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Higher Order Standard Model cross sections at 7 TeV

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——— Anyone I Missed from the list ———-

(On behalf of the CMS Collaboration)

Abstract

This note provides a compilation of the higher-order Standard Model cross sections using the latest available calculations for proton-proton collisions with 7 TeV centre-of-mass energy. The cross sections are based on a given choice of scale and parton distribution functions (PDFs) widely used in the CMS Collaboration for Monte Carlo simulations. The scale uncertainties and PDF uncertainties are provided for these choices. Cross sections using other higher order PDFs are also outlined along with their uncertanities.

1 Introduction

The LHC has recently started delivering proton-proton collisions at a centre-of-mass energy of 7 TeV. Physics analyses at the LHC frequently depend on various inputs from theory that are only known with limited accuracy. An important parameter to compare simulations and data is the predicted cross section for the former. The cross section calculations depend on various orders of perturbation theory as well as the determination of PDFs.

Most often there is no unique choice of which prescription should be used in a given analysis when comparing the simulations to the data. This study aims at establishing a convention as well as a certain set of choices based on inputs from the Monte Carlo simulations that are currently being used in the CMS collaboration. The higher order cross sections are then computed using these choices, and uncertanities due to the underlining assumptions are also computed.

In Section 2, guidelines for the calculation of K-factors based on higher order cross sections along with given scales and PDF uncertainties are provided. In Section 3 the assumptions made for these calculations are given, followed by the results in Section 4 and finally, in Section 5 we summarize the results.

2 Normalization factors, Scale and PDFs

Normally as a general rule, the highest-order available calculation should be used when calculating cross-sections along with dependencies on kinematics. The generator level cuts for a given production should be taken into account in the calculation of the K-factors. This requires that the leading order (LO) parton shower based MC and the next-to-leading order (NLO) calculation use the same or similar order PDF. If possible, the normalization μ_R and factorization scale μ_F should be taken into account for the given choice. Other ingradients such as strong coupling constants, as well as PDFs μ_R and μ_F needs to be similar between the leading and higer order calculations. Additionally, the order of the PDFs used should match with the order of the matrix-element calculations in the ratio for the K-factors, with the exception for next-to-next-leading order (NNLO), where additionally one has to take into account a NLO PDF.

2.1 Scale Uncertainties

The calculation of cross-sections in a given order in perturbation theory implies a dependence on both renormalization (μ_R) and factorization (μ_F) scales. These are typically considered to be the same as the central value (μ_0) of the scale. For estimating the scale uncertainty, the scale choices are varied in the units of μ_0. Although μ_R and μ_F can be varied independently, in this study we vary by the same units at the same time. The uncertainity in the scale choice is then determined by varying $1/2\mu_0 < \mu_R, \mu_F < 2\mu_0$.

2.2 PDFs

Generally, most recent PDF sets should be used for cross section and acceptance calculations. If in an analysis the acceptance is studied using PYTHIA [5] or HERWIG [6], the LO PDF (CTEQ6M [4] used in CMS simulations) should be used as a central value. However, the errors on cross sections and hence the errors on acceptance are always computed with respect to the nominal choice. We compute the PDF uncertainties using the prescription provided by the CTEQ Collaboration [4].

For a given central choice of scale and PDF, we estimate the errors based on N PDF sets of eigenvectors for an observable X. We use 2 PDF sets for each of the N eigenvectors, along the $\pm$ directions respectively. The uncertanity due to the PDFs is then defined as:

$$\Delta X = \frac{1}{2}\sqrt{\Sigma(X_i^+ - X_i^-)^2} \tag{1}$$

where X_i^+ and X_i^- are the values of X computed from the two PDF sets along $\pm$ direction of the $i-$th eigenvector. The additional statistical errors due to limited MC statistics can be evaluated by reweighting the MC events as a function of the parton flavours q_1 and q_2, parton momenta x_1, x_2 as well as μ_F. Finally, it should be noted that if the MC simulations are produced using a given LO PDF with a pre-determined choice of α_s, it is difficult to factorize the dependence, thus the residual dependence on α_s can be estimated by reweighting.

3 Central values and choices for generator parameters

We study the cross sections using the most appropriate and latest available calculations. FEWZ [3] is used for the computation of NNLO cross sections involving W and Z bosons, while we use MCFM 5.8 [1] for the rest of the SM processes at LO and NLO in perturbation theory. The study is performed for proton-proton collisions at a centre-of-mass energy of 7 TeV. The input parameters are the same used for the nominal MC simulation in CMS.

Some of the parameter settings in accordence with the PDG [2] recommendation for performing the calculations are given in Table 1.

Input parameters	Values for Central Choice
PDF Set W boson mass	CTEQ6M 80.398 GeV
W boson Width	2.141 GeV
Z boson mass	91.1876 GeV
Z boson Width	2.4952 GeV
t quark mass	172.5 GeV
b quark mass	4.8 GeV
c quark mass	1.27 GeV
fine-structure constant	0.007297352

Table 1: Input parameters used for obtaining the central value for various SM processes.

— Need to check if any other jet choices for MCFM are needed ————

4 Higher order cross sections

Table 2 summerizes the NNLO cross section computed for W and Z bosons. PDF errors are based on general-purpose CTEQ6M along with 40 eigenvector sets [4].

Processes	Generator	Phase Space cuts	Order	Final state	Cross-section (pb) PDF = CTEQ6M	Error (pb) Scale, PDF
W^+	FEWZ	-	NNLO	$W \rightarrow l\nu_l, l = e, \mu, \tau$	16670	$\pm$114, $\pm$ 843
W^-	FEWZ	-	NNLO	$W \rightarrow l\nu_l, l = e, \mu, \tau$	11379	$\pm$146, $\pm$ 759
Total W	FEWZ	-	NNLO	$W \rightarrow l\nu_l, l = e, \mu, \tau$	28049	$\pm$186, $\pm$ 1134
Z/γ^*	FEWZ	$m_{ll} >$ 20 GeV	NNLO	Exclusive $Z \rightarrow e^+e^-$	1495	$\pm$37, $\pm$74
Z/γ^*	FEWZ	$m_{ll} >$ 50 GeV	NNLO	Exclusive $Z \rightarrow e^+e^-$	969	$\pm$19, $\pm$37

Table 2: NNLO cross sections for W and Z bosons. The cross sections are computed for exclusive decays to leptons. The final inclusive values for W are obtained using appropriate branching fractions from the PDG [2].

The errors due to scale variations contribute to $\approx 1, 2\%$ for W and $Z\gamma^*$ decays. The PDF variations are $\approx 4, 5\%$, respectively. Table 3 shows the LO and NLO cross sections for various SM processes. Processes with c and b quarks are treated using the massive-quark scheme.

The cross sections for $t\bar{t}$ are in very good agreement with $\sigma_{t\bar{t}}^{NNLL} = 165 \pm 10$ pb using NNLL resummations [7], with a top mass of 173 GeV. Similarly, the single top production in s-channel agrees well with the NNLL approximations studies [8] within errors $\sigma_{Singletop}^{NNLL} = 4.6 \pm 0.06 \pm 0.13$ pb. The results presented here can serve to compute K-factors, which can be defined as the ratio N^{k}LO/LO for the analysis.

5 Summary and Conclusions

Calculations of higher-order cross sections for several SM processes in pp collisions at 7 TeV are provided in this note. The cross sections are computed using the FEWZ and MCFM calculators for a given choice of parameters.

Processes	Generator	Phase Space cuts	Order	Final state	Cross-section (pb) PDF = CTEQ6M	Error (pb) Scale, PDF
$t\bar{t}$	MCFM	-	NLO	Inclusive	154.5	$\pm$20.1, $\pm$ xx
t^+ s-channel	MCFM	-	NLO	Inclusive	2.6	$\pm$0.1, $\pm$ xx
t^- s-channel	MCFM	-	NLO	Inclusive	1.4	$\pm$0.1, $\pm$ xx
Total t s-channel	MCFM	-	NLO	Inclusive	4.0	$\pm$0.1, $\pm$ xx
t^+ t-channel	MCFM	-	NLO	Inclusive	41.7	$\pm$1.2, $\pm$ xx
t^- t-channel	MCFM	-	NLO	Inclusive	21.5	$\pm$0.6, $\pm$ xx
Total t t-channel	MCFM	-	NLO	Inclusive	63.2	$\pm$1.3, $\pm$ xx
$W^+\bar{t}$	MCFM	-	NLO	Inclusive	5.3	$\pm$0.6, $\pm$ xx
W^-t	MCFM	-	NLO	Inclusive	5.3	$\pm$0.6, $\pm$ xx
Total tW	MCFM	-	NLO	Inclusive	10.6	$\pm$0.8, $\pm$ xx
$W^+\bar{c}$	MCFM	-	NLO	Inclusive	1718	$\pm$157, $\pm$ xx
W^-c	MCFM	-	NLO	Inclusive	1910	$\pm$164, $\pm$ xx
Total Wc	MCFM	-	NLO	Inclusive	3628	$\pm$227, $\pm$ xx
$W^+b\bar{b}$	MCFM	-	LO	Inclusive	22.1	$\pm 4, 4$, $\pm$ xx
$W^-b\bar{b}$	MCFM	-	LO	Inclusive	13.2	$\pm$2.5, $\pm$ xx
Total $Wb\bar{b}$	MCFM	-	LO	Inclusive	35.3	$\pm$5.1, $\pm$ xx
$Z/\gamma^*b\bar{b}$	MCFM	$m_{ll} >$ 20 GeV	LO	Inclusive	67.3	$\pm$18.8, $\pm$ xx
W^+W^-	MCFM	-	NLO	Inclusive	43	$\pm$1.5, $\pm$ xx
$W^+Z\gamma^*$	MCFM	$m_{ll} >$ 40 GeV	NLO	Inclusive	11.8	$\pm$0.6, $\pm$ xx
$W^-Z\gamma^*$	MCFM	$m_{ll} >$ 40 GeV	NLO	Inclusive	6.4	$\pm$0.4, $\pm$ xx
Total $WZ\gamma^*$	MCFM	$m_{ll} >$ 40 GeV	NLO	Inclusive	18.2	$\pm$0.7, $\pm$ xx
$Z/\gamma^*Z/\gamma^*$	MCFM	$m_{ll} >$ 40 GeV	NLO	Inclusive	5.9	$\pm$0.15, $\pm$ xx

Table 3: LO and NLO cross sections for various SM processes. The cross sections are generally computed for inclusive decays.

The dominant systematic errors on the cross sections are due to the uncertainities in the PDFs, which are typically of the order of $(y1 - y2)$ % on the total cross sections. The scale uncertanities within the variation of $1/2\mu_0 < \mu_R, \mu_F < 2\mu_0$ are found to be at $(x1 - x2)$ % level.

References

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