Connecting the baryons to the dark matter of the Universe

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In collaboration with Mar Ciscar and Jérôme Vandecasteele. JCAP 01 (2024) 028, and works in preparation.

Rencontres de Moriond
La Thuile
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Introduction

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

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

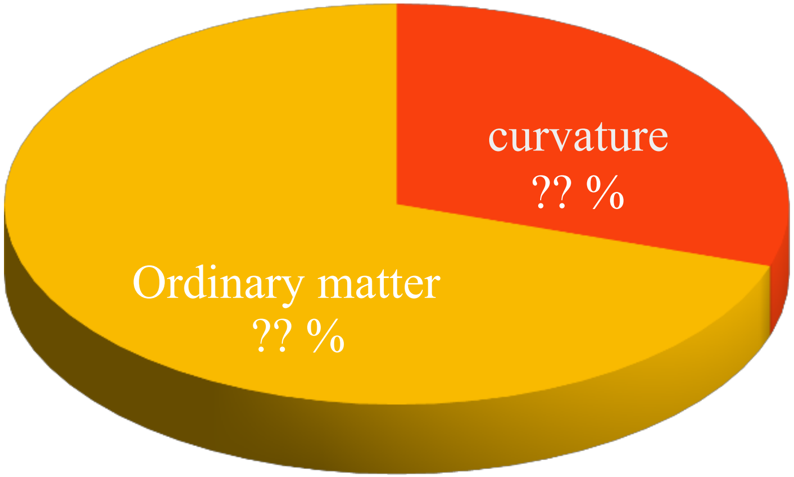
• A baryon asymmetry could be dynamically generated from a baryon symmetric Universe, if the following conditions are satisfied (Sakharov'67):

1) Violation of baryon number
2) C and CP violation.
3) Departure from thermal equilibrium.

Baryogenesis

Introduction

The cosmic pie in 1967



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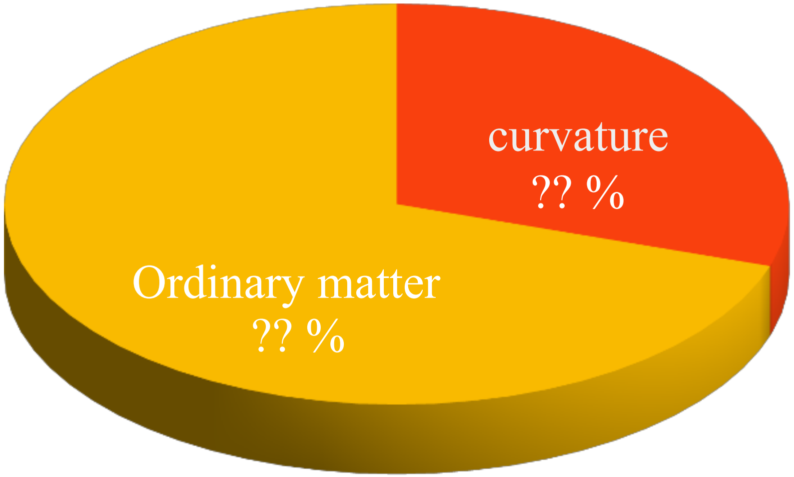

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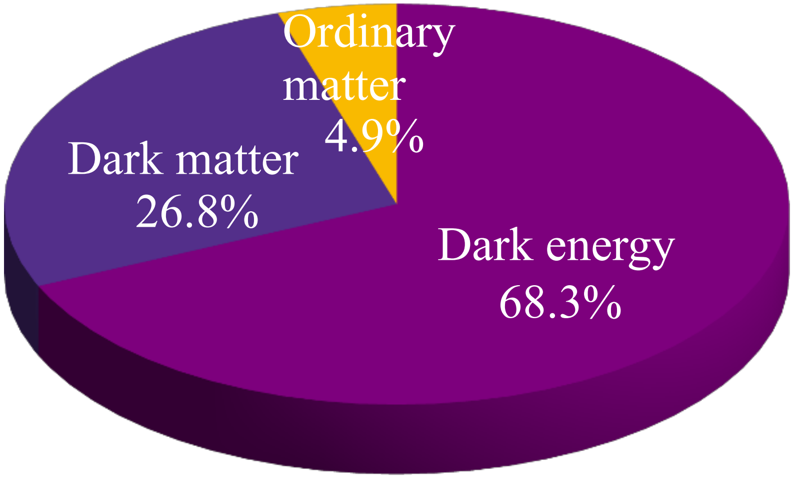

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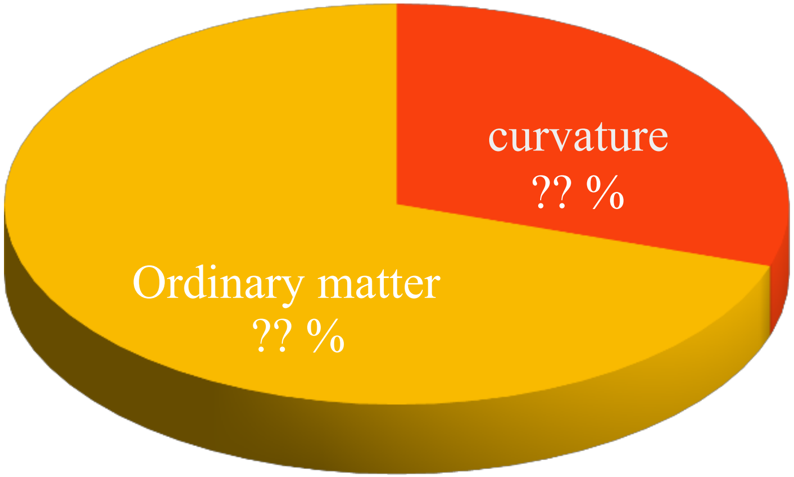

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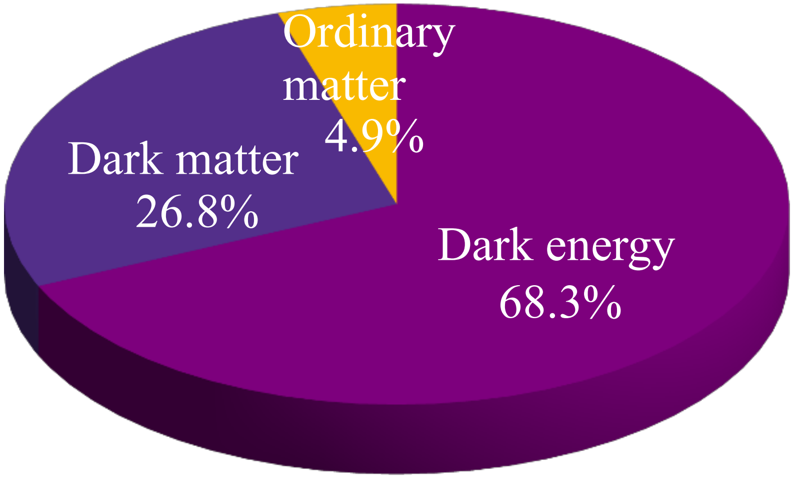

There is no evidence for a baryon asymmetry in our Universe

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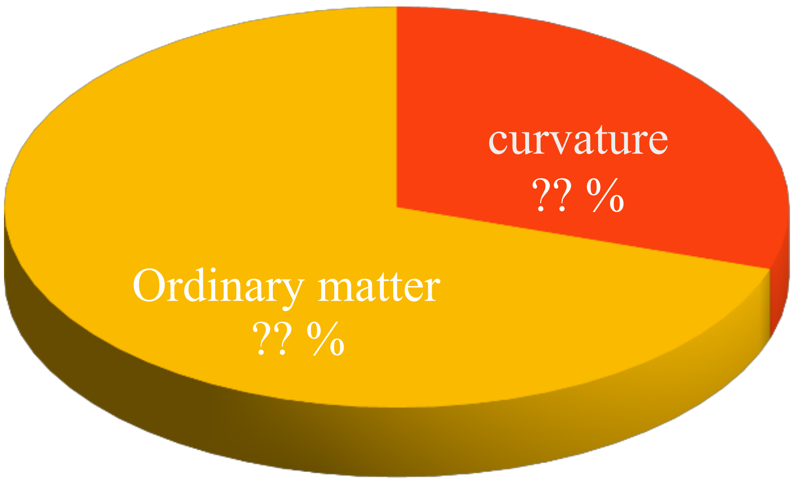

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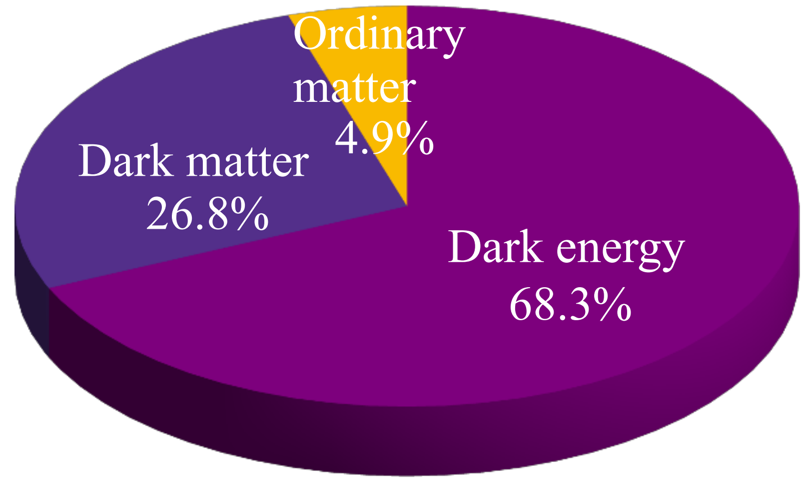

There is no evidence for a baryon asymmetry in our Universe

- 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.

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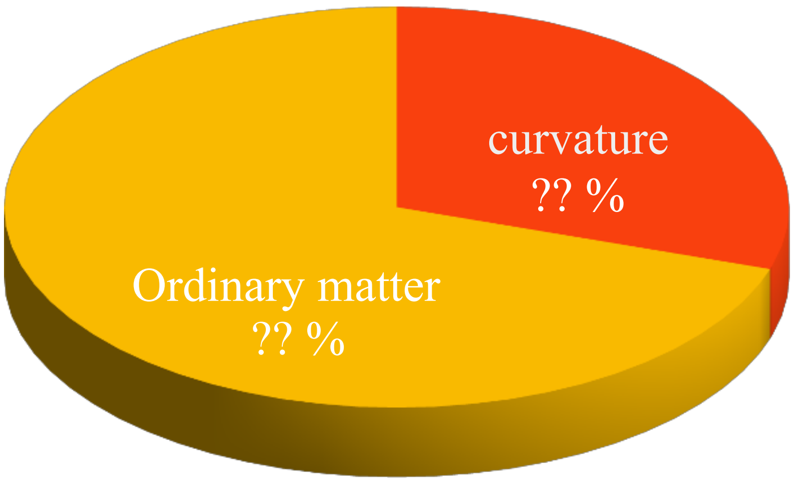

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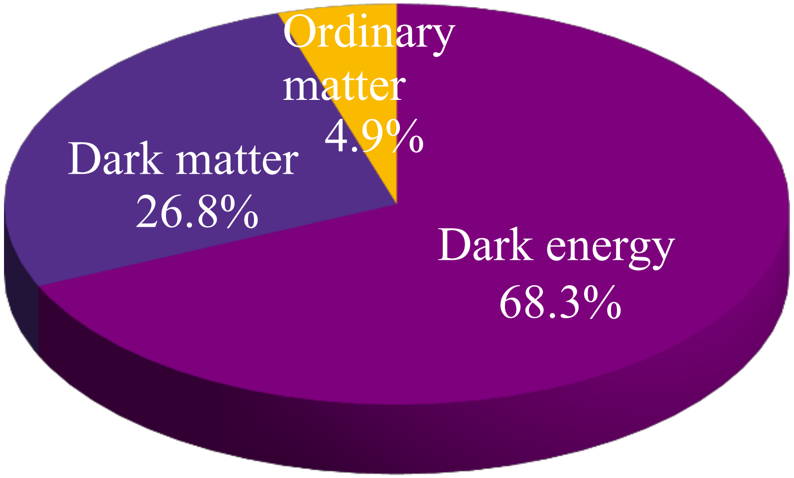

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The Sakharov conditions may not be necessary

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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  Generates more N than $\overline{N}$. For example, from the out of equilibrium decay of a heavy particle, à la leptogenesis.

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  "Neutron portal" $\overline{N} d_{\rm R} \, \overline{u^c_{\rm R}} d_{\rm R}$. Transmits the asymmetry in N to the visible sector and generates a quark-antiquark asymmetry

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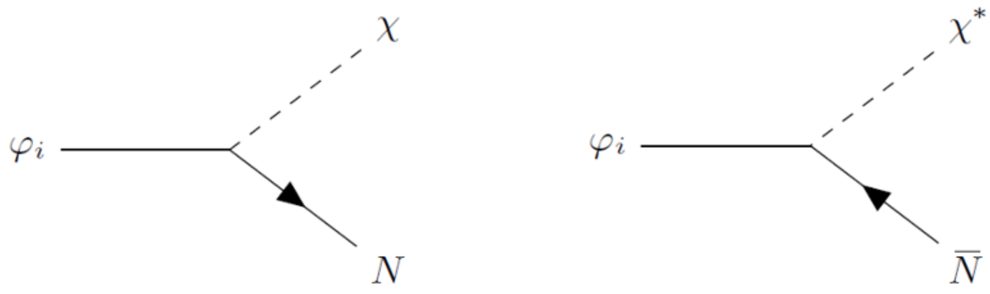

+ loops

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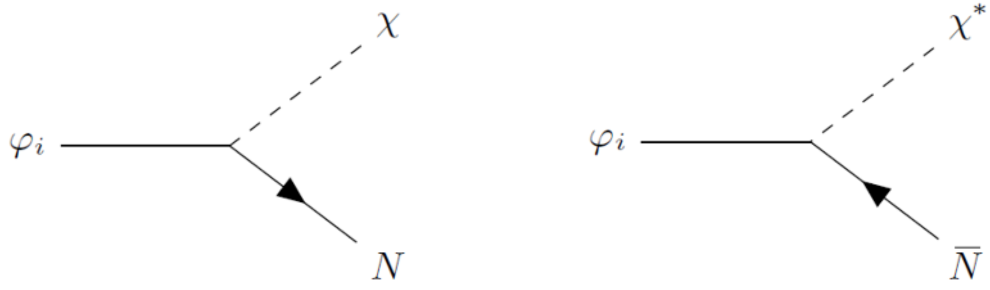

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Bonus: χ is absolutely stable, due to the conservation of baryon number.

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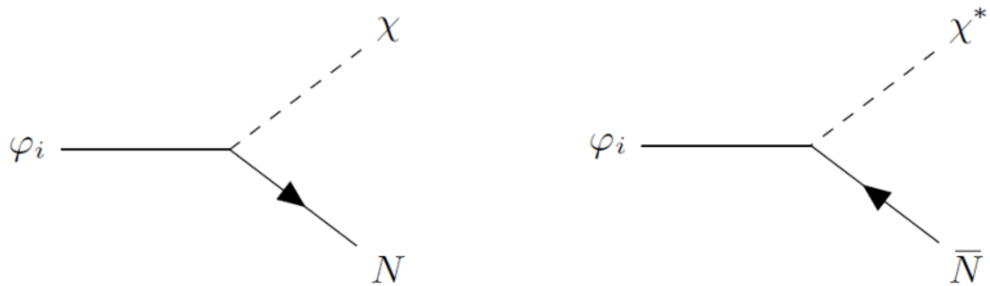

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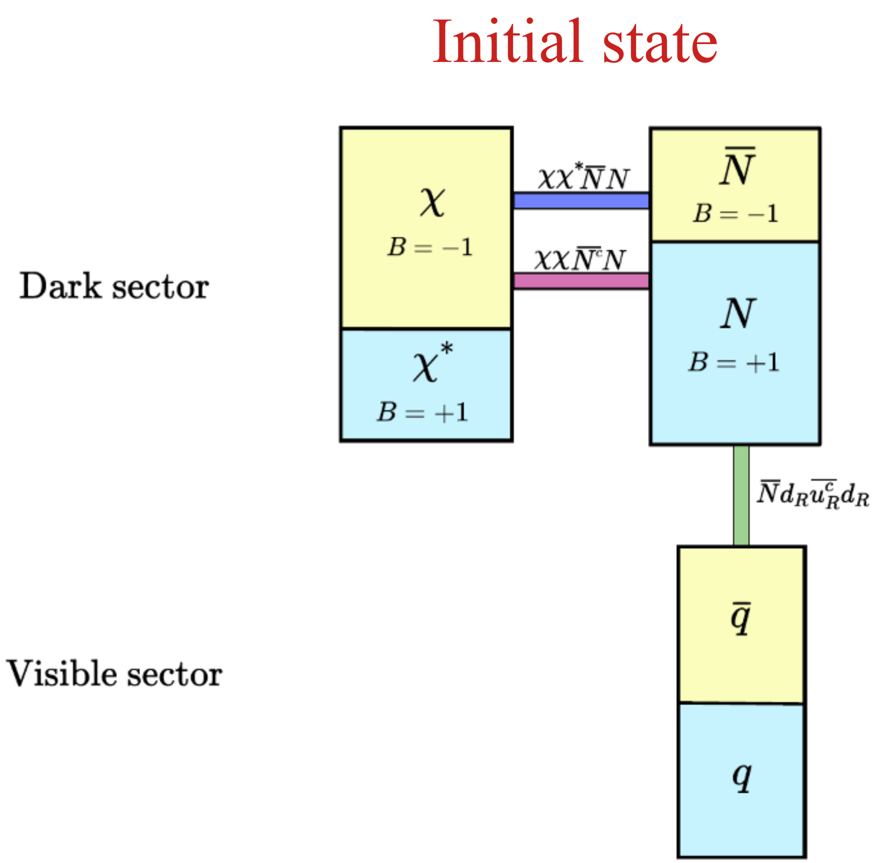
quark-antiquark asymmetry ⟺ **dark matter stability** ⟺ **proton stability**

A simple scenario



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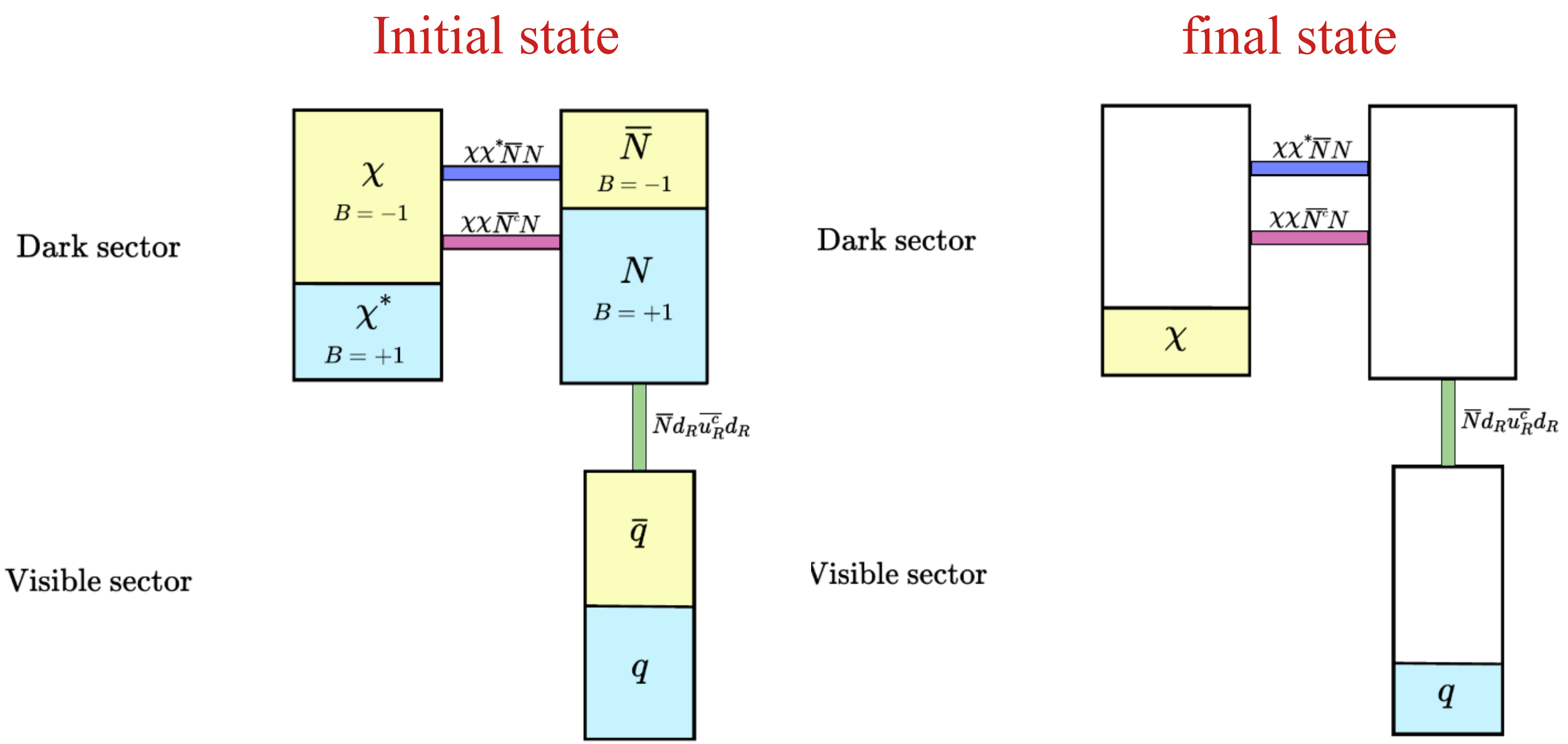
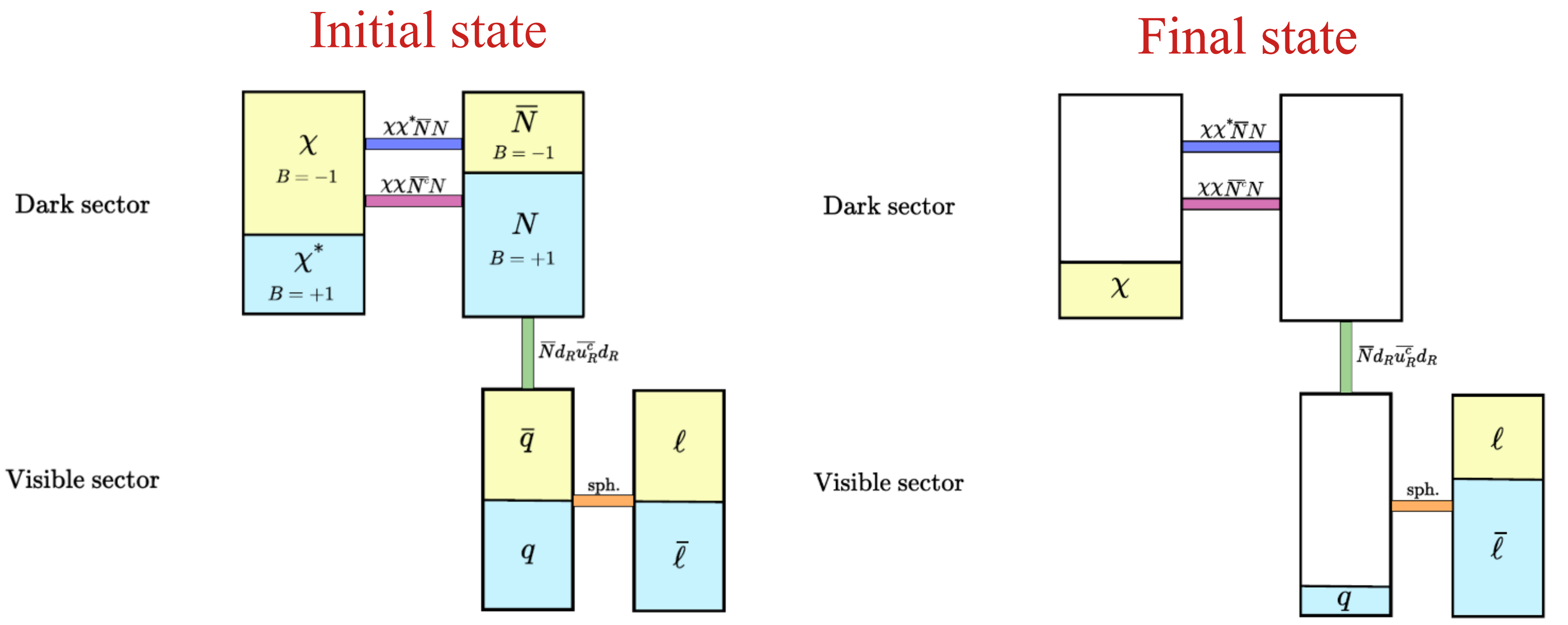
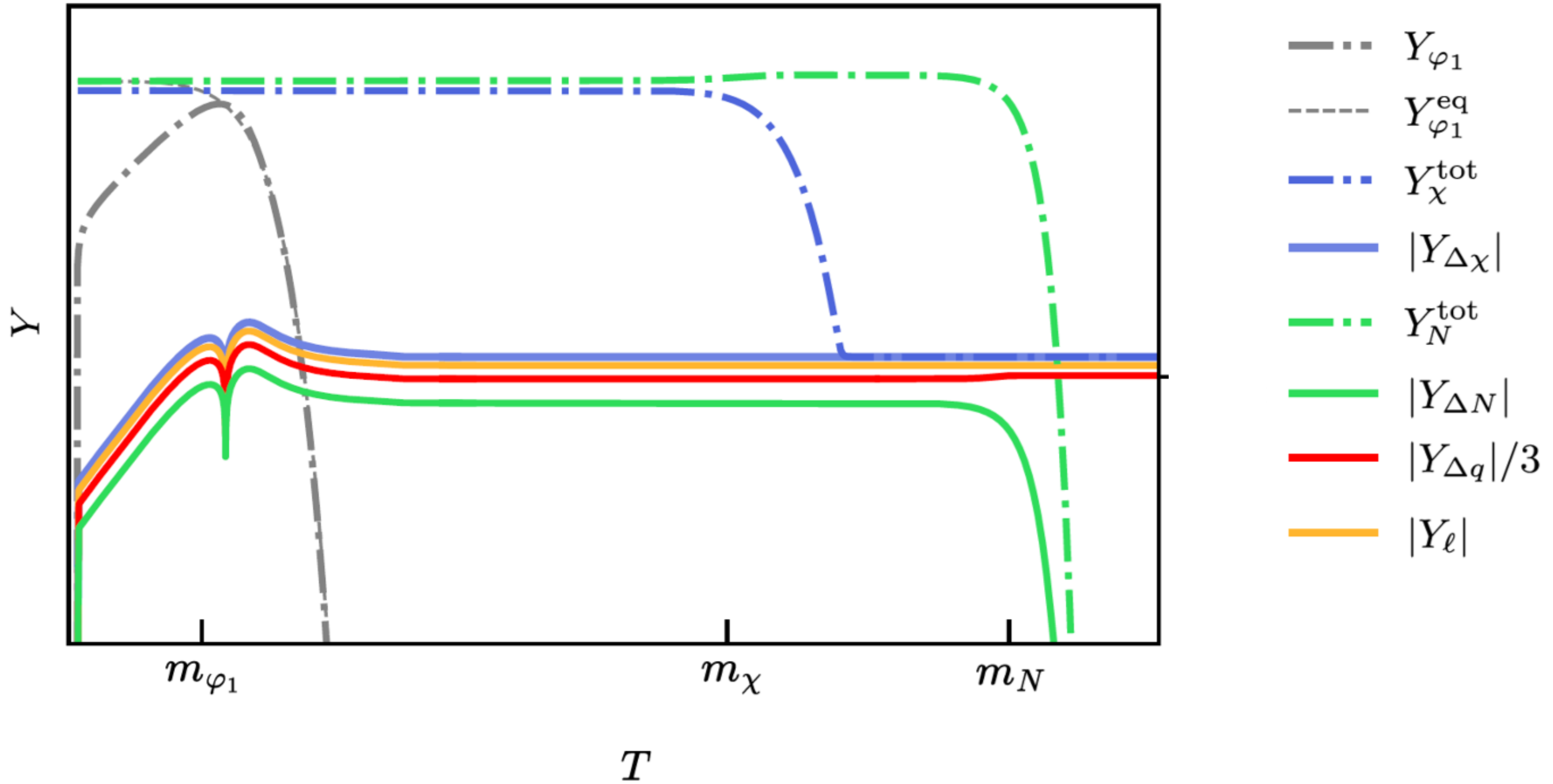


A more refined scenario



Evolution of the various yields



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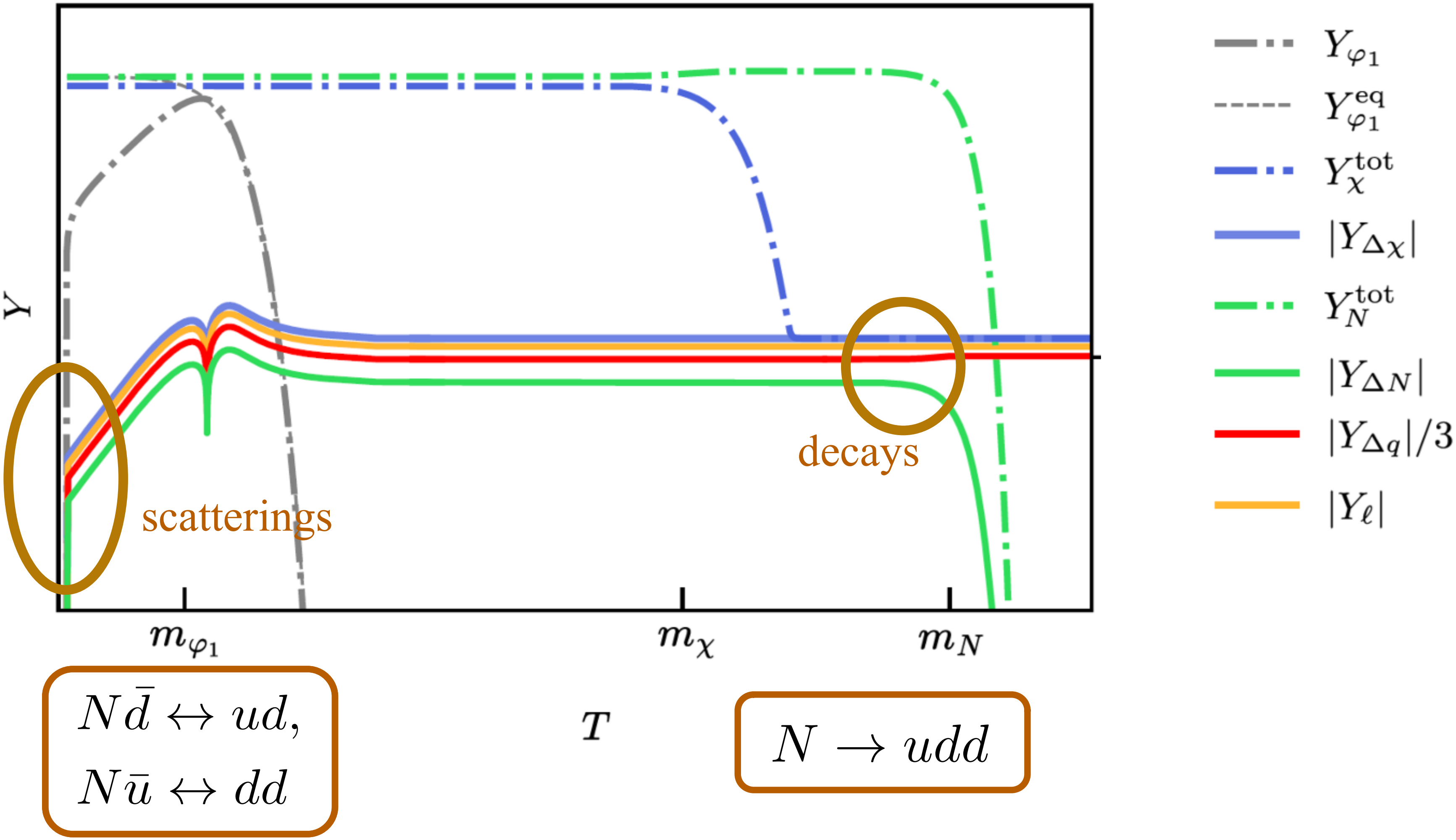

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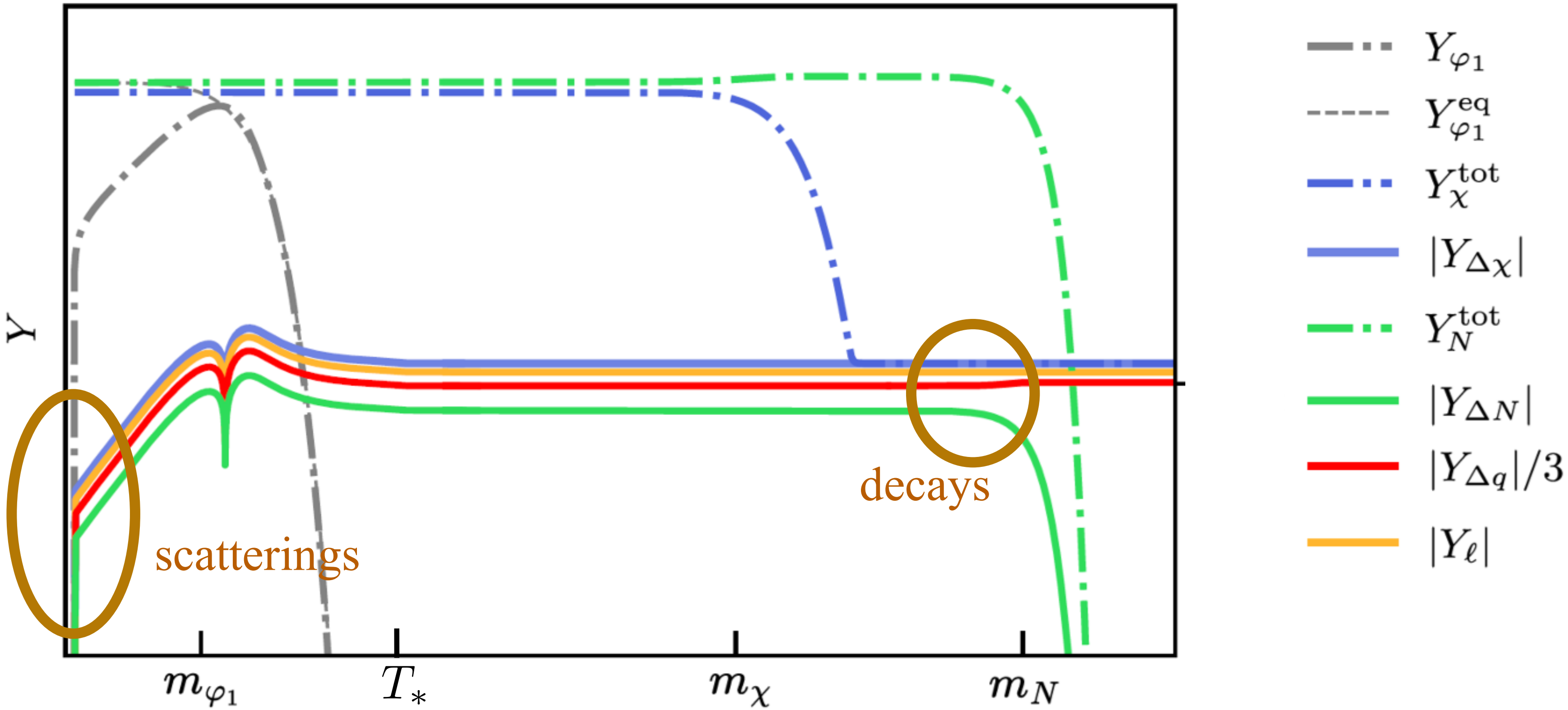

$$Y_{\Delta q,0} = \frac{141}{122} Y_{\Delta N}(T_*)$$

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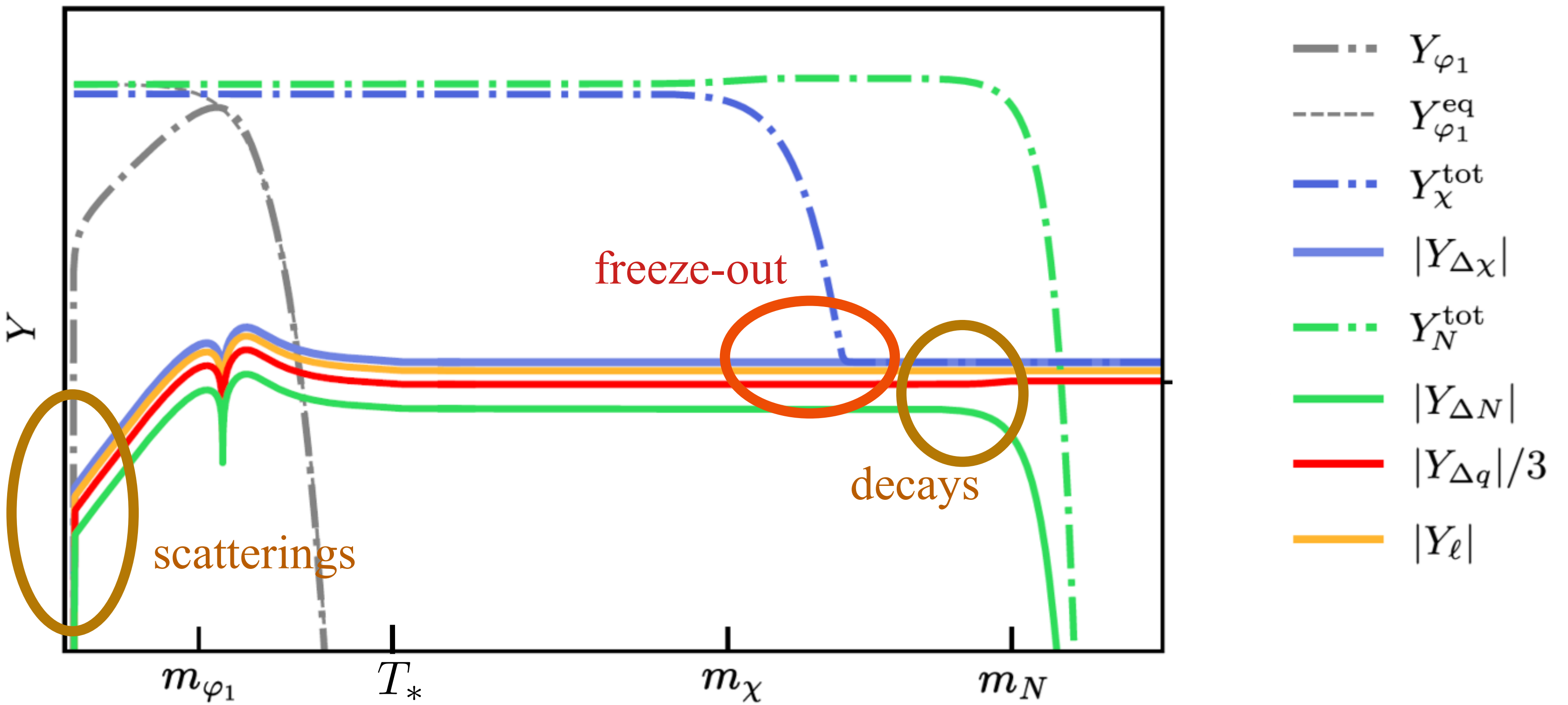

$$Y_{\Delta q,0} = \frac{141}{122} Y_{\Delta N}(T_*)$$

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

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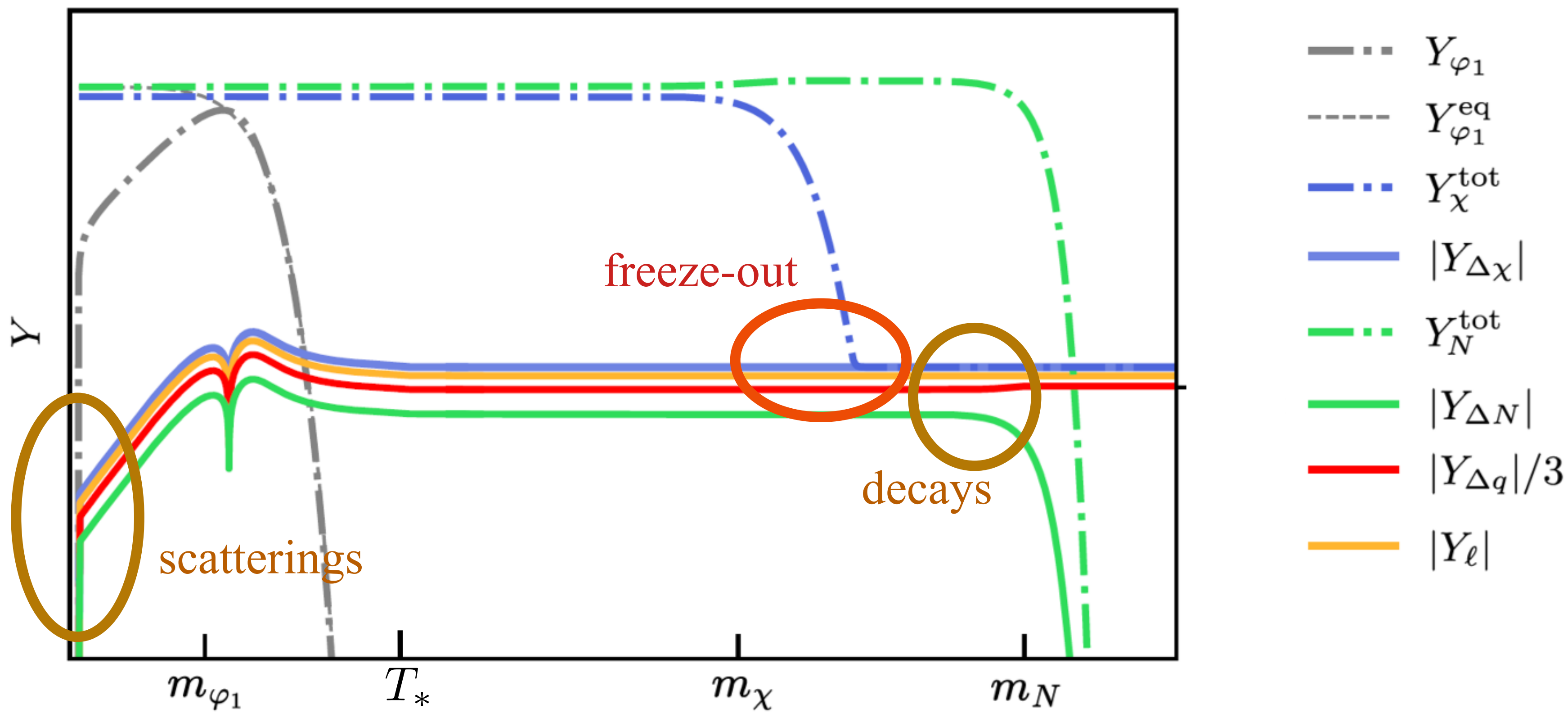


$$Y_{\Delta q,0} = \frac{141}{122} Y_{\Delta N}(T_*)$$

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

$$Y_{\Delta N}(T_*) \simeq 2.3 \times 10^{-10}$$

$$m_\chi \simeq 1.9\,{\rm GeV}.$$

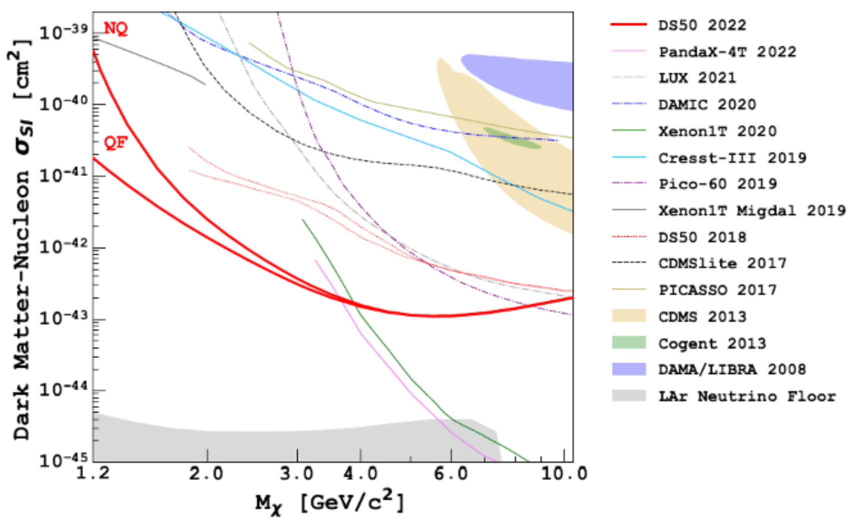
Experimental tests

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

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

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

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

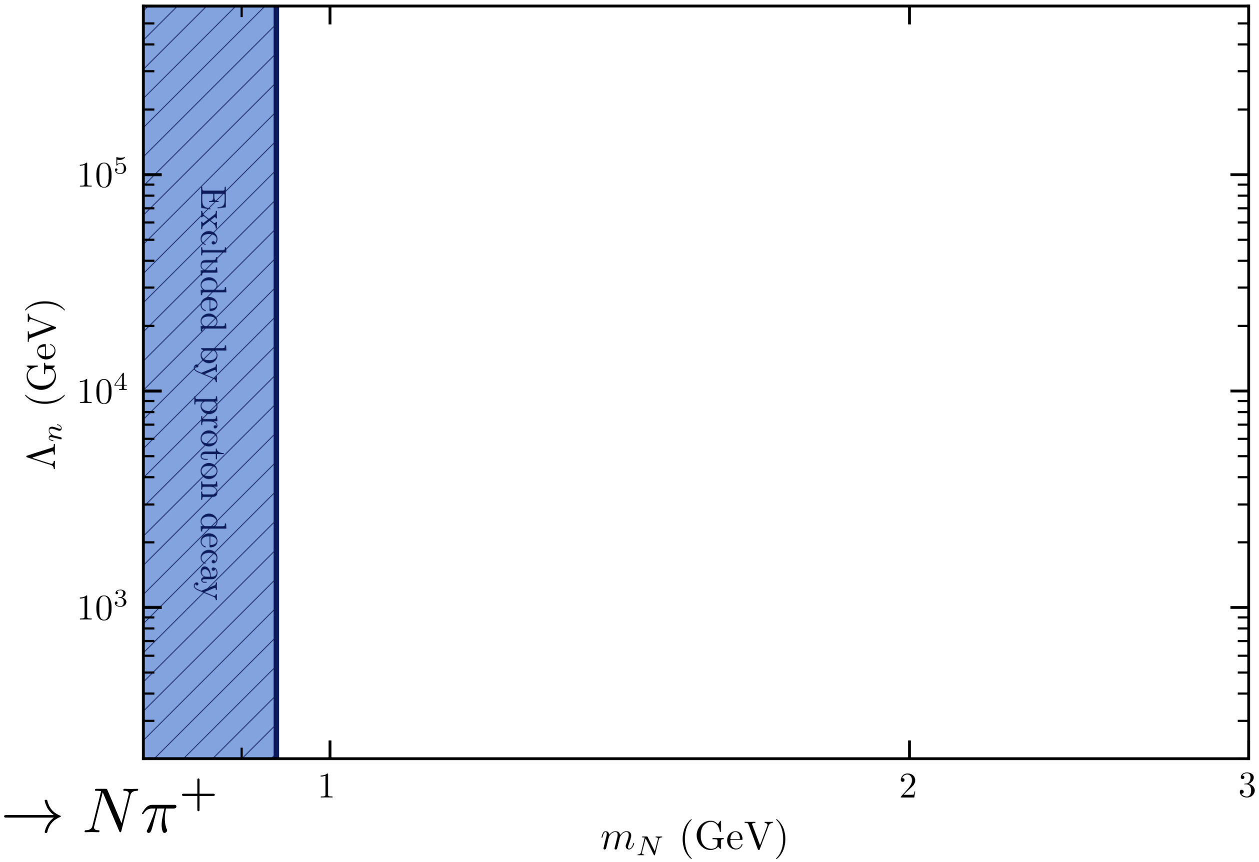


$\Rightarrow \lambda_{\chi H} \lesssim 10^{-2}$

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 $\frac{1}{\Lambda_n^2}\overline{N}d_R\,\overline{u_R^c}d_R$



$p \to N\pi^+$

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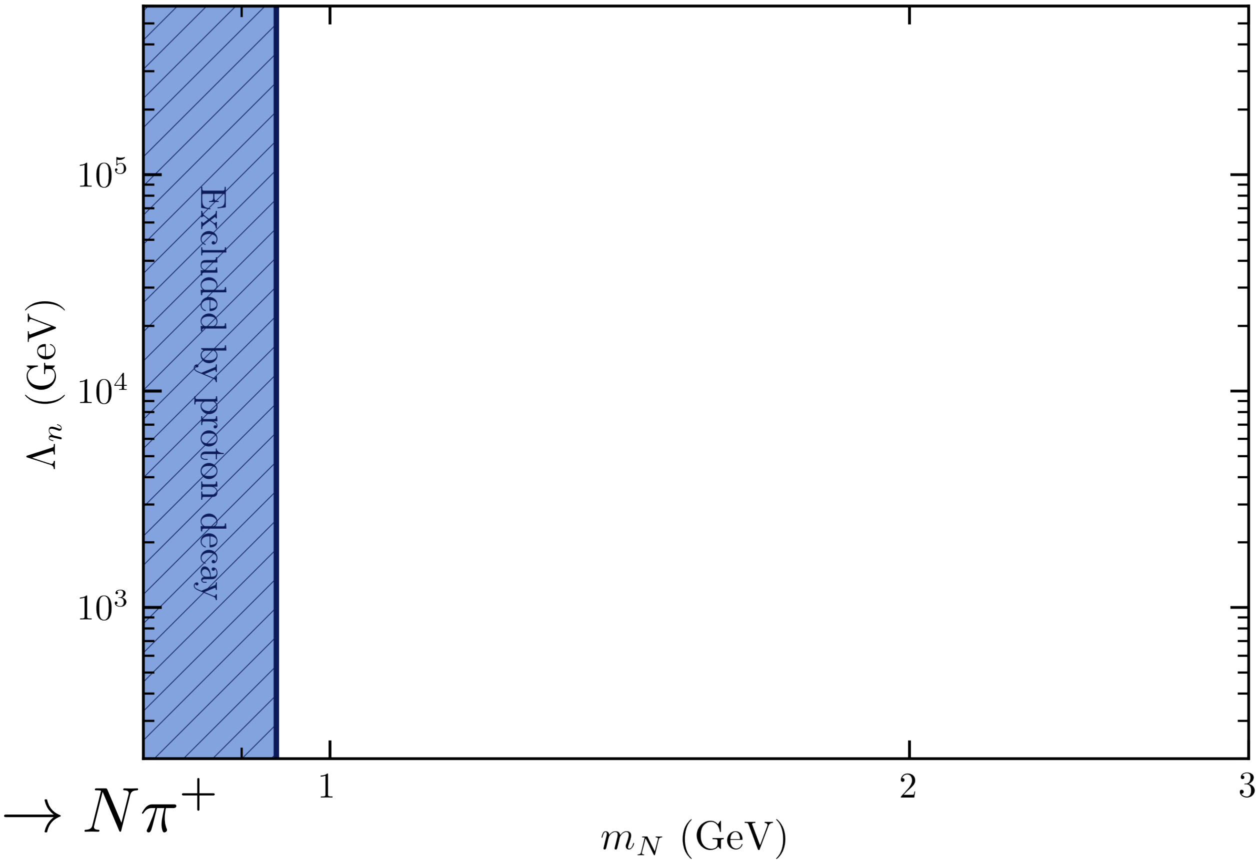

$p \to N\pi^+$

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

No search reported in the PDG.

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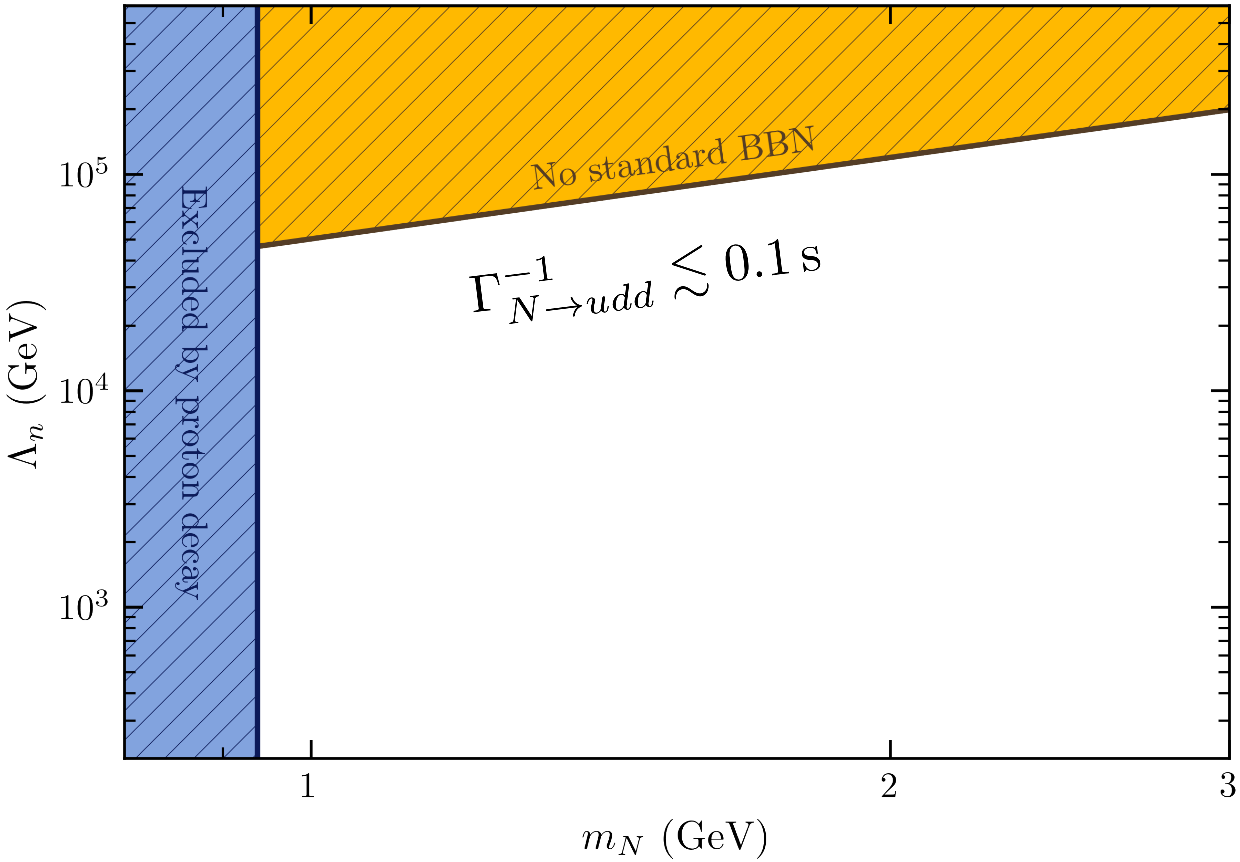

$$\Gamma^{-1}_{N\to udd} \approx 1.6\ \mathrm{s}\left(\frac{\Lambda_n}{10^5\ \mathrm{GeV}}\right)^4\left(\frac{\mathrm{GeV}}{m_N}\right)^5,$$

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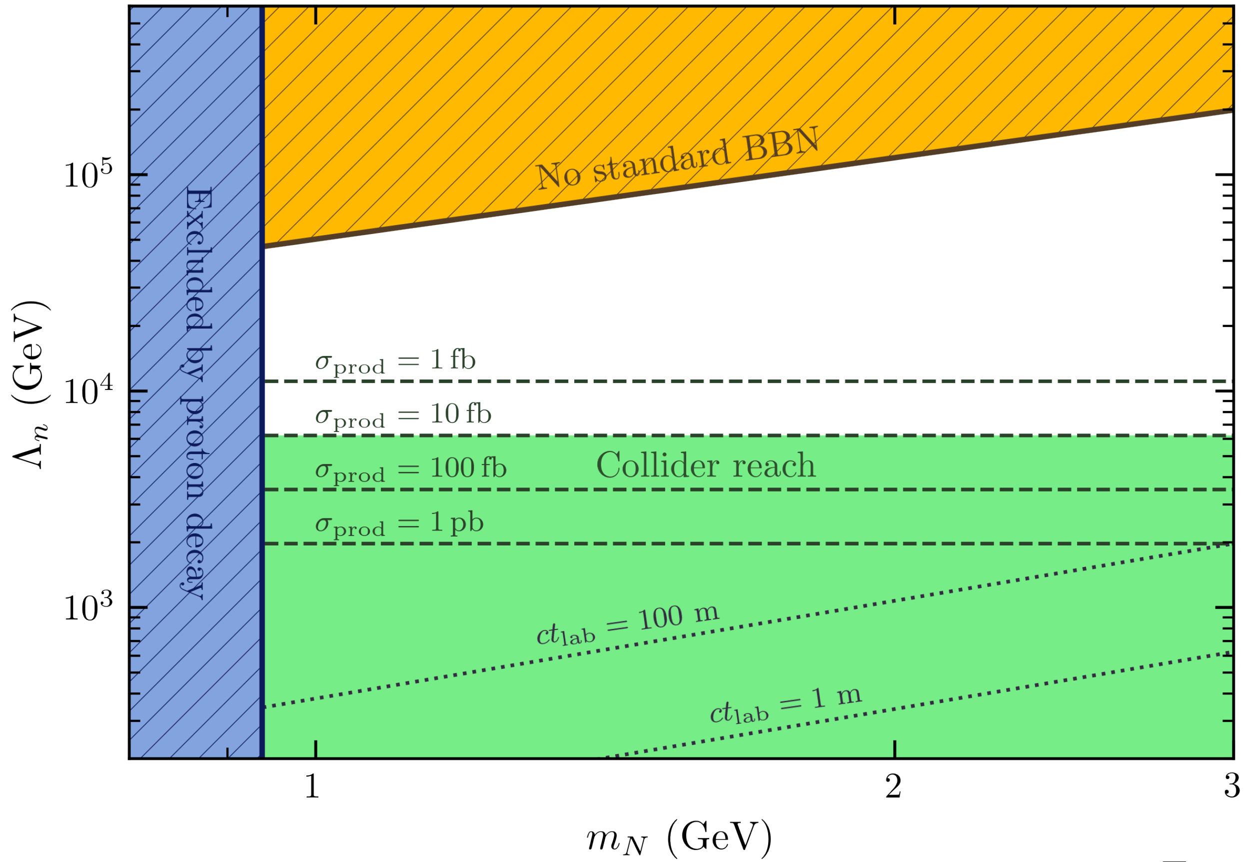

N production in pp collisions through $ud \to N\bar{d}, dd \to N\bar{u}$

Experimental tests

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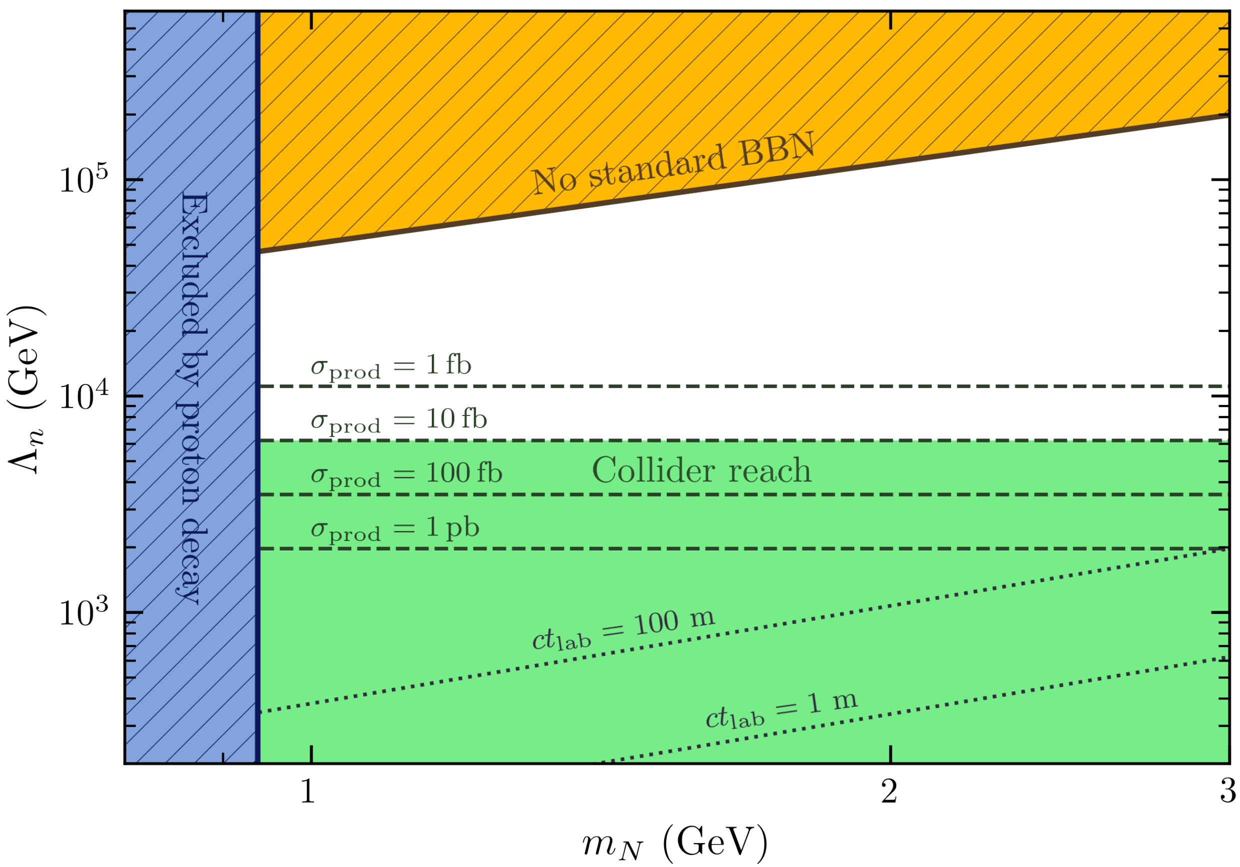

- The EFT may break down. Additional signatures from the production of the mediator.
- These constraints are not valid for different baryon-portals, e.g. the "charmed-Omega" portal $\overline{N}s_R\overline{c^c_R}s_R$
- No search exists on baryon → meson + invisible

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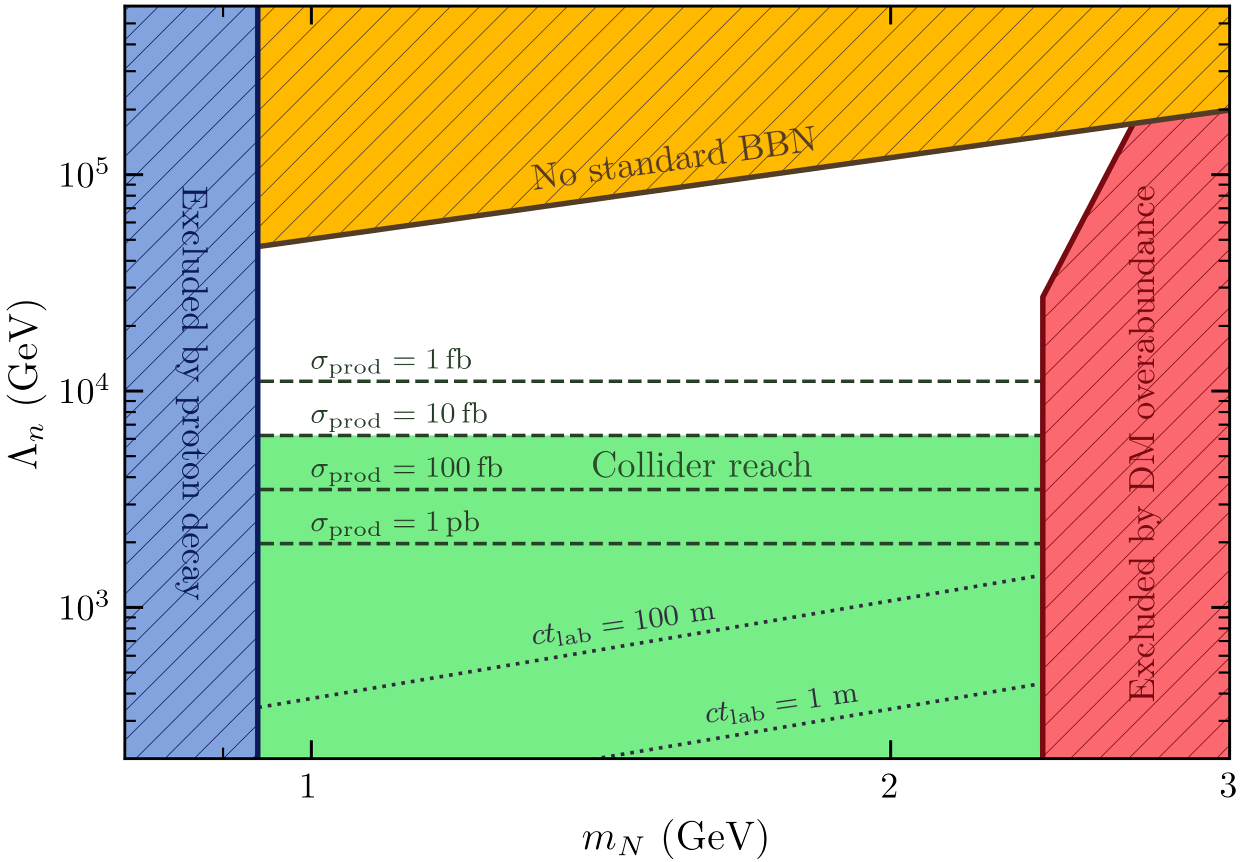

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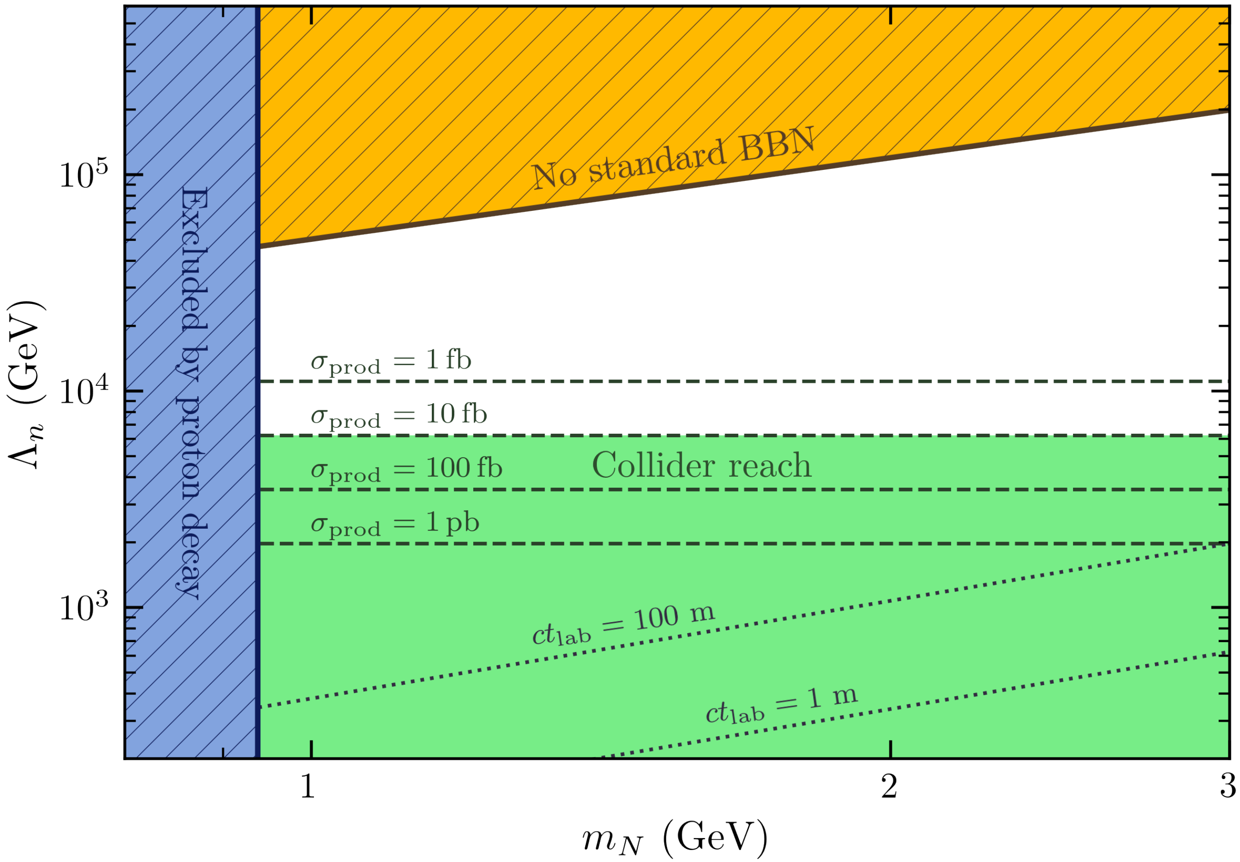
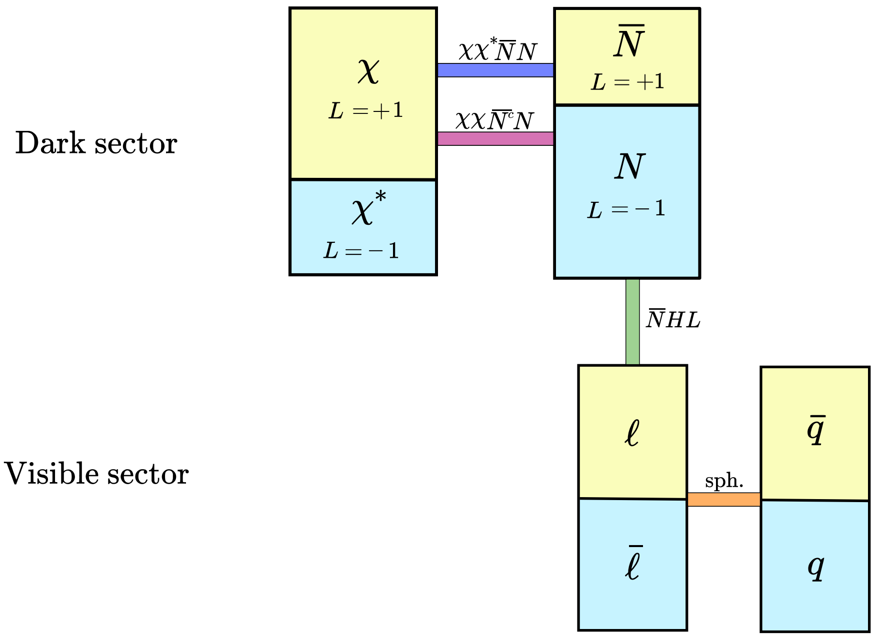


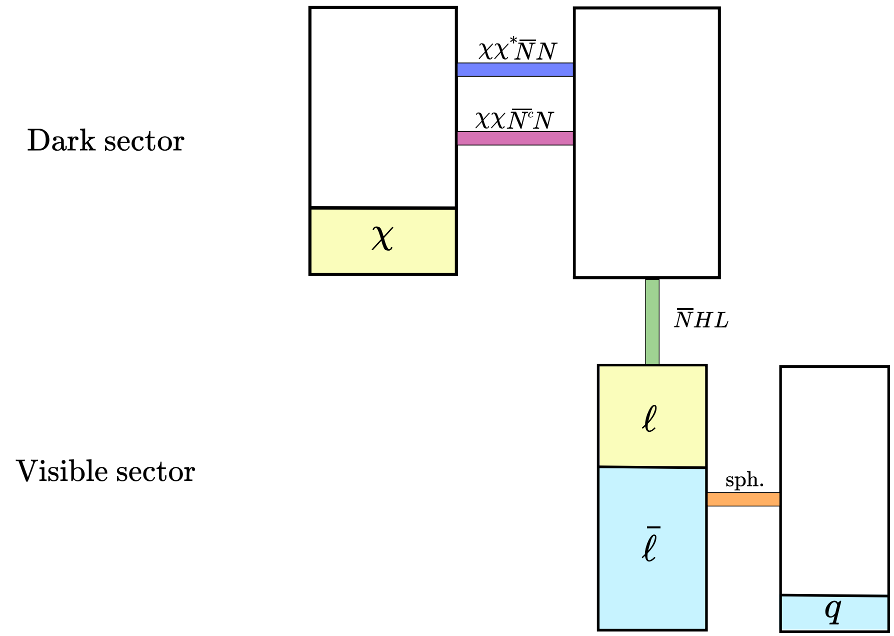
The rate of annihilations $\chi\chi^* \to N\overline{N}$ must be sufficiently efficient at freeze-out.

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

A leptonic version

AI. Proff. In preparation





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. The scenario leads to signals at collider experiments and in flavor physics.