Matrix-element corrections to $gg/q\bar{q} \rightarrow$ Higgs in HERWIG

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Abstract

We describe the HERWIG implementation of real matrix-element corrections to direct Higgs hadroproduction at Tevatron and Large Hadron Collider (LHC) and compare it to other approaches existing in literature and describing the transverse momentum distribution of the Higgs boson.

1. THE HIGGS TRANSVERSE MOMENTUM

In order to investigate Higgs boson production via $gg \rightarrow$ Higgs (see Ref. [1]), one needs to account for multi-parton radiation for the sake of performing trustworthy phenomenological analyses [2, 3, 4]. Standard Monte Carlo (MC) algorithms [5]–[7] describe parton radiation in the soft and/or collinear approximation of the parton shower (PS), but can have regions of phase space, so-called ‘dead zones’, where no radiation is allowed. Here, one can however rely on higher-order tree-level results, as in this region the radiation is neither softly nor collinearly enhanced. Several methods have been recently suggested in order to match PS and fixed-order matrix elements (MEs) [8, 9], also including the virtual one-loop terms [10–12].

2. THE HERWIG IMPLEMENTATION

In this note, we briefly mention that the same strategy which has already been used to implement real ME corrections to $e^+e^- \rightarrow$ quark pairs [13], Deep Inelastic Scattering (DIS) [14], top quark decay [15] and vector boson hadroproduction [16] has now also been adopted for the case of Higgs hadroproduction via gluon-gluon fusion and quark-antiquark annihilation [17], in the context of the HERWIG event generator [5, 6]. That is, the dead zone is here populated by using the exact next-to-leading order (NLO) tree-level ME result and the PS in the already-populated region is corrected using the exact amplitude any time an emission is capable of being the hardest so far.

3. NUMERICAL RESULTS AND COMPARISONS

The MEs squared for the real corrections to $gg \rightarrow H$ that we have used can be found in [18], where top mass effects are fully included. The real NLO corrections to $q\bar{q} \rightarrow H$ are instead rather straightforward: the formulae we used can be read from Eq. (3.62) of [19] with appropriate Yukawa couplings and crossing. In the new HERWIG default version, in line with [16], ME corrections use the Higgs transverse mass $m_T^2 = q_T^2 + m_H^2$ as the scale for $\alpha_S$ and for the Parton Distribution Functions (PDFs) while the $gg, q\bar{q} \rightarrow H$ contributions use $m_T^2$. We shall also assume that the intrinsic transverse momentum of the initial-state partons is equal to $q_{T,int} = 0$, the HERWIG default value.

By adopting the HERWIG defaults, we first consider Higgs production at the Tevatron and the LHC within the MC itself, by plotting the $q_T$ distribution with (solid histogram) and without (dotted) ME corrections: see Fig. 1. Beyond $q_T \approx m_H/2$ the ME-corrected version allows for many more events. In fact, one can prove that, within the standard algorithm, $q_T$ is constrained to be $q_T < m_H$. At small $q_T$ the prediction which includes ME corrections displays a suppression. By default, after the latter are put in place, the total normalization still equals the LO rates. Hence, it is obvious that the enhancement at large $q_T$ implies a reduction of the number of events which are generated at small $q_T$ values.

In Fig. 2 (left plot) we present the improved HERWIG spectrum (solid) for the LHC, along with the result obtained running the so-called ‘$H +$ jets’ process (dotted), where the hard process is always one
Fig. 1: Higgs transverse momentum distribution according to HERWIG with (solid) and without (dotted) ME corrections, at Tevatron (left, \( \sqrt{s_{pp}} = 2 \) TeV) and LHC (right, \( \sqrt{s_{pp}} = 14 \) TeV). We have set the Higgs mass to \( m_H = 115 \) GeV.

Fig. 2: Left: comparison of ME-corrected HERWIG predictions (solid) to the ‘\( H + \) jets’ result from Ref. [18] (dotted). Centre: comparison of ME-corrected HERWIG predictions (solid) to the NLO and resummed calculation of Ref. [20] (dotted). Right: comparison of ME-corrected HERWIG predictions (solid) to the MC@NLO results from the code described in Ref. [21] (dotted). Here, \( q\bar{q} \to H \) processes have been turned off.

of the corrections to \( gg \to H \). In order to perform such a comparison, we have turned the \( q\bar{q} \to H \) hard process off, as ‘\( H + \) jets’ in HERWIG does not currently implement the corrections to quark-antiquark annihilation. Furthermore, we have chosen \( q_{T \text{min}} = 30 \) GeV for the ‘\( H + \) jets’ generation. As expected, at small \( q_T \) the two predictions are fairly different but at large transverse momentum they agree well.

In Fig. 2 (centre plot) we compare the new HERWIG version with the resummed calculation of Ref. [20]. For the sake of comparison with HERWIG, which includes leading logarithms and only some subleading terms, we use the results of Ref. [20] in the NLL approximation (rather than the default NNLL one), matched to the NLO prediction. In order for such a comparison to be trustworthy, we have to make parameter choices similar to Ref. [20]: namely, we adopt a top quark with infinite mass in the loop and \( m_H = 125 \) GeV, with \( \alpha_S \) and PDFs (both from HERWIG defaults) evaluated at \( m_H^2 \). While the normalization (LO in HERWIG, NLO in Ref. [20]) and the small-\( q_T \) behaviour of the two curves are clearly different, the large-transverse-momentum predictions are in good agreement, as in both approaches it is the real NLO ME that dominates the event generation at large \( q_T \).

Finally, in Fig. 2 (right plot), we compare the results of standard HERWIG after ME corrections with the so-called ‘MC@NLO’ event generator (version 2.2) of Ref. [21], the latter implementing both real and virtual corrections to the hard-scattering process, in such a way that predicted observables (including normalization) are correct to NLO accuracy. As version 2.2 of the MC@NLO includes only the corrections to Higgs production in the gluon-fusion channel, we again have turned the quark-annihilation process off in our routines. As observed in the comparison with the resummed calculation, the two spectra differ in normalization and at small \( q_T \), but agree in the large-transverse-momentum region.
4. CONCLUSIONS

Between the described implementation and the one available within the MC@NLO option, we believe that HERWIG is presently a reliable event generator for (direct) Higgs production from parton fusion at hadron colliders both at small and large transverse momentum. In fact, all currently available ME corrections will play an important role to perform any analysis on Higgs searches at present and future colliders. In particular, the option described here may be the most convenient choice for when the phase space is limited to transverse momentum values such that \( q_T \gtrsim m_H \).

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