Vector Portals to the Twin Sector

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SUSY
23 May 2019

Bishara, CV 1811.05977
Chacko, Kilic, Najjari, CV 1904.11990

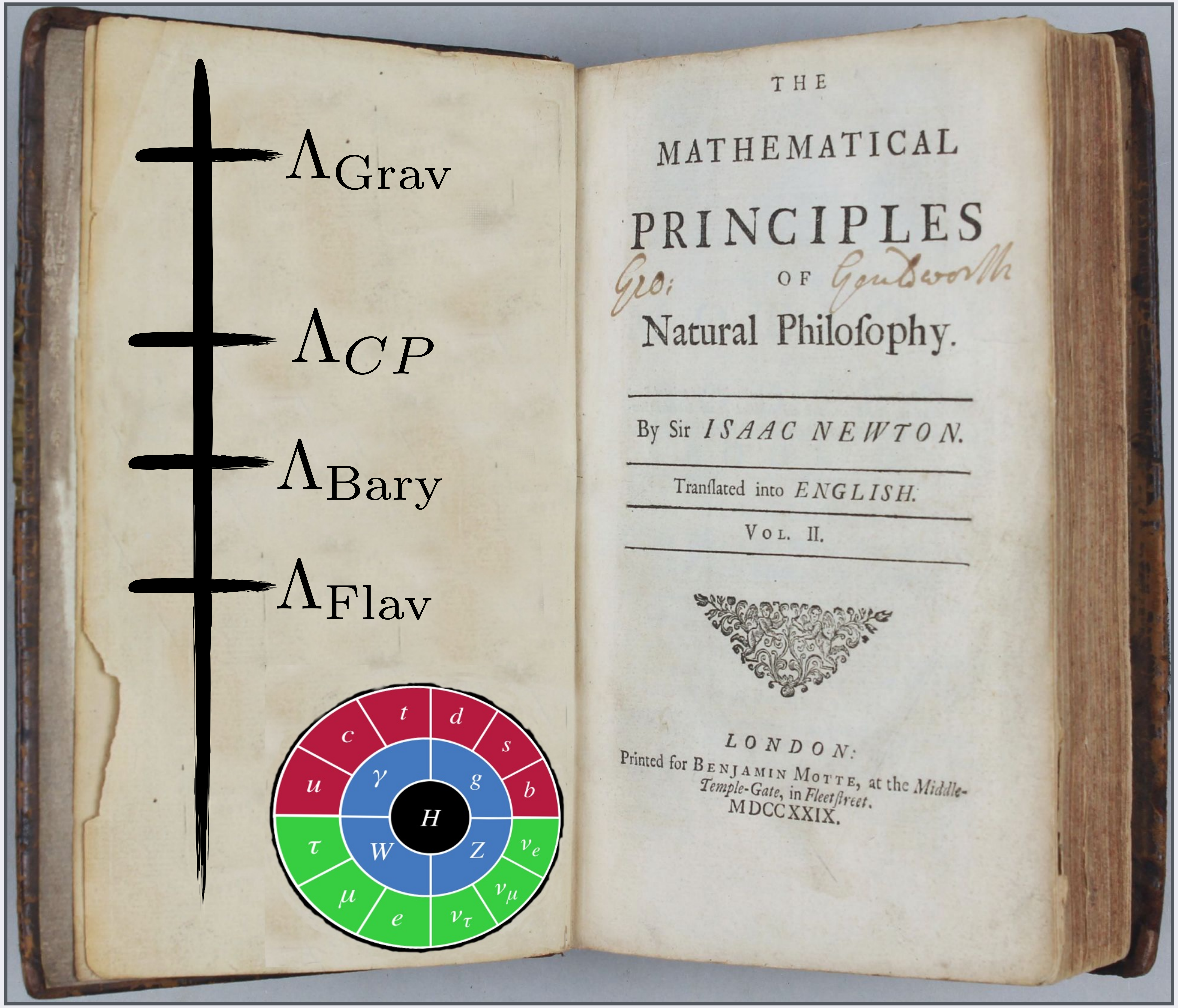
Some Natural Philosophy

The SM is an EFT

In EFTs, elementary scalars, like the Higgs, “should” have masses at the cutoff

In the SM, a 125 GeV Higgs is surprising, weird, awkward, maybe even unnatural

The lack of collider discoveries does not mean this isn’t a problem anymore, just the opposite



(Color) Neutral Naturalness

Beginning in 2005, a class of symmetry based solutions to the Hierarchy Problem have emerged

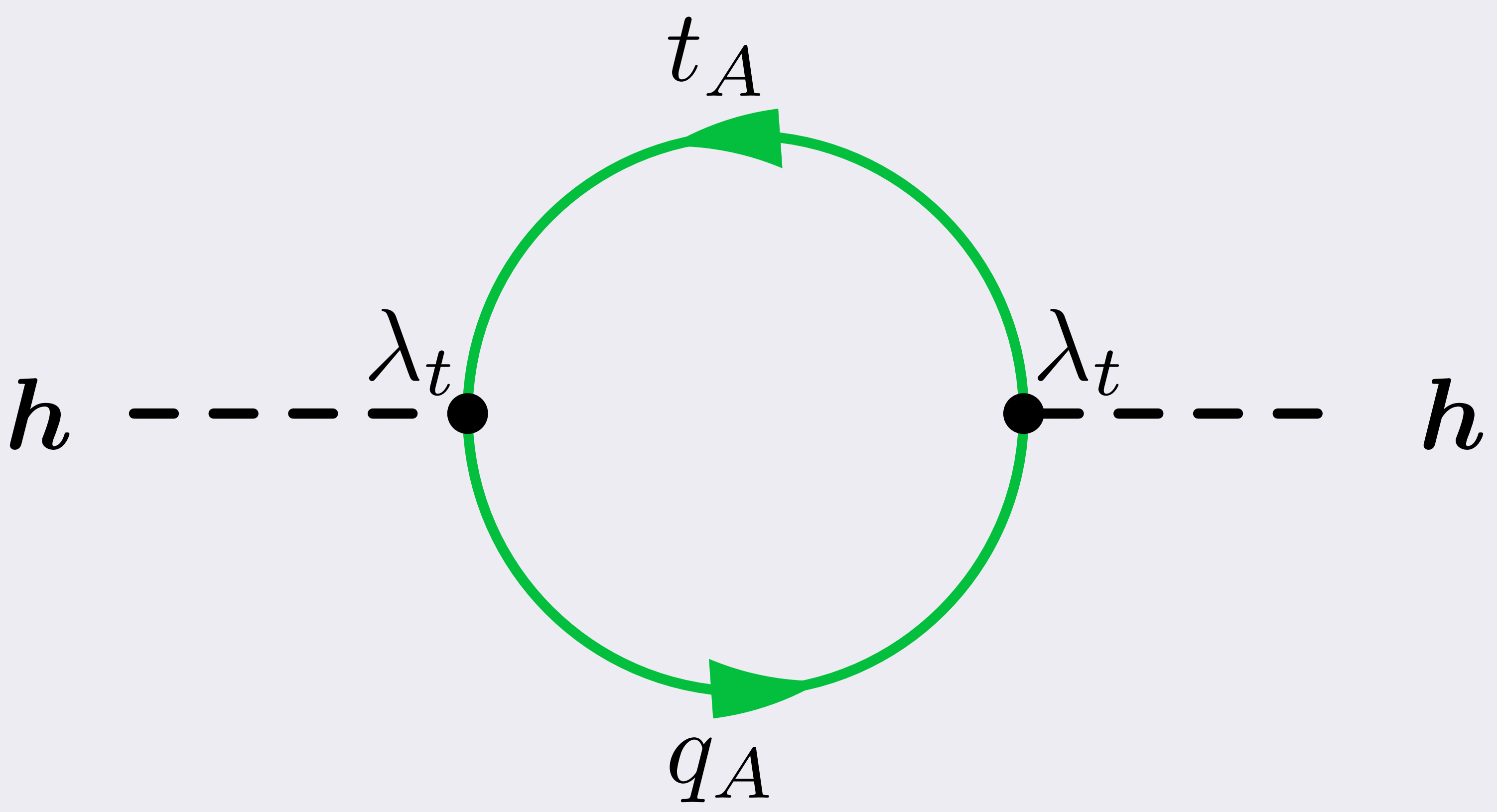
These models predict symmetry partners of the top quark that are not charged under SM color

Bounds from direct colored production effectively vanish

	Scalar Top Partner	Fermion Top Partner
All SM Charges	SUSY	pNGB & RS
EW Charges	Folded SUSY	Quirky Little Higgs
No SM Charges	Hyperbolic Higgs & Tripled Top	Twin Higgs

Cheng, Li, Salvioni, CV
1803.03651

New!



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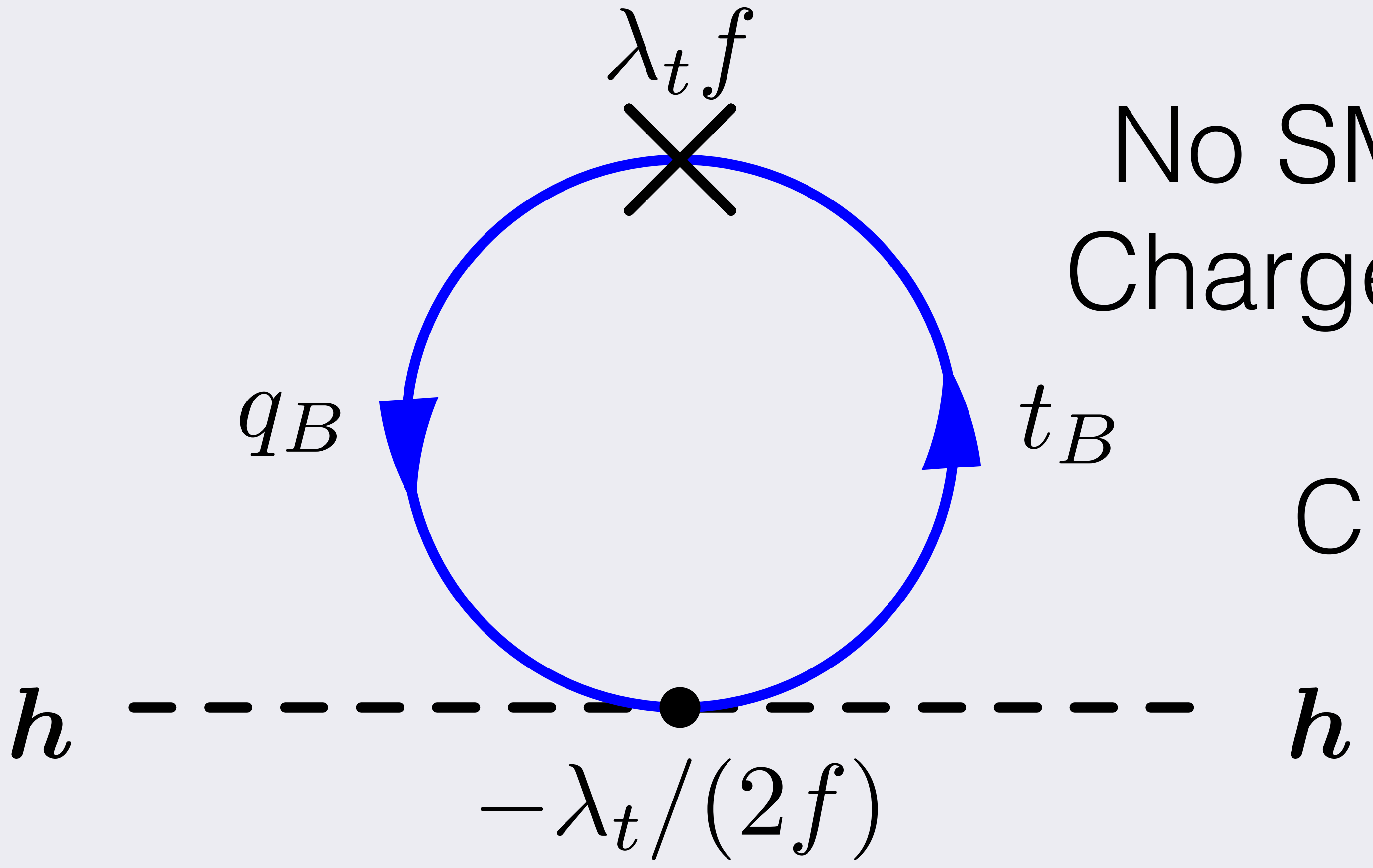


Twin Higgs

Chacko, Goh, Harnik, hep-ph/0506256

Make a twin copy of the SM matter and gauge structure and assume a Z_2 exchange symmetry between the SM and its twin

In the Higgs sector, assume an approximate global $SU(4)$ symmetry, with two $SU(2)$ subgroups gauged

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

When H gets a VEV f, the $SU(4)$ breaks to $SU(3)$, yielding 7 pNGBs
6 of these are eaten by the A and B sector $SU(2)$ gauge bosons

Left with one physical pNGB, our 125 GeV Higgs

Twin Higgs Physics

The Z_2 symmetry predicts equal VEV in A and B sectors

$$\frac{v}{f} \equiv \vartheta$$

$$v_A = f \sin\vartheta, \;\; v_B = f\cos\vartheta \quad m_B = m_A \cot\vartheta$$

The pNGB structure implies the Higgs couplings to A sector states is

$$g_{\rm A} = g_{\rm SM}\cos\vartheta$$

This already in tension with Higgs measurements…

However, the Z_2 can be softly broken, without reintroducing divergences, to make

$$v_B \gg v_A$$

Lifting the twin top mass does reintroducing tuning $\sim \dfrac{3\lambda_t^2}{8\pi^2} m_T^2 \ln\dfrac{\Lambda^2}{m_T^2}$

Twin Higgs Variations

The twin sector need not be a perfect copy. The Fraternal twin Higgs includes only the minimal third generation   Craig, Katz, Strassler, Sundrum, 1501.05310

The bottom and tau Yukawas can also depart from the exact Z_2

These variations can address cosmological issues and lead to viable dark matter (though both can exist in the Mirror Model also)

We take the Mirror model (exact Z_2) and fraternal model as the extremes in a model space spectrum

Testing the Twin Higgs Framework

How can we determine if nature is keeping the observed Higgs mass light using a twin Higgs framework?

We might address this question by through portals to the twin sector:

The Higgs portal h (Talk to me later, but not enough on its own)

The Hypercharge Portal B_μ (This talk)

The heavy Higgs portal H (See Can's talk Wednesday)

Beyond minimal Twin Higgs Portals

Singletons $\psi \xrightarrow{Z_2} \pm\psi$ (This talk)

Hypercharge Portal

Chacko, Kilic, Najjari, CV 1904.11990

In the twin Higgs framework the SM and twin sectors are charged under different gauge groups, which largely prevents the two sectors mixing

But, the a kinetic mixing of the two Hypercharge field strengths $B_{\mu\nu}B'^{\mu\nu}$ is gauge invariant and Z_2 preserving

If the twin Hypercharge boson is massless then the bounds on mixing with SM hypercharge are ~ 10^{-9} , not relevant at colliders

Bounds are much weaker for massive twin hypercharge, whose mass might come from Stuckelberg mass or from an additional Higgs doublet

$$\mathcal{L} \supset -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}B'_{\mu\nu}B'^{\mu\nu} + \frac{\epsilon}{2}B'_{\mu\nu}B^{\mu\nu} + \frac{m_{B'}^2}{2}B'_{\mu}B'^{\mu}$$

See Batell, CV 1904.10468 for some interesting effects related to breaking twin hypercharge

Hypercharge Portal

Because Hypercharge is the portal, there is mixing with the twin Z and twin photon, both of which are massive

$$\mathcal{L} \supset -\frac{1}{4}W_{\mu\nu}W^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} - \frac{1}{4}Z'_{\mu\nu}Z'^{\mu\nu} + \frac{m_{A'}^2}{2}A'_{\mu}A'^{\mu} + \frac{m_{Z'}^2}{2}Z'_{\mu}Z'^{\mu}$$

$$+ \frac{\epsilon\,\cos(\theta_W - \phi)}{2}B_{\mu\nu}A'^{\mu\nu} - \frac{\epsilon\,\sin(\theta_W - \phi)}{2}B_{\mu\nu}Z'^{\mu\nu}$$

Twin Neutral Boson Mixing Angle

This leads to indirect bounds from precision electroweak measurements and signals in direct LHC searches

LHC Discovery Potential

The neutral twin bosons can be produced at the LHC through their coupling to SM quarks

They can be most easily discovered in di-lepon resonances

In the mirror model the number and charges of the twin states is known, the widths of the Z' and A' are functions of f, ϵ , and $m_{B'}$

Measuring both masses and one rate to di-leptons specifies all parameters

The remaining di-lepton rate is a prediction, which can be compared with experiment, testing the model

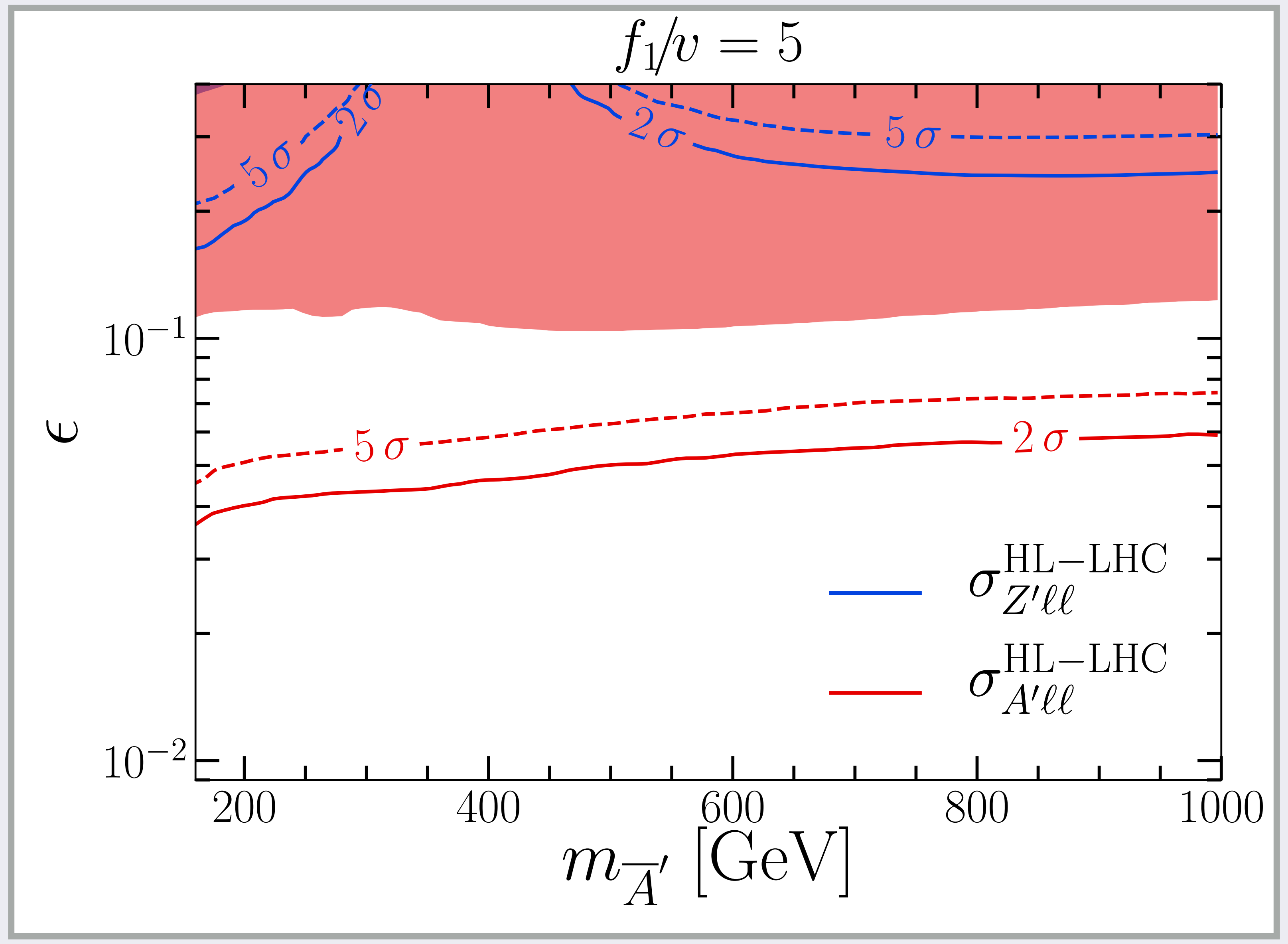
However, there is still ambiguity from how the twin photon obtains a mass

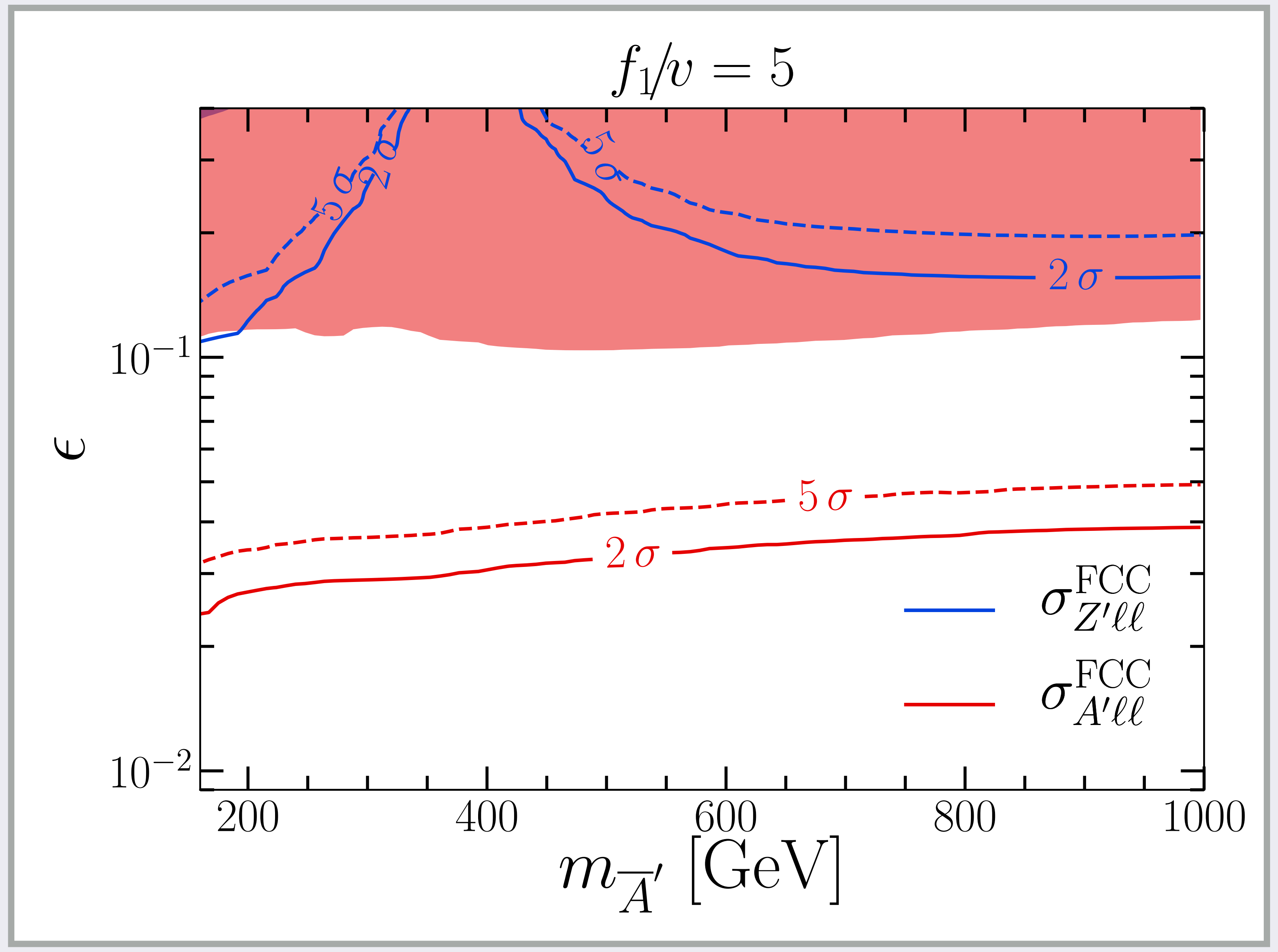
Collider Discovery Potential

13 TeV HL-LHC

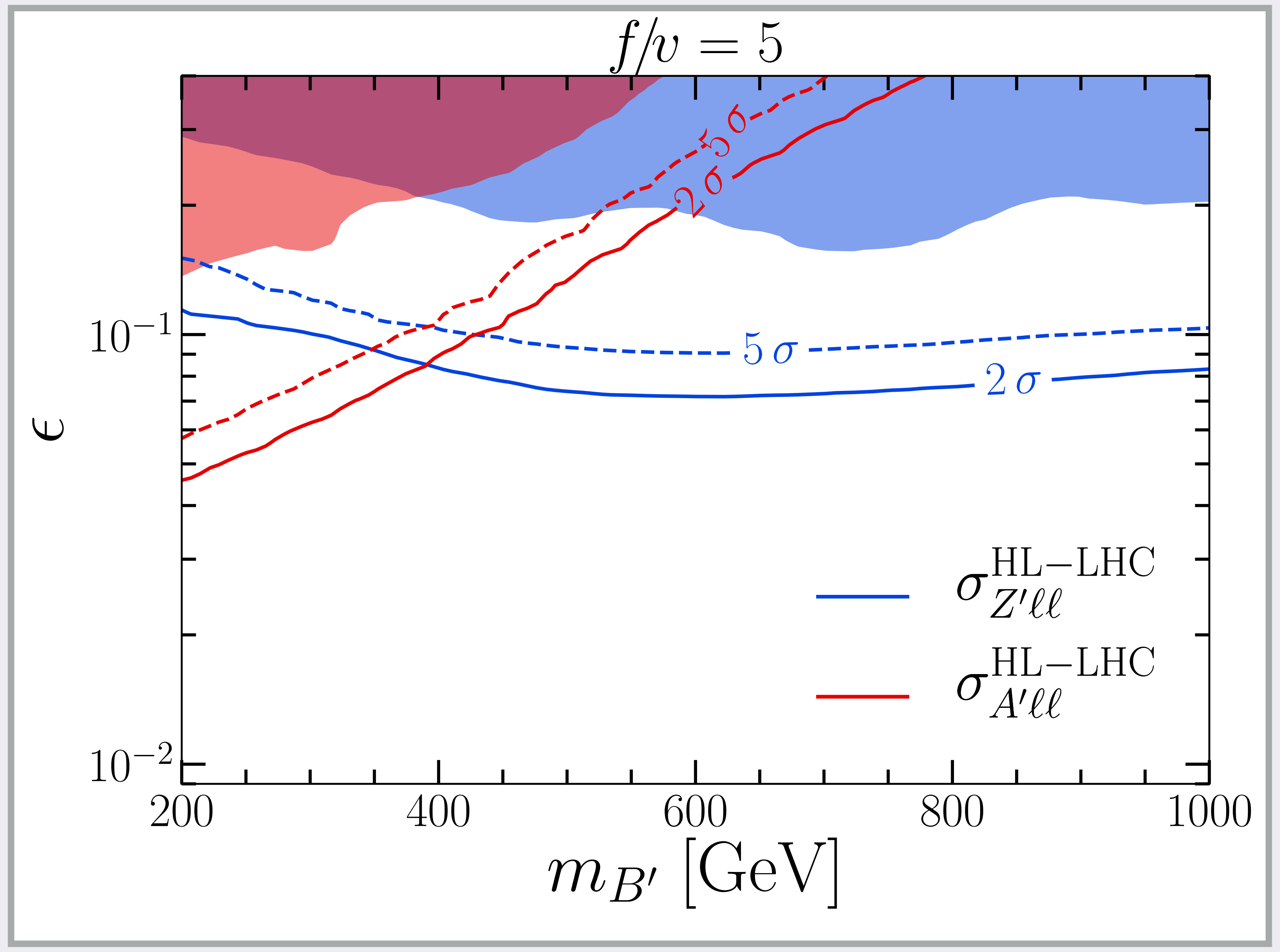
100 TeV FCC

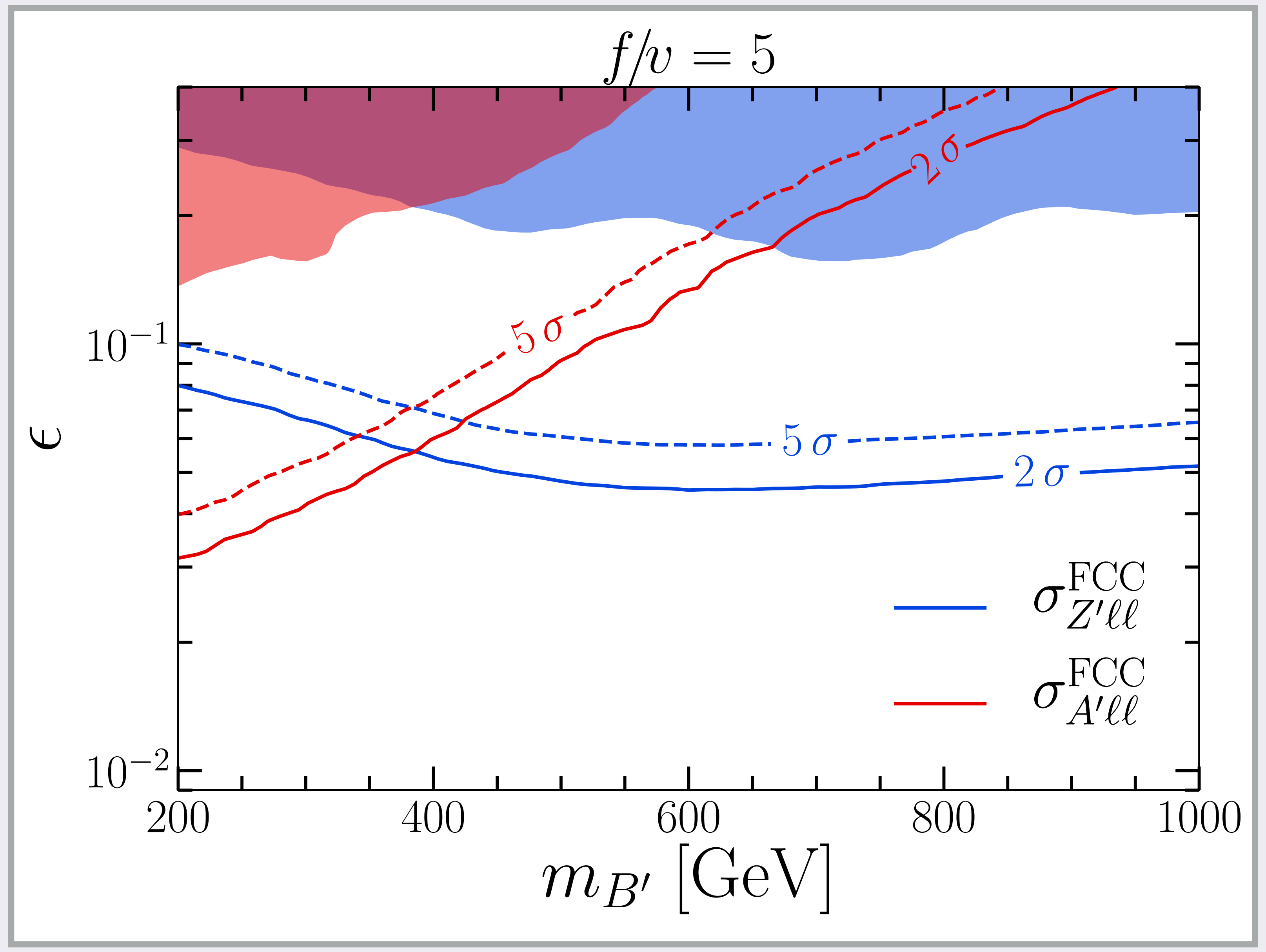
Two Doublet





One Doublet





Singleton Portals

Bishara and CV 1811.05977

The portals we have mentioned already exist in the minimal twin Higgs scenario

Notice that all the portal fields are gauge singlets, at least after EWSB

This makes sense because the portal fields must connect the sectors with completely different gauge groups

All twin Higgs particles have a twin partner, at least before symmetry breaking

Children that are not part of a multiple birth (not twins or triplets etc) are called singletons

We call fields that have no twin under the discrete Z_2 singletons

Singleton Interactions

Under the discrete symmetry, singletons transform by at most a phase

$$\psi \xrightarrow{Z_2} \pm\psi$$

This implies the schematic form for their couplings

$$\psi\left(\mathcal{O}_A \pm \mathcal{O}_B\right)$$

Clearly ψ must be a SM gauge singlet, which restricts possible renormalizable interactions

See Liu, Weiner 1905.00861 for a recent exploration of fermionic singletons

Vector Singletons

Vector singletons can be the vector bosons of a new gauge symmetry

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

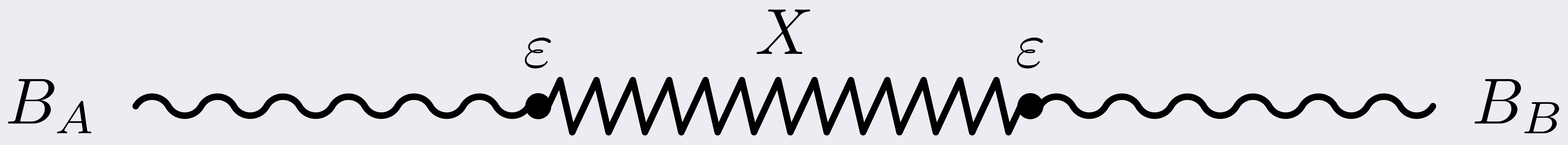
If a $U(1)$ then there can also be kinetic mixing

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

The bounds on such massless mixing are severe

We take the singleton to be massive, this could be due to a Stueckelberg mass or a new Higgs sector

What about the mixing of the two massless hypercharges?

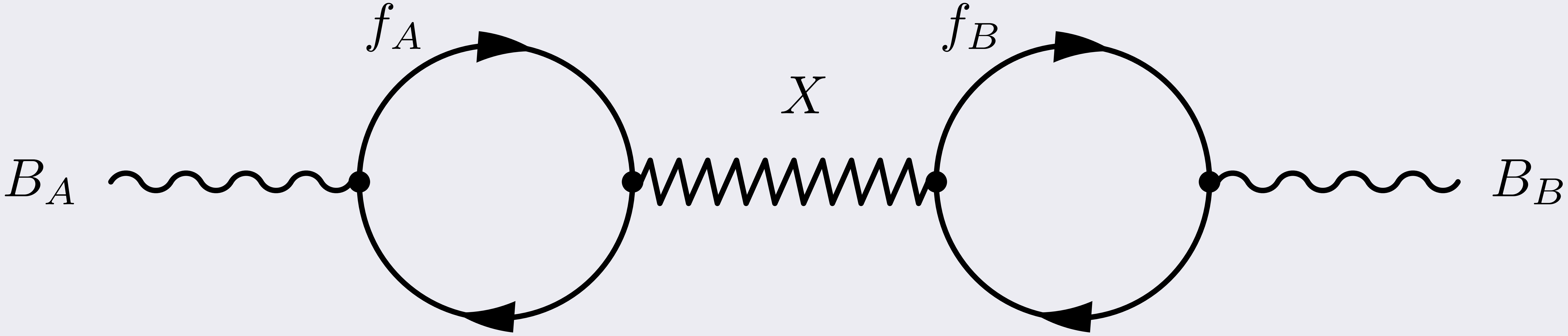


$$\Rightarrow \varepsilon^2 B_{A\mu\nu} B_B^{\mu\nu}$$

Kinetic Mixing

Kinetic mixing from above the cutoff is a free parameter, but can be quite small

Between the cutoff and m_X mixing is generated by SM and twin fermions

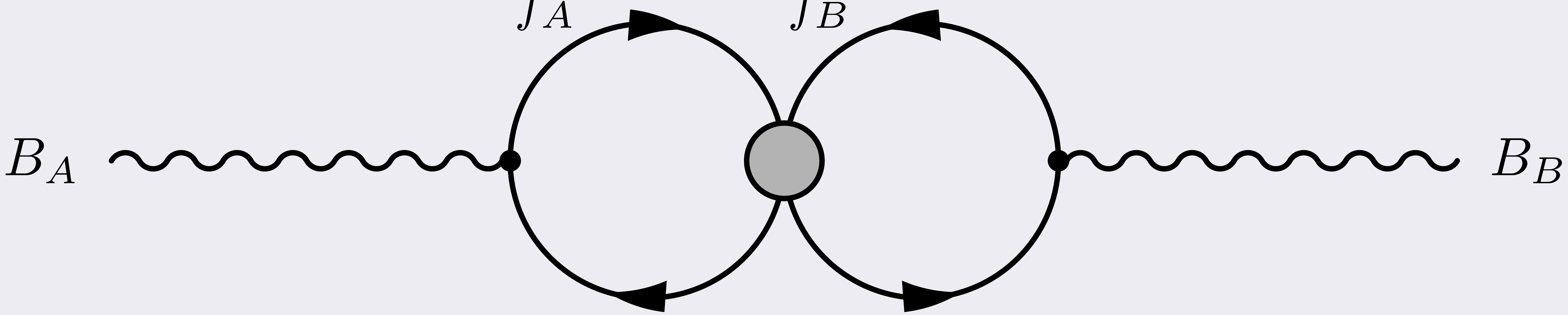


$$\varepsilon \sim \frac{g_X g_Y}{24\pi^2} \left[\sum_f Y_f x_f \ln \frac{m_X^2}{\Lambda_{\mathrm{UV}}^2} \right]$$

Can be both anomaly free and vanishing mixing for gauged $L_\mu - L_\tau$

Kinetic Mixing

Below the mass of the X_μ no additional mixing is generated



This generates the operator but no kinetic mixing

$$B_{A,B\mu\nu}\frac{\partial^2}{m_X^2}B^{\mu\nu}_{A,B}$$

For a heavy vector, this means the fermions in the loop are well approximated as massless

Of course, if the twin hypercharge has a large enough mass there are no problems

LHC Singleton Signals

Collider signals depend strongly on which fermions are charged under the singleton

Efficient production primarily through light quarks

Di-lepton signals make for easy discovery

Neither of these are guaranteed by direct coupling

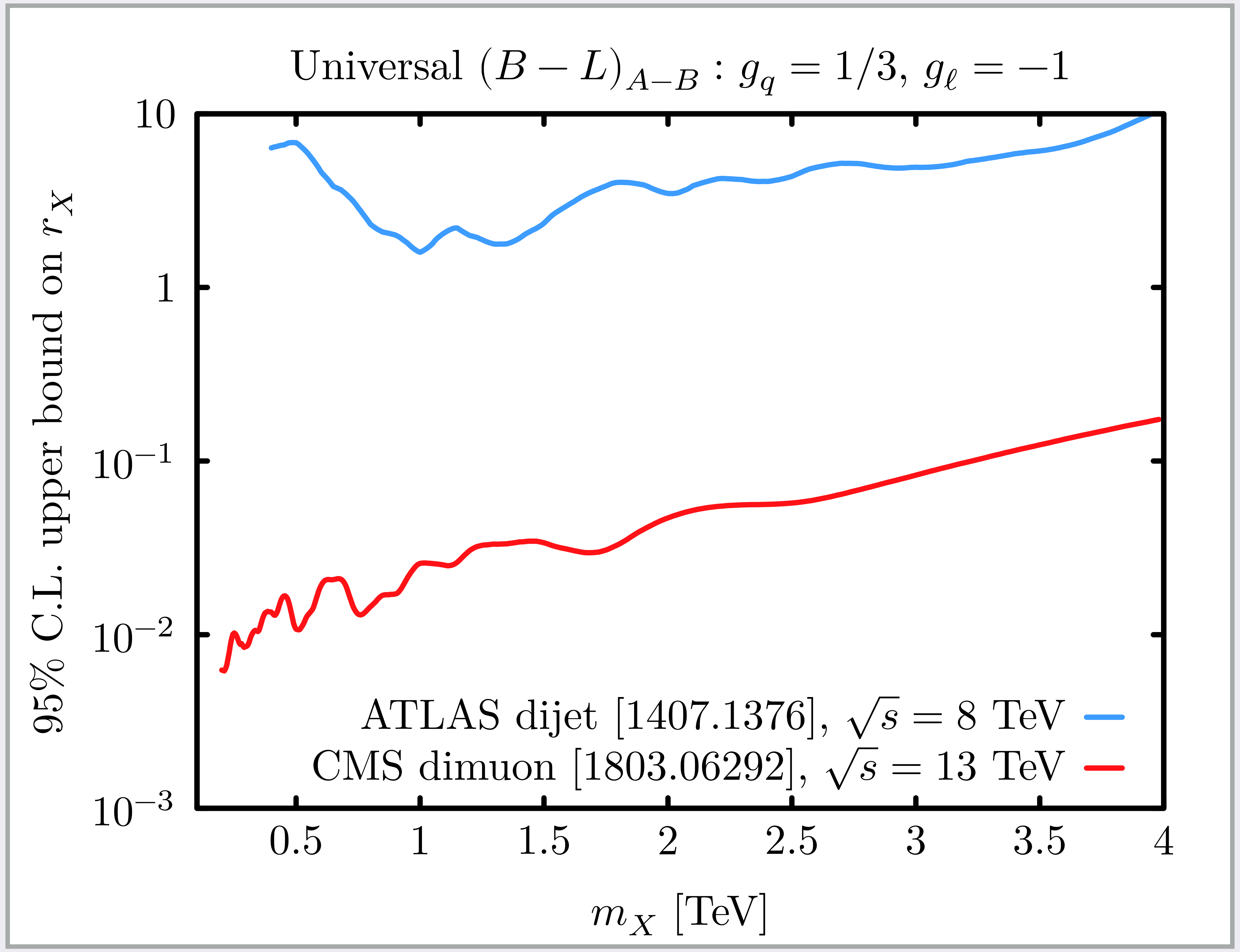
However, kinetic mixing through hypercharge produces both quark and lepton couplings

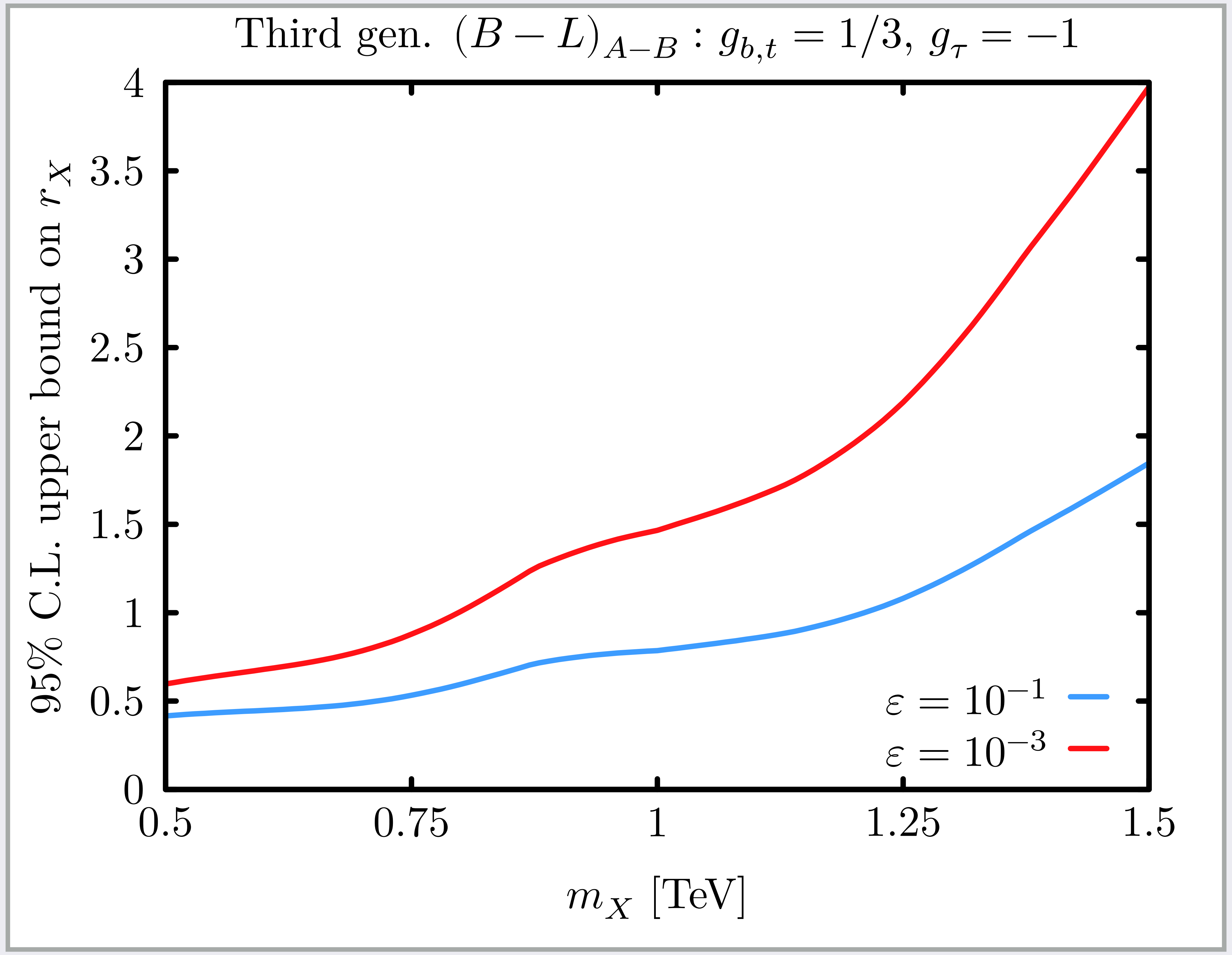
Bounds on Singleton Coupling

With both quark and lepton couplings strong bounds result

Much weaker if only the third generation is charged

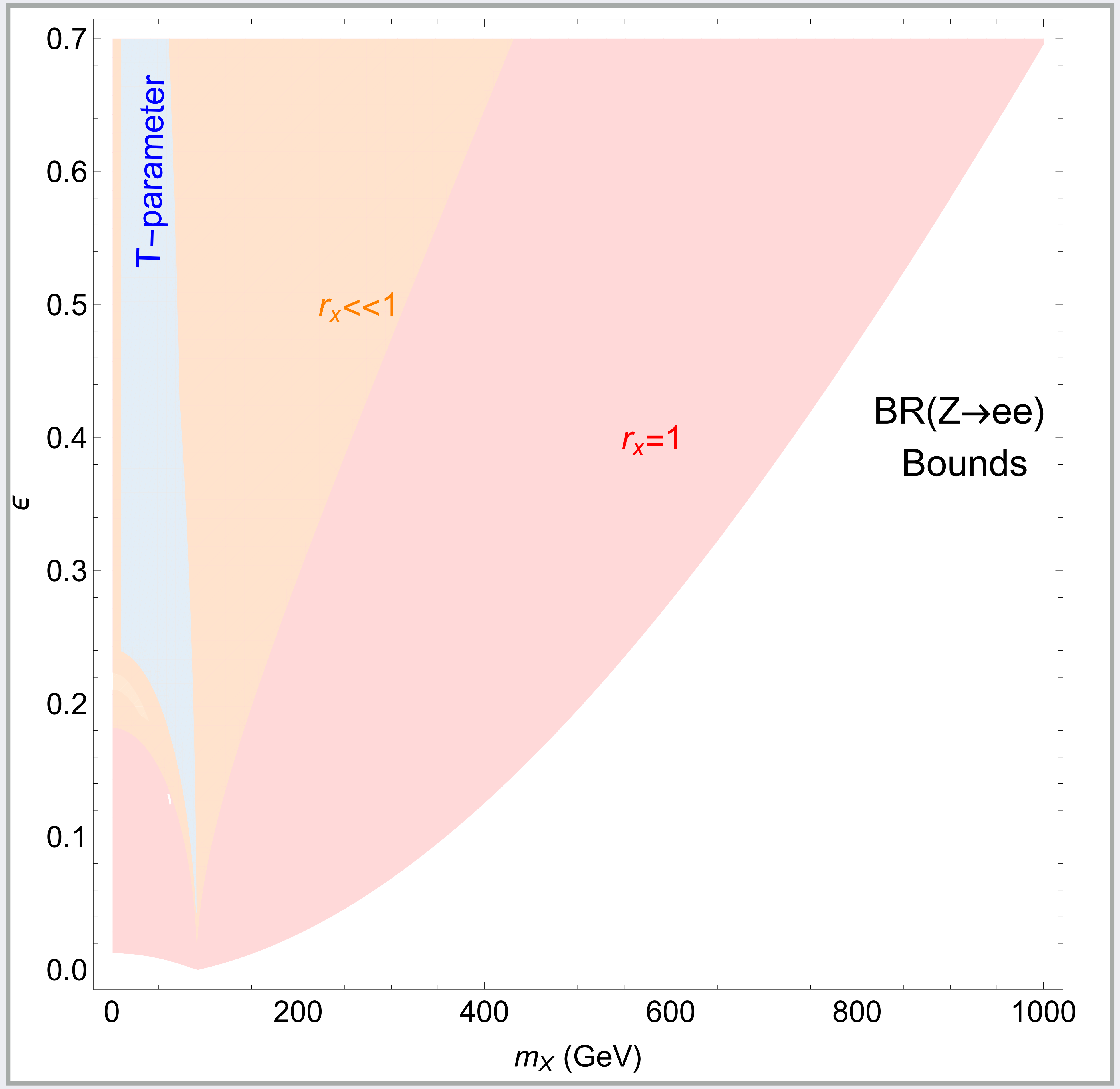
$$r_X = g_X/g$$

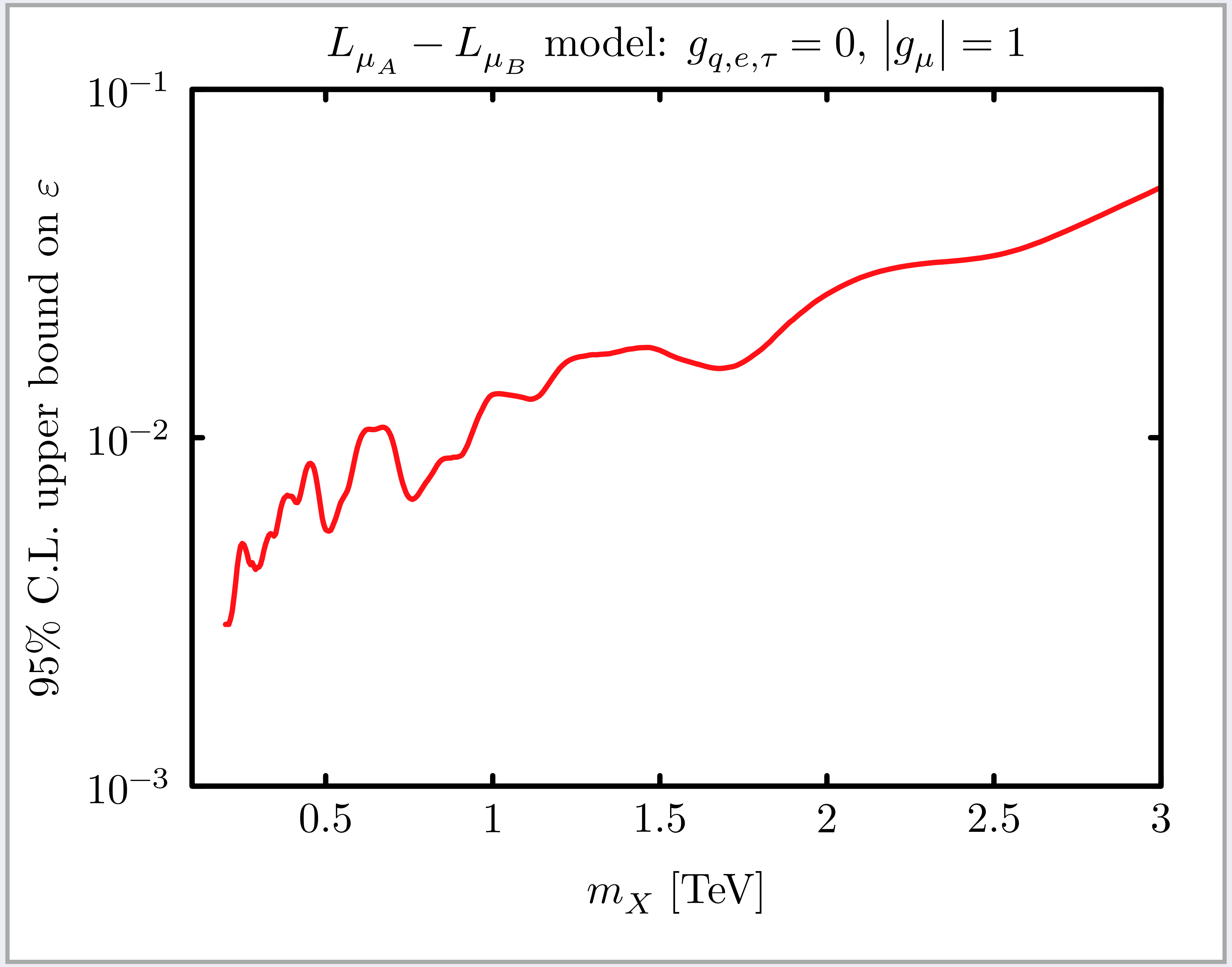




Bounds on Kinetic Mixing

If there are no direct quark couplings the bounds are on the kinetic mixing





Conclusions

While the twin sector is SM neutral, it can be probed at the LHC and future colliders

The hypercharge portal provides predictive links to the twin states

These can be used at the LHC and future colliders to explore the hidden sector

Singleton portals are a new class of connections to the twin sector

These portals may also be discovered at the LHC, and can produce signals in flavor physics, cosmology, and neutrinos

Higgs Couplings

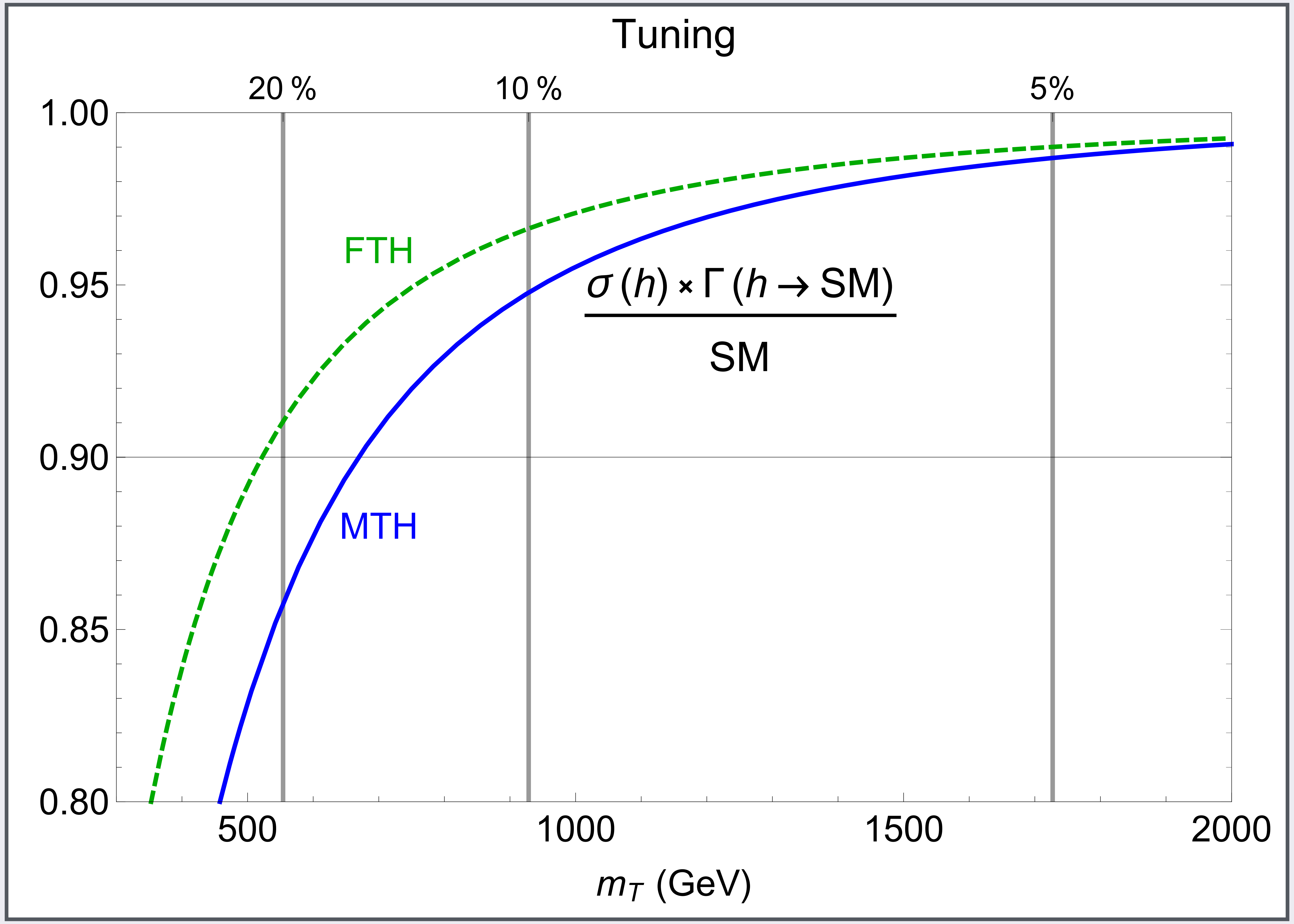
Recall that Higgs couplings are reduced $g_{\mathrm{A}} = g_{\mathrm{SM}} \cos\vartheta$

This reduces Higgs rates to SM states

The HL-LHC is expected to measure these rates to 10%

Probes~500-700 GeV twin tops

Future lepton colliders can reach multi-TeV masses through better than 1% precision

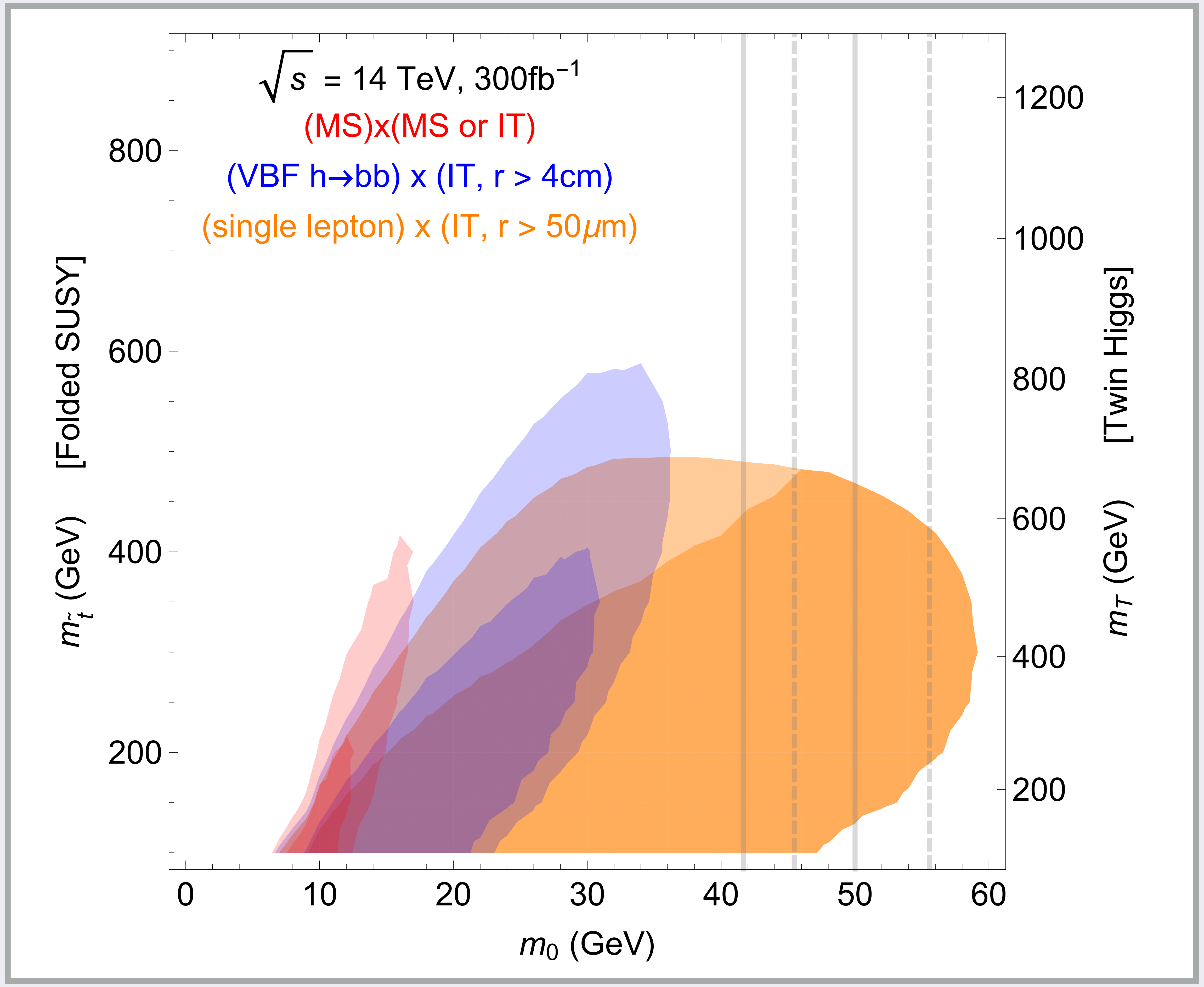


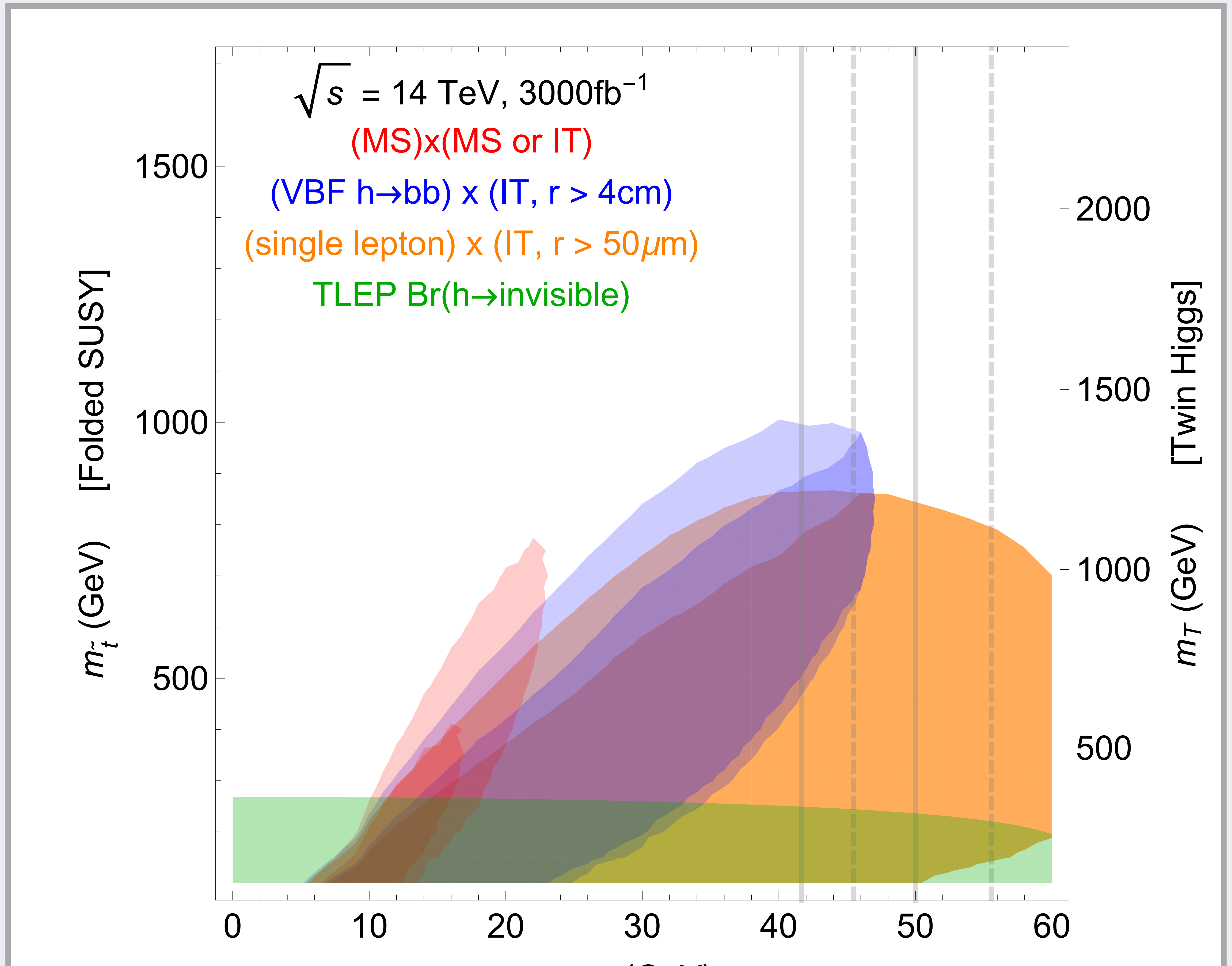
See Burdman, Chacko, de Lima, Harnik, CV 1411.3310

Exotic Higgs Decays

FTH Glueballs are expected to have masses between about 15 to 30 GeV

The LHC has potential to discover these exotic decays





Curtin, CV 1506.06141

Scalar Singletons

The only possible renormalizable scalar interactions are

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

If ϕ is even under the discrete symmetry or charged, then it only couples to terms invariant under the Higgs sector global symmetry

This means that it does not couple to the physical Higgs, a pNGB of the broken symmetry

If ϕ is odd under Z_2 and a real field, then its VEV provides a Z_2 breaking mass term in the Higgs potential

Such a term is required by measurements of Higgs couplings

Fermionic Singletons

Right-handed neutrinos are the obvious fermionic singleton

$$Y_\nu \left(\overline{L}_A H_A \pm \overline{L}_B H_B\right) \nu_R + \frac{m_R}{2} \overline{\nu}^c_R \nu_R + \text{H.c.}$$

This generates mixing between the visible and twin neutrinos

Such mixing can produce appealing cosmology
Csaki, Kuflik, Lombardo 1703.06884

But in this simple set-up $(\nu_A,\ \nu_B)\, \frac{Y_\nu^2}{m_R} \begin{pmatrix} v_A^2 & \pm v_A v_B \\ \pm v_A v_B & v_B^2 \end{pmatrix} \begin{pmatrix} \nu_A \\ \nu_B \end{pmatrix}$

The mixing is too large $\sin\theta_\nu = \frac{v_A}{\sqrt{v_A^2 + v_B^2}}$

Other scenarios may give interesting signals