Effects of *eett* operators in the measurement of the Higgs trilinear coupling at lepton colliders

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Why this setting

- in trilinear Higgs self coupling λ_3 one of the last things in the SM, that is not measured (precisely) (Currently $\mathcal{O}(100\%)$) [ATLAS, 2024; CMS, 2019])
- using SMEFT the main change can be described by the coefficient of $\mathcal{O}_H = (HH^\dagger)^3$

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- $e^+e^- - t\bar{t}$ couplings not restricted very well by measurements currently and are predicted by many BSM models, also enters at NLO
- Question: Would the presence of contributions to these couplings spoil the measurement of the trilinear Higgs coupling in lepton colliders?

SMEFT - trilinear Higgs coupling

$$V(h) = m_h^2 h^2 + \kappa_3 \lambda_3^{\mathrm{SM}} h^3 + \kappa_4 \lambda_4^{\mathrm{SM}} h^4 \,, \tag{1}$$

Triliniear Higgs coupling λ_3 in the following parametrised by

$$\delta\kappa_3 \equiv \frac{\lambda_3}{\lambda_3^{\mathsf{SM}}} - 1 = -\frac{2v^4}{\Lambda^2 m_h^2}\mathcal{C}_H + \frac{3v^2}{\Lambda^2}\left(\mathcal{C}_{H\Box} - \frac{1}{4}\mathcal{C}_{HD}\right) \,, \tag{2}$$

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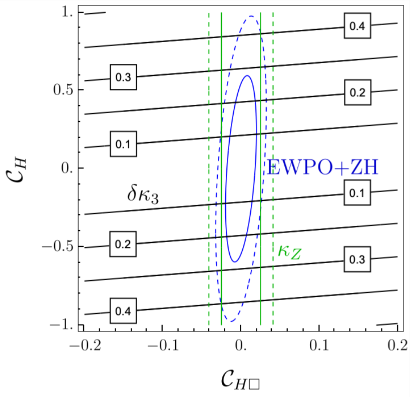
$$\begin{aligned} \mathcal{O}_H &= (H^\dagger H)^3 \,, \\ \mathcal{O}_{H\Box} &= (H^\dagger H)\Box(H^\dagger H) \,, \\ \mathcal{O}_{HD} &= |H^\dagger D_\mu H|^2 \,, \end{aligned} \tag{3}$$

with $\Box \equiv \partial_\mu \partial^\mu$.

$\mathcal{C}_{H\Box}$-$\mathcal{C}_H$ Plane



SMEFT - trilinear Higgs coupling

Neglect $\mathcal{O}_{H\Box}$ and $\mathcal{O}_{HD}$ in the following (highly contrained by electroweak precision observables):

$$\delta\kappa_3 = -\frac{2v^4}{\Lambda^2 m_h^2}\mathcal{C}_H$$

$$\mathcal{O}_H = (H^\dagger H)^3$$

SMEFT - $e^+e^- - t\bar{t}$ interactions

The SMEFT operators modifying $e^+e^- - t\bar{t}$ interactions are:

$$
\begin{aligned}
[\mathcal{O}_{lq}^{(1)}]_{1133} &= (\bar{\ell}_1\gamma_\mu\ell_1)(\bar{q}_3\gamma^\mu q_3) \\
[\mathcal{O}_{lq}^{(3)}]_{1133} &= (\bar{\ell}_1\gamma_\mu\sigma^I\ell_1)(\bar{q}_3\gamma^\mu\sigma^I q_3) \\
[\mathcal{O}_{qe}]_{3311} &= (\bar{q}_3\gamma^\mu q_3)(\bar{e}_1\gamma_\mu e_1) \\
[\mathcal{O}_{lu}]_{1133} &= (\bar{\ell}_1\gamma_\mu\ell_1)(\bar{u}_3\gamma^\mu u_3) \\
[\mathcal{O}_{eu}]_{1133} &= (\bar{e}_1\gamma_\mu e_1)(\bar{u}_3\gamma^\mu u_3)
\end{aligned}
\tag{4}
$$

SMEFT setting

So in general restrict: 5+1 Coefficients

- $[\mathcal{C}_{lq}^{(1)}]_{1133}$, $[\mathcal{C}_{lq}^{(3)}]_{1133}$, $[\mathcal{C}_{lu}]_{1133}$, $[\mathcal{C}_{qe}]_{3311}$, $[\mathcal{C}_{eu}]_{1133}$
- $\mathcal{C}_H$

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- $\mathcal{C}_H$

$\Rightarrow$ need more than $e^+e^- \to ZH$ to restrict this parameter space

Observables at Tree Level

Tree level effects in:

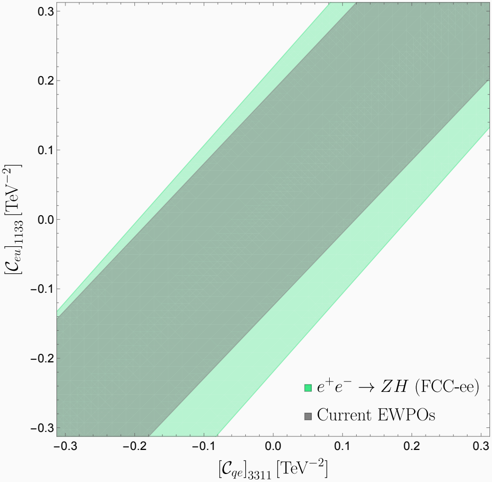
- R_b, R_t $\left(R_a = \frac{\sigma(e^+e^- \to a\bar{a})}{\sum_{q=u,d,s,c,b} \sigma(e^+e^- \to a\bar{a})}\right)$ [Greljo et al., 2024]
- and Drell-Yan ($pp \to e^+e^-$) [Allwicher et al., 2023]

Observables at 1-Loop

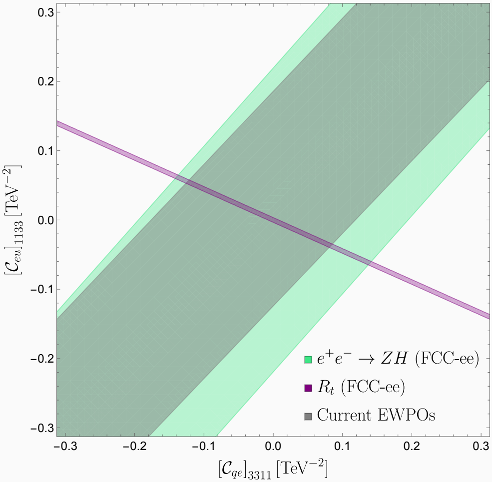
Operators entering at Loop level in

- $e^+e^- \to ZH$ (main effect for *eett*-operators through RG-effects) [de Blas et al., 2019; Celada et al., 2024]
- Electroweak Precision Observables (EWPOs eg. Z/W-pole observables) [de Blas et al., 2019; Bernardi et al., 2022; Blondel and Janot, 2021; LEP-Collaboration et al., 2004; Maura et al., 2025a]

Restricted Regions



Restricted Regions



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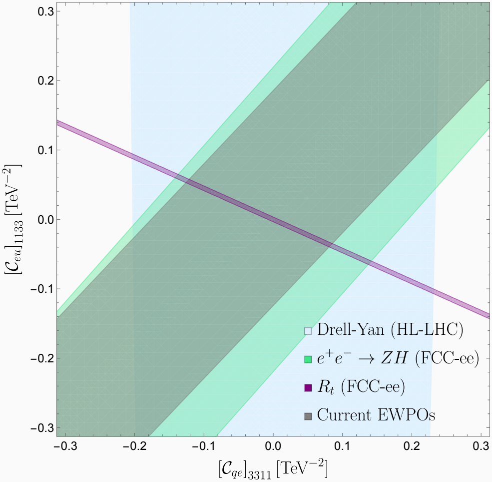

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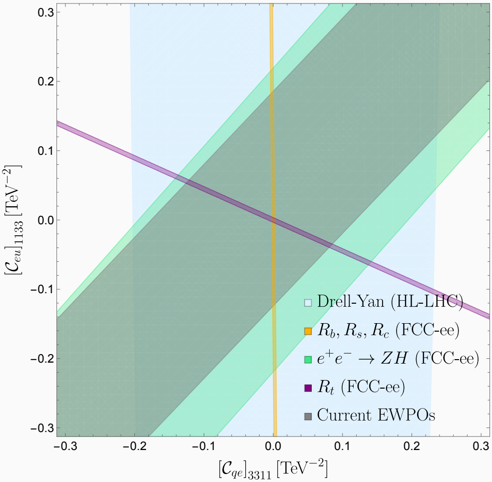

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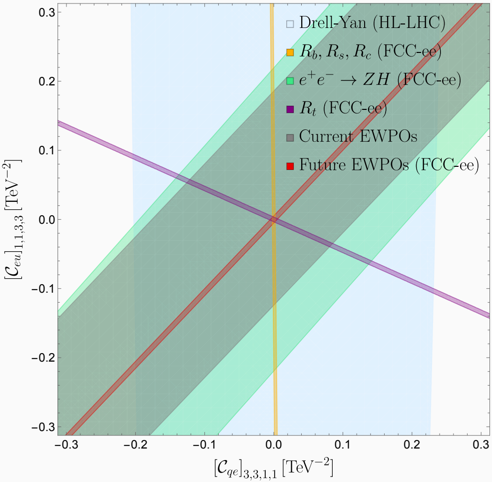

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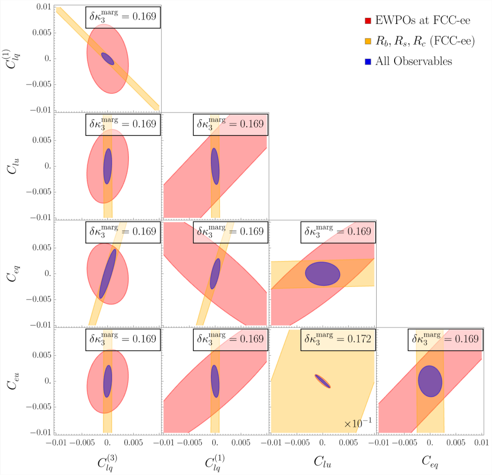
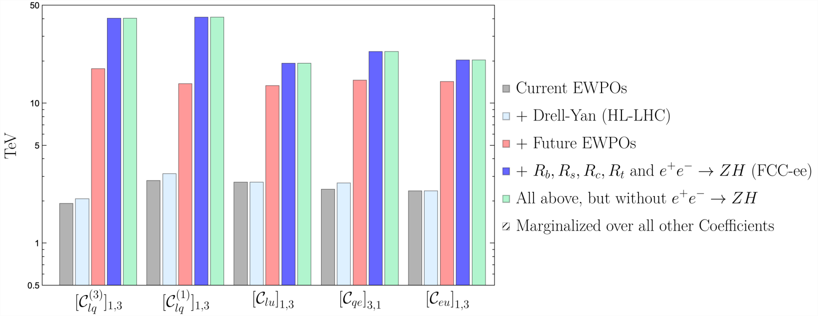


Fitting the coefficients to the data/data projections



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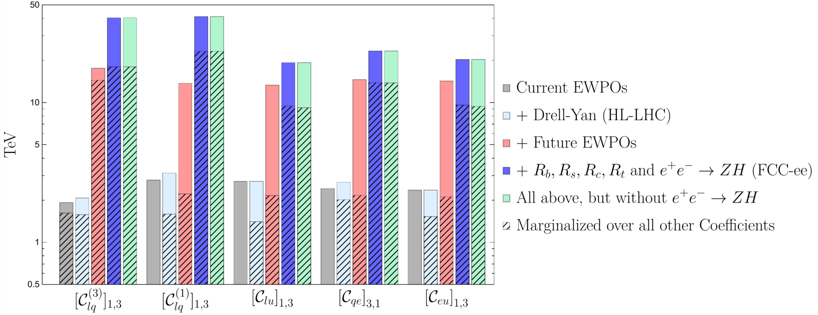

Triliniear Higgs Coupling

- *eett*-coefficients restricted enough to get a good picture on the trilinear higgs coupling?

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- *eett*-coefficients restricted enough to get a good picture on the trilinear higgs coupling?
- yes!

$$\delta\kappa_3^{\text{sep}} = 0.169 \quad \rightarrow \quad \delta\kappa_3^{\text{marg}} = 0.172$$

$$\delta\kappa_3^{\text{marg, wo. } R_q} = 0.176$$

UV Assumptions

- top- and electrophilic hypothesis to get the *eett*-interactions ($U(2)$ in quark sector with a third generation dominance and $U(1)_e$ in the lepton sector)

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- opens up space for more operators:
  - 2 scalar operators ($[\mathcal{O}_{lequ}^{(1)}]_{1133}$, $[\mathcal{O}_{lequ}^{(3)}]_{1133}$)
  - 5 four-quark operators ($[\mathcal{O}_{qq}^{(1)}]_{3333}$, $[\mathcal{O}_{qq}^{(3)}]_{3333}$, $[\mathcal{O}_{uu}]_{3333}$, $[\mathcal{O}_{qu}^{(1)}]_{3333}$, $[\mathcal{O}_{qu}^{(8)}]_{3333}$)
  - 3 four-lepton operators ($[\mathcal{O}_{ee}]_{1111}$, $[\mathcal{O}_{le}]_{1111}$, $[\mathcal{O}_{ll}]_{1111}$)

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  - 3 four-lepton operators ($[\mathcal{O}_{ee}]_{1111}$, $[\mathcal{O}_{le}]_{1111}$, $[\mathcal{O}_{ll}]_{1111}$)
- do not contribute to $e^+e^- \to ZH$ observable (in $m_e = 0$ limit), but in the other considered observables

UV assumptions - $\delta\kappa_3$

$$\delta\kappa_3^{\text{sep}} = 0.169 \quad \rightarrow \quad \delta\kappa_3^{\text{marg, all UV ops}} \approx 0.23$$

- comparable with 25 % with a $U(2)^5$ symmetry with a dominance of the 3rd generation [Maura et al., 2025b]

Conclusion

- No problem to measure BSM *eett*-interactions and the trilinear Higgs self coupling at the same time in future projections (FCC-ee)
- important observables: R_b, *EWPOs* and $e^+e^- \to ZH$
- see paper (in progress): specific UV examples, symmetry assumptions and a more precise analysis of the parameter space

Backup: UV Example

$$-\mathcal{L}_{S_1} = (y^{ql}_{S_1})_{ij} S_1^\dagger \bar{q}^c_{L,i} i\sigma_2 l_{L,j} (y^{eu}_{S_1})_{ij} S_1^\dagger \bar{e}^c_{R,i} u_{R,j} + \text{ h.c.} \tag{5}$$

$$-\mathcal{L}_{R_2} = (y^{lu}_{R_2})_{ij} R_2^\dagger i\sigma_2 \bar{l}^T_{L,i} u_{R,j} + (y^{eq}_{R_2})_{ij} R_2^\dagger \bar{e}_{R,i} q_{L,j} + \text{ h.c.} \tag{6}$$

Backup: UV Example

$$[C_{lq}^{(1)}]_{1133} = \frac{1}{4}\frac{(y_{S_1}^{ql})^*_{31}(y_{S_1}^{ql})_{31}}{M_{S_1}^2} \tag{7}$$

$$[C_{lq}^{(3)}]_{1133} = -\frac{1}{4}\frac{(y_{S_1}^{ql})^*_{31}(y_{S_1}^{ql})_{31}}{M_{S_1}^2} \tag{8}$$

$$[C_{eu}]_{1133} = \frac{1}{2}\frac{(y_{S_1}^{eu})^*_{i13}(y_{S_1}^{eu})_{13}}{M_{S_1}^2} \tag{9}$$

$$[C_{lu}]_{1133} = -\frac{1}{2}\frac{(y_{R_2}^{lu})^*_{13}(y_{R_2}^{lu})_{13}}{M_{R_2}^2} \tag{10}$$

$$[C_{qe}]_{3311} = -\frac{1}{2}\frac{(y_{R_2}^{eq})^*_{13}(y_{R_2}^{eq})_{13}}{M_{R_2}^2}, \tag{11}$$