Z'_{BL} portal dark matter and LHC Run-2 results

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1. Introduction

Dark Matter = One of the most exciting puzzles of cosmology and particle physics

Required properties of DM:
1. electric charge neutral
2. lifetime > age of the Universe
3. cold

There is **NO** dark matter candidate in the Standard Model!

→ need theories beyond the SM

In this talk, I'll discuss
the minimal B-L model with a dark matter candidate.

2. The minimal B-L model with DM candidate

The global B-L symmetry in the SM is gauged.

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_{B-L}$	Z_2
q_L^i	**3**	**2**	$1/6$	$1/3$	$+$
u_R^i	**3**	**1**	$2/3$	$1/3$	$+$
d_R^i	**3**	**2**	$-1/3$	$1/3$	$+$
ℓ_L^i	**1**	**2**	$-\frac{1}{2}$	-1	$+$
e_R^i	**1**	**1**	-1	-1	$+$
H	**1**	**2**	$-\frac{1}{2}$	0	$+$
N_R^j j=1,2	**1**	**1**	0	-1	$+$
N_R	**1**	**1**	0	-1	$-$
Φ	**1**	**1**	0	$+2$	$+$

3 generations of right-handed neutrinos
a B-L Higgs field

Z_2 parity is introduced.

↓

We assign odd parity to one right-handed neutrino.

↓

The conservation of the Z_2 parity ensures the stability of the Z_2-odd N_R.

→ Dark matter candidate

Okada, Seto, PRD 82 (2010) 023507

Yukawa interaction & Higgs potential

Yukawa interaction

$$\mathcal{L}_{\text{Yukawa}} \supset -\sum_{i=1}^{3}\sum_{j=1}^{2} Y_D^{ij}\overline{\ell_L^i} H N_R^j - \frac{1}{2}\sum_{k=1}^{2} Y_N^k \Phi \overline{N_R^{kC}} N_R^k - \frac{1}{2} Y_N \Phi \overline{N_R^C} N_R + \text{H.c.}$$

Higgs potential

$$V = m_H^2 (H^\dagger H) + m_\Phi^2 (\Phi^\dagger \Phi) + \lambda_H (H^\dagger H)^2 + \lambda_\Phi (\Phi^\dagger \Phi)^2 + \lambda_{H\Phi} (H^\dagger H)(\Phi^\dagger \Phi)$$

$$\langle H \rangle = \begin{pmatrix} \frac{v}{\sqrt{2}} \\ 0 \end{pmatrix} \qquad \langle \Phi \rangle = \frac{v_{BL}}{\sqrt{2}}$$

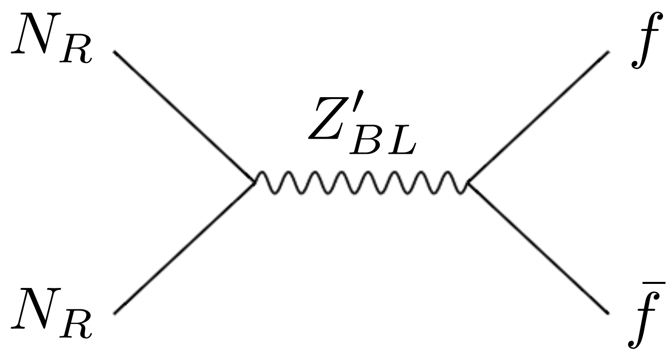
After the B-L symmetry breaking,
the Majorana neutrinos, the DM particle and the B-L gauge boson acquire their masses.

$$m_N^j = \frac{Y_N^j}{\sqrt{2}} v_{BL}, \quad m_{\text{DM}} = \frac{Y_N}{\sqrt{2}} v_{BL}, \quad m_{Z'} = 2 g_{BL} v_{BL}$$

Z'_{BL} portal dark matter

The dark matter particle can communicate with the SM particles through the Z'_{BL} boson.

= **Z'_{BL} portal dark matter**



Only three free parameters are involved in dark matter physics analysis.

- B-L gauge coupling (α_{BL})
- Z'_{BL} boson mass ($m_{Z'}$)
- dark matter mass (m_{DM})

3. Cosmological constraint on Z'$_{BL}$ portal DM

The observed dark matter relic abundance

$$\Omega_{\rm DM}h^2 = 0.1198 \pm 0.0015 \quad \text{(Planck 2015)}$$

The dark matter relic abundance is evaluated by integrating the Boltzmann equation.

Boltzmann equation

$$\frac{dY}{dx} = -\frac{s\langle\sigma v\rangle}{xH(m_{\rm DM})}(Y^2 - Y_{\rm EQ}^2)$$

$$s = \frac{2\pi^2}{45} g_\star \frac{m_{\rm DM}^3}{x^3}$$

$$H(m_{\rm DM}) = \sqrt{\frac{4\pi^3}{45} g_\star} \frac{m_{\rm DM}^2}{M_{\rm Pl}}$$

$$sY_{\rm EQ} = \frac{g_{\rm DM}}{2\pi^2} \frac{m_{\rm DM}^3}{x} K_2(x)$$

$x = m_{DM}/T$

$M_{Pl} = 1.22 \times 10^{19}\,\mathrm{GeV}$: the Planck mass

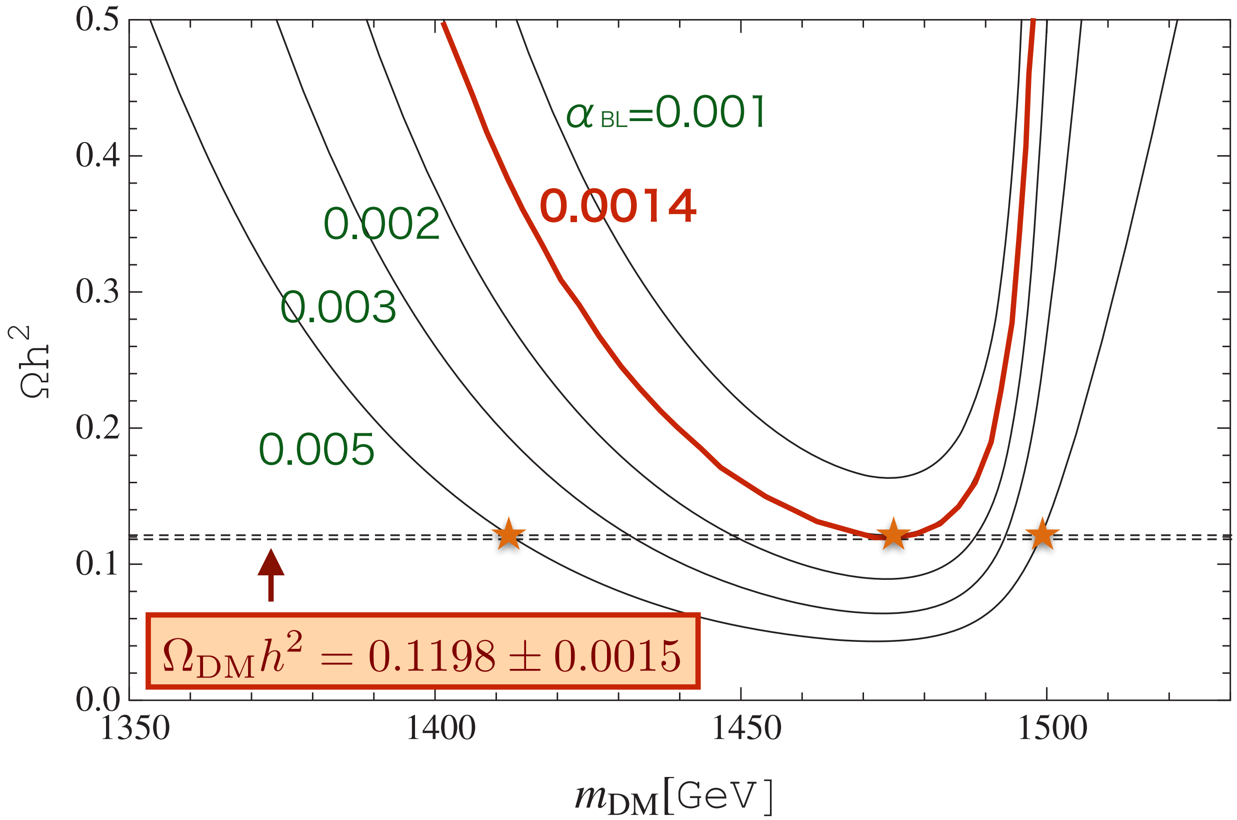
$g_{DM} = 2$: the number of DM d.o.f

$g_* = 106.75$: for the SM particles

K_2 : the modified Bessel function

Results of numerical analysis

For various values of α_{BL}, the DM relic abundance is calculated as a function of the dark matter mass for $m_{Z'}$=3 TeV.



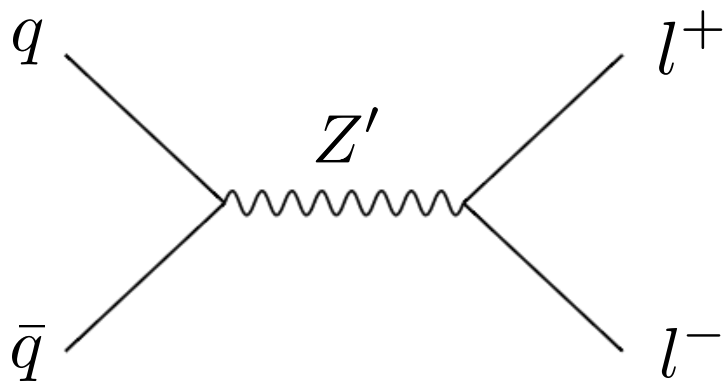
As we lower α_{BL},
relic abundance becomes larger.

For a fixed $m_{Z'}$
there is a lower bound on α_{BL} from the DM relic abundance constraint.

The lower bound on α_{BL} as a function of Z'_{BL} mass

4. Interpretation of LHC Run-2 results

The ATLAS and CMS collaborations are searching for Z' boson resonance with dilepton final state at the LHC Run-2.



The upper limits of the Z' boson production cross section have been obtained by ATLAS and CMS collaborations.

Z’BL production cross section

The differential cross section for the process $pp \to Z'_{BL} + X \to l^+l^- + X$ with respect to the invariant mass $M_{\ell\ell}$ of the final state dilepton.

$$\boxed{\frac{d\sigma}{dM_{\ell\ell}} = \sum_{a,b} \int_{\frac{M_{\ell\ell}^2}{E_{\rm CM}^2}}^{1} dx \frac{2M_{\ell\ell}}{xE_{\rm CM}^2} f_a(x,Q^2) f_b\left(\frac{M_{\ell\ell}^2}{xE_{\rm CM}^2}, Q^2\right) \hat{\sigma}(q\bar{q} \to Z'_{BL} \to \ell^+\ell^-)}$$

f_a : the parton distribution function for a parton "a"

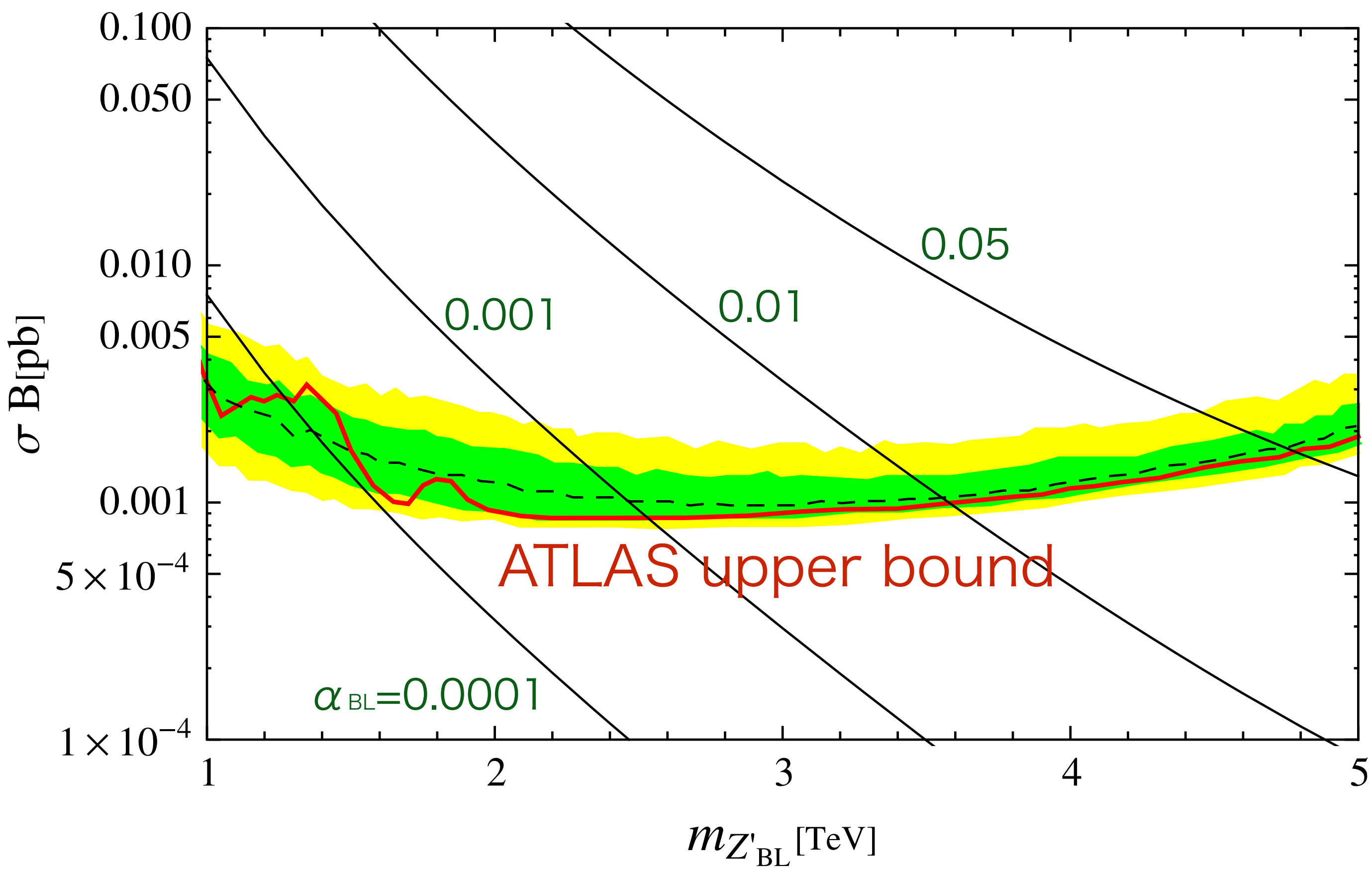
$E_{CM} = 13$ TeV : the energy of the LHC Run 2

The cross section for the colliding partons.

$$\boxed{\hat{\sigma} = \frac{4\pi\alpha_{BL}^2}{81} \frac{M_{\ell\ell}^2}{(M_{\ell\ell}^2 - m_{Z'}^2)^2 + m_{Z'}^2\Gamma_{Z'}^2}}$$

Z’BL mass bound from ATLAS at LHC Run-2

We calculated the cross section of the process
$pp \to Z'_{BL} + X \to l^+ l^- + X$ for various values of α_{BL}.



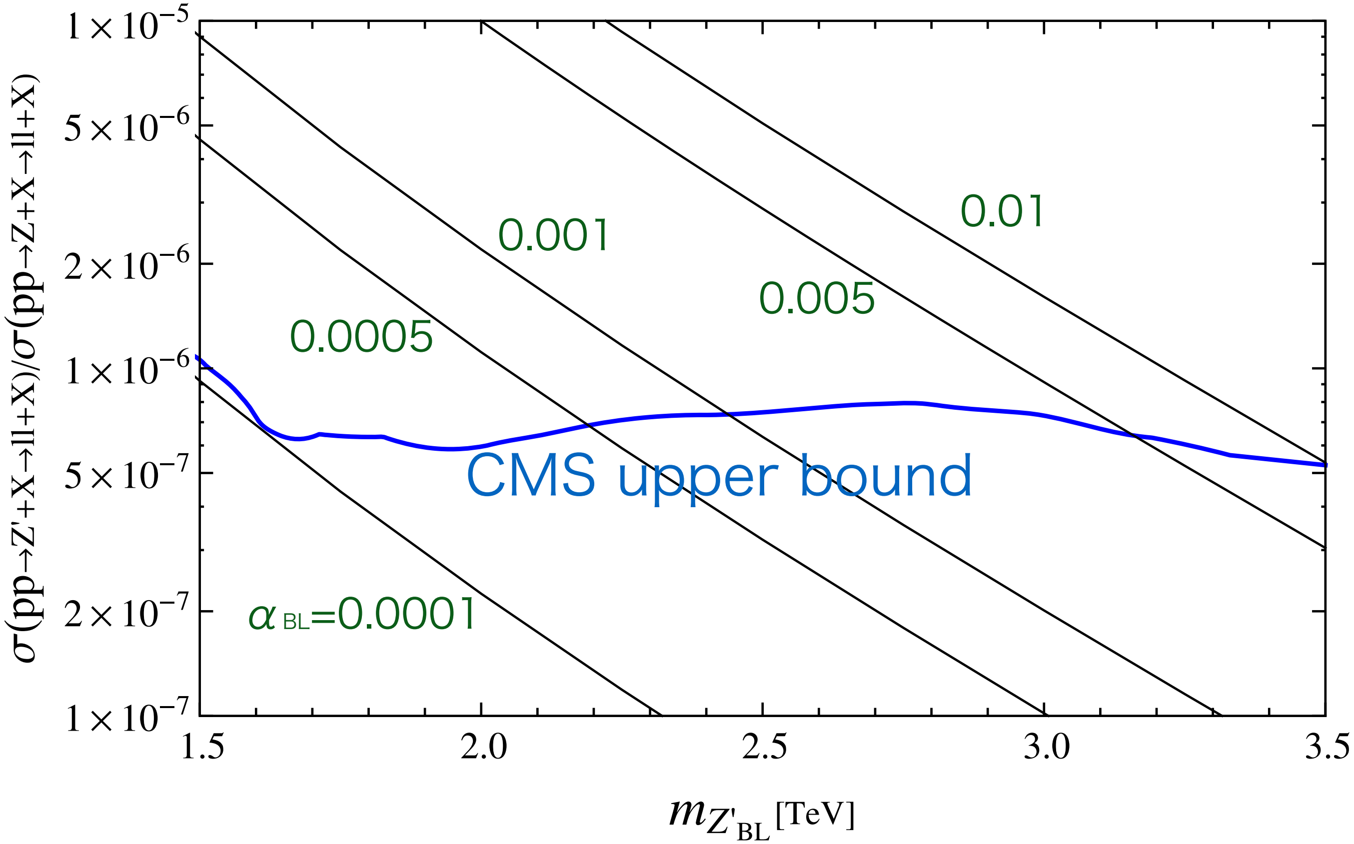
For a fixed $m_{Z'}$ there is an upper bound on α_{BL} to satisfy ATLAS bound.

The ATLAS collaboration, ATLAS-CONF-2015-070

The upper bound on α_{BL} as a function of Z’BL mass

Z'_{BL} mass bound from CMS at LHC Run-2

We did the same analysis for the CMS bound.

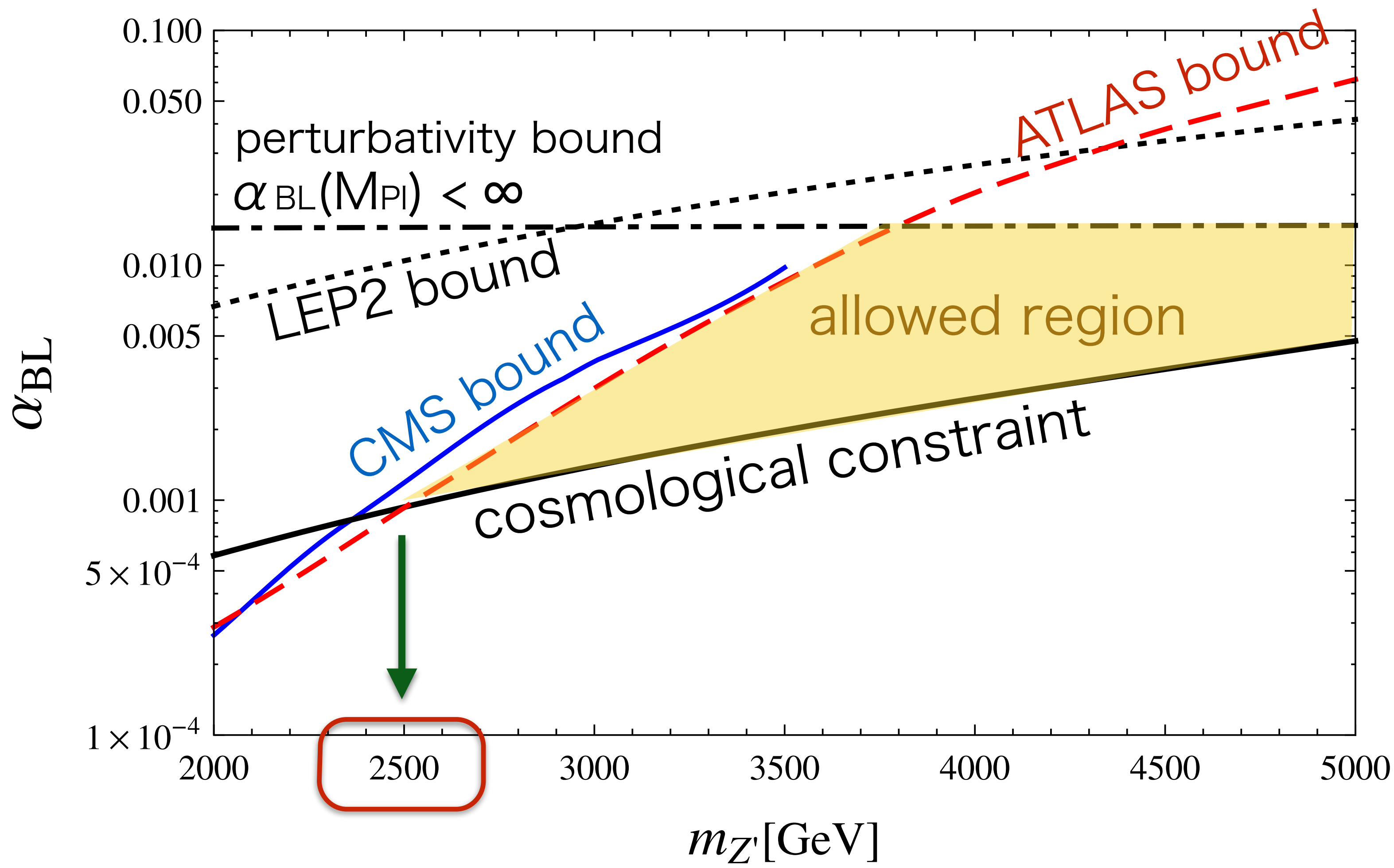


For a fixed $m_{Z'}$ there is an upper bound on α_{BL} to satisfy CMS bound.

The CMS collaboration, CMS-PAS-EXO-15-005

The upper bound on α_{BL} as a function of Z'_{BL} mass

Combining all constraints



We found the lower bound on the Z'$_{BL}$ boson mass
mz' > 2.5 TeV.

5. Conclusions

We have considered the minimal gauged B-L extension of the standard model with a right-handed neutrino dark matter.

In this model, the dark matter particle communicates with the standard model particles through the B-L gauge boson(Z'_{BL} boson), and this "Z'_{BL} portal" dark matter scenario is controlled by only three parameters,

- gauge coupling
- Z'_{BL} boson mass
- dark matter mass

5. Conclusions

We have considered a variety of phenomenological constraints on this “Z'_{BL} portal” dark matter scenario.

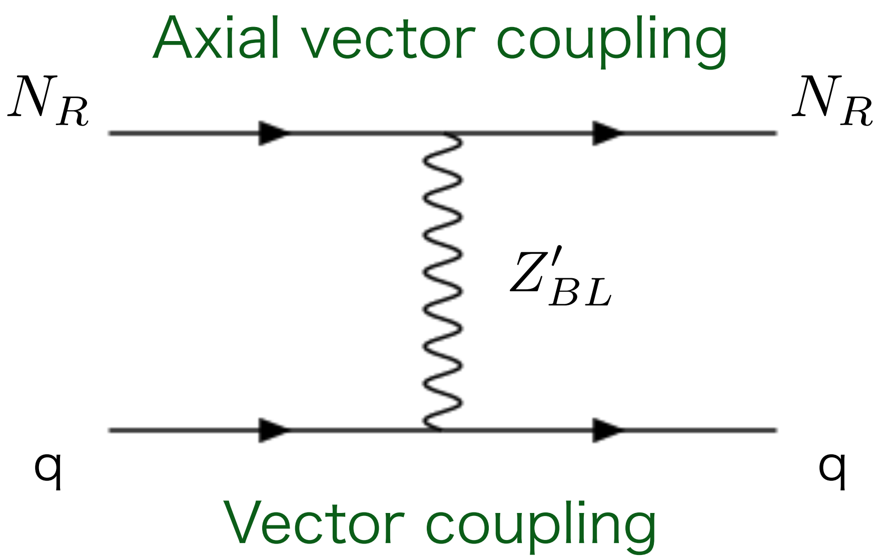
- relic abundance constraint
- LHC Run-2 bounds
- LEP2 bound
- perturbativity bound of running gauge coupling up to Planck mass

We have found the lower bound on the Z'_{BL} boson mass of **$m_{Z'} > 2.5$TeV**.

Thank you

for your attention!

Direct and indirect detection

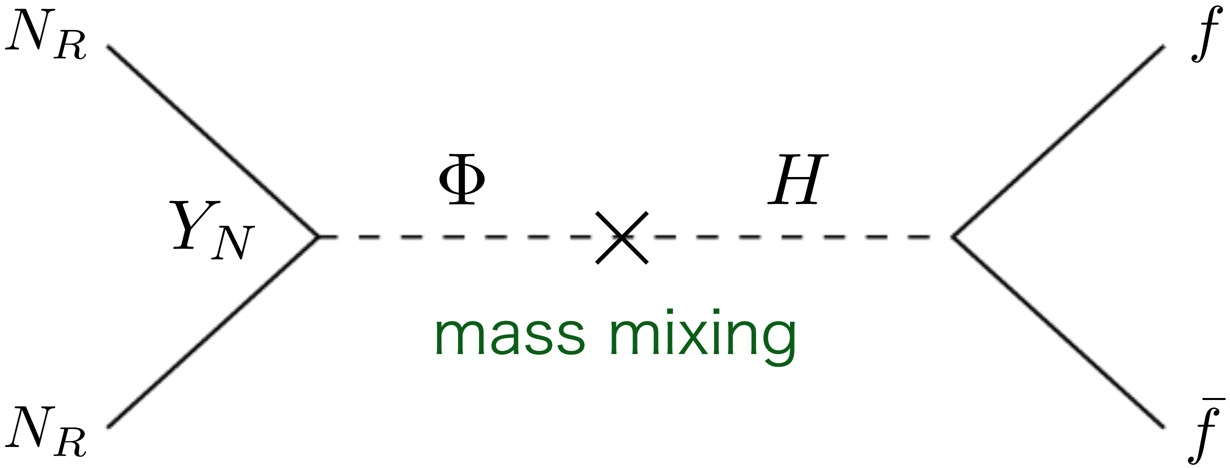


In non-relativistic limit,
the scattering cross section of DM with nucleon is vanishing.

$$\sigma(N_R q \to N_R q) \to 0$$

B-L Higgs portal dark matter

B-L Higgs portal dark matter is also possible.



Free parameters

- B-L Higgs mass (m_Φ)
- Φ-H mixing mass
- dark matter mass (m_{DM})