$t\bar{t}Z$ reweighting studies with SMEFT@NLO

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LHC EFT prediction note
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Introduction

Previous presentation (link to the slides):
• Successfully generated MC samples for the ttZ process using MadGraph and the SMEFTatNLO model.
• Comparison of most interesting kinematic distributions for different dimension-6 operators.
• Validation of the reweighting introducing a different way to compute the uncertainties.

To do list:
• Compare the new uncertainty with sumW2.
• Check the performance of the reweighting for smaller values of Wilson coefficients.
• Compare reweighting method with separate sample method.
• Compare SMEFTatNLO with SMEFTsim.
SMEFT with $t\bar{t}Z$

• Studying the $t\bar{t}Z$ process it is possible to probe the **interaction** between the **top** quark and the **Z** boson.

• Contributions from **dimension-6** operators would lead in **energy growths** for some specific operators:

\[
\begin{align*}
O_{tG} & & O_{\phi t} & & O_{tZ} & & O_{tW} \\
O_{\phi Q}^{(-)} & & O_{\phi Q}^{(3)} & & O_{\phi Q}^{(3)}
\end{align*}
\]
Sample generation

\[ \mathcal{L} = \frac{1}{\Lambda^0} \mathcal{L}^{(d=4)}_{SM} + \frac{1}{\Lambda} \mathcal{L}^{(d=5)} + \frac{1}{\Lambda^2} \mathcal{L}^{(d=6)} + \ldots \]

- MC samples generated with MadGraph5 (v2.6.5) using the SMEFT@NLO (v1.0.3) and SMEFTsim_topU3l.
- Madspin card for the decay of the Z into two leptons.
- Production of nanoGEN files to test the reweighting and the effect of the operators on relevant variables of the process.
- Event showered with PYTHIA8.
- Reweighting validation performed comparing samples obtained setting the Wilson coefficients trough the customize card with sample produced using the reweighting card.
Top $p_t$ distributions

Comparison between samples obtained through the customize card with sample produced using the reweighting card.

Custom error:

$$\Delta_{\text{bin}} = \left( \frac{1}{N} \sum_i w_i^{\text{BSM}} \right) \sqrt{\sum_j (w_j^{\text{BSM}})^2} + \left( \frac{1}{N} \sum_i w_i^{\text{SM}} \right) \sqrt{\sum_j (w_j^{\text{BSM}} - w_j^{\text{BSM}})^2}$$
Comparison between samples obtained through the **customize** card with sample produced using the **reweight** card.

Custom error:

$$
\Delta_{\text{bin}} = \left( \frac{1}{N} \sum_i w_i^{\text{BSM}} \right) \sqrt{ \sum_j \left( w_j^{\text{BSM}} \right)^2 } + \\
\left( \frac{1}{N} \sum_i w_i^{\text{SM}} \right) \sqrt{ \sum_j \left( w_j^{\text{BSM}} - w_j^{\text{BSM}} \right)^2 }
$$
Top $p_t$ distributions

Same plots as before but for Wilson coefficient equal to 0.1, i.e. close to the current best limit.

Smaller fluctuations.
$Z p_t$ distributions

Same plots as before but for Wilson coefficient equal to 0.1, i.e. close to the current best limit.

Smaller fluctuations.
Attempt for the separate sample method

Attempt to generate linear and quadratic part separately in SMEFTatNLO.

```
generate p p > t t~ z QCD=2 QED=1 NP^2==2 [QCD] @0

aMCatNLOError: Poles do not cancel, run cannot continue
```

```
generate p p > t t~ z QCD=2 QED=1 NP^2==4 [QCD] @0

FKSProcessError : Cannot map born/real configurations between
g g > z t t~ NP<=2 QCD<=2 QED<=1 [ all = QCD ] NP^2==4 and
g g > z t t~ g NP<=2 QCD<=3 QED<=1 WEIGHTED<=12 [ all = QCD ] NP^2==4
(i,j=6,4): not same number of configurations: 30 38
```
Generation with SMEFTsim

Generation of ttZ at LO + 1 jet:

- Main settings for the generation of the samples:
  1. Dynamical scale choice = 3
  2. MLM matching
  3. xqcut = 30

- Restrict card wrote on purpose for the set of operators considered.

- Wilson coefficient chosen to compare with the operators already studied with SMEFTatNLO.

\[
\begin{align*}
\mathcal{L}_{6}^{(6)} & \quad \text{ctGRe} \quad - gs \quad \text{ctG} \\
\mathcal{L}_{6}^{(6)} & \quad - \text{ctWRe} \quad \text{ctW} \\
& \quad - \text{ctWRe} \ c_{\theta} + \text{ctBRe} \ s_{\theta} \quad \text{ctZ} \\
\end{align*}
\]

\[
\begin{align*}
\text{ctG} = 1 & \quad \longrightarrow \quad \text{ctGRe} = - g_{s} \\
\text{ctZ} = 1 \text{ and } \text{ctW} = 0 & \quad \longrightarrow \quad \text{ctBRe} = \frac{1}{\sin(\theta_{W})}
\end{align*}
\]
Top $p_t$ distributions

- Samples produced using the reweight card.
- 1M events for SMEFTatNLO and ~500k event for SMEFTsim.
- Wilson coefficient set to the values previously showed.
**Z p_t distributions**

- Samples produced using the reweight card.
- 1M events for SMEFTatNLO and ~500k events for SMEFTsim.
- Wilson coefficient set to the values previously showed.
Leading jet $p_t$ distributions

- Samples produced using the reweight card.
- 1M events for SMEFTatNLO and ~500k events for SMEFTsim.
- Wilson coefficient set to the values previously showed.
Conclusions

Successfully generated $t\bar{t}Z$ process using MadGraph reweighting.

- Custom error is slightly bigger than sumW2.
- The reweighting is working fine even if there are some fluctuations at high $p_T$ for large value values of Wilson coefficients.
- The separate sample method is not working at the moment.
- The NLO with LO comparison seems to be reasonable with few differences probably due to the virtual corrections.
Backup slides
Top and Z $p_t$ distributions

Comparison between SM distributions and SMEFT distributions obtained through reweighting.

- Excess for the $O_{tZ}$ and $O_{tG}$ operators show energy growth in $\bar{t}tZ$.
- Small and flat effect visible for the $O_{\phi t}$ and $O^{(-)}_{\phi Q}$ operators.
- No effect for the remaining ones.
Leading jet and lepton $p_t$ distributions

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