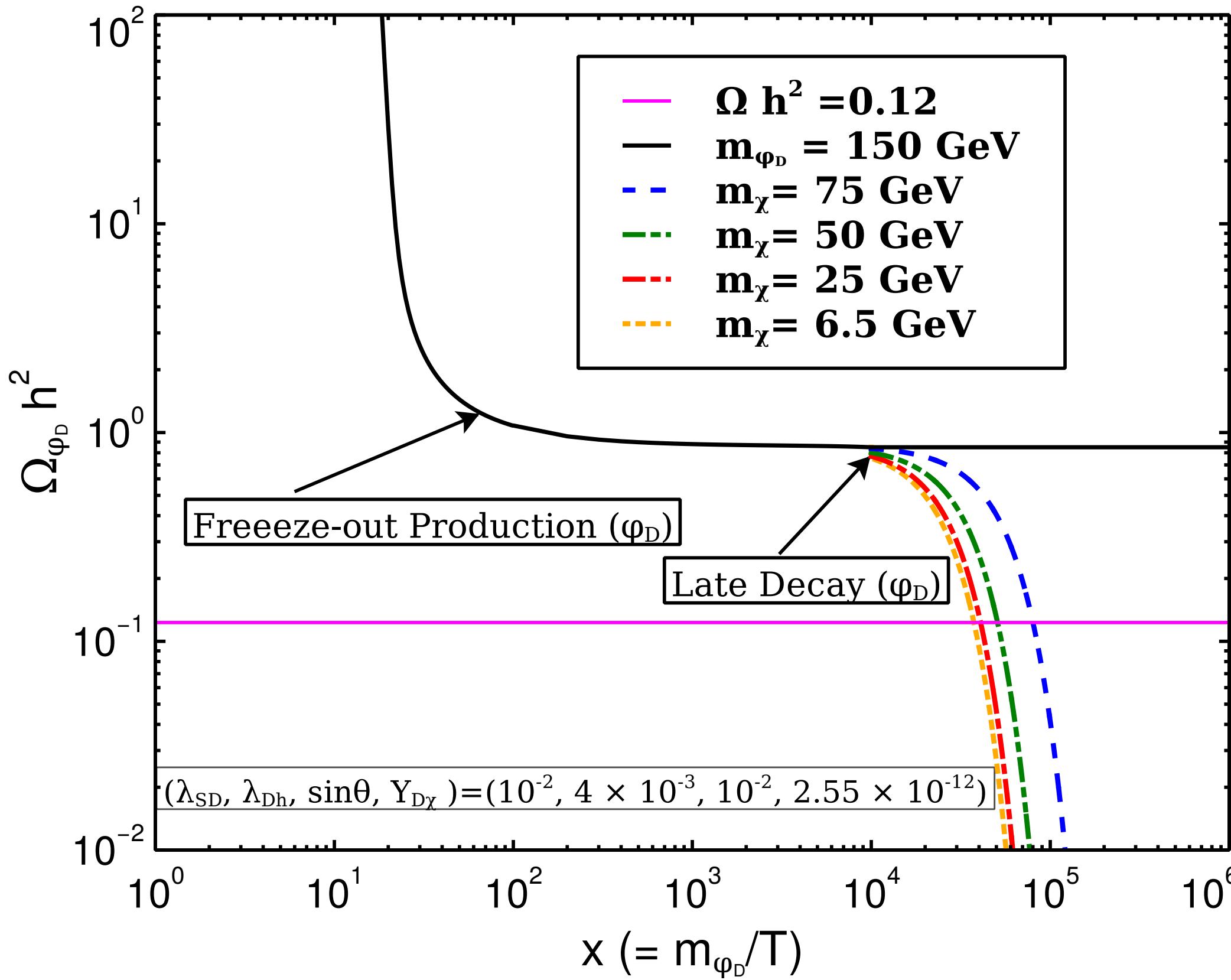
Freeze-in dominated Scenario

$$\Omega_\chi h^2 = \Omega_\chi^{TFI} h^2 + \frac{m_\chi}{m_{\phi_D}} \Omega_{\phi_D}^{FO} h^2$$

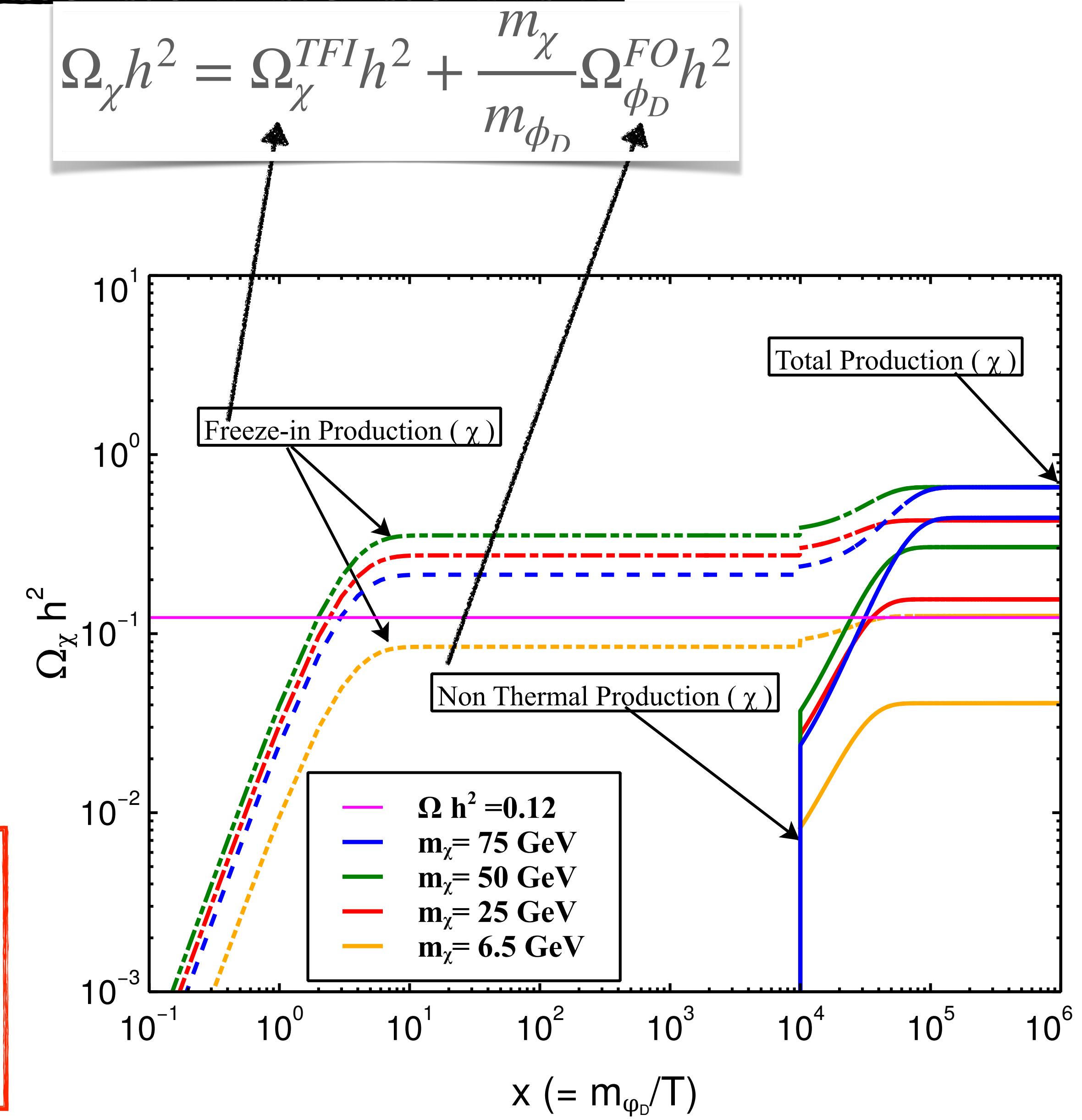


Sizable interaction of ϕ_D with the bath particles \rightarrow Lower $\Omega_{\phi_D}^{FO} h^2 \rightarrow$ Lower contribution

Sizable super-WIMP contribution

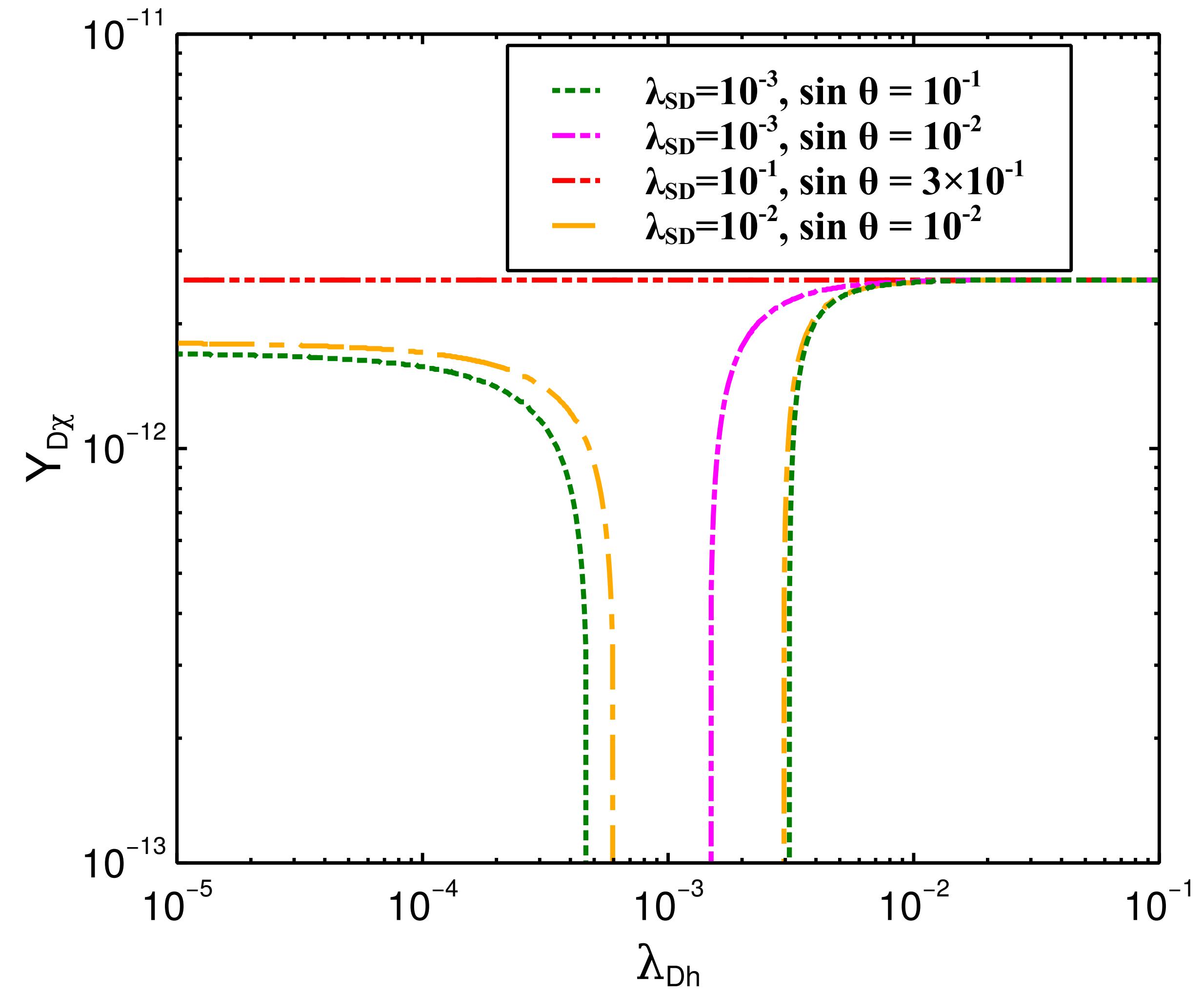
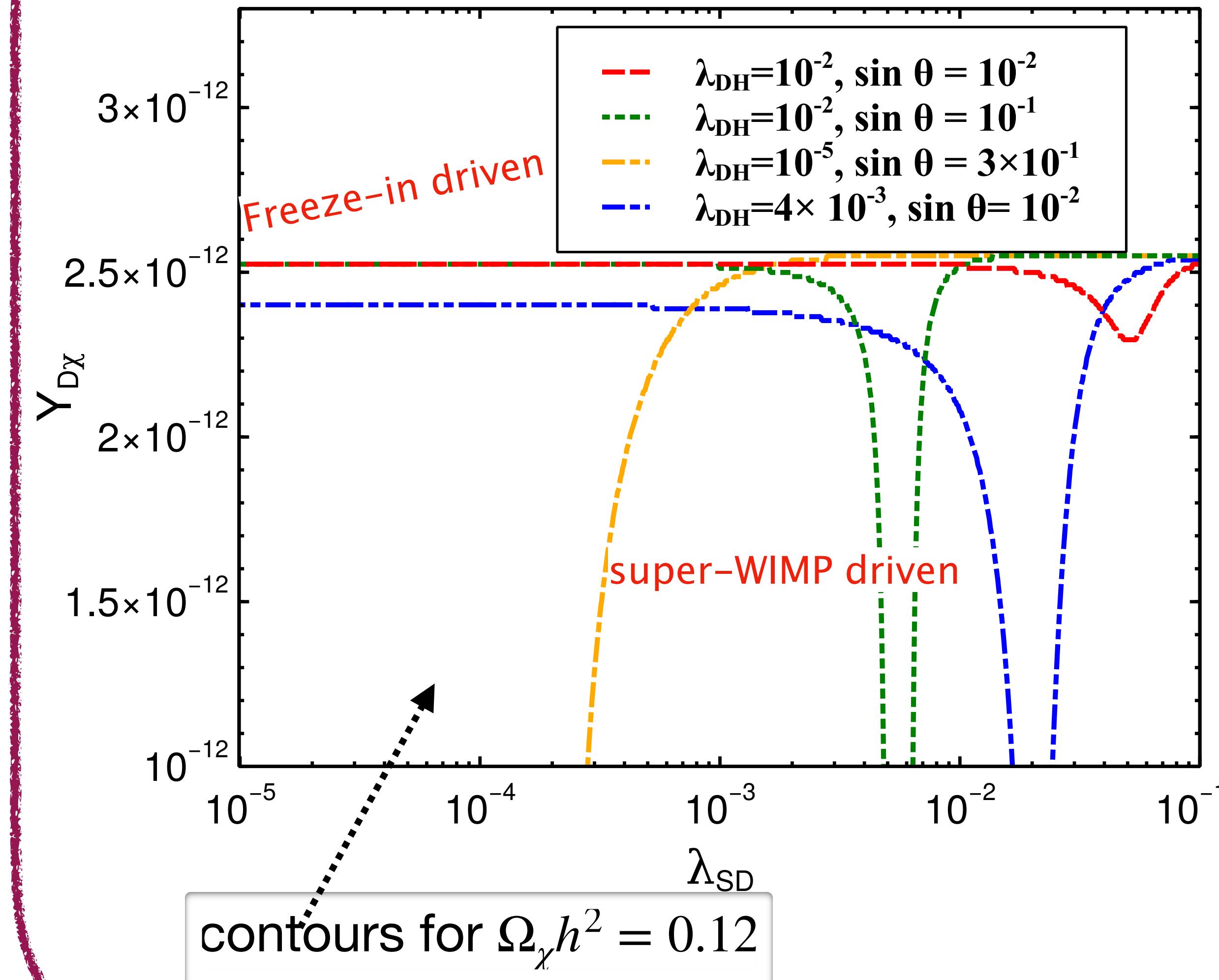


suppressed interaction of ϕ_D with bath particles \rightarrow large abundance
 $\Omega_{\phi_D}^{FO} h^2 \rightarrow$ larger contribution to the total DM relic density



Couplings for measured relic density

$$m_\chi = 10 \text{ GeV}, m_{\phi_D} = 100 \text{ GeV}$$



Summary

- Non-observation of any WIMP signal at various experiment indicates towards other possibilities.
- We explored the Freeze-in mechanism for DM genesis in an extended $U(1)_{B-L}$ model, where a Z_2 odd fermion χ serves as FIMP DM candidate. Another Z_2 odd scalar named as super-WIMP provides additional contribution to DM abundance due to its out of equilibrium decay.
- Depending on the choice of parameters, DM production can be driven by the Freeze-in or super-WIMP mechanism or both.

Thank you
