Chapter 1

Analysis of Backgrounds for $b\bar{b}\tau^+\tau^-$ final state

The dominant background processes coupled with $pp \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ via gluon fusion for the SM and through b quark fusion and gluon fusion for the MSSM are studied, and results are presented in this chapter. The neutral Higgs boson decays to $\tau^+\tau^-$ with a branching ratio of about 10% which is much smaller than that of $\phi \to b\bar{b}$ which is 60%. However, this process is considered to be more promising than the $4b$ final state because the backgrounds can be swept out by adjusting different cuts for the invariant mass of τ leptons which also will be discussed in this chapter. In this study we consider the largest decay mode of $\tau^+\tau^-$which is where one decays to leptons and other to a tau jet with $Br(\tau \to e/\mu) = 35.2\%$ and $Br(\tau \to \pi/\rho/a_1) = 54.8\%$. The dominant tree level processes we consider here are listed below.

1. $pp \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + X$
2. $pp \to c\bar{c}\tau^+\tau^- \to q\bar{q}lj_\tau + X$
3. $pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + X$
4. $pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}l^\pm\tau^\pm \to b\bar{b}lj_\tau + X$
5. $pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}ljj + X$
6. $pp \to tW^\pm \to bW^\pm\bar{b}W^\pm \to bljj + X$

$\mathcal{L}(fb^{-1})$	30	300
$P_T(GeV)$	$P_T(b, l, j_\tau) > 15, 20, 40$	$P_T(b, l, j_\tau) > 30, 20, 40$
η	$\lvert\eta(b)\rvert$, $\lvert\eta(l)\rvert$, $\lvert\eta(j_\tau)\rvert < 2.5$	$\lvert\eta(b)\rvert$, $\lvert\eta(l)\rvert$, $\lvert\eta(j_\tau)\rvert < 2.5$
ΔR	$\Delta R(lj_\tau) > 0.4$	$\Delta R(lj_\tau) > 0.4$
$\not{E}_T(GeV)$	$\not{E}_T > 40$	$\not{E}_T > 50$

Table 1.1: Basic cuts used for the production of the Higgs via $pp \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$.

1.1 Calculation Tools

Cross sections were calculated for an LHC center of mass energy $\sqrt{s} = 14\ TeV$ and for low (30 fb^{-1}) and high (300 fb^{-1}) luminosities. Other than the tools explained, we have used slightly different cuts here for the $4b$ backgrounds than in previous chapters. They are listed in Table 1.1. In the processes including $t\bar{t}$, the events with extra b jets are vetoed if both b jets pass the selection cut which is $|M_{bb} - M_h| \leq 0.15 * M_h$ where M_{bb} is the invariant mass of $b\bar{b}$. Processes 5 and 6 have two light jets in the final state. We required that only one pass the cuts and then be mistagged as j_τ.

Though we apply the basic cuts mentioned in the table, backgrounds cannot be reduced significantly with only these basic cuts. Since there are no tau leptons in the final state of these processes, we have to reconstruct them from the kinematics of observable particles. As mentioned in Chapter 2, we use the Collinear Approximation and follow the procedure explained in [1] to reconstruct the momenta of tau leptons(P_{τ_1} ,P_{τ_2}). Based on the reconstructed momenta, the mass of the Higgs boson is the invariant mass of the $\tau^+\tau^-$ pairs, $m_{\tau\tau} = (P_{\tau_1} + P_{\tau_2})^2$. By properly setting cuts on $m_{\tau\tau}$, we can remove most background events and enhance the discovery potential. Here we set $|m_{\tau\tau} - M_h| \leq 0.15 * M_h$ which reduced the cross section of the SM signal from $0.047\ fb$ to $0.065\ fb$ while all the background values can be reduced significantly. Table 1.2 presents the cross section values before and after the mass reconstruction from tau leptons. These values are calculated for SM Higgs $Mh = 125.5\ GeV$.

Process	With basic cuts	Cut on $m\tau\tau$
$pp \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + X$	2.03	0.216
$pp \to q\bar{q}\tau^+\tau^- \to q\bar{q}lj_\tau + X$	3.21	0.370
$pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj + X$	17.2	0.469
$pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}l^\pm\tau^\pm \to b\bar{b}lj + X$	55.0	0.806
$pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}ljj + X$	977	9.66
$pp \to tW^\pm \to bW^\pm\bar{b}W^\pm \to bljj + X$	51.9	0.263

Table 1.2: Cross sections for the background processes listed after and before the cut apply on reconstructed mass from tau leptons. All the values are in fb and tagging efficiencies and K factors have not been included for these values.

The efficiency of tau jet triggering is 26%, and we assume that the charged leptons can be 100% correctly identified. The tagging probabilities of identifying fake jets as J_τ is $\epsilon_{u,d,c,s} = 1/400$ and $\epsilon_b = 1/700$. For the higher order corrections, results were multiplied with relevant K factors, and a K factor of 1.3 was used for first two processes[2]; $K = 2$ for $t\bar{t}$ [3] [4], and $K = 1.5$ were included for the processes with tW [5].

1.2 Numerical Results

The dominant background processes explained above compared to the SM signal of $pp \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ for different luminosities are presented in Tables 1.3 and 1.4. Same cuts and scales were applied for the signal too.

$\sigma_s(\mathcal{L} = 30(fb^{-1}))$	0.079
$\sigma_b(q\bar{q}\tau^+\tau^-)$	0.002
$\sigma_b(t\bar{t})$	0.26
$\sigma_b(tW)$	0.00035
N_s	2
N_s/N_b	0.3
N_{ss}	0.85

Table 1.3: Cross sections evaluated for the signal $gg \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ in the SM along with dominant backgrounds for $\mathcal{L} = 30\ fb^{-1}$ and $S/\sqrt{B}$ is presented in the last row.

Backgrounds were calculated for the MSSM neutral Higgs production via b quark fusion and were analyzed towards the signal discussed in Chapter 3. Again we consider two high $tan\ \beta$ values to see how we can increase the significance towards future measurements of trilinear Higgs coupling. Tables 1.5 and 1.7 give the cross section of

$\sigma_s(\mathcal{L} = 300fb^{-1})$	0.0596
$\sigma_b(q\bar{q}\tau^+\tau^-)$	0.001
$\sigma_b(t\bar{t})$	0.177
$\sigma_b(tW)$	0.0002
N_s	18
N_s/N_b	0.33
N_{ss}	2.4(7.7)

Table 1.4: Cross sections evaluated for the signal $gg \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ in the SM along with dominant backgrounds for $\mathcal{L} = 300(3000)\ fb^{-1}$ and $S/\sqrt{B}$ is presented in the last row.

MSSM Higgs production via b quark fusion which is $bb \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ along with relevant background processes. N_{ss} was calculated for different luminosities and for different $tan\ \beta$ values. In the Tables 1.5 and 1.7, q refers to quarks including b, and $\sigma_b(pp \to q\bar{q}\tau^+\tau^-/h)$ is the total background from process 1 and 2 listed above. Here we discuss the Higgs signal so that ϕ^0 has the contributions from all three A^0, h^0 and H^0. With the approximations for the SUSY parameters we set in FeynHiggs, the mass of the light Higgs maintains almost a constant value as $tan\ \beta$ increases. So for the most of the parameter space$(M_A, tan\ \beta)$, we considered the contributions from pseudoscalar and heavy Higgs.

Tables 1.6 and 1.8 present the results for the production of MSSM Higgs via gluon fusion and Higgs decaying into $b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + X$ for low and high luminosities

M_A	200 GeV	400 GeV	800 GeV
$\sigma_s(tan\,\beta = 30)$	2.44×10^{-2}	1.9×10^{-3}	3.4×10^{-5}
$\sigma_s(tan\,\beta = 50)$	1.89×10^{-1}	1.47×10^{-2}	2.63×10^{-4}
$\sigma_b(pp \to q\bar{q}\tau^+\tau^-/h)$	1.35×10^{-1}	5.87×10^{-2}	1.03×10^{-2}
$\sigma_b(pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}lj_\tau))$	3.29	1.77	4.1×10^{-1}
$\sigma_b(pp \to tW \to bW^\pm\bar{b}W^\pm \to bljj)$	$6.79 \times 10{-}4$	$1.46 \times 10{-}4$	$1.25 \times 10{-}5$
$\sigma_b(total)$	3.42	1.82	4.21×10^{-1}
$N_s(tan\,\beta = 30)$	1	0	0
$N_s(tan\,\beta = 50)$	6	0	0
$N_s/N_b(tan\,\beta = 30)$	7.1×10^{-3}	1.04×10^{-3}	8.08×10^{-5}
$N_s/N_b(tan\,\beta = 50)$	5.5×10^{-2}	8.08×10^{-3}	6.2×10^{-4}
$N_{ss}(tan\,\beta = 30)$	0.07	0.0077	0.00017
$N_{ss}(tan\,\beta = 50)$	0.56	0.06	0.002

Table 1.5: The MSSM Higgs production via b quark fusion $b\bar{b} \to \phi^0\phi^0 \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + X$ at $\sqrt{s} = 14\,TeV$ for $\mathcal{L} = 30fb^{-1}$. All cross section values are in fb.

M_A	σ_s	σ_b	N_s	N_s/N_b	N_{ss}
$200\ GeV$	3.85	3.42	116	1.13	11.42
$400\ GeV$	3.74×10^{-1}	1.82	11	0.2	1.52
$800\ GeV$	9.61×10^{-3}	0.421	0	0.0023	0.08

Table 1.6: The MSSM Higgs production via gluon fusion $gg \to \phi^0\phi^0 \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ at $\sqrt{s} = 14\,TeV$ for $\mathcal{L} = 30fb^{-1}$. These results are for $tan\ \beta = 50$, and all values are in fb.

respectively. These values are calculated for $tan\ \beta = 50$, and again the contributions from heavy Higgs are also considered.

M_A	200 GeV	400 GeV	800 GeV
$\sigma_s(tan\,\beta = 30)$	1.99×10^{-2}	1.81×10^{-3}	3.34×10^{-5}
$\sigma_s(tan\,\beta = 50)$	1.61×10^{-1}	1.51×10^{-2}	2.85×10^{-4}
$\sigma_b(pp \to q\bar{q}\tau^+\tau^-/h)$	7.7×10^{-2}	4.38×10^{-2}	9.14×10^{-3}
$\sigma_b(pp \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}lj_\tau))$	1.57	7.6×10^{-1}	1.91×-1
$\sigma_b(pp \to tW \to bW^\pm\bar{b}W^\pm \to bljj)$	4.4×10^{-4}	1.13×10^{-2}	1.08×10^{-5}
$\sigma_b(total)$	1.65	8.18×10^{-1}	2.0×10^{-2}
$N_s(tan\,\beta = 30)$	6	1	0
$N_s(tan\,\beta = 50)$	48	5	0
$N_s/N_b(tan\,\beta = 30)$	1.21×10^{-2}	2.21×10^{-3}	1.67×10^{-4}
$N_s/N_b(tan\,\beta = 50)$	9.7×10^{-2}	1.85×10^{-2}	1.42×10^{-3}
$N_{ss}(tan\,\beta = 30)$	0.268(0.848)	0.0347(0.11)	0.0013(0.004)
$N_{ss}(tan\,\beta = 50)$	2.16(6.84)	0.289(0.915)	0.011(0.035)

Table 1.7: MSSM Higgs production via b quark fusion $b\bar{b} \to \phi^0\phi^0 \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ at $\sqrt{s} = 14\,TeV$ for $\mathcal{L} = 300(3000)fb^{-1}$. All cross section values are in fb.

M_A	σ_s	σ_b	N_s	N_s/N_b	N_{ss}
200 GeV	2.91	1.65	875	1.77	39.3
400 GeV	3.44×10^{-1}	0.818	103	0.422	6.06
800 GeV	9.4×10^{-3}	0.2	3	0.047	0.364

Table 1.8: MSSM Higgs production via gluon fusion $gg \to \phi^0\phi^0 \to b\bar{b}\tau^+\tau^- \to b\bar{b}lj_\tau + \not{E}_T$ at $\sqrt{s} = 14\,TeV$ for $\mathcal{L} = 300(3000)fb^{-1}$. These values are calculated for $tan\ \beta = 50$, and all cross section values are in fb.

References

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