

Minimal Genesis of Asymmetric Dark Matter

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Based on: **2511.10731** in collaboration with
 Miguel Escudero Abenza (CERN) and Thomas Hambye (ULB)



VNIVERSITAT
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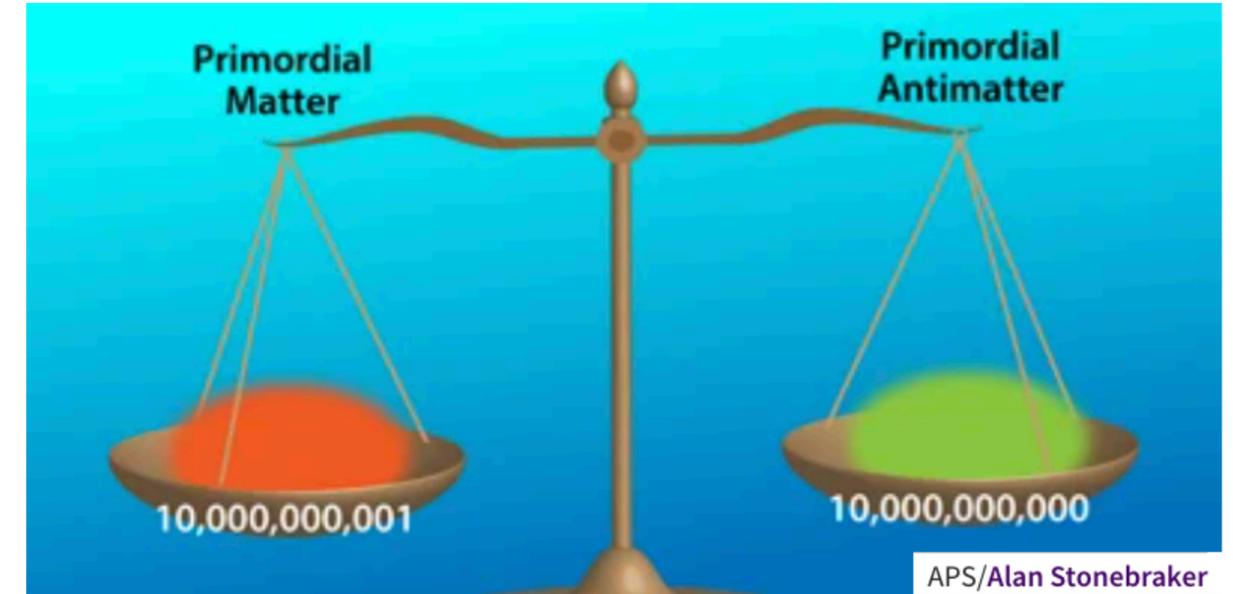


Matter-Antimatter asymmetry and Dark Matter

The Standard Model fails to provide an explanation for both

Observations tell us about their densities “today”:

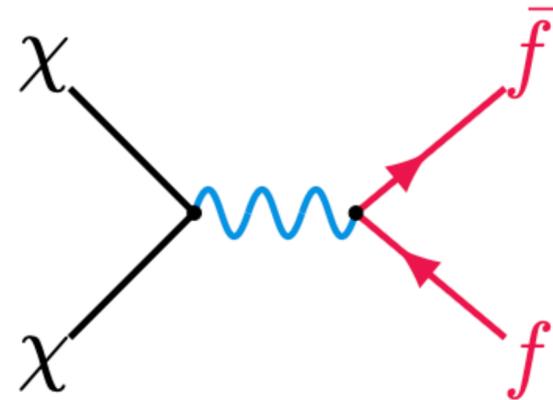
$$Y_{\Delta B} = \frac{n_B - n_{\bar{B}}}{s} \sim 9 \times 10^{-11} \quad \Omega_B \equiv \frac{\rho_B}{\rho_c} \sim 0.05$$



$$\Omega_{DM} \sim 5 \times \Omega_B \sim 0.26 \quad \text{coincidence or connection?}$$

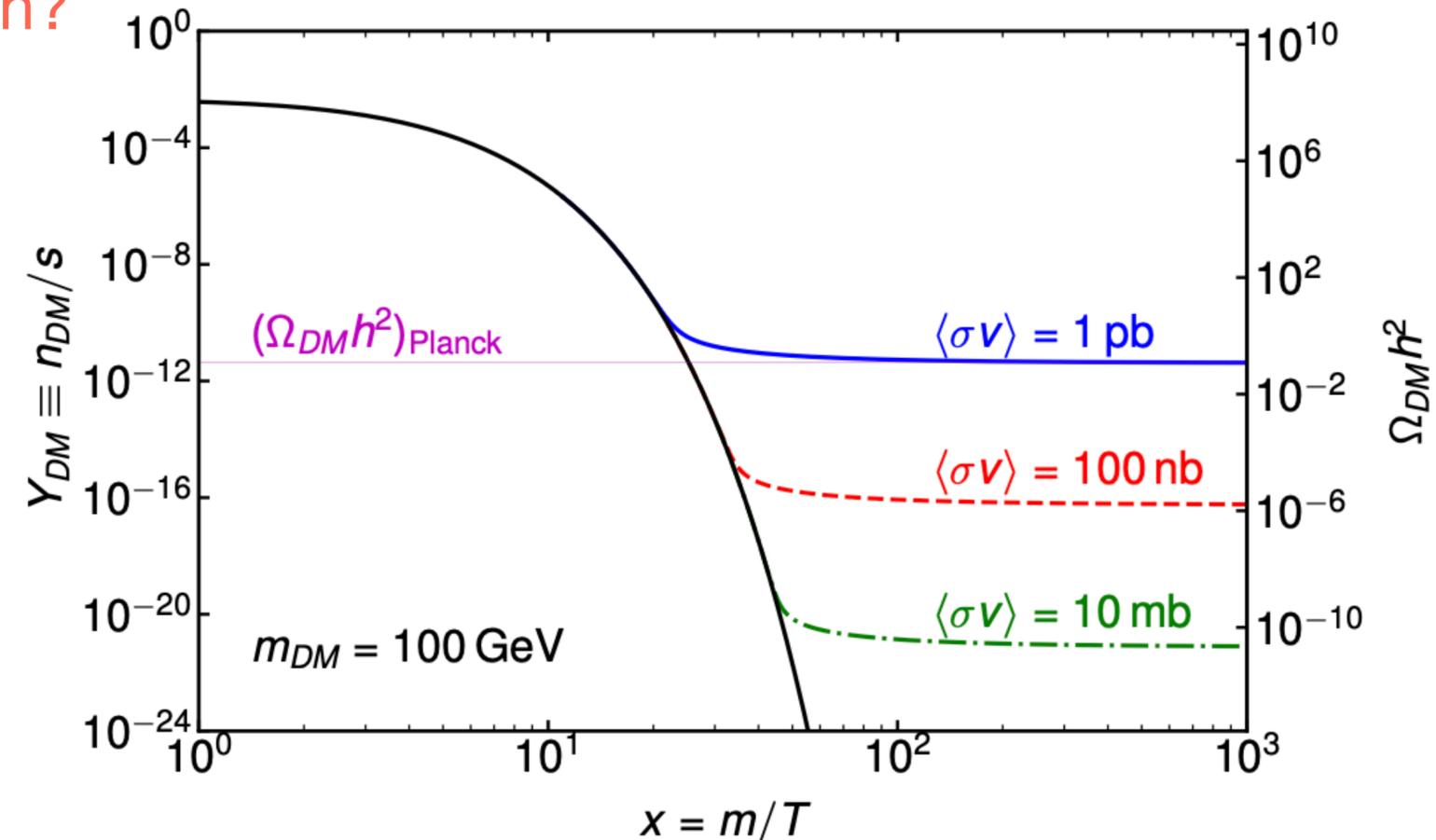
Good old “wimp miracle”:

thermal freezeout



“weak-ish” scale mass + cross section works!

But no signal in experiments so far!



Matter-Antimatter asymmetry and Dark Matter

What if we take the connection seriously?

$$\frac{\Omega_{DM}}{\Omega_B} = \frac{\rho_{DM}}{\rho_B} \sim \frac{m_{DM} n_{DM}}{m_B n_B} \sim 5$$

$$n_{DM} \sim n_B \Rightarrow m_{DM} \sim 5m_B \sim 5 \text{ GeV}$$

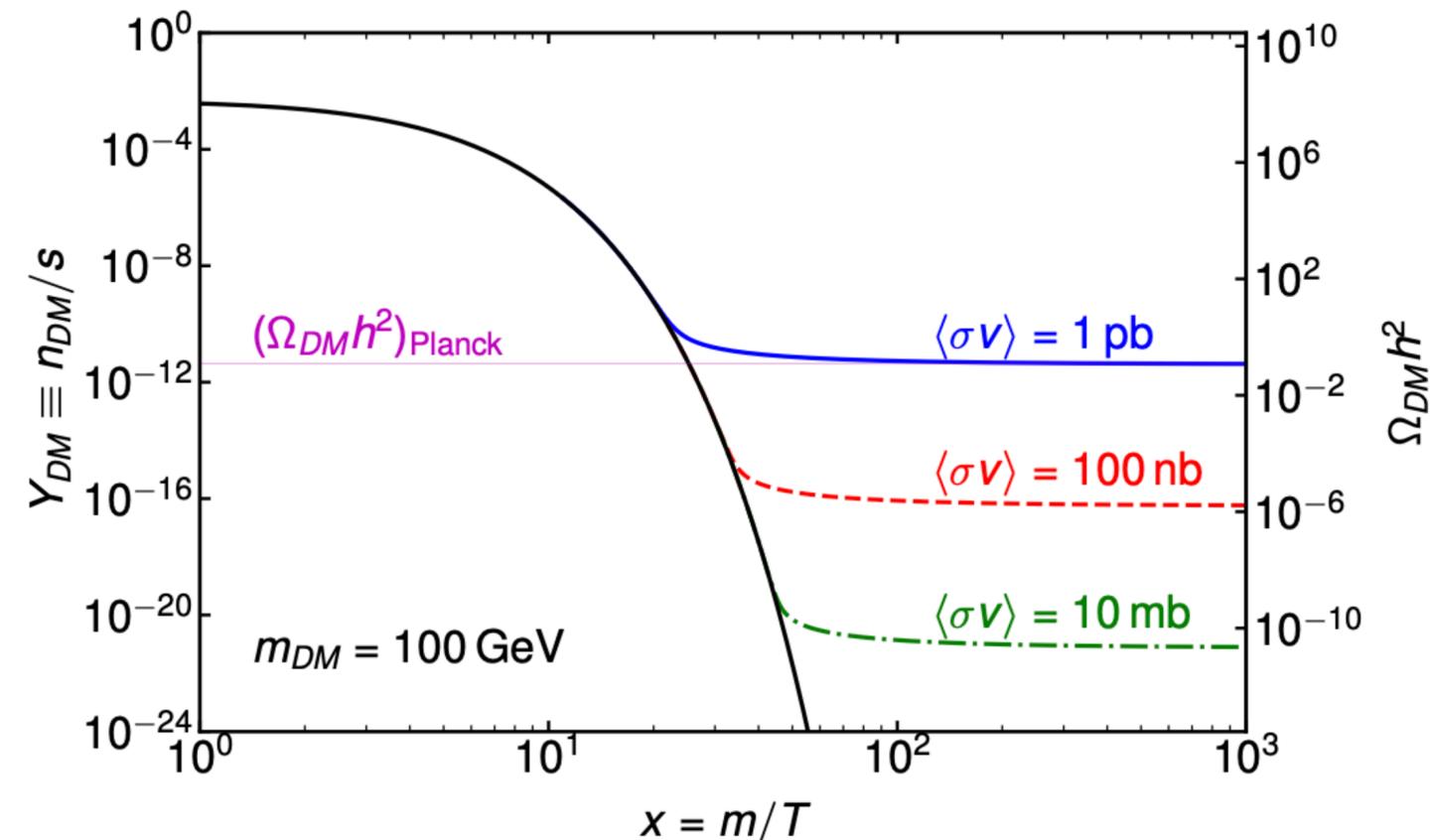
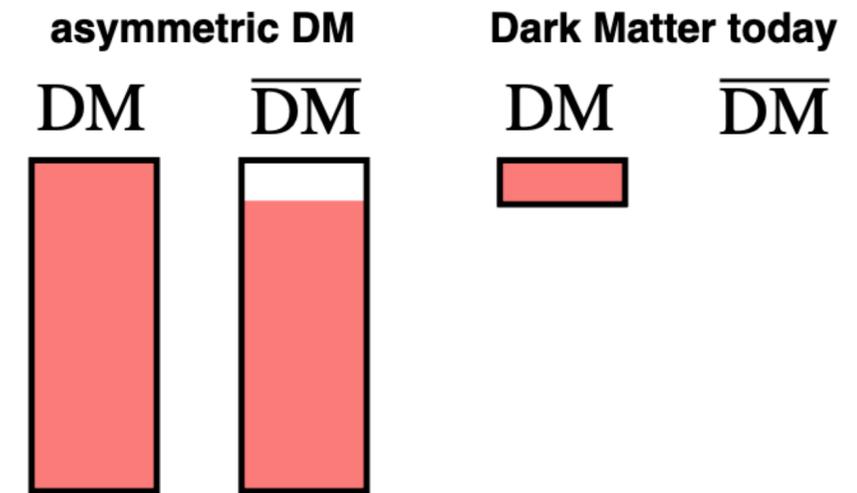
Many different possible realisations and deviations!

Relic density set by an asymmetry:
Asymmetric Dark Matter

Very rich literature!

Excellent reviews e.g. 1203.1247, 1305.4939,
1308.0338, 1310.1904, 2406.01705, ++

Crucial: annihilation of the symmetric component



Matter-Antimatter asymmetry and Baryogenesis

In the SM

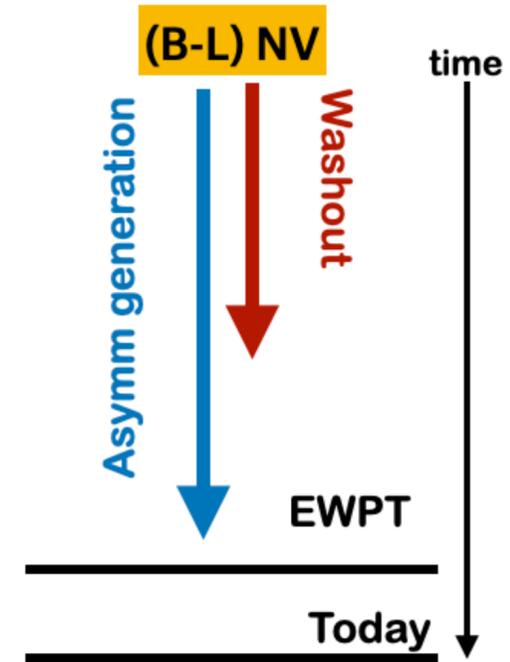
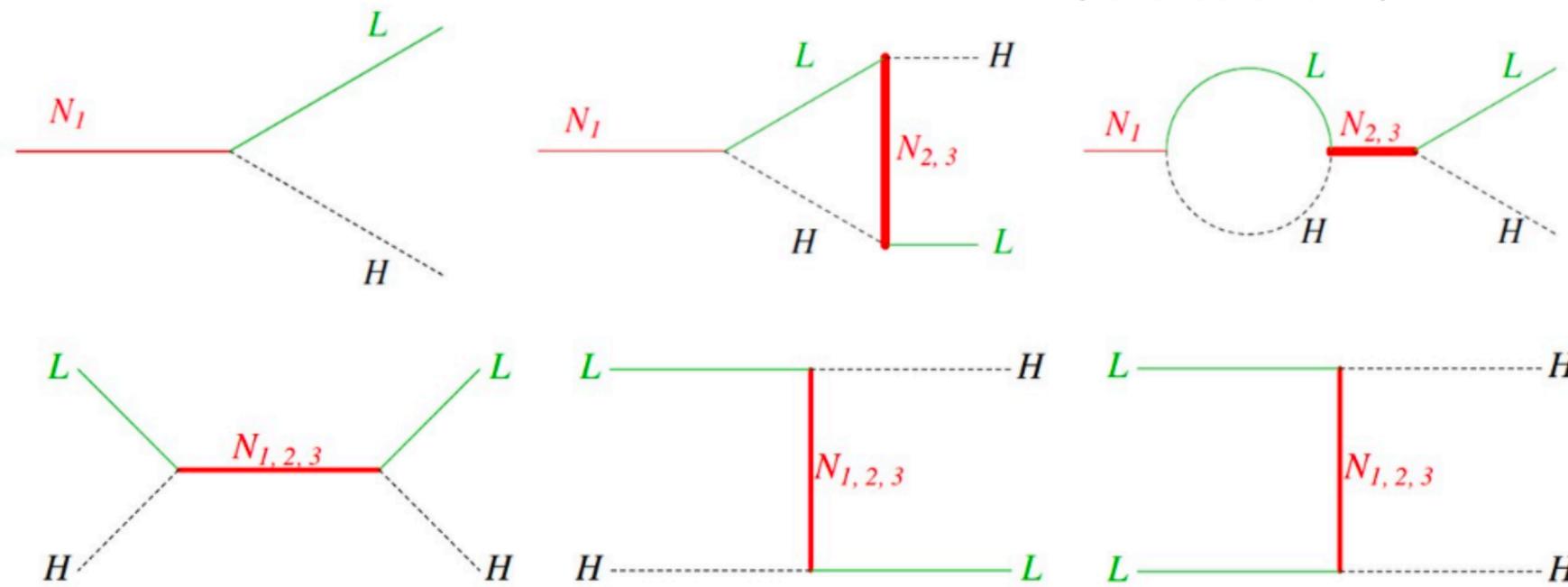
baryon number violation

C and CP violation

departure from thermal equilibrium

Simple example: thermal leptogenesis

Fukugita, Yanagida 84
Guidice et al. 04



Affleck-Dine

Thermal L-genesis

Resonant/by oscillation L-genesis

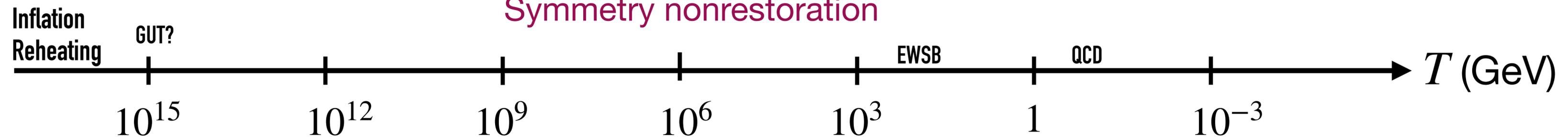
Symmetry nonrestoration

EW B-genesis

Post-sphaleron direct BG

Mesogenesis

← relevant for our mechanism



Baryogenesis and ADM

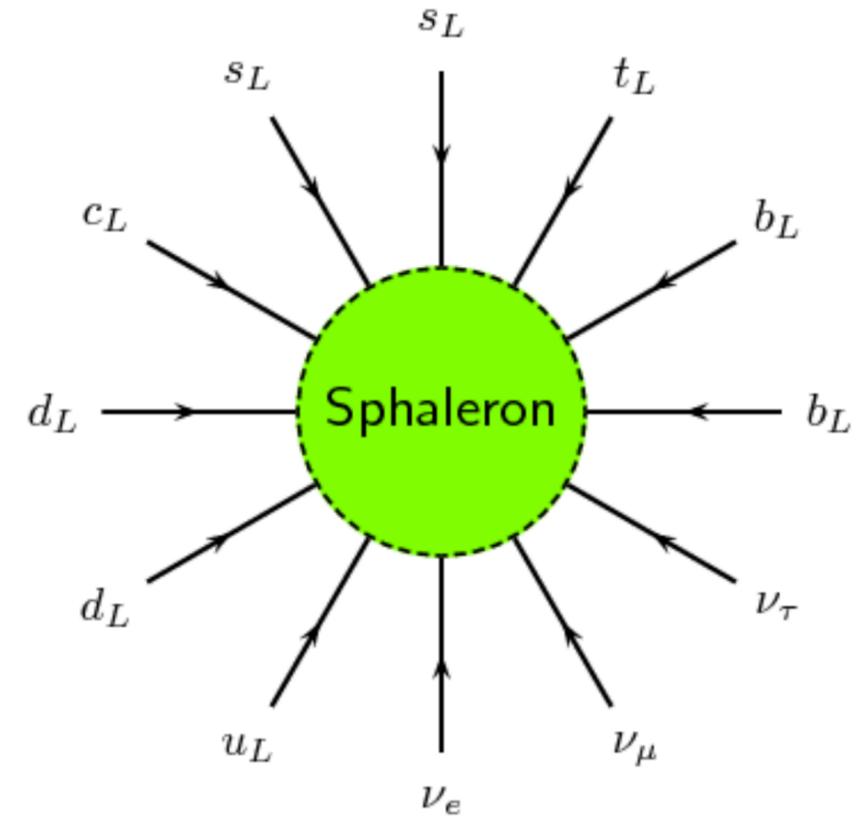
Before EW symmetry breaking:

SM Yukawa interactions + “sphalerons” + hypercharge conservation=>

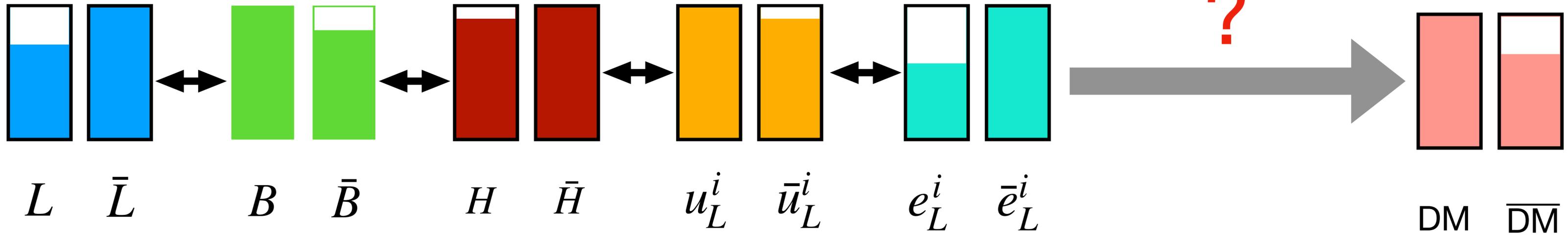
The chemical potentials of thermal species are related

$$\frac{Y_X}{Y_X^{eq}} \sim \exp\left(\frac{\mu_X}{T}\right) \simeq 1 + \frac{\mu_X}{T}$$

$$\frac{Y_{\Delta X}}{Y_X^{eq}} = \frac{Y_X - Y_{\bar{X}}}{Y_X^{eq}} \simeq 2\frac{\mu_X}{T}$$



$$3(\mu_{u_L} + 2\mu_{d_L}) + \sum_i \mu_{\nu_i} = 0$$



$$\mu_B = -\frac{28}{51}\mu_L$$

$$\mu_H = \frac{4}{51}\mu_L$$

$$\mu_{u_L^i} = -\frac{7}{153}\mu_L$$

$$\mu_{e_L^i} = \frac{51}{7}\mu_L$$

Baryogenesis and ADM

One of the “minimal” frameworks: use a portal to transfer asymmetry from visible to dark sector

Some of the setups proposed before:

$$N^2(LH)^2 + N^2\bar{L}L$$

Cohen and Zurek `09

$$(H^\dagger X_2)^2 + X_1^2 |H|^2$$

Servant and Tulin `13

$$\phi^2(LH)^2 + |\phi|^2 |H|^2$$

Ibe, Matsumoto, Yanagida `12

$$\chi^2 H^n + \text{gauge annihilation}$$

Boucenna, Krauss, Nardi `15

N, X_1 : fermion singlet

ϕ : scalar singlet

X_2 : fermion doublet

χ : fermion/scalar multiplet

Features:

No new source of CP-violation

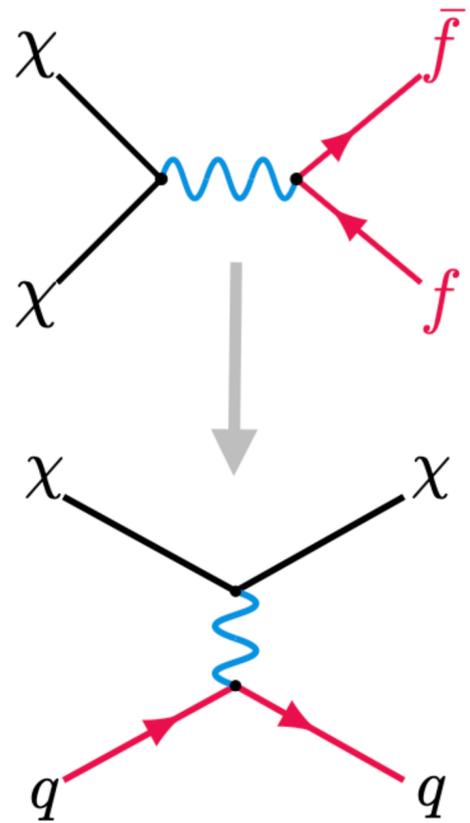
Minimal dark particle sector

Easy to test (many of the minimal cases are ruled out already)

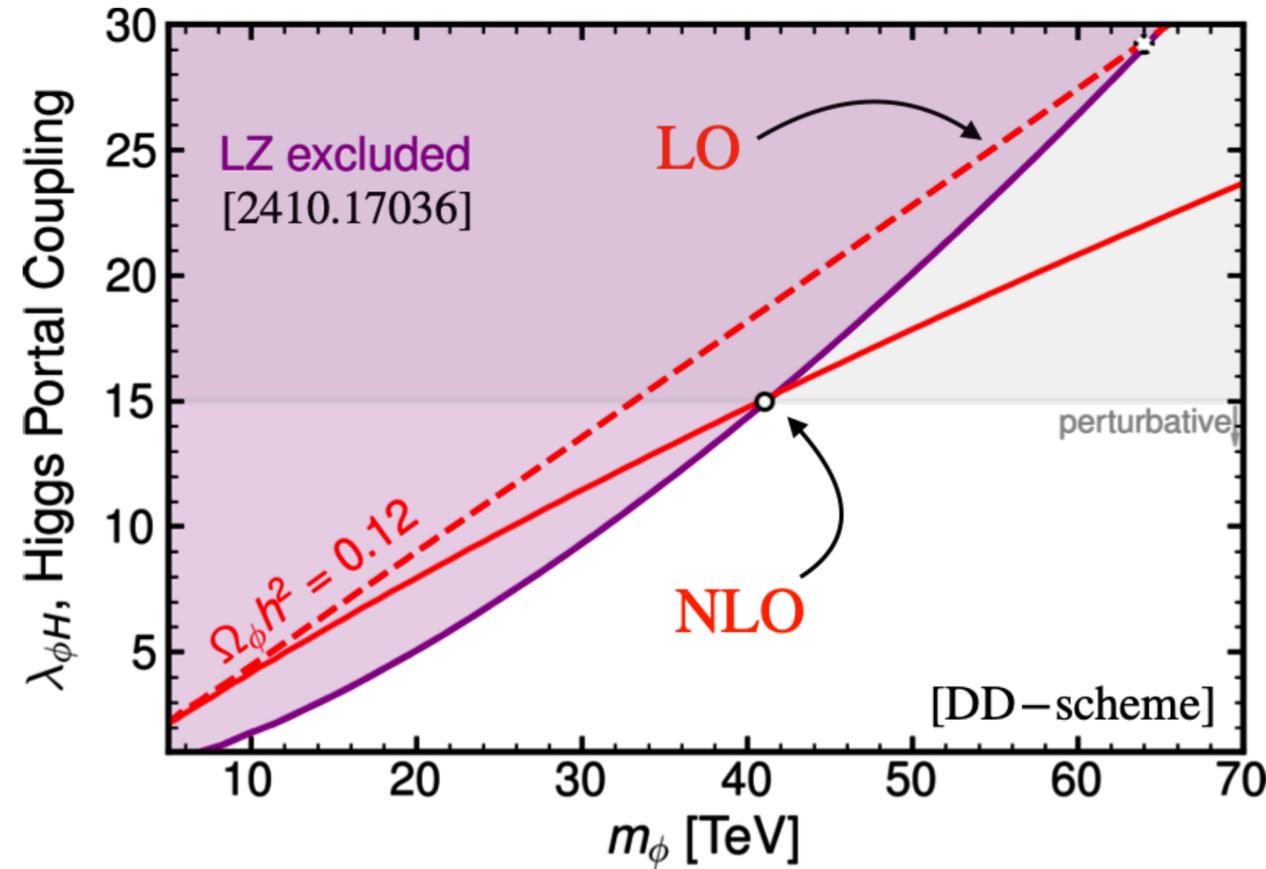
Nonrenormalisable higher-dimensional operators=> hiding potential UV complications

The killer: Direct Detection

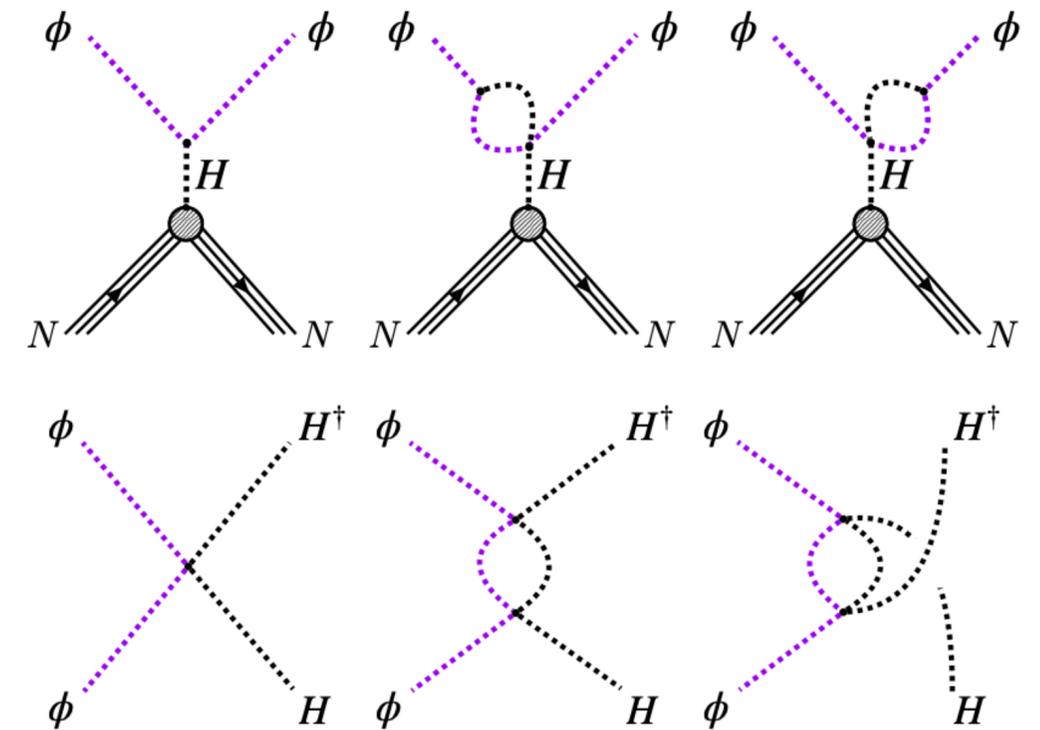
The symmetric component annihilation channel => direct detection



Example: $\lambda_{\phi H} |\phi|^2 |H|^2$
 complex scalar singlet DM



2505.02408
 Escudero and Hambye



Other challenges: hyperchargeless DM stabilised by Z_2 => DM^2 term allowed => washout of asymmetry
 large cLFV for portals involving charged leptons

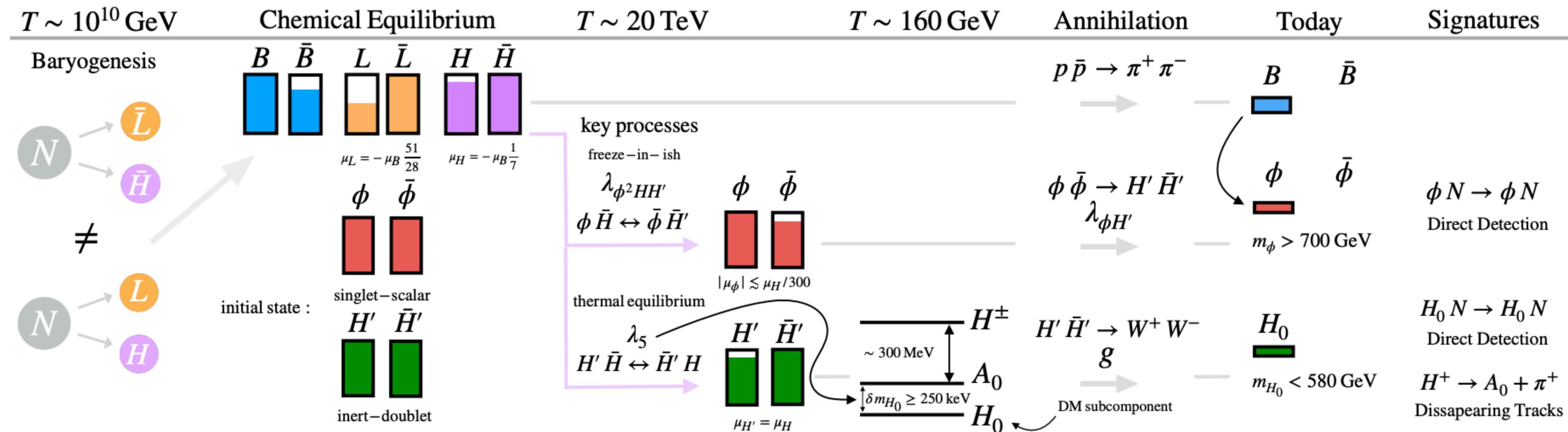
Our proposal: two “good old friends” and fully renormalisable

Z_4 : $[\phi]$: 1, $SU(2)_L$ singlet : **dominant asymmetric DM**
 $[\mathcal{H}']$: -2, $SU(2)_L$ doublet : **subdominant DM**

$$\lambda_{\phi^2 HH'} \phi^2 H^\dagger H' + \frac{\lambda_5}{2} (H^\dagger H')^2$$

$m_\phi > m_H$
 ↑ ↗ ↑
 Asymmetry transfer Splits neutral components of H'

Minimal Baryogenesis induced Asymmetric Dark Matter



The field content and the asymmetry transfer mechanism

Z_4 : $[\phi]$: 1, $SU(2)_L$ singlet : dominant asymmetric DM
 $[\mathcal{H}']$: -2, $SU(2)_L$ doublet : subdominant DM

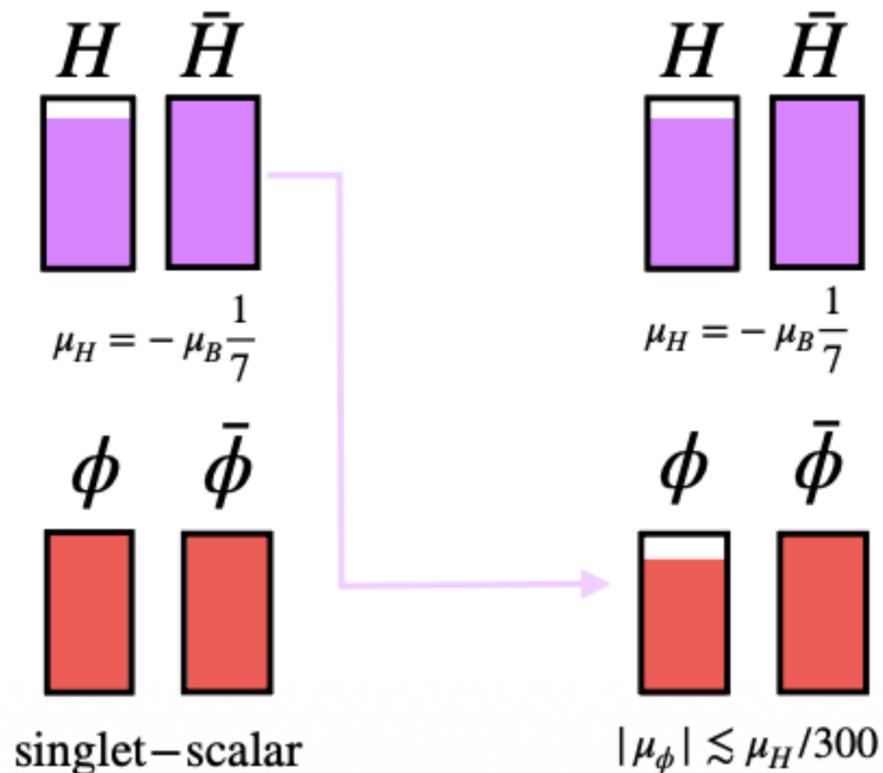
Comments: Z_2 : DM² washout terms; $U(1)$ local: killed by DD; $U(1)$ global: killed by star cooling

Two possible asymmetry transfer portals

$$\lambda_{\phi^2 HH'} \phi^2 H^\dagger H'$$

↓

$$\phi\phi \leftrightarrow H\bar{H}'$$

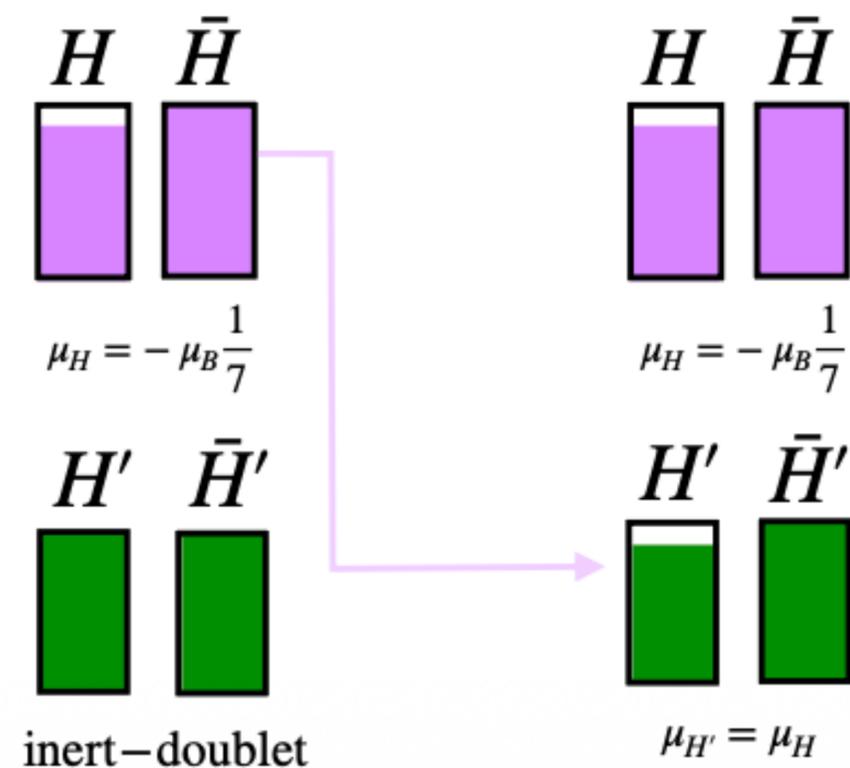


$$\frac{\lambda_5}{2} (H^\dagger H')^2$$

↓

$$HH \leftrightarrow H'H'$$

✓ will reach in equilibrium in our scenario



Not in full equilibrium in our scenario
 \Rightarrow freeze-in-ish

Direct detection constraints and fate of DM candidates

Annihilation of the symmetric component of the dominant DM: ϕ

$$\lambda_{\phi H'} |\phi|^2 |H'|^2 \quad \longrightarrow \quad \phi\bar{\phi} \rightarrow H'\bar{H}'$$

ϕ -nucleon scattering at loop level \Rightarrow DD rate suppressed



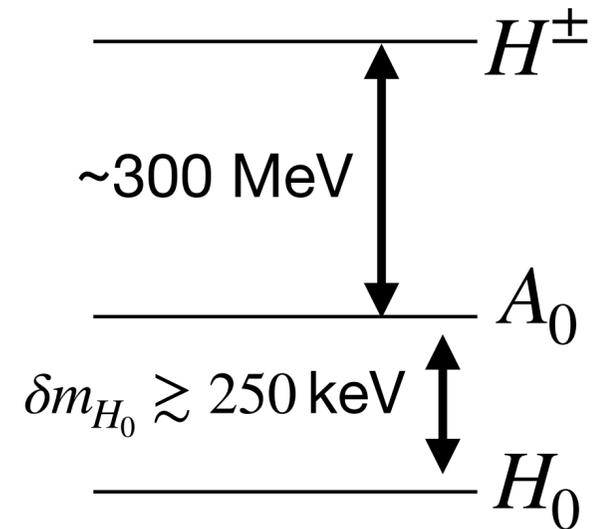
Fate of the symmetric component of the subdominant DM: H'

Annihilation by $\lambda_3 |H|^2 |H'|^2$ and/or $\lambda_4 (H^\dagger H')^2$ excluded by DD

$$\Omega_{H_0} h^2 \sim 0.12 \left(\frac{m_{H'}}{580 \text{ GeV}} \right)^2 \quad \boxed{\text{subdominant if } m_{H'} < 580 \text{ GeV}}$$

Z-exchange DD signal is absent if $\delta m_{H_0} \gtrsim 250 \text{ keV}$

$$\frac{\lambda_5}{2} (H^\dagger H')^2$$



Fate of the asymmetric component of the subdominant DM: H'

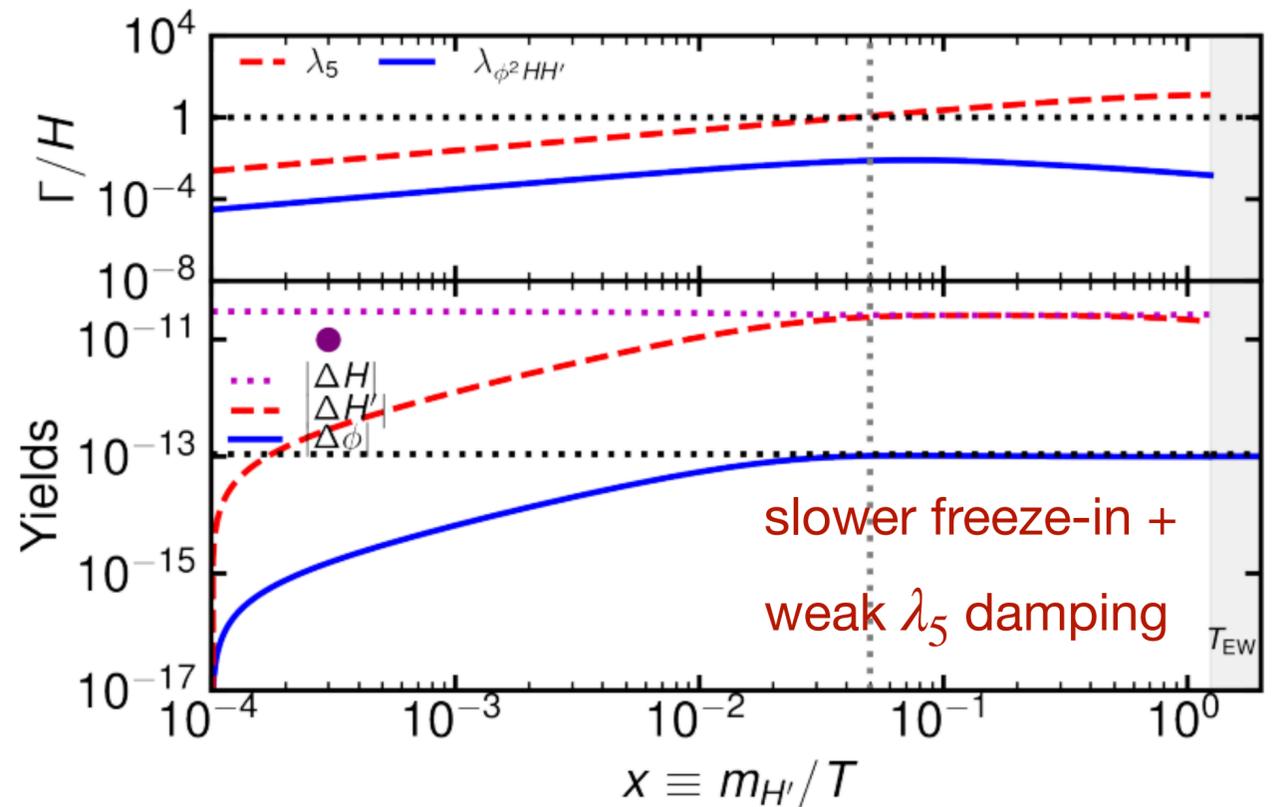
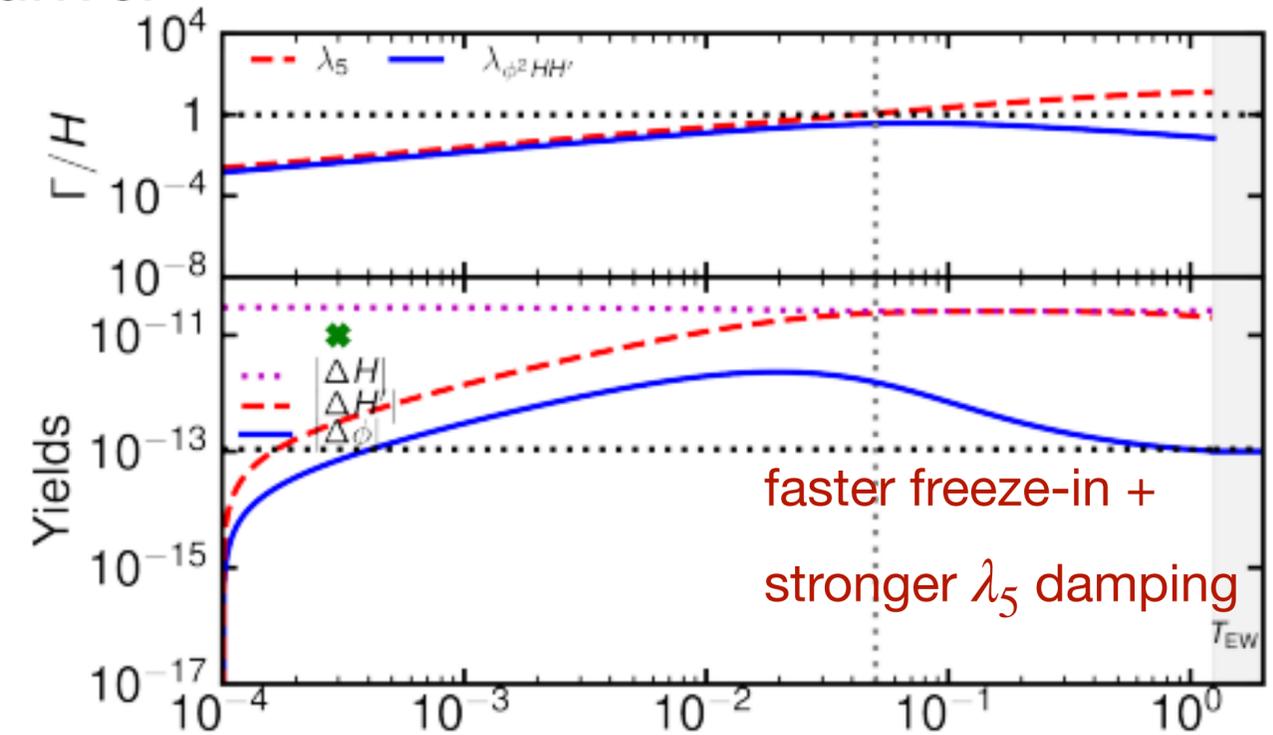
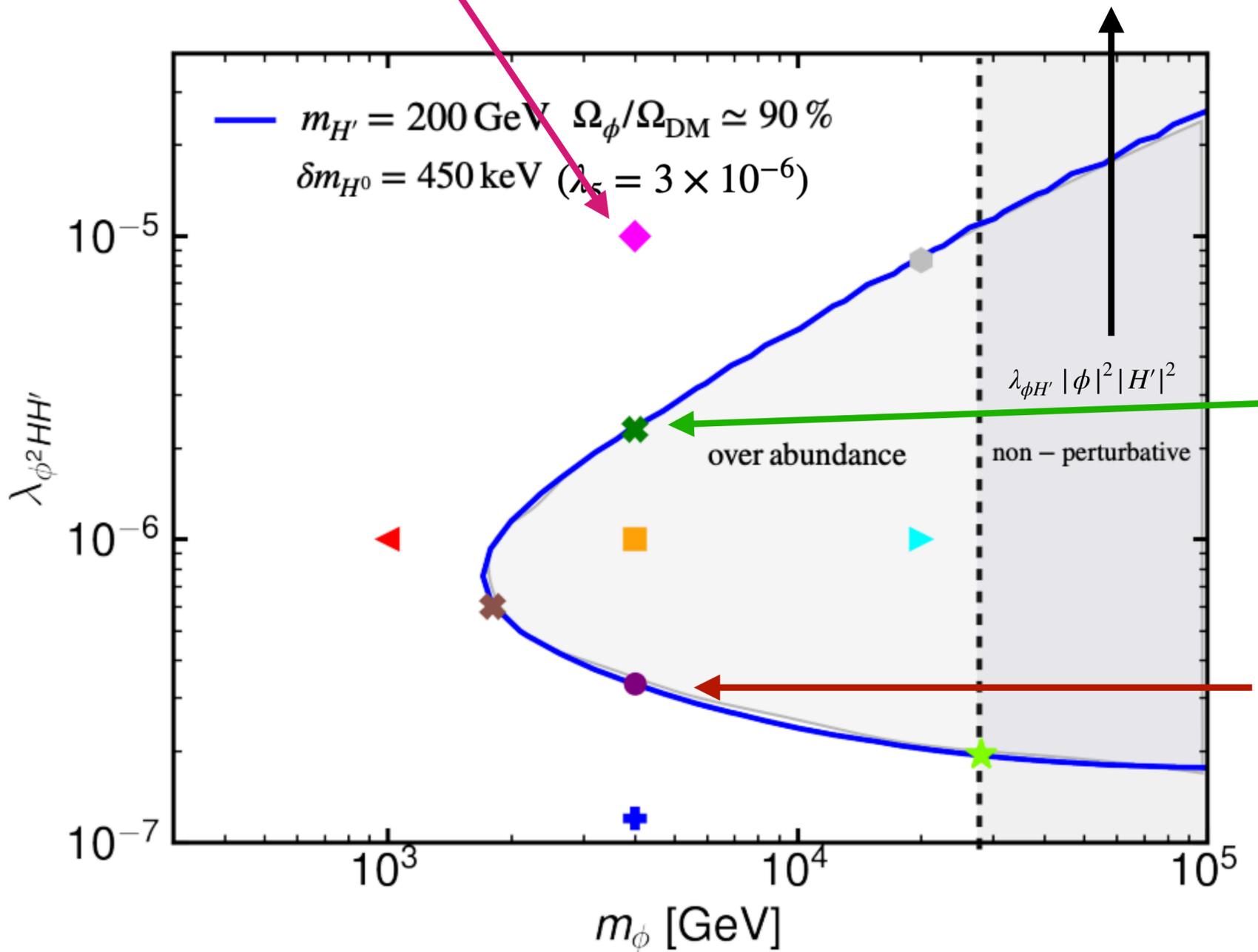
$$\frac{\lambda_5}{2} (H^\dagger H')^2 \longrightarrow \begin{array}{l} HH \leftrightarrow H'H' \\ H\bar{H}' \leftrightarrow \bar{H}H' \end{array} \longrightarrow \text{Asymmetry washout} \quad \oplus \quad \text{fast oscillations post EWSB}$$

Parameter Space and benchmark points

too strong λ_5 damping

symmetric annihilation driver

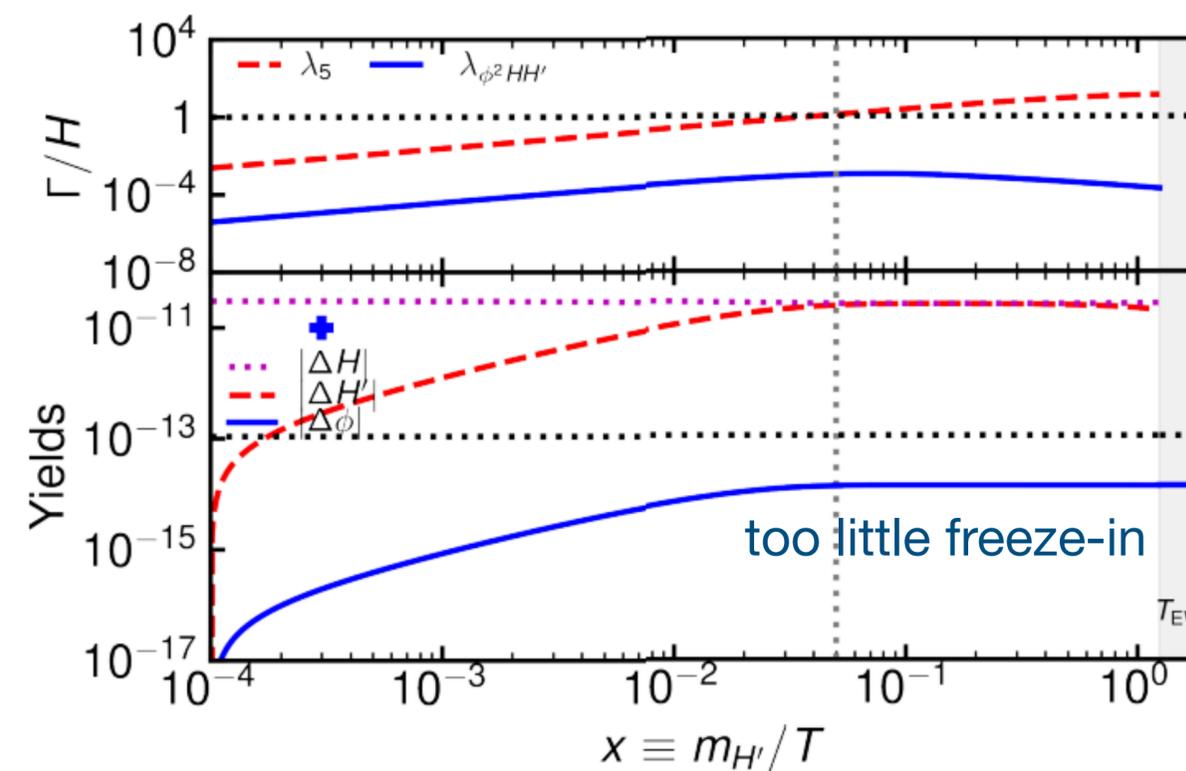
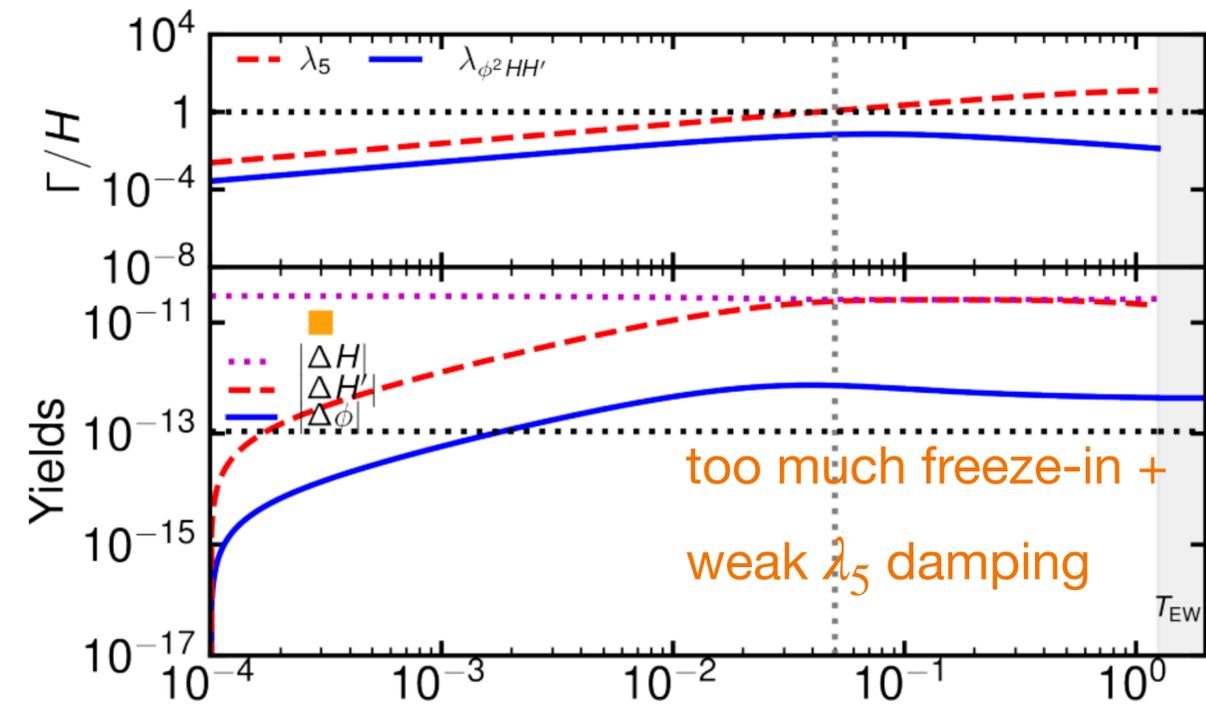
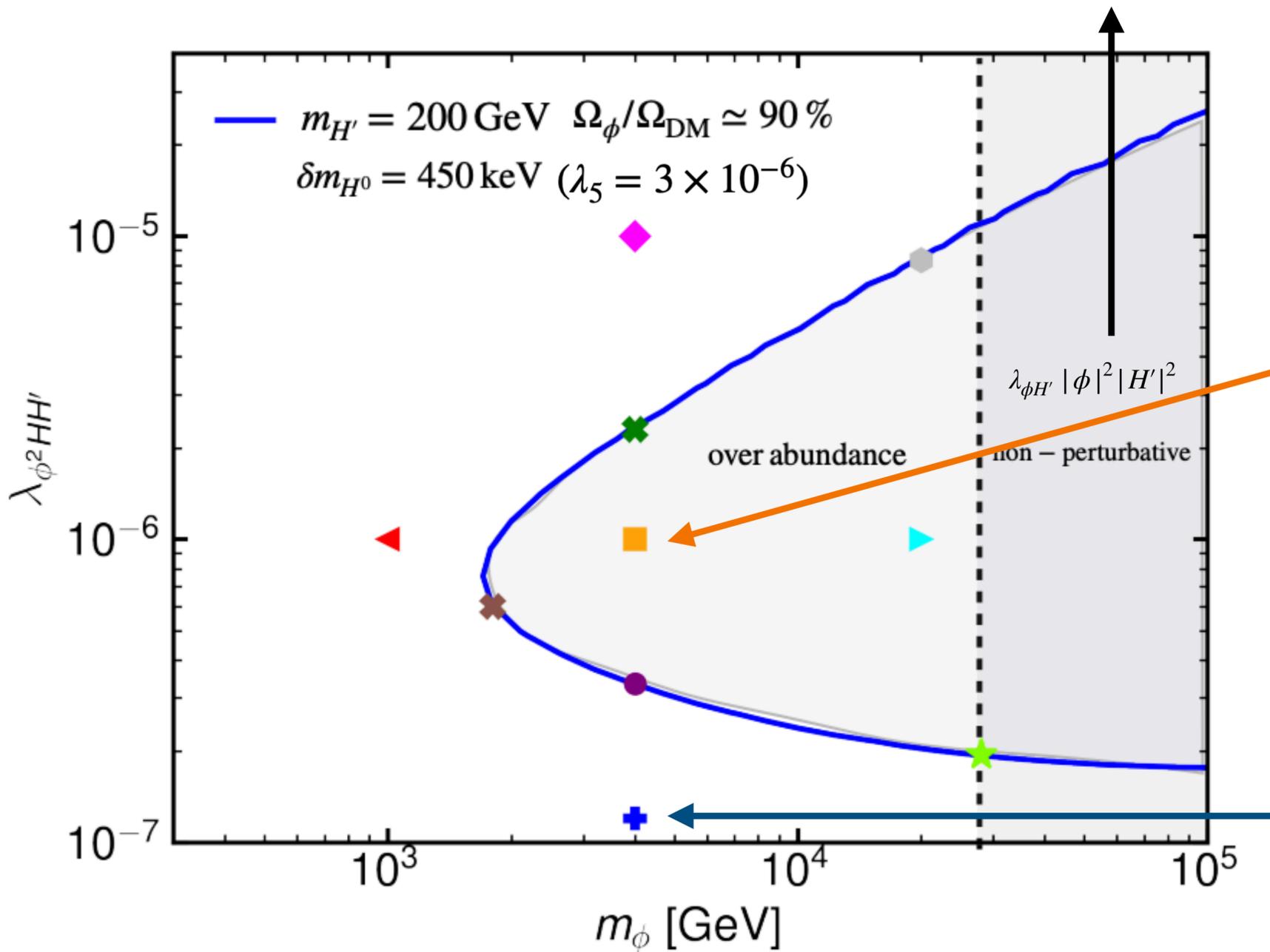
$$\lambda_{\phi^2 HH'} \phi^2 H^\dagger H' + \frac{\lambda_5}{2} (H^\dagger H')^2$$



Parameter Space and benchmark points

symmetric annihilation driver

$$\lambda_{\phi^2 HH'} \phi^2 H^\dagger H' + \frac{\lambda_5}{2} (H^\dagger H')^2$$



Signatures

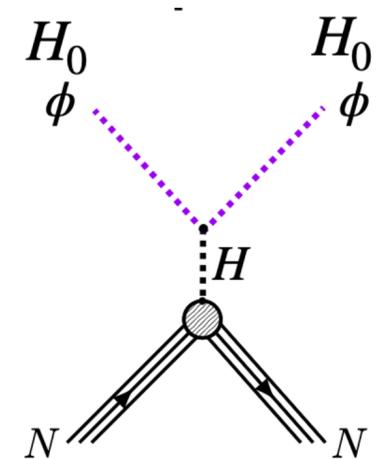
Overall for the mechanism to work, we have the constraints

[eff.]	$700 \text{ GeV} \lesssim m_\phi \lesssim 30 \text{ TeV}$,	[pert.]
[DD]	$200 \text{ keV} \lesssim \delta m_{H_0} \lesssim 5 \text{ MeV}$,	[eff.]
[LEP]	$70 \text{ GeV} \lesssim m_{H'} < 580 \text{ GeV}$,	[DMab]
	$\lambda_{\phi H'} > m_\phi / (2 \text{ TeV})$.	[$\bar{\phi}\phi$ annihilation]

Direct detection: an expected order of magnitude improvement in sensitivity @XLZD & PandaX-xT:

$$V(H, H', \phi) \in + \lambda_{\phi H} |\phi|^2 |H|^2 + \lambda_{\phi H'} |\phi|^2 |H'|^2$$

$$V(H, H', \phi) \in + \lambda_3 |H|^2 |H'|^2 + \lambda_4 |H^\dagger H'|^2$$



Not essential for our mechanism but can be sizeable

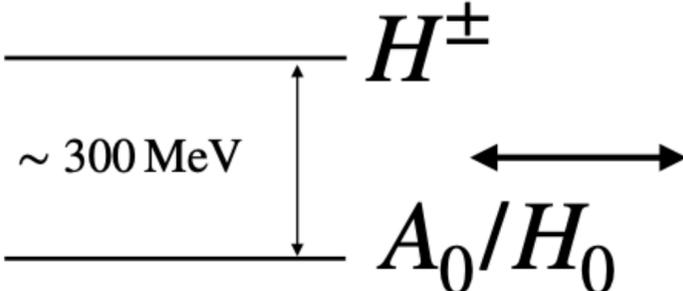
controls charged-neutral mass splitting

$$m_{H^\pm} - m_{H_0} \simeq \frac{\lambda_4 v_H^2}{4m_{H'}} \lesssim 700 \text{ MeV}. \quad [\text{LZ}, \lambda_3 = 0]$$

Signatures

We have a clear prediction for H' mass: [LEP] $70 \text{ GeV} \lesssim m_{H'} < 580 \text{ GeV}$, [DMab]

EW corrections: $\sim 300 \text{ MeV}$



$$m_{H^\pm} - m_{H_0} \simeq \frac{\lambda_4 v_H^2}{4m_{H'}} \lesssim 700 \text{ MeV}. \quad [\text{LZ}, \lambda_3 = 0]$$

Long-Lived charged state $10^{-3} \text{ ns} \lesssim \tau_{H^+} \lesssim 1 \text{ ns}$

Production is only electroweak:

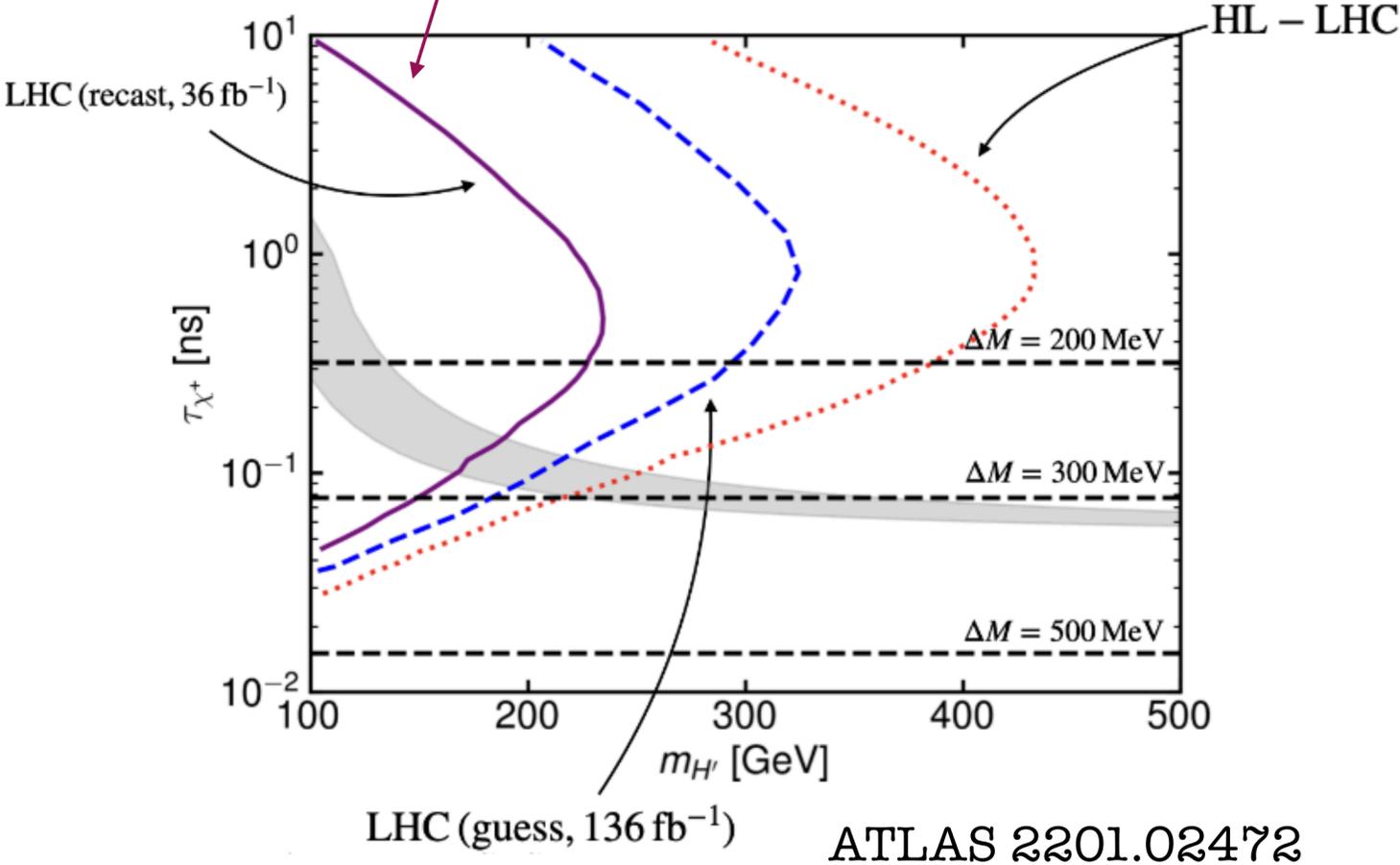
x section $\sim 1/30$ x that of Wino and $1/8$ x that of Higgsino

$$m_{H^\pm} - m_{H_0} < m_\pi : H^+ \rightarrow \ell^+ \nu$$

$$m_{H^\pm} - m_{H_0} > m_\pi : H^+ \rightarrow \pi^+ + H_0(A_0)$$

$$m_{H^\pm} - m_{H_0} > 500 \text{ MeV} : H^+ \rightarrow u\bar{d}A_0 \text{ (prompt)}$$

2008.08581: Belyaev et al.



Summary

Many existing minimal ADM frameworks are in tension with improved DD limits

We proposed potentially one of the simplest minimal frameworks from baryogenesis induced ADM

- Only renormalisable interactions
- Only two new particles
- Two component dark matter
- Clear prediction for H' mass within reach of future searches and potential DD signal

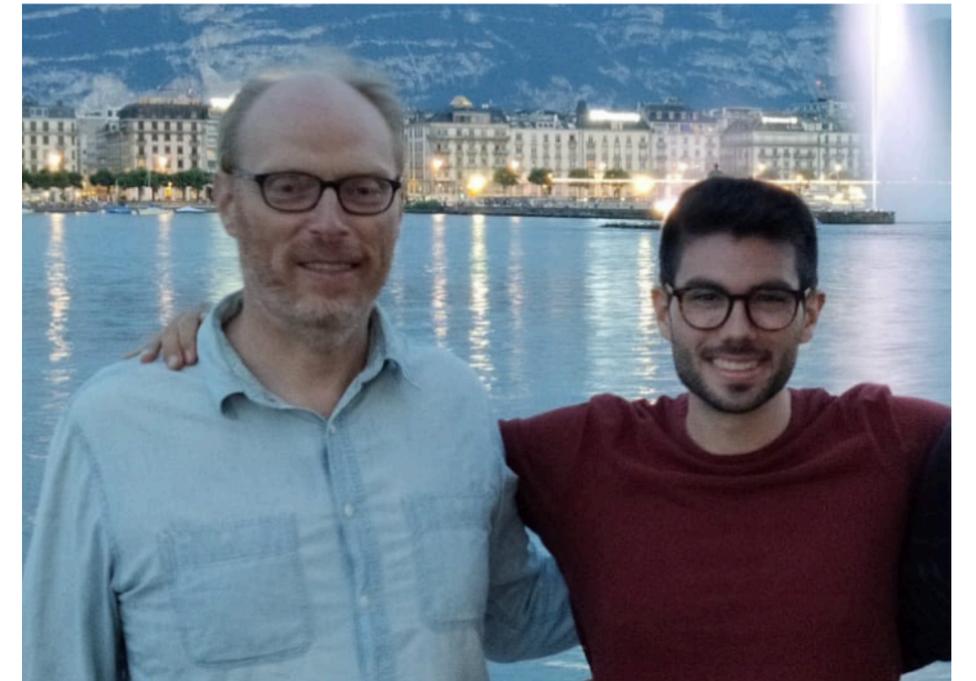
$$Z_4 : \begin{array}{l} [\phi] : 1, SU(2)_L \text{ singlet} \\ [H'] : -2, SU(2)_L \text{ doublet} \end{array}$$

Acknowledgements

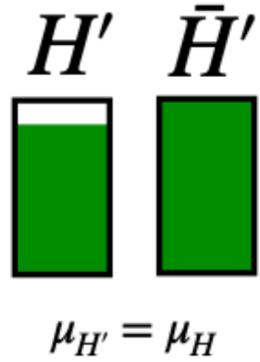
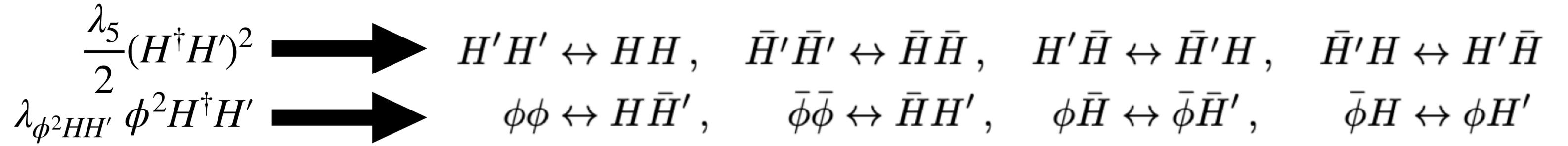
Thank you to the organisers
for the invitation and the
amazing organisation

Thanks to my amazing collaborators
Thomas Hambye (L) & Miguel Escudero (R)
for countless exciting discussions and ideas
to make and kill endless scenarios

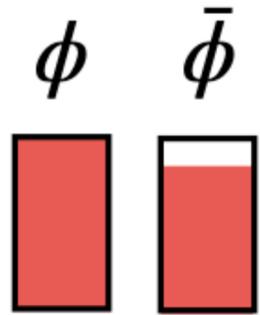
Thank you for your attention!



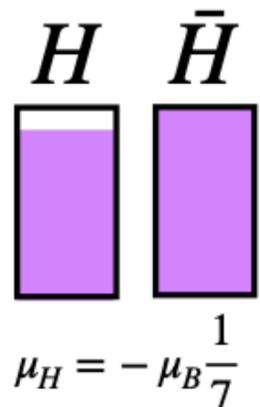
Relevant processes and Boltzmann equation framework



$$\begin{aligned} \frac{d\Delta_{H'}}{dx} = -\frac{s}{Hx} &\left\{ + 2(\langle \sigma v(H'H' \rightarrow HH) \rangle + \langle \sigma v(H'\bar{H} \rightarrow \bar{H}'H) \rangle) Y_{H'}^{\text{eq}} \left[\Delta H' - \frac{Y_{H'}^{\text{eq}}}{Y_H^{\text{eq}}} \Delta H \right] \right. \\ &\left. + \left(\frac{1}{2} \langle \sigma v(\phi\phi \rightarrow H\bar{H}') \rangle Y_\phi^{\text{eq}} + 2 \langle \sigma v(\phi\bar{H} \rightarrow \bar{\phi}\bar{H}') \rangle Y_H^{\text{eq}} \right) \left[2\Delta\phi + \frac{Y_\phi^{\text{eq}}}{Y_{H'}^{\text{eq}}} \Delta H' - \frac{Y_\phi^{\text{eq}}}{Y_H^{\text{eq}}} \Delta H \right] \right\} \end{aligned}$$



$$\frac{d\Delta_\phi}{dx} = -\frac{s}{Hx} \left\{ + (2 \langle \sigma v(\phi\bar{H} \rightarrow \bar{\phi}\bar{H}') \rangle Y_H^{\text{eq}} + \langle \sigma v(\phi\phi \rightarrow H\bar{H}') \rangle Y_\phi^{\text{eq}}) \left[2\Delta\phi + \frac{Y_\phi^{\text{eq}}}{Y_{H'}^{\text{eq}}} \Delta H' - \frac{Y_\phi^{\text{eq}}}{Y_H^{\text{eq}}} \Delta H \right] \right\}$$



$$\frac{d\Delta_H}{dx} = -\frac{13}{79} \frac{d\Delta_{H'}}{dx}. \quad (B - L \text{ and } Q \text{ conservation and all SM interactions active})$$

Backup :mass impact

