Phenomenology of Twin Photon

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Mirror Twin Higgs Models

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

  Mirror Twin Higgs Chacko, Goh & Harnik (2005)

- In Mirror Twin Higgs models, 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

- The quadratic divergences of the Standard Model and Mirror Twin Higgs models cancel each others exactly. In fact its cancelled by states that carry no charge under the SM gauge groups. Discovery of these states at LHC is therefore difficult.
- For cancellation of quadratic divergences, $\mid H_A \mid^2 \mid H_B \mid^2$ interaction is needed.
- The SM and twin SM interact through the Higgs portal and U(1) gauge kinetic mixing.
- A soft Z_2 symmetry breaking ensures that , the VEV of the twin Higgs, is greater than , the VEV of the SM Higgs. The bound from higgs measurement is $\frac{f}{v} \leq 3$.
- Twin fermions are heavier than SM fermions . $\frac{f}{v} \leq 5$ is required to solve hyrarchy problem.

SM B – Twin B_T mixing

$B'_{\mu\nu}B^{\mu\nu}$ is only other renormalizable coupling.

There are two possibilities that $B'^{\mu\nu}$ is massless or massive.

- B' is massless: bound on mixing is 10^{-12}, is not relevant for colliders, at least 3 loop is not generated.
- B' is massive: the bounds are weaker.
  - Stueckelberg mechanism
  - Extend the SM to two Higgs doublet, it can get mass through Higgs mechanism.

B' is a linear combination of A' and Z'. Hypercharge mixes with both! It is different from the usual hidden photon case. Z' is necessarily massive, $m_{Z'} \leq 500$ GeV

Toy model

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

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

- Twin photon A' is massive with mass $m_{A'}$ by the Stueckelberg mechanism.

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

Toy model

- The gauge boson kinetic term by the following redefinition of fields can be diagonalized.

$$\begin{pmatrix} B_0 \\ A'_0 \end{pmatrix} = \begin{pmatrix} 1 & \frac{-\epsilon}{\cos\theta} \\ 0 & \sqrt{1 - \frac{\epsilon^2}{\cos^2\theta}} \end{pmatrix} \begin{pmatrix} B \\ A' \end{pmatrix}$$

we define:

$$\omega \equiv \frac{\epsilon}{\cos\theta\sqrt{1 - \frac{\epsilon^2}{\cos^2\theta}}}$$

$$\rho \equiv \frac{m_{A'}}{m_{Z_0}}$$

Toy model

- In addition, we define mass eigenstates (Z,A')

$$\begin{pmatrix} Z \\ A' \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} Z_0 \\ A'_0 \end{pmatrix}$$

- For $\epsilon \ll 1$ and $(\rho - 1) > 1$, the mixing angle α is given by,

$$\alpha \sim \frac{\epsilon \tan\theta}{\rho - 1}$$

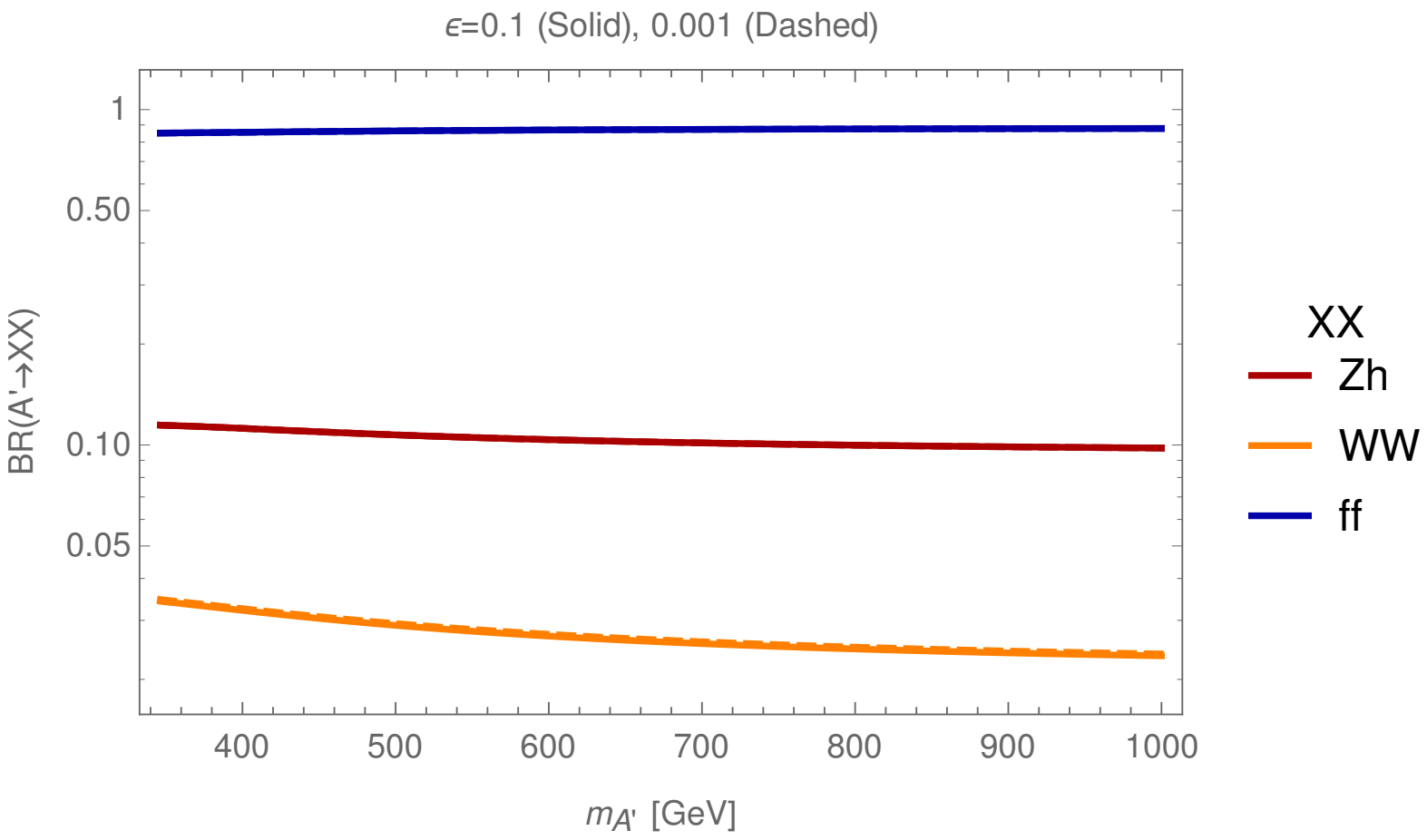
The mass eigenvalues are

$$m_Z^2 = m_{Z_0}^2 \left(1 - \frac{\omega^2 \sin\theta^2}{\rho^2 - 1}\right), \quad m_{A'}^2 = m_{Z_0}^2 \rho^2 \left(1 + \frac{\omega^2 \sin\theta^2}{\rho^2 - 1}\right)$$

Is it possible to observe the twin photon and twin Z at the LHC?

Can we prove that they are mirror of SM photon and Z?

Branching ratio of twin photon to SM



Is it possible to observe the twin photon and twin Z at the LHC?

ATLAS-CONF-2017-027

- Search for the dilepton final state using 36.1 fb^{-1} of proton proton collision at center of mass energy 13 TeV with the ATLAS detector.
- For the twin photon with mass 500 GeV :
  - the cross section for a twin photon is: $\epsilon^2 \times 80pb$
  - the branching ratio into muons is: $\frac{\epsilon^2}{8}$
  - which results in a bound of $\epsilon \sim \frac{1}{7}$

Bound from LEP

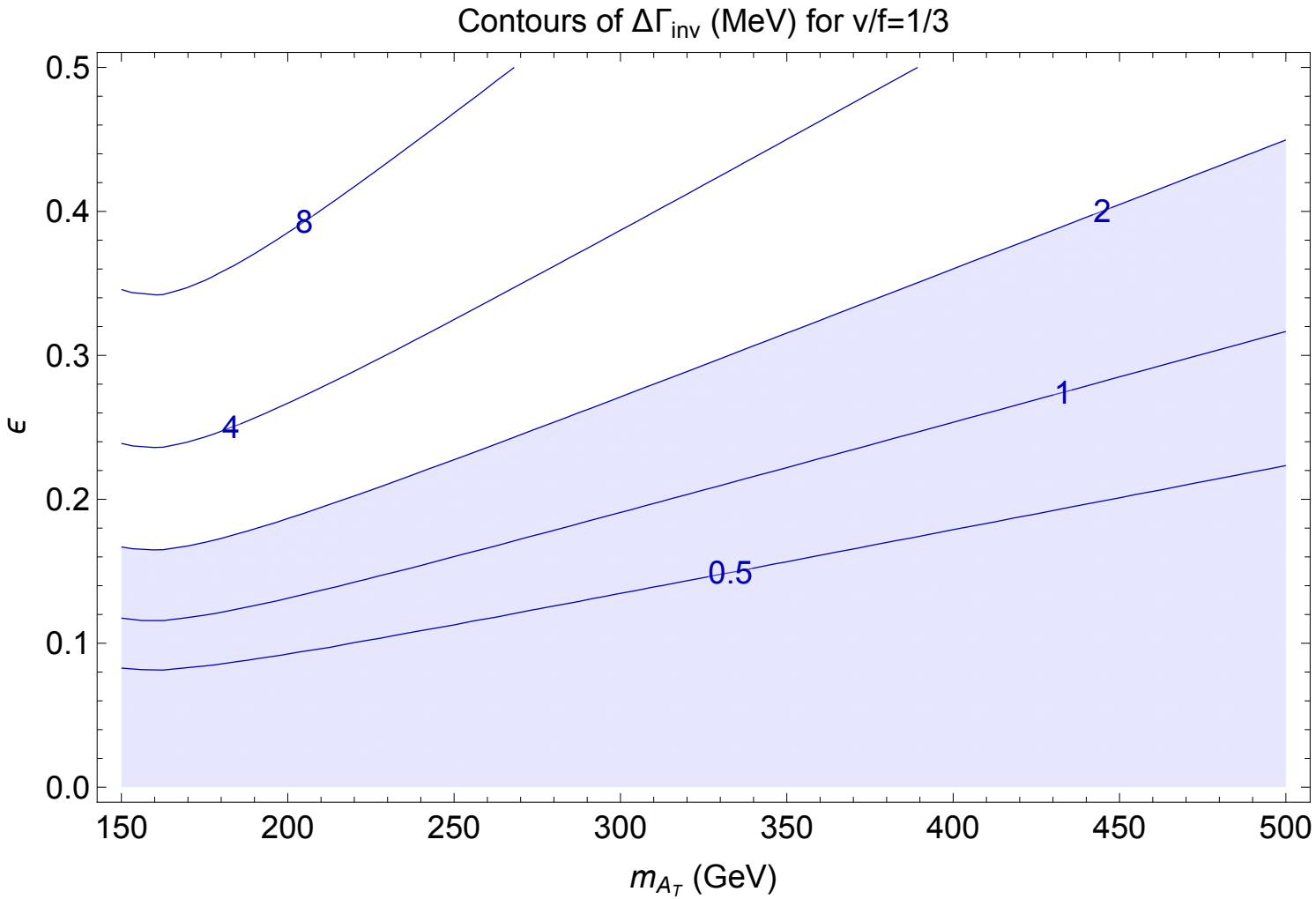
LEP experiment put a bound on the invisible width of Z boson,

$$\Gamma_{inv}^{new} < 2.0 \text{ MeV}$$

In twin Higgs models,

$$\Delta\Gamma_{\text{inv}} = \left(1 - (\cos\alpha - \omega \sin\theta \sin\alpha)^2\right)\Gamma_{\nu}^{Z} - \Gamma_{\text{Twin}}^{Z}.$$

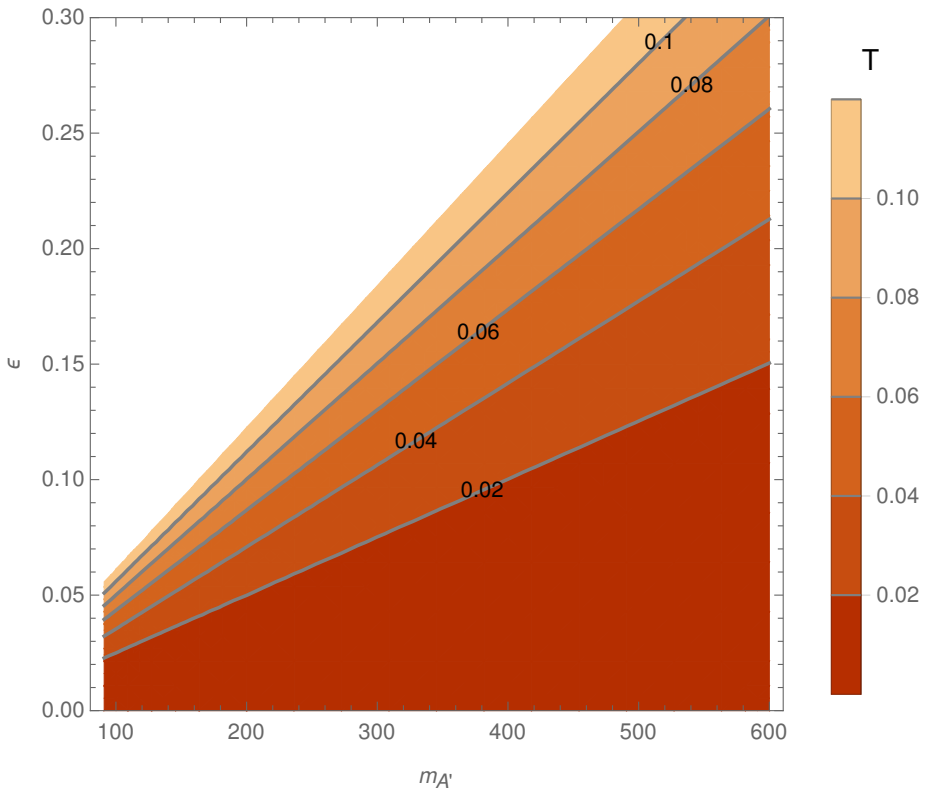
Constraints from invisible decay width of Z boson at LEP



Precision Measurements constraints

Tree-level mass mixing now leads to modifications to both the mass and couplings of the Z. We express the modification of mass in terms of the T parameter,

$$\alpha T \simeq \frac{\epsilon^2 \tan^2\theta}{(\rho^2 - \epsilon^2 \tan^2\theta - 1)}$$



Is it possible to observe the twin photon and twin Z at the LHC?

Yes!

Can we prove that they are mirror of SM photon and Z?

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the mass matrix of twin photon and Z

$$\frac{1}{2}\left(A'_{0\mu} \;\; Z'_{0\mu}\right)\begin{pmatrix} c_W^2 m_{B'}^2 & -s_W c_W m_{B'}^2 \\ -s_W c_W m_{B'}^2 & m_{Z'_0}^2 + s_W^2 m_{B'}^2 \end{pmatrix}\begin{pmatrix} A'_{0\mu} \\ Z'_{0\mu} \end{pmatrix}$$

2 unknown parameters: f and Stueckelberg mass of B'.

If we discover these particles, then from their masses we can extract both parameters.

The charges of twin particles are known $\Rightarrow$ the widths of the A' and Z' are predicted.

Can we measure the widths at the LHC? A test of twin Higgs model!

Conclusions

- 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.
- If , after discovery , we can measure the widths of these particles, we can test the twin Higgs model.