

The anomalous Zbb couplings: From LEP to LHC

Bin Yan

Los Alamos National Laboratory

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

Status of Zbb couplings

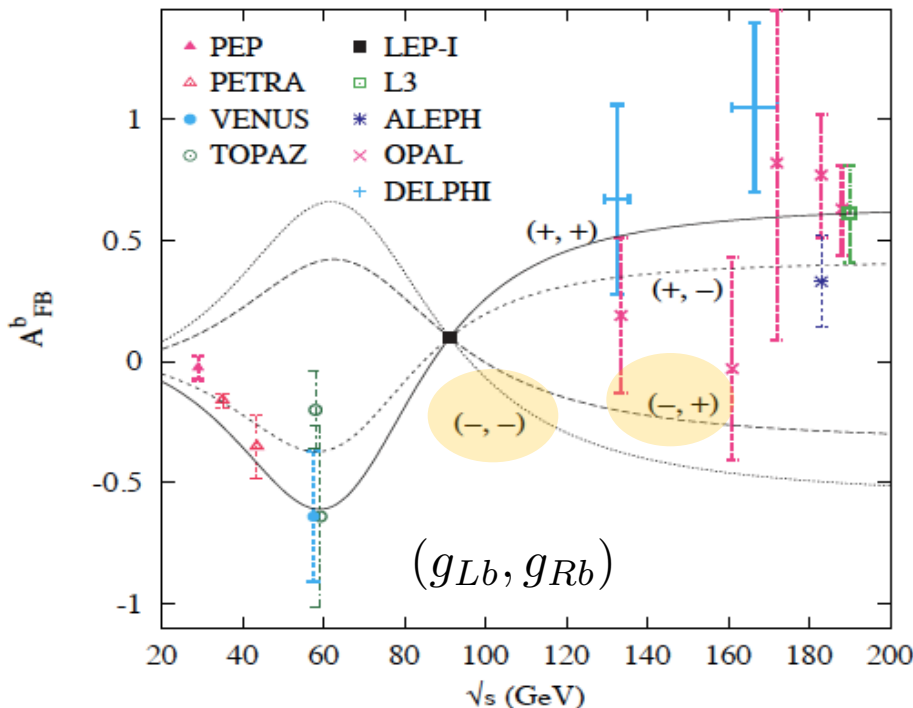
	measured value	SM prediction
R_b^0	0.21629 ± 0.00066	0.21578 ± 0.00011
$A_{FB}^{0,b}$	0.0992 ± 0.0016	0.1032 ± 0.0004
A_b	0.923 ± 0.020	0.93463 ± 0.00004

Gfitter Group:
EPJC74 (2014)3046

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



2.5 σ deviation with SM prediction



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

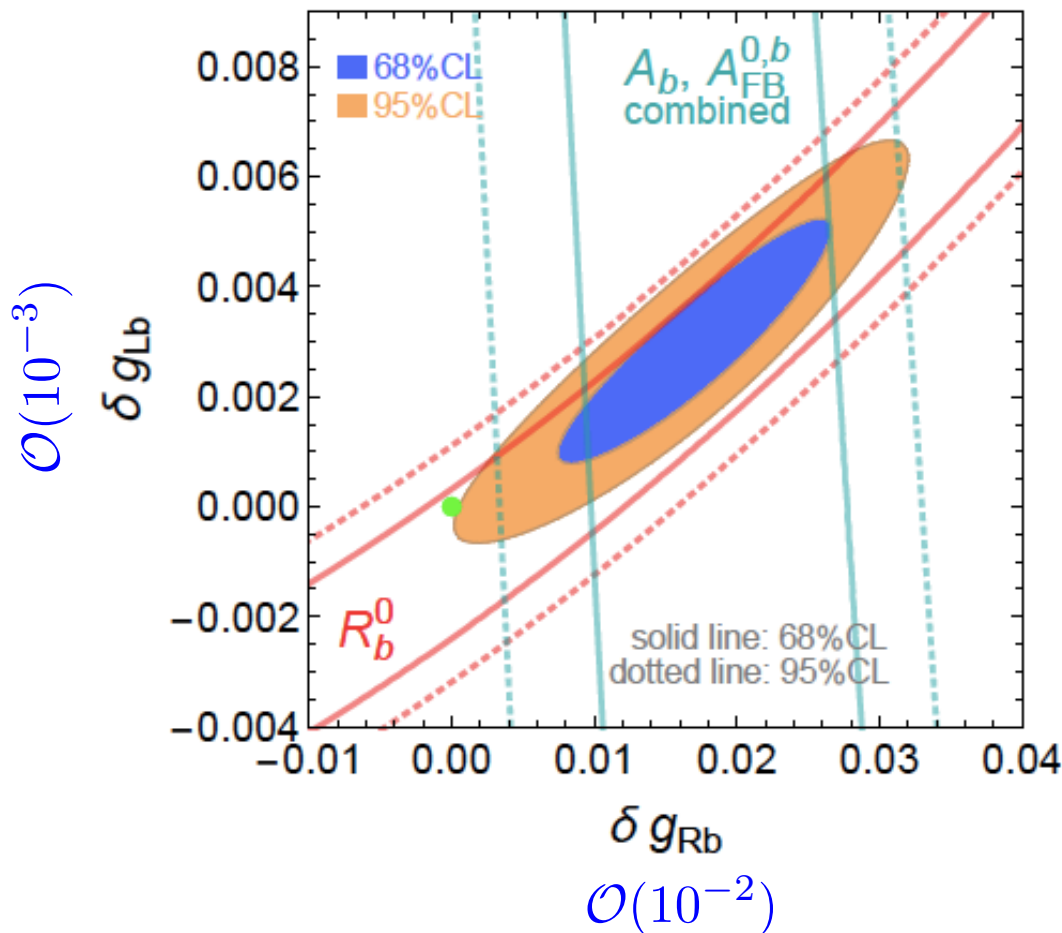
$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu (g_{Lb} \bar{b}_L \gamma^\mu b_L + g_{Rb} \bar{b}_R \gamma^\mu b_R)$$

$g_{Lb} < 0$ was Excluded

g_{Rb} Could be positive and negative

Status of Zbb couplings

$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu (g_{Lb} \bar{b}_L \gamma^\mu b_L + g_{Rb} \bar{b}_R \gamma^\mu b_R) \quad \text{S. Gori, J. Gu, L. T. Wang, JHEP04(2016)062}$$



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 $O(3)$**

Many new physics models

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



Statistical Fluctuation or Systematic error?

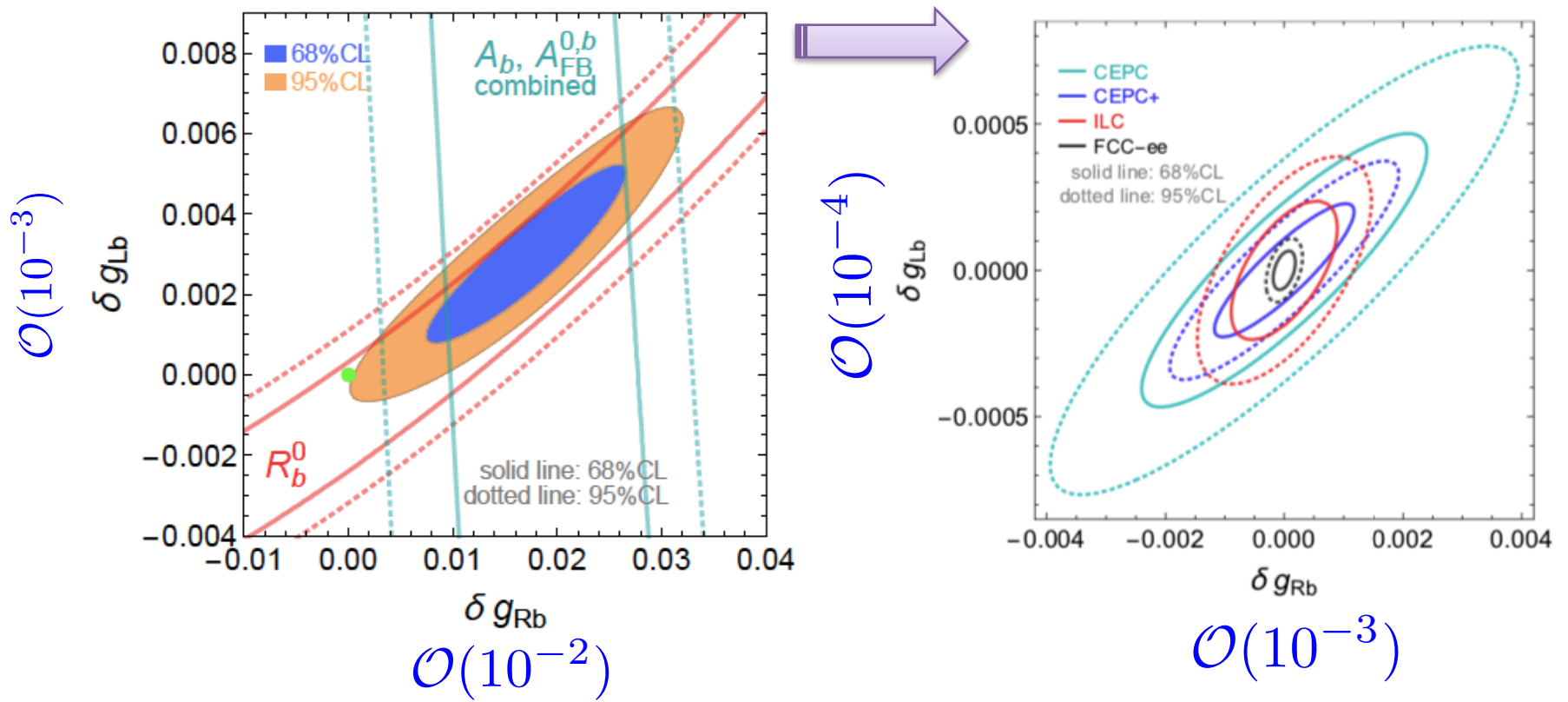
New experiments: e.g. CEPC

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



Should we wait for the next generation lepton colliders?

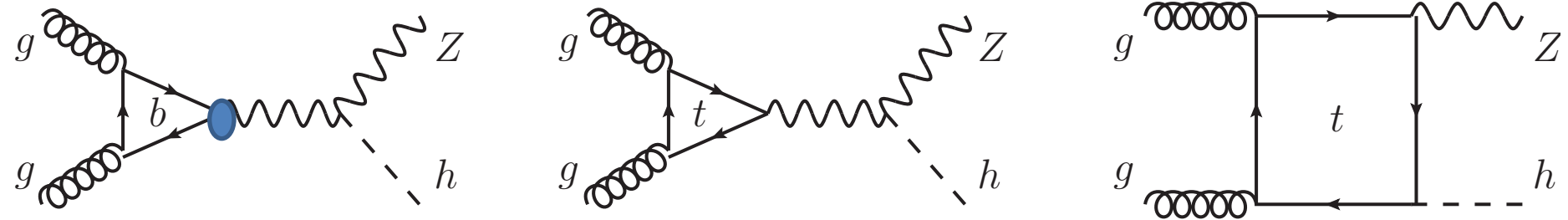
The possibility of LHC?

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

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

$$\mathcal{L} = \frac{g_W}{2c_W} \bar{b} \gamma_\mu (\kappa_v^b v_b^{\text{SM}} - \kappa_a^b a_b^{\text{SM}} \gamma_5) b Z_\mu + \frac{m_Z^2}{v} \kappa_Z h Z_\mu Z^\mu$$

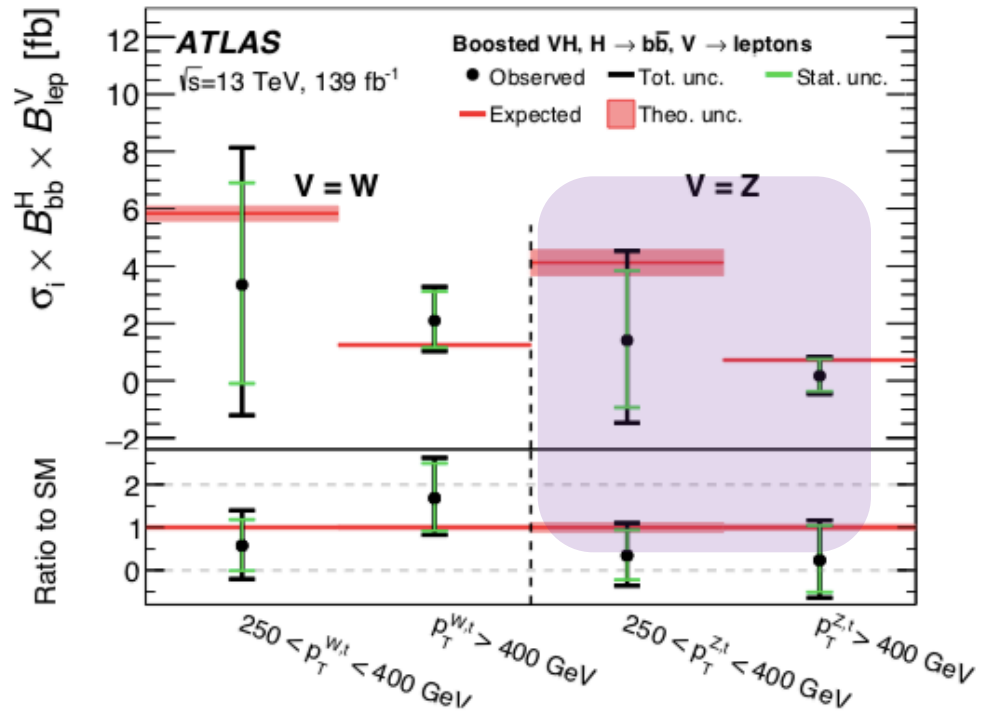
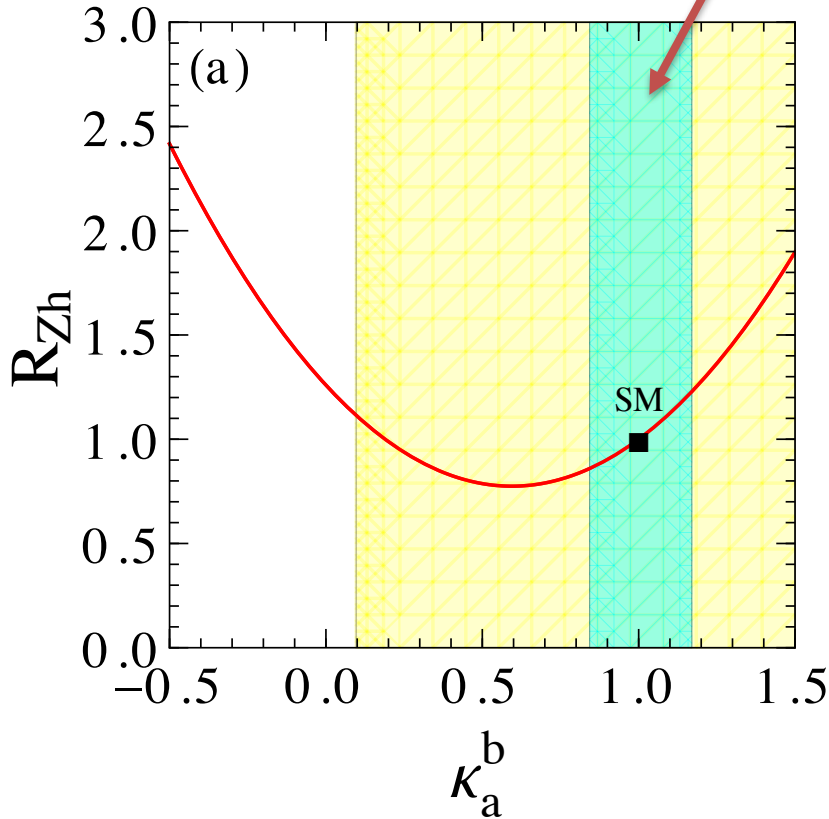
$$+ \frac{g_W}{2c_W} \bar{t} \gamma_\mu (\kappa_v^t v_t^{\text{SM}} - \kappa_a^t a_t^{\text{SM}} \gamma_5) t Z_\mu - \frac{m_t}{v} \kappa_t \bar{t} t h, \quad (1)$$

Cross sections @LHC

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

High P_T^Z data

ATLAS: 2008.02508



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

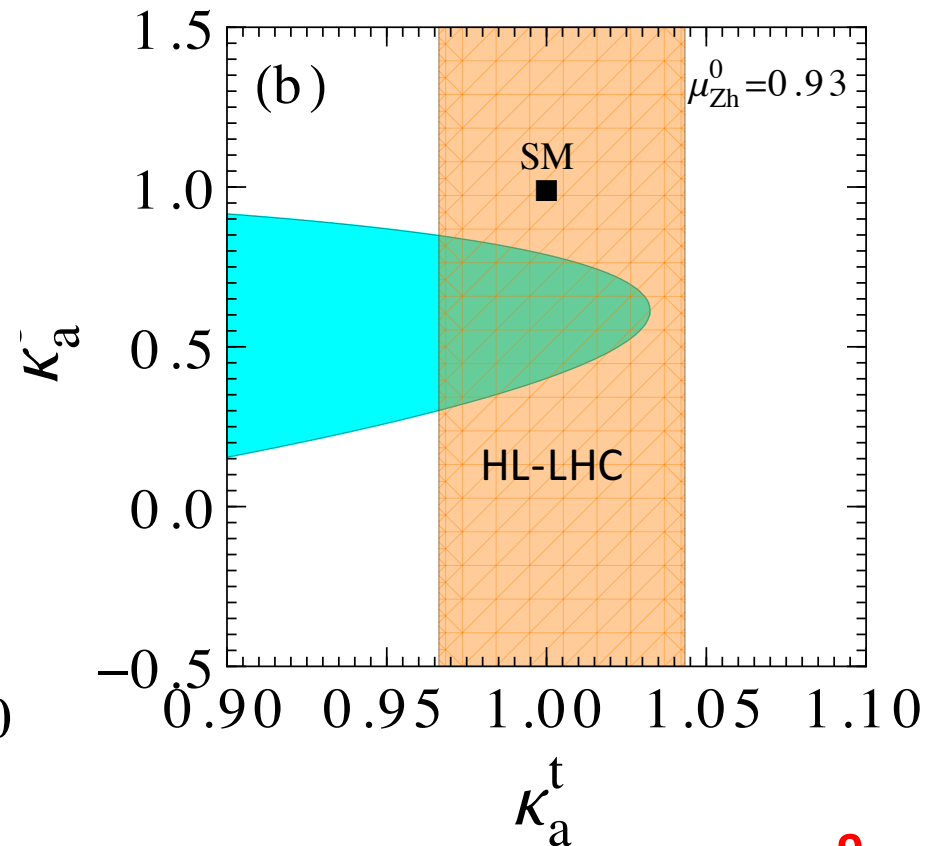
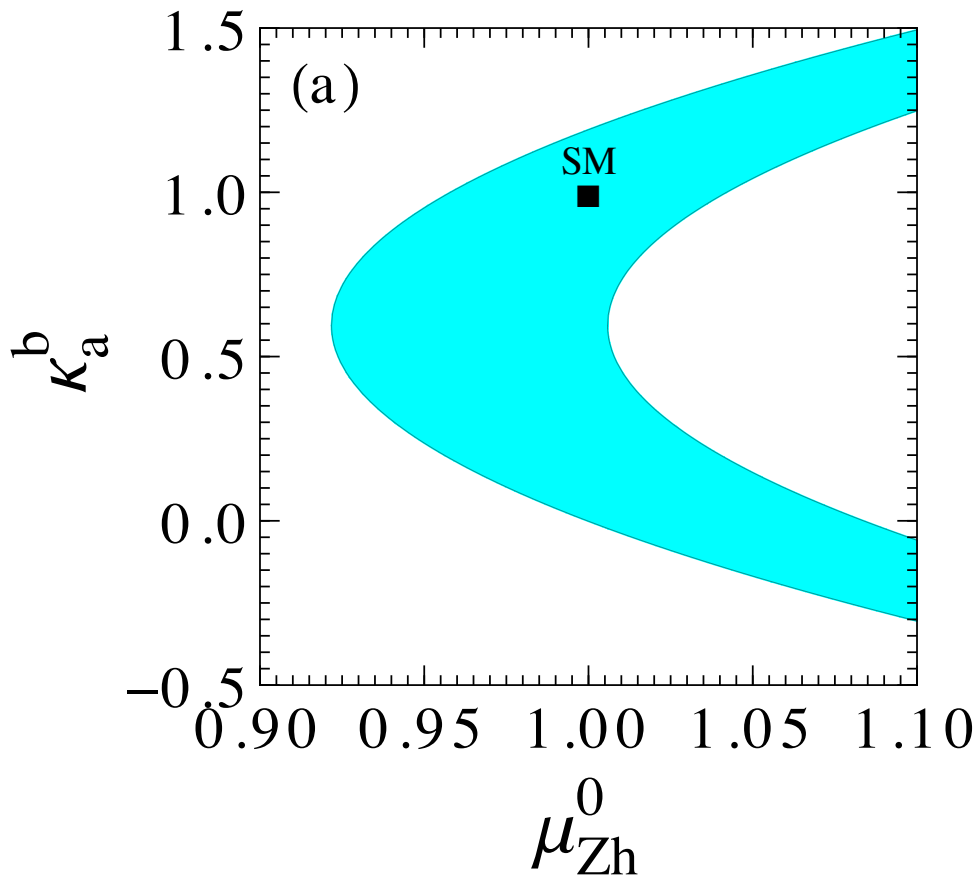
High P_T^Z data gives the most important impact for the limits

Sensitivity@HL-LHC

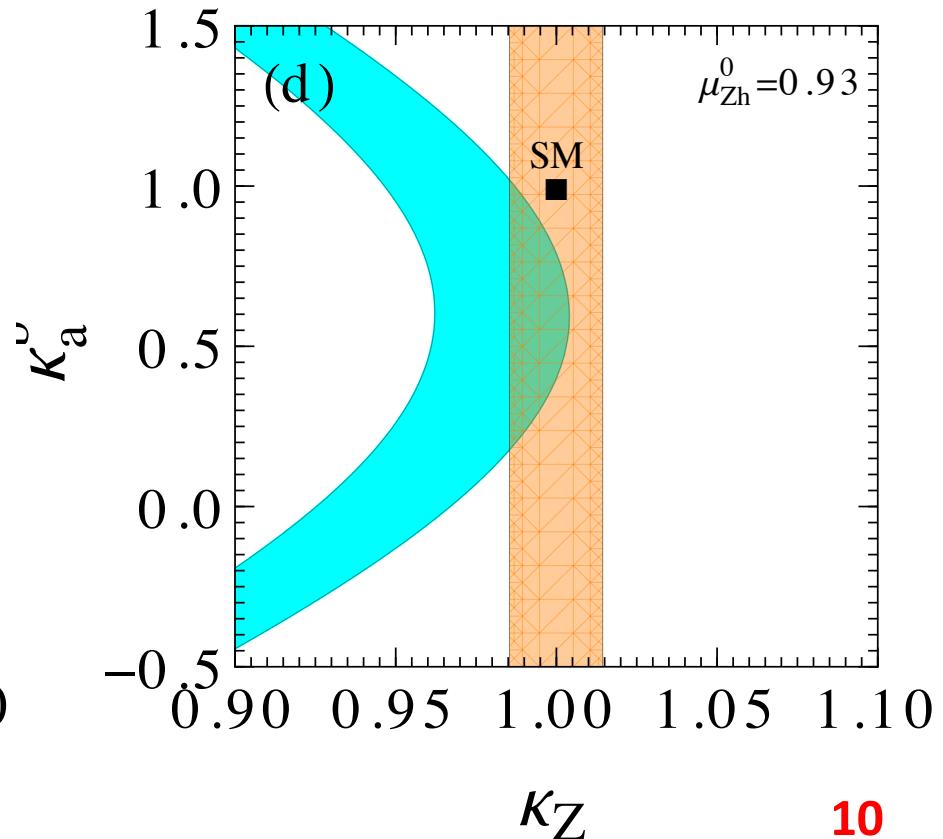
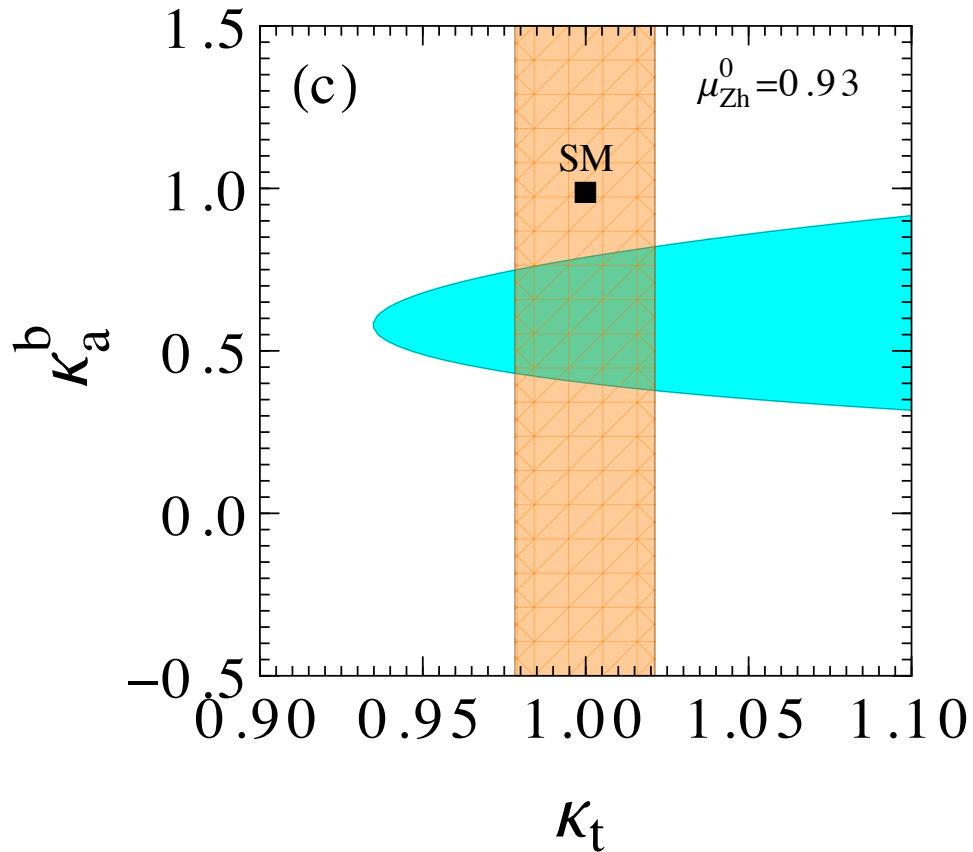
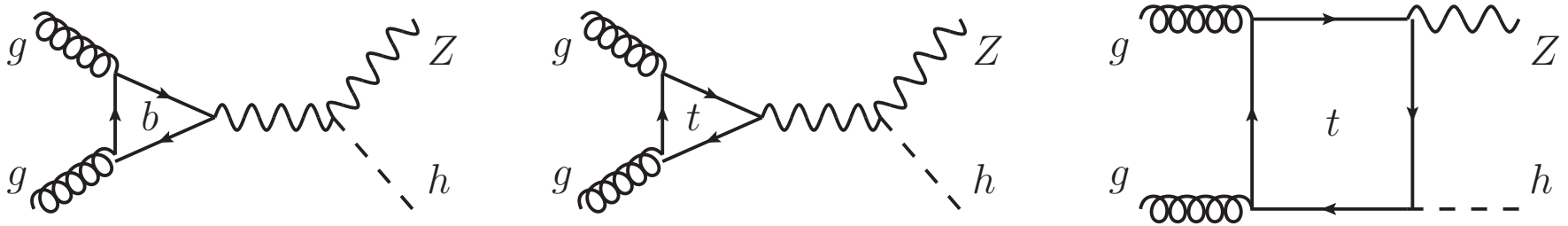
The expected limits is sensitive to the **central value of the signal strength**

The conclusion is **not sensitive** to the other **top quark couplings**

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

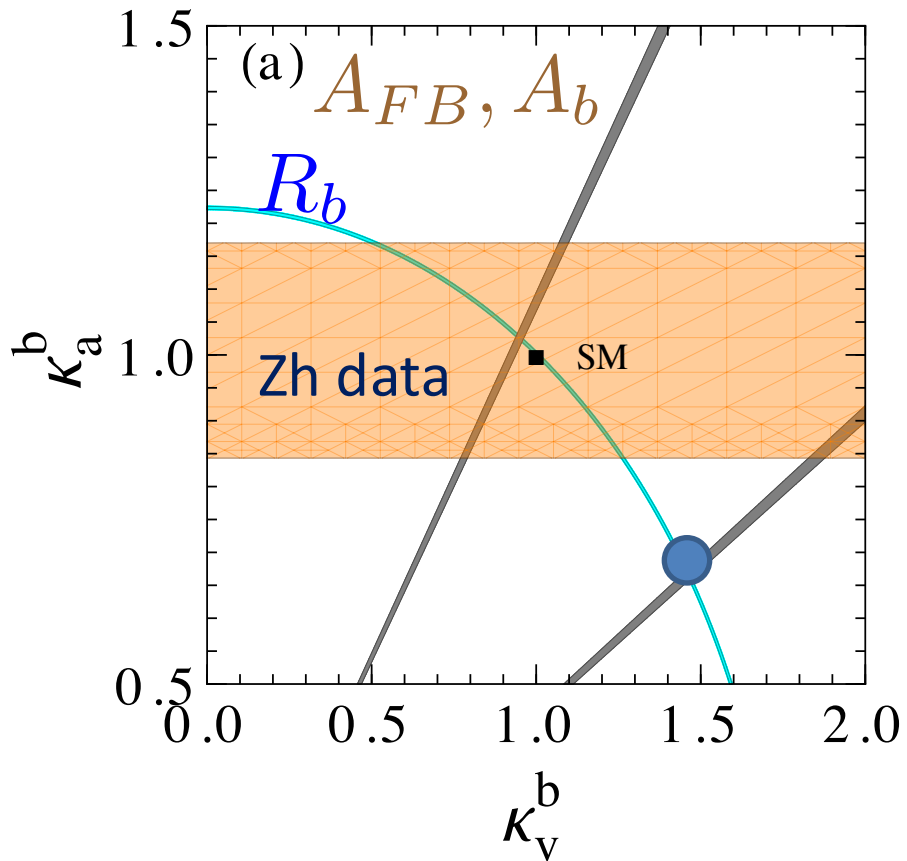


Sensitivity@HL-LHC

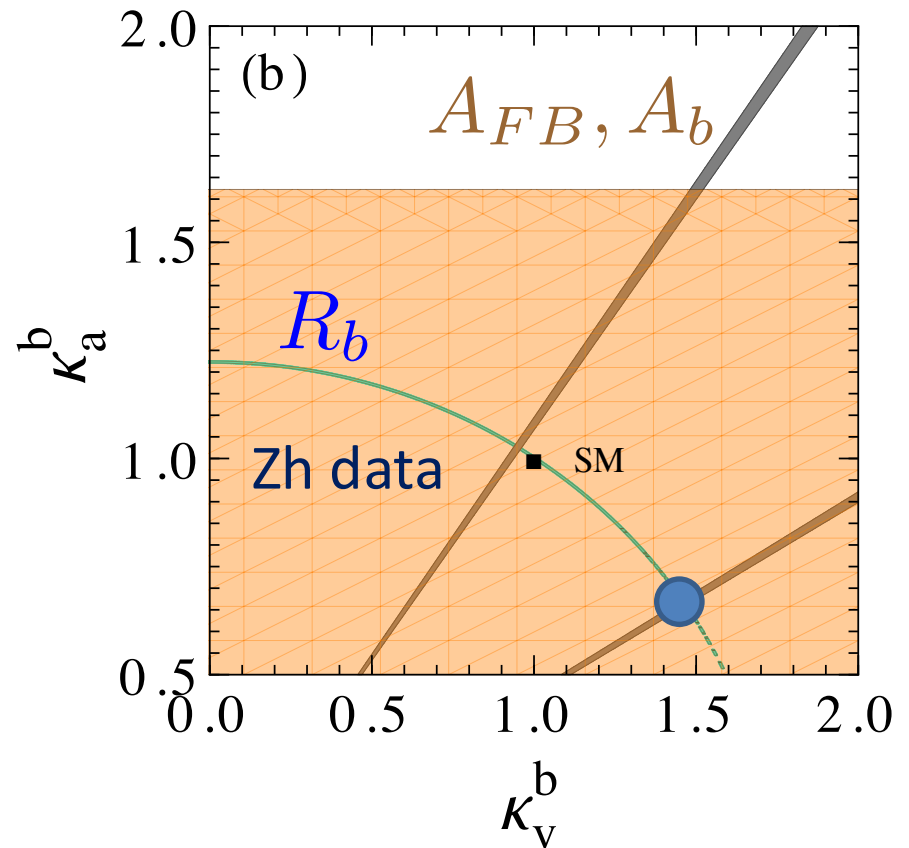


Break the Zbb coupling degeneracy

Current Zh data could break the degeneracy

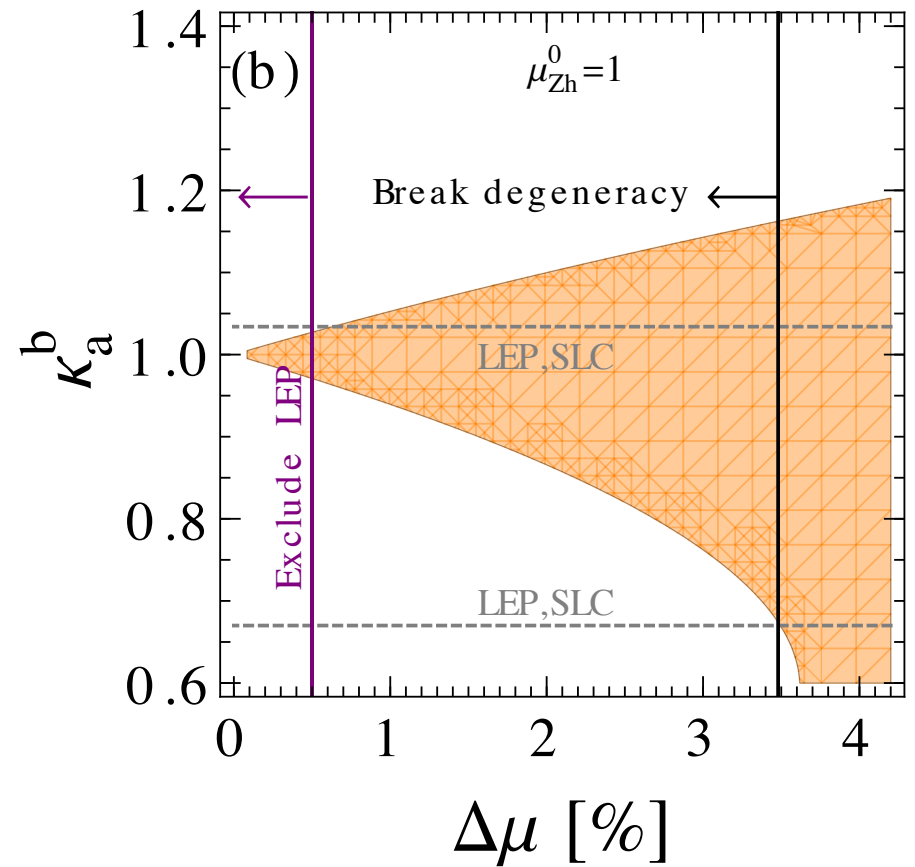
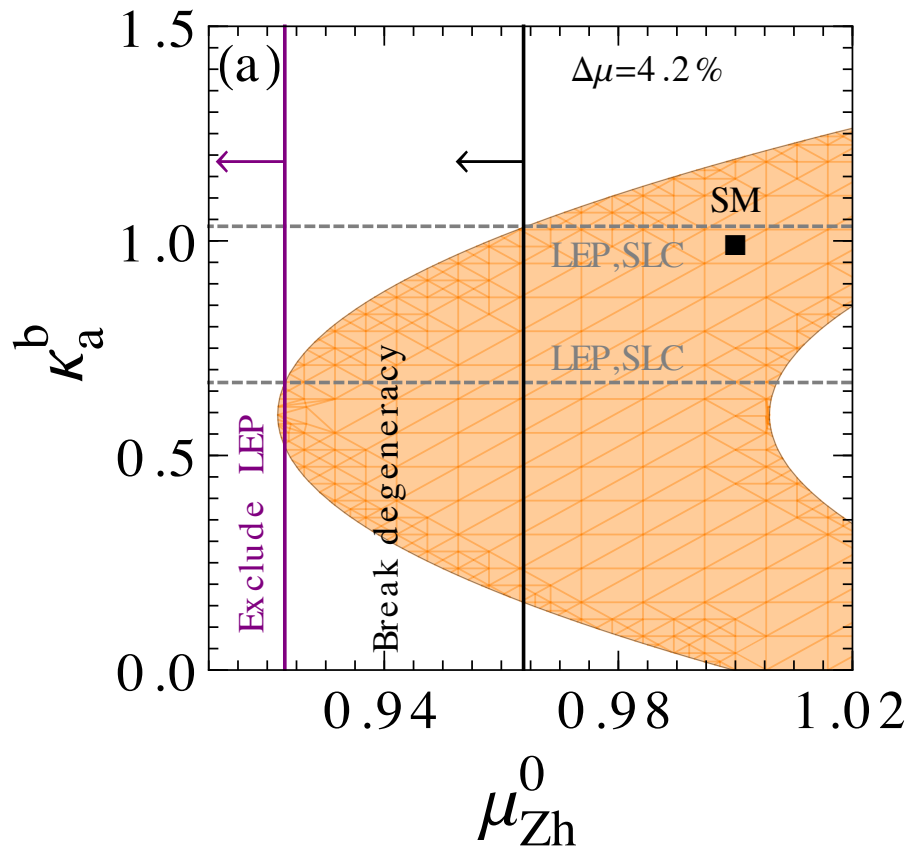


Including all Zh data



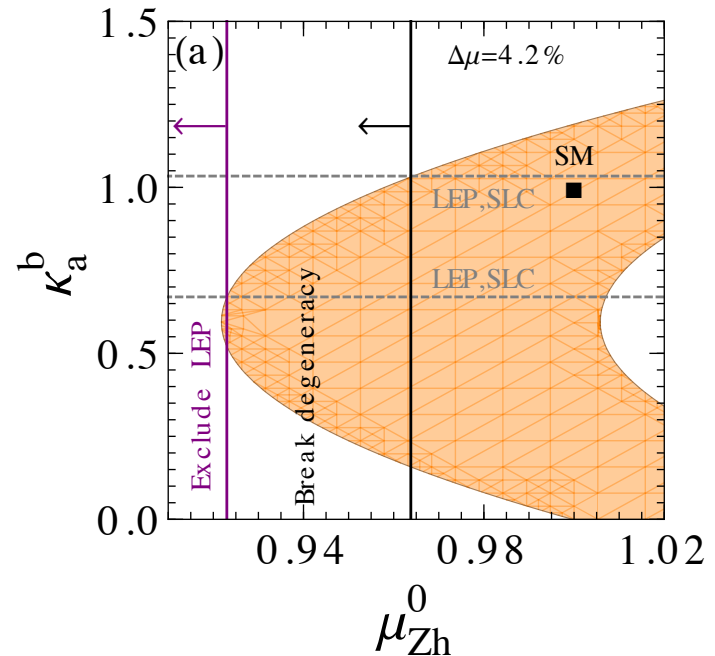
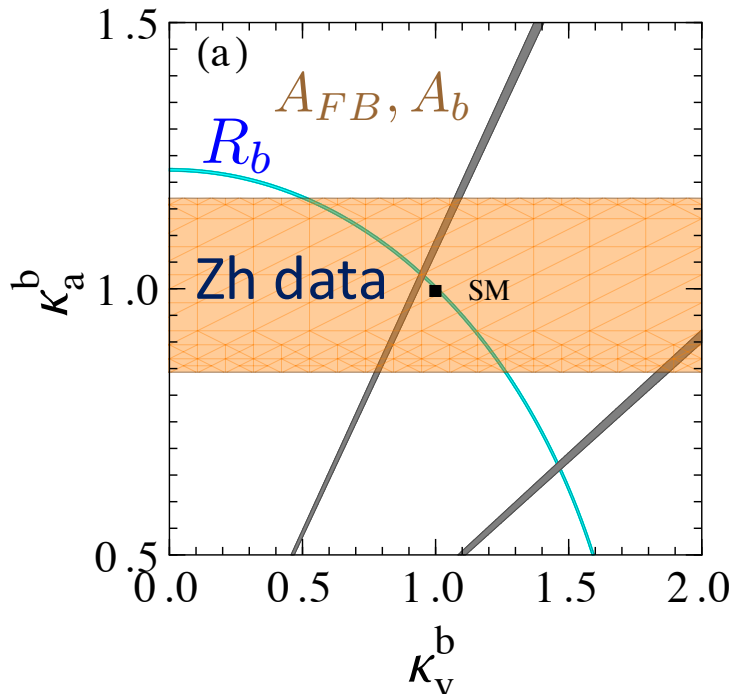
Removing the two high P_T^Z data **11**

Break the Zbb coupling degeneracy

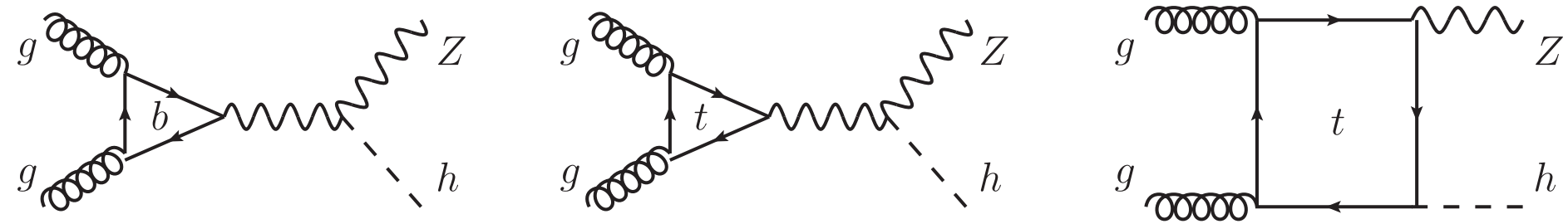


Summary

- A. We proposed a new method to probe the $Zb\bar{b}$ 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 $Zb\bar{b}$ coupling;
- C. The HL-LHC could verify or exclude the $Zb\bar{b}$ couplings.



Zbb couplings@LHC



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

$$M_{++0}^{\Delta} = 2 \frac{\sqrt{\lambda}}{m_Z} \sum_{t,b} \left[\kappa_a^q \kappa_Z \frac{a_q^{\text{SM}} g_{hZZ}}{m_Z^2} (F_{\Delta}(s, m_q^2) + 2) \right] N,$$

$$M_{++0}^{\square} = -\frac{4}{m_Z \sqrt{\lambda}} \kappa_a^t \kappa_t g_{htt} a_t^{\text{SM}} m_t [F_{++}^0 + (t \leftrightarrow u)] N,$$