Probing Top-quark Operators with Precision Electroweak Measurements

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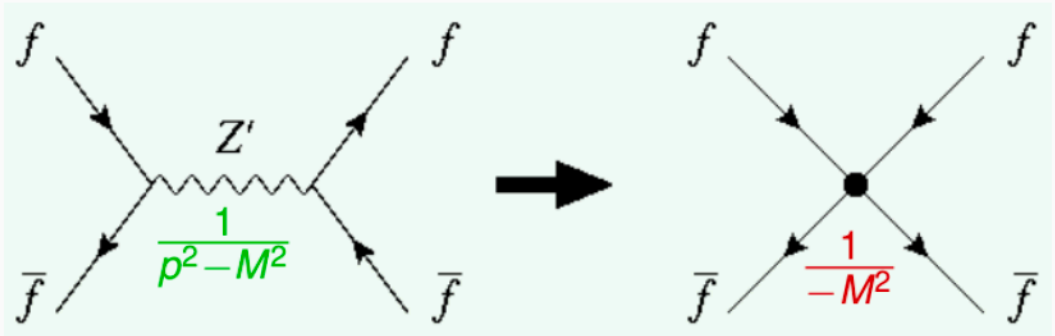
Based on 2205.05655 with Yuhao Wang, Cen Zhang, Lei Zhang, Jiayin Gu

Motivation

1, At LEP1/2, low-energy precision measurements, and e^+e^- collider in the future, we can use loops to open up more possibilities. Loop factor suppression will be compensated for by the precision.

2, Our study is one of the many first steps towards a more complete loop-level SMEFT global analysis.

Theoretical framework



$$\frac{1}{p^2 - M^2} = \frac{1}{-M^2}\left[1 + \left(\frac{p^2}{M^2}\right) + \left(\frac{p^2}{M^2}\right)^2 + \cdots\right]$$

$$\mathcal{L}_{\text{Eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \sum_i \frac{C_i^{(8)}}{\Lambda^4} O_i^{(8)} + \cdots$$

Theoretical framework

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star\left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\,\widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\,G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\,\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\,W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\,B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\,\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\,\widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q^{(1)}_{qq}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q^{(3)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q^{(1)}_{lq}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q^{(3)}_{lq}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q^{(1)}_{qu}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q^{(1)}_{ud}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q^{(8)}_{qu}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q^{(8)}_{ud}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q^{(1)}_{qd}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q^{(8)}_{qd}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(q^{\gamma j}_s)^T C l^k_t\right]$
$Q^{(1)}_{quqd}$	$(\bar{q}^j_p u_r)\varepsilon_{jk}(\bar{q}^k_s d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$Q^{(8)}_{quqd}$	$(\bar{q}^j_p T^A u_r)\varepsilon_{jk}(\bar{q}^k_s T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(q^{\gamma m}_s)^T C l^n_t\right]$
$Q^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$Q^{(3)}_{lequ}$	$(\bar{l}^j_p\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}u_t)$		

[Grzadkowski, Iskrzynski, Misiak, Rosiek, 2010]

Theoretical framework

$$Q_{\varphi Q}^{(3)} = i\left(\phi^\dagger \tau^I D_\mu \phi\right)\left(\bar{Q}\gamma^\mu \tau^I Q\right)$$

$$Q_{\varphi Q}^{(1)} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{Q}\gamma^\mu Q\right)$$

$$Q_{\varphi t} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{t}\gamma^\mu t\right)$$

$$Q_{\varphi b} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{b}\gamma^\mu b\right)$$

$$Q_{\varphi tb} = i\left(\tilde{\phi}^\dagger D_\mu \phi\right)\left(\bar{t}\gamma^\mu b\right)$$

$$Q_{tW} = \left(\bar{q}\sigma^{\mu\nu}\tau^I t\right)\tilde{\phi}W_{\mu\nu}^I$$

$$Q_{bW} = \left(\bar{q}\sigma^{\mu\nu}\tau^I b\right)\phi W_{\mu\nu}^I$$

$$Q_{tB} = \left(\bar{q}\sigma^{\mu\nu} t\right)\tilde{\phi}B_{\mu\nu}$$

$$Q_{bB} = \left(\bar{q}\sigma^{\mu\nu} b\right)\phi B_{\mu\nu}$$

[Cen Zhang, Nicolas Greiner, Scott Willenbrock, 2012]

Theoretical framework

Impose a $U(2)_u \otimes U(2)_d \otimes U(2)_q \otimes U(3)_l \otimes U(3)_e$ flavor symmetry

$\psi^2\varphi^3$	X^3	$\varphi^4 D^2$
$Q_{u\varphi}^{ij} = (\varphi^\dagger\varphi)(\bar{q}_i u_j \widetilde{\varphi})$ $Q_{d\varphi}^{ij} = (\varphi^\dagger\varphi)(\bar{q}_i d_j \varphi)$	$Q_W = \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D} = \left(\varphi^\dagger D^\mu \varphi\right)^\star \left(\varphi^\dagger D_\mu \varphi\right)$
$\psi^2\varphi^2 D$	$\psi^2 X \varphi$	$X^2\varphi^2$
$Q_{\varphi l}^{ij(1)} = \left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)(\bar{l}_i \gamma^\mu l_j)$	$Q_{uW}^{ij} = (\bar{q}_i \sigma^{\mu\nu} u_j)\tau^I \widetilde{\varphi} W_{\mu\nu}^I$	$Q_{\varphi WB} = \varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$
$Q_{\varphi l}^{ij(3)} = \left(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi\right)(\bar{l}_i \tau^I \gamma^\mu l_j)$	$Q_{uB}^{ij} = (\bar{q}_i \sigma^{\mu\nu} u_j)\widetilde{\varphi} B_{\mu\nu}$	
$Q_{\varphi e}^{ij} = \left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)(\bar{e}_i \gamma^\mu e_j)$	$Q_{dW}^{ij} = (\bar{q}_i \sigma^{\mu\nu} d_j)\tau^I \varphi W_{\mu\nu}^I$	
$Q_{\varphi q}^{ij(1)} = \left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)(\bar{q}_i \gamma^\mu q_j)$	$Q_{dB}^{ij} = (\bar{q}_i \sigma^{\mu\nu} d_j)\varphi B_{\mu\nu}$	
$Q_{\varphi q}^{ij(3)} = \left(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi\right)(\bar{q}_i \tau^I \gamma^\mu q_j)$		
$Q_{\varphi u}^{ij} = \left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)(\bar{u}_i \gamma^\mu u_j)$		
$Q_{\varphi d}^{ij} = \left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)(\bar{d}_i \gamma^\mu d_j)$		
$Q_{\varphi ud}^{ij} = i(\widetilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$		
$(\bar{L}L)(\bar{L}L)$	$(\bar{R}R)(\bar{R}R)$	$(\bar{L}L)(\bar{R}R)$
$Q_{ll}^{prst} = (\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_{ee}^{prst} = (\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$	$Q_{le}^{prst} = (\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{lq}^{prst(1)} = (\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{eu}^{prst} = (\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$	$Q_{lu}^{prst} = (\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
$Q_{lq}^{prst(3)} = (\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_{ed}^{prst} = (\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$	$Q_{ld}^{prst} = (\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
		$Q_{qe}^{prst} = (\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$

$$
\begin{aligned}
Q_{\varphi Q}^{(+)} &\equiv Q_{\varphi Q}^{(1)} + Q_{\varphi Q}^{(3)}, \\
Q_{lQ}^{(+)} &\equiv Q_{lQ}^{(1)} + Q_{lQ}^{(3)}, \\
Q_{\varphi Q}^{(-)} &\equiv Q_{\varphi Q}^{(1)} - Q_{\varphi Q}^{(3)}, \\
Q_{lQ}^{(-)} &\equiv Q_{lQ}^{(1)} - Q_{lQ}^{(3)},
\end{aligned}
$$

Theoretical framework

	Experiment	Observables
Low Energy	CHARM/CDHS/ CCFR/NuTeV/ APV/QWEAK/ PVDIS	Effective Couplings
Z-pole	LEP/SLC	Total decay width Γ_Z Hadronic cross-section σ_{had} Ratio of decay width R_f Forward-Backward Asymmetry A_{FB}^f Polarized Asymmetry A_f
W-pole	LHC/Tevatron/ LEP/SLC	Total decay width Γ_W Branch Ratio of W Decay $Br(W \to l\nu_l)$ Mass of W Boson M_W
$ee \to qq$	LEP/TRISTAN	Hadronic cross-section σ_{had} Ratio of cross-section R_f Forward-Backward Asymmetry for b/c A_{FB}^f
$ee \to ll$	LEP	cross-section σ_f Forward-Backward Asymmetry A_{FB}^f Differential cross-section $\frac{d\sigma_f}{dcos\theta}$
$ee \to WW$	LEP	cross-section σ_{WW} Differential cross-section $\frac{d\sigma_{WW}}{dcos\theta}$

[J Erler and A Freitas. Electroweak model and constraints on new physics.] [D Geiregat, Gaston Wilquet, U Binder, H Burkard, U Dore, W Flegel, H Grote, T Mouthuy, H Øverås, J Panman, et al. First observation of neutrino trident production.]

[Aielet Efrati, Adam Falkowski, and Yotam Soreq. Electroweak constraints on flavorful effective theories.]

[Morad Aaboud, Georges Aad, Brad Abbott, Jalal Abdallah, O Abdinov, Baptiste Abeloos, Syed Haider Abidi, OS AbouZeid, Nadine L Abraham, Halina Abramowicz, et al. Measurement of the W-boson mass in pp collisions at $\sqrt{s} = 7GeV$ with the ATLAS detector.]

[Electroweak Measurements in Electron–Positron Collisions at W-Boson-Pair Energies at LEP.]

[A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model.]

[Measurement of the cross-section and forward-backward charge asymmetry for the b and c-quark in e^+e^- annihilation with inclusive muons at $\sqrt{s} = 58GeV$]

Theoretical framework

1, The first class involves the third generation quarks

$$Q_{\varphi Q}^{(1)}, Q_{\varphi Q}^{(3)}, Q_{\varphi t}, Q_{\varphi b}, Q_{\varphi\varphi}, Q_{tW}, Q_{tB}, Q_{bW}, Q_{bB}$$

2, The second class have tree-level contribution to $e^+e^- \to \bar{f}f(f \neq t), e^+e^- \to W^+W^-$.

$$Q_{\varphi Q}^{(1)}, Q_{\varphi Q}^{(3)}, Q_{\varphi u}, Q_{\varphi d}, Q_{\varphi l}^{(1)}, Q_{\varphi l}^{(3)}, Q_{\varphi e}, Q_{ll}^{'}, Q_{\varphi D}, Q_{\varphi WB}, O_W$$

3, The third class are 4-fermion operators that directly contribute to the $e^+e^- \to \bar{f}f(f \neq t, b)$ and several low energy scattering processes at tree level.

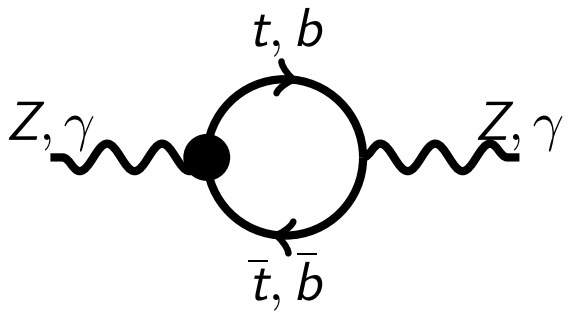
$$Q_{qe}, Q_{eu}, Q_{ed}, Q_{lq}^{(1)}, Q_{lq}^{(3)}, Q_{lu}, Q_{ld}, O_{ll}, Q_{ee}, Q_{le}$$

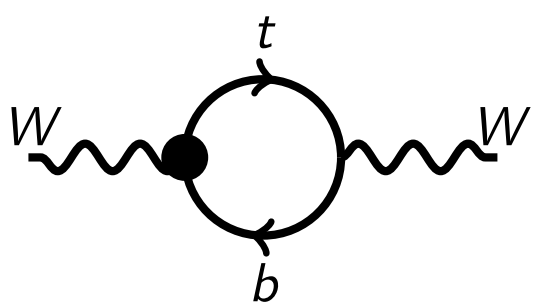
4, The fourth class are 4-fermion operators that directly contribute to the $e^+e^- \to b\bar{b}$ at tree level.

$$Q_{lQ}^{(1)}, Q_{lQ}^{(3)}, Q_{lb}, Q_{eQ}, Q_{eb}$$

Theoretical framework

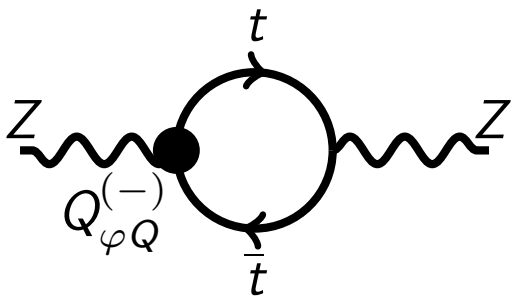
1, For observable without Zbb couplings, the nine operators modify the self-energies of W, Z, γ at loop-level, and therefore affect all measurements indirectly.





Example

$$
\begin{aligned}
Q_{\varphi Q}^{(-)} &= Q_{\varphi Q}^{(1)} - Q_{\varphi Q}^{(3)} \\
&= -\left(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi\right)(\bar{q}_3 \tau^I \gamma^\mu q_3) + \left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)(\bar{q}_3 \gamma^\mu q_3) \\
&= -\left(\varphi^\dagger i \overleftrightarrow{D}_\mu^1 \varphi\right)(\bar{q}_3 \tau^1 \gamma^\mu q_3) - \left(\varphi^\dagger i \overleftrightarrow{D}_\mu^2 \varphi\right)(\bar{q}_3 \tau^2 \gamma^\mu q_3) \\
&- \left(\varphi^\dagger i \overleftrightarrow{D}_\mu^3 \varphi\right)(\bar{q}_3 \tau^3 \gamma^\mu q_3) + \left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)(\bar{q}_3 \gamma^\mu q_3) \\
&= \frac{-igv^2}{\sqrt{2}} W_\mu^+ (\bar{b} \gamma_\mu t) + \frac{igv^2}{\sqrt{2}} W_\mu^- (\bar{t} \gamma_\mu b) + \frac{igZ_\mu}{\cos\theta_W} v^2 \bar{t} \gamma_\mu t + \ldots\ldots
\end{aligned}
$$



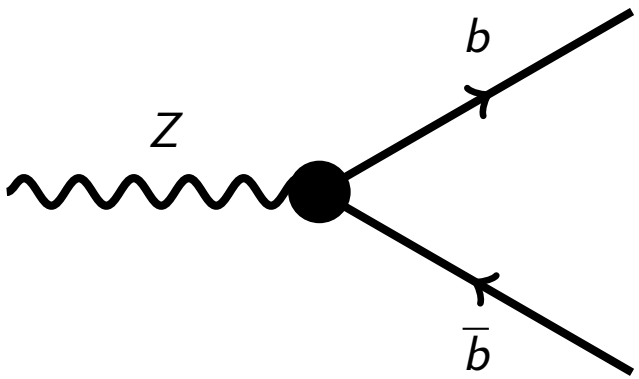
2, For observable with Zbb couplings, $Q_{\varphi Q}^{(+)}$, $Q_{\varphi b}$, Q_{bW}, Q_{bB} modify the $Z \to b\bar{b}$ measurements at tree-level.

$$Q_{\varphi Q}^{(+)} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{Q}\gamma^\mu Q\right)$$

$$Q_{\varphi b} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{b}\gamma^\mu b\right)$$

$$Q_{bW} = \left(\bar{q}\sigma^{\mu\nu}\tau^I b\right)\phi W^I_{\mu\nu}$$

$$Q_{bB} = \left(\bar{q}\sigma^{\mu\nu} b\right)\phi B_{\mu\nu}$$



3, For observable with Zbb couplings, $Q_{\varphi Q}^{(-)}$, $Q_{\varphi t}$, Q_{tW}, Q_{tB} not only modify the self-energies of W, Z, γ at loop-level, but also modify the $Zb\bar{b}$ vertex at loop-level.

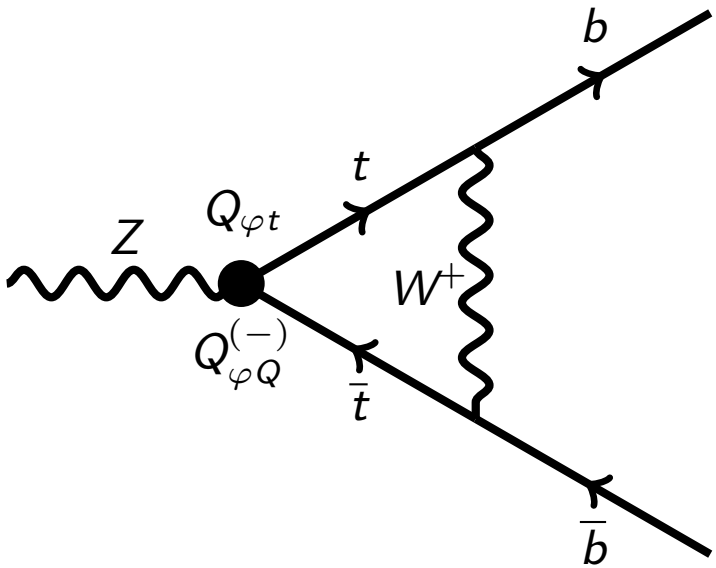
$$Q_{\varphi Q}^{(-)} = i\left(\phi^\dagger \tau^I D_\mu \phi\right)\left(\bar{Q}\gamma^\mu \tau^I Q\right)$$

$$Q_{\varphi t} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{t}\gamma^\mu t\right)$$

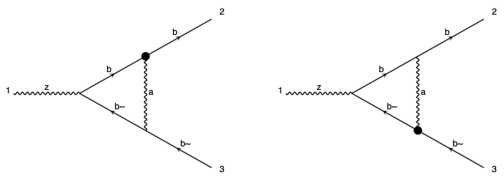
$$Q_{\varphi tb} = i\left(\tilde{\phi}^\dagger D_\mu \phi\right)\left(\bar{t}\gamma^\mu b\right)$$

$$Q_{tW} = \left(\bar{q}\sigma^{\mu\nu}\tau^I t\right)\tilde{\phi}W^I_{\mu\nu}$$

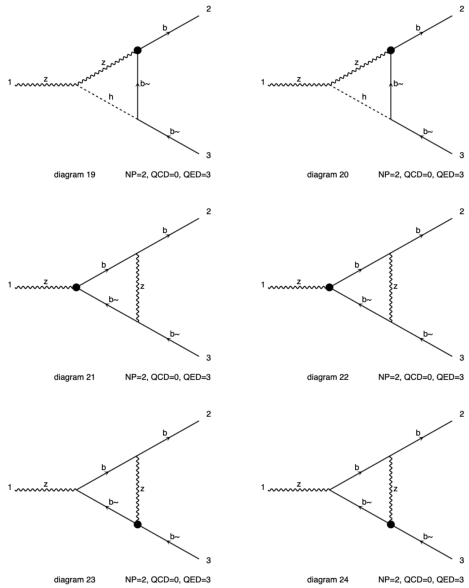
$$Q_{tB} = \left(\bar{q}\sigma^{\mu\nu} t\right)\tilde{\phi}B_{\mu\nu}$$



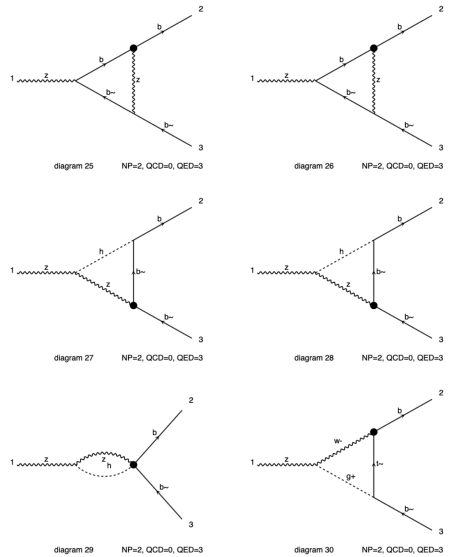
Theoretical framework



Diagrams made by MadGraph5_aMC@NLO

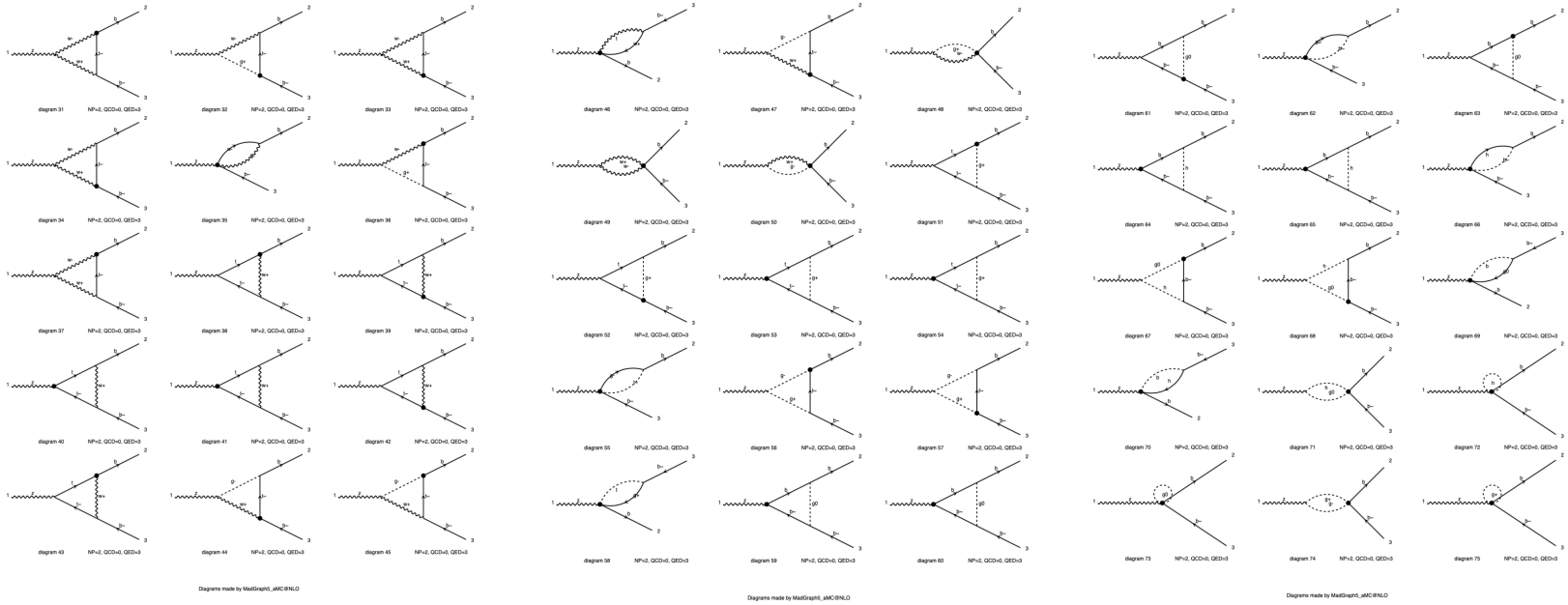


Diagrams made by MadGraph5_aMC@NLO



Diagrams made by MadGraph5_aMC@NLO

Theoretical framework



Theoretical framework

To better understand the impacts of the 3rd-generation-quark operators, we trade $\frac{c_{\varphi D}}{\Lambda^2} Q_{\varphi D}$ and $\frac{c_{\varphi WB}}{\Lambda^2} Q_{\varphi WB}$ in the Warsaw basis for $\frac{c_{D\varphi B}}{\Lambda^2} iD^\mu \varphi^\dagger D^\nu \varphi B_{\mu\nu}$ and $\frac{c_{D\varphi W}}{\Lambda^2} iD^\mu \varphi^\dagger \sigma_a \varphi W^a_{\mu\nu}$:

$$
\begin{aligned}
Q_{D\varphi B} &\equiv iD_\mu \phi^\dagger D_\nu \phi B^{\mu\nu} \\
&= -\frac{g'}{4} Q_{\varphi B} + \frac{g'}{2} \sum_\psi Y_\psi Q^{(1)}_{\varphi\psi} + \frac{g'}{4} Q_{\varphi\Box} + g' Q_{\varphi D} - \frac{g}{4} Q_{\varphi WB} \\
Q_{D\varphi W} &\equiv iD_\mu \phi^\dagger \sigma_a D_\nu \phi W^{a\mu\nu} \\
&= \frac{g}{4} \sum_F Q^{(3)}_{\varphi F} + \frac{g}{4} \left(3Q_{\varphi\Box} + 8\lambda_\phi Q_\varphi - 4\mu_\phi^2 \left(\phi^\dagger \phi\right)^2 \right) + \\
&+ \frac{g}{2} \left(y^e_{ij} \left(Q_{e\varphi}\right)_{ij} + y^d_{ij} \left(Q_{d\varphi}\right)_{ij} + y^u_{ij} \left(Q_{u\varphi}\right)_{ij} + \text{ h.c. } \right) \\
&- \frac{g'}{4} Q_{\varphi WB} - \frac{g}{4} Q_{\varphi W},
\end{aligned}
$$

Results

Operator	$C_{\varphi t}$	$C_{\varphi Q}^{(+)}$	$C_{\varphi Q}^{(-)}$	$C_{\varphi tb}$	C_{tW}	C_{tB}	$C_{t\varphi}$
$\mu_{EFT} = 125\text{GeV}$	2.5	1.3	3.2	9.3	0.2	0.07	0.9
$\mu_{EFT} = 1000\text{GeV}$	1.3	0.5	4.3	1.3	0.6	0.08	0.9
Current	2.3	5.1	1.2	5.3	0.06	0.145	3.9
Our results	0.286	0.04	0.336	14.8	0.822	0.592	–

[Ethier J J, Magni G, Maltoni F, et al. Combined SMEFT interpretation of Higgs, diboson, and top quark data from the LHC]

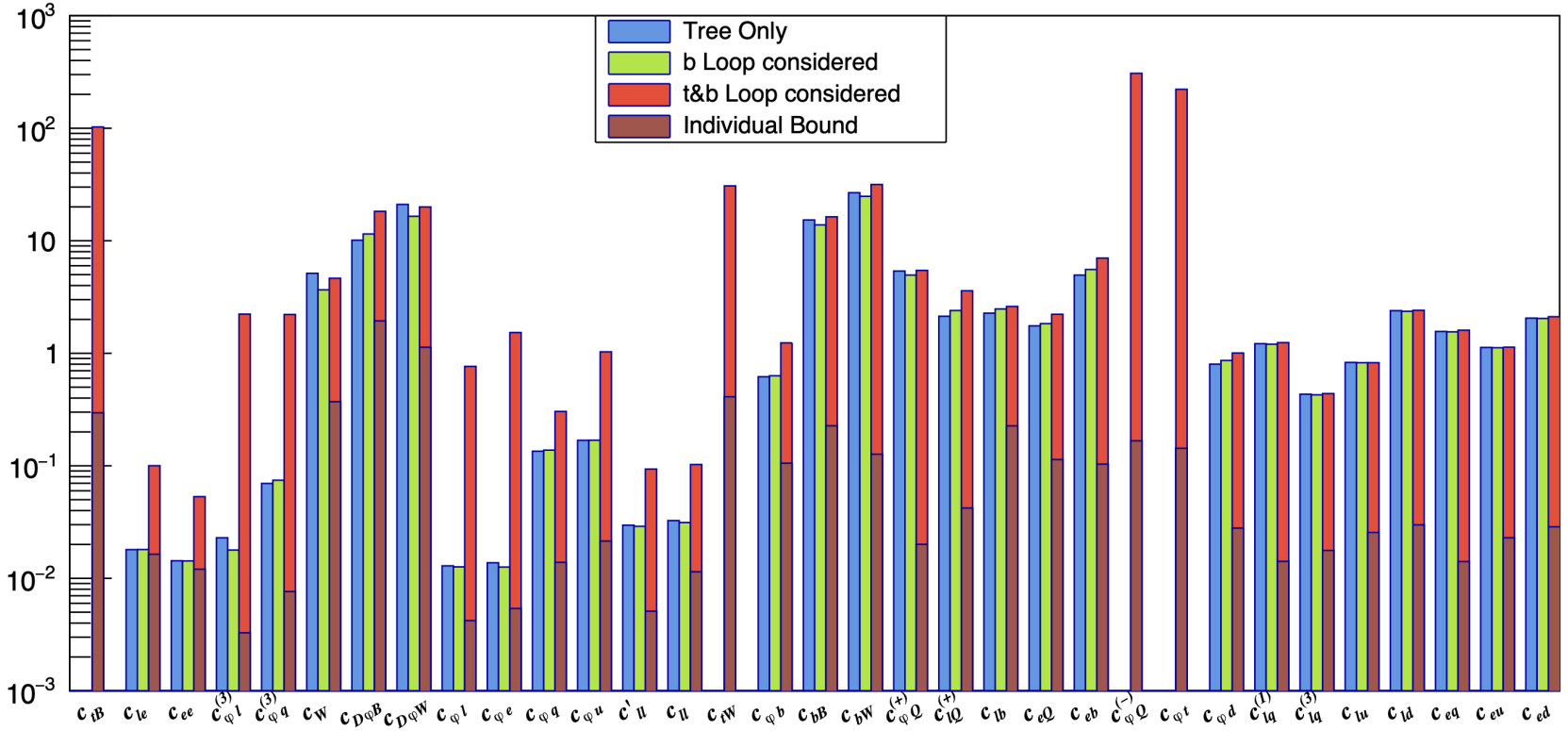
[Alioli S, Cirigliano V, Dekens W, et al. Right-handed charged currents in the era of the Large Hadron Collider [J/OL].]

[Maltoni F, Vryonidou E, Zhang C. Higgs production in association with a top-antitop pair in the Standard Model Effective Field Theory at NLO in QCD [J/OL].]

[Buckley A, Englert C, Ferrando J, et al. Constraining top quark effective theory in the LHC Run II era [J/OL].]

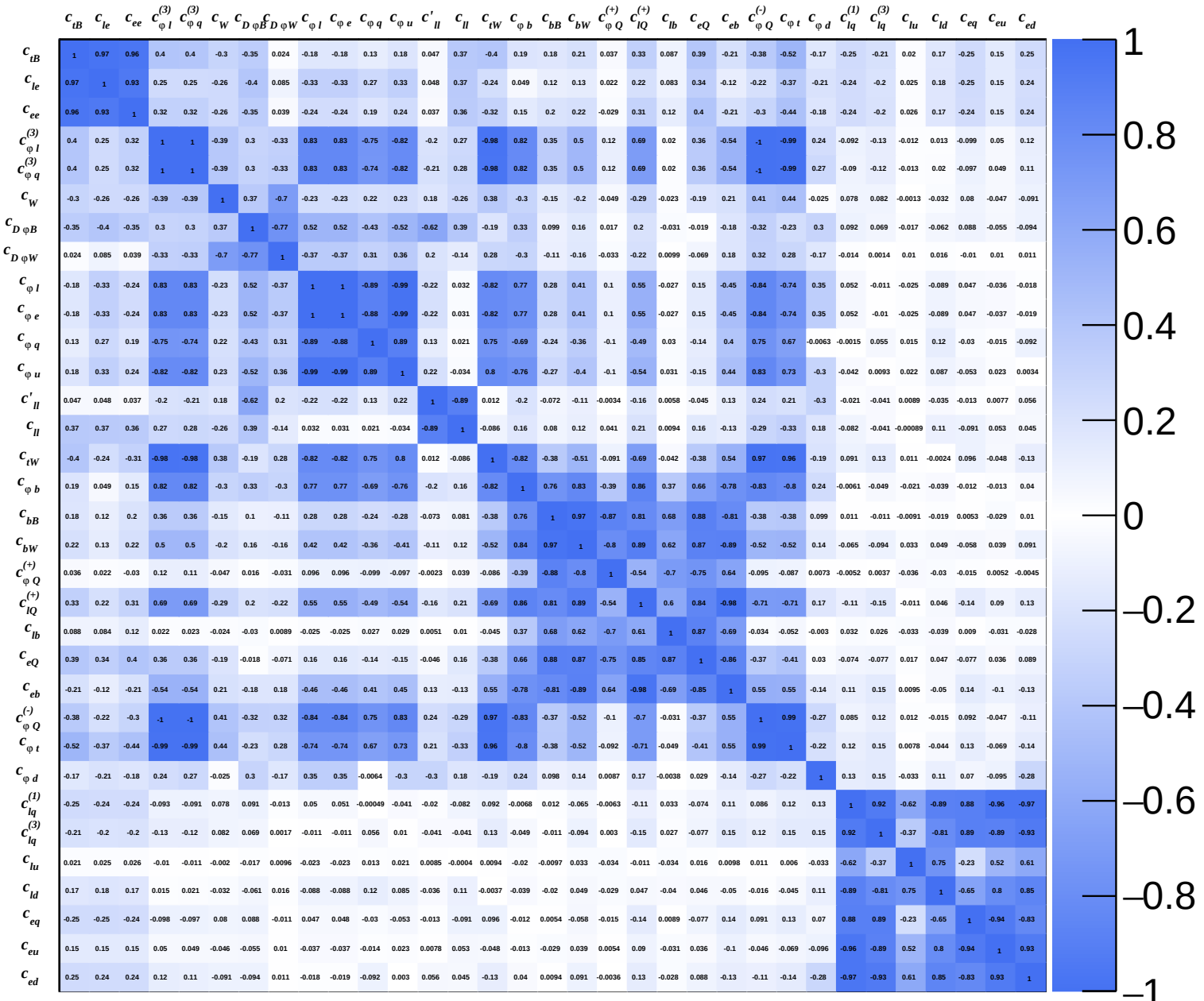
[Vryonidou E, Zhang C. Dimension-six electroweak top-loop effects in Higgs production and decay]

Results

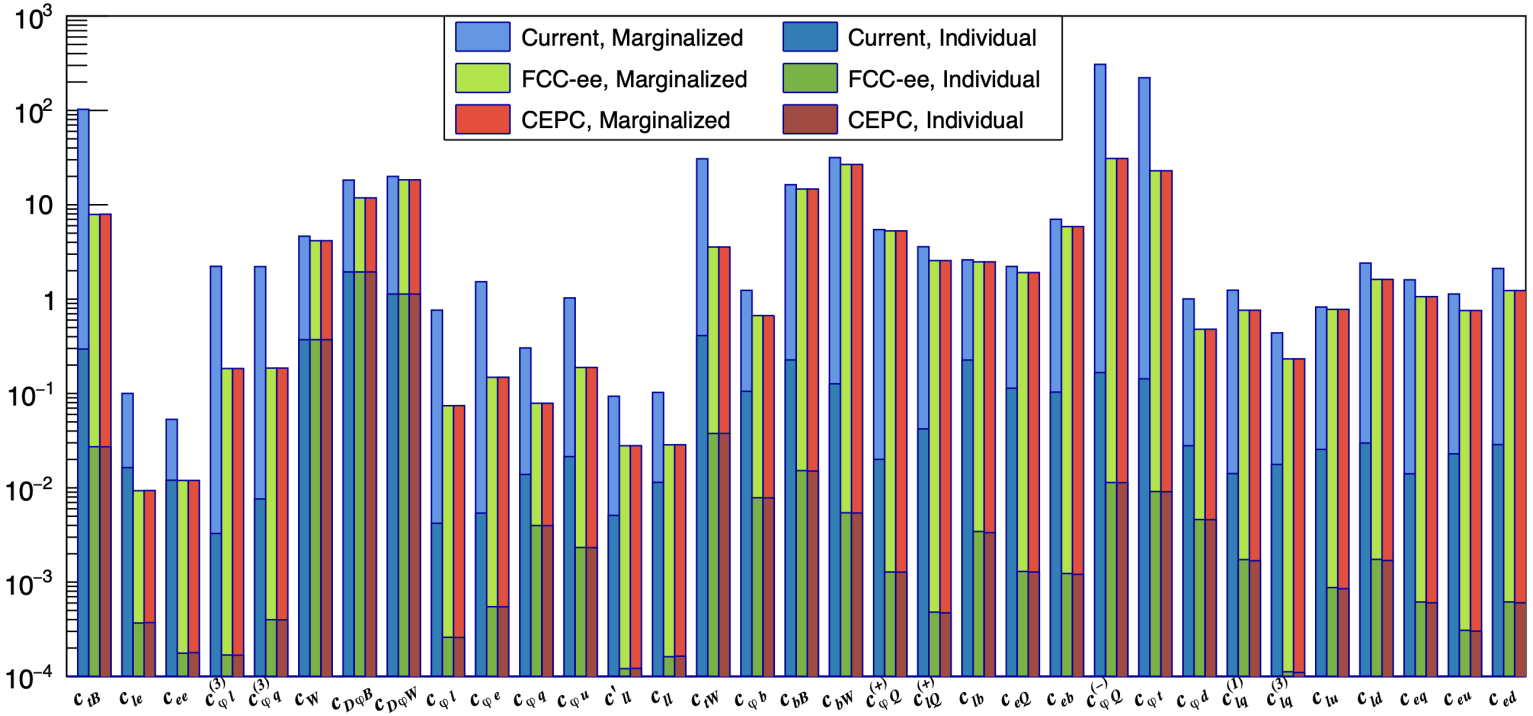

Tree Only
b Loop considered
t&b Loop considered
Individual Bound
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
c_{tB} c_{le} c_{ee} $c_{\varphi l}^{(3)}$ $c_{\varphi q}^{(3)}$ c_W $c_{D\varphi B}$ $c_{D\varphi W}$ $c_{\varphi l}$ $c_{\varphi e}$ $c_{\varphi q}$ $c_{\varphi u}$ c_{ll}' c_{ll} c_{tW} $c_{\varphi b}$ c_{bB} c_{bW} $c_{\varphi Q}^{(+)}$ $c_{lQ}^{(+)}$ c_{lb} c_{eQ} c_{eb} $c_{\varphi Q}^{(-)}$ $c_{\varphi t}$ $c_{\varphi d}$ $c_{lq}^{(1)}$ $c_{lq}^{(3)}$ c_{lu} c_{ld} c_{eq} c_{eu} c_{ed}

Results(tree level)

Results(tree level+loop level)



Results


Current, Marginalized
Current, Individual
FCC-ee, Marginalized
FCC-ee, Individual
CEPC, Marginalized
CEPC, Individual
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
c_{tB} c_{le} c_{ee} $c_{\varphi l}^{(3)}$ $c_{\varphi q}^{(3)}$ c_W $c_{D\varphi B}$ $c_{D\varphi W}$ $c_{\varphi l}$ $c_{\varphi e}$ $c_{\varphi q}$ $c_{\varphi u}$ c_{ll}' c_{ll} c_{tW} $c_{\varphi b}$ c_{bB} c_{bW} $c_{\varphi Q}^{(+)}$ $c_{lQ}^{(+)}$ c_{lb} c_{eQ} c_{eb} $c_{\varphi Q}^{(-)}$ $c_{\varphi t}$ $c_{\varphi d}$ $c_{lq}^{(1)}$ $c_{lq}^{(3)}$ c_{lu} c_{ld} c_{eq} c_{eu} c_{ed}

Conclusions

1. The outstanding precision of these measurements (especially at future lepton colliders) could be sensitive to many important loop contributions of the new physics.
2. The tree-level contributions of the bottom dipole operators to the electroweak processes are non-negligible.
3. Our study is one of the many first steps towards a more complete loop-level SMEFT global analysis, for which many improvements are still needed.

Thank you for your attention!