Vector DM from hidden local SU(2)

Takaaki Nomura (Sichuan Univ.)

Collaborated with Hiroshi Okada(APCTP) and Seokhoon Yun(INFN)

(arXiv:2012.11377)

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1. Introduction

Existence and nature of DM is mystery in physics

DM as new particle is one of the attractive scenario

- ✧**No electric charge, no color, Non-baryonic**
- ✧**Weakly interacting**
- ✧**Stable in cosmological scale**

A DM model with hidden gauge symmetry is interesting

- **DM stability from hidden gauge symmetry**
- **Dark gauge symmetry provide DM or Z' or dark photon**
- **Vector DM + Z' mediator from non-Abelian case**

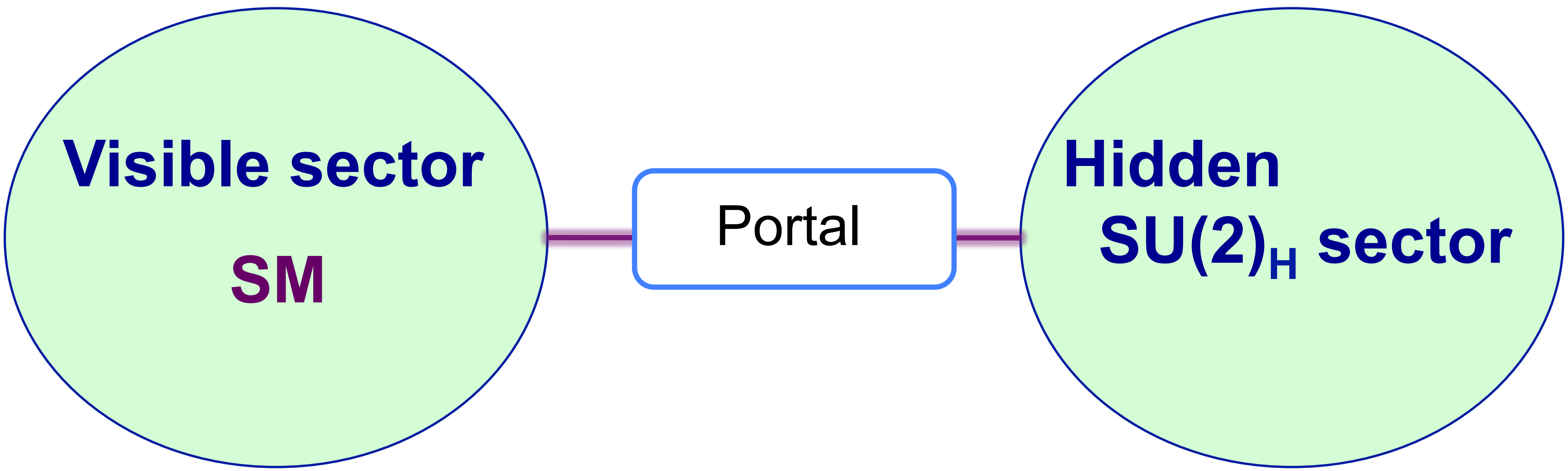
  Natural resonant annihilation is realized for vector DM

  $2m_X = m_{Z'}$: when $SU(2)_H$ is broken by quintet scalar VEV

  $SU(2)_H \times U(1)_{B-L}$ model C. W. Chiang, T. N, J. Tandean, (JHEP 01, 2014)

Structure of our scenario

❖Singlet under $SU(2)_H$ ❖Singlet under G_{SM}



Two sector can interact via scalar mixing and/or gauge boson mixing

⇨ We consider kinetic mixing associated with $SU(2)_H$ and $U(1)_Y$

❖ In previous work we consider mass mixing in $U(1)_{B-L}$ and $SU(2)_H$

2. Model

A model

❖ $G_{SM} \times SU(2)_H$ gauge symmetry

❖ New field contents: $SU(2)_H$

***Scalar fields**

Quintet: $\Phi = (\phi_2, \phi_1, \phi_0, \phi_{-1}, \phi_{-2})$ Triplet: $\varphi = \varphi^a \frac{\sigma^a}{2}$

***Gauge boson**

$SU(2)_H : (X_\mu^1, X_\mu^2, X_\mu^3)$

❖ Scalar VEV and symmetry breaking

$$< \Phi >= (v_\Phi / \sqrt{2}, 0, 0, 0, 0) \qquad < \varphi >= \frac{1}{2\sqrt{2}} \begin{pmatrix} v_\varphi & 0 \\ 0 & -v_\varphi \end{pmatrix}$$

$SU(2)_H \rightarrow Z_2$

Eigen value of $\sigma^3/2$ is even(odd) → Parity even(odd)

❖ X^1 and X^2 are Z_2 odd and our DM candidate

Hidden Gauge Sector with SM $U(1)_Y$

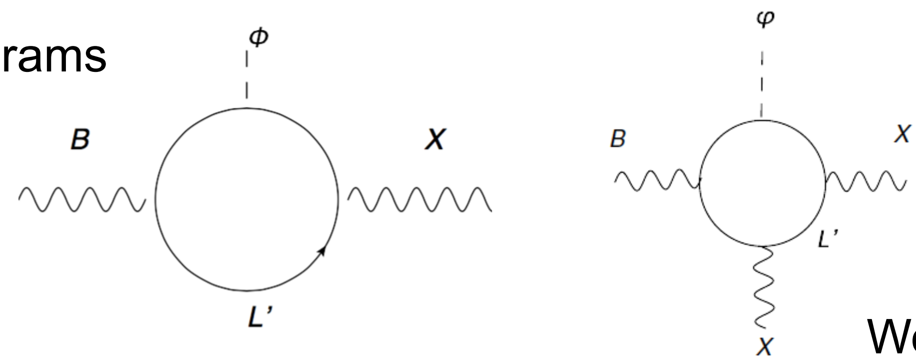
To connect $SU(2)_H$ and $U(1)_Y$ we introduce dim 5 operator

$$-\frac{C_\phi}{\Lambda}\varphi^a X^{a\mu\nu} B_{\mu\nu}$$

It can be generated introducing field charged under $SU(2)_H$ and $U(1)_Y$

e.g. $SU(2)_H$ doublet fermion L' with $U(1)_B$ charge -1

1-loop diagrams



Work in progress

We use the Lagrangian :

$$L = -\frac{1}{4} X^{a\mu\nu} X^a_{\mu\nu} - \frac{1}{4} B^{\mu\nu} B_{\mu\nu} - \frac{C_\phi}{\Lambda}\varphi^a X^{a\mu\nu} B_{\mu\nu}$$

Hidden Gauge Sector with SM $U(1)_Y$

$$L = -\frac{1}{4}X^{a\mu\nu}X^a_{\mu\nu} - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{C_\phi}{\Lambda}\varphi^a X^{a\mu\nu}B_{\mu\nu}$$

$$\left(\sin\chi \equiv \sqrt{2}C_\varphi v_\varphi/\Lambda \right)$$

$$+D^\mu\Phi D_\mu\Phi + Tr[D^\mu\varphi D_\mu\varphi] \quad \Rightarrow \quad \mathcal{L}_{\rm KM} = -\frac{1}{2}\sin\chi X^3_{\mu\nu}\tilde{B}^{\mu\nu}$$

Diagonalizing kinetic terms

$$B_\mu \to B_\mu - \tan\chi X^3_\mu$$

$$X^3_\mu \to \frac{1}{\cos\chi}X^3_\mu$$

For tiny χ ⇒

$$B_\mu \to B_\mu - \chi X^3_\mu$$

$$X^3_\mu \to X^3_\mu$$

Gauge boson mass term after symmetry breaking $X^\pm_\mu = \left(X^1_\mu \mp X^2_\mu\right)/\sqrt{2}$

$$L_M = \frac{1}{2}m^2_{Z_{SM}}\tilde{Z}_\mu\tilde{Z} + m^2_{Z_{SM}}\chi\sin\theta_W\tilde{Z}_\mu X^{3\mu} + \frac{1}{2}m^2_{X^3}X^3_\mu X^{3\mu} + m^2_{X^\pm}X^+_\mu X^{-\mu},$$

$$m^2_{Z_{SM}} = \frac{v^2}{4}(g^2+g^2_B), \quad m^2_{X^3} = 4g^2_X v^2_\Phi, \quad m^2_{X^\pm} = g^2_X v^2_\Phi\left(1+\frac{v^2_\varphi}{v^2_\Phi}\right),$$

Hidden gauge boson masses and interactions

- Z,Z' masses and Z-Z' mixing:

$$m^2_{Z,Z'} = \frac{1}{2}(m^2_{X^3} + m^2_{Z_{SM}}) \mp \frac{1}{2}\sqrt{(m^2_{X^3} - m^2_{Z_{SM}})^2 + 4\chi^2 \sin^2\theta_W m^4_{Z_{SM}}},$$

$$\tan 2\theta_{ZZ'} = \frac{2\sin\theta_W \chi m^2_{Z_{SM}}}{m^2_{Z_{SM}} - m^2_{X^3}},$$

- DM mass: $m^2_{X^\pm} = g^2_X v^2_\Phi \left(1 + \frac{v^2_\varphi}{v^2_\Phi}\right)$ ⇨ $m_{Z'} \simeq 2m_{X^\pm}(1+R_M)^{-\frac{1}{2}}$

$$R_M \equiv v^2_\varphi / v^2_\Phi$$

- Relevant DM interactions:

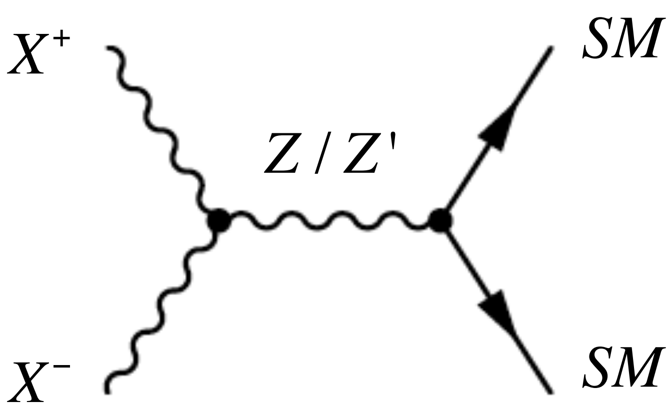
$$\mathcal{L} \supset i g_X C_{ZZ'}\Big[(\partial_\mu X^+_\nu - \partial_\nu X^+_\mu)X^{-\mu}Z'^\nu - (\partial_\mu X^-_\nu - \partial_\nu X^-_\mu)X^{+\mu}Z'^\nu + \frac{1}{2}(\partial_\mu Z'_\nu - \partial_\nu Z'_\mu)(X^{+\mu}X^{-\nu} - X^{-\mu}X^{+\nu})\Big],$$

$$\left(CZZ'(SZZ') = \cos\theta_{ZZ'}(\sin\theta_{ZZ'})\right)$$

$$\mathcal{L}_{Z'ff} = \frac{g}{\cos\theta_W} Z'_\mu \bar{f}\gamma^\mu \left[-S_{ZZ'}(T_3 - Q\sin^2\theta_W) + C_{ZZ'}\chi Y \sin\theta_W\right] f.$$

3. DM phenomenology

DM annihilation and interaction with nucleon



Z' exchange is dominant for DM annihilation

⇨ Resonant enhancement

Relic density is estimated by micrOMEGAs

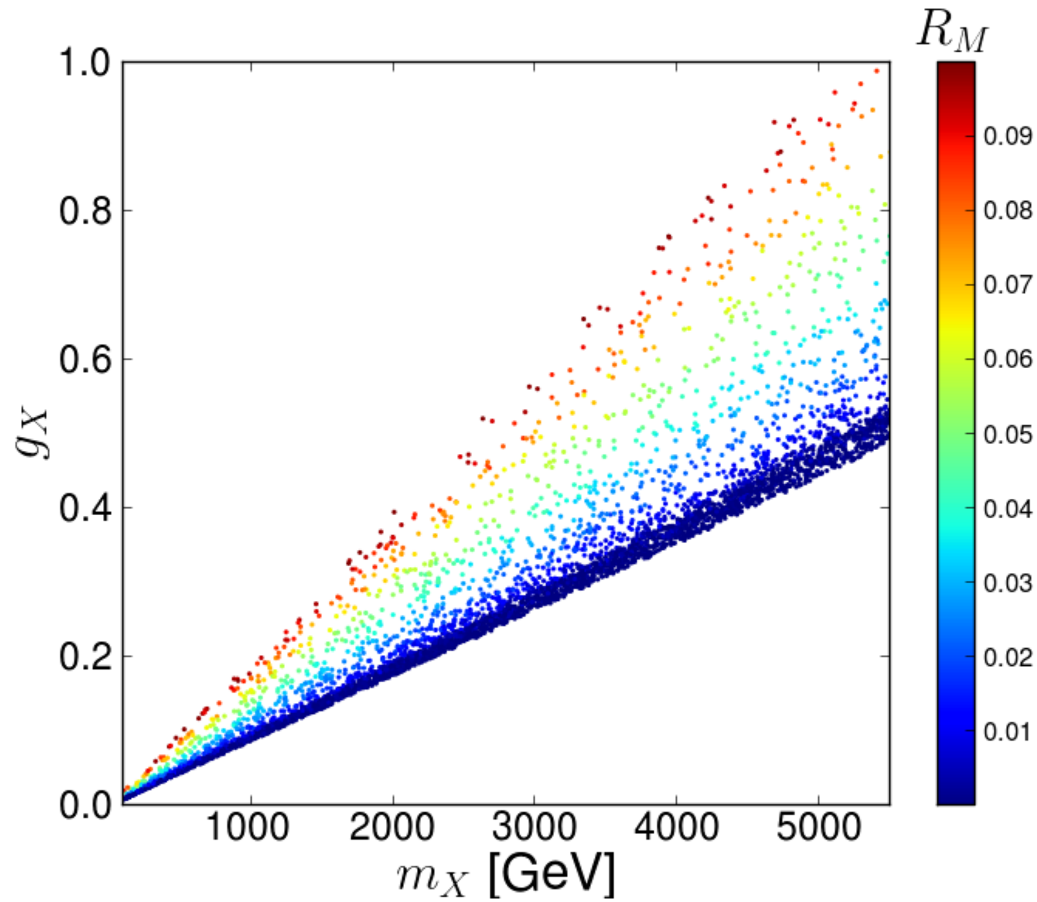
DM-Nucleon scattering cross section

$$\sigma_{NX} = \frac{2 g_X^2 g^2}{\pi \cos^2\theta_W} \left(\frac{m_{X^\pm} m_N}{m_X + m_N} \right)^2 \left(\frac{S_{ZZ'} C^V_{NNZ}}{m_Z^2} + \frac{C_{ZZ'} C^V_{NNZ'}}{m_{Z'}^2} \right)^2$$

$$C^V_{ppZ} = C_{ZZ'} \left(\frac{1}{4} - \sin^2\theta_W \right), \quad C^V_{nnZ} = C_{ZZ'} \left(-\frac{1}{4} \right),$$

$$C^V_{ppZ'} = -S_{ZZ'} \left(\frac{1}{4} - \sin^2\theta_W \right) + \frac{3}{2} C_{ZZ'} \sin\theta_W \delta, \quad C^V_{nnZ'} = \frac{1}{4} S_{ZZ'} + \frac{1}{2} C_{ZZ'} \sin\theta_W \delta.$$

Parameter region realizing observed relic density



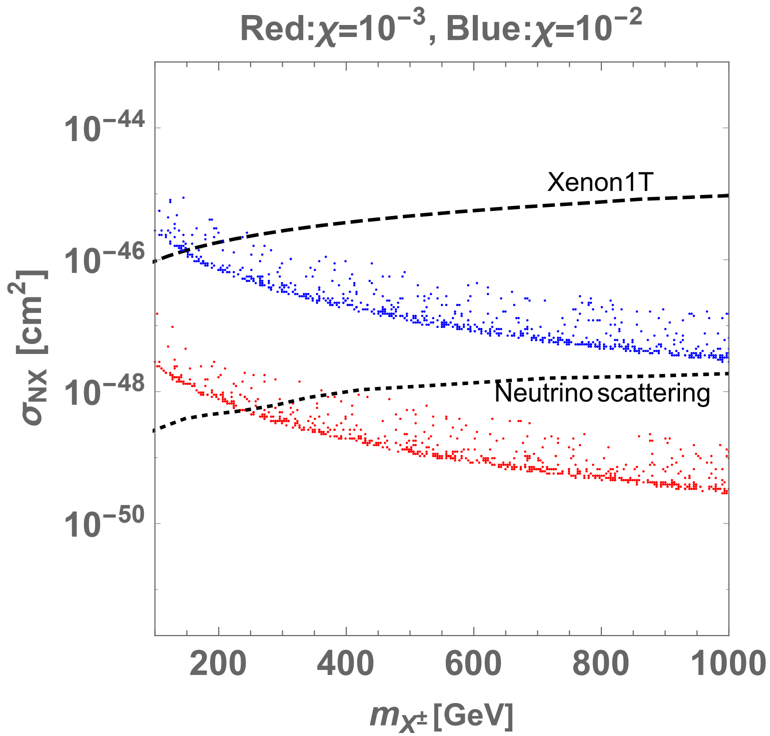
Parameters are scanned fixing $\chi = 10^{-3}$

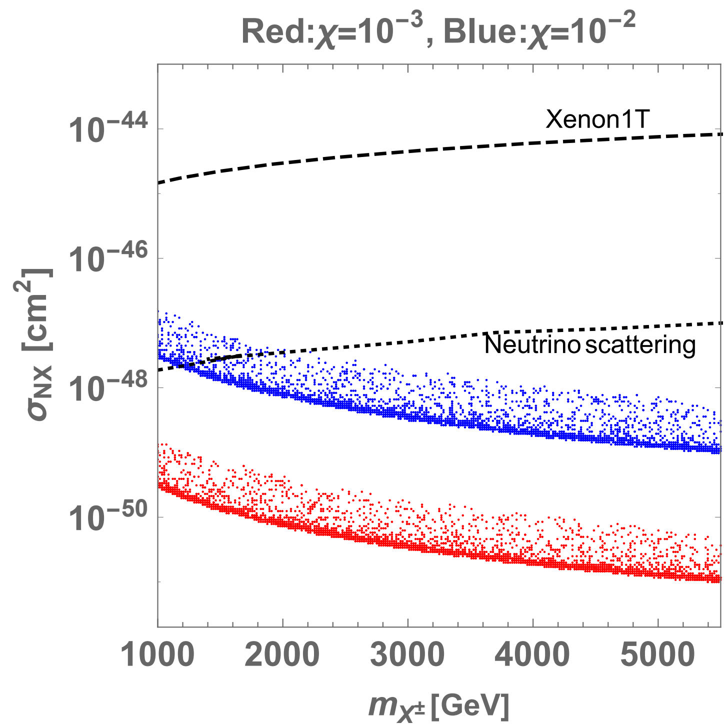
Approximated range

$$0.11 < \Omega h^2 < 0.13$$

- O(0.01)-O(1) gauge coupling for 100 GeV – 5500 GeV DM mass
- Larger R_M → larger gauge coupling

DM-Nucleon scattering cross section





Compared with Xenon1T constraint

XENON (2018)

- Most of parameter region is allowed
- It is difficult to detect DM when kinetic mixing parameter is small

Summary and discussion

Construction of model with dark SU(2) model

✧Remnant Z_2 symmetry as a subgroup of SU(2)

✧DM candidate is hidden SU(2) gauge bosons

✧DM interaction with SM through kinetic mixing

Application to DM phenomenology

✧Relic density of DM

✧Constraints from direct detection

Appendix

Z_2 symmetry as a remnant of $SU(2)_H$

Suppose SU(2) quintet and triplet scalars Φ,Φ' get VEVs as

$< \phi_0 > \neq 0, < \phi'_1 > \neq 0$ For components with eigenvalue of T_3 is 0 and 2

$$\exp\left[iT_3\pi\right]\left|Vacuum\right\rangle = \left|Vacuum\right\rangle$$ **Remaining discrete symmetry**

Then for any particle with odd T_3 value

$$\exp\left[iT_3\pi\right]X = \exp\left[i(2n+1)\pi\right]X = -X$$

⇨ Z_2 symmetry: odd/even for field with odd/even T_3 value

The lightest Z_2 odd particle in dark sector is DM

Scalar VEV and hidden gauge boson masses

When a component of scalar $SU(2)_H$ multiplet (characterized by l,m) gets VEV

$$\frac{g_X^2}{4}\left[(C^+_{\ell,m})^2+(C^-_{\ell,m})^2\right]v_\Phi^2 X^+_\mu X^{-\mu}+\frac{g_X^2}{2}m^2 v_\Phi^2 X^3_\mu X^{3\mu}$$
$$\equiv m^2_{X^\pm}X^+_\mu X^{-\mu}+\frac{1}{2}m^2_{X^3}X^3_\mu X^{3\mu}.$$

$$X^\pm_\mu \equiv (X^1_\mu \mp i X^2_\mu)/\sqrt{2}$$

$$C^+_{\ell,m}\equiv\sqrt{(\ell-m)(\ell+m+1)} \text{ and } C^-_{\ell,m}\equiv\sqrt{(\ell+m)(\ell-m+1)}.$$

Mass relation

$$\frac{m^2_{X^3}}{m^2_{X^\pm}}=\frac{4m^2}{(C^+_{\ell,m})^2+(C^-_{\ell,m})^2}=\frac{4m^2}{(\ell-m)(\ell+m+1)+(\ell+m)(\ell-m+1)}.$$

Z-Z' mixing

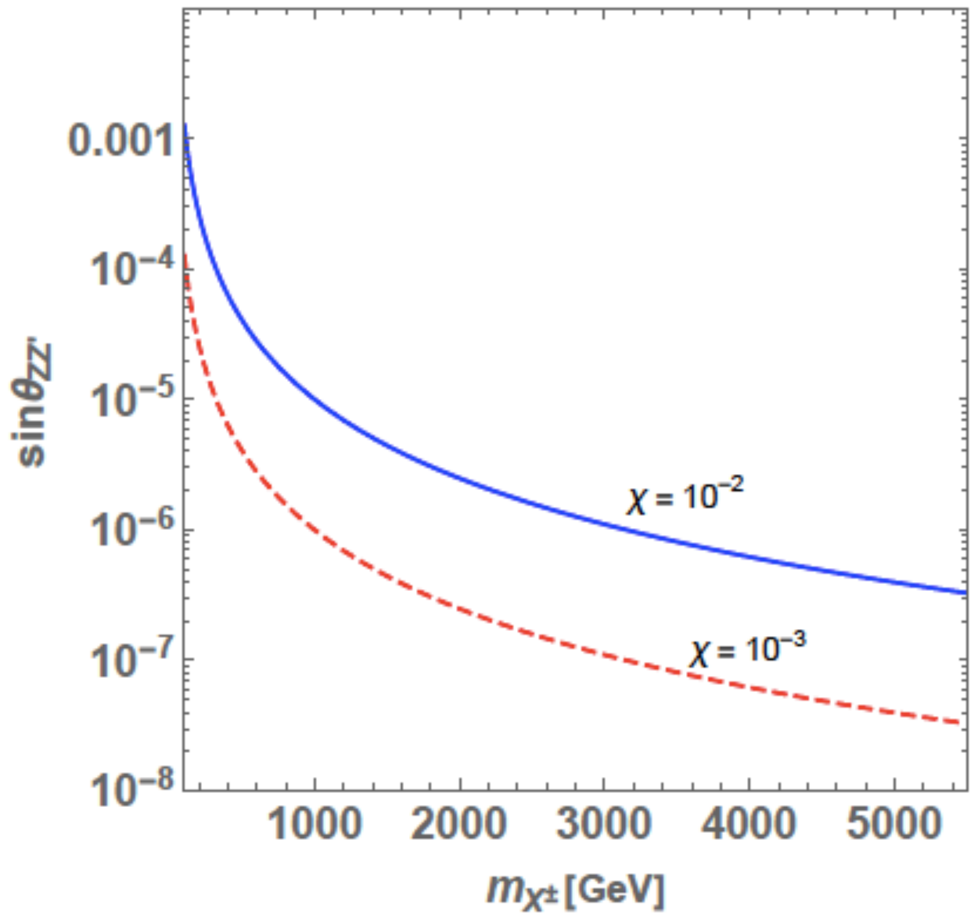


FIG. 1: $\sin\theta_{ZZ'}$ as a function of $m_{\chi^\pm}$ for $\chi = 10^{-2}$ and 10^{-3} where we fix $2v_\varphi^2/v_\Phi^2 = 0.01$.