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ABSTRACT

We analyze the production of supersymmetric charged Higgs bosons via vector boson fusion at SSC energies.

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I. VECTOR BOSON FUSION AND CHARGED HIGGS BOSON PRODUCTION

The minimal supersymmetric version of the standard model requires at least two $SU(2)_L$ Higgs doublets in order to generate masses for up and down quarks. Therefore, it exhibits a rich spectrum of Higgs bosons which contains two neutral scalars (H_1^0 and H_2^0), one neutral pseudoscalar (H_3^0) and a pair of charged scalars ($H^\pm$).

The superconducting supercollider (SSC) will be adequate for studying the production of heavy Higgs particles which are out of reach of the planned e^+e^- machines. The natural candidates to be studied in hadronic colliders are $H^\pm$ because they are expected to be heavier than M_W in the minimal model with soft supersymmetry breaking. In this paper we are concerned with their production via vector boson fusion. We investigate processes yielding pairs H^+H^- and $W^\pm H^\mp$ and compare them with other mechanisms.

In a generic two-doublet model there are seven independent parameters in the Higgs potential. However, supersymmetry reduces this number to three,[1,2] which we take to be $M_{H^\pm}$, $M_{H_2^0}$ and M_W. The others can be obtained through the following relations

$$M_{H_3^0}^2 = M_{H^\pm}^2 - M_W^2 .$$

$$M^2_{H^0_1} = M^2_{H^0_3} + M^2_Z - M^2_{H^0_2}$$

$$\tan 2\alpha = \tan 2\beta \left[\frac{M^2_{H^0_1} + M^2_{H^0_2}}{M^2_{H^0_3} - M^2_Z} \right]$$

and

$$\tan 2\beta = \mathrm{sign}(v_2 - v_1) \sqrt{\frac{\left(M^2_{H^0_1} - M^2_Z\right)\left(M^2_Z - M^2_{H^0_2}\right)}{M^2_{H^0_1} M^2_{H^0_2}}}$$

where $\tan\beta = v^2/v^1$ is the ratio of vacuum expectation values, and $M_{H^0_1} > M_{H^0_2}$. In this paper we shall assume that $\mathrm{sign}(v_2 - v_1) = +1$ is the favored sector, since it emerges naturally in models with $m_t > m_b$. Further details about this Higgs system may be found in Appendix A of Ref. [2].

We shall compute the rapidity distribution at zero rapidity $(d\sigma/dy|_{y=0})$ in proton-proton collisions for the following subprocesses:

$$W^+W^- \rightarrow H^+H^- \quad , \tag{1a}$$

$$ZZ \rightarrow H^+H^- \quad , \tag{1b}$$

$$W^\pm W^\pm \rightarrow H^\pm H^\pm \quad , \tag{1c}$$

$$ZZ \rightarrow W^\mp H^\pm \quad , \tag{1d}$$

$$W^+W^- \rightarrow W^\pm H^\mp \quad , \tag{1e}$$

$$W^\pm W^\pm \rightarrow W^\pm H^\pm \quad . \tag{1f}$$

In order to do so, we use the effective vector boson approximation[3] to write

$$\left.\frac{d\sigma}{dy}\right|^{pp\rightarrow X+x'}_{y=0} = \int_{\tau_{min}}^{1} \frac{d\tau}{1+\delta_{ij}} \left[V^i_p(\sqrt{\tau}).V^j_p(\sqrt{\tau}) + (i \leftrightarrow j) \right] \hat{\sigma}_{V_iV_j\rightarrow X}^{(\tau s)} \tag{2}$$

where $V^i_p(x)$ is the vector boson structure function in the proton which is given by convolution of the quark distributions in the proton with the vector boson distribution in the quark, τ_{min} is the value of τ at the threshold of the subprocess and $\hat{\sigma}_{V_iV_j\rightarrow X}$ is the cross section of the subprocess being analyzed.

In the high-energy limit the cross sections involving longitudinally polarized vector bosons dominate over those involving transverse polarizations.[4] Therefore, we shall compute only the former contributions to processes (1a) to (1f). The calculation of the elementary cross sections are simplified if we employ the Equivalence Theorem.[5] At high energies, the amplitudes for longitudinally polarized gauge bosons in the external state, to the leading order in M_V/E (where E is the energy of the gauge boson), are equal to the ones obtained by substituting the vector bosons by the associated Goldstone boson generated by the spontaneous symmetry breaking, i.e.:

$$M(W^\pm_L, Z^0_L)_U = M(\omega^\pm, z^0)R_\xi + O(M_V/E) \quad ,$$

where the left hand side is evaluated in the unitary gauge, whereas the right hand side is evaluated in the R_ξ-gauge. $\omega^\pm(z^0)$ are Goldstone bosons associated with the longitudinal polarization of $W^\pm(Z^0)$.

II. RESULTS AND CONCLUSIONS

We evaluated the rapidity distribution at y=0 for the various process (1a) to (1f). In the numerical calculations we used $M_W = 82.5$ GeV and $\sin^2\vartheta_W = 0.226$. The Q^2-dependent quark distribution functions were those of set 2 of Ref. [6].

Processes (1a) to (1c) are one to three orders of magnitude smaller than the Drell-Yan one $(q\bar{q} \to \gamma, Z_0 \to H^+H^-)$. The production of $W_L^\pm H$ via $Z_L Z_L$ fusion gives a contribution, which is smaller than the ones coming from processes (1a) to (1c). In the standard model the production of Higgs bosons via WW(ZZ) fusion is enhanced, for large M_H, since the vertex $V_L V_L H_0$ is proportional to M_H/M_V. In the supersymmetric standard model these couplings do not exhibit such an enhancement. The reactions (1e) and (1f) give measurable cross sections, whose contributions are shown in Figs. 2 and 3, respectively, where for comparison, we have also drawn the result for H^+H^- pair production via Drell-Yan mechanism.

From Fig. 2 one can learn that if $M_{H_2^0} > 40$ GeV

and $M_{H^\pm} \leq 300 - 400$ GeV, the cross section for producing $W_L^\pm H^\mp$ via $W_L^\pm W_L^\mp$ fusion is of the order of the Drell-Yan contribution for H^+H^- pair production, with the advantage of having a better signal provided by the WH final state. By looking at Fig. 4 similar conclusions can be drawn.

We now turn to the possibility of observing events with a WH in the final state. The detection of the Higgs in its quark decay modes do not seem promising since the signal to QCD background ratio is of order 10^{-4} [9]. The use of rare decay modes is discouraging due to the smallness of the cross section. The possibility left for detecting its signal will be through the neutralino/chargino modes.

The above conclusions holds true for a pair H^+H^- in the final state, that is, it is difficult to detect H^+H^- pairs coming from $q\bar{q}$ fusion or gg fusion.

Our conclusion is that it will be a very hard task to observe Higgs pairs or the associate production (WH). Probably the charged Higgs boson will be seen, at SSC energies, only through its single production. In this case the most promising mechanism seems to be quark fusion $(t\bar{b} \to H^+)$ [10].

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FIGURE CAPTIONS

Fig. 1 - Feynman diagrams associated to processes (1a) to (1f).

Fig. 2 - Rapidity distribution at $y=0$ for Drell-Yan ($q\bar{q} \to \gamma$, $Z_0 \to H^+H^-$) (solid curve), $\omega^+\omega^- \to \omega^\pm H^\mp$ with $M_{H_2^0}$ = 9.38 GeV (dotted curve), $M_{H_1^0}$ = 46.9 GeV (dot-dashed curve), and $M_{H_2^0}$ = 84.4 GeV (dashed curve, in pp collisions at $\sqrt{s}$ = 40 TeV.

Fig. 3 - Rapidity distributions at $y=0$ for Drell-Yan ($q\bar{q} \to \gamma$, $Z_0 \to H^+H^-$) (solid curve), $\omega^\pm\omega^\pm \to \omega^\pm H^\pm$ with $M_{H_2^0}$ = 9.38 GeV (dotted curve), $M_{H_2^0}$ = 46.8 GeV (dot-dashed curve), and $M_{H_2^0}$ = 84.4 GeV (dashed curve) in pp collisions at $\sqrt{s}$ = 40 TeV.

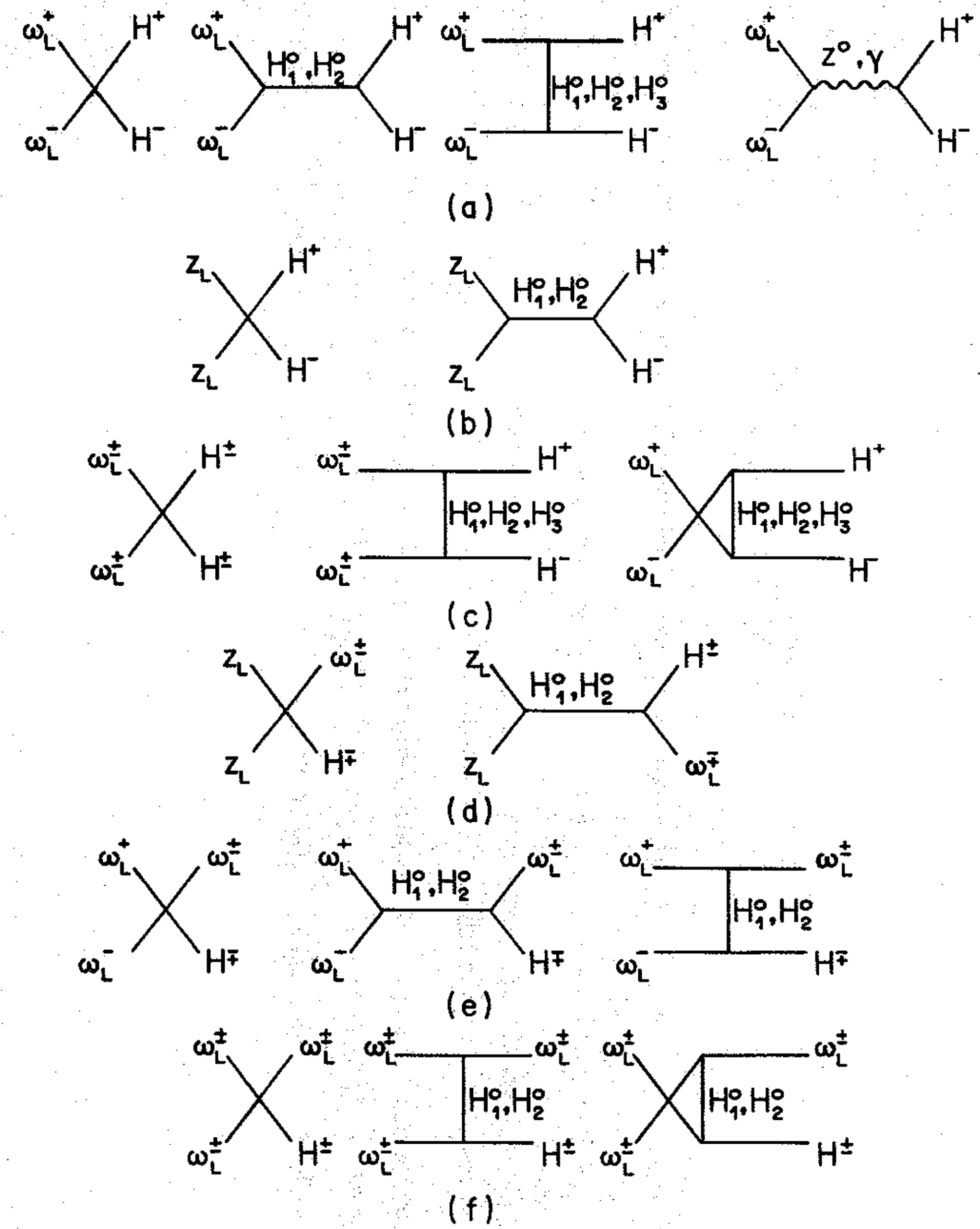

Figure 1

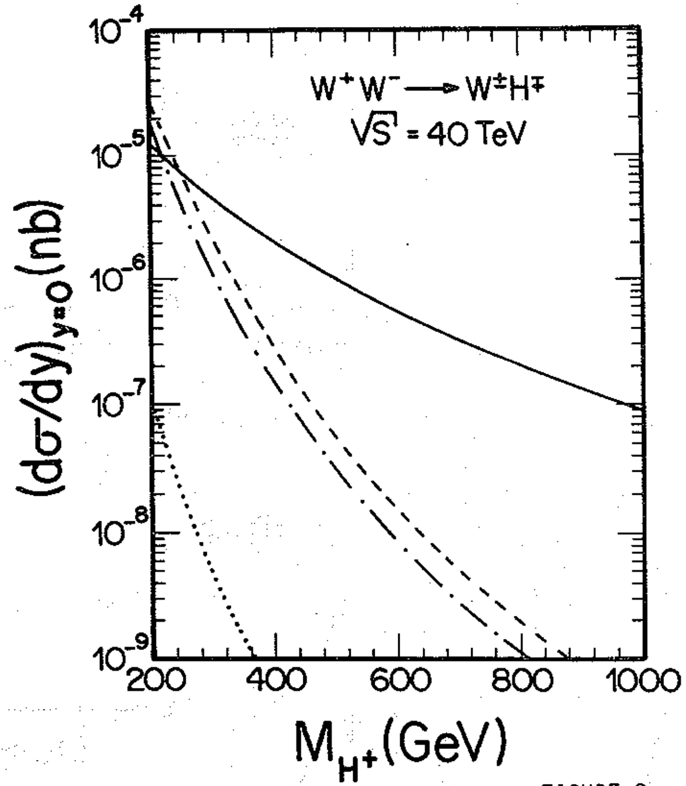

FIGURE 2

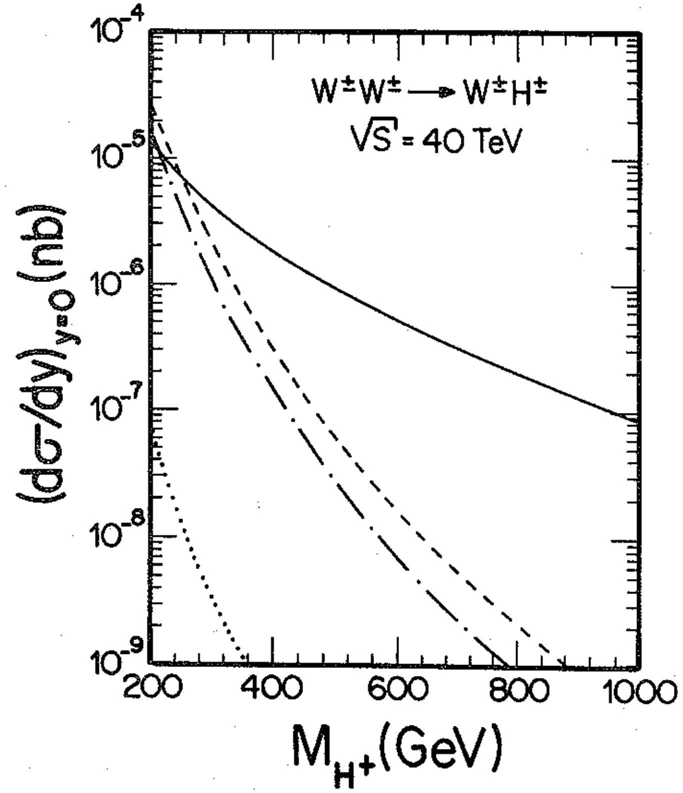

FIGURE 3