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Supersymmetric Higgs bosons discovery potential at hadron colliders through the *bg* channel

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We explore the discovery potential of the supersymmetric Higgs bosons through the bg channel at the Fermilab Tevatron and CERN LHC. Compared with the process $qq' \to WH$, this channel is more advantageous to finding the supersymmetric Higgs bosons at the Tevatron if $\tan\beta$ is larger than 10.

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One of the most important physics goals for future high energy physics is the discovery of the Higgs boson. Recent direct search in the CERN LEP2 experiments running at $\sqrt{s}=183$ GeV via $e^+e^- \to Z^*H$ yields a lower bound of ~ 89.9 GeV on the standard model (SM) Higgs mass [1]. Next year's running at 192 GeV will explore up to a Higgs boson mass of about 96 GeV [2]. After LEP2 the search for the Higgs particles will be continued at the CERN Large Hadron Collider (LHC) for Higgs boson masses up to the theoretical upper limit. Before the LHC comes into operation it is worth considering whether the Higgs boson can be discovered from the existing hadron collider, the Tevatron. Much study has been made in the detection of a Higgs boson at the Tevatron [3,4]. In Ref. [2], it was pointed out that if the Higgs boson is discovered at LEP2, it should be observed at the Tevatron's Run II with c.m. energy $\sqrt{s}=2$ TeV and an integrated luminosity $\sim 10\ \mathrm{fb}^{-1}$, through the production subprocess $q\overline{q'} \to WH$, followed by $W \to l\overline{\nu}$ and $H \to b\overline{b}$; and if the Higgs boson lies beyond the reach of LEP2, $m_H \geqslant (95-100)$ GeV, then a 5-σ discovery will be possible in the above production subprocess in a future Run III with an integrated luminosity 30 fb^{-1} for masses up to $m_H \approx 125$ GeV. However, we notice that this channel cannot work for large $\tan\beta$ [5]. Recently, Ref. [6] has studied the Higgs boson discovery potential of the process $gg \to H$ [7] at Tevatron, and found that the SM-like Higgs boson could be found if its mass lies in the range of 135 to 180 GeV. In the literature, there are also many works [8] discussing Higgs boson discovery abilities with b quarks at hardon colliders. For example, in the first reference of Ref. [8], the process $P\overline{P} \to b\overline{b}HX$, in which the actual physical subprocess of the inclusive rate of Higgs production associated with bottom quarks is $gg \to b\overline{b}H$, has been examined. In this paper we examine the Higgs–bottom-quark association production $p\overline{p} \to bH(\overline{b}H)X$ in which the actual physical subprocess is $bg \to bH$. It is evident that this process is different from $p\overline{p} \to b\overline{b}HX$ in tagging only one b quark in our case.

As we know, the distributions of the sea b quark and gluon grow rapidly for the small x region. When $x<0.1$, the gluon distribution function is far larger than the u quark distribution function, and the same thing occurs for the sea b quark when $x<0.01$. So the Tevatron and LHC are good places to examine the bg channel.

It is well known that the couplings of CP-even neutral Higgs bosons to down-type quarks in supersymmetric (SUSY) models are given by [9]

$$\frac{-igm_D \cos\alpha}{2m_W \ \cos\beta} \quad \text{for } H^0 D\overline{D}, \tag{1}$$

$$\frac{-igm_D \sin\alpha}{2m_w \ \cos\beta} \quad \text{for } h^0 D\overline{D}. \tag{2}$$

When $\tan\beta \geqslant 35$ the couplings of H^0, h^0 to the b quark can be as large as those to the t quark. Therefore, it is possible to

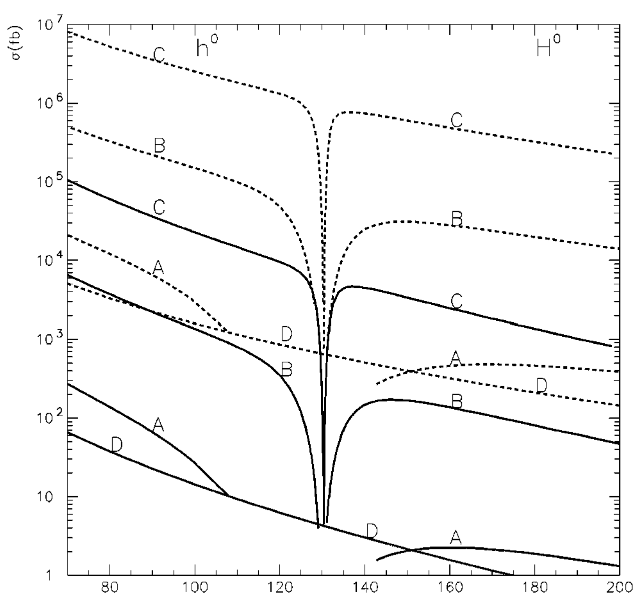

FIG. 1. The total cross sections versus m_H for case (I), where $m_S=1$ TeV, and the solid and dashed lines represent the results at Tevatron and LHC, and A, B, C, and D represent $\tan\beta=2,10,40$ and in the SM, respectively.

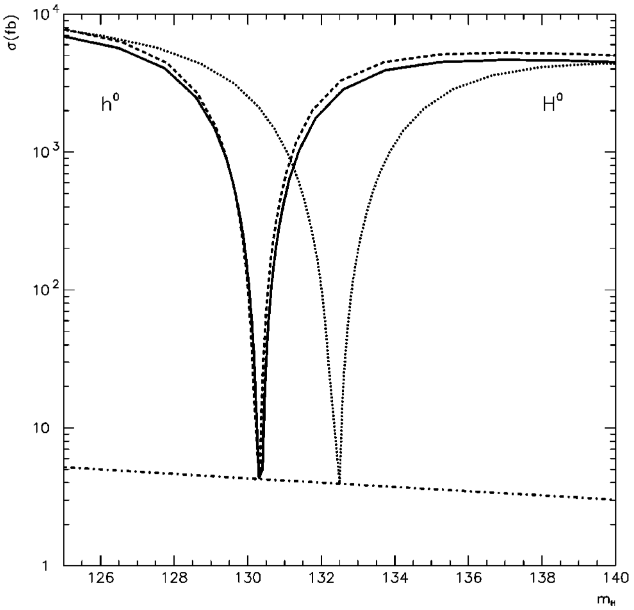

FIG. 2. The total cross sections versus m_H, where $m_S=1$ TeV, $\tan\beta=40$, and the solid, dashed, dotted, and dot-dashed lines represent the results for case (I), (II), (III) and in SM, respectively. For case (II), $A_t=A_b=0$ and $\mu=-500$ GeV; for case (III), $A_t=A_b=\mu=-500$ GeV.

discover SUSY Higgs bosons, in particular for large $\tan\beta$, at Tevatron through the bg channel.

Including radiative corrections, the mixing angle α in Eqs. (1) and (2) is determined by

$$\tan 2\alpha=\frac{\sin 2\beta(m_A^2+m_Z^2)-2R_{12}}{\cos 2\beta(m_A^2-m_Z^2)+R_{22}-R_{11}}, \quad -\frac{\pi}{2}<\alpha\leqslant 0, \tag{3}$$

where R_{ij} are the radiative corrections to the mass matrix of the neutral Higgs bosons in the $\{H_1^0,H_2^0\}$ basis and have been given in Refs. [10,11]. An analysis of the couplings of Higgs bosons to vector bosons, up-type and down-type quarks in both large $\tan\beta$ and large m_A limits has been performed [12] and some numerical results for $\tan\beta=1.5$ and 30 in vanishing mixing case have been given in Ref. [13]. For our purpose, we shall concentrate on the general analysis of the couplings of Higgs bosons to down-type quarks, based on the results given in Ref. [11]. In order to simplify discussions we assume $m_Q=m_U=m_D=m_S$ and consider the following three representative cases.

(I) The case where $A_t=A_b=\mu=0$. There is no mixing between top squarks as well as between bottom squarks in this case. It should be noted that this case is of only an academic excise ($\mu=0$ is ruled out by chargino and neutralino searches at LEP2). The leading corrections come from the top-squark-loop and can be written as

$$R_{11}=R_{12}=0, \tag{4}$$

$$R_{22}=\frac{3G_F}{\sqrt{2}\pi^2}\frac{m_t^4}{\sin^2\beta}\log\left(1+\frac{m_S^2}{m_t^2}\right), \tag{5}$$

where terms of order $m_Z^2/(m_S^2+m_i^2)$ $(i=t,b)$ or m_b^2/m_t^2 have been neglected.

(II) The case where $\mu\neq 0$, $A_t=A_b=0$. The radiative corrections depend on $\tan\beta$ strongly. A large mixing between bottom squarks happens while the mixing between top squarks is still small if $\tan\beta$ is large and μ is not too small.[1] With $\mu>100$ GeV, $\tan\beta\geqslant m_t/m_b$, and in the range of m_S from 500 GeV to 1 TeV, $R_{12}\sim R_{11}\sim$ a few thousandth of R_{22}.

(III) The case where $\mu\sim A_t\sim A_b\neq 0$. There is a large mixing between top squarks. The mixing between bottom squarks is large if $\tan\beta$ is large. In this case, for $\mu>100$ GeV and $\tan\beta\geqslant m_t/m_b$, the radiative corrections to nondiagonal matrix element R_{12} can reach more than ten percents of the raditive corrections to the diagonal matrix element R_{22} while the radiative corrections to the other diagonal matrix element R_{11} is still far smaller than R_{22}.

We calculate the cross sections of $bg\to bh^0$ and $bg\to bH^0$ in all the above cases for different $\tan\beta$. Through the paper, m_A and $\tan\beta$ are choosen as input parameters. The loop corrected masses of Higgs bosons h^0 and H^0 [11] are used in calculations. The numerical results are given in Figs. 1 and 2.

In Fig. 1, we show the cross sections of the processes $bg\to bh^0$ and $bg\to bH^0$ for case (I) assuming $m_S=1$ TeV. From these curves, we can see that in a very wide region of m_H, the cross sections are much larger than that in SM, and can reach dozens of pb at Tevatron and 10^3 pb at LHC for large $\tan\beta$, which is due to the enhancement of the couplings of $h_0-b-\bar{b}$ and $H-b-\bar{b}$ compared to the SM case. Compared with the $q\overline{q'}\to WH$ channel, the $bg\to bH$ channel is more advantageous to searching for SUSY Higgs bosons if $\tan\beta$ is larger than 10, because for the $q\overline{q'}\to WH$ channel the cross sections for the supersymmetric Higgs bosons are always smaller than the SM case, especially for large $\tan\beta$, which is due to the suppression of $\sin(\beta-\alpha)$ [5], and the cross sections at most reach 1 pb at Tevatron for the interesting mass region of 95–125 GeV. Compared with the gluon-fusion mechanism $gg\to H$ which is the dominant mechanism for neutral Higgs boson productions at LHC for small and moderate values of $\tan\beta$, the $bg\to bH$ channel can compete with it at Tevatron and LHC if $\tan\beta\geqslant 35$. One can also see from the figure that when the mass of the lightest Higgs boson approaches its upper limit, the cross sections come back to the SM case, which is due to the reason that the couplings of the lightest Higgs boson is the same as the SM case when its mass approaches upper limit.

From our numerical results, we find that the cross sections in cases (II) and (III) are similar to those in case (I) in most

[1]In supergravity models due to the radiative electroweak symmetry breaking mechanism one usually has $|\mu|\geqslant M_{1/2}$ at electroweak scale [14] so that the condition is satisfied.

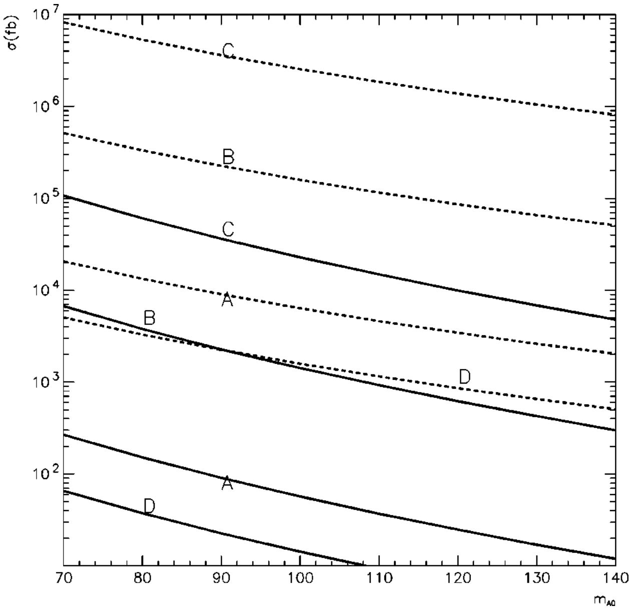

FIG. 3. The total cross sections versus m_{A0}, where the solid and dashed lines represent the results at Tevatron and LHC, respectively, and A, B, C, and D represent $\tan\beta=2,10,40$ and in the SM.

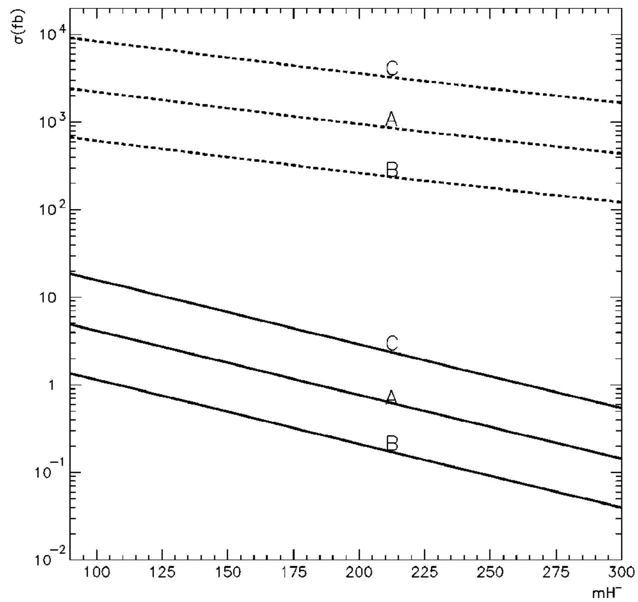

FIG. 4. The total cross sections versus m_{H^-}, where solid and dashed lines represent the results at Tevatron and LHC, respectively, and A, B, and C represent $\tan\beta=2,10,40$, respectively.

of range of Higgs masses (below 120 GeV for h^0 mass and above 140 GeV for H^0 mass), except in a narrow range around 130 GeV where the cross sections in case (III) are significantly different from those in case (I). As an example, in Fig. 2 we show the cross sections of three cases in the narrow mass region at Tevatron. It is evident from the figure that the upper limit of h^0 mass for case (III) increases by about two GeV compared to case (I), while much less variations appear for case (II).

We did similar calculations for $m_S=0.5$ TeV. The result is that the cross sections have little changes while the shift of the upper limit of h^0 mass is significant.

Figures 3 and 4 are devoted to the processes $bg\to bA^0$ and $bg\to tH^-$. Since the coupling of psedoscalar Higgs boson to b quark is proportional $\tan\beta$, the cross sections increase quadraticly with the increment of $\tan\beta$ and can reach several dozens pb at Tevatron. We notice that the cross section of the charged Higgs boson for $\tan\beta=10$ is smaller than those of $\tan\beta=2$ and 40, which is the consequence of the competitive between the couplings $m_t/\tan\beta$ and $m_b\tan\beta$.

To summarize, as a complementary process of $qq'\to WH$ and $gg\to H$, bg channel could be very important in finding the supersymmetric Higgs bosons at Tevatron and LHC. In particular, it is possible to find the SUSY neutral Higgs bosons at Tevatron via bg channel if $\tan\beta\geqslant 10$. Anyway, the real Monte Carol simulation including QCD and electroweak corrections is needed, and will give the further information for experiments.

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[1] P. McNamara, ICHEP '98, Vancouver, 1998.

[2] C. Quigg, FERMILAB-CONF-98/059-T, hep-ph/9802320.

[3] A. Stange, W. Marciano, and S. Willenbrock, Phys. Rev. D **49**, 1354 (1994); **50**, 4491 (1994); S. Kim, S. Kuhlman, and W. Yao, CDF-ANAL-EXOTIC-PUBLIC-3904, 1996; W. Yao, FERMILAB-CONF-96-383-E, 1996; J. Womersley, D0 Note 3227, 1997; S. Parke, FERMILAB-CONF-97/335-T.

[4] T. Han and S. Willenbrock, Phys. Lett. B **273**, 167 (1990); J. Ohnemus and W.J. Stirling, Phys. Rev. D **47**, 2722 (1993); H. Baer, B. Bailay, and J.F. Owens, *ibid.* **47**, 2730 (1993); S. Smith and S. Willenbrock, *ibid.* **54**, 6696 (1969).

[5] C.S. Li and S.H. Zhu, Phys. Lett. B **444**, 224 (1998); Q.H. Cao, C.S. Li, and S.H. Zhu, hep-ph/9810458.

[6] T. Han and R.J. Zhang, Phys. Rev. Lett. **82**, 25 (1999).

[7] H. Georgi, S. Glashow, M. Machacek, and D. V. Nanopoulos, Phys. Lett. **40**, 692 (1978).

[8] D. Dicus, T. Stelzer, Z. Sullivan, and S. Willenbrock, hep-ph/9811492; Z. Kunszt and F. Zwirner, Nucl. Phys. **B385**, 3 (1992); M. Drees, M. Guchait, and P. Roy, Phys. Rev. Lett. **80**, 2047 (1998); **81**, 2394(E) (1998); M. Carena, S. Mrenna, and C. Wagner, Phys. Rev. D (to be published); J. Dai, J. Gunion, and R. Vega, Phys. Lett. B **345**, 29 (1995); **387**, 801 (1996); J. Diaz-Cruz, H.-J. He, T. Tait, and C.-P. Yuan, Phys. Rev. Lett. **80**, 4641 (1998); C. Balazs, J. Diaz-Cruz, H.-J. He, T. Tait, and C.-P. Yuan, Phys. Rev. D **59**, 055016 (1999); D. Choudhury, A. Datta, and S. Raychaudhuri, hep-ph/9809552; C. Kao and N. Stepanov, Phys. Rev. D **52**, 5025 (1995); V. Barger and C. Kao, Phys. Lett. B **424**, 69 (1998).

[9] J. Gunion, H. Haber, G. Kane, and S. Dawson, *The Higgs Hunter's Guide* (Addison-Wesley, Reading, MA, 1990).

[10] Y. Okada, M. Yamaguchi, and T. Yanagida, Prog. Theor. Phys. **85**, 1 (1991); H. Haber and R. Hempfling, Phys. Rev. Lett. **66**, 1815 (1991); J. Ellis, G. Ridolfi, and F. Zwirner, Phys. Lett. B **257**, 83 (1991).

[11] M. Carena, M. Quiros, and C. Wagner, Nucl. Phys. **B461**, 407 (1996).

[12] W. Loinaz and J. Wells, Phys. Lett. B **445**, 178 (1998).

[13] M. Spiral, Fortschr. Phys. **46**, 203 (1998).

[14] M. Drees and M. M. Nojiri, Nucl. Phys. **B369**, 54 (1992).