Trying to catch the elusive $A^0$ and more. Reactions initiated by $b$–quarks and the Higgs sector of the MSSM

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Abstract

We study the cross sections for the production of a neutral, intermediate mass Higgs boson in the processes $pp \rightarrow tq^{'}\Phi$, $pp \rightarrow tW^{-}\Phi$ and $pp \rightarrow bZ^{0}\Phi$ in the Minimal Supersymmetric Standard Model ($\Phi = H^{0}, h^{0}$ and $A^{0}$) at Supercollider energies. The additional heavy particles ($t, W, Z$) in the final state can be used for tagging purposes, increasing the signal to background ratio. These reactions are dominated by $bq$ and $bg$ fusion. Their relevance for Higgs particle searches is discussed taking into account the expected efficiencies and purities for $b$–tagging. We find that, for $\tan\beta = 30$, the cross sections for $pp \rightarrow bZ^{0}\Phi$ are larger than $14 \text{ pb}$, over the whole intermediate range of $M_{A^{0}}$, for $A^{0}$ and at least one of the other two Higgses. Therefore this reaction is an excellent candidate for the discovery of one or more MSSM Higgs particles.

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Introduction

Both in the Standard Model (SM) and in the Minimal Supersymmetric Standard Model (MSSM) the Higgs mechanism is assumed, after the spontaneous symmetry breaking of the $SU(2) \times U(1)$ gauge group, to give masses to gauge bosons, to fermions and, in the latter, to their supersymmetric partners.

While in the SM a doublet of complex scalar fields is sufficient to induce the symmetry breaking, in the MSSM this requires two doublets.

Of the initial degrees of freedom, three are employed to give a longitudinal polarization to the weak gauge bosons $Z^0$ and $W^\pm$; the remaining ones, one for the SM and five for the MSSM, appear in the theory as interacting scalar particles: the Higgs bosons.

The SM Higgs $\phi$ is a $CP$–even neutral particle; among the MSSM Higgses three are neutral, the $CP$–even ones $H^0$ and $h^0$ and the $CP$–odd one $A^0$, and two charged, the $H^\pm$’s. The three neutral Higgs states of the MSSM will be collectively indicated by $\Phi$.

Unitarity of the theory imposes a SM upper limit \[1\]

\[ M_\phi \lesssim \left( \frac{8 \sqrt{2} \pi}{3 G_F} \right)^{1/2} \sim 1 \text{ TeV}, \]

where $G_F$ is the Fermi electroweak constant. The analysis is more complicated in models with an extended Higgs sector \[2\], such as the MSSM, but similar arguments indicate that at least one neutral scalar must have mass below $\sim 1$ TeV \[3, 4\].

In the simplest version of the MSSM all Higgs masses are predicted at tree level as a function of $\tan \beta$, the ratio of the vacuum expectation value of the two doublets, and $M_{A^0}$, the mass of the $CP$–odd state. At one–loop these predictions are substantially modified and an additional dependence on the top mass $m_t$ and on the common squark mass $m_{\tilde{t}}$ is introduced. One has \[3\]:

\[ M_{h^0, H^0}^2 = \frac{1}{2} [M_{A^0}^2 + M_{Z^0}^2 + \epsilon/\sin^2 \beta] \]

\[ \pm \left\{ [(M_{A^0}^2 - M_{Z^0}^2) \cos 2\beta + \epsilon/\sin^2 \beta]^2 + (M_{A^0}^2 + M_{Z^0}^2)^2 \sin^2 2\beta \right\}^{1/2}, \] \[ (2) \]

where

\[ \epsilon = \frac{3 e^2}{8 \pi^2 M_W^2 \sin^2 \theta_W} m_t^4 \ln \left( 1 + \frac{m_t^2}{m_{\tilde{t}}^2} \right). \] \[ (3) \]

The squark mass scale $m_{\tilde{t}}$ is expected to be of the order of 1 TeV. The mixing angle $\alpha$ in the $CP$–even sector, which together with $\beta$ determines all couplings of the MSSM Higgses (table I), is defined by

\[ \tan 2\alpha = \frac{(M_{A^0}^2 + M_{Z^0}^2) \sin 2\beta}{(M_{A^0}^2 - M_{Z^0}^2) \cos 2\beta + \epsilon/\sin^2 \beta}. \] \[ (4) \]

As it will be discussed in more detail later on, we are mainly interested in the intermediate range mass for $A^0$, which is the region in parameter space which is the most
difficulty to explore experimentally. For relatively large values of \( \tan\beta \), two different regimes can be distinguished depending on whether \( M_{A^0} \) is smaller or larger than a threshold value of 100–130 GeV. For lower \( M_{A^0}, M_{H^0} \approx 110 \) GeV while \( M_{\phi^0} \approx M_{A^0} \) and \( \alpha \approx -90^\circ \), while for larger \( M_{A^0} \) the role of \( h^0 \) and \( H^0 \) are exchanged and \( \alpha \approx 0^\circ \). The region in between these two regimes, where all the couplings of \( h^0 \) and \( H^0 \) to quarks are simultaneously suppressed, corresponds to the intermediate mass region for \( A^0 \).

Only lower limits on the Higgs masses have been extracted at present colliders. LEP experiments, from the results of searches for \( Z^0 \phi \) events, derive a bound

\[
M_\phi \gtrsim 62.5 \text{ GeV},
\]

for the SM Higgs \( \phi \). Using the reactions \( e^+ e^- \rightarrow Z^0 h^0 \) and \( e^+ e^- \rightarrow h^0 A^0 \), the lower limits on MSSM neutral Higgses are presently

\[
M_{h^0} \gtrsim 44.5 \text{ GeV} \quad \text{and} \quad M_{A^0} \gtrsim 45 \text{ GeV},
\]

for the typical choice of parameters \( m_t = 140 \) GeV and \( m_t = 1 \) TeV [3].

Extensive studies have been carried out on the detectability of a Higgs particle by the next generation of high energy colliders \([3, 6, 7, 8, 9, 10, 11]\). The region \( M_\phi < 80 \) GeV will be studied at LEP II. For \( M_{A^0} < 80 \)–90 GeV one or both of the two processes \( e^+ e^- \rightarrow Z^0 h^0 \) and \( e^+ e^- \rightarrow h^0 A^0 \) will be discovered. Higgses with larger masses will be searched for at \( pp \) colliders like LHC (\( \sqrt{s} = 16 \) TeV) and SSC (\( \sqrt{s} = 40 \) TeV). The intermediate–mass range 80 GeV \( \sim M_\phi \lesssim 130 \) GeV is the most difficult one. In this range a Higgs boson \( \Phi \) mainly decays to \( bb \) pairs, both in the SM and, for a large choice of parameters, in the MSSM. Because of the huge QCD background, its detection in this channel results very difficult. The discovery of a Higgs in the two–photon inclusive mode requires an extremely good photon–pair mass resolution. However, it has been established that the associated production of a SM Higgs \( \phi \) with a \( W^\pm \) boson \([12, 13]\) or a \( tt \) \([14, 15]\) pair, followed by the decays \( \phi \rightarrow \gamma \gamma \) and \( W \rightarrow \ell \nu \), can be revealed with the diphoton mass resolution expected from SSC/LHC detectors \([16]\). Requiring the presence of a highly energetic and isolated lepton in the final state is a very effective method to enhance the signal to background ratio. The branching ratio to \( \gamma \gamma \) depends crucially on the Higgs coupling to the top quark. In the MSSM this mode can be exploited for the discovery of \( H^0 \) for 80 GeV \( < M_{A^0} < 100 \) GeV and for the discovery of \( h^0 \) for \( M_{A^0} > 170 \) GeV. For \( M_\phi > 130 \) GeV the four–lepton mode guarantees, in general, the detection of the SM Higgs. In the MSSM this decay channel is only useful for the \( H^0 \) for moderate \( \tan\beta \) and 100 GeV \( < M_{A^0} < 300 \) GeV.

Recently, it has been suggested \([17]\) that with the \( b \)-tagging capabilities of SSC experiments, and possibly LHC ones if the higher luminosity and larger number of tracks per event can successfully be dealt with, it may be possible to detect a Higgs boson in the \( tt \Phi \) production channel, requiring one \( t \) to decay semileptonically and using the hadronic decay \( \Phi \rightarrow b\bar{b} \). This idea could be used both for the SM Higgs \( \phi \) and, over a wide range of the parameter space, for at least one of the MSSM Higgses \( h^0 \) or \( H^0 \). In particular this would close the “window of inobservability” which remained in previous analysis for 100 GeV \( < M_{A^0} < 170 \) GeV and \( \tan\beta \) larger than about 2. This channel is useless for \( A^0 \) because its coupling to \( t \)–quarks is suppressed by \( 1/\tan\beta \).
It would be interesting to know whether vertex–tagging of the b’s can disentangle the rather large signal from $gg \to b\bar{b}A^0$ from the enormous $b\bar{b}b\bar{b}$ QCD background.

In this paper we study the following reactions:

$$b + q(\bar{q}) \longrightarrow t + q'(\bar{q}') + \Phi,$$  \hspace{1cm} (7)

$$b + g \longrightarrow t + W^- + \Phi,$$  \hspace{1cm} (8)

$$b + g \longrightarrow b + Z^0 + \Phi.$$  \hspace{1cm} (9)

with the purpose to extend the range in parameter space for which more than one MSSM Higgs can be detected, and in particular to enlarge the regions of observability of $H^0$ and $A^0$. All these reactions

1. contain $b$–quarks and therefore may be enhanced for large $\tan\beta$;

2. have additional heavy particles $t, W, Z$ in the final state which can produce highly energetic and isolated leptons. This could be particularly useful at LHC, somewhat relaxing the requirements on $b$–tagging devices by decreasing the trigger rate and drastically reducing the background.

The first process (7) is the supersymmetric version of the reaction studied in \textsuperscript{[18]} in the SM. It can be interpreted as the dominant contribution to $gg \to t\bar{b}q'\Phi$ corresponding to the gluon which splits into a collinear $b\bar{b}$ pair. The cross section depends on the Higgs coupling to $b$ and $t$–quarks and to vector bosons; moreover it is known that there are large cancellations among different diagrams, therefore it is impossible to obtain the MSSM cross section simply multiplying the SM result by an overall factor.

The second one (8), again if read as a shorthand for $gg \to b\bar{b}W^-t\Phi$, represents the contribution to $gg \to b\bar{b}W^-W^+\Phi$ which does not proceed through $gg \to tt\Phi$ and consequent $t$ decay. Therefore it is expected to be a small correction to $gg \to tt\Phi$ whenever this reaction is relatively large. It could however be important in regions in which $tt\Phi$ production is suppressed, in particular for $A^0$.

The last reaction (9) is described at tree level by the same set of diagrams that describes (8), with a $Z^0$ replacing the $W^-$ boson and consequently with a $b$–quark in place of a $t$–quark in the final state. The lighter mass of the $b$ makes this reaction kinematically favored in comparison to (8). The branching ratio of the $Z^0$ to light leptons is smaller than the corresponding one for $W$’s, but the signature is much cleaner and does not suffer from the huge background from $top$ production. The presence of a $Z^0$ has the additional advantage of allowing a very good measurement of the position of the primary vertex and therefore facilitates the search for secondary vertices.

In the following section, we give some details of the calculation and the values adopted for the various parameters. Section III is devoted to a discussion of the obtained results. Conclusions are in section IV.

**Calculation**

The Feynman diagrams describing at tree–level and in the unitary gauge the reaction (7) are shown in fig.1. Some of the ones corresponding to (8)–(9) are depicted in fig.2.
The diagrams with a direct coupling of $\Phi$ to the light quark line have been neglected, since they vanish in the massless limit. In fig.2 five diagrams are not shown. Four can be obtained obtained exchanging the attachment of the vector bosons in (1) to (4), the fifth exchanging the gluon and the higgs attachements in (5).

For a $SM$ Higgs only the first three diagrams of fig.1 and the first four of fig.2 contribute; in the $MSSM$ case, for a $CP$–odd Higgs boson ($\Phi = A^0$), the diagrams with the coupling $VV A^0$, where $V = W^{\pm}, Z^0$, vanish.

Moreover, for the process (4) there are additional contributions from diagrams containing a massless antiquark line which are included in our results.

We have evaluated the matrix elements in different ways. All amplitudes have been calculated, using spinor techniques [19, 20, 21, 22], in two different gauges, the unitary and the Feynman one, and checked for gauge and BRST invariance [23, 24, 25]. For process (4) we have also computed the cross section using the time–honored trace method.

Then, the matrix elements have been numerically integrated over phase space using VEGAS [26].

For the electroweak parameters we have chosen $\sin^2 \theta_W = 0.2325$ and $\alpha_{em} = 1/128$, with the masses $M_{Z^0} = 91.173$ GeV and $M_W = M_{Z^0} \cos \theta_W$. For the quark masses the values $m_t = 150$ GeV and $m_b = 5$ GeV have been used throughout, while $u, d, s$ and $c$ quarks have been considered massless.

The strong coupling constant $\alpha_s$ and the parton distribution functions have been consistently evaluated at a scale equal to the subprocess invariant mass. We have used the one loop expression for $\alpha_s$, with $\Lambda_{QCD} = 150$ MeV and five active flavors.

In all of the calculations the structure function set HMRSB has been used [27]. Changing the scale and/or distribution function choice should not affect our predictions by more than a factor of two.

We have analyzed the mass range $50$ GeV $< M_{A^0} < 180$ GeV for $\tan \beta = 2, 15$ and 30, adopting the one–loop expression (3) for the $MSSM$ neutral Higgs masses. For the $MSSM$ charged Higgs masses we have maintained the tree–level expression

$$M_{H^\pm}^2 = M_{A^0}^2 + M_W^2,$$

(10)

since one–loop corrections are quite small if compared with the corresponding ones for neutral Higgses [28].

### Results

Our results are presented in fig.3 through 6. In order to assess their significance it is useful to recall, as a reference point, that, in the regions in which detection of $h^0$ or $H^0$ through their tagged hadronic decay is possible [17], the cross section for $t \bar{t} h^0, H^0$ is about 5 $pb$.

In fig.3 we show a number of cross sections for $\tan \beta = 2$. As expected they are generally small. The cross sections for $b + g \rightarrow t + W + h^0$ and $b + g \rightarrow b + Z^0 + h^0$ increase sharply at $M_{A^0} \approx 130$ GeV and $M_{A^0} \approx 170$ GeV respectively. This is due to the onset of the decay channel $H^\pm \rightarrow W^\pm h^0$ in the first case and $A^0 \rightarrow Z^0 h^0$ in the second.
In order to check the consistency of our results in the threshold regions we have also estimated the two cross sections in the narrow width approximation, assuming diagram 5 in fig.2 to give the dominant contribution. We have computed the cross section for \( g(p_1) + b(p_2) \rightarrow b(p_3) + A^0(p_4) \) with the following result:

\[
|\mathcal{M}(bg \rightarrow bA)|^2_{\text{ave}} = \frac{2\pi^2 \alpha_s m_b^2 \tan^2 \beta}{3M_W^2 \sin^2 \theta_W} \left[ \frac{2m_b^2 M_A^2}{(s - m_b^2)^2} + \frac{2m_b^2 M_A^2}{(t - m_b^2)^2} \right]
\]

\[+ \frac{2u(2m_b^2 - u)}{(s - m_b^2)(t - m_b^2)} + \frac{4m_b^2 - M_A^2 - u}{(s - m_b^2)} + \frac{4m_b^2 - M_A^2 - u}{(t - m_b^2)} \] (11)

where \( s = (p_1 + p_2)^2, t = (p_1 - p_3)^2 \) and \( u = (p_1 - p_4)^2 \). The cross section for \( b + g \rightarrow t + H^- \) has been taken from ref. [2], while the branching ratios and the corresponding widths have been derived from the formulae given in [2] using the one-loop-corrected masses. We obtain \( \sigma(b + g \rightarrow b + A^0 + \text{c.c.}) \times \text{BR}(A^0 \rightarrow Z^0 h^0) = .5 \text{ pb} \) at \( M_{A^0} = 180 \text{ GeV} \) and \( \sigma(b + g \rightarrow t + H^- + \text{c.c.}) \times \text{BR}(H^- \rightarrow W^- h^0) = 1.3(7) \text{ pb} \) at \( M_{A^0} = 140(180) \text{ GeV} \) in reasonable agreement with the full result. Therefore we conclude that, for \( \tan \beta = 2 \), the processes we have examined have cross sections at most of the order of 1 \( \text{ pb} \), even when new decay channels open for intermediate–state particles.

In fig.4 we present the cross section for \( b + q(\bar{q}) \rightarrow t + q'(\bar{q}') + \Phi \) for large values of \( \tan \beta \). The cross sections for \( h^0 \) and \( H^0 \) follow the trend of the respective coupling to the \( t \), particularly for \( \tan \beta = 30 \). In the \( SM \) there are large cancellations between diagrams (2) and (3) in fig.1. In the supersymmetric case this cancellation is not substantially upset because the factors which suppress the couplings of the two Higgses to the top and to the vector bosons are of similar magnitude throughout the whole range in \( M_{A^0} \) under consideration. Therefore the change of the cross section reflects the change in the contribution of diagram (1). In order to evaluate the number of events produced by the various reactions one can adopt the SDC estimates of a 30% efficiency for single \( b \)-tagging. Then, assuming a factor of two reduction of the signal for acceptance and kinematical cuts, the probability of detecting three \( b \)'s together with one high–\( p_T \) lepton from top or \( W \) decay is about \( 2.7 \times 10^{-3} \). This gives 27 events per standard SSC year \( (L = 10^4 \text{ pb}^{-1}) \) in the \( t\Phi \) final state for a cross section of \( 1 \text{ pb} \). The corresponding figure for the \( tW\Phi \) final state would be twice as large.

The cross section for \( bg \rightarrow tW\Phi \) is presented in fig.5. This reaction results in a final state which is very similar to \( t\bar{t}\Phi \). The higher luminosity of the gluon and the presence of a strong vertex in place of an electroweak one do not compensate the effect of producing an additional heavy particle and the rate is generally smaller, for a given Higgs mass, than the corresponding rate for reaction (7) in fig.4. Summing the results in fig.4 and 5, at \( \tan \beta = 30 \), one obtains for \( A^0 \) a cross section which varies exponentially from about 3 \( \text{ pb} \) at \( M_{A^0} = 50 \text{ GeV} \), to 2 \( \text{ pb} \) at \( M_{A^0} = 100 \text{ GeV} \), to approximately .8 \( \text{ pb} \) at \( M_{A^0} = 180 \text{ GeV} \).

We remark that for \( \tan \beta = 15 \) and 30 the decay channel \( H^\pm \rightarrow W^\pm h^0 \) opens up at \( M_{A^0} \approx 180 \text{ GeV} \). However the coupling of the \( H^\pm \) to \( h^0W^\pm \) is strongly suppressed at large \( \tan \beta \) and the contribution from diagram 5 in fig.2 is negligible and the crossing of the threshold gives no visible effect in the cross sections for \( b + g \rightarrow t + W + h^0 \).
In fig. 6 we give the cross sections for $b + g \rightarrow b + Z^0 + \Phi^0$, $\Phi = h, H, A$ which are by far the most relevant results we have obtained. At least two of the three Higgses have cross sections larger than 14 pb over the whole intermediate range of $M_{A^0}$ for $\tan \beta = 30$. As obvious the $A^0$ cross section for $\tan \beta = 15$ is simply one fourth of the cross sections for $\tan \beta = 30$. The same relationship between the cross sections at the two values of $\tan \beta$ also holds for $h^0$ in the region $M_{A^0} < 100$ GeV and for $H^0$ in the region $M_{A^0} > 120$ GeV, where the masses of the two $CP$–even Higgs bosons are approximately independent of $M_{A^0}$. Outside these two regions the cross sections for $h^0$ and $H^0$ decrease rapidly. To get a feeling for the expected rates we notice that taking into account the 6% branching ratio of $Z^0$ to light leptons, again assuming the SDC estimates for the single $b$–tagging efficiency and the usual factor of two reduction for acceptance, a cross section of 1 pb corresponds to 27 events per SSC year, in which one $Z^0$ decays to $\ell^+ \ell^-$ and both $b$’s from the Higgs decay are detected. In this case the dominant background comes from $b\bar{b}Z^0$ production. In \[30\] the total cross section for $p\bar{p} \rightarrow b\bar{b}Z^0$ has been found to be about 3.6 nb. Whether or not the $A^0$ can be detected in the $b\bar{b} \ell^+ \ell^-$ mode depends therefore on the $b\bar{b}$ mass–spectrum of the background and on the detector mass resolution. We have left this subject for future studies. If all three $b$’s are required to be tagged, then one expects about 9 events per SSC year for each pb of cross section. Possible backgrounds to this channel are the irreducible one from $bb\bar{b}Z^0$ production, possibly with a small contribution from $t\bar{t}bbZ^0$, and $b\bar{b}Z^0 + jets$ in which one jet is misidentified as a $b$. Unfortunately, to our knowledge, no estimate for these processes is available but it is very difficult to imagine that they could be larger than the background to three $b$’s and one high–$p_T$ lepton which has been studied in \[17\]. Therefore we believe that reaction (9) is a good candidate for the detection of $\mathcal{MSSM}$ Higgs bosons at large values of $\tan \beta$.

We have not made a complete study of reactions (7)–(9) at LHC, but we have checked in a few cases that the usual $6 \div 10$ reduction factor applies to the cross sections.

Conclusions

In this paper we have studied, in the $\mathcal{MSSM}$, a number of processes for the production of a neutral, intermediate mass Higgs boson with additional heavy particles in the final state which can be used for tagging purposes. We find that, for large values of $\tan \beta$, the cross sections for $pp \rightarrow bZ^0\Phi$ are of the order of 10 pb or more, over the whole intermediate range of $M_{A^0}$, for $A^0$ and at least one of the other two Higgses.

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Table Captions

table I  $\mathcal{MSSM}$ neutral Higgs couplings to the massive fermions $\tau, b$ and $t$, and to the massive gauge bosons $W^{\pm}$ and $Z^0$.

Figure Captions

fig.1  Feynman diagrams contributing in the lowest order to $bg \rightarrow tq'\Phi$, where $q, q' = u, d, s, c$ and $\Phi = \phi, H^0, h^0, A^0$, as appropriate. For the $\mathcal{SM}$ Higgs ($\Phi = \phi$) only the first three contribute, while in the $\mathcal{MSSM}$ case, for a $CP$–odd Higgs boson ($\Phi = A^0$), diagram (3) is absent.

fig.2  Basic Feynman diagrams contributing in the lowest order to $bg \rightarrow qV\Phi$, where $q = b, t; V = W^-, Z^0$ and $\Phi = \phi, H^0, h^0, A^0$, as appropriate. For the $\mathcal{SM}$ Higgs ($\Phi = \phi$) only the first four contribute, while in the $\mathcal{MSSM}$ case, for a $CP$–odd Higgs boson ($\Phi = A^0$), diagram (4) is absent.

fig.3  Cross sections for a number of processes $b + q(\bar{q}) \rightarrow t + q'(\bar{q}') + \Phi, b + g \rightarrow t + W^- + \Phi$ and $b + g \rightarrow b + Z^0 + \Phi$ plus their charge conjugated at SSC for $m_t = 150$ GeV and $\tan \beta = 2$. Each curve is labeled with the name of the Higgs boson it refers to.

fig.4  Cross sections of the processes $b + q(\bar{q}) \rightarrow t + q'(\bar{q}') + \Phi^0, \Phi = h, H, A$ and their charge conjugated at SSC for $\tan \beta = 15$ (lower curves) and $\tan \beta = 30$ (upper curves). The top mass is 150 GeV.

fig.5  Cross sections of the processes $b + g \rightarrow t + W^- + \Phi^0, \Phi = h, H, A$ and their charge conjugated at SSC for $\tan \beta = 15$ (lower curves) and $\tan \beta = 30$ (upper curves). The top mass is 150 GeV.

fig.6  Cross sections of the processes $b + g \rightarrow b + Z^0 + \Phi^0, \Phi = h, H, A$ and their charge conjugated at SSC for $\tan \beta = 15$ (lower curves) and $\tan \beta = 30$ (upper curves).
|       | $h^0$       | $H^0$       | $A^0$       |
|-------|-------------|-------------|-------------|
| $t\bar{t}$ | $\frac{\cos \alpha}{\sin \beta}$ | $\frac{\sin \alpha}{\sin \beta}$ | $-i\gamma_5 \cot \beta$ |
| $b\bar{b}, \tau\bar{\tau}$ | $-\frac{\sin \alpha}{\cos \beta}$ | $\frac{\cos \alpha}{\cos \beta}$ | $-i\gamma_5 \tan \beta$ |
| $W^+W^-, Z^0 Z^0$ | $\sin (\beta - \alpha)$ | $\cos (\beta - \alpha)$ | 0 |
| $H^\pm W^\mp$ | $\cos (\alpha - \beta)$ | $\sin (\alpha - \beta)$ | 1 |
| $A^0 Z^0$ | $\cos (\alpha - \beta)$ | $\sin (\alpha - \beta)$ | 0 |

Table I
Fig. 1
Fig. 2