PROCEEDINGS OF SCIENCE

Associated b- Quark Higgs Boson Production at the LHC

S. Dawson*
Brookhaven National Laboratory, Upton, New York 11973
E-mail: dawson@bnl.gov

C. B. Jackson
University of Texas, Arlington, Texas 76019
E-mail: cbjackson@uta.edu

P. Jaiswal
YITP, Stony Brook University, Stony Brook, New York 11794
E-mail: pjaiswal@quark.phy.bnl.gov

The associated production of a Higgs boson with a b quark is a discovery mode for an MSSM Higgs boson at large $\tan\beta$. We present updates on the production rate at the LHC, along with a discussion of the importance of the SQCD corrections from squark and gluino loops. We also discuss the purely electroweak contributions.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

*Speaker.

PoS(ICHEP 2010)052

Figure 1: Feynman diagrams for $g+b \rightarrow b+\phi$, where $\phi = h^0, H^0$ or A^0.

1. Introduction

The search for a Higgs boson is one of the most important tasks for the CERN Large Hadron Collider. In the Standard Model, there is a single neutral Higgs boson. In the minimal supersymmetric model (MSSM), however, there are five Higgs bosons–two neutral Higgs bosons, h^0 and H^0, a pseudoscalar, A^0, and two charged Higgs bosons, $H^\pm$, and the strategy for discovery is quite different from in the Standard Model[1]. In the MSSM, the couplings of the Higgs bosons to b quarks can be significantly enhanced and, for a large range of parameter space, Higgs production in association with b quarks is the major discovery channel. The hadronic production rate for the associated production of a Higgs boson and a b quark is well understood [1, 2, 3, 4, 5]. In a 5-flavor number PDF scheme, the lowest order process for producing a Higgs boson in association with b quarks is $b\overline{b} \rightarrow \phi$ when no b quarks are tagged in the final state and $bg \rightarrow b\phi$ when a single b quark is tagged. The Tevatron experiments have produced limits on both of these processes as a function of the $b\overline{b}\phi$ coupling.

In this note, we present results for the process $bg \rightarrow b\phi$ at the LHC, including NLO QCD corrections, NLO SQCD corrections from squark and gluino loops[6], and the purely electroweak corrections[7].

2. Basic Setup

The tree level diagrams for $g+b \rightarrow b+\phi$ are shown in Fig. 1. The lowest order (LO) rate and the NLO QCD corrected rate for the production of a Standard Model Higgs boson at the LHC for the process $bg \rightarrow bH$ are shown in Fig. 2 for $\sqrt{s} = 7\ TeV$. The inclusion of the NLO QCD corrections increases the rate significantly and also reduces the renormalization and factorization scale dependence. The $b\overline{b}H$ coupling, $g^{SM}_{b\bar{b}H}$, is $\overline{m_b}(\mu)/v$, where $v = 246\ GeV$ and $\overline{m_b}(\mu)$ is the $\overline{MS}$ running b quark mass at 1-loop for the lowest order predictions, and at 2-loops for the NLO predictions.

In the MSSM, the bottom quark Yukawa couplings to the neutral Higgs bosons are:

$$g^{MSSM}_{b\bar{b}h^0} = -\frac{\sin\alpha}{\cos\beta} g^{SM}_{b\bar{b}H} \qquad\qquad g^{MSSM}_{b\bar{b}H^0} = \frac{\cos\alpha}{\cos\beta} g^{SM}_{b\bar{b}H}\ , \tag{2.1}$$

where α is the angle which diagonalizes the neutral Higgs mass matrix and $\tan\beta$ is the ratio of the neutral Higgs boson vacuum expectation values. The NLO QCD corrected rates for production of

[1]The MSSM neutral Higgs bosons are generically denoted by ϕ.

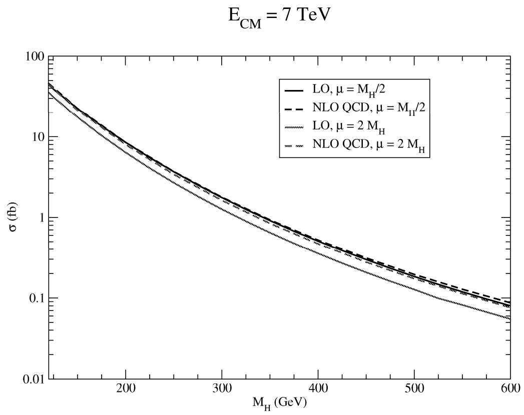

Figure 2: Lowest order (LO) and NLO QCD results for the Standard Model process $pp \to b(\overline{b})HX$ at the LHC with $\sqrt{s} = 7\ TeV$, $p_T^b > 25\ GeV$, $\mid \eta_b \mid < 2.5$, and $\Delta R > .4$. The renormalization/factorization scales are set equal to μ.

an MSSM neutral Higgs boson can be derived from Fig. 2 by rescaling the couplings using Eq. 2.1. For large $\tan\beta$, the MSSM rates can be orders of magnitude larger than the Standard Model rates.

The dominant SQCD radiative corrections for large squark and gluino masses can be taken into account by including the squark and gluino contributions to the $b\bar{b}\phi$ vertices only, i.e. by replacing the tree level Yukawa couplings by the radiative corrected ones[8, 9].

$$\begin{aligned} g^{MSSM}_{b\bar{b}h^0} &= -g^{SM}_{b\bar{b}H}\frac{1}{1+\Delta_b}\left[\frac{\sin\alpha}{\cos\beta} - \Delta_b\frac{\cos\alpha}{\sin\beta}\right] , \\ g^{MSSM}_{b\bar{b}H^0} &= g^{SM}_{b\bar{b}H}\frac{1}{1+\Delta_b}\left[\frac{\cos\alpha}{\cos\beta} + \Delta_b\frac{\sin\alpha}{\sin\beta}\right] , \end{aligned} \tag{2.2}$$

with

$$\Delta_b = \mu\tan\beta\frac{2\alpha_s}{3\pi}M_{\tilde{g}}I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}}) , \tag{2.3}$$

where $m_{\tilde{b}_{1,2}}$ and $M_{\tilde{g}}$ denote the sbottom and gluino masses, μ is the Higgs mixing parameter, and the function I is,

$$I(a,b,c) = \frac{[a^2b^2\ln(\frac{a^2}{b^2}) + b^2c^2\ln(\frac{b^2}{c^2}) + a^2c^2\ln(\frac{c^2}{a^2})]}{(a^2-b^2)(b^2-c^2)(a^2-c^2)} . \tag{2.4}$$

Rescaling the $bb\phi$ couplings by Eq. 2.2 yields the result for MSSM Higgs bosons labelled "IBA" in Fig. 3. In Ref. [6], a complete calculation of all of the contributions from squark and gluino loops to the process $pp \to b\phi$ was presented and is shown in Fig. 3 as the curve labelled "NLO

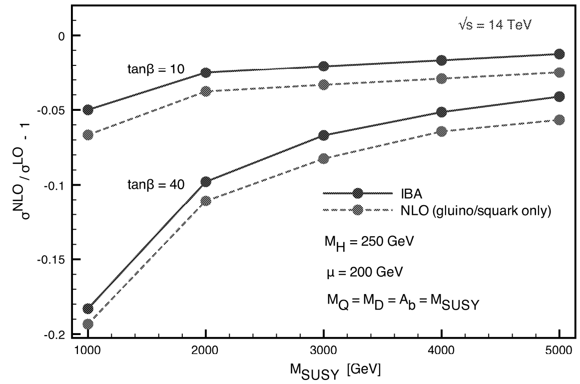

Figure 3: Comparison of the full SQCD calculation including the effects of squark and gluino loops exactly with the approximate result (Eq. 2.2) for the rate for $pp \rightarrow bH^0$ at the LHC. The outgoing b quark satisfies $p_T^b > 20\ GeV$ and $\mid \eta_b \mid < 2.5$.

(gluino/squark only)". We see that the rescaling of Eq. 2.2 is an accurate approximation for the contribution of squark and gluino loops for SUSY masses on the TeV scale. These contributions can be numerically significant. For squark and gluino masses of $\mathcal{O}(1TeV)$ and $\tan\beta = 40$, they change the rate by roughly 20%. (Since the rate is directly proportional to μ, whether it is an increase or decrease depends on the sign of μ.)

3. Electroweak Corrections

The $1-$loop weak corrections to the process $bg \rightarrow bH$ consist of self energy, vertex, and box diagrams containing Standard Model particles. The tree level process vanishes when $m_b = 0$, but there are one-loop weak contributions which do not vanish in this limit. The electroweak contributions to the $b\overline{b} \rightarrow \phi$ MSSM process have been computed in Ref. [10] and are well approximated by an on-shell rescaling of the $b\overline{b}\phi$ coupling.

The cross section can be expressed as,

$$\sigma(bg \rightarrow b\phi)_{NLO} = \sigma(bg \rightarrow b\phi)_0 \left(1 + \Delta_{QCD} + \Delta_{QED} + \Delta_{WK}\right), \tag{3.1}$$

where σ_0 is the Born cross section derived using the effective vertices of Eq. 2.2. Fig. 4 shows the weak corrections to the Standard Model process, $pp \rightarrow bH$. The curve labelled "Improved Born Approximation" is derived by rescaling the $b\overline{b}H$ vertex to include the electroweak corrections obtained for the on-shell process $H \rightarrow b\overline{b}$, while the curve labelled "Total" is an exact one-loop calculation of the electroweak corrections to the process $bg \rightarrow bH$. The weak corrections are well

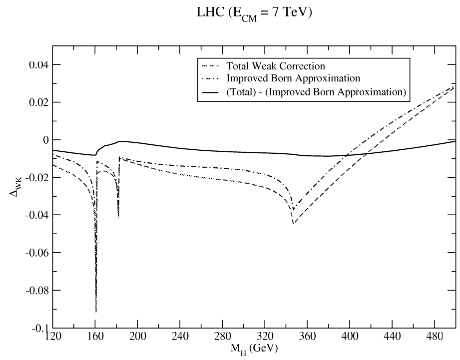

Figure 4: LHC results for the weak corrections to $pp \to b(\overline{b})H$ with $\sqrt{s} = 7\ TeV$, $p_T^b > 25\ GeV$, and $\mid \eta_b \mid < 2.5$. The solid black curve represents the contributions which cannot be factorized into an effective $\overline{b}bH$ vertex contribution and is less than 1% for $M_H < 500\ GeV$.

approximated by the Improved Born Approximation, with the remaining corrections always less than 1%. Except near the W^+W and ZZ resonances, Δ_{WK} in the Standard Model is significantly smaller than the uncertainties from the QCD scale variation and the PDF uncertainties for $M_H < 400\ GeV$. For heavy Higgs masses ($M_H \sim 1\ TeV$), the weak corrections are large (of $\mathcal{O}(20\ \%)$).

4. Conclusion

The production rate for $pp \to b\phi$ for MSSM Higgs bosons is well understood. The QCD and SQCD one-loop corrections are large and must be included for an accurate prediction, while the electroweak contributions are a few % for moderate Higgs masses.

References

[1] S. Dawson, C. B. Jackson, L. Reina and D. Wackeroth, Mod. Phys. Lett. A **21**, 89 (2006) [arXiv:hep-ph/0508293].

[2] S. Dawson, C. B. Jackson, L. Reina and D. Wackeroth, Phys. Rev. Lett. **94**, 031802 (2005) [arXiv:hep-ph/0408077].

[3] S. Dawson, C. B. Jackson, L. Reina and D. Wackeroth, Phys. Rev. D **69**, 074027 (2004) [arXiv:hep-ph/0311067].

[4] J. M. Campbell *et al.*, arXiv:hep-ph/0405302.

[5] S. Dittmaier, M. 1. Kramer and M. Spira, Phys. Rev. D **70**, 074010 (2004) [arXiv:hep-ph/0309204].

[6] S. Dawson and C. B. Jackson, Phys. Rev. D **77**, 015019 (2008) [arXiv:0709.4519 [hep-ph]].

[7] S. Dawson and P. Jaiswal, Phys. Rev. D **81**, 073008 (2010) [arXiv:1002.2672 [hep-ph]].

[8] L. J. Hall, R. Rattazzi and U. Sarid, Phys. Rev. D **50**, 7048 (1994) [arXiv:hep-ph/9306309].

[9] M. S. Carena, D. Garcia, U. Nierste and C. E. M. Wagner, Nucl. Phys. B **577**, 88 (2000) [arXiv:hep-ph/9912516].

[10] S. Dittmaier, M. 1. Kramer, A. Muck and T. Schluter, JHEP **0703**, 114 (2007) [arXiv:hep-ph/0611353].