Exploring Twin Higgs Models via the Higgs and Hypercharge Portals

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Chacko, Kilic, SN and Verhaaren, arXiv:1711.05300 & 1904.11990

Mirror Twin Higgs Model

- The Twin Higgs framework is an elegant approach to solve the little hierarchy problem of the Standard Model (SM).

  Chacko, Goh, Harnik (2005)

- In Mirror Twin Higgs model, the SM is extended to include a complete mirror copy of the SM, with its own particle content and gauge groups.
- By a discrete Z_2 twin symmetry, the SM and twin particles are related .
- The mirror particles are not charged under SM gauge symmetry.

Mirror Twin Higgs Models

- In Twin Higgs model the quadratic divergences of the SM Higgs due to the SM particles are canceled exactly by the twin sector particles. In fact they are cancelled by states that carry no charge under the SM gauge groups. Discovery of these states at LHC is therefore difficult.
- The SM and twin sector interact through the Higgs portal and $U(1)$ gauge kinetic mixing.
- A soft Z_2 symmetry breaking ensures that twin Higgs VEV f is greater than the SM Higgs VEV v. Current bound from Higgs coupling measurements is $f/v \geq 3$.
- Twin fermions are heavier than SM fermions by a factor of f/v. To require the model be less than $\%10$ tuned indicates $f/v \leq 6$, i.e. the twin top should not be too heavy.

The Twin Higgs Portal

$$V(H_A, H_B) = -\mu^2 \left(H_A^\dagger H_A + H_B^\dagger H_B \right) + \lambda \left(H_A^\dagger H_A + H_B^\dagger H_B \right)^2 + m^2 \left(H_A^\dagger H_A - H_B^\dagger H_B \right) + \delta \left[\left(H_A^\dagger H_A \right)^2 + \left(H_B^\dagger H_B \right)^2 \right]$$

- This potential depends on 4 parameters, μ, λ, m and δ.

Higgs Couplings

- For stable vacuum, we require

$$\frac{m_H}{m_h} \geq \frac{m_T}{m_t} = \frac{f}{v} = \cot(\vartheta)$$

  where $\vartheta = \frac{f}{\sqrt{2}\,v}$.

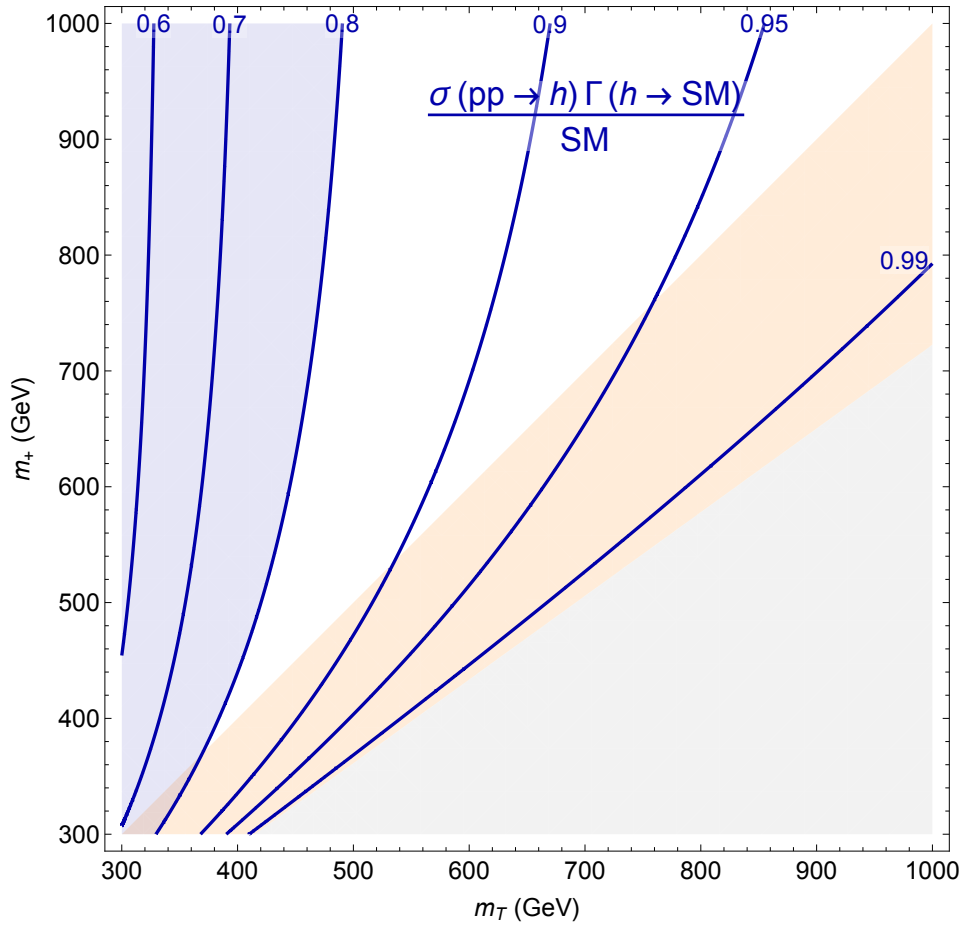
- Twin Higgs mixes with the light Higgs, with mixing angle θ. So Higgs couplings are reduced, similar to any pNGB models,

- Coupling deviations,

$$g_h^A = g_{SM}\cos(\vartheta - \theta)$$

$$g_H^A = g_{SM}\sin(\vartheta - \theta)$$

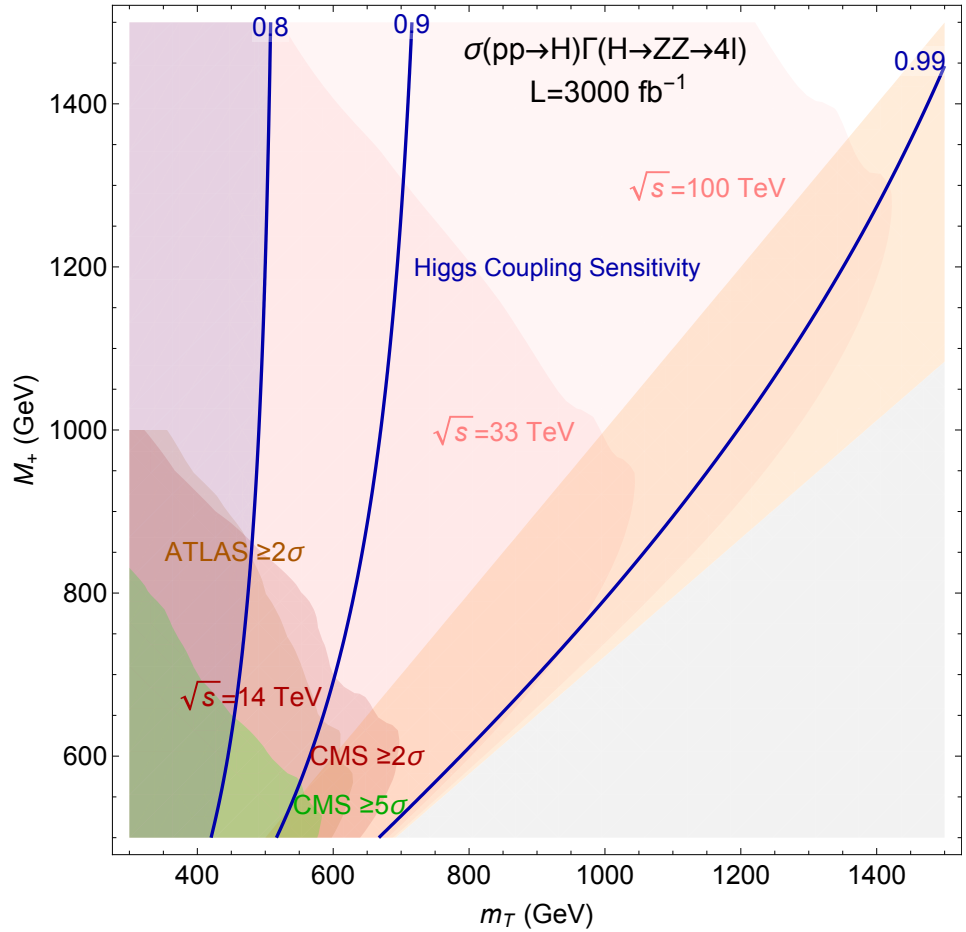
- about 10% after HL-LHC.



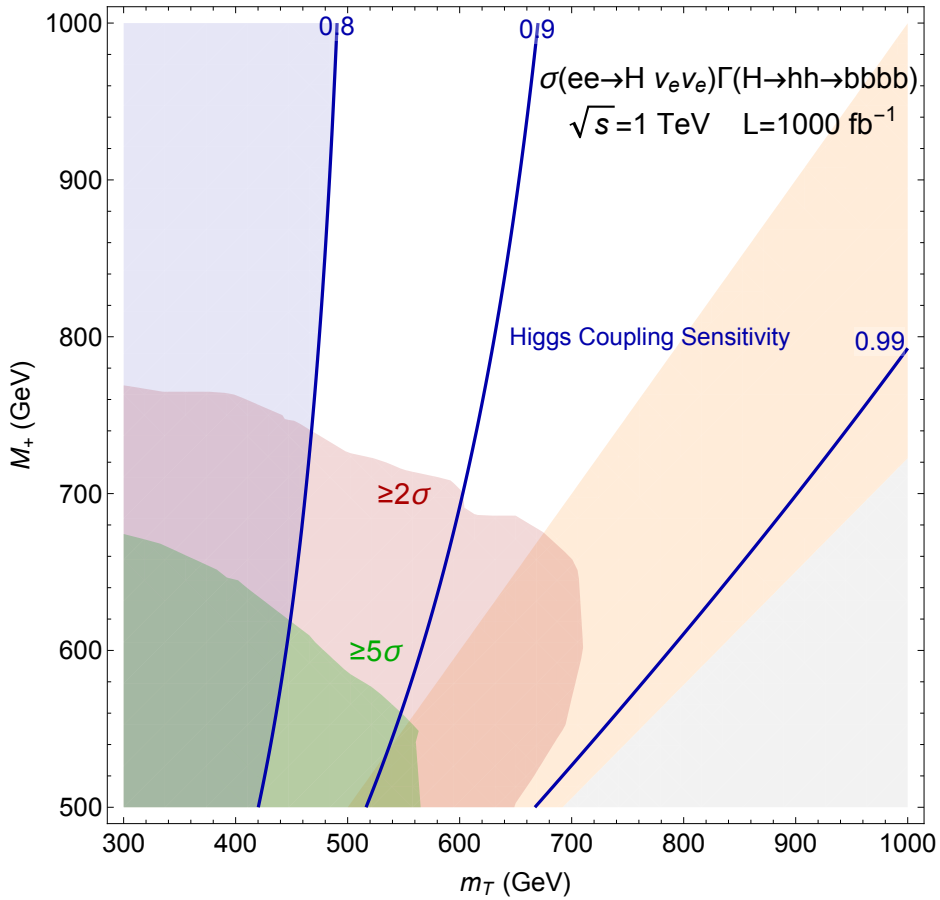
Projected LHC Reach with ZZ

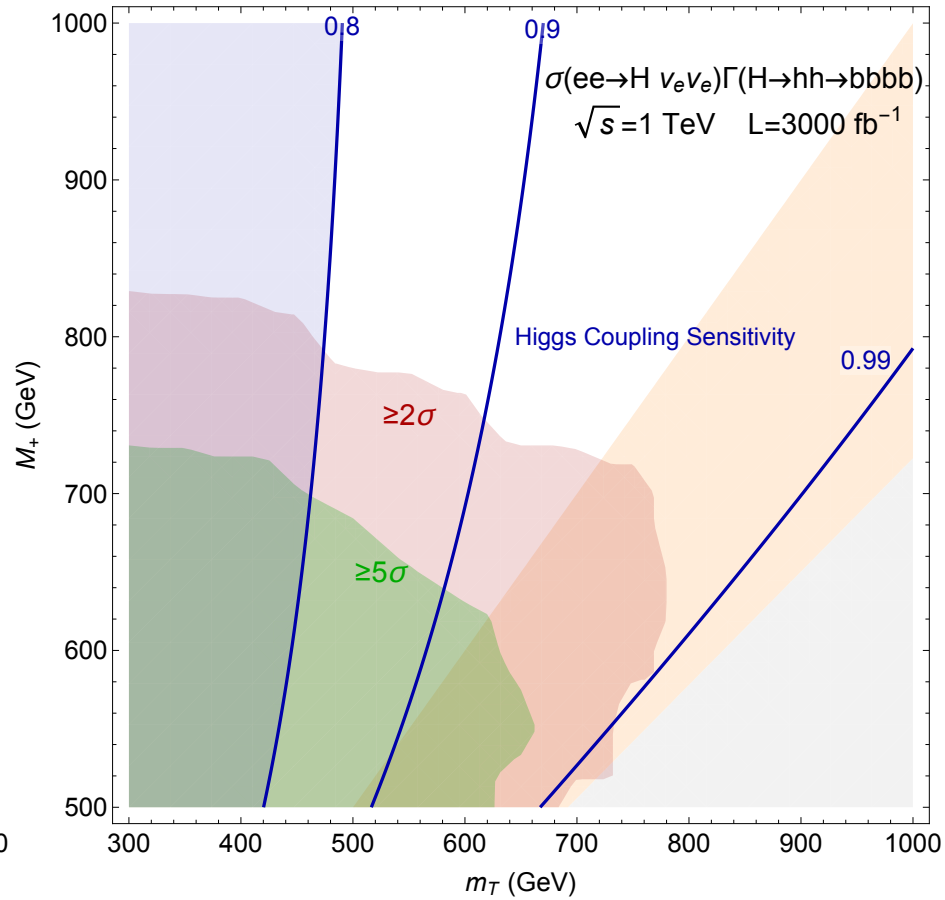
see also A. Ahmed, arXiv:1711.03107

- Using CMS-PAS-FTR-13-024 and ATL-PHYS-PUB-2013-016 we find the projected reach for $pp \to H \to ZZ \to \ell\ell\ell\ell$
- Clearly, the LHC can test the Twin Higgs for some parameter regions
- How does it improve for a linear collider?

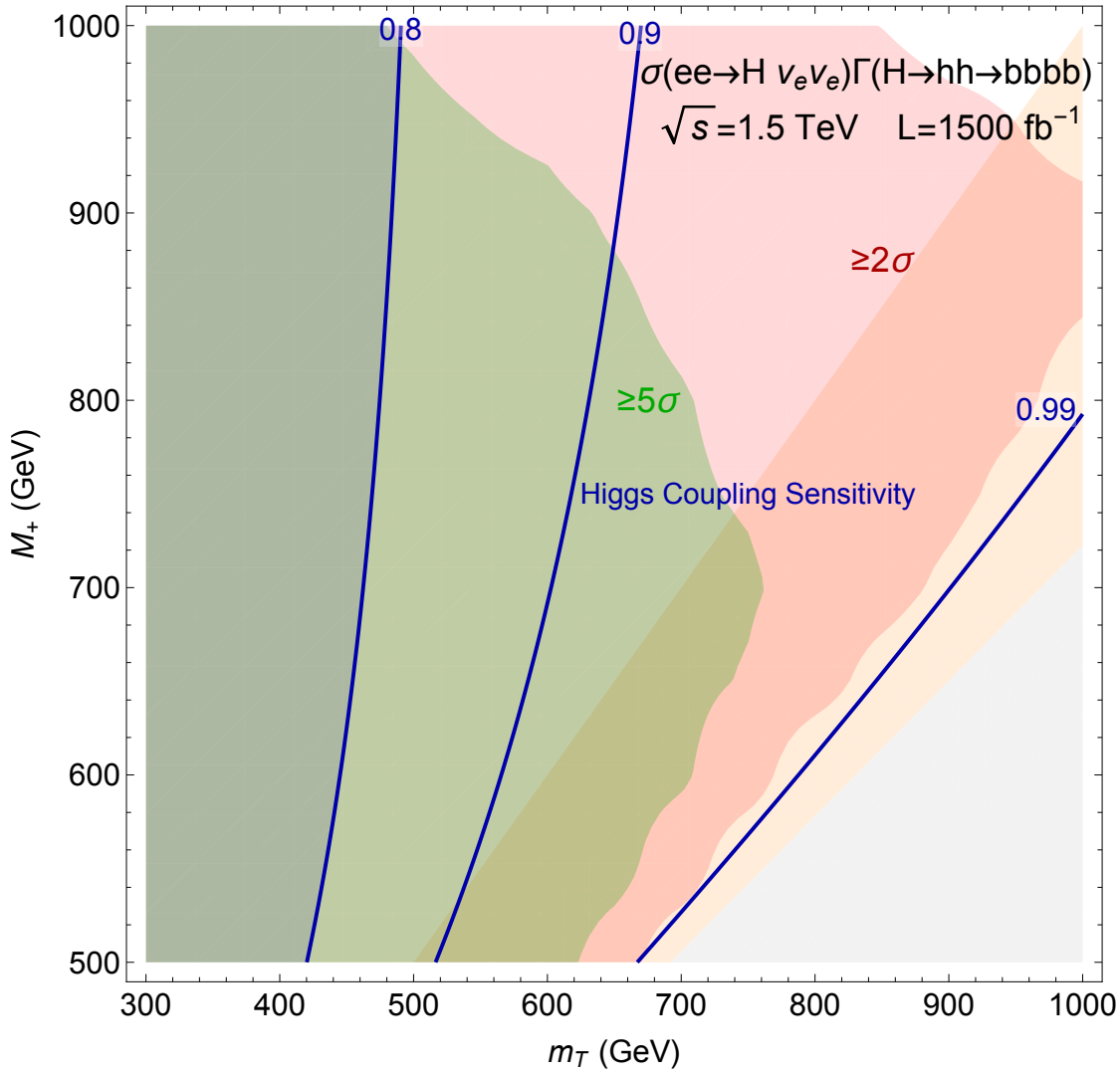


Twin Higgs observability potential at the ILC





Twin Higgs observability potential at the CLIC



Hypercharge Portal

Apart from the Higgs portal, the hypercharge mixing $B'_{\mu\nu}B^{\mu\nu}$ is only other renormalizable coupling which connects the SM and twin sectors.

There are two possibilities:

- If the twin Hypercharge boson B' is massless then the bounds on mixing with SM hypercharge are 10^{-9}, which is not relevant for colliders.
- For massive B' the bounds are weaker.
  B' can acquire mass by
  - Stueckelberg mechanism
  - Extending the Higgs sector.

The hypercharge boson B' is a linear combination of A' and Z'. SM hypercharge mixes with both!

Hypercharge Portal

Lagrangian for kinetically mixed $U(1)_T$ and $U(1)_Y$

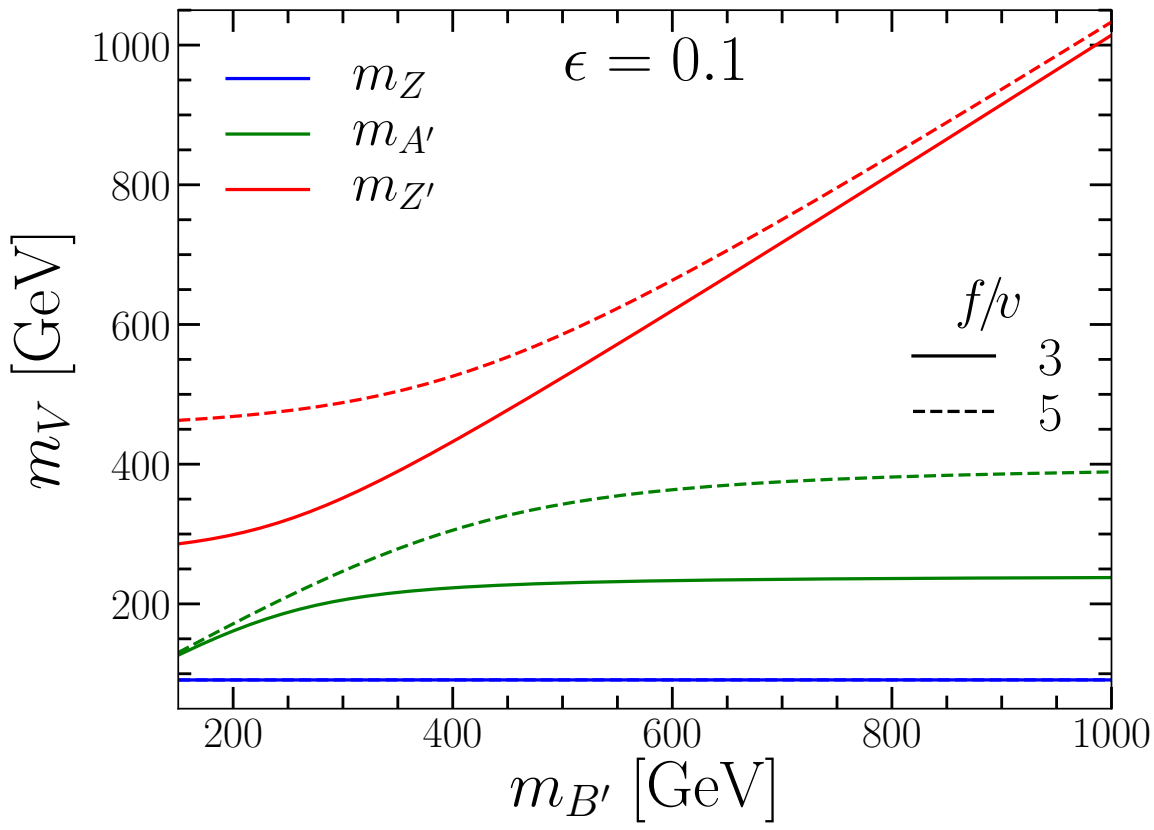
$$\mathcal{L} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W_{\mu\nu}W^{\mu\nu} - \frac{1}{4}B'_{\mu\nu}B'^{\mu\nu} + \frac{\epsilon}{2\cos\theta}B'_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{B'}B'_{\mu}B'^{\mu}$$

- In this talk I focus on the case where B' gets mass $m_{B'}$ by the Stueckelberg mechanism.
- The Hypercharge portal interaction is parametrized as

$$\boxed{\frac{\epsilon}{2\cos\theta}B'_{\mu\nu}B^{\mu\nu}}$$

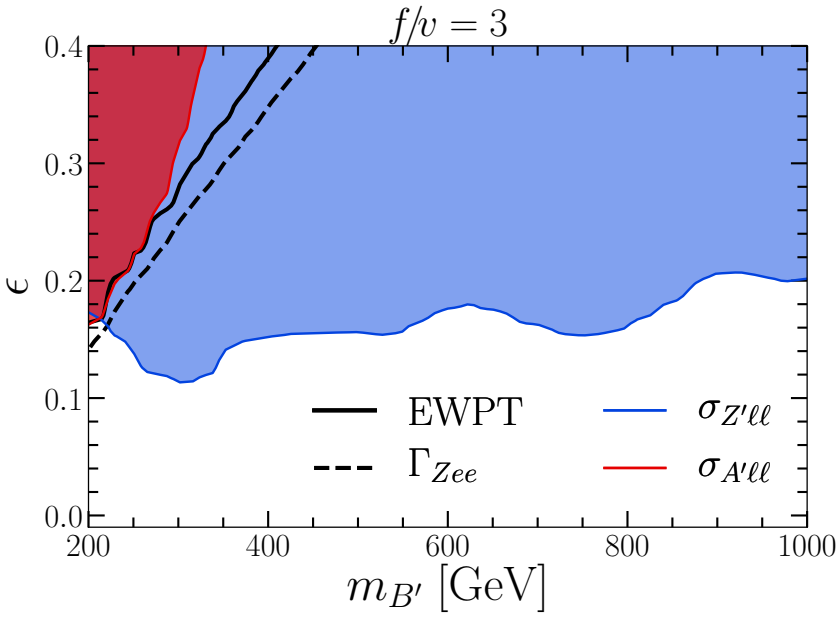
Physical twin neutral gauge bosons

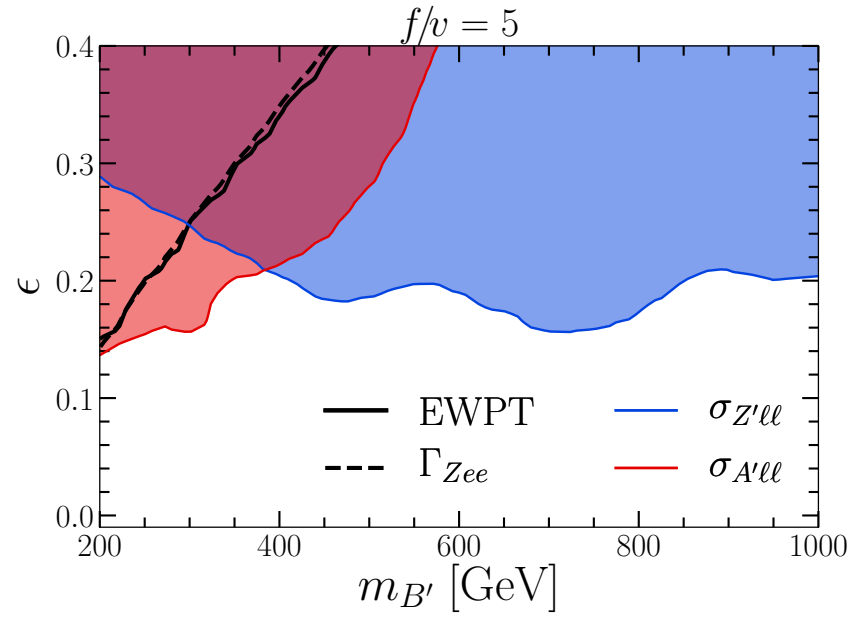
- The physical twin neutral gauge bosons A' and Z' masses as a function of $m_{B'}$ and ϵ:



Existing bounds on twin hypercharge

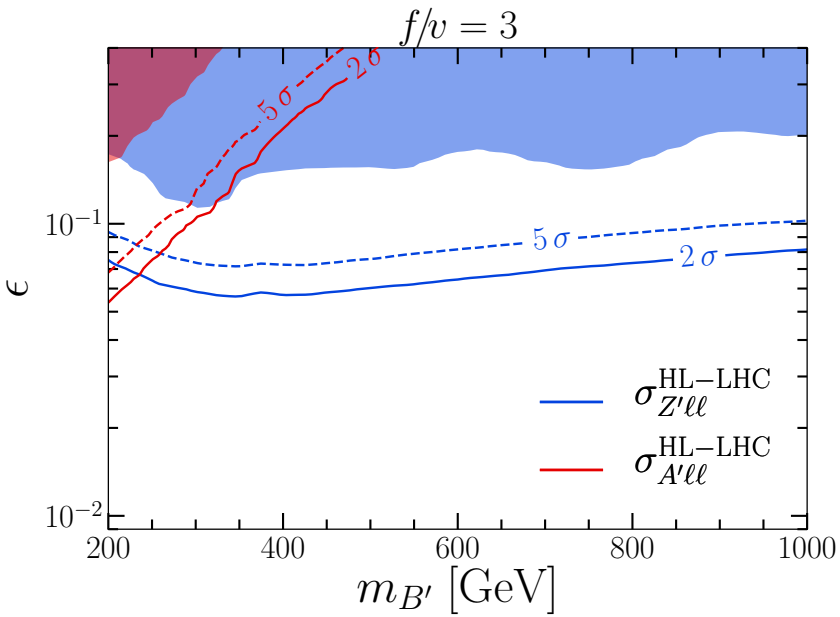
- The twin neutral gauge bosons (A', Z') mixing with SM bosons lead to indirect bounds from electroweak precision tests (EWPT) and partial width of $Z \to ee$
- Direct LHC searches of (A', Z') also put constraints.

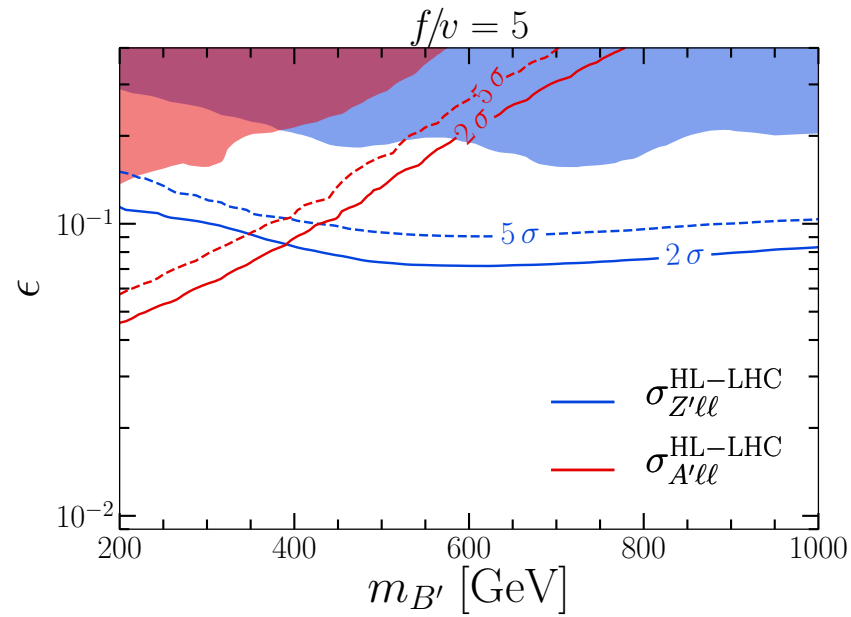




Twin hypercharge at HL-LHC

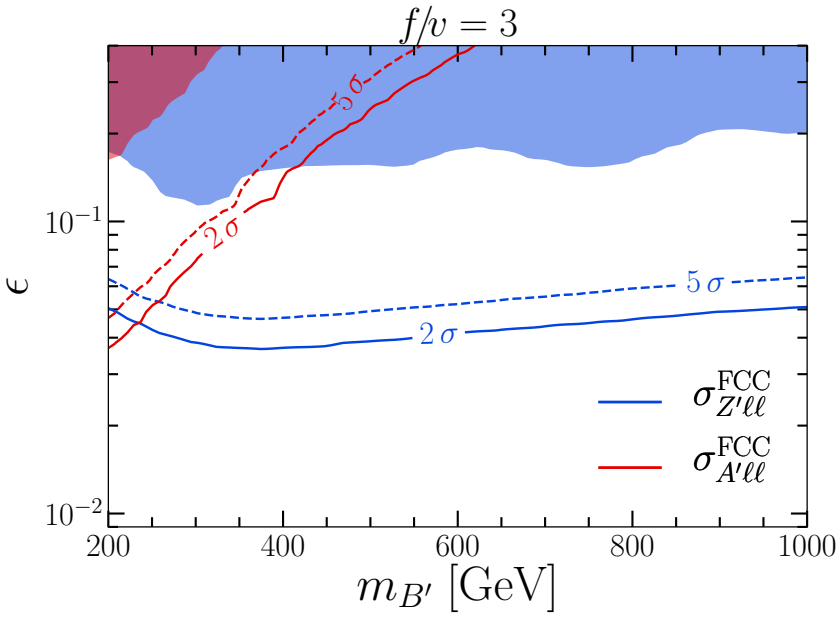
- Projections for discovery reach of A' and Z' in the dilepton channel at the HL-LHC ($3000\ \text{fb}^{-1}$ luminosity).

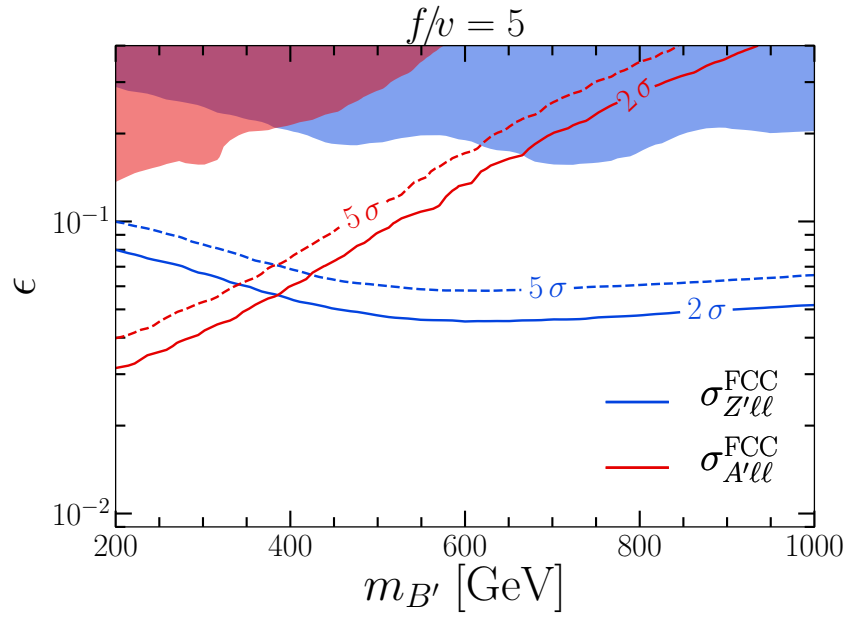




Twin hypercharge at future 100 TeV collider

- Projections for discovery reach of A' and Z' in the dilepton channel at the future 100 TeV hadron collider.





Conclusions

- The Twin Higgs framework gives an elegant solution to the hierarchy problem of the SM.
- We found that the high luminosity LHC can potentially discover the twin sector Higgs.
- However, linear colliders such as the ILC or CLIC have much better precision and greater reach, allowing them to test the Twin Higgs mechanism.
- The mirror twin Higgs predicts both twin photon and twin Z.
- These can interact with the SM through hypercharge portal.
- The LHC can potentially discover these particles.

The Twin Higgs Portal

- This potential depends on 4 parameters, μ, λ, m and δ.
- The potential must reproduce the electroweak VEV and the observed mass of the light Higgs, 125 GeV, that fixes 2 combinations of the 4 parameters. Higgs production cross section and invisible decay width would fix a third combination. Then a measurement of the mass of twin sector Higgs fixes all 4 parameters!
- Once all 4 parameters are known, the production cross section, width and branching ratios of the twin sector Higgs are all predicted.
- A measurement of twin sector Higgs events to any SM final state then overdetermines the system and can establish global symmetry of Higgs potential!