Chapter 1

Higgs Production Through b Quark Fusion

In MSSM, the neutral Higgs are dominantly produced from bottom quark fusion. The Higgs coupling to the fermion depends on m_f/v term, where m_f is mass of the fermion while v is the vacuum expectation value. Since $m_b \approx 4.7\ GeV$, this Yukawa coupling is weak, which leads to a very small cross section for associated production of Higgs bosons. With the introduction of more than one Higgs doublet in MSSM, this Yukawa coupling can be enhanced by a factor of $1/cos\beta$ and therefore the cross section associated with bottom quarks can be enhanced by choosing high $tan\ \beta$. Therefore for $tan\ \beta > 7$ bottom quark fusion is the dominant process to produce neutral Higgs bosons in MSSM. [**?**] present NLO calculation for the total cross section of Higgs pair production via bottom quark fusion($b\bar{b} \rightarrow hh$) at LHC in the SM. A study of supersymetric QCD corrections for the Higgs pair production via bottom quark has been presented in [1]. [2] [3] [4] [5] are few more studies about heavy quark fusion and [6], [7] are few studies done on Higgs boson production in association with single bottom quark. In this study we focused on the production of neutral Higgs bosons with a bottom quark pair(b and $\bar{b}$) followed by Higgs decay in to a pair of bottom quarks and one Higgs decay into $b\bar{b}$ while the other Higgs decay into $\tau^+\tau^-$. These processes are specially interested here because they consist diagrams with trilinear Higgs couplings which leads to measuring trilinear Higgs coupling at LHC. Production cross sections of neutral Higgs bosons in MSSM will be mainly discussed in this chapter

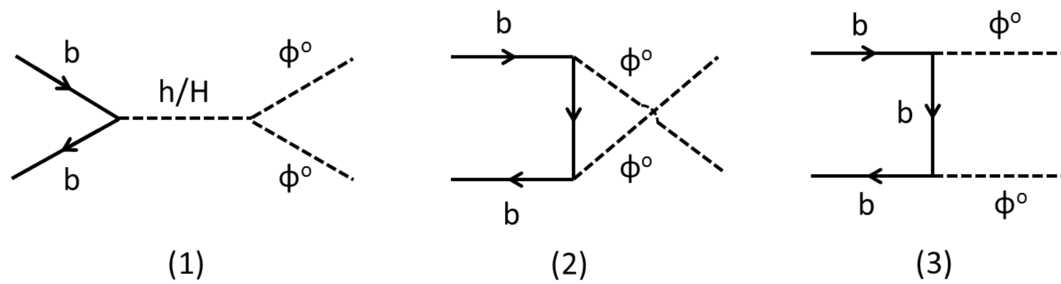

Figure 1.1: The lowest order Feynman diagrams for the production of Higgs boson pair in MSSM from b quark fusion, $\phi = h^0, H^0, A^0$

and numerical results will be presented for both SM and MSSM.

1.1 Leading order cross section for $b\bar{b} \to \phi^0\phi^0 + X$ in MSSM

Figure 1.1 gives the tree level Feynman diagrams for $b\bar{b} \to \phi^0\phi^0$ in MSSM.

For the given Feynman diagrams, $b(p_1)\bar{b}(p_2) \to \phi^0(p_3)\phi^0(p_4)$, the cross section can be simply written as,

$$\sigma_{LO} = \int dx_1 dx_2 [b(x_1)\bar{b}(x_2) + \bar{b}(x_1)b(x_2)] * \widehat{\sigma}_{LO}(b\bar{b} \to \phi^0\phi^0) \tag{1.1}$$

where $b(x)$ and $\bar{b}(x)$ are the LO parton distribution functions for the bottom quarks and $\widehat{\sigma}_{LO}$ is the parton level cross section for $(b\bar{b} \to \phi^0\phi^0)$. Parton level differential cross section over the two body phase space can be written as,

$$\frac{d\sigma}{d\Omega} = \left(\frac{\hbar c}{8\pi}\right)^2 \frac{S\,|M|^2}{(E_1+E_2)^2} \frac{|p_f|}{|p_i|} \tag{1.2}$$

$|p_f|$ is the magnitude of either outgoing momentum and $|p_i|$ is the magnitude of either incoming momentum. M is the average amplitude for the process and ,

$$|M|^2 = \left(\frac{1}{3}\frac{1}{3})\right)\left(\frac{1}{2}\frac{1}{2})\right)\sum_{spin,color}|M_0|^2$$

The amplitude for each diagram can be written in the following form.

$$M_s^0 = \left(\frac{ig_{hbb}g_{h\phi\phi}}{s - {M_h}^2 + iM_h\Gamma_h} + \frac{ig_{Hbb}g_{H\phi\phi}}{s - {M_H}^2 + iM_H\Gamma_H}\right)\left(\overline{v}(p_2)P_L u(p_1) + \overline{v}(p_2)P_R u(p_1)\right)\delta_{\alpha\beta}$$

$$M_t^0 = \frac{g_{\phi bb}^2}{t}\left(\overline{v}(p_2)\wp_3 P_L u(p_1) + \overline{v}(p_2)\wp_3 P_R u(p_1)\right)\delta_{\alpha\beta}$$

$$M_u^0 = -\frac{g_{\phi bb}^2}{u}\left(\overline{v}(p_2)\wp_3 P_L u(p_1) + \overline{v}(p_2)\wp_3 P_R u(p_1)\right)\delta_{\alpha\beta}$$

where α, β are color indices ,$P_{R,L} = (1 \pm \gamma_5)/2$ $\;s, t, u$ are Mandelstam variables. The $g_{\phi bb}$ denotes Yukawa couplings and $g_{h\phi\phi}$ and $g_{H\phi\phi}$ are trilinear Higgs couplings given in appendix.

The total amplitude was calculated by squaring the corresponding spin and color averaged matrix elements including interference terms. The amplitude was calculated analytically as well as using Mad Graph to have a better comparison.

1.2 Calculation Tools

The cross section is calculated using the Narrow width Approximation(NWA) for $pp \to \phi^0\phi^0 \to b\bar{b}b\bar{b} + X$ via $b\bar{b} \to \phi^0\phi^0$ where, $\phi^0 = h^0, A^0, H^0$ for MSSM and ϕ^0 is SM Higgs boson with $m_h = 126\ GeV$ for SM. The parton distributions of MSTW2008 was used for this calculation and both the factorization and renormalization scales were set to $\mu_R = \mu_F = \sqrt{\hat{s}}$. Masses, couplings and other constants were calculated same as discussed in Chapter 2 for gluon fusion processes.

1.3 Numerical Results

1.3.1 Standard Model

In the SM, bottom quark fusion can produce Higgs pairs at a small rate compared to gluon fusion. However here we evaluate the leading order cross section for the production of standard model Higgs pair as an initiation for the extended models. In order to include the higher order corrections , the results were multiplied by K factor. Leading order cross section evaluated for Higgs pair production from $b\bar{b}$ in SM are given in Table 1.1. The overall cross section for the processes after the decay of Higgs are also included in this table and the cuts explained in the relevant sections in gluon fusion were used here for the final state particles.

- Higgs decay into $b\bar{b}\tau\tau$

$mh = 120GeV$ Cross section is $0.0104fb$ smgghh.dat Distributions, cross sections , analytically and Mgme

1.3.2 Higgs pair production from b quark fusion in MSSM

Higgs pair production via bottom quark fusion in MSSM is more interested due to enhanced Yukawa couplings in two Higgs doublet Models. These enhanced Higgs pair

	$M_H = 123$ GeV	$M_H = 126$ GeV	$M_H = 129$ GeV
$\sigma(b\bar{b} \to hh)$	8.96×10^{-2}	8.55×10^{-2}	8.16×10^{-2}
$\sigma(b\bar{b} \to hh \to b\bar{b}b\bar{b} + X)$	3.70×10^{-2}	3.06×10^{-2}	2.47×10^{-2}
$\sigma(b\bar{b} \to hh \to b\bar{b}\tau^+\tau^- \to b\bar{b}l_\tau j_\tau + E_T + X)$			

Table 1.1: Leading order cross section in fb for Standard Model Higgs pair production via b quark fusion. Cross sections for the complete processes after Higgs decay is also given in the table.

production rates are significant in exploring trilinear Higgs couplings at LHC. Hence calculation of production cross sections through b quark at LHC is motivated for MSSM. The cross sections for $pp \to \phi^0\phi^0 \to b\bar{b}b\bar{b} + X$ and $pp \to \phi^0\phi^0 \to b\bar{b}\tau^+\tau^- \to b\bar{b}l_{\tau+X}$ were evaluated at $\sqrt{s} = 14\ TeV$ for $\phi^0 = A^0, h^0, H^0$ three neutral Higgs bosons in MSSM. Fig. **??** is the production of pseudo scalar as a function of free parameter M_A for two $tan\ \beta$ values. Associated production of pseudo scalars via gluon fusion is also plotted here in dashed line. Compared to the cross sections in SM Higgs production via $b\bar{b}$ fusion, it is highly increased in MSSM due to $tan\ \beta$ and is a significant rate compared to gluon fusion.

Pseudo scalars produced from $b\bar{b}$ decays into $b\bar{b}$ was considered and $\sigma(pp \to A^0A^0 \to b\bar{b}b\bar{b} + X$ vs Mass of pseudo scalar was plotted(see Fig.1.3). As can be seen from the figure cross sections from $b\bar{b}$ is nearly close to the cross sections evaluated from gluon fusion even having smaller PDF's for b quark compared to gluon PDFs. Overall the pseudo scalar production from b quark fusion greatly enhanced the cross sections with

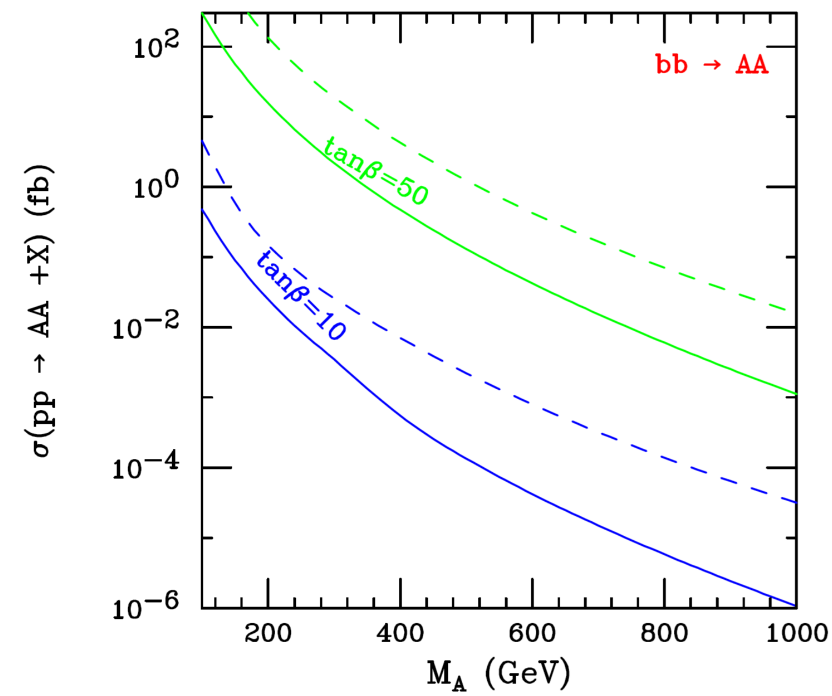

Figure 1.2: Leading Order cross sections for the pair production of pseudo scalar from bottom quark fusion versus mass M_A(solid line). Also included the cross sections from gluon fusion for same $tan\beta$ values(dashed line). Green represents $tan\ \beta = 50$ and blue represents $tan\ \beta = 10$ for both b quark and gluon fusion.

high $tan\ \beta$ values for $b\bar{b}$ channel leaving a possibility of meassuring trilinear Higgs coupling for MSSM.

The leading order cross section for the production of higgs via b quark fusion was calculated and fig gives the cross section for two different values of $tan\beta$. Cross section for the production of two higgs via b quark fusion was first calculated and **??** shows the signal cross section for $bb \rightarrow\ A_0A_0$ for two selected $tan\ \beta$ values.

decay into 4b distributions cross sections LightHiggs Higgs production bb-¿hh

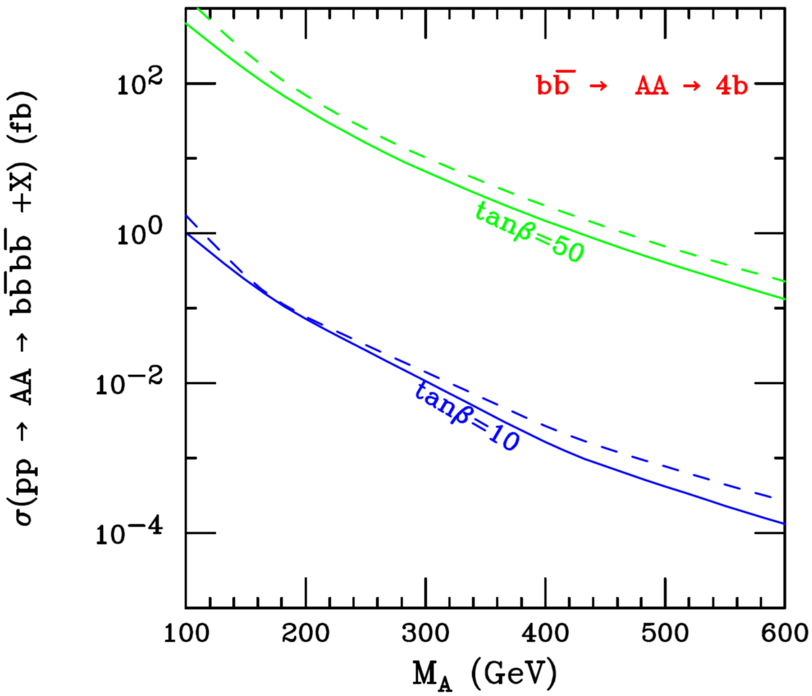

Figure 1.3: LO cross sections evaluated for $b\bar{b}b\bar{b}$ final state via pseudo scalars from b quark fusion(solid line). 4b final state calculated in chapter 2, for gluon fusion through pseudo scalars are also presented here (dashed line). Green represents $tan\ \beta = 50$ and blue represents $tan\ \beta = 10$ for both b quark and gluon fusion.

decay into 4b distributions cross sections Heavy Higgs

As shown in **??** the previous chapter, for $tan\ \beta\ > 10$, M_A and M_H almost degenerate and the total cross section is .....

1.4 Conclusion

Higgs production via b quark fusion have been studied by several groups [2] [3] [4] [5] [6] [1] [7].

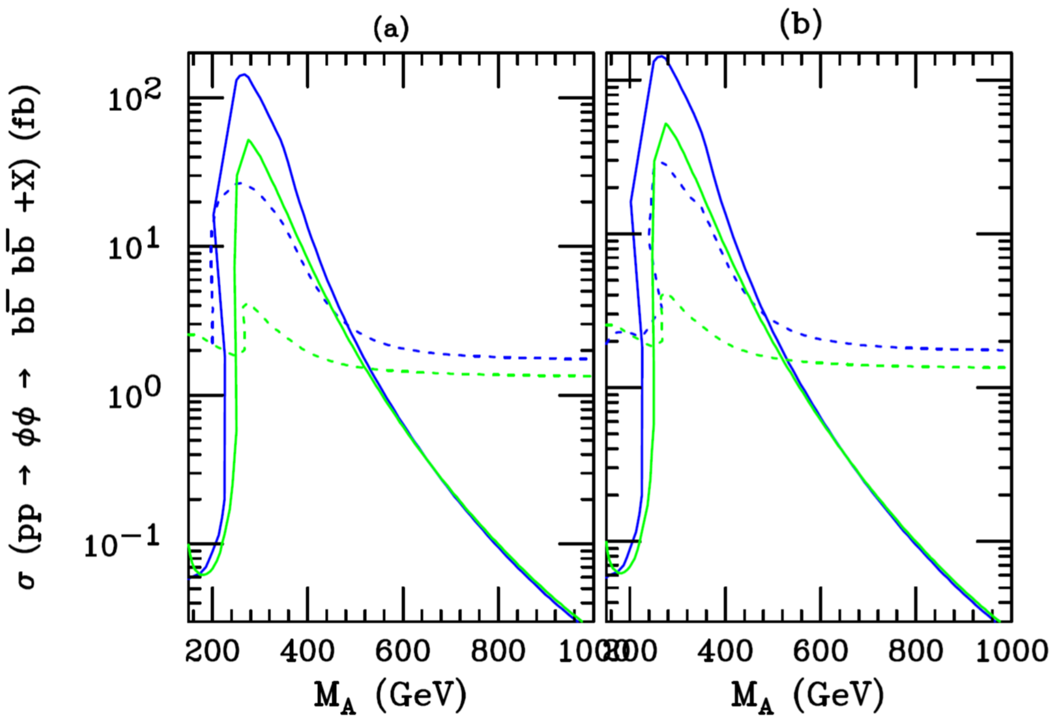

Figure 1.4: bbbbbbbbbbbb

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