Impact of NLO QCD/EW corrections in EFT fits

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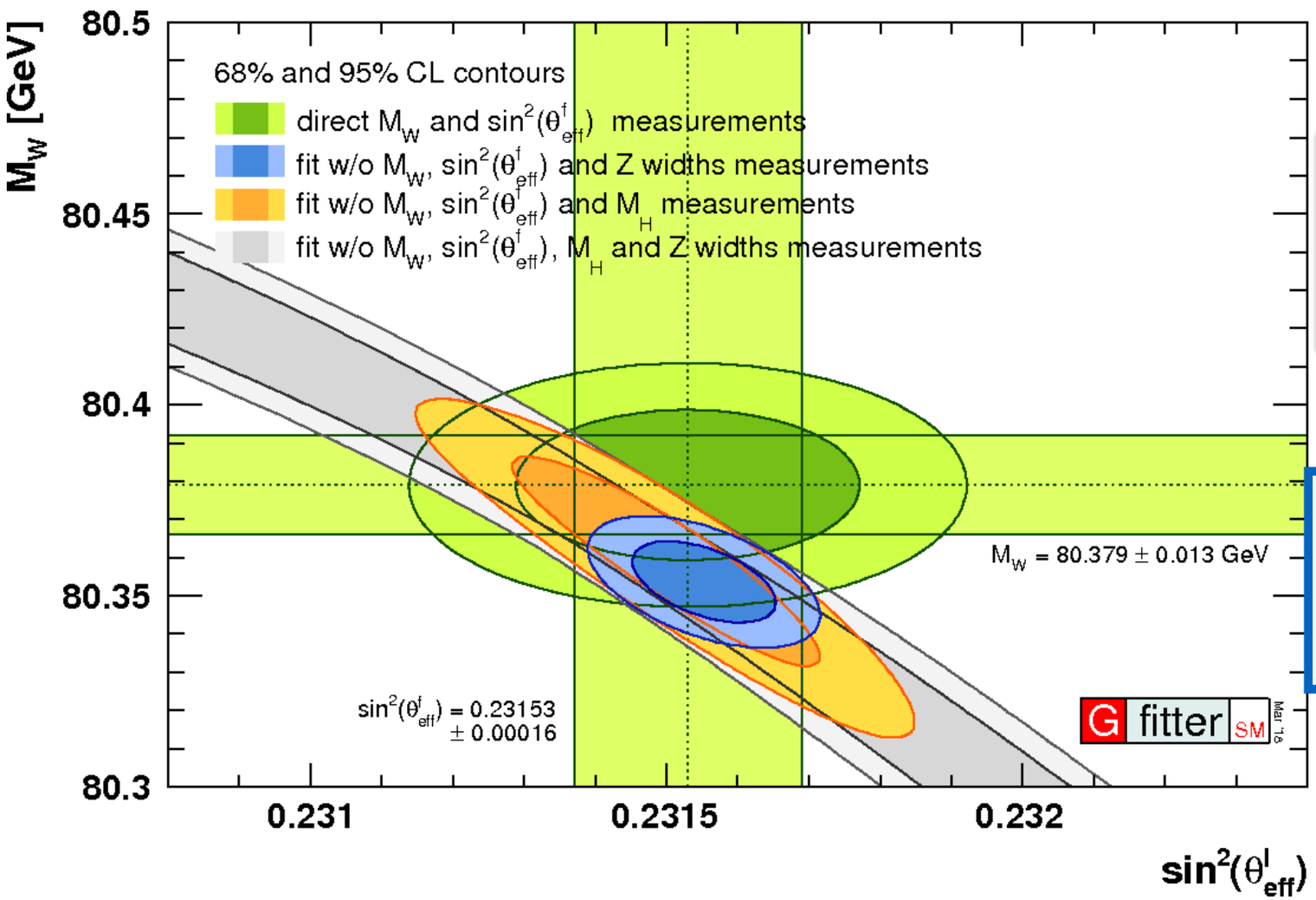
S. Dawson, PPG, arXiv:1909.02000

Precision physics can give information on new physics



Anything that can modify a PO will do it.

Any inconsistency could be an indication of NP

How can we systematically look for new physics?

Assume the SM is low energy limit of an EFT

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_{k=5} \sum_{i} \frac{\mathscr{C}_i^k}{\Lambda^{k-4}} \mathcal{O}_i^k$$

Scale of new physics

Operators respect SM gauge symmetries

The theory is renormalizable order by order in powers of Λ

We consider only Dimension-6 operators

We use EWPO to study the effects of NLO corrections on SMEFT

Induced effective couplings

$$
\begin{aligned}
L \equiv\ & 2M_Z\sqrt{\sqrt{2}G_\mu}Z_\mu\left[g_L^{Zq}+\delta g_L^{Zq}\right]\bar{q}\gamma_\mu q + 2M_Z\sqrt{\sqrt{2}G_\mu}Z_\mu\left[g_R^{Zu}+\delta g_R^{Zu}\right]\bar{u}_R\gamma_\mu u_R \\
& +2M_Z\sqrt{\sqrt{2}G_\mu}Z_\mu\left[g_R^{Zd}+\delta g_R^{Zd}\right]\bar{d}_R\gamma_\mu d_R + 2M_Z\sqrt{\sqrt{2}G_\mu}Z_\mu\left[g_L^{Zl}+\delta g_L^{Zl}\right]\bar{l}\gamma_\mu l \\
& +2M_Z\sqrt{\sqrt{2}G_\mu}Z_\mu\left[g_R^{Ze}+\delta g_R^{Ze}\right]\bar{e}_R\gamma_\mu e_R + 2M_Z\sqrt{\sqrt{2}G_\mu}\left(\delta g_R^{Z\nu}\right)\bar{\nu}_R\gamma_\mu\nu_R \\
& +\frac{\bar{g}_2}{\sqrt{2}}\left\{W_\mu\left[(1+\delta g_L^{Wq})\bar{u}_L\gamma_\mu d_L + \left(\delta g_R^{Wq}\right)\bar{u}_R\gamma_\mu d_R\right]\right. \\
& \left. +W_\mu\left[(1+\delta g_L^{Wl})\bar{\nu}_L\gamma_\mu e_L + \left(\delta g_R^{W\nu}\right)\bar{\nu}_R\gamma_\mu e_R\right] + h.c.\right\}.
\end{aligned}
$$

Do not interfere with SM

Not independent at LO due to SU(2)

$$
\begin{aligned}
\delta g_L^{Wq} &= \delta g_L^{Zu} - \delta g_L^{Zd} \\
\delta g_L^{Wl} &= \delta g_L^{Z\nu} - \delta g_L^{Ze}.
\end{aligned}
$$

7 new parameters (3+2*2)

At LO effective couplings depend on (Warsaw basis)

$\mathcal{O}_{ll}$	$(\bar{l}\gamma_\mu l)(\bar{l}\gamma^\mu l)$	$\mathcal{O}_{\phi WB}$	$(\phi^\dagger\tau^a\phi)\, W^a_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{\phi D}$	$\left(\phi^\dagger D^\mu\phi\right)^* \left(\phi^\dagger D_\mu\phi\right)$
$\mathcal{O}_{\phi e}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{e}_R\gamma^\mu e_R)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{u}_R\gamma^\mu u_R)$	$\mathcal{O}_{\phi d}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{d}_R\gamma^\mu d_R)$
$\mathcal{O}^{(3)}_{\phi q}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\,\phi)(\bar{q}\tau^a\gamma^\mu q)$	$\mathcal{O}^{(1)}_{\phi q}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{q}\tau^a\gamma^\mu q)$	$\mathcal{O}^{(3)}_{\phi l}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\,\phi)(\bar{l}\tau^a\gamma^\mu l)$
$\mathcal{O}^{(1)}_{\phi l}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{l}\tau^a\gamma^\mu l)$				

Only 8 combinations can be probed at a time

$$M_W, g_L^{zu}, g_L^{zd}, g_L^{ze}, g_L^{z\nu}, g_R^{zu}, g_R^{zd}, g_R^{ze}$$

At NLO 10 combinations but 32 operators

NLO corrections are computed at order $\mathcal{O}(\frac{v^2}{\Lambda^2})$

SM is renormalized in OS | Operators are treated as $\overline{\text{MS}}$

$$\mathscr{C}_i(\mu) = \mathscr{C}_{0,i} - \frac{1}{2\epsilon}\frac{1}{16\pi^2}\gamma_{i,j}\mathscr{C}_j$$

RGE mixing: new operators enter here

E. Jenkins, A. Manohar, M. Trott JHEP 1310 (2013) 087, JHEP 1401 (2014) 035;
R. Alonso, E. Jenkins, A. Manohar, M. Trott JHEP 1404 (2014) 159

Input scheme α, G_μ, M_Z

Most precisely known inputs

$$G_\mu = \frac{1}{\sqrt{2}v^2}\left(1 + \frac{v^2}{\Lambda^2}(2\mathscr{C}_{\phi l}^{(3)} - \mathscr{C}_{ll}) + \Delta_r\right)$$

Relationship between parameters changed at tree level

SM and SMEFT at NLO $\Delta_r = \Delta_{r,SM} + \frac{v^2}{\Lambda^2}\Delta_{r,EFT}$

S. Dawson, PPG, PRD 97 (2018) no.9, 093003

New (large) input scheme uncertainties

$$M_W^2 = \frac{M_z^2}{2}\left(1 + \sqrt{1 - \frac{\sqrt{8}\pi\alpha(1+\Delta r)}{G_\mu M_z^2}}\right) + \delta M_W^{SMEFT}$$

SM Quantum corrections (known)

$\Delta r \rightarrow \Delta r(M_Z, G_\mu, \alpha, M_h, m_t, \alpha_s)$

Dubovyk, A. Freitas, J. Gluza, T. Riemann, and J. Usovitsch: arXiv:1906.08815; A. Fritas: arXiv: 1401.2447; M. Awramik, M. Czakon, A. Freitas, and G. Weiglein; arXiv: arXiv:hep-ph/0311148

EFT corrections

Many new operators at NLO

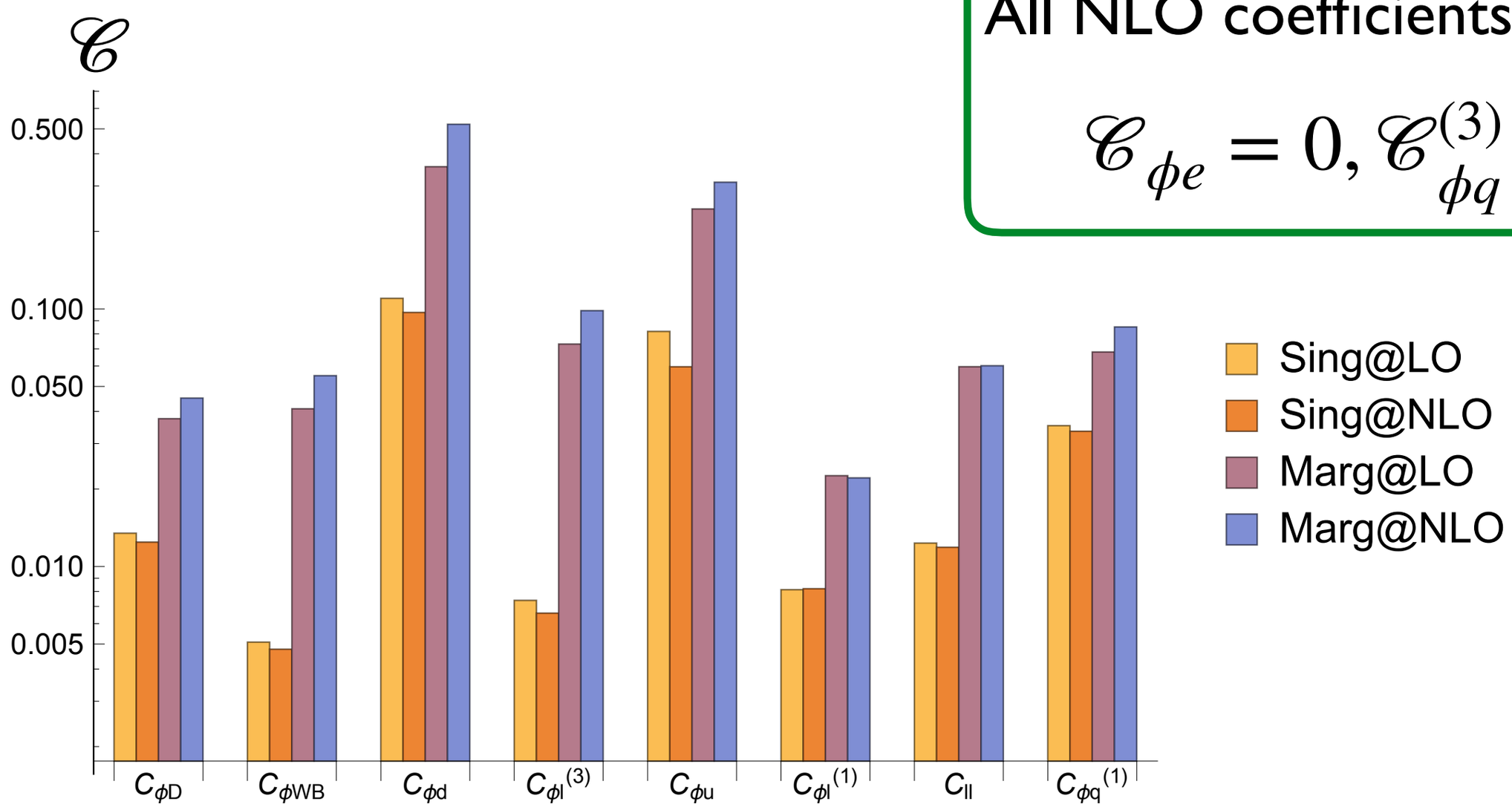
$$\delta M_W^{LO} = \frac{v^2}{\Lambda^2}\left\{-29.827\mathcal{C}_{\phi l}^{(3)} + 14.914\mathcal{C}_{ll} - 27.691\mathcal{C}_{\phi D} - 57.479\mathcal{C}_{\phi WB}\right\}$$

$$\begin{aligned}\delta M_W^{NLO} = \frac{v^2}{\Lambda^2}\Big\{&-35.666\mathcal{C}_{\phi l}^{(3)} + 17.243\mathcal{C}_{ll} - 30.272\mathcal{C}_{\phi D} - 64.019\mathcal{C}_{\phi WB}\\ &-0.137\mathcal{C}_{\phi d} - 0.137\mathcal{C}_{\phi e} - 0.166\mathcal{C}_{\phi l}^{(1)} - 2.032\mathcal{C}_{\phi q}^{(1)} + 1.409\mathcal{C}_{\phi q}^{(3)} + 2.684\mathcal{C}_{\phi u}\\ &+0.438\mathcal{C}_{lq}^{(3)} - 0.027\mathcal{C}_{\phi B} - 0.033\mathcal{C}_{\phi\Box} - 0.035\mathcal{C}_{\phi W} - 0.902\mathcal{C}_{uB} - 0.239\mathcal{C}_{uW} - 0.15\mathcal{C}_W\Big\}\end{aligned}$$

Fit on PO: $M_W, \Gamma_W, \Gamma_Z, \sigma_h, R_l, R_b, R_c, A_{l,FB}, A_{b,FB}, A_{c,FB}, A_l, A_b, A_c$

All NLO coefficients put to 0

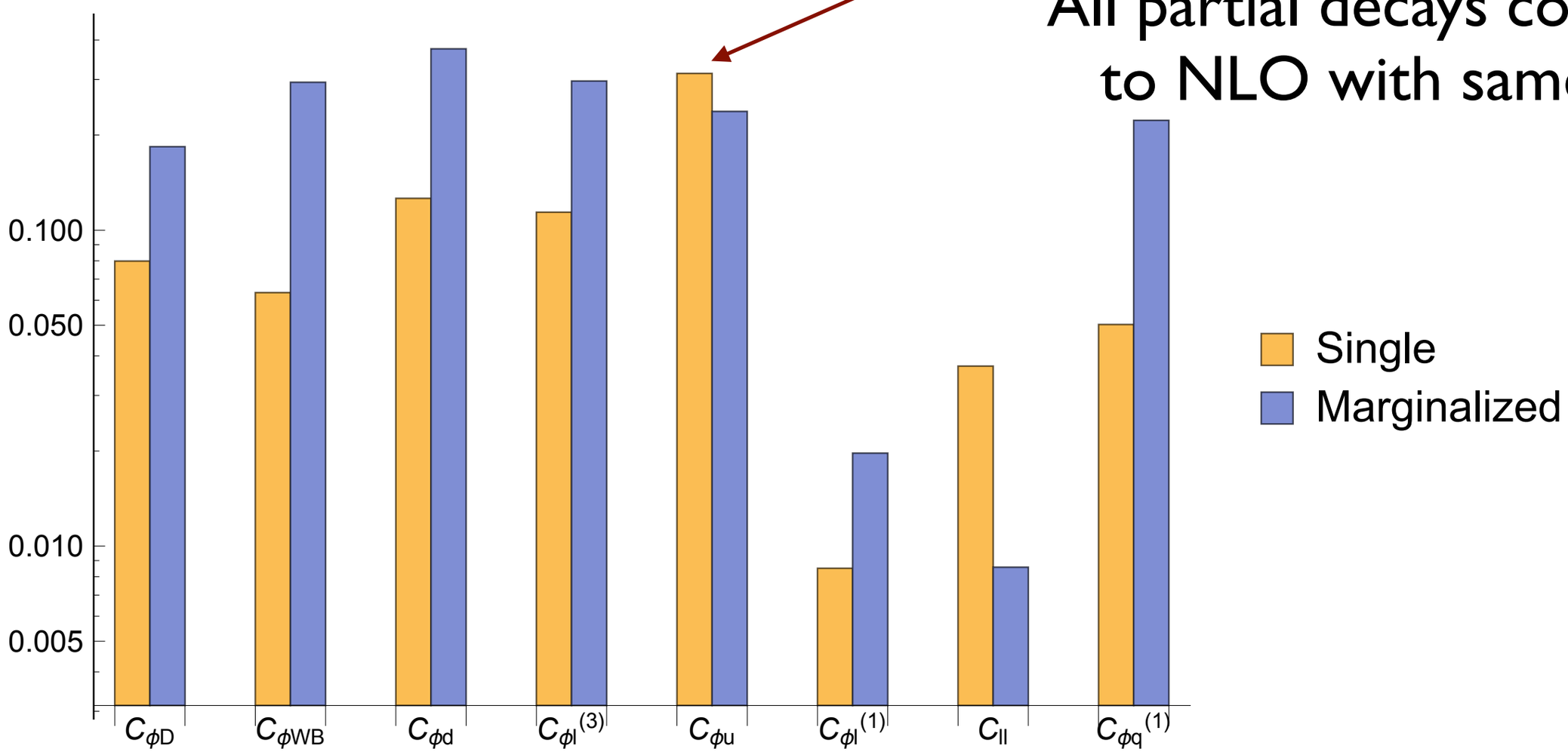
$$\mathscr{C}_{\phi e} = 0, \mathscr{C}^{(3)}_{\phi q} = 0$$



Size of NLO corrections

Strongest bounds from Γz

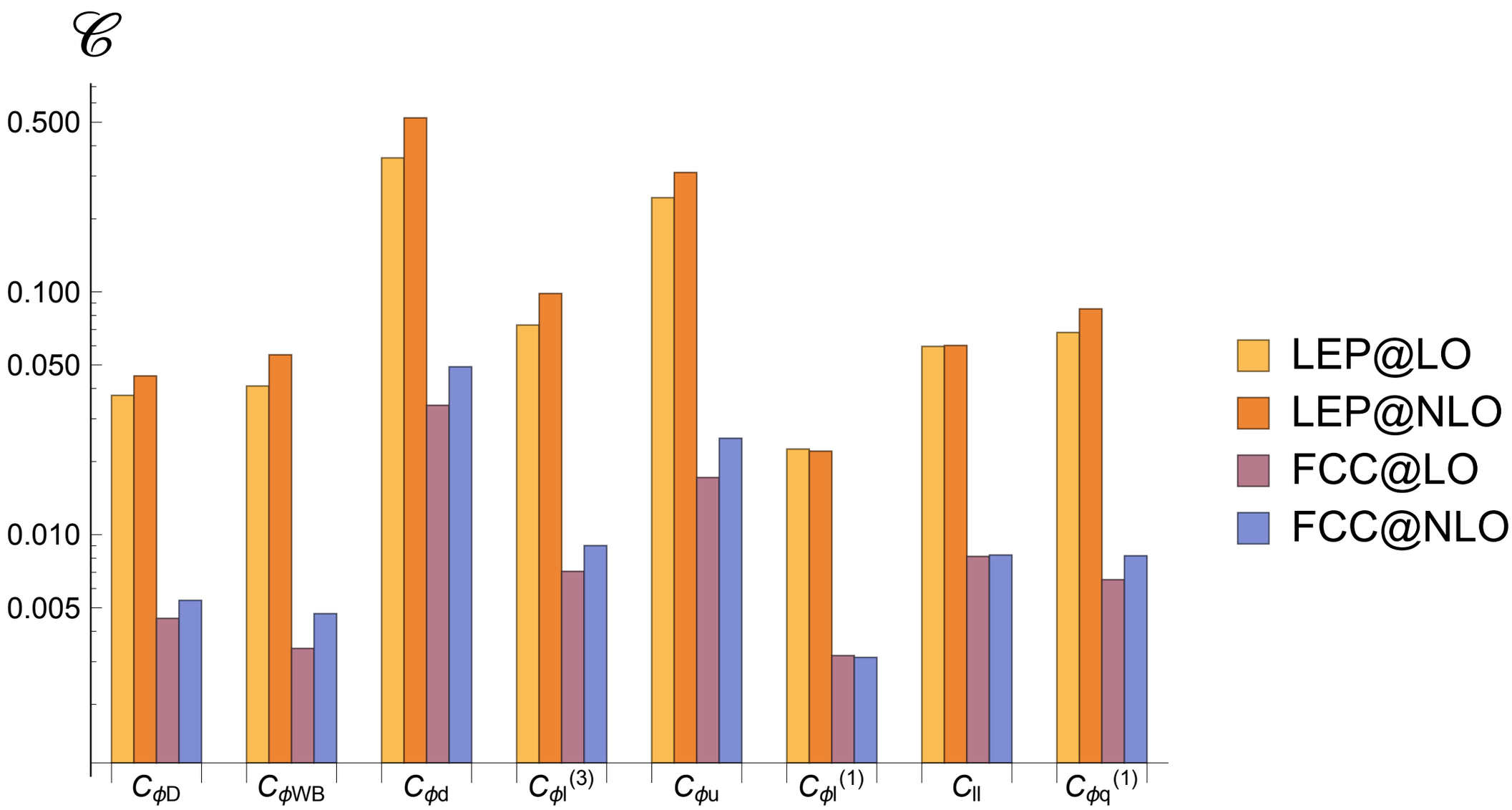
All partial decays contribute to NLO with same sign.



Large NLO corrections seem to propagate

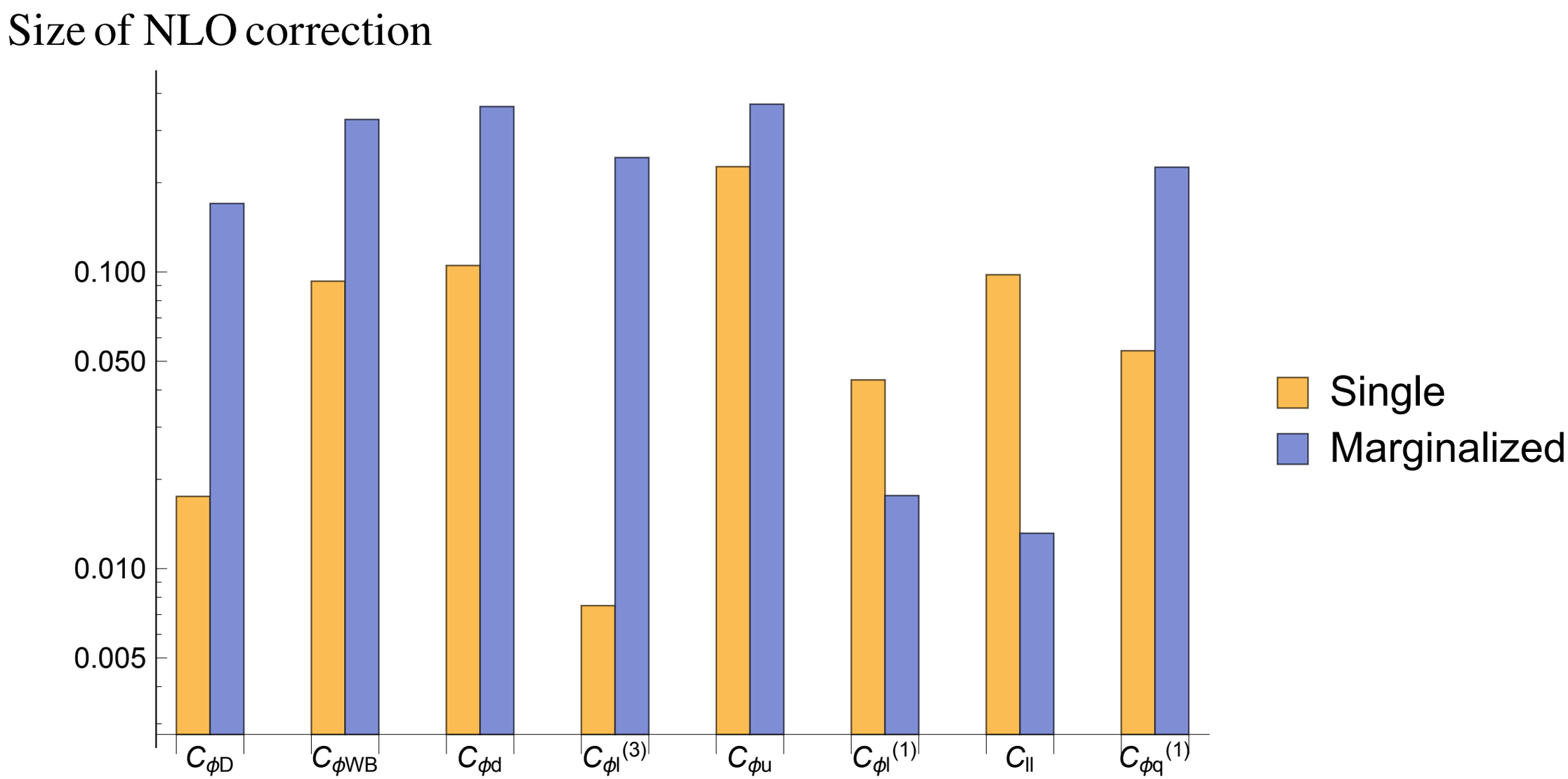
Marginalized fit LEP vs FCC-ee

Standard Model Theory for the FCC-ee Tera-Z stage; arXiv:1809.01830v3



Similar behavior (better reach)

Single vs. Marg. fit at FCC-ee



Large effects (20~30%) in marginalized fits

Conclusions

- I have presented a calculation of the complete NLO EW and QCD corrections to the EWPO in the SMEFT.
- and used it to test their effects on the EFT fits.
- NLO effects are possibly large and should be taken into account.
- I considered only EWPO, similar studies for Higgs and Top data are necessary.
- A more general fit, that uses Higgs and Top results and measurements at other regimes could include omitted (NLO) operators.