Jet-vetoed Higgs cross section in gluon fusion at N^{3}LO+NNLL with small-R resummation[a]

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Predictions for the jet-veto efficiency and zero-jet cross section in Higgs production through gluon fusion are presented. The results incorporate the N^{3}LO corrections to the total cross section, the NNLO corrections to the 1-jet rate, NNLL resummation for the jet p_t, LL resummation for the jet radius dependence, and known finite-mass corrections. For 13 TeV collisions, and using our default choice for the renormalisation and factorisation scales, $\mu_0 = m_H/2$, the matched prediction for the zero-jet cross section increases the pure N^{3}LO prediction by about 2% and the two have comparable uncertainties. Relative to NNLO+NNLL results, the new prediction for the zero-jet cross section is 3% larger and the uncertainty reduces from about 10% to 4%. We comment on the validity of the resummation in this regime and on the interpretation of the results.

1 Introduction

In some Higgs boson decay modes (most notably WW^* and $\tau\tau$), it is standard to perform different analyses depending on the number of accompanying jets. This is because different jet multiplicities have different dominant backgrounds. Of particular importance for the WW decay is the zero-jet case, where the dominant top-antitop background is dramatically reduced. For precision studies it is important to predict accurately the fraction of signal events that survive the zero-jet constraint, and to assess the associated theory uncertainty. Jet-veto transverse momentum thresholds used by ATLAS and CMS are relatively soft ($p_{\mathrm{t,veto}} \sim 25-30$ GeV), hence QCD real radiation is constrained by the cut and the imbalance between virtual and real corrections results in logarithms of the form $\ln(p_{\mathrm{t,veto}}/m_H)$ that should be resummed to all orders in the coupling constant. This resummation has been carried out to next-to-next-to-leading logarithmic accuracy (NNLL , i.e. including all terms $\alpha_s^n \ln^k(p_{\mathrm{t,veto}}/m_H)$ with $k \geq n-1$ in the logarithm of the cross section) and matched to next-to-next-to-leading order (NNLO) in [1,2,3]. More recently, the N^{3}LO total gluon-fusion cross section has been computed in [4], and the NNLO corrections to the Higgs plus one-jet cross-section was obtained in [5,6,7,8]. Moreover, the LL resummation of logarithms of the jet-radius R has been studied in [9].

All these recent results were merged together [11] to obtaind a prediction for the jet-veto cross-section accurate at the N^{3}LO+NNLL+LL$_R$ order. The effect of heavy-quark masses has been considered following the procedure outlined in [12]. The code used to produce the following results can be downloaded from [b].

[a] Work in collaboration with Andrea Banfi, Fabrizio Caola, Frédéric A. Dreyer, Gavin P. Salam, Giulia Zanderighi, Falko Dulat

[b] `https://jetvheto.hepforge.org/`

2 $N^3LO+NNLL+LL_R$ cross section at 13 TeV

In this section we report predictions for the jet-veto efficiency and cross section in Higgs-boson production in gluon fusion at the LHC. The reader should refer to the original work [11] for additional information. The fixed-order prediction is obtained by combining the N^3LO total cross section for Higgs production in gluon fusion [4] and the inclusive one-jet cross section at NNLO [7], both in the heavy-top limit. In the latter, the qq channel is included only up to NLO, and missing NNLO effects are estimated to be well below scale variation uncertainties [6]. Exact top- and bottom-mass effects up to NLO are included in the jet-veto efficiency and cross section [13]. Beyond NLO, we use the heavy-top result, without any modifications. The resummation of the logarithms $\ln(m_H/p_{\rm t,veto})$ NNLL accuracy is performed following the procedure of [1], with the treatment of quark-mass effects as described in [12]. Finally, logarithms of the jet radius are resummed to LL accuracy, following the approach of [9].

We consider 13 TeV LHC collisions with a Higgs-boson mass of $m_H = 125$ GeV. For the top and bottom pole quark masses, we use $m_t = 172.5$ GeV and $m_b = 4.75$ GeV. Jets are defined using the anti-k_t algorithm [14], with radius parameter $R = 0.4$, and perform the momentum recombination in the standard E scheme (i.e. summing the four-momenta of the pseudo-particles). We use PDF4LHC15 parton distribution functions at NNLO with $\alpha_s(m_Z) = 0.118$ (`PDF4LHC15_nnlo_mc`) [15]. The impact of higher-order logarithmic corrections is probed by introducing a resummation scale Q as shown in [1]. The central prediction for the jet-veto efficiency is obtained by using the matching scheme (a) [11], setting the renormalisation and factorisation scales to $\mu_R = \mu_F = m_H/2$, and the resummation scale relative to both top and bottom contributions to $Q = Q_0 = m_H/2$. To determine the perturbative uncertainties for the jet-veto efficiency we follow the Jet-Veto efficiency (JVE) method as outlined in [11]. This differs from the original method of [10,1] which has been modified to take into account the excellent convergence observed at the perturbative order considered here [11]. The uncertainty band is determined as described below.

We vary μ_R, μ_F by a factor of 2 in either direction, requiring $1/2 \le \mu_R/\mu_F \le 2$. Maintaining central $\mu_{R,F}$ values, we also vary Q in the range $\frac{2}{3} \le Q/Q_0 \le \frac{3}{2}$. As far as the small-$R$ effects are concerned, subleading logarithmic effects are estimated by means of a second resummation scale R_0, which acts as the initial radius for the evolution of the gluon-jet fragmentation which gives rise to the $\ln R$ terms. We choose the default value $R_0 = 1.0$, and vary it conservatively by a factor of two in either direction. Finally, keeping all scales at their respective central values, we replace the default matching scheme (a) with scheme (b), as defined in [11]. The final uncertainty band is obtained as the envelope of all the above variations. We do not consider here the uncertainties associated with the parton distributions (which mostly affect the cross section, but not the jet-veto efficiency), the value of the strong coupling or the impact of finite quark masses on terms beyond NLO. Moreover, our results do not include electro-weak effects.

Starting from the jet-veto efficiency, the zero-jet cross section is obtained as $\Sigma_{0-\rm jet}(p_{\rm t,veto}) = \sigma_{\rm tot}\,\epsilon(p_{\rm t,veto})$, and the inclusive one-jet cross section as $\Sigma_{\ge 1-\rm jet}(p_{t,\rm min}) = \sigma_{\rm tot}\,(1-\epsilon(p_{t,\rm min}))$. The associated uncertainties are obtained by combining in quadrature the uncertainty on the efficiency obtained as explained in [11] and that on the total cross section, for which we use plain scale variations. In the left plot of Figure 1 we show the comparison between our best prediction for the jet-veto cross section ($N^3LO+NNLL+LL_R$) and the previous NNLO+NNLL accurate prediction, both including mass effects. We see that the impact of the N^3LO correction on the central value is in the range 2-3% at relevant jet-veto scales. The uncertainty band is significantly reduced when the N^3LO corrections are included, going from about 10% at NNLO down to about 4% N^3LO. Figure 1 (right) shows the comparison between the $N^3LO+NNLL+LL_R$ prediction and the pure N^3LO result. We observe a shift of the central value of the order of 2% for $p_{\rm t,veto} > 25$ GeV when the resummation is included. In that same $p_{\rm t,veto}$ region, the uncertainty associated with the N^3LO prediction is at the 3% level, comparable with that of the $N^3LO+NNLL+LL_R$ prediction. The fact that resummation effects are nearly of the same order

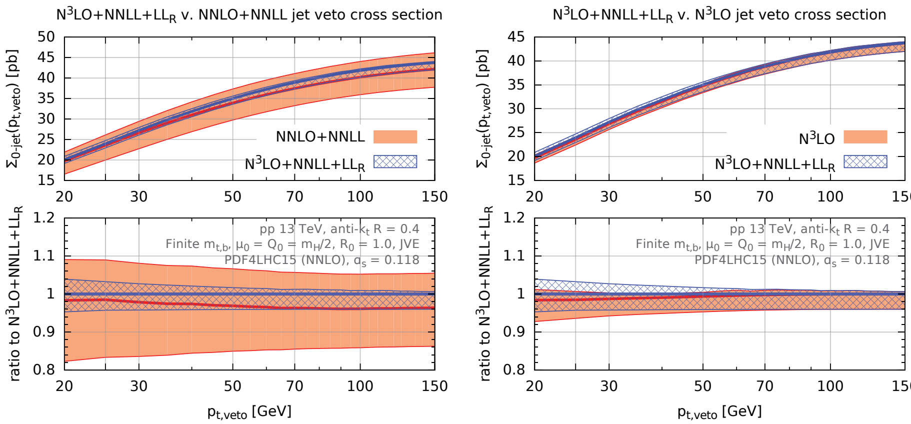

Figure 1 – N^{3}LO+NNLL+LL$_R$ best prediction for the jet-veto cross section (blue/hatched) compared to NNLO+NNLL (left) and fixed-order at N^{3}LO (right).

as the uncertainties of the fixed order calculation suggests that the latter might be accidentally small. This situation is peculiar to our central renormalisation and factorisation scale choice, $\mu_R = \mu_F = m_H/2$, and does not occur at, for instance, $\mu_R = \mu_F = m_H$ (see [11] for details and numerical results for the LHC).

In summary, we have observed that N^{3}LO effects amount to a 3% increase with respect to the NNLO result, and resummation effects on top of the the N^{3}LO prediction yield a further 2% increase for the zero-jet cross section. Given that the jet-veto logarithms that we are resumming are not yet dramatically large at these $p_{t,\text{veto}}$ values, one may wonder whether the latter increase is accidental given that the resummation does not account for regular higher-order terms which could be sizeable. In order to study this, we plot in figure 2 the remainder of the fixed-order perturbative expansion defined as the difference between the fixed-order prediction at a given perturbative order and the corresponding expansion of the resummed result. The remainder is shown as a fraction of the fixed-order result, which quantifies how much of the latter is accounted for by the jet-veto logarithms. The right plot of figure 2 shows the remainder at 13 TeV for the NLO, NNLO, and N^{3}LO predictions. We observe that the NNLO and N^{3}LO remainders amount to about 20% of the respective fixed-order cross section, indicating that the logarithms constitute the dominant part of the perturbative expansion. At these $p_{t,\text{veto}}$ scales, however, the α_s suppression is still effective, which explains why the fixed-order prediction still gives a good description of the 0-jet cross section.

In the NNLO and N^{3}LO remainder shown in the right plot of figure 2 we do not subtract the constant terms of the expansion (indicated by C_2 and C_3 in the plots). These constant terms are taken into account in the matching, but for a precise numerical determination of the individual contributions one should use stable runs down to very small values of $p_{t,\text{veto}}$. This can be easily done at NNLO, and the impact of including the NNLO constant C_2 is shown in the left plot of figure 2.[c] We see that when one includes the C_2 in the expansion, the remainder tends to become even smaller (between 10% and 15%) at the relevant $p_{t,\text{veto}}$ scales.

Given that the constants C_2 and C_3 are included in our matched result, we conclude that the 2% difference between the N^{3}LO and the matched predictions for the 0-jet cross section genuinely accounts for about 80% of yet higher-order effects

[c]The plot shows the remainder in the case of 8 TeV colliseions. This choice for the centre-of-mass energy is irrelevant for this study. The situation will not change for 13 TeV collisions.

for this observable. Therefore these effects must be taken into account for a precise determination of the zero-jet cross section.

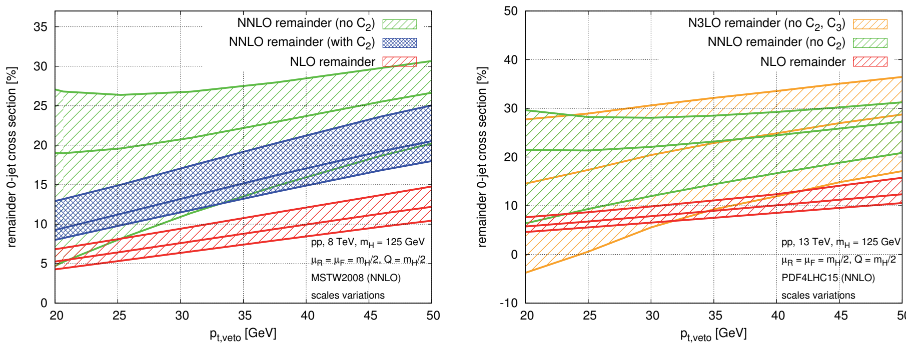

Figure 2 – The left plot shows the remainder of the 0-jet cross section at NLO and NNLO at 8 TeV, after subtracting the resummed jet-veto logarithms. The right plot shows the remainder at 13 TeV up to N^{3}LO.

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