The anomalous $Zbb$ couplings: From LEP to LHC

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Bin Yan, C.-P. Yuan, arxiv:2101.06261
### Status of Zbb couplings

<table>
<thead>
<tr>
<th></th>
<th>measured value</th>
<th>SM prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_b^0)</td>
<td>0.21629 ± 0.00066</td>
<td>0.21578 ± 0.00011</td>
</tr>
<tr>
<td>(A_{FB}^{0,b})</td>
<td>0.0992 ± 0.0016</td>
<td>0.1032 ± 0.0004</td>
</tr>
<tr>
<td>(A_b)</td>
<td>0.923 ± 0.020</td>
<td>0.93463 ± 0.00004</td>
</tr>
</tbody>
</table>

2.5\(\sigma\) deviation with SM prediction

\[ R_b = \frac{\Gamma(Z \to b\bar{b})}{\sum_q \Gamma(Z \to q\bar{q})} \]

Gfitter Group: EPJC74 (2014)3046


\[ \mathcal{L} \supset \frac{g}{c_W} Z_\mu (g_{Lb} \bar{b}_L \gamma^\mu b_L + g_{Rb} \bar{b}_R \gamma^\mu b_R) \]

\(g_{Lb} < 0\) was Excluded

\(g_{Rb}\) Could be positive and negative
Status of Zbb couplings

\[ \mathcal{L} \supset \frac{g}{c_W} Z_\mu (g_{L\bar{b}} \bar{b}_L \gamma^\mu b_L + g_{R\bar{b}} \bar{b}_R \gamma^\mu b_R) \]

S. Gori, J. Gu, L. T. Wang, JHEP04(2016)062

Strong constraint for the left-handed Zbb coupling and large deviation of the right-handed Zbb coupling
Status of Zbb couplings

A. How to break the degeneracy of the right-handed Zbb coupling?

New experiments: e.g. CEPC

B. How to explain the LEP data?

New Physics?

e.g. Custodial symmetry O(3)

K. Agashe, R. Contino, L. Rold, A. pomarol, 2006’

Statistical Fluctuation or Systematic error?

New experiments: e.g. CEPC
The degeneracy of right-handed Zbb coupling could be broken by scanning the energy.
Should we wait for the next generation lepton colliders?  

The possibility of LHC?  

\[ Z \rightarrow b\bar{b}? \]

Other possibilities?
Zbb couplings@LHC

charge conjugation invariance:

(1) Only axial vector components will contribute to the cross section;

(2) Only top and bottom quark will contribute to the scattering

\[
\mathcal{L} = \frac{g_W}{2c_W} \bar{b}_\gamma \mu (\kappa^b_v v^b_{b,SM} - \kappa^b_a a^b_{b,SM} \gamma_5) b Z_\mu + \frac{m_Z^2}{v} \kappa_Z h Z_\mu Z^\mu \\
+ \frac{g_W}{2c_W} \bar{t}_\gamma \mu (\kappa^t_v v^t_{t,SM} - \kappa^t_a a^t_{t,SM} \gamma_5) t Z_\mu - \frac{m_t}{v} \kappa_t \bar{t} h, \quad (1)
\]
Cross sections @LHC

\[ R_{Zh} = \frac{\sigma(gg \rightarrow Zh)}{\sigma(gg \rightarrow Zh)_{SM}} \]

High \( P_T^Z \) data

ATLAS: 2008.02508

![Graph showing data points and fit curves for \( R_{Zh} \) vs. \( \kappa_a^b \) with shaded regions for SM and observed data points.]

High \( P_T^Z \) data gives the most important impact for the limits
Sensitivity@HL-LHC

The expected limits is sensitive to the central value of the signal strength

$$\mathcal{L} \supset -\frac{g_W}{2c_W} \bar{b}_\mu k_a^b a_b^S M \gamma_5 b Z_\mu - \frac{g_W}{2c_W} \bar{t}_\mu k_a^t a_t^S M \gamma_5 t Z_\mu$$

The conclusion is not sensitive to the other top quark couplings

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The conclusion is not sensitive to the other top quark couplings
Sensitivity@HL-LHC

\[ \mu_{Z_h}^0 = 0.93 \]

\[ k_a \]

\[ k_t \]

\[ K_t \]

\[ K_{Z_h} \]
Break the Zbb coupling degeneracy

Current Zh data could break the degeneracy

Including all Zh data

Removing the two high $P_T^Z$ data
Break the Zbb coupling degeneracy

(a) $\Delta \mu = 4.2\%$

(b) $\mu_{Zh}^0 = 1$

Exclude LEP

Break degeneracy
Summary

A. We proposed a new method to probe the Zbb coupling through Zh production at the LHC and the results are not sensitive to the top quark couplings;

B. The Zh data at the 13 TeV LHC can resolve the apparent degeneracy of the Zbb coupling;

C. The HL-LHC could verify or exclude the Zbb couplings.
The contribution dominant by the $(++0)$ and $(-0)$ helicity amplitudes:

\[
M_{++0}^{\Delta} = 2 \frac{\sqrt{\lambda}}{m_Z} \sum_{t,b} \left[ \kappa_a^q \kappa_Z a_q^{SM} \frac{g_{hZZ}}{m_Z^2} \left( F_\Delta(s,m_q^2) + 2 \right) \right] N, \\
M_{++0}^{\Box} = -\frac{4}{m_Z \sqrt{\lambda}} \kappa_t^a \kappa_t g_{htt} a_t^{SM} m_t \left[ F_+^0 + (t \leftrightarrow u) \right] N,
\]