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Impact of NLO QCD/EW in EFT fits

**Introduction**

Precision physics can give information on new physics

How can we systematically look for new physics?

Anything that can modify a PO will do it.

Any inconsistency could be an indication of NP
Assume the SM is low energy limit of an EFT

\[ \mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{k=5} \sum_{i} \frac{\mathcal{C}_{ki}}{\Lambda^{k-4}} \mathcal{O}_{ki} \]

Scale of new physics

Operators respect SM gauge symmetries

The theory is renormalizable order by order in powers of \( \Lambda \)

We consider only Dimension-6 operators

We use EWPO to study the effects of NLO corrections on SMEFT
Effective Z and W couplings

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

Do not interfere with SM

Not independent at LO due to SU(2)

7 new parameters (3+2*2)

\[
\delta g_L^{Wq} = \delta g_L^{Zu} - \delta g_L^{Zd}
\]
\[
\delta g_L^{Wl} = \delta g_L^{Z\nu} - \delta g_L^{Ze}.
\]
At LO effective couplings depend on (Warsaw basis)

<table>
<thead>
<tr>
<th>$O_{ll}$</th>
<th>$(\bar{l}<em>i \gamma</em>{\mu} l)(\bar{l}_j \gamma^{\mu} l)$</th>
<th>$O_{\phi WB}$</th>
<th>$(\phi^\dagger \gamma^{a} \phi) W_{\mu \nu}^a B^{\mu \nu}$</th>
<th>$O_{\phi D}$</th>
<th>$(\phi^\dagger D^\mu \phi)^* (\phi^\dagger D_{\mu} \phi)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_{\phi e}$</td>
<td>$(\phi^\dagger i \bar{D}_\mu \phi)(\bar{e}_R \gamma^{\mu} e_R)$</td>
<td>$O_{\phi u}$</td>
<td>$(\phi^\dagger i \bar{D}_\mu \phi)(\bar{u}_R \gamma^{\mu} u_R)$</td>
<td>$O_{\phi d}$</td>
<td>$(\phi^\dagger i \bar{D}_\mu \phi)(\bar{d}_R \gamma^{\mu} d_R)$</td>
</tr>
<tr>
<td>$O^{(3)}_{\phi q}$</td>
<td>$(\phi^\dagger i \bar{D}_\mu \phi)(\bar{q}_R \gamma^{\mu} q)$</td>
<td>$O^{(1)}_{\phi q}$</td>
<td>$(\phi^\dagger i \bar{D}_\mu \phi)(\bar{q}_R \gamma^{\mu} q)$</td>
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<td>$(\phi^\dagger i \bar{D}_\mu \phi)(\bar{l}_R \gamma^{\mu} l)$</td>
</tr>
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<td>$(\phi^\dagger i \bar{D}_\mu \phi)(\bar{l}_R \gamma^{\mu} l)$</td>
<td></td>
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</tr>
</tbody>
</table>

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 $\mathcal{O}\left(\frac{v^2}{\Lambda^2}\right)$.

SM is renormalized in OS

Operators are treated as $\overline{\text{MS}}$

$$C_i(\mu) = C_{0,i} - \frac{1}{2\epsilon} \frac{1}{16\pi^2} \gamma_{i,j} C_j$$

RGE mixing: new operators enter here

Impact of NLO QCD/EW in EFT fits

SMEFT @ NLO

Input scheme \(\alpha, G_\mu, M_Z\)

Most precisely known inputs

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

Relationship between parameters changed at tree level

SM and SMEFT at NLO

\[ \Delta_r = \Delta_{r,SM} + \frac{v^2}{\Lambda^2} \Delta_{r,EFT} \]

New (large) input scheme uncertainties

S. Dawson, PPG, PRD 97 (2018) no.9, 093003
\[ M_W^2 = \frac{M_Z^2}{2} \left( 1 + \sqrt{1 - \frac{\sqrt{8\pi\alpha(1 + \Delta r)}}{G_\mu M_Z^2}} \right) + \delta M_W^{\text{SMEFT}} \]

**SM Quantum corrections (known)**

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

**EFT corrections**

\[ \delta M_W^{\text{LO}} = \frac{v^2}{\Lambda^2} \left\{ -29.827C_{\phi l}^{(3)} + 14.914C_{ll} - 27.691C_{\phi D} - 57.479C_{\phi WB} \right\} \]

\[ \delta M_W^{\text{NLO}} = \frac{v^2}{\Lambda^2} \left\{ -35.666C_{\phi l}^{(3)} + 17.243C_{ll} - 30.272C_{\phi D} - 64.019C_{\phi WB} \right. \]

\[ \left. -0.137C_{\phi d} - 0.137C_{\phi e} - 0.166C_{\phi l}^{(1)} - 2.032C_{\phi q}^{(1)} + 1.409C_{\phi q}^{(3)} + 2.684C_{\phi u} \right. \]

\[ +0.438C_{lq}^{(3)} - 0.027C_{\phi B} - 0.033C_{\phi \Box} - 0.035C_{\phi W} - 0.902C_{uB} - 0.239C_{uW} - 0.15C_W \]
Impact of NLO QCD/EW in EFT fits

Single vs Marg. at LEP

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

\( C_{\phi e} = 0, C^{(3)}_{\phi q} = 0 \)
Impact of NLO QCD/EW in EFT fits

Size of NLO corrections

Strongest bounds from $\Gamma_z$:
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)
Impact of NLO QCD/EW in EFT fits

Single vs. Marg. fit at FCC-ee

Size of NLO correction

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.