Abstract

When considering the transverse momentum distribution ($q_T$) of the Higgs boson production it is necessary to separate the small $q_T$ region ($q_T \ll M_H$) from the medium and large ($q_T \gtrsim M_H$) one, the former being treated by means of resummation techniques of logarithmically-enhanced contributions and the latter by fixed-order perturbation theory. Then these two approaches have to be consistently matched to avoid double-counting in the intermediate $q_T$ region. Here soft gluon resummation is implemented up to NNLL order and the matching to the corresponding NLO perturbative result is performed. Numerical results are shown for the LHC. The main features of the differential distribution turn out to be quite stable with respect to perturbative uncertainties.

An accurate theoretical prediction of the transverse-momentum ($q_T$) distribution of the Higgs boson at the LHC can be important to enhance the statistical significance of the signal over the background and to improve strategies for the extraction of the signal. In what follows we consider the most relevant production mechanism: the gluon initiated process via a top-quark loop.

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It is convenient to consider and treat separately the large-$q_T$ and small-$q_T$ regions of the spectrum. Roughly speaking, the large-$q_T$ region is identified by the condition $q_T \gtrsim M_H$. In this region, the perturbative series is controlled by a small expansion parameter, $\alpha_S(M_H^2)$, and calculations based on the truncation of the series at a fixed-order in $\alpha_S$ are theoretically justified and reliable. The LO calculation $O(\alpha_S^2)$ was reported in Ref. [2]; it shows that the large-$M_t$ approximation (the limit of an infinitely-heavy top quark) works well as long as both $M_H$ and $q_T$ are smaller than $M_t$. In the framework of this approximation, the NLO QCD corrections were computed first numerically [3] and later analytically [4, 5].

In the small-$q_T$ region ($q_T \ll M_H$), where the bulk of events is produced, the convergence of the fixed-order expansion is spoiled, since the coefficients of the perturbative series in $\alpha_S(M_H^2)$ are enhanced by powers of large logarithmic terms, $\ln^n(M_H^2/q_T^2)$. To obtain reliable perturbative predictions, these terms have to be systematically resummed to all orders in $\alpha_S$ [6]; see also the list of references in Sect. 5 of Ref. [7]. In the case of the Higgs boson, resummation has been explicitly worked out at leading logarithmic (LL), next-to-leading logarithmic (NLL) [8, 9] and next-to-next-to-leading logarithmic (NNLL) [10] level. The fixed-order and resummed approaches have then to be consistently matched at intermediate values of $q_T$, so as to avoid the introduction of ad-hoc boundaries between the large-$q_T$ and small-$q_T$ regions.

In this work the formalism described in Ref. [11] is used to compute the Higgs boson $q_T$ distribution at the LHC. In particular, it includes the most advanced perturbative information that is available at present: NNLL resummation at small $q_T$ and NLO calculations at large $q_T$. As the matching procedure could introduce higher order corrections in the intermediate $q_T$ region, it proves useful to put a constrain on the integral over $q_T$ of the differential distribution, which should reproduce the total cross section result (known at NLO [12] and NNLO [13]). More details and formulas can be found in Ref. [14]. Other recent phenomenological predictions can be found in [15].

In the following, quantitative results at NLL+LO and NNLL+NLO accuracy are presented. At NLL+LO accuracy the NLL resummed result is matched with the LO perturbative result, while at NNLL+NLO accuracy the NNLL resummed result is matched with the NLO perturbative result. As for the evaluation of the fixed order results, the Monte Carlo program of Ref. [3] has been used. The numerical results are obtained by choosing $M_H = 125$ GeV and using the MRST2002 set of parton distributions [17]. They slightly differ from those presented in [14], where we used the
MRST2001 set [16]. At NLL+LO, LO parton densities and 1-loop $\alpha_S$ have been used, whereas NLO parton densities and 2-loop $\alpha_S$ for the NNLL+NLO matching.

Figure 1: LHC results at NLL+LO accuracy.

The NLL+LO results at the LHC are shown in Fig. 1. In the left-hand side, the full NLL+LO result (solid line) is compared with the LO one (dashed line) at the default scales $\mu_F = \mu_R = M_H$. We see that the LO calculation diverges to $+\infty$ as $q_T \to 0$. The effect of the resummation is relevant below $q_T \sim 100$ GeV. In the right-hand side we show the NLL+LO band that is obtained by varying $\mu_F = \mu_R$ between $1/2M_H$ and $2M_H$. The scale dependence increases from about $\pm 10\%$ at the peak to about $\pm 20\%$ at $q_T = 100$ GeV.

The NNLL+NLO results at the LHC are shown in Fig. 2. In the left-hand side, the full result (solid line) is compared with the NLO one (dashed line) at the default scales $\mu_F = \mu_R = M_H$. The NLO result diverges to $-\infty$ as $q_T \to 0$ and, at small values of $q_T$, it has an unphysical peak (the top of the peak is close to the vertical scale of the plot) which is produced by the numerical compensation of negative leading logarithmic and positive subleading logarithmic contributions. It is interesting to compare the LO and NLL+LO curves in Fig. 1 and the NLO curve in Fig. 2. At $q_T \sim 50$ GeV, the $q_T$ distribution sizeably increases when going from LO to NLO and from NLO to NLL+LO. This implies that in the intermediate-$q_T$ region there are important contributions that have to be resummed to all orders rather than simply evaluated at the next perturbative order. The $q_T$ distribution is (moderately) harder at NNLL+NLO than at NLL+LO accuracy. The
height of the NNLL peak is a bit lower than the NLL one. This is mainly due to the fact that the total NNLO cross section (computed with NLO parton densities and 2-loop $\alpha_S$), which fixes the value of the $q_T$ integral of our resummed result, is slightly smaller than the NLO one, whereas the high-$q_T$ tail is higher at NNLL order, thus leading to a reduction of the cross section at small $q_T$. The resummation effect starts to be visible below $q_T \sim 100$ GeV, and it increases the NLO result by about 40% at $q_T = 50$ GeV. The right-hand side of Fig. 2 shows the scale dependence computed as in Fig. 1. The scale dependence is now about $\pm 8\%$ at the peak and increases to $\pm 20\%$ at $q_T = 100$ GeV. Comparing Figs. 1 and 2, we see that the NNLL+NLO band is smaller than the NLL+LO one and overlaps with the latter at $q_T \lesssim 100$ GeV. This suggests a good convergence of the resummed perturbative expansion.

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