Single Charged and Neutral Supersymmetric Higgs Bosons Production with Jet at pp Colliders

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Abstract

In the framework of Minimal Supersymmetric Standard Model Higgs bosons production via gluino/squark loop in the processes $gu \rightarrow H^+d$, $gd \rightarrow H^-u$, $gq \rightarrow H_0^0q$ are studied.
If Higgs sector of the gauge theory contains additional Higgs fields besides standard doublet, after spontaneous symmetry violation more than one physical Higgs bosons arise.

In particular, in the Minimal Supersymmetric Standard Model (MSSM) (see [1], [2] and references therein) the Higgs sector contains two doublets of Higgs bosons with opposite hypercharge ($Y=\pm 1$) and after spontaneous symmetry violation the following physical states appear: charged Higgs bosons $H^\pm$, and three neutral ones, $H^0_1, H^0_2, H^0_3$.

If the mass of the $H^\pm$-boson is less than $m_t - m_b$, it may be produced in $t$-quarks decays [3]-[5]:

$$t \rightarrow H^+ b$$

However, if $m_t - m_b < m_H$ this decay is kinematically forbidden.

That is why it is necessary to study new mechanisms for the production of heavy (i.e. with masses $m_t - m_b < m_H$) charged Higgs bosons.

Here we study the following mechanisms of SUSY Higgs bosons production in $pp$-collisions:

$$gu \rightarrow H^+ d,$$  \hspace{1cm} (2)

$$gd \rightarrow H^- u,$$  \hspace{1cm} (3)

$$gq \rightarrow \tilde{H}^0_i q$$  \hspace{1cm} (4)

which proceed via squark/gluino loop (Fig.1).

It must be noted that besides the squark/gluino loop contribution there is also the tree contribution [4]. It is of interest to compare both contributions. The cross section of the tree contribution to the subprocess (2) is of order $O(\alpha_s \alpha \frac{m^2_q}{m_W} \tan^2 \beta)$, whereas the loop contribution is of order $O(\alpha_s^3 \alpha \sin^2 2\beta)$. Besides the tree contribution is supressed by the smallness of the heavy quarks (s,c,b,...) inside protons. Thus we expect that the loop contribution will dominate over the tree at not very large $\tan \beta$. It must be noted that besides the squark/gluino loop contribution there are also contributions from squarks.
and t-quarks loops in the process (4). The heavy quark and squark contribution in the process (4) and the process:

$$ gg \rightarrow H^0_i g $$

has been considered in [7] - [14].

Using Higgs bosons interactions with scalar quarks (see formula (4.19) in ref. [1]):

$$ L = - \frac{g}{\sqrt{2}} m_W \sin 2\beta (H^+ u_L^* d_L + H.c.) - \frac{g m_Z}{\cos \theta_W} \sum \left( (T_{3i} - e_i \sin^2 \theta_W) q^*_{iL} q_{iL} + e_i \sin^2 \theta_W) q^*_{iR} q_{iR} \right) (H^0_1 \cos(\alpha + \beta) - H^0_2 \sin(\alpha + \beta)) $$

(6)

for the gauge invariant amplitude of the process (2) we obtain:

$$ M = \sqrt{2} \alpha_2^2 m_W \sin 2\beta u(k_1) T^a \gamma_\mu P_L u(k_2) (G^a_{\mu\nu}(F_1 k_{1\nu} + F_2 k_{2\nu}) + \epsilon_{\mu\nu\lambda\rho} G^a_{\lambda\rho}(F_3 k_{1\rho} + F_4 k_{2\rho})). $$

(7)

Here

$$ G^a_{\mu\nu} = k_\mu A^a_\nu - k_\nu A^a_\mu $$

(8)

$$ F_1 = N f_3 + \frac{1}{N} f_1, $$

(9)

$$ F_2 = N f_4 + \frac{1}{N} f_2, $$

(10)

$$ F_3 = \frac{N}{2} \int_0^1 dx \int_0^{1-x} dy A_3, $$

(11)

$$ F_4 = \frac{N}{2} \int_0^1 dx \int_0^{1-x} dy x D, $$

(12)

(where $N = 3$ number of colours),

$$ f_1 = \int_0^1 dx \int_0^{1-x} dy (-x + y) A_1 - y A_2, $$

(13)
\[ f_2 = \int_0^1 dx \int_0^{1-x} dy ((x+y)A_2 - yA_1), \]  
\[ f_3 = \int_0^1 dx \int_0^{1-x} dy (x + y)(-A_3), \]  
\[ f_4 = \int_0^1 dx \int_0^{1-x} dy x(1 - x - y)D, \]  
\[ A_i = \frac{1}{a_i^2} (\log(a_i(1-x-y)+b_i) + \frac{a_i(1-x-y)}{a_i(1-x-y)+b_i}), \]  
\[ D = \frac{1-x-y}{b_3(a_3(1-x-y)+b_3)}. \]  
\[ a_1 = (m_H^2 - t)y + sx, \]  
\[ b_1 = -m_y^2x - m_u^2(1-x) + ty(1-x-y) + i\epsilon, \]  
\[ a_2 = (m_H^2 - t)y + ux, \]  
\[ b_2 = b_1, \]  
\[ a_3 = (m_H^2 - u)x + sy + m_d^2 - m_u^2, \]  
\[ b_3 = -m_d^2(1-x) - m_u^2x + ux(1-x-y) + i\epsilon. \]  

In our calculations we use \( m_u = m_d \) approximation because in MSSM for left scalar quarks (if we neglect masses of the light quarks) we have:

\[ m_u^2 - m_d^2 = (1 - \sin^2 \theta_W)m_Z^2 \cos 2\beta. \]
The processes of the neutral Higgs bosons production via gluino/squark loop may be obtained from formulas (7)-(21), taking into account (6), by the following replacements:

\[ m_W \sin(2\beta) \rightarrow m_Z (\sum_{i} T^3_i - e_i \sin(\theta_W))^2 \tilde{q}_i L \tilde{q}_i L + e_i \sin(\theta_W))^2 \tilde{q}_i R \tilde{q}_i R \cos(\alpha + \beta) \quad (26) \]

\[ m_W \sin(2\beta) \rightarrow m_Z (\sum_{i} T^3_i - e_i \sin(\theta_W))^2 \tilde{q}_i L \tilde{q}_i L + e_i \sin(\theta_W))^2 \tilde{q}_i R \tilde{q}_i R \sin(\alpha + \beta) \quad (27) \]

for \( H^0_{1,2} \)-bosons respectively. In the case of the charged Higgs bosons production only left scalar quarks in loop contribute to the processes (2),(3). It must be noted also that in case of the neutral scalar Higgs bosons production in the subprocess (4) the total amplitude is the sum of both pure both left and right scalar quarks loop contributions, the pure \( t \)-quark loop contribution and the gluino/squark loop contribution. The tree and loop contribution do not interfere with each other.

It must be noted also, in case of the neutral Higgs bosons production the total amplitude is the sum of the gluino/squark amplitude and pure \( t \)-quark and squark amplitude.

For the differential cross section of the subprocess (2) we obtain the following result:

\[ \frac{d\sigma}{dt} = -\frac{\alpha^3 m_W^2}{128 \pi \sin^2 \theta_W} (\sin 2\beta)^2 \frac{t}{s} \left( s^2 (|F_1|^2 + |F_3|^2) + u^2 (|F_2|^2 + |F_4|^2) \right) \quad (28) \]

Here we use the following notations: \( s = (k_1 + k)^2 \), \( t = (k_1 - k^2)^2 \), \( u = (k_1 - k_3)^2 \), \( m_H \) is the mass of \( H^+ \) or \( H^0 \)-bosons.

\[ \sigma(pp \rightarrow H^+ + jet + X) = \int_{\frac{m_H^2}{s_0}}^{1} dx_1 \int_{\frac{m_H^2}{t_0}}^{1} dx_2 \sigma(x_1 x_2 s_0)(u(x_1)g(x_2) + u(x_2)g(x_1)) \quad (29) \]

with replacements

\[ u(x) \rightarrow d(x), u(x) + d(x) \quad (30) \]
for $H^-$ and $H^0_1$ Higgs bosons respectively. For structure functions we use parametrizations of ref. [15].

The numerical result will be presented in the nearest future. The work in this direction is in progress.

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References

[1] J.F. Gunion, H.E. Haber, Nucl. Phys. V. B272, (1986) 1

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

[3] S.L. Glashow, E.E. Jenkins, Phys. Lett. B196 (1987), 233

[4] V. Barger, J.L. Hewett, R.J.N. Phillips, Phys. Rev. D41, (1990) 3421

[5] M. Drees, D.P. Roy, Phys. Lett. B269, (1991) 155

[6] R.M. Barnett, H.E. Haber, D.E. Soper, Nucl. Phys. B306 (1988) 697

[7] M. Chainchian, I. Liede, J. Lindfors, D.P. Roy, Preprint HU-TFT-87-27, Helsinki, (1987)

[8] I. Hinchliffe, S. F. Novaes, Phys. Rev. D38 (1988) 3475

[9] R.K. Ellis, H.E. Hinchliffe, M.E. Soldate, J.J. van der Bij, Nucl. Phys. B297 (1988) 221

[10] U. Baur, E.W.N. Glover, Nucl. Phys B339 (1990) 38

[11] D. Graudenz, M. Spira, P.M. Zerwas, Phys. Lett. B264, (1991) 440;
    Phys. Rev. Lett. V. 70 (1993) 1372;

[12] R.P. Kauffman, Phys. Rev. D44 (1991) 1415; D45 (1992) 1512

[13] C.P. Yuan, Phys. Lett. B283 (1992) 395

[14] S. Dawson, R.P. Kauffman, Phys. Rev. Lett. V. 68 (1992) 2273

[15] E. Eichten et. al., Rev. of Mod. Phys. v. 56 (1984) 579
Figure 1: Diagrams corresponding to the processes (2)-(4).