

Minimal Baryogenesis induced Asymmetric Dark Matter

Miguel Escudero Abenza

miguel.escudero@cern.ch

based on: 2511.10731

with Thomas Hambye and Chandan Hati

and on 2607.XXXXX with David Cerdeño,
Pietro Ghedini, Guilherme Guedes, Thomas
Hambye, Abel Muñoz and Elena Pressendo

Sydney-CPPC

18-06-2026

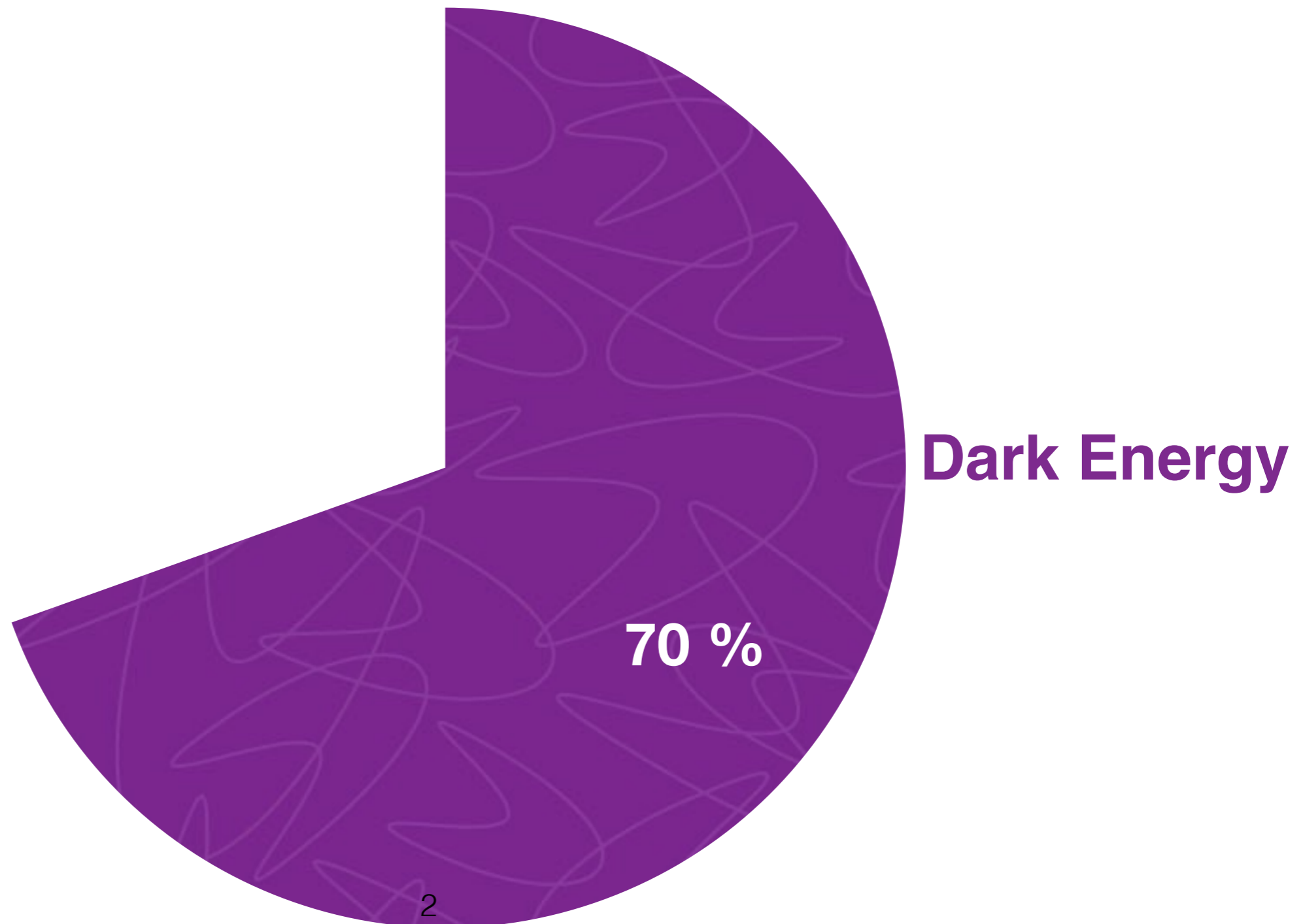


The Energy Budget of the Universe

$$\Omega_i \equiv \frac{\rho_i}{\rho_{\text{tot}}}$$

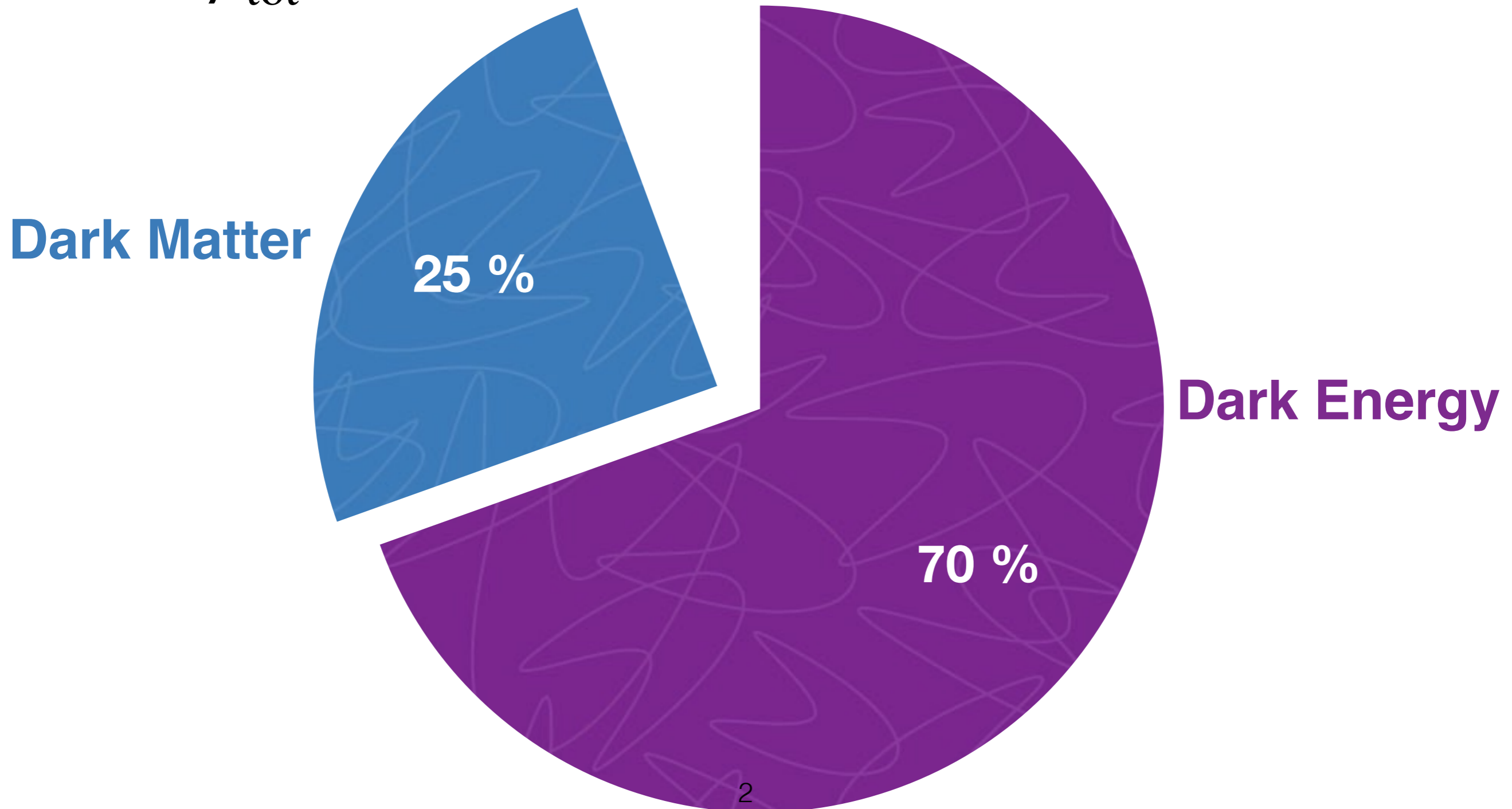
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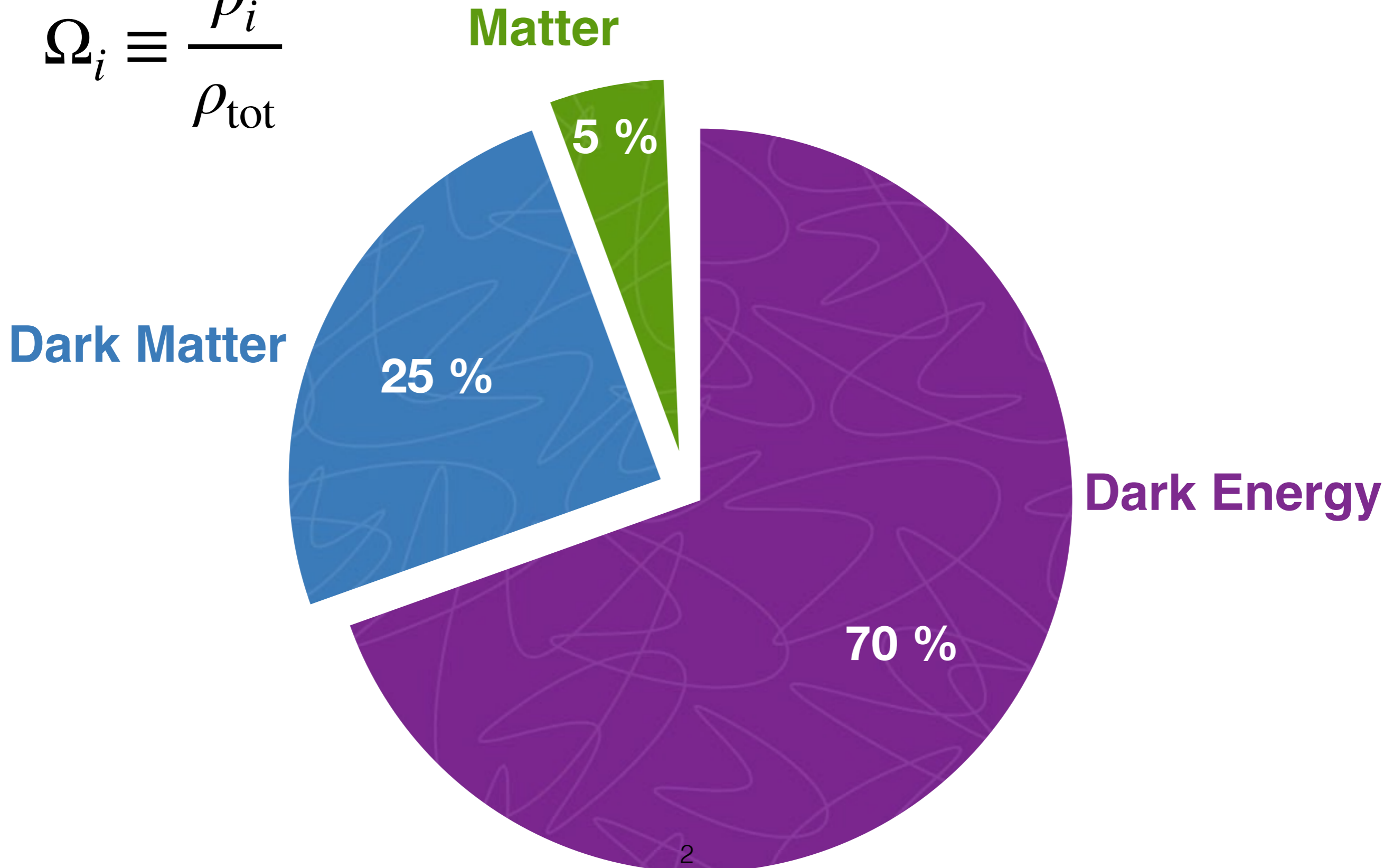
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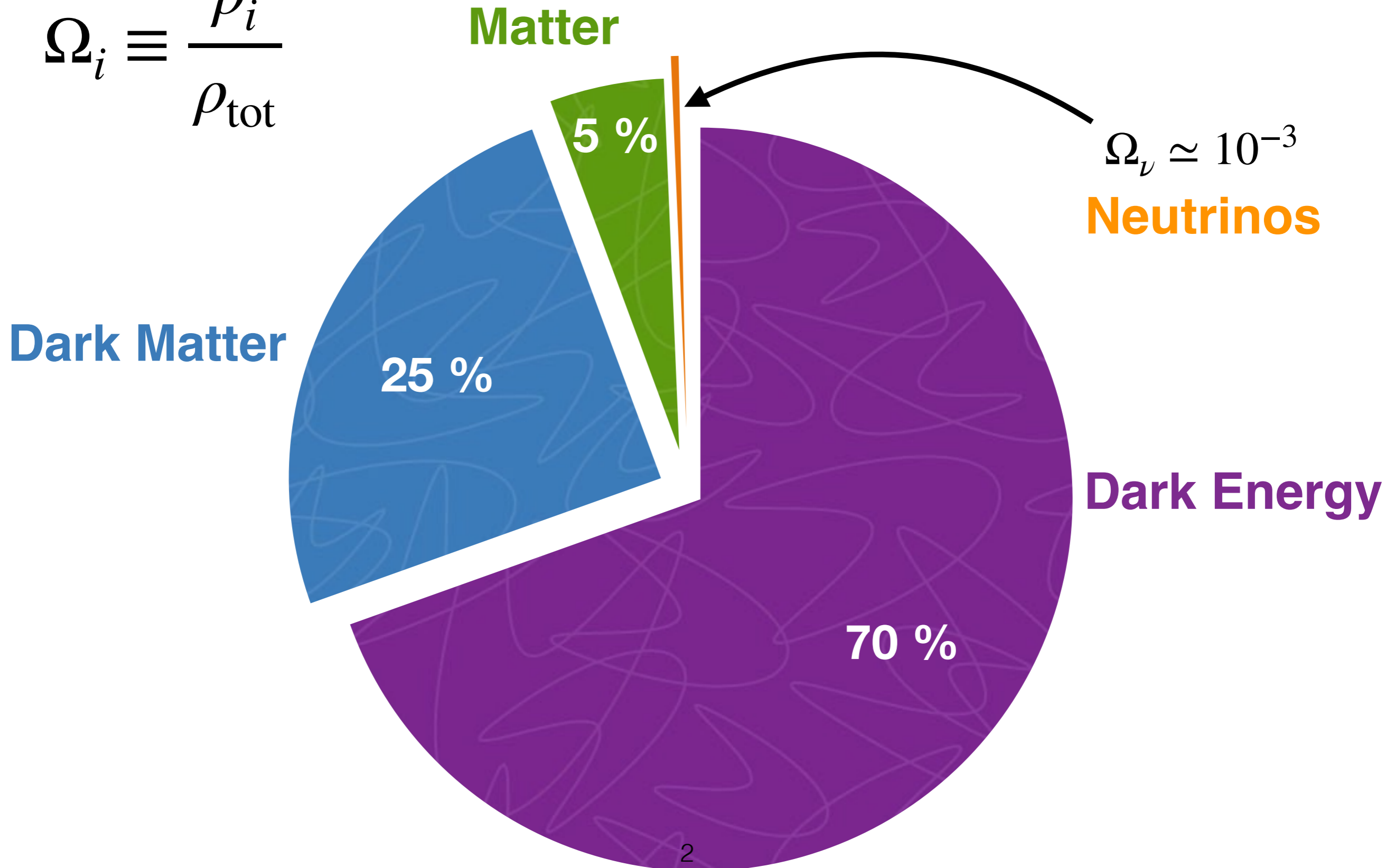
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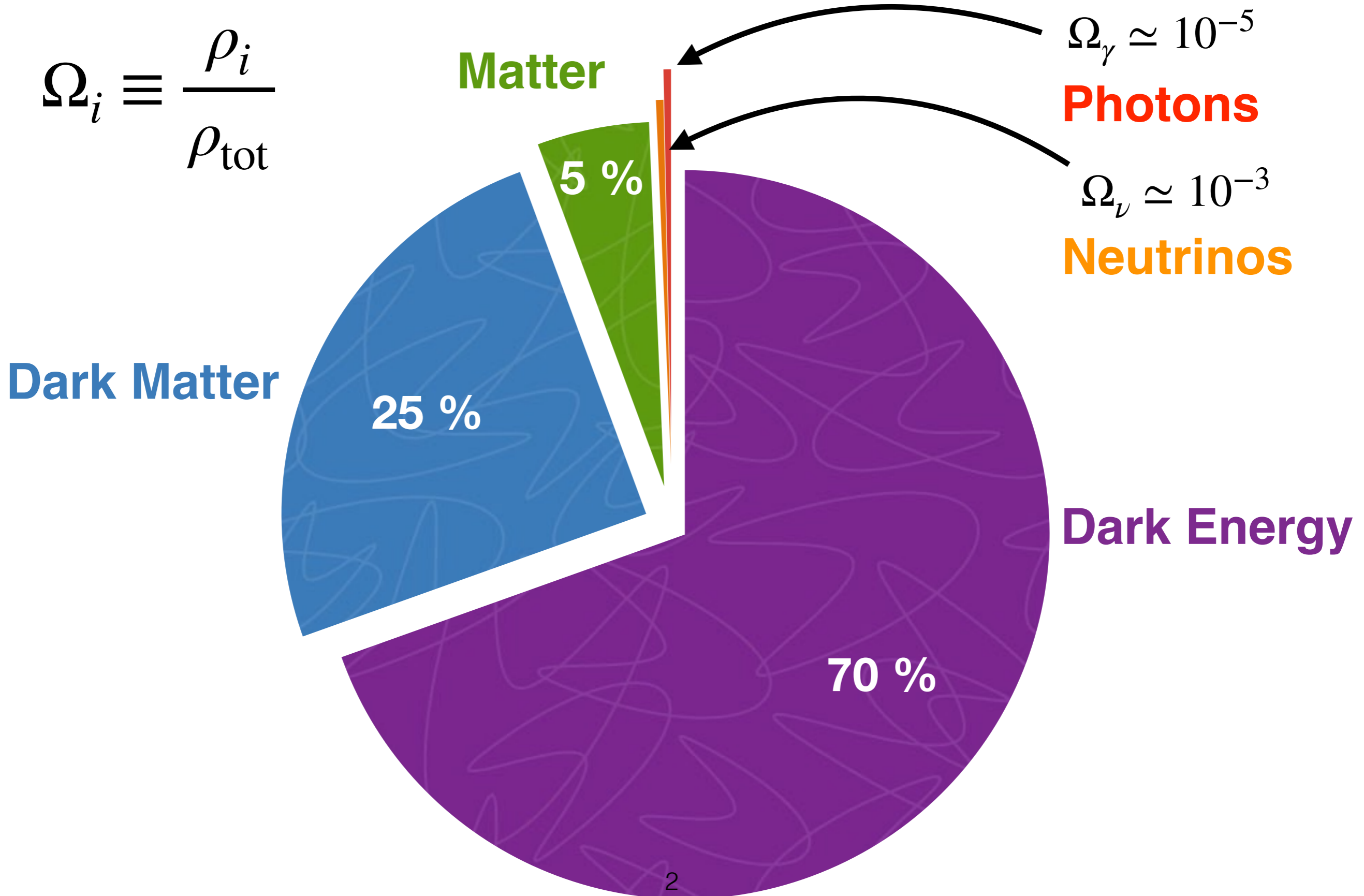
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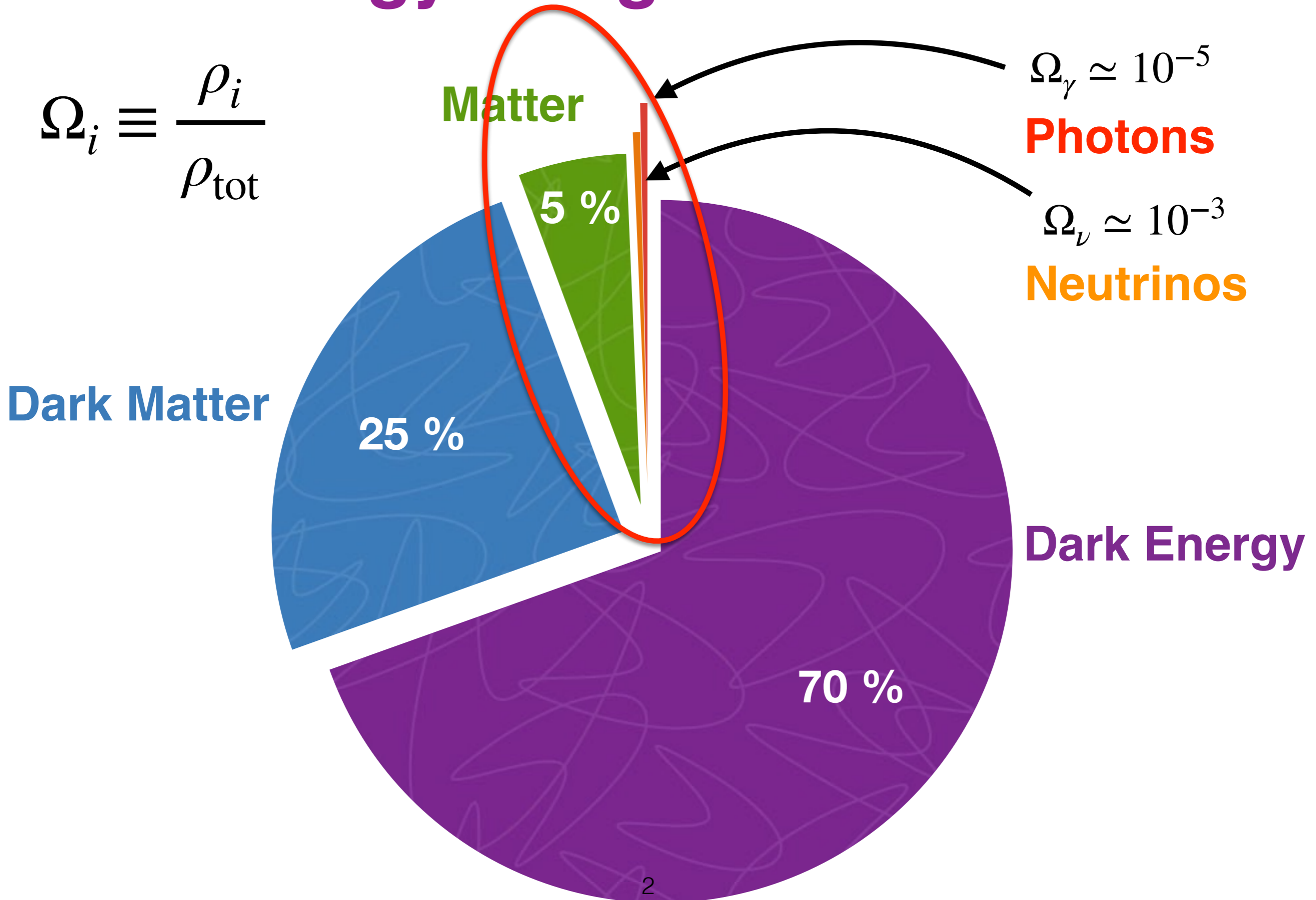
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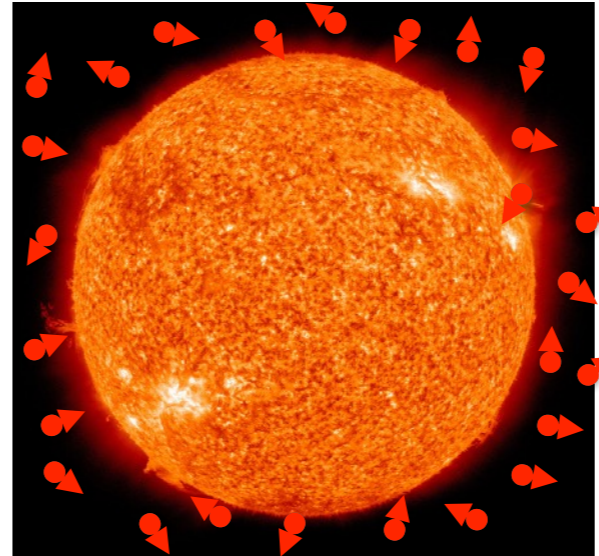
Antimatter in the Universe?

We have no evidence for antimatter structures

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No nearby antimatter stars

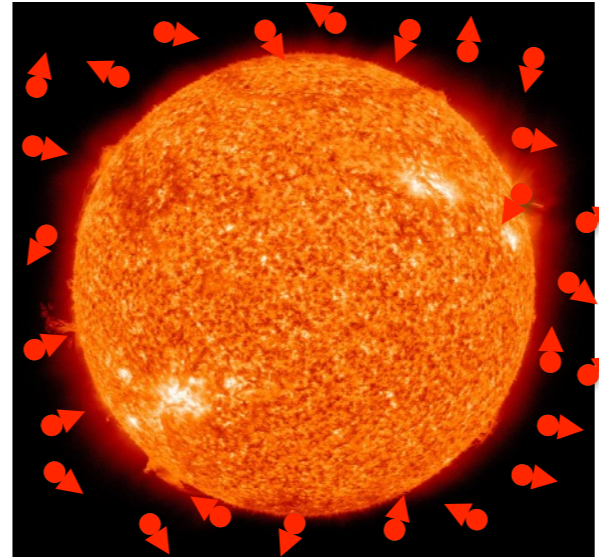


see Dupourque,
Tibaldo, von Ballmoos
[2103.10073]

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**No antigalaxy cluster
collisions**

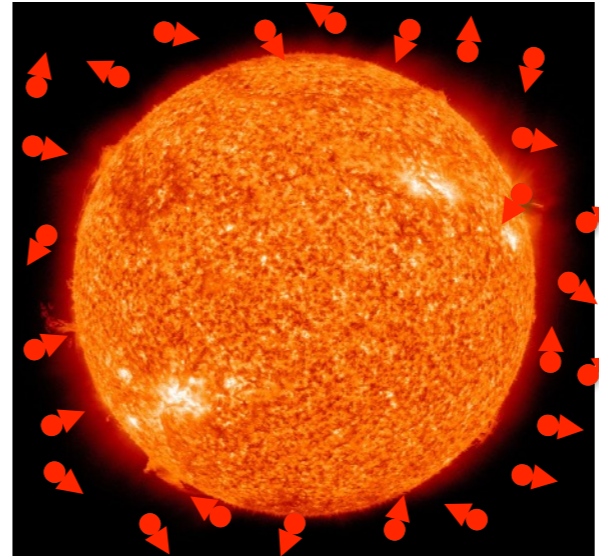


see Steigman '76

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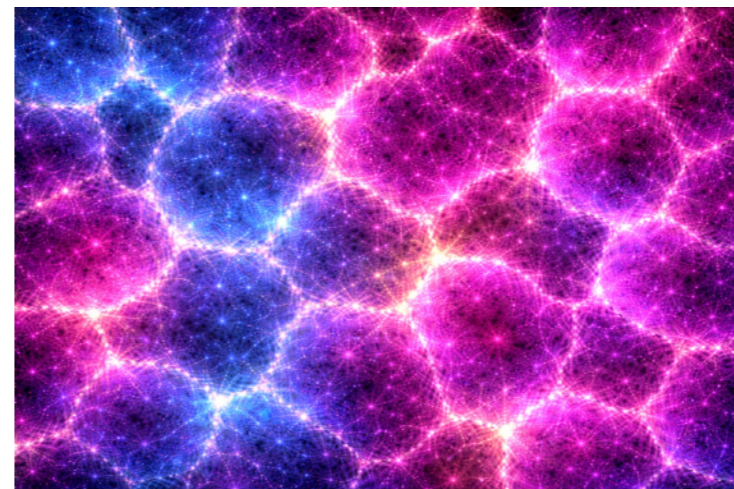
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[2103.10073]

**No antigalaxy cluster
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see Steigman '76

**No mergers of matter-
antimatter domains**



see Cohen, de Rújula
& Glashow [astro-ph/
9707087]

An Asymmetric Universe

Conclusion: We live in a Universe where structures are made of matter and not of antimatter.

An Asymmetric Universe

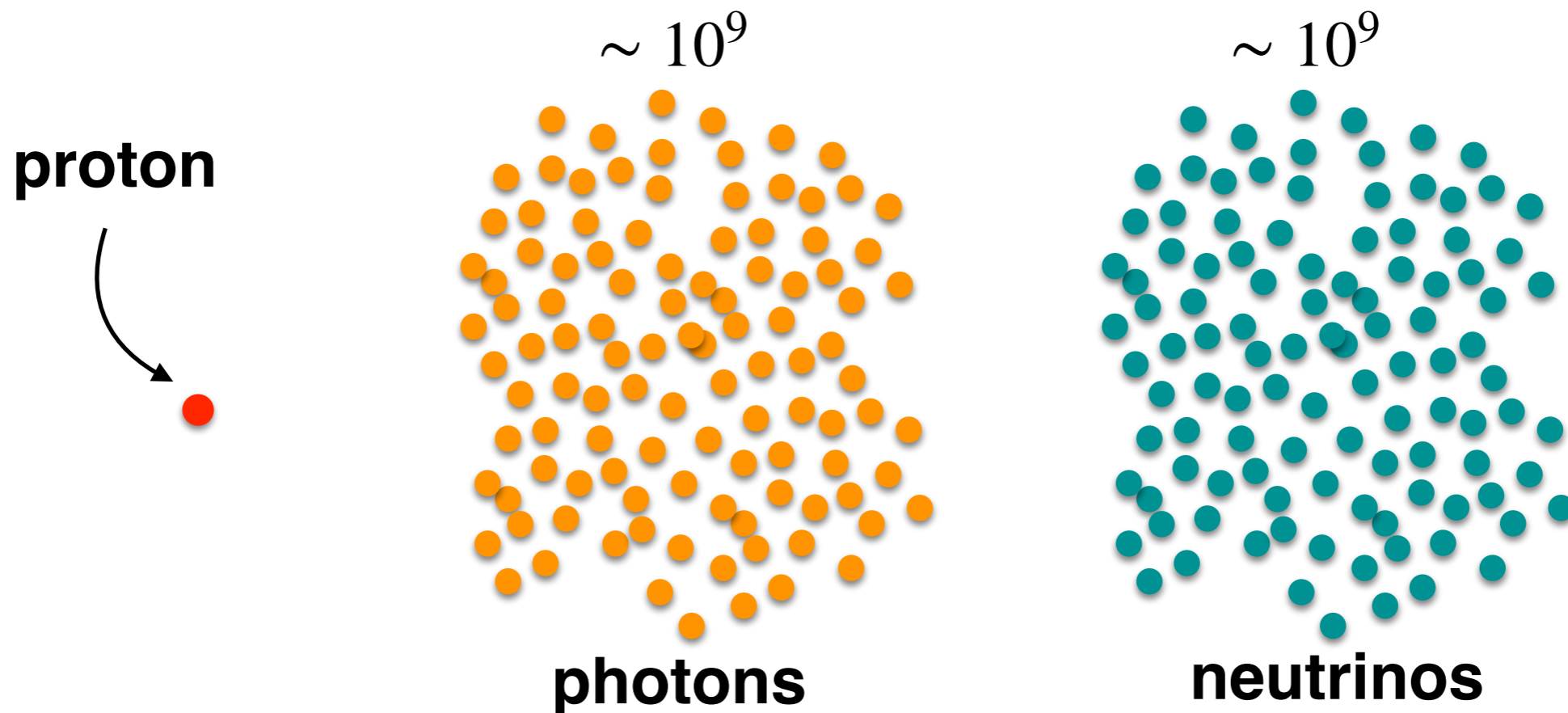
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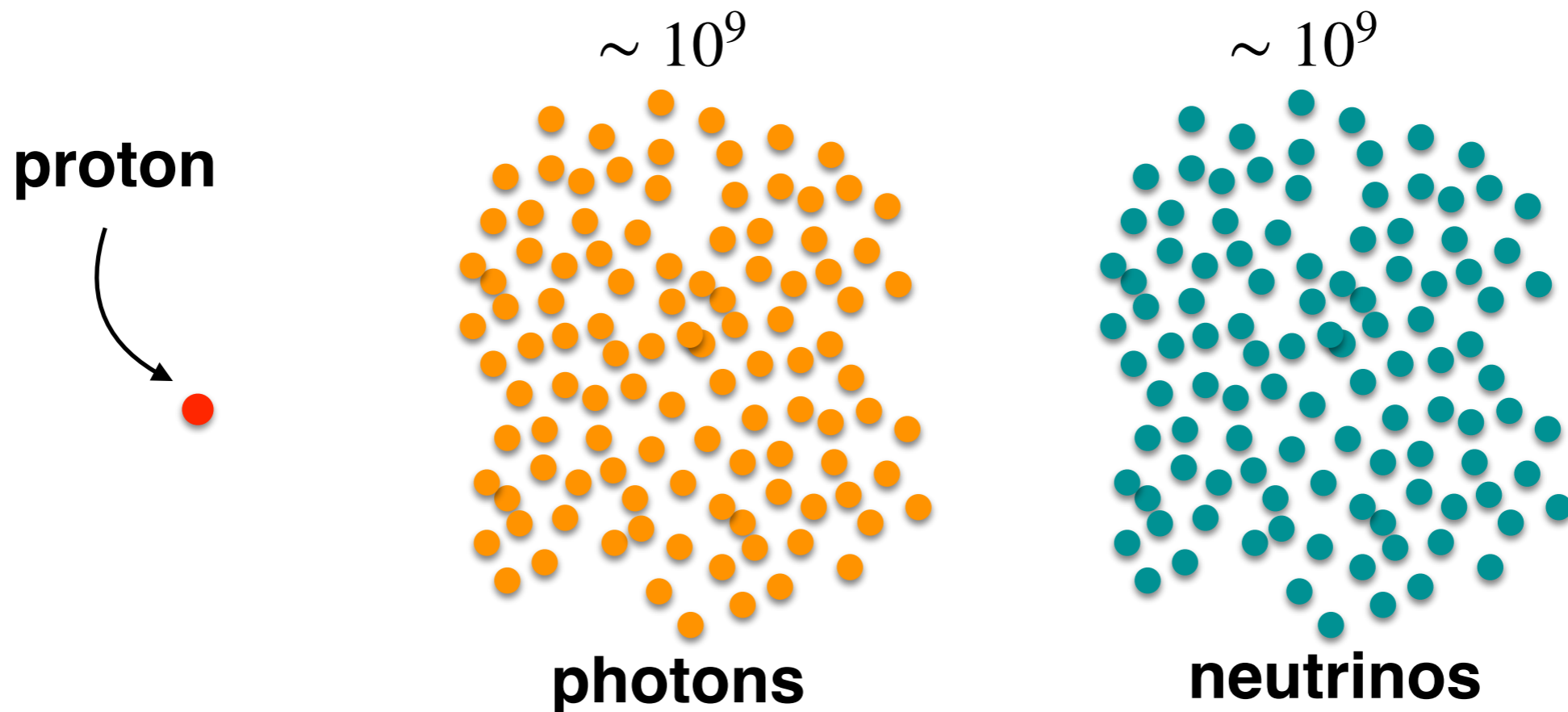
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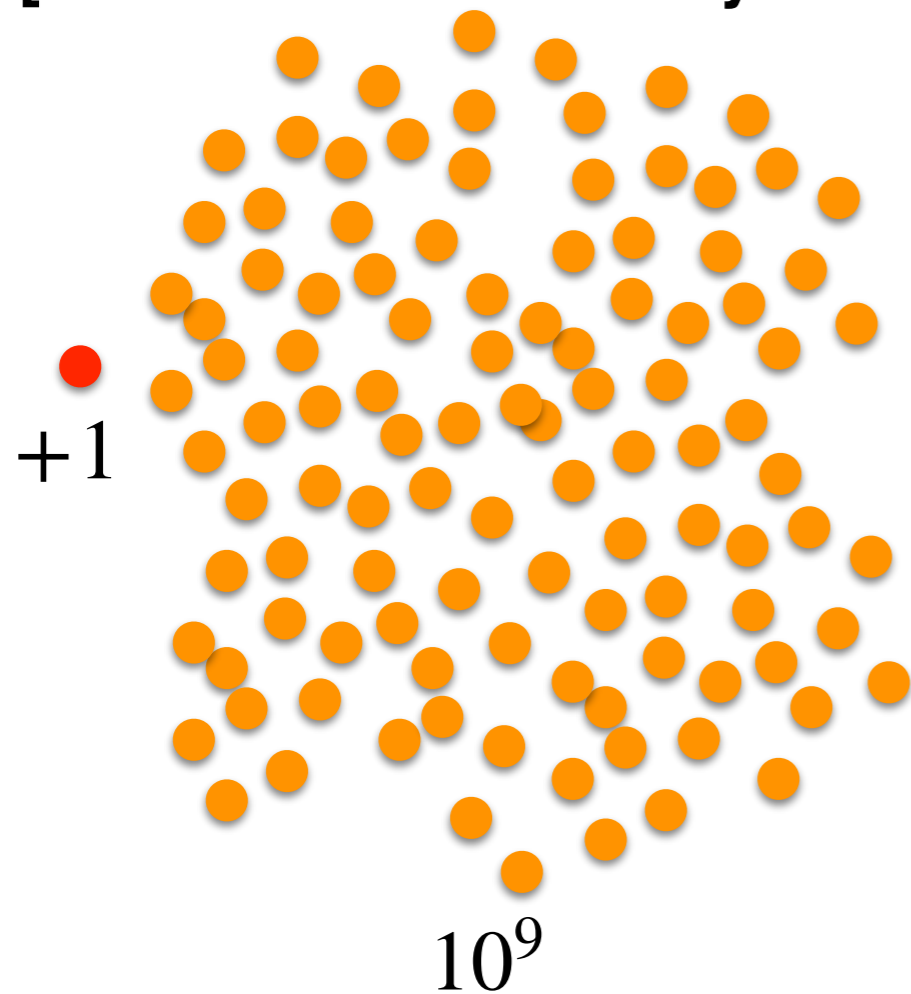
Huge number of photons per baryon

$$\eta_b \equiv n_b/n_\gamma \simeq 10^{-9}$$

A Universe without antimatter

- Photon
- Baryon
- Antibaryon

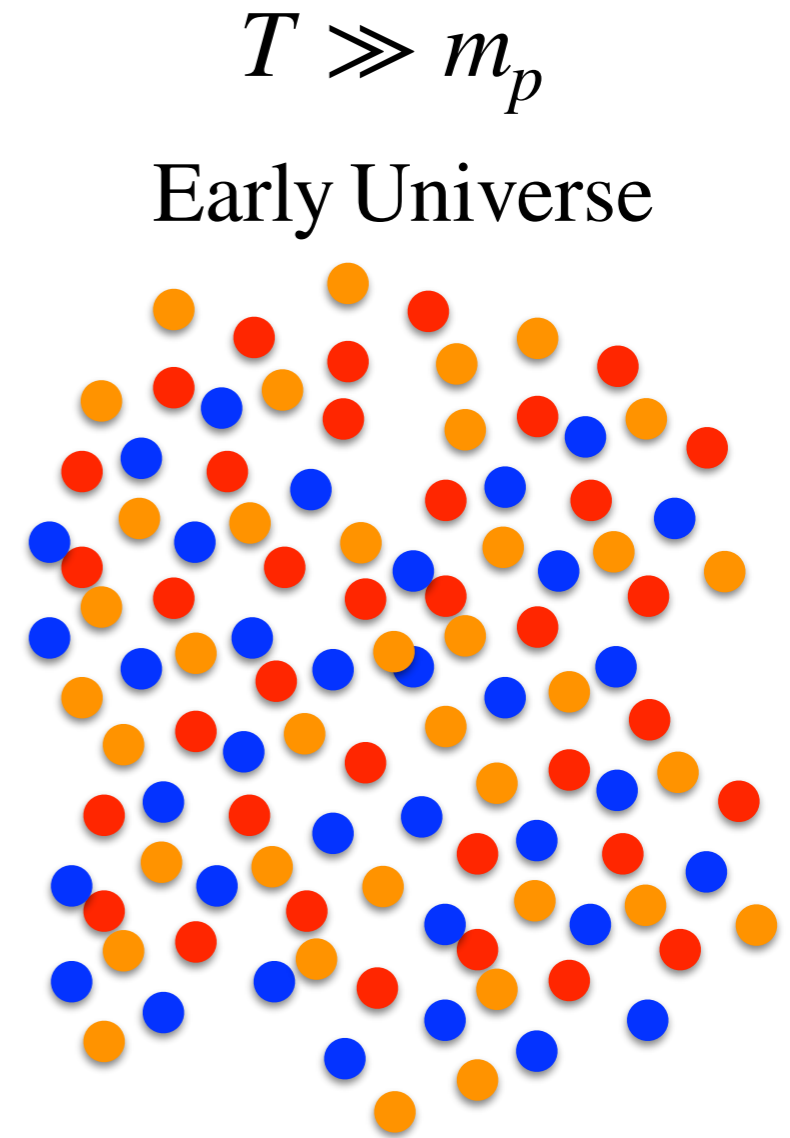
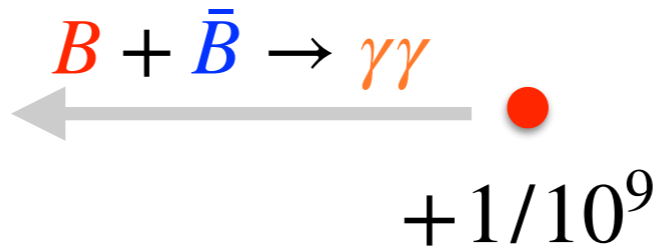
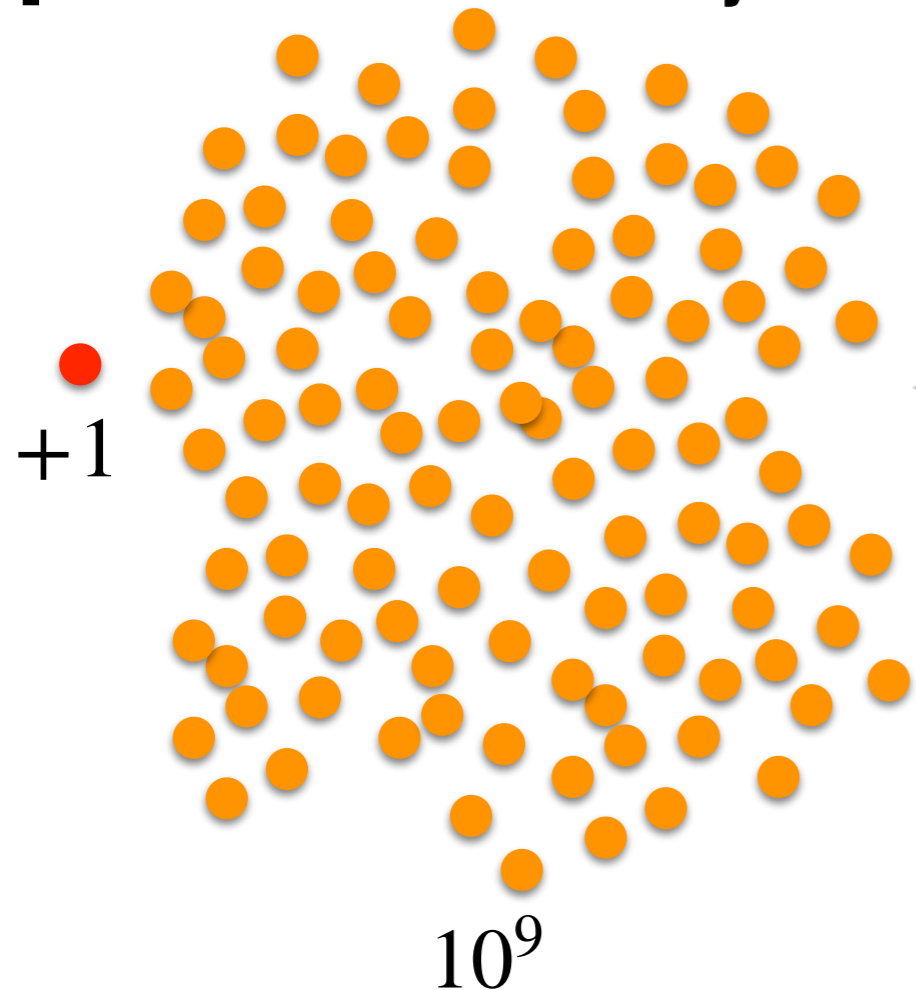
$T \simeq 3 \text{ K}$
Today's Universe
[no antimatter and only matter]



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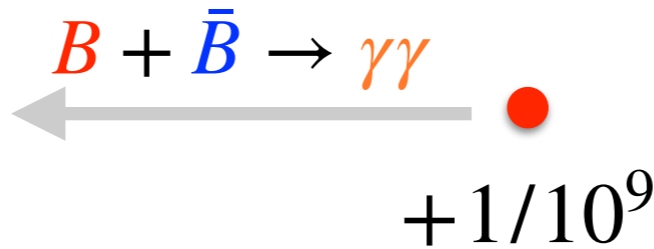
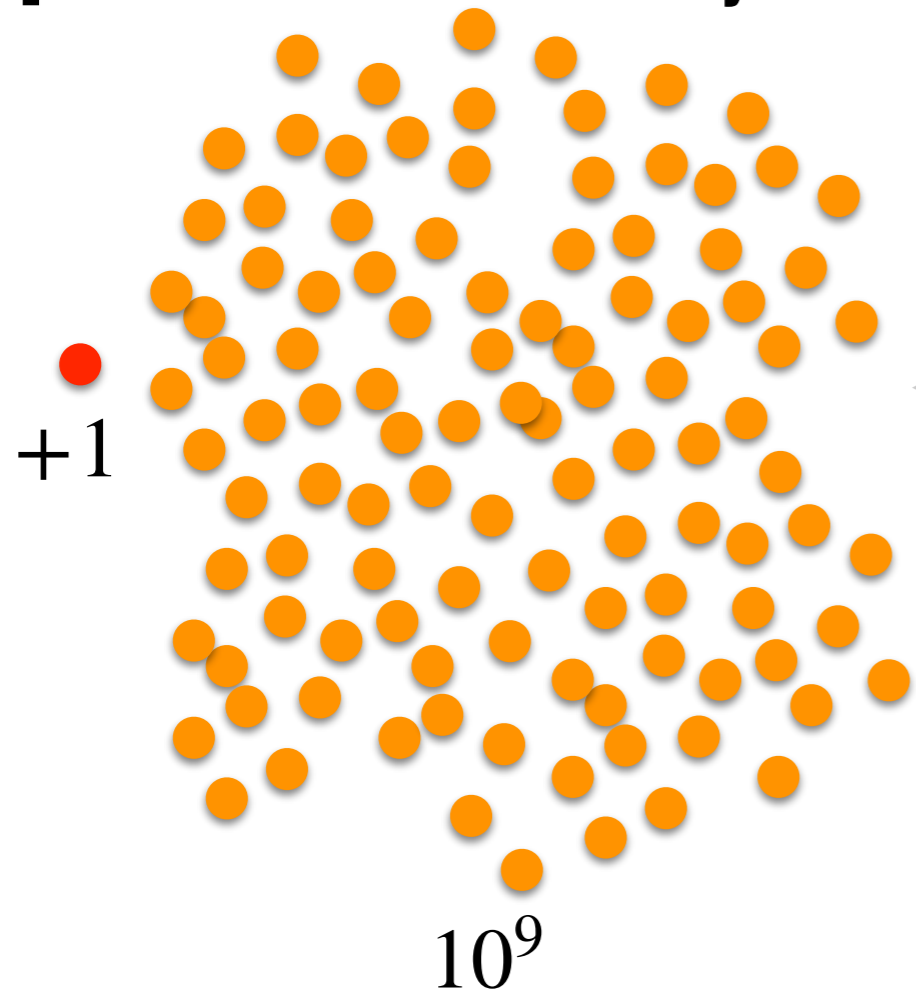


Because there was a primordial asymmetry between matter and antimatter!

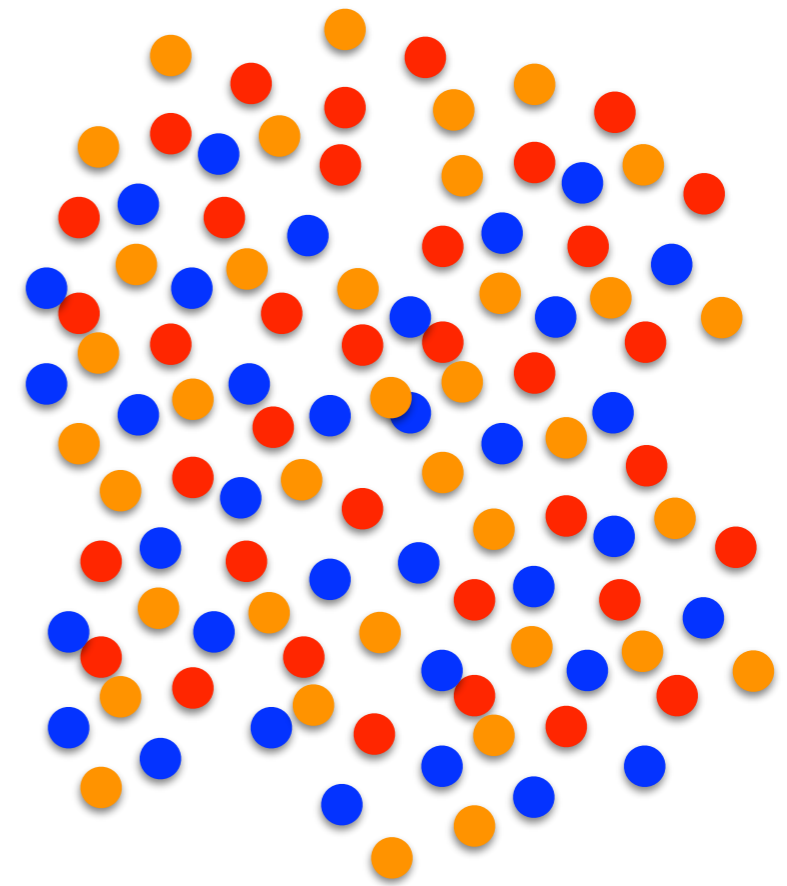
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$T \gg m_p$
Early Universe

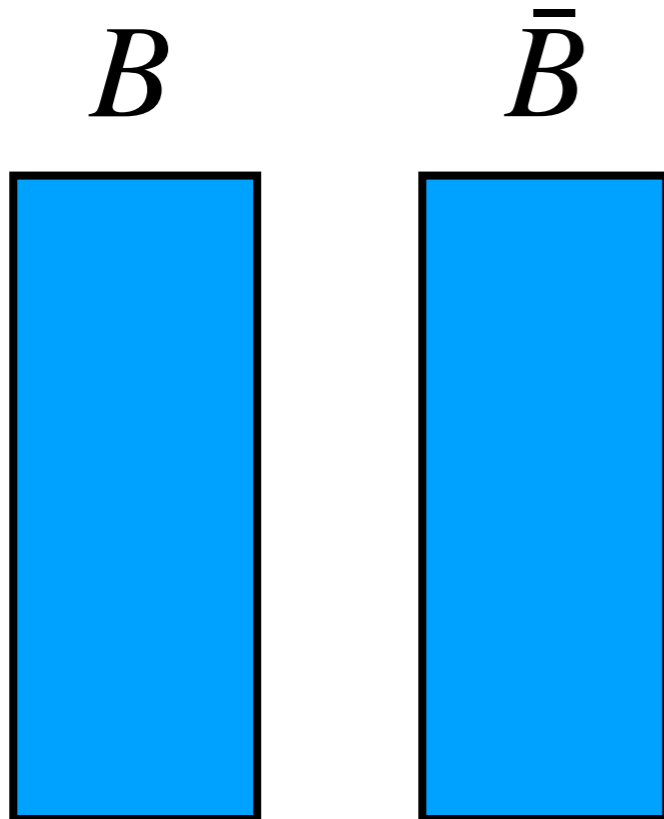


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But, how was this asymmetry generated?

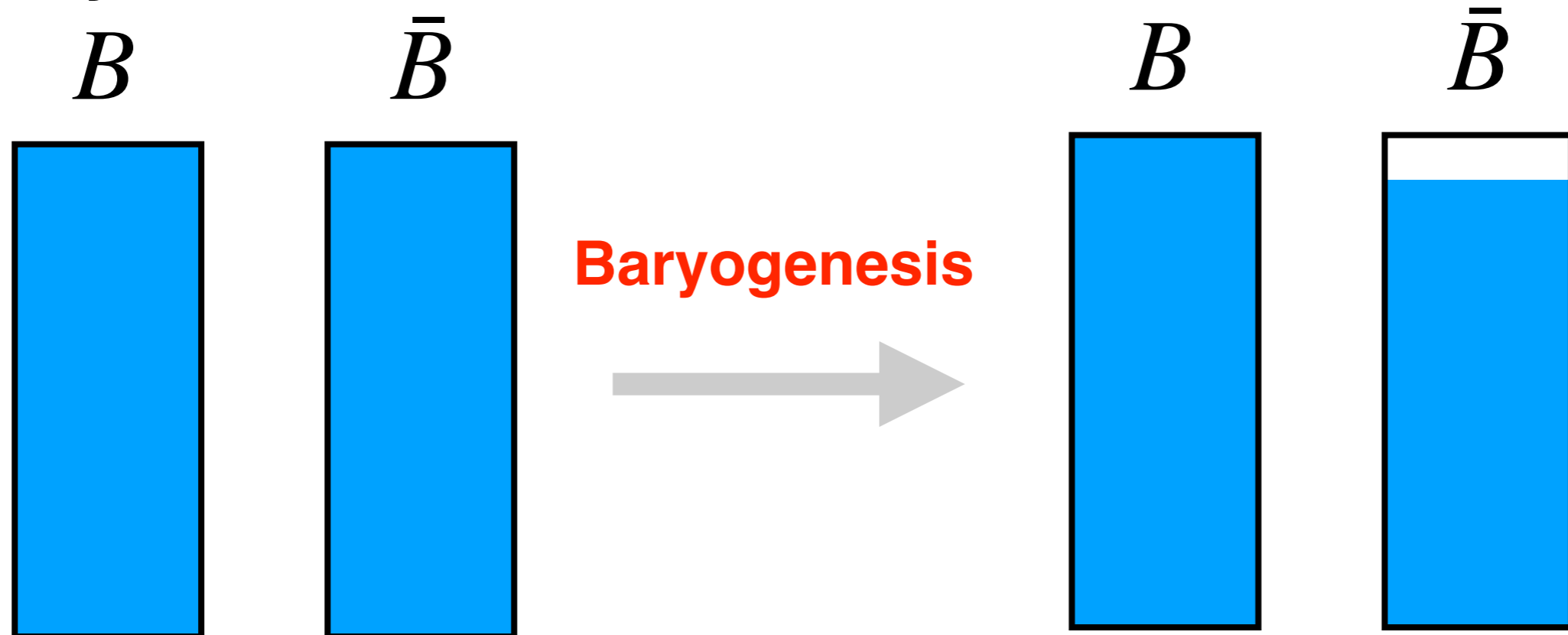
Baryogenesis

The dynamical mechanism which starting from a baryon-symmetric state leads to Universe with more baryons than antibaryons!



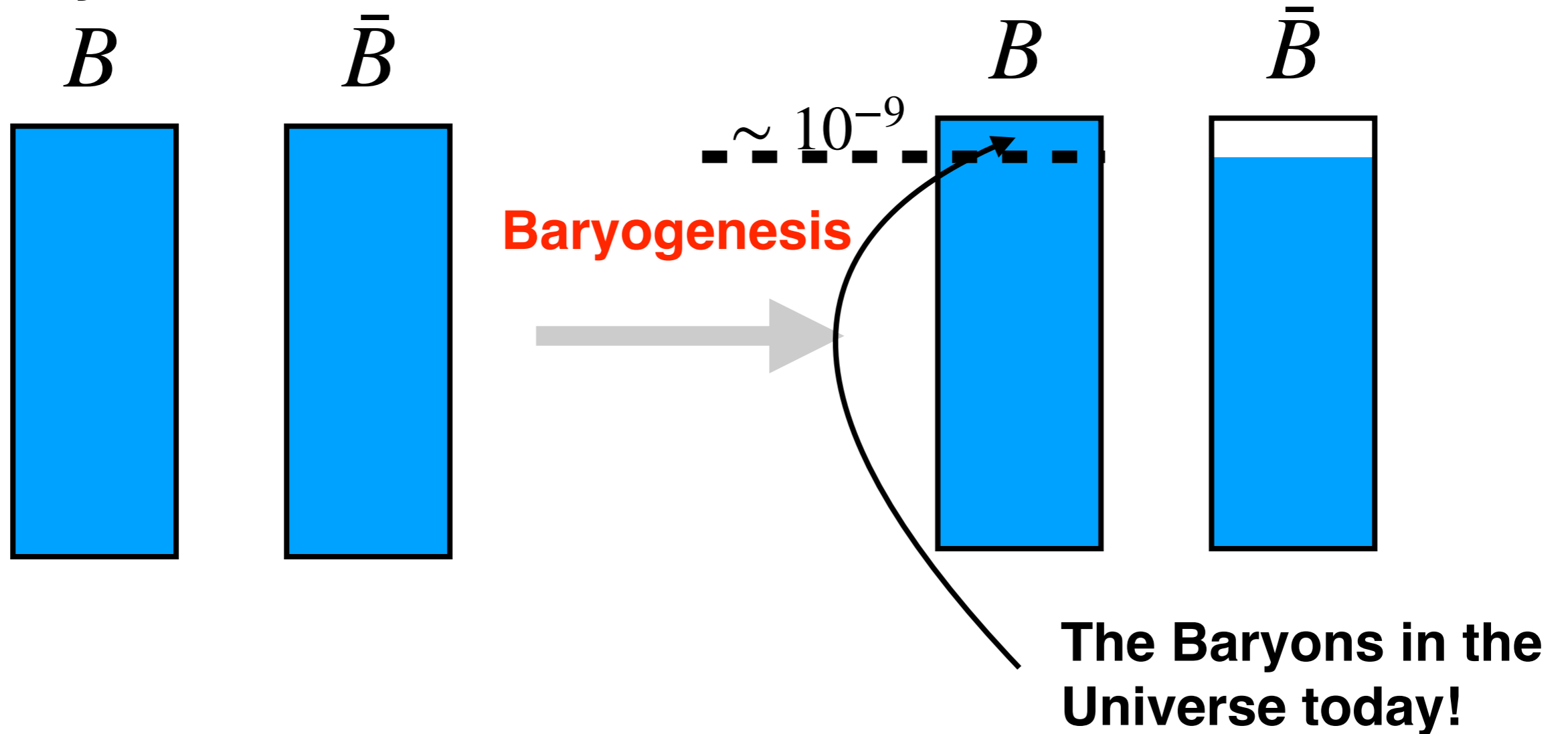
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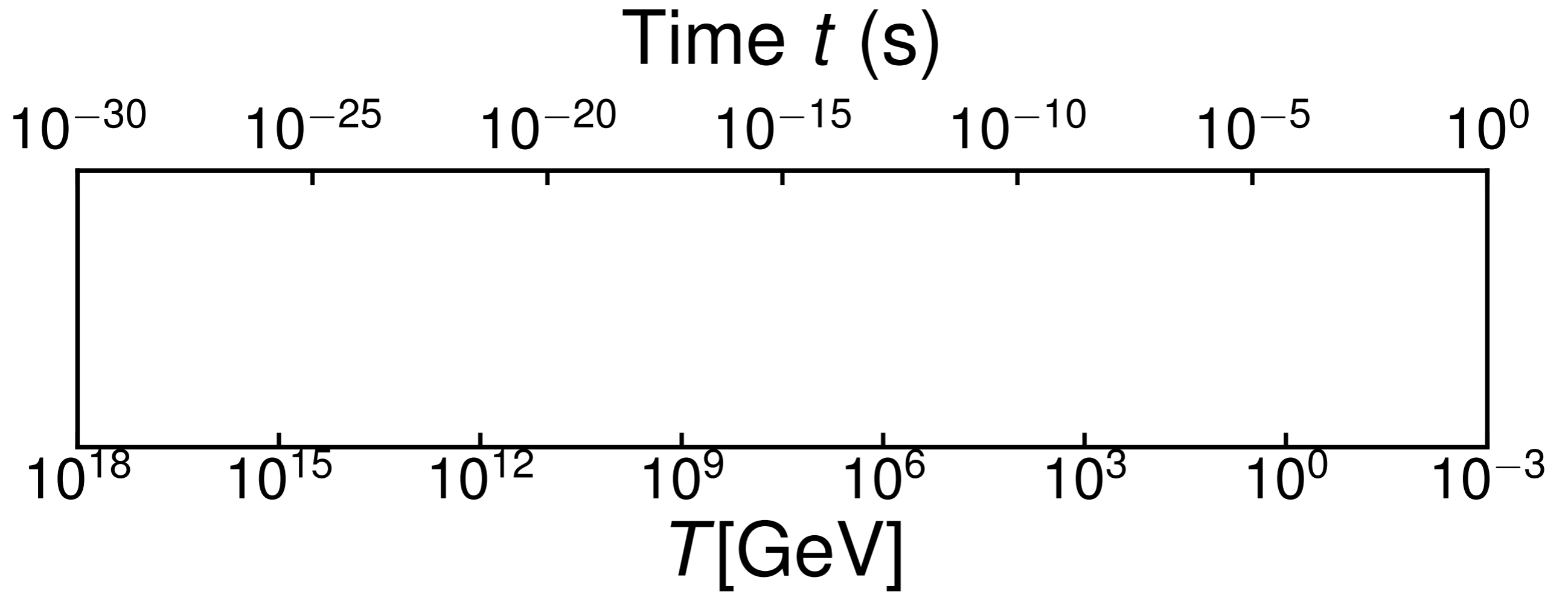


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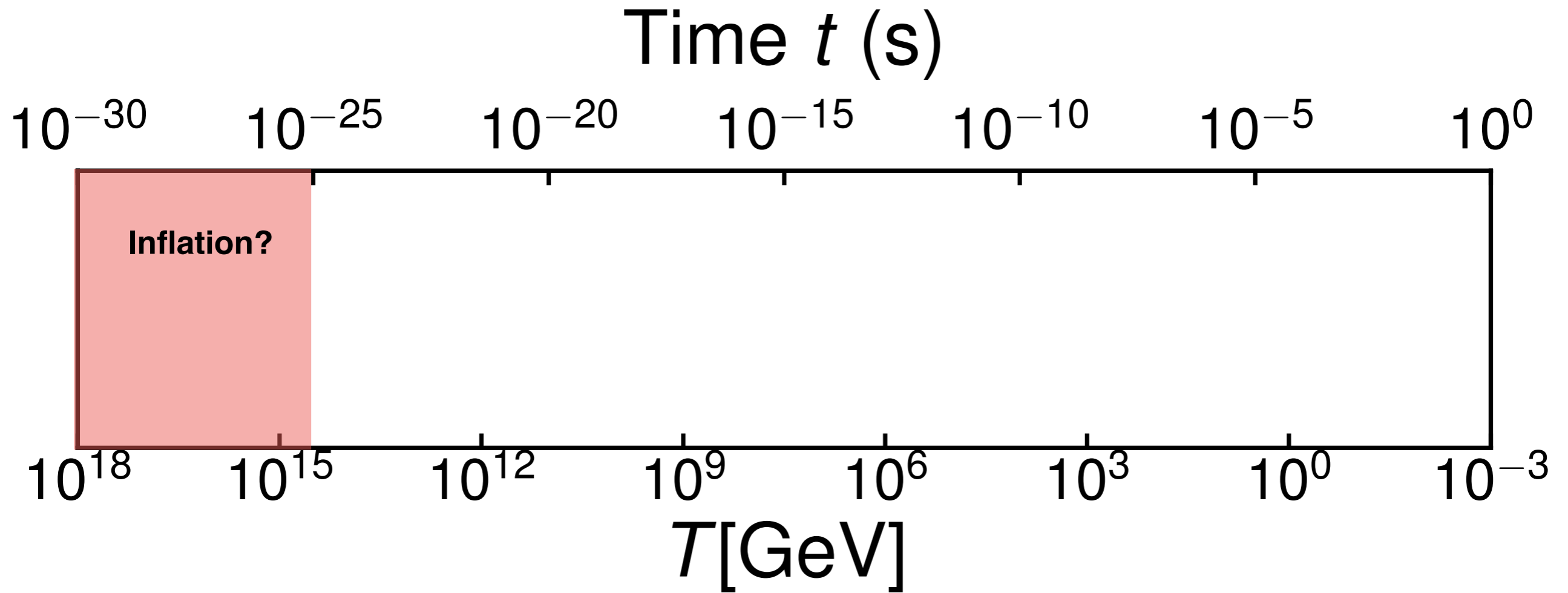
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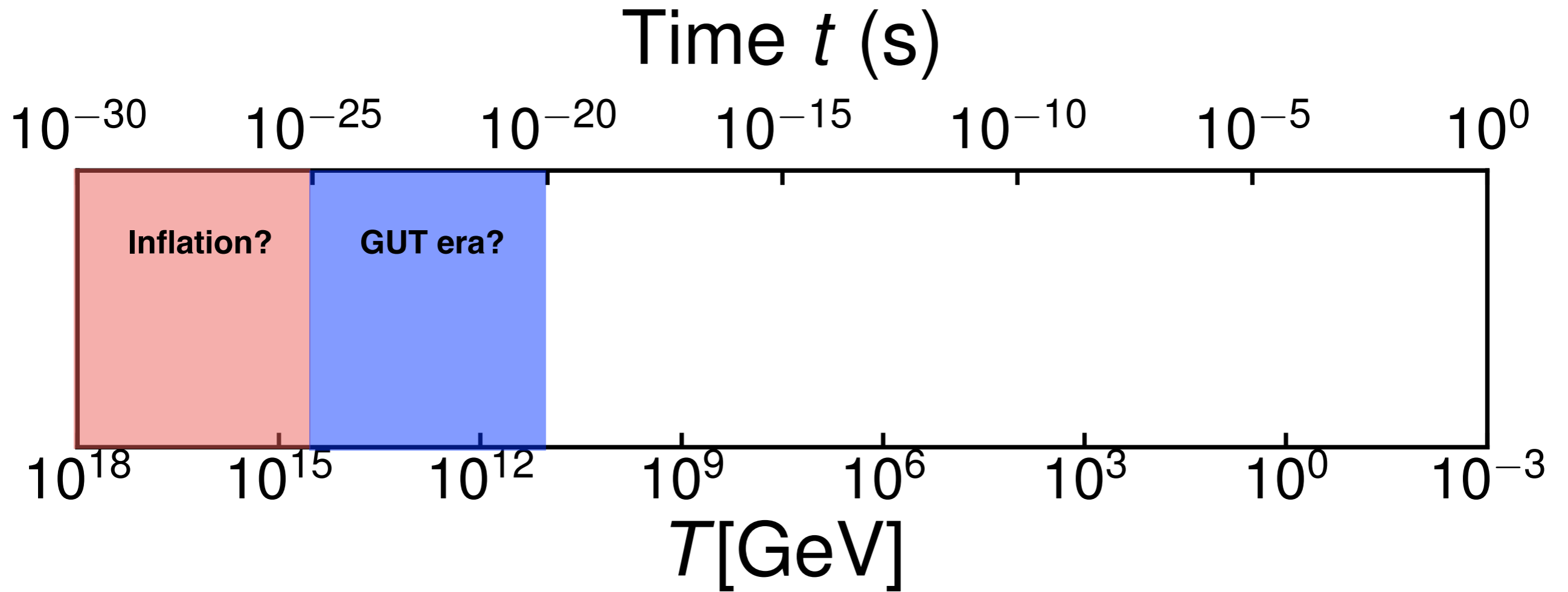
A tentative timeline of the Early Universe



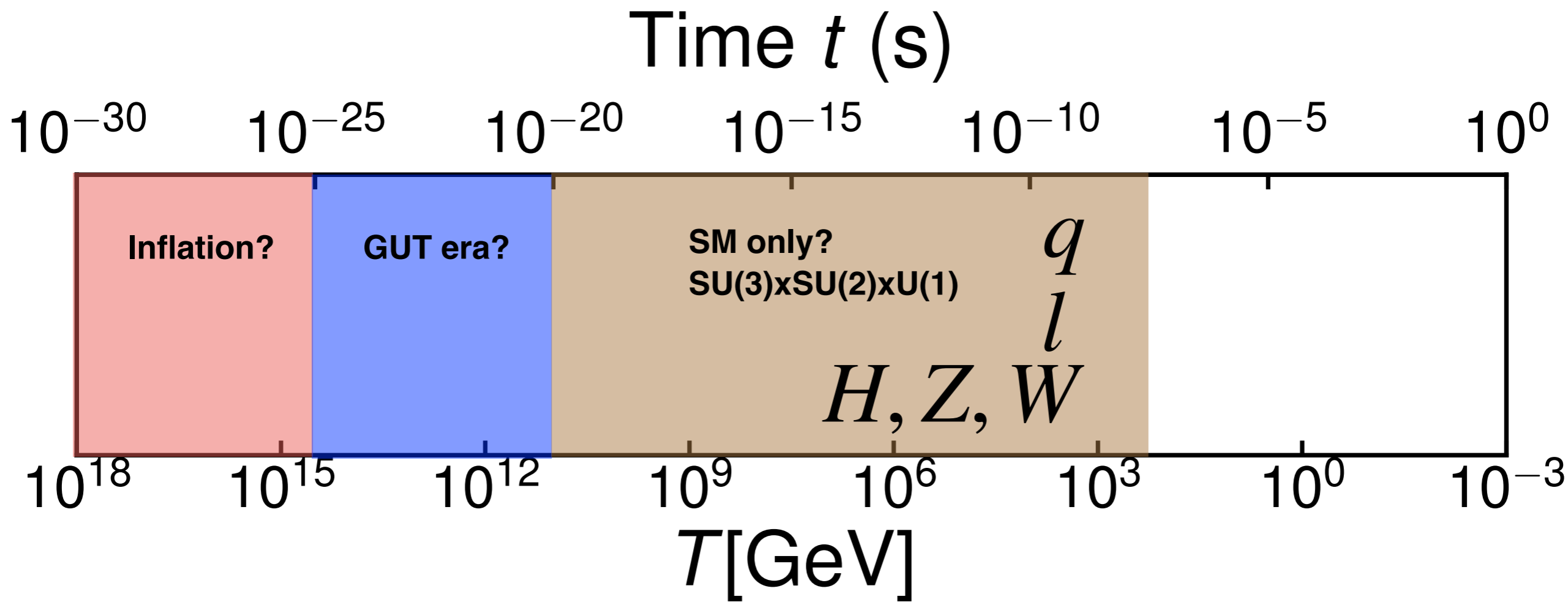
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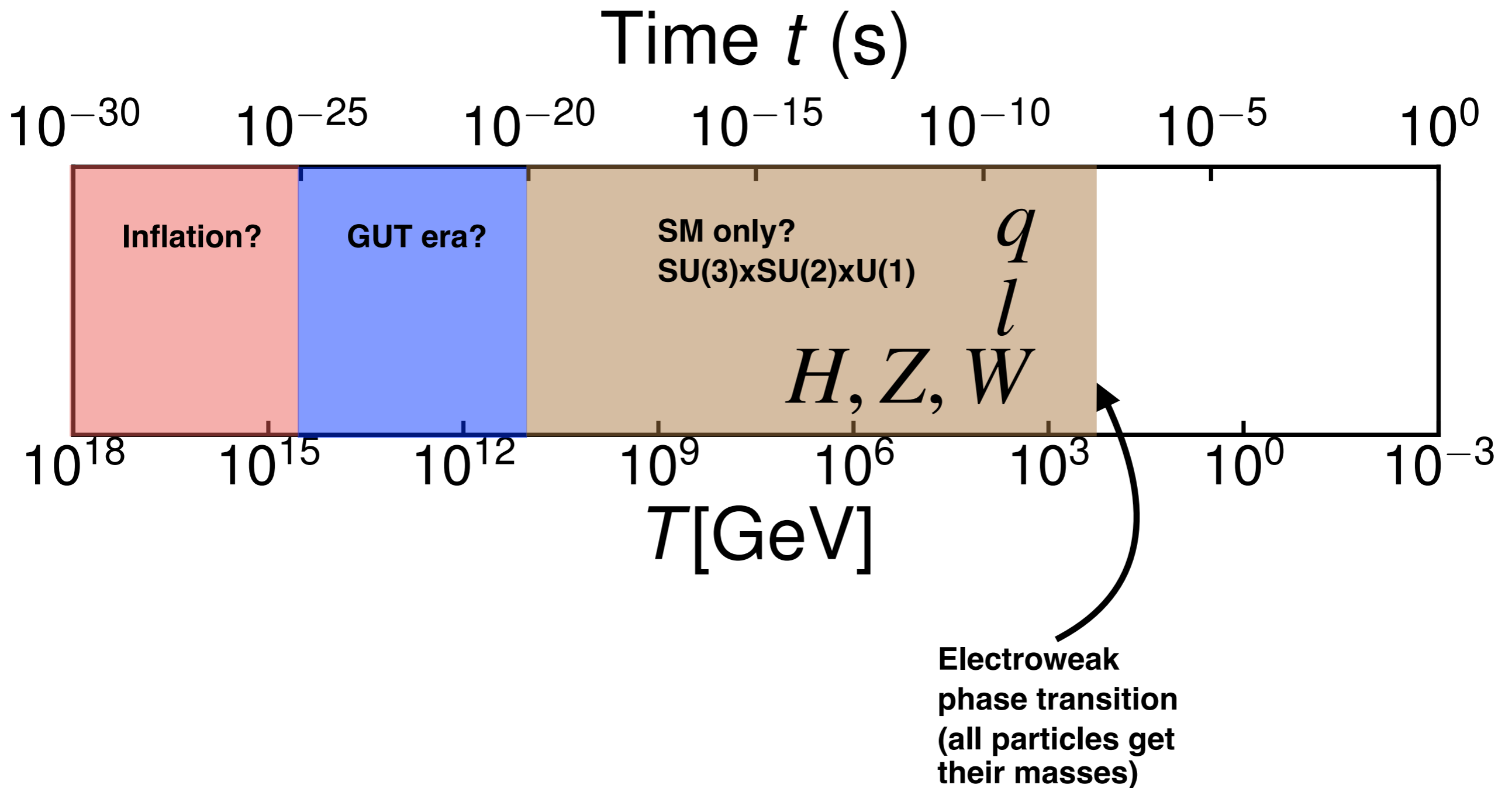
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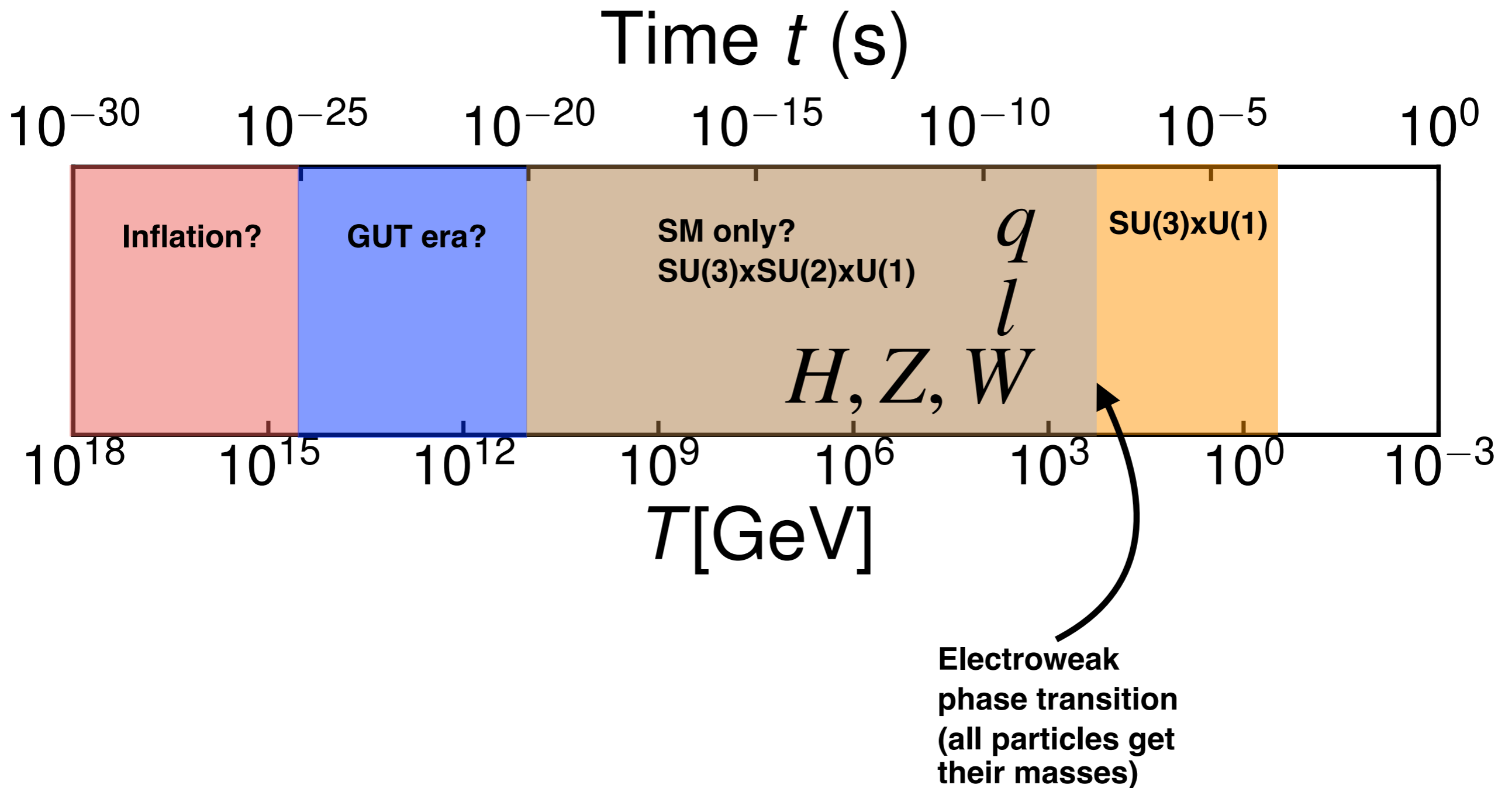
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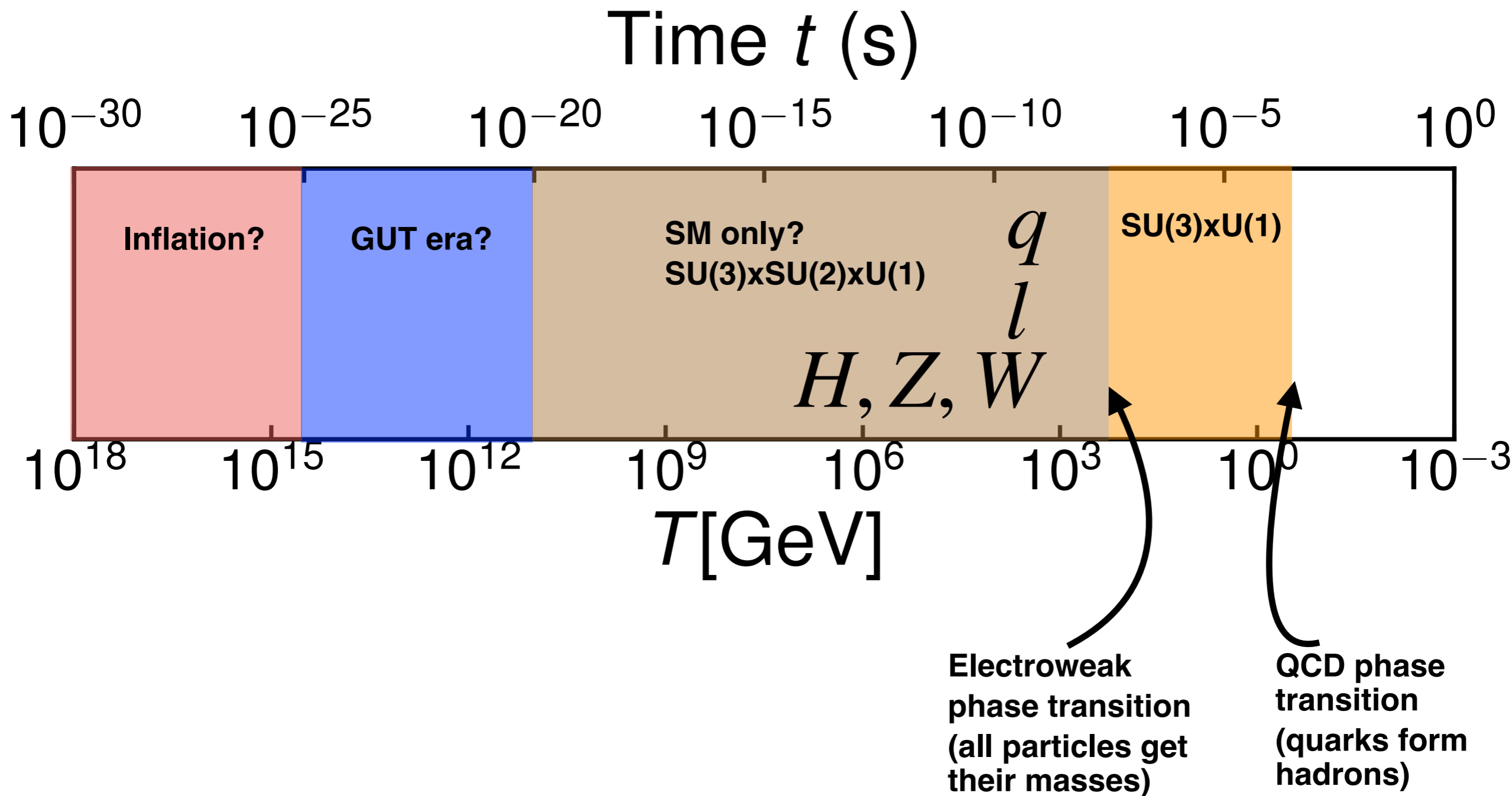
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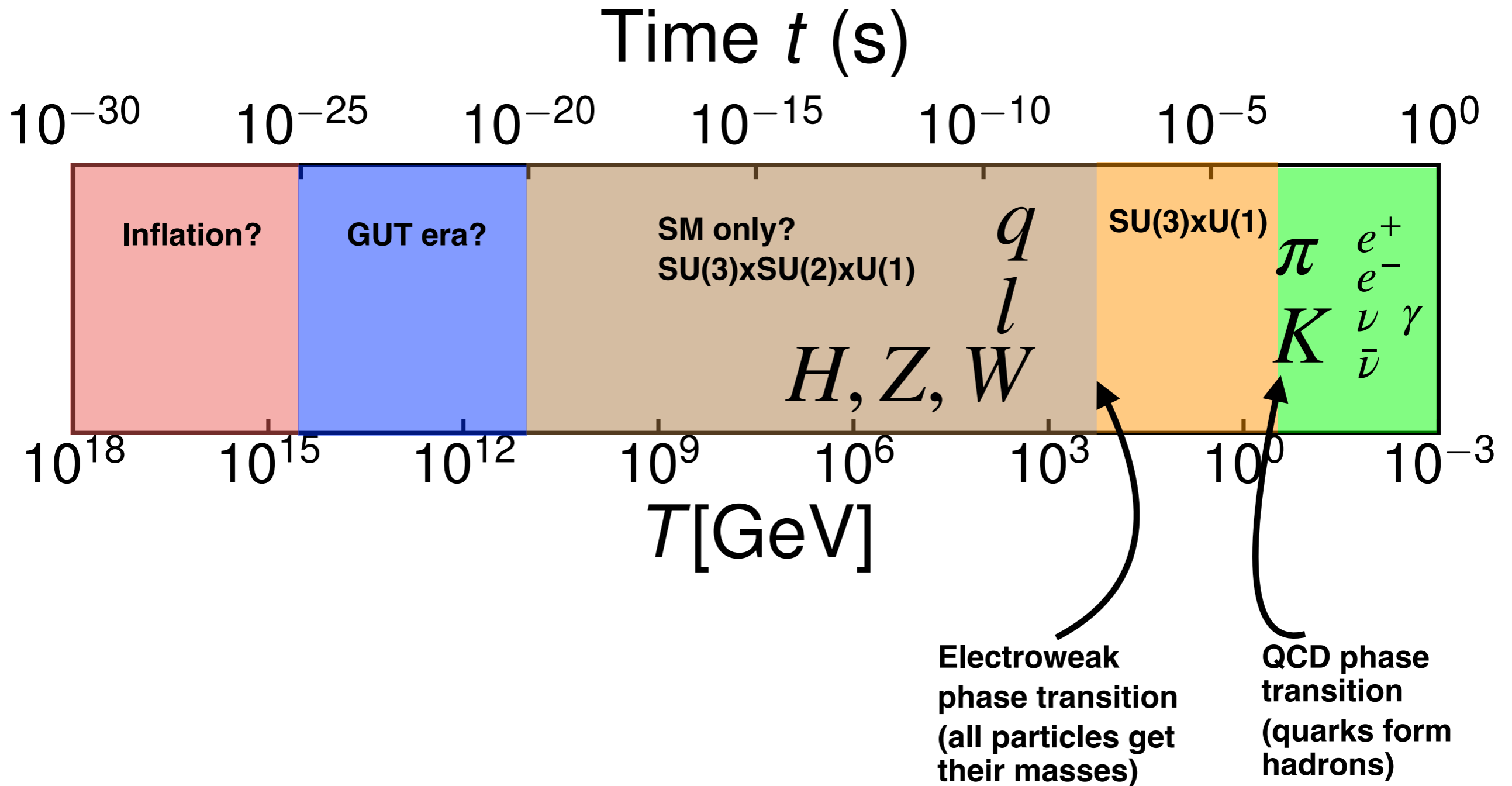
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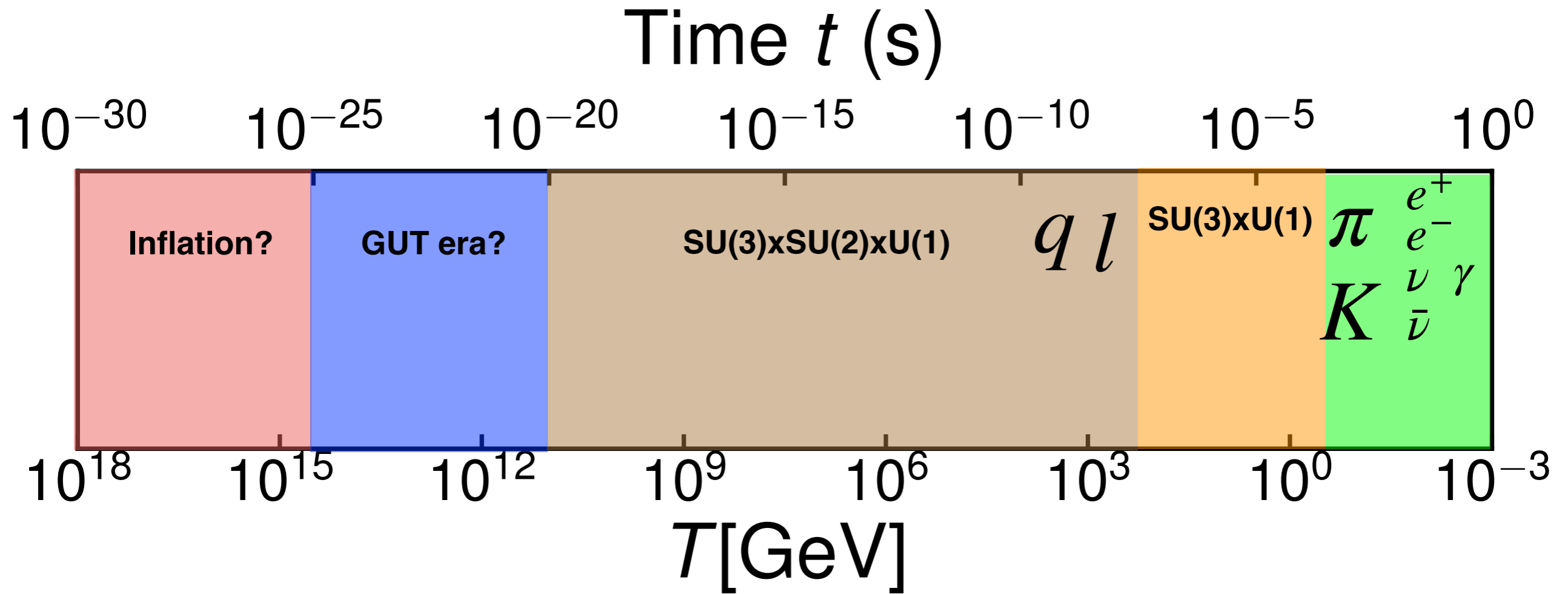
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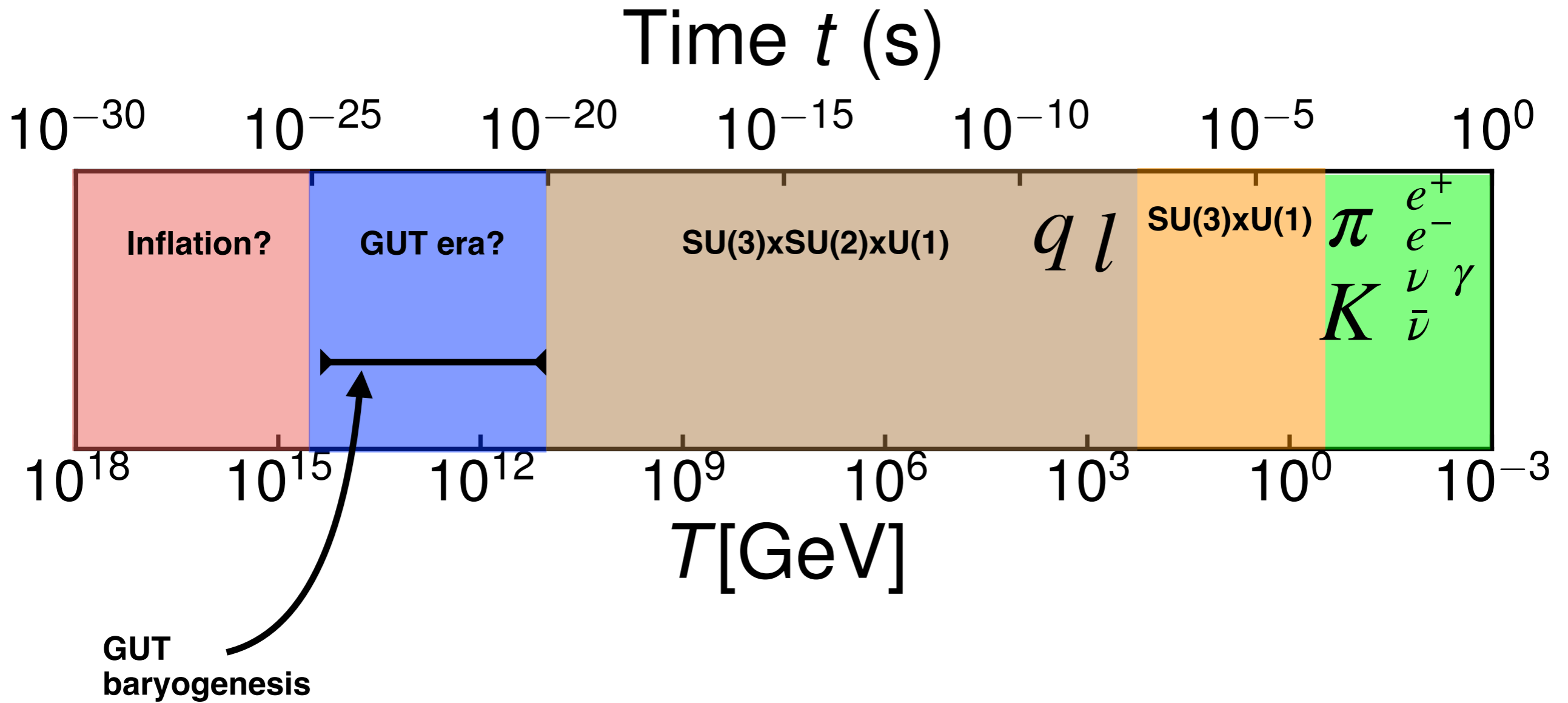
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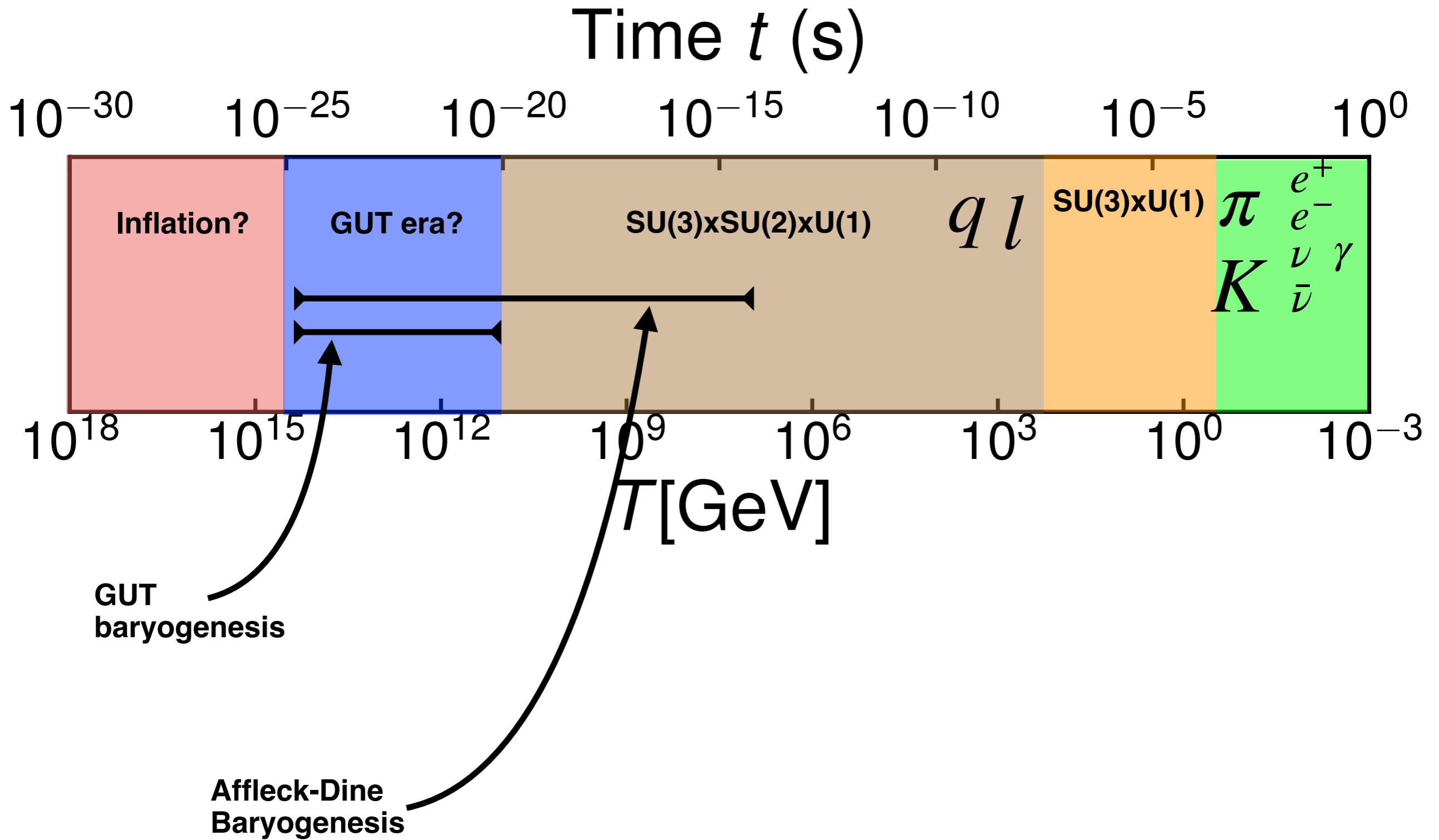
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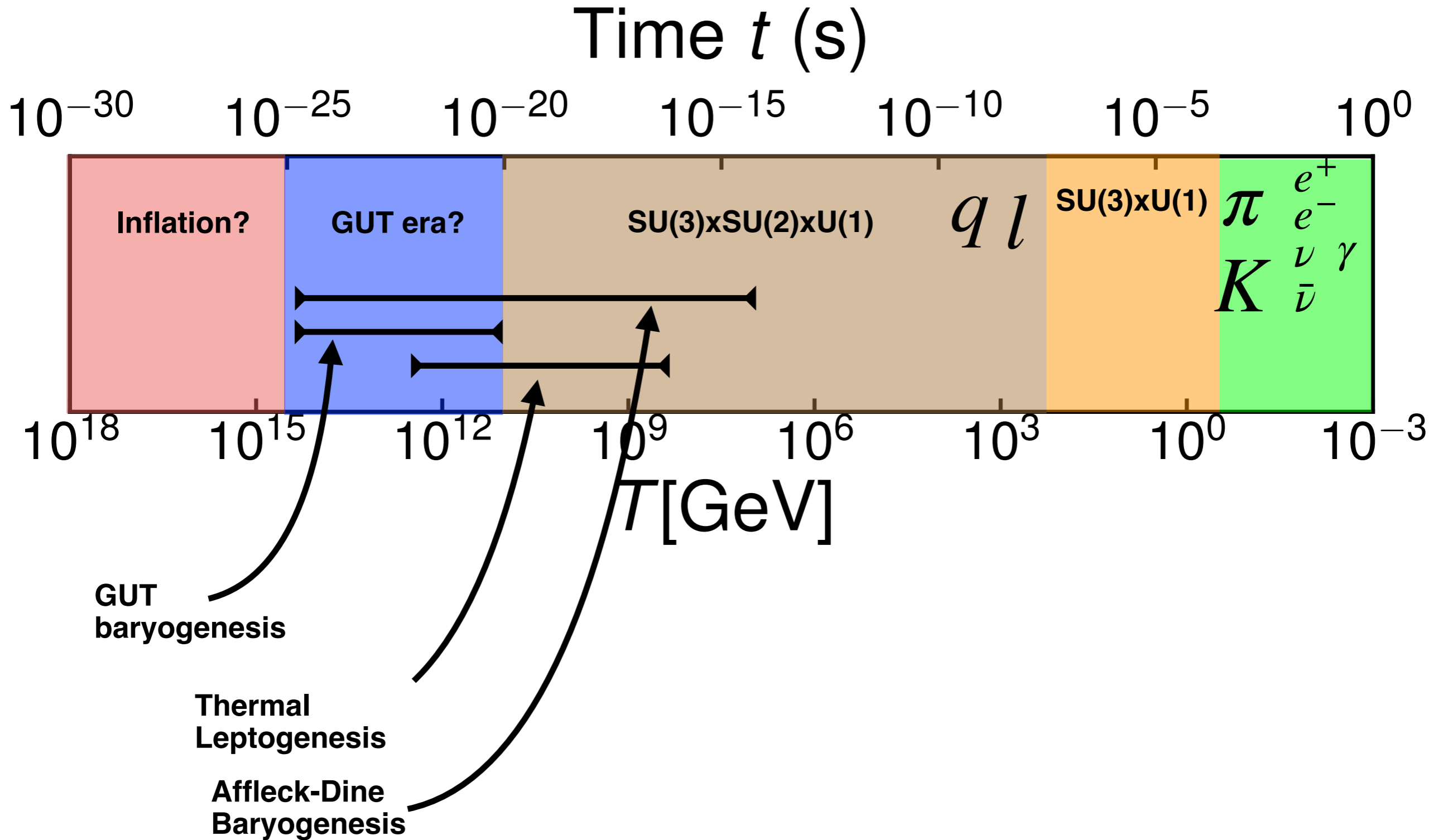
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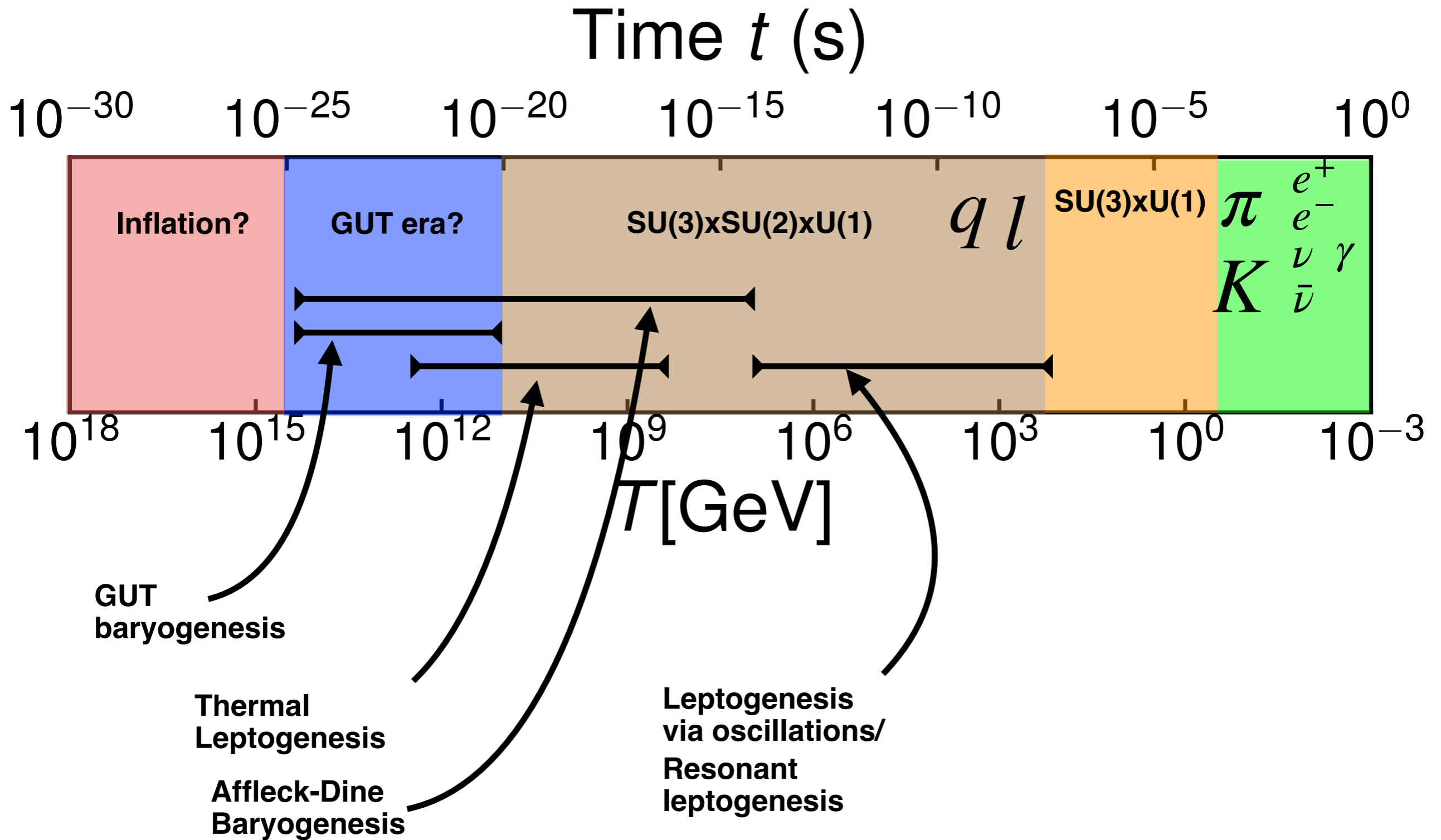
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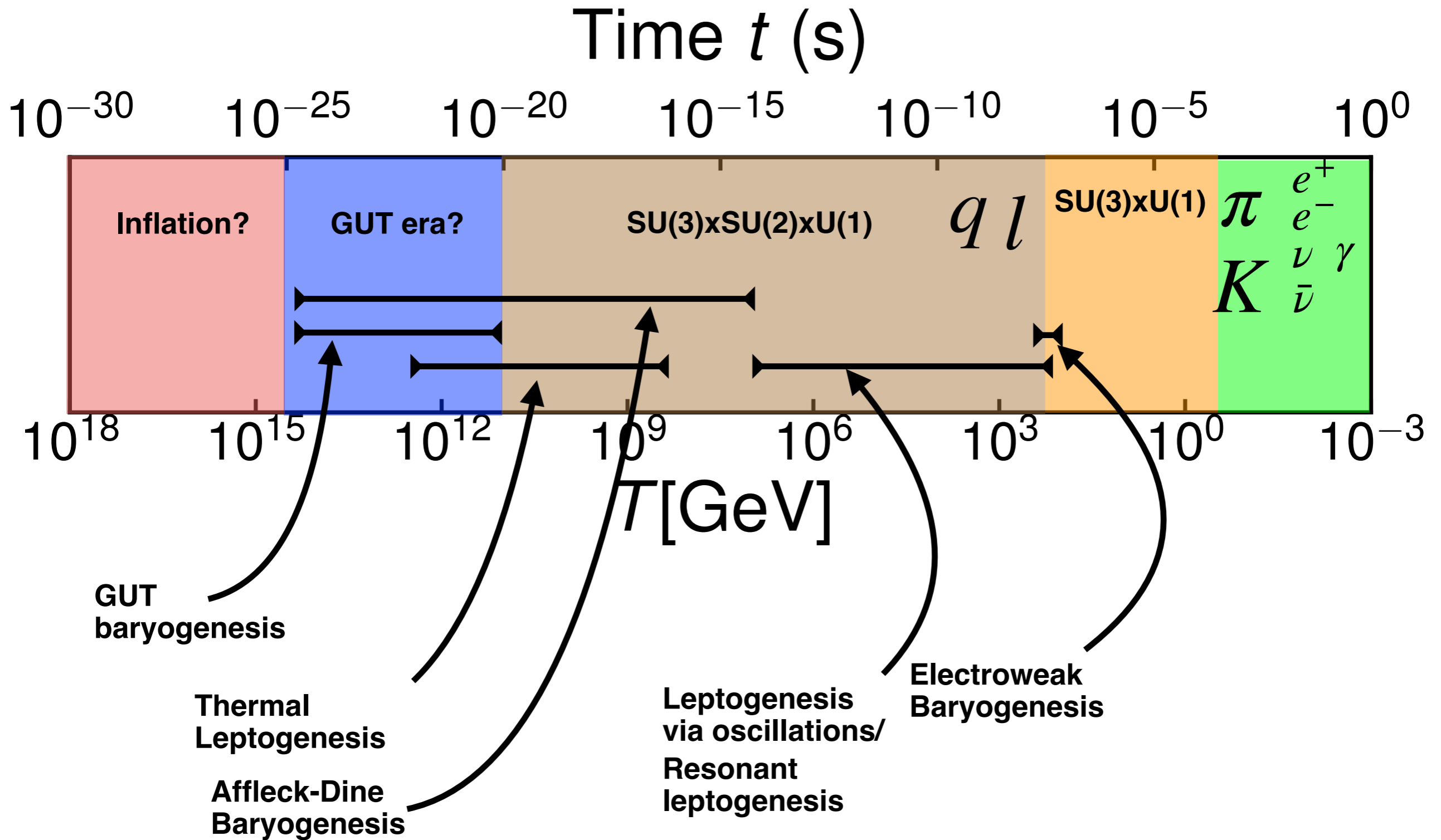
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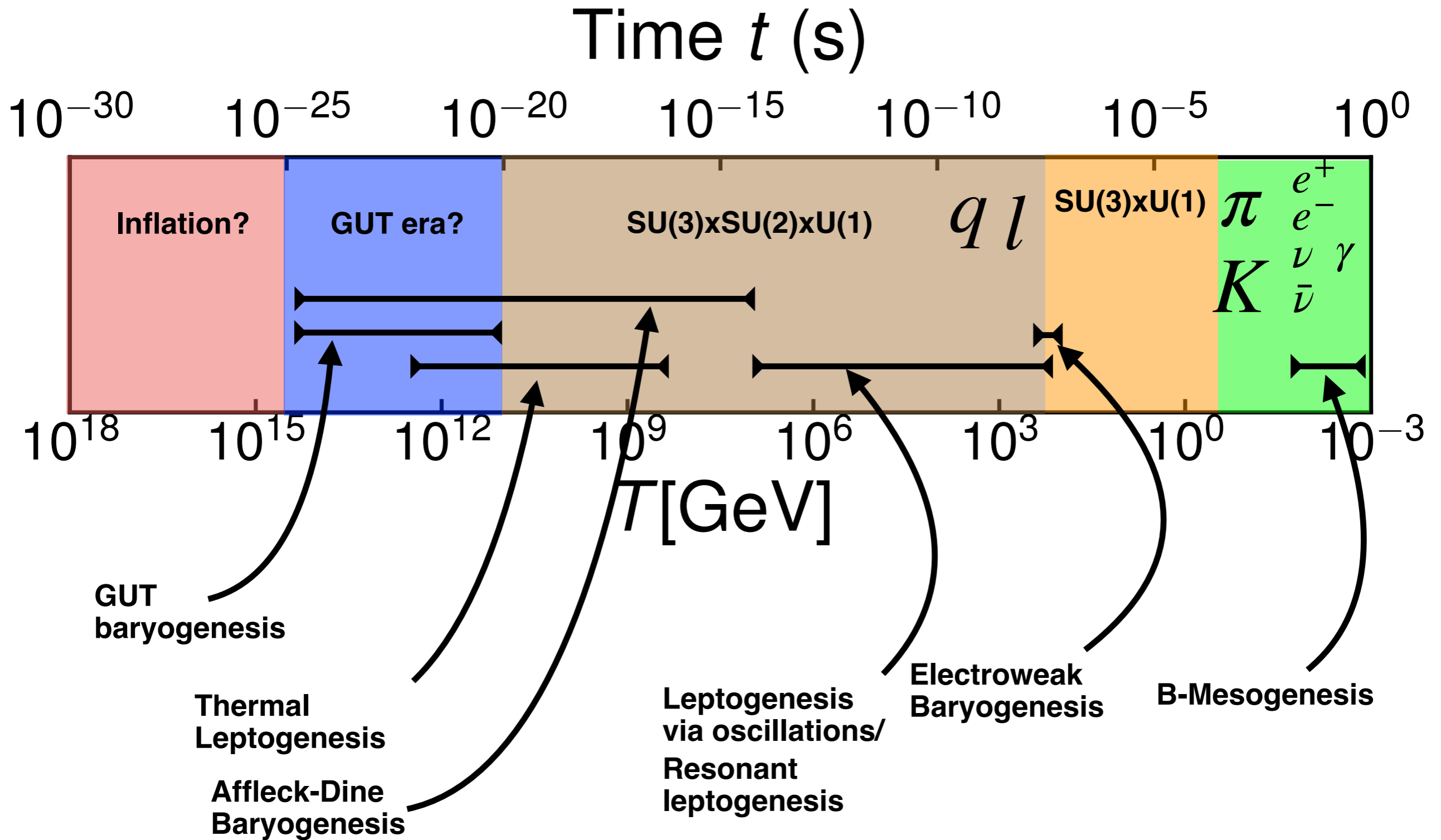
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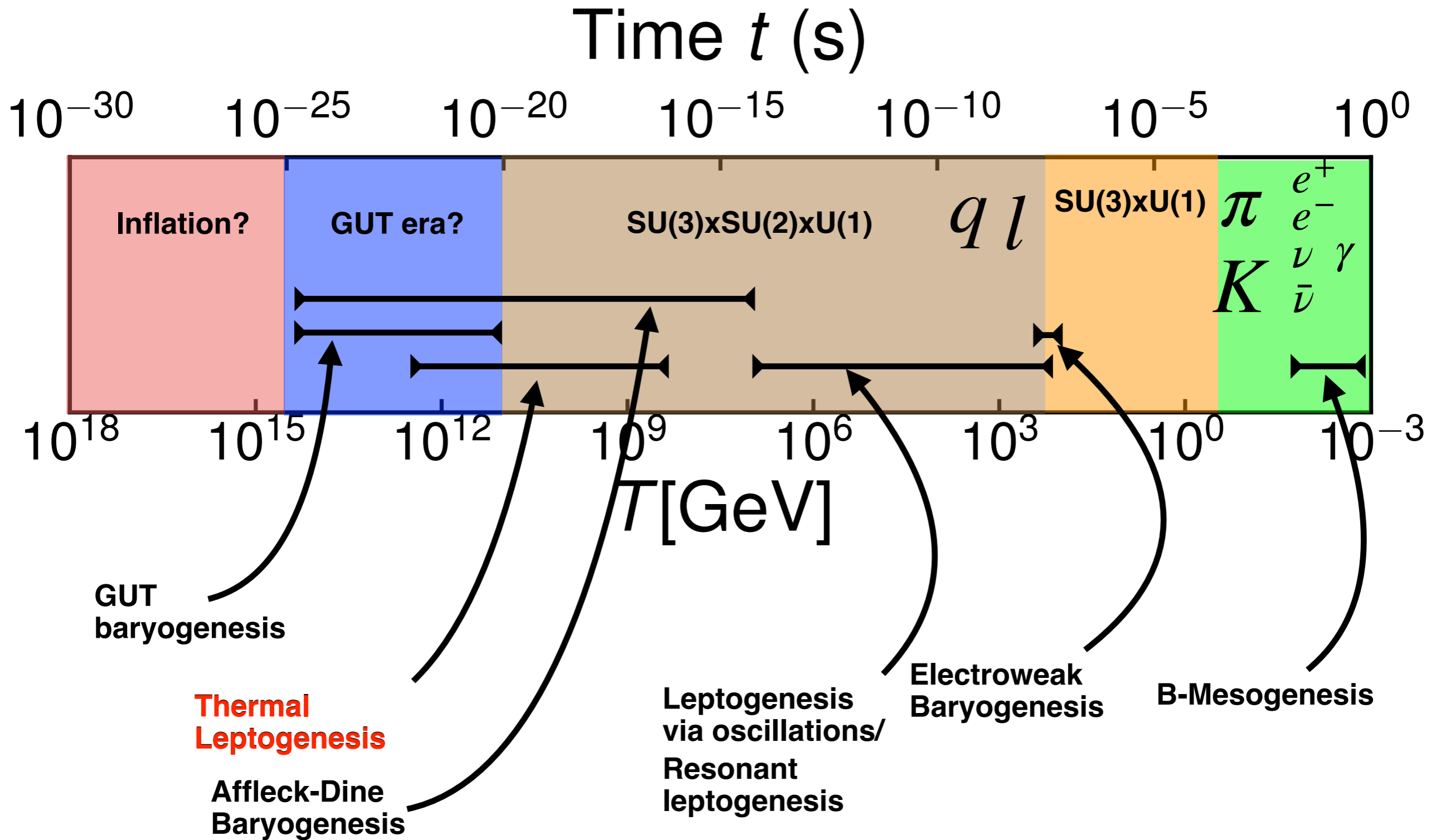
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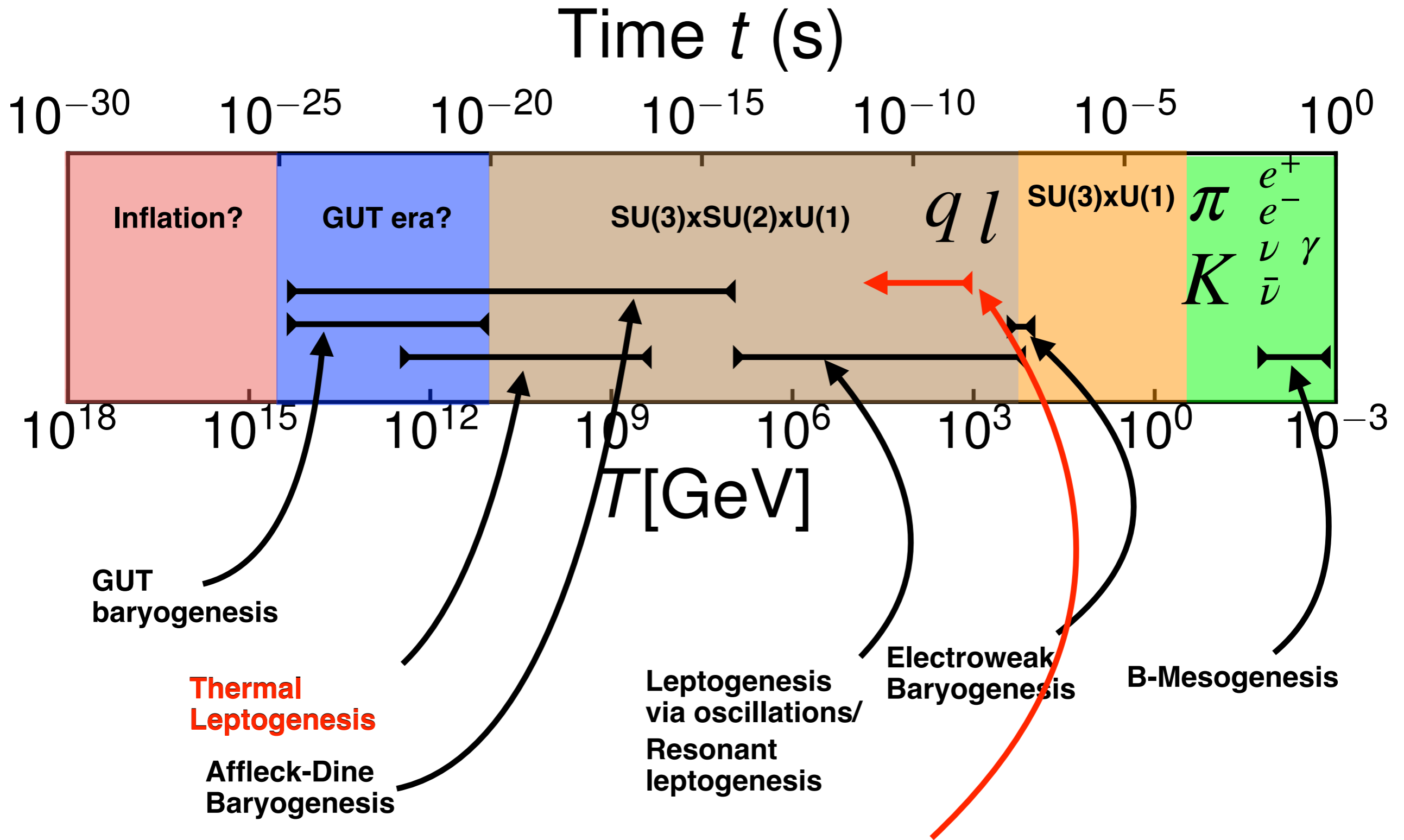


Baryogenesis



*not an exhaustive list, but it does include some of the most popular models

Baryogenesis



The asymmetric dark matter scenario I will present is compatible with all the models to the left.

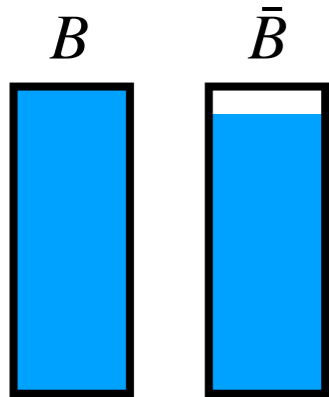
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We know that if the baryon asymmetry of the Universe was generated before the electroweak phase transition, then all states in the SM but W^\pm had different numbers of particles than antiparticles:

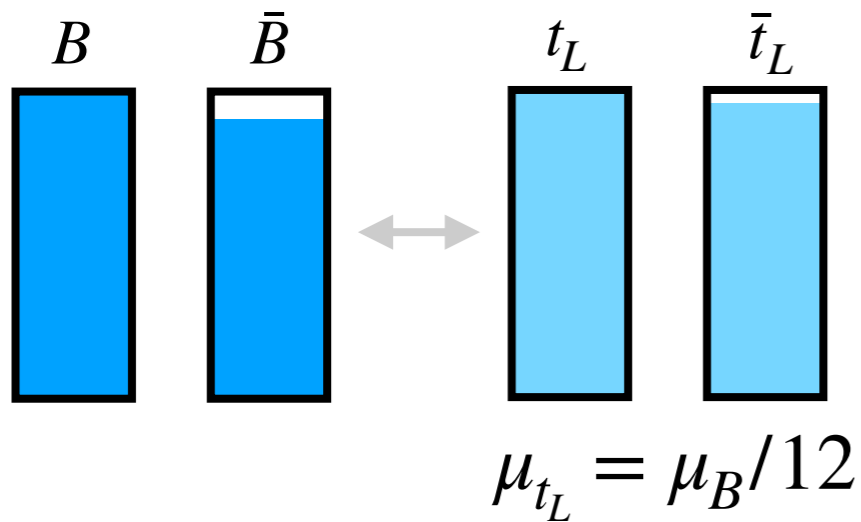
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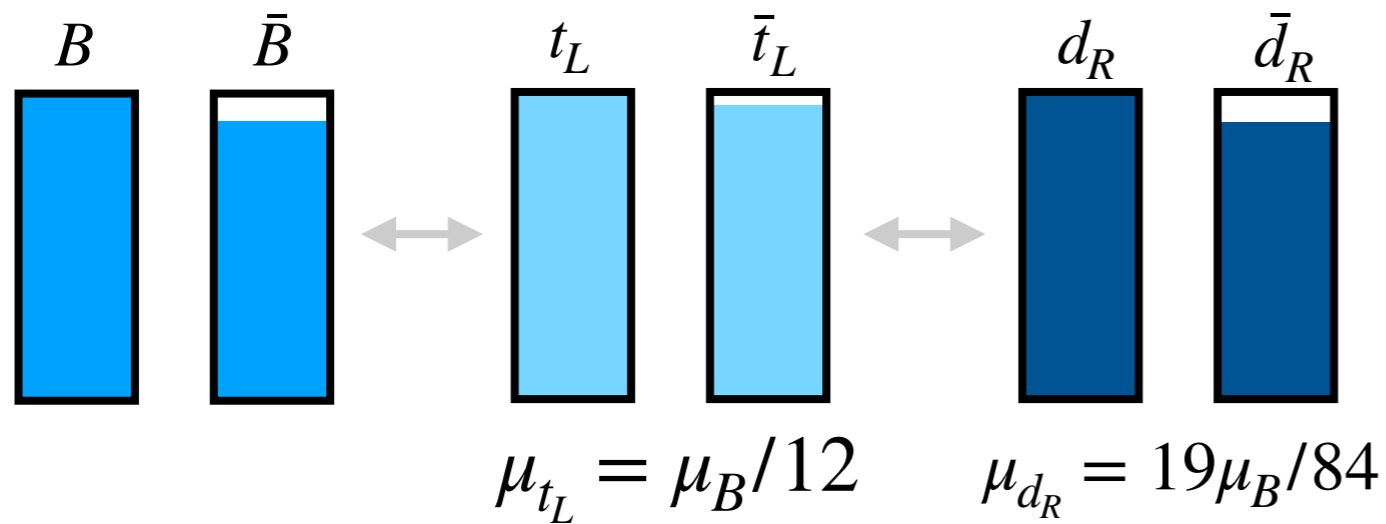
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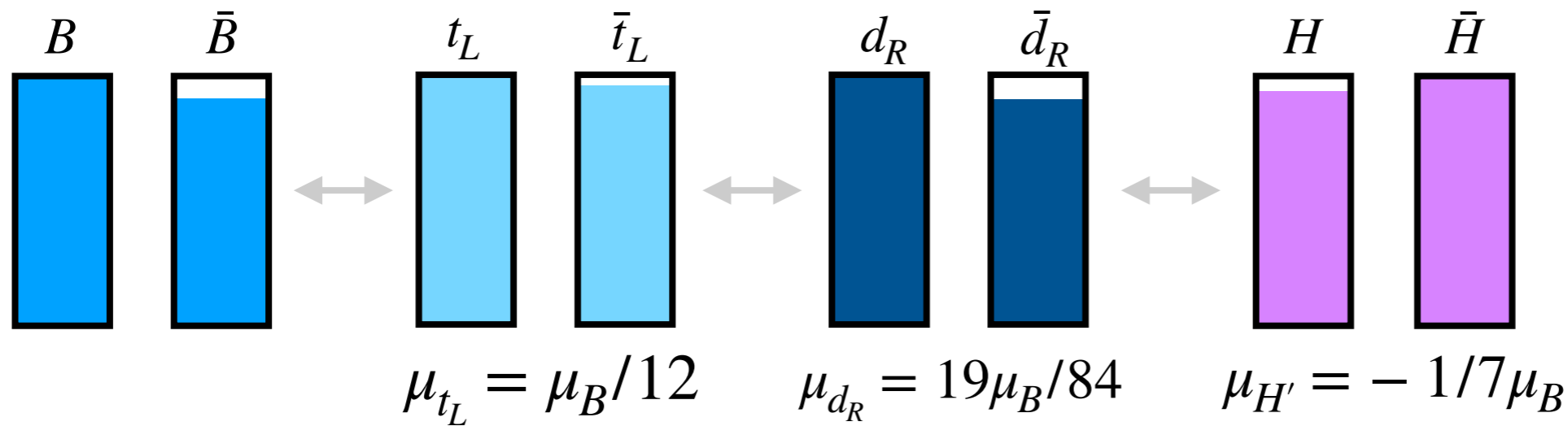
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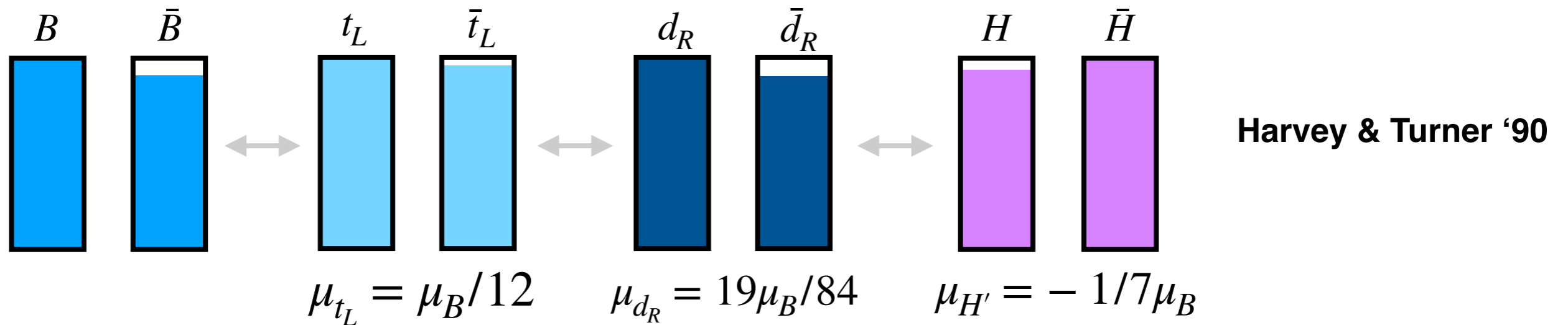
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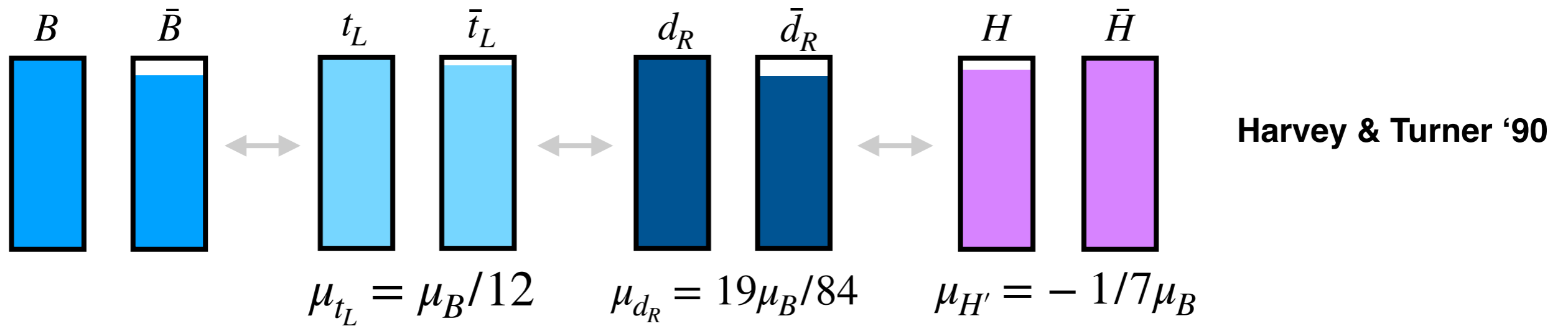
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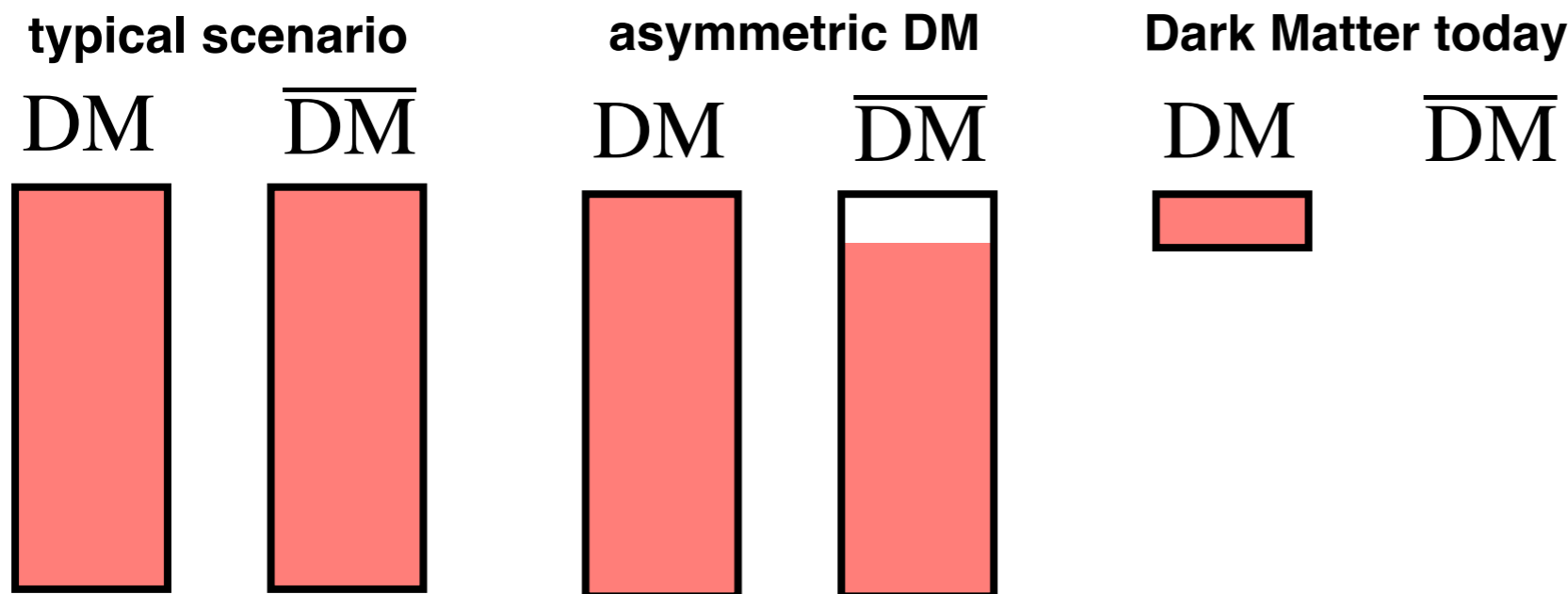
Can dark matter be asymmetric?

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Early Refs.

- Hut & Olive '79
- Nussinov '85
- Barr, Chivukula & Farhi '90
- Kaplan '92
- Dodelson, Greene & Widrow '92

Reviews:

- Cirelli, Strumia & Zupan [2406.01705]
- Petraki & Volkas [1305.4939]
- Zurek [1308.0338]

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Models which relate an existing baryon asymmetry and transfer it to the Dark Matter (which are in most cases based on effective operators)

Kaplan, Luty & Zurek [0901.4117]
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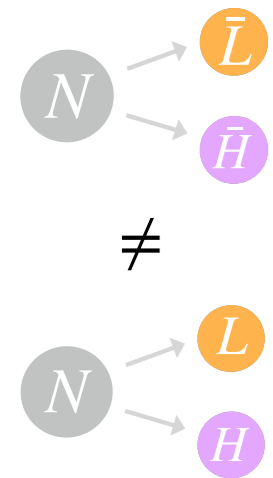
Why could this be interesting?

Use a relic that we know should be there (from e.g. thermal Leptogenesis) and employ mechanisms that we know operate in the early Universe in the visible sector (thermal freeze-out)

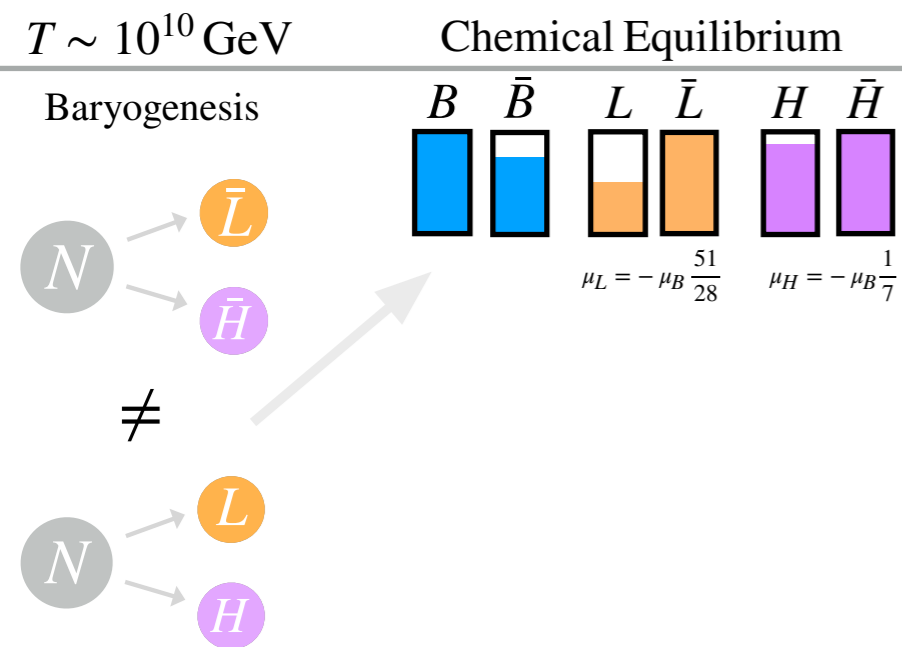
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$T \sim 10^{10}$ GeV

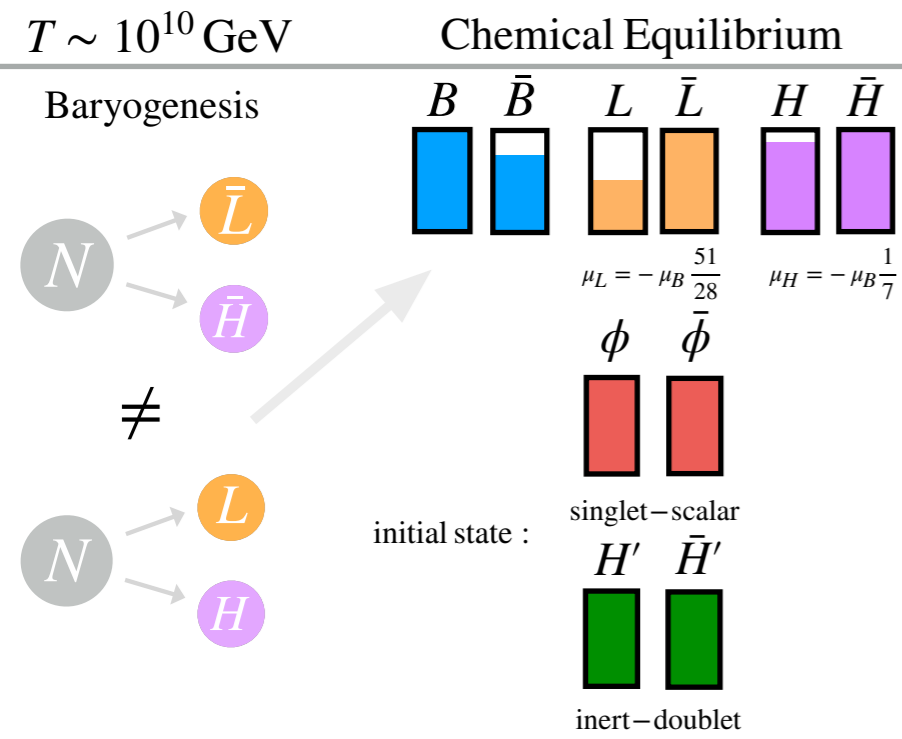
Baryogenesis



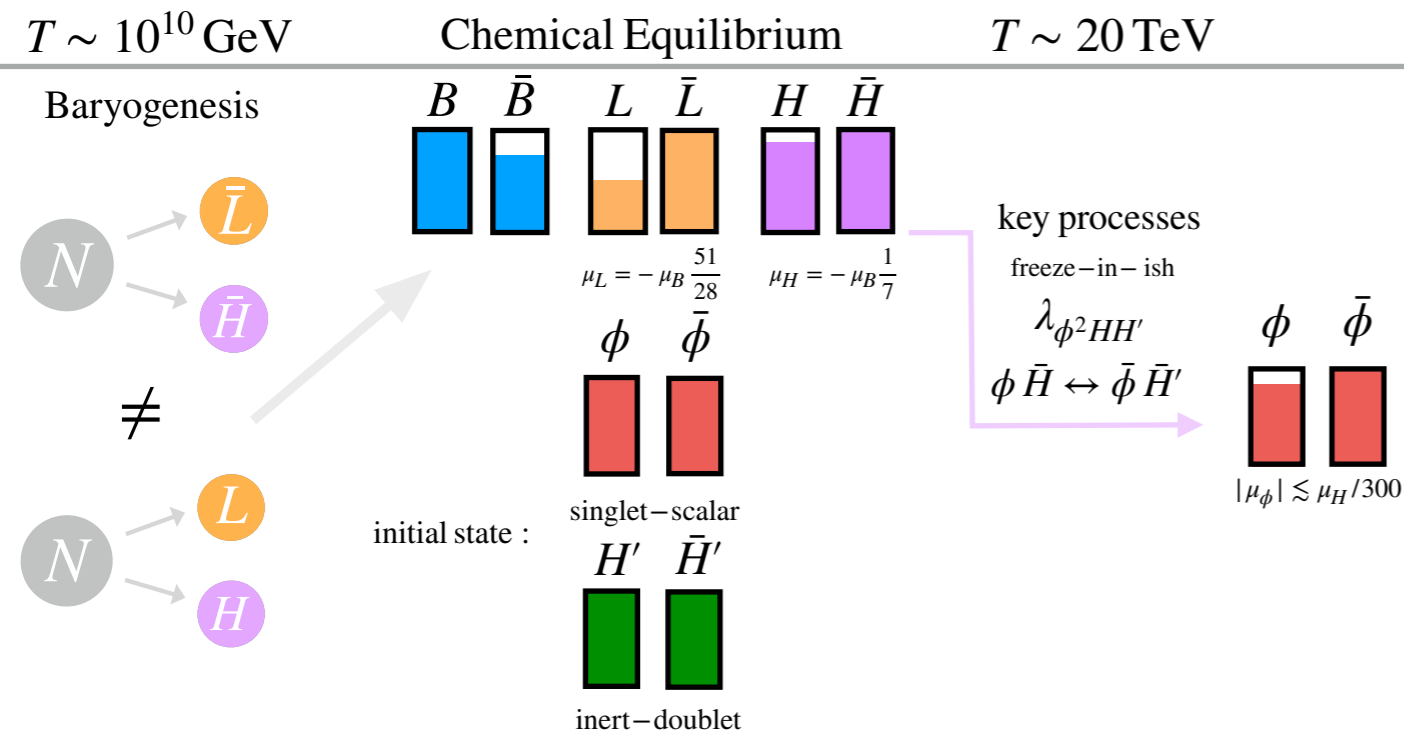
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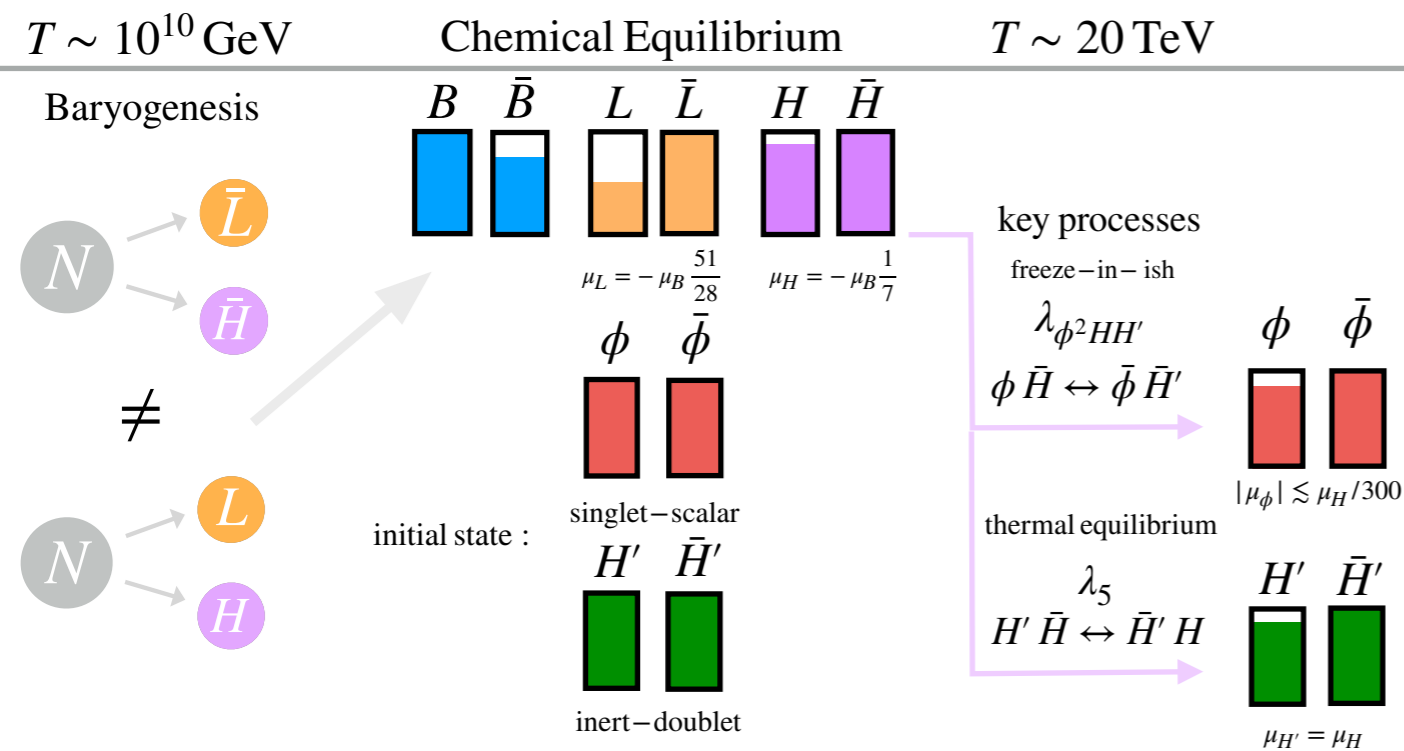
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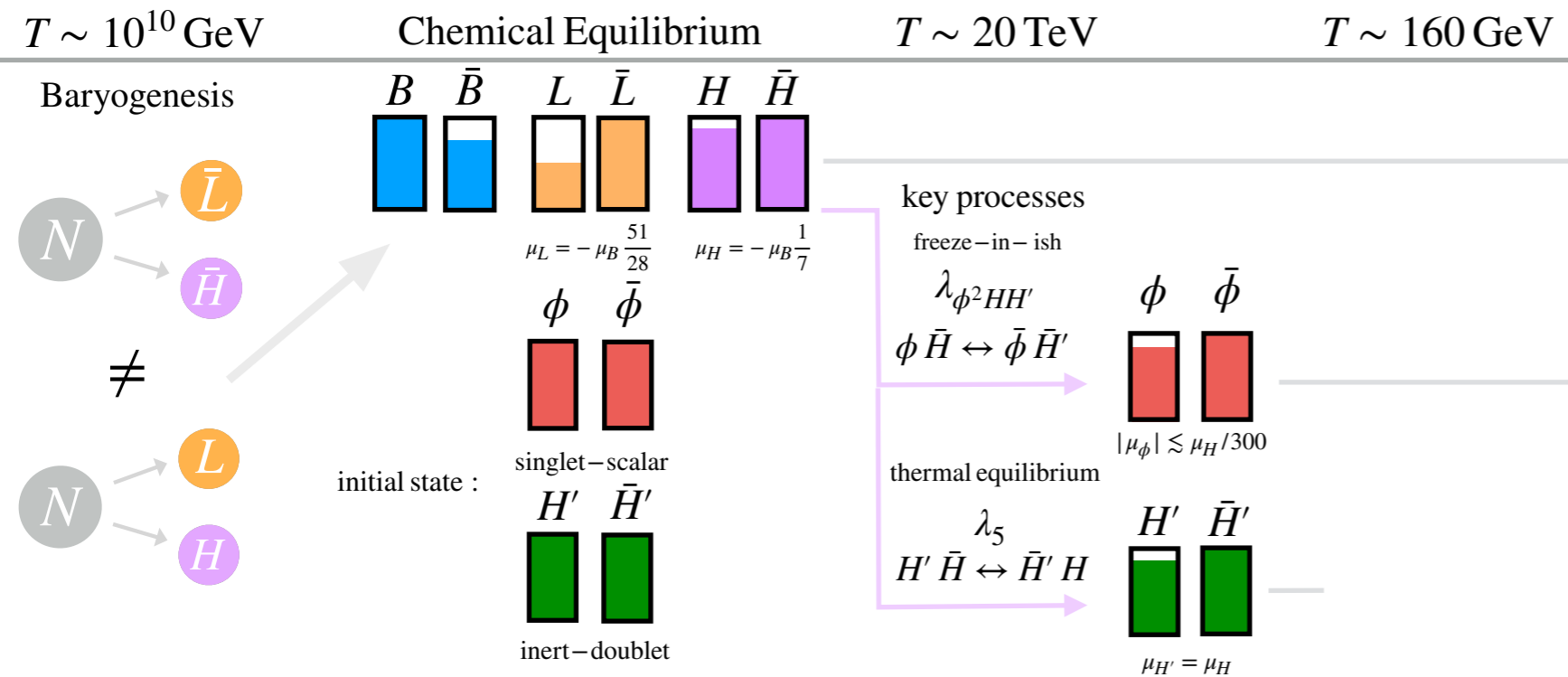
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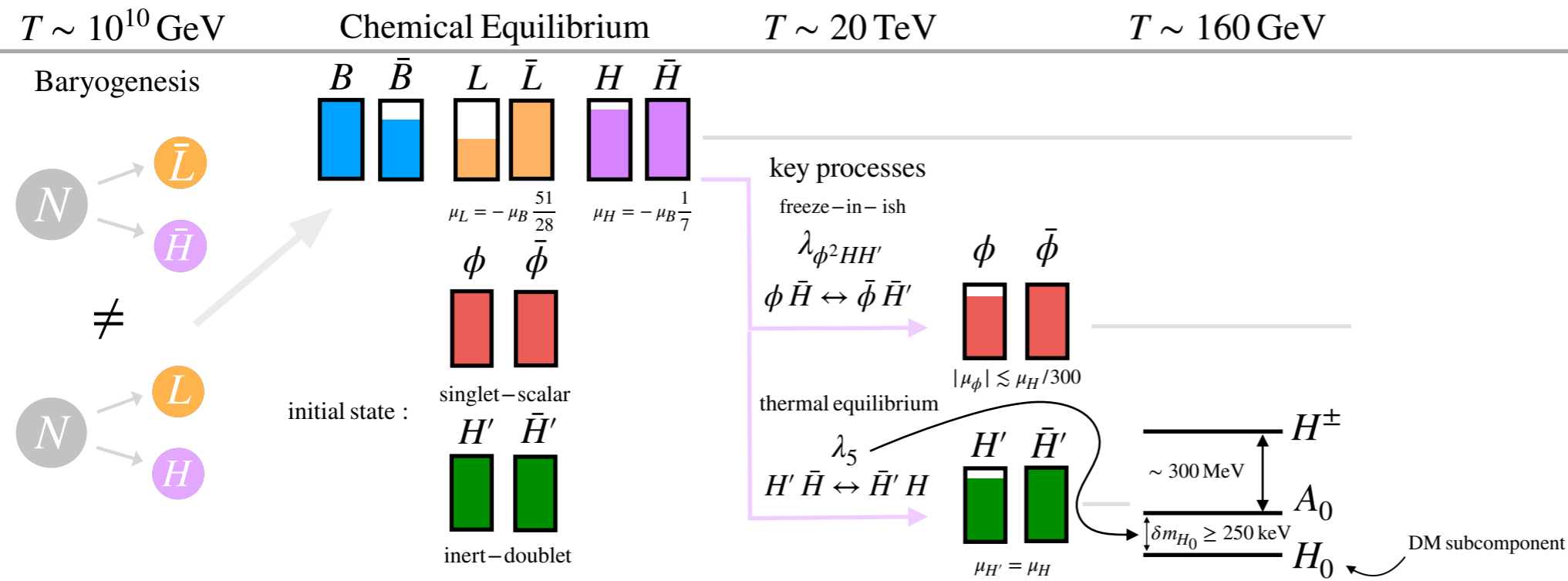


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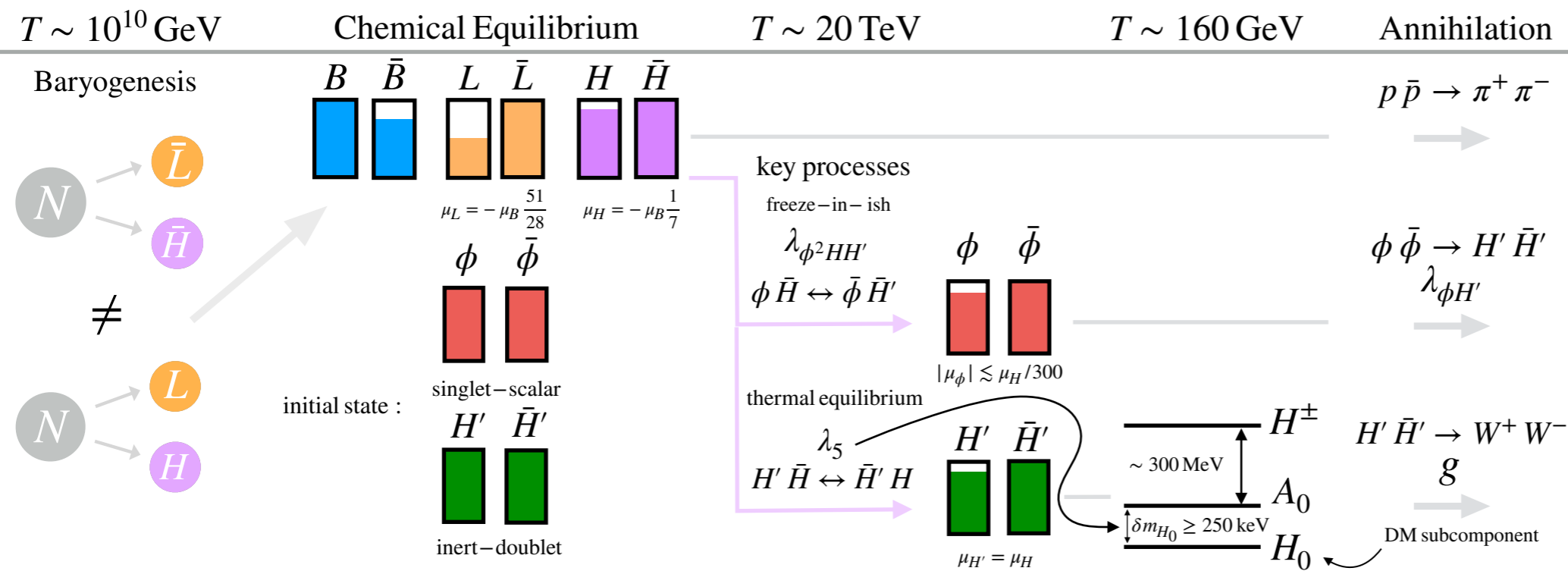
The scenario

Minimal Baryogenesis induced Asymmetric Dark Matter



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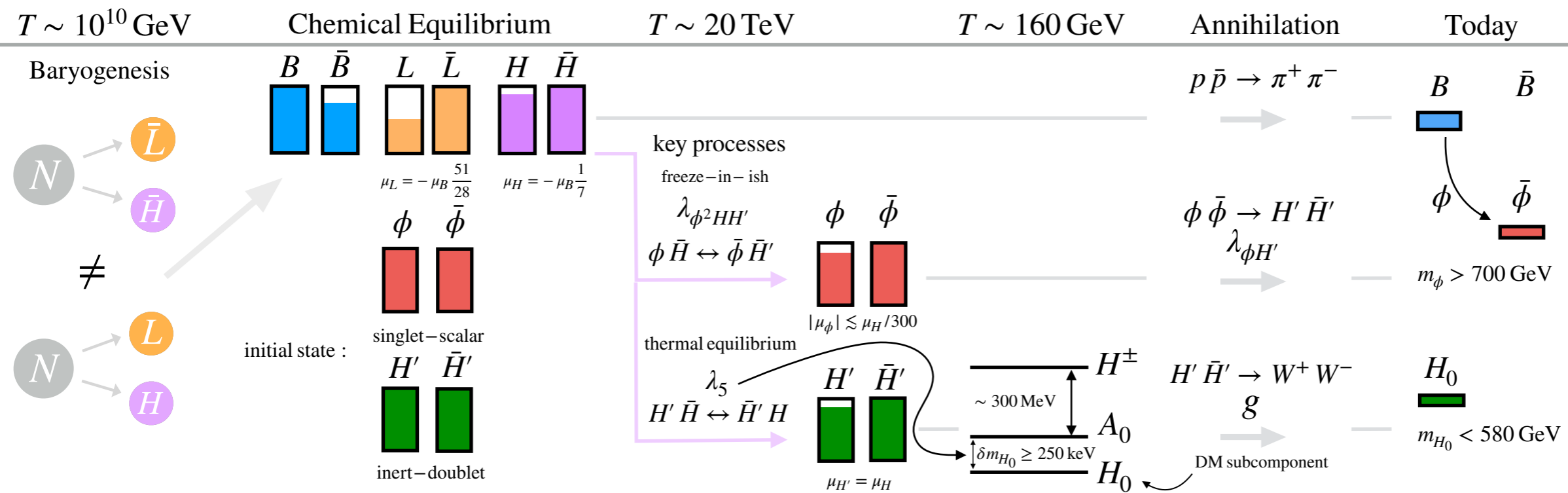
Minimal Baryogenesis induced Asymmetric Dark Matter



The scenario

[2511.10731] Escudero, Hambye & Hati

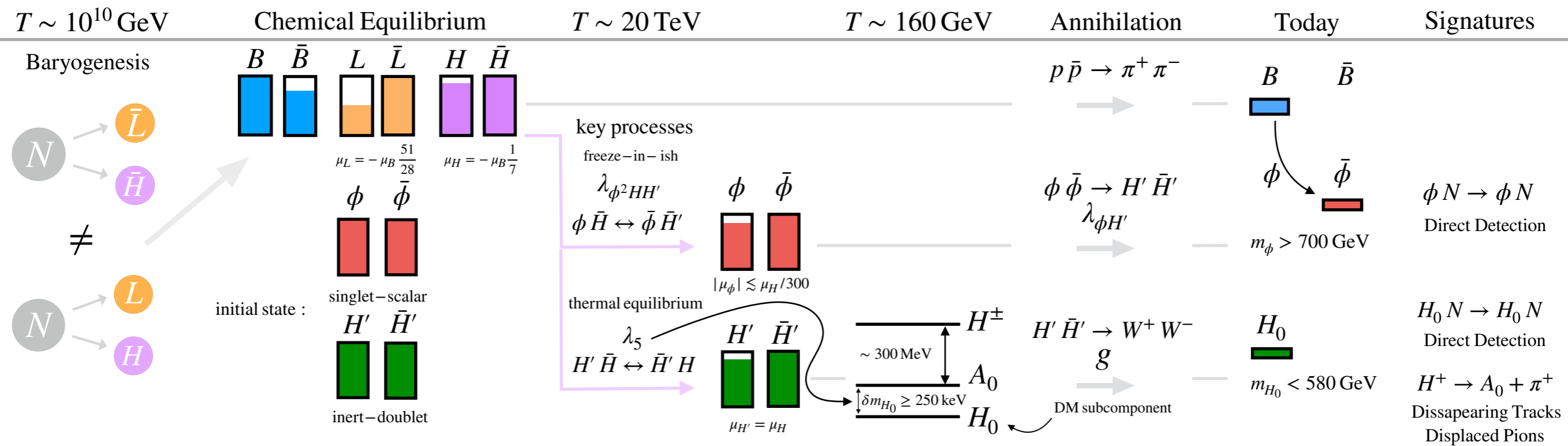
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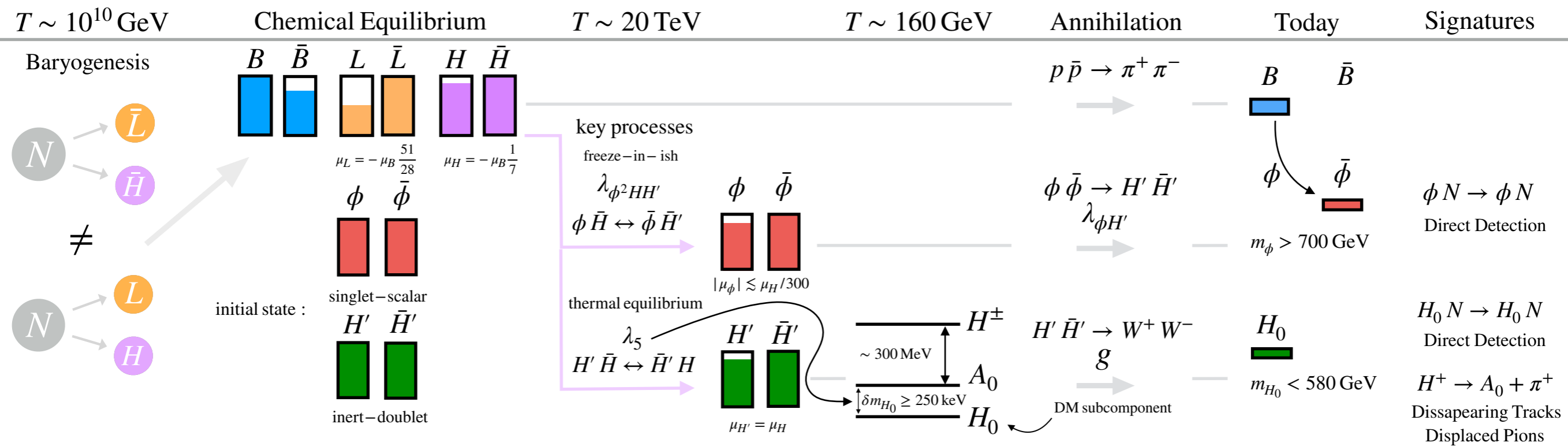
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The rest of the talk:

The elements of the model

ϕ (complex singlet scalar)	+1	Z_4
H' (inert Higgs doublet)	-2	

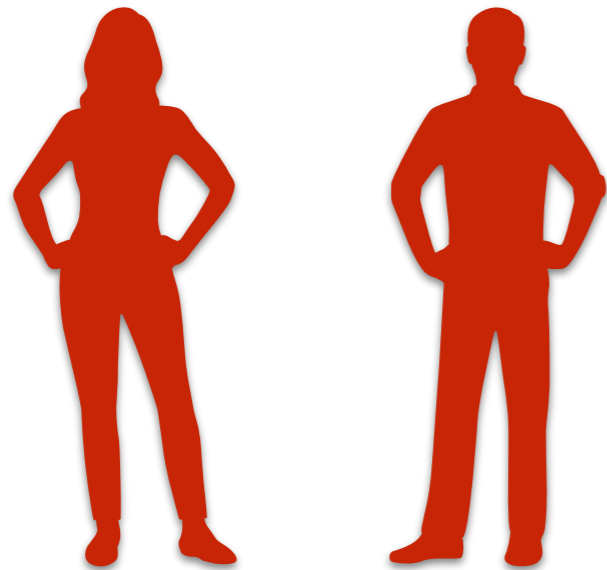
How it avoids issues that are fatal in other scenarios

Early Universe dynamics

Signatures at Collider Experiments and for Direct Detection

Discussion!

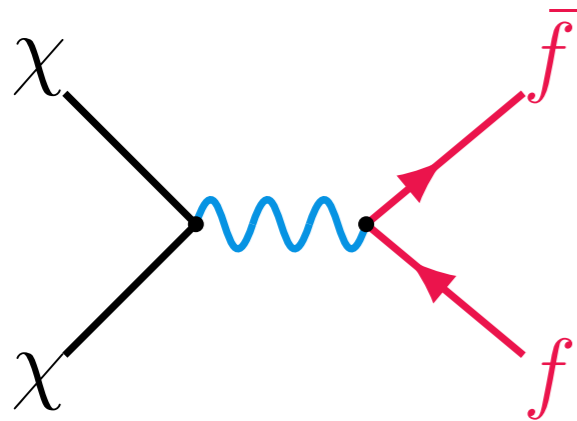
Please, feel free to stop me and ask questions at any point during the talk!
They are most welcome! 😊



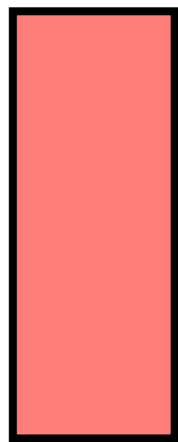
Questions from students, early career researchers, and professors are all very welcome!

Thermal Freeze-out

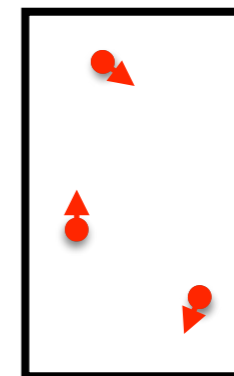
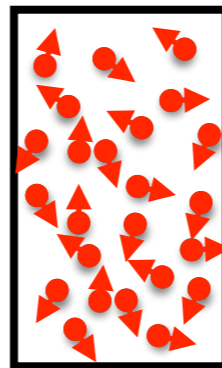
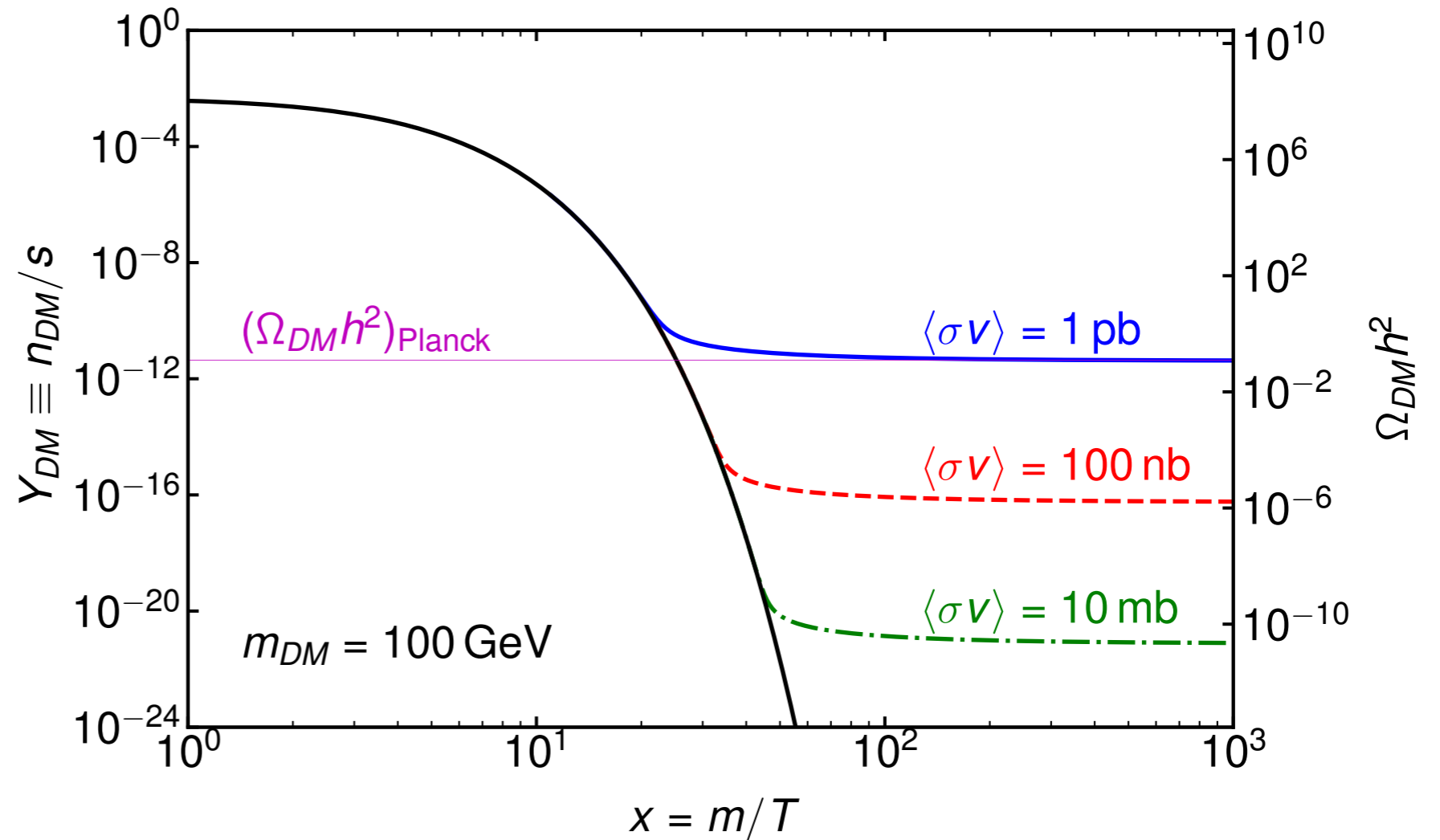
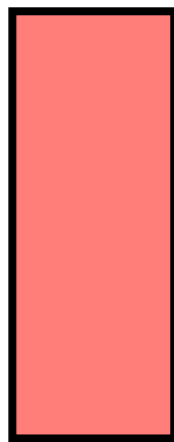
WIMP freeze-out



DM

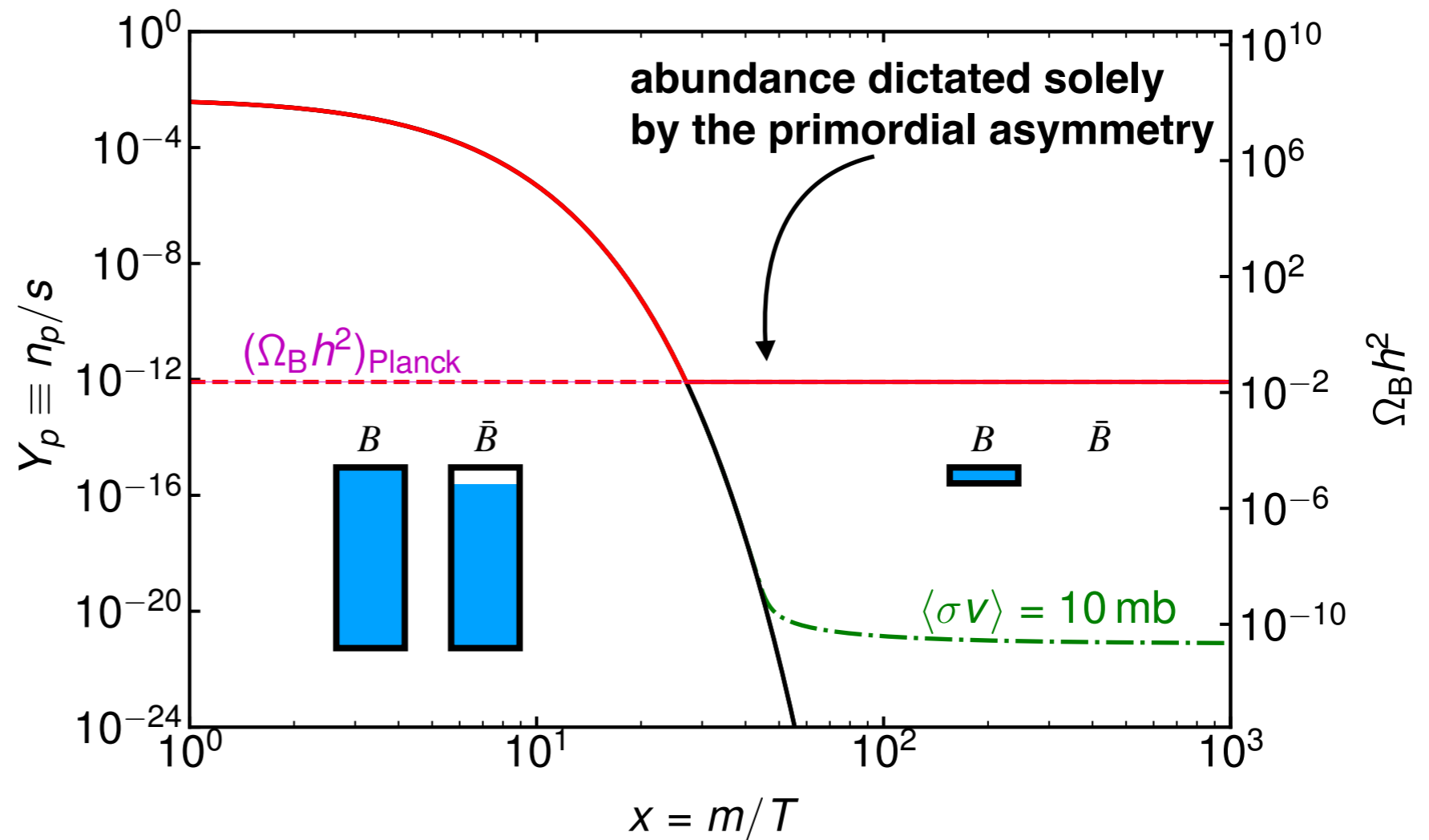
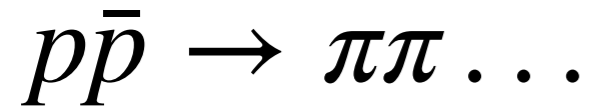


$\overline{\text{DM}}$



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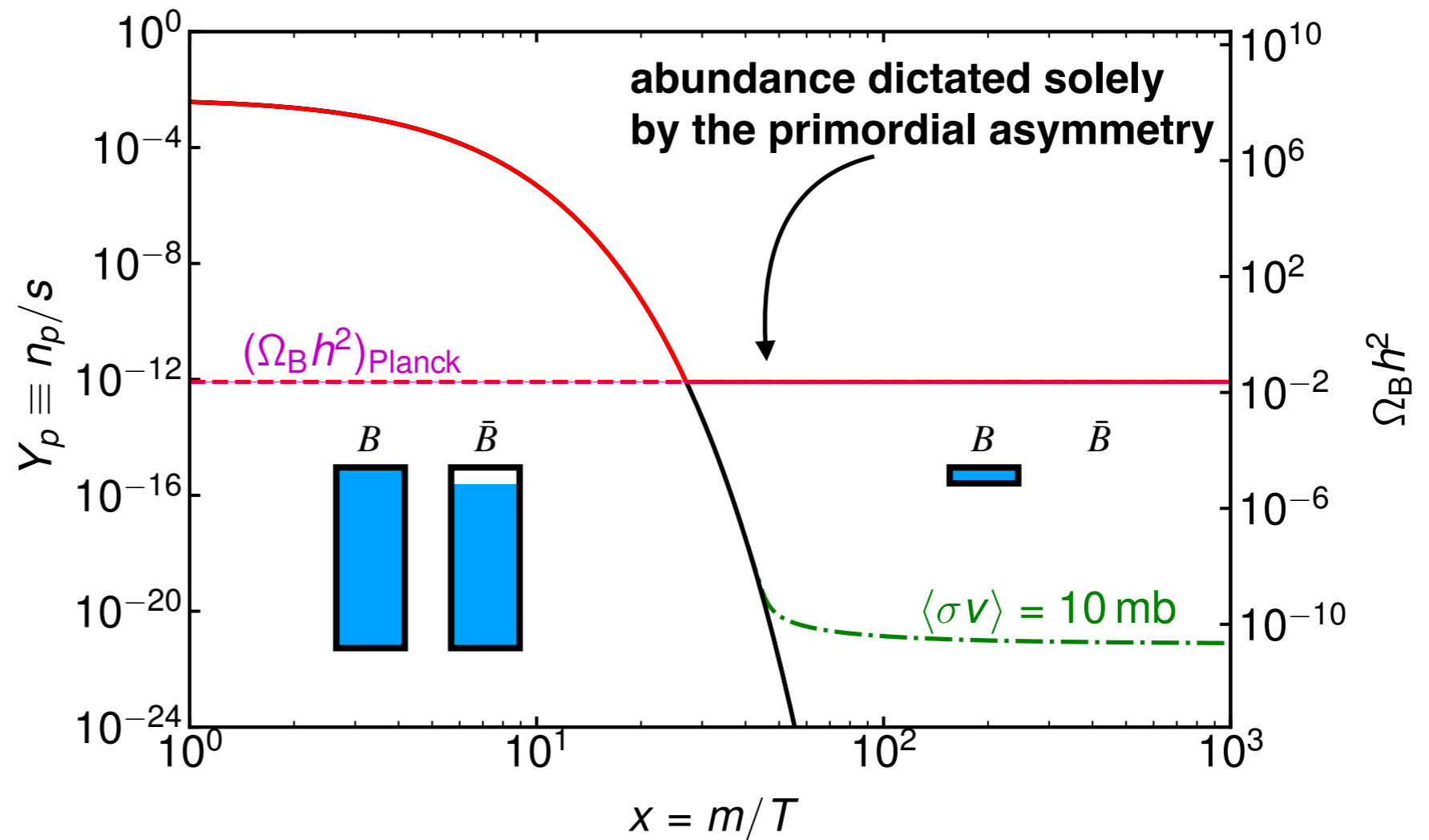
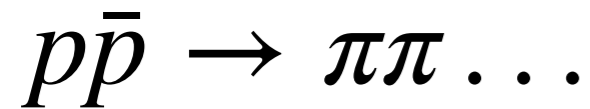
proton-antiproton
freeze-out



- No antiparticles today

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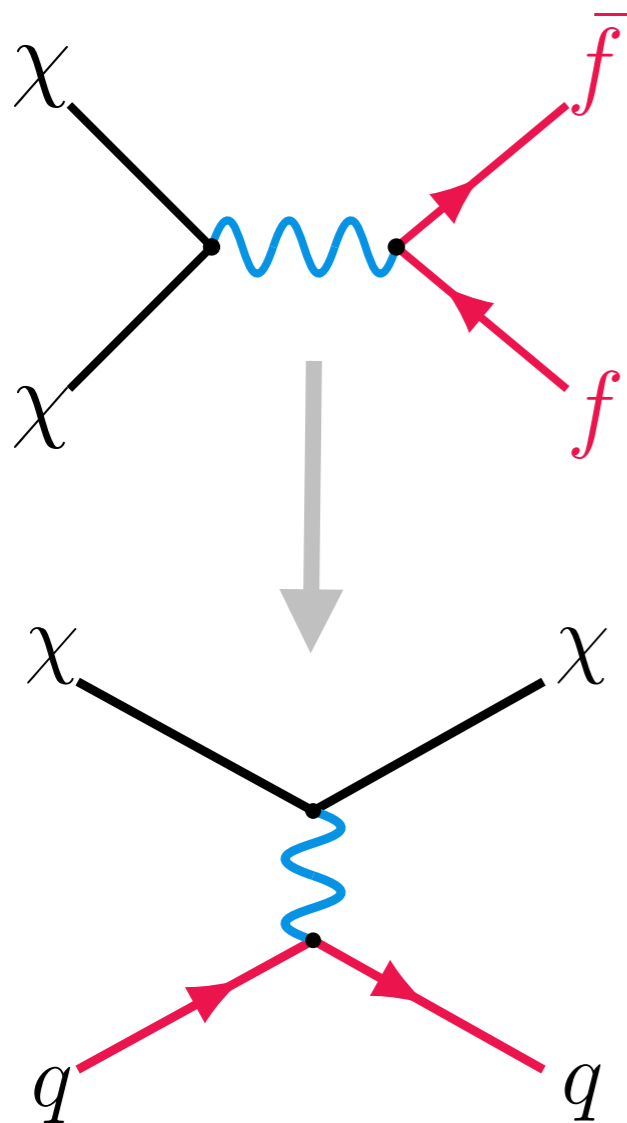
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- Key requirement for asymmetric dark matter:

Annihilation cross section larger than for a WIMP $\langle\sigma v\rangle > \langle\sigma v\rangle^{\text{WIMP}}$

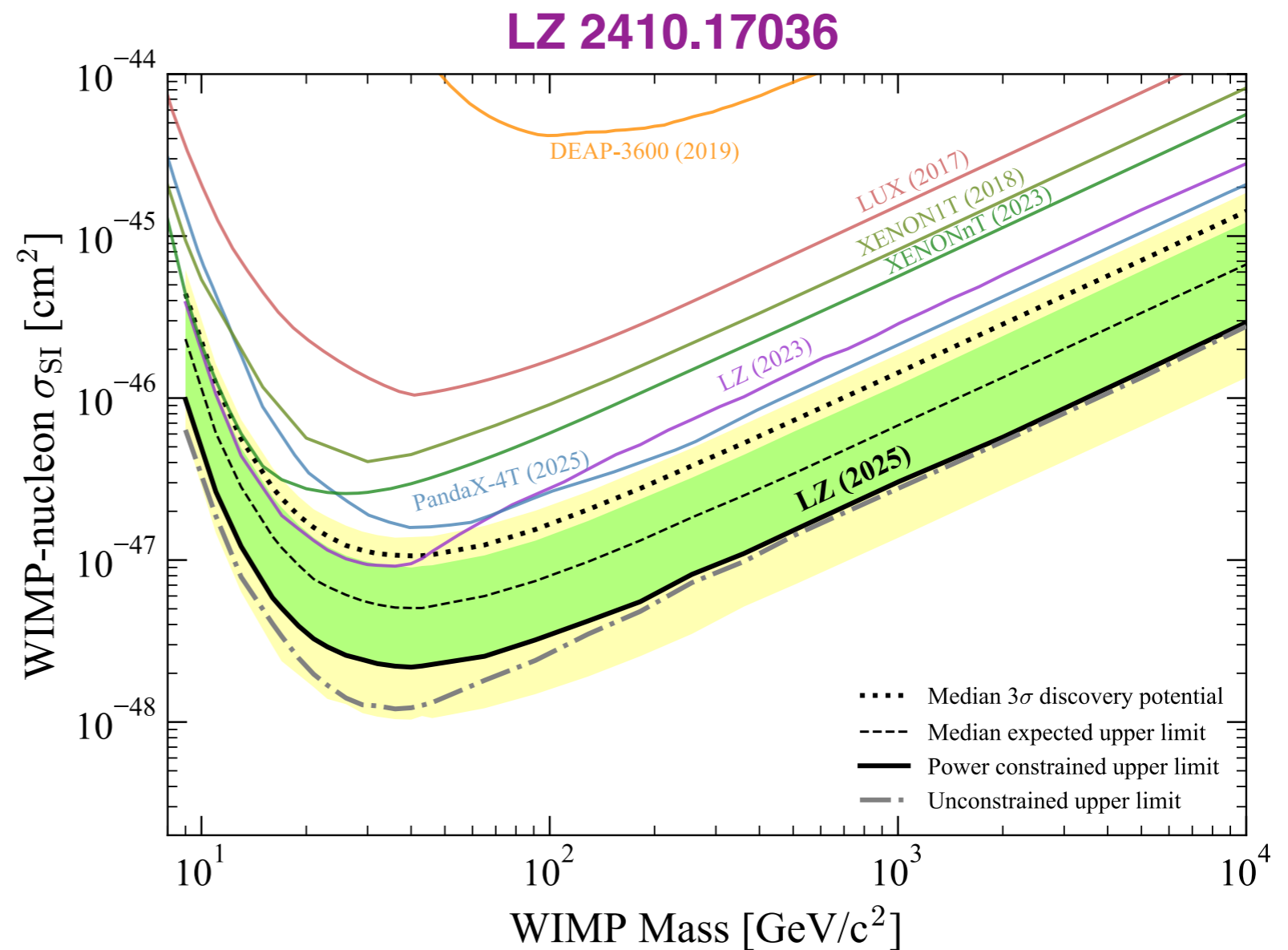
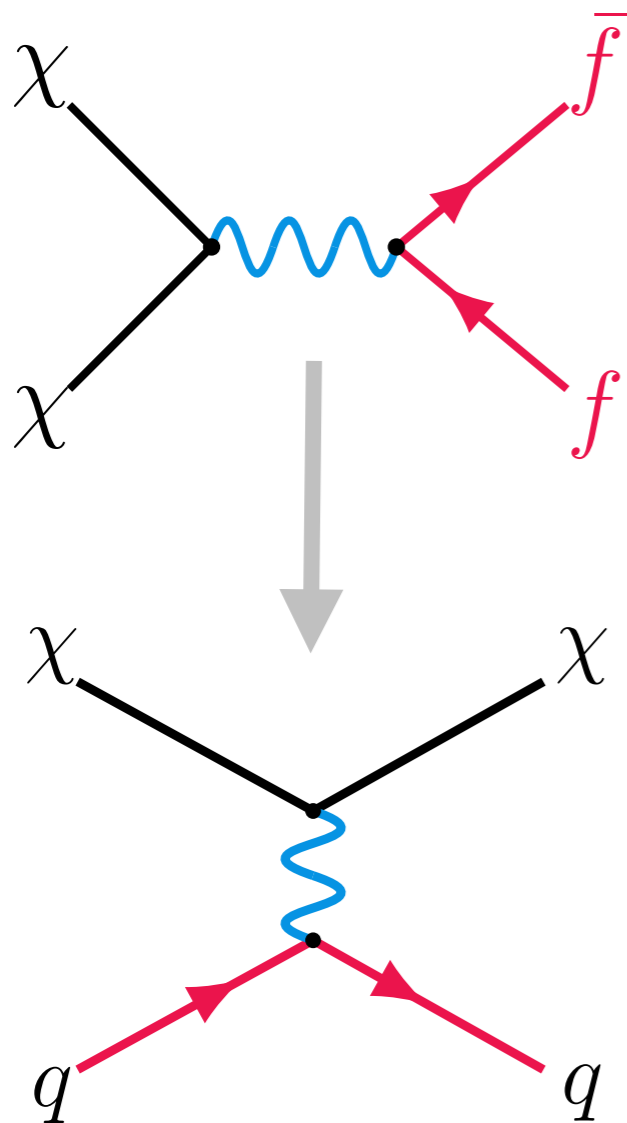
The issue: Direct Detection!

If annihilations into Standard Model species are efficient, then the interaction rates with nuclei should be large, but we have no signal from dark matter direct detection.



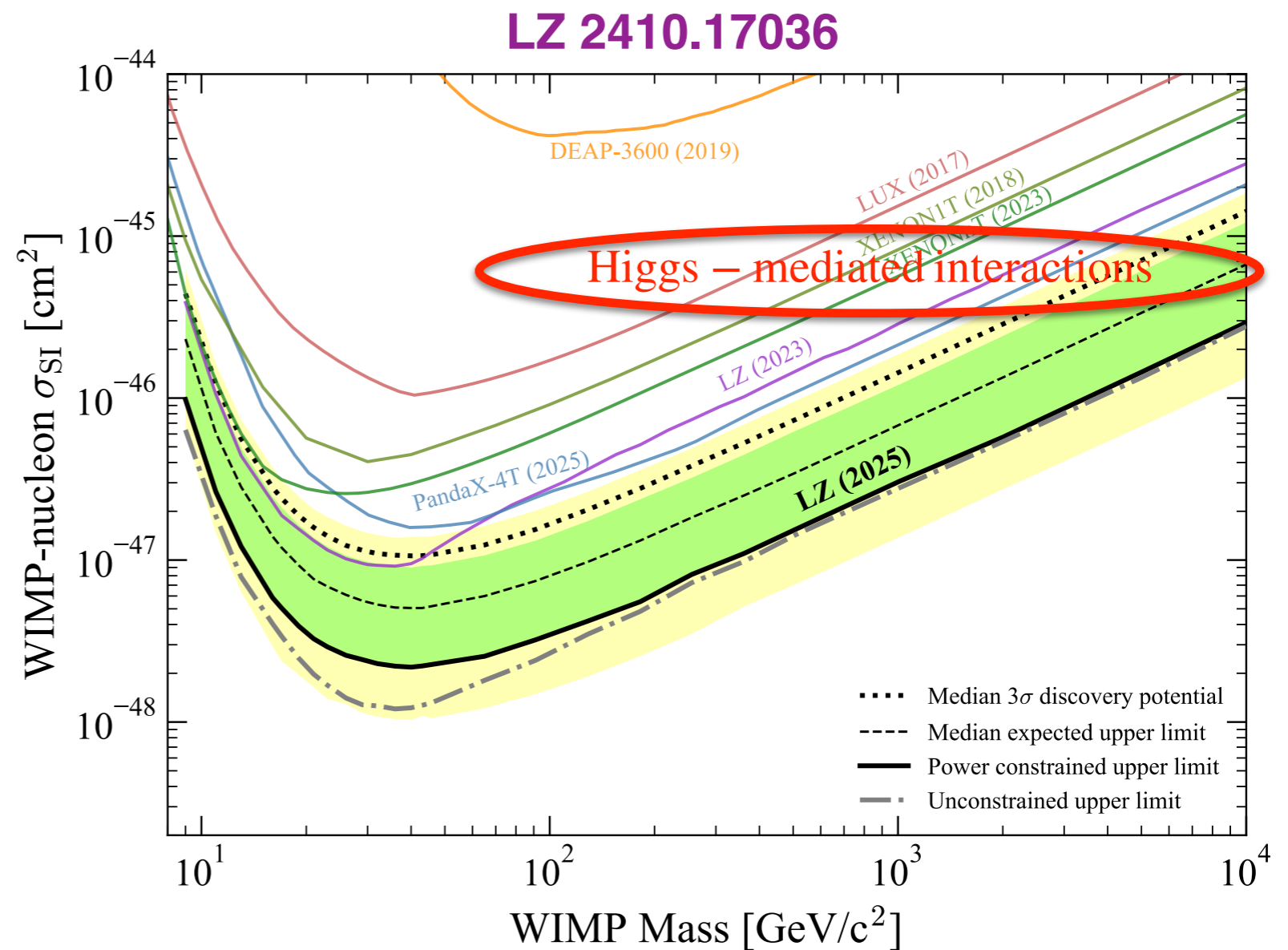
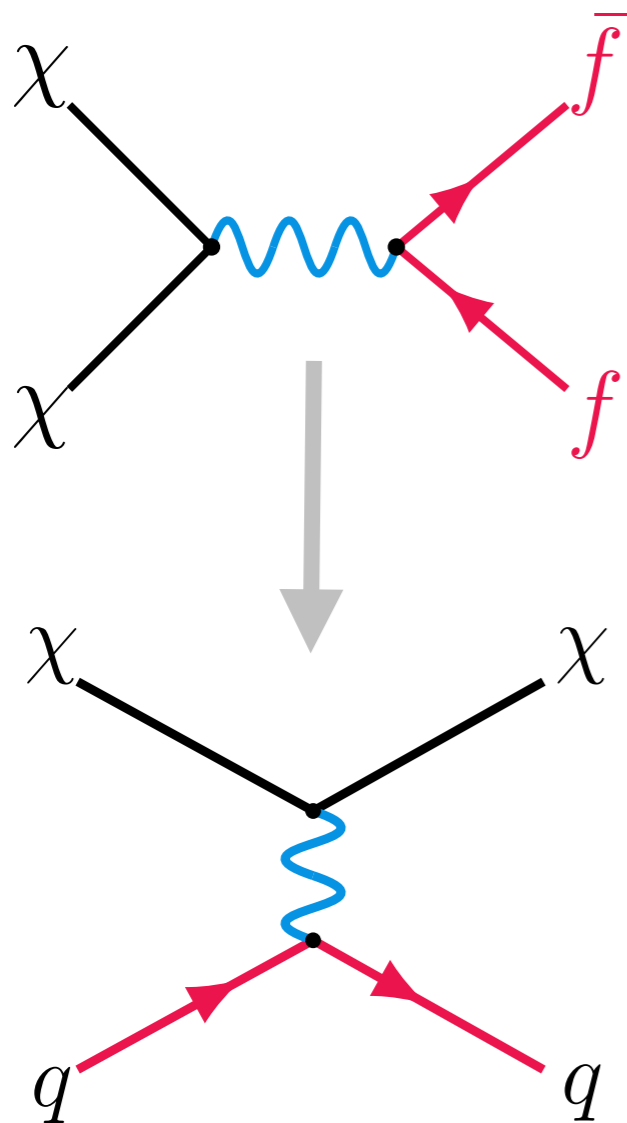
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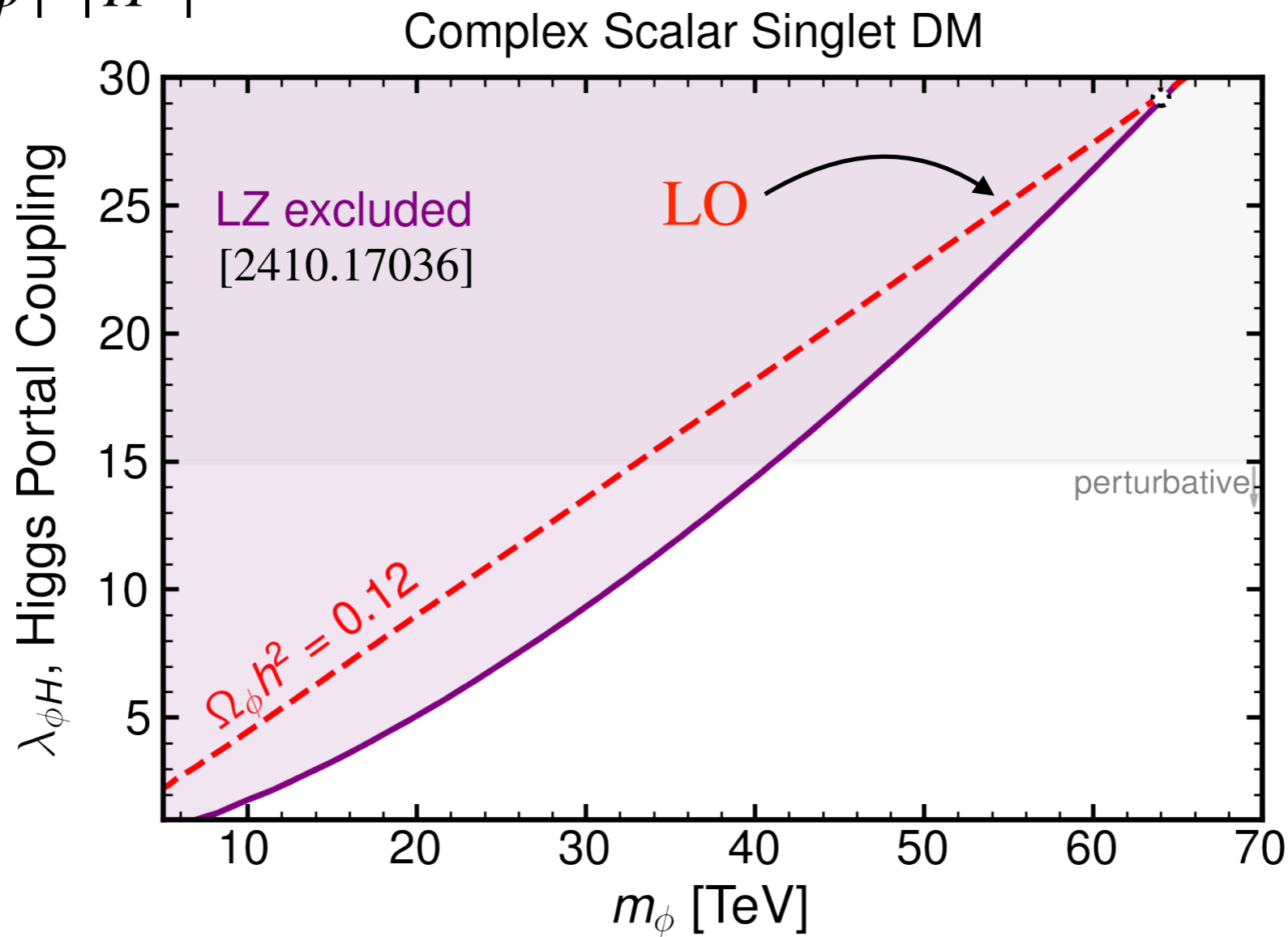
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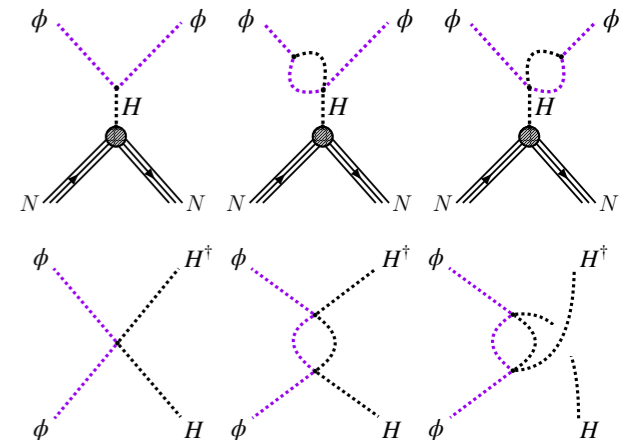
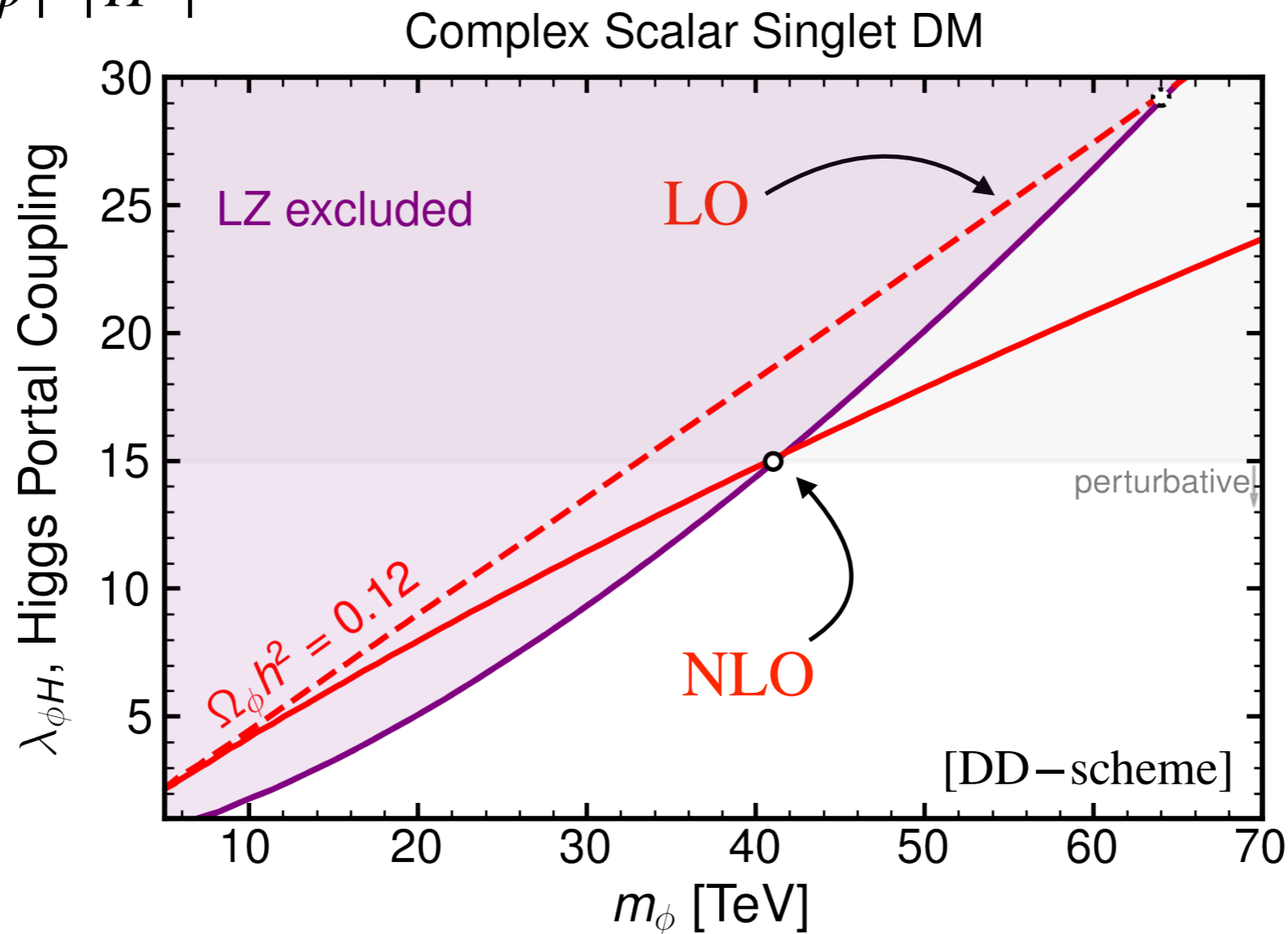
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Escudero & Hambye
[2505.02408]

We showed that the recent LZ limit (2025) is so strong that it rules out a singlet complex scalar dark matter in the perturbative regime

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One needs to connect the Standard Model asymmetries to the dark matter

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**Renormalizable
operators:**

$$L : LH'N, L\phi\psi_d, LH'\Sigma,$$
$$l : l\phi N, lH'\psi_d,$$
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Cohen & Zurek
[0909.2035]

$$\frac{1}{\Lambda^4} X^2 (LH)^2$$

Servant & Tullin
[1304.3464]

$$\frac{1}{\Lambda} X^2 (H)^2$$

Boucenna, Krauss & Nardi [1503.01119]

$$\frac{1}{\Lambda^m} X^2 (H)^n$$

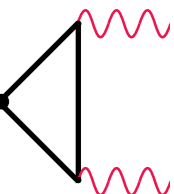
Ibe, Matsumoto & Yanagida [1110.5452]

$$\frac{1}{\Lambda^3} \phi^2 (LH)^2$$

Dhen & Hambye [1503.03444]:

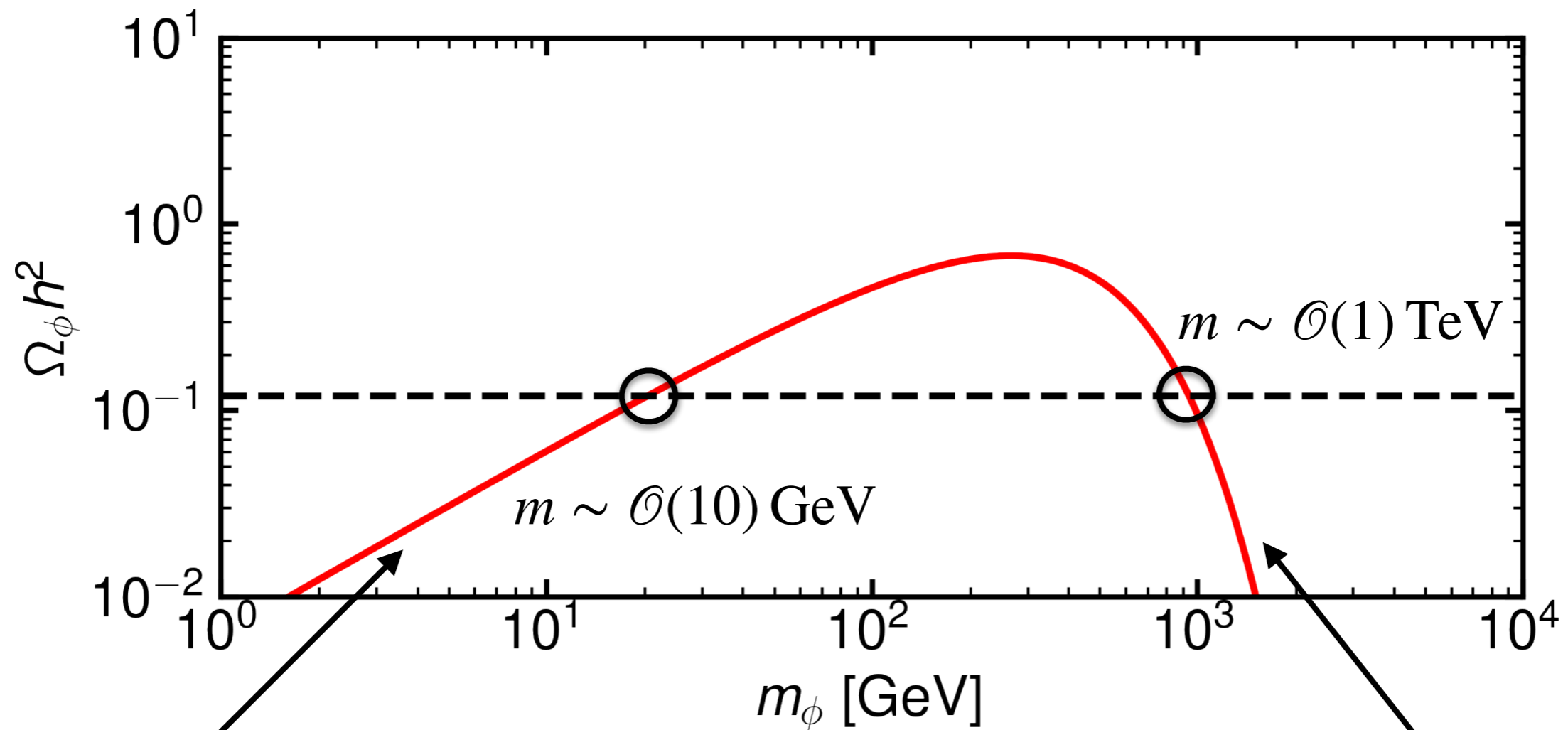
$$\lambda_5 (HH')^2$$

e.g. Blennow, Fernández-Martínez, García-García, Lizana 2605.20336



Typical Dark Matter Abundance

Take a dark matter particle that couples in a non-self conjugated way to the Higgs and remains in thermal equilibrium with it until T_{EW}

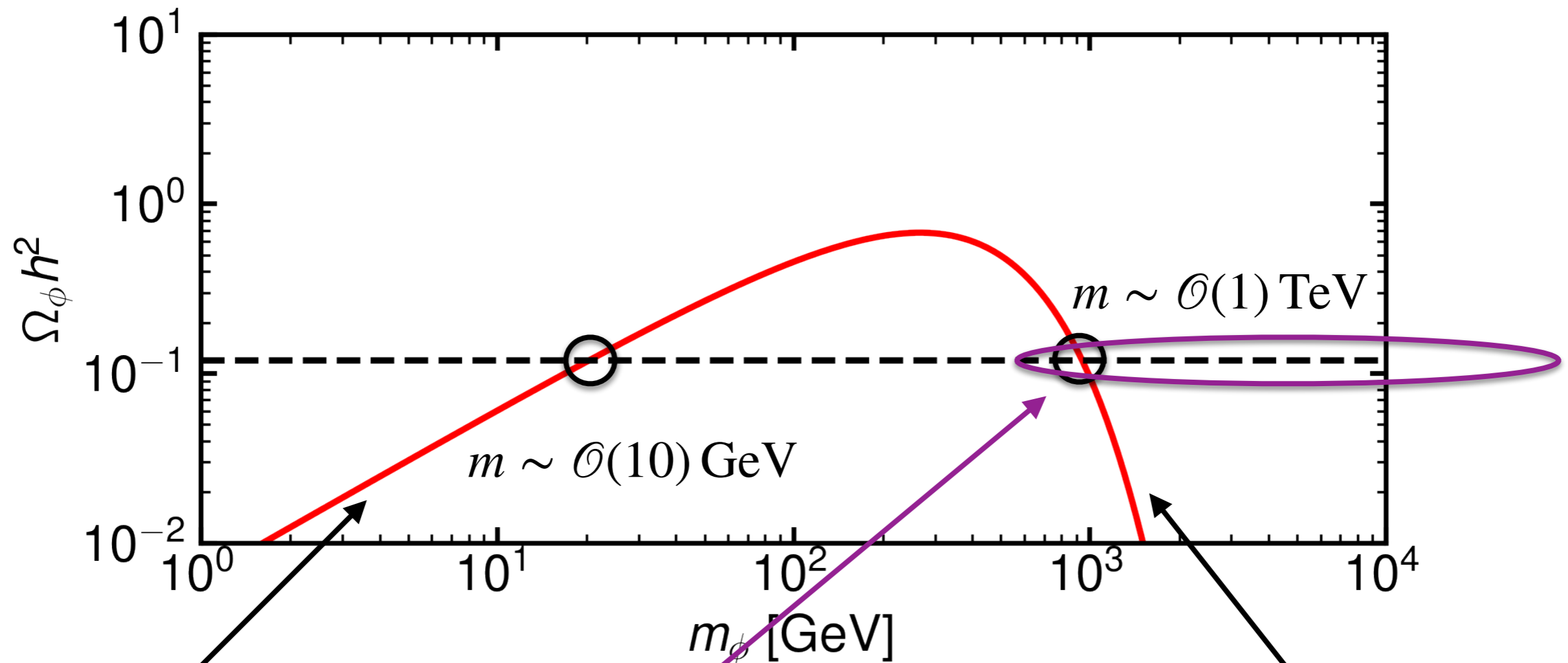


Linear scaling with mass

Exponential
Boltzmann
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Linear scaling with mass

Our model works in a sort of freeze-in fashion and the parameter space of interest is $m_\phi > 700$ GeV

Exponential Boltzmann suppression

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Our Model

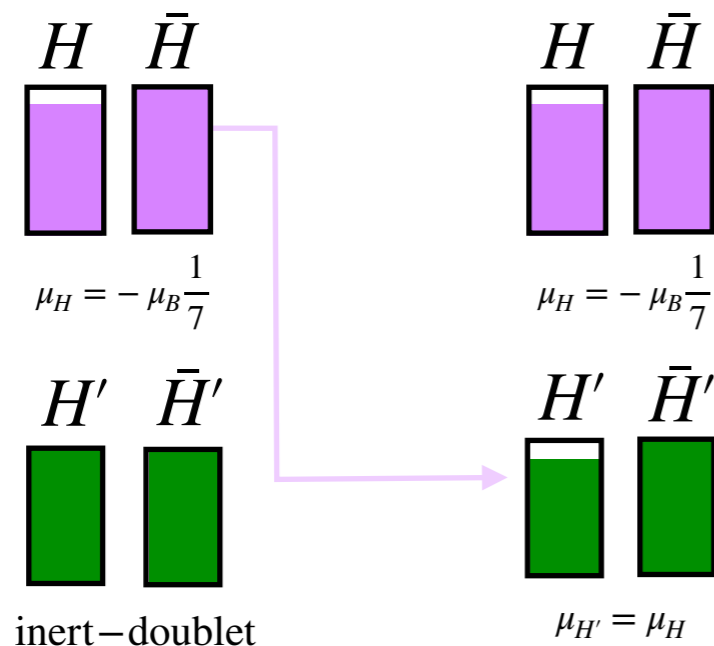
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$$V = \lambda_5 (H^\dagger H')^2 + \text{h.c.}$$

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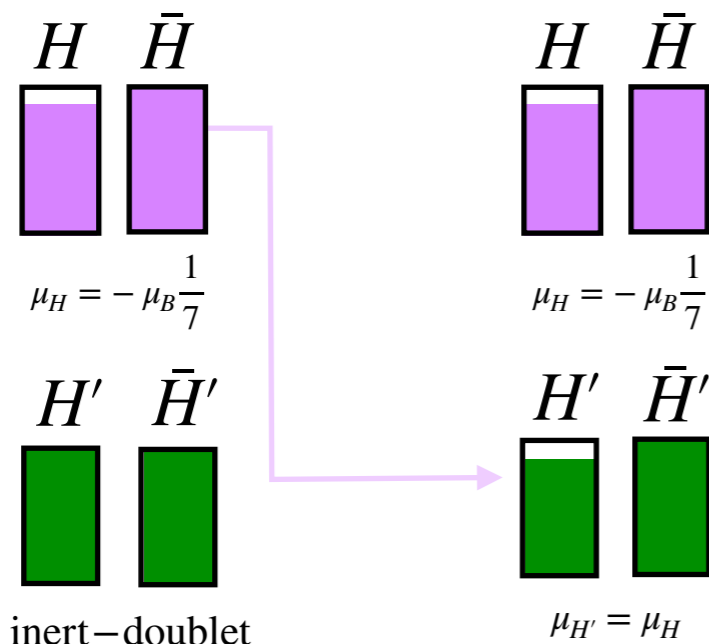
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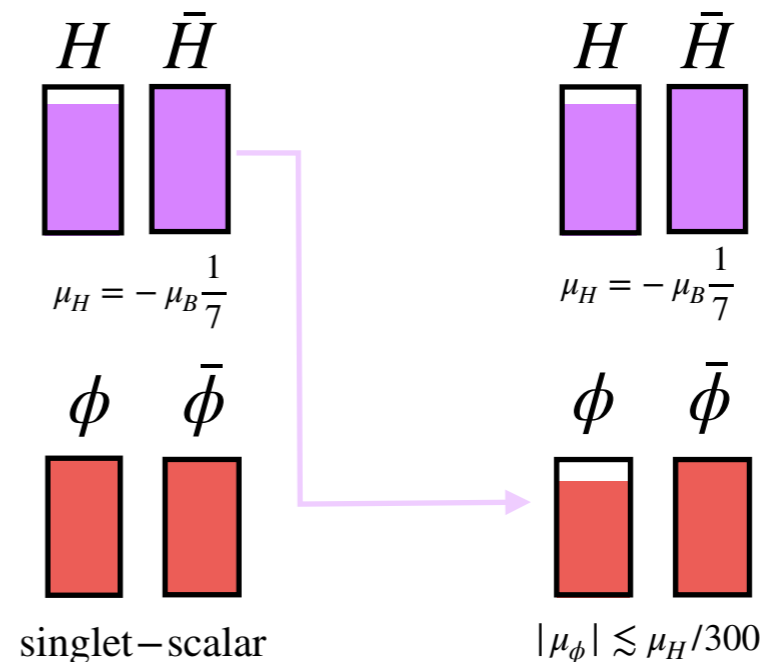
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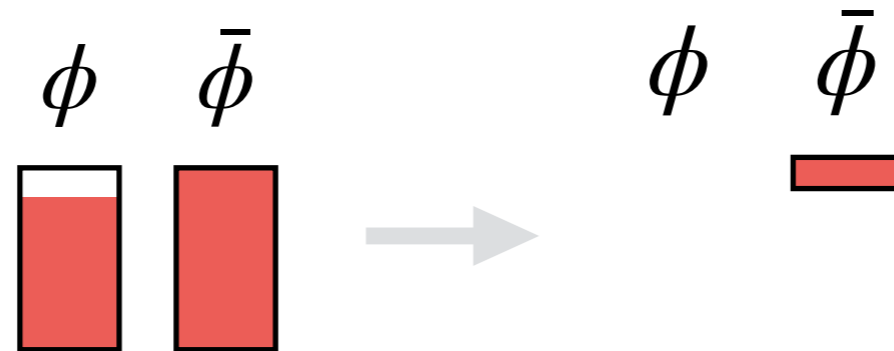
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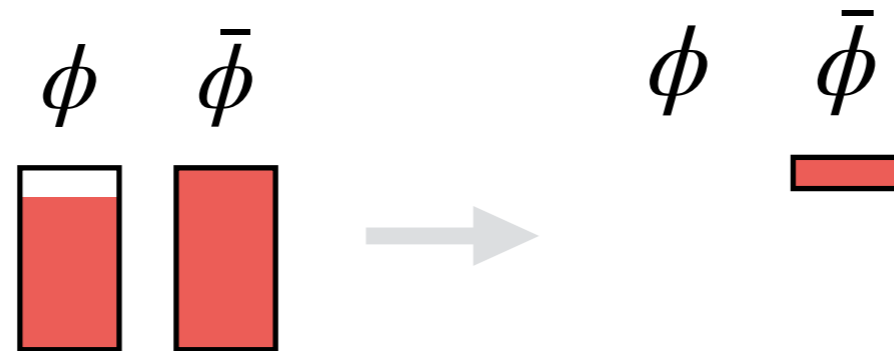
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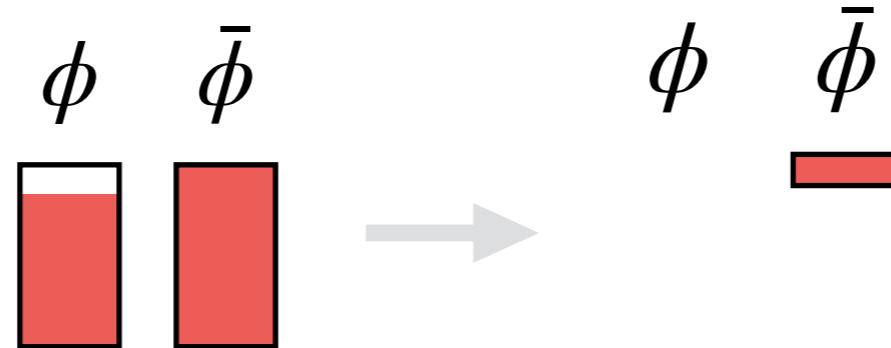


H_0 or A_0 end up being a subcomponent of Dark Matter: $\Omega_{H_0} h^2 \simeq 0.12 \left(\frac{m_{H'}}{580 \text{ GeV}} \right)^2$

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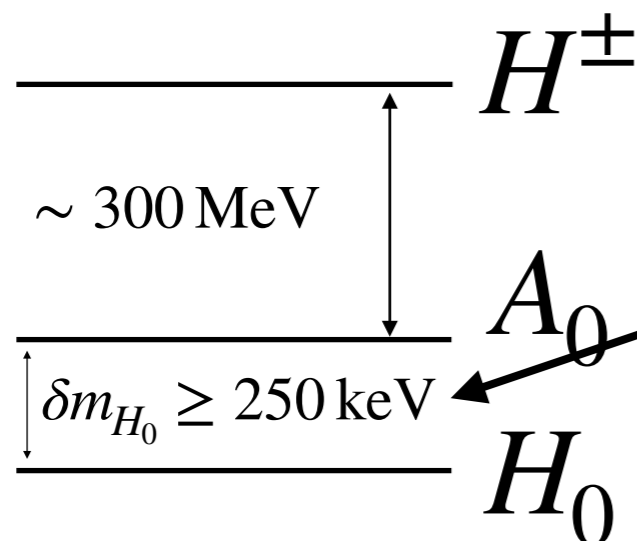
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4) We have a Higgs doublet as DM fraction and it talks with the Z boson:



$$V = \lambda_5 / 2 (H^\dagger H')^2 + \text{h.c.}$$

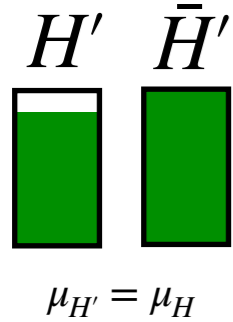
the same λ_5 interaction provides the mass splitting which avoids being ruled out by direct detection

Relevant processes in the EU

Relevant processes:

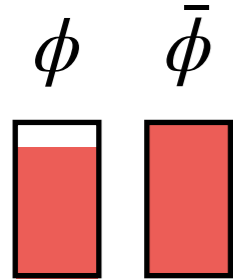
$$\begin{aligned}
 H'H' \leftrightarrow HH, \quad \bar{H}'\bar{H}' \leftrightarrow \bar{H}\bar{H}, \quad H'\bar{H} \leftrightarrow \bar{H}'H, \quad \bar{H}'H \leftrightarrow H'\bar{H} \quad (\text{induced by } \lambda_5) \\
 \phi\phi \leftrightarrow H\bar{H}', \quad \bar{\phi}\bar{\phi} \leftrightarrow \bar{H}H', \quad \phi\bar{H} \leftrightarrow \bar{\phi}\bar{H}', \quad \bar{\phi}H \leftrightarrow \phi H' \quad (\text{induced by } \lambda_{\phi^2 HH'})
 \end{aligned}$$

Boltzmann equations:



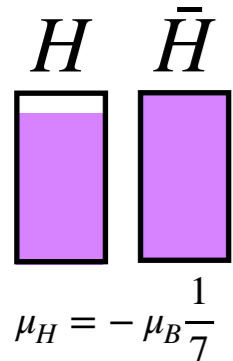
$\mu_{H'} = \mu_H$

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



$\mu_H = -\mu_B \frac{1}{7}$

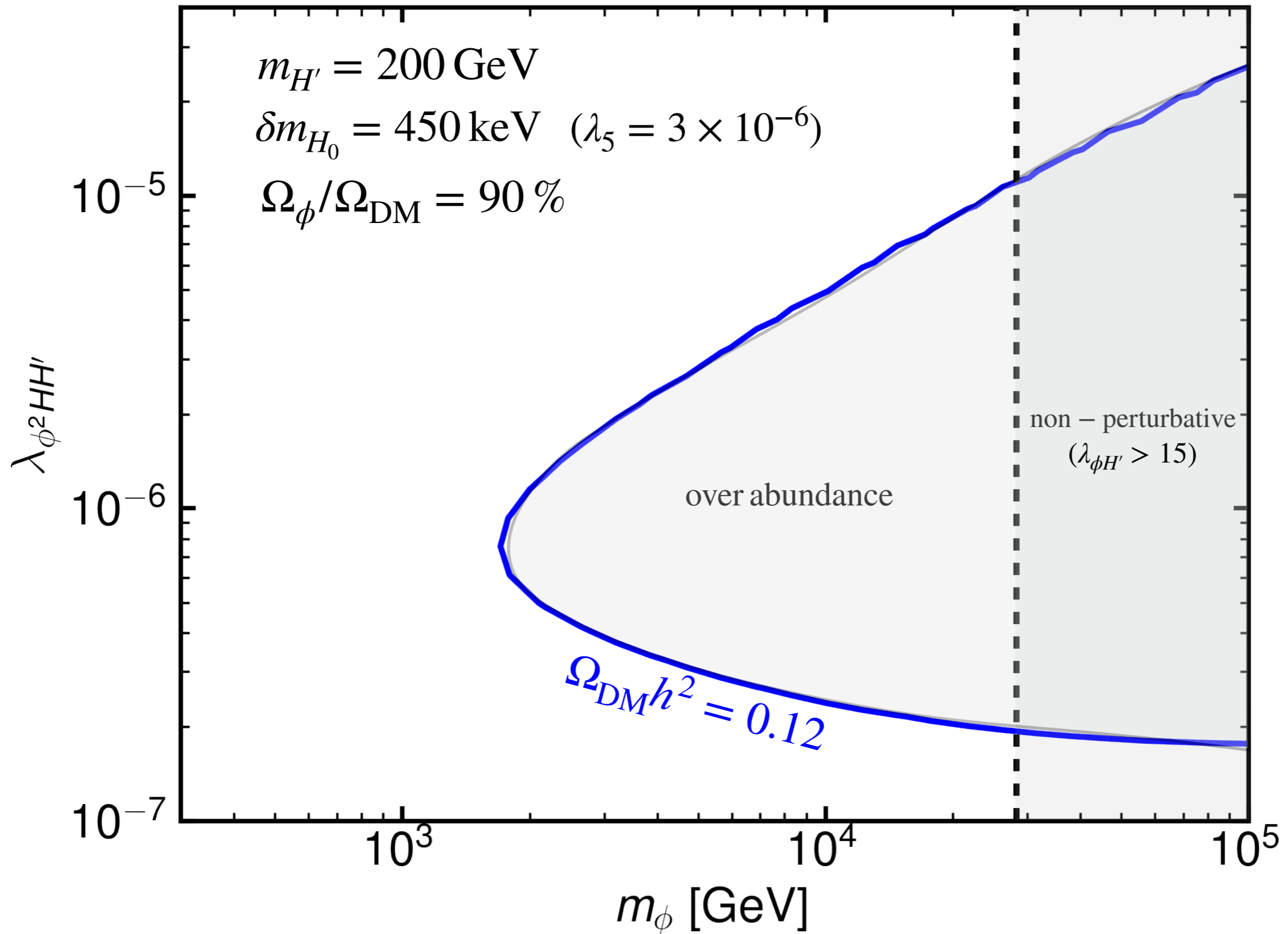
$$\frac{d\Delta_{\phi}}{dx} = -\frac{s}{Hx} \left\{ + (2 \langle \sigma v(\phi\bar{H} \rightarrow \bar{\phi}\bar{H}') \rangle Y_H^{\text{eq}} + \langle \sigma v(\phi\phi \rightarrow H\bar{H}') \rangle Y_{\phi}^{\text{eq}}) \left[2\Delta\phi + \frac{Y_{\phi}^{\text{eq}}}{Y_{H'}^{\text{eq}}} \Delta_{H'}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



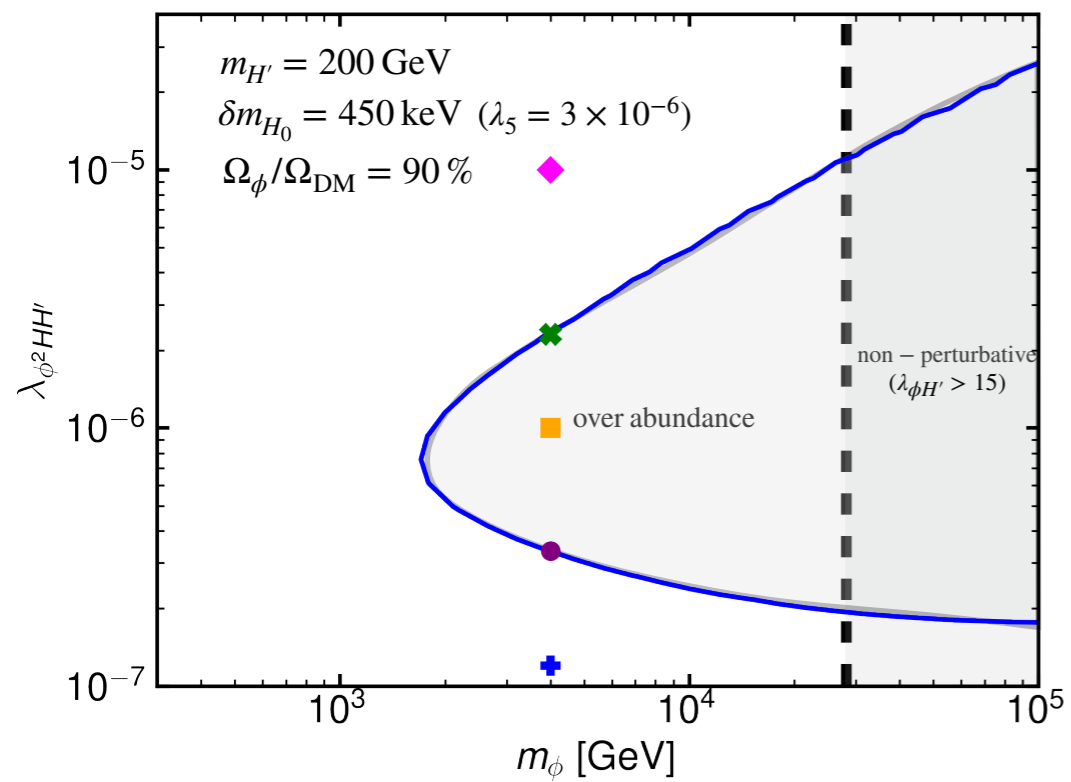
$\mu_H = -\mu_B \frac{1}{7}$

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

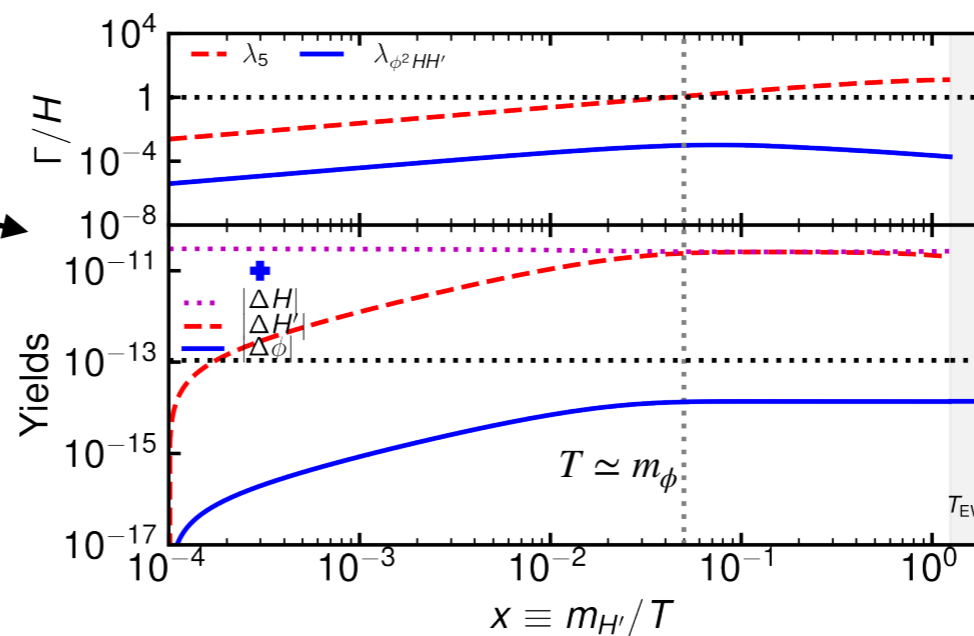
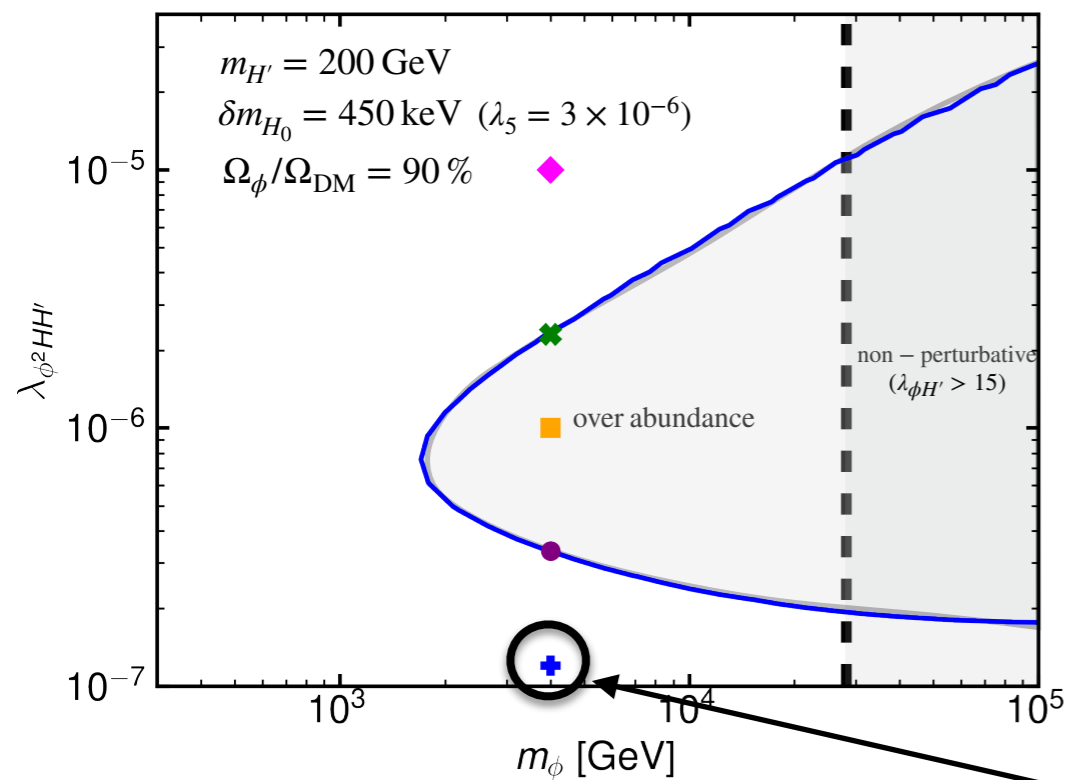
Parameter Space



Some examples

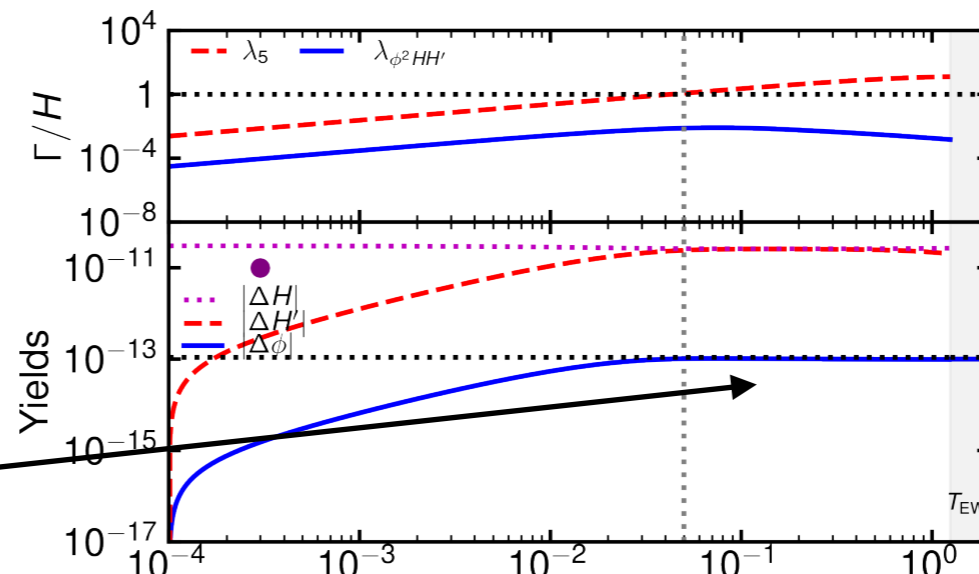
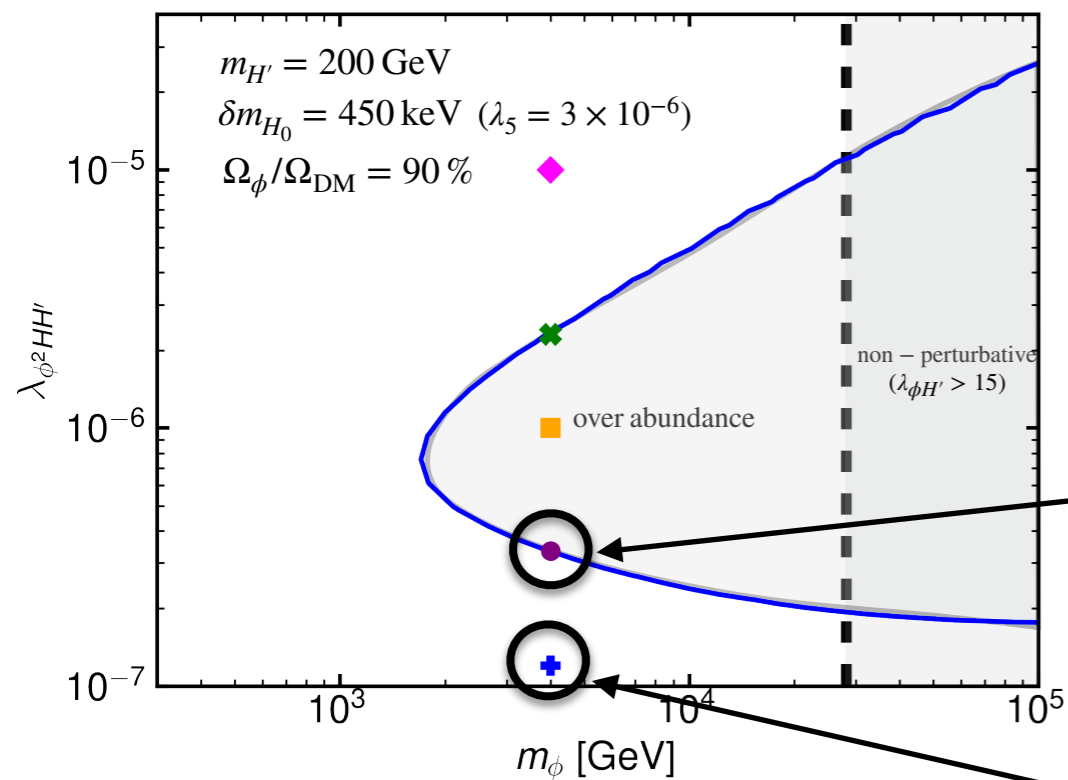


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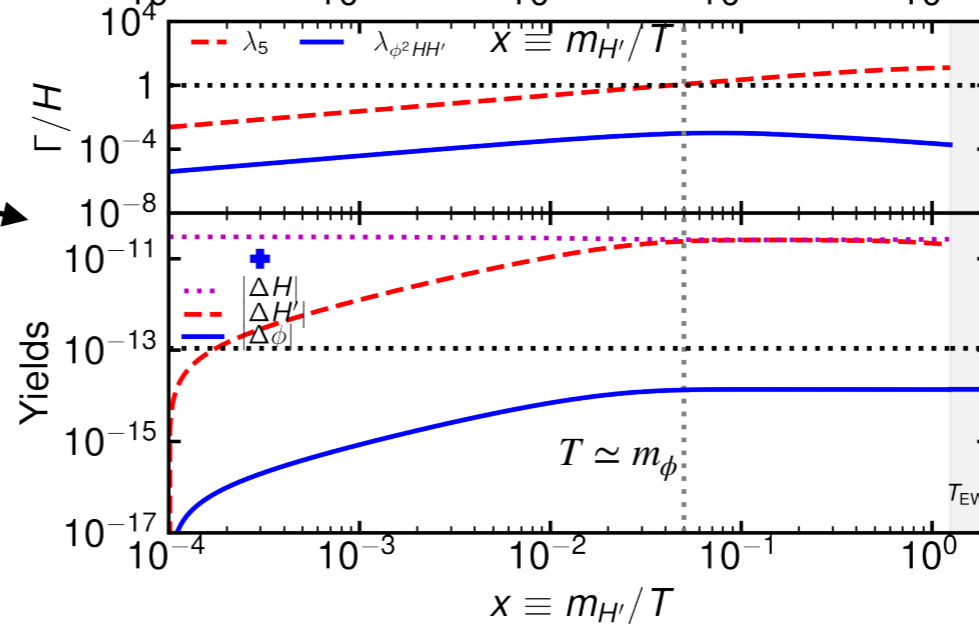


freeze-in (too little)

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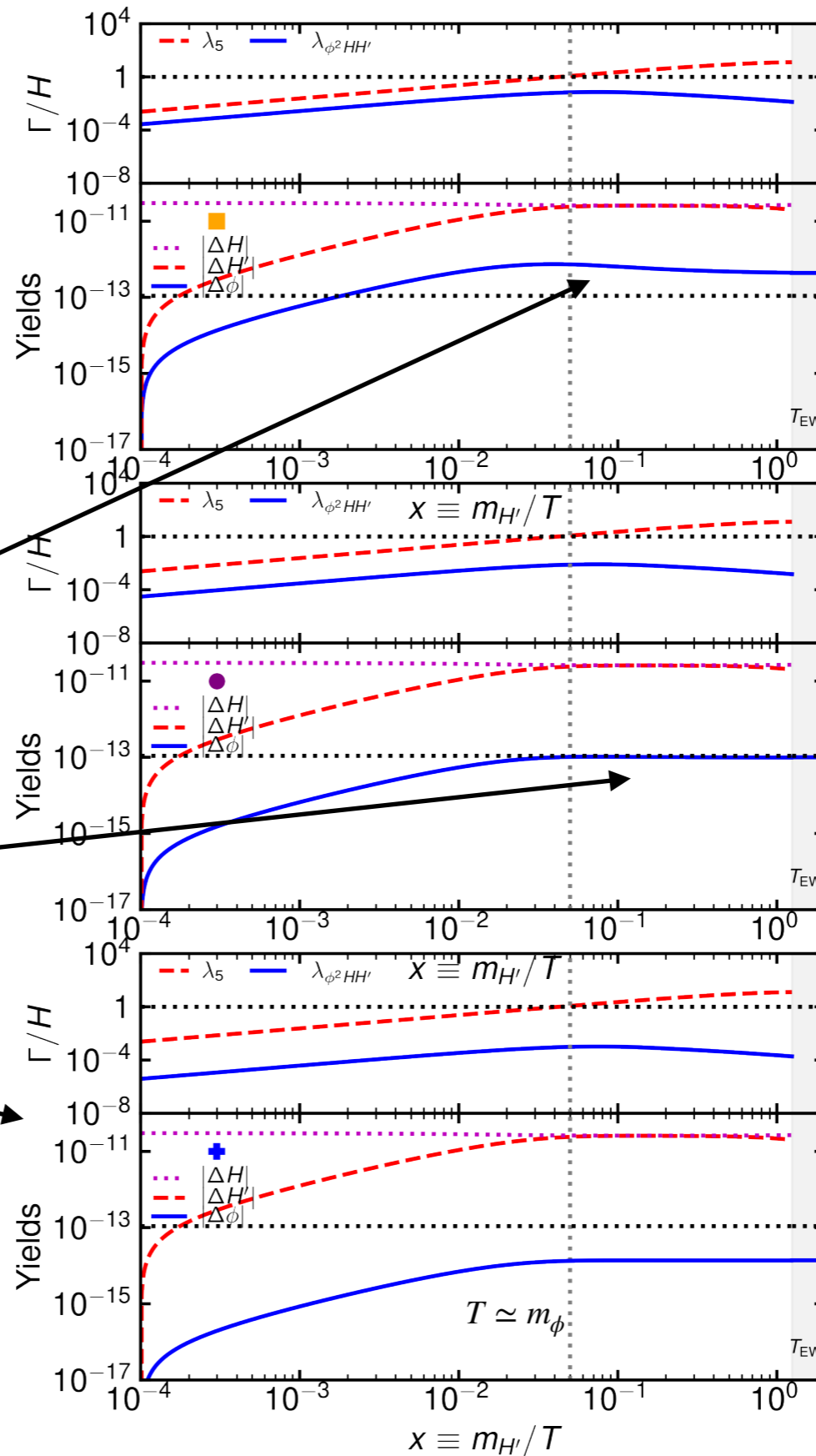
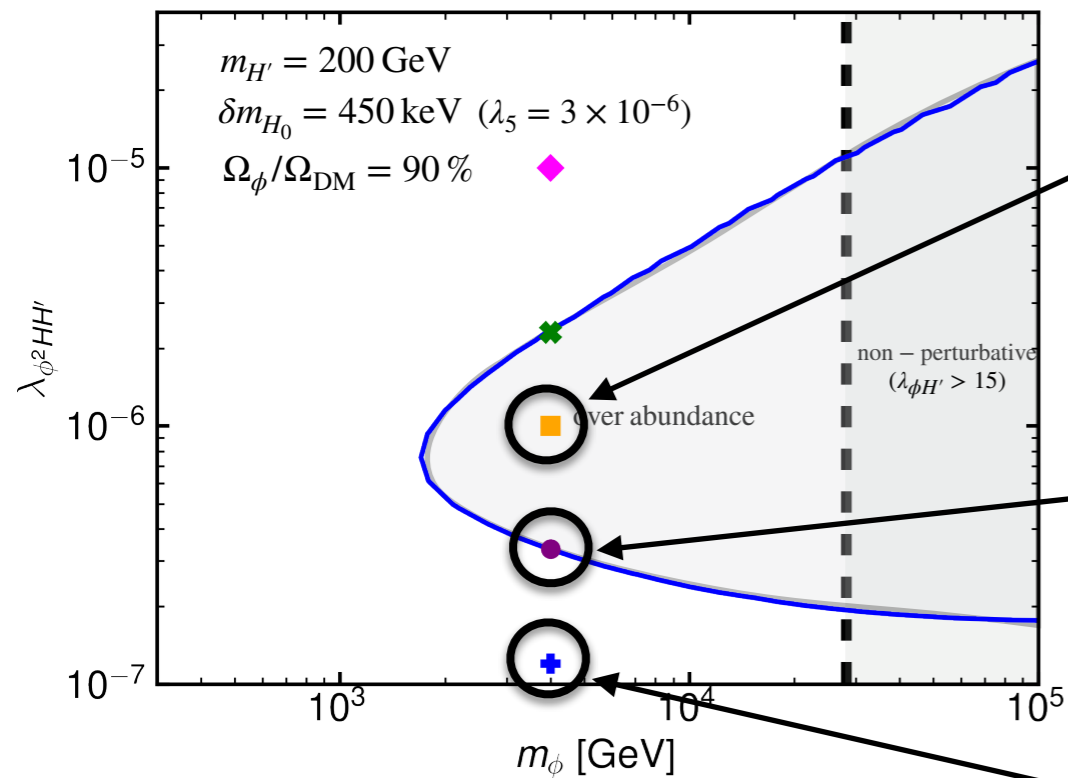


freeze-in + a bit of damping from H' thermalization



freeze-in (too little)

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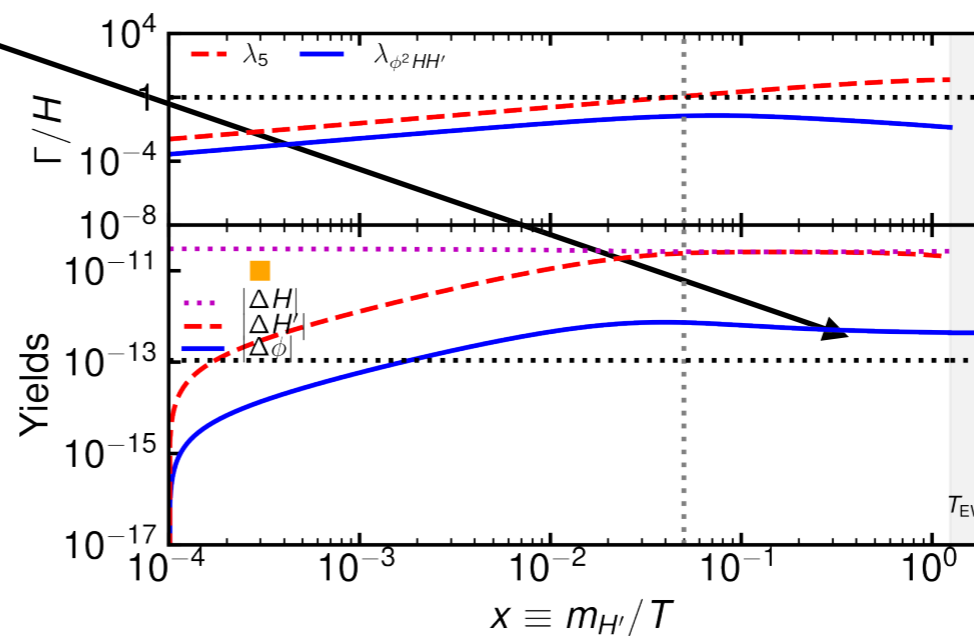
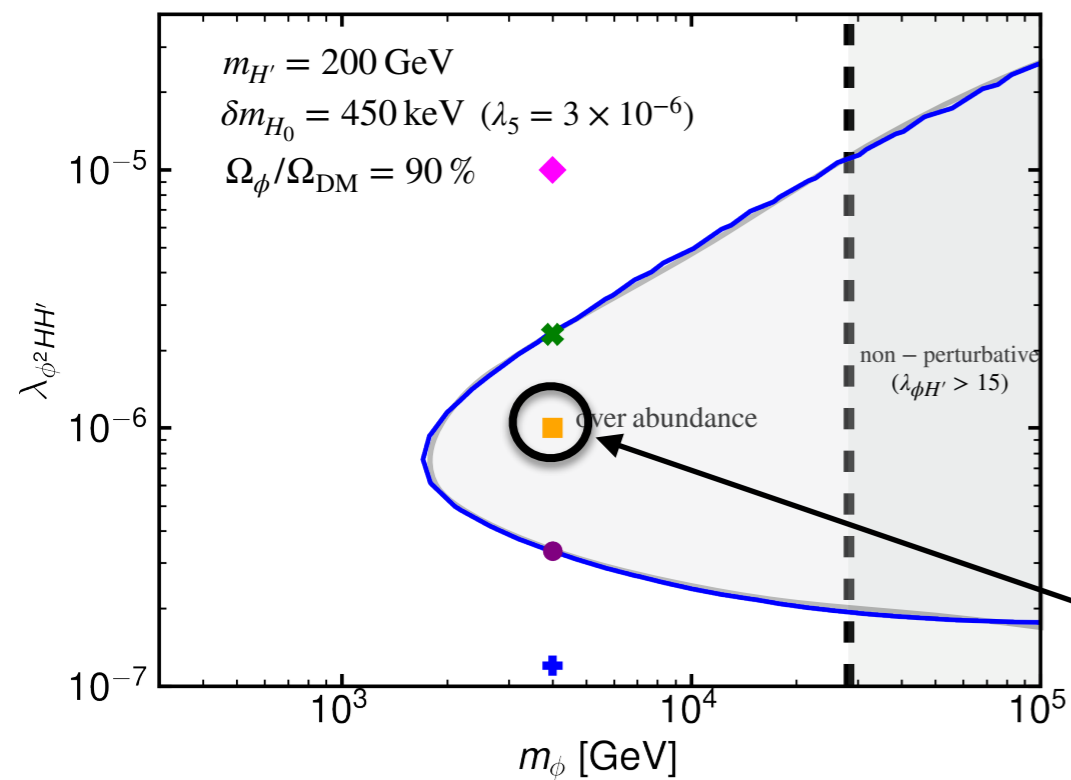


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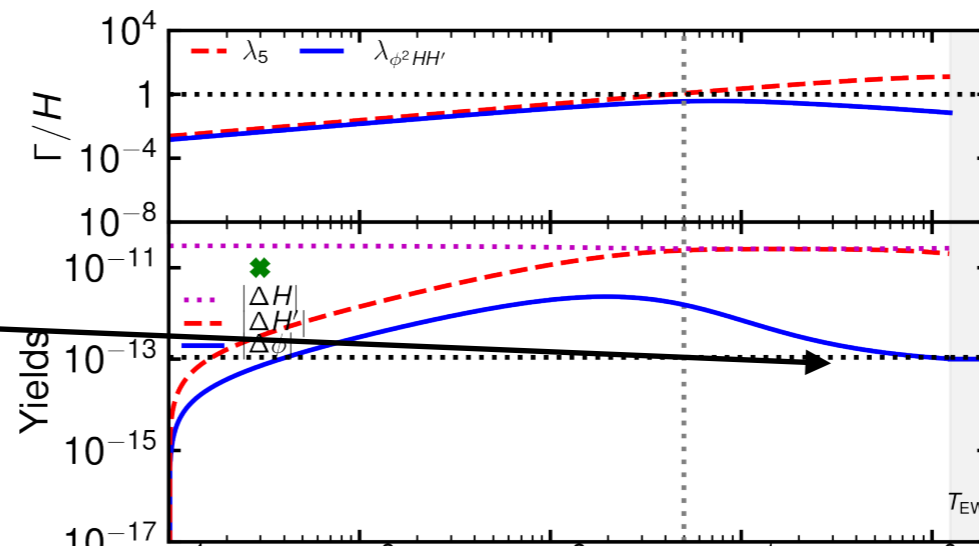
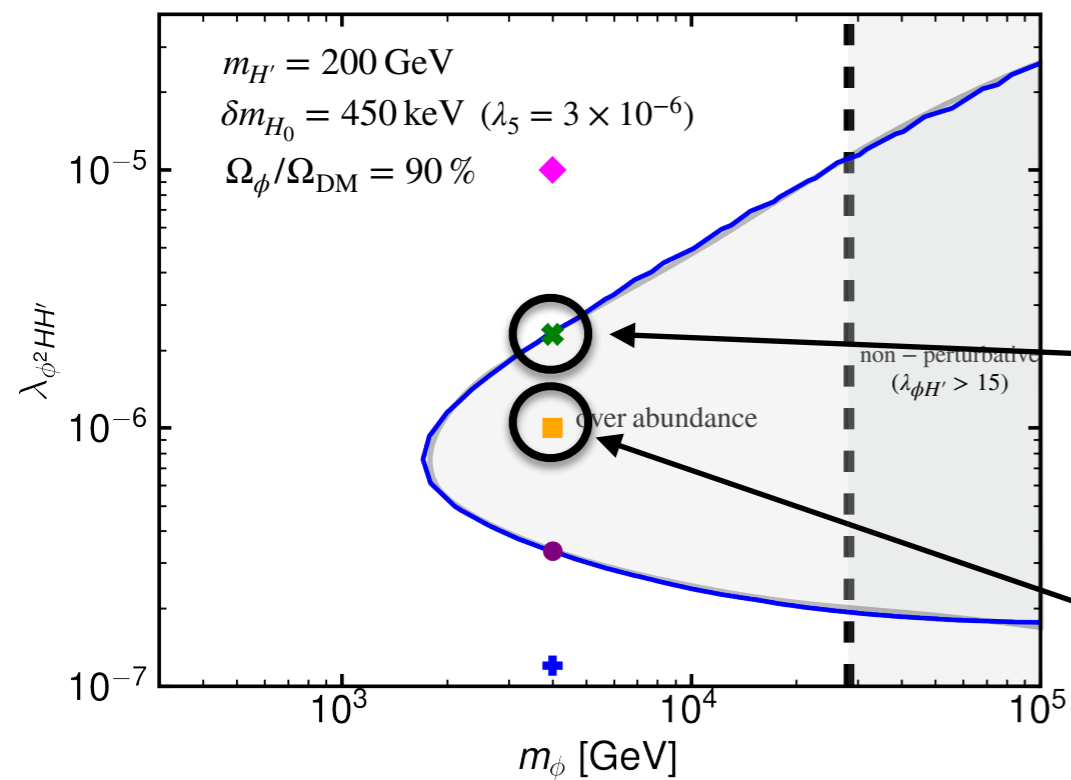
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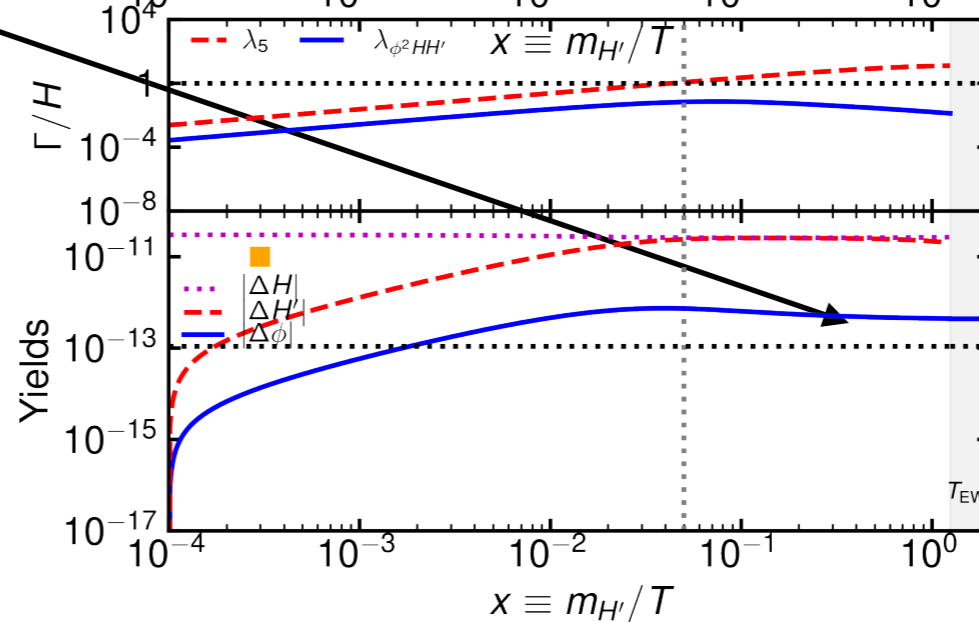


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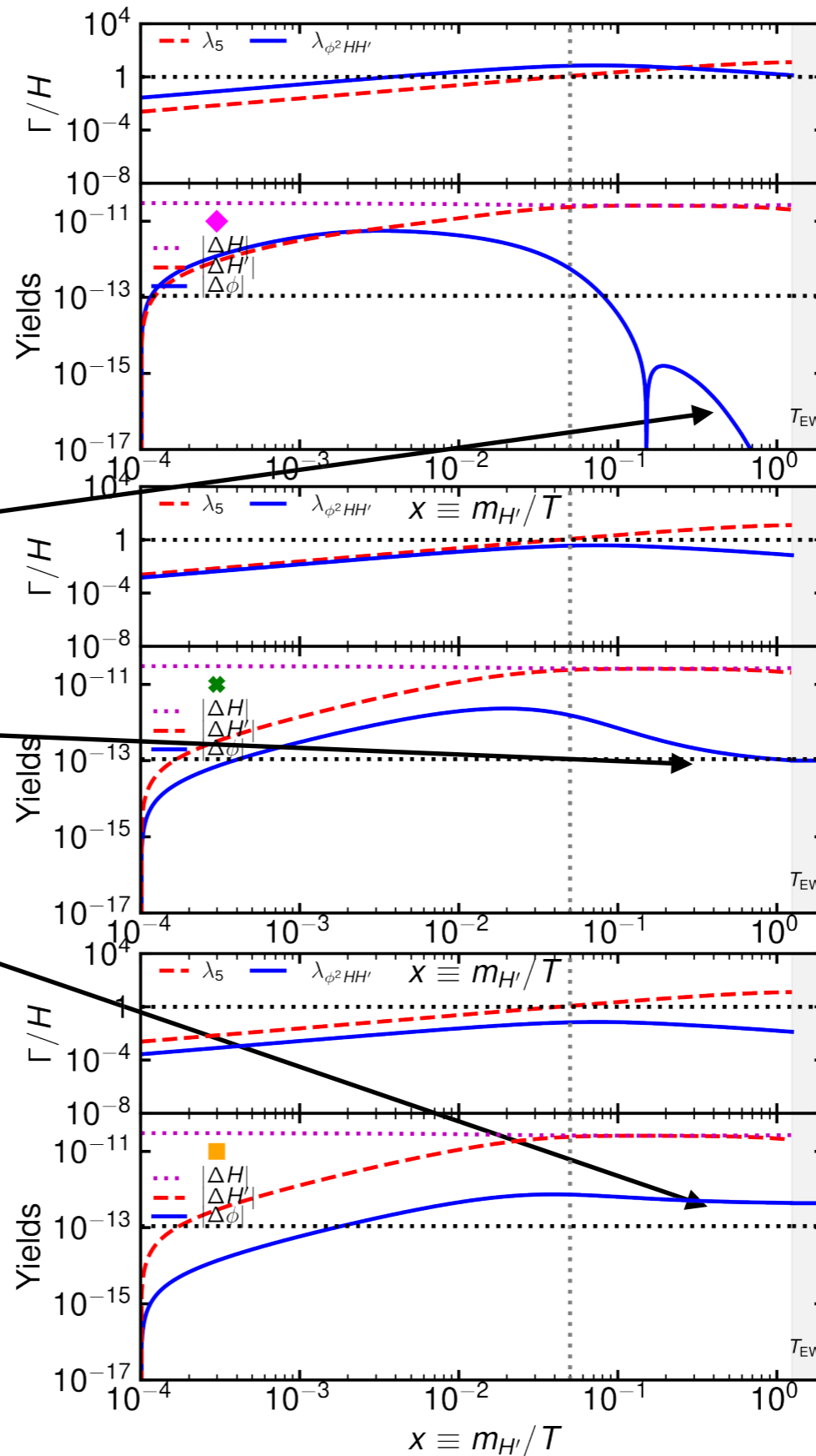
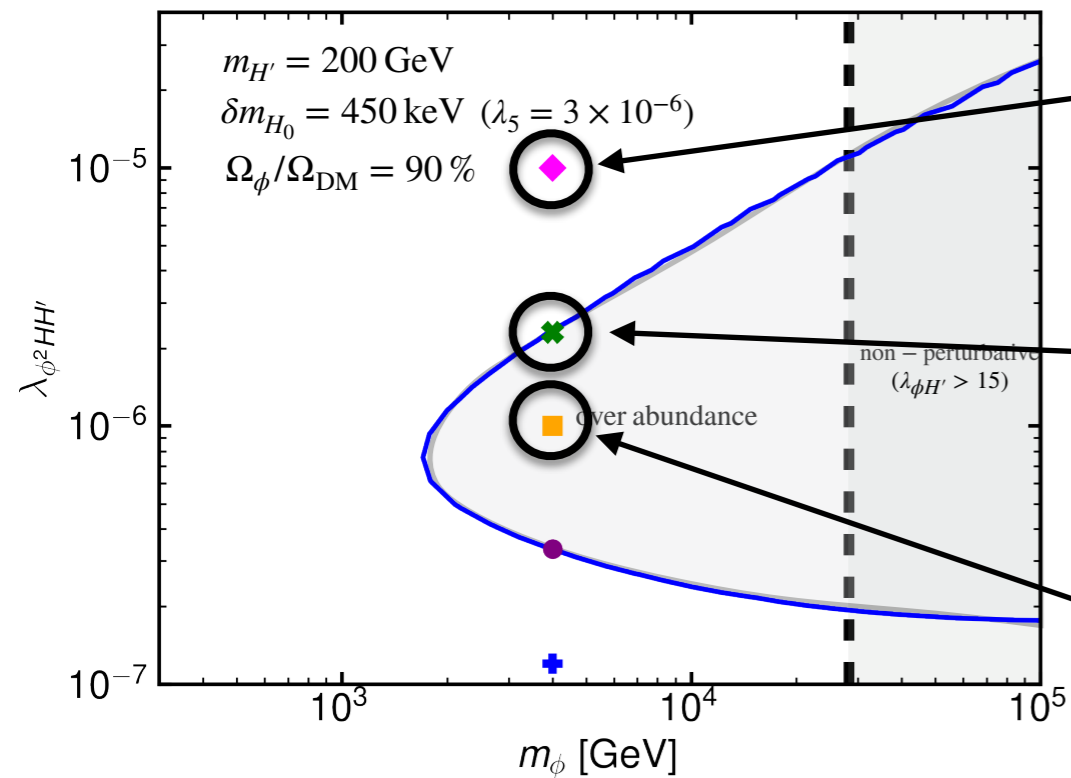


freeze-in with the right damping from H' thermalization



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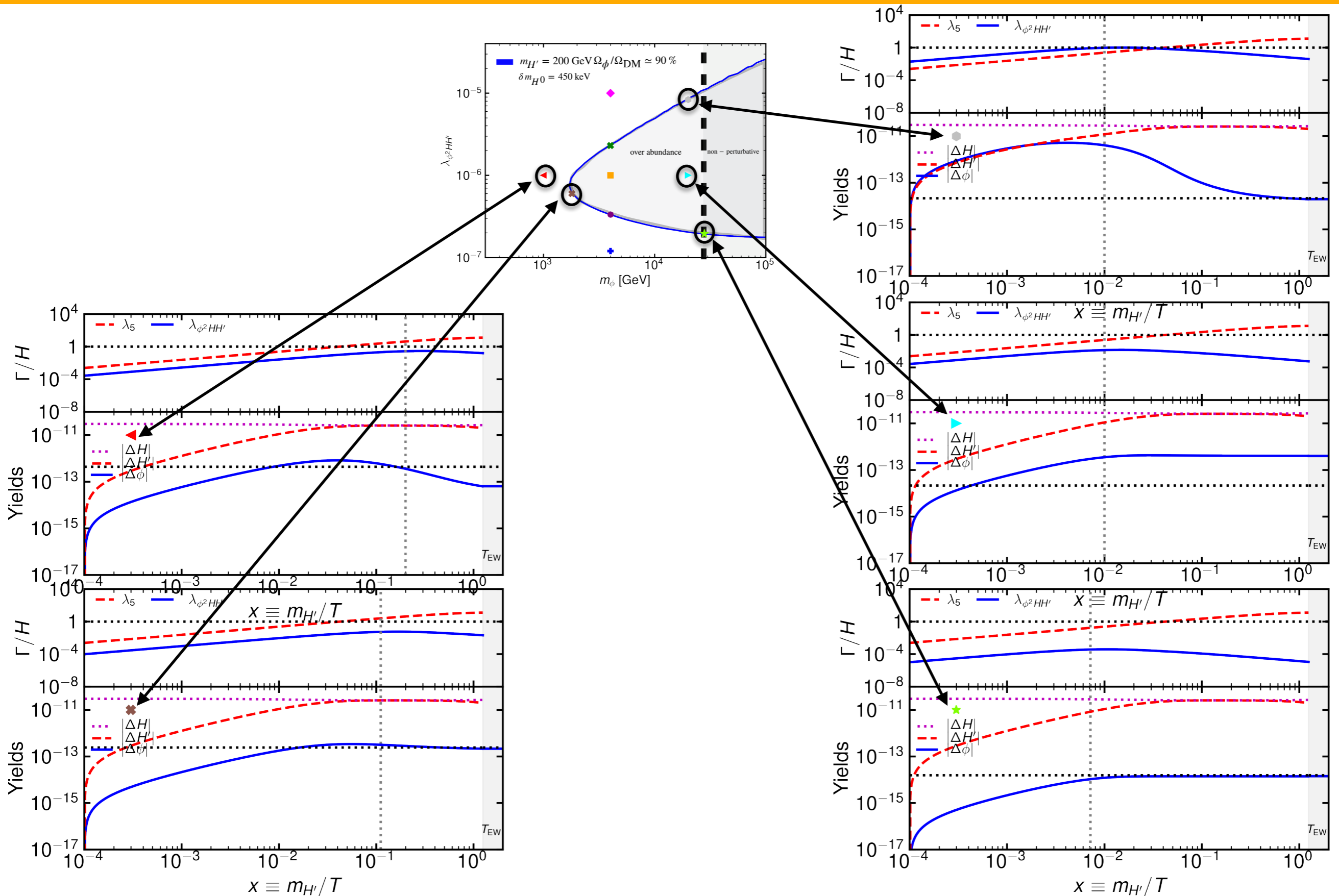


Thermal equilibrium of both rates make the phi asymmetry 0!

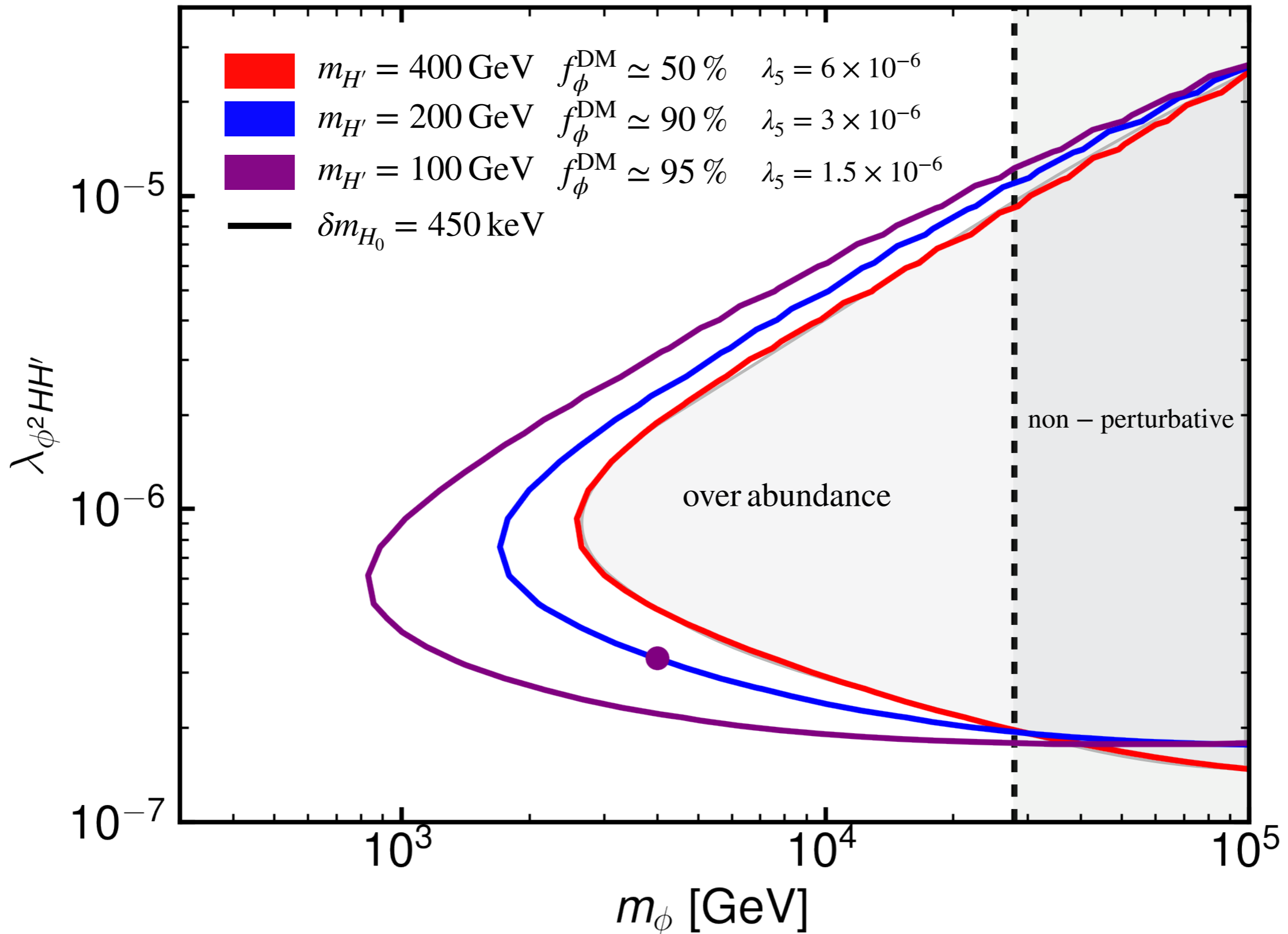
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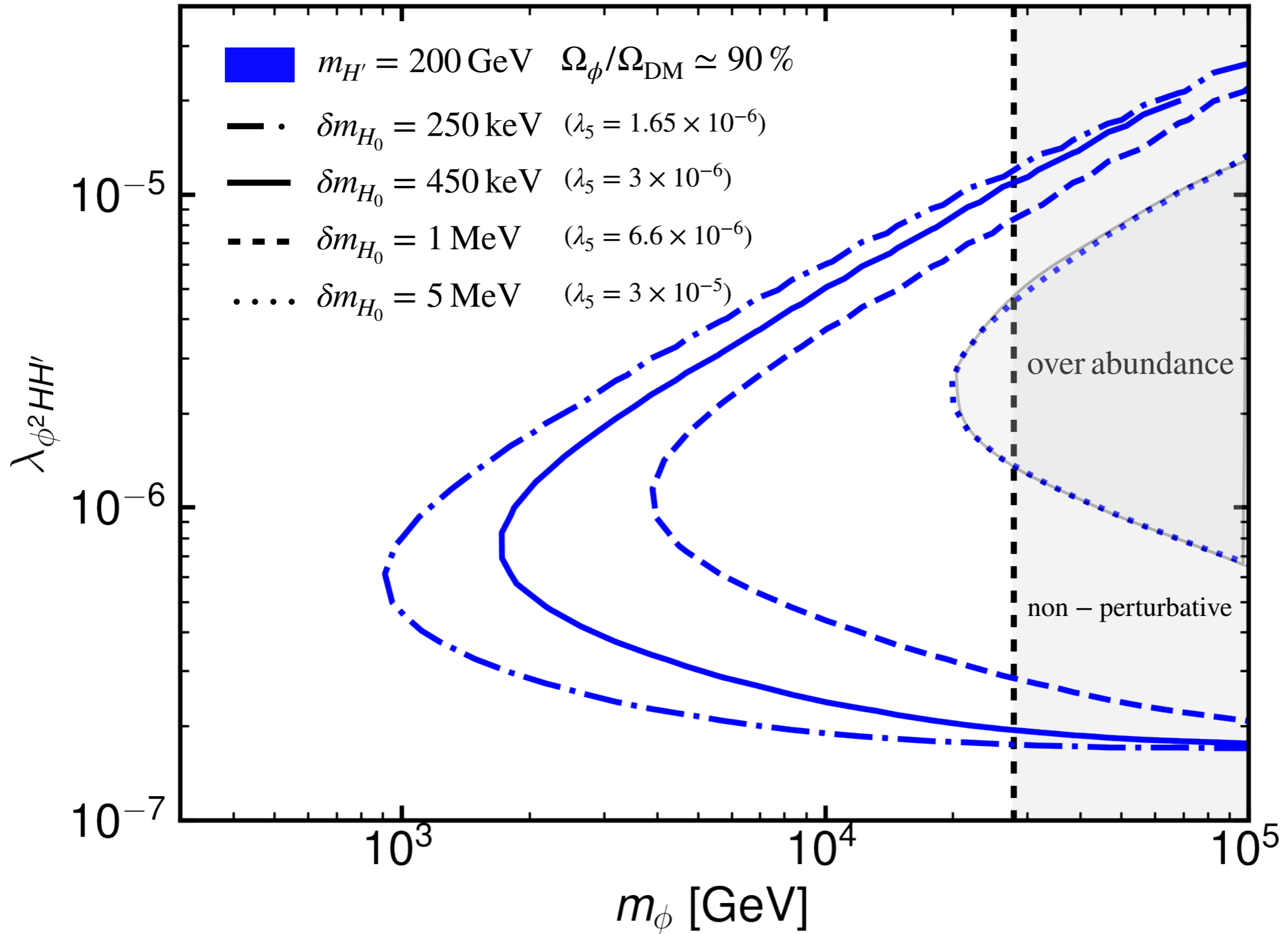
Other Benchmarks



Parameter Space



Parameter Space



Parameter Space

The mass would be too light
and the ϕ asymmetry would
be too small

$$700 \text{ GeV} \lesssim m_\phi \lesssim 30 \text{ TeV}$$

symmetric annihilations
non-perturbative

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The mass would be too light
and the ϕ asymmetry would
be too small

$$700 \text{ GeV} \lesssim m_\phi \lesssim 30 \text{ TeV}$$

symmetric annihilations
non-perturbative

Invisible Z width [LEP]

$$46 \text{ GeV} \lesssim m_{H'} < 580 \text{ GeV}$$

The lighter H' the more
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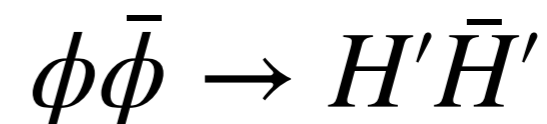
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Required for the annihilation of dark matter in the early Universe



Direct Detection Signals

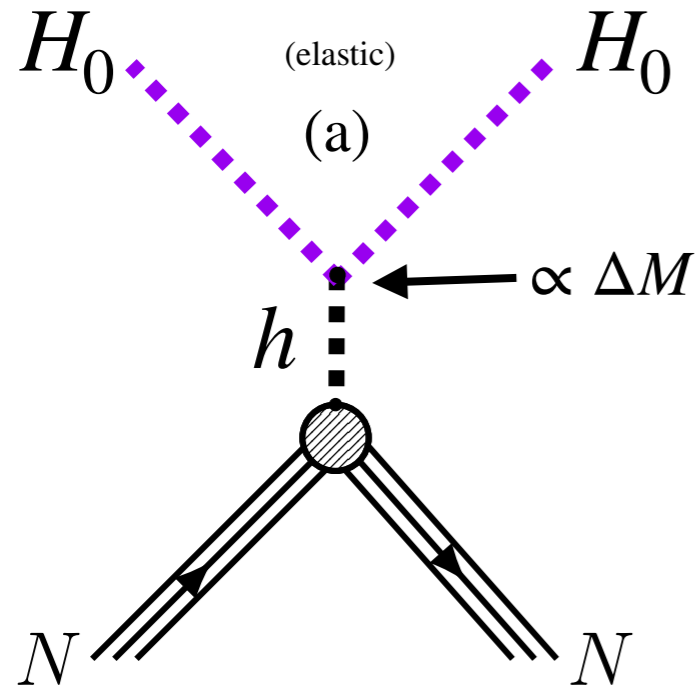
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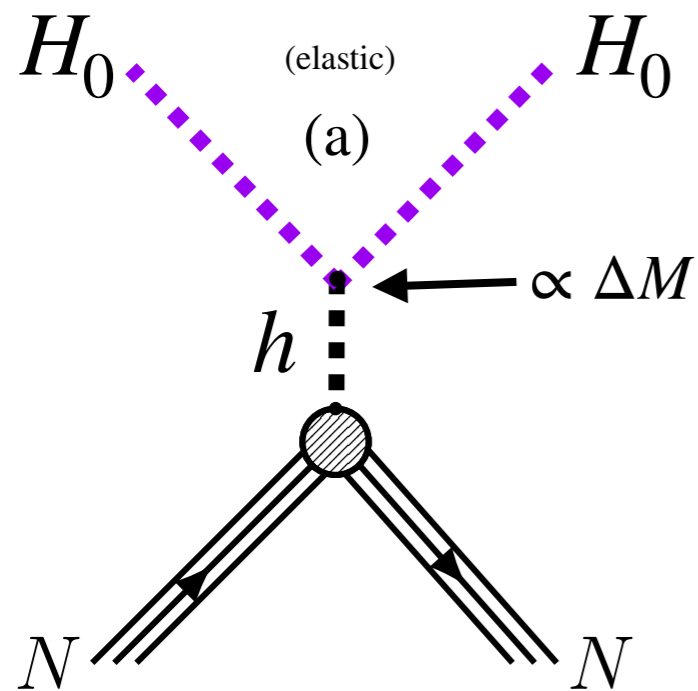


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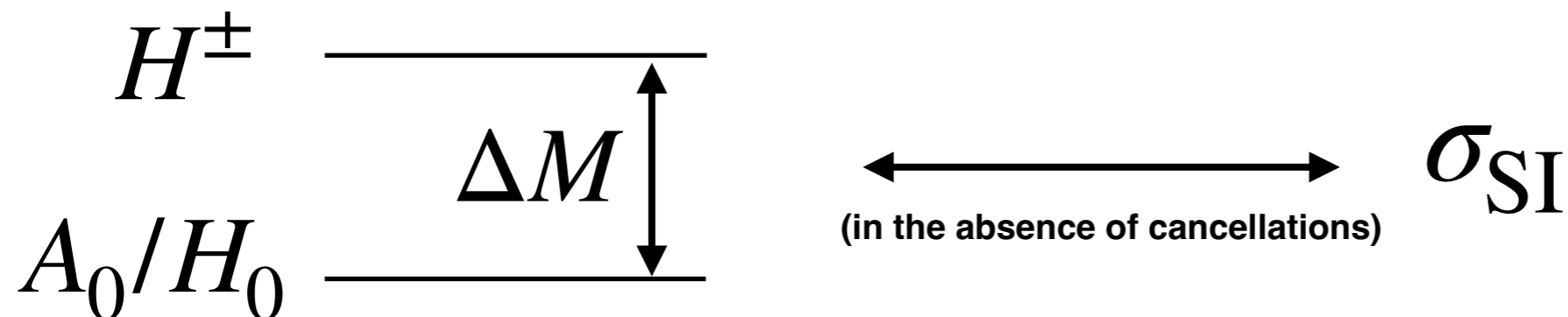
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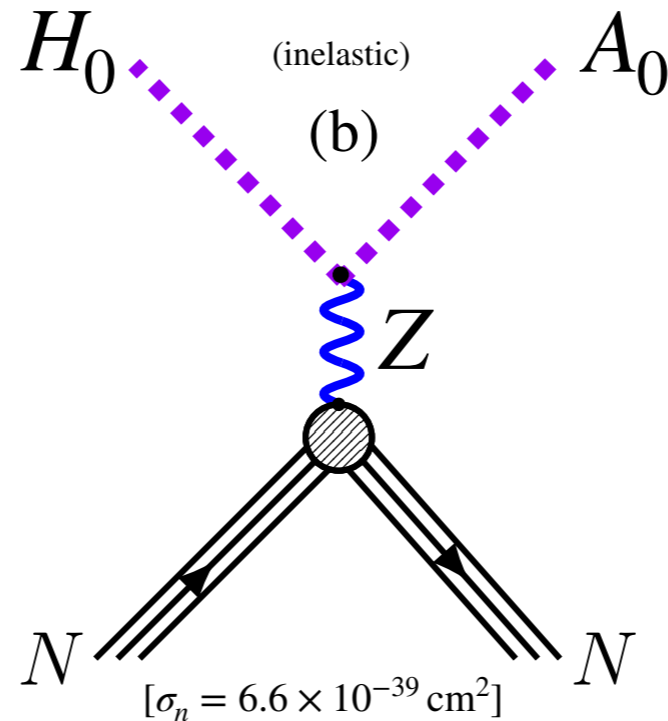
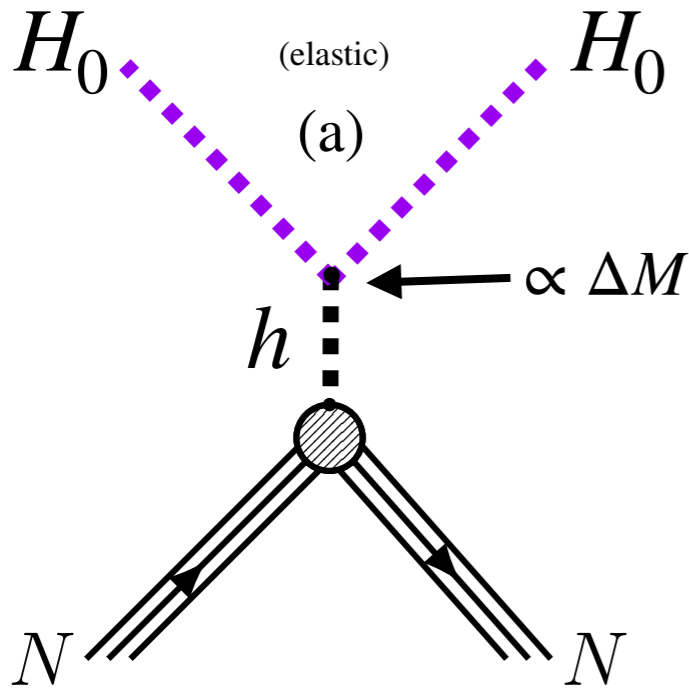
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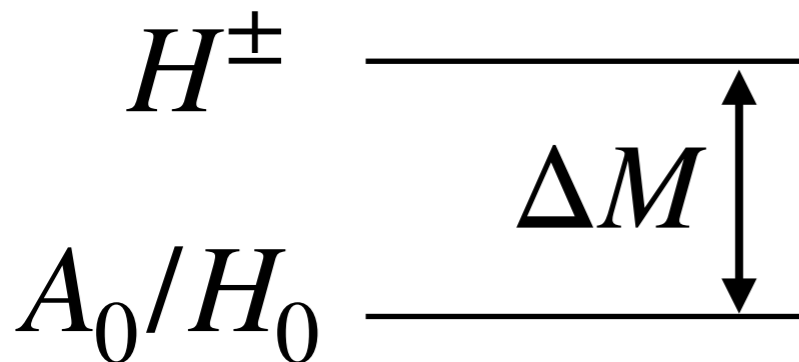
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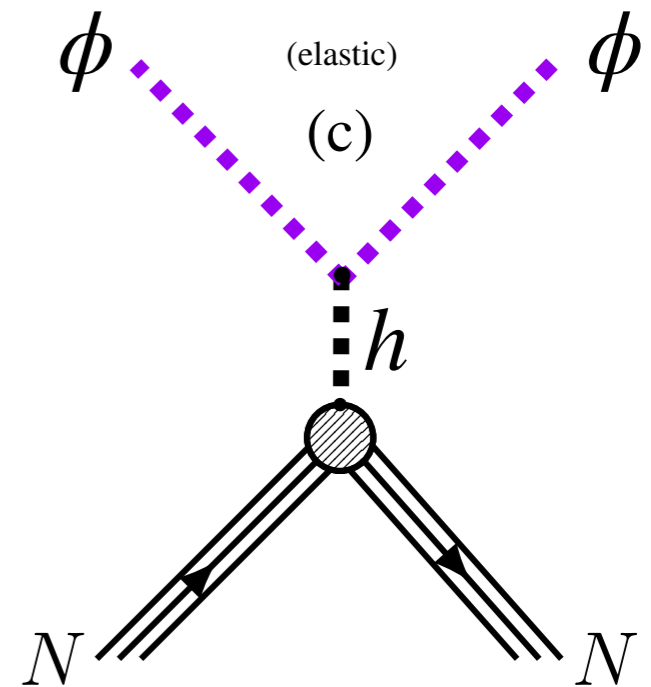
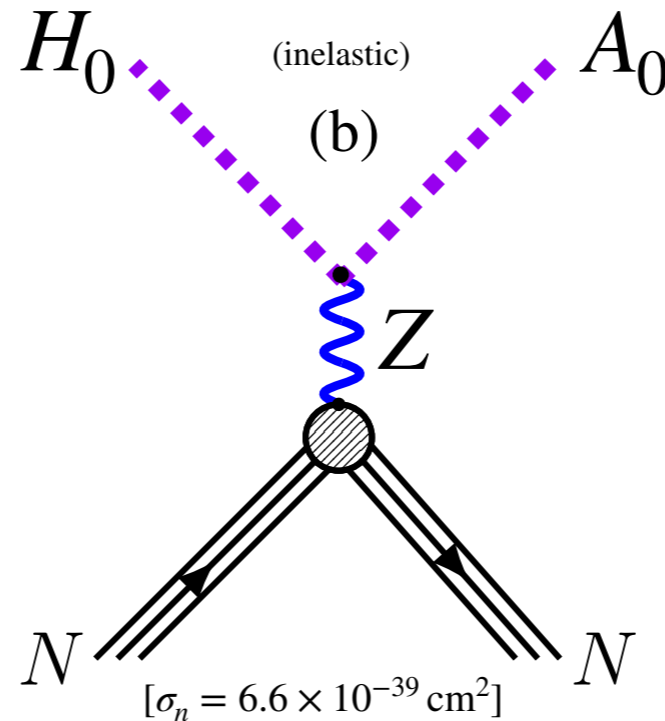
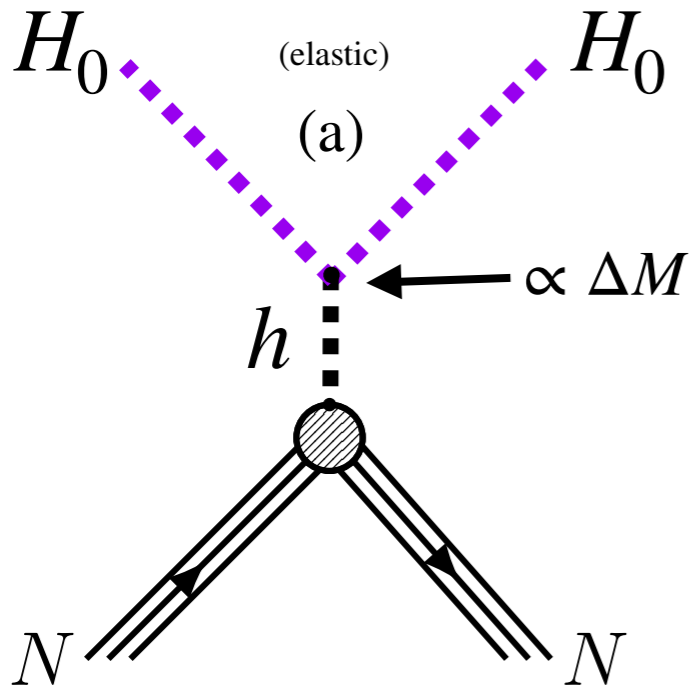
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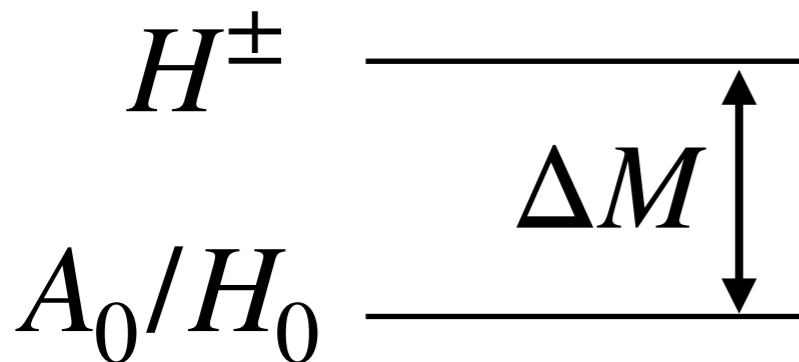
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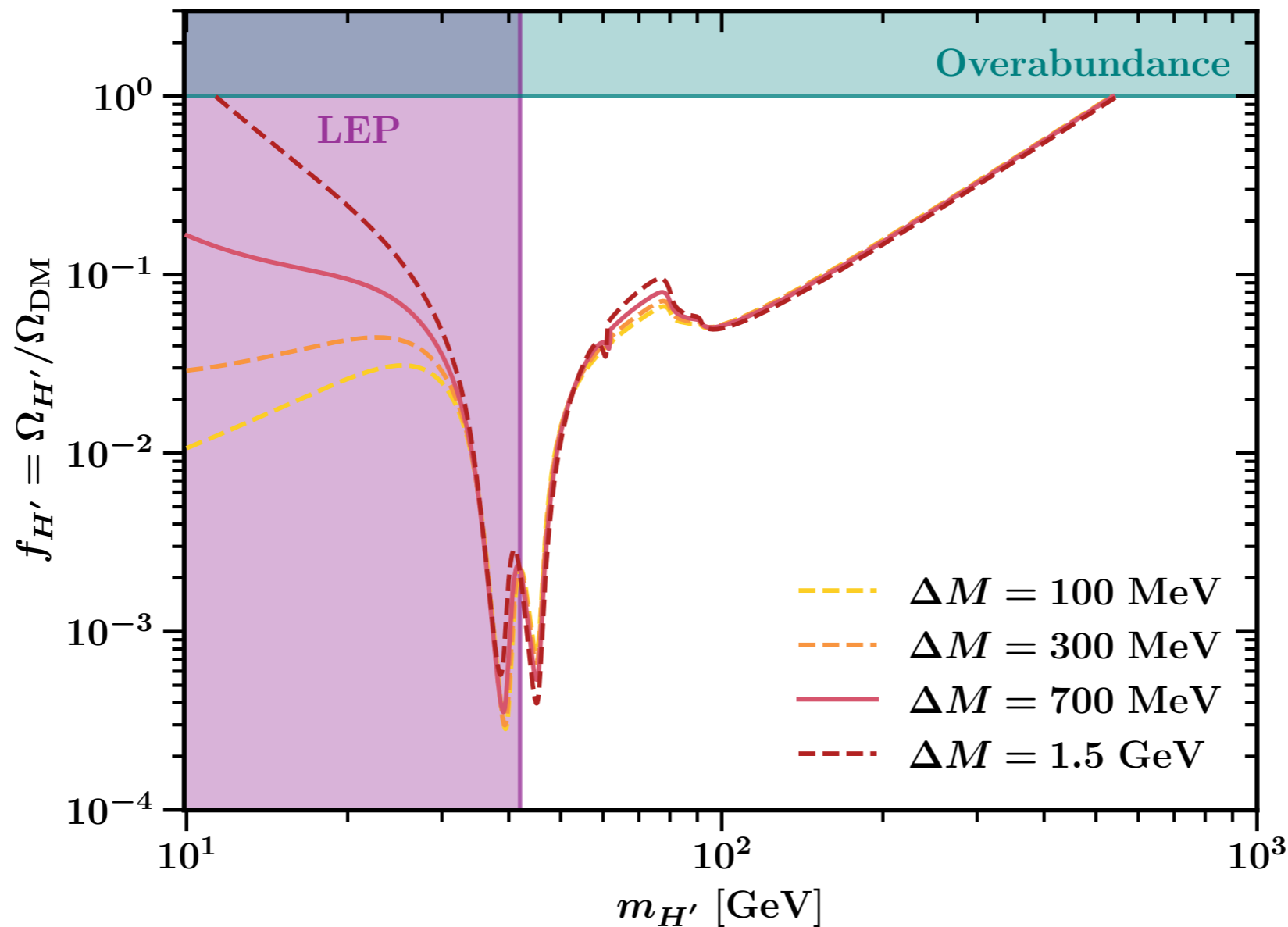
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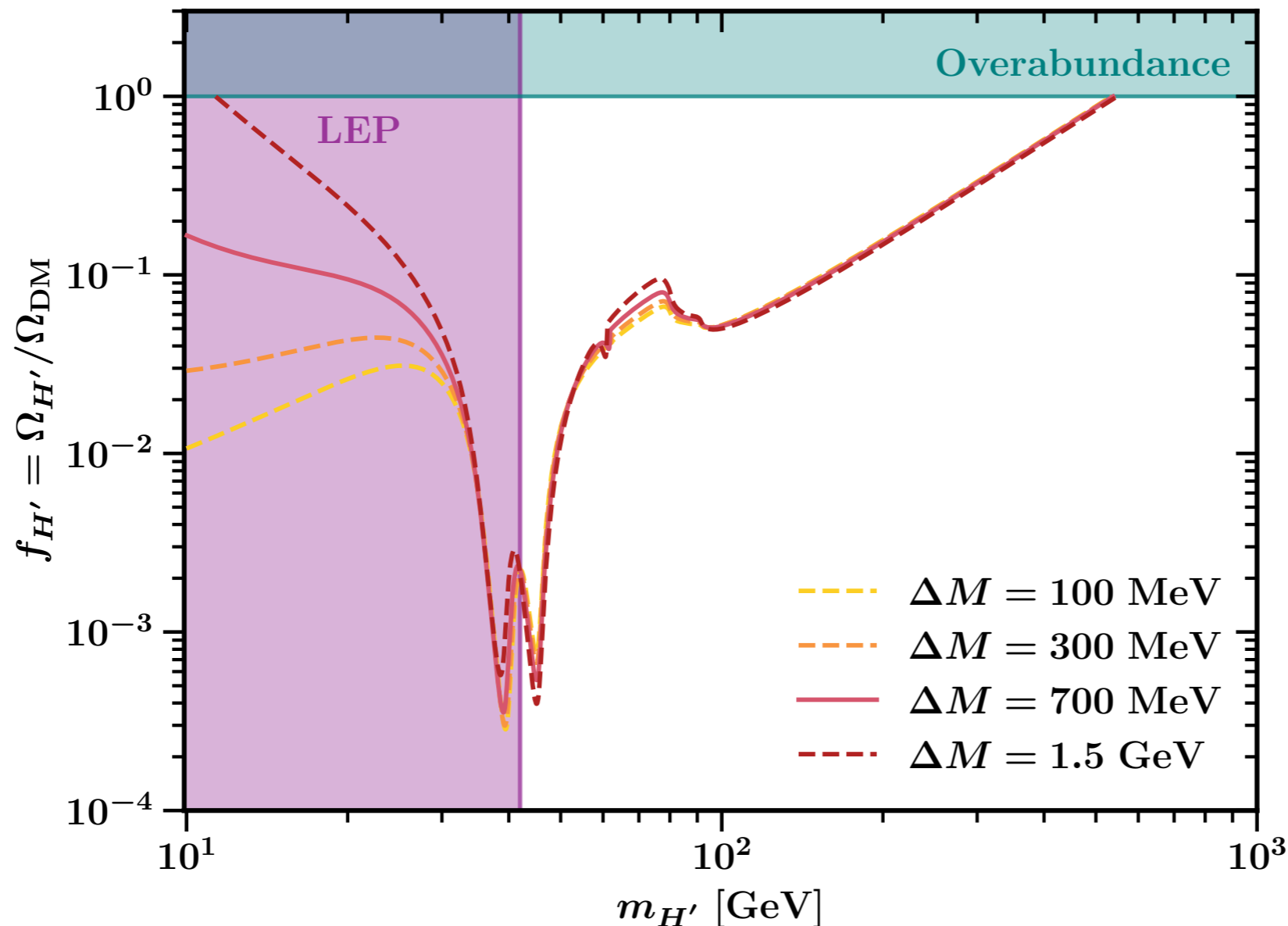
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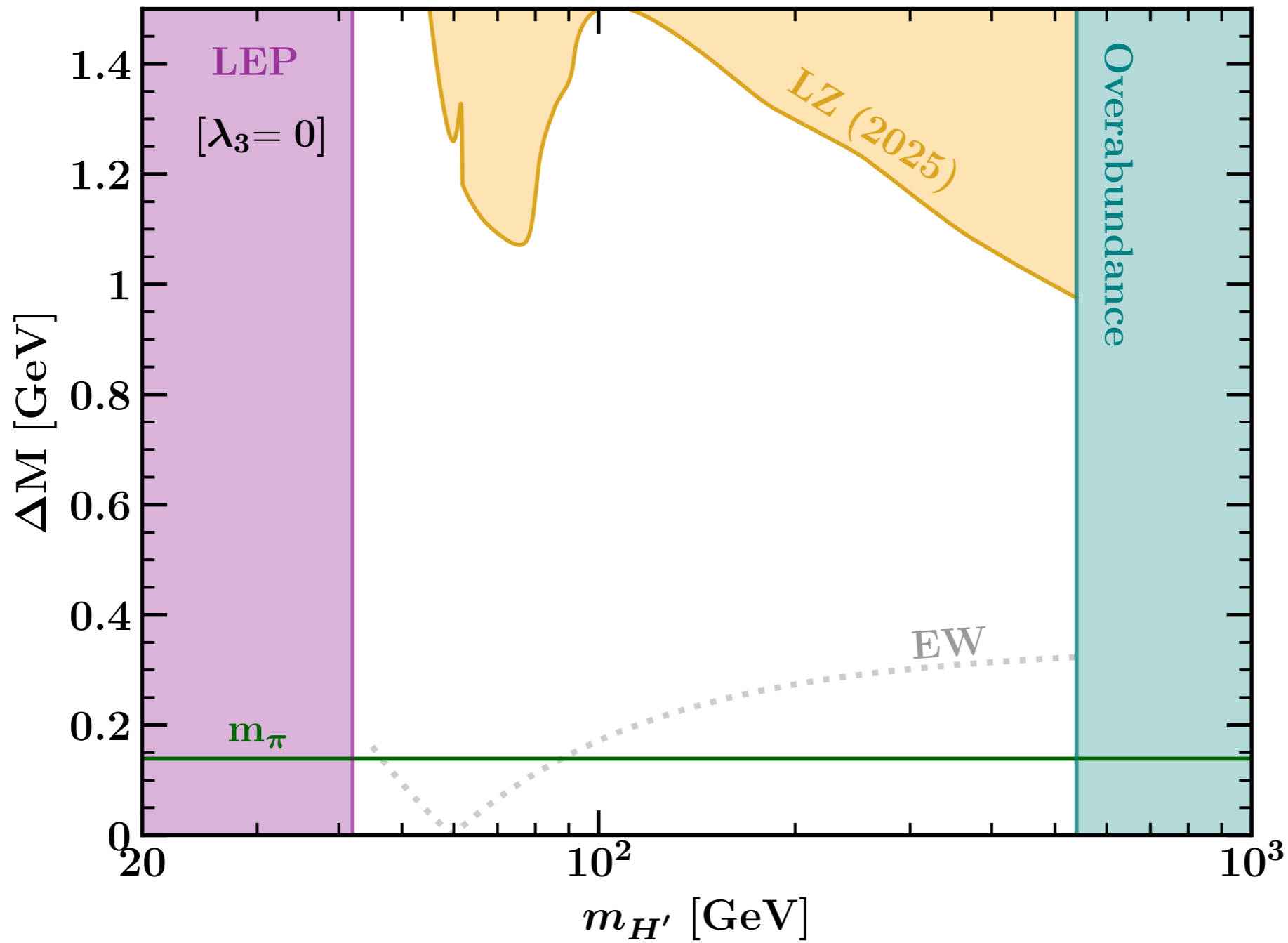
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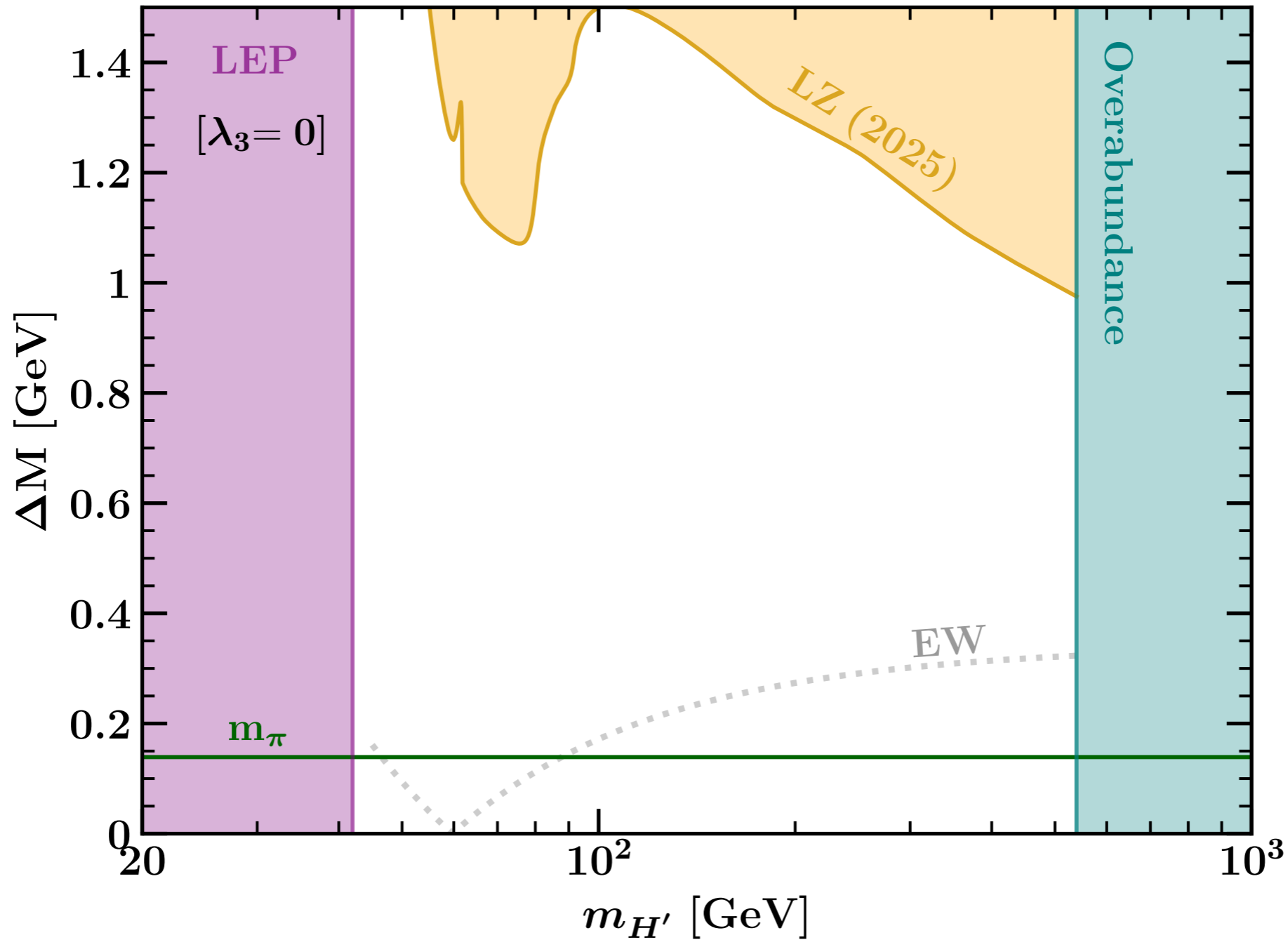
Hence, we can make sharp predictions for the direct detection rates today!

The lighter H' is the more asymmetric dark matter is!

Direct Detection Signals



Direct Detection Signals



Limits from LZ already tell us that the doublet needs to be quite compressed!

$$\begin{array}{l}
 H^\pm \\
 H_0
 \end{array}
 \quad \text{—————} \quad \Delta M \lesssim 1 \text{ GeV}$$

Next Generation

2026:

Xenon-nT

LZ

PandaX-4T

~ 5 tonne – year

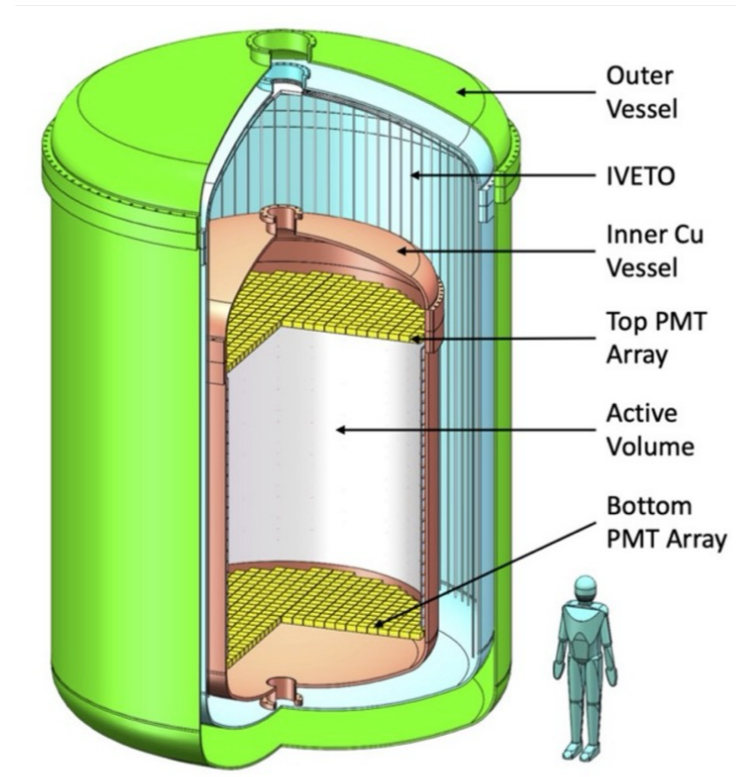
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2028-



PandaX-xT LXe

20 T

PANDAX-xT

~ 200 tonne – year

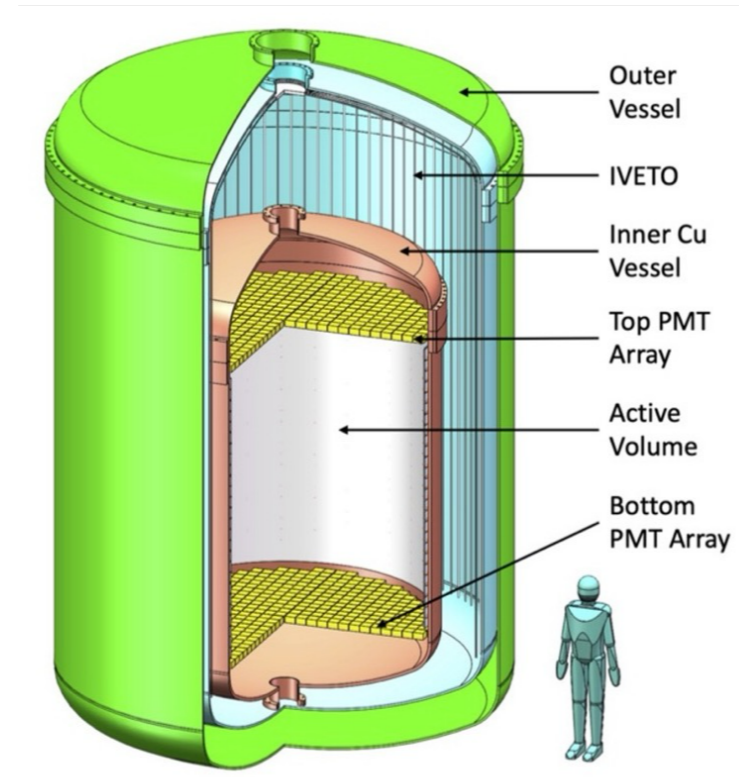
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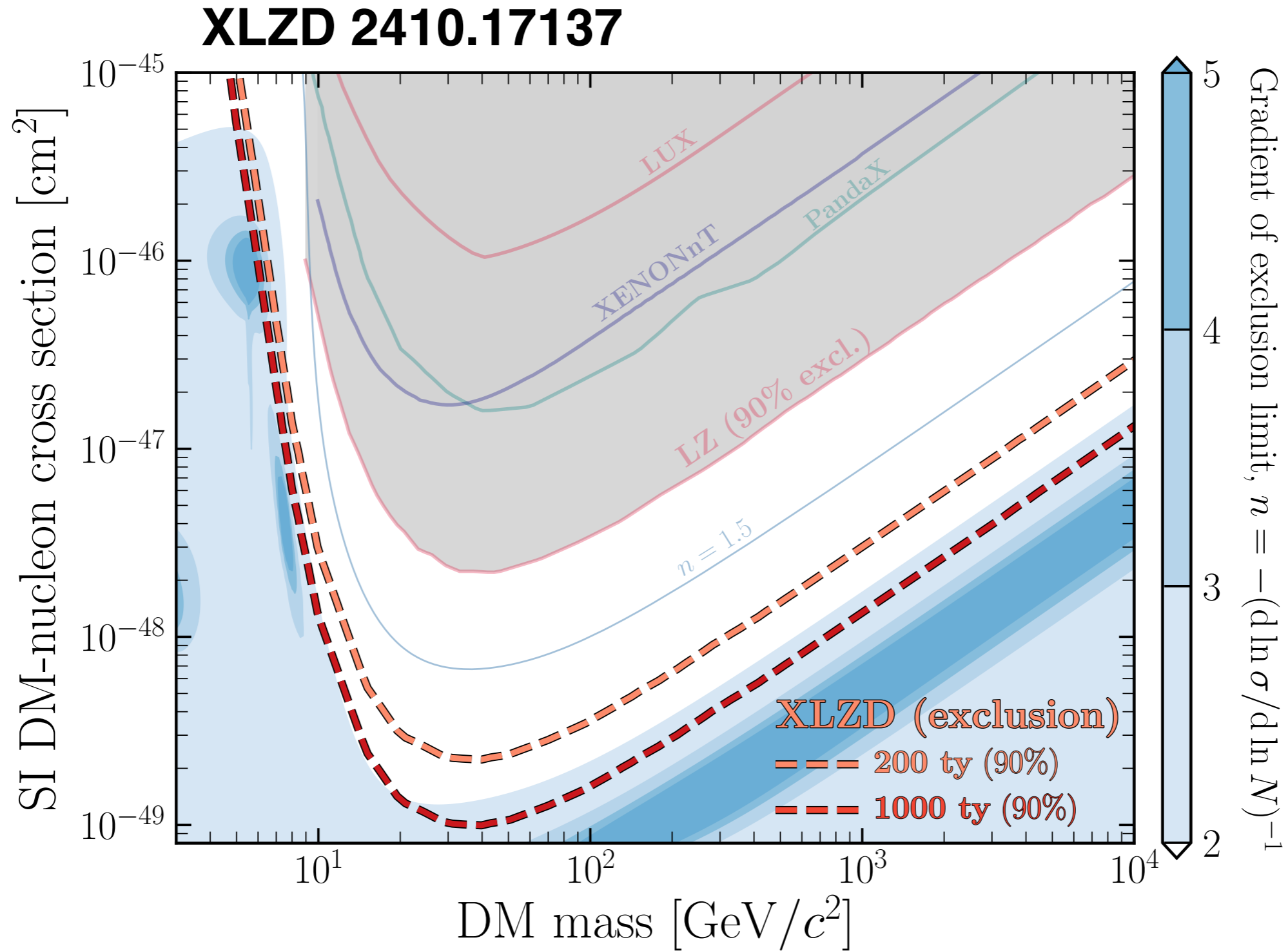


60 T

XLZD

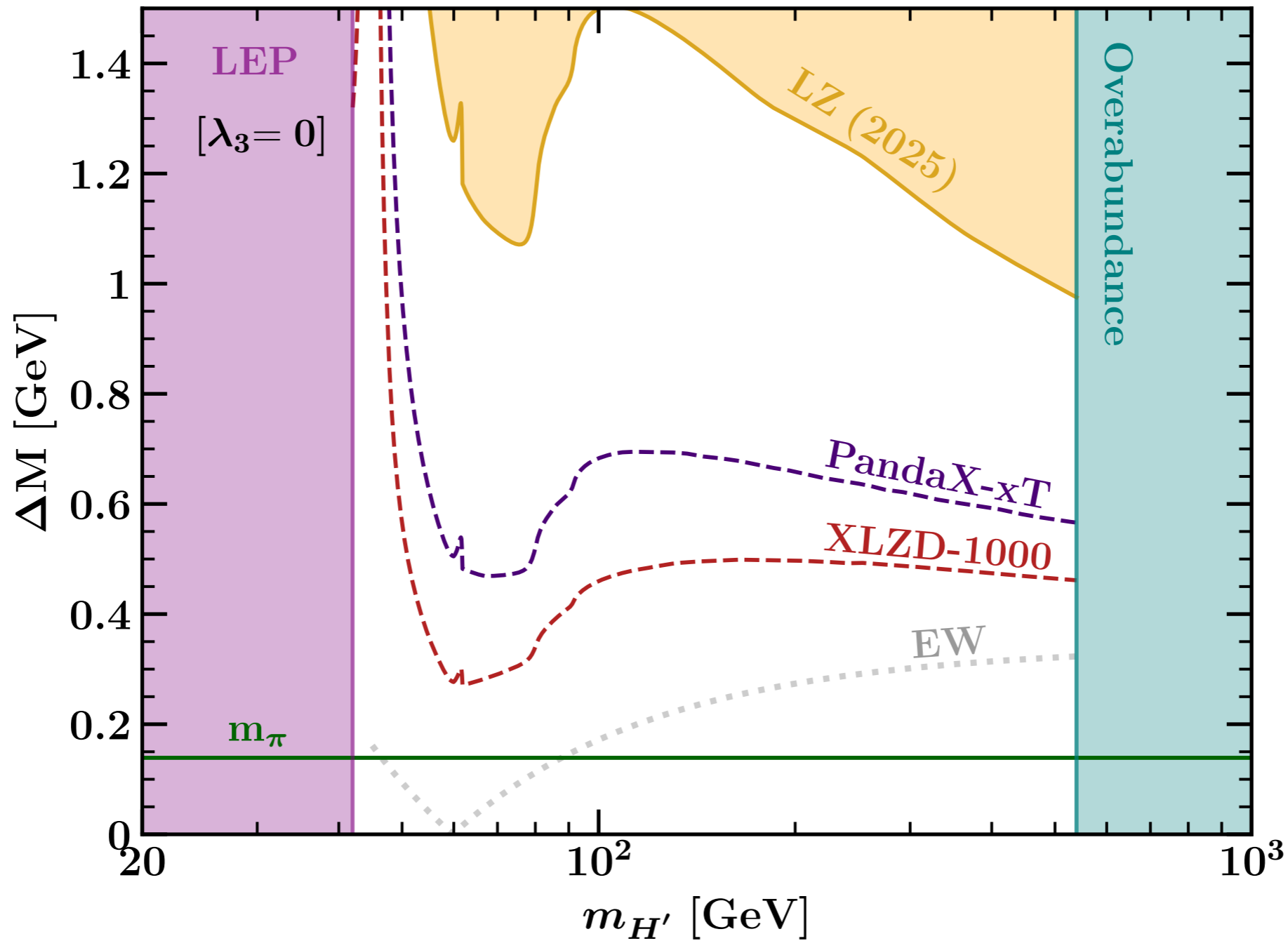
~ 1000 tonne – year

Next Generation



Factors of ~15-25 improvement wrt LZ at the doors of the neutrino floor.

Direct Detection Signals

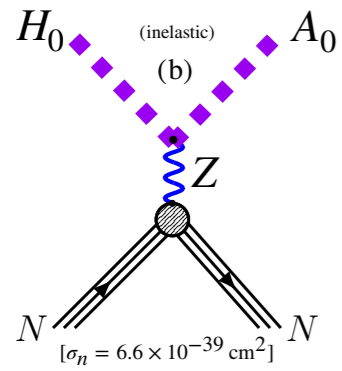


Sensitivities

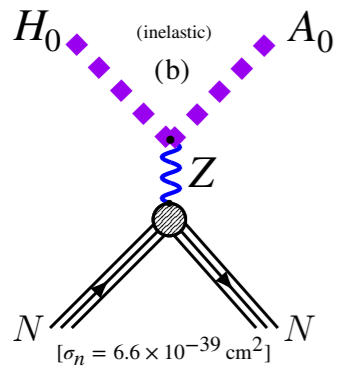
$\Delta M \lesssim 0.6 \text{ GeV}$ PandaX-xT or XLZD-200

$\Delta M \lesssim 0.4 \text{ GeV}$ XLZD-1000 or ARGO-3000

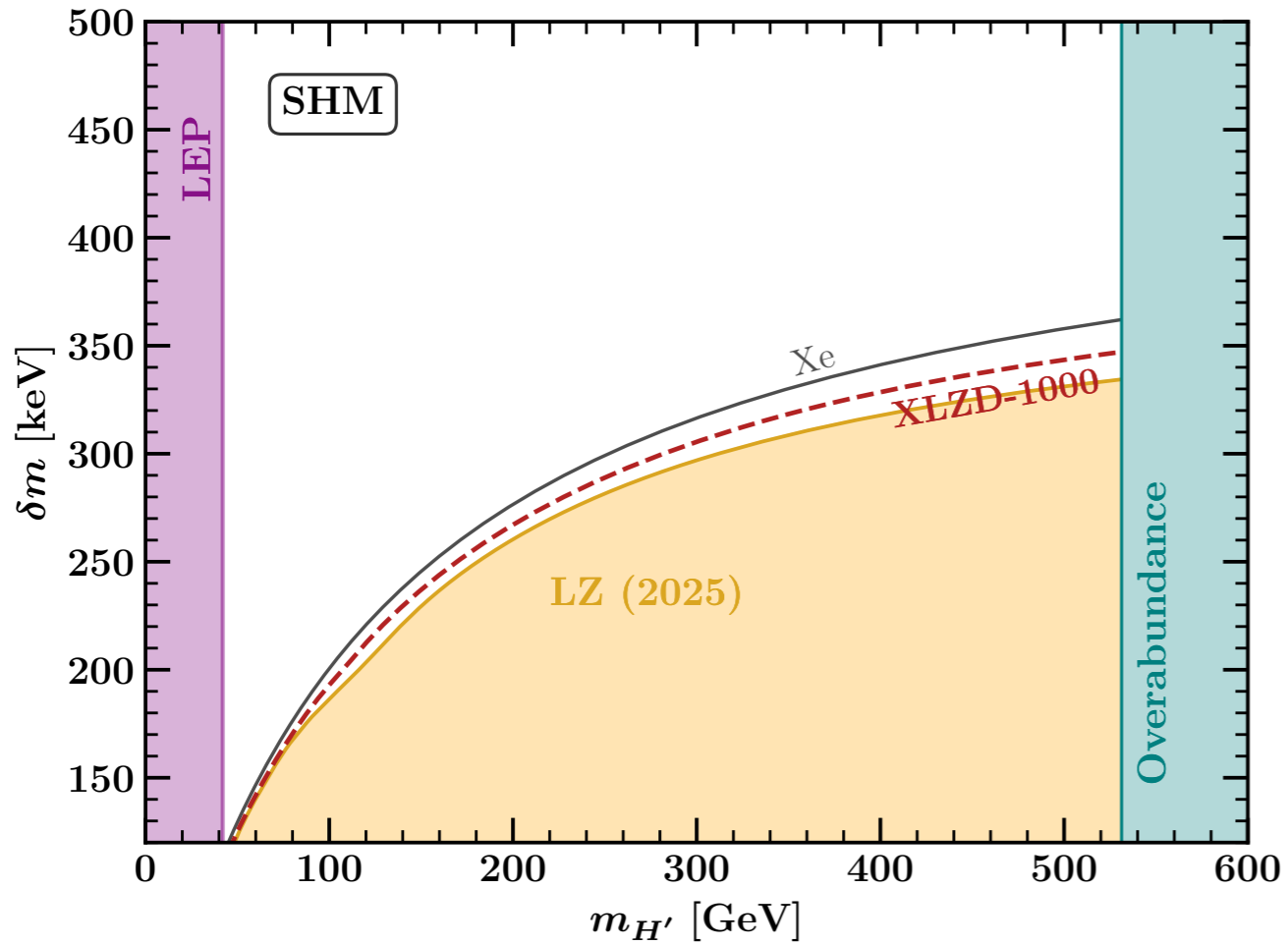
The Inelastic Channel



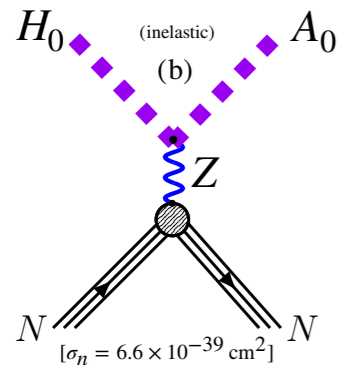
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Standard Halo Model



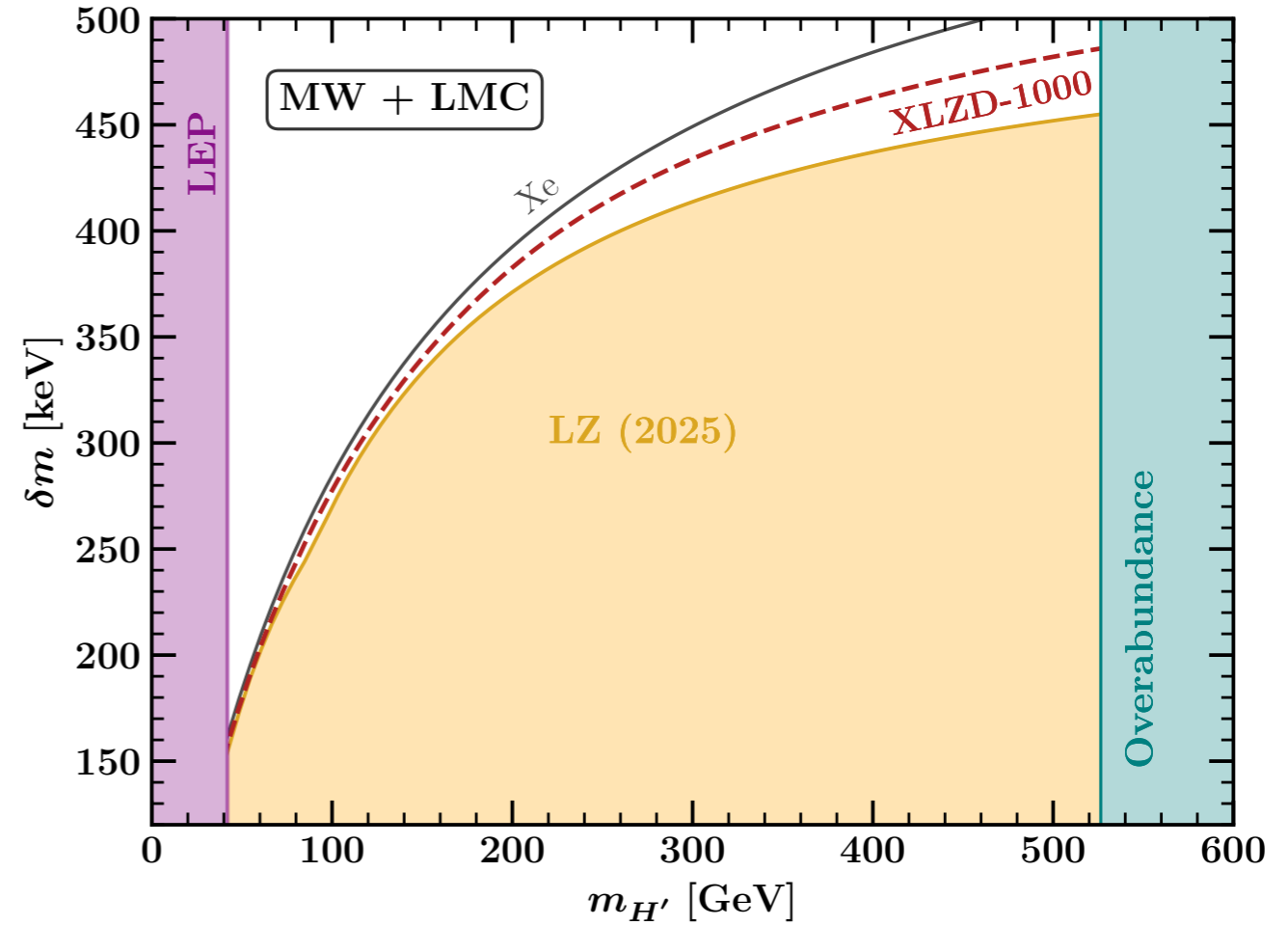
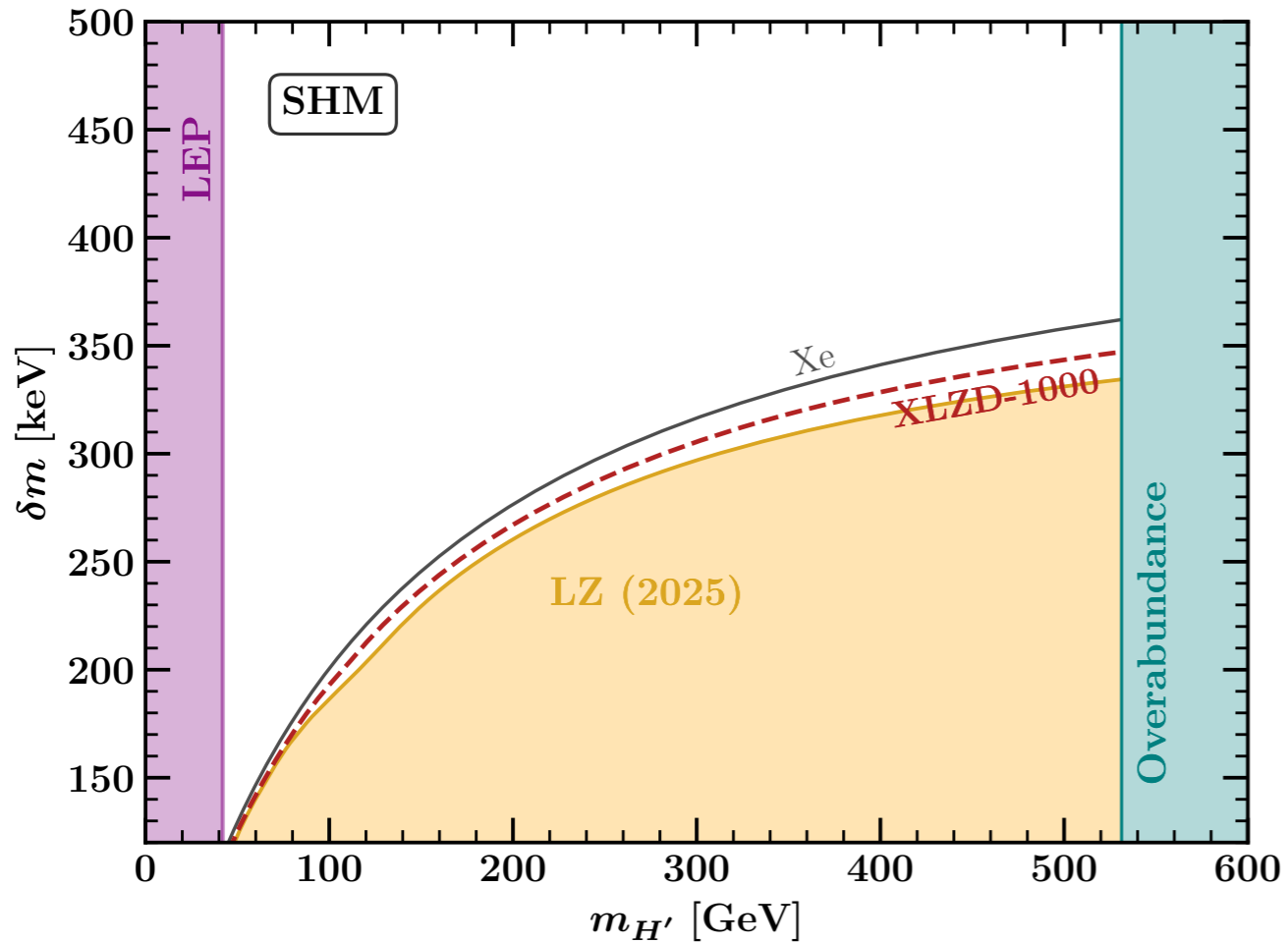
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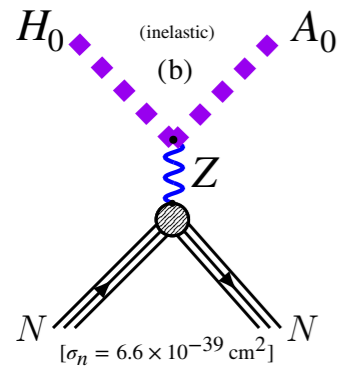
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see also Reynoso-Cordova, Bozorgnia, Piro [2409.09119] and Smith-Orlik et al. [2302.04281]



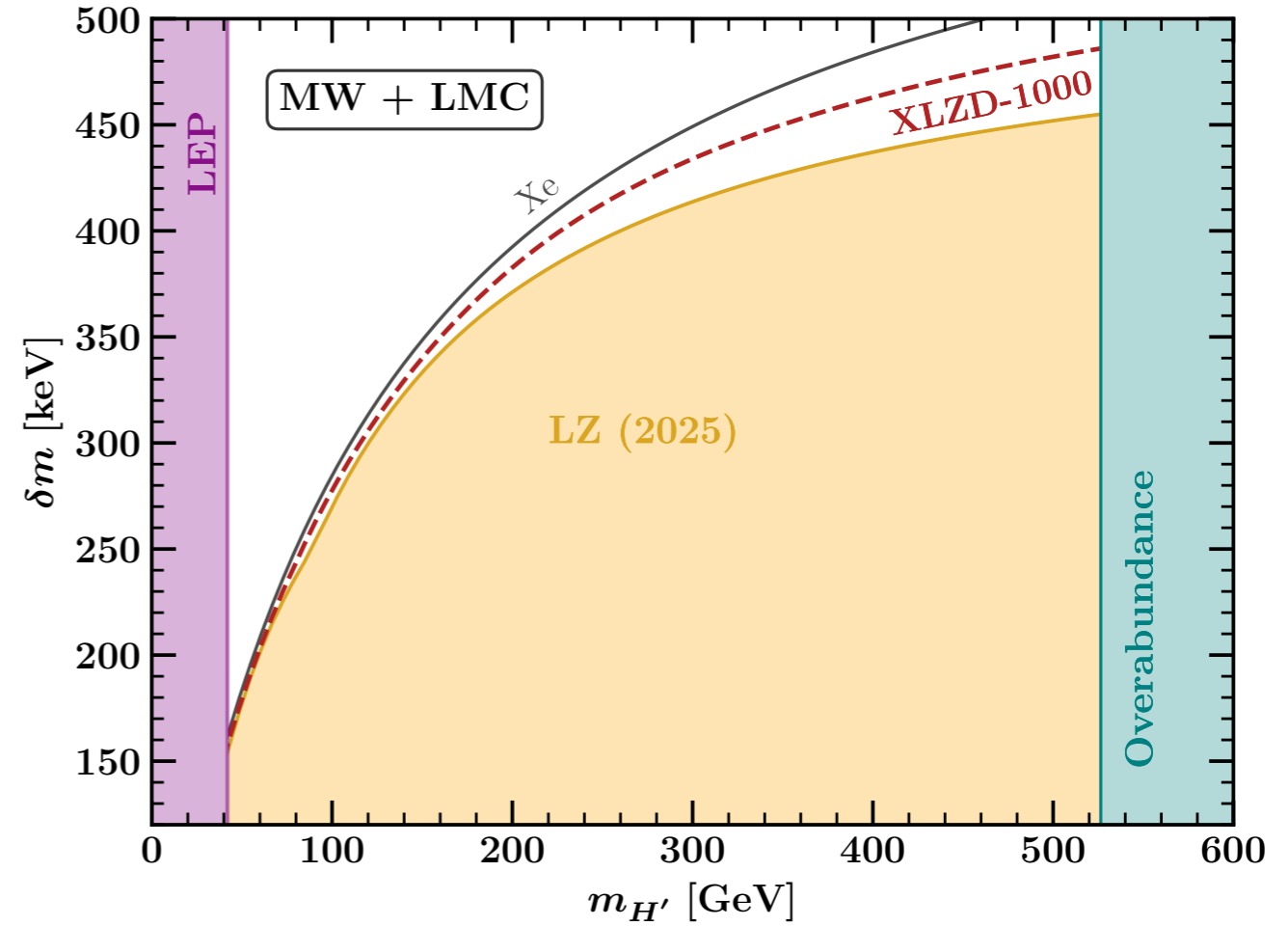
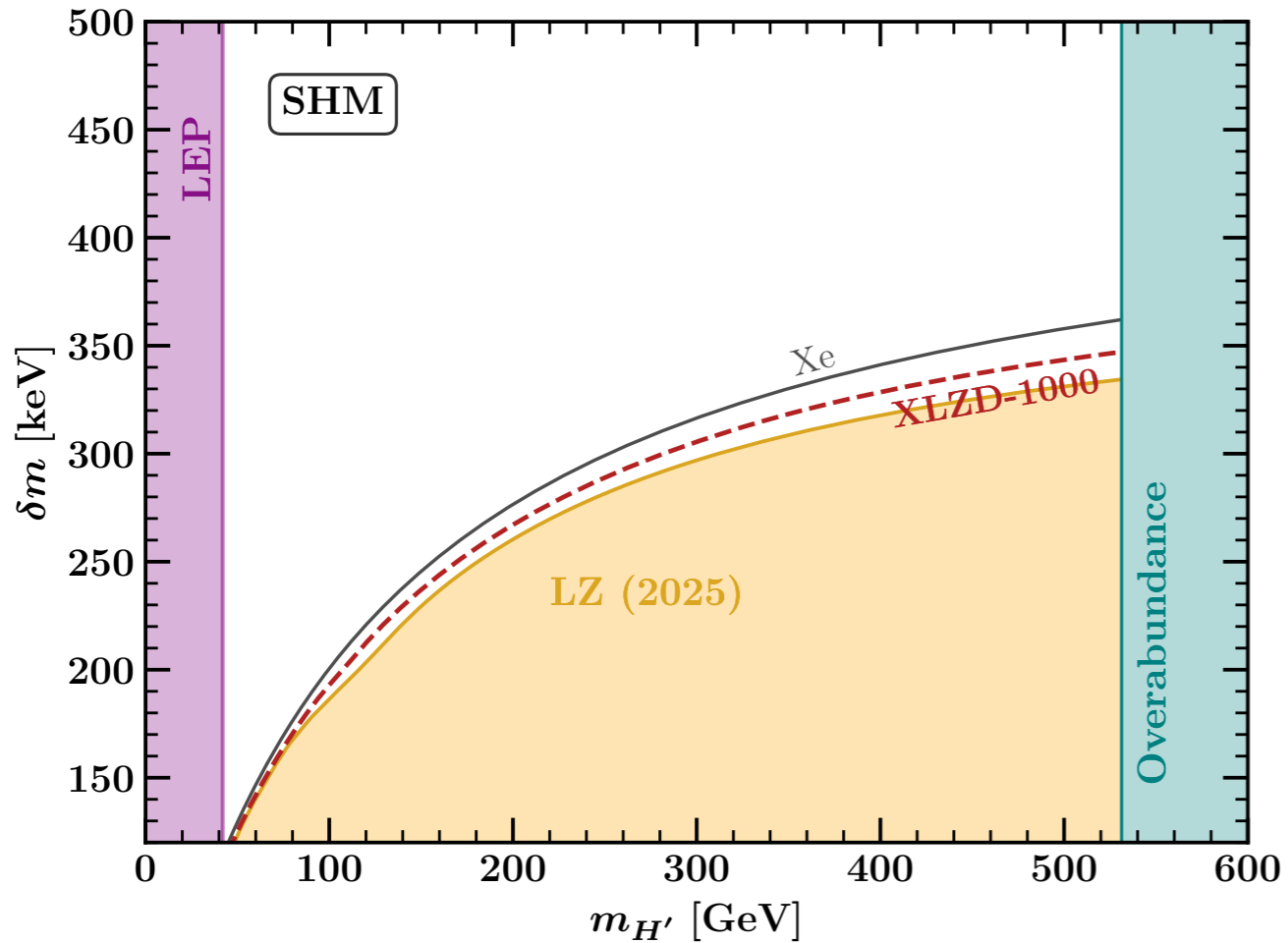
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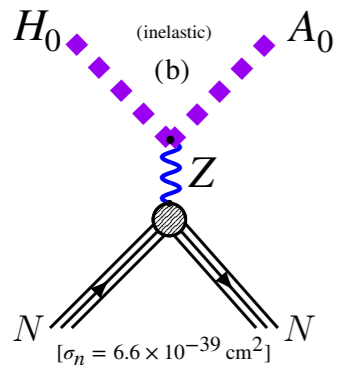
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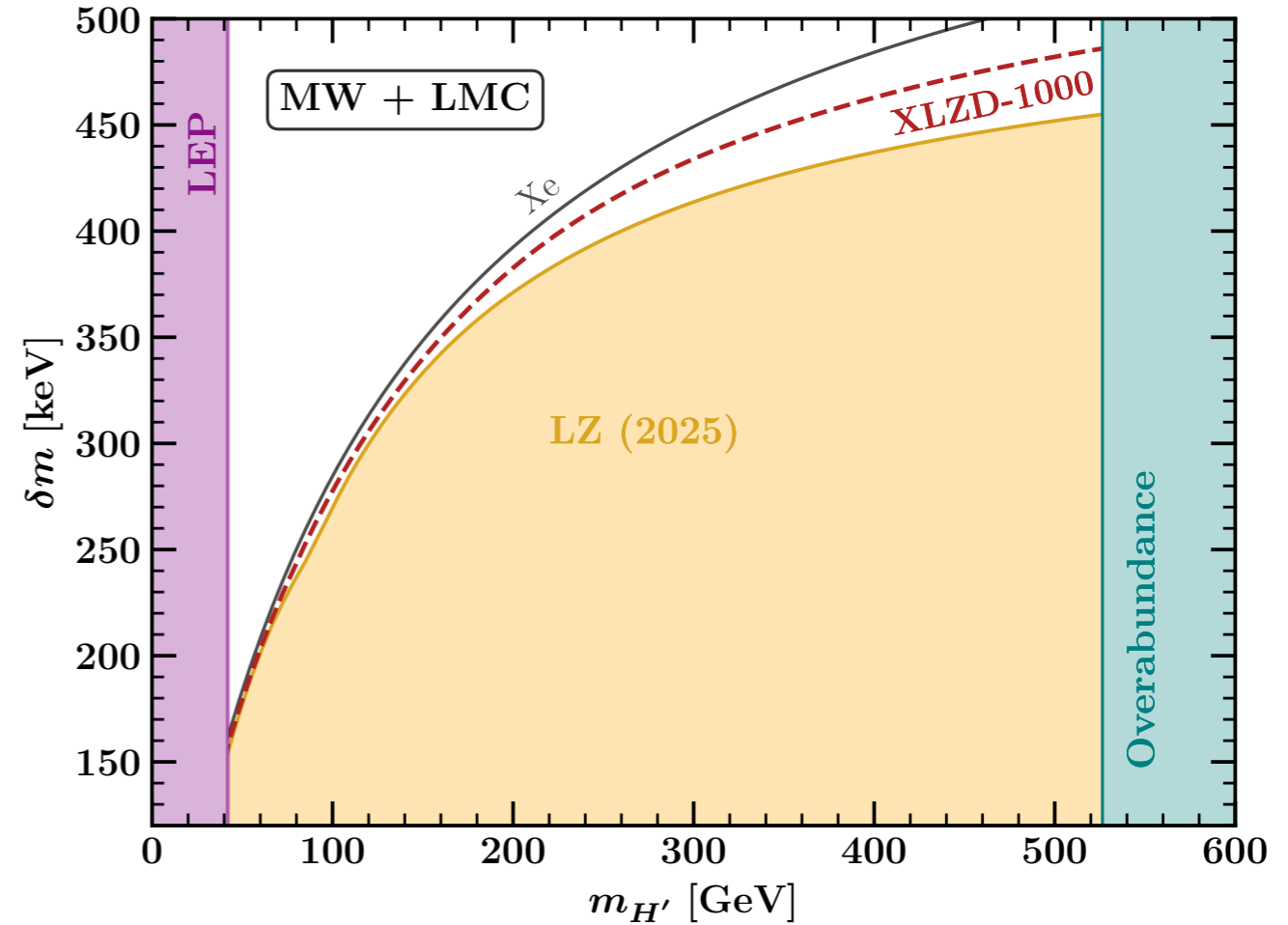
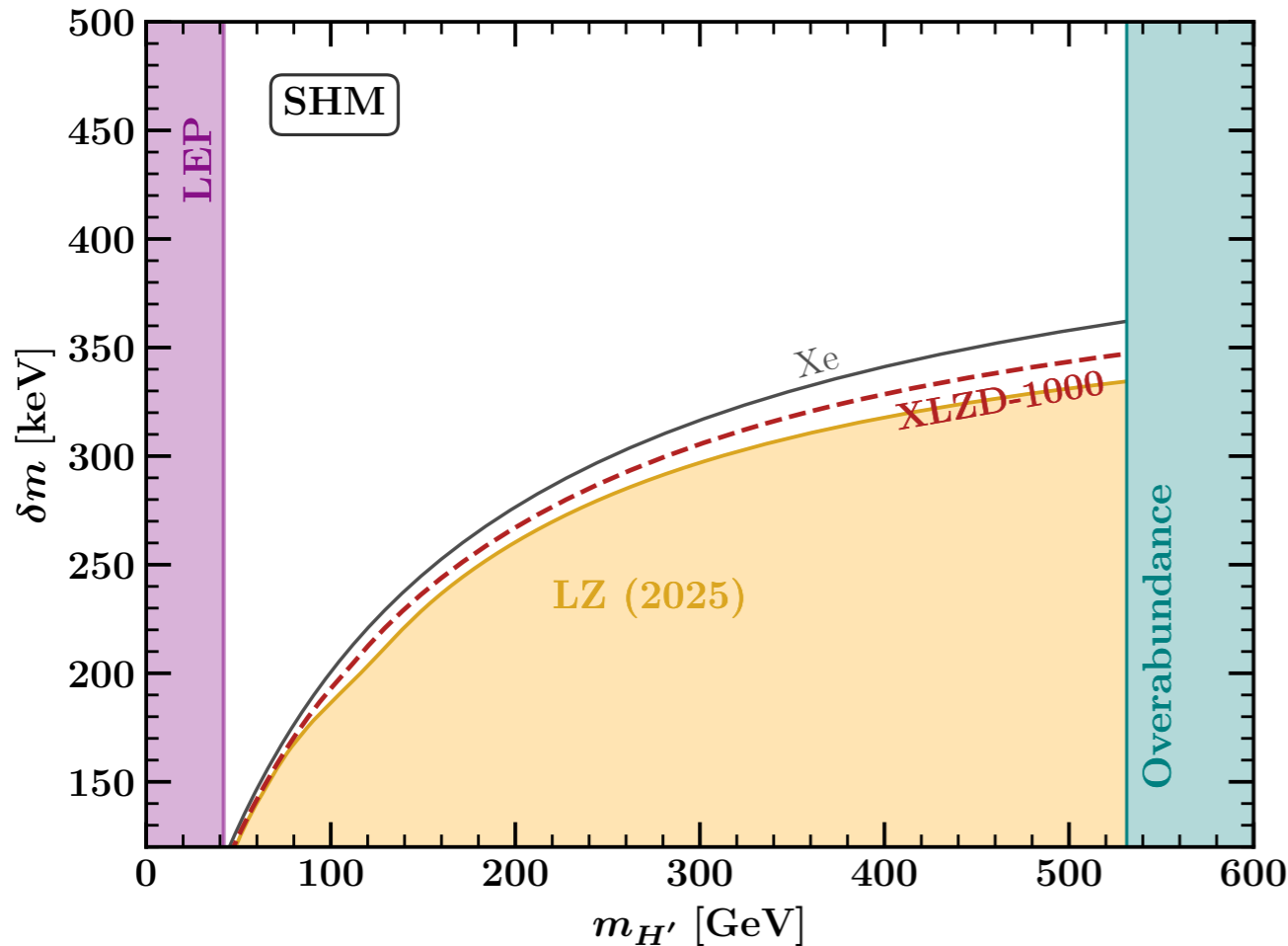
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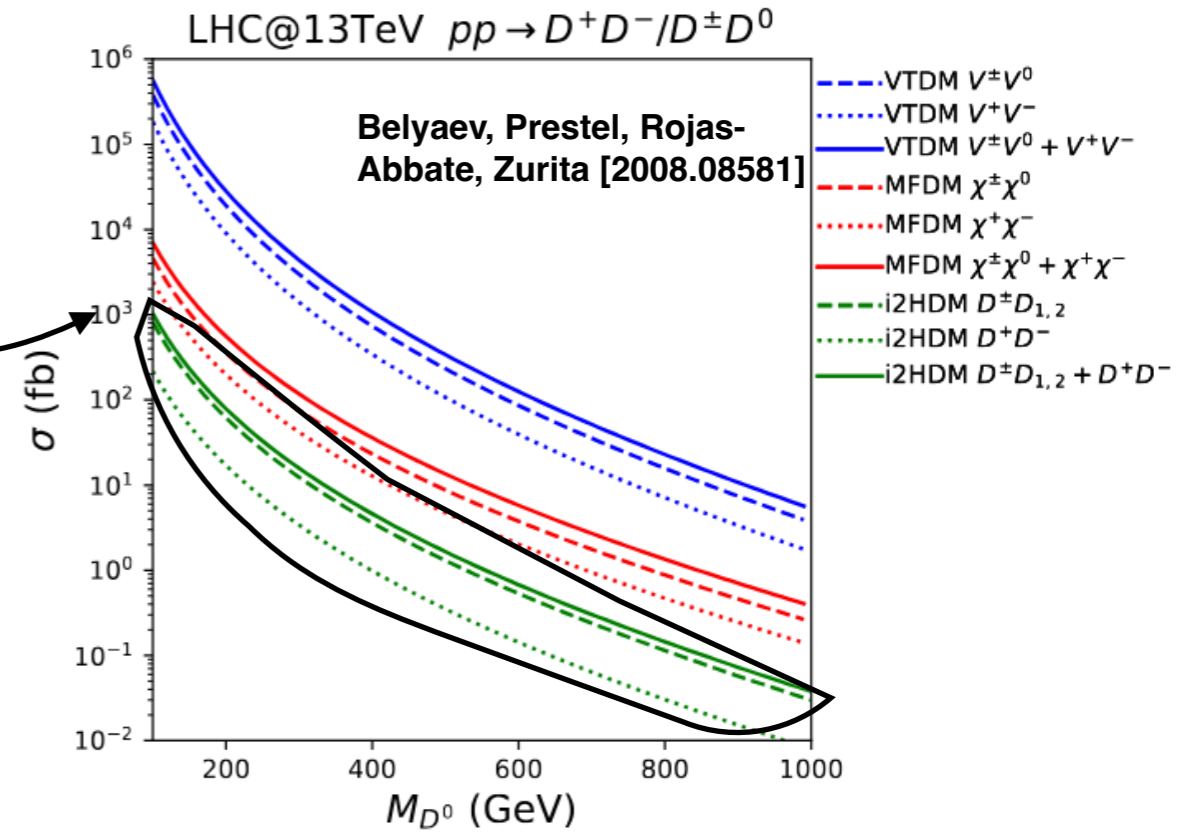
$\gtrsim 300 \text{ keV}$ $\overleftrightarrow{\delta m}$ A_0 $\lesssim 5 \text{ MeV}$
Z-induced DD H_0 **Efficiency of the mechanism**

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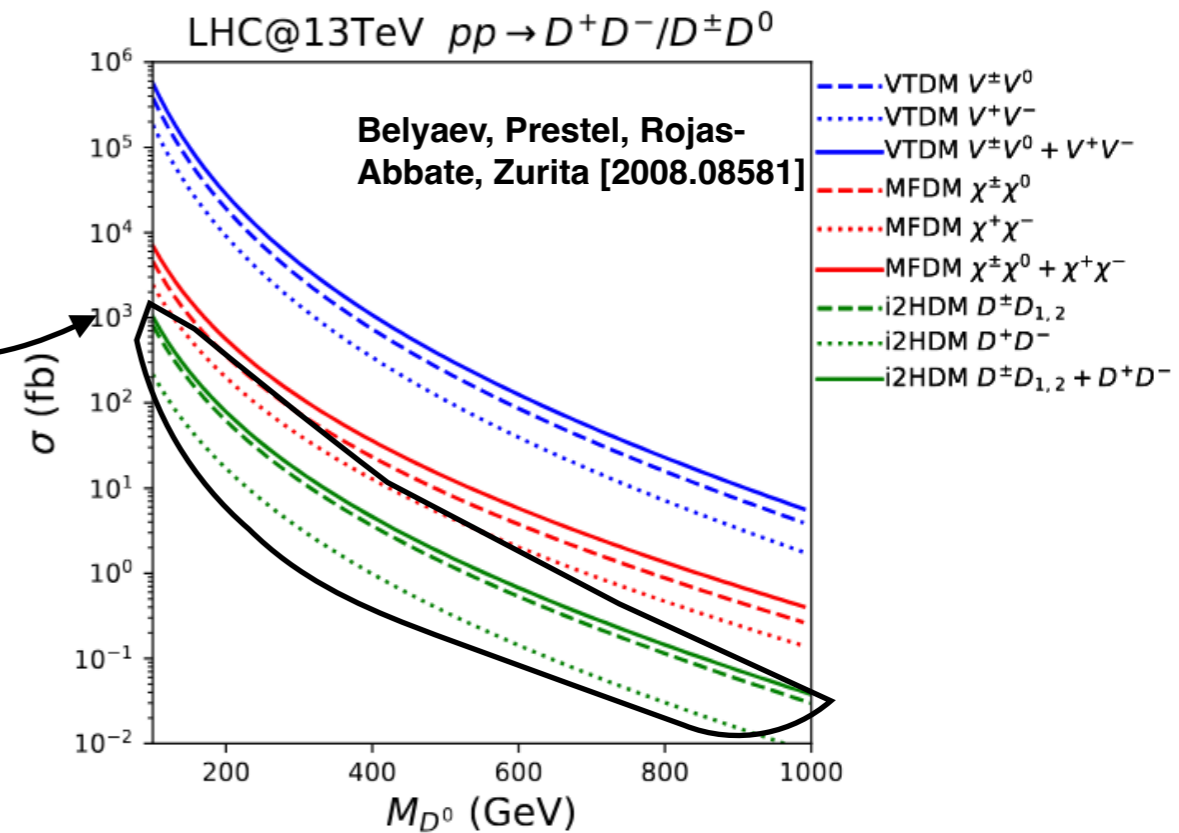


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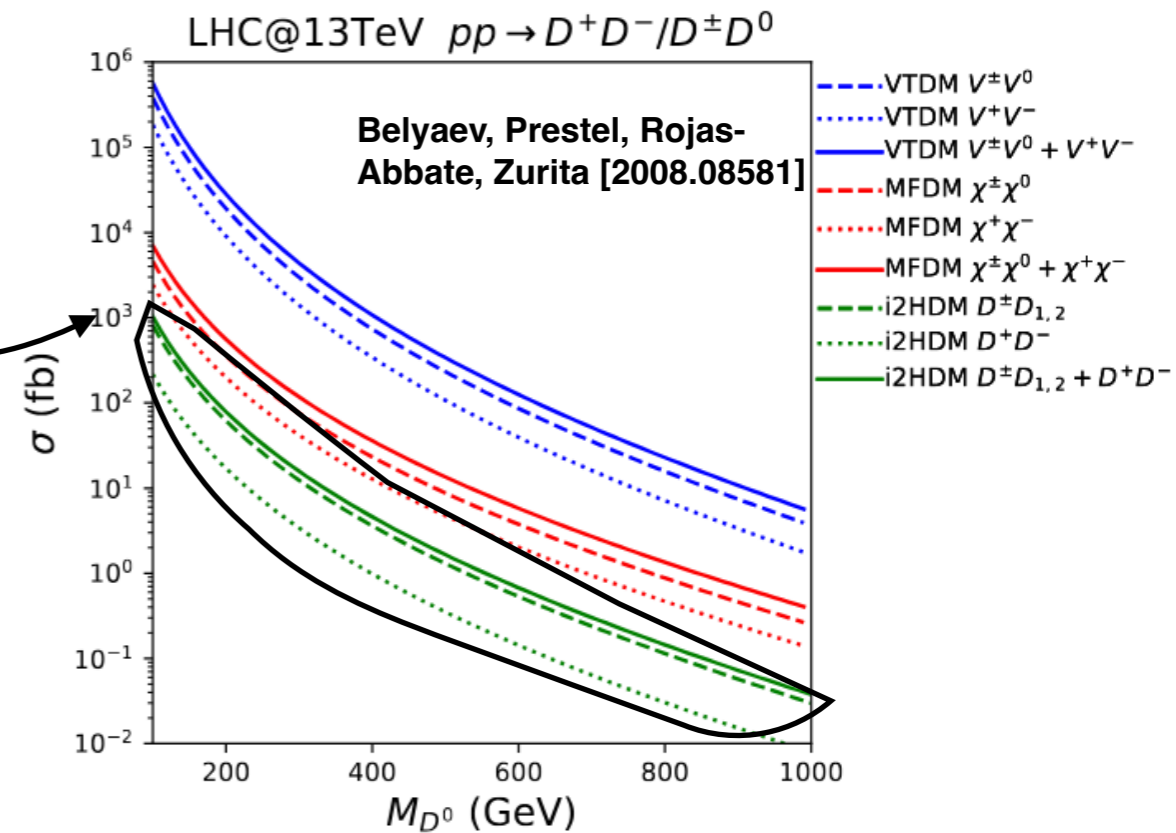
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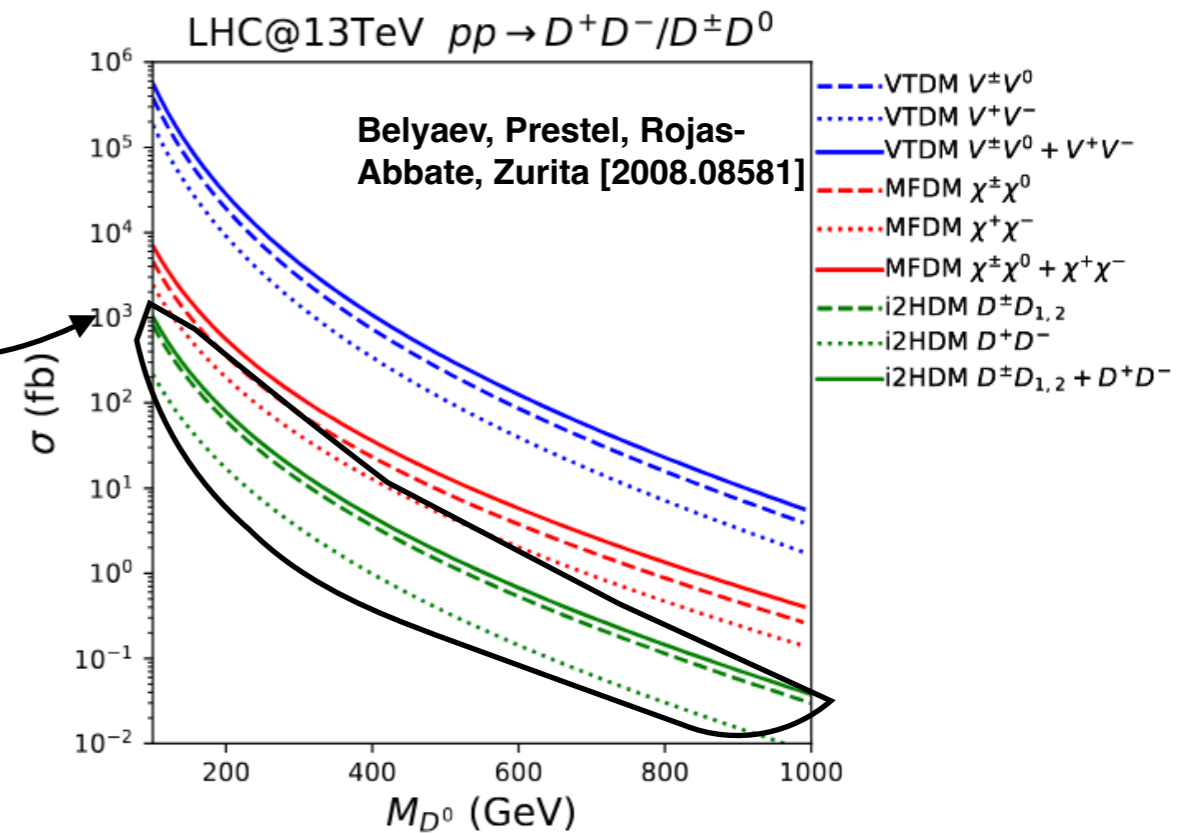
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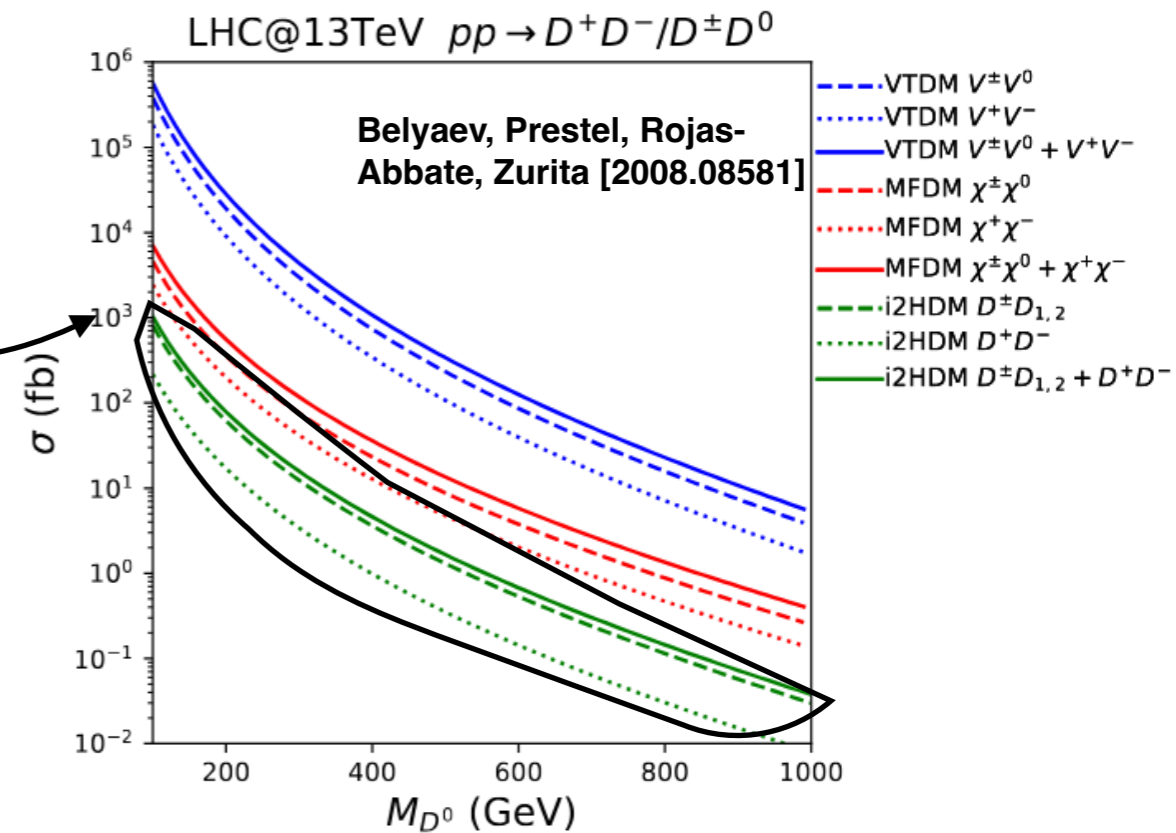
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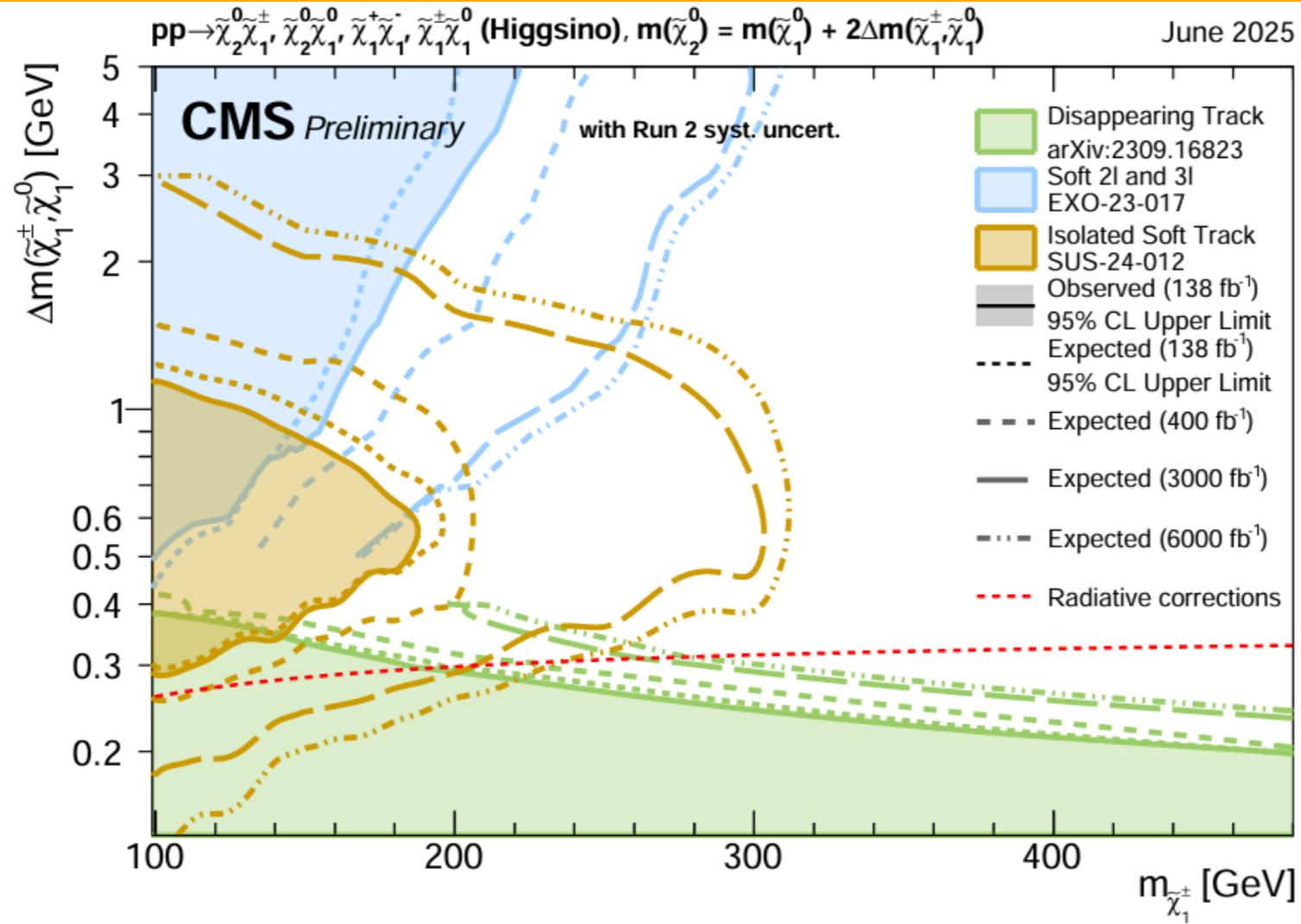
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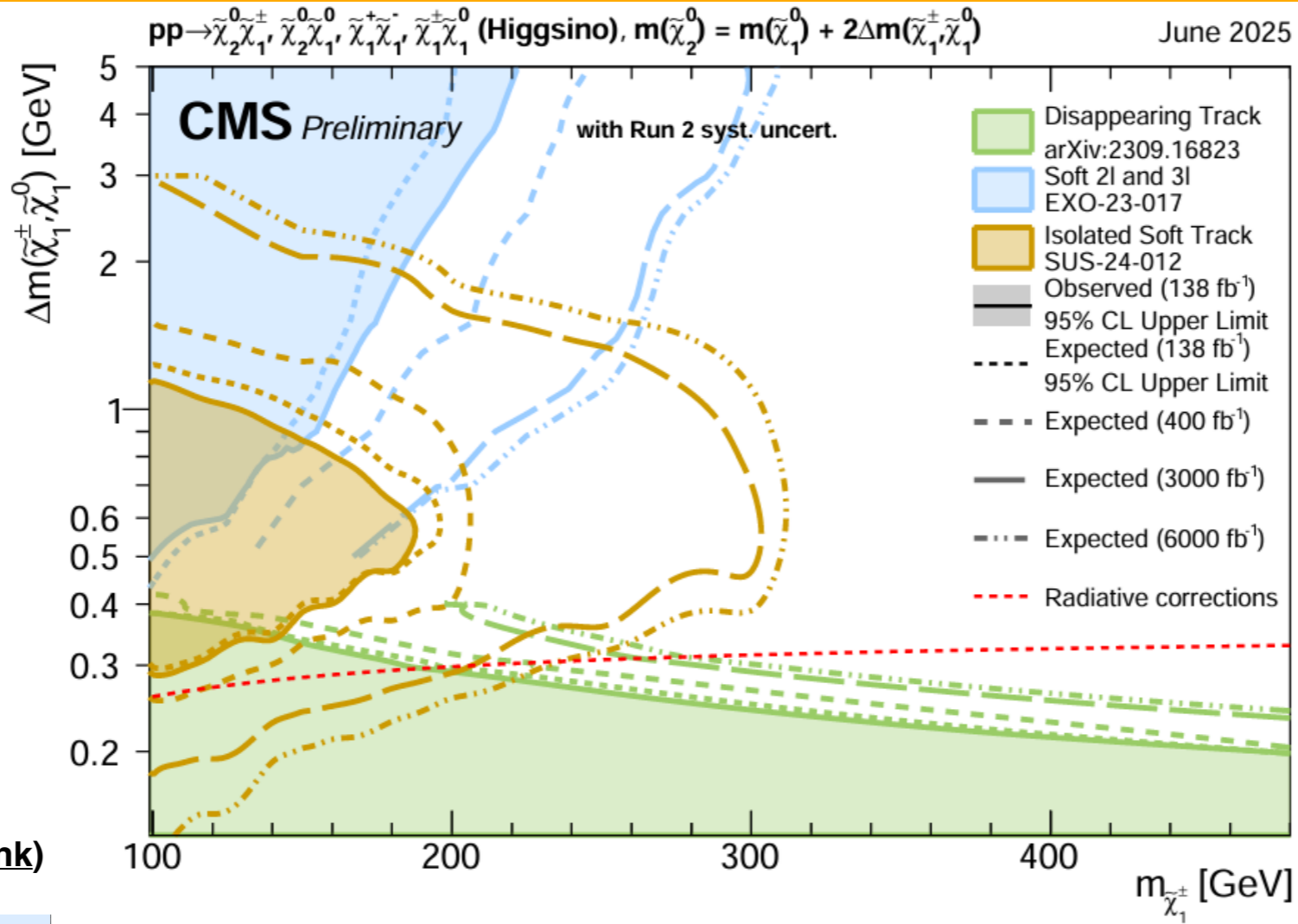
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It can nevertheless lead to striking signatures such as disappearing charged tracks or displaced pions.

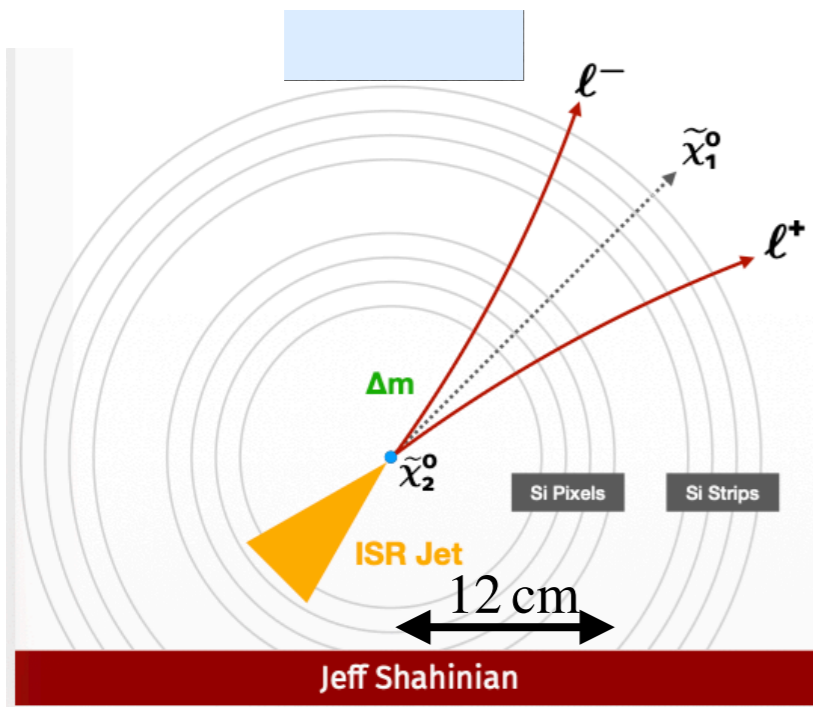
Current LHC searches



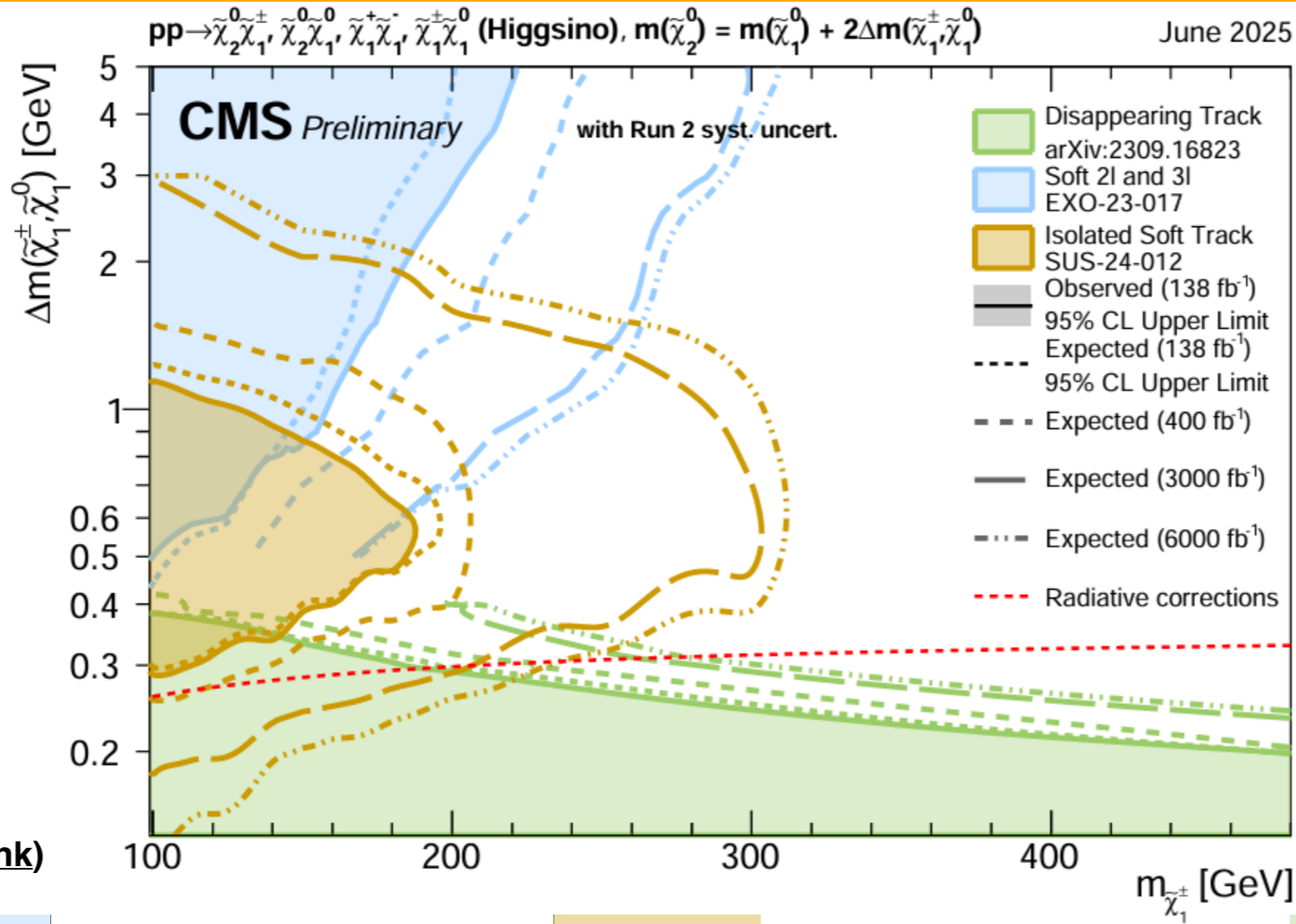
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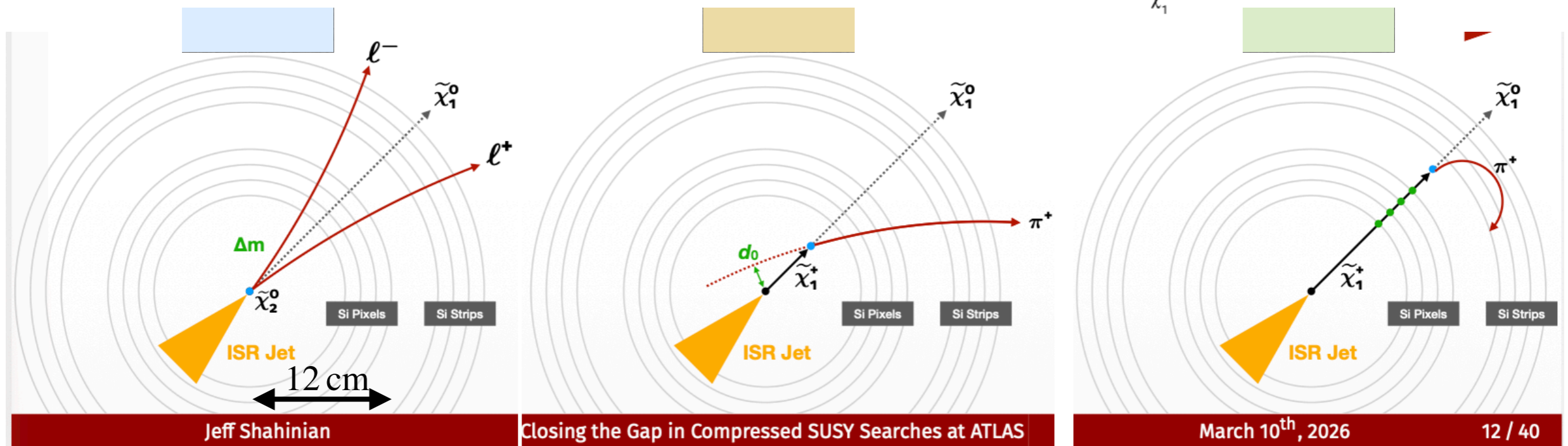
taken from Jeff Shahinian ([link](#))



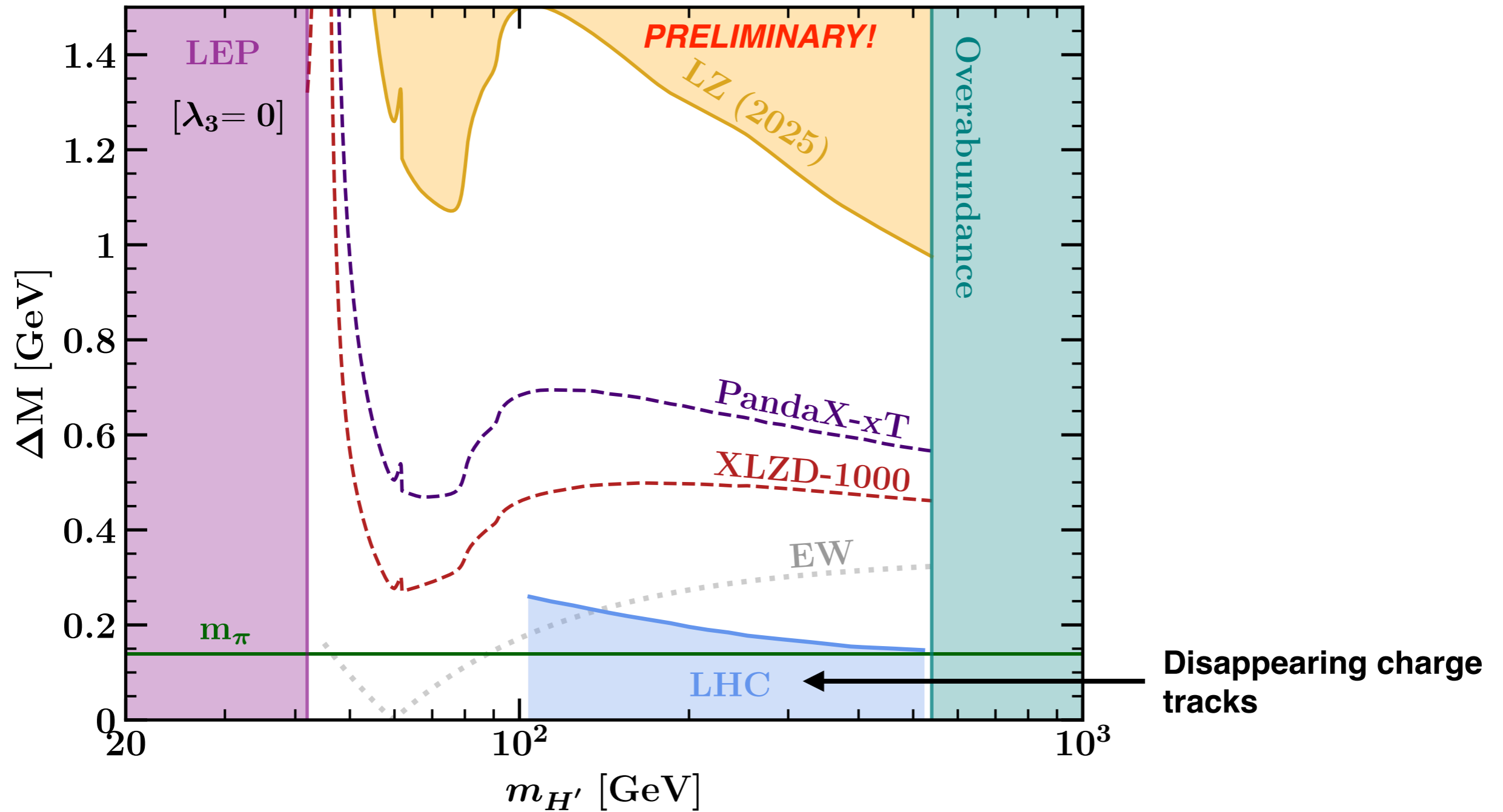
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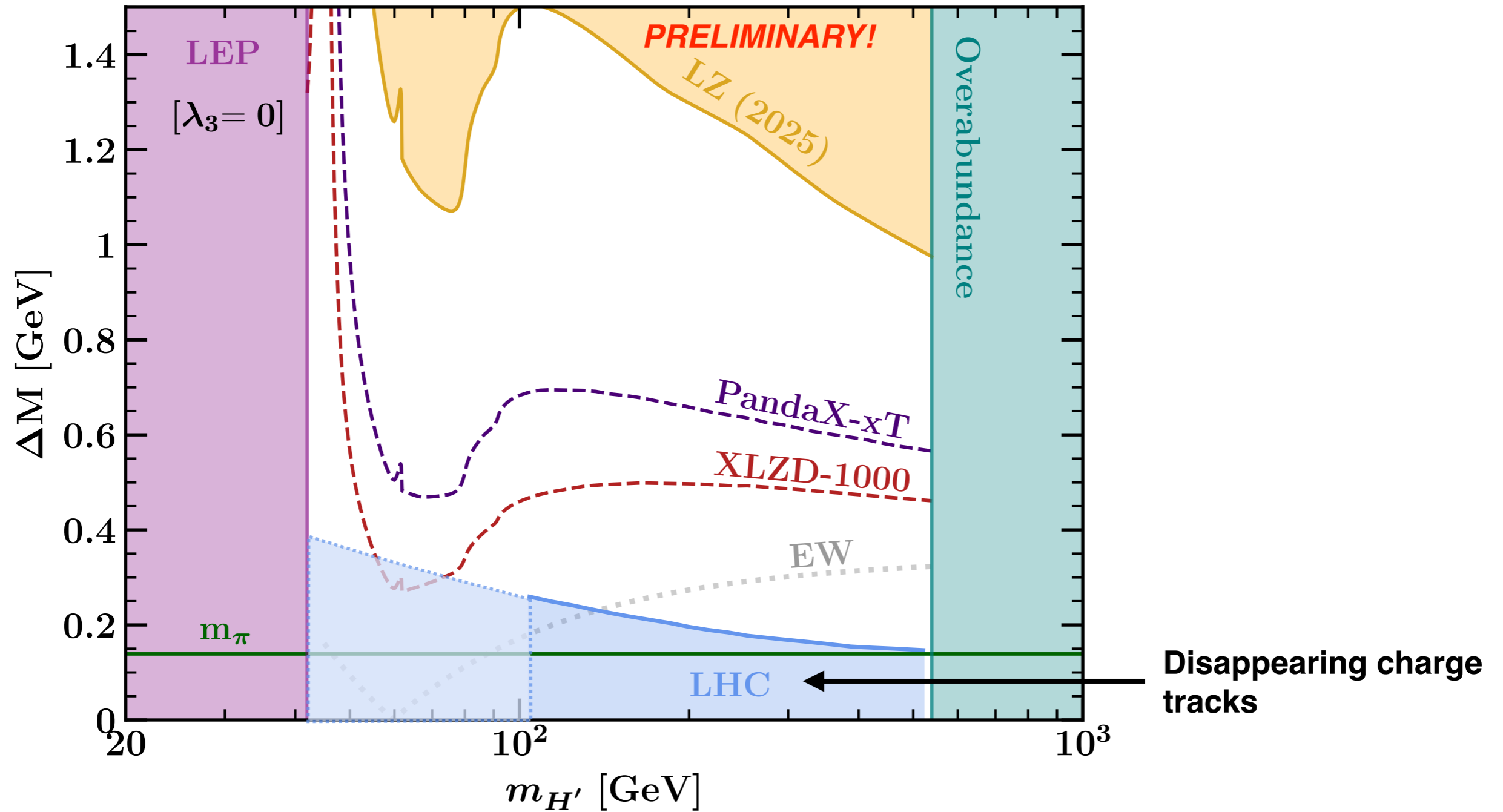
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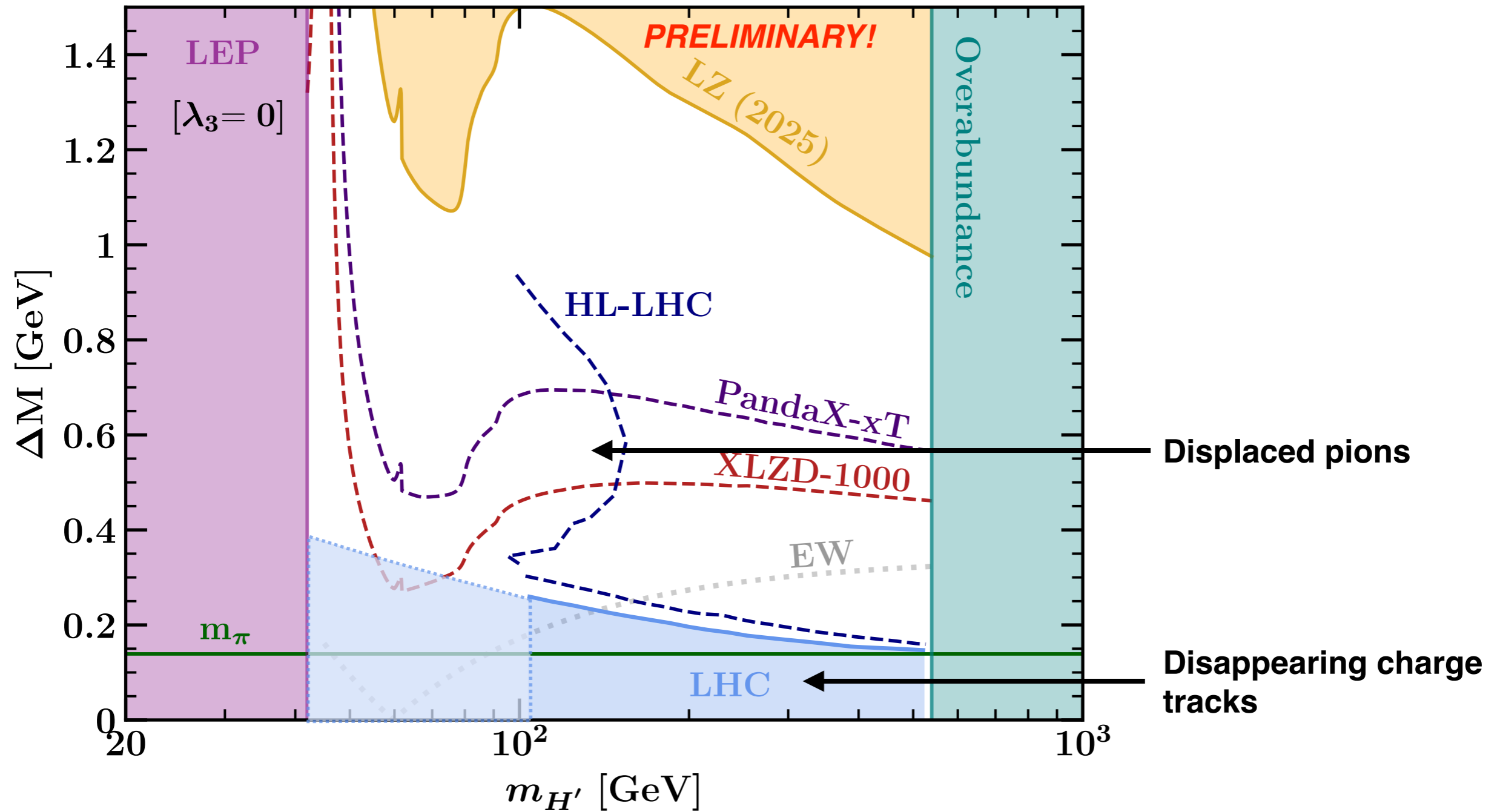
Global results



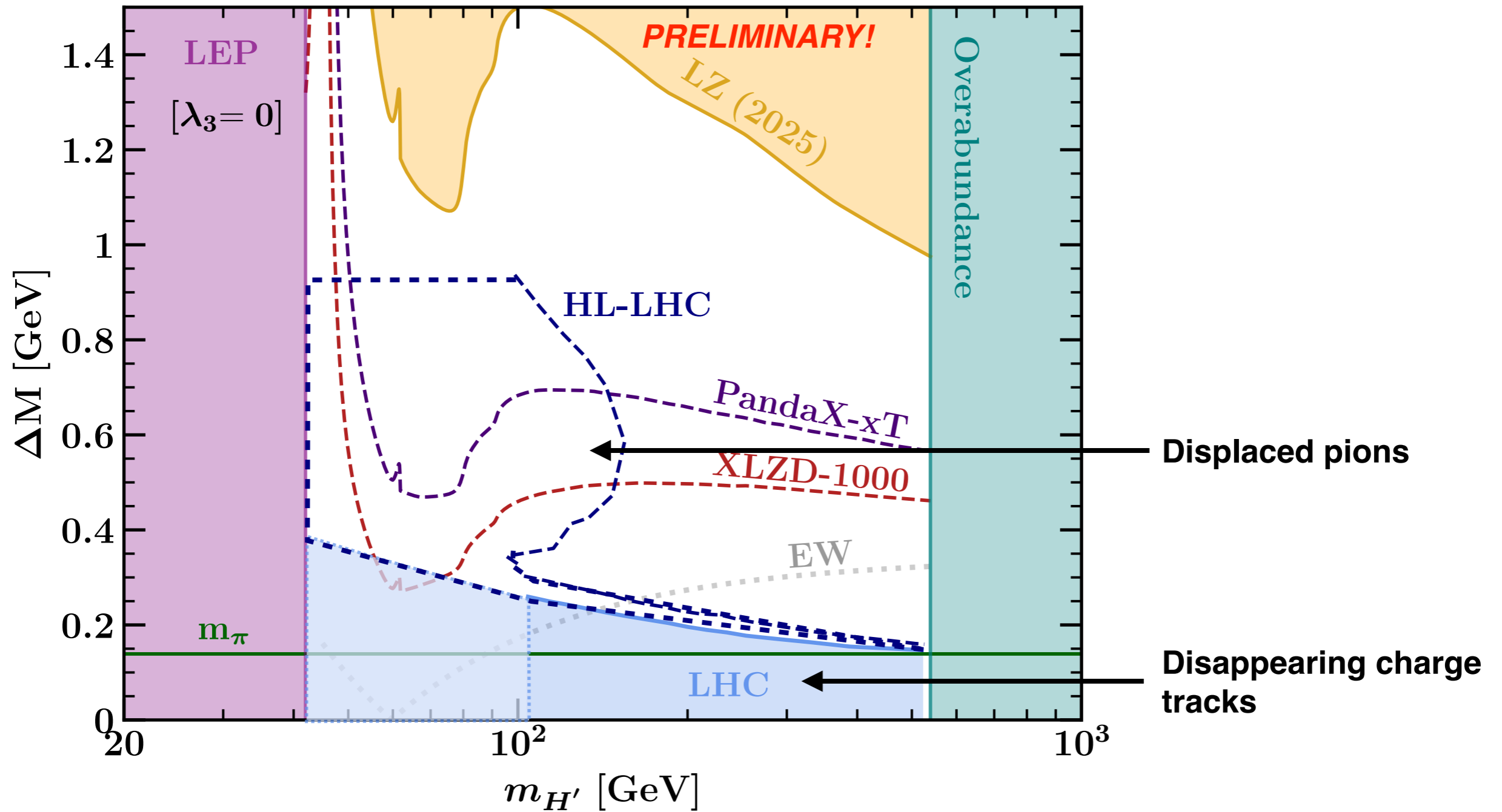
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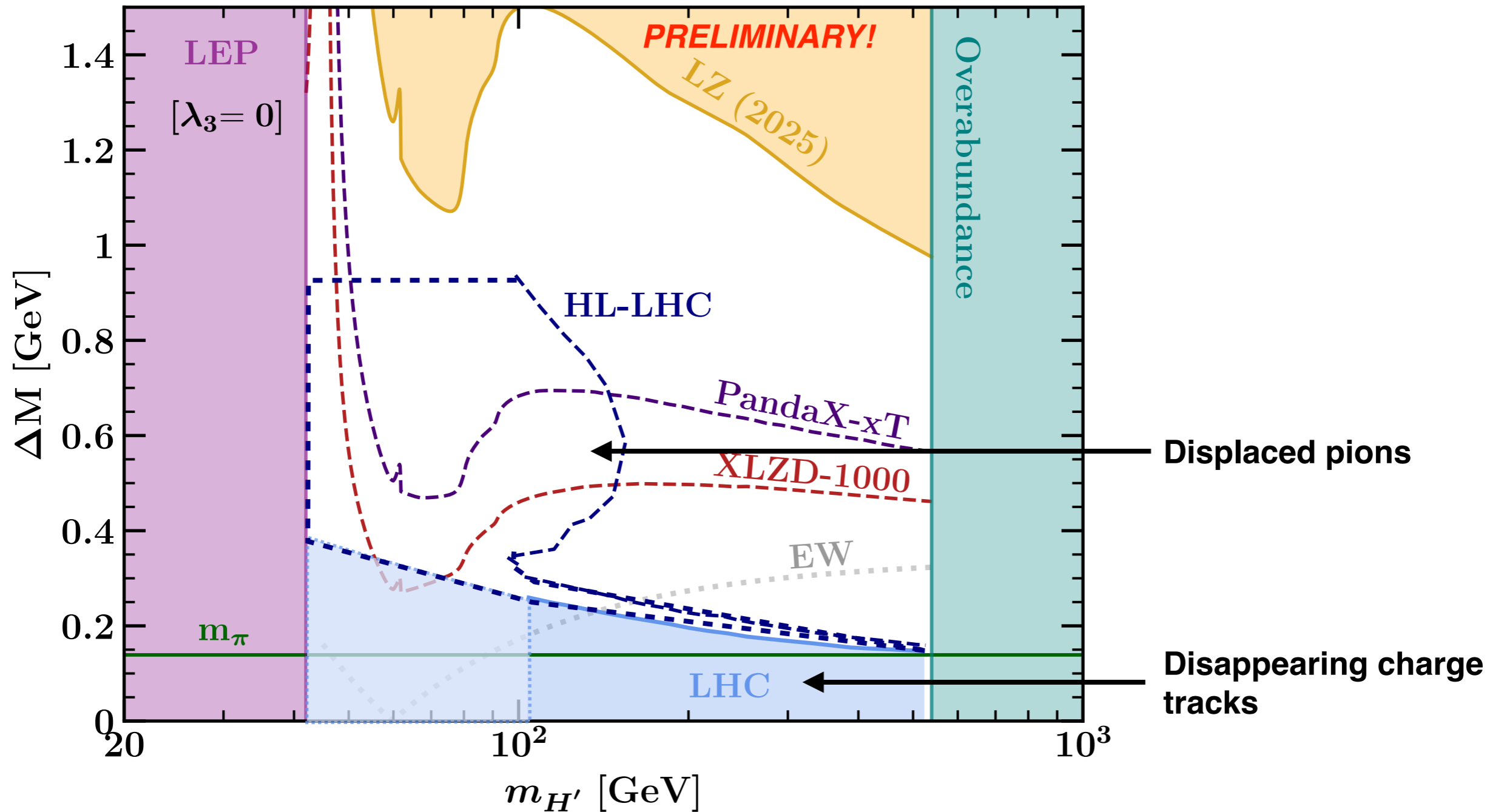
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In the absence of cancellations a large fraction of the parameter space can be tested by Direct Detection experiments and the HL-LHC.

Summary: Theory

Proposed what we think may be the simplest Baryogenesis induced Asymmetric Dark Matter model

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Only two new BSM fields: ϕ (complex singlet scalar) $+1$ Z_4
 H' (inert Higgs doublet) -2

Multicomponent dark matter ϕ $\bar{\phi}$ H_0

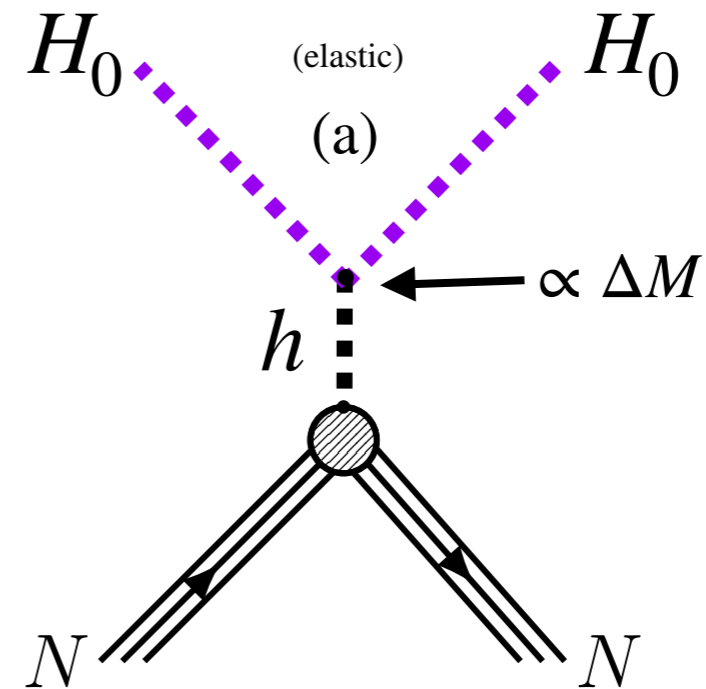
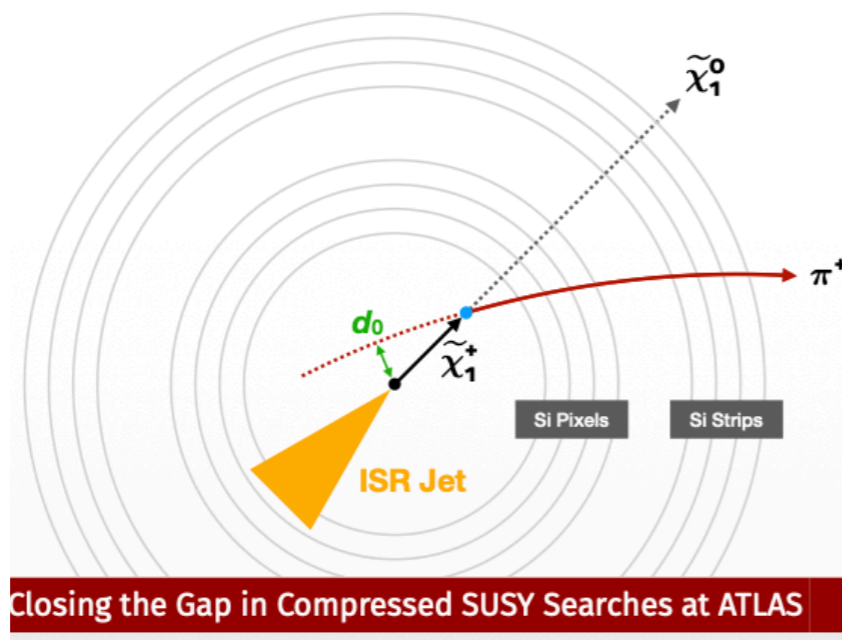

We can relate the dark matter abundance to the baryon asymmetry of the Universe, as generated by e.g. Leptogenesis. Compatible with all baryogenesis mechanisms working at $T > 1$ TeV.

Summary: Signals

The cosmology of the mechanism requires a light and compressed inert Higgs doublet

This H' is relatively unconstrained at the moment and can be as light as 46 GeV!

The model is very predictive and we have shown that in the absence of cancellations (i.e. $\lambda_3 \neq -\lambda_4$) the scenario can be tested by a combination of Direct Detection experiments and the HL-LHC.



Outlook/Theory/Cosmology

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The interaction Lagrangian:

$$\begin{aligned} V(H, H', \phi) &= m^2 |\phi|^2 + m_{H'}^2 |H'|^2 + \lambda_{\phi H} |\phi|^2 |H|^2 \quad (2) \\ &+ \lambda_{\phi H'} |\phi|^2 |H'|^2 + \lambda_3 |H|^2 |H'|^2 + \lambda_4 |H^\dagger H'|^2 \\ &\lambda_{\bar{\phi}^2 H H'} \bar{\phi}^2 H^\dagger H' + \left(\frac{\lambda_{\phi^2 H H'}}{2} \phi^2 H^\dagger H' + h.c. \right) + \frac{\lambda_5}{2} \left((H^\dagger H')^2 + h.c. \right). \end{aligned}$$

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 \sim 10^{-6} & \quad \sim 10^{-6} \quad \sim 10^{-6} \quad \sim 10^{-6} \\
 H\bar{H}' \rightarrow \bar{\phi}\bar{\phi} & \quad H\bar{H}' \rightarrow \phi\phi \quad HH \leftrightarrow H'H' \quad \phi\phi \rightarrow \bar{\phi}\bar{\phi}
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 \sim 10^{-6} \quad & \sim 10^{-6} \quad \sim 10^{-6} \quad \sim 10^{-6} \\
 H\bar{H}' \rightarrow \bar{\phi}\bar{\phi} \quad & H\bar{H}' \rightarrow \phi\phi \quad HH \leftrightarrow H'H' \quad \phi\phi \rightarrow \bar{\phi}\bar{\phi}
 \end{aligned}$$

Hierarchy of couplings which is technically natural. Nevertheless, can one find a theoretical reason as to why?

Outlook/Theory/Cosmology

We need a Z4 symmetry, U(1)s do not work. Are there more set ups?

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Having a renormalizable model not only makes it simple but allows us to highlight that CP is a good symmetry. The CP violating effects are negligible because the couplings are tiny!

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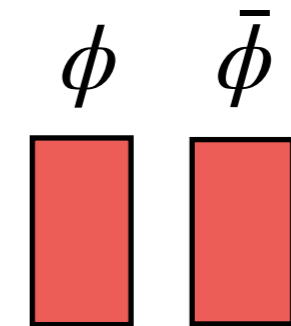
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the same is not true for symmetric freeze-in!

Acknowledgements

Great thanks to my outstanding collaborators!

Thomas Hambye



Chandan Hati



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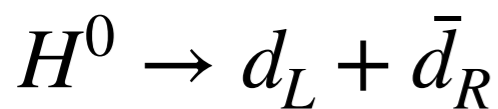
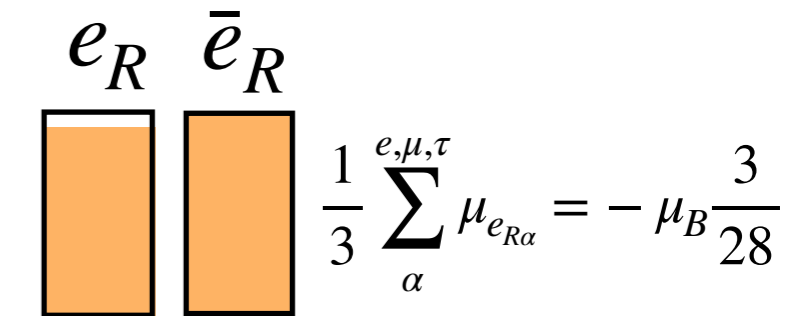
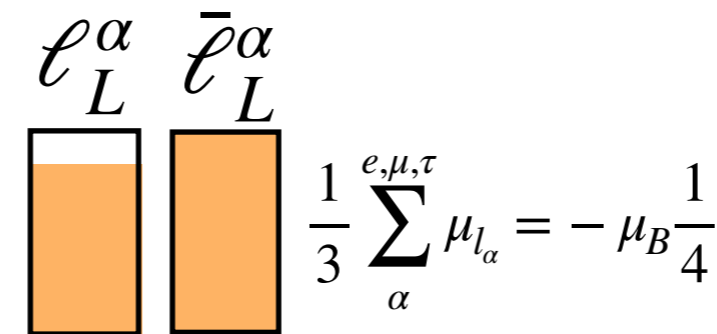
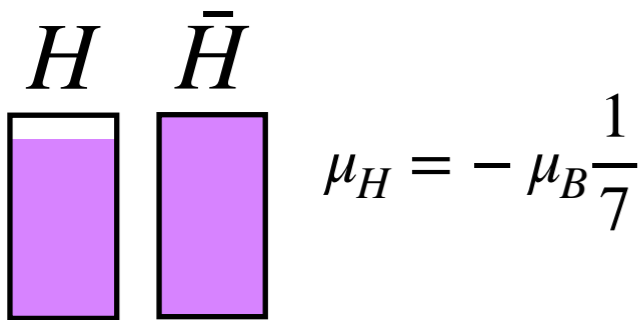
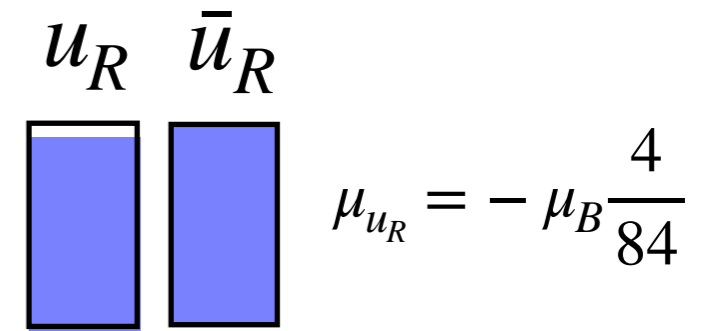
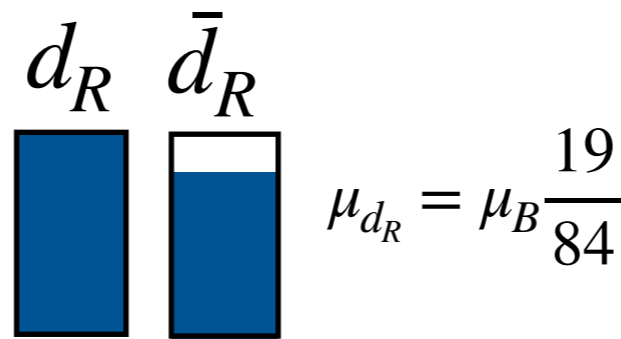
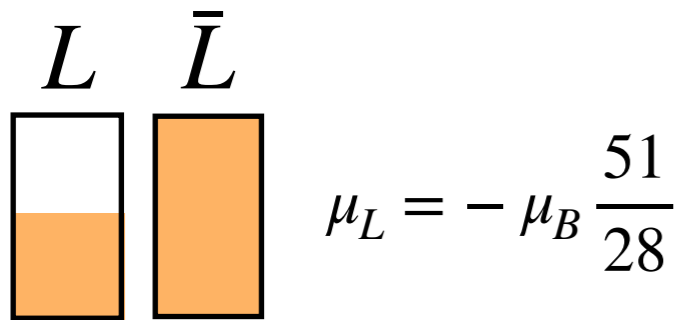
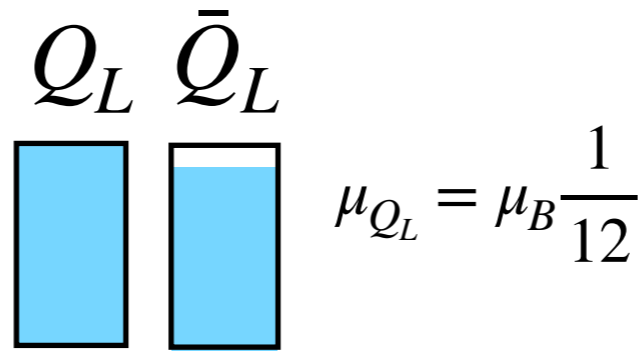
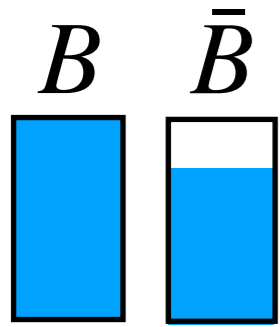


Guilherme Guedes



Thanks for the invitation and for your attention!
Questions, comments and criticism are most welcome

Chemical relations in the SM



Note that this ends up being multiplied by two as we have also the neutrinos!

all components in the doublets have the same chemical potential due to the fact that $\mu_W = 0$.