The anomalous Zbb couplings at the LHC and ep colliders

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Bin Yan, C.-P. Yuan, arxiv:2101.06261 (Accepted by PRL)
Bin Yan, Zhite Yu and C.-P. Yuan, arxiv: 2107.02134 (Submitted to PRL)

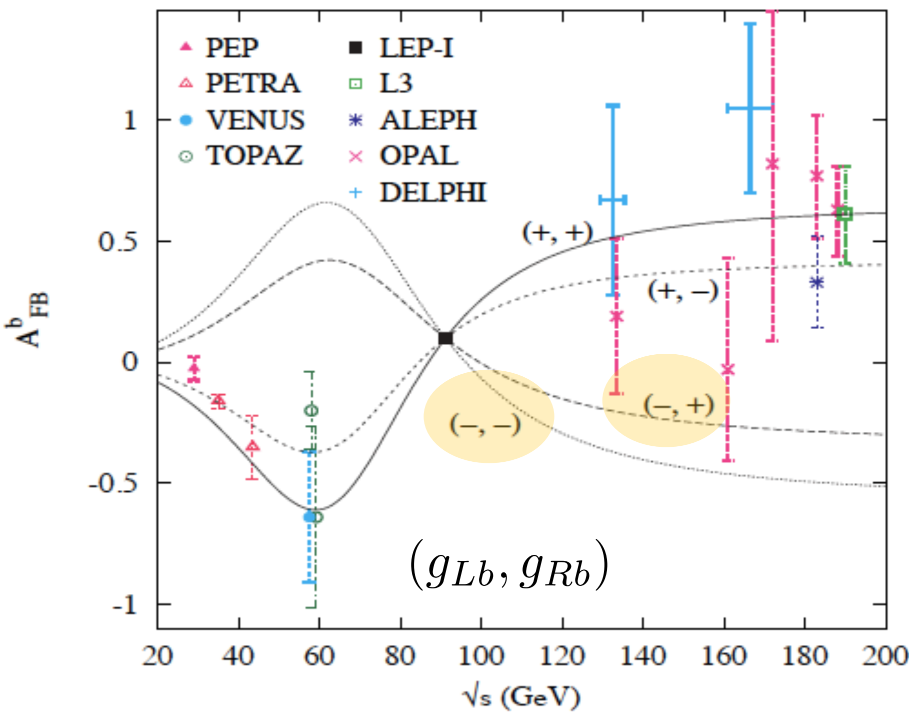
Status of Zbb couplings

	measured value	SM prediction
R_b^0	0.21629 ± 0.00066	0.21578 ± 0.00011
$A_{\mathrm{FB}}^{0,b}$	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

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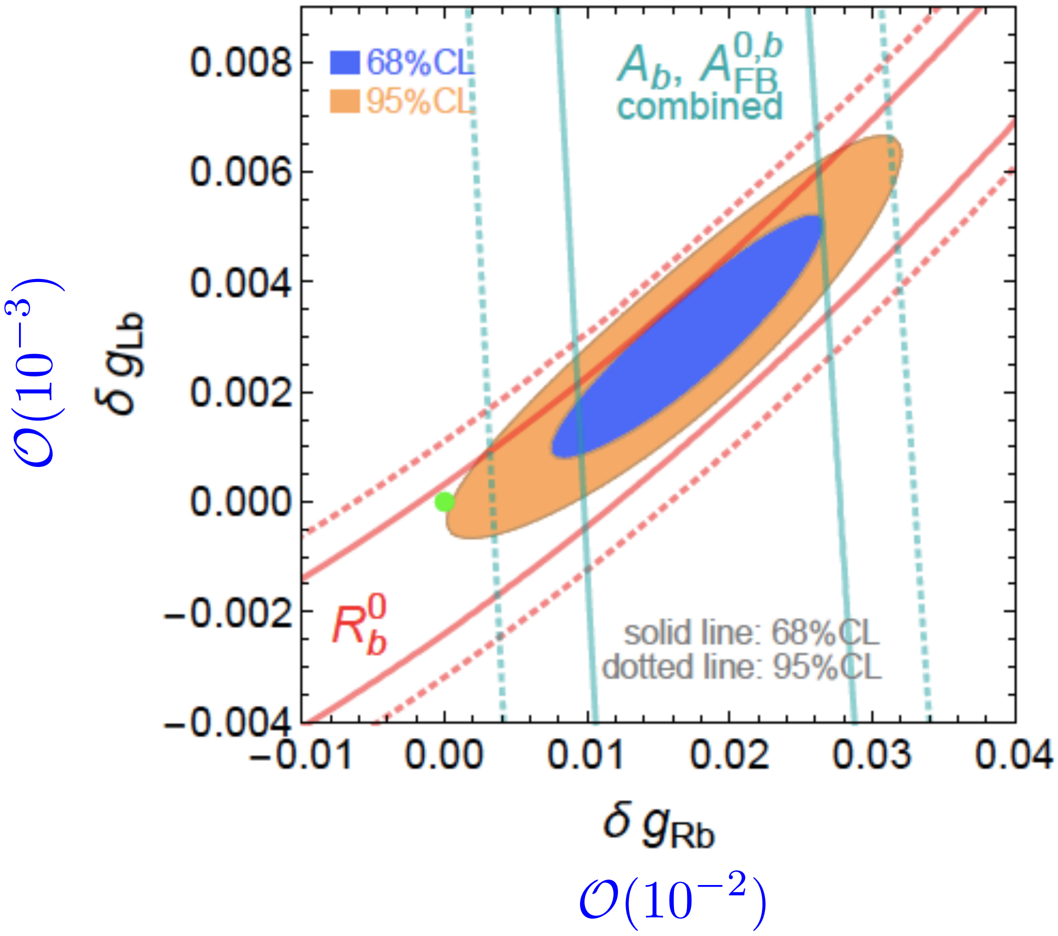
S. Gori, J. Gu, L. T. Wang, JHEP04(2016)062



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?

Many new physics models

e.g. Custodial symmetry O(3)+heavy quark

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

⇨ Statistical Fluctuation or Systematic error?

New experiments: e.g. CEPC

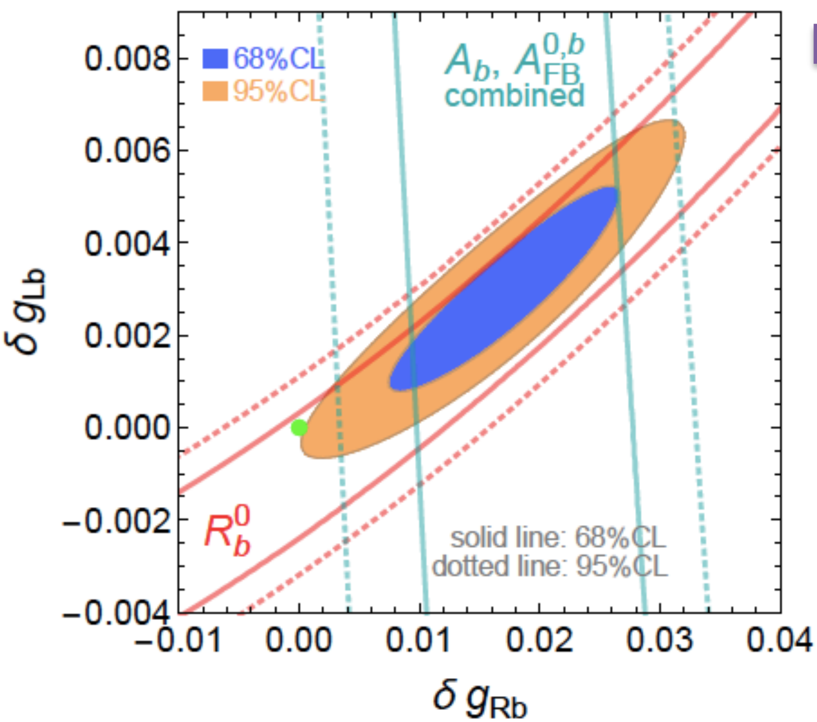
Zbb couplings@ future colliders

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

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

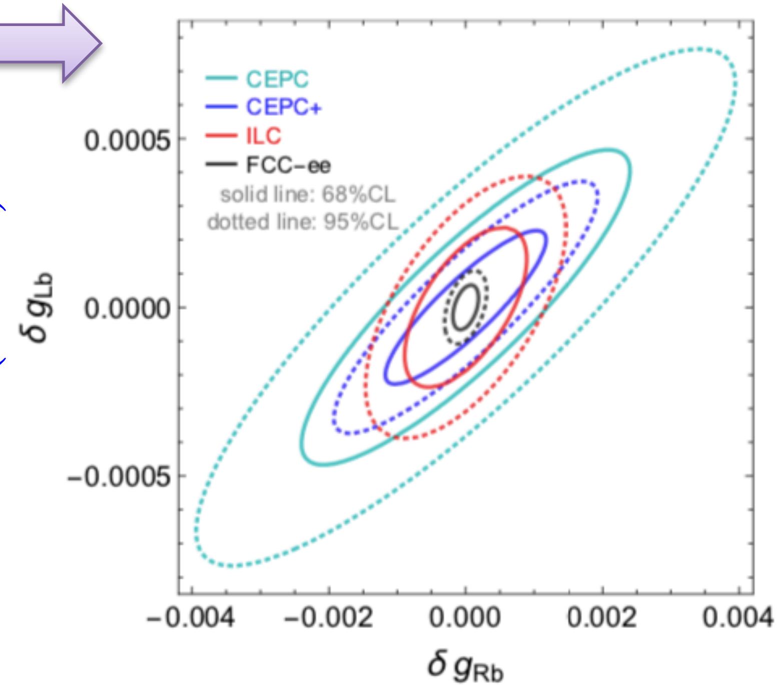
S. Gori, J. Gu, L. T. Wang, JHEP04(2016)062

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



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

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



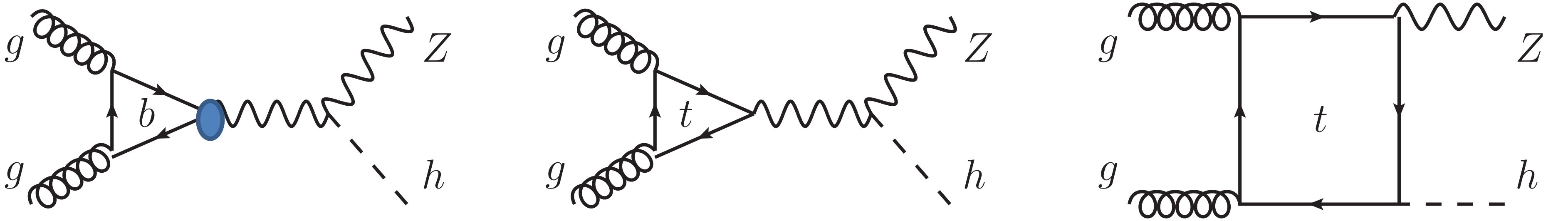
$\mathcal{O}(10^{-3})$

Should we wait for the next generation lepton colliders?

The possibility of LHC and ep colliders (HERA and EIC)?

A. Zbb couplings@LHC

charge conjugation invariance:



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

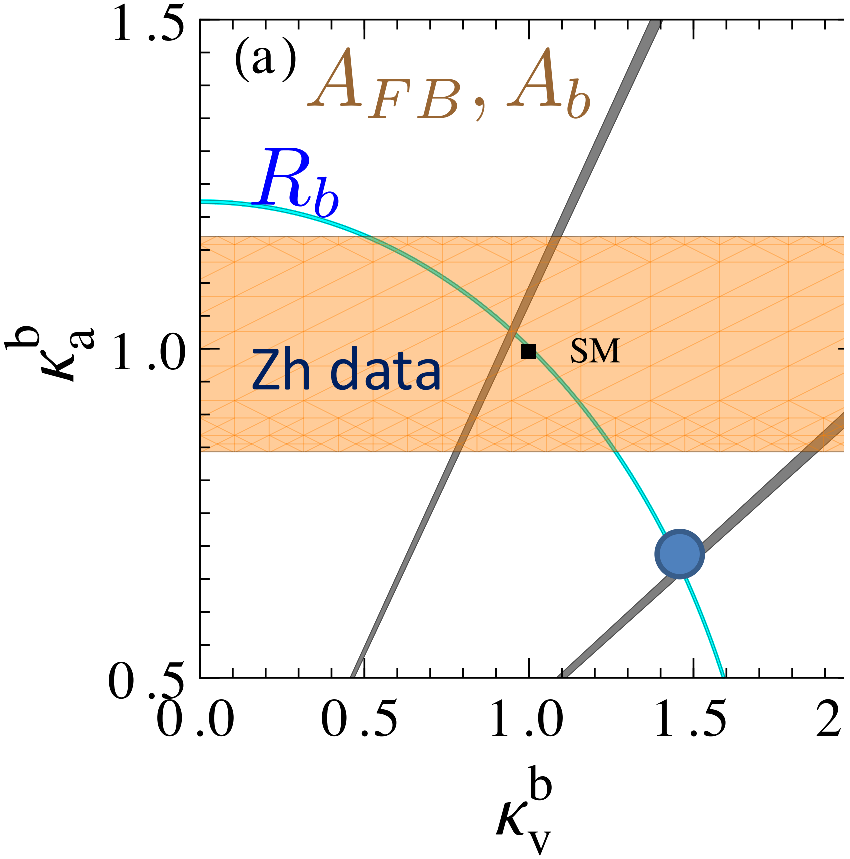
(2) Only top and bottom quark will contribute to the scattering

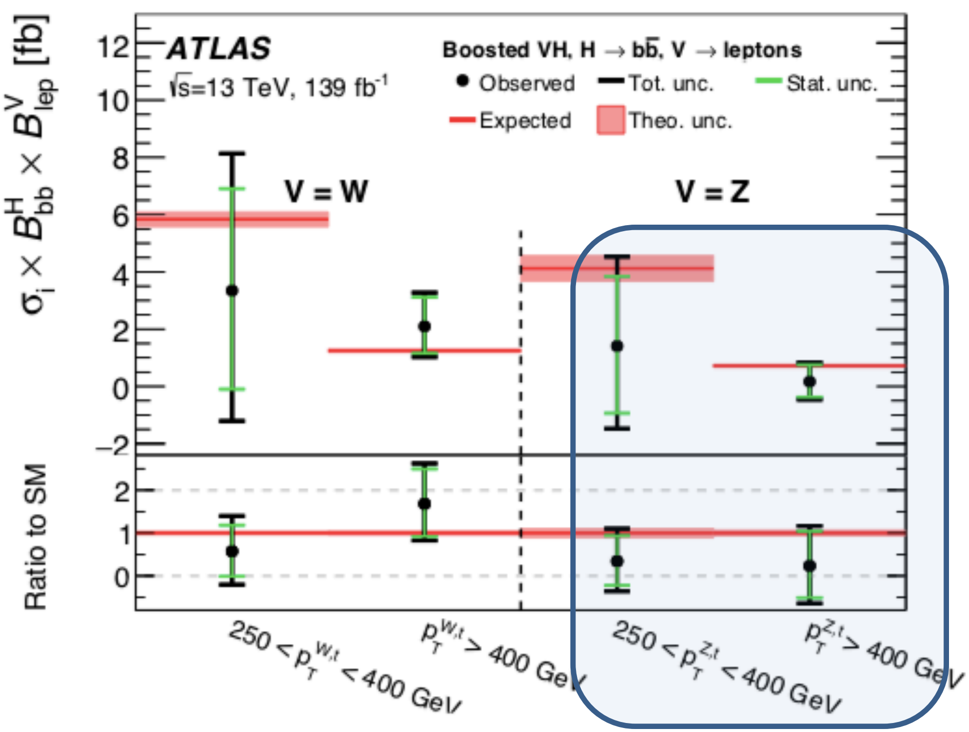
$$\mathcal{L} = \frac{g_W}{2c_W}\bar{b}\gamma_\mu(\kappa_v^b v_b^{\rm SM} - \kappa_a^b a_b^{\rm SM}\gamma_5)bZ_\mu + \frac{m_Z^2}{v}\kappa_Z hZ_\mu Z^\mu$$
$$+ \frac{g_W}{2c_W}\bar{t}\gamma_\mu(\kappa_v^t v_t^{\rm SM} - \kappa_a^t a_t^{\rm SM}\gamma_5)tZ_\mu - \frac{m_t}{v}\kappa_t\bar{t}th, \qquad (1)$$

Break the Zbb coupling degeneracy

Current Zh data could break the degeneracy

ATLAS: 2008.02508



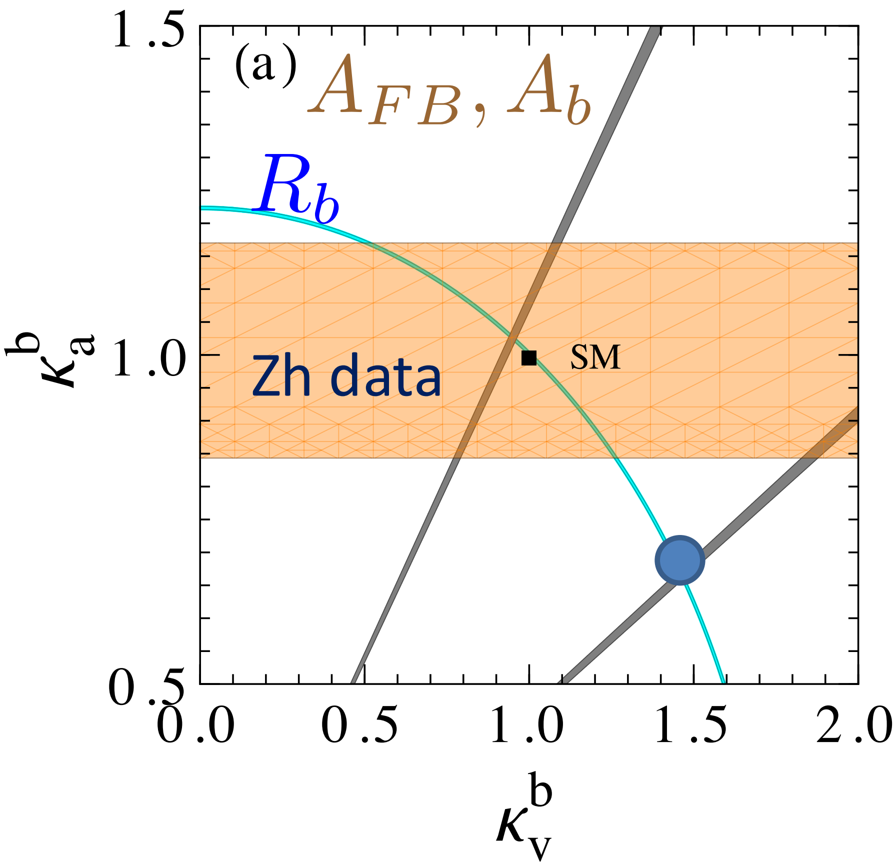


Including all Zh data

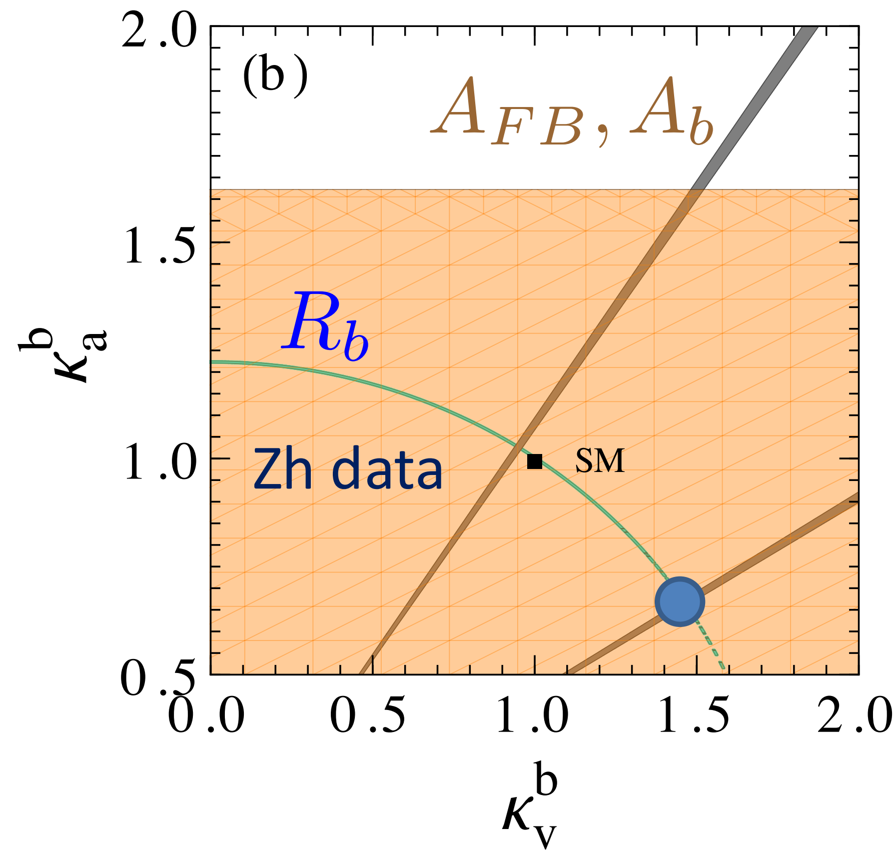
the two high P_T^Z data play an important role

Break the Zbb coupling degeneracy

Current Zh data could break the degeneracy

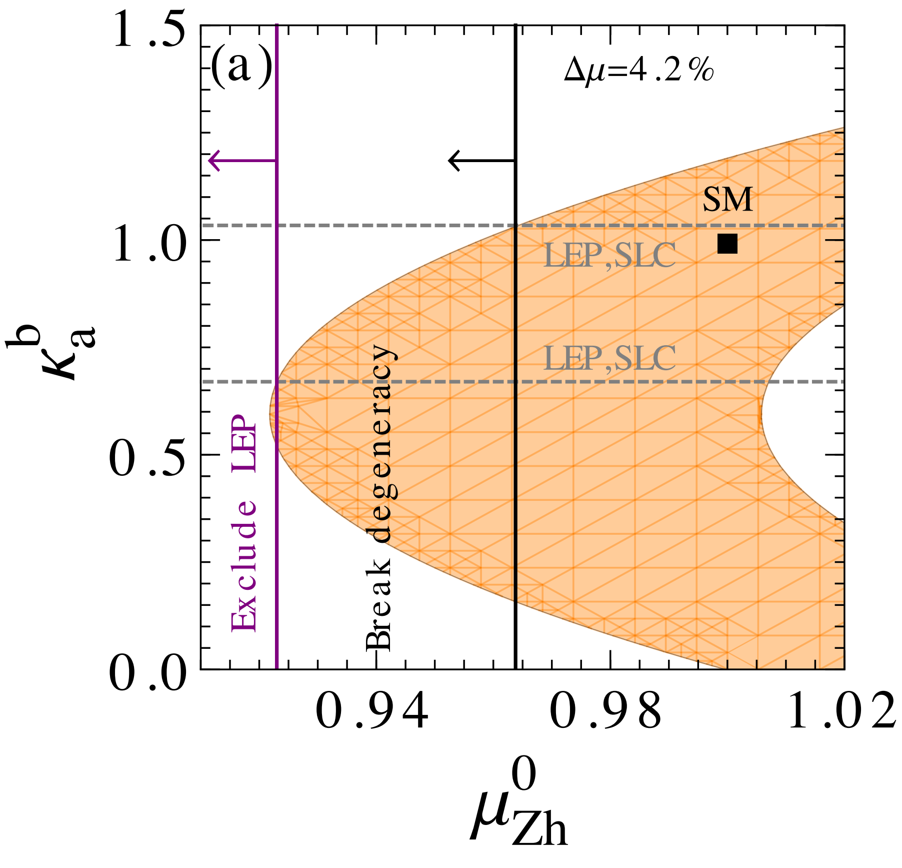


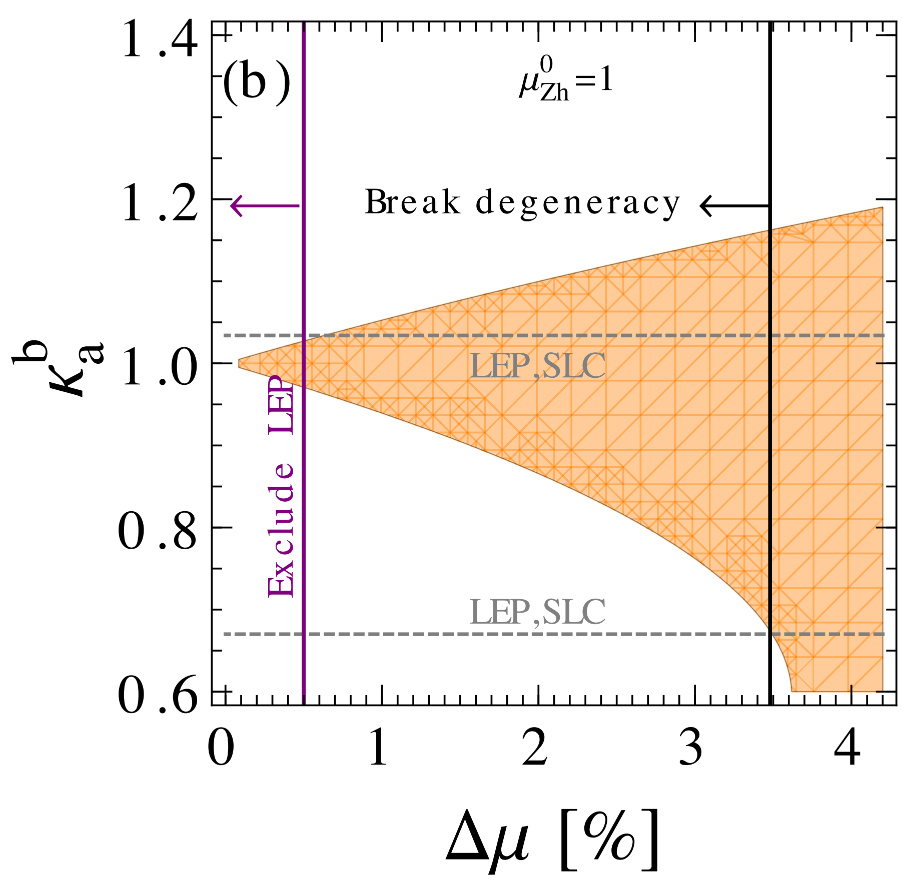
Including all Zh data



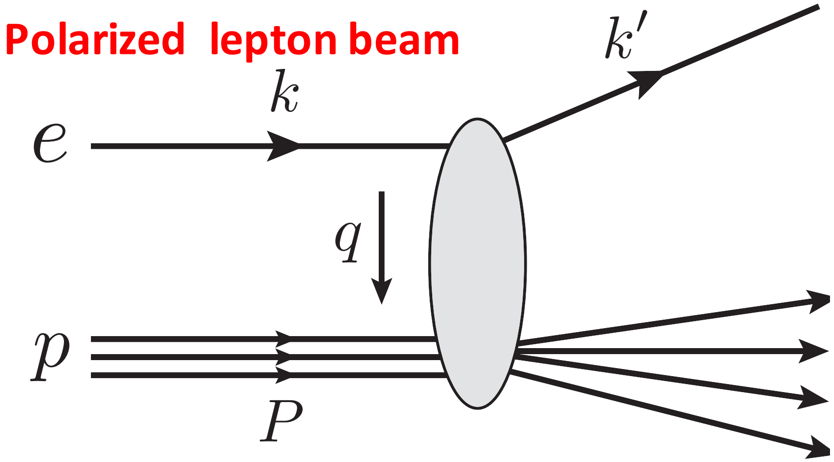
Removing the two high P_T^Z data

Break the Zbb coupling degeneracy





B. Zbb couplings@HERA and EIC



Single-Spin asymmetry (SSA):

$$A_e^b = \frac{\sigma_{b,+}^{\text{tot}} - \sigma_{b,-}^{\text{tot}}}{\sigma_{b,+}^{\text{tot}} + \sigma_{b,-}^{\text{tot}}}$$

+,-: right-handed and left-handed lepton

1. Photon only diagrams will cancel in SSA
2. The leading contribution is from the interference between photon and Z boson
3. It is sensitive to the vector component of the Zbb coupling

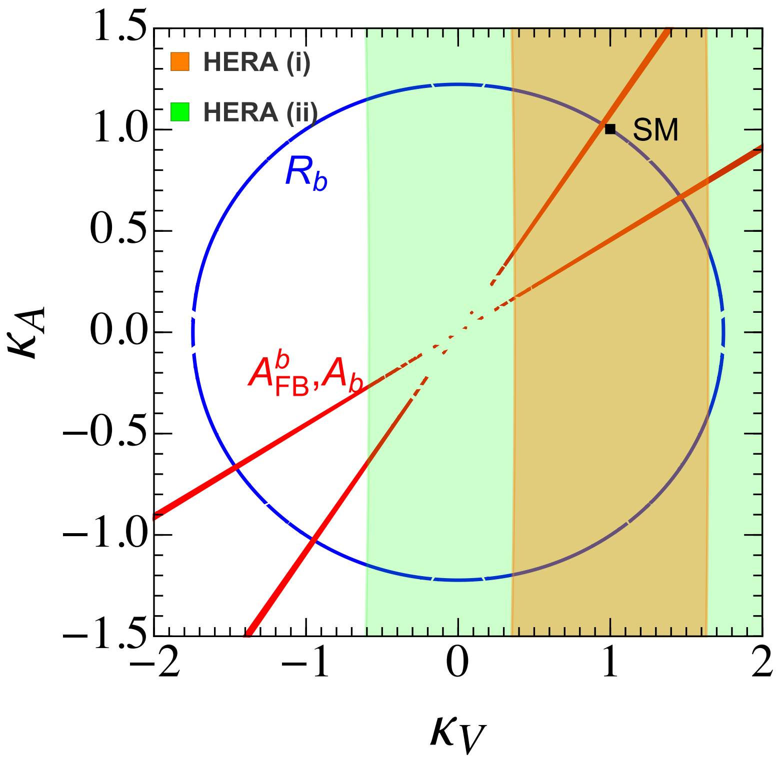
Zbb couplings@HERA

H1	R	L
e^-p	$47.3\,\mathrm{pb}^{-1}$, 0.36	$104.4\,\mathrm{pb}^{-1}$, −0.258
e^+p	$101.3\,\mathrm{pb}^{-1}$, 0.325	$80.7\,\mathrm{pb}^{-1}$, −0.37
ZEUS	R	L
e^-p	$71.2\,\mathrm{pb}^{-1}$, 0.29	$98.7\,\mathrm{pb}^{-1}$, −0.27
e^+p	$78.8\,\mathrm{pb}^{-1}$, 0.32	$56.7\,\mathrm{pb}^{-1}$, −0.36

JHEP 09, 061 (2012)

Eur. Phys. J. C 62, 625 (2009)

Phys. Rev. D 87, 052014 (2013)



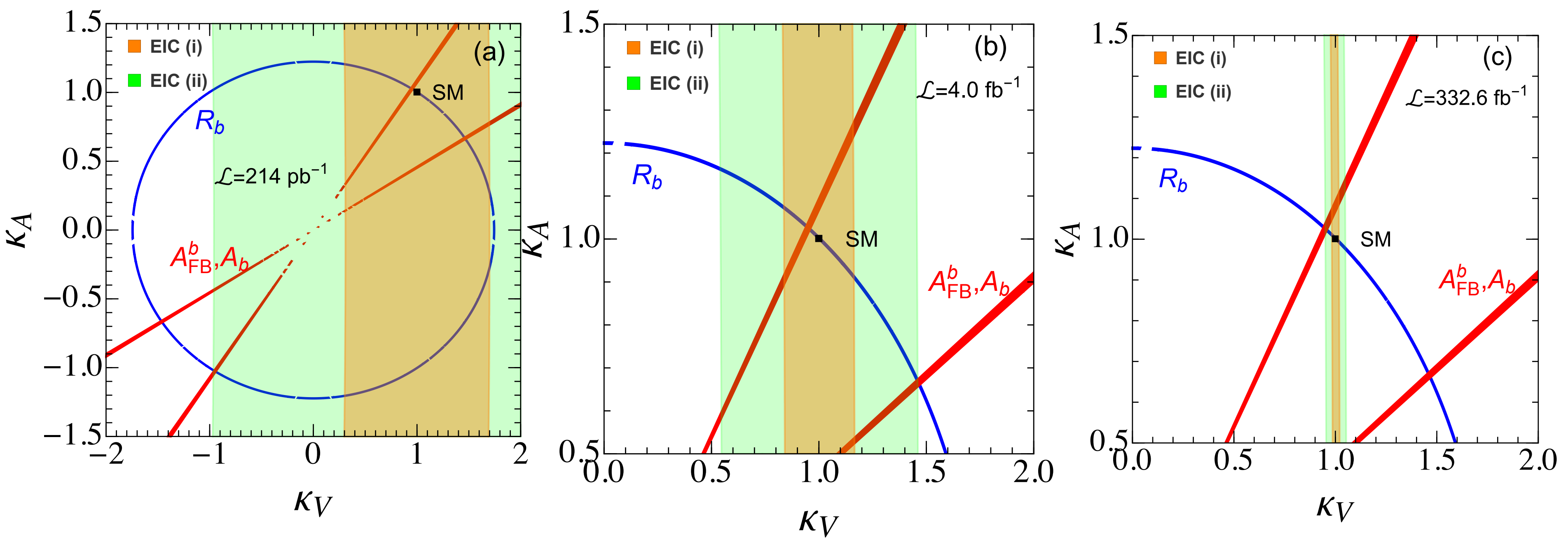
Simplified-ACOT-chi scheme@NNLO

$$(i)\ \epsilon_q^b = 0.001, \quad \epsilon_c^b = 0.03, \quad \epsilon_b = 0.7;$$
$$(ii)\ \epsilon_q^b = 0.01, \quad \epsilon_c^b = 0.2, \quad \epsilon_b = 0.5.$$

1. The SSA is sensitive to κ_V
2. $\kappa_{V,A} < 0$ could be excluded by HERA data
3. It could be used to crosscheck the off-Z-pole data

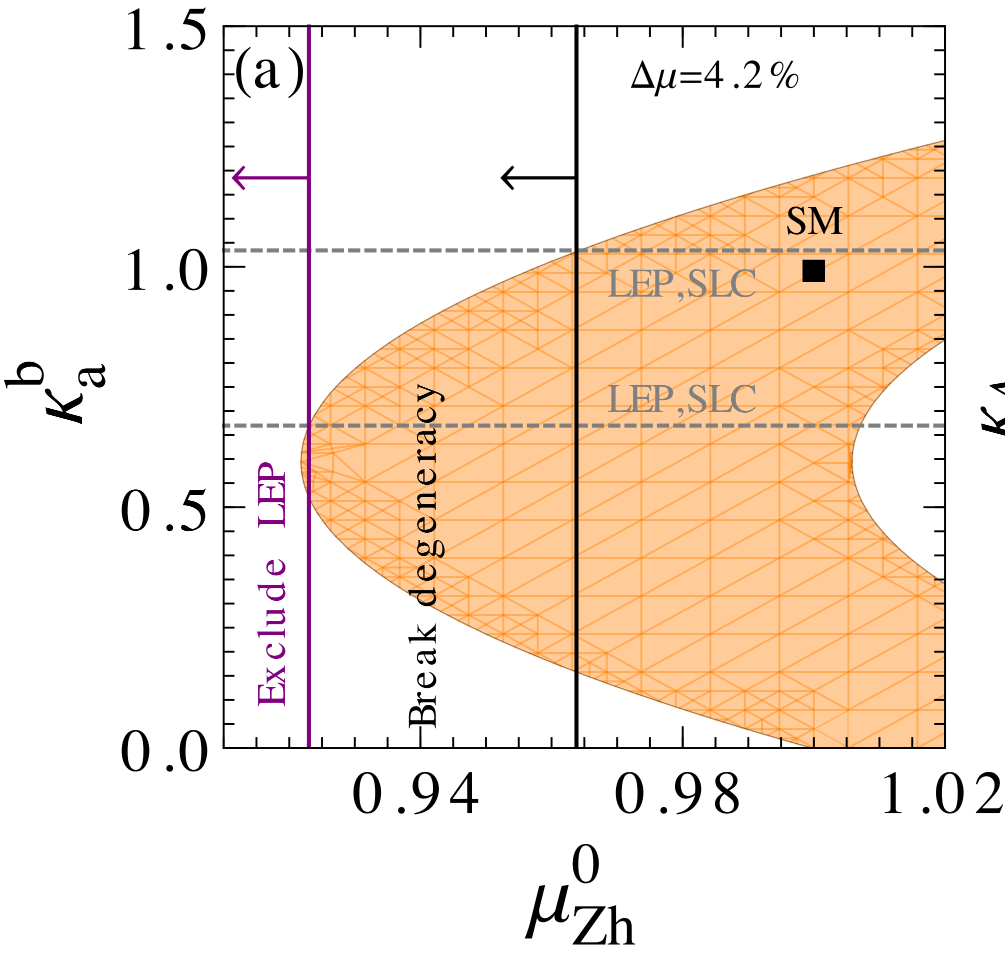
Zbb couplings@EIC

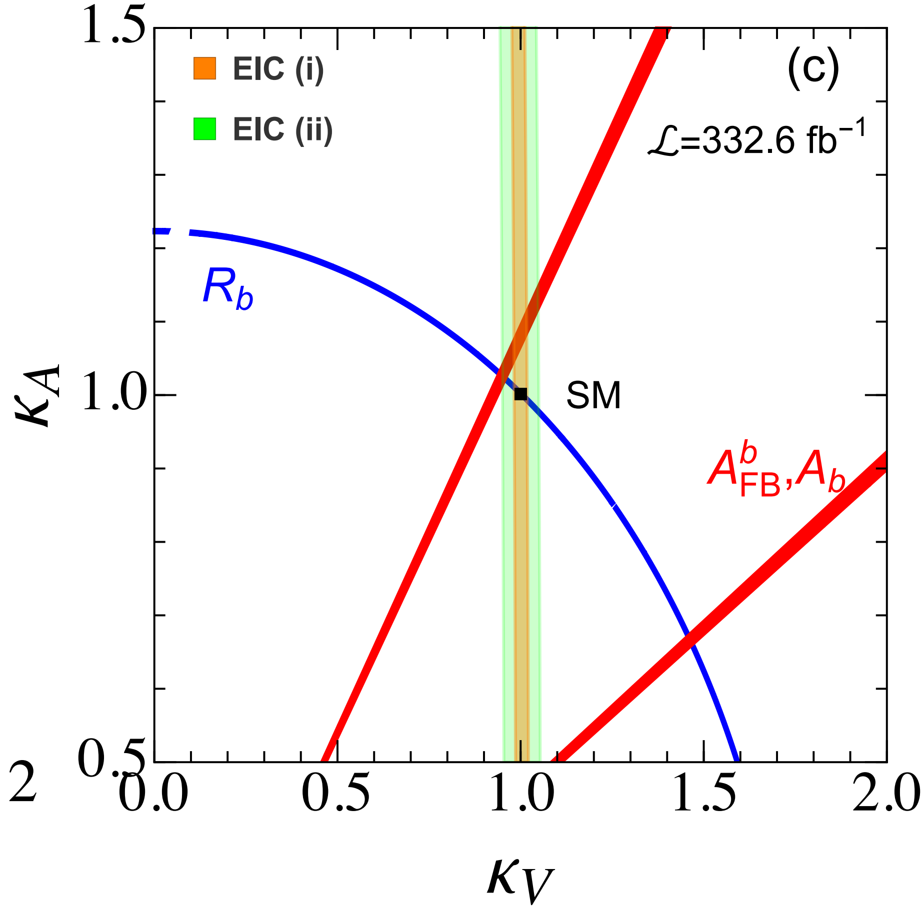
$$E_{\rm cm} = 141 \text{ GeV}, P_e = 0.7$$



$(i) : \mathcal{L} > 27 \text{ pb}^{-1};$	$(i) : \mathcal{L} > 0.5 \text{ fb}^{-1};$	$(i) : \mathcal{L} > 42.0 \text{ fb}^{-1};$
$(ii) : \mathcal{L} > 214 \text{ pb}^{-1}.$	$(ii) : \mathcal{L} > 4.0 \text{ fb}^{-1}.$	$(ii) : \mathcal{L} > 332.6 \text{ fb}^{-1}.$

LHC vs. EIC





LHC: axial vector component of Zbb coupling

EIC: vector component of Zbb coupling

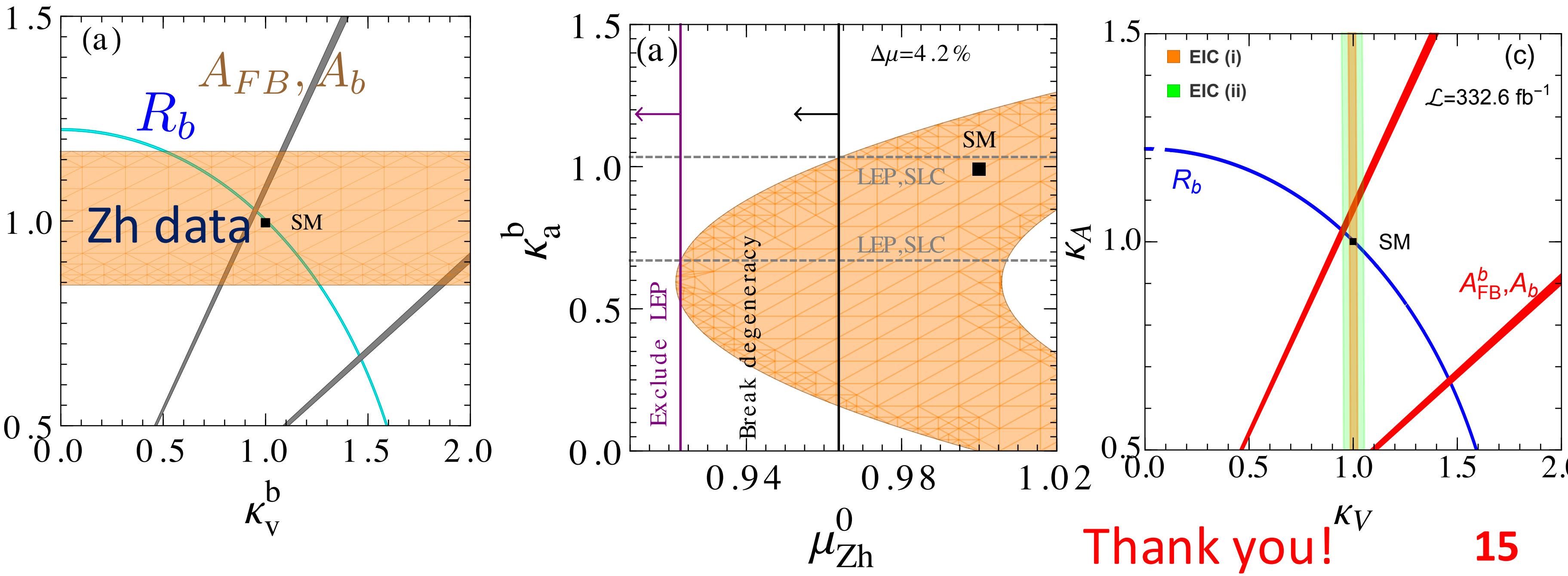
Summary

A. We proposed two new methods to probe the Zbb coupling at the LHC and ep colliders

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

C. Zh cross section depends on the axial-vector Zbb coupling, while the SSA in HERA and EIC is sensitive to the vector Zbb coupling ;

D. It is hopeful to verify or exclude the LEP measurement by those new methods.



Thank you!