the short summary

Probing anomalous ZZH/WWH couplings at the ILC

21th, October, 2021, T.Ogawa
on behalf of the ILD collaboration and ILC-IDT-WG3

Effective Field Theory (EFT) and anomalous ZZH/WWH at the ILC

-. Model independent test of the gauge-Higgs sector based on SMEFT Lagrangian consist of dim-6 operators. "Warsaw" basis, SU2xU1 gauge invariant, Lorentz invariant

After SSB,

T. Barklow et al., PRD 97, 053004 (2018)

$$\Delta\mathscr{L}_h = -\eta_h\lambda_0 v_0 h^3 + \frac{\theta_h}{v_0} h\partial_\mu h\partial^\mu h \quad \longleftarrow \text{(Higgs)}$$

$$+\eta_Z \frac{m_Z^2}{v_0} Z_\mu Z^\mu h + \frac{1}{2}\eta_{2Z}\frac{m_Z^2}{v_0^2} Z_\mu Z^\mu h^2 \quad \longleftarrow \text{(same structure with the SM)}$$

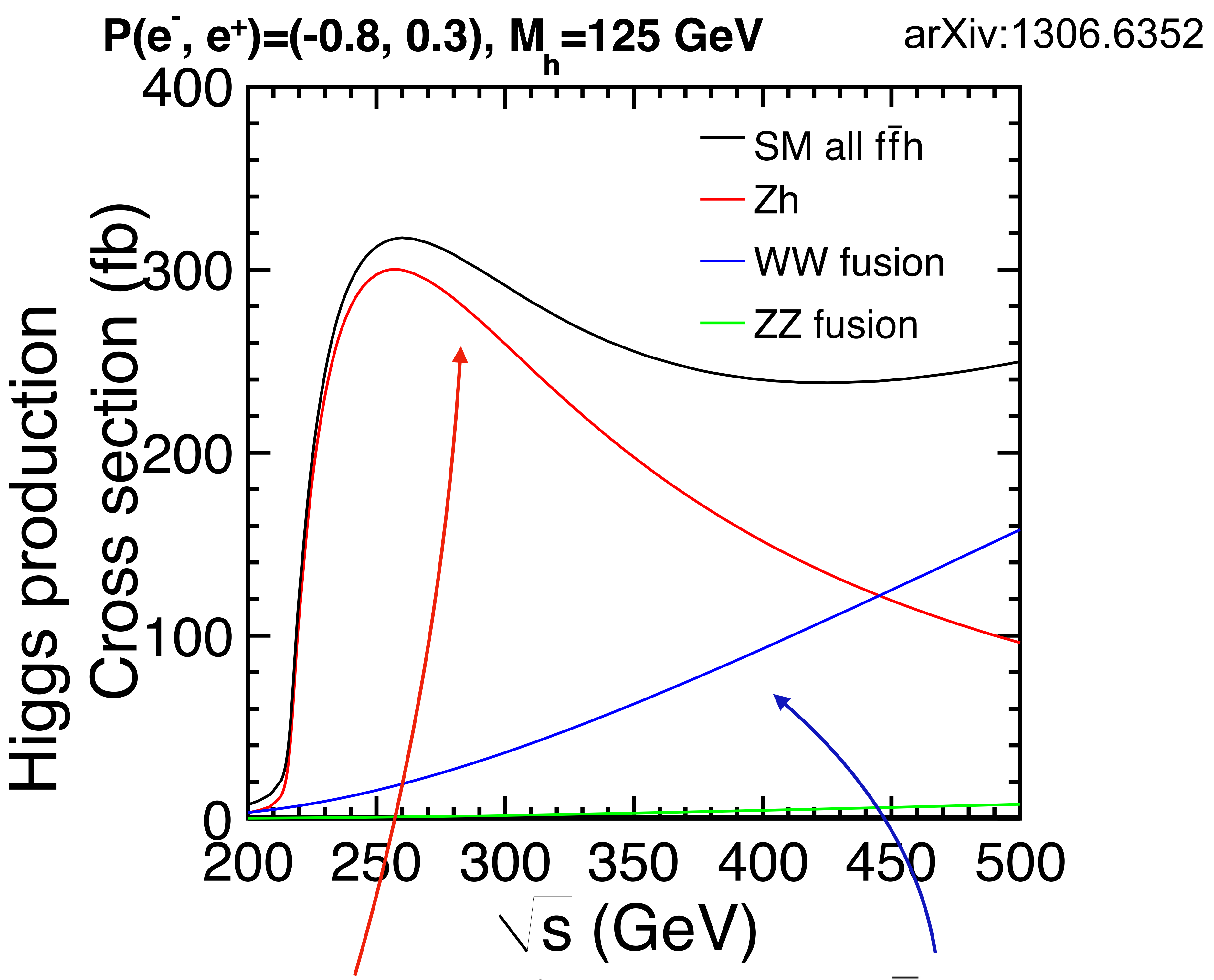
$$+\eta_W \frac{2m_W^2}{v_0} W_\mu^+ W^{-\mu} h + \eta_{2W}\frac{m_W^2}{v_0^2} W_\mu^+ W^{-\mu} h^2$$

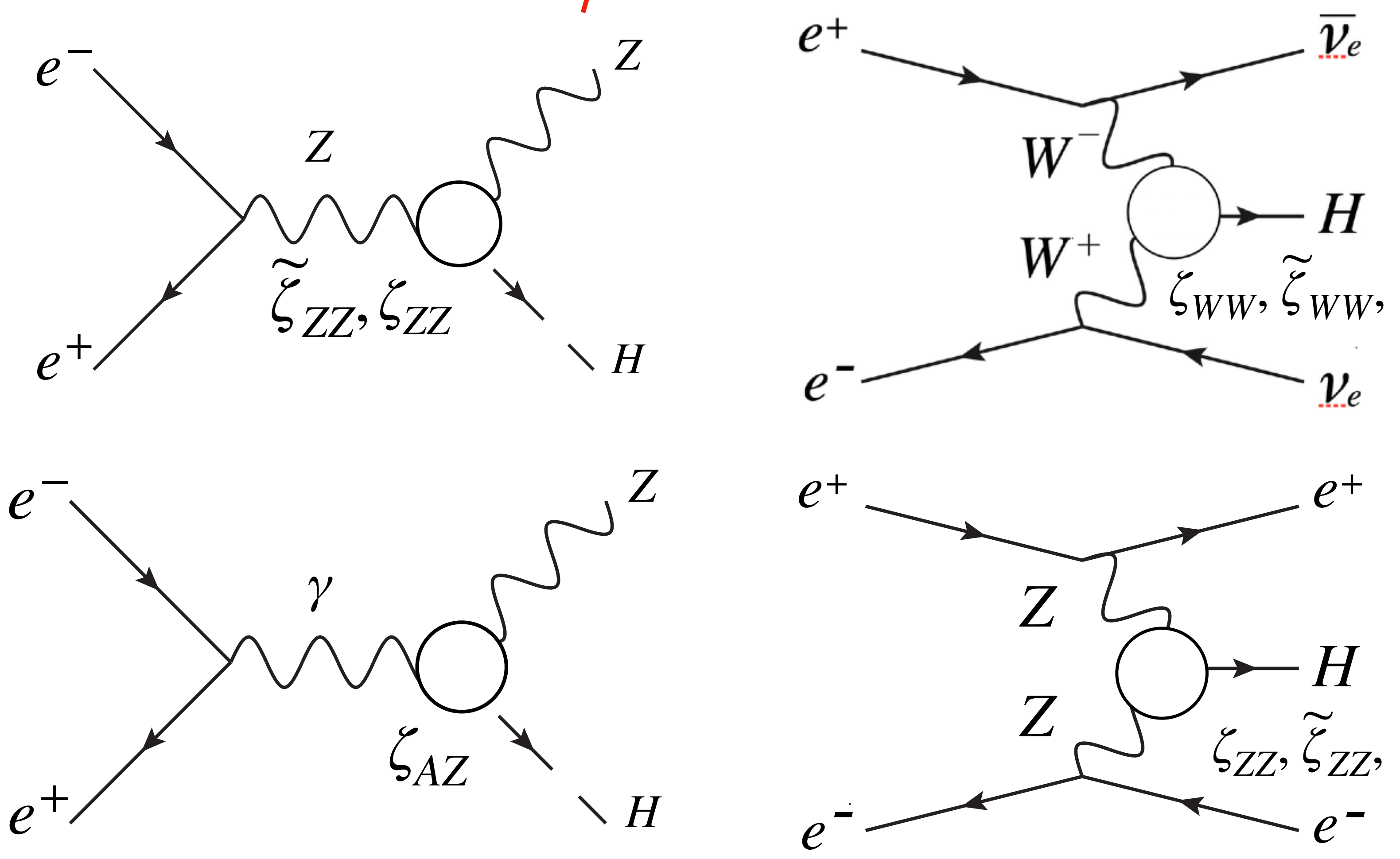
(new tensor structures)

$$+\frac{1}{2}\left(\zeta_{ZZ}\frac{h}{v_0} + \frac{1}{2}\zeta_{2Z}\frac{h^2}{v_0^2}\right)\hat{Z}_{\mu\nu}\hat{Z}^{\mu\nu} + \left(\zeta_{WW}\frac{h}{v_0} + \frac{1}{2}\zeta_{2W}\frac{h^2}{v_0^2}\right)\hat{W}_{\mu\nu}^+\hat{W}^{-\mu\nu}$$

$$+\frac{1}{2}\left(\zeta_{AA}\frac{h}{v_0} + \frac{1}{2}\zeta_{2A}\frac{h^2}{v_0^2}\right)\hat{A}_{\mu\nu}\hat{A}^{\mu\nu} + \left(\zeta_{AZ}\frac{h}{v_0} + \zeta_{2AZ}\frac{h^2}{v_0^2}\right)\hat{A}_{\mu\nu}\hat{Z}^{\mu\nu}$$

$$+\frac{1}{2}\left(\tilde{\zeta}_{ZZ}\frac{h}{v_0} + \frac{1}{2}\tilde{\zeta}_{2Z}\frac{h^2}{v_0^2}\right)\hat{Z}_{\mu\nu}\hat{\tilde{Z}}^{\mu\nu} + \left(\tilde{\zeta}_{WW}\frac{h}{v_0} + \frac{1}{2}\tilde{\zeta}_{2W}\frac{h^2}{v_0^2}\right)\hat{W}_{\mu\nu}^+\hat{\tilde{W}}^{-\mu\nu}$$





In addition,

$H \to WW^*$ is included.

$H \to ZZ^*$ is not included.

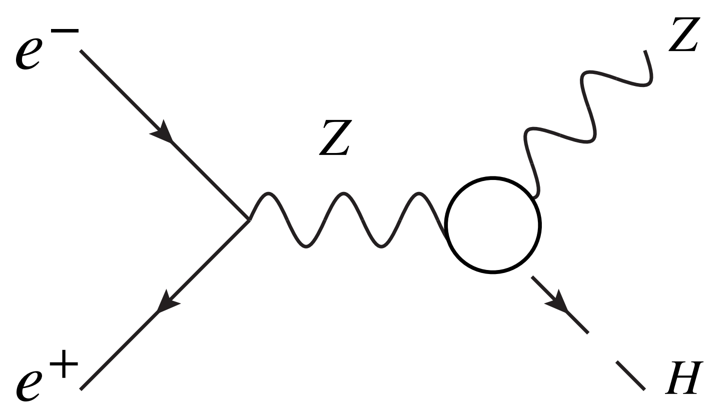
Variation of kinematics due to the anomalous ZZH

$$\mathcal{L}_{\mathrm{ZZH}} = M_Z^2\left(\frac{1}{v} + \frac{a_Z}{\Lambda}\right) Z_\mu Z^\mu H + \frac{b_Z}{2\Lambda}\hat{Z}_{\mu\nu}\hat{Z}^{\mu\nu}H + \frac{\widetilde{b}_Z}{2\Lambda}\hat{Z}_{\mu\nu}\widetilde{\hat{Z}}^{\mu\nu}H.$$

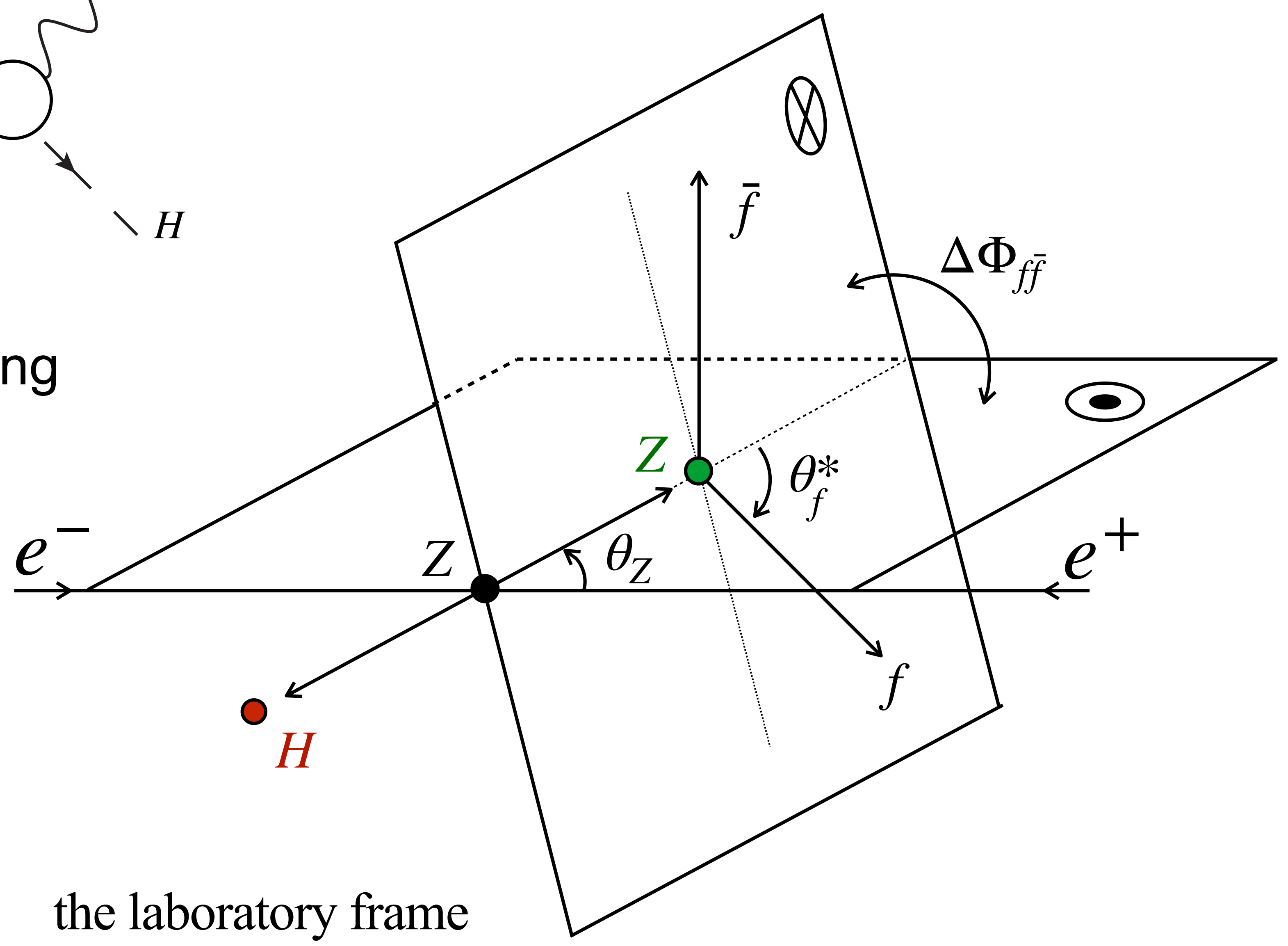
Rescaling the normalization.

parity-conserving interaction
scalar : CP-even interaction

parity-conserving interaction
pseudo-scalar : CP-odd interaction



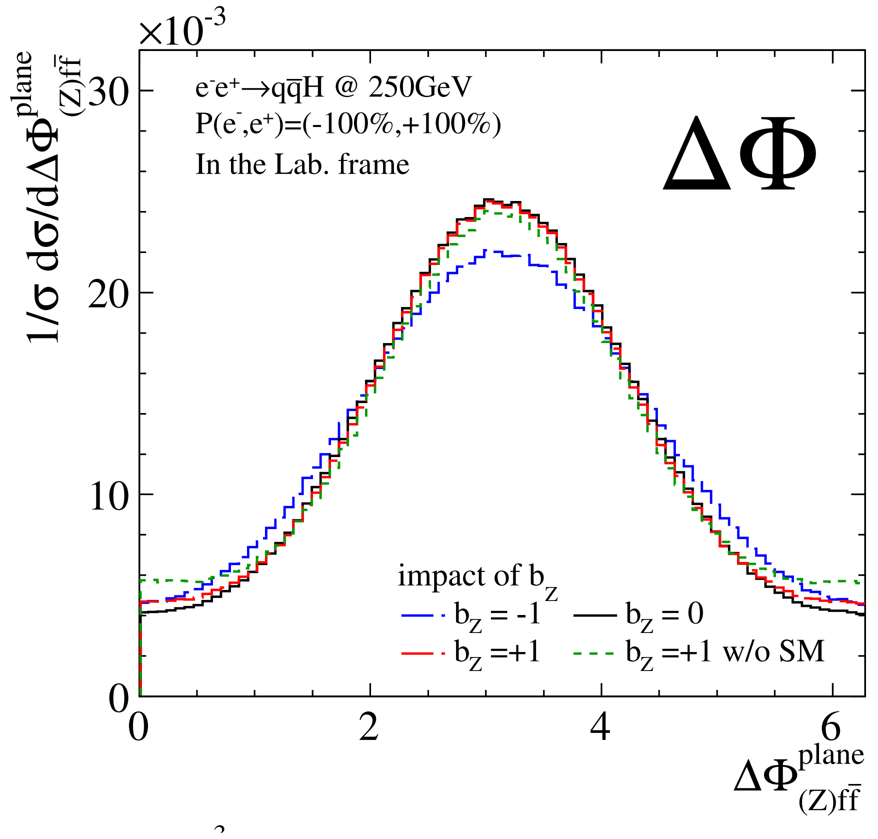
The Higgs strahlung



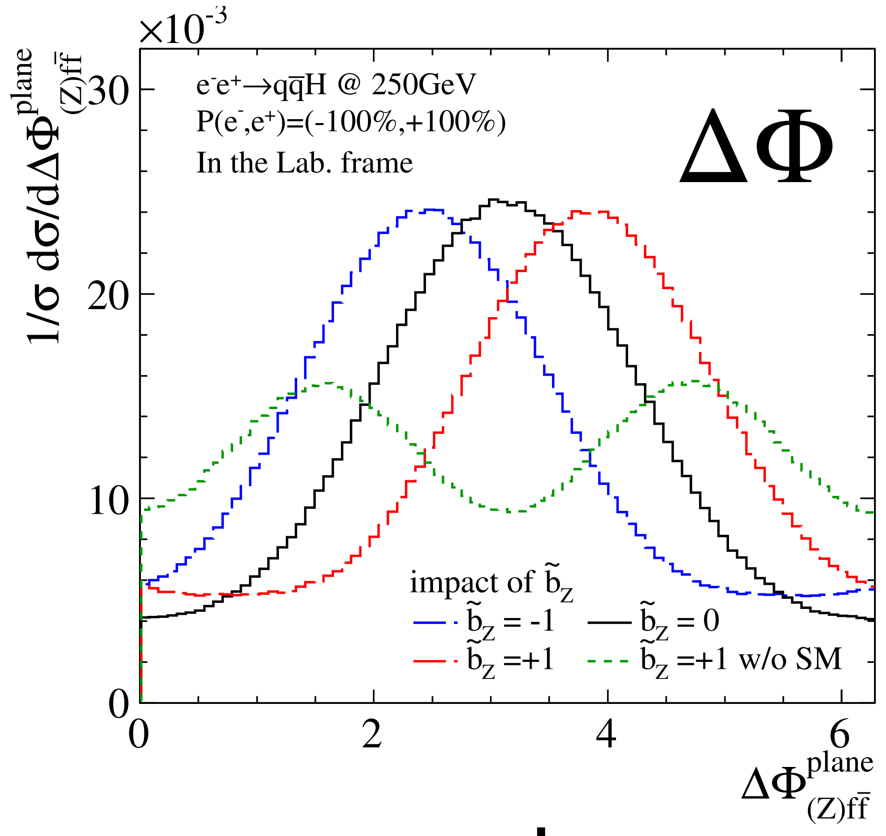
the laboratory frame

$e^+e^- \to Zh \to q\bar{q}h$ *250 GeV*

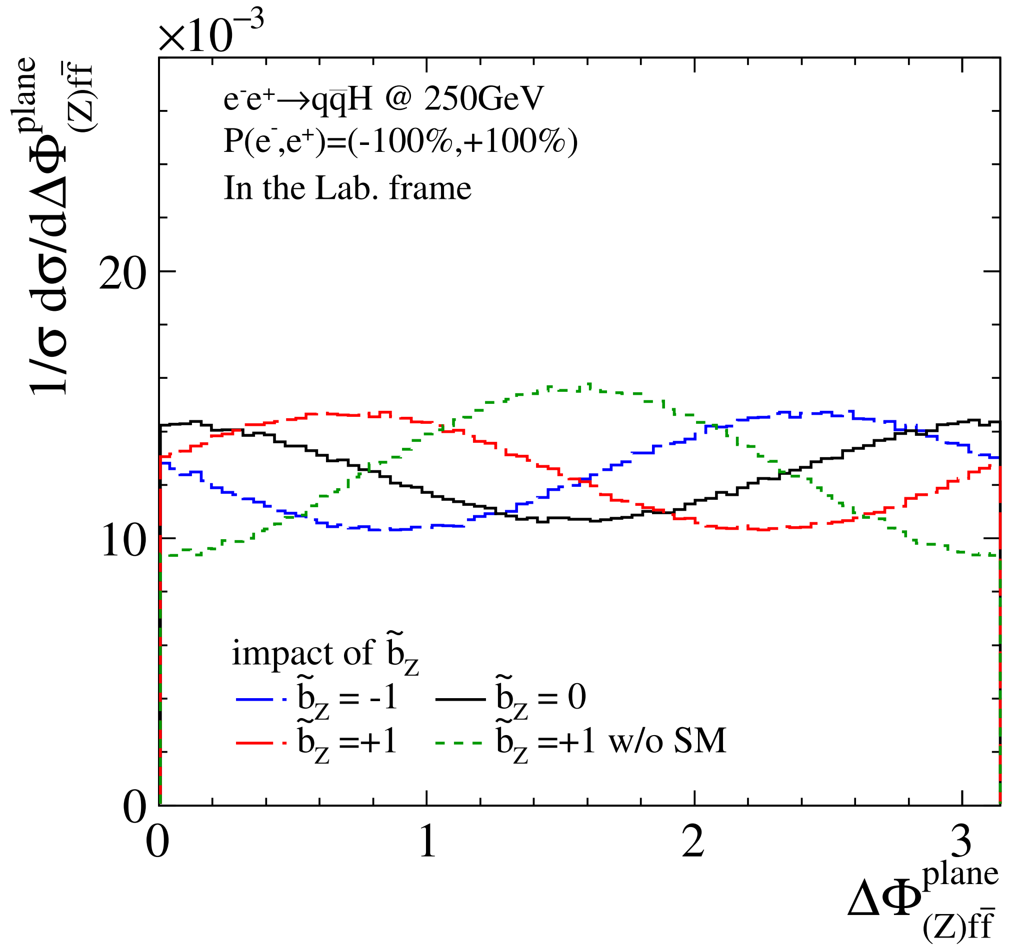
b term



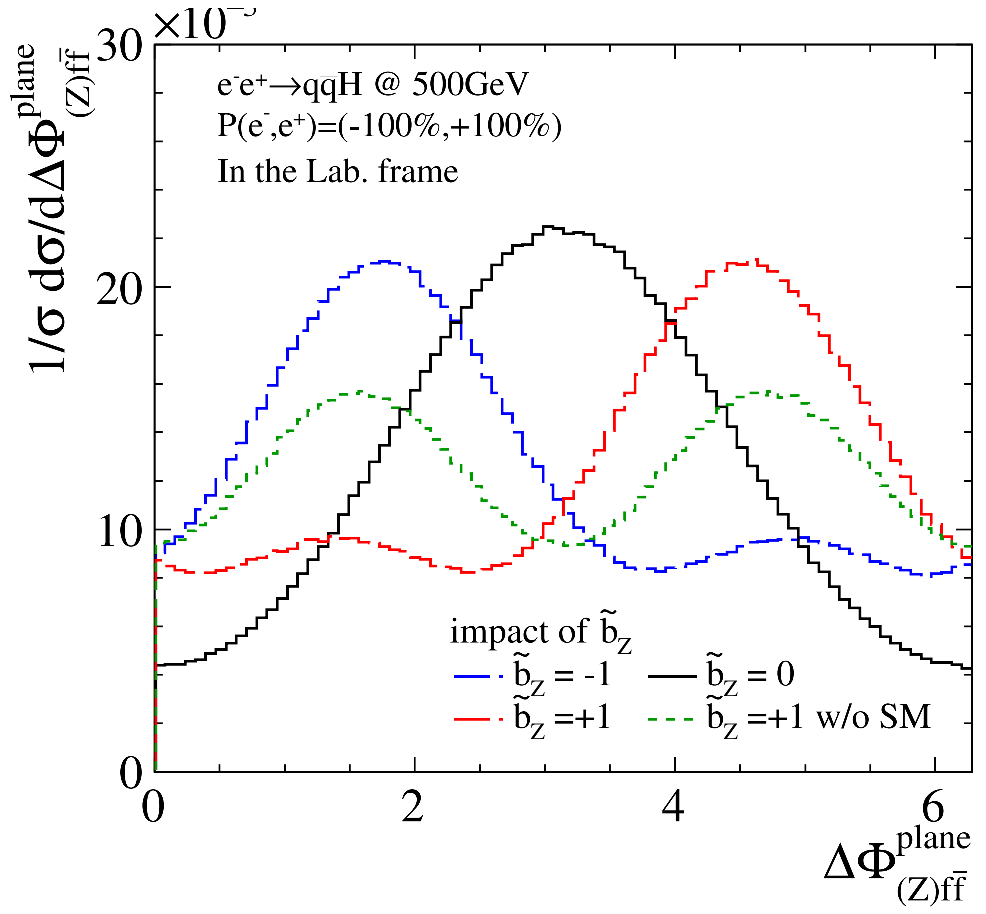
bt term



No Jet charge ID



Goes to 500 GeV



Analysis: Detector effects and sensitivity to ZZH

-. Geant4 based full simulation using International Large Detector (ILD) model for the ILC.

-. All detector effects are considered by detector response matrix. Theoretical shape is smeared

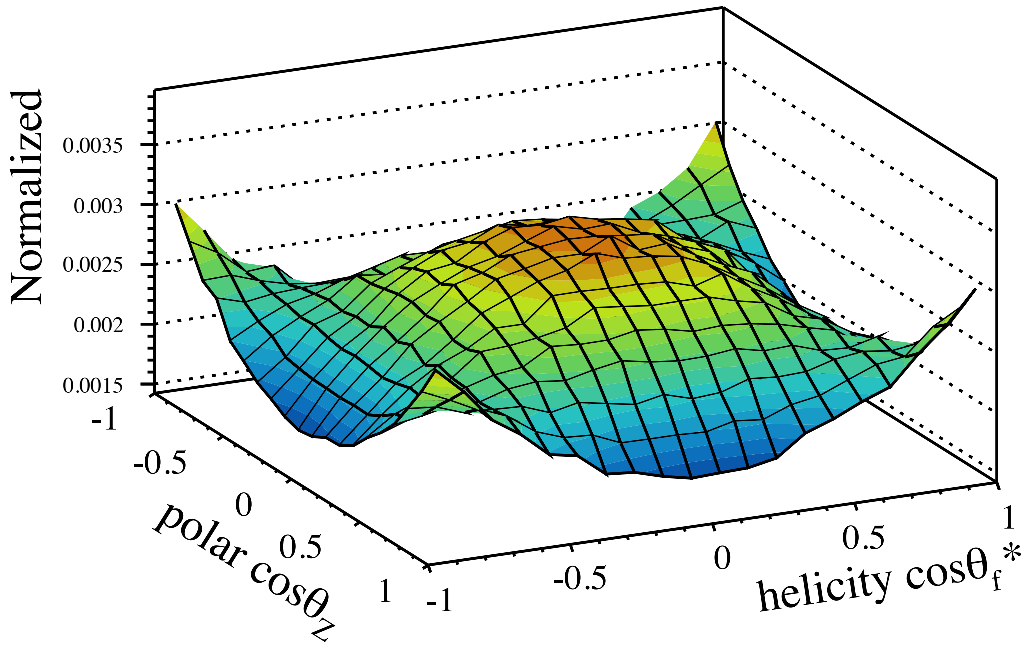
-. All SM backgrounds are considered.

$$\chi^2_{\rm shape} = \sum_{j=1}^{n} \left[\frac{N_{\rm SM} \sum_{i=1}^{n} \left(S_i^{\rm SM} \cdot f_{ji}^{\rm Det} - S_i^{\rm BSM} \cdot f_{ji}^{\rm Det} \right)}{\Delta n_{\rm SM}^{\rm obs}(x_j)} \right]^2$$

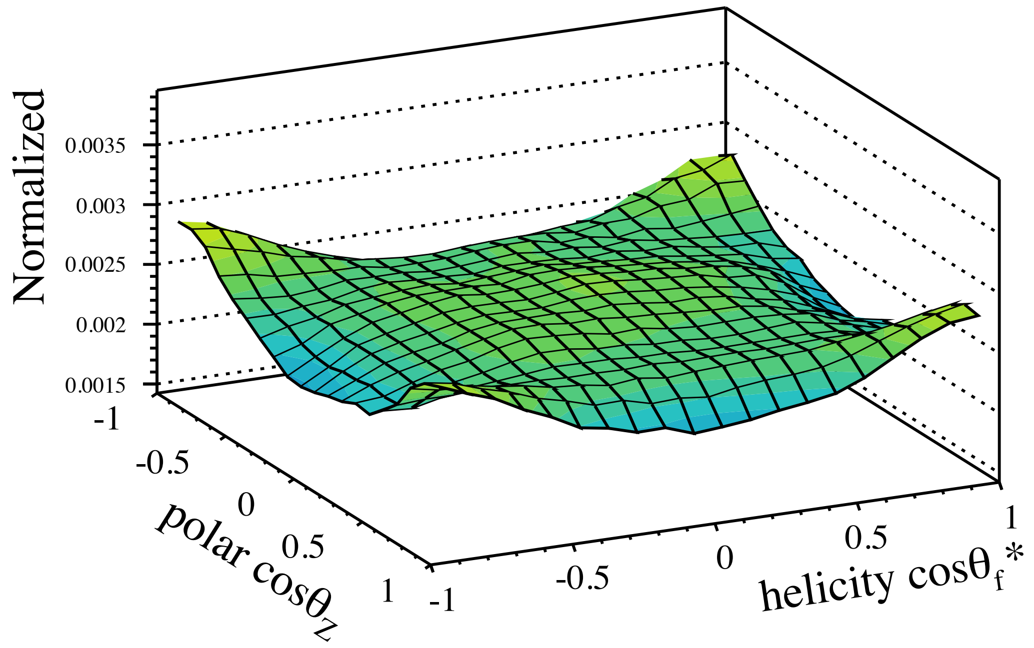
shape detector effects

$e^+e^- \to Zh \to q\bar{q}h$ 250 GeV

polar angle of Z vs helicity angle of q form Z

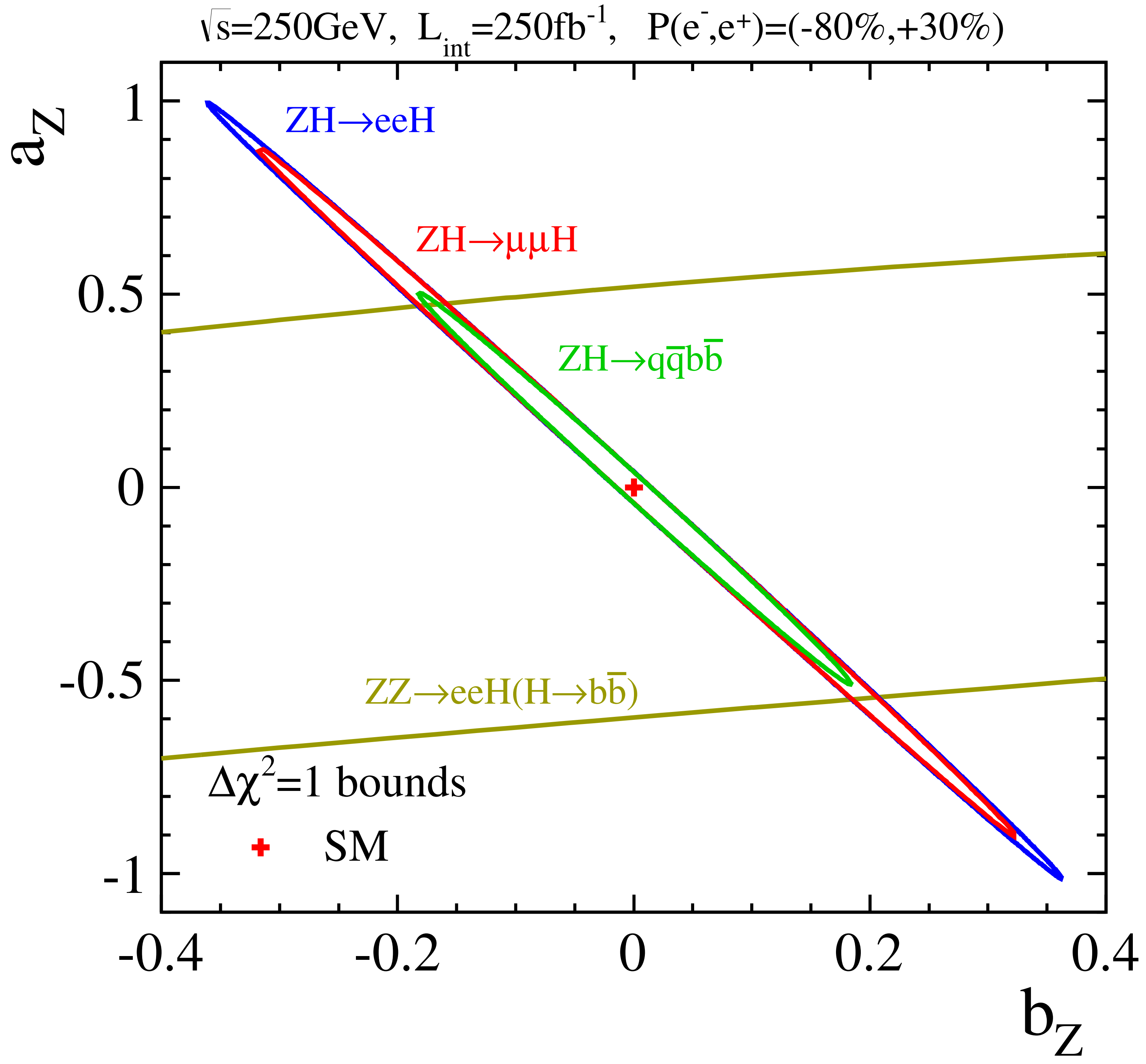


Theoretical
shape of observables



After including
the detector effects

Three-parameter fit and its projection onto a-b plane.



-. qqH has significant sensitivity even w/o jet charge identification.

-. The ZZ-fusion can disentangle the correlation because of different sigh in matrix element. → gets significant at 500GeV.

Constraints on VVH, and comparison with HL-LHC

-. ATLAS and CMS report the sensitivity to VVH.

ATLAS (arXiv:1712.02304v2) VVH using 36.1 fb-1

$$\mathscr{L}_0^V = \left\{ \kappa_{SM} \left[\frac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W_\mu^+ W^{-\mu} \right] + \cdots \right.$$
$$- \frac{1}{4} \frac{1}{\Lambda} \left[\kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + \tan\alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu} \right]$$
$$\left. - \frac{1}{2} \frac{1}{\Lambda} \left[\kappa_{HWW} W_{\mu\nu}^+ W^{-\mu\nu} + \tan\alpha \kappa_{AWW} W_{\mu\nu}^+ \tilde{W}^{-\mu\nu} \right] \right\} X_0$$

Referring to the table10 in arXiv:1712.02304v2 $(\kappa_{HZZ} = \kappa_{HWW})$

2sigma constraints on κ_{HVV} is [-0.6, 4.2] → [−0.06, 0.46] @ HL-LHC
2sigma constraints on κ_{AVV} is [-4.4, 4.4] → [−0.48, 0.48] @ HL-LHC

-. Our study gives the sensitivity to all dim-6 VVH tensor structures:

The full SMEFT Lagrangian is shown in PRD 97, 053004 (2018)

$$\Delta\mathscr{L}_h = \ldots \quad + \eta_Z \frac{m_Z^2}{v_0} Z_\mu Z^\mu h + \ldots \quad + \eta_W \frac{2m_W^2}{v_0} W_\mu^+ W^{-\mu} h + \ldots$$
$$\ldots \quad + \frac{1}{2} \left(\zeta_{ZZ} \frac{h}{v_0} + \frac{1}{2} \zeta_{2Z} \frac{h^2}{v_0^2} \right) \hat{Z}_{\mu\nu} \hat{Z}^{\mu\nu} + \left(\zeta_{WW} \frac{h}{v_0} + \frac{1}{2} \zeta_{2W} \frac{h^2}{v_0^2} \right) \hat{W}_{\mu\nu}^+ \hat{W}^{-\mu\nu}$$
$$\ldots \quad + \frac{1}{2} \left(\tilde{\zeta}_{ZZ} \frac{h}{v_0} + \frac{1}{2} \tilde{\zeta}_{2Z} \frac{h^2}{v_0^2} \right) \hat{Z}_{\mu\nu} \hat{\tilde{Z}}^{\mu\nu} + \left(\tilde{\zeta}_{WW} \frac{h}{v_0} + \frac{1}{2} \tilde{\zeta}_{2W} \frac{h^2}{v_0^2} \right) \hat{W}_{\mu\nu}^+ \hat{\tilde{W}}^{-\mu\nu}$$

$\sqrt{s} = 250 + 500$ GeV with $\int \mathrm{Ldt} = \mathrm{H20}$ (~20 years)

$\kappa_{HZZ} = 8.1\zeta_{ZZ}$

2sigma bound of κ_{HVV} is ± 0.026
2sigma bound of κ_{AVV} is ± 0.044

ILC can give good synergy to HL-LHC results.

The current our results do not include jet charge ID and light flavor c/s tagging. These improvements are ongoing.

Flavor-Tagging of Quark Pairs at e+e- Higgs/Top Factories¶ @ Higgs21 by A. Irles

Strange Quark as a Probe for New Physics in the Higgs Sector¶ @ Higgs21 by M. Basso