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Differential Higgs+jet production in bottom quark annihilation and gluon fusion

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Abstract

We present recent developments concerning Higgs production in bottom quark annihilation and gluon fusion. For bottom quark annihilation, we show the transverse momentum distribution of the associated jets. Furthermore, we discuss the distribution of events into n-jet bins for n=0 and $n > 0$ at NNLO and NLO, respectively. For gluon fusion, the quality of the heavy-top limit for differential quantities at $\mathcal{O}(\alpha_s^4)$ is studied by taking into account higher order terms in the $1/m_{\text{top}}$ expansion.

Keywords: Higgs production, Higher order calculations, Hadron Colliders

1. Introduction

After the recent discovery of a scalar particle [1, 2] which may turn out to be the Higgs Boson [3, 4] the task is now to explore its properties in detail, in particular its fermionic and bosonic couplings. This is crucial in order to identify it as a Standard Model (SM) Higgs Boson or one embedded in a theory beyond Standard Model (BSM) e.g. a supersymmetric (SUSY) Higgs Boson. For this purpose precision predictions of the production and decay rate are needed from the theoretical side [5].

In the SM the most important production mechanism is gluon fusion, where the Higgs is mediated through a top quark loop. Due to the complicated loop structure at leading order (LO), higher order correction are usually performed in the so-called heavy-top limit, where the top quark is assumed to be infinitely heavy. For the inclusive cross section [6–8], the heavy-top limit has been validated to a very good precision [9–11], while for differential observables only rather few studies, none of them exceeding the leading order, have been performed until recently [12–14].

In SUSY extensions, e.g. the minimal supersymmetric standard model (MSSM), associated production of a Higgs and bottom quarks can supersede gluon fusion for large $\tan\beta$. Two approaches to calculate its cross section have been pursued in the literature. In the so-called four-flavor scheme (4FS) one assumes the proton to contain only four light quark flavors and the gluon [15–17], while in the five-flavor scheme (5FS) one allows parton distribution functions (PDFs) for the bottom quark in addition [18, 19]. In the 4FS, the infrared divergencies of the final state bottom quarks are regulated by a finite bottom mass m_b. This leads to potentially large logarithms $\ln(m_b/m_H)$. These logarithms are formally resummed into the bottom PDFs in the 5FS.

In the first part of this talk we will present some recent developments concerning Higgs+n-jet production in bottom quark annihilation in the 5FS, where we will focus on aspects specific to the associated jets. In the final part of this talk we will discuss the validation of the heavy-top limit for differential quantities in gluon fusion.

2. Higgs+n-jet production in bottom quark annihilation

Since in the MSSM bottom quark-associated Higgs production may actually be the dominant mechanism for Higgs production, the studies done for H+jet production in gluon fusion should be supplemented by the bottom-annihilation contribution. Therefore we built a fully differential Monte Carlo integrator for Higgs+jet production in bottom quark annihilation through NLO [20, 21] using the well known dipole subtraction method [22]. The corresponding LO diagrams are shown in Fig. 1(a) and 1(b). Two representative NLO diagrams are given in Fig. 1(c) and 1(d). Several checks on the results have been performed: The so-called α-parameter

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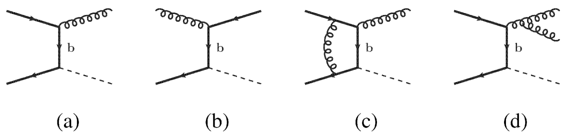

Figure 1: The two LO diagrams (a) $b\bar{b} \to gH$, (b) $gb \to bH$ and two representative diagrams at NLO for (c) virtual corrections and (d) real emission.

has been implemented [23, 24] to prove the consistency of the dipole subtraction procedure. We compared the transverse momentum and rapidity distribution of the Higgs to Ref. [25]; observables specific to identified bottom quarks have been cross checked with `MCFM` [26, 27]; and a complete comparison of quantities including jets has been performed with the fully automated program `aMC@NLO` [28–31].

We present results for the LHC at 7 TeV with a Higgs mass of 120 GeV. The central factorization- (μ_F) and renormalization-scale (μ_R) is $\mu_0 \equiv m_H/4$. Furthermore, all numbers are produced with the MSTW2008 [32] PDFs and the corresponding strong coupling constant. We insert the bottom quark mass of the $b\bar{b}H$ Yukawa coupling in the $\overline{\text{MS}}$-scheme at the scale μ_R, derived from $m_b(m_b) = 4.2$ GeV. Jets are defined using the anti-k_T algorithm with jet radius $R = 0.4$, $p_T^{\text{jet}} > 20$ GeV and $|y^{\text{jet}}| < 4.8$. The results are given in the SM, but according to the studies of [33, 34], they are applicable to the MSSM by simply rescaling the $b\bar{b}H$ coupling.

In Fig. 2 we show the transverse momentum distribution of the hardest jet and the corresponding K-factor. To account for effects of high-p_T jets, the central scale choice is modified to be

$$\mu_F = \mu_R = \frac{1}{4}\sqrt{m_H^2 + (p_{T,1}^{\text{jet}})^2}. \tag{1}$$

For this scale choice we observe rather small perturbative corrections < 10% and a flat dependence of the K-factor once $p_{T,1}^{\text{jet}}$ is larger than 50 GeV.

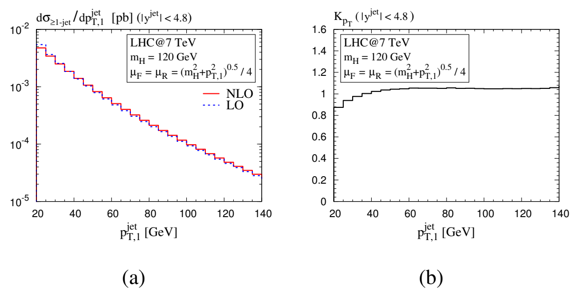

Figure 2: (a) Transverse momentum distribution of the hardest jet and (b) the corresponding K-factor. From Ref. [21].

With the knowledge of the total cross section [19] our machinery is capable of calculating the jet-vetoed (or H + 0-jet) cross section at NNLO by simply subtracting the jet contributions from the total cross section

$$\sigma_{\text{jet-veto}} \equiv \sigma_{0\text{-jet}} = \sigma_{\text{tot}} - \sigma_{\geq 1\text{-jet}}. \tag{2}$$

This allows us to evaluate the distribution of events into $H + n$-jet bins for $n = 0, 1, 2$ at NNLO, NLO and LO, respectively.[1]

In Fig. 3(a) the decomposition of the total inclusive cross section (solid, red, no uncertainties) into the exclusive H + 0-jet (black, dotted) and inclusive H+jet (blue, dashed) rate is shown. Fig. 3(b) illustrates the relative contributions normalized by the total cross section. Similar to what was found for gluon fusion [36] the contributions including jets increase for higher Higgs masses. The error bands emerge from the quadratically added PDF [32] and the scale uncertainties. We vary μ_R and μ_F around the central scale μ_0 within $[0.5\mu_0, 2\mu_0]$.

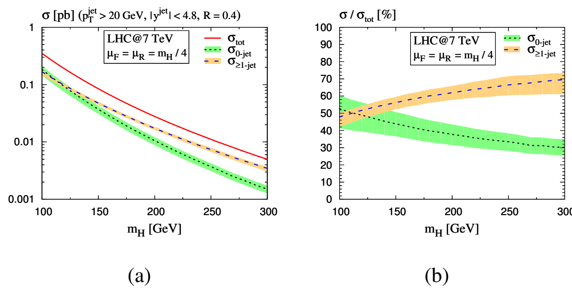

Figure 3: (a) Higgs mass dependence of the H + 0- and ≥ 1-jet contributions to the total cross section at NNLO and NLO, respectively, from Ref. [21], and (b) the relative contributions normalized by the total cross section.

3. Validation of the heavy-top limit for differential Higgs production in gluon fusion

In the second part of this talk we investigate the question if the heavy-top approximation of the gluon fusion cross section prediction is an accurate approach for differential quantities. Since higher order corrections, beyond NLO, of the gluon fusion process with the exact top mass dependence are not feasible with current technology, the usual procedure is to calculate the size of perturbative corrections in the heavy-top limit and rescale the cross including the exact top mass dependence by the obtained K-factor. The top mass effects are considered to be small in this procedure. This has been proven

[1] The fully differential cross section for $b\bar{b} \to H$ through NNLO was obtained recently [35].