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Detecting Higgs bosons with muons at hadron colliders

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Abstract

We investigate the prospects for the discovery of neutral Higgs bosons with a pair of muons by direct searches at the CERN large hadron collider (LHC) as well as by indirect searches in the rare decay $B_s \to \mu^+\mu^-$ at the Fermilab Tevatron and the LHC. Promising results are found for the minimal supersymmetric standard model, the minimal supergravity (mSUGRA) model, and supergravity models with non-universal Higgs masses (NUHM SUGRA). For $\tan\beta \simeq 50$, we find that (i) the contours for a branching fraction of $B(B_s \to \mu^+\mu^-) = 1 \times 10^{-8}$ in the parameter space are very close to the 5σ contours for $pp \to b\phi^0 \to b\mu^+\mu^- + X$, $\phi^0 = h^0, H^0, A^0$ at the LHC with an integrated luminosity (L) of 30 fb^{-1}, (ii) the regions covered by $B(B_s \to \mu^+\mu^-) \geqslant 5 \times 10^{-9}$ and the discovery region for $b\phi^0 \to b\mu^+\mu^-$ with 300 fb^{-1} are complementary in the mSUGRA parameter space, (iii) in NUHM SUGRA models, a discovery of $B(B_s \to \mu^+\mu^-) \simeq 5 \times 10^{-9}$ at the LHC will cover regions of the parameter space beyond the direct search for $b\phi^0 \to b\mu^+\mu^-$ with $L = 300$ fb^{-1}.

1. Introduction

The minimal supersymmetric standard model (MSSM) [1] has two Higgs doublets ϕ_1 and ϕ_2 that couple to fermions with weak isospin $-1/2$ and $+1/2$ 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 (SUSY) 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 ($\tan\beta \equiv v_2/v_1$).

In the MSSM and two Higgs doublet models with model II of Yukawa interactions, the couplings of down type quarks and leptons with the neutral Higgs bosons are proportional to $1/\cos\beta$. Thus a large value of $\tan\beta$ greatly enhances the production rate of Higgs bosons produced in association with bottom quarks as well as the branching fraction of the rare decay $B_s \to \mu^+\mu^-$ mediated by neutral Higgs bosons.

If $\tan\beta \gtrsim 10$, the MSSM neutral Higgs bosons are dominantly produced from bottom quark fusion $b\bar{b} \to \phi^0$ [3–7] at the CERN large hadron collider (LHC). For a Higgs boson produced along with one bottom quark at high transverse momentum (p_T), the leading-order subprocess is $bg \to b\phi^0$ [8–12]. If two high p_T bottom quarks are required in association with a Higgs boson, the leading order subprocess should be $gg \to b\bar{b}\phi^0$ [3,13–16]. We note that the importance of the process with a bottom quark was suggested by the authors of Ref. [10].

The LHC has a great potential to discover the inclusive muon pair channel for neutral Higgs bosons of minimal supersymmetry [17–19]. Recently, it was found that the discovery channel with one energetic bottom quark [20] greatly improves the discovery potential of the LHC beyond the inclusive channel without bottom quarks [17] ($pp \to \phi^0 \to \mu^+\mu^- + X$) and the associated channel with two bottom quarks [13] ($pp \to b\bar{b}\phi^0 \to b\bar{b}\mu^+\mu^- + X$). Since the ATLAS and the CMS both have excellent muon mass resolution, this discovery channel will provide

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a good opportunity to reconstruct the Higgs boson mass at the LHC with high precision.

We follow the strategies developed in Ref. [20] to investigate the discovery at the LHC of a neutral Higgs boson produced with one bottom quark followed by Higgs decay into a muon pair. We work within the framework of the minimal supersymmetric model, the minimal supergravity unified model, and supergravity unified models with non-universal Higgs boson masses at the grand unified scale ($M_{\rm GUT}$).

In the minimal supergravity unified model [21], the significance of $pp \to \phi^0 \to \mu^+\mu^- + X$ is greatly improved by a large $\tan\beta$ [22] because the large $b\bar{b}\phi^0$ couplings make m_A and m_H small through the evolution of renormalization group equations [23]. Consequently, the production cross section is further enhanced by a large value of $\tan\beta$.

The rare decay $B_s \to \mu^+\mu^-$ has a small branching fraction

$$B(B_s \to \mu^+\mu^-) = 3.4 \times 10^{-9} \tag{1}$$

in the standard model (SM) of electroweak interactions [24,25]. A recent calculation [26] suggests

$$B(B_s \to \mu^+\mu^-) = (5.1 \pm 1.1) \times 10^{-9} \tag{2}$$

with updated parameters. The current experimental upper limit is

$$B(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-7} \tag{3}$$

obtained by the Collider Detector at Fermilab (CDF) and the DØ Collaborations [27]. While this branching fraction is small in the SM, it could become large in supersymmetric models [28–46] and this rare decay provides a possible opportunity for the CDF and the DØ experiments to discover new physics in the near future.

In this Letter, we investigate the discovery potential of the direct searches for the Higgs bosons $pp \to b\phi^0 \to b\mu^+\mu^- + X$ at the LHC and that of the indirect searches for Higgs bosons in $B_s \to \mu^+\mu^-$ at the Fermilab Tevatron Run II within the framework of supersymmetric models. We make three major contributions: (a) studying the LHC discovery potential for $pp \to b\phi^0 \to b\mu^+\mu^- + X$ in the minimal supergravity model (mSUGRA) and in supergravity models with non-universal Higgs bosons masses at $M_{\rm GUT}$ (NUHM SUGRA), (b) evaluating $B(B_s \to \mu^+\mu)$ in NUHM SUGRA models, and (c) comparing these two promising channels in the MSSM, the mSUGRA, and non-universal SUGRA models. In Section 2, we discuss our strategies and results for the minimal supersymmetric standard model. Sections 3 presents the discovery contours in the parameter space of the mSUGRA model as well as that of the NUHM SUGRA models. Conclusions are drawn in Section 4.

2. The minimal supersymmetric Standard Model

In this section, we consider the direct searches for $pp \to b\phi^0 \to b\mu^+\mu^- + X$ at the LHC and indirect searches for Higgs bosons in $B_s \to \mu^+\mu^-$ at the Fermilab Tevatron Run II within the framework of the minimal supersymmetric standard model.

2.1. $b\phi^0 \to b\mu^+\mu^-$

Applying previous calculations [20] for the Higgs signal at the LHC we evaluate the cross section of $pp \to b\phi^0 \to b\mu^+\mu^- + X$ with the Higgs production cross section $\sigma(pp \to b\phi^0 + X)$ multiplied by the branching fraction of the Higgs decay into muon pairs $B(\phi^0 \to \mu^+\mu^-)$. The cross section for $pp \to b\phi^0 + X$ ($\phi^0 = H^0, h^0, A^0$) via $bg \to b\phi^0$ is calculated with the parton distribution functions of CTEQ6L1 [47] with a factorization scale $\mu_F = M_H/4$ [6,48]. Unless explicitly specified, b represent a bottom quark (b) or an anti-bottom quark ($\bar{b}$). We have also taken the renormalization scale to be $M_H/4$ that effectively reproduces the effects of next-to-leading order (NLO) [10] with a K factor of one for the Higgs signal. The bottom quark mass in the $\phi^0 b\bar{b}$ Yukawa coupling is chosen to be the NLO running mass $m_b(\mu_R)$ [49], which is calculated with $m_b(\text{pole}) = 4.7$ GeV and the NLO evolution of the strong coupling [50].

In our analysis, we consider dominant physics backgrounds to the final state of $b\mu^+\mu^-$ from $bg \to b\mu^+\mu^-$ ($b\mu\mu$) as well as $gg \to b\bar{b}W^+W^-$ and $q\bar{q} \to b\bar{b}W^+W^-$ ($bbWW$) followed by the decays of $W^\pm \to \mu^\pm\nu_\mu$. In addition, we have included the background from $bg \to b\mu^+\nu\mu^-\bar{\nu}$ and $\bar{b}g \to \bar{b}\mu^-\bar{\nu}\mu^+\nu$, which has major contributions from $bg \to tW^-$ and $\bar{b}g \to \bar{t}W^+$ (tW). The muons from b decays can be removed effectively with isolation cuts [17]. We apply a K factor of 1.3 for the $b\mu\mu$ background [51], a K factor of 2 for $bbWW$ [52,53], and a K factor of 1.5 for tW [54]. Furthermore, we consider backgrounds from $pp \to j\mu^+\mu^- + X$, $j = g, q$ or $\bar{q}$ with $q = u, d, s, c$, where a jet is mistagged as a b with a K factor of 1.3 for these processes.

We adopt the acceptance cuts as well as the b-tagging and mistagging efficiencies of the ATLAS Collaboration [19]. In each event, two isolated muons are required to have $p_T(\mu) > 20$ GeV and $|\eta(\mu)| < 2.5$.

For an integrated luminosity (L) of 30 fb^{-1}, we require (i) $p_T(b, j) > 15$ GeV; (ii) $|\eta(b, j)| < 2.5$, and (iii) the missing transverse energy ($\not{E}_T$) should be less than 20 GeV to reduce the background from $bbWW$ and tW which contains neutrinos. The b-tagging efficiency (ϵ_b) is taken to be 60%; the probability that a c-jet is mistagged as a b-jet (ϵ_c) is 10% and the probability that any other jet is mistagged as a b-jet (ϵ_j) is taken to be 1%. For $m_\phi < 100$ GeV, we change the requirement to $p_T(\mu) > 10$ GeV for muons in both the Higgs signal and the background.

For a higher integrated luminosity of 300 fb^{-1}, we require $p_T(b, j) > 30$ GeV and $\epsilon_b = 50\%$. In addition, the missing transverse energy ($\not{E}_T$) in each event should be less than 40 GeV.

To study the discovery potential of $pp \to b\phi^0 + X \to b\mu^+\mu^- + X$ at the LHC, we calculate the background from the SM processes of $pp \to b\mu^+\mu^- + X$ in the mass window of $m_\phi \pm \Delta M_{\mu^+\mu^-}$ where $\Delta M_{\mu^+\mu^-} \equiv 1.64[(\Gamma_\phi/2.36)^2 + \sigma_m^2]^{1/2}$ [19]. Γ_ϕ is the total width of the Higgs boson, and σ_m is the muon mass resolution which we take to be 2% of the Higgs boson mass [19].

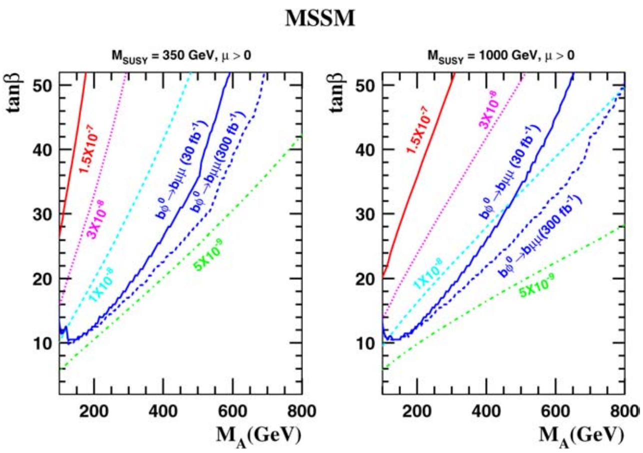

Fig. 1. Discovery contours for $pp \to b\phi^0 \to b\mu\bar{\mu} + X$ at the LHC and contours of the branching of $B_s \to \mu^+\mu^-$ in the minimal supersymmetric standard model for (a) $m_{\tilde{g}} = m_{\tilde{f}} = 350$ GeV $= -A_f$ and (b) $m_{\tilde{g}} = m_{\tilde{f}} = 1000$ GeV $= -A_f$. The discovery region is the part of the parameter space above the contour.

2.2. $B_s \to \mu^+\mu^-$

In our analysis for $B_s \to \mu^+\mu^-$ within the framework of minimal supersymmetry, we follow the approach in Refs. [29,42] and adopt the formulas in Ref. [42]. We make the following choices: (i) The matrix of the up-type Yukawa couplings is diagonal; (ii) The down-type Yukawa coupling matrix is $F_D = DV_{\mathrm{CKM}}^\dagger$, where D is the matrix diagonalized from F_D and V_{CKM} is the Cabibbo–Kobayashi–Maskawa matrix; (iii) We neglect the masses of the d and the s quarks as well as terms that are second order or higher in the Wolfenstein parameter λ; (iv) At the tree level, the CKM matrix is the only source for flavor changing neutral current (FCNC), and (v) we include FCNC contributions from one-loop diagrams involving charginos and up-type squarks as well as gluino and down-type squarks.

In addition, we adopt a common mass scale for supersymmetric (SUSY) particles and parameters $M_{\mathrm{SUSY}} = m_{\tilde{g}} = m_{\tilde{f}} = \mu = -A_f$, where $A_f = A_t = A_b = A_\tau$ are the trilinear couplings for the third generation. Two values of M_{SUSY} are considered: (a) $M_{\mathrm{SUSY}} = 350$ GeV and (b) $M_{\mathrm{SUSY}} = 1000$ GeV.

In Fig. 1, we present the contours for the branching fraction in the MSSM $B(B_s \to \mu^+\mu^-) = 1.5 \times 10^{-7}$ (current experimental limit), 3×10^{-8}, 1×10^{-8}, and 5×10^{-9} as well as the discovery contours of $b\phi^0 \to b\mu^+\mu^-$ for integrated luminosities of 30 fb^{-1} and 300 fb^{-1} at the LHC in the $(m_A, \tan\beta)$ plane for two values of common masses: (a) $M_{\mathrm{SUSY}} = m_{\tilde{g}} = m_{\tilde{f}} = 350$ GeV, and (b) $M_{\mathrm{SUSY}} = m_{\tilde{g}} = m_{\tilde{f}} = 1000$ GeV.

We note that for $M_{\mathrm{SUSY}} = 350$ GeV, the LHC will be able to discover $pp \to b\phi^0 \to b\mu^+\mu^- + X$ with an integrated luminosity (L) of 30 fb^{-1} in a significantly large region of the parameter plane beyond $B(B_s \to \mu^+\mu^-) = 3 \times 10^{-8}$. If the gluino and scalar fermions have a common mass of approximately 1 TeV then the contour for a branching fraction of $B(B_s \to \mu^+\mu^-) = 1 \times 10^{-8}$ in the parameter plane is very close to the 5σ contour for $pp \to b\phi^0 \to b\mu^+\mu^- + X$ at the LHC with $L = 30$ fb^{-1}.

Furthermore, with a higher luminosity of 300 fb^{-1}, the LHC will be able to discover $pp \to b\phi^0 \to b\mu^+\mu^- + X$ for $M_{\mathrm{SUSY}} = 1000$ GeV in a very large region or the $(m_A, \tan\beta)$ plane. The discover contour for high luminosity with a large M_{SUSY} is very close to the contour for $B(B_s \to \mu^+\mu^-) = 5 \times 10^{-9}$ that is not far away from the SM expectation.

3. Supersymmetric unified models

In this section, we consider both $pp \to b\phi^0 \to b\mu^+\mu^- + X$ and $B_s \to \mu^+\mu^-$ in the minimal supergravity model and supergravity models with non-universal boundary conditions for the Higgs boson masses at the grand unified scale (M_{GUT}). We evolve supersymmetry masses and couplings from the grand unified scale using two-loop renormalization equations in ISAJET 7.72 [55] to calculate MSSM masses, mixing angles and couplings. The following theoretical requirements are imposed on the evolution of renormalization group equations: (i) radiative electroweak symmetry breaking (EWSB) is achieved; (ii) the correct vacuum for EWSB is obtained (tachyon free); and (iii) the lightest SUSY (LSP) particle is the lightest neutralino (χ_1^0).

3.1. The minimal supergravity unified model

In the minimal supergravity (mSUGRA) model [21], supersymmetry is broken in a hidden sector and SUSY breaking is communicated to the observable sector through gravitational interactions. The mSUGRA parameters are chosen to be a scalar mass (m_0), a gaugino mass ($m_{1/2}$), a trilinear coupling (A_0), the sign of a Higgs mixing parameter (μ), and the ratio of Higgs field vacuum expectation values at the electroweak scale ($\tan\beta = v_2/v_1$). The value of A_0 only significantly affects results for high $\tan\beta$; we initially take $A_0 = 0$ and study the A_0 dependence later.

Fig. 2 displays the discovery contours of $b\phi^0 \to b\mu^+\mu^-$ for an integrated luminosity of 30 fb^{-1} and 300 fb^{-1} at the LHC as well as contours for four values of the branching fraction $B(B_s \to \mu^+\mu^-)$ in the $(m_{1/2}, m_0)$ plane of the mSUGRA model for four values of $\tan\beta = 20$, 30, 40, and 50. Also shown are the parts of the parameter space (i) disfavored by theoretical requirements or (ii) excluded by the chargino search at LEP 2 with $m_{\chi_1^\pm} < 103$ GeV.

There are several interesting aspects to note in Fig. 2.

(i) If $\tan\beta \lesssim 30$, only a tiny region of the parameter space with small values of $m_{1/2}$ and m_0 will likely lead to observable signals for either $B_s \to \mu^+\mu^-$ at the Tevatron Run II or $b\phi^0 \to b\mu^+\mu^-$ at the LHC.

(ii) For $\tan\beta \lesssim 40$, direct searches for $b\phi^0 \to b\mu^+\mu^-$ at the LHC with $L = 30$ fb^{-1} covers a much large region in the mSUGRA parameter space than $B(B_s \to \mu^+\mu^-) \geqslant 1 \times 10^{-8}$.

(iii) If $\tan\beta \gtrsim 50$, the discovery contour for $b\phi^0 \to b\mu^+\mu^-$ at the LHC with $L = 30$ fb^{-1} is very close to the contour for $B(B_s \to \mu^+\mu^-) \geqslant 1 \times 10^{-8}$ in the mSUGRA parameter space. In addition, both discovery channels at

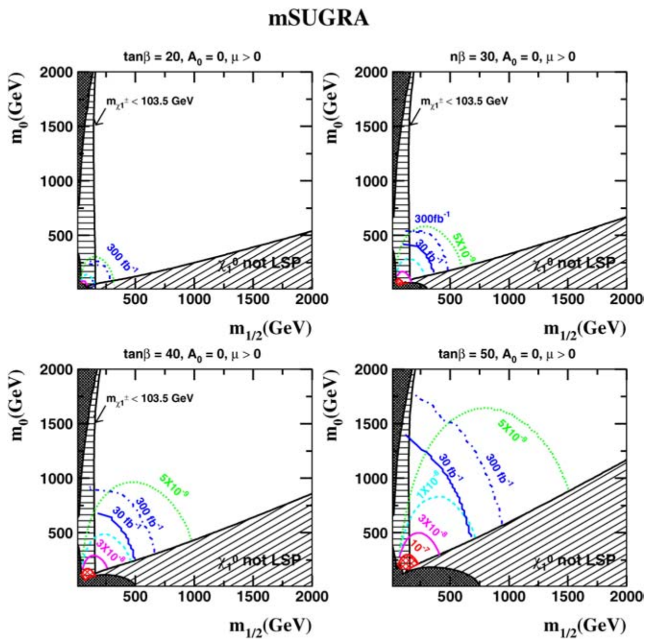

Fig. 2. Discovery contours for $pp \to b\phi^0 \to b\mu\bar{\mu} + X$ at the LHC and contours of the branching of $B_s \to \mu^+\mu^-$ in the minimal supergravity unified model for (a) $\tan\beta = 20$, (b) $\tan\beta = 30$, (c) $\tan\beta = 40$, and (d) $\tan\beta = 50$. Also shown are the parts of the parameter space (i) excluded by theoretical requirements (slant-hatched and dark shaded), or (ii) excluded by the chargino search at LEP 2 (horizontally-hatched).

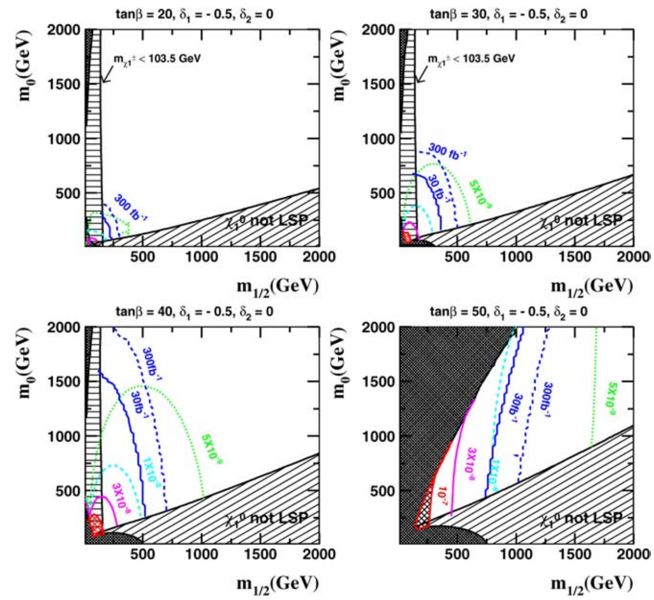

Fig. 3. The 5σ contours for $pp \to b\phi^0 \to b\mu\bar{\mu} + X$ at the LHC with an integrated luminosity of 30 fb^{-1} and 300 fb^{-1} as well as contours for the branching fraction of $B_s \to \mu^+\mu^-$ in the $(m_{1/2}, m_0)$ plane of a non-universal SUGRA model with $\mu > 0$, $A_0 = 0$ and non-universal boundary conditions $\delta_1 = -0.5$ and $\delta_2 = 0$, for (a) $\tan\beta = 20$, (b) $\tan\beta = 30$, (c) $\tan\beta = 40$, and (d) $\tan\beta = 50$. Also shown are the parts of the parameter space (i) excluded by theoretical requirements (slant-hatched and dark shaded), or (ii) excluded by the chargino search at LEP 2 (horizontally-hatched).

the LHC become complementary. The direct searches for $b\phi^0 \to b\mu^+\mu^-$ with $L = 300$ fb^{-1} covers a significant region beyond the contour of $B(B_s \to \mu^+\mu^-) = 5 \times 10^{-9}$. Likewise, the rare decay with $B(B_s \to \mu^+\mu^-) \geqslant 5 \times 10^{-9}$ covers a large region beyond the discovery contour of the direct search for $b\phi^0 \to b\mu^+\mu^-$ with $L = 300$ fb^{-1}.

3.2. *The mSUGRA model with non-universal Higgs masses*

In our analysis for non-universal supergravity models, the GUT-scale Higgs masses are parametrized as

$$m^2_{H_i}(\mathrm{GUT}) = (1 + \delta_i) m_0^2, \quad i = 1, 2. \tag{4}$$

The non-universality of Higgs-boson masses at M_{GUT} can significantly affect the values of Higgs masses and couplings at the weak scale [56–59].

We find that a decrease in m_{H_1} with a negative δ_1 as well as an increase in m_{H_2} with a positive δ_2 at M_{GUT} will lead to a smaller mass at the electroweak scale for the Higgs pseudoscalar (A^0) or the heavier Higgs scalar (H^0) than that in the mSUGRA model. Therefore, we choose three sets of values for δ_i to study the discovery potential for detecting Higgs bosons with muons in SUGRA models with non-universal Higgs boson masses: (i) $\delta_1 = -0.5$, $\delta_2 = 0$, (ii) $\delta_1 = 0$, $\delta_2 = 0.5$, and (iii) $\delta_1 = -0.5$, $\delta_2 = 0.5$.

In Fig. 3, we present the discovery contours of $b\phi^0 \to b\mu^+\mu^-$ for integrated luminosities of 30 fb^{-1} and 300 fb^{-1} at the LHC as well as contours for four values of the branching fraction $B(B_s \to \mu^+\mu^-)$ in the $(m_{1/2}, m_0)$ plane for a NUHM SUGRA model with $\delta_1 = -0.5$ and $\delta_2 = 0$ with $\tan\beta = 20$, 30,

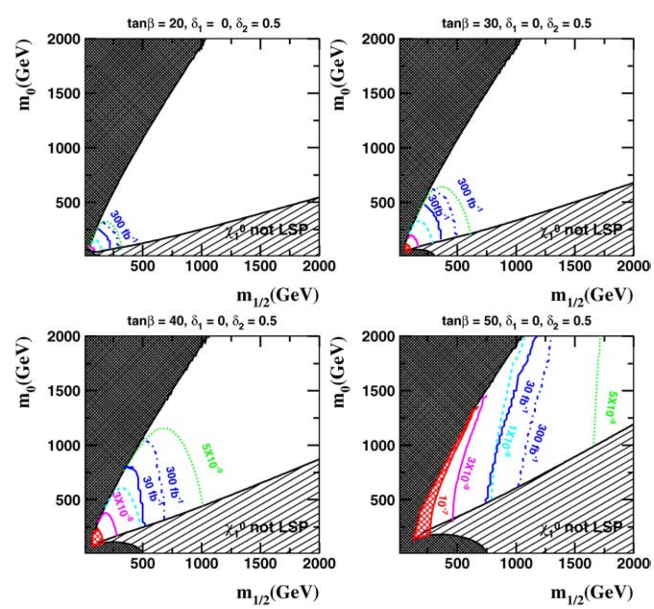

Fig. 4. The 5σ contours for $pp \to b\phi^0 \to b\mu\bar{\mu} + X$ at the LHC with an integrated luminosity of 30 fb^{-1} and 300 fb^{-1} as well as contours for the branching fraction of $B_s \to \mu^+\mu^-$ in the $(m_{1/2}, m_0)$ plane of a non-universal SUGRA model with $\mu > 0$, $A_0 = 0$ and non-universal boundary conditions $\delta_1 = 0$ and $\delta_2 = 0.5$, for (a) $\tan\beta = 20$, (b) $\tan\beta = 30$, (c) $\tan\beta = 40$, and (d) $\tan\beta = 50$. Also shown are the parts of the parameter space (i) excluded by theoretical requirements (slant-hatched and dark shaded), or (ii) excluded by the chargino search at LEP 2 (horizontally-hatched).

40, and 50. In addition, we show the regions of the parameter space (i) disfavored by theoretical requirements or (ii) excluded by the chargino search at LEP 2 with $m_{\chi_1^\pm} < 103$ GeV.

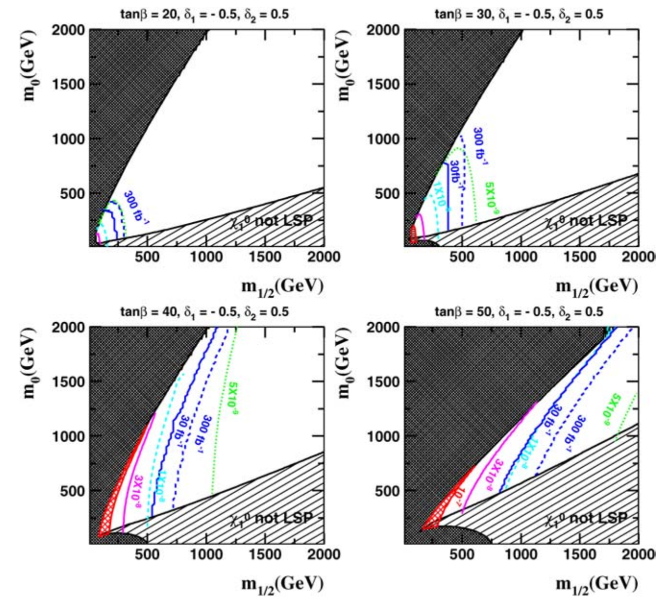

Fig. 5. The 5σ contours for $pp \to b\phi^0 \to b\mu\bar{\mu} + X$ at the LHC with an integrated luminosity of 30 fb^{-1} and 300 fb^{-1} as well as contours for the branching fraction of $B_s \to \mu^+\mu^-$ in the $(m_{1/2}, m_0)$ plane of a non-universal SUGRA model with $\mu > 0$, $A_0 = 0$ and non-universal boundary conditions $\delta_1 = -0.5$ and $\delta_2 = 0.5$, for (a) $\tan\beta = 20$, (b) $\tan\beta = 30$, (c) $\tan\beta = 40$, and (d) $\tan\beta = 50$. Also shown are the parts of the parameter space (i) excluded by theoretical requirements (slant-hatched and dark shaded), or (ii) excluded by the chargino search at LEP 2 (horizontally-hatched).

Fig. 4 shows contours for four values of the branching fraction $B(B_s \to \mu^+\mu^-)$ in the $(m_{1/2}, m_0)$ plane in a supergravity unified model with $\delta_1 = 0$ and $\delta_2 = 0.5$. Also shown are the discovery contours of $pp \to b\phi^0 \to b\mu^+\mu^- + X$ for integrated luminosities of 30 fb^{-1} and 300 fb^{-1} at the LHC in the $(m_{1/2}, m_0)$ plane for four values of $\tan\beta = 20$, 30, 40, and 50.

If both Higgs boson masses are different from the common scalar mass at M_{GUT}, then theoretically favored region shrinks greatly. We present contours for four values of the branching fraction $B(B_s \to \mu^+\mu^-)$ in the $(m_{1/2}, m_0)$ plane in a supergravity unified model with $\delta_1 = -0.5$ and $\delta_2 = 0.5$ in Fig. 5. In addition, we show the discovery contours of $pp \to b\phi^0 \to b\mu^+\mu^- + X$ for integrated luminosities of 30 fb^{-1} and 300 fb^{-1} at the LHC in the $(m_{1/2}, m_0)$ plane for four values of $\tan\beta = 20$, 30, 40, and 50.

In all three NUHM SUGRA cases that we have considered, m_A and m_H are smaller than those in the mSUGRA model for the same values of m_0 and $m_{1/2}$. Consequently, both $b\phi^0 \to b\mu^+\mu^-$ and $B_s \to \mu^+\mu^-$ will be able to cover regions of the parameter space with larger values of m_0 and $m_{1/2}$. We note that for $\tan\beta \gtrsim 50$, the observable region for $b\phi^0 \to b\mu^+\mu^-$ at the LHC with $L = 30\ \text{fb}^{-1}$ is comparable to that of $B(B_s \to \mu^+\mu^-) \geqslant 1 \times 10^{-8}$. However, the contour for $B(B_s \to \mu^+\mu^-) = 5 \times 10^{-9}$ lies beyond the discovery contour for $b\phi^0 \to b\mu^+\mu^-$ at the LHC with $L = 300\ \text{fb}^{-1}$.

In the NUHM SUGRA model with $\delta_1 = -0.5$ and $\delta_2 = 0$ ($m_{H_1} = 0.707 m_0$ and $m_{H_2} = m_0$), most of the $(m_{1/2}, m_0)$ plane is theoretically favored for $\tan\beta \lesssim 40$. If m_{H_2} is larger than m_0 with $\delta_2 = 0.5$, the theoretically disfavored region grows rapidly as the value of $\tan\beta$ increases.

4. Conclusions

In supersymmetric models, the muon pair discovery channels offer great promise for the detection of indirect Higgs signatures in $B_s \to \mu^+\mu^-$ at the Fermilab Tevatron as well as for the direct signal of $pp \to b\phi^0 \to b\mu^+\mu^- + X$ at the CERN LHC.

If scalar fermions and gluino have a mass close to 1000 GeV, then the exclusion contours of the Tevatron search for $B(B_s \to \mu^+\mu^-) \simeq 1 \times 10^{-8}$ are comparable to the discovery contours of the LHC search for $b\phi^0 \to b\mu^+\mu^-$ with an integrated luminosity of 30 fb^{-1}. However, if SUSY particles have a mass close to 350 GeV, the direct search for $b\phi^0 \to b\mu^+\mu^-$ at the LHC becomes much more promising than $B_s \to \mu^+\mu^-$.

In supergravity unified models, the branching fraction of $B_s \to \mu^+\mu^-$ and the significance of $pp \to b\phi^0 \to b\mu^+\mu^- + X$ are greatly improved by a large $\tan\beta$ because the large $b\bar{b}\phi^0$ couplings make m_A and m_H small through the evolution of renormalization group equations and enhance the production cross section for Higgs bosons even more. In the mSUGRA model and in supergravity models with non-universal Higgs masses, the direct signal of $b\phi^0 \to b\mu^+\mu^-$ at the LHC can be discovered with a luminosity of 30 fb^{-1} in a large region of the parameter space that is comparable to that of $B(B_s \to \mu^+\mu^-) = 1 \times 10^{-8}$ for $\tan\beta \lesssim 50$.

For a large value of $\tan\beta$, the Tevatron Run II with an integrated luminosity of 10 fb^{-1} will be able to observe the indirect Higgs signal with $B(B_s \to \mu^+\mu^-) \lesssim 1 \times 10^{-7}$ [45] which then can be confirmed by the direct search of $pp \to b\phi^0 \to b\mu^+\mu^- + X$ at the LHC [20]. Even if there are no signs of new physics at the Tevatron Run II, we will be able to set meaningful limits on important parameters such as the Higgs masses and the ratio of the vacuum expectation values of Higgs fields $\tan\beta \equiv v_2/v_1$ [43] for the MSSM with minimal flavor violation. The Tevatron Run II with an integrated luminosity of 8 fb^{-1} will be able to exclude $B(B_s \to \mu^+\mu^-) \lesssim 3 \times 10^{-8}$ [60] which then can provide important guidance to detect $pp \to b\phi^0 \to b\mu^+\mu^- + X$ at the LHC [20].

If $\tan\beta \gtrsim 50$, the regions covered by $B(B_s \to \mu^+\mu^-) \geqslant 5 \times 10^{-9}$ and the discovery region for $b\phi^0 \to b\mu^+\mu^-$ with 300 fb^{-1} are complementary in the mSUGRA parameter space: the direct searches for $b\phi^0 \to b\mu^+\mu^-$ with $L = 300\ \text{fb}^{-1}$ can cover a significantly large region beyond $B(B_s \to \mu^+\mu^-) \geqslant 5 \times 10^{-9}$, and vice versa. However, in NUHM SUGRA models, a discovery of $B(B_s \to \mu^+\mu^-) \simeq 5 \times 10^{-9}$ at the LHC will cover regions of the parameter space beyond the direct search for $b\phi^0 \to b\mu^+\mu^-$ with $L = 300\ \text{fb}^{-1}$.

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