PROCEEDINGS OF SCIENCE

Modelling uncertainties of $t\bar{t}W$ in multi-lepton channel

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We compare fixed order and parton shower matched predictions for the process $pp \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell\ell^{\pm}\overset{(-)}{\nu}_\ell b\bar{b} + X$ at NLO in QCD, including the orders $O(\alpha_s^3\alpha^6)$ and $O(\alpha_s\alpha^8)$. The comparison is performed at the integrated and differential fiducial level at the LHC with $\sqrt{s} = 13$ TeV. In the absence of parton shower matching procedure that includes the full off-shell effects for this process at NLO in QCD, we propose a new prescription. It enables the inclusion of approximate full off-shell effects to currently available parton shower matched predictions at NLO in QCD.

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1. Introduction

The associated production of a top pair and a $W^{\pm}$ gauge boson is an important SM process. It displays a rich phenomenology as a signal process, with applications such as the charge asymmetry [1–3]. Furthermore, it is the dominant background to $t\bar{t}H$ in the multi-lepton decay channels [4–7]. Despite good agreement in the SM, a slight tension between experimental measurements and theoretical predictions has been persistently apparent in comparisons so far. This has been attributed to mis-modelling of the process on the theory side. Thus, with the purpose of improving on current theory predictions, we present a direct comparison of state-of-the-art fixed order and parton shower matched predictions in ref. [8]. Additionally we also propose a prescription, which aims to combine the best aspects of the modelling approaches.

2. Analysis Setup

We present predictions for $pp \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell\ell^{\pm}\bar{\nu}_\ell b\bar{b} + X$ at NLO in QCD. Here ℓ labels $\ell \in \{e, \mu\}$ The calculation includes two main contributions, which can be categorized by the coupling order: the NLO QCD correction to the QCD Born at order $O(\alpha_s^3\alpha^6)$ and the NLO QCD corrections to the pure EW Born $O(\alpha_s\alpha^8)$. For ease of notation, they will be labelled $t\bar{t}W$ QCD and $t\bar{t}W$ EW respectively. We provide fixed order predictions and parton shower matched predictions (NLO+PS). Fixed order predictions include full off-shell predictions, the full NWA and NWA with LO decays. They are generated using the Helac-Nlo software [9–15]. Parton shower matched predictions are generated via Powheg-Box [16–22] and MG5_aMC@NLO [23–26]. Various details are considered to align fixed order and parton shower matched predictions. These are discussed in detail in [8].

3. Results

Results for the integrated fiducial cross section are shown in table 1. The subleading $t\bar{t}W$ EW contribution is sizeable and around 13% of the dominant $t\bar{t}W$ QCD contribution. The full off-shell effects amount to 0.1% for $t\bar{t}W$ QCD and a surprising 9% for $t\bar{t}W$ EW. The enhancement for $t\bar{t}W$ EW is due to $WW \to WW$ scattering diagrams. The size of NLO QCD corrections to the decays is −6% for $t\bar{t}W$ QCD and +15% for $t\bar{t}W$ EW. Neglecting NLO QCD corrections to the

$t\bar{t}W^{\pm}$	$t\bar{t}W$ QCD	$t\bar{t}W$ EW
Full off-shell	$1.58^{+3\%}_{-6\%}$	$0.206^{+22\%}_{-17\%}$
NWA	$1.57^{+3\%}_{-6\%}$	$0.190^{+22\%}_{-16\%}$
$\text{NWA}_{\text{LOdec}}$	$1.66^{+10\%}_{-10\%}$	$0.162^{+22\%}_{-16\%}$
Powheg-Box	$1.40^{+11\%}_{-11\%}$	$0.133^{+21\%}_{-16\%}$
MG5_aMC@NLO	$1.40^{+11\%}_{-11\%}$	$0.136^{+21\%}_{-6\%}$

Table 1: Integrated fiducial cross sections for $pp \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell\ell^{\pm}\bar{\nu}_\ell b\bar{b} + X$ at NLO in QCD at order $O(\alpha_s^3\alpha^6)$ and $O(\alpha_s\alpha^8)$) for various modelling approaches.

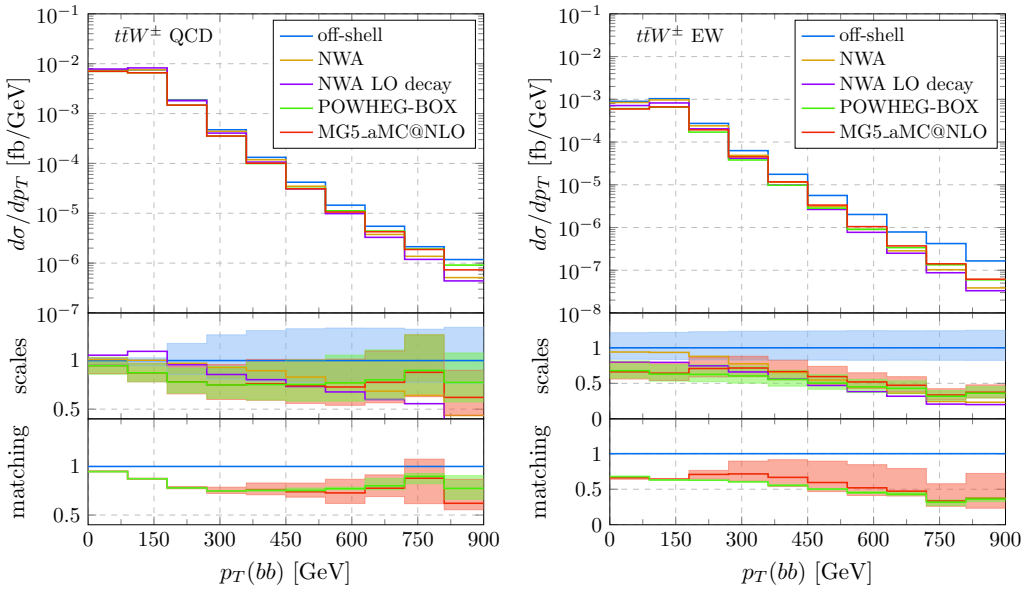

Figure 1: Differential fiducial cross section for $pp \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell\ell^\pm\bar{\nu}_\ell b\bar{b} + X$ at NLO in QCD at order $O(\alpha_s^3\alpha^6)$ (left) and $O(\alpha_s\alpha^8)$ (right). The first panel displays absolute predictions for various modelling approaches, whereas the second panel shows the ratio to the full off-shell predictions with scale uncertainty bands. The last panel displays matching uncertainties for NLO+PS predictions.

decays also impacts the size of the theoretical scale uncertainty for $t\bar{t}W$ QCD. It increases from at most 6% for full off-shell predictions and the full NWA, to 10% for $\text{NWA}_{\text{LOdec}}$. On the other hand, the scale uncertainty for $t\bar{t}W$ EW is unaffected by the modelling and it is LO like, due to the non-trivial α_s dependence appearing at NLO. Parton shower matched predictions generated with POWHEG-BOX and MG5_aMC@NLO are in perfect agreement with each other. They exhibit a similar scale dependence to $\text{NWA}_{\text{LOdec}}$ for both $t\bar{t}W$ QCD and $t\bar{t}W$ EW. Compared to fixed order predictions, NLO+PS predictions have a smaller central value because of the multiple radiations. Differential predictions for the transverse momentum of the two hardest b-jet system for $t\bar{t}W$ QCD and $t\bar{t}W$ EW are displayed in figure 1. Full off-shell predictions have a harder high p_T spectrum due to single-resonant contributions, which are not present in any of the other modelling approaches. The discrepancies are more pronounced for $t\bar{t}W$ EW, where the scale uncertainty bands do not overlap. Parton shower matched predictions agree well with each other within scale and matching uncertainties.

	$t\bar{t}W^{\pm}$ QCD+EW
Full off-shell	$1.79^{+6\%}_{-7\%}$
NLO+PS	$1.53^{+12\%}_{-11\%}$
NLOPS+$\Delta\sigma$	$1.56^{+13\%}_{-13\%}$

Table 2: Integrated fiducial cross sections for $pp \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell\ell^\pm\bar{\nu}_\ell b\bar{b} + X$ at NLO in QCD at order $O(\alpha_s^3\alpha^6)$ and $O(\alpha_s\alpha^8)$) for various modelling approaches.

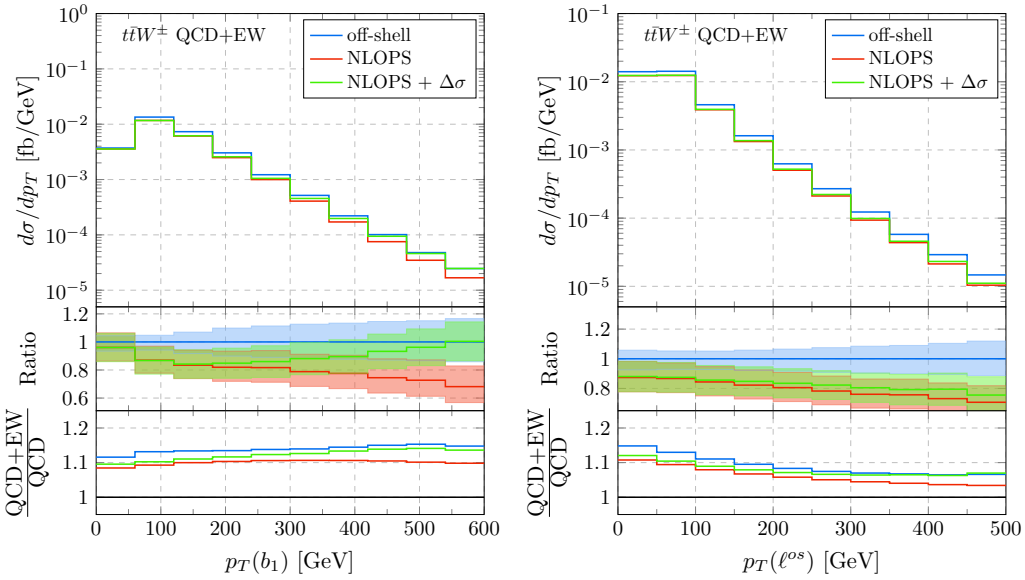

Figure 2: Differential fiducial cross section for $pp \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell\ell^\pm\bar{\nu}_\ell b\bar{b} + X$ at NLO in QCD including both dominant coupling orders. The first panel shows absolute predictions for various modelling approaches, whereas the second panel shows the ratio to the full off-shell predictions with scale uncertainty bands. The last panel displays the sub-leading $t\bar{t}W$ EW contribution in the ratio.

Parton shower matched predictions can be improved by including full off-shell effects according to:

$$\frac{d\sigma^{\text{th}}}{dX} = \frac{d\sigma^{\text{NLO+PS}}}{dX} + \frac{d\Delta\sigma_{\text{off-shell}}}{dX}, \qquad \frac{d\Delta\sigma_{\text{off-shell}}}{dX} = \frac{d\sigma^{\text{NLO}}_{\text{off-shell}}}{dX} - \frac{d\sigma^{\text{NLO}}_{\text{NWA}}}{dX} \tag{1}$$

where $\Delta\sigma_{\text{off-shell}}$ is constructed by removing the double resonant contributions from the full off-shell predictions in an approximate way. This prescription has a small impact on the integrated fiducial cross section, which increases by about 2%. We expect to see bigger contributions from $\Delta\sigma_{\text{off-shell}}$ at the differential level. For this purpose, in figure 2 we show the tranverse momentum of the hardest b-jet on the left and of the opposite-sign lepton on the right. The improved NLOPS+$\Delta\sigma$ predictions in the bulk of the distributions, whereas towards the high p_T tails they receive full off-shell contributions. These contributions impact b-jet observables more than lepton observables.

4. Conclusions

In conclusion, in the absence of a resonance aware matching of full off-shell predictions to parton showers at NLO in QCD, we suggest the prescription in eq. (1) for comparisons with unfolded experimental data.

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