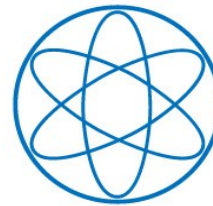


GeV-Scale Dark Matter stabilized by Baryon Number Conservation

Alejandro Ibarra



In collaboration with Mar Císcar-Monsalvatje, Jérôme Vandecasteele and Martina Sabová

ICFP 2026
Beijing
October 2026

Introduction

- Cosmological observations suggest that our Universe contains many more baryons than antibaryons.

$$Y_{B,0} = \left. \frac{n_B - n_{\bar{B}}}{s} \right|_0 = (8.75 \pm 0.23) \times 10^{-11}$$

- A baryon asymmetry could be dynamically generated from a baryon symmetric Universe, if the following conditions are satisfied (Sakharov'67):
 - 1) Violation of baryon number
 - 2) C and CP violation.
 - 3) Departure from thermal equilibrium.

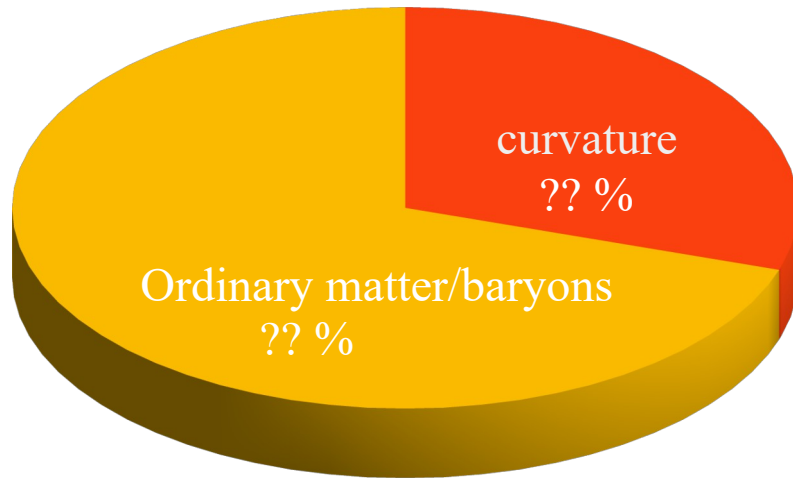
Baryogenesis

All these conditions are fulfilled in the Standard Model, but not in sufficiently large amounts.

Evidence for Physics beyond the Standard Model

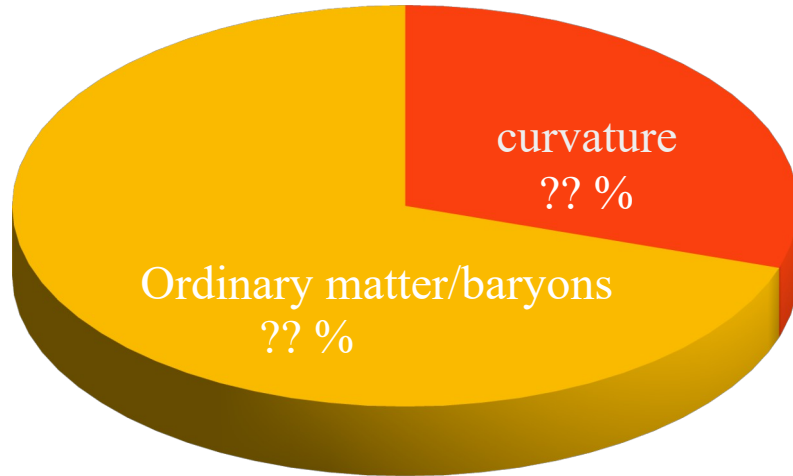
Rethinking the Sakharov conditions

The cosmic pie in 1967

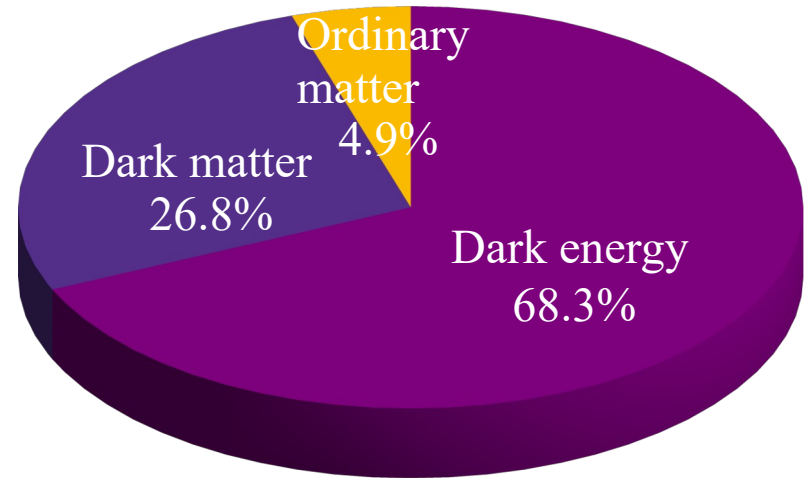


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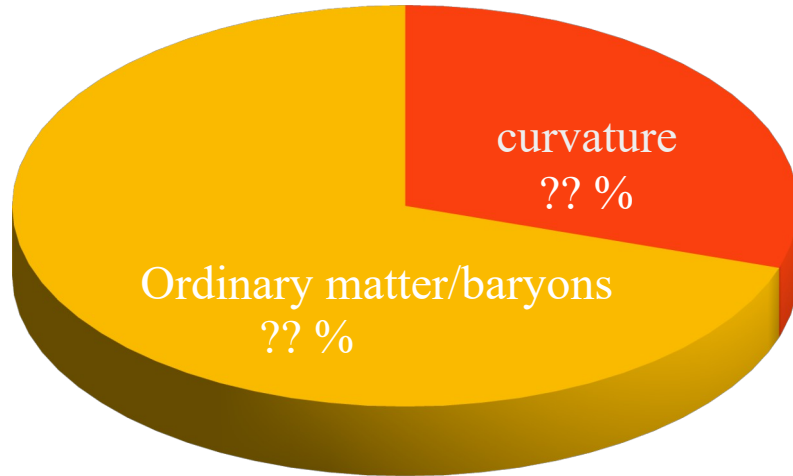


The cosmic pie in the 2020s

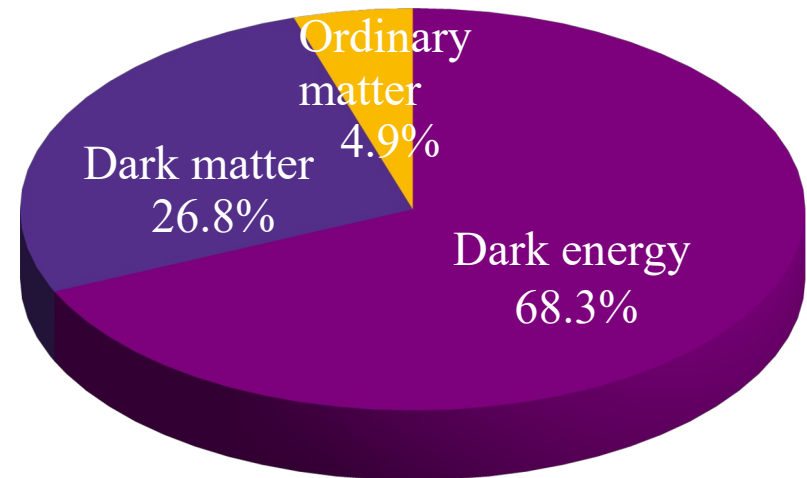


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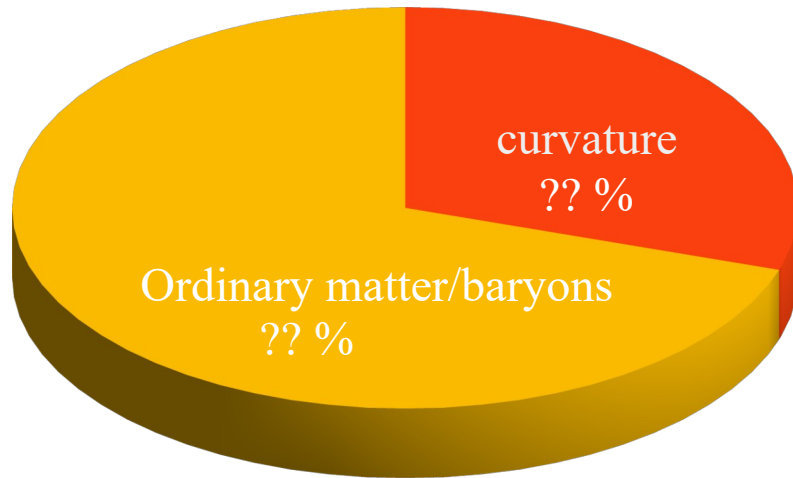
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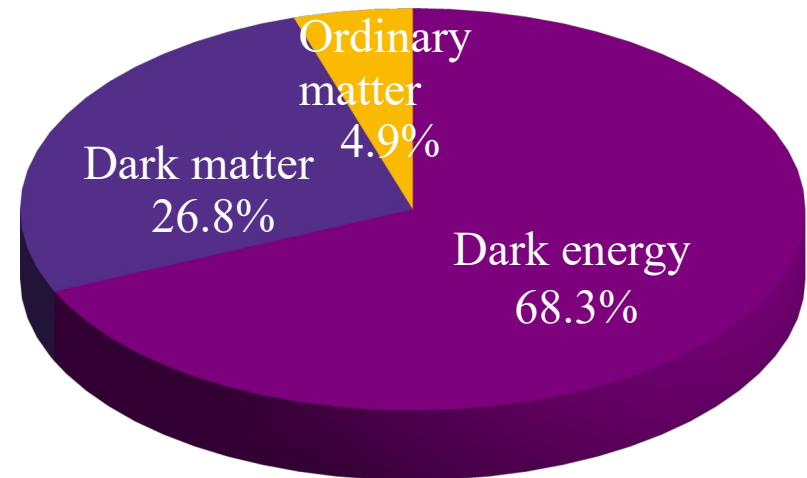
There is no evidence for a baryon asymmetry in our Universe

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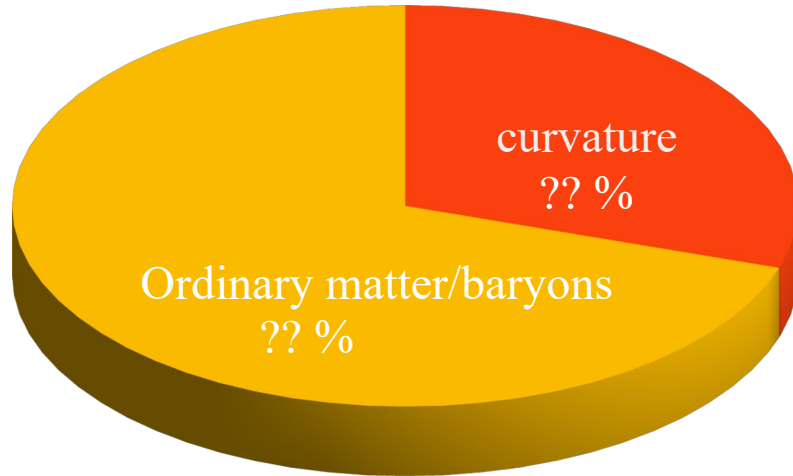


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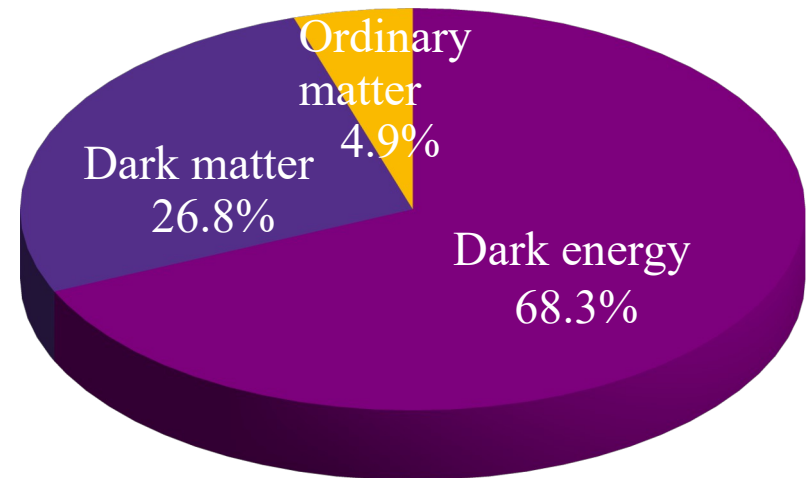
- Observations only show that there are more quarks than antiquarks.
$$Y_{\Delta q,0} = (2.63 \pm 0.07) \times 10^{-10}$$
- Dark sector particles could also carry baryon number
- The Universe could even be baryon symmetric.

Rethinking the Sakharov conditions

The cosmic pie in 1967



The cosmic pie in the 2020s



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The Sakharov conditions may not be necessary

An alternative recipe to cook the cosmic pie

Assume that there are dark sector particles with baryon number.

A quark-antiquark asymmetry will be generated if:

- C- and CP-violation in the dark sector.
To generate an asymmetry between a particle carrying baryon number and its antiparticle
- Portal interactions between dark sector and visible sector.
To transmit the asymmetry to the visible sector.
- Departure from thermal equilibrium.

A simple scenario

- ◆ Complex scalar, χ , with baryon number -1
- ◆ Dirac fermion, N , with baryon number +1
- ◆ Standard Model quarks, with baryon number 1/3
- ◆ Baryon number conservation.

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“Neutron portal” $\bar{N} d_R \overline{u_R^c} d_R$. Transmits the asymmetry in N to the visible sector and generates a quark-antiquark asymmetry
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A simple scenario

The role of the complex scalar χ

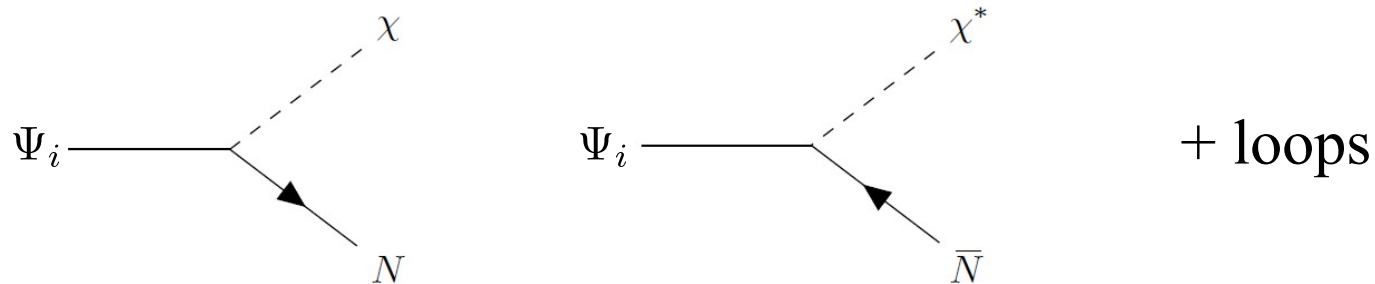
A corresponding asymmetry in χ ensures the conservation of the baryon number throughout the history of the Universe.

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For instance, if the asymmetry in N is generated from the decays of a heavy Majorana fermion, the same decay generates an identical asymmetry in χ .

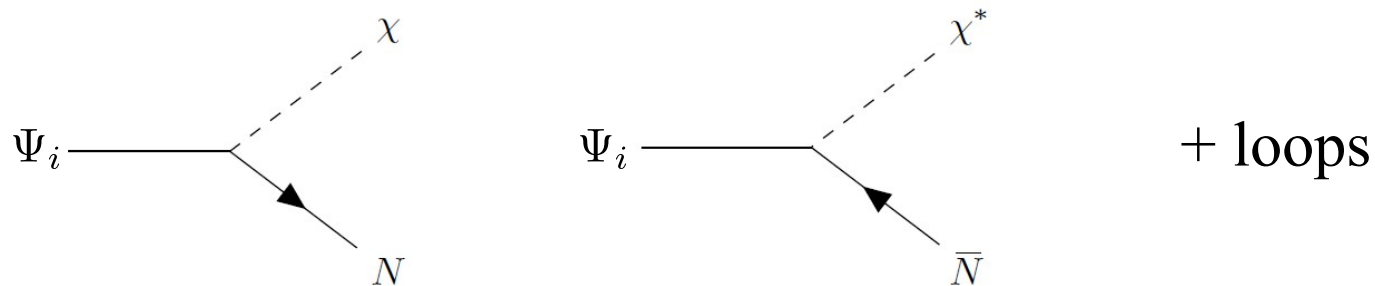


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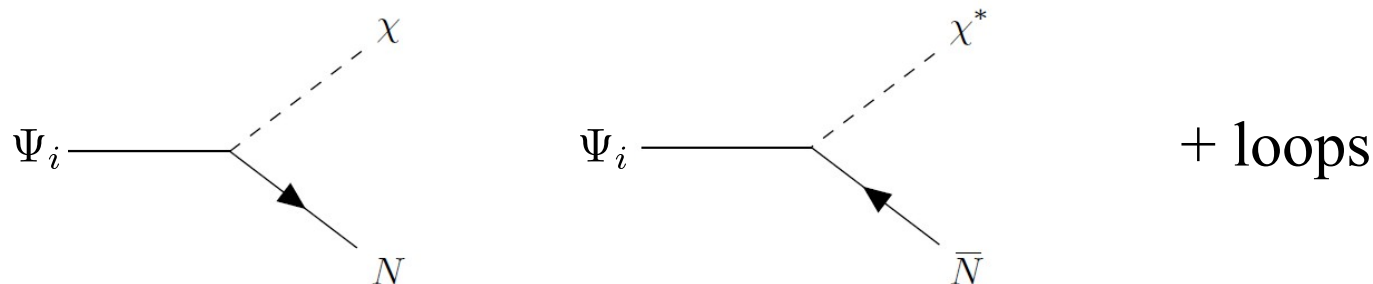
Bonus: χ is absolutely stable, due to the conservation of baryon number.

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quark-antiquark
asymmetry



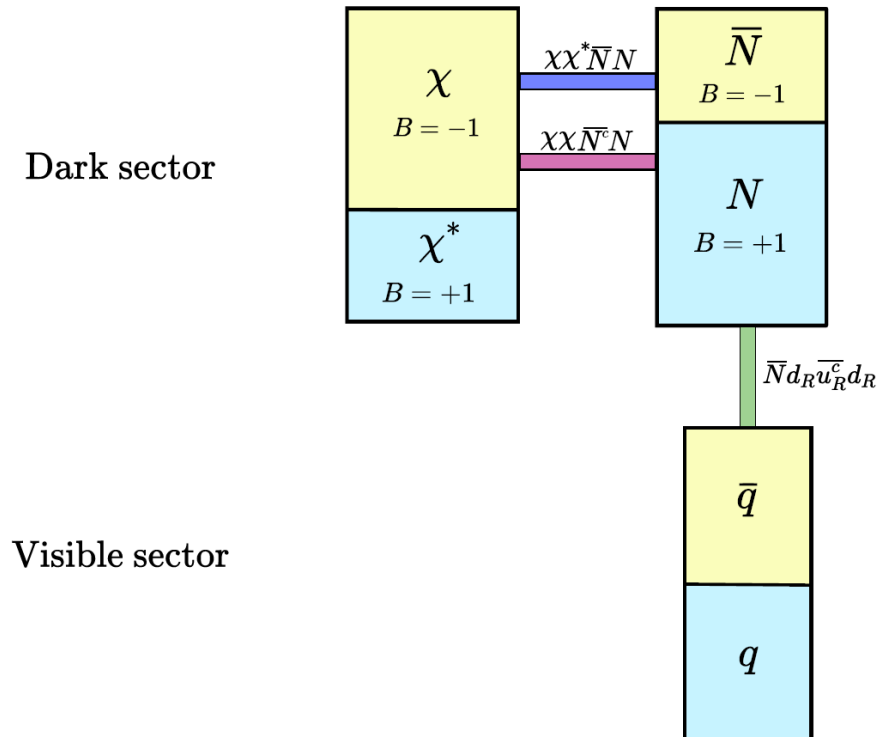
dark matter
stability



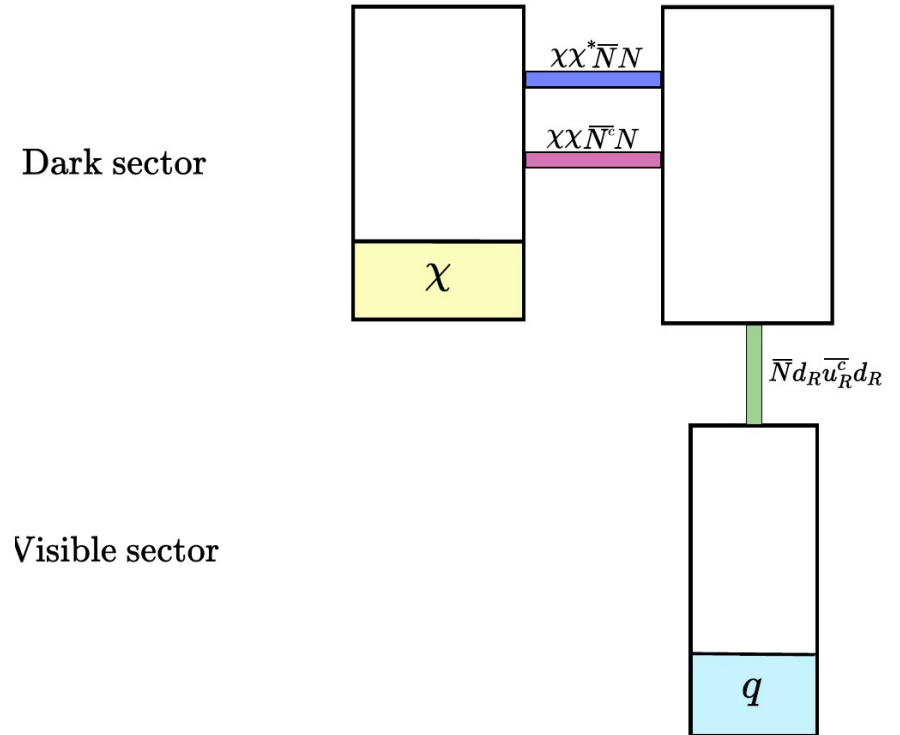
proton
stability

A simple scenario

high T



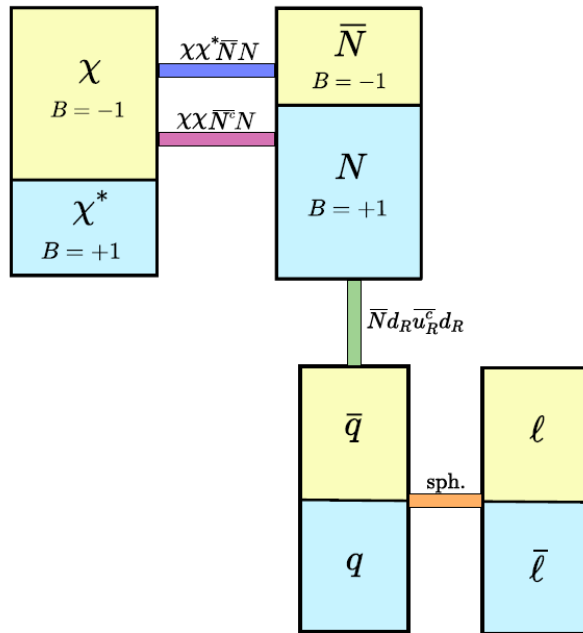
Low T



A more refined scenario

high T

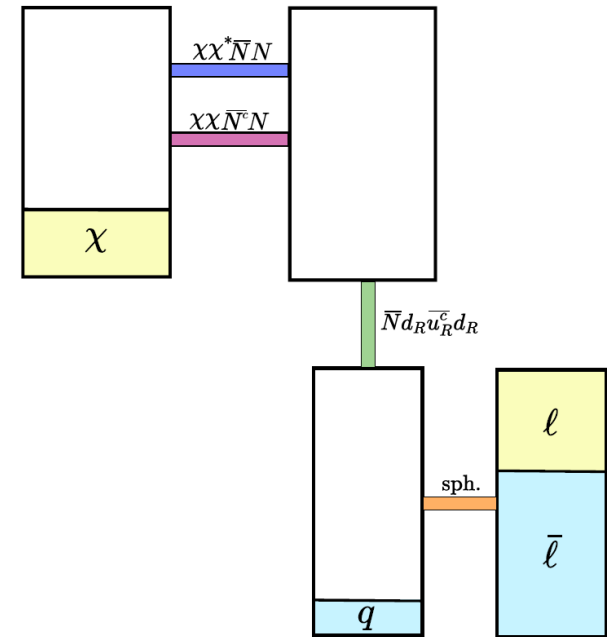
Dark sector



Visible sector

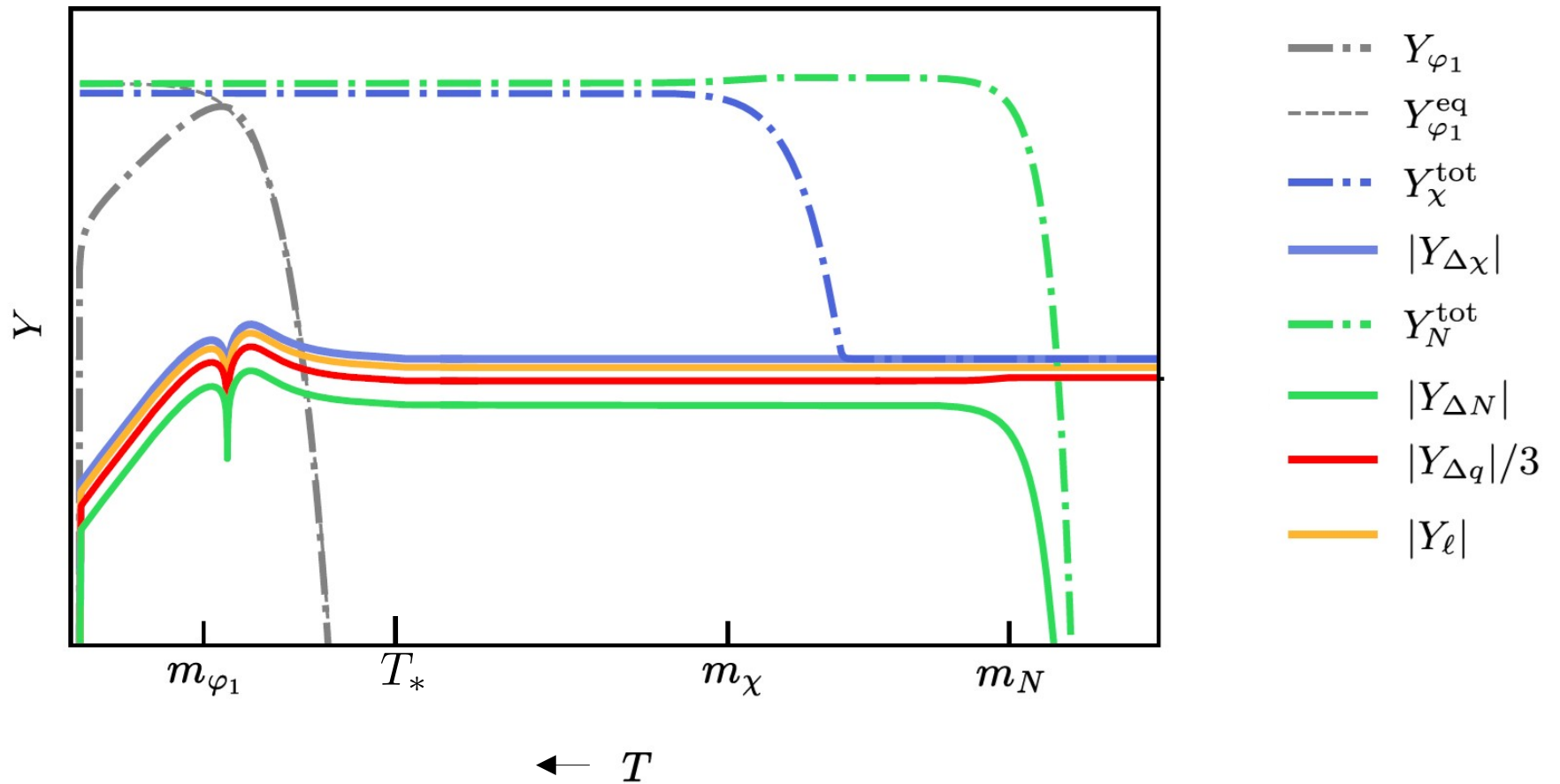
Low T

Dark sector

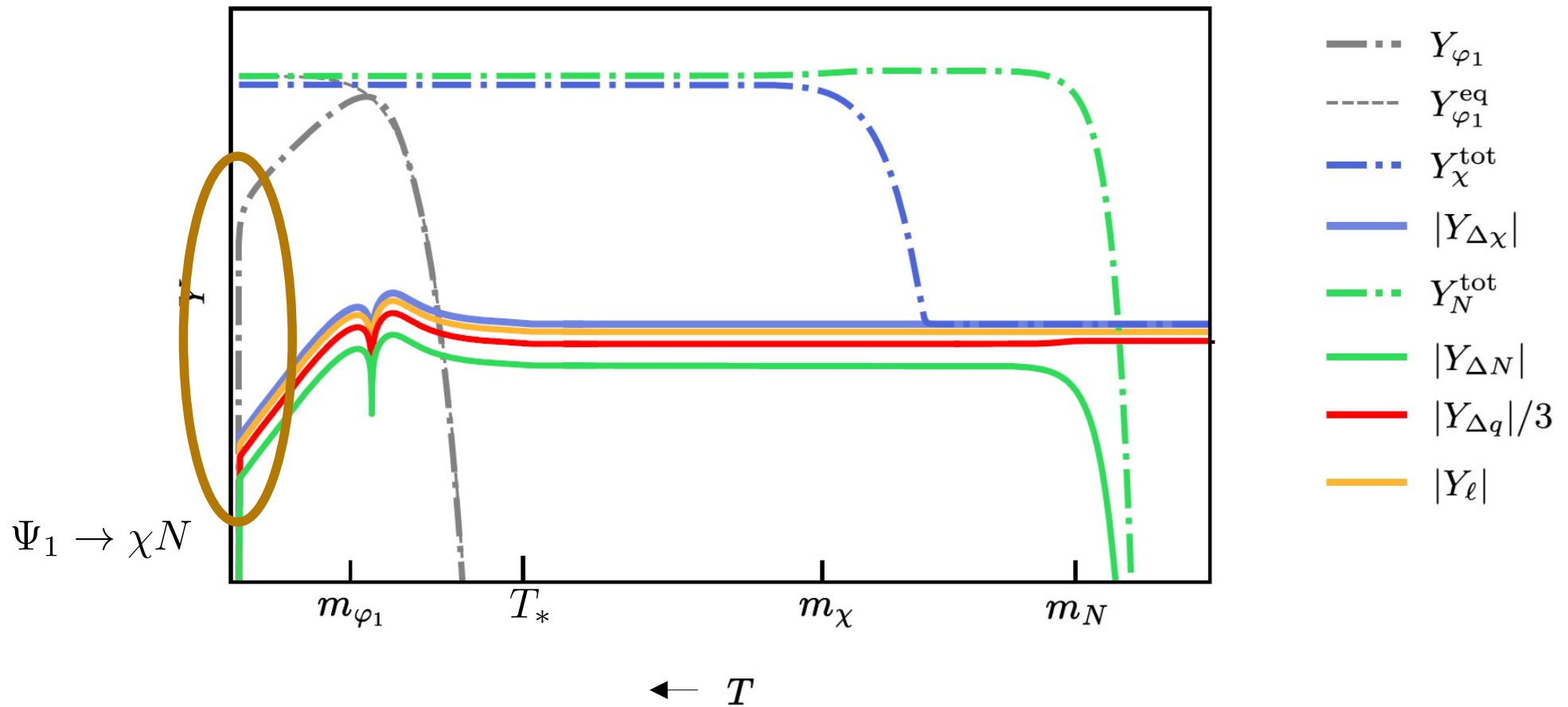


Visible sector

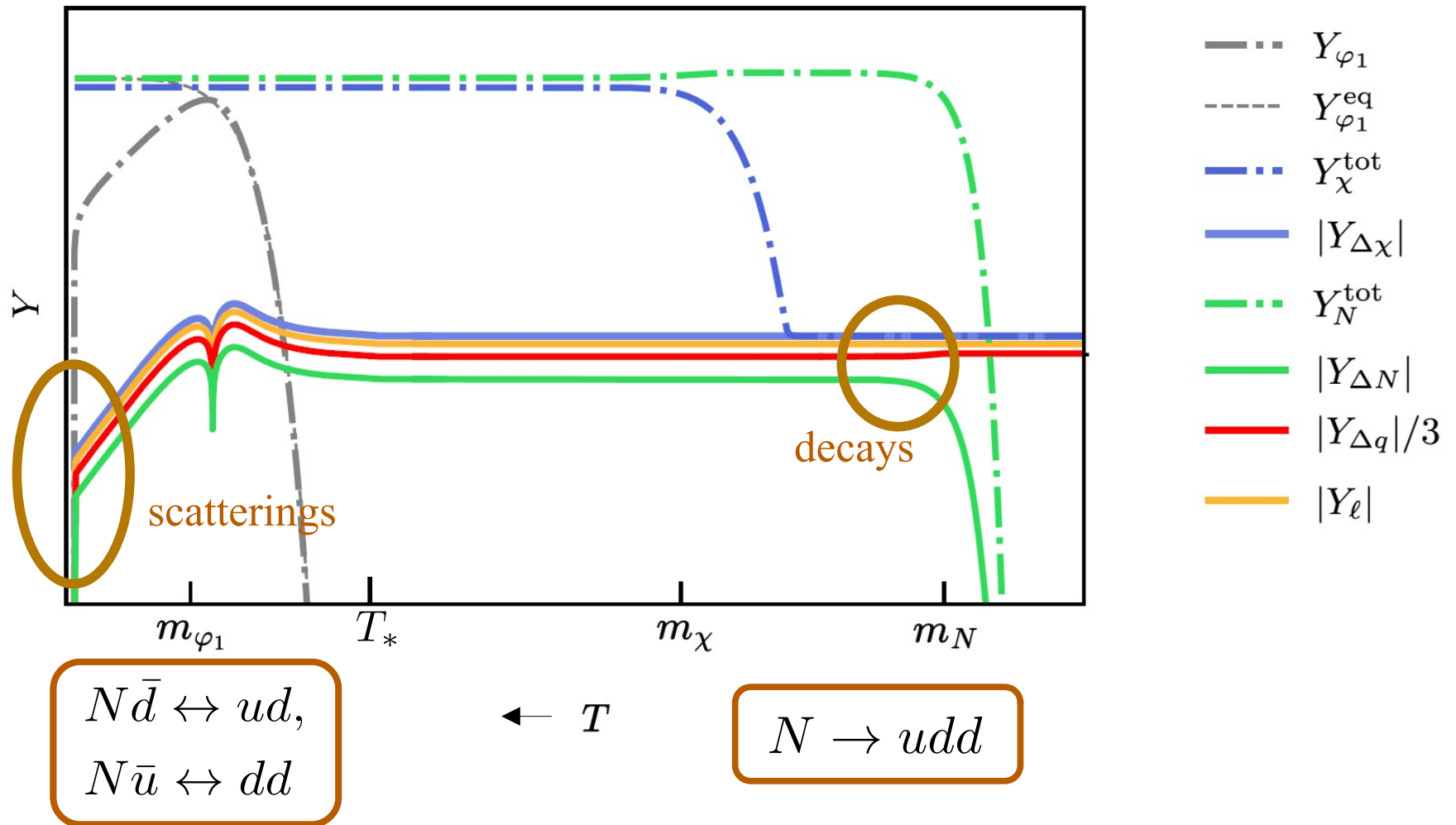
Evolution of the various yields



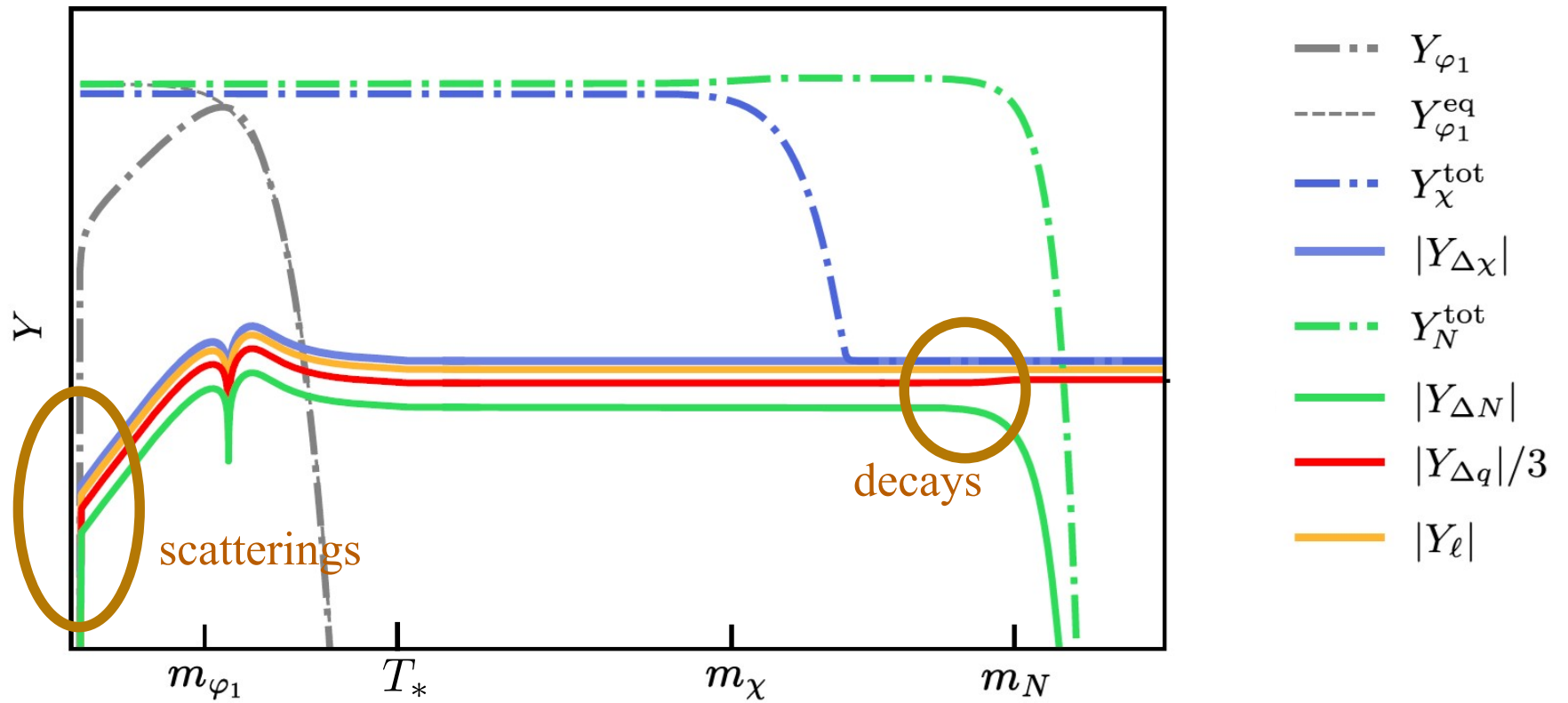
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Evolution of the various yields

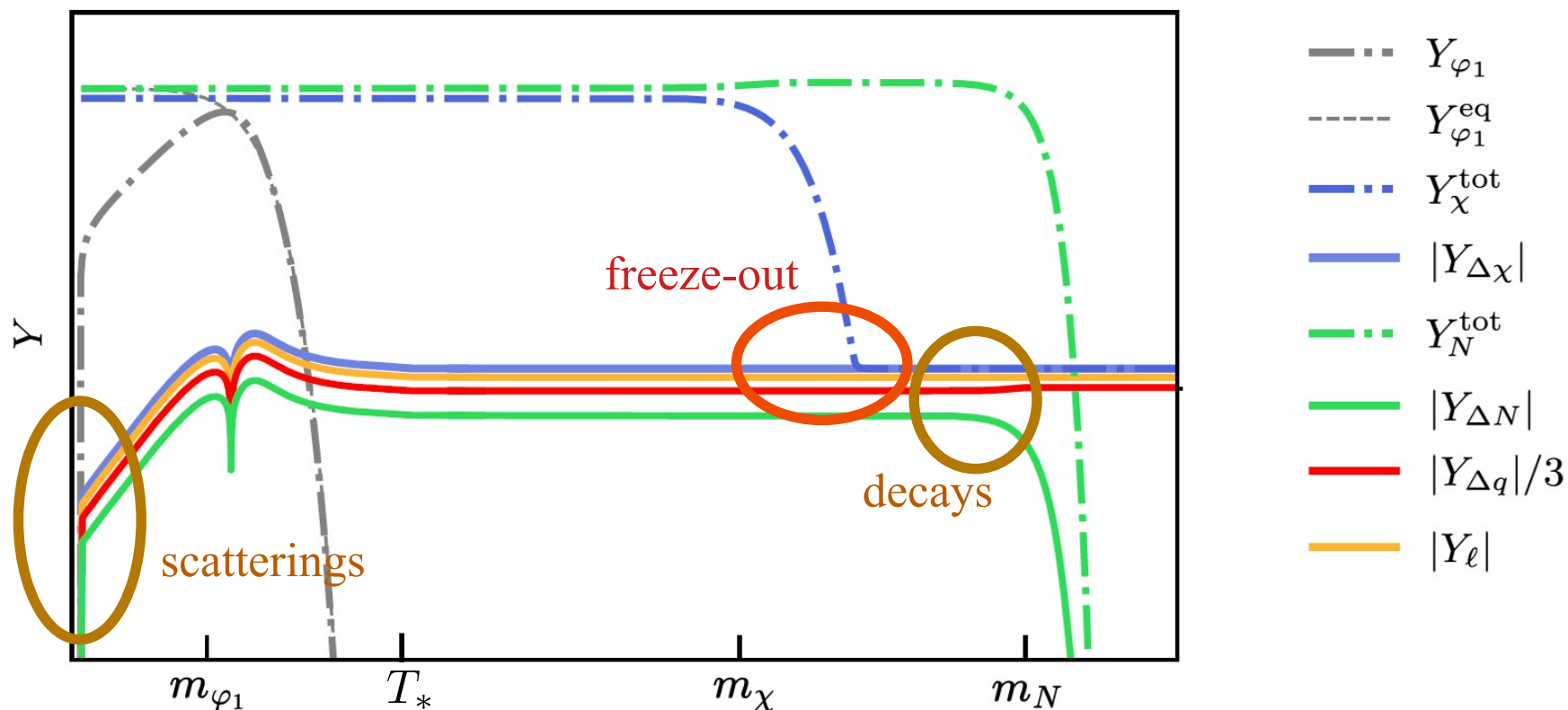


Evolution of the various yields



$$Y_{\Delta q,0} = \frac{141}{122} Y_{\Delta N}(T_*)$$

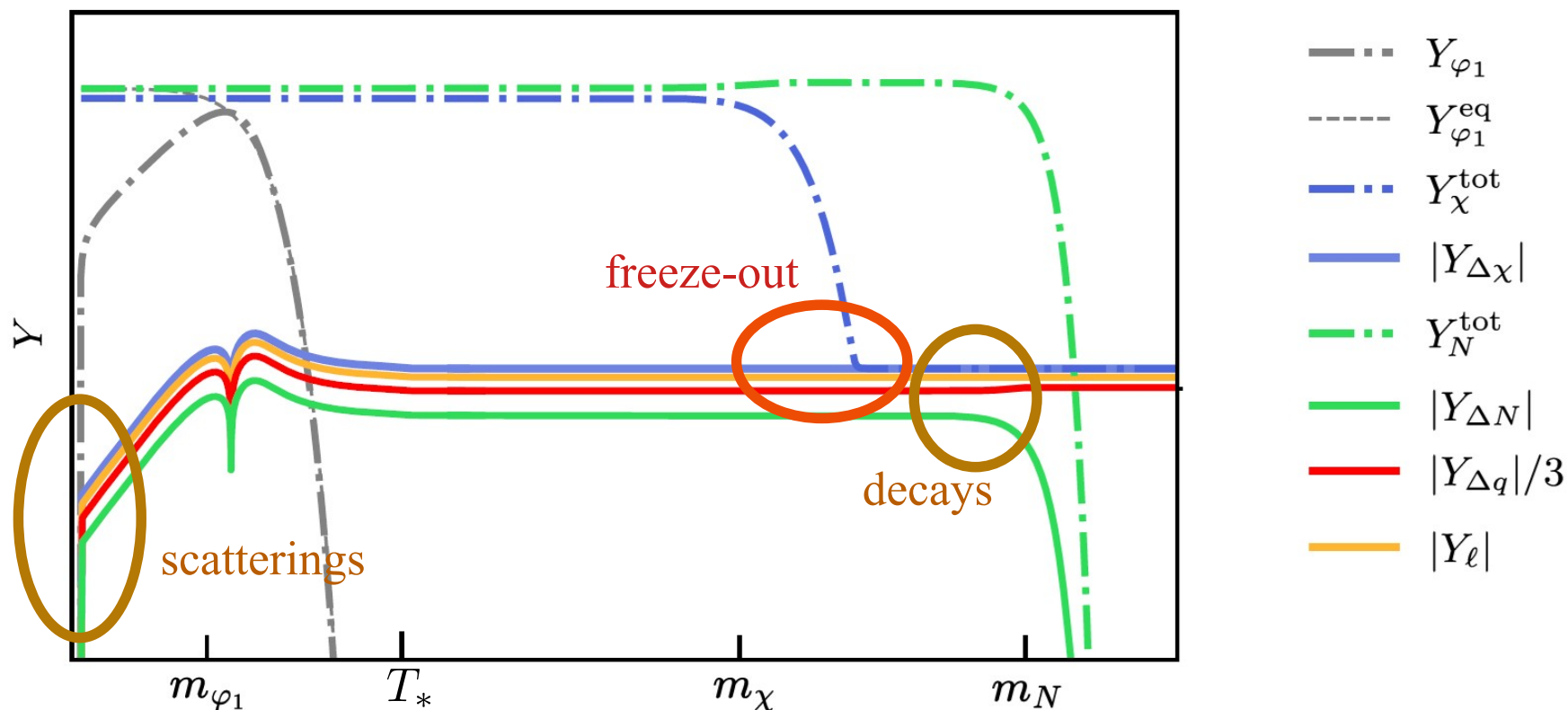
Evolution of the various yields



$$Y_{\Delta q,0} = \frac{141}{122} Y_{\Delta N}(T_*)$$

$$\Omega_{\text{DM},0} h^2 \simeq 2.8 \times 10^8 Y_{\Delta N}(T_*) \frac{m_\chi}{\text{GeV}}.$$

Evolution of the various yields



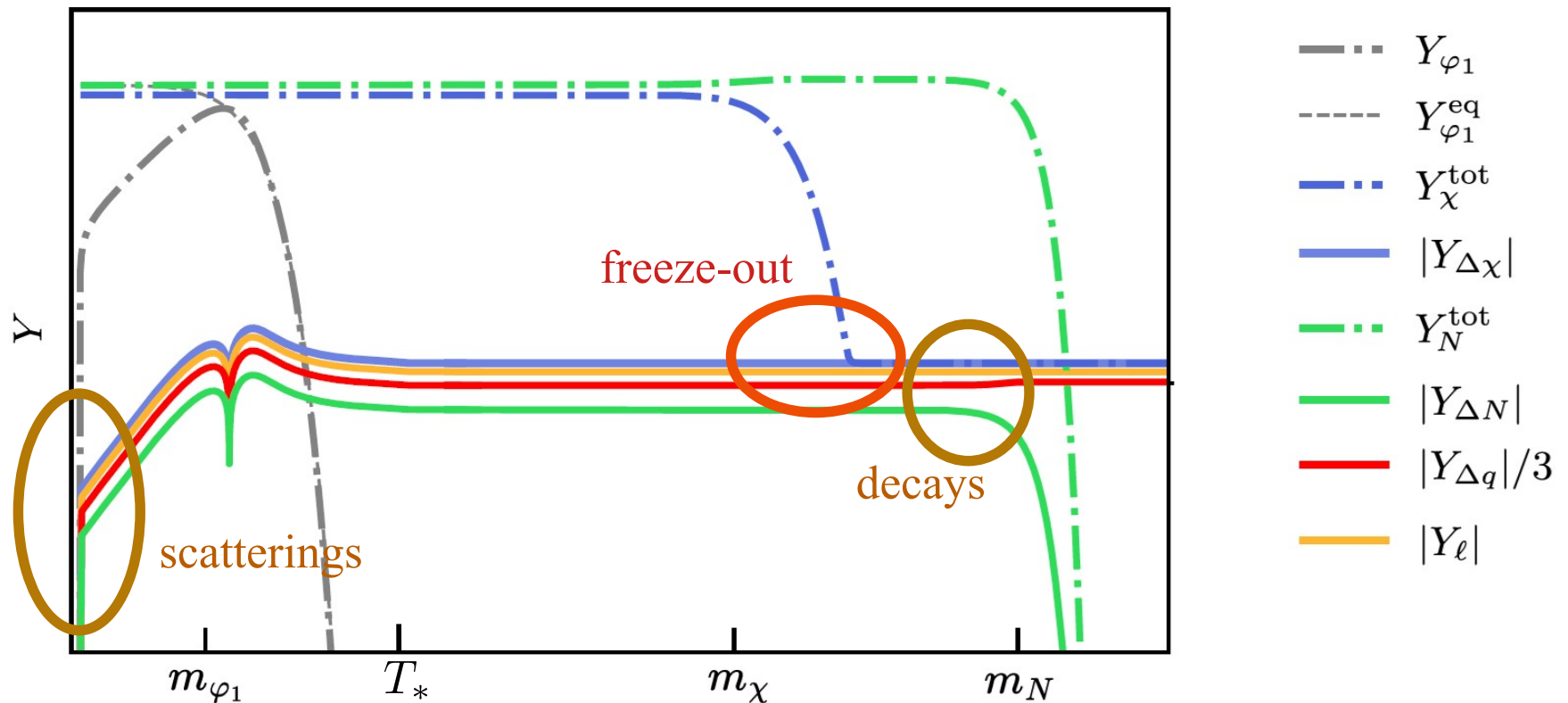
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$$m_\chi \simeq 1.9 \text{ GeV}.$$

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why should
 $m_\chi/m_p = \mathcal{O}(1)??$

A model of composite scalar dark matter

In progress with M. Sabová

		spin	$SU(2)_D$	B
Particle content:	ϕ_1	0	2	$-1/2$
	ϕ_2	0	2	$-1/2$
	N	$1/2$	1	$+1$

The symmetry allows the gauge singlet invariant $\epsilon_{ab}\phi_1^a\phi_2^b$ with $B=-1$ and $\epsilon^{ab}\phi_{1a}^\dagger\phi_{2b}^\dagger$ with $B=+1$.

If $SU(2)_D$ is strongly coupled, the bound state of ϕ_1 and ϕ_2 has spin 0 and $B=-1$:

$$\epsilon_{ab}\phi_1^a\phi_2^b \rightarrow f_\chi\chi$$

χ has the correct properties

A model of composite scalar dark matter

In progress with M. Sabová

Remarks:

- 1) The dark matter stability is not due to $SU(2)_D$, but due to the baryon number conservation

If B conservation is not imposed, the gauge symmetry allows

$$\mathcal{L} = \lambda_{\phi H} (\epsilon_{ab} \phi_1^a \phi_2^b) H^\dagger H$$

$$\mathcal{L} = \frac{\lambda_{\phi H} f_\chi v}{\sqrt{2}} \chi h \longrightarrow \text{DM decay}$$

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$$\mathcal{L} = \frac{\lambda_{\phi H} f_\chi v}{\sqrt{2}} \chi h \longrightarrow \text{DM decay}$$

- 2) The scale of confinement of the $SU(2)_D$ is comparable to the one of $SU(3)_C$

$$b = \frac{11}{3} C_2(G) - \frac{1}{3} \sum_s T(R_s) \quad \begin{array}{l} \text{SU(3)}_C \text{ with six quarks in } \mathbf{3}: b = 7 \\ \text{SU(2)}_D \text{ with two scalars in } \mathbf{2}: b = 7 \end{array}$$

If the couplings are comparable, $\Lambda_{\text{QCD}} \sim \Lambda_D$

If $m_{\phi_i} \ll \Lambda_D$, then $m_\chi/m_p = \mathcal{O}(1)$

A model of composite scalar dark matter

In progress with M. Sabová

3) To generate the initial asymmetries we introduce a Majorana fermion with zero baryon number.

The C and CP violating decays

$$\Psi_i \rightarrow \epsilon_{ab} \phi_1^a \phi_2^b N, \epsilon_{ab} \phi_1^{a*} \phi_2^{b*} \bar{N}$$

Generate asymmetries $(Y_{\phi_1} - Y_{\phi_1^*}) = (Y_{\phi_2} - Y_{\phi_2^*}) = (Y_N - Y_{\bar{N}})$ while keeping the total baryon number conserved.

A model of composite scalar dark matter

In progress with M. Sabová

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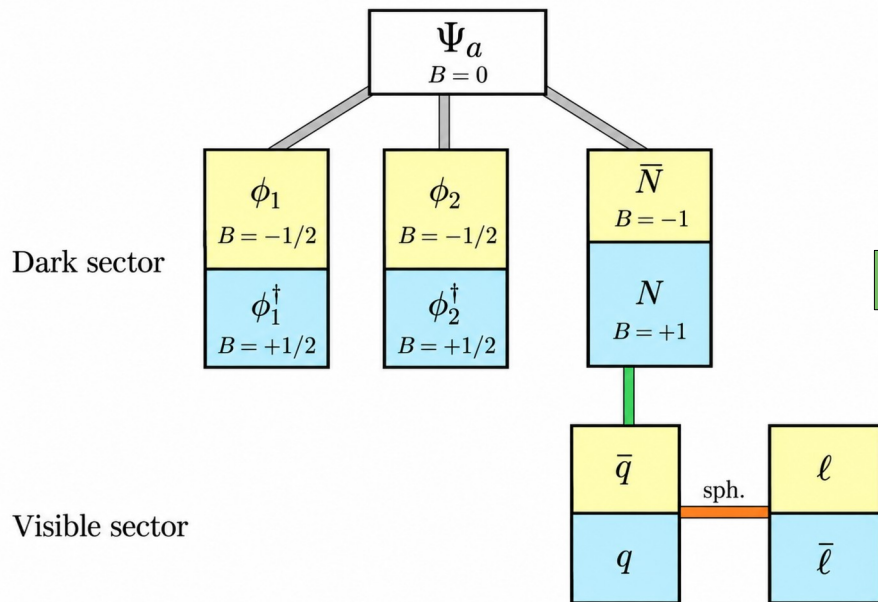
Generate asymmetries $(Y_{\phi_1} - Y_{\phi_1^*}) = (Y_{\phi_2} - Y_{\phi_2^*}) = (Y_N - Y_{\bar{N}})$ while keeping the total baryon number conserved.

4) The symmetric part of the ϕ_i population annihilates into dark gluons

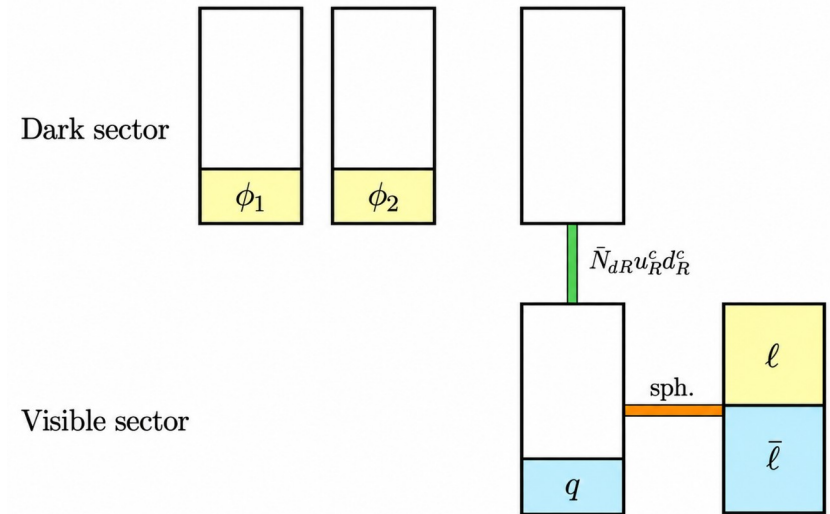
$$\phi_i \phi_i^* \rightarrow g_D g_D$$

A model of composite scalar dark matter

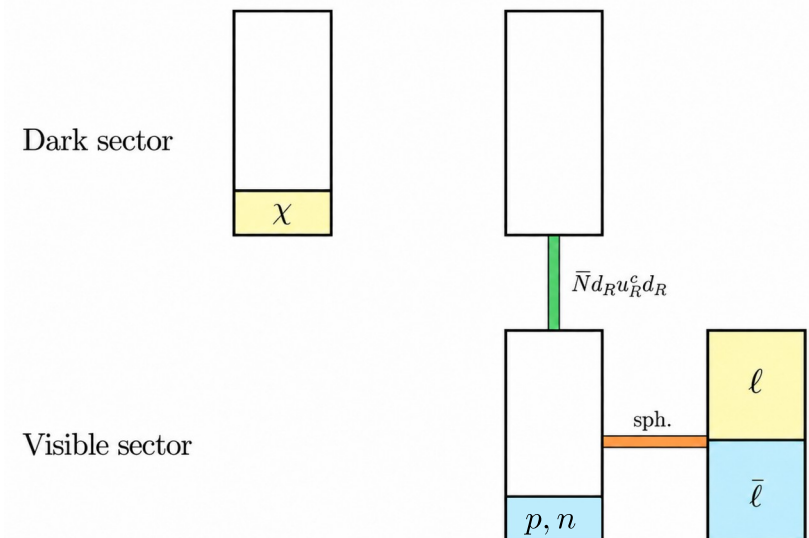
Generation of asymmetries from ψ decay



Annihilation of the symmetric part of ϕ_i
Transmission of the asymmetry in N to the visible sector



Confinement of ϕ and quarks



Conclusions

- There is no evidence for a baryon asymmetry in our Universe. Observations only show that there are more quarks than antiquarks.
- Dark sector particles could also carry baryon number. If this is the case, a quark-antiquark asymmetry could be generated without fulfilling the Sakharov conditions.
- We have presented a simple scenario where the baryon number is conserved, and that generates a quark-antiquark asymmetry. As a bonus, the dark matter particle is stable due to the baryon number conservation, and is predicted to have a mass of a few GeV. These scenario can be realized in simple models of composite dark matter with scalar constituents.

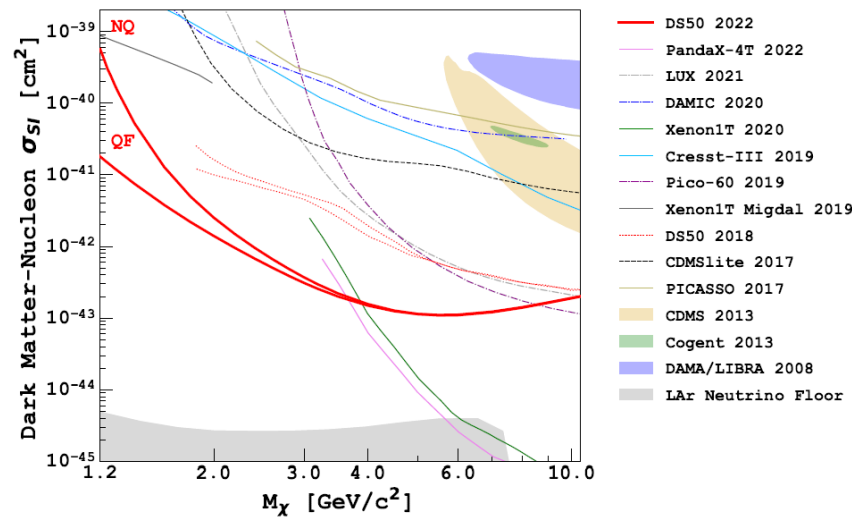
Experimental tests

1) Higgs portal $\lambda_{\chi H} |\chi|^2 |H|^2$

- Higgs invisible decay $h \rightarrow \chi\chi^*$

From $\text{BR}(h \rightarrow \text{inv}) < 0.18$, $\Rightarrow \lambda_{\chi H} \lesssim 10^{-2}$

- Direct detection: same analysis as for the singlet scalar DM model

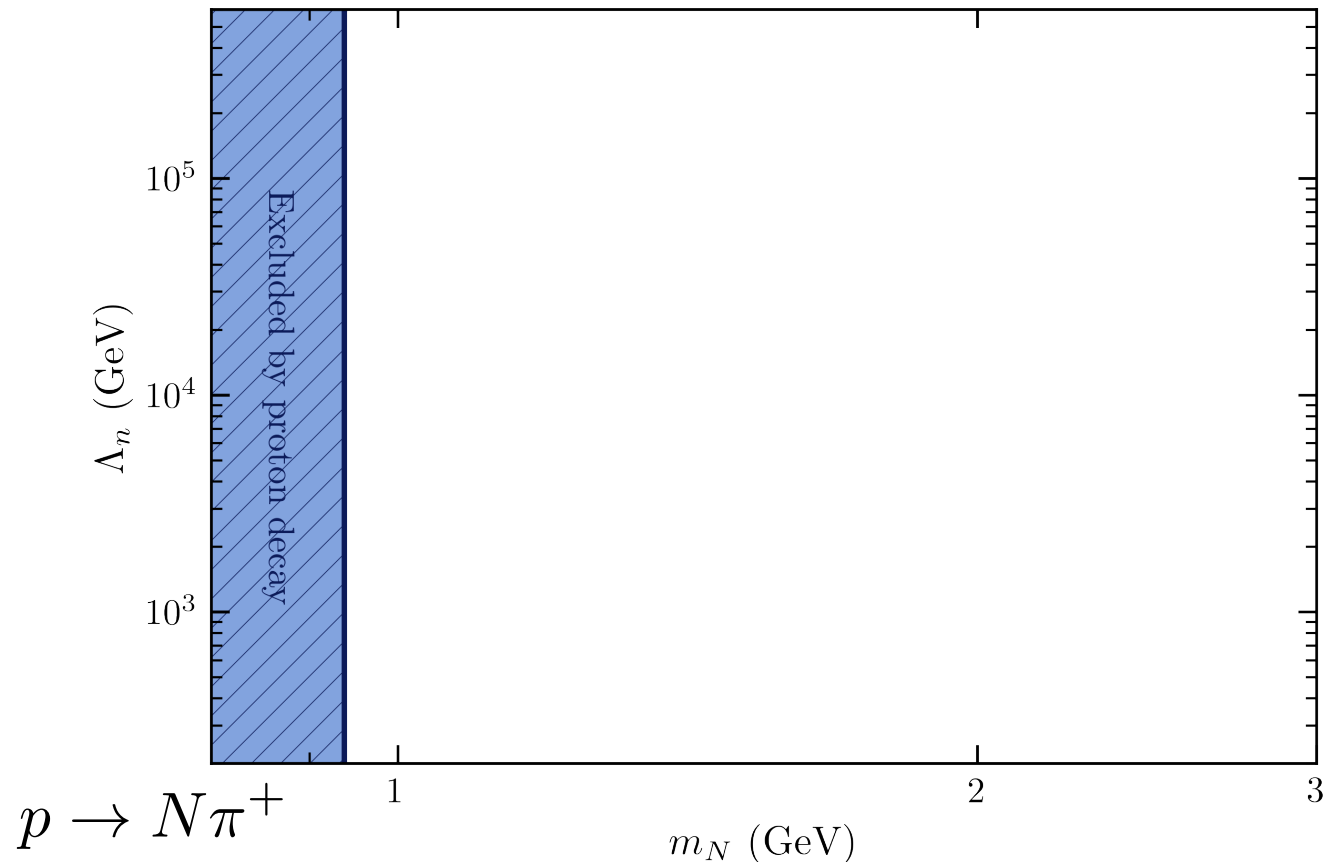


$$\Rightarrow \lambda_{\chi H} \lesssim 10^{-2}$$

Note: the Higgs portal generates a contribution to the dark matter mass.
To keep $m_\chi \sim$ a few GeV, $\Rightarrow \lambda_{\chi H} \lesssim 2 \times 10^{-4}$

Experimental tests

2) Neutron portal $\frac{1}{\Lambda_n^2} \overline{N} d_R \overline{u}_R^c d_R$

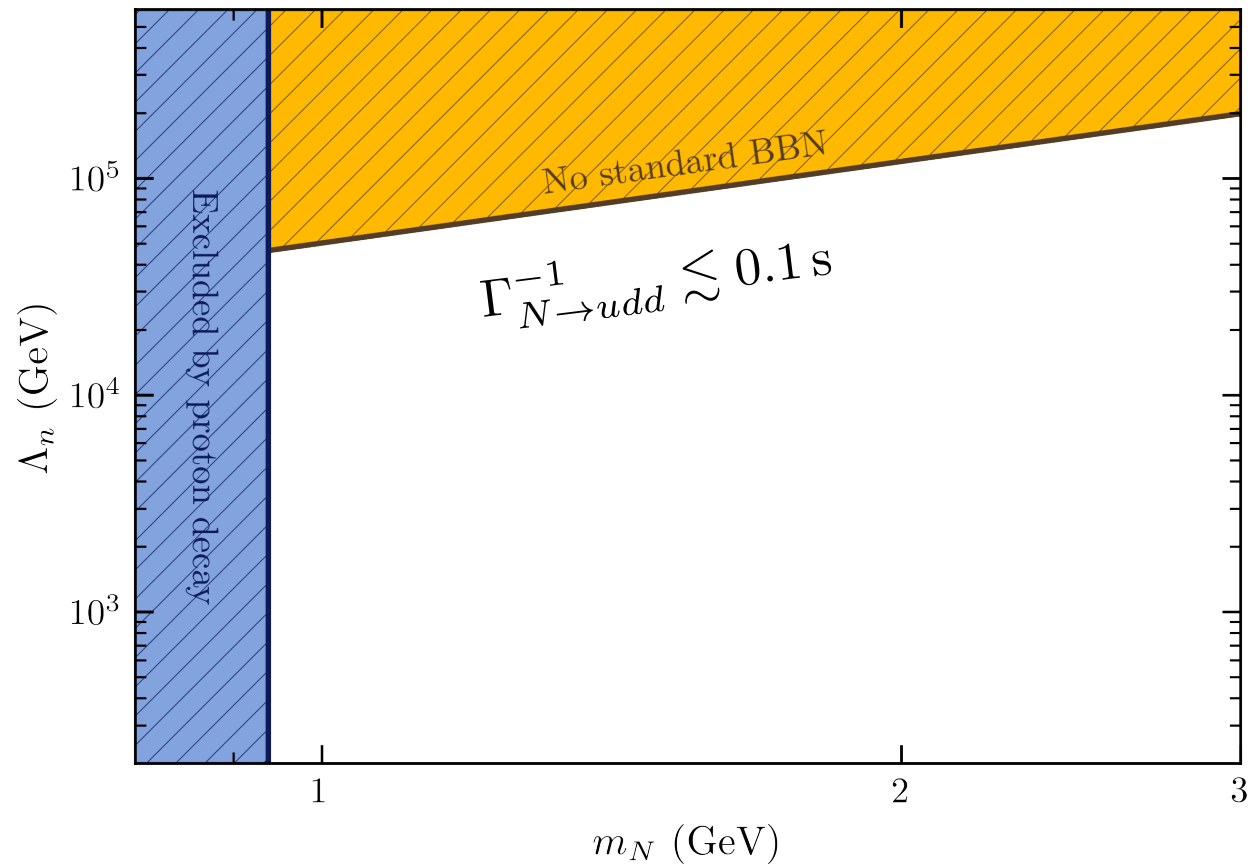


Larger N masses could be probed searching for $\Delta^+ \rightarrow N \pi^+$

No search reported in the PDG. In our framework, it is a B-conserving decay

Experimental tests

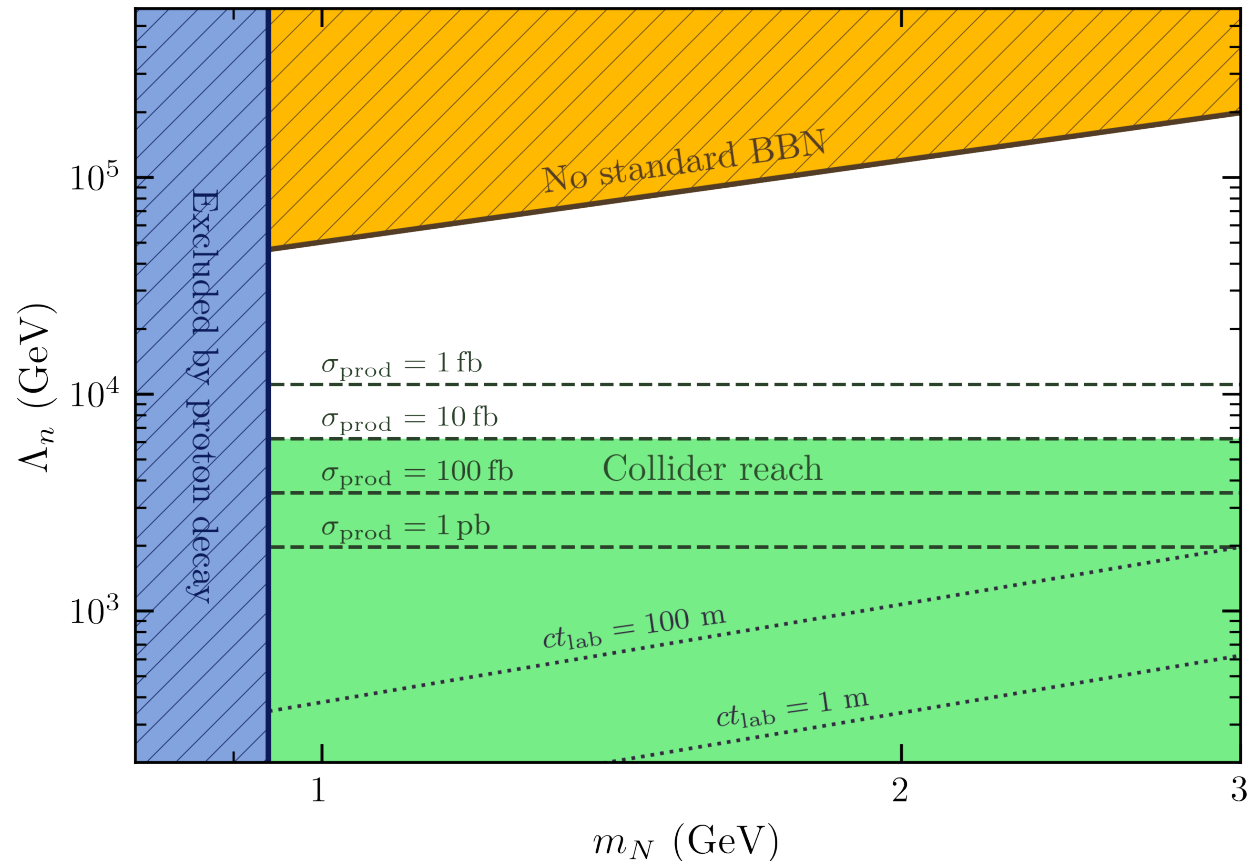
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$$\Gamma_{N \rightarrow udd}^{-1} \approx 1.6 \text{ s} \left(\frac{\Lambda_n}{10^5 \text{ GeV}} \right)^4 \left(\frac{\text{GeV}}{m_N} \right)^5,$$

Experimental tests

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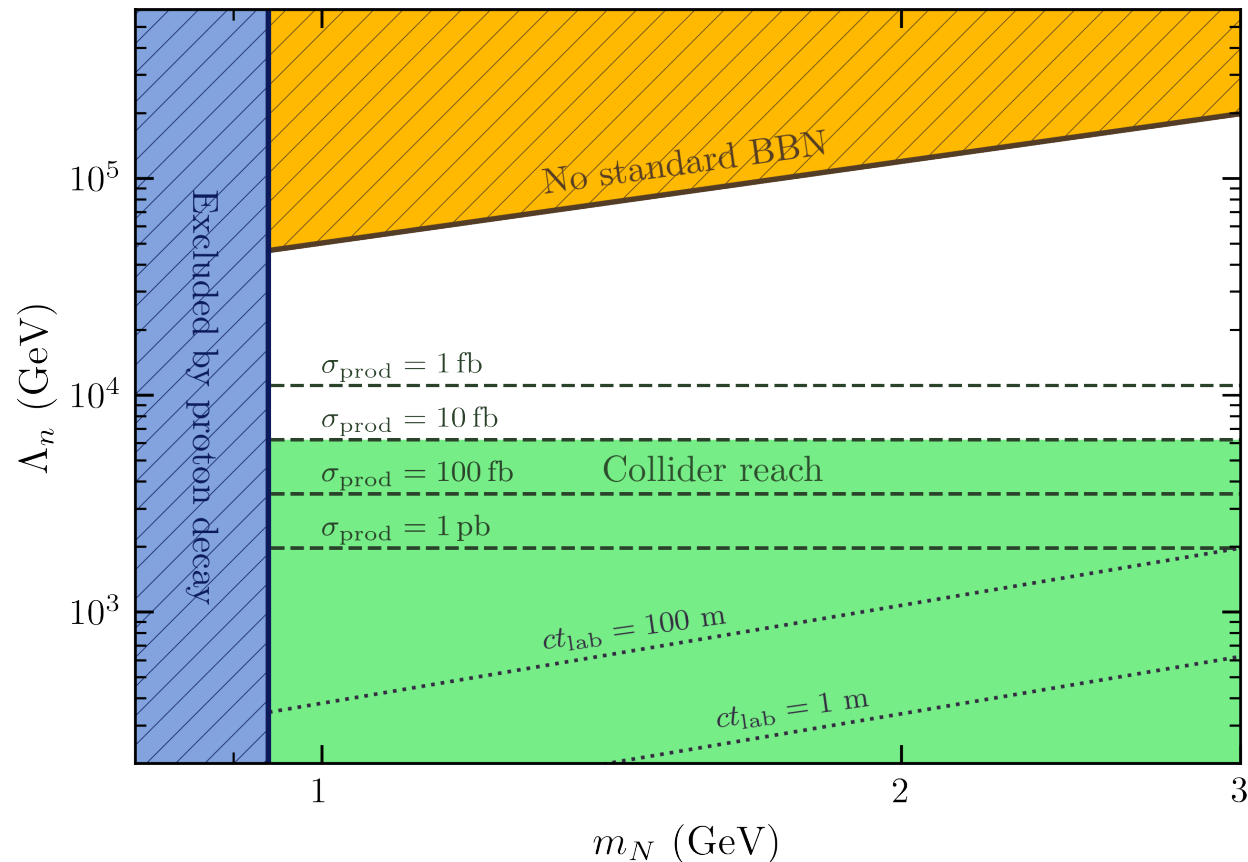


N production in pp collisions through $ud \rightarrow N\bar{d}, dd \rightarrow N\bar{u}$

$$\sigma_{pp \rightarrow N + \text{jet}} \approx 2 \text{ fb} \left(\frac{f_{\text{PDF}}}{10^{-2}} \right) \left(\frac{10^4 \text{ GeV}}{\Lambda_n} \right)^4$$

Experimental tests

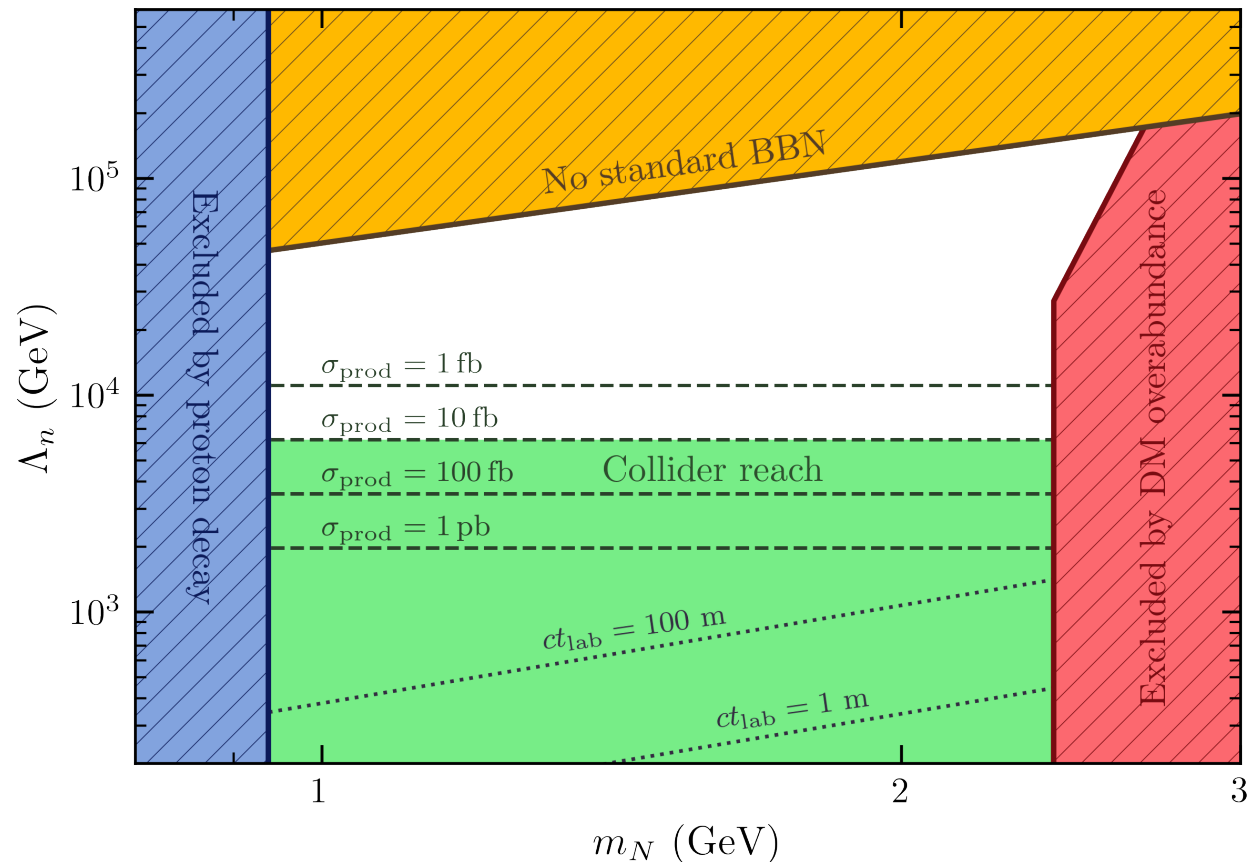
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- The EFT may break down. Additional signatures from the production of the mediator.
- These constraints are not valid for different baryon-portals, e.g. the “charmed-Omega” portal $\bar{N} s_R \bar{c}_R^c s_R$
- **No search exists on baryon $\rightarrow$ meson + invisible**

Experimental tests

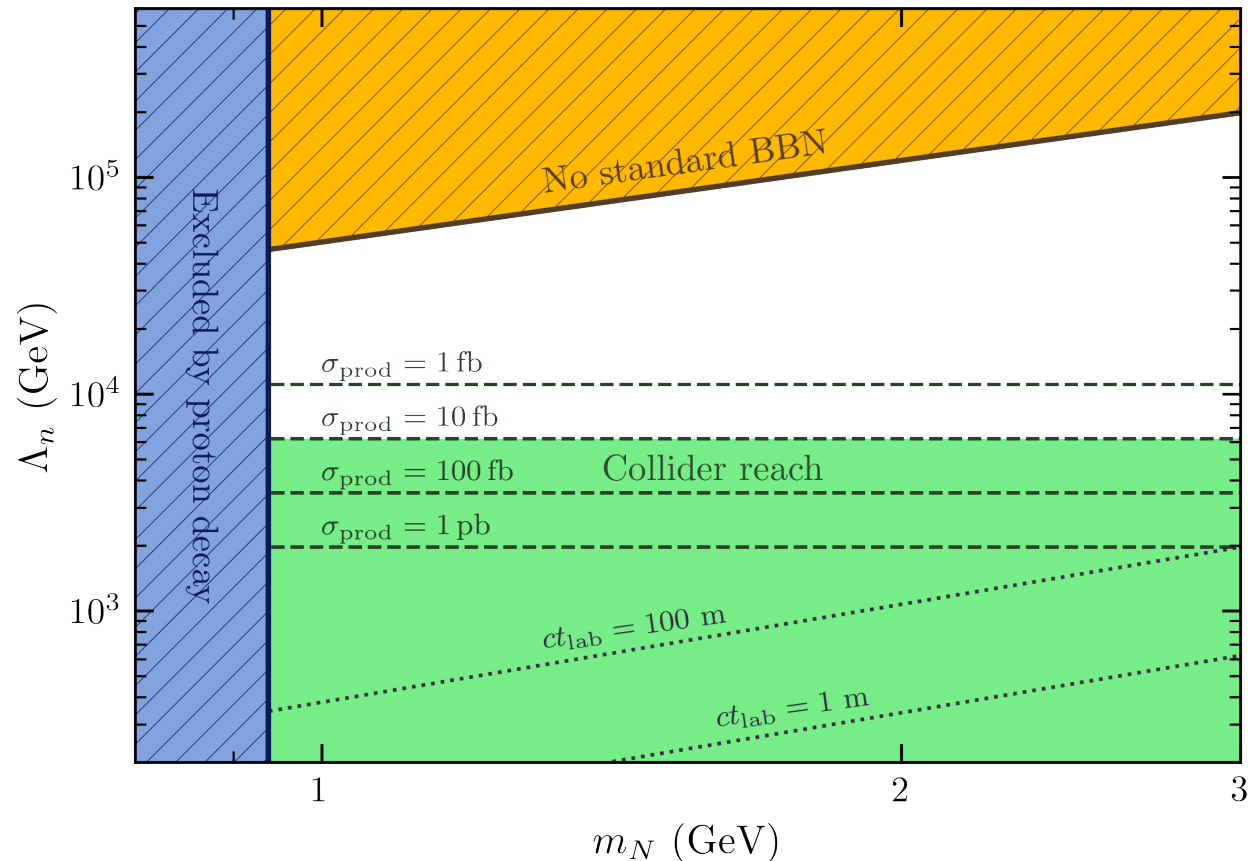
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The rate of annihilations $\chi\chi^* \rightarrow N\overline{N}$ must be sufficiently efficient at freeze-out.

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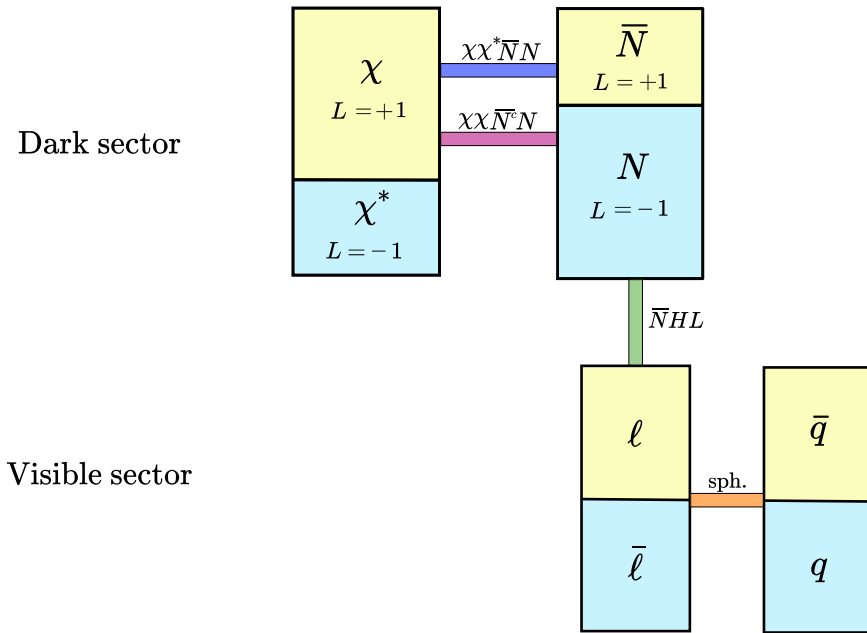
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This limit can be avoided if the DM annihilates into other dark sector particles.

A leptonic version

AI. Proff. To appear

high T



Low T

