PROCEEDINGS OF SCIENCE

EW corrections on top-quark pair production: the impact of the photon PDF

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In this proceeding we present the combination of NNLO QCD and NLO EW corrections to $t\bar{t}$ distributions, focusing on the effect of the photon PDF. We compare the LUXQED and NNPDF3.0QED PDF sets for specific distributions. We further discuss the effect of the EW corrections with respect to the pure QCD ones including scale and PDF uncertainties for both these PDF sets. We focus on the top-quark pair invariant mass, top-quark transverse momentum for 13 TeV and on the top-quark pair rapidity for 8 TeV.

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1. Introduction

The results discussed in this proceeding are part of what is presented in [1]. The $t\bar{t}$ observables have been calculated including the QCD corrections beyond the NLO [2–16]. The new run of LHC at 13 TeV will decrease the experimental uncertainties and furthermore there is a reported tension between theory and experiment in the top-quark p_T distribution at 8 TeV [17, 18]. Furthermore, many studies on the NLO EW corrections to $t\bar{t}$ production are already available [19–30]. Having the complete NLO EW corrections requires the photon-induced contributions. On top of that these contributions may accidentally compensate part of the Sudakov suppression rendered by the virtual EW corrections. The PDF sets that include the photon PDF are the MRST2004QED [31], the NNPDF2.3QED [32], the APFEL_NN2.3QED [33, 34], the CT14QED [35] and the more recent NNPDF3.0QED [36] and LUXQED [37]. Comparisons between the NNPDF2.3QED and CT14QED PDF sets in the $t\bar{t}$ process are presented in [38, 39]. Similar differences have been pointed out in dilepton final states [40, 41] between the NNPDFQED and the CT14QED, LUXQED PDF sets.

2. Calculation framework

In this work we realise a NNLO QCD + NLO EW calculation for $t\bar{t}$ distributions. For the NNLO QCD part we use the calculational techniques of [5] and for the NLO EW part we use an extension of the MADGRAPH5_AMC@NLO framework [42] already validated in [43–45]. In figure 1 we show a pictorial representation of the perturbative orders considered in the calculation.

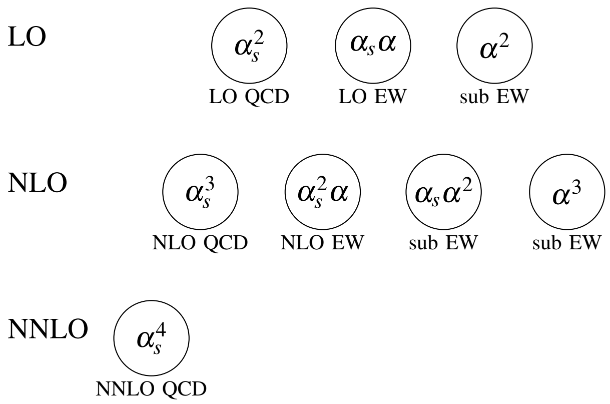

Figure 1: Perturbative orders included in the calculation.

The inclusion of the NNLO QCD corrections reduce significantly the scale uncertainties. Therefore, in contrast to what is done in [38], we include the subleading $\alpha^2, \alpha_s\alpha^2, \alpha^3$ orders, which we denote as sub EW. For any observable Σ we define the QCD, EW and QCD+EW orders as shown in equation 2.1.

$$\begin{aligned}
\Sigma_{\text{QCD}} &\equiv \Sigma_{\text{LO QCD}} + \Sigma_{\text{NLO QCD}} + \Sigma_{\text{NNLO QCD}} \\
\Sigma_{\text{EW}} &\equiv \Sigma_{\text{LO EW}} + \Sigma_{\text{NLO EW}} + \Sigma_{\text{sub EW}} \\
\Sigma_{\text{QCD+EW}} &\equiv \Sigma_{\text{QCD}} + \Sigma_{\text{EW}}
\end{aligned} \tag{2.1}$$

We have used the 5-flavour scheme for the calculation and the EW parameters are defined in the G_μ-scheme. In equation 2.2 we show the input parameters of the calculation.

$$
\begin{aligned}
&m_t = 173.3 \text{ GeV}\,, m_H = 125.09 \text{ GeV}\,, m_W = 80.385 \text{ GeV}\,, m_Z = 91.1876 \text{ GeV}\,,\\
&G_\mu = 1.1663787 \cdot 10^{-5} \text{ GeV}^{-2}\,,\\
&\mu = \frac{m_{T,t}}{2} \text{ for the } p_T(t) \text{ distribution}, \ \mu = \frac{m_{T,\bar{t}}}{2} \text{ for the } p_T(\bar{t}) \text{ distribution},\\
&\mu = \frac{H_T}{4} = \frac{1}{4}(m_{T,t} + m_{T,\bar{t}}) \text{ for the } m(t\bar{t}), y_{avt}, y(t\bar{t}) \text{ distributions.}
\end{aligned}
\tag{2.2}
$$

The observables $p_{T,\text{avt}}, y_{avt}$ are the average of the two top p_T, y distributions respectively. The scale choice for each observable is based on the principle of the fastest convergence and is taken from [5]. For the theoretical uncertainties we use the 7-point variation within the interval $\{\mu/2 < \mu_f, \mu_r < 2\mu\}$. In the following section we focus on the comparison between the NNPDF3.0QED and LUXQED PDF sets at 13 TeV.

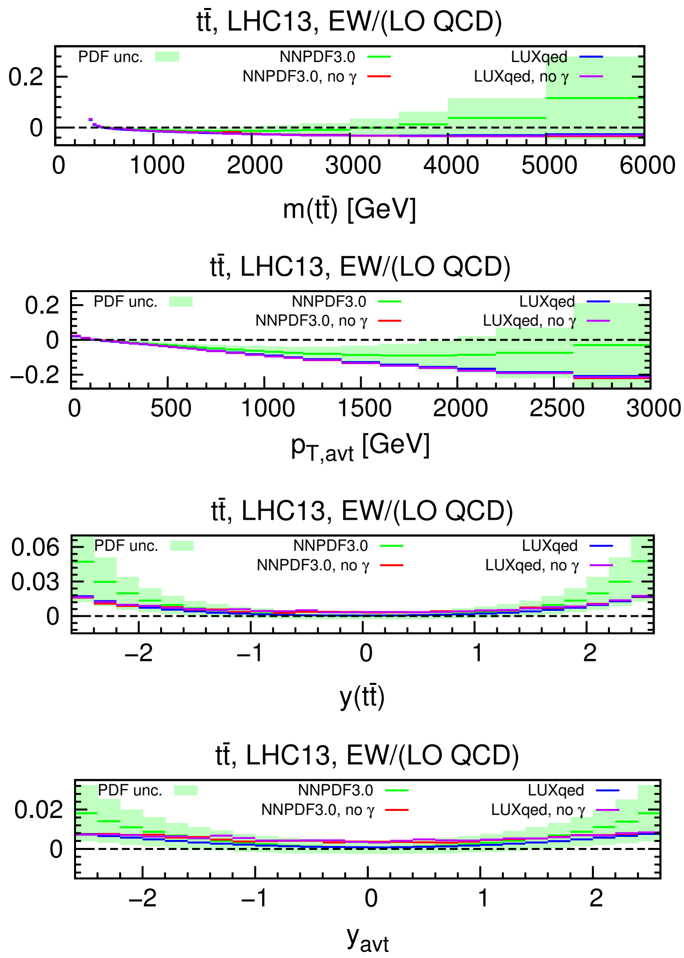

Figure 2: The impact of the photon PDF for the $m(t\bar{t}), p_{T,\text{avt}}, y_{\text{avt}}, y_{t\bar{t}}$ distributions for the NNPDF3.0QED and the LUXQED PDF sets.

3. Results

We first compare the two PDF sets for all the differential distributions and for a more detailed discussion we restrict ourselves to the $m(t\bar{t})$, $p_{T,\mathrm{avt}}$ and $y(t\bar{t})$ ones. In figure 2 we present the ratio EW/(LO QCD). For both the PDF sets considered we further artificially set the photon PDF equal to zero in order to isolate the effect of the photon-induced contributions. In these distributions we can see that the impact of the photon PDF is large for the NNPDF3.0QED PDF set, accompanied with large uncertainties. On the other hand this effect is negligible for the LUXQED PDF set. In all cases the LUXQED is equivalent to the NNPDF3.0QED - no γ and they are in agreement within the uncertainties.

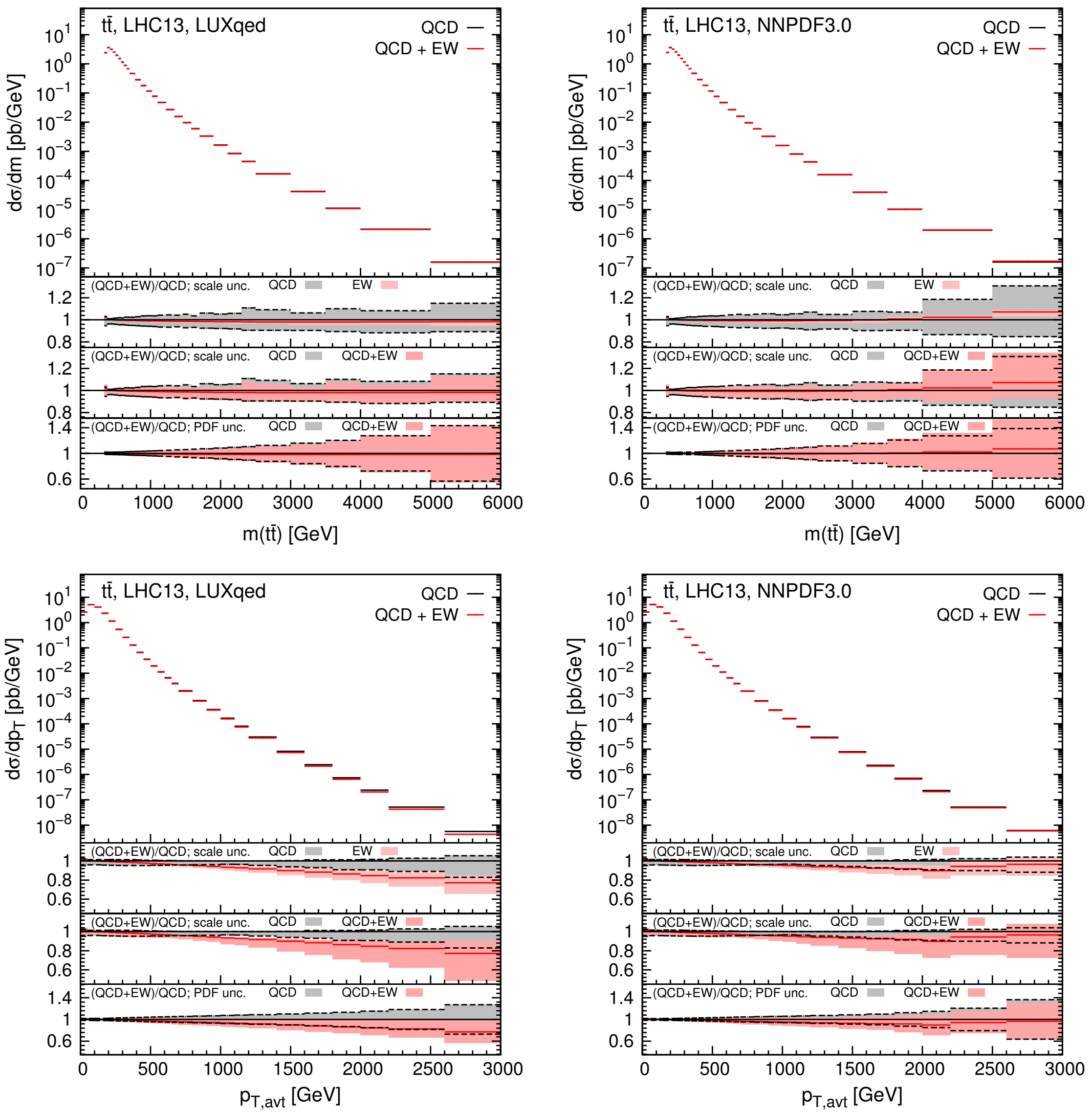

Figure 3: The $m(t\bar{t})$ (top) and $p_{T,\mathrm{avt}}$ (bottom) distributions at 13 TeV. The format of the plots is explained in the text.

Focusing on specific differential distributions at 13 TeV we show the $m(t\bar{t})$ and $p_{T,\mathrm{avt}}$ results (fig. 3). The format of the plots is the following. In the main panel we show the distributions of the QCD (black) and QCD+EW (red) according to the definitions of equation 2.1. In the three insets we show the ratio (QCD+EW)/QCD. In the first inset we put the scale uncertainties of the QCD and the EW separately and in the second inset the QCD and the QCD+EW ones. In the third inset we show the PDF uncertainties of the QCD and of the QCD+EW. On the left plot of fig 3 we have the results with the LUXQED and on the right plot the ones with the NNPDF3.0QED. Starting with the $m(t\bar{t})$ distribution and looking at the first inset, we can see that in both cases the EW corrections are small. One can also notice in the third inset that at the high $m(t\bar{t})$ region the dominant theory uncertainty is coming from the PDFs rather than from the scale variation. In the $p_{T,\mathrm{avt}}$ distribution the situation is different. In the LUXQED case, the EW corrections reach the $\sim -20\%$ at the tail of the distribution due to the Sudakov suppression. On top of that the QCD+EW result deviates from the pure QCD one already at the ~ 1 TeV range outside the QCD scale uncertainty band. Moving to the right plot we see that for the NNPDF3.0QED case, the photon-induced contributions compensate the negative Sudakov logarithms and reduce in absolute value the EW corrections.

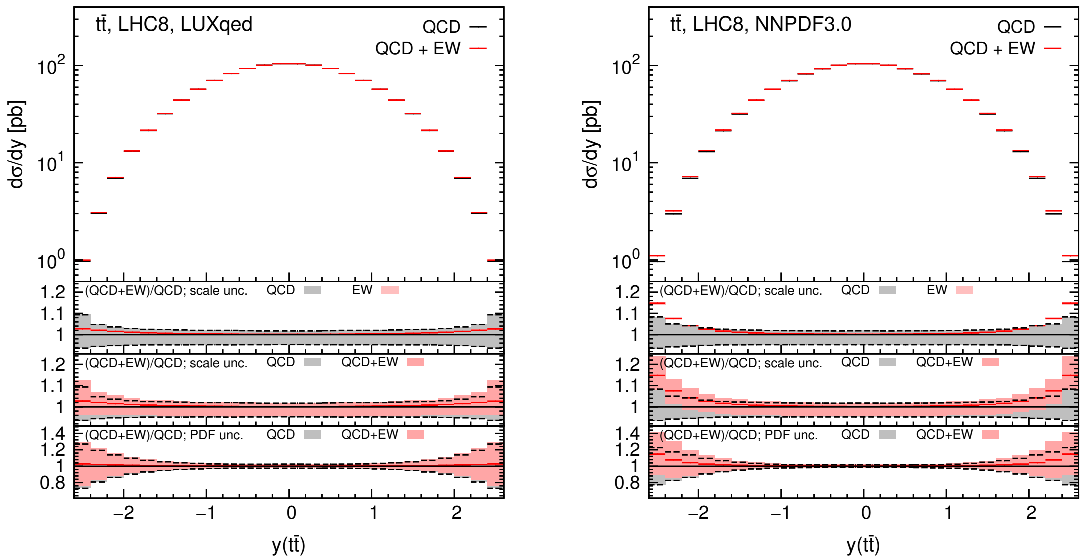

Figure 4: The $y(t\bar{t})$ distribution at 8 TeV. The format of the plot is explained in the text.

For the $y(t\bar{t})$ distribution we move to 8 TeV (fig 4). The reason is that with lower $\sqrt{s}$ we probe higher Bjorken x values, which are more sensitive to the photon-indiced contributions. In the right plot of figure 4 we see that for the NNPDF3.0QED case there is a $\sim 15\%$ effect due to the photon PDF at the large rapidity regions.

4. Conclusions

In this proceeding we show part of the work presented in [1]. We restrict ourselves to the additive combination of the NNLO QCD and NLO EW corrections to $t\bar{t}$ distributions and focus on the impact of the photon-induced contributions. We compare at differential level the results obtained with the LUXQED and NNPDF3.0QED PDF sets. The results with the former show a negligible effect of the photon-induced contributions being in the lower limit of the uncertainty band of the latter. The NNPDF3.0QED PDF set predicts a large photon PDF effect with large uncertainties. The EW corrections are small for both the PDF sets in the $m(t\bar{t})$ distribution, but they are large and PDF set dependent in the case of the $p_{T,\mathrm{avt}}$ distribution at 13 TeV and the $y(t\bar{t})$ distribution at 8 TeV.

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