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HIGGS RADIATION OFF BOTTOM QUARKS AT HADRON COLLIDERS

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Higgs-boson production in association with bottom quarks, $p\bar{p}/pp \to b\bar{b}H + X$, is an important discovery channel for supersymmetric Higgs particles at the Tevatron and the LHC. The next-to-leading order QCD corrections to the parton processes $q\bar{q}, gg \to b\bar{b}H$ and results for total cross sections as well as for distributions in the transverse momenta of the bottom quarks are presented. A comparison with results involving bottom densities is performed.

The Higgs mechanism [1] is a cornerstone of the Standard Model (SM) and its supersymmetric extensions. The masses of the fundamental particles, electroweak gauge bosons, leptons, and quarks, are generated by interactions with Higgs fields. The search for Higgs bosons is thus one of the most important endeavours in high-energy physics and is being pursued at the upgraded proton–antiproton collider Tevatron with a centre-of-mass (CM) energy of 1.96 TeV, followed in the near future by the proton–proton collider LHC with 14 TeV CM energy.

Various channels can be exploited to search for Higgs bosons at hadron colliders. Higgs radiation off bottom quarks, $q\bar{q}, gg \to b\bar{b}H$ (see Fig. 1), [2] is the dominant Higgs-boson production mechanism in supersymmetric theories at large $\tan\beta$, where the bottom–Higgs Yukawa coupling is strongly enhanced. The parameter $\tan\beta = v_2/v_1$ is the ratio of the vacuum expectation values of the two Higgs fields generating the masses of up- and down-type particles in supersymmetric extensions of the SM. $H = H_{\rm SM}, h^0, H^0$ may denote the SM Higgs boson or any of the CP-even neutral Higgs bosons of supersymmetric theories.

Note that the inclusive cross-section prediction for the process $gg \to b\bar{b}H$ develops potentially large logarithmic terms $\propto \log(Q/m_b)$ which arise from the splitting of gluons into $b\bar{b}$ pairs, since the b-quark mass acts as a cutoff for the collinear singularity. The large scale Q corresponds to the upper limit of the collinear region up to which factorization is valid. It has been argued that Q is of the order of $M_H/4$ or less [3]. The $\log(Q/m_b)$ terms can be summed to all orders in perturbation theory by introducing bottom parton densities [4], provided that the b-quarks

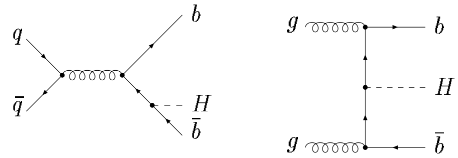

Figure 1. A generic set of diagrams for the Born level.

are produced predominantly at small transverse momentum. The LO process in this approach is Higgs-boson production through $b\bar{b}$ fusion, $b\bar{b} \to H$. The first order corrections comprise the $\mathcal{O}(\alpha_s)$ corrections to $b\bar{b} \to H$ and the LO process $gb \to bH$ [5]. The second-order corrections, involving $b\bar{b} \to H$ at NNLO, have been completed recently [6].

Higgs searches in the $b\bar{b}H$ channel, however, do in general employ cuts on the b-quark transverse momenta and thus require theoretical predictions for exclusive final states. In this case the calculation is based on the parton processes $q\bar{q}, gg \to b\bar{b}H$. In the following we review the NLO QCD predictions for associated $b\bar{b}H$ production at the Tevatron and the LHC in the SM. The calculation of the NLO QCD corrections has been presented in Refs. [7–10]. In LO, the transition to the MSSM can be done by a simple rescaling of cross sections and distributions according to the modified bottom-quark Yukawa coupling, since the LO matrix element is proportional to this coupling. In NLO, this rescaling is spoiled by one-loop diagrams in which the Higgs boson couples to a closed top-quark loop. However, our calculation reveals that these contributions only amount to about $-5\%(-10\%)$ of the NLO cross section at the Tevatron (LHC) in the SM. Thus, to a very good approximation, also the cross sections and distributions including NLO QCD corrections follow the simple LO rescaling. All scales have been set equal and are varied around the central value $\mu_0 = (2m_b + M_H)/2$. Figure 2 shows the scale dependence for both the total cross section and the cross section with two high-p_T bottom quarks. The reduction of the spurious scale dependence at NLO is particularly striking for the exclusive cross section where both b-quarks are required to be produced with $p_T > 20$ GeV. We note that the $b\bar{b}H$ cross section at the Tevatron and the LHC is completely dominated by the gluon-gluon fusion and gluon-(anti)quark scattering reactions.

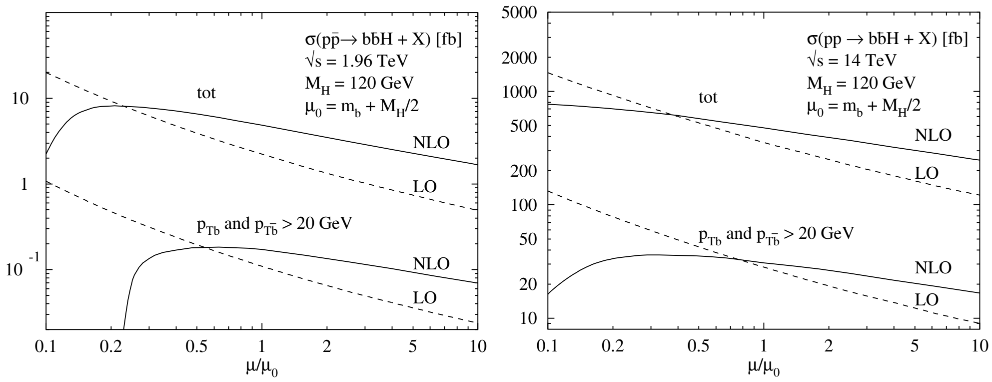

Figure 2. Variation of the LO and NLO cross sections with the renormalization and factorization scales for $b\bar{b}H + X$ production at the Tevatron and the LHC.

The total cross section for associated $b\bar{b}H$ production at the Tevatron and the LHC is displayed in Fig. 3 as a function of the Higgs-boson mass. We have varied all scales between $\mu_0/4$ and μ_0. For the central choice $\mu = \mu_0/2$ the NLO QCD corrections increase the theoretical prediction significantly, by a factor $1.6 - 2.3$

at the Tevatron and 1.1 − 1.8 at the LHC. For comparison the error bands of the approach based on bottom densities are shown at NNLO [6]. When including higher-order QCD corrections, the results obtained in the two approaches are in reasonable numerical agreement. In particular, the cross-section predictions for $b\bar{b}H$ production at the LHC are compatible within their respective scale uncertainties. We would like to emphasize, however, that in spite of the numerical agreement between the $q\bar{q}, gg \to b\bar{b}H$ and $b\bar{b} \to H$ cross-section predictions, the intrinsic uncertainties of both approaches have not yet been fully quantified. A similar reasonable agreement has been found in the case that only one bottom jet is required to develop a transverse momentum $p_T > 20$ GeV, while the other bottom jet is integrated out [11].

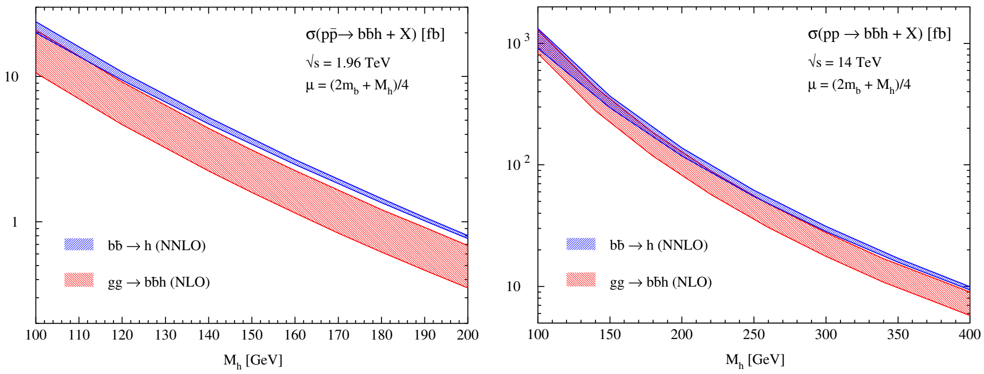

Figure 3. Variation of the LO and NLO cross sections with the renormalization and factorization scales for $b\bar{b}H + X$ production at the Tevatron and the LHC.

In Fig. 4 we show the cross section with one or two high-p_T bottom quarks as a function of the minimal b-quark transverse momentum. We observe sizeable positive corrections if the b-quarks are produced at small p_T. If both b-quarks are required to be produced with larger $p_T \gtrsim 20$ GeV the NLO corrections reduce the LO prediction.

In summary, the strong scale dependence of the LO predictions for the processes $p\bar{p}/pp \to b\bar{b}H + X$, which provide important search channels for supersymmetric Higgs bosons, requires the inclusion of QCD corrections. For the total cross section, we find a reduction of the spurious scale dependence at NLO. Our results are in reasonable numerical agreement with calculations based on the bottom-quark fusion process. We find a drastic reduction of the scale dependence at NLO when the Higgs boson is produced in association with high-p_T bottom quarks. The improved NLO predictions for the exclusive cross sections can thus be taken as a base for experimental analyses at the Tevatron and the LHC.

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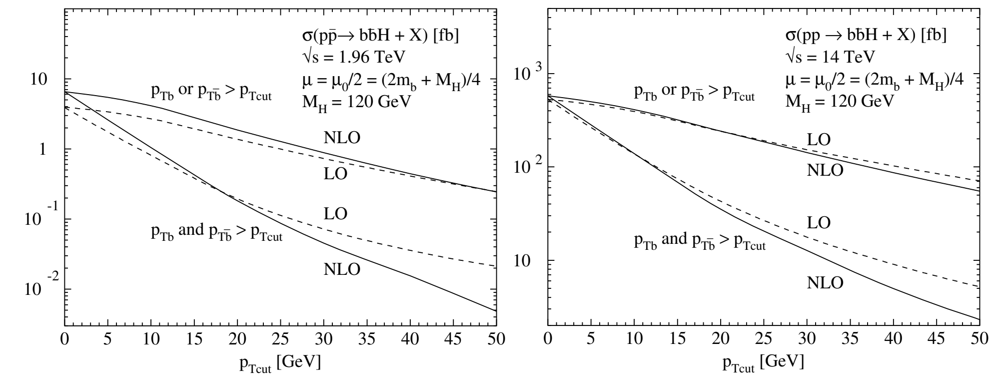

Figure 4. Cross section for $b\bar{b}H+X$ production at the Tevatron and LHC with one or two high-p_T bottom quarks as a function of the minimal b-quark transverse momentum.

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