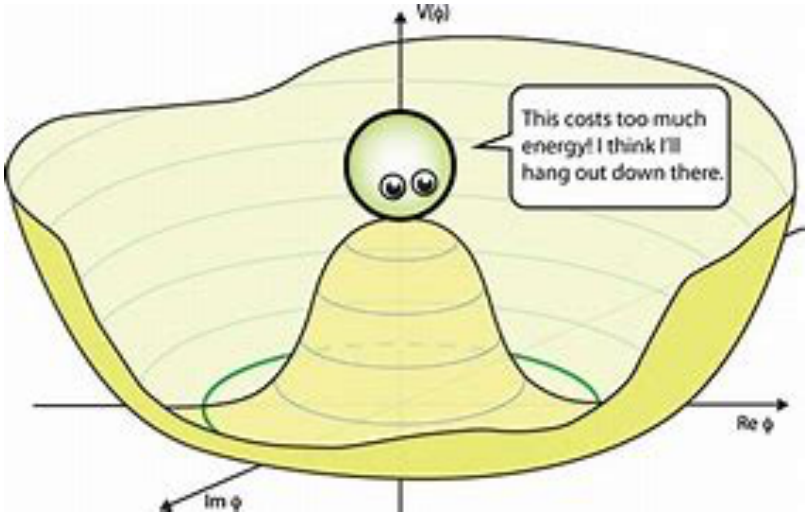
Probing the electroweak symmetry breaking with Higgs production at the LHC

Bin Yan
Los Alamos National Laboratory

Higgs potential and BSM opportunity
Aug 27-31, 2021

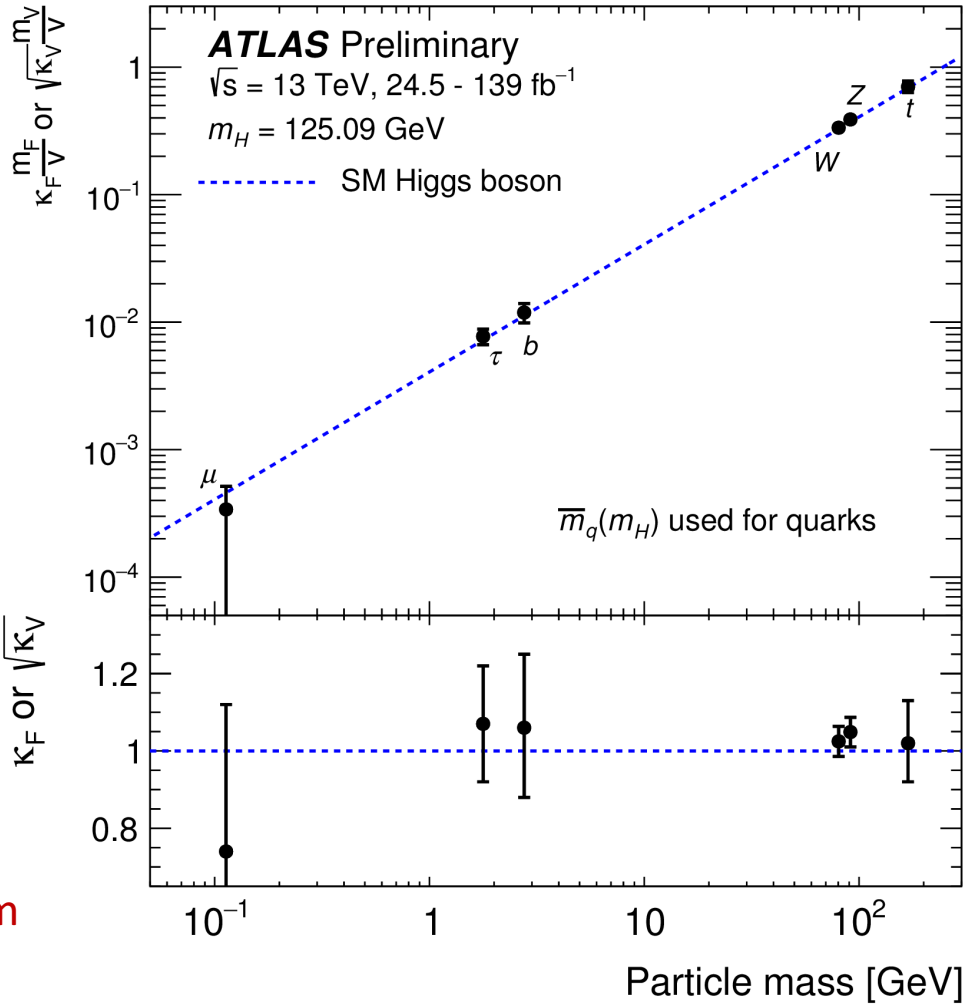
K. P. Xie and Bin Yan, PLB820(2021)136515

Higgs couplings and EWSB

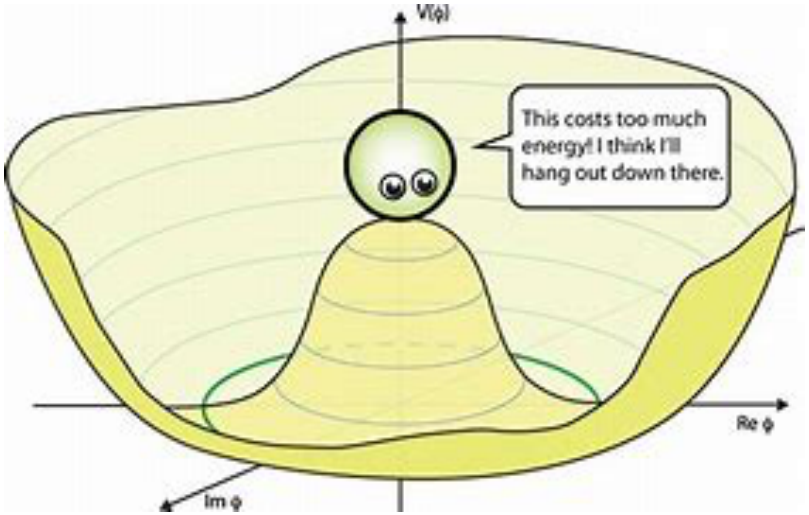


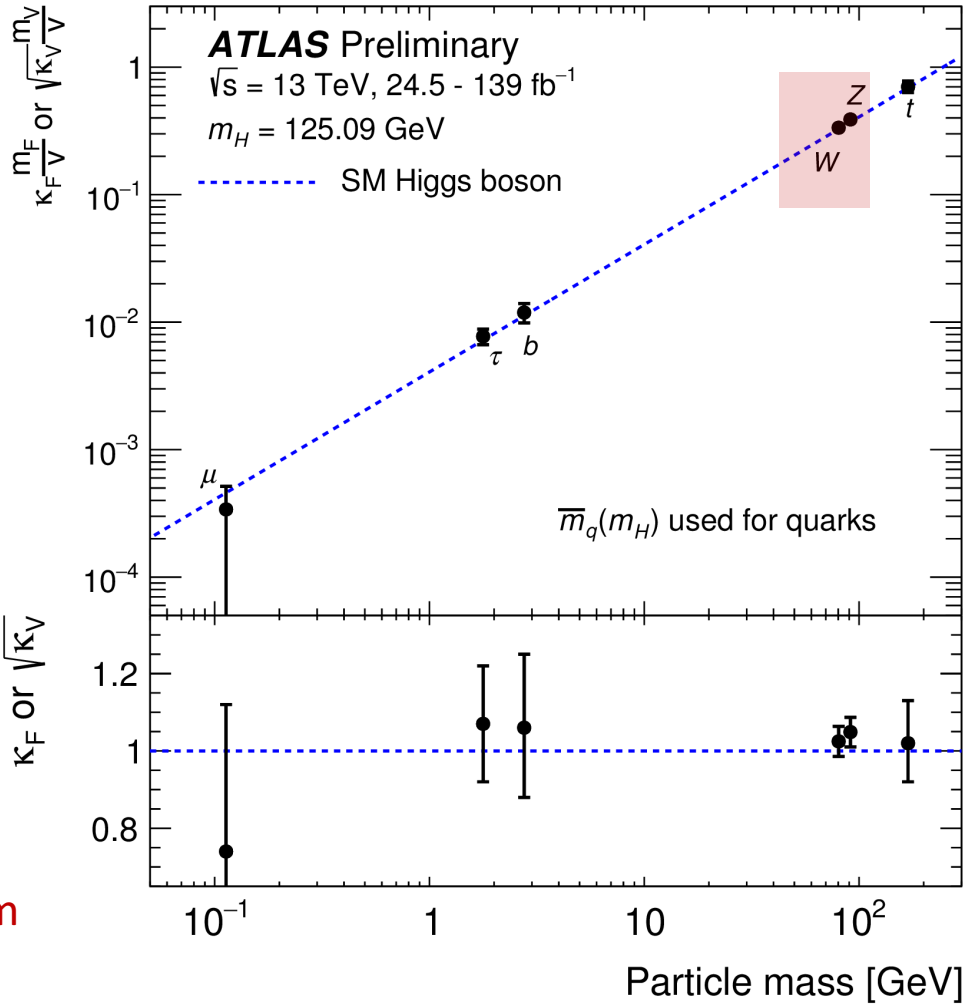
Higgs mechanism

All fundamental particles get their mass from Higgs boson vev



Higgs couplings and EWSB





Higgs mechanism

All fundamental particles get their mass from Higgs boson vev

Higgs couplings and EWSB

$$\mathcal{L}_{hVV} = \kappa_W g^{\rm SM}_{hWW} h W^+_\mu W^{-\mu} + \frac{\kappa_Z}{2} g^{\rm SM}_{hZZ} h Z_\mu Z^\mu,$$

$$g^{\rm SM}_{hVV} = 2m^2_V/v \qquad\qquad \lambda_{WZ} \equiv \frac{\kappa_W}{\kappa_Z}$$

To verify the EWSB, we need to determine:

(1)The magnitude of the Higgs couplings

(2) The relative size between hWW and hZZ couplings

Higgs couplings and New Physics

$$\mathcal{L}_{hVV} = \kappa_W g^{\rm SM}_{hWW} h W^+_\mu W^{-\mu} + \frac{\kappa_Z}{2} g^{\rm SM}_{hZZ} h Z_\mu Z^\mu,$$

(1) The magnitude of Higgs couplings @NP

For example:

Q. H. Cao, L. X. Xu, Bin Yan and S. H. Zhu, PLB789(2019)233-237

Composite Higgs models

$$\kappa_W = \kappa_Z = \sqrt{1-\xi}, \quad \xi = \frac{v^2}{2f^2}$$

(2) The negative relative sign of Higgs couplings @NP

I. Low, J. Lykken, JHEP10(2010)053

It depends on the custodial representation of Higgs.

$\lambda_{WZ} < 0$ e.g. fiveplet in Georgi-Machacek model

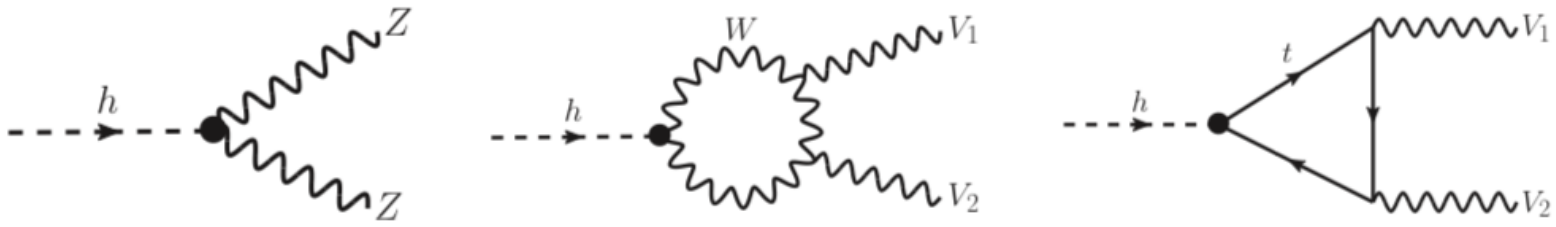
So…

How to fix the relative sign between hWW and hZZ couplings

EWSB@LHC and lepton colliders

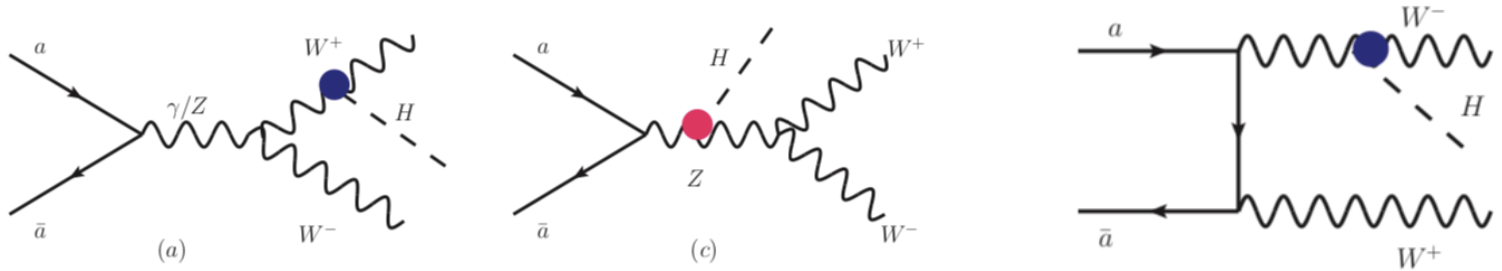
Y. Chen, M. Spiropulu, D. Stolarski and R. V. Morales, PRL117(2016)24,241801

LHC:

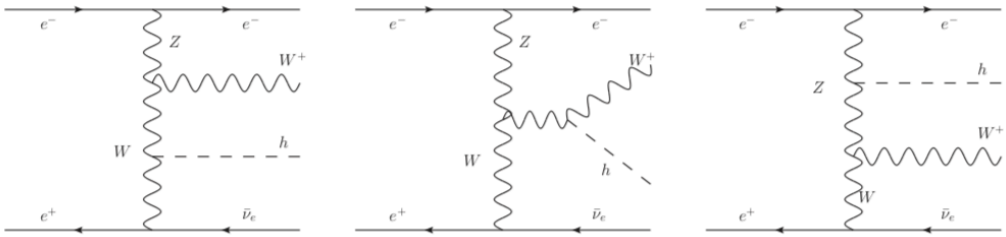


Lepton colliders:

C.W Chiang, X. G. He and G. Li, JHEP08(2018) 126

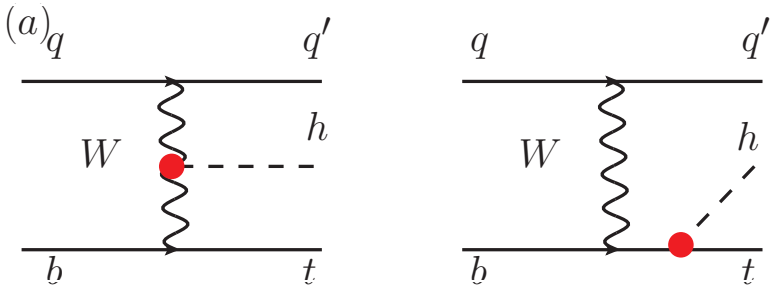


D. Stolarski and Y. Wu, PRD102(2020)3,033006



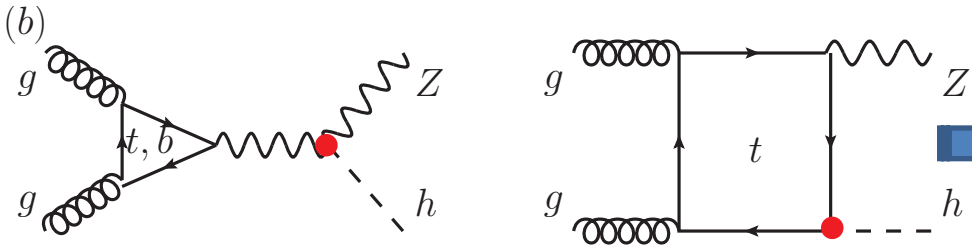
th and Zh production

K. P. Xie and Bin Yan, PLB820(2021)136515



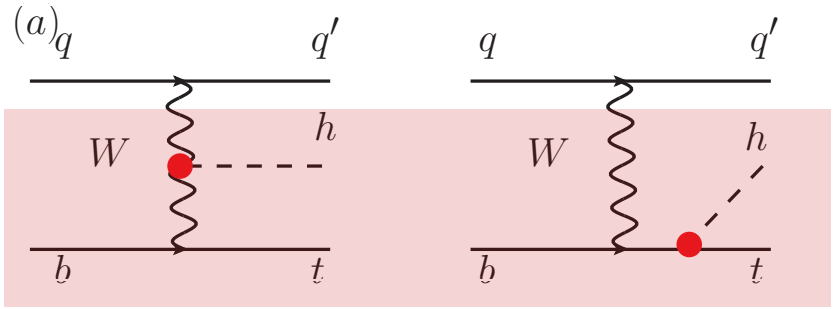
Cross section is sensitive to the relative sign between htt and hWW

Top quark Yukawa coupling as a bridge



Cross section is sensitive to the relative sign between htt and hZZ

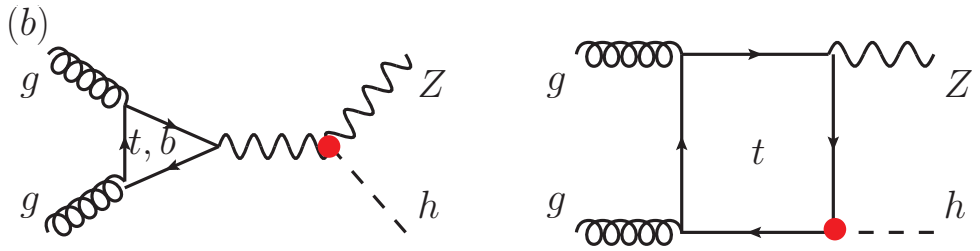
High Energy behavior



relative sign between htt and hWW

$$bW^{\mu} \to ht$$

$$M \sim \bar{u}(t)\left[m_t(\kappa_t - \kappa_W) + \left(\frac{2m_W^2}{u}\kappa_W + \frac{m_t^2}{s}\kappa_t\right)\not{p}_W\right]P_L u(b)$$



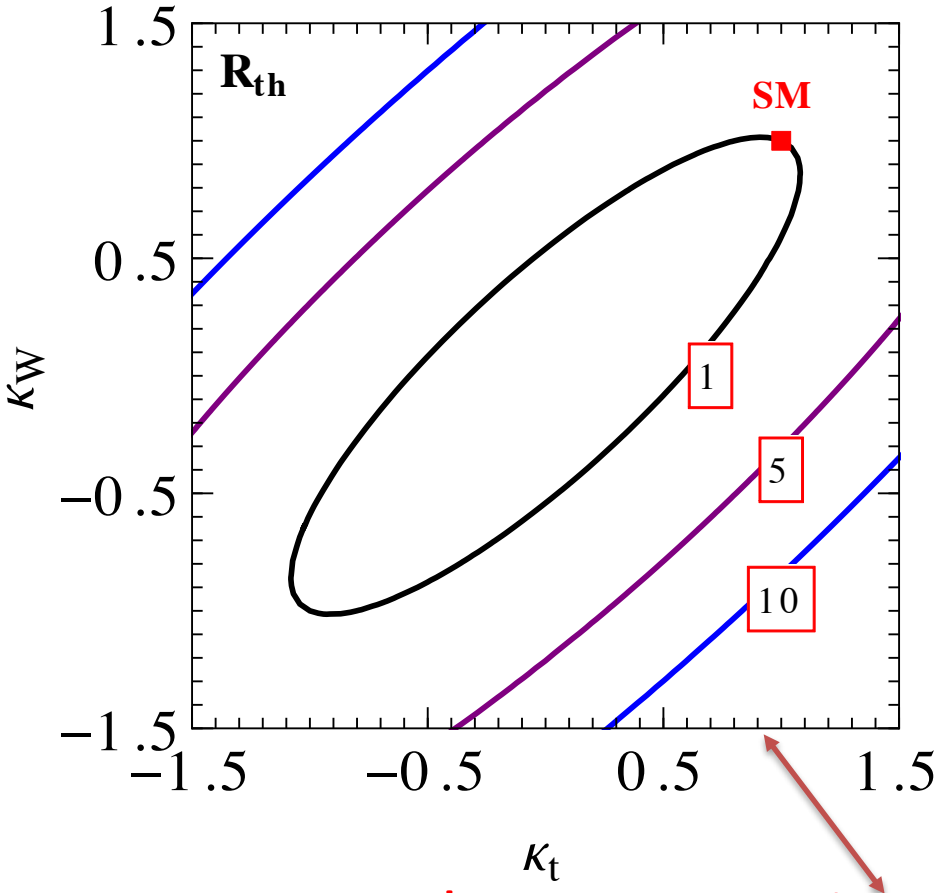
relative sign between htt and hZZ

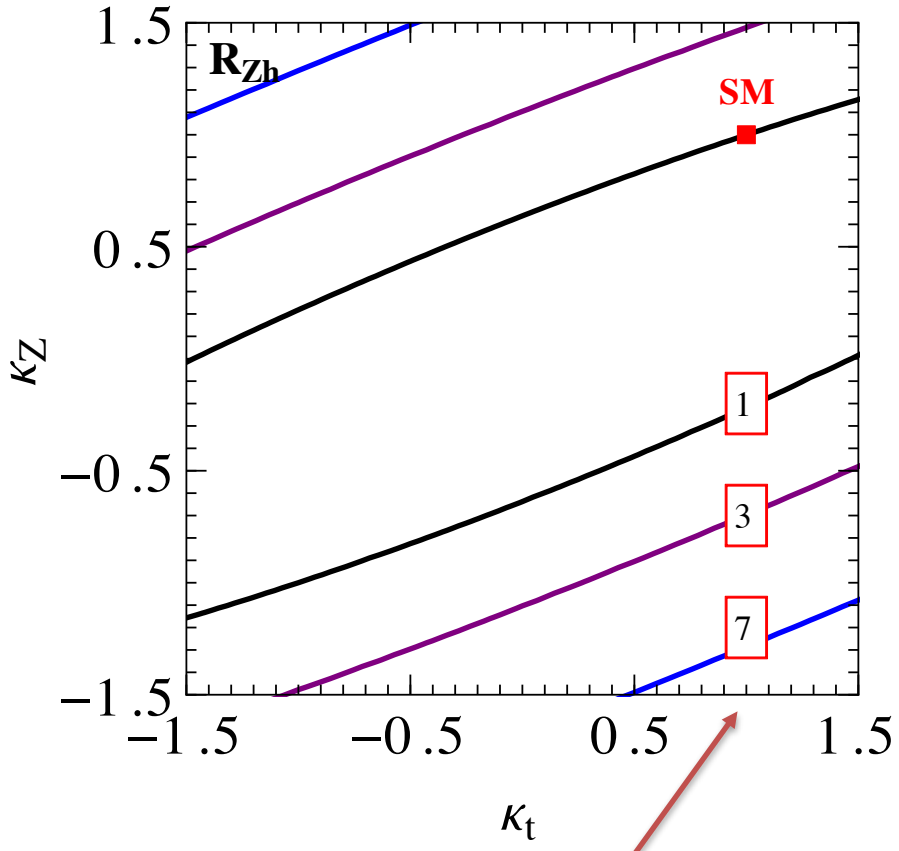
$$M_{\pm,\pm,0} \sim \frac{m_t^2}{m_Z^2}(\kappa_Z - \kappa_t)\log^2\left(-\frac{s}{m_t^2}\right)$$

Cross sections@ 13 TeV LHC

$$R_{th} = \frac{\sigma(pp \to th)}{\sigma^{\rm SM}(pp \to th)}$$

$$R_{Zh} = \frac{\sigma(gg \to Zh)}{\sigma^{\rm SM}(gg \to Zh)}$$

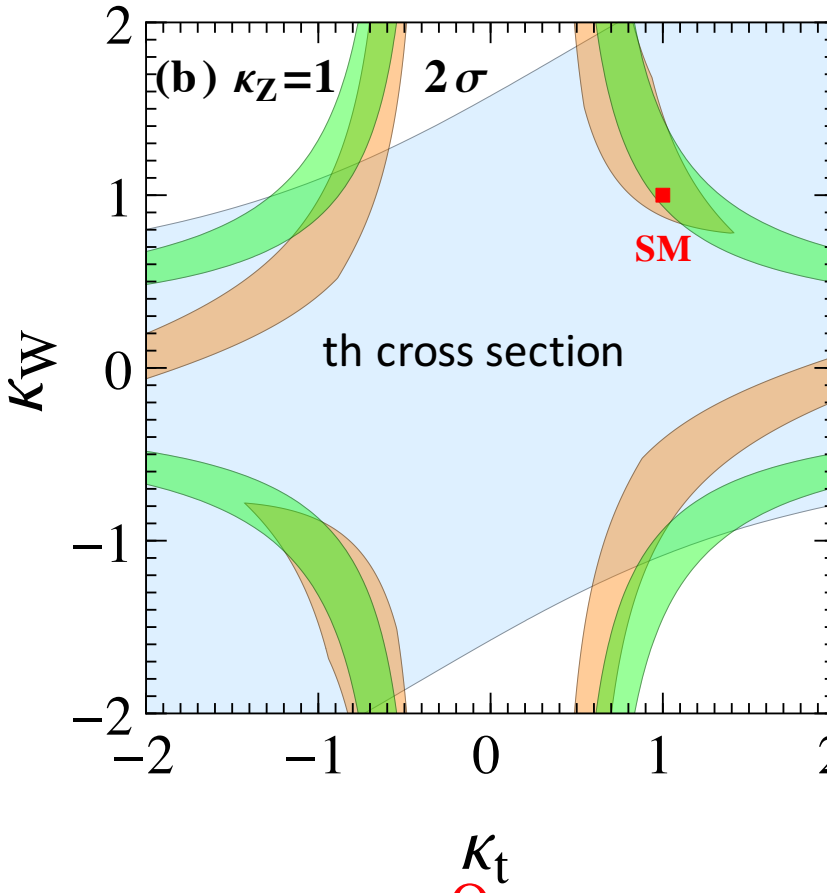




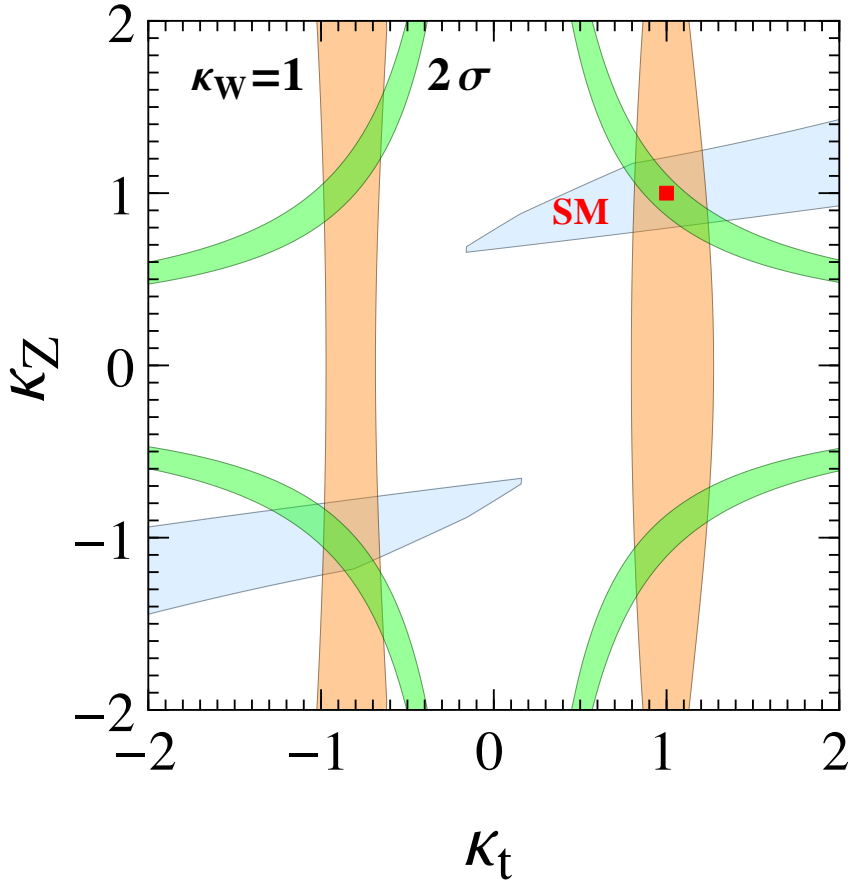
The cross sections will be large enhanced

Limits from current LHC

Orange: tth
Green: ggF, h->WW
Blue: th



Orange: tth cross section
Green: ggF, h->ZZ
Blue: Zh

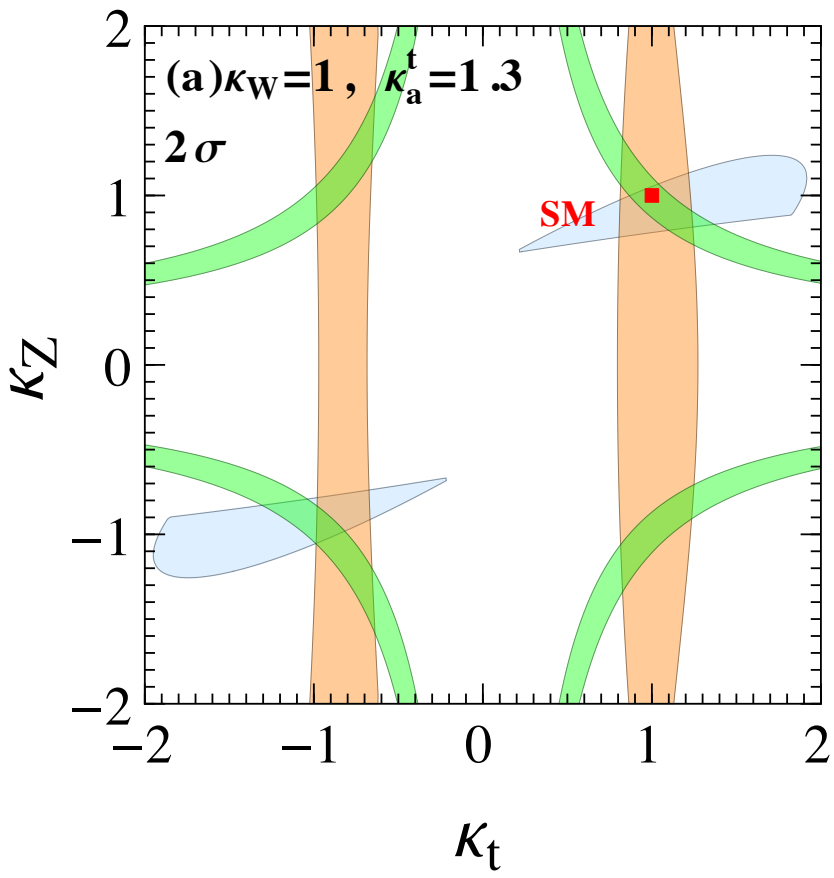


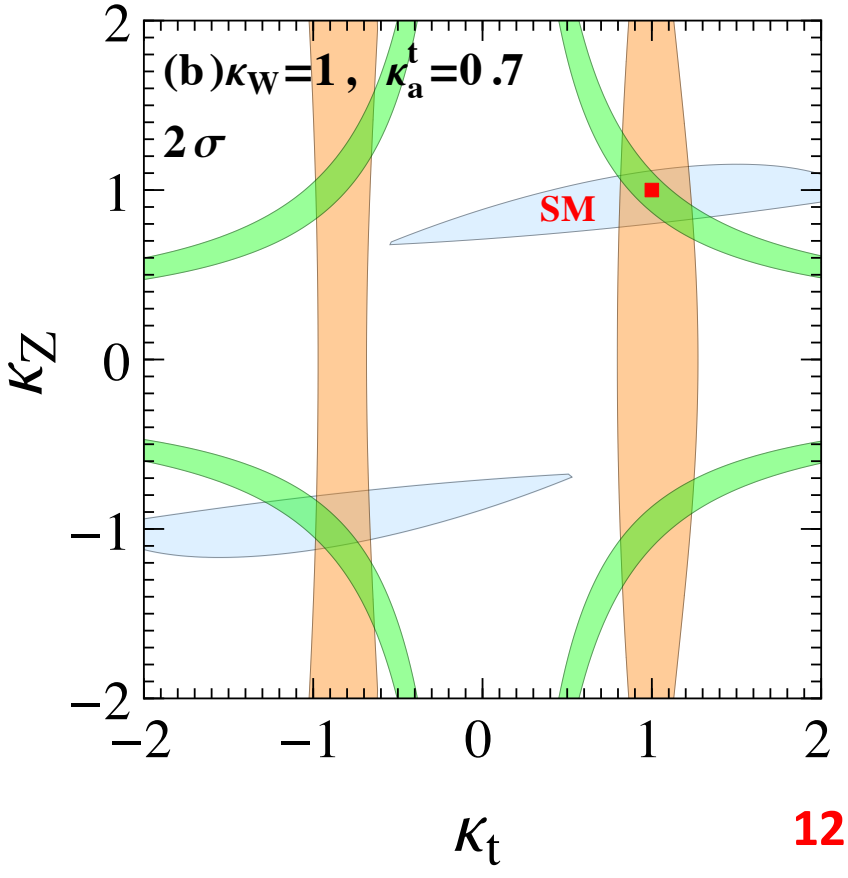
$\kappa_t \kappa_W < 0$ Excluded by current data $\kappa_t \kappa_Z < 0$

Limits from current LHC

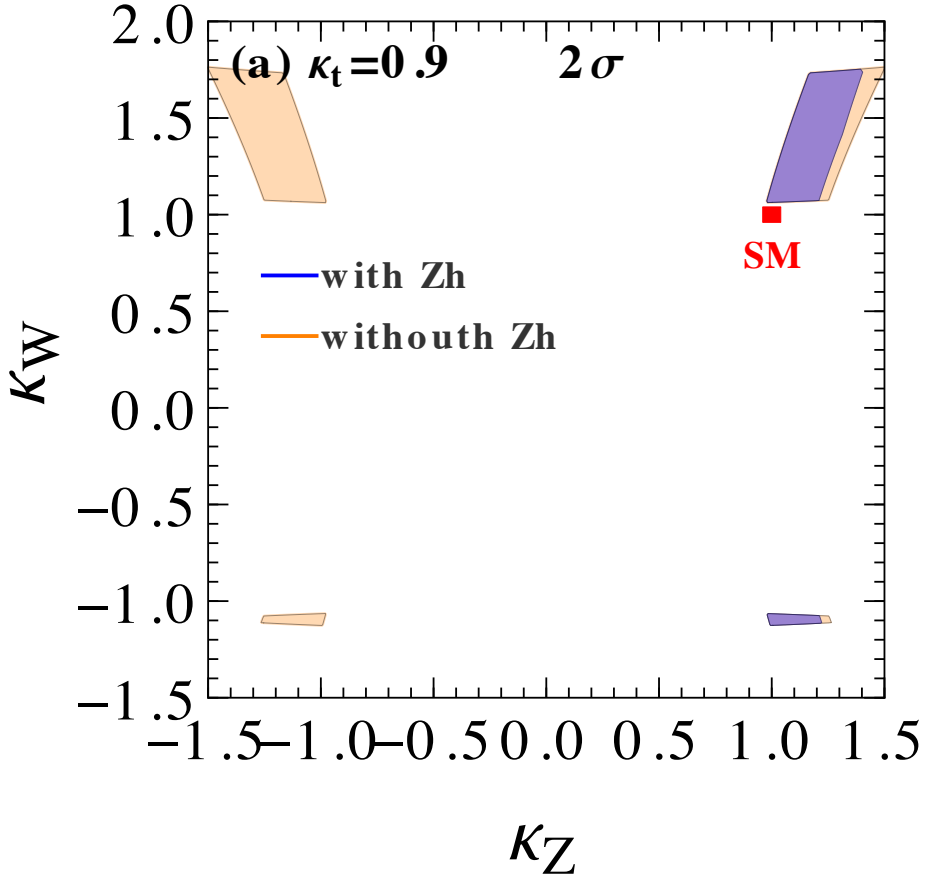
$\kappa_t \kappa_Z < 0$ was excluded by current data is not sensitive to the assumption of Ztt coupling

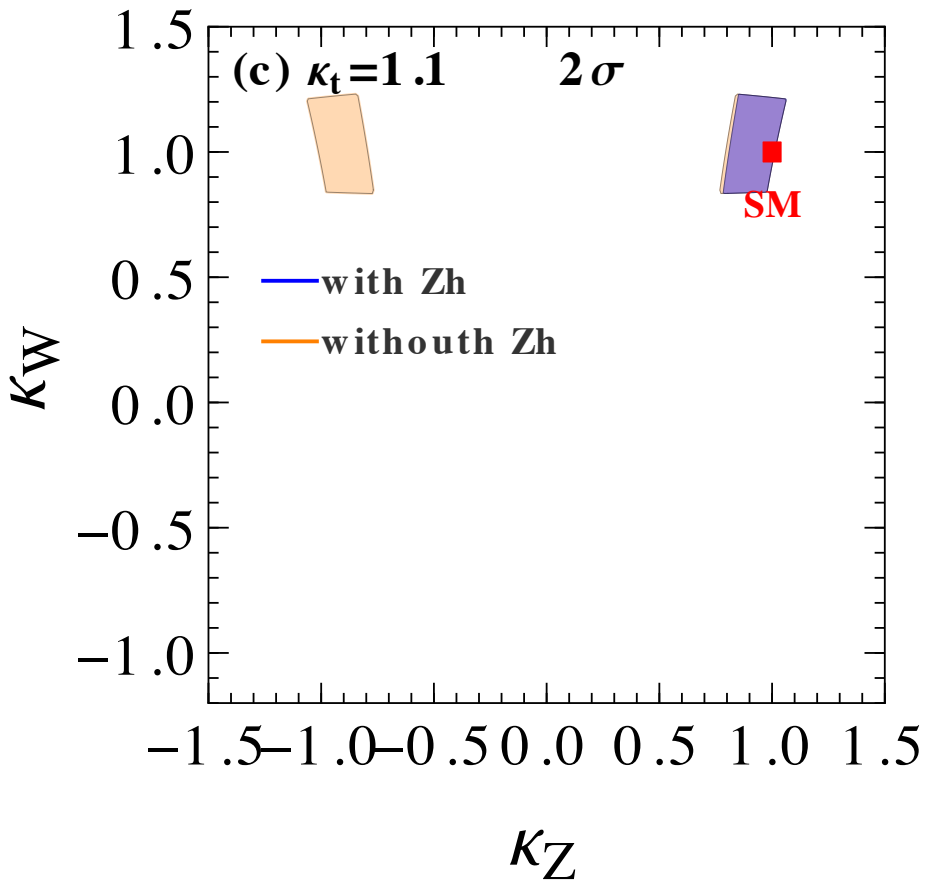
Orange: tth cross section
Green: ggF, h->ZZ
Blue: Zh





Limits from current LHC



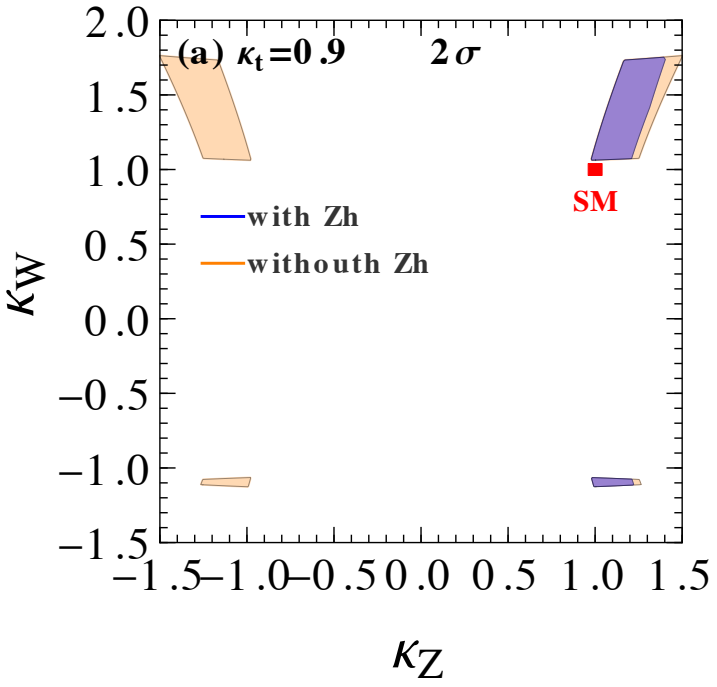


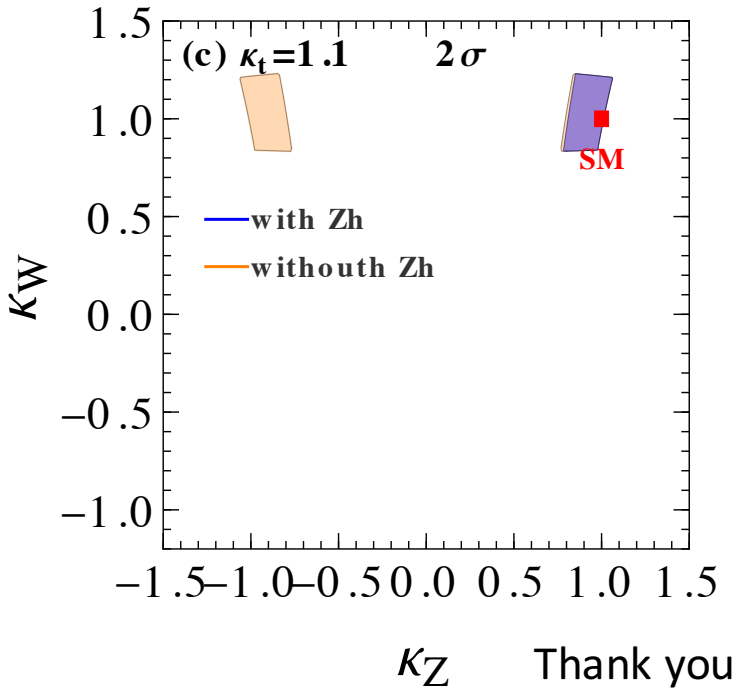
Summary

A. We proposed a new method to pin down the relative sign between hWW and hZZ couplings, which is a key part to verify the EWSB;

B. Combing th and Zh data at the 13 TeV LHC, the data favors the same sign of hWW and hZZ couplings.

C. This conclusion is not sensitive to the other possible new physics in Zh production.





Thank you!