Unlocking the Inelastic Dark Matter window with Vector Mediators

Ana Luisa Foguel

in collaboration with Peter Reimitz and Renata Z. Funchal

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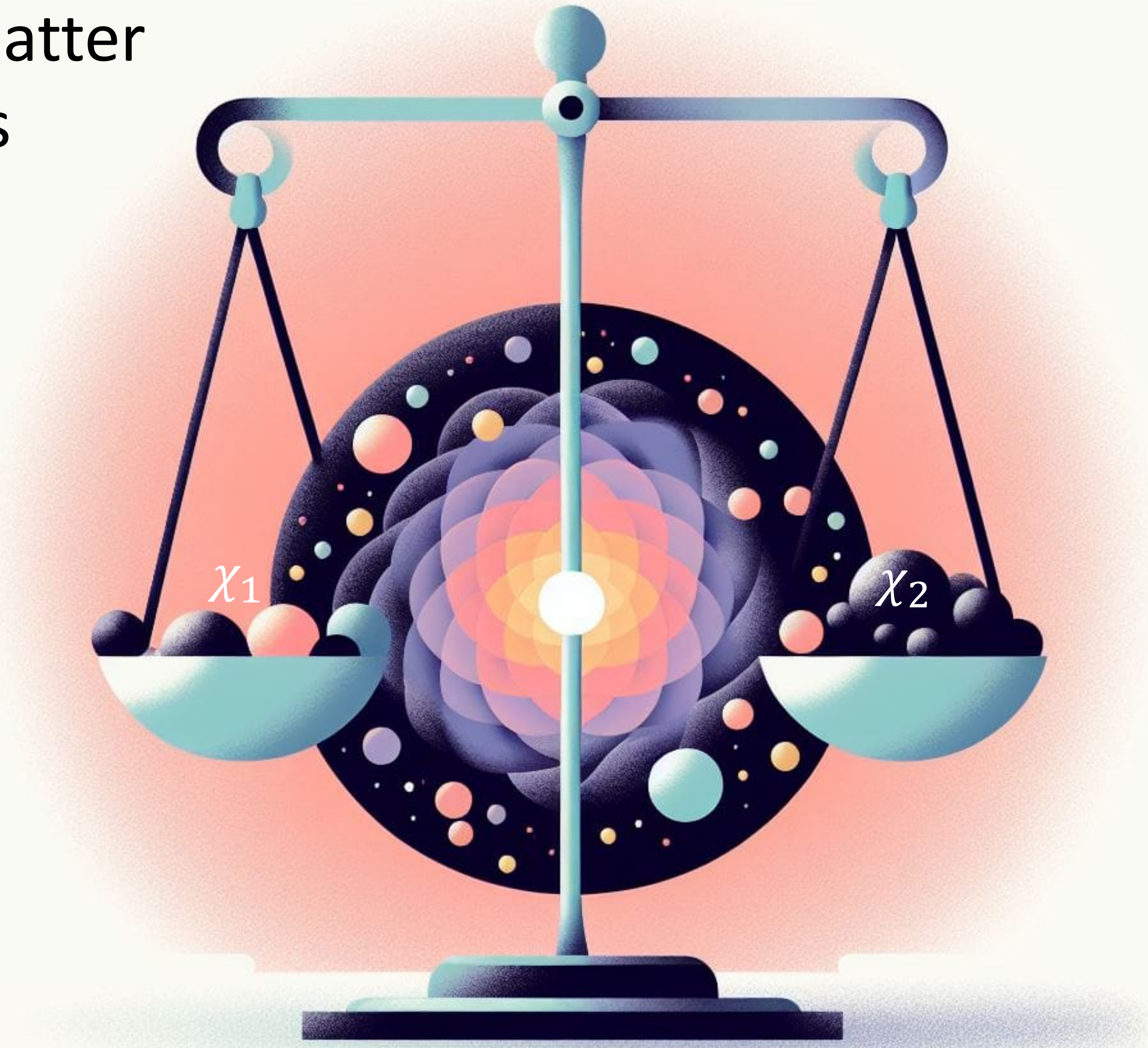
afoguel@usp.br

University of São Paulo, São Paulo, Brazil

IFT/UAM, Madrid, Spain

Dark Matter and Neutrinos School

07 May 2025

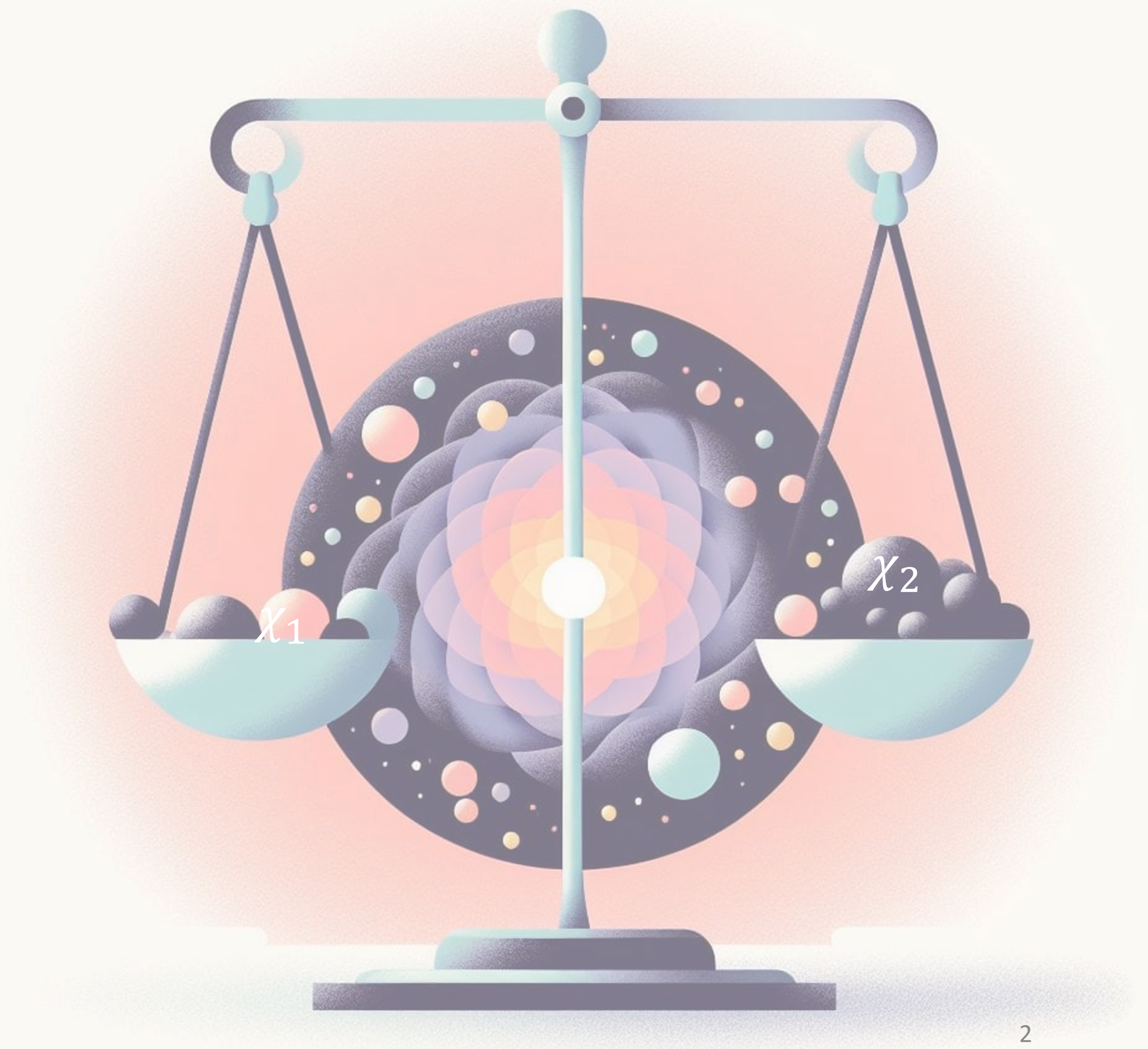


IFUSP Instituto de Física da USP

FAPESP

Outline

1. Introduction and Motivations
2. Inelastic Dark Matter
   - Theoretical framework
   - Decay Rates
3. Relic Density Computation
4. ReD-DeLiVeR code
5. Bounds
6. Conclusions

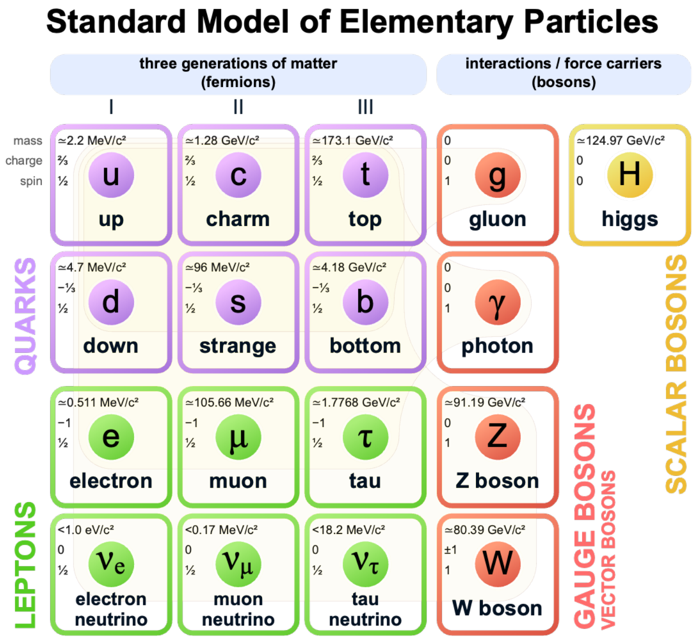


Introduction and Motivations

Standard Model (SM)

→ most successful description of the fundamental interactions between elementary particles (up to this date!)

→ several confirmed experimental predictions



However... it cannot be the final theory of Nature!

There are several problems and unanswered questions

- Hierarchy Problem
- Neutrino Masses
- Dark Matter candidates + ⋯

?

How can we find a solution?

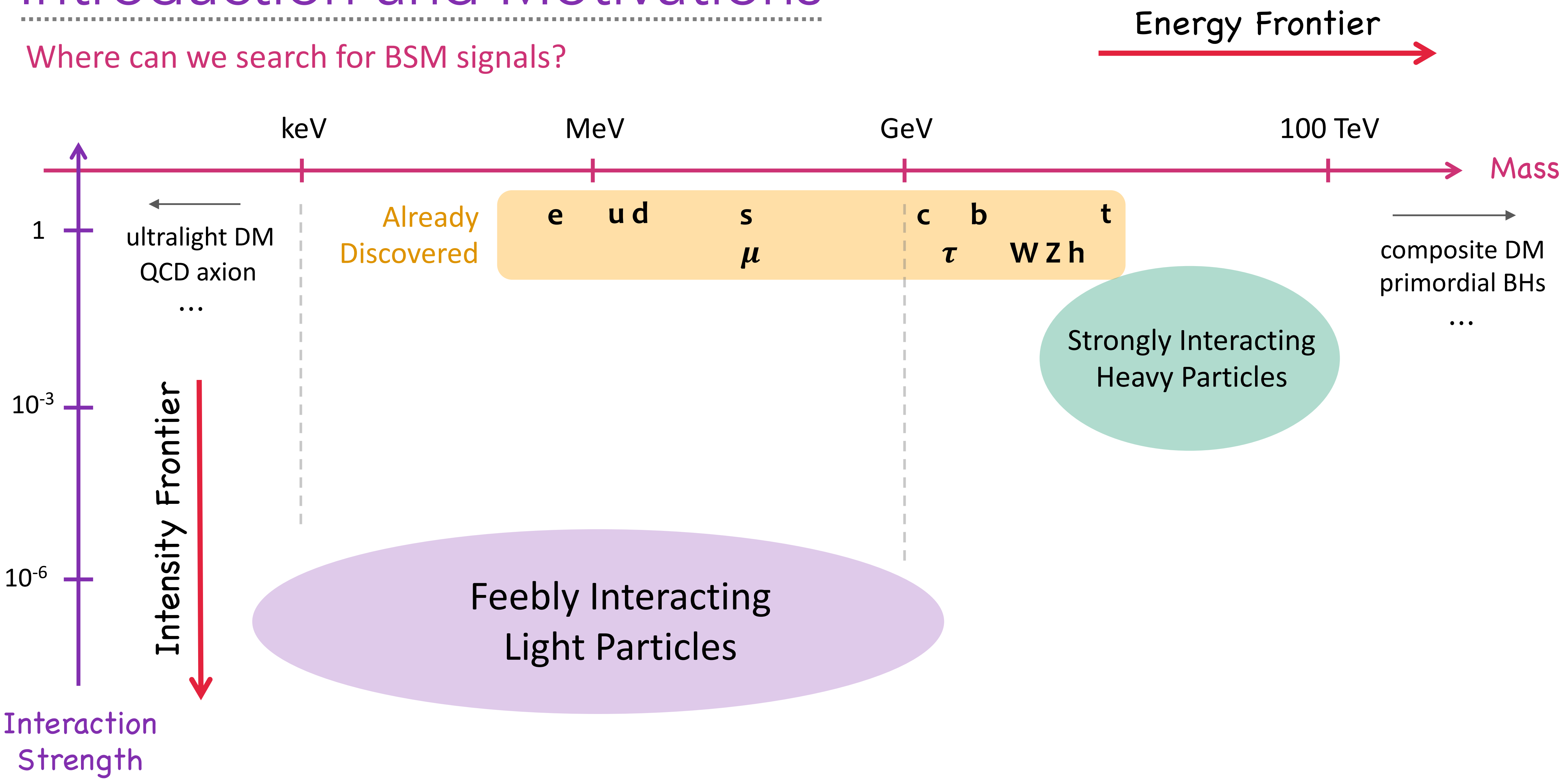
We need to rely on Beyond the Standard Model (BSM) theories

SM gauge group

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$$

Introduction and Motivations

Where can we search for BSM signals?



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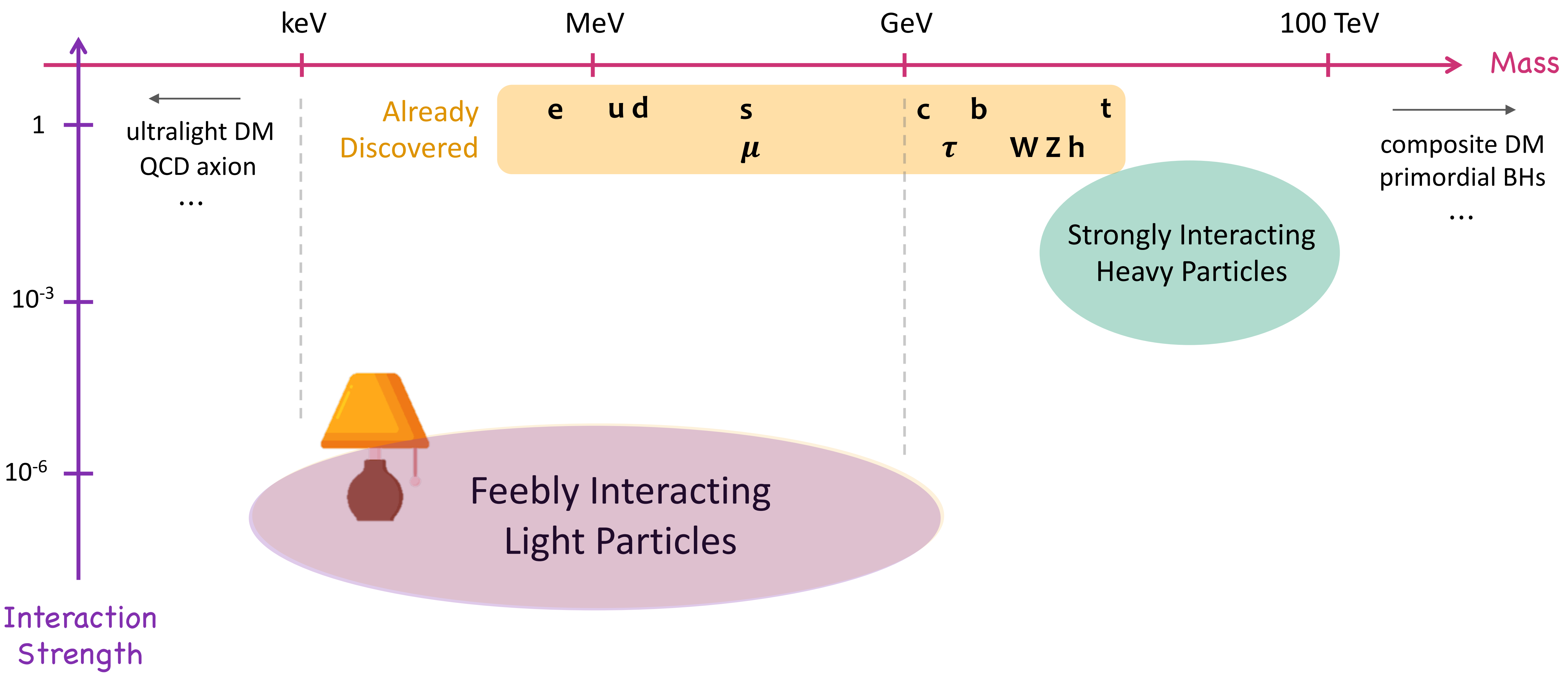

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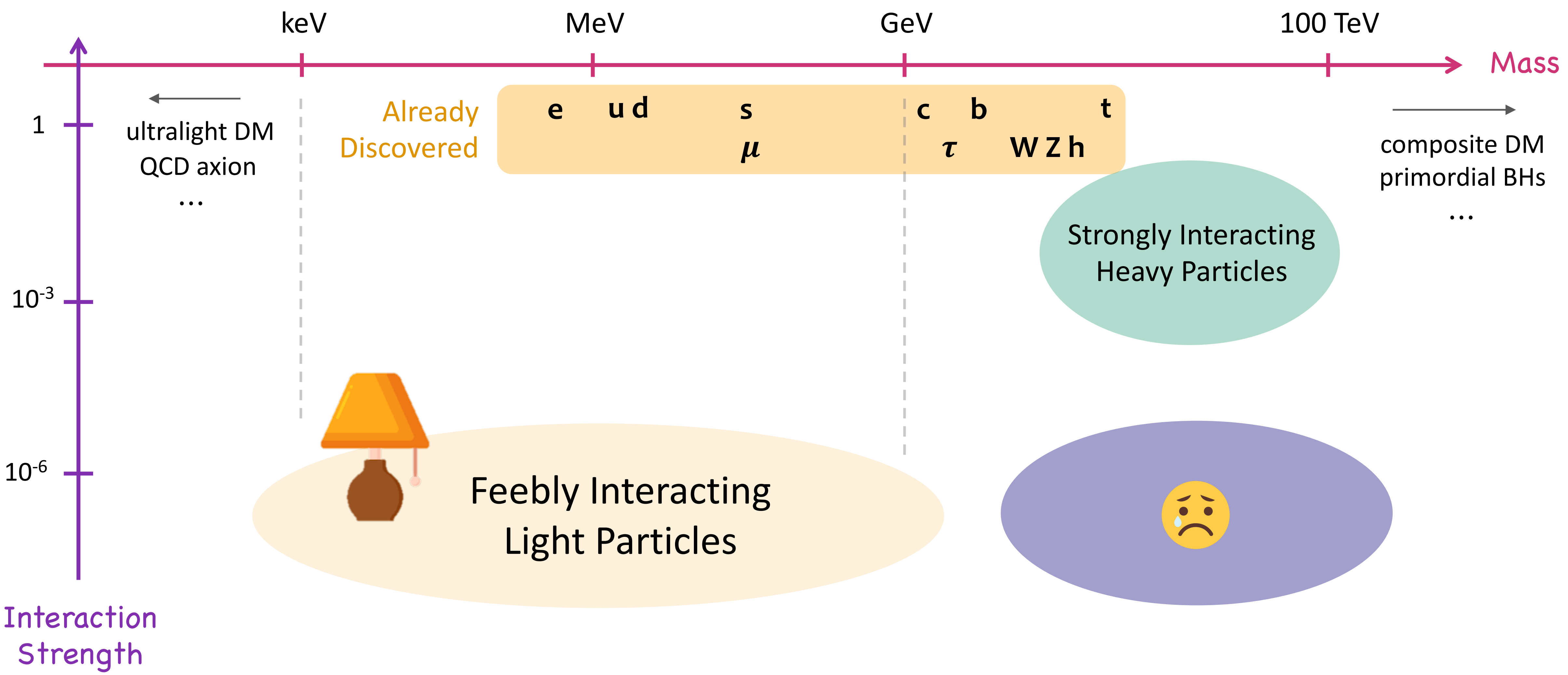
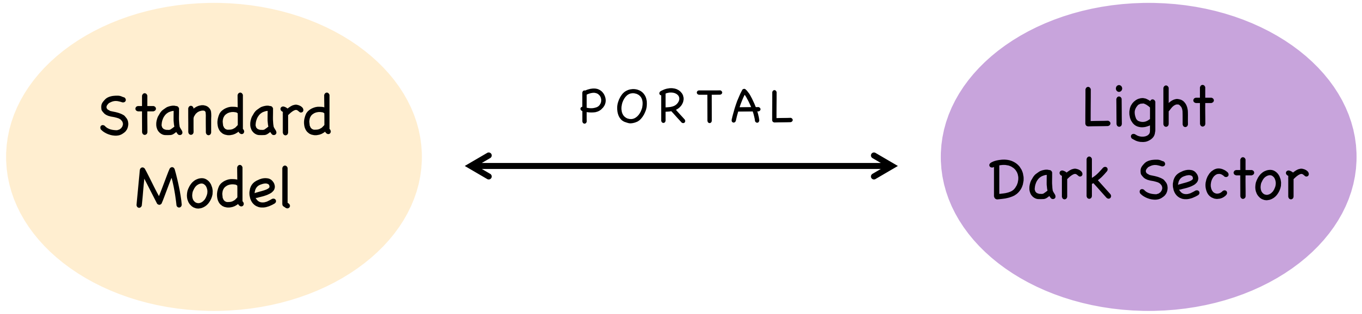


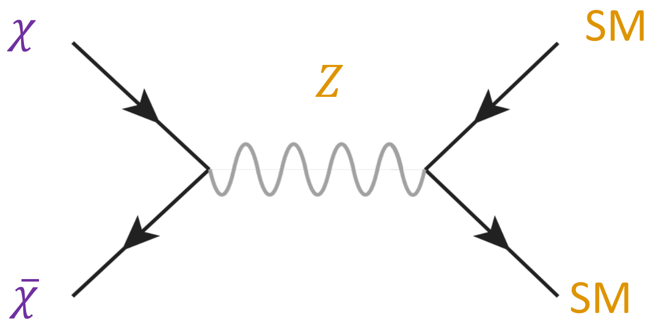
Introduction and Motivations

How can we search for light particle BSM signals?



Suppose we have particles χ and $\bar{\chi}$ in the dark sector

natural possibility: couple to the gauge bosons of weak interactions



However...

$$\langle \sigma v \rangle \sim \frac{m_\chi^2}{m_Z^4}$$

which means that lowering the DM mass decreases the thermal-average cross section

→ DM is overproduced!

Lee-Weinberg bound

$$m_\chi \gtrsim 2\,\mathrm{GeV}$$

Introduction and Motivations

How can we search for light particle BSM signals?

Lee-Weinberg bound

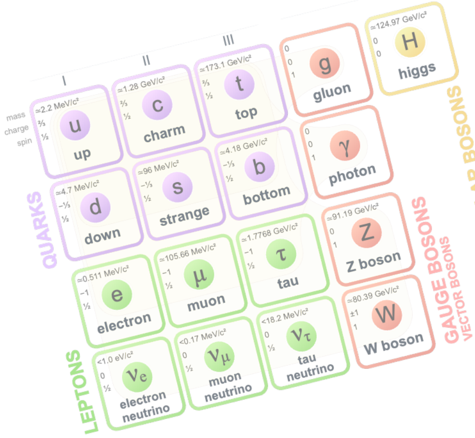
$$m_\chi \gtrsim 2\,\mathrm{GeV}$$

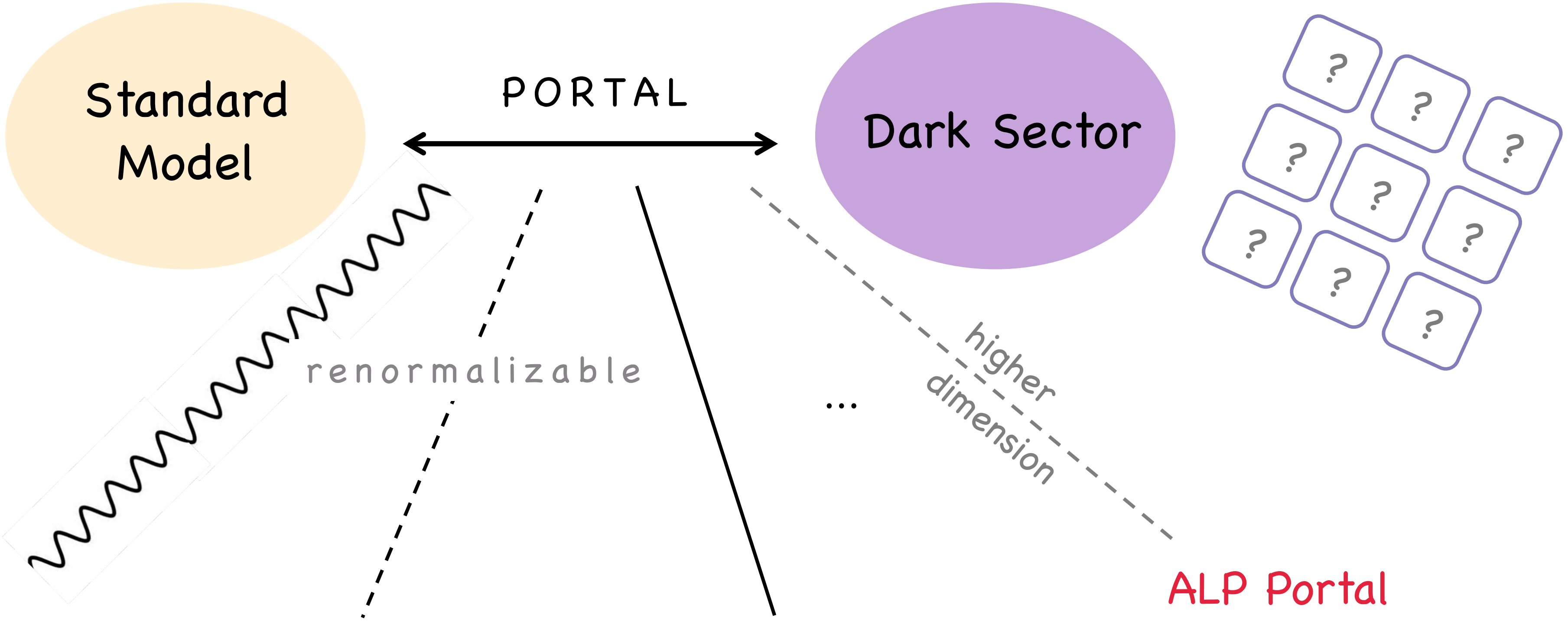
$\Rightarrow$ So, how can we explore sub-GeV dark sectors?

solution: inclusion of new light dark sector mediator states!

These light mediators will act as portals between the dark sector and the SM.

How can we search for light particle BSM signals?





Vector Portal

$$\mathcal{L}_{\rm KM} = \epsilon\, \hat{Z}_{Q\mu\nu}\hat{B}^{\mu\nu}$$

dark boson

Scalar Portal

$$V(H,S) \supset \kappa\,|H|^2|S|^2$$

dark Higgs

Neutrino Portal

$$\mathcal{L} \supset -y^{\alpha} L_{\alpha} H N + \mathrm{h.c.}$$

Heavy Neutral Lepton

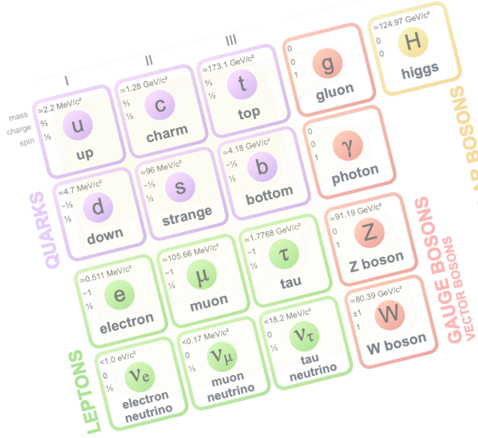
ALP Portal

axion-like-particle

a → photons
→ leptons
→ ...

Introduction and Motivations · Hidden Portals

How can we search for light particle BSM signals?

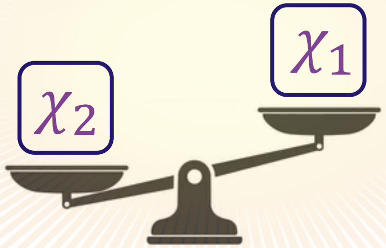


Standard Model

PORTAL

Dark Sector

Inelastic Dark Matter



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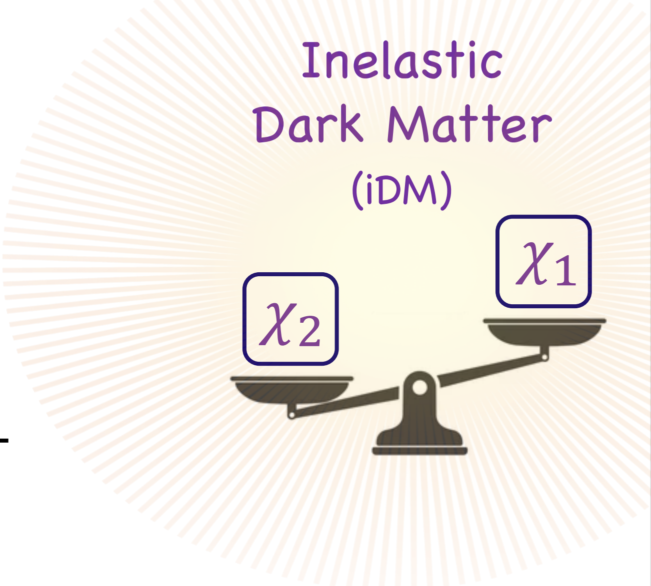
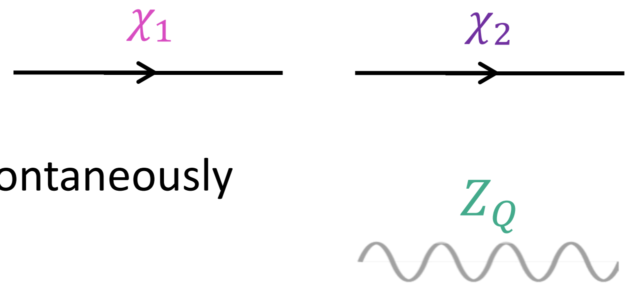
Inelastic Dark Matter

Theoretical Framework



Dark Sector

- two-component Weyl fermions forming a Dirac pair $\Rightarrow$ pseudo-Dirac pair
- new vector mediator coming from a spontaneously broken $\mathrm{U}(1)_\mathrm{Q}$ abelian gauge symmetry



From the diagonalization of the fermion mass terms

$$\mathcal{L} \supset \underbrace{-m_D \psi_1 \psi_2}_{\text{Dirac}} - \underbrace{\frac{1}{2}(\delta_1\, \psi_1^2 + \delta_2\, \psi_2^2)}_{\text{Majorana}} + \text{h.c.}\,, \qquad \text{with} \qquad \delta_{1,2} \ll m_D$$

$\Rightarrow$ mass eigenstates

$$\chi_1 \simeq \frac{i}{\sqrt{2}}(\psi_1 - \psi_2), \qquad \chi_2 \simeq \frac{1}{\sqrt{2}}(\psi_1 + \psi_2)\,,$$

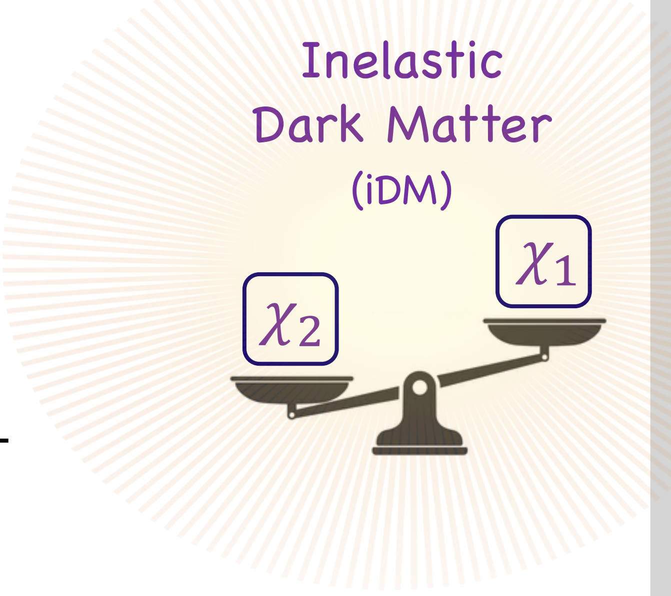
pseudo-Dirac pair with nearly degenerate masses

$$m_{1,2} \simeq m_D \mp \frac{1}{2}(\delta_1 + \delta_2) \quad \Rightarrow$$

Mass splitting

$$\boxed{\Delta := \frac{m_2 - m_1}{m_1} = \frac{\delta_1 + \delta_2}{m_1} < 1}$$

Inelastic Dark Matter



Theoretical Framework

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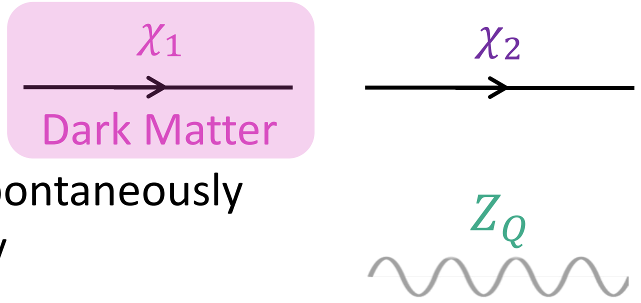
pseudo-Dirac pair



From the diagonalization of the fermion mass terms

Dirac — Majorana

$$\mathcal{L} \supset -m_D\psi_1\psi_2 - \frac{1}{2}(\delta_1\,\psi_1^2 + \delta_2\,\psi_2^2) + \text{h.c.}\,, \qquad \text{with} \qquad \delta_{1,2} \ll m_D$$

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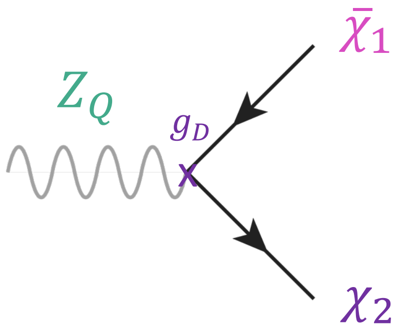
Inelastic Dark Matter



Theoretical Framework

The interaction term with the mediator turns to be off-diagonal

$$\mathcal{L} \supset g_D Z_{Q\mu}(\psi_1^\dagger \bar{\sigma}^\mu \psi_1 - \psi_2^\dagger \bar{\sigma}^\mu \psi_2) \longrightarrow \mathcal{L}_{\text{int}}^{\text{D}} = \frac{i}{2} g_D Z_{Q\mu} \bar{\chi}_2 \gamma^\mu \chi_1 + \text{h.c.}$$

Motivations

- **Thermal relics:** DM abundance can be computed via thermal freeze-out.
- **Evades indirect and direct detection experimental limits**

The heavier state χ_2 can decay into the DM candidate χ_1, depleting its abundance

$\Rightarrow$ no present-day population of heavier states to co-annihilate with the DM $\rightarrow$ avoid indirect detection signals

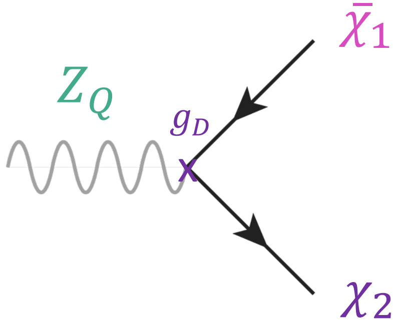
$\Rightarrow$ similarly, direct detection signals depend on up-scatter of the light state, which is kinematically suppressed

- **Evades stringent CMB limits**

Since the abundance of χ_2 is already reduced during recombination era, coannihilations that would inject energy into the plasma are suppressed.

Inelastic Dark Matter

Theoretical Framework



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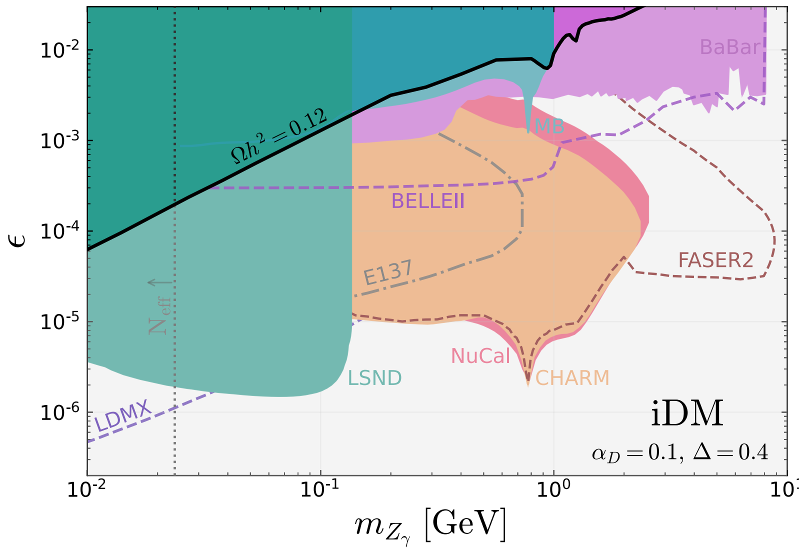
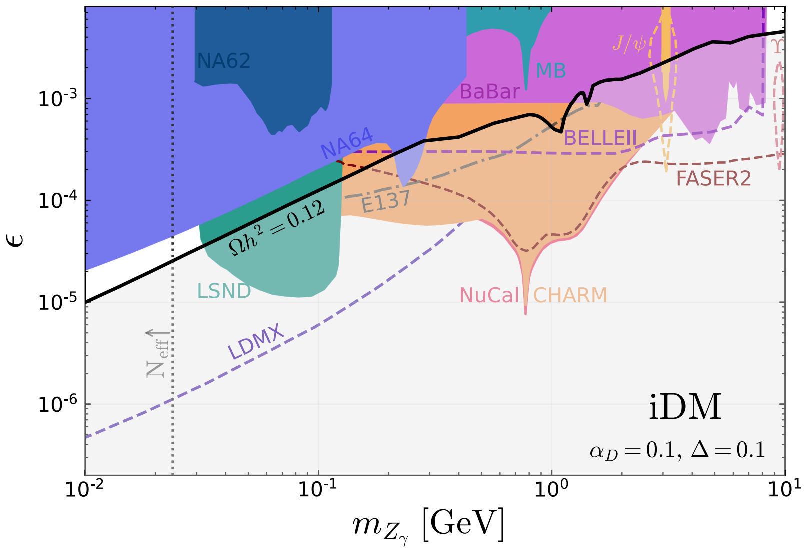
What's new?

- In the literature: only considered the minimal scenario with a secluded dark photon portal Z_D

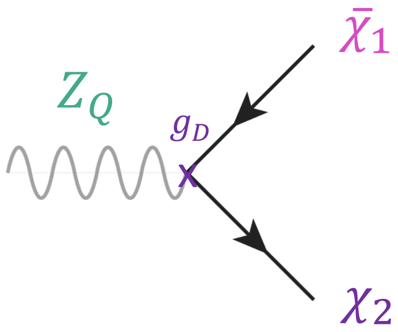
However… this case has been nearly completely ruled out by experimental limits…





Inelastic Dark Matter

Theoretical Framework



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What's new?

- This work: we consider the case of generic charges for the $\mathrm{U}(1)_\mathrm{Q}$ group

$\Downarrow$

vector mediator also couples to the SM via direct terms depending on the choice of charge

$$\mathcal{L}_{\rm int}^{\rm SM} = e\epsilon J^\mu_{\rm em} Z_{Q\mu} - g_Q J_Q^\mu Z_{Q\mu}$$

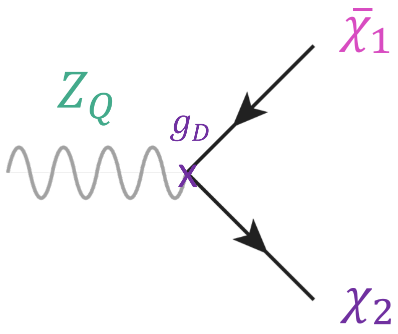
$$J_Q^\mu = \sum_f q_Q^f \, \bar{f}\gamma^\mu f + \sum_{\ell=e,\mu,\tau} q_Q^{\nu_\ell} \, \bar{\nu}_\ell \gamma^\mu P_L \nu_\ell,$$

$$Q = x_B B - x_e L_e - x_\mu L_\mu - x_\tau L_\tau$$

x_B	x_e	x_μ	x_τ	Q	q_Q^f			
					quarks	e/ν_e	μ/ν_μ	τ/ν_τ
1	1	1	1	$B-L$	$\frac{1}{3}$	-1	-1	-1
1	0	0	3	$B-3L_\tau$	$\frac{1}{3}$	0	0	-3
1	0	0	0	B	$\frac{1}{3}$	0	0	0
0	0	-1	1	$L_\mu - L_\tau$	0	0	1	-1

Inelastic Dark Matter

Theoretical Framework



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$$\mathcal{L}_{\rm int}^{\rm SM} = e\epsilon J^\mu_{\rm em} Z_{Q\mu} - g_Q J^\mu_Q Z_{Q\mu}$$

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ALF, P. Reimitz, R.Z. Funchal
arXiv:2410.00881 [hep-ph]

iDM$_Q$ models

free parameters: $m_{Z_Q},\ R,\ \Delta,\ g_Q,\ \alpha_D$

$$Q = x_B B - x_e L_e - x_\mu L_\mu - x_\tau L_\tau$$

x_B	x_e	x_μ	x_τ	Q	q_Q^f quarks	e/ν_e	μ/ν_μ	τ/ν_τ
1	1	1	1	$B-L$	$\frac{1}{3}$	-1	-1	-1
1	0	0	3	$B-3L_\tau$	$\frac{1}{3}$	0	0	-3
1	0	0	0	B	$\frac{1}{3}$	0	0	0
0	0	-1	1	$L_\mu - L_\tau$	0	0	1	-1

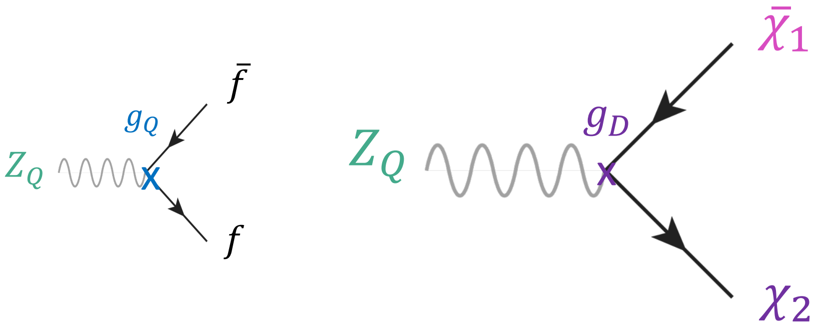
Inelastic Dark Matter · Decay Rates

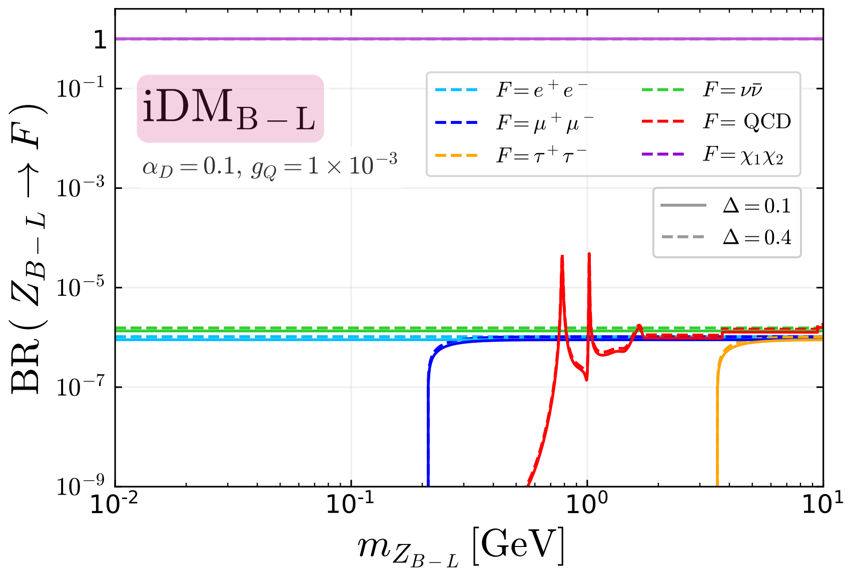
Hierarchy $m_{Z_Q} > m_1 + m_2$

Limit $g_D \gg g_Q$

Mediator

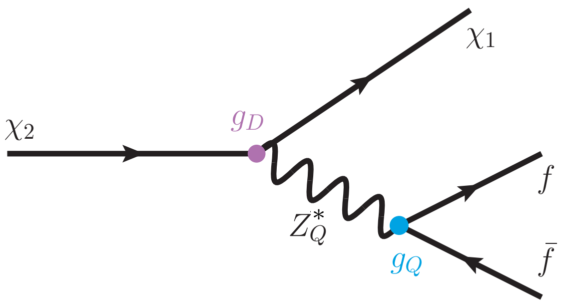
prompt-decay

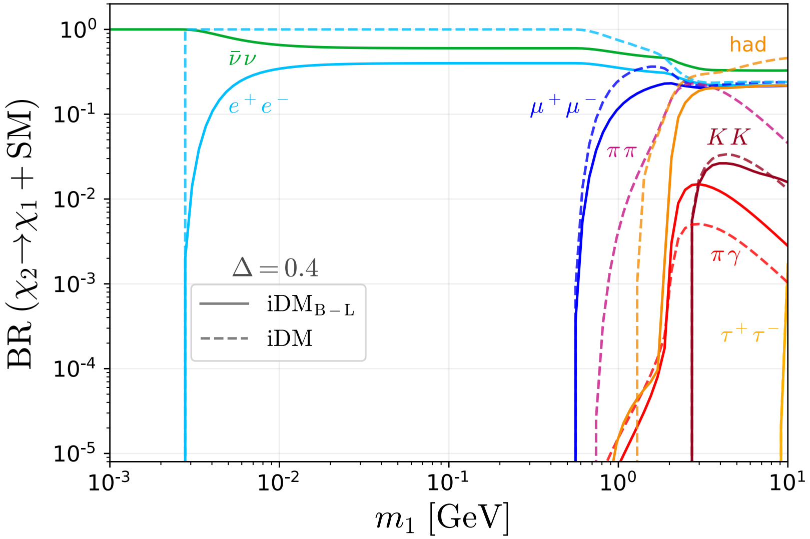


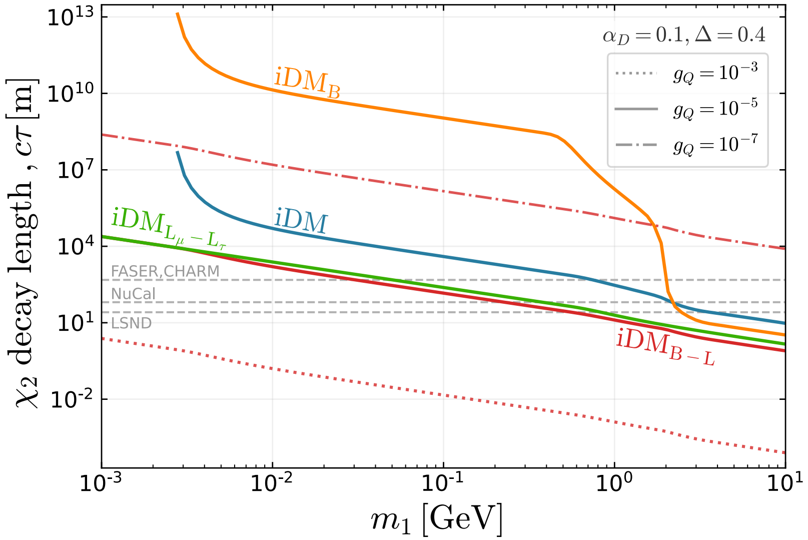


+

Dark fermion







Inelastic Dark Matter · Relic Density Computation

Boltzmann Equation

$$\frac{\mathrm{d}Y_{1,2}}{\mathrm{d}x} = \frac{s}{Hx}\Bigg[-\langle\sigma v\rangle_{12\to ff}\left(Y_1Y_2 - Y_1^{\mathrm{eq}}Y_2^{\mathrm{eq}}\right) \pm 2\,\langle\sigma v\rangle_{22\to 11}\left((Y_2)^2 - \left(Y_1\frac{Y_2^{\mathrm{eq}}}{Y_1^{\mathrm{eq}}}\right)^2\right)$$

$$\pm\left(\langle\sigma v\rangle_{2f\to 1f}Y_f^{\mathrm{eq}} + \frac{1}{s}\langle\Gamma\rangle_{2\to 1ff}\right)\left(Y_2 - Y_1\frac{Y_2^{\mathrm{eq}}}{Y_1^{\mathrm{eq}}}\right)\Bigg],$$

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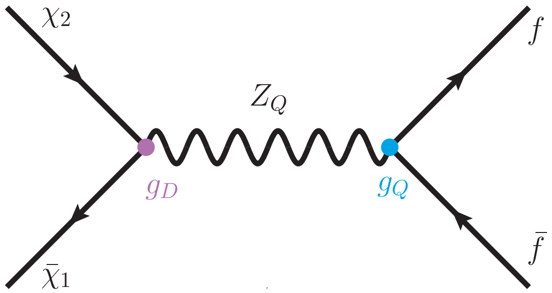

a) $\chi_1\,\chi_2 \to \mathrm{SM}$

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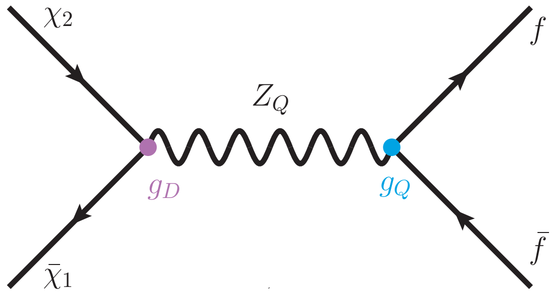

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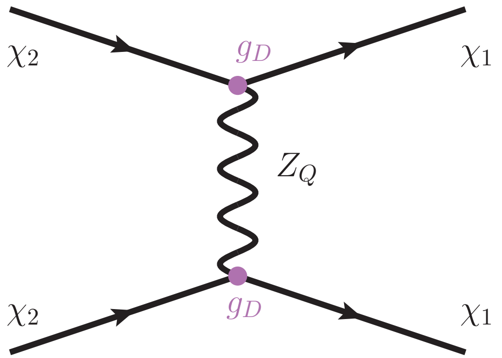

b) $\chi_2\,\chi_2 \to \chi_1\,\chi_1$

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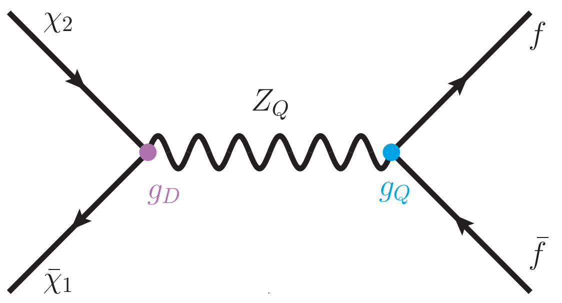

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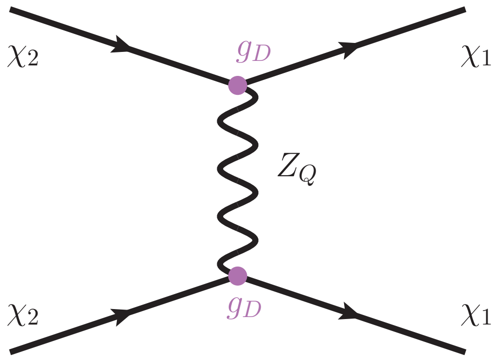

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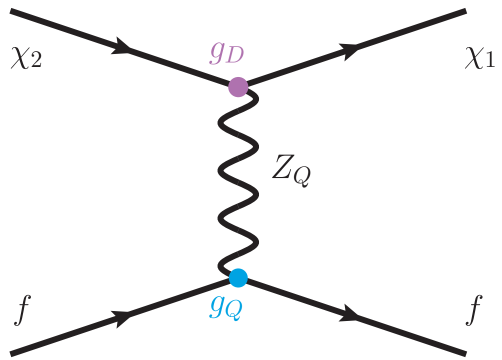

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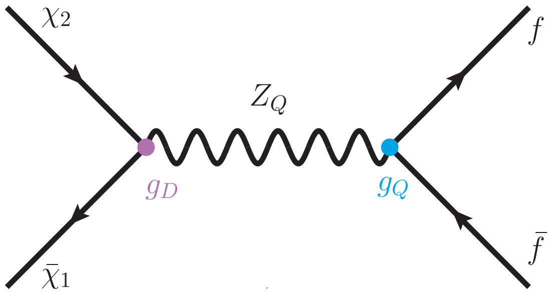
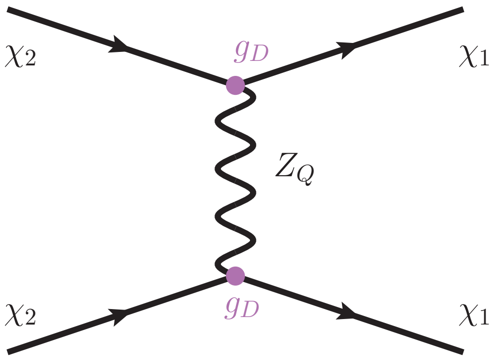
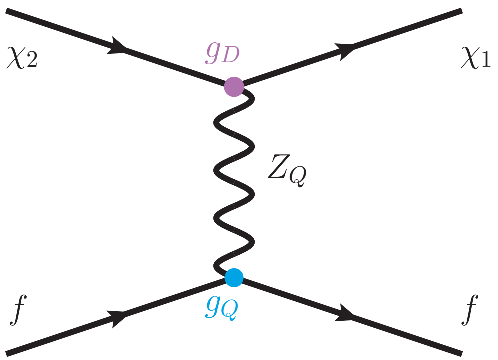


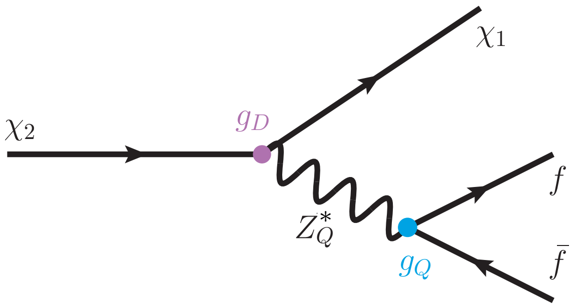
a) $\chi_1\,\chi_2 \to$ SM



b) $\chi_2\,\chi_2 \to \chi_1\,\chi_1$



c) $\chi_2\,f \to \chi_1\,f$



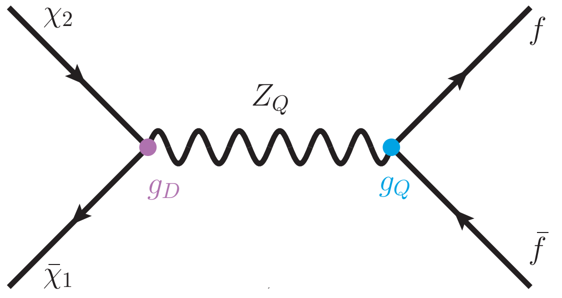
d) $\chi_2 \to \chi_1 + $ SM

Inelastic Dark Matter · Relic Density Computation

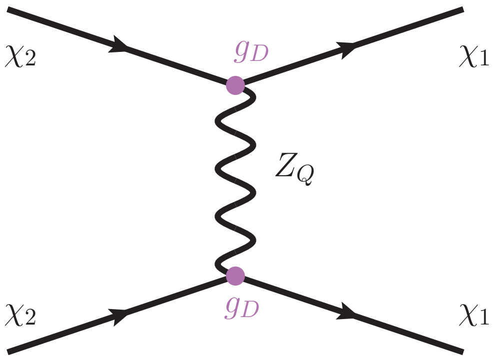
Boltzmann Equation

$$\frac{\mathrm{d}Y_{1,2}}{\mathrm{d}x} = \frac{s}{Hx}\left[-\langle \sigma v \rangle_{12\to ff}\left(Y_1 Y_2 - Y_1^{\mathrm{eq}} Y_2^{\mathrm{eq}}\right) \pm 2\langle \sigma v \rangle_{22\to 11}\left((Y_2)^2 - \left(Y_1 \frac{Y_2^{\mathrm{eq}}}{Y_1^{\mathrm{eq}}}\right)^2 \right) \right.$$
$$\left. \pm \left(\langle \sigma v \rangle_{2f\to 1f} Y_f^{\mathrm{eq}} + \frac{1}{s}\langle \Gamma \rangle_{2\to 1ff}\right)\left(Y_2 - Y_1 \frac{Y_2^{\mathrm{eq}}}{Y_1^{\mathrm{eq}}}\right)\right],$$

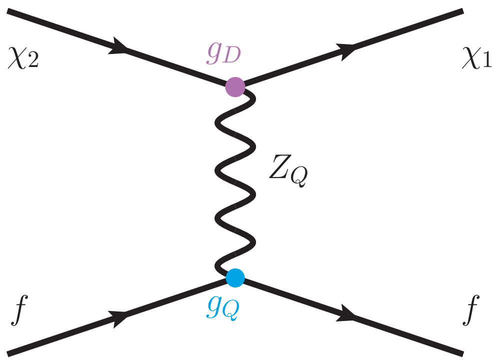
coannihilations dominate!



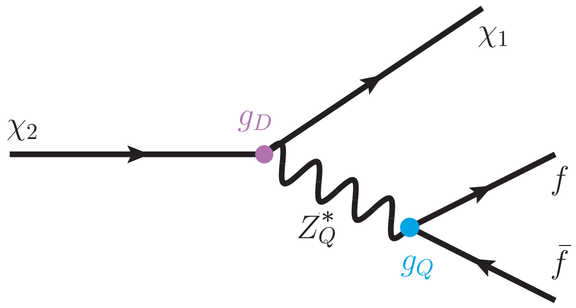
a) $\chi_1\,\chi_2 \to \mathrm{SM}$



b) $\chi_2\,\chi_2 \to \chi_1\,\chi_1$



c) $\chi_2\,f \to \chi_1\,f$



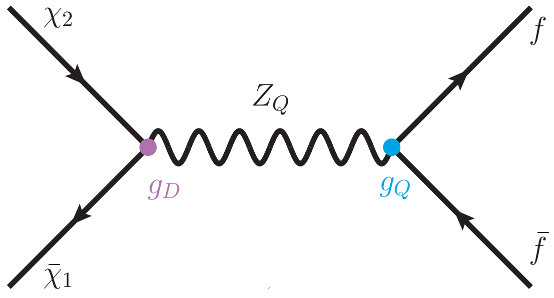
d) $\chi_2 \to \chi_1 + \mathrm{SM}$

Inelastic Dark Matter · Relic Density Computation

Boltzmann Equation

$$\frac{\mathrm{d}Y_{1,2}}{\mathrm{d}x} = \frac{s}{Hx}\left[-\langle\sigma v\rangle_{12\to ff}\left(Y_1Y_2 - Y_1^{\mathrm{eq}}Y_2^{\mathrm{eq}}\right) \pm 2\langle\sigma v\rangle_{22\to 11}\left((Y_2)^2 - \left(Y_1\frac{Y_2^{\mathrm{eq}}}{Y_1^{\mathrm{eq}}}\right)^2\right) \pm \left(\langle\sigma v\rangle_{2f\to 1f}Y_f^{\mathrm{eq}} + \frac{1}{s}\langle\Gamma\rangle_{2\to 1ff}\right)\left(Y_2 - Y_1\frac{Y_2^{\mathrm{eq}}}{Y_1^{\mathrm{eq}}}\right)\right],$$

coannihilations dominate!

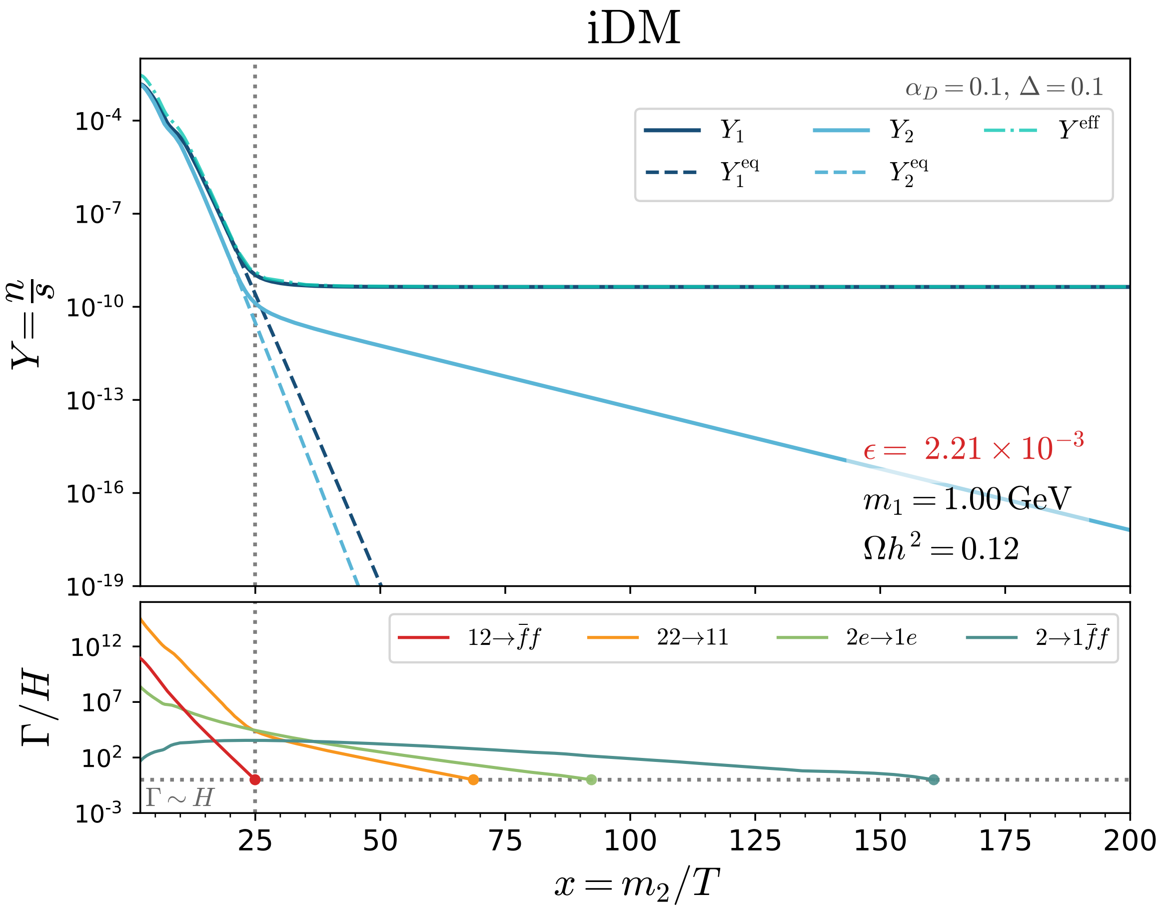


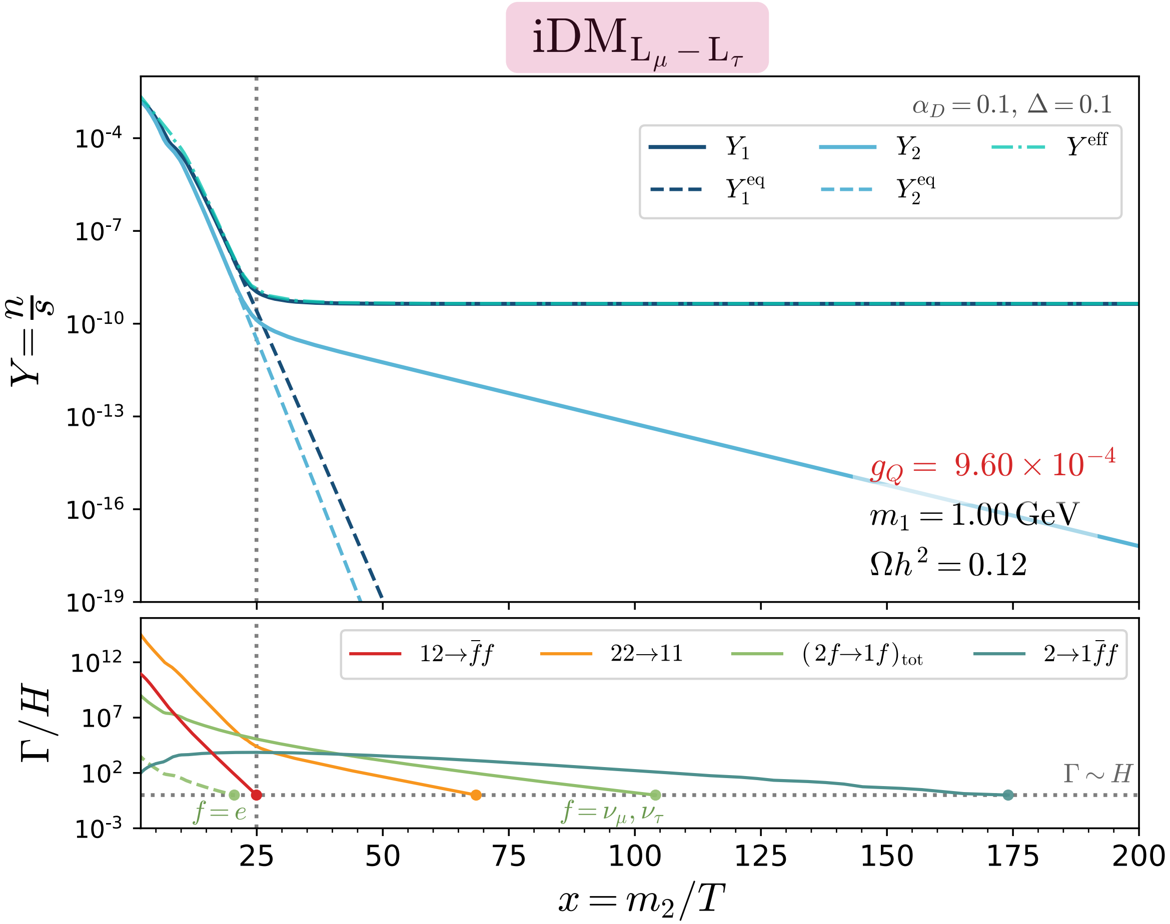
a) $\chi_1\,\chi_2 \to \mathrm{SM}$

we can simplify by considering $n = n_1 + n_2$

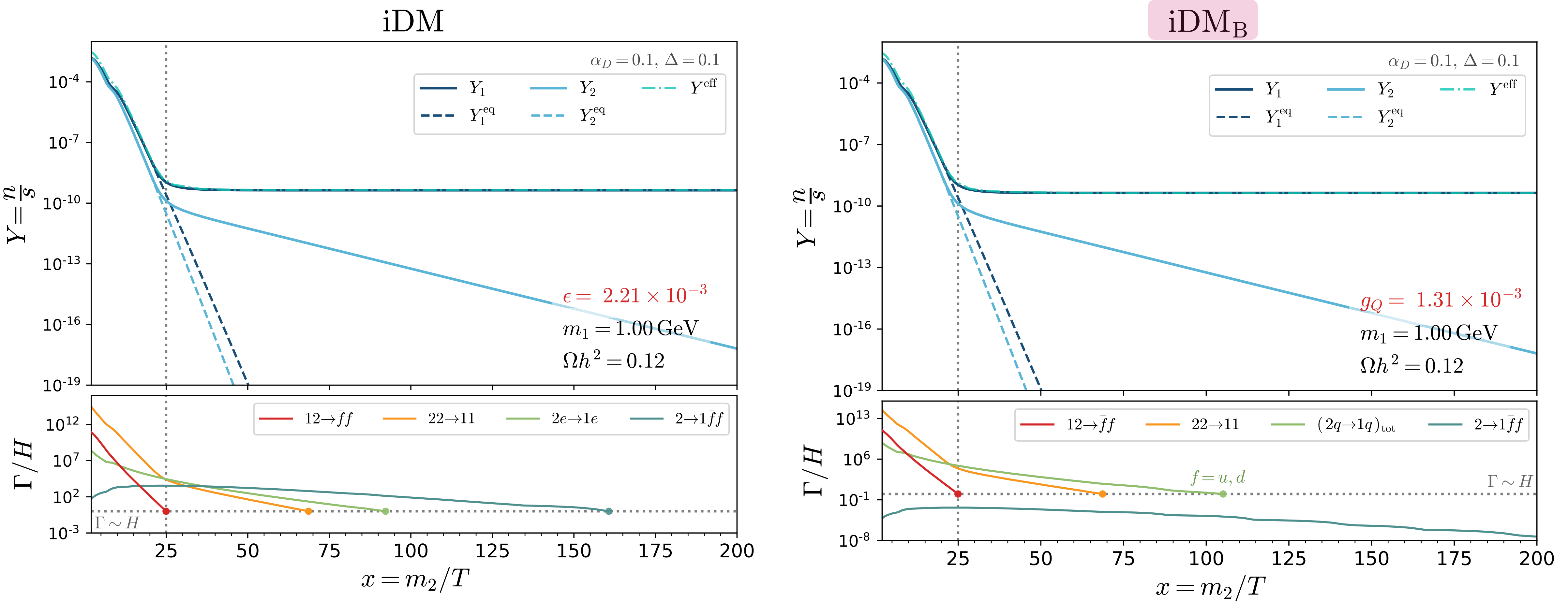
$$\boxed{\frac{dY}{dx} = -2\frac{s}{xH}\langle\sigma v\rangle_{\mathrm{eff}}\left(Y^2 - Y_{\mathrm{eq}}^2\right) \qquad \langle\sigma v\rangle_{\mathrm{eff}} = \langle\sigma v\rangle_{12\to ff}\frac{n_1^{\mathrm{eq}}n_2^{\mathrm{eq}}}{(n^{\mathrm{eq}})^2}}$$

Inelastic Dark Matter · Relic Density Computation





Inelastic Dark Matter · Relic Density Computation



Inelastic Dark Matter · ReD-DeLiVeR code

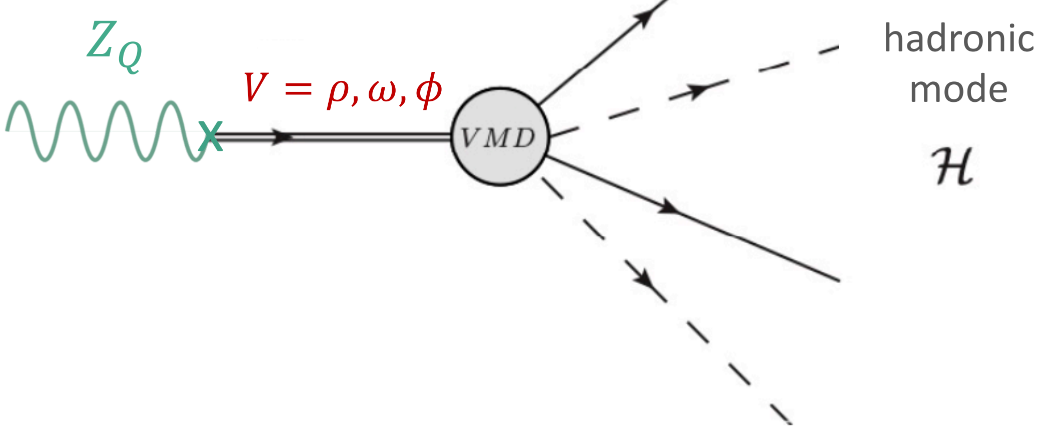
ReD-DeLiVeR (Relic Density with DeLiVeR)

- update of the previous python package DELIVER (Decays of Light Vectors Revised), which can be used to compute decay rates and branching ratios for user-defined $\mathrm{U}(1)_\mathrm{Q}$ charges,
- **key feature**: includes a complete set of hadronic decays (20 channels)

channel	resonances
$\pi\gamma$	$\boldsymbol{\rho}, \omega, \boldsymbol{\omega'}, \boldsymbol{\omega''}, \boldsymbol{\phi}$
$\pi\pi$	$\rho, \rho', \ldots$
3π	$\boldsymbol{\rho}, \boldsymbol{\rho''}, \omega, \omega', \omega'', \phi$
4π	$\rho, \rho', \rho'', \rho'''$
KK	$\boldsymbol{\rho}, \ldots, \boldsymbol{\omega}, \ldots, \phi, \ldots$
$KK\pi$	$\boldsymbol{\rho}, \boldsymbol{\rho'}, \boldsymbol{\rho''}, \phi, \phi', \phi''$

channel	resonances
$\eta\gamma$	$\rho, \rho', \omega, \phi$
$\eta\pi\pi$	ρ, ρ', ρ''
$\omega\pi \to \pi\pi\gamma$	ρ, ρ', ρ''
$\omega\pi\pi$	ω''
$\phi\pi$	ρ, ρ'
$\eta'\pi\pi$	ρ'''
$\eta\omega$	ω', ω''
$\eta\phi$	ϕ', ϕ''
$p\bar{p}/n\bar{n}$	$\rho, \rho', \ldots, \omega, \omega', \ldots$
$\phi\pi\pi$	ϕ', ϕ''
$K^*(892)K\pi$	ρ'', ϕ'
6π	ρ'''

ALF, P. Reimitz, R.Z. Funchal [JHEP 04 (2022)119]



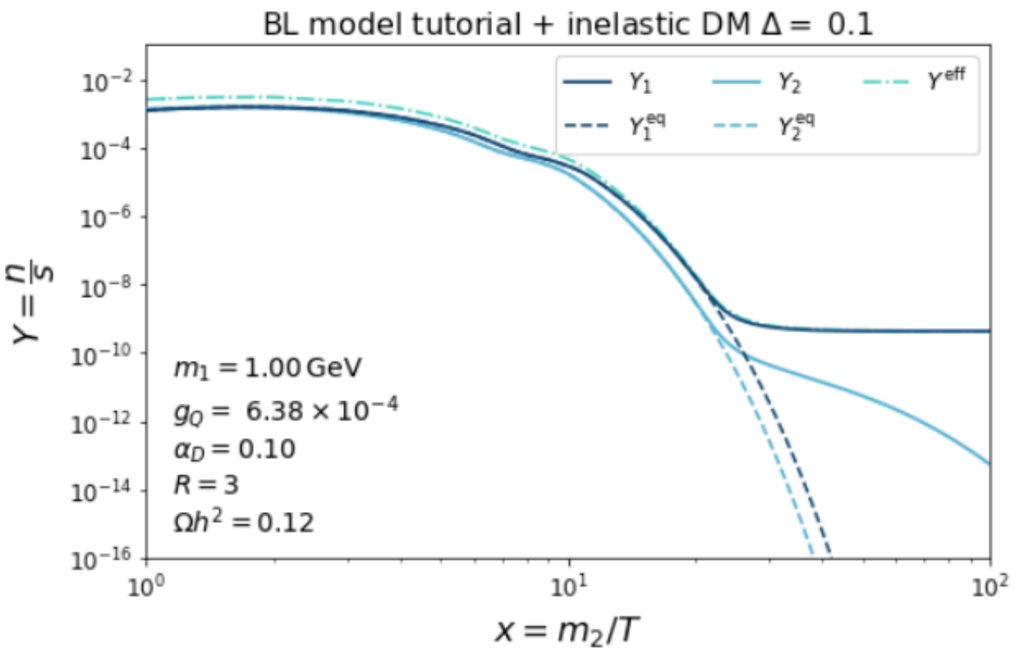
Inelastic Dark Matter · ReD-DeLiVeR code

ReD-DeLiVeR (Relic Density with DeLiVeR)

- update of the previous python package DELIVER (**De**cays of **Li**ght **Ve**ctors **R**evised), which can be used to compute decay rates and branching ratios for user-defined $\mathrm{U}(1)_Q$ charges,

- **key feature**: includes a complete set of hadronic decays (20 channels)

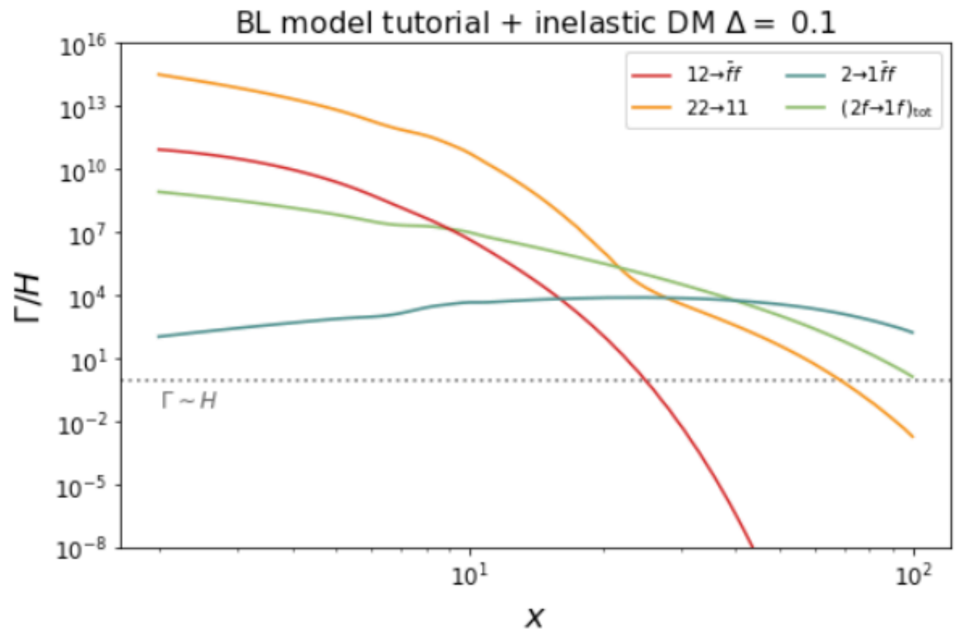
- **new version**:
  - inclusion of DM candidates: simplified DM models; inelastic DM
  - computation of relic density and rates



Inelastic Dark Matter · ReD-DeLiVeR code

ReD-DeLiVeR (Relic Density with DeLiVeR)

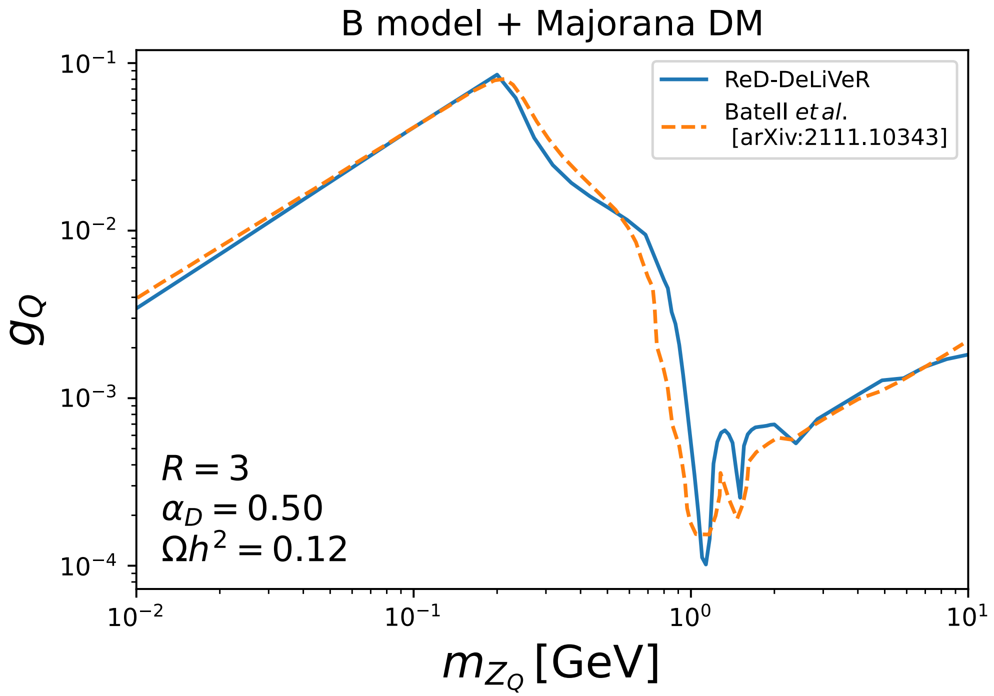
- update of the previous python package DELIVER (**De**cays of **Li**ght **Ve**ctors **R**evised), which can be used to compute decay rates and branching ratios for user-defined $U(1)_Q$ charges,
- **key feature**: includes a complete set of hadronic decays (20 channels)
- **new version**:
  - inclusion of DM candidates { simplified DM models, inelastic DM }
  - computation of relic density and rates



Inelastic Dark Matter · ReD-DeLiVeR code

ReD-DeLiVeR (Relic Density with DeLiVeR)

- update of the previous python package `DELIVER` (**De**cays of **Li**ght **Ve**ctors **R**evised), which can be used to compute decay rates and branching ratios for user-defined $\mathrm{U(1)_Q}$ charges,
- **key feature**: includes a complete set of hadronic decays (20 channels)
- **new version**:
  - inclusion of DM candidates: simplified DM models; inelastic DM
  - computation of relic density and rates
  - computation of thermal targets



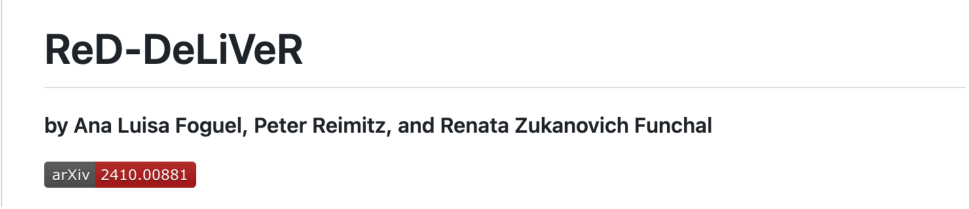
specially for B-coupled models, it is very important to compute correctly the hadronic contributions

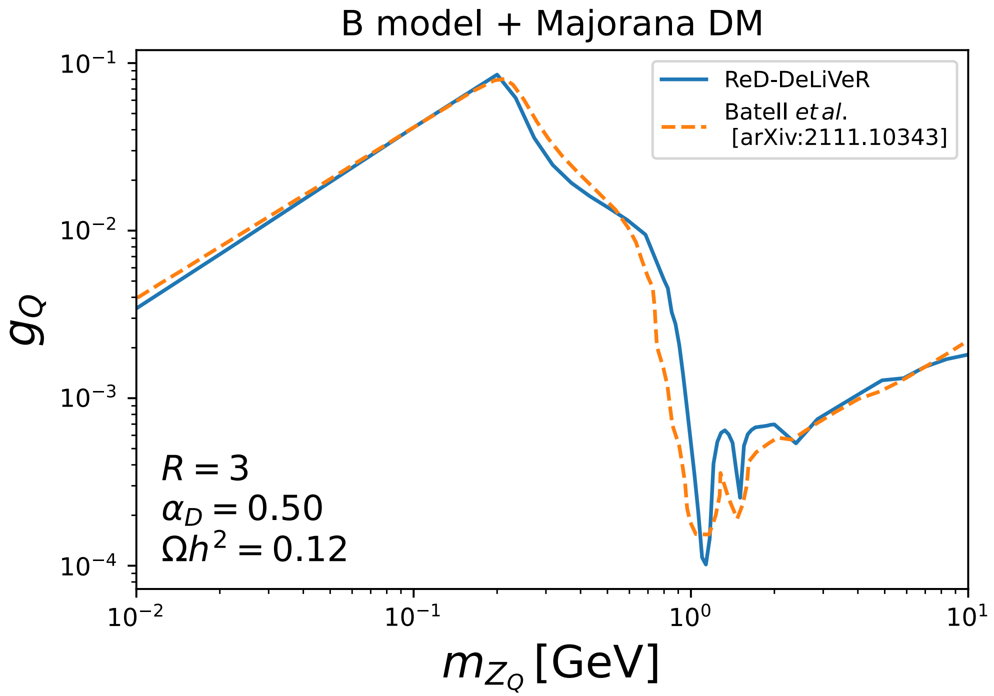
Inelastic Dark Matter · ReD-DeLiVeR code

ReD-DeLiVeR (Relic Density with DeLiVeR)

- update of the previous python package DELIVER (**De**cays of **Li**ght **Ve**ctors **R**evised), which can be used to compute decay rates and branching ratios for user-defined $U(1)_Q$ charges,
- **key feature**: includes a complete set of hadronic decays (20 channels)
- **new version**:
  - inclusion of DM candidates { simplified DM models, inelastic DM }
  - computation of relic density and rates
  - computation of thermal targets
- publicly available on GitHub together with a **Tutorial**!

https://github.com/anafoguel/ReD-DeLiVeR

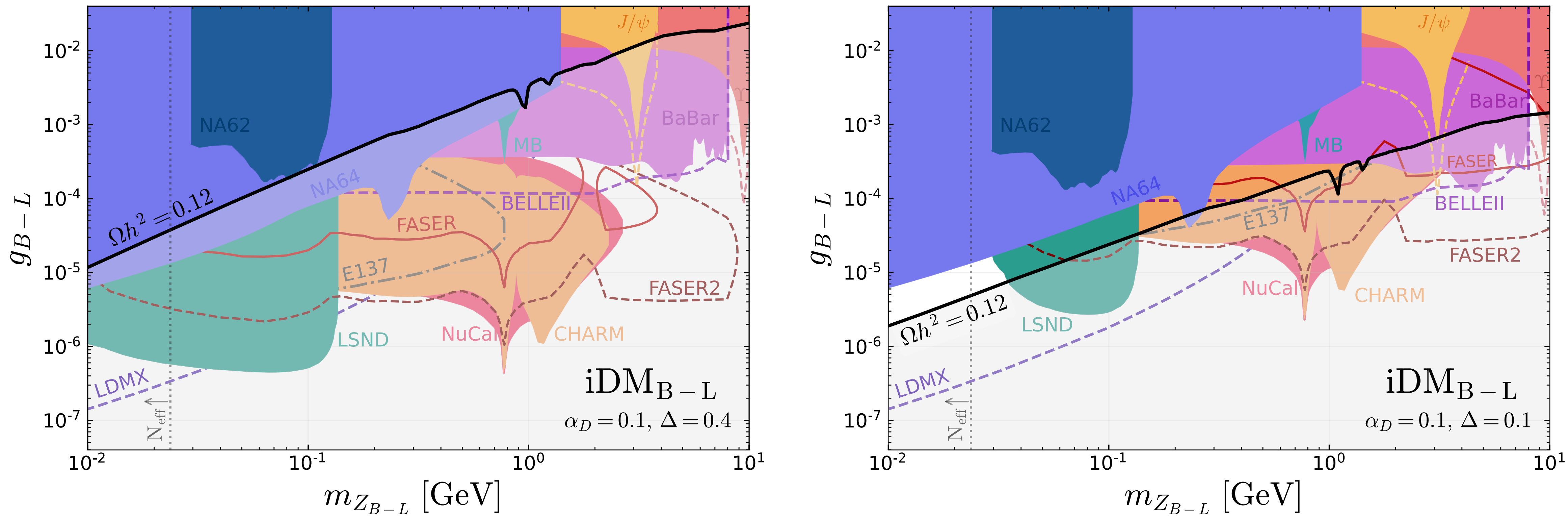




specially for B-coupled models, it is very important to compute correctly the hadronic contributions

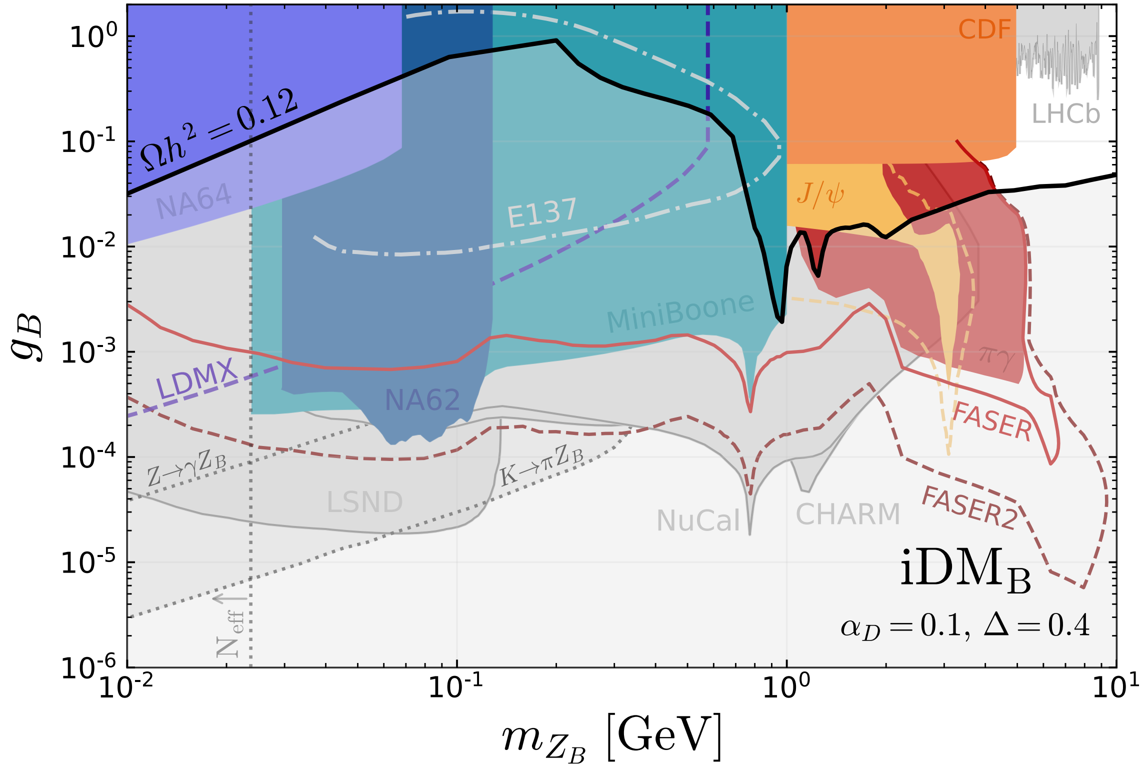
Inelastic Dark Matter · Bounds

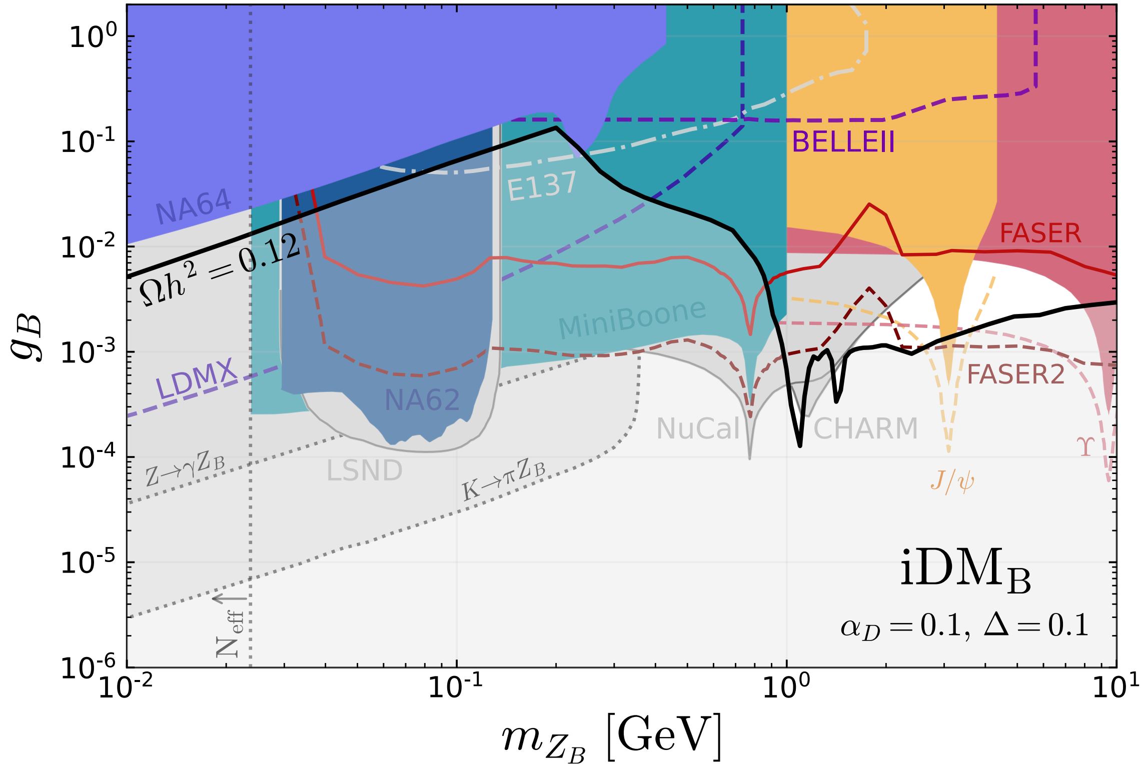
iDM_{B-L}



Inelastic Dark Matter · Bounds

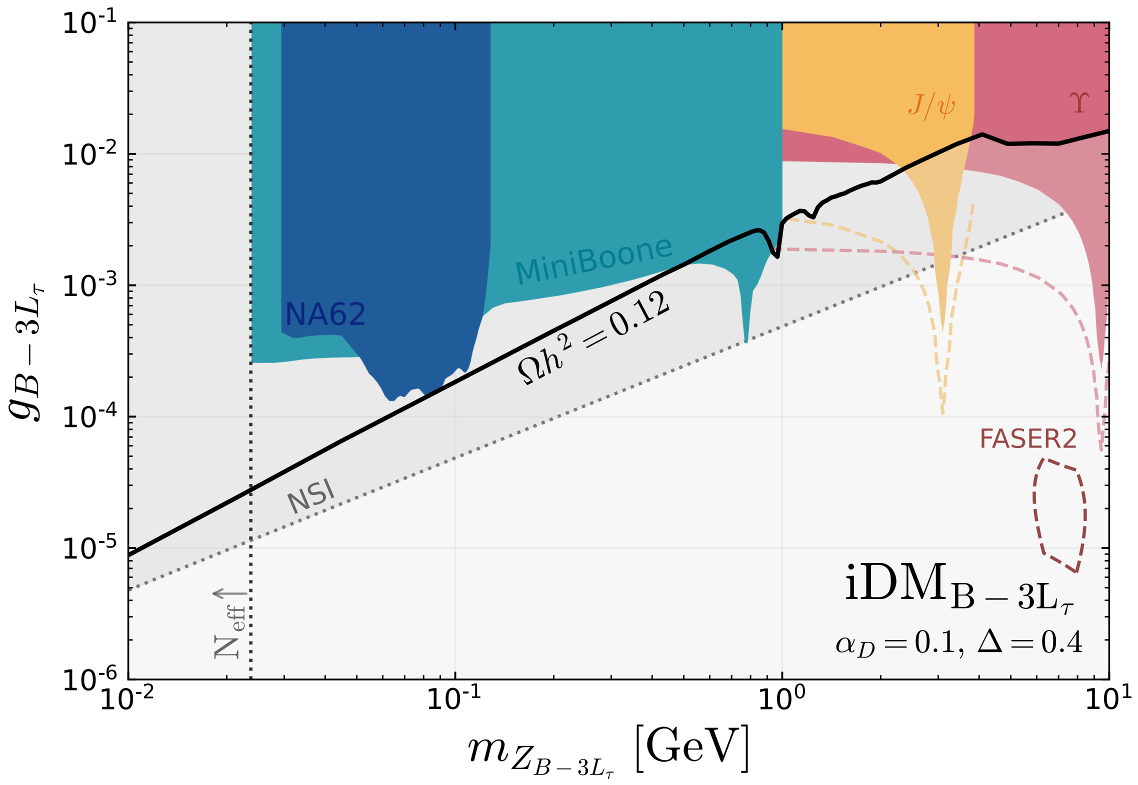
iDM$_B$

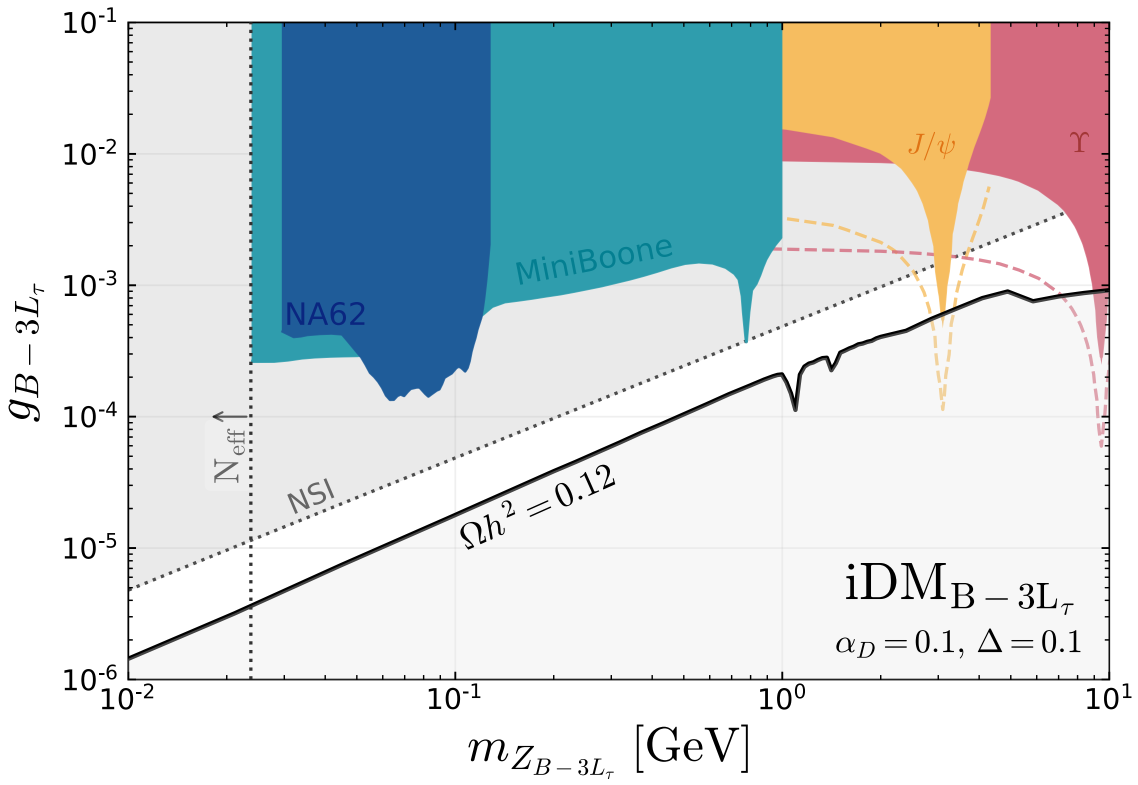




Inelastic Dark Matter · Bounds

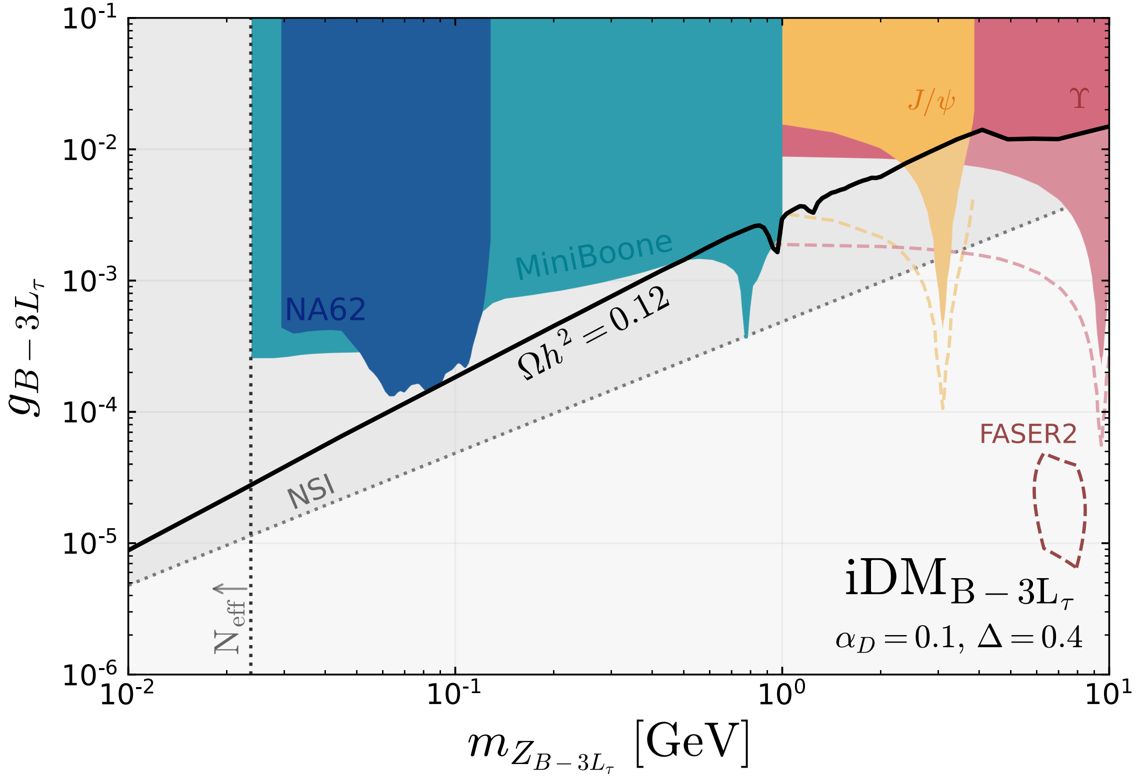
iDM_{B-3L_τ}

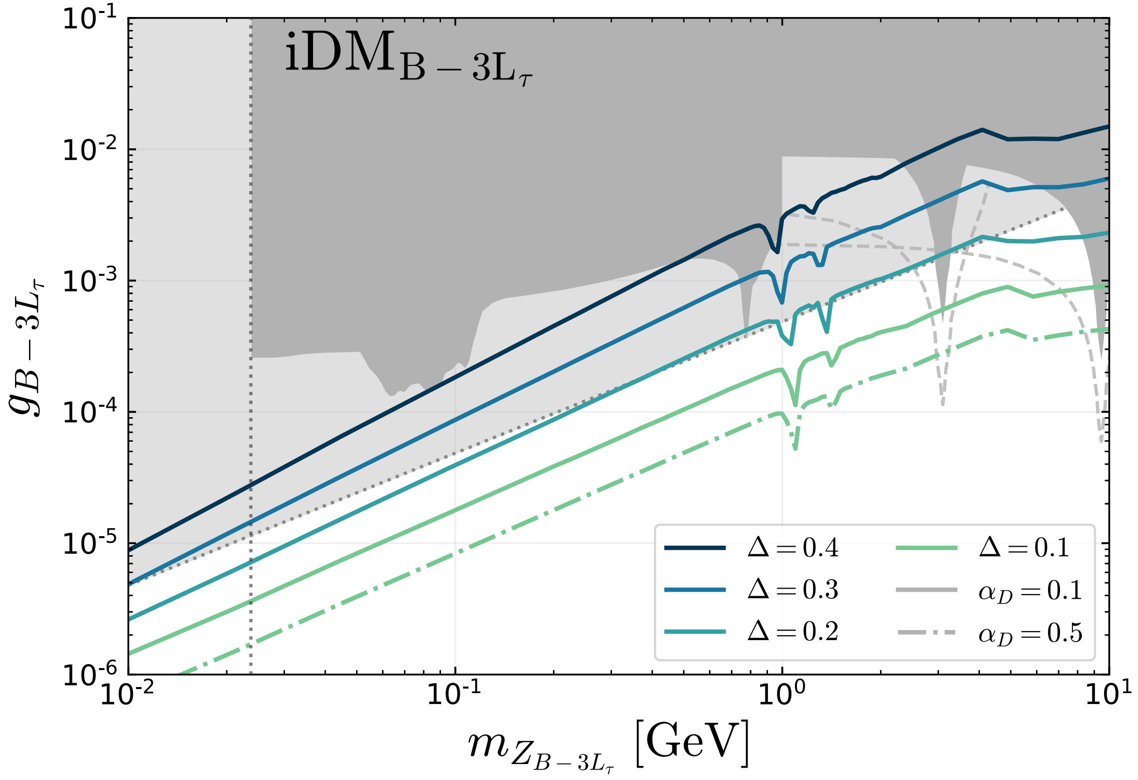




Inelastic Dark Matter · Bounds

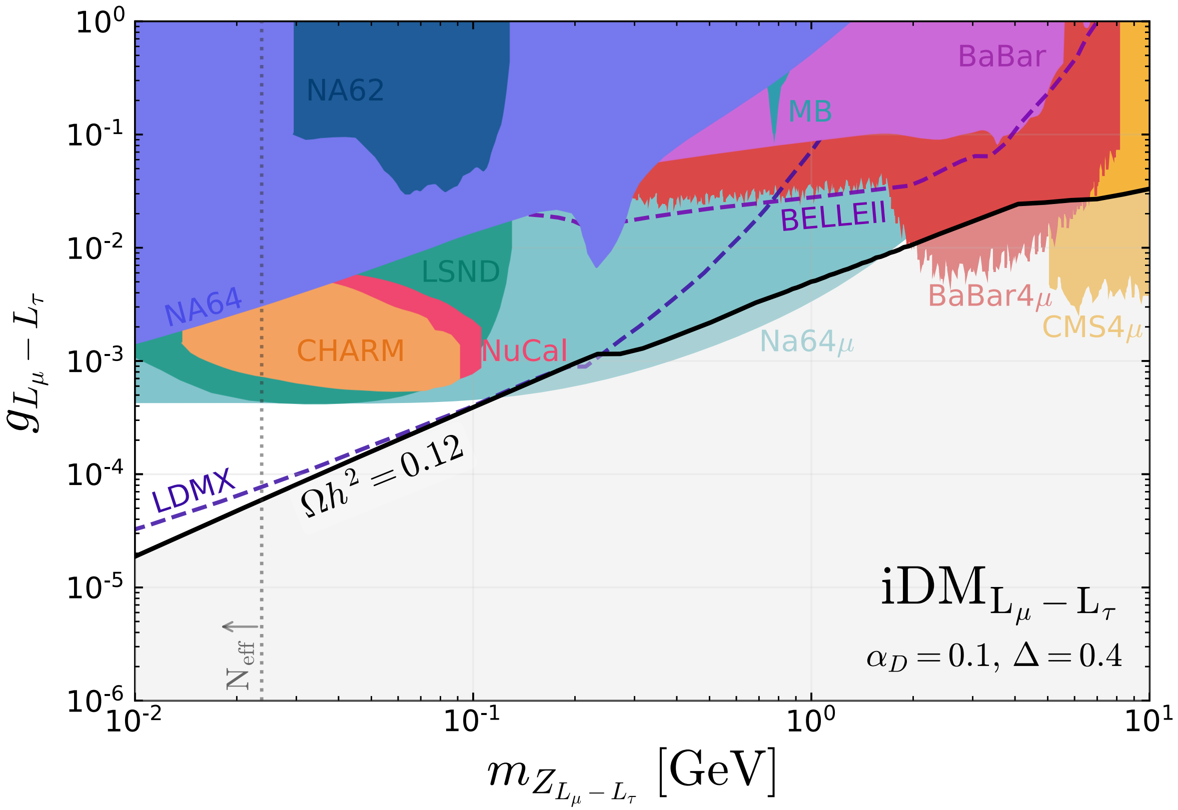
iDM_{B-3L_τ}

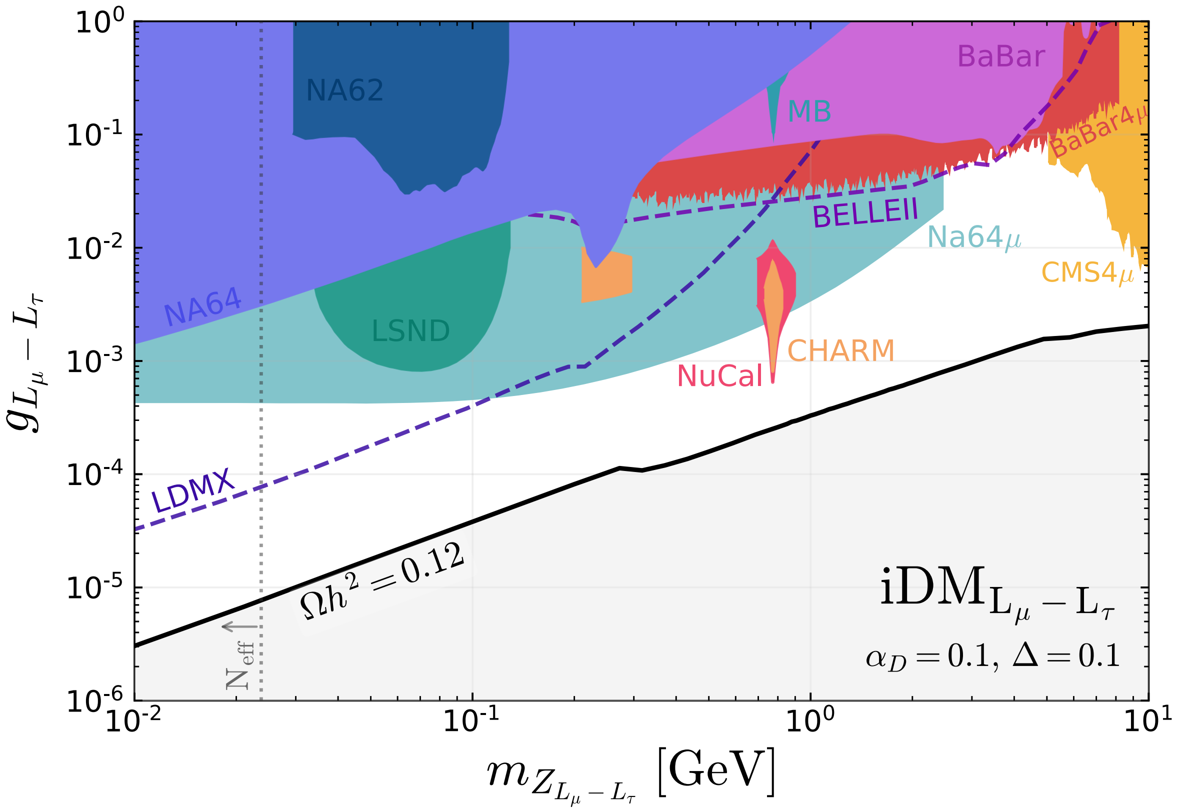




Inelastic Dark Matter · Bounds

$\mathrm{iDM}_{L_\mu - L_\tau}$





Conclusions

- Light Feebly Interacting Particles can shed light in several unanswered questions of the SM
- As experiments increase their luminosities, and we enter the intensity frontier era of particle physics, we increase the capabilities to probe new light sectors.
- As a guiding principle, we consider different portals between the Dark Sector and the SM
- In this work we considered a **vector portal** to a fermionic **inelastic Dark Matter** sector

thermal relics

evade indirect and direct detection

evade CMB bounds

general vector mediators

iDM_Q

- We developed a code that computes the relic density ReD-DeLiVeR
- With general mediators, we showed that we can unlock new regions of the parameter space of the vanilla dark photon model

$$B - 3L_\tau \qquad L_\mu - L_\tau$$

Thank you for your kind attention!

BACKUP

Inelastic Dark Matter

DM Thermal Freeze-out · WIMP miracle

We know that freeze-out happens when $\Gamma \sim H$

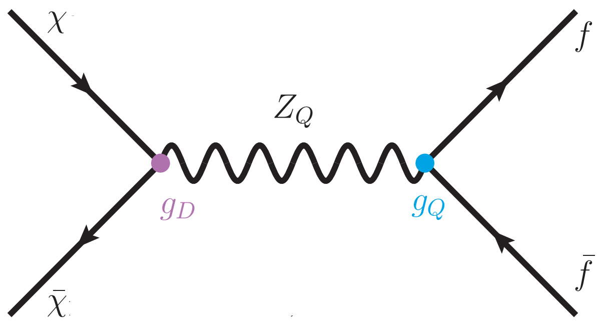
$$m_\chi \sim \alpha_{\rm eff} \sqrt{T_{\rm eq} M_{\rm Pl}} \sim \alpha_{\rm eff} \times 30\,{\rm TeV}$$

WIMP miracle

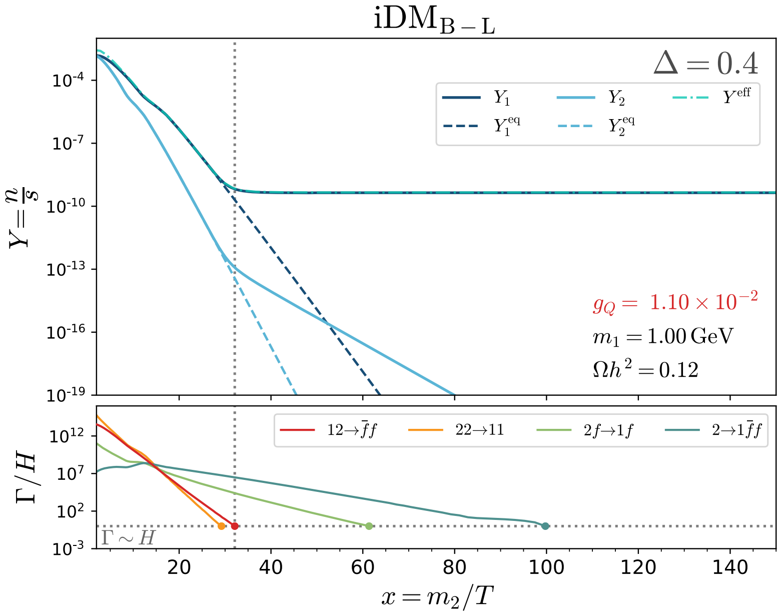
For couplings similar to the electroweak coupling $(\alpha_{\rm eff} \sim 10^{-2}) \Rightarrow$ EW scale emerges naturally

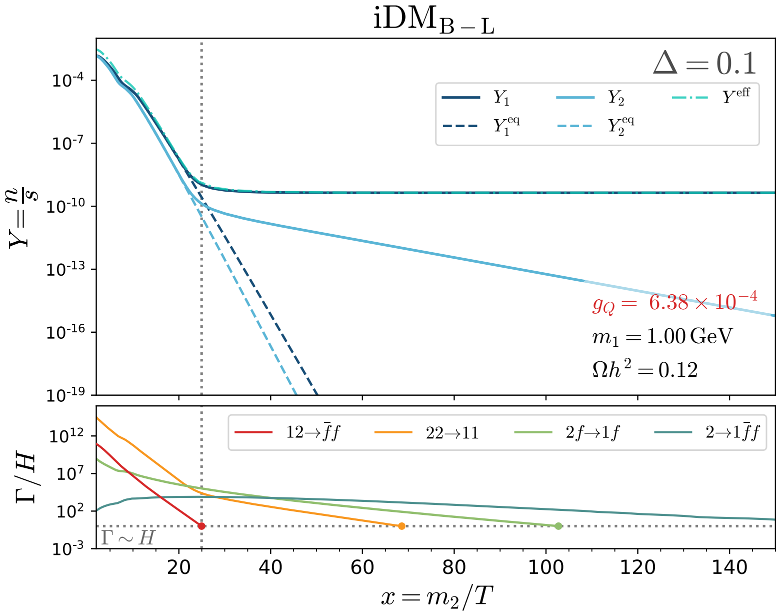
However, this also implies that

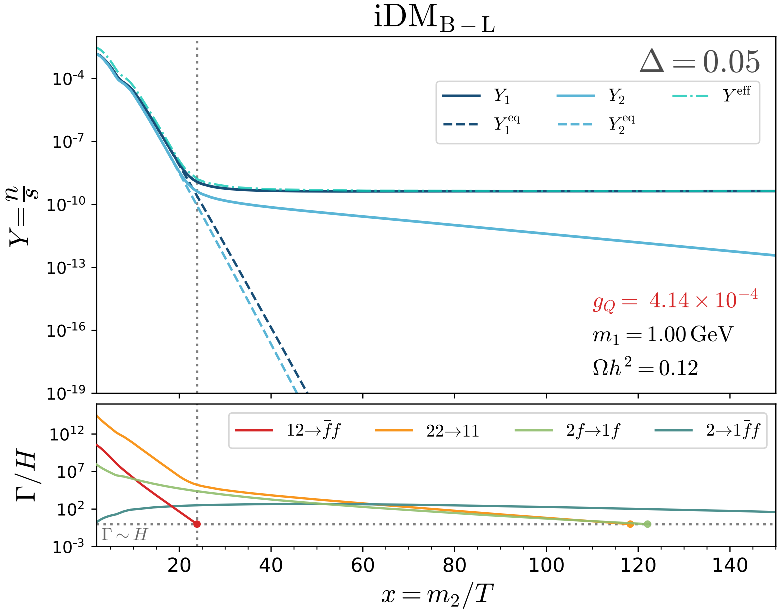
$$m_{\rm DM} \gtrsim \frac{m_Z^2}{(T_{\rm eq}\, m_{\rm Pl})^{1/2}} \sim {\rm GeV}.$$

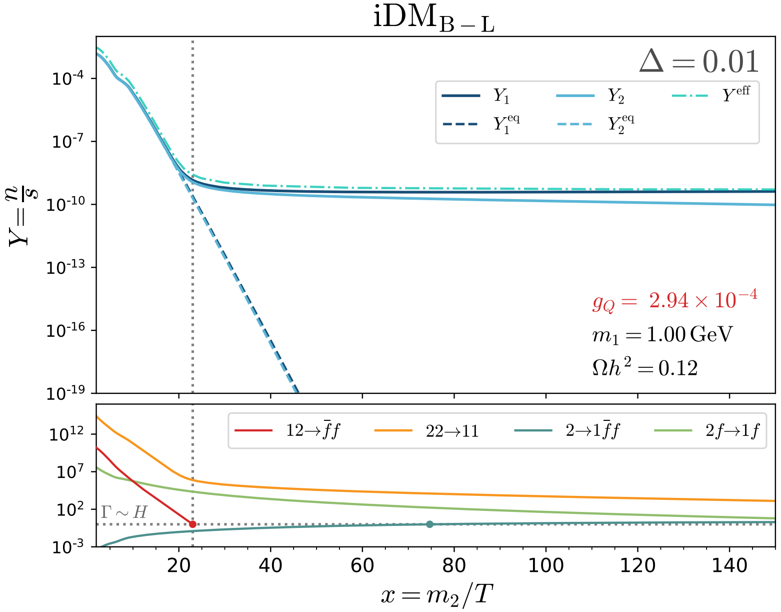


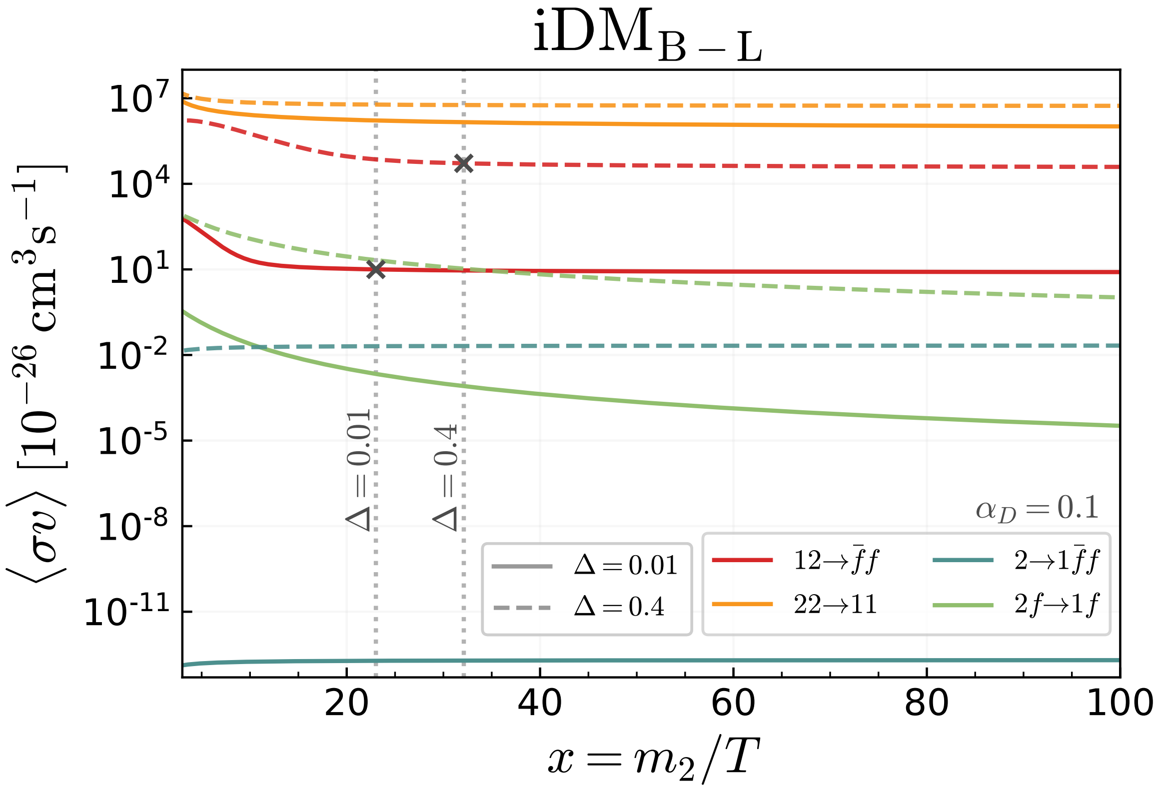
Hence, sub-GeV DM motivates the presence of new light mediators


$\mathrm{iDM_{B-L}}$
$\Delta = 0.4$
Y_1 Y_2 Y^{eff}
Y_1^{eq} Y_2^{eq}
$g_Q = 1.10 \times 10^{-2}$
$m_1 = 1.00\,\mathrm{GeV}$
$\Omega h^2 = 0.12$
$Y = \frac{n}{s}$
$12 \to \bar{f}f$ $22 \to 11$ $2f \to 1f$ $2 \to 1\bar{f}f$
Γ/H
$\Gamma \sim H$
$x = m_2/T$

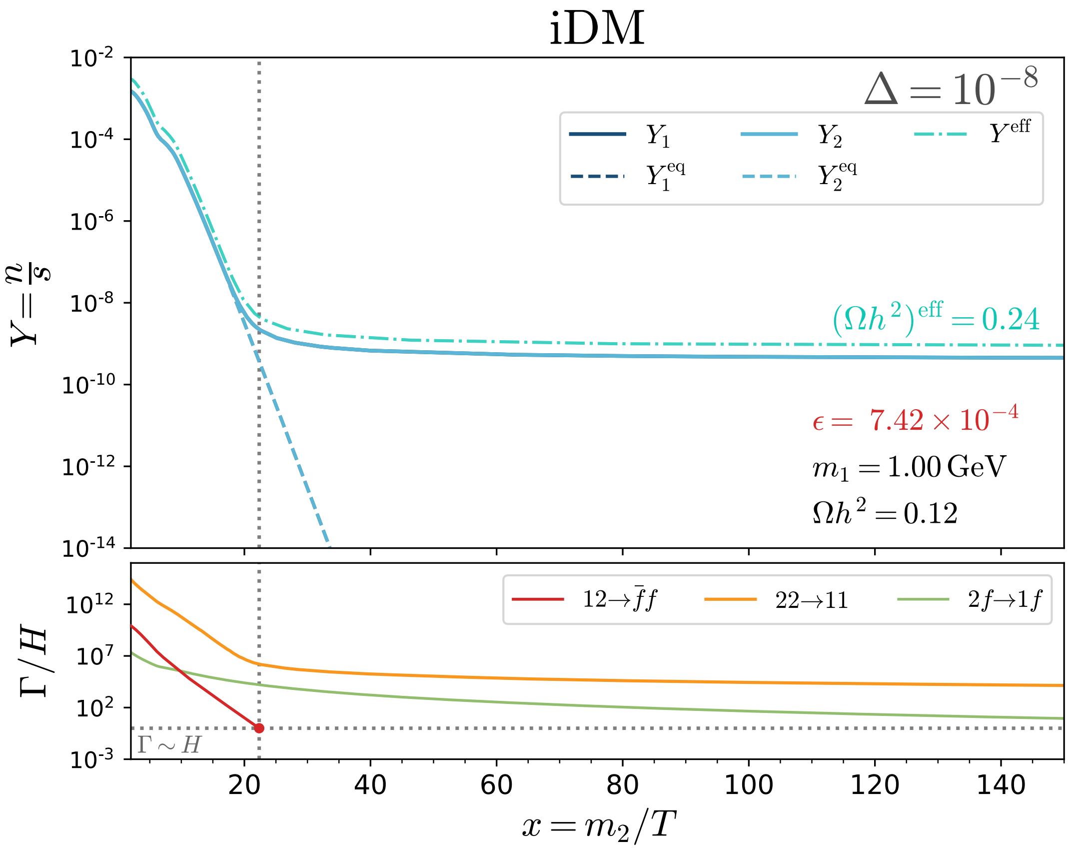

$\mathrm{iDM_{B-L}}$
$\Delta = 0.1$
Y_1 Y_2 Y^{eff}
Y_1^{eq} Y_2^{eq}
$g_Q = 6.38 \times 10^{-4}$
$m_1 = 1.00\,\mathrm{GeV}$
$\Omega h^2 = 0.12$
$Y = \frac{n}{s}$
$12 \to \bar{f}f$ $22 \to 11$ $2f \to 1f$ $2 \to 1\bar{f}f$
Γ/H
$\Gamma \sim H$
$x = m_2/T$


$\mathrm{iDM_{B-L}}$
$\Delta = 0.05$
Y_1 Y_2 Y^{eff}
Y_1^{eq} Y_2^{eq}
$g_Q = 4.14 \times 10^{-4}$
$m_1 = 1.00\,\mathrm{GeV}$
$\Omega h^2 = 0.12$
$Y = \frac{n}{s}$
$12 \to \bar{f}f$ $22 \to 11$ $2f \to 1f$ $2 \to 1\bar{f}f$
Γ/H
$\Gamma \sim H$
$x = m_2/T$

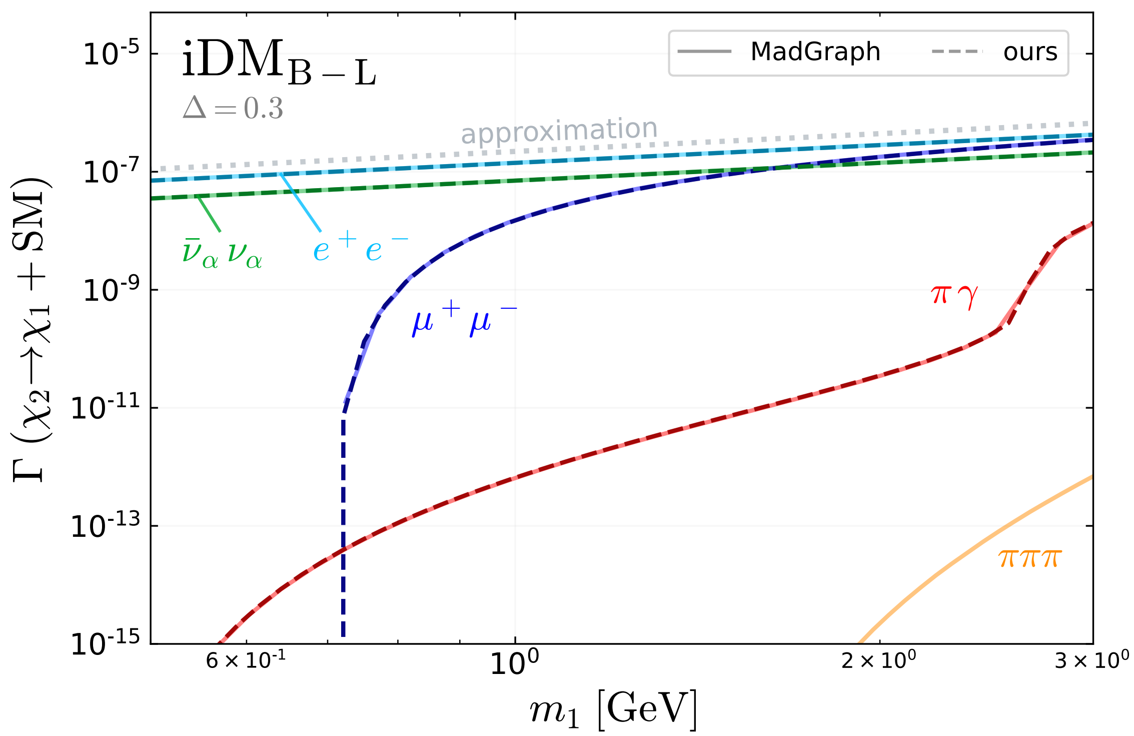

$\mathrm{iDM_{B-L}}$
$\Delta = 0.01$
Y_1 Y_2 Y^{eff}
Y_1^{eq} Y_2^{eq}
$g_Q = 2.94 \times 10^{-4}$
$m_1 = 1.00\,\mathrm{GeV}$
$\Omega h^2 = 0.12$
$Y = \frac{n}{s}$
$12 \to \bar{f}f$ $22 \to 11$ $2 \to 1\bar{f}f$ $2f \to 1f$
Γ/H
$\Gamma \sim H$
$x = m_2/T$



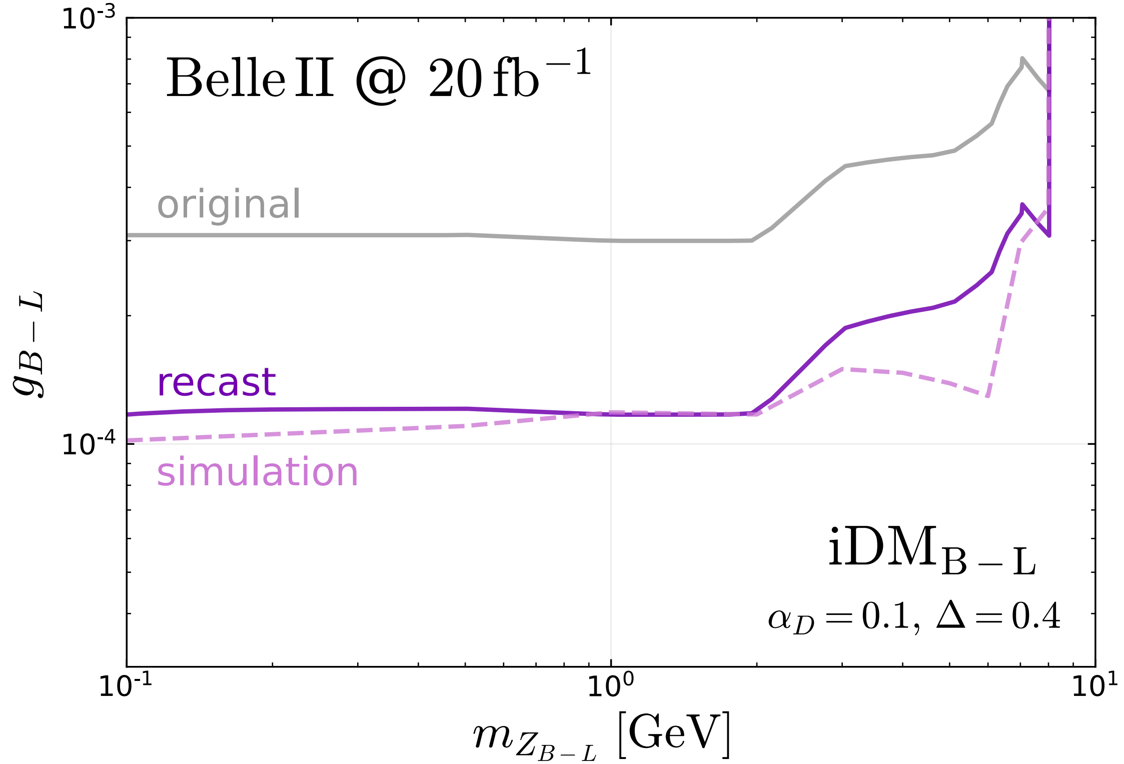
$\mathrm{iDM_{B-L}}$
$\langle\sigma v\rangle\,[10^{-26}\,\mathrm{cm^3 s^{-1}}]$
$x = m_2/T$
$\Delta = 0.01$
$\Delta = 0.4$
$\alpha_D = 0.1$
$12\to\bar{f}f$
$22\to11$
$2\to1\bar{f}f$
$2f\to1f$



iDM
$\Delta = 10^{-8}$
$Y = \frac{n}{s}$
Y_1
Y_2
Y^{eff}
Y_1^{eq}
Y_2^{eq}
$(\Omega h^2)^{\mathrm{eff}} = 0.24$
$\epsilon = \ 7.42\times10^{-4}$
$m_1 = 1.00\,\mathrm{GeV}$
$\Omega h^2 = 0.12$
Γ/H
$\Gamma\sim H$
$12\to\bar{f}f$
$22\to11$
$2f\to1f$
$x = m_2/T$

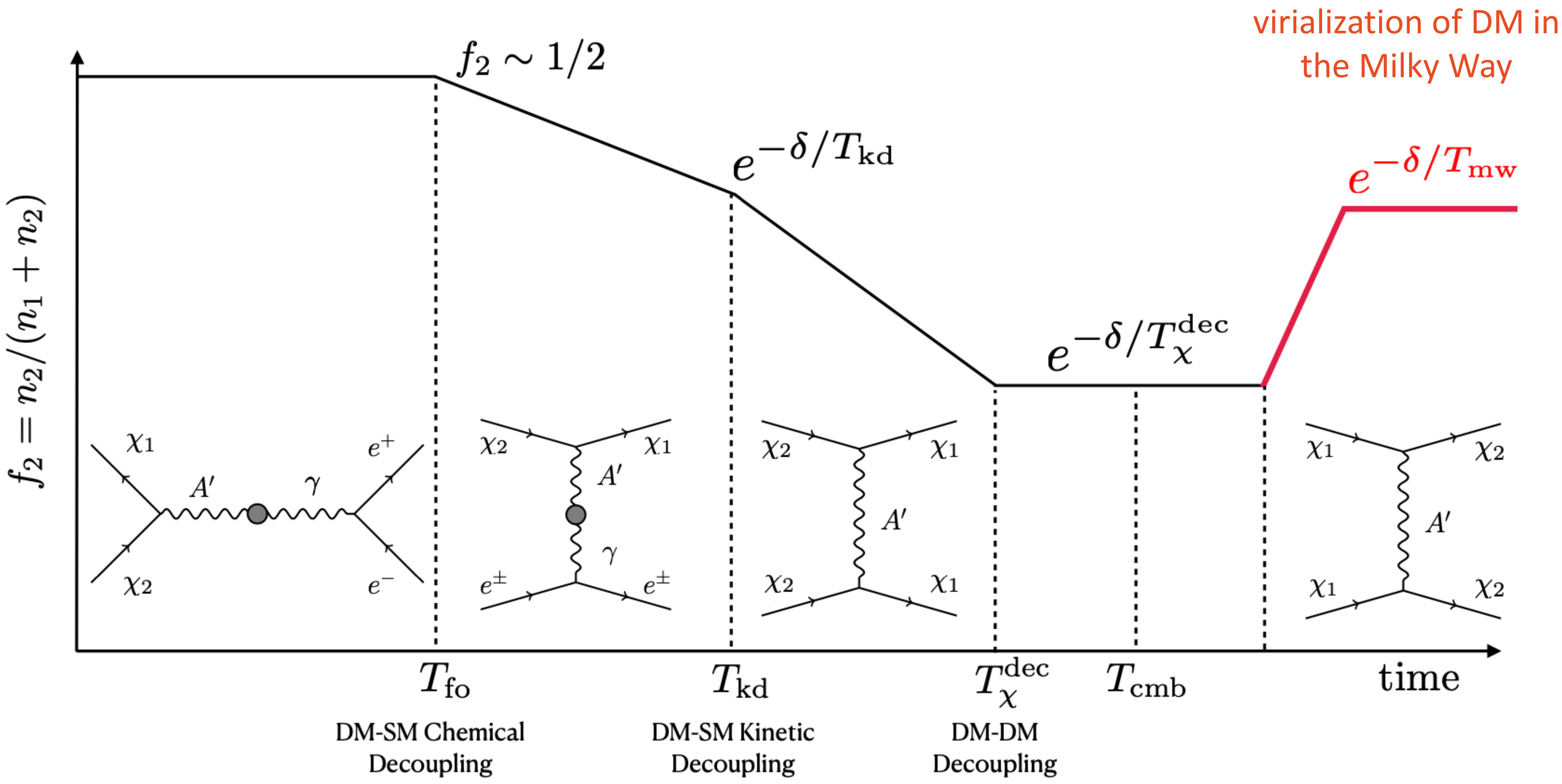


$\mathrm{iDM_{B-L}}$
$\Delta = 0.3$
MadGraph
ours
approximation
$\bar{\nu}_\alpha \nu_\alpha$
e^+e^-
$\mu^+\mu^-$
$\pi\gamma$
$\pi\pi\pi$
$\Gamma\ (\chi_2 \to \chi_1 + \mathrm{SM})$
m_1 [GeV]



Belle II @ $20\,\mathrm{fb}^{-1}$
original
recast
simulation
$\mathrm{iDM_{B-L}}$
$\alpha_D = 0.1,\ \Delta = 0.4$
g_{B-L}
$m_{Z_{B-L}}$ [GeV]

Inelastic Dark Matter

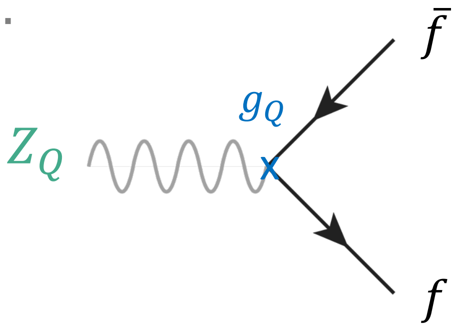


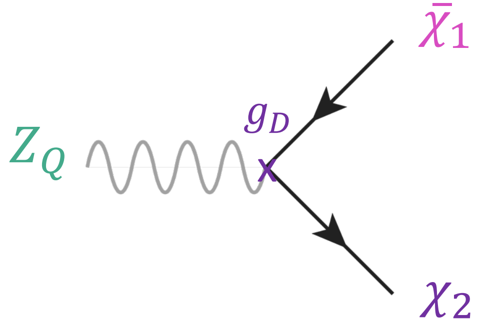
arXiv:2311.00032v1 [hep-ph]

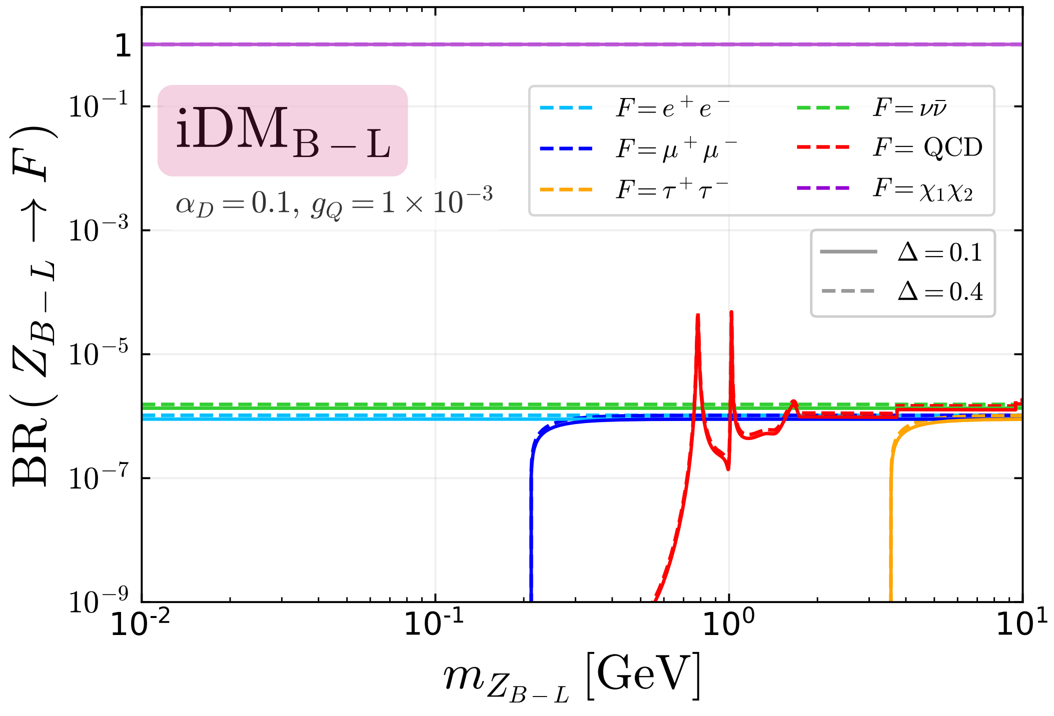
Inelastic Dark Matter · Decay Rates

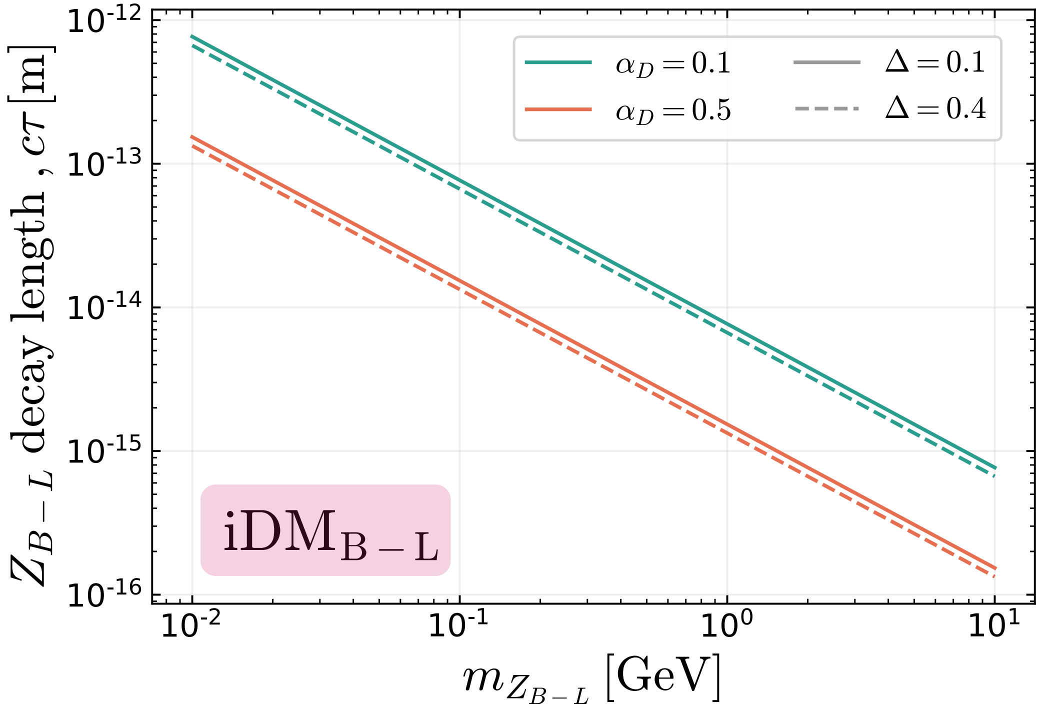
Decay rates · Mediator

- Hierarchy $m_{Z_Q} > m_1 + m_2$
- Limit $g_D \gg g_Q$





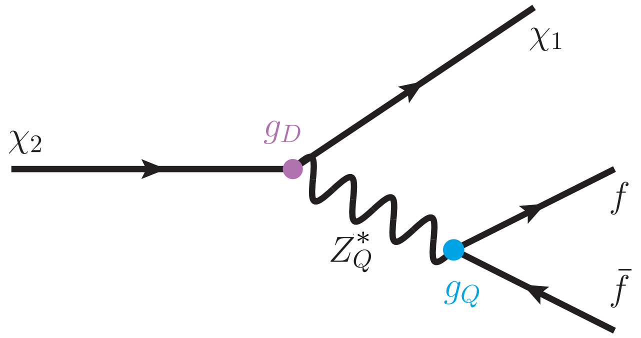




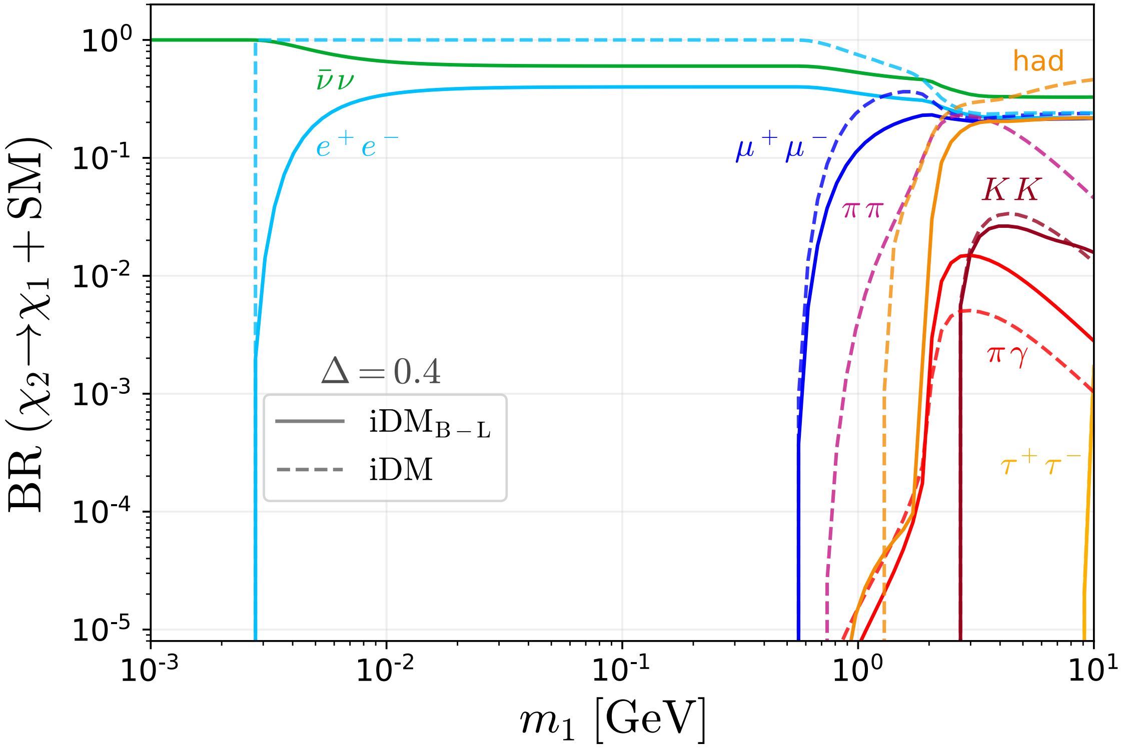
prompt-decay

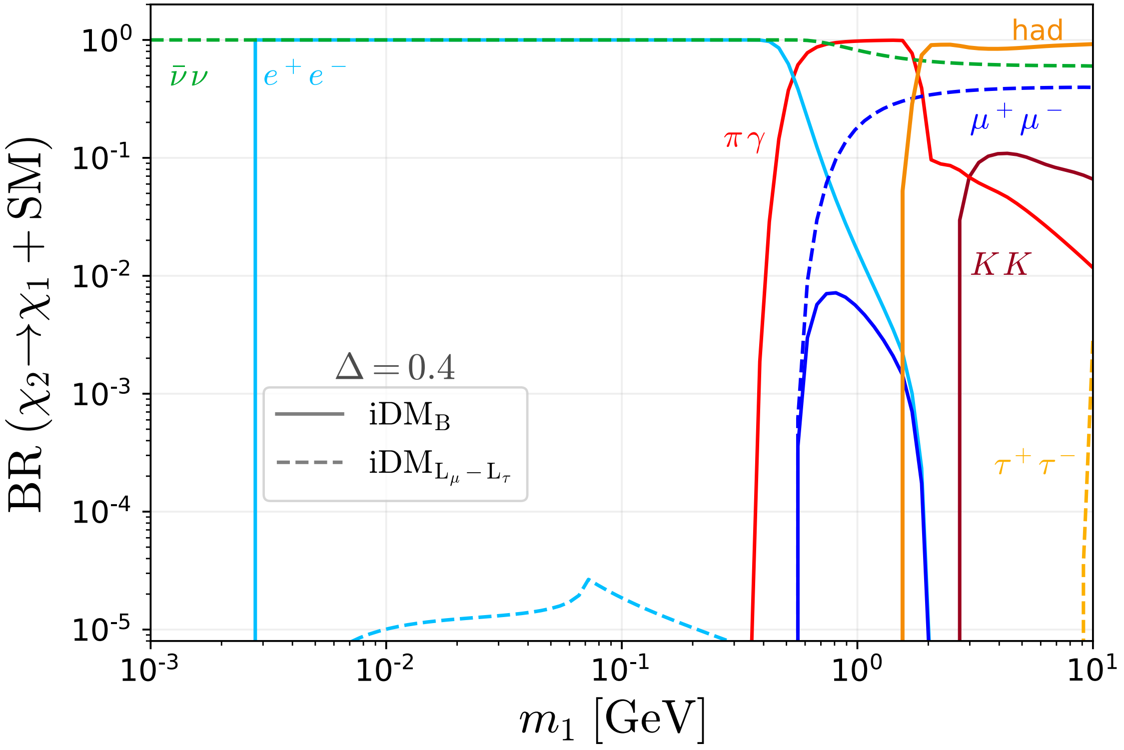
Inelastic Dark Matter · Decay Rates

Decay rates · Dark fermion χ_2



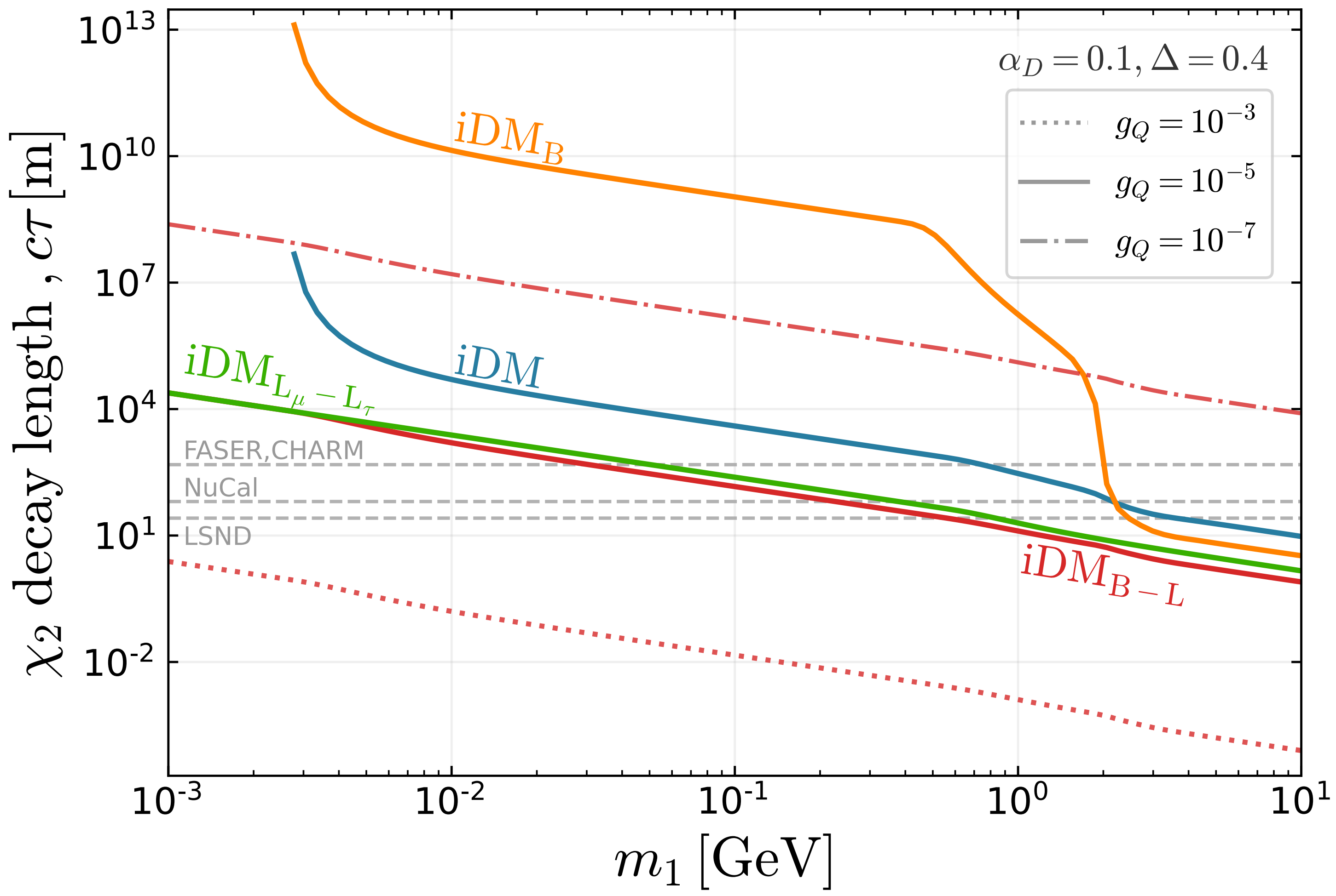
$$\Gamma(\chi_2 \to \chi_1 \bar{f} f) \simeq \frac{4\,\alpha_Q\,\alpha_D\,\Delta^5\,m_{Z_Q}}{15\pi R^5}$$





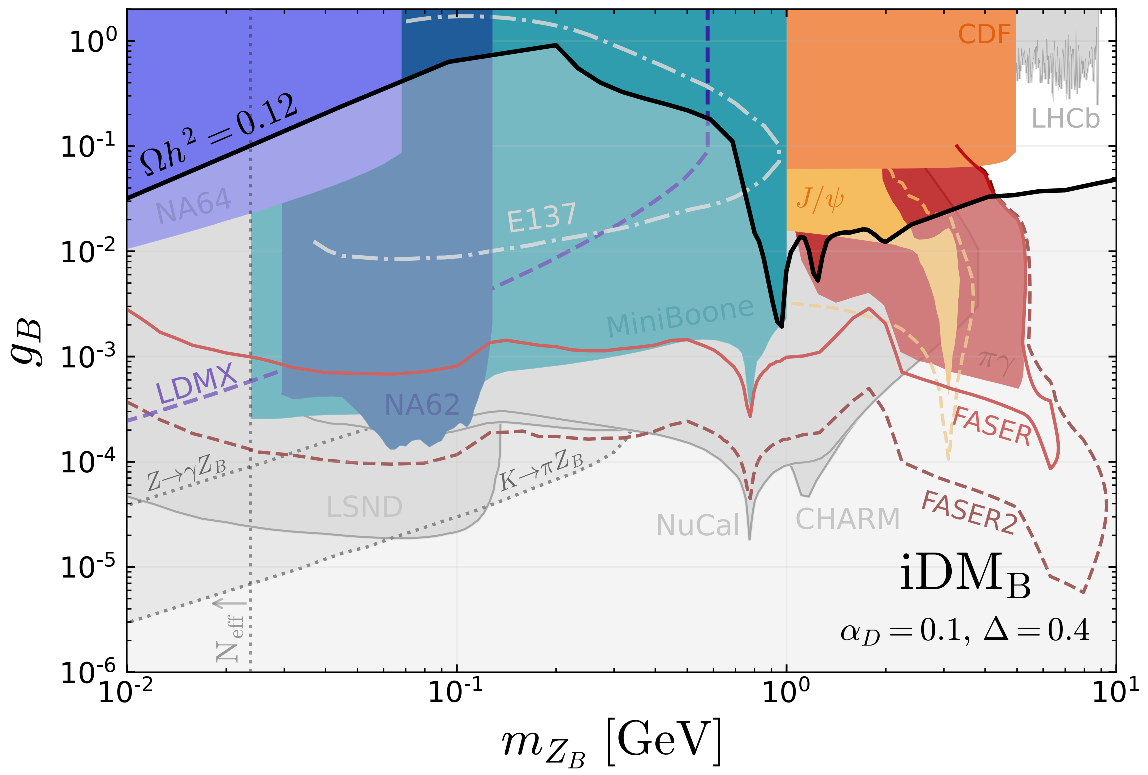
Inelastic Dark Matter · Decay Rates

Decay rates · Dark fermion χ_2



Inelastic Dark Matter · Bounds

iDM_B



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