Discovering the Higgs bosons of minimal supersymmetry with bottom quarks

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A B S T R A C T

We investigate the prospects for the discovery of a neutral Higgs boson produced with one bottom quark followed by Higgs decay into a pair of bottom quarks at the CERN Large Hadron Collider (LHC) and the Fermilab Tevatron Collider. We work within the framework of the minimal supersymmetric standard model. The dominant physics background is calculated with realistic acceptance cuts and efficiencies including the production of $b\bar{b}b\bar{b}$, $b\bar{b}b\bar{b}$, $j\bar{b}b\bar{b}$ ($j=g,q,q_1,q_u,d,s,c$), $t\bar{t} \rightarrow b\bar{b}j\ell\nu$, and $t\bar{t} \rightarrow b\bar{b}jjjj$. Promising results are found for the CP-odd pseudoscalar ($A^0$) and the heavier CP-even scalar ($H^0$) Higgs bosons with masses up to 800 GeV for the LHC with an integrated luminosity ($L$) of 30 fb$^{-1}$ and up to 1 TeV for $L = 300$ fb$^{-1}$.

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1. Introduction

The Fermilab Tevatron Run II has been taking data since March 2001, and the CERN Large Hadron Collider (LHC) is planned to start running in Autumn 2009. One of the most important experimental goals of the Tevatron Run II and the LHC is the search for the mechanism of electroweak symmetry breaking—to discover the Higgs bosons or to prove their non-existence.

In the Standard Model, only one Higgs doublet is required to generate mass for both gauge bosons and elementary fermions, and the Higgs boson is the only particle remaining to be discovered in high energy experiments. In the minimal supersymmetric standard model (MSSM) [1], the Higgs sector has Yukawa interactions with two doublets, $\phi_1$ and $\phi_2$, whose neutral components couple to fermions with weak isospin $t_3 = -1/2$ and $t_3 = +1/2$ respectively [2]. After spontaneous symmetry breaking, there remain five physical Higgs bosons: a pair of singly charged Higgs bosons $H^\pm$, two neutral CP-even scalars $H^0$ (heavier) and $h^0$ (lighter), and a neutral CP-odd pseudoscalar $A^0$. The Higgs potential is constrained by supersymmetry such that all tree-level Higgs boson masses and couplings are determined by just two independent parameters, commonly chosen to be the mass of the CP-odd pseudoscalar ($M_A$) and the ratio of vacuum expectation values of neutral Higgs fields ($\tan \beta \equiv v_2/v_1$).

At the LHC, gluon fusion ($gg \rightarrow \phi^0$, $\phi^0 = h^0, H^0, A^0$) is the major source of neutral Higgs bosons in the MSSM for $\tan \beta$ less than 5. For $\tan \beta > 7$, neutral Higgs bosons are dominantly produced from bottom quark fusion $b\bar{b} \rightarrow \phi^0$ [3–7]. Since the Yukawa couplings of $\phi^0 b\bar{b}$ are enhanced by $1/\cos \beta$, the production rate of neutral Higgs bosons associated with bottom quarks, especially that of the $A^0$ or the $H^0$, is enhanced at large $\tan \beta$.

For a Higgs boson produced along with a single bottom quark at high transverse momentum ($p_T$), the leading-order subprocess is $gg \rightarrow b\bar{b} \phi^0$ [8–12]. If two high $p_T$ bottom quarks are required in association with a Higgs boson, the leading order subprocess should be $gg \rightarrow b\bar{b} \phi^0$ [3,13–16]. In 2002, it was suggested that the search at the LHC for a Higgs boson produced along with a single bottom quark with large $p_T$ should be more promising than the production of a Higgs boson associated with two high $p_T$ bottom quarks [10]. This has already been shown to be the case for the $\mu^+\mu^-$ decay mode of the Higgs bosons [17].

For large $\tan \beta$, the $\tau^+\tau^-$ decay mode [18,19] can be a promising discovery channel for the $A^0$ and the $H^0$ in the MSSM. Recently, the discovery channel $b\phi^0 \rightarrow b\tau^+\tau^-$ has been demonstrated to offer great promise at the LHC to search for the $A^0$ and the $H^0$ up to $M_A = 1$ TeV [20].

The Higgs decay into $bb$ has the largest branching fraction for large values of $\tan \beta$. However, the inclusive channel of $pp \rightarrow \phi^0 \rightarrow b\bar{b} + X$ is very challenging at the LHC owing to the extremely large QCD background. Previous theoretical studies have focused on the associated production of $b\bar{b} \phi^0 \rightarrow b\bar{b} \phi^0$ [21–23]. Realiistic simulations by the ATLAS and the CMS Collaborations with parton showering lead to pessimistic results [24–26], because the trigger for the $4b$ final state requires high $p_T$ bottom quarks for $pp \rightarrow b\bar{b} \phi^0 \rightarrow b\bar{b} \phi^0 \rightarrow b\bar{b} + X$. The requirement of four high $p_T$ $b$-quarks removes most of the Higgs events. Moreover, integrating over the fourth $b$-quark to study a $3b$ signal requires a careful inclusion of higher order corrections in the four-flavor scheme. These poten-
of bottom quark mass in the we take the effects of next-to-leading order (NLO) corrections [10]. Therefore, we take the bottom quark (via bg) to produce the Higgs signal. The SM physics background is discussed in Section 292. This choice of scale effectively reproduces the leading-log corrections are absorbed into the PDFs in the five flavor scheme which we employ.

In this Letter, we present the prospects for discovering the MSSM neutral Higgs bosons produced with a single high pT bottom quark (b or b) followed by Higgs decay into a pair of bottom quarks. We calculate the Higgs signal and the dominant Standard Model (SM) backgrounds with exact matrix elements as well as realistic cuts and efficiencies. Furthermore, we present promising 5σ discovery contours at the LHC in the (M_A, tan β) plane. Section 2 shows the production cross sections and branching fractions for the Higgs signal. The SM physics background is discussed in Section 3. Sections 4 and 5 present the discovery potential at the LHC and the Fermilab Tevatron Run II. Optimistic conclusions are drawn in Section 6.

The final state of bbb has dominant physics backgrounds coming from (a) bg → bb, (b) cg → cbb, (c) qg → qbb with q = u, d, s, (d) q̄q → gbb with q = u, d, s, c, and (e) gg, q̄q → t̄t → bbjjc̄v, or gg, q̄q → t̄t → bbjjj. We have computed the cross section of the Higgs signal and physics background utilizing MadGraph [31,32] and HELAS [33] to generate matrix elements. To reduce the physics background while keeping most of the signal events, we require that in each event there are three jets (at least two b-jets) which satisfy the following requirements:

(a) we consider two sets of cuts for an integrated luminosity (L) of 30 fb^{-1} (low luminosity, LL): (i) p_T(j_1) > 50 GeV, p_T(j_2) > 30 GeV and p_T(j_3) > 20 GeV (low p_T cuts), or (ii) p_T(j_1, j_2, j_3) > 70 GeV (CMS 3+jet trigger) [26] as well as the pseudorapidity, |η| < 2.5 for all jets, where p_T(j_1) > p_T(j_2) > p_T(j_3), or (b) for L = 300 fb^{-1} (high luminosity, HL) we check two sets of cuts: (i) p_T(j_1, j_2, j_3) > 75 GeV (ATLAS 3+jet trigger) [25] or (ii) p_T(j_1, j_2, j_3) > 150 GeV (ATLAS 3+jet trigger for high luminosity) [25] as well as |η| < 2.5 for all jets,

(c) there is at least one pair of bottom quarks in the Higgs mass window such that |M_{bb} - M_0| < ΔM_{bb}, where ΔM_{bb} = MAX(22 GeV, σ_M), choosing σ_M = 0.10 × M_0 or 0.15 × M_0 for L = 30 fb^{-1} and σ_M = 0.15 × M_0 or 0.20 × M_0 for L = 300 fb^{-1},

(d) all three jets are separated with ΔR = √Δφ^2 + Δη^2 > 0.7 (where φ is the angle between two jets in the transverse plane),

(e) the missing transverse energy (E_T) should be less than 40 GeV.

In addition, we veto events with more than three jets passing the cuts p_T(j) > 15 GeV and |η| < 2.5. We take the b-tagging efficiency to be ε_b = 0.6 (LL) or ε_b = 0.5 (HL), the probability that charm quark may be misidentified is ε_c = 0.15, and the probability that a light quark or a gluon may be misidentified as a bottom quark is ε_j = 0.01. For the backgrounds arising from bbb and jbb [21] as well as those from t̄t [34], we assume a K factor of 2 when computing the significance as discussed below. In practice we find that the t̄t backgrounds are negligible after cuts, although we include them for completeness.
The signal cross section of of \( \text{Fig. 3.} \)

The transverse-momentum distribution for (a) the Higgs signal from \( \ttb \) with \( M_A = 200 \text{ GeV} \) and tan\( \beta = 10, 50 \) as well as for (b) the physics background from \( \ttb \). We require \( p_T(b) > 10 \text{ GeV} \) and \( |\eta| < 2.5 \) in this figure. The vertical, dashed lines illustrate cuts at 20 GeV and 70 GeV.

\[
\sqrt{s} = 14 \text{ TeV}
\]

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2}
\caption{The transverse-momentum distribution for (a) the Higgs signal from \( \ttb \) with \( M_A = 200 \text{ GeV} \) and tan\( \beta = 10, 50 \) as well as for (b) the physics background from \( \ttb \). We require \( p_T(b) > 10 \text{ GeV} \) and \( |\eta| < 2.5 \) in this figure. The vertical, dashed lines illustrate cuts at 20 GeV and 70 GeV.}
\end{figure}

In Fig. 2, we present the transverse-momentum distribution \( \frac{d\sigma}{dp_T(b) > 10 \text{ GeV} \text{ and } |\eta| < 2.5 \text{ in this figure.}} \)

4. The discovery potential at the LHC

To study the discovery potential of \( pp \rightarrow \phi^0 \rightarrow \ttb + X \) (\( \phi^0 = H^0, \tilde{h}^0, A^0 \)) at the LHC, we calculate the Higgs signal as well as the SM physics background in the mass window of \( M_A \pm \Delta M_{\phi^0} \) where \( \Delta M_{\phi^0} = \text{MAX}(22 \text{ GeV}, 0.10 \times M_A) \) or \( \Delta M_{\phi^0} = \text{MAX}(22 \text{ GeV}, 0.15 \times M_A) \) for an integrated luminosity of 30 fb\(^{-1}\).

In Fig. 3 we show the cross section of \( \sigma(pp \rightarrow \phi^0 \rightarrow \ttb + X) \), for \( \tan \beta = 10 \) and 50, with a common mass for scalar quarks, scalar leptons and the gluino \( m_1 = m_2 = \mu = 1 \text{ TeV} \). We also present the background cross sections with no \( K \) factor in the mass window of \( M_A \pm \Delta M_{\phi^0} \) for the dominant SM processes \( pp \rightarrow \ttb + X \) and \( pp \rightarrow \ttb + X, j = q, \tilde{q}, g \), with (a) low \( p_T \) cuts and (b) CMS 3-jet trigger. The cuts and tagging efficiencies are included with \( \Delta M_{\phi^0} = 0.10 \times M_A \). In addition, we present the 5\( \sigma \) cross section for \( L = 30 \text{ fb}^{-1} \). The cross section of the Higgs signal with \( \tan \beta \approx 50 \) can be larger than the 5\( \sigma \) cross section for \( M_A \lesssim 800 \) after acceptance cuts. Requiring higher transverse momenta \( (p_T > 70 \text{ GeV}) \) greatly reduces the background and the Higgs signal for \( M_A < 200 \text{ GeV} \).

We define the signal to be observable if the lower limit on the signal plus background is larger than the corresponding upper limit on the background [35,36], namely,

\[
L(\sigma_s + \sigma_b) - N\sqrt{L(\sigma_s + \sigma_b)} > L\sigma_b + N\sqrt{L\sigma_b}
\]

which corresponds to

\[
\sigma_s > \frac{N^2}{L}[1 + 2\sqrt{L\sigma_b}/N].
\]

Here \( L \) is the integrated luminosity, \( \sigma_s \) is the cross section of the Higgs signal, and \( \sigma_b \) is the background cross section. Both cross sections are taken to be within a bin of width \( \pm \Delta M_{\phi^0} \) centered at \( M_A \). In this convention, \( N = 2.5 \) corresponds to a 5\( \sigma \) signal. We take the integrated luminosity \( L \) to be 30 fb\(^{-1}\) and 300 fb\(^{-1}\) [24].

For \( \tan \beta \geq 10 \), \( M_A \) and \( M_{\tilde{g}} \) are almost degenerate when \( M_A \gtrsim 125 \text{ GeV} \), while \( M_A \) and \( m_h \) are very close to each other for \( M_A \lesssim 125 \text{ GeV} \) in the MSSM [37]. Therefore, when computing the discovery reach, we add the cross sections of the \( A^0 \) and the \( h^0 \) for \( M_A < 125 \text{ GeV} \) and those of the \( A^0 \) and the \( H^0 \) for \( M_A \gtrsim 125 \text{ GeV} \) [24,26,38].

Fig. 4 shows the 5\( \sigma \) discovery contours for the MSSM Higgs bosons where the discovery region is the part of the parameter space above the contour. We have chosen \( M_{\tilde{b} \tilde{b}} = m_{\tilde{b}} = m_{\tilde{t}} = \mu = 1 \text{ TeV} \). If \( M_{\tilde{b} \tilde{b}} \) is smaller, the discovery region of \( A^0, H^0 \rightarrow \ttb \) will be slightly reduced for \( M_A \gtrsim 250 \text{ GeV} \), because the Higgs bosons can decay into supersymmetric (SUSY) particles [39] and the branching fraction of \( \phi^0 \rightarrow \ttb \) is suppressed. For \( M_A \lesssim 125 \text{ GeV} \), the discovery region of \( H^0 \rightarrow \ttb \) is slightly enlarged for a smaller \( M_{\tilde{b} \tilde{b}} \), but the observable region of \( h^0 \rightarrow \ttb \) is slightly reduced because the lighter top squarks make the \( H^0 \) and the \( h^0 \) lighter; also the \( H^0 \ttb \) coupling is enhanced while the \( h^0 \ttb \) coupling is reduced [38].

In addition, we have studied the effect of an invariant-mass cut, using only the two jets with highest \( p_T \) as the candidate pair. Table 1 presents the cross section corresponding to two schemes: (a) requiring \( |M_{ij} - M_{\phi^0}| < \Delta M_{\phi^0} \), and (b) requiring \( |M_{ij} - M_{\phi^0}| < \Delta M_{\phi^0} \). We find that for \( M_A \gtrsim 400 \), it is more advantageous to apply an invariant-mass cut only on the two leading b jets. For lower masses using any pair of the three leading jets leads to higher significance. We also show the ratio of signal to background in this figure. We have chosen a set of cuts, \( p_T(j_1, j_2, j_3) > 100, 80, 70 \text{ GeV} \), which tends to maximize this ratio. Less stringent cuts can improve the nominal statistical significance in the low mass regions, but for high masses and low \( \tan \beta \) the small signal to background ratio would require excellent understanding of backgrounds and systematic errors.

Furthermore, we have studied the effects of SUSY particles on the \( \phi^0 \ttb \) Yukawa couplings at large \( \tan \beta \). The SUSY contributions can be described with an effective Lagrangian and a function \( \Delta_\beta [40-43] \) such that the bottom quark mass in Yukawa couplings becomes

\[
m_b \rightarrow \frac{m_b}{1 + \Delta_\beta}
\]
The 5σ discovery contours at the LHC with √s = 14 TeV for (a) L = 30 fb⁻¹ and low pT, (b) L = 30 fb⁻¹ and high pT > 70 GeV, (c) L = 300 fb⁻¹ and pT > 75 GeV, and (d) L = 300 fb⁻¹ and pT > 150 GeV, in the M̃b versus tanβ plane. The signal includes φ² = A² and h² for M̃b < 125 GeV, and φ² = A² and H² for M̃b > 125 GeV. The discovery region is the part of the parameter space above the contours.

where SUSY QCD corrections lead to

$$\Delta_b = \frac{2\alpha_s}{3\pi} m_\tilde{g}\tan \beta I(m_{b_1}, m_{b_2}, m_\tilde{g})$$

for bottom squarks and gluinos, and the auxiliary function is

$$l(a, b, c) = \frac{1}{(a^2 - b^2)(b^2 - c^2)(c^2 - a^2)} \times \left(\frac{a^2 - b^2}{b^2} \ln \frac{a^2}{b^2} + \frac{b^2 - c^2}{c^2} \ln \frac{b^2}{c^2} + \frac{c^2 - a^2}{a^2} \ln \frac{c^2}{a^2}\right).$$

Then the cross section can be estimated with a simple formula [43]

$$\sigma(pp \rightarrow b\phi^0 + X) \times B(\phi^0 \rightarrow b\tilde{b}) \approx \sigma_{SM}(pp \rightarrow bH + X) \times \frac{\tan^2 \beta}{(1 + \Delta_b)^2} \times \frac{9}{(1 + \Delta_b)^2 + 9}.$$

In our analysis of SUSY effects, we adopt the conventions in Refs. [12, 44] and have used a more complete estimate, including the effects of the modified Higgs width in the full BWR calculation. Table 2 shows the cross section including (a) no SUSY effects, (b) contributions from bottom squarks and gluinos, and (c) contributions from bottom squarks and gluinos as well as from top squarks and Higgsinos. The top squark/Higgsino loops give an additional effective correction to m̃b, \[ \Delta_b^I = \frac{\alpha_t}{4\pi} A_t \mu \tan \beta I(m_{b_1}, m_{b_2}, m_\mu). \]

Table 1

<table>
<thead>
<tr>
<th>Mass (GeV)</th>
<th>Signal</th>
<th>Background</th>
<th>Significance (N_{SIM}/\sqrt{N_S + N_B})</th>
<th>N_{SIM}/N_B</th>
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</thead>
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<tr>
<td>200</td>
<td>M_{12}</td>
<td>44.2</td>
<td>3.82</td>
<td>1.12 × 10⁻²</td>
</tr>
<tr>
<td>400</td>
<td>M_{12}</td>
<td>23.5</td>
<td>1.57</td>
<td>3.52 × 10⁻³</td>
</tr>
<tr>
<td>800</td>
<td>M_{12}</td>
<td>1.42</td>
<td>0.208</td>
<td>1.02 × 10⁻⁴</td>
</tr>
<tr>
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<td>M_{12}</td>
<td>178</td>
<td>20.2</td>
<td>4.48 × 10⁻²</td>
</tr>
<tr>
<td>400</td>
<td>M_{12}</td>
<td>104</td>
<td>6.99</td>
<td>1.56 × 10⁻²</td>
</tr>
<tr>
<td>800</td>
<td>M_{12}</td>
<td>6.99</td>
<td>1.02</td>
<td>5.00 × 10⁻³</td>
</tr>
<tr>
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<td>M_{12}</td>
<td>961</td>
<td>75.0</td>
<td>2.42 × 10⁻¹</td>
</tr>
<tr>
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<td>M_{12}</td>
<td>2770</td>
<td>115</td>
<td>1.91 × 10⁻¹</td>
</tr>
<tr>
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<td>M_{12}</td>
<td>563</td>
<td>36.2</td>
<td>8.43 × 10⁻²</td>
</tr>
<tr>
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<td>M_{12}</td>
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<td>39.8</td>
<td>6.66 × 10⁻²</td>
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<tr>
<td>800</td>
<td>M_{12}</td>
<td>44.7</td>
<td>4.96</td>
<td>1.87 × 10⁻²</td>
</tr>
</tbody>
</table>

Table 2

Effect of \( \Delta_b \) in \( M_{SUSY} \) (no mixing) scenario. Cross sections in fb for \( pp \rightarrow b\phi^0 \rightarrow b\bar{b} + X \) using high \( p_T > 70 \text{ GeV} \) cuts. Tagging efficiencies have not been applied.

<table>
<thead>
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<th>Mass (GeV)</th>
<th>( \Delta_b = 0 )</th>
<th>( \frac{g}{b} )</th>
<th>( \frac{g}{b} + H/t )</th>
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</thead>
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<tr>
<td>200</td>
<td>( \mu = +200 )</td>
<td>698(708)</td>
<td>646(658)</td>
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<td>( \mu = -200 )</td>
<td>699(703)</td>
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<td>( \mu = +200 )</td>
<td>155(155)</td>
<td>143(144)</td>
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<td>( \mu = -200 )</td>
<td>156(155)</td>
<td>168(167)</td>
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<td>( \mu = +200 )</td>
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<td>( \mu = -200 )</td>
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<tr>
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<td>( \mu = +200 )</td>
<td>233(233)</td>
<td>172(172)</td>
</tr>
<tr>
<td>800</td>
<td>( \mu = -200 )</td>
<td>233(233)</td>
<td>325(325)</td>
</tr>
</tbody>
</table>

5. The Discovery Potential at the Fermilab Tevatron

To study the discovery potential of Higgs decays into bottom quark pairs at the Fermilab Tevatron Run II, we require:
Fermilab Tevatron Run II

(a) $\tan \beta(\beta) > 15$ GeV (b) $\tan \beta(\beta) > 50, 30, 15$ GeV

Fig. 5. The 5σ discovery contours at the Fermilab Tevatron Run II for an integrated luminosity ($L$) of 4 fb$^{-1}$, 10 fb$^{-1}$, 20 fb$^{-1}$ in the $M_A$ versus $\tan \beta$ plane. The signal includes $\phi^0 = A^0$ and $H^0$ for $M_A < 125$ GeV, and $\phi^0 = A^0$ and $H^0$ for $M_A > 125$ GeV. The discovery region is the part of the parameter space above the contours.

(i) three $b$ quarks or 3 jets (at least two $b$ jets) with $p_T > 15$ GeV or $p_T(j_1, j_2, j_3) > 50, 30, 15$ GeV, $|\eta(b, j)| < 2.0$, and a $b$-tagging efficiency $\epsilon_b = 50\%$ [30],
(ii) the angular separation between each pair of jets should be $\Delta R > 0.4$ [45],
(iii) the invariant mass of the reconstructed bottom quark pairs should be within the mass window of the Higgs mass with $\Delta M_{bb} = \text{MAX}(0.1 \times M_{bb}, 20$ GeV).

Fig. 5 show the 5σ discovery contours for the MSSM Higgs bosons, where the discovery region is the part of the parameter space above the curves. The discovery contours for $\Delta M_{bb} = 0.10 \times M_{bb}$ [46] are comparable to those presented in this figure.

We find that the Tevatron Run II can discover neutral Higgs bosons in the MSSM for a value of $\tan \beta$ slightly less than 30 with an integrated luminosity of 4 fb$^{-1}$ and $M_A < 120$ GeV. For $\tan \beta > 50$, the Tevatron Run II will be able to discover the Higgs bosons up to $M_A \sim 160$ GeV with $L = 4$ fb$^{-1}$, and up to $M_A \sim 200$ GeV with $L = 20$ fb$^{-1}$. Our results are consistent with those found in Refs. [23,45,47].

6. Conclusions

The associated production of a Higgs boson with a bottom quark, followed by the Higgs decay into bottom quark pairs, is a promising channel for the discovery of the neutral Higgs bosons in the minimal supersymmetric standard model at the LHC. The $A^0$ and the $H^0$ should be observable in a large region of parameter space with $\tan \beta \gtrsim 10$. The associated final state of $\phi^0 \rightarrow b\bar{b}$ could discover the $A^0$ and the $H^0$ at the LHC with an integrated luminosity of 30 fb$^{-1}$ if $M_A \lesssim 800$ GeV. At a higher luminosity of 300 fb$^{-1}$, the discovery region in $M_A$ is expanded up to $M_A = 1$ TeV for $\tan \beta \sim 50$.

In our analysis, we make a mass cut, requiring the reconstructed Higgs mass to lie in the mass window $M_\phi \pm \Delta M_\phi$. We note that improvements in the discovery potential will be possible by narrowing $\Delta M_\phi$ if the bottom quark pair mass resolution can be improved. In regions of high mass and low $\tan \beta$ the ratio of signal to background events is very low. Discovery in these regions would require either excellent understanding of backgrounds in order to lower systematic errors below the few percent level, or better discrimination between signal and background due to narrower $\Delta M_{bb}$ or improved $b$-tagging. Our results using three $b$'s are more promising than those found in previous studies based on 4b analyses [21,22,25,26].

The discovery of the associated final state of $\phi^0 \rightarrow b\bar{b}$ along with $\phi^0 \rightarrow b\tau^+\tau^-$ [20] and $\phi^0 \rightarrow b\mu^+\mu^-$ [17] will provide information about the Yukawa couplings of $f \phi^0$: $f = b, \tau, \mu$, for fermions with $t_3 = -1/2$. Furthermore, the muon pair channel can also be observable in a significantly large region and the muon pair channel will provide a good opportunity to precisely reconstruct the masses for MSSM Higgs bosons [13,17,38]. In concert, this family of channels may provide an excellent window on the Yukawa sector of the MSSM.

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References

H.E. Haber, G.L. Kane, Phys. Rep. 117 (1985) 75.

S. Heinemeyer, W. Hollik, G. Weiglein, Phys. Rev. D 58 (1998) 091701; and
references therein.


