Singleton Portals to the Twin Sector

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FB, C. B. Verhaaren [1811.05977] – accepted for publication in JHEP

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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DESY.

Motivation

- An elementary scalar (the Higgs) is sensitive to New Physics at higher scales – light mass implies tuning
- Since Higgs couples strongly to the top → symmetry solution with colored partners
- But LHC searches for NP has put stringent constraints on colored top partners
- Neutral naturalness remains an allowed and attractive paradigm
- However, mainly accessible via the Higgs portal – not much information

What can we do to unravel the structure of a twin sector?

The mirror twin Higgs (MTH)

Chacko, Goh, Harnik, hep-ph/0506256

$$V(\Phi) = -m^2|\Phi|^2 + \lambda|\Phi|^4$$

Where $\Phi \sim \square$ of global $SU(4)$

The VEV of Φ then breaks $SU(4) \to SU(3)$ which results in **7 goldstones**

Mirror the SM and gauge weak isospin
$SU(2)_A \times SU(2)_B \subset SU(4)$ under which Φ transforms as

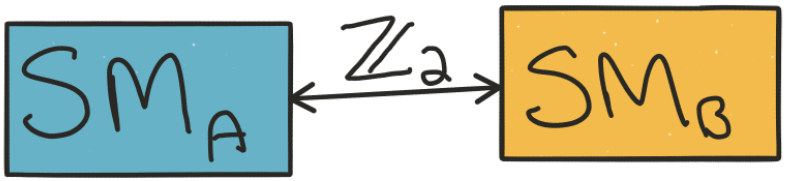
$$\Phi = \begin{pmatrix} H_A \\ H_B \end{pmatrix}$$

$\Rightarrow$ 6 goldstones eaten by $W_{A,B}$, $Z_{A,B}$; 1 is the SM Higgs

MTH cont'd and FTH

Chacko, Goh, Harnik, hep-ph/0506256

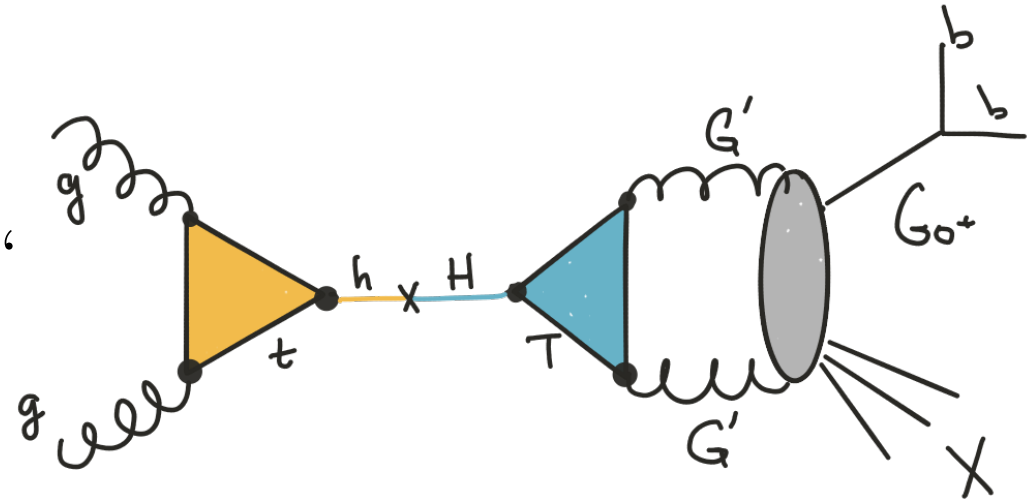
- Quadratic terms are genrated radiatively but if A and B sector gauge couplings are symmetric under discrete symmetry, then these terms are SU(4) invariant and do not give mass to the goldstone



so, $\Psi_A \overset{\mathbb{Z}_2}{\longleftrightarrow} \Psi_B$ etc.

FRATERNAL TWIN HIGGS

(FTH) ≡ mirror what you need → 3rd gen. fermions + gauge



FTH: Craig, Katz, Strassler, Sundrum [1501.05310];

Renormalizable portals to NP

Scalar	$H^\dagger H$	$S^\dagger S$
Vector	$B^{\mu\nu}$	$X_{\mu\nu}$
Fermionic	HL	N

The only guaranteed portal in TH

$B \equiv B_A$, $X \equiv B_B$: only other renormalizable portal without additional states in the low energy spectrum

Barbieri, Gregoire and Hall [hep-ph/0509242]

Singleton portals

- After “EWSB”, the physical Higgses and the photons of the A and B sectors can mix because they are neutral under A & B gauge groups
- However, there is another class of gauge-singlet states that can mix the two sector without violating any symmetries:
  - They have no twin partner, but,
  - They transform under the discrete Z_2 symmtery

$$\psi \xrightarrow{Z_2} \pm\psi \ , \quad \psi\,(\mathcal{O}_A \pm \mathcal{O}_B)$$

Singleton portals

- Scalar portal

$$\Delta\mathcal{L} = \kappa\phi\left(|H_A|^2 \pm |H_B|^2\right) + \lambda_{H\phi}\,|\phi|^2\left(|H_A|^2 + |H_B|^2\right)$$

- Fermionic portal

$$-\Delta\mathcal{L} = \left(\overline{L}_A\, Y_A\, \nu_R\right) H_A \pm \left(\overline{L}_B\, Y_B\, \nu_R\right) H_B + \frac{m_R}{2}\overline{\nu}_R^c \nu_R + \text{h.c.}$$

- Vector portal

$$-\frac{\varepsilon}{2}\left(B_A^{\mu\nu} \pm B_B^{\mu\nu}\right) X_{\mu\nu}$$

$$g_X X^\mu \left[\overline{f}_A \gamma_\mu \left(C_V + \gamma_5 C_A\right) f_A \pm \overline{f}_B \gamma_\mu \left(C_V + \gamma_5 C_A\right) f_B\right]$$

Vector singleton portal

- Consider the Lagrangian

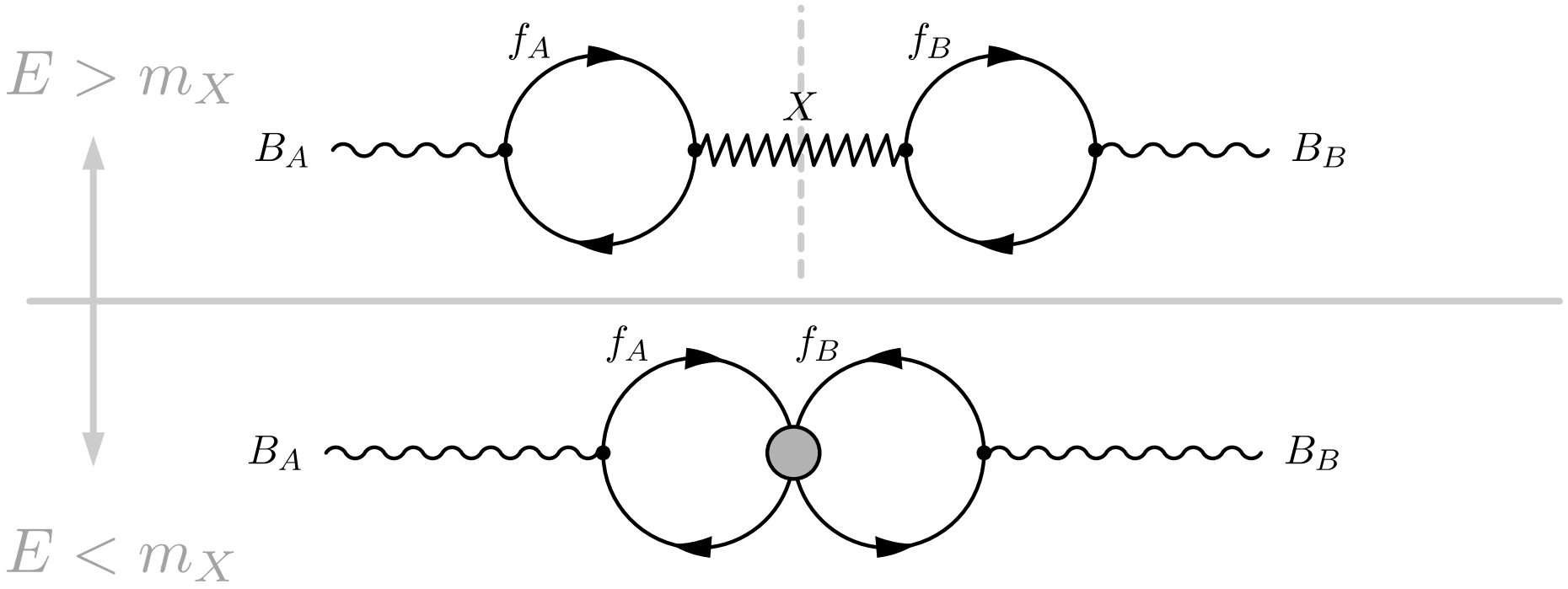
$$\mathcal{L}_X = -\frac{1}{4} X_{\mu\nu} X^{\mu\nu} + \frac{m_X^2}{2} X_\mu X^\mu + g_X X_\mu \left(J_A^\mu \pm J_B^\mu \right)$$

- It is convenient to define $r_X = g_X / g_2^{\mathrm{SM}}$
- Look at three benchmark scenarios:

Model	x_A^q	$x_A^{t,b}$	x_A^e	x_A^μ	x_A^τ	x_B^q	$x_B^{t,b}$	x_B^e	x_B^μ	x_B^τ
$(B-L)_{A-B}$	$1/3$	$1/3$	1	1	1	$1/3$	$1/3$	1	1	1
$(B-L)_{3,A-3,B}$	·	$1/3$	·	·	1	·	$1/3$	·	·	1
$L_{\mu_A-\mu_B}$	·	·	·	1	·	·	·	·	1	·

Vector singleton: kinetic mixing

$$\varepsilon \sim \frac{g_X g_Y}{24\pi^2} \left(\sum_f Y_f x_f \right) \ln \frac{m_X^2}{\Lambda_{\rm UV}^2}.$$

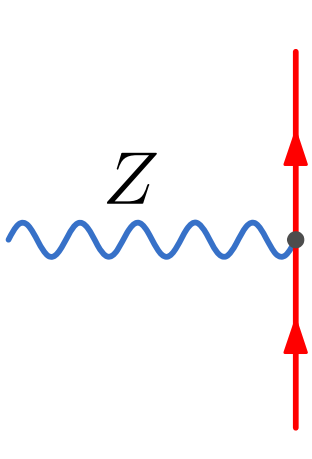


$$\sim \frac{g_X^2 g_Y^2}{576\pi^4} \frac{q^2}{m_X^2} \sum_{f_A} Y_{f_A} x_{f_A} \ln \frac{m_{f_A}^2}{m_X^2} \sum_{f_B} Y_{f_B} x_{f_B} \ln \frac{m_{f_B}^2}{m_X^2},$$

Consequences: couplings of Z bosons

SM Z coupling

coupling to B sector fermions
$\propto B$ "electric" charge



$$\sim g^{\mathrm{A}}_{Zff}\left(1+\varepsilon^2\right) - g_2\varepsilon^2(Q_A \pm Q_B)$$
$$-\varepsilon g_X(x_A + x_B) \pm \varepsilon^2 g^{\mathrm{B}}_{Zff}$$
$$+A \leftrightarrow B$$

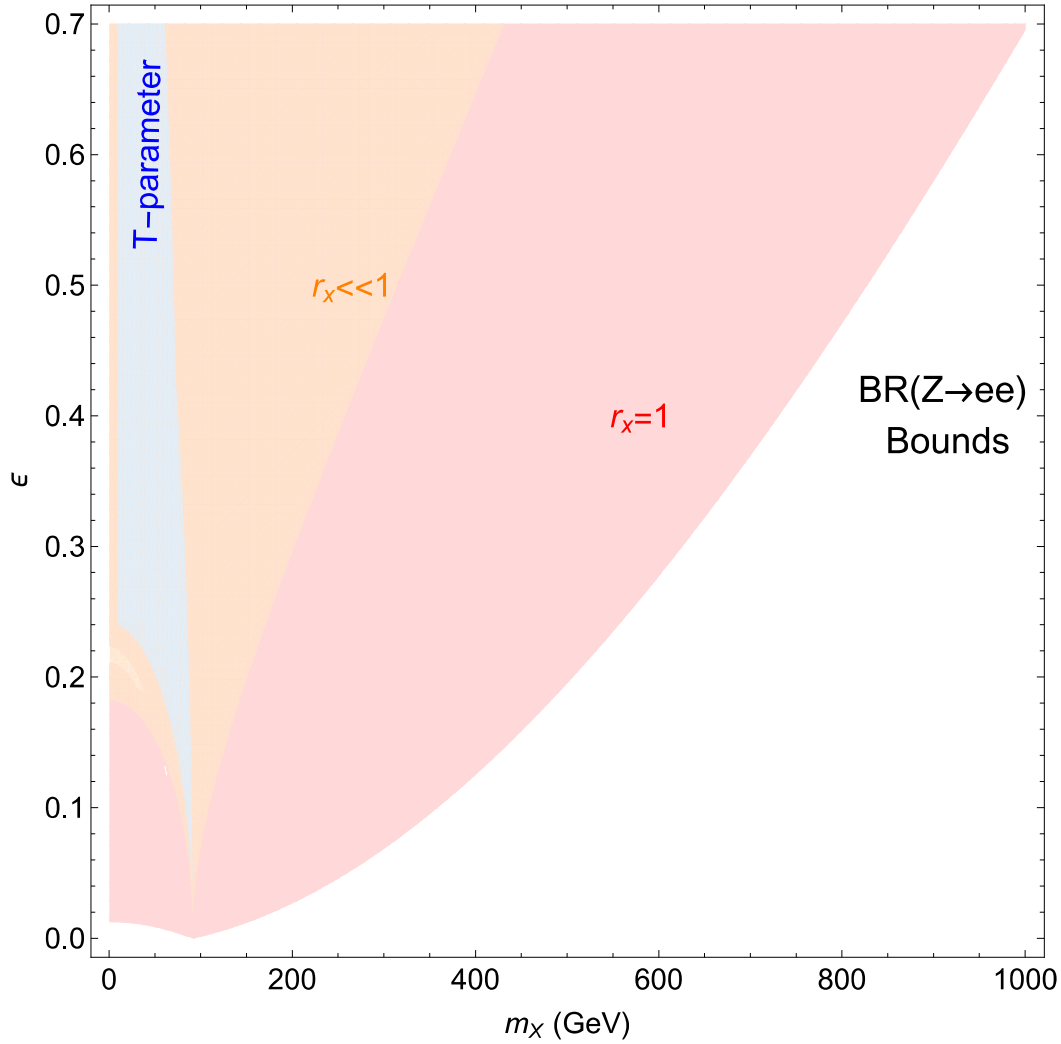
universal deviations
(suppressed due to two step mixing)

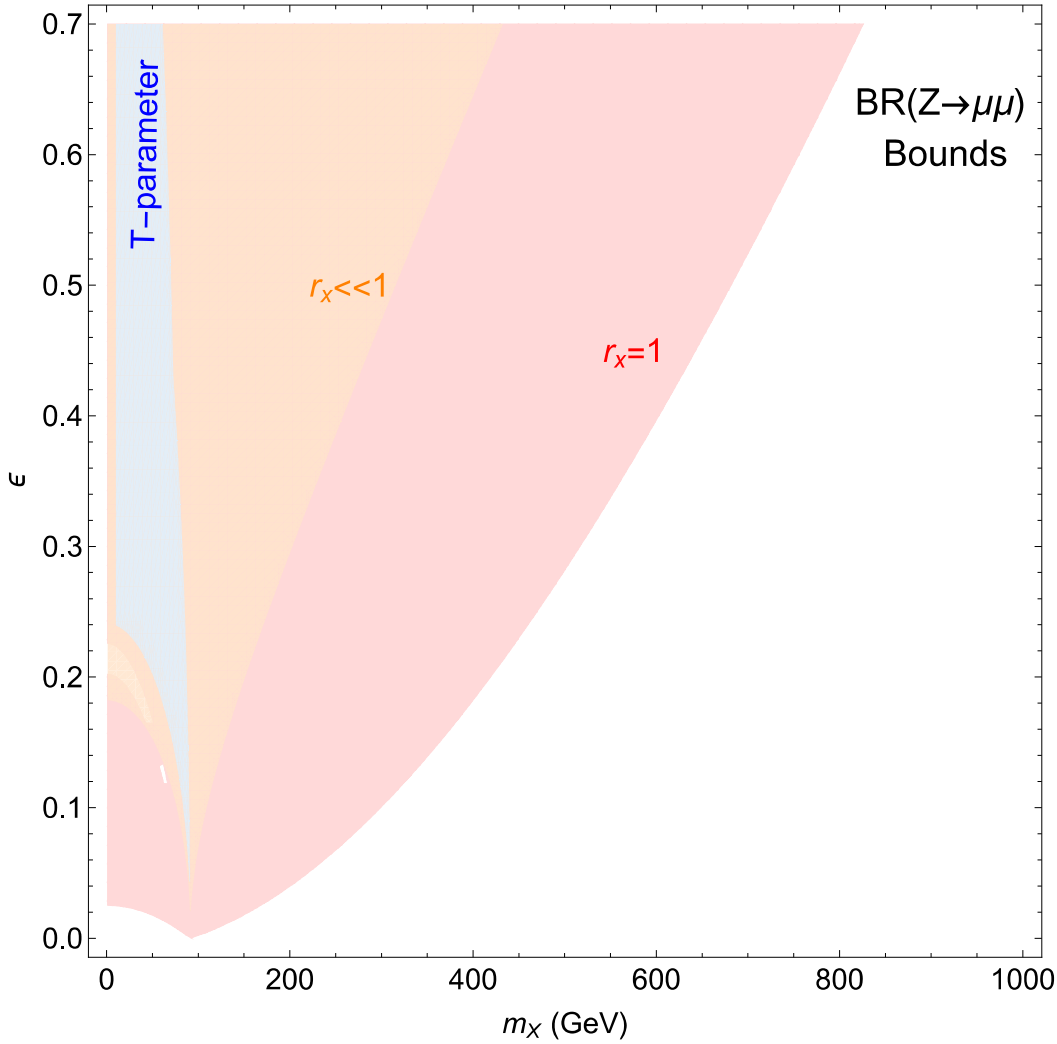
linear in ε!

coupling of A & B fermions
to the X gauge boson
$\rightarrow$ non-universal dep. on
gauged currents!

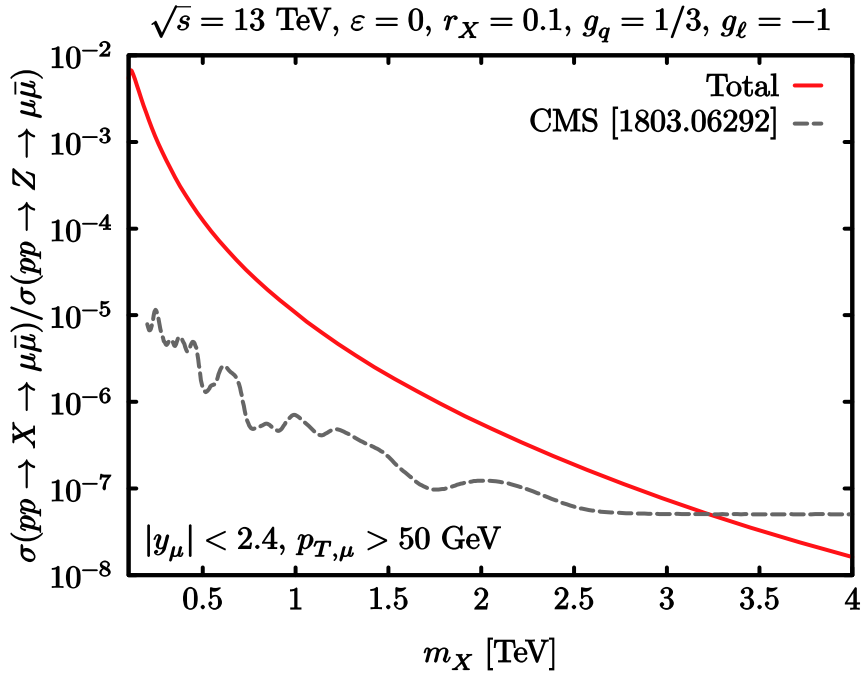
- ▷ Coupling of SM Z to B fermions
- ▷ Coupling os Z_B to SM fermions

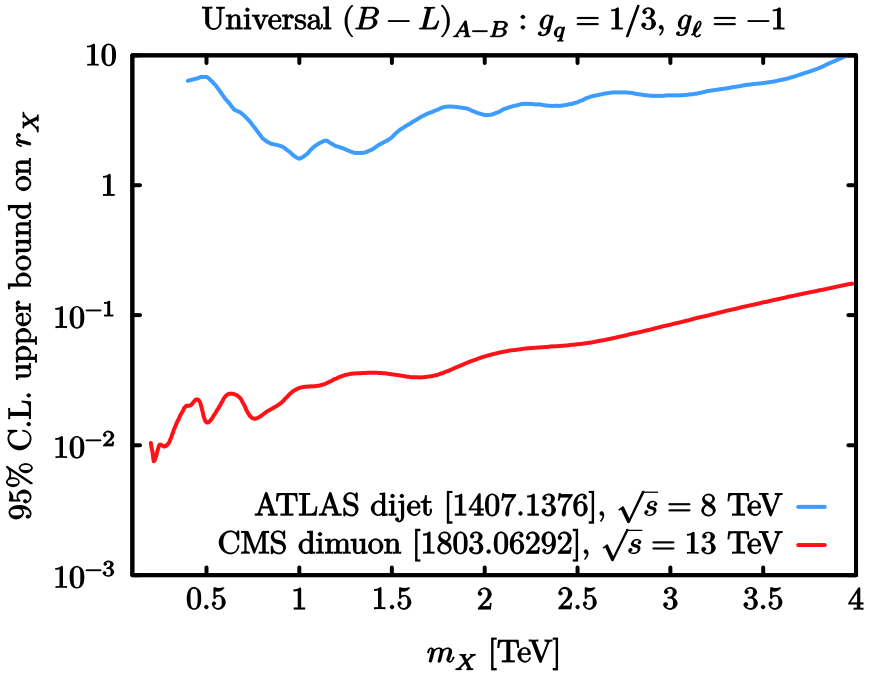
Indirect bounds

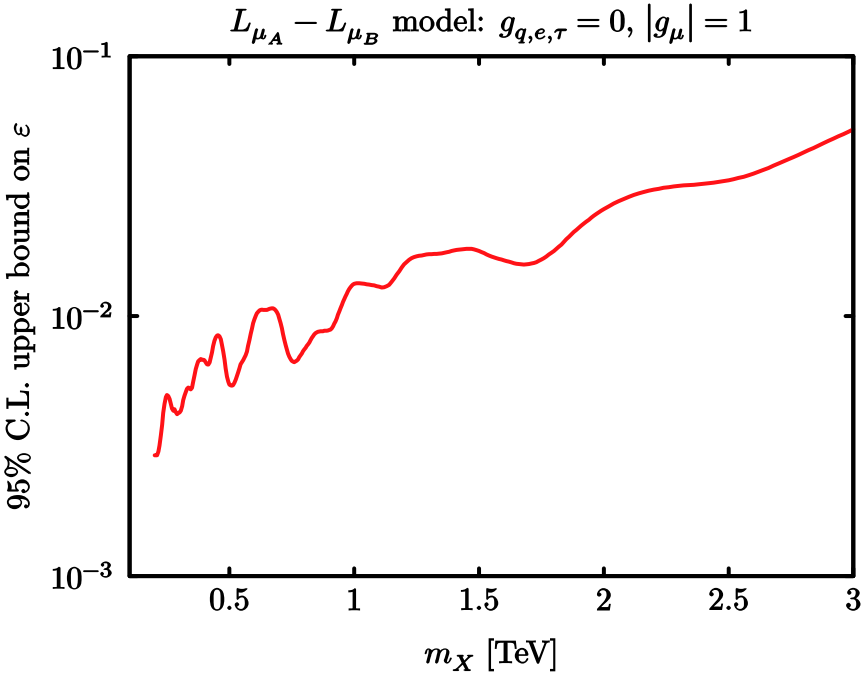


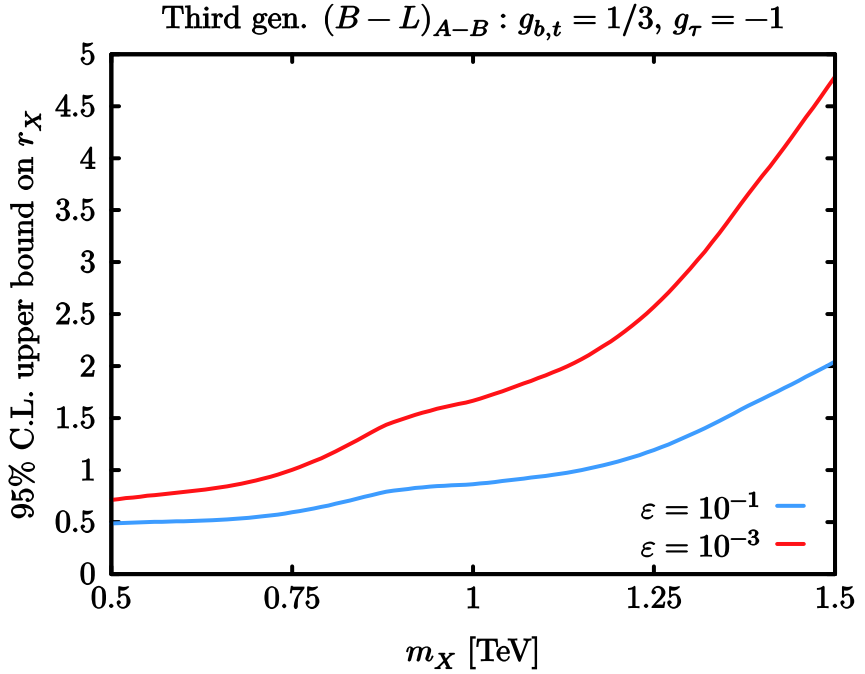


Searches at the LHC









Summary and outlook

- Singleton portals to the twin sector offer a phenomenologically rich avenue to explore the structure of the twin sector
- Can directly produce twin Z boson and twin photon at hadron colliders!
- Scalar singleton can explain origin of soft Z_2 breaking
- The vector portal gauge boson, if realized, would be within reach of HL-LHC and future colliders

Thank you!