Chapter 1

Analysis of Backgrounds for $(b\bar{b})(b\bar{b})$ final state

The dominant background processes associated with two Higgs production at the LHC, discussed in previous two chapters, are analyzed here. We discuss the relevant background processes coupled with $pp \to b\bar{b}b\bar{b}$ via gluon fusion for the SM and through b quark fusion for the MSSM. The Standard Model Higgs boson pair production with a $b\bar{b}b\bar{b}$ final state has been studied in [1] recently, and they discuss how to reduce large backgrounds through BDRS[2] approach.

However, with the highest branching ratio of 60% for $b\bar{b}$ channel in the SM, the highest cross sections at LHC result from gluon fusion with 4b final state. This process has not been of interest due to the large QCD backgrounds coupled to this process. However, we discuss the dominant tree level background events for the 4b final state resulting from parton collisions at the LHC. We try to reduce backgrounds by introducing a special mass cut and the reordering method explained in Chapter 2. This way we can increase the $S/\sqrt{B}$ ratio significantly and study the possibility of using this signal to measure trilinear Higgs couplings at the LHC. The relevant basic tree level processes considered here are,

1. $pp \to b\bar{b}b\bar{b}/h$
2. $pp \to b\bar{b}c\bar{c}/h$
3. $pp \to b\bar{b}jj/h$ where $j = u, d, s, g$

1.1 Calculation Tools

Cross sections were calculated for an LHC center of mass energy $\sqrt{s} = 14\ TeV$. Both renormalization and factorization scales were set to $\sqrt{\hat{s}}$, and MSTW2008 pdf were used here. The transition matrix elements were generated using a standalone version of MadGraph[3], and the cross sections were evaluated by integrating over the phase space using a FORTRAN program. In this study the tagging efficiency for b jet is set as $\epsilon_b = 60\%$ for $\mathcal{L} = 30 fb^{-1}$ and $\epsilon_b = 50\%$ for $\mathcal{L} = 300 fb^{-1}$ and $3000 fb^{-1}$. Mistagging probabilities of fake jets as b jet are set to $\epsilon_c = 10\%$ and $\epsilon_j = 1\%$. As discussed in Chapter 2, several cuts were applied for the background namely, $P_T(b_i) > 30\ GeV$, $\eta(b_i) < 2.5$ and $\Delta_{bb} \geq 0.4$ where $i = 1, 2, 3, 4$ denotes final state b jets. These basic cuts could not improve the signal to background ratio significantly. With the introduction of special reordering and mass cuts(explained in chapter 2) for $M_{b_1 b_2}$ and $M_{b_3 b_4}$, we could remove 90% of the background while saving 80% of the signal. Fig. 1.1 is the mass distribution for the major background process which is $pp \to b\bar{b}b\bar{b}/h$ in the 4b final state. Invariant masses for each pair are evaluated after reordering so that M_{12} is the pair which has maximum $|xmbb - M_A|$ where $xmbb$ is the invariant mass between relevant b jets. K factors for Higgs pair production at each energy were calculated using the formula given in [4]. A K-factor of 1.5 was applied to the QCD$(b\bar{b})(b\bar{b})$ background.

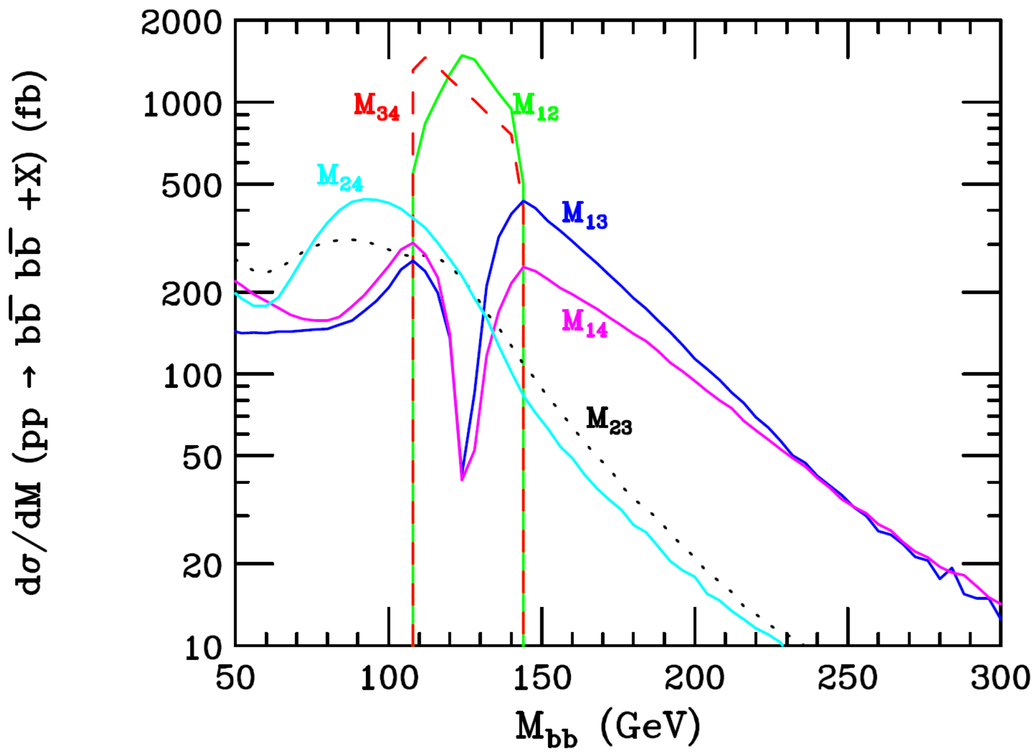

Figure 1.1: The mass distribution of final state b jets for the dominant background process $pp \to b\bar{b}b\bar{b}/h + X$, with the special mass reordering explained in the text.

Energy (TeV)	$pp \to hh \to 4b$	$pp \to b\bar{b}b\bar{b}/h$	$pp \to b\bar{b}c\bar{c}/h$	$pp \to b\bar{b}jj/h$	Total BG
13	4.57	6.80×10^3	1.44×10^4	1.16×10^6	1.56×10^3
14	5.40	7.90×10^3	1.66×10^4	1.35×10^6	1.81×10^3
33	2.90×10^1	3.61×10^4	7.61×10^4	5.92×10^6	8.27×10^3
60	7.77×10^1	9.23×10^4	1.95×10^5	1.52×10^7	2.10×10^4
100	1.68×10^2	1.90×10^5	4.13×10^5	3.18×10^7	4.45×10^4

Table 1.1: Cross sections (in fb) for SM Higgs production via gluon fusion for $\mathcal{L} = 30fb^{-1}$. In the 6th column, Total BG is the background value after considering relevant tagging efficiencies and K-factors.

1.2 Standard Model through Gluon Fusion

Table 1.1 shows the cross sections obtained in this study for SM Higgs production (with Higgs decaying into 4 b jets) via gluon fusion along with the dominant tree level backgrounds for several energies. The 3rd 4th and 5th columns of this table give the values of three major backgrounds listed earlier. Tagging efficiencies or K-factors are not counted towards these values. For the third background(5th column) listed in this table, only $pp \to b\bar{b}gg$ and $pp \to b\bar{b}ug$ were considered since the contribution from all other combinations of jets is negligible. The 6th column gives the total contribution of all dominant background processes along with tagging efficiencies and QCD corrections.

Table 1.2 presents the calculated significance values for different luminosities vs energies. The significance of the signal vs background can be defined as,

$$N_{SS} = \frac{N_s}{\sqrt{N_b}}$$

where $N_s = \mathcal{L} \times \sigma_s$ is the number of signal events and $N_b = \mathcal{L} \times \sigma_b$ is the number of events for background.

Luminosity / $\sqrt{s}$	$\mathcal{L} = 30 fb^{-1}$	$\mathcal{L} = 300 fb^{-1}$	$\mathcal{L} = 3000\ fb^{-1}$
$13\,TeV$	0.634	2.01	6.34
$14\,TeV$	0.695	2.19	6.94
$33\,TeV$	1.74	5.51	17.5
$60\,TeV$	2.92	9.26	29.3
$100\,TeV$	4.36	13.8	43.7

Table 1.2: Calculated N_{ss} values for different integrated luminosities and energies for the SM Higgs production via gluon fusion.

As can be seen from the Table 1.2, we could improve $S/\sqrt{B}$ significantly for the $4b$ final state with the introduction of new mass cut. For $\sqrt{s} = 14\ TeV$, $N_{ss} = 2.19(6.94)$ with 14(137) signal events for the integrated luminosities of 300(3000) fb^{-1} which shows that there is a possibility of measuring trilinear Higgs couplings at the LHC in the future.

$\sqrt{s}$	N_s	N_s/N_b	N_{ss}
14 TeV	137	0.003	6.94

Table 1.3: Calculated $N_s, N_s/N_b, N_{ss}$ values for integrated luminosity of 3000 fb^{-1} and for $\sqrt{s} = 14$ TeV for the SM Higgs production via gluon fusion.

1.3 MSSM through b Quark Fusion

Here we discuss the backgrounds associated with MSSM Higgs production followed by Higgs decay into two pairs of b quarks. The processes are the same as we discussed for the SM gluon fusion though we have two free parameters here M_A and $tan\beta$. As could be seen from chapter 3, b quark fusion is more important for high values of $tan\ \beta$ and therefore we chose $tan\ \beta$ to be 30, 50, and cross sections were calculated for several values of M_A. For the signal $bb \to \phi\phi \to b\bar{b}b\bar{b} + X$ was considered, and for the chosen value of $tan\beta$, the contribution from the pseudo scalar and heavy Higgs were counted. For the evaluation of background processes, both renormalization and factorization scales were set to $\sqrt{\hat{s}}$. Table 1.4 presents the backgrounds and $S/\sqrt{B}$, calculated for low luminosity ($\mathcal{L} = 30\ fb^{-1}$) with transverse momentum $P_T > 20\ GeV$ for all b jets and tagging efficiency of 60%. Fig. 1.5 presents the same information for high luminosity $\mathcal{L} = 300$ (3000) fb^{-1} and $P_T > 30\ GeV$ and $\epsilon_b = 50\%$. All other cuts are the same as explained before and $\sqrt{s} = 14$ TeV.

M_A	$200\ GeV$	$400\ GeV$	$800\ GeV$
$\sigma_s(tan\,\beta = 30)$	1.1	3.8×10^{-2}	4.9×10^{-4}
$\sigma_s(tan\,\beta = 50)$	8.54	3.04×10^{-1}	3.86×10^{-3}
$\sigma_b(pp \to b\bar{b}b\bar{b}/h)$	5.93×10^{3}	3.26×10^{2}	6.38
$\sigma_b(pp \to b\bar{b}c\bar{c}/h)$	3.86×10^{5}	4.09×10^{4}	2.33×10^{3}
$\sigma_b(pp \to b\bar{b}jj/h)$	3.29×10^{7}	3.48×10^{6}	2.09×10^{5}
$\sigma_b(total)$	7.6×10^{3}	7.47×10^{2}	4.1×10^{1}
$N_s(tan\,\beta = 30)$	36	1	0
$N_s(tan\,\beta = 50)$	256	9	0
$N_s/N_b\ (tan\,\beta = 30)$	1.58×10^{-4}	5.08×10^{-5}	1.21×10^{-5}
$N_s/N_b\ (tan\,\beta = 50)$	1.12×10^{-3}	4.06×10^{-5}	9.45×10^{-5}
$N_{ss}(tan\,\beta = 30)$	0.08	0.008	0.0004
$N_{ss}(tan\,\beta = 50)$	0.54	0.06	0.003

Table 1.4: MSSM Higgs production via b quark fusion $b\bar{b} \to \phi^0\phi^0 \to b\bar{b}b\bar{b} + X$at LHC at $\sqrt{s} = 14\,TeV$ for $\mathcal{L} = 30fb^{-1}$.

M_A	200 GeV	400 GeV	800 GeV
$\sigma_s(tan\ \beta = 30)$	1.1	3.8×10^{-2}	4.9×10^{-4}
$\sigma_s(tan\ \beta = 50)$	8.54	3.04×10^{-1}	3.86×10^{-3}
$\sigma_b(pp \rightarrow b\bar{b}b\bar{b}/h)$	3.01×10^3	2.6×10^2	6.35
$\sigma_b(pp \rightarrow b\bar{b}c\bar{c}/h))$	2.05×10^5	3.23×10^4	2.27×10^3
$\sigma_b(pp \rightarrow b\bar{b}j\bar{j}/h)$	1.71×10^7	2.74×10^6	1.99×10^5
$\sigma_b(total)$	2.65×10^3	3.99×10^2	2.72×10^1
$N_s(tan\ \beta = 30)$	300	11	0.2
$N_s(tan\ \beta = 50)$	2562	9	1
$N_s/N_b\ (tan\ \beta = 30)$	4×10^{-4}	9.5×10^-5	1.8×10^{-6}
$N_s/N_b\ (tan\ \beta = 50)$	3.0×10^{-3}	7.6×10^{-4}	1.4×10^{-5}
$N_{ss}(tan\ \beta = 30)$	0.4(1.17)	0.03(0.10)	$1.6 \times 10^{-3}(5.2 \times 10^{-3})$
$N_{ss}(tan\ \beta = 50)$	2.87(9.07)	0.263(0.83)	$1.3 \times 10^{-2}(4.0 \times 10^{-2})$

Table 1.5: MSSM Higgs production via b quark fusion $b\bar{b} \rightarrow \phi^0\phi^0 \rightarrow b\bar{b}b\bar{b} + X$ at $\sqrt{s} = 14\,TeV$ for $\mathcal{L} = 300(3000)fb^{-1}$. All cross section values are in fb.

References

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