The anomalous Zbb couplings: From LEP to LHC

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Bin Yan, C.-P. Yuan, arxiv:2101.06261

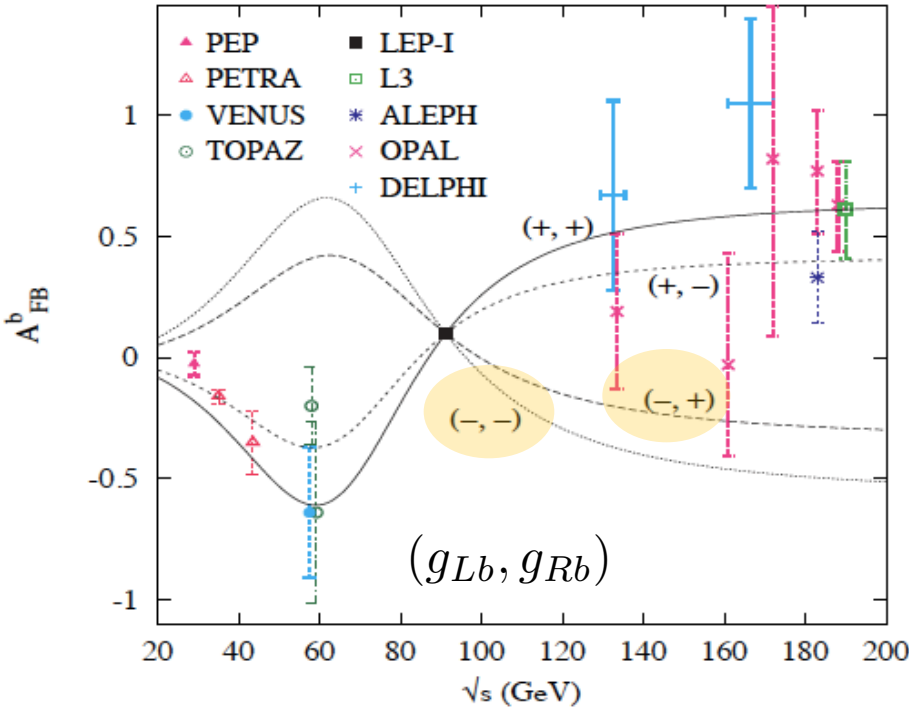
Status of Zbb couplings

	measured value	SM prediction
R_b^0	0.21629 ± 0.00066	0.21578 ± 0.00011
$A_{\rm FB}^{0,b}$	0.0992 ± 0.0016	0.1032 ± 0.0004
$\mathcal{A}_b$	0.923 ± 0.020	0.93463 ± 0.00004

Gfitter Group:
EPJC74 (2014)3046

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

2.5σ deviation with SM prediction



D. Choudhury, T. M. P. Tait, C.E.M. Wagner,
PRD 65(2002)053002

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

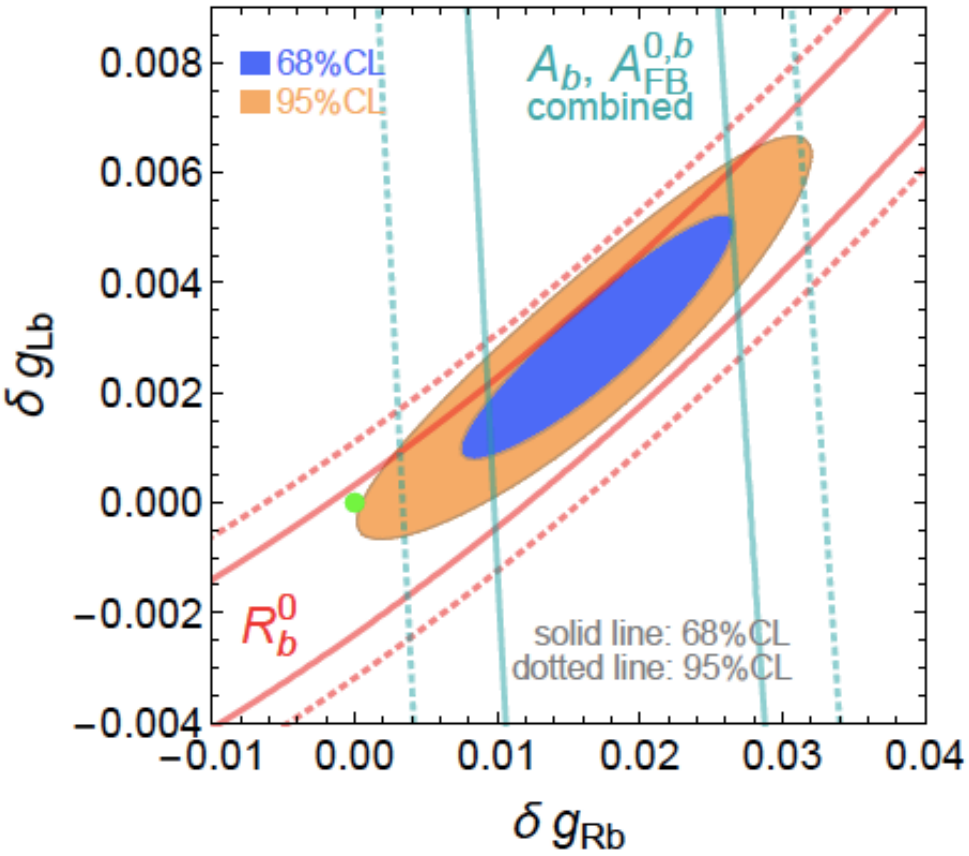
$g_{Lb} < 0$ was Excluded

g_{Rb} Could be positive and negative

Status of Zbb couplings

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

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



$\mathcal{O}(10^{-3})$

$\mathcal{O}(10^{-2})$

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)

Many new physics models

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

⇨ Statistical Fluctuation or Systematic error?

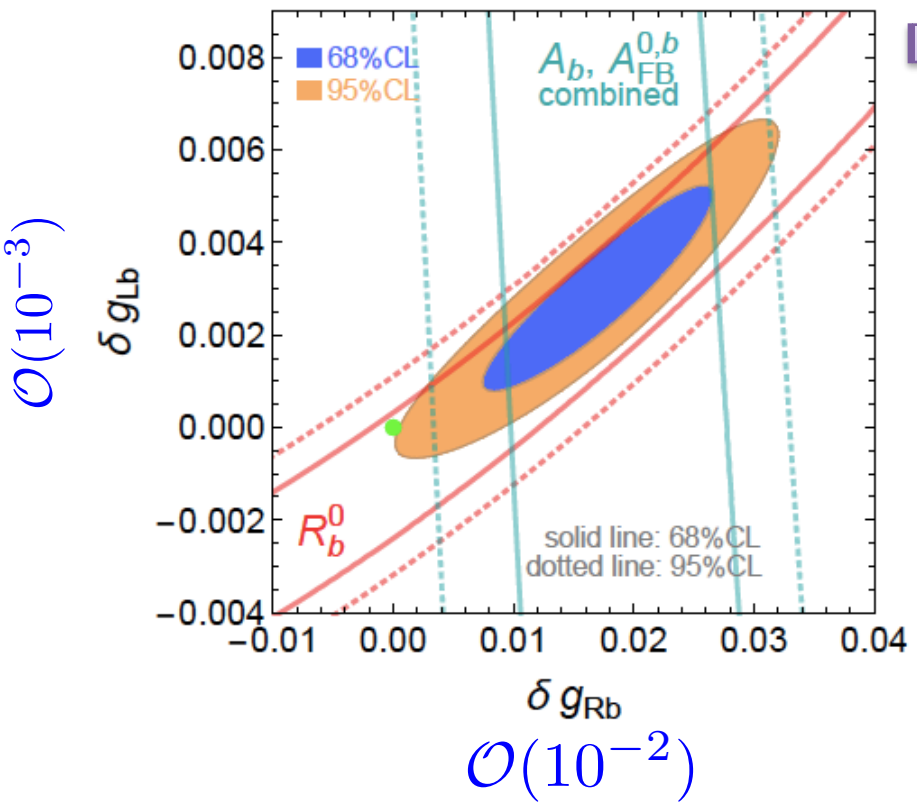
New experiments: e.g. CEPC

Zbb couplings@ future colliders

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

The degeneracy of right-handed Zbb coupling could be broken by scanning the energy

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



$\mathcal{O}(10^{-3})$

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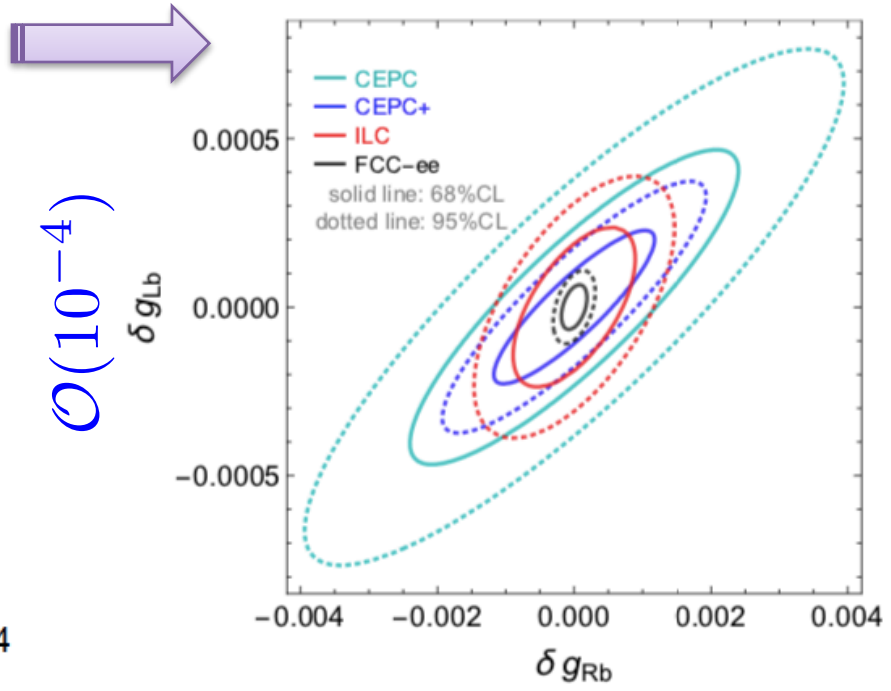


$\mathcal{O}(10^{-4})$

$\mathcal{O}(10^{-3})$

Should we wait for the next generation lepton colliders?

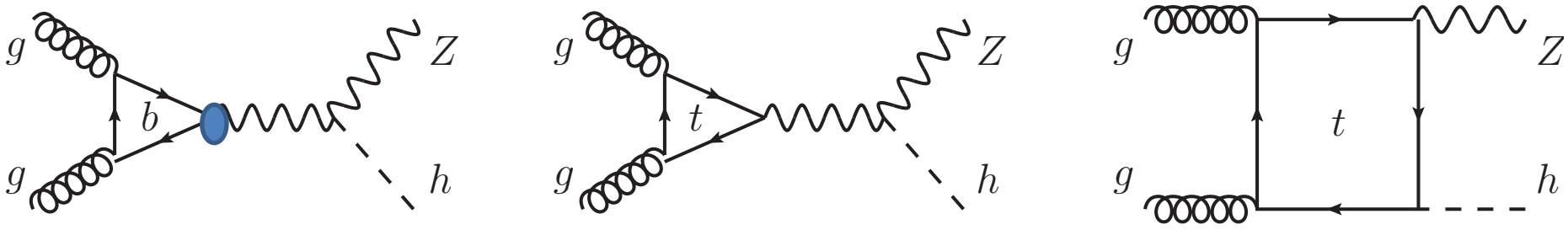
<u>The possibility of LHC?</u>

$Z \to b\bar{b}?$

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

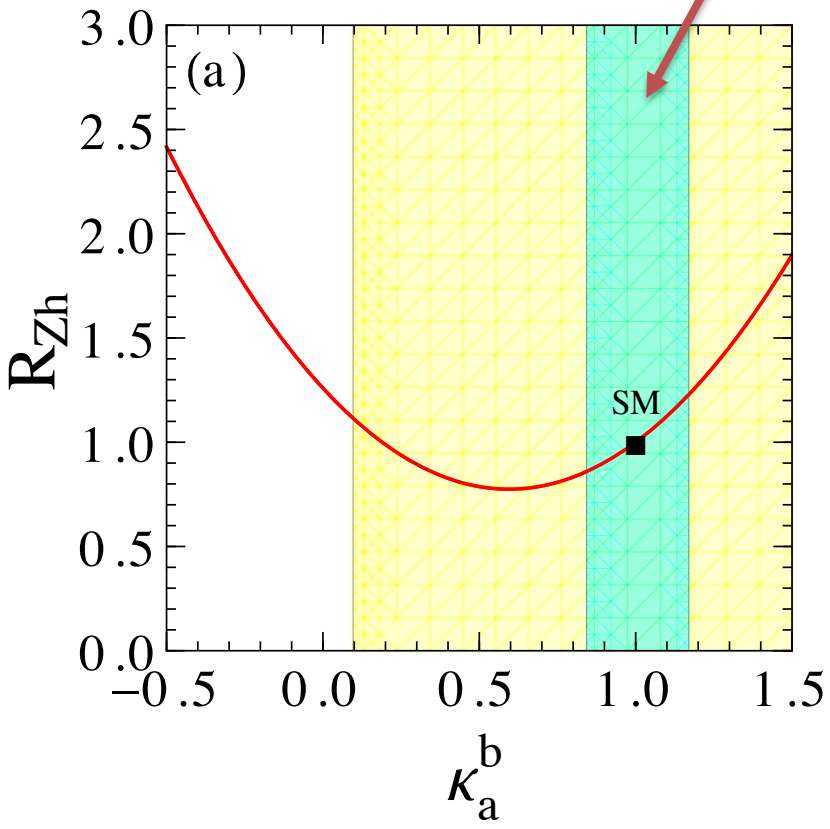
$$\mathcal{L} = \frac{g_W}{2c_W}\bar{b}\gamma_\mu(\kappa_v^b v_b^{\mathrm{SM}} - \kappa_a^b a_b^{\mathrm{SM}}\gamma_5)bZ_\mu + \frac{m_Z^2}{v}\kappa_Z h Z_\mu Z^\mu$$
$$+ \frac{g_W}{2c_W}\bar{t}\gamma_\mu(\kappa_v^t v_t^{\mathrm{SM}} - \kappa_a^t a_t^{\mathrm{SM}}\gamma_5)tZ_\mu - \frac{m_t}{v}\kappa_t\bar{t}th, \qquad (1)$$

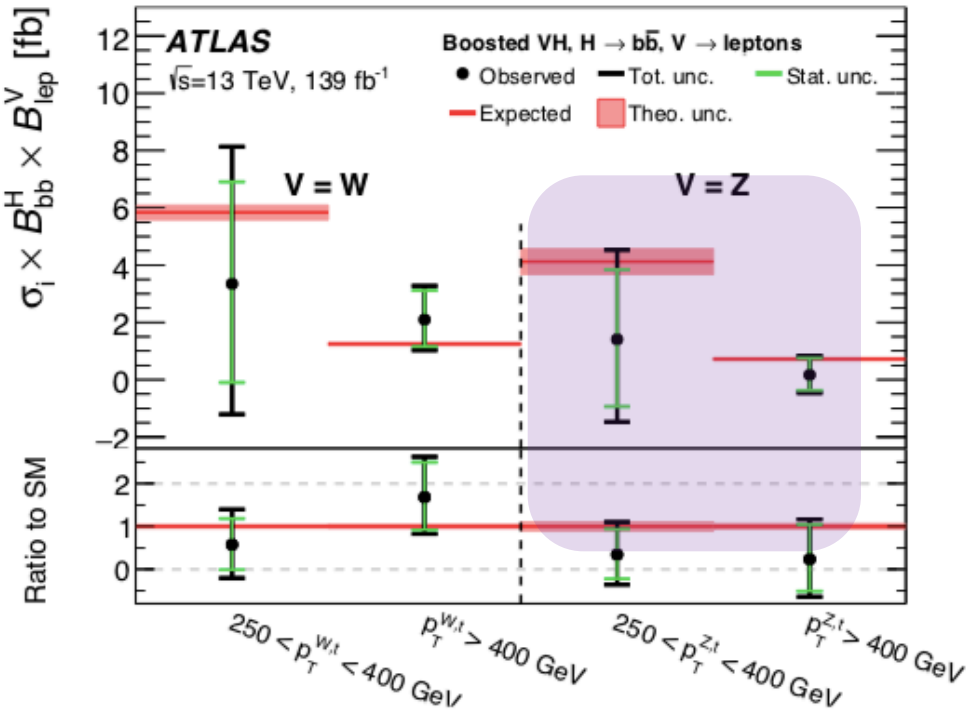
Cross sections @LHC

$$R_{Zh} = \frac{\sigma(gg \to Zh)}{\sigma(gg \to Zh)_{\mathrm{SM}}}$$

High P_T^Z data

ATLAS: 2008.02508





$$\mathcal{L} \supset -\frac{g_W}{2c_W}\bar{b}\gamma_\mu \kappa_a^b a_b^{\mathrm{SM}} \gamma_5 b Z_\mu$$

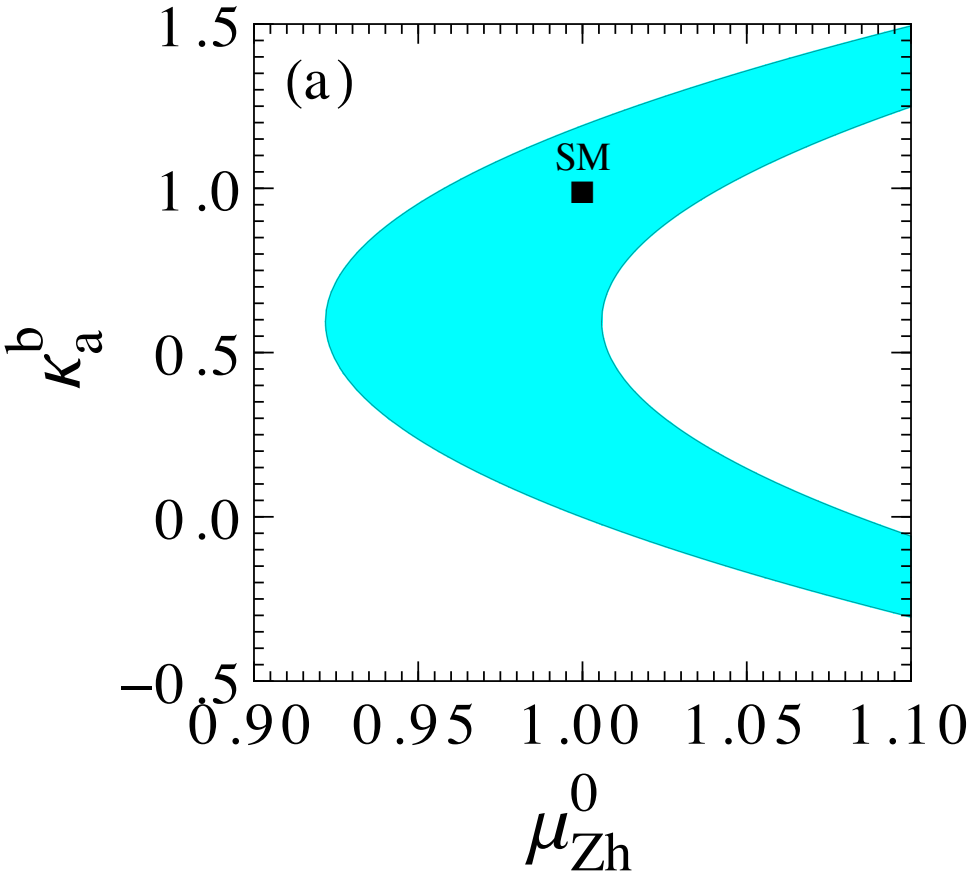
High P_T^Z data gives the most important impact for the limits

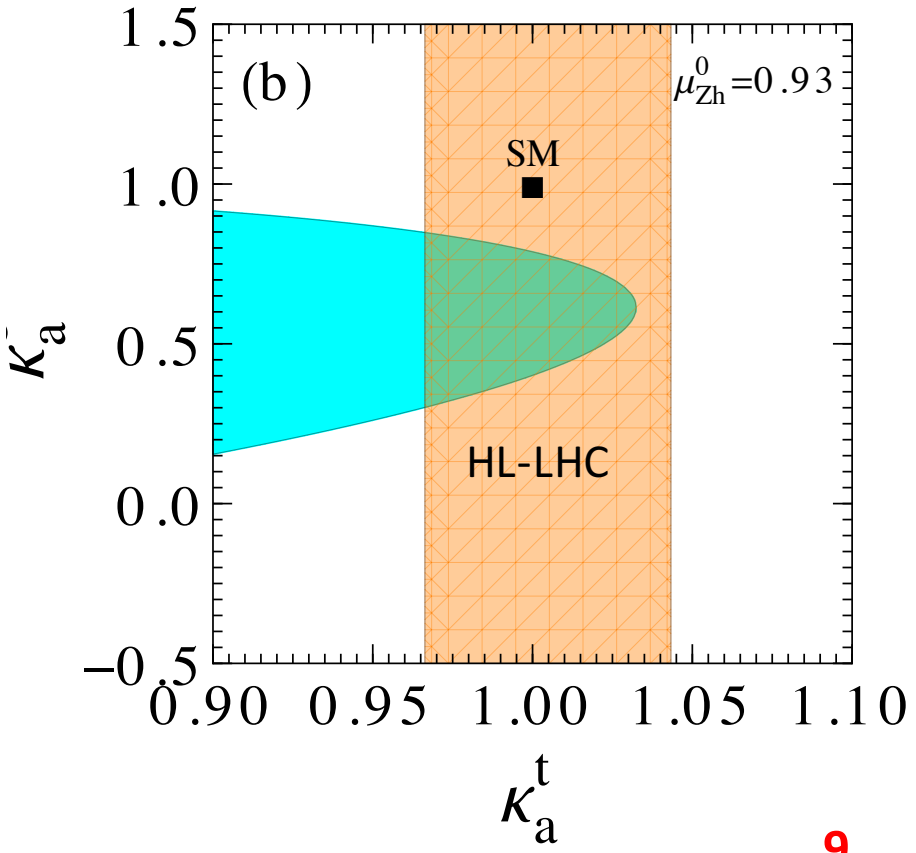
Sensitivity@HL-LHC

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

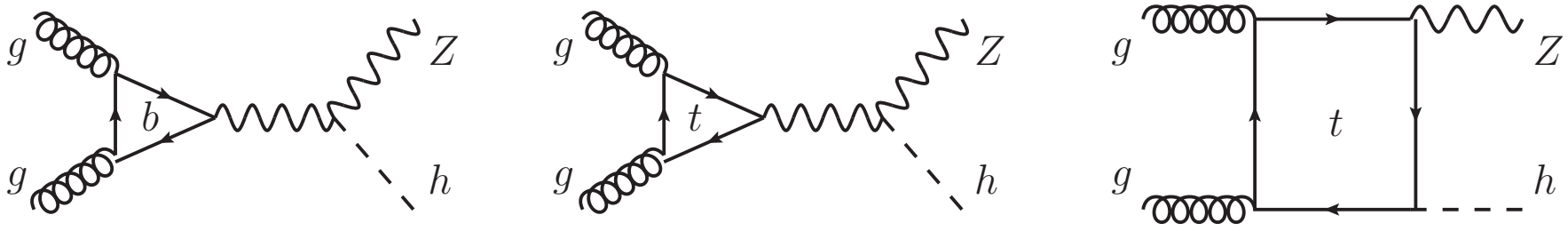
The conclusion is not sensitive to the other top quark couplings

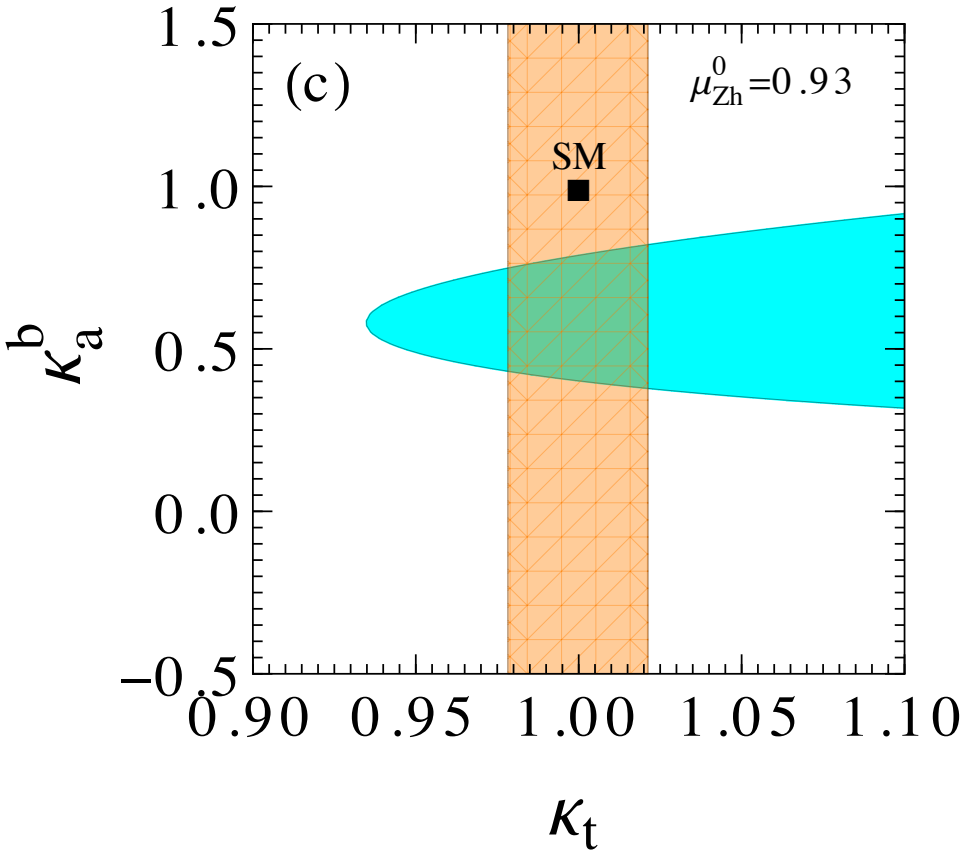
$$\mathcal{L} \supset -\frac{g_W}{2c_W}\bar{b}\gamma_\mu \kappa_a^b a_b^{\mathrm{SM}} \gamma_5 b Z_\mu - \frac{g_W}{2c_W}\bar{t}\gamma_\mu \kappa_a^t a_t^{\mathrm{SM}} \gamma_5 t Z_\mu$$

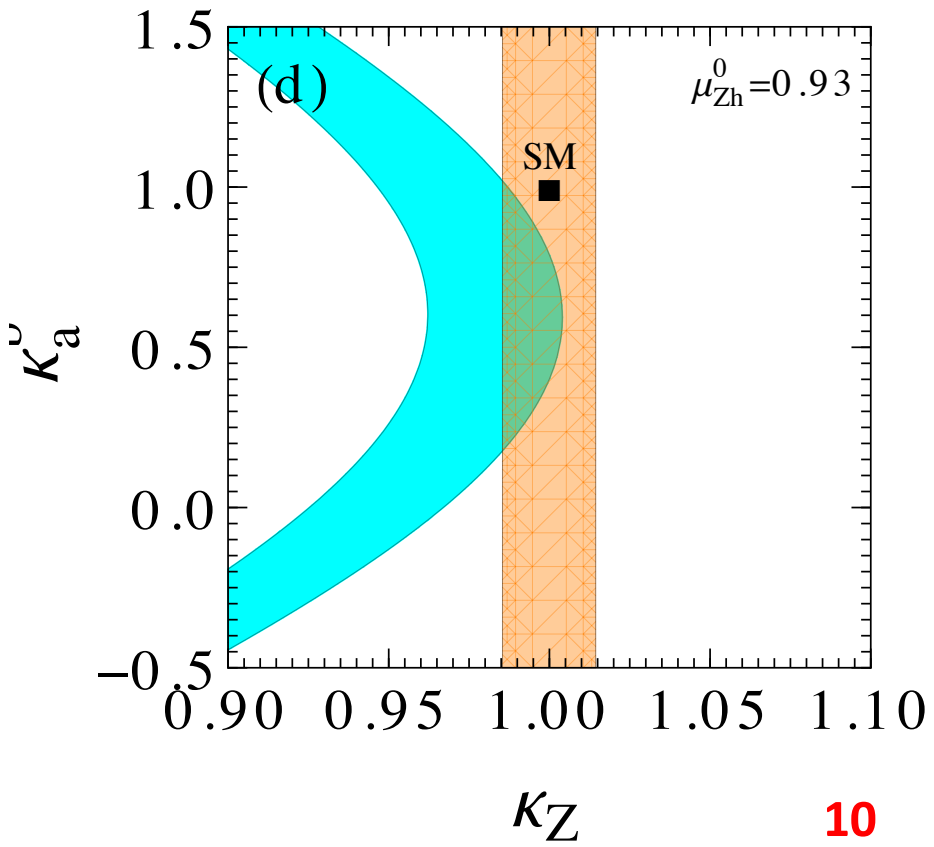




Sensitivity@HL-LHC

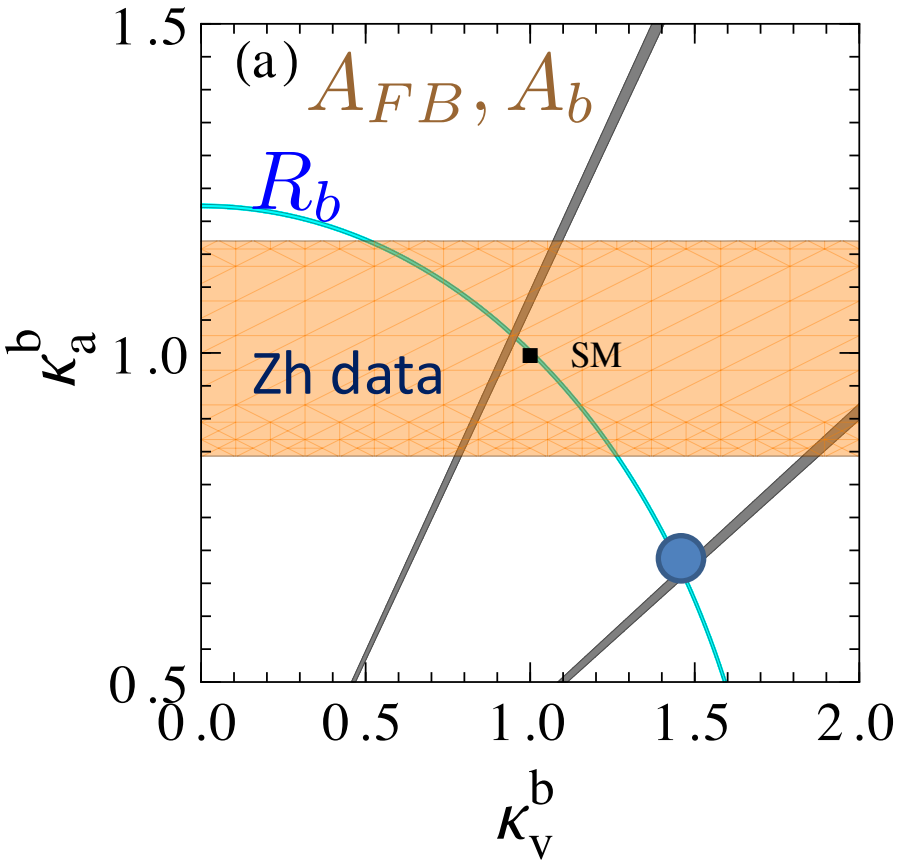




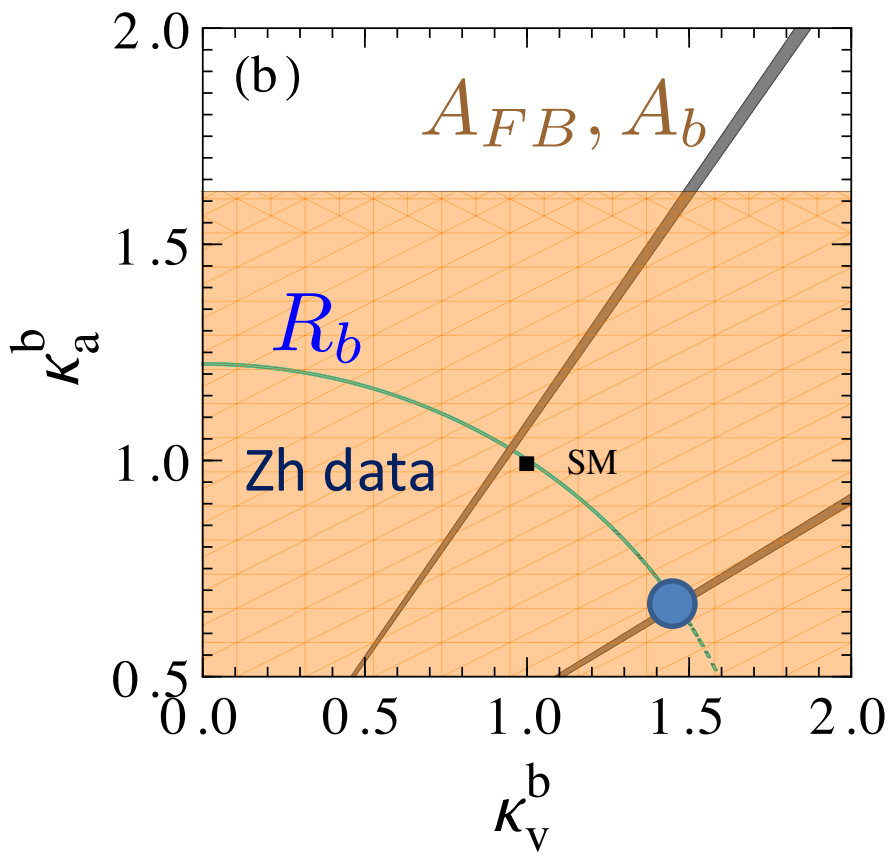


Break the Zbb coupling degeneracy

Current Zh data could break the degeneracy

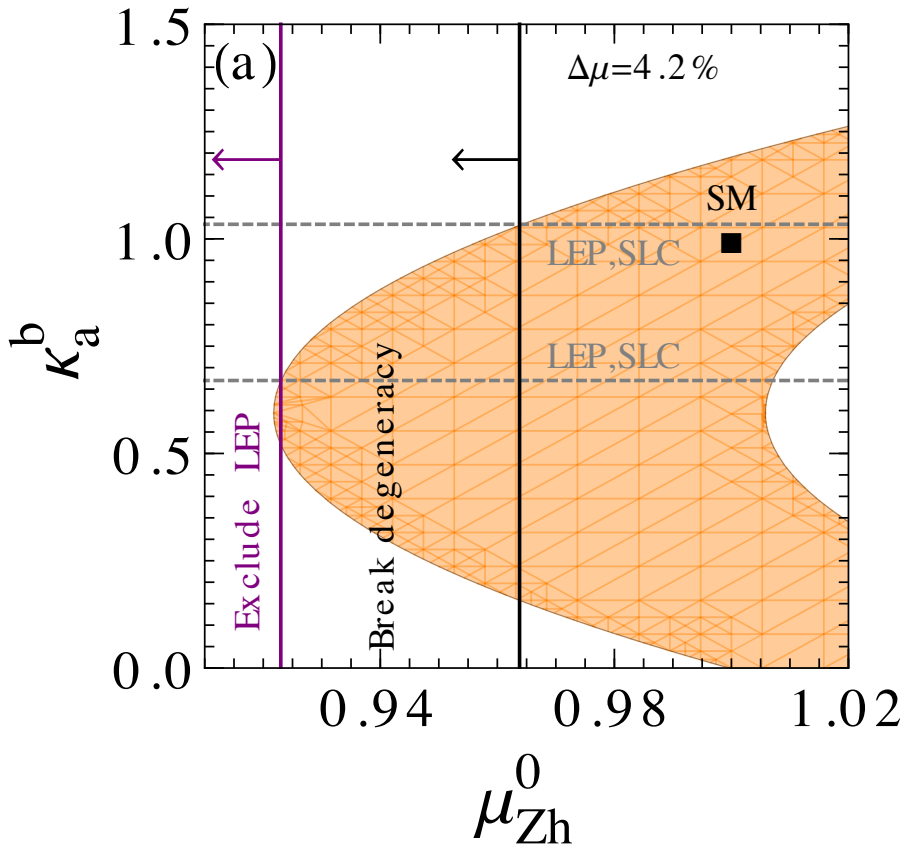


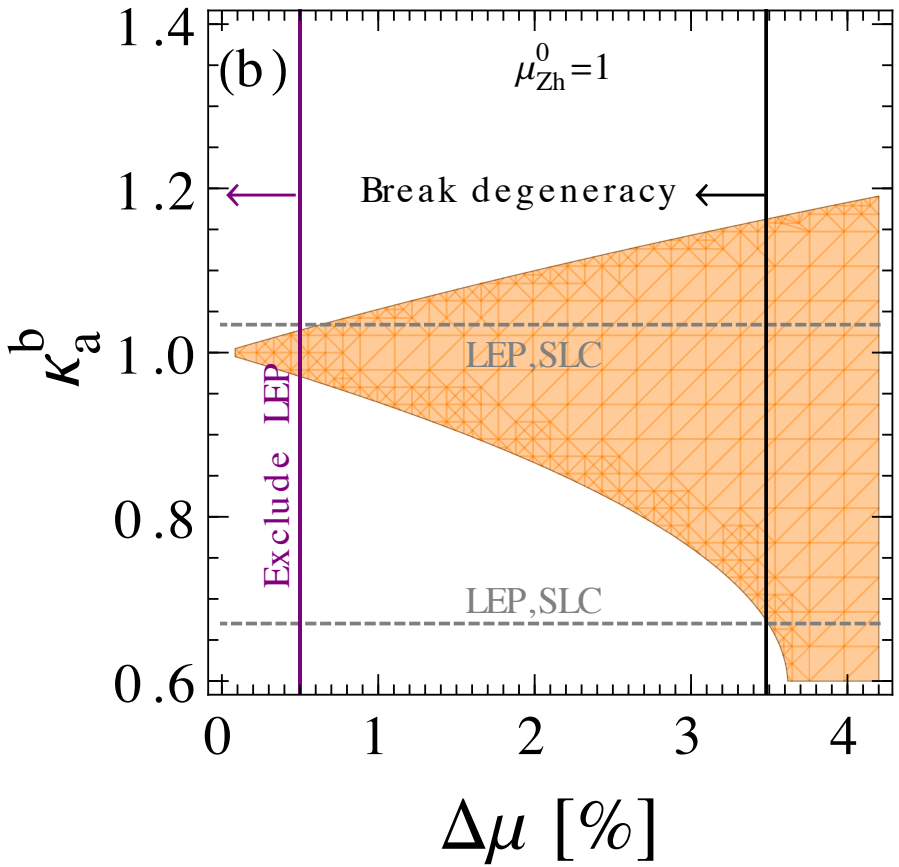
Including all Zh data



Removing the two high P_T^Z data

Break the Zbb coupling degeneracy



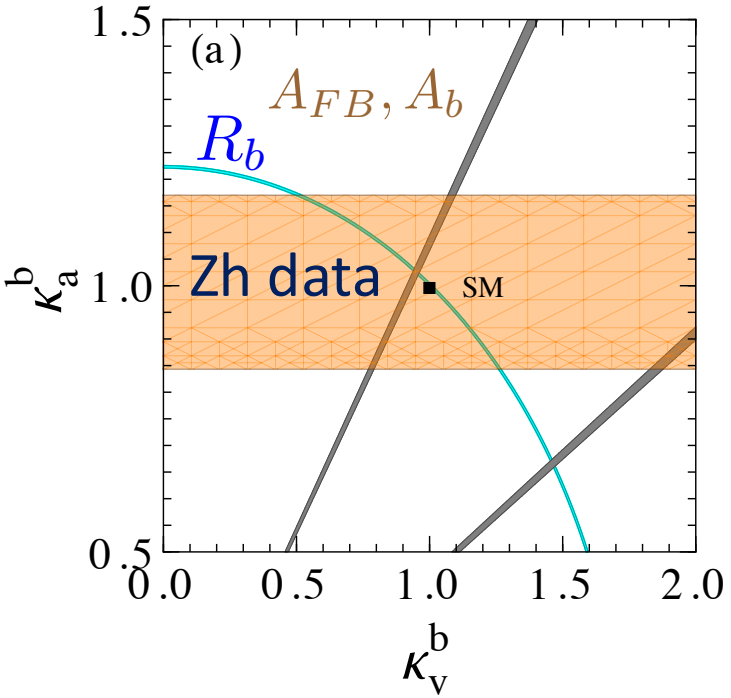


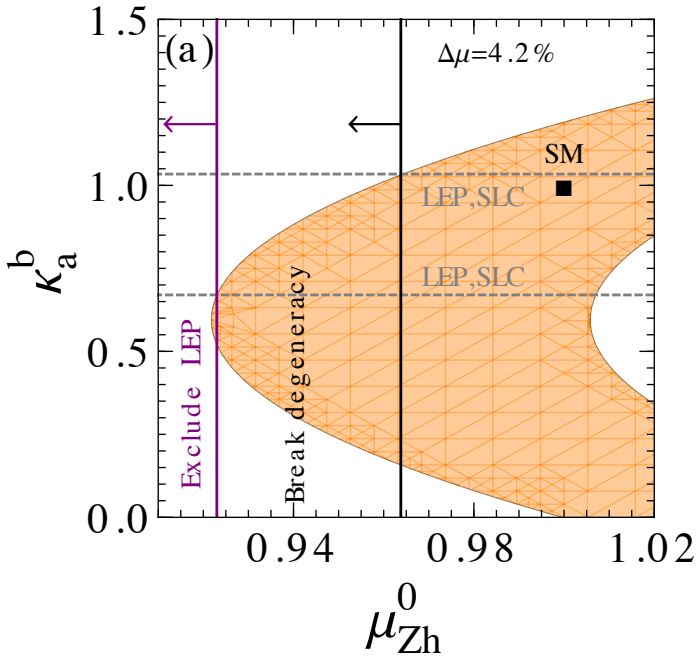
Summary

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;

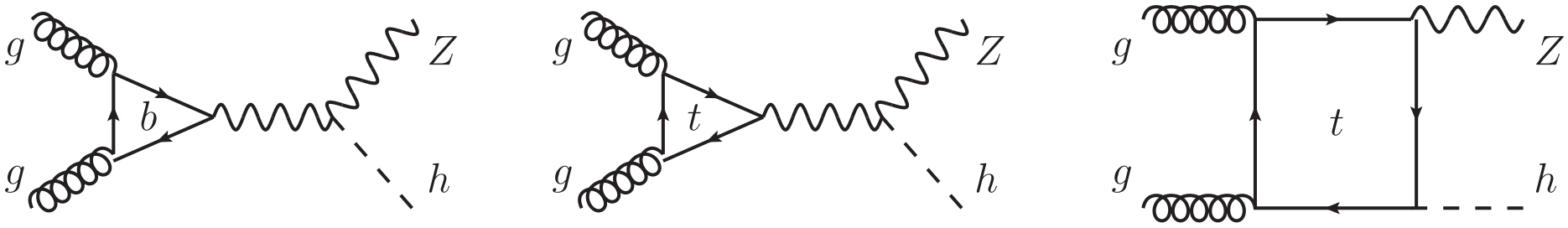
B. The Zh data at the 13 TeV LHC can resolve the apparent degeneracy of the Zbb coupling;

C. The HL-LHC could verify or exclude the Zbb couplings.





Zbb couplings@LHC



The contribution dominant by the (++0) and (--0) helicity amplitudes:

$$M^{\triangle}_{++0} = 2\frac{\sqrt{\lambda}}{m_Z}\sum_{t,b}\left[\kappa^q_a\kappa_Z\frac{a^{\rm SM}_q g_{hZZ}}{m^2_Z}\left(F_{\triangle}(s,m^2_q)+2\right)\right]N,$$

$$M^{\square}_{++0} = -\frac{4}{m_Z\sqrt{\lambda}}\kappa^t_a\kappa_t g_{htt}a^{\rm SM}_t m_t\left[F^0_{++}+(t\leftrightarrow u)\right]N,$$