Generator level analysis of Higgs signal in the MSSM for high tanβ

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Abstract

The cross-section for the Higgs production mechanism gg $\rightarrow$ H b$\bar{\text{b}}$ in the MSSM is enhanced for the parameters M_A = 150GeV and tanβ=50. The decay channel H$\rightarrow$ $\mu^+\mu^-$ and the two main backgrounds, Drell-Yan processes and t$\bar{\text{t}}$ production, were studied at the event generator level using Pythia 8. It was shown that the signal to background ratio can be enhanced by applying cuts based on b-tagging and the transverse energies of the jets.

Contents

1 Introduction

The CMS (Compact Muon Solenoid) detector is a multipurpose detector at the LHC (Large Hadron Collider), designed to search for evidence of Higgs particles and physics beyond the standard model, such as supersymmetry. As the LHC has been designed to provide extremely high luminosity, 10^9 collisions will occur each second, of which 100 "interesting" events each second will pass the trigger system. The probability for producing a Higgs particle is extremely low compared to most other Standard Model particles, so the challenge is identify a Higgs signal amongst this vast number of events. Monte Carlo simulations are run to identify which channels should be used to search for the Higgs, and what particular signatures may be used separate Higgs events from background processes.

This study used Monte Carlo event simulations to investigate the possibility of the CMS detector finding evidence for the neutral Higgs particle H^0, in the Minimal Supersymmetric Standard Model with high tanβ. This report will briefly explain some theory of Higgs particles in the MSSM, then discuss the specific process studied and its main backgrounds. Possible cuts, one based on jet energy measurements, and one based on b-tagging, will be suggested.

2 Higgs Particles in the MSSM

In the Standard Model (SM), the Higgs mechanism is required to explain the non-zero masses of the gauge-bosons Z^0, W^+ and W^-. A complex Higgs doublet must be introduced, and leads to a single Higgs particle, whose mass is unknown but whose coupling to bosons and fermions can be calculated.

The Minimal Supersymmetric Standard Model (MSSM) requires that there are two complex Higgs doublets, which give mass to the fermions and gauge bosons. After symmetry breaking, the theory predicts five Higgs particles: the neutral scalars h^0 and H^0, the neutral psuedoscalar A^0 and two charged particles H^+ and H^-. At tree level, their properties depend on just two parameters: conventionally we use the mass of A^0, and $\tan\beta$, where $\tan\beta$ is the ratio of the vacuum expectation values of the two Higgs doublets. [1][2]

3 The Higgs event

This analysis considered high values of $\tan\beta$: the specific values chosen were $\tan\beta = 50$ and $m_A = 150$GeV. The program FeynHiggs [5] was used to calculate the properties of the Higgs particles, giving $m_h = 130.4$GeV and $m_H = 150.2$GeV.

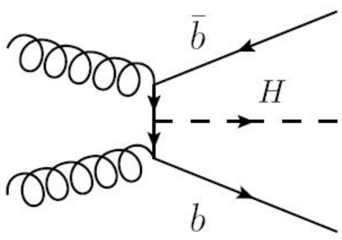

Figure 1: The Higgs production process

The Higgs production process chosen for study was gg $\rightarrow$ H $b\bar{b}$ and $q\bar{q} \rightarrow$ H $b\bar{b}$ (Figure 1). With the above choice of parameters, the coupling of H^0 to b-type quarks is 41.2 times higher than in the SM, leading to a cross-section for this process of $\sigma = 2.8 \times 10^{-7}$mb. The coupling of h^0 to b-type quarks is only 4.9 times higher than the SM value, and there is more background at 130GeV, so in this study only the H^0 signal was considered.

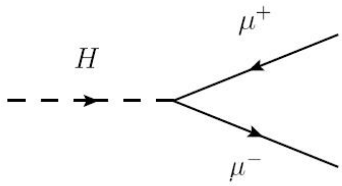

Figure 2: The Higgs decay channel

The Higgs decay channel $H \rightarrow \mu^+\mu^-$ has a branching ratio of 4.1×10^{-4}. The overall cross-section for gg or $q\bar{q} \rightarrow$H$b\bar{b} \rightarrow \mu^+\mu^- b\bar{b}$ is then 1.1×10^{-10}mb. Although the branching ratio to muons is small, this channel was chosen for study because lepton channels have a relatively low background in a p-p collider, and because the muon tracking systems in the CMS detector allow the momenta of the muons to be accurately measured. Provided the muon pair that come from Higgs decay can be identified, the mass of the Higgs may be reconstructed using

$$m_H = \sqrt{(E_{\mu^+} + E_{\mu^-})^2 - (\underline{p}_{\mu^+} + \underline{p}_{\mu^-})^2}$$

The muons that come from the Higgs decay have high transverse momenta and energy, so within each event the two oppositely charged muons with the highest energies were chosen to use to reconstruct m_H. They were also required to have $p_T > 20$GeV and to be inside the muon detector range ($\eta < 2.4$).

4 Modelling

The Monte Carlo event generator Pythia 8 was used to generate the signal and two main background processes: Drell Yan and $t\bar{t}$ events. A centre-of-mass collision energy of 14TeV was used, and the Beyond the Standard Model parameters calculated with FeynHiggs were input. At parton level, initial state radiation, final state radiation, and beam remnant treatments were turned on, but multiple interactions were not simulated due to time and computing power constraints. At hadron level, hadronization and decay processes were turned on.

5 Main Background Processes

The largest background comes from the Drell-Yan process.[3] This is the decay of a Z boson to a pair of oppositely charged leptons, in this case the decay to $\mu^+\mu^-$ (Figure 3). The overall cross-section gor Z $\rightarrow \mu^+\mu^-$ is 7.8×10^{-6}mb, but it is strongly peaked around 91GeV (ie. M_Z). By applying a phase-space cut at the generator level such that the total invariant mass of the muon pair is between 125 and 175GeV, the cross-section can be reduced to 1.16×10^{-8}mb. For comparison, the cross-section for the Higgs signal is 1.1×10^{-10}mb.

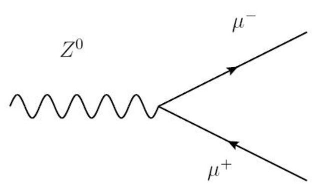

Figure 3: Drell-Yan background events

The other main background process is $t\bar{t}$ production by gluons or quarks (Figure 4). The top quarks nearly always decay to W and b; the b quarks hadronise to form b-jets. The Ws can decay to a muon and a muon neutrino, with a branching ratio of 10%. The cross-section for this process is 5.4×10^{-9}mb. Other decay chains from $t\bar{t}$ also produce muons, for example $W^+ \rightarrow \tau^+\nu_\tau \rightarrow \mu^+\nu_\mu\nu_\tau$, but including these processes appeared to make little difference to the results, once cuts described in Section 3 were applied.

6 Jet transverse energy cuts

The cellJet algorithm in Pythia 8 was used to reconstruct jets. The algorithm divided space into 32×50 cells labelled by their ϕ position and their pseudorapidity, η, with the

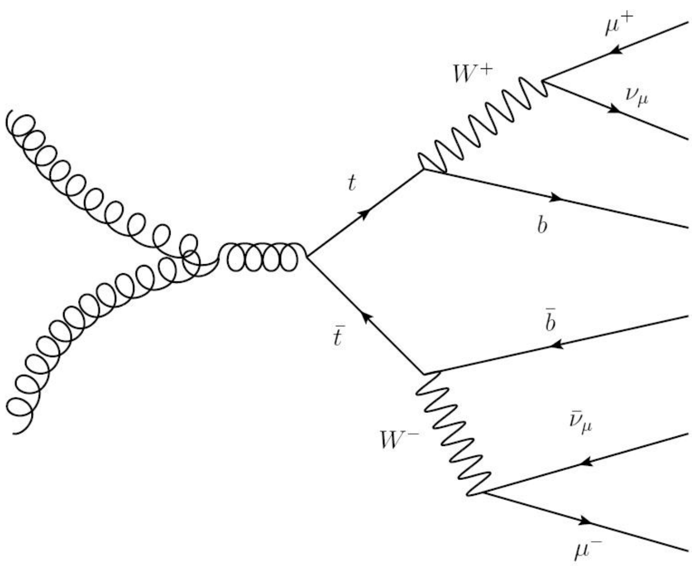

Figure 4: $t\bar{t}$ background events

condition that $\eta < 5$ as this is the maximum pseudorapidity that the detector covers. (Pseudorapidity is a function of the angle from the beam axis, and is given by $\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$, so takes larger values for particles with high momenta along the beam axis.) If the transverse energy through any cell was higher than the seed value of 1.5GeV, the algorithm constructed a cone around the cell with radius $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.5$. Then if the total transverse energy through the cone exceeded the threshold value of 5GeV, the cone was labelled as a jet.

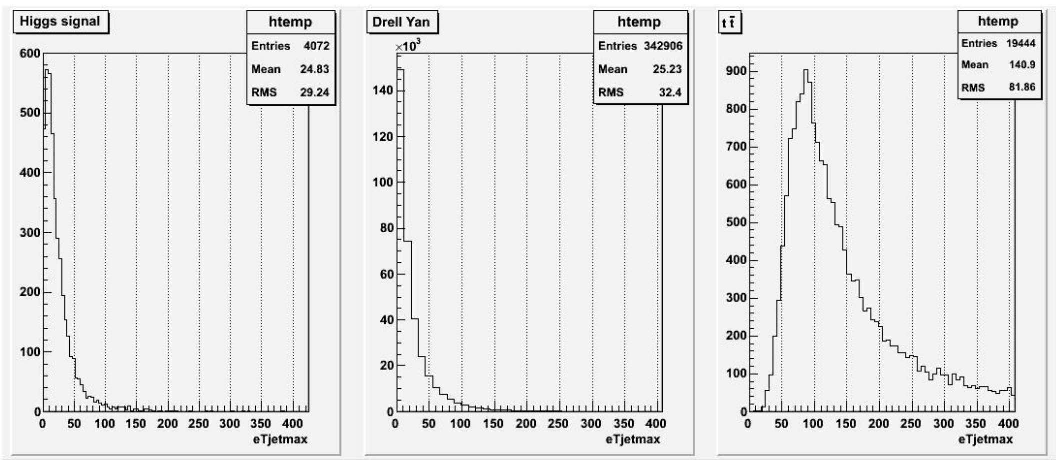

Figure 5: E_T of the highest E_T jet in each event

The jet properties for the backgrounds and signal were compared. The most marked difference was in the transverse energy (E_T) of the jets. Figure 5 shows the E_T of the highest E_T jet in each event. The $t\bar{t}$ jets tend to have much higher E_T and it is clear that most of the $t\bar{t}$ background can be eliminated by applying a cut at 50GeV, whilst losing only a small amount of the signal. The results of this cut can be seen by a comparison of figures 8 and 9.

7 B-tagging

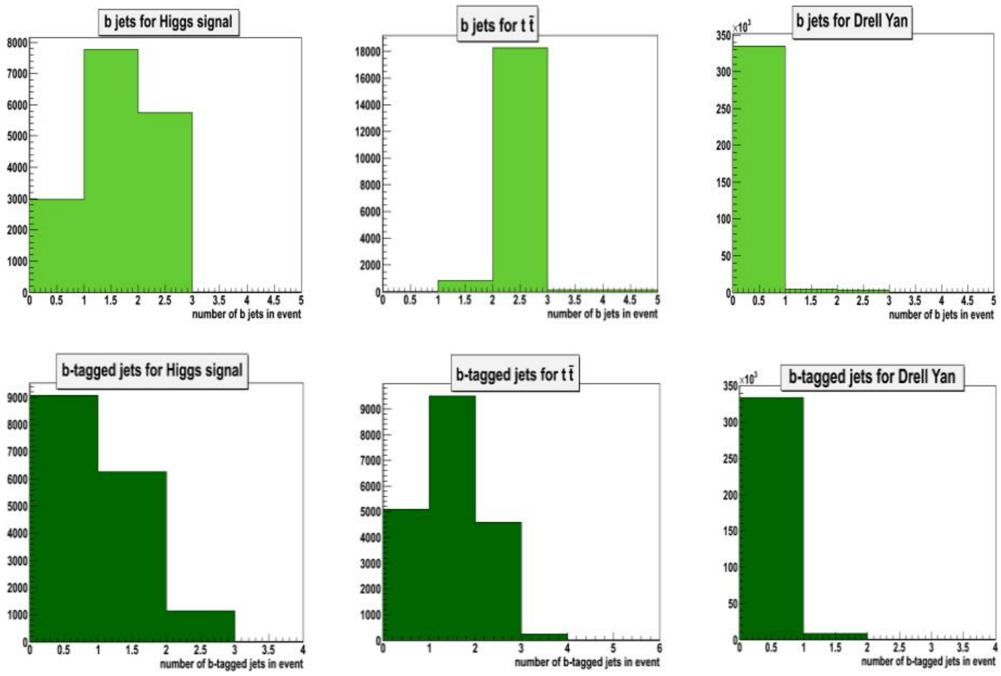

Figure 6: A comparison of proportions of the number of b jets within detector range, and the number labelled as b-tagged jets, for the signal and background. (The y-axis labels are related to the number of events originally generated so should be ignored).

Drell Yan events make up by far the biggest background, as seen in figure 8. The signal always produces b quarks, which hadronise to form b jets, whereas the Drell Yan background very rarely contains b jets. Luckily, b jets have a number of distinguishing properties. Firstly, B hadrons have sufficient life-time (1.57ps) that they travel some distance (around 5mm) before decaying to lighter hadrons, but they do not reach the detector. We can track the origin of the jet precisely enough that it is sometimes possible to show that does not come exactly from the interaction point. Secondly, the B is much more massive than its decay products, so the b jets tend to have high multiplicity, and the decay products have high invariant masses. Thirdly, semi-leptonic decays of B hadrons tend to produce low-energy leptons with high momentum perpendicular to the jet, although the low branching ratio means this is only useful in some cases. B-tagging algorithms use a combination of these effects to tag jets that come from b quarks [4]: currently a typical algorithm has a 50% efficiency for correctly tagging a true b jet, and a <1% probability of b-tagging a non-b jet.

This analysis was only at generator level: a complete simulation of a b-tagging algorithm was not attempted. However, the efficiencies of the b-tagging algorithm were simulated as follows: for jets with $\eta < 2.5$, a random number generator was used to select 50% of the b jets, and 1% of the non-b jets. These were labelled as b-tagged. The number of b jets and b-tagged jets within the detector range are shown in Figure 6 for the Higgs

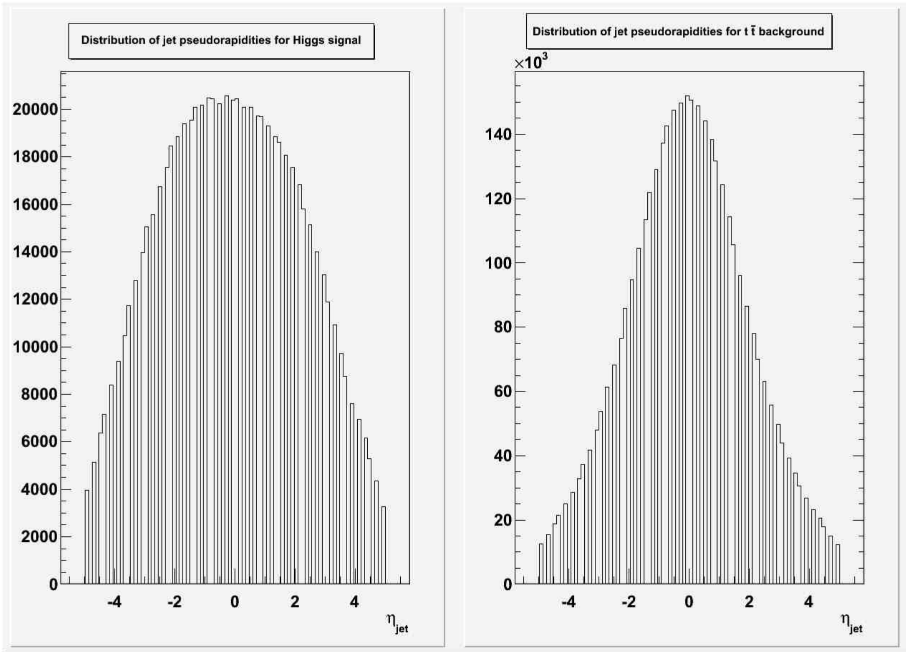

Figure 7: The distribution of jet pseudorapidities for Higgs signal and $t\bar{t}$ backgound

signal and both background processes. It is clear that requiring events to have at least one b-tagged jet will cut the vast majority of the Drell Yan background. The results of such a cut are shown in Figure 10.

No jets with $\eta > 2.5$ were b-tagged, because it is very difficult to identify b-jets in the forward region of the detector. This is a big disadvantage in this case, because the jets from Higgs decay tend to have high pseudorapidities (figure 7). As seen in Table 1, applying a cut requiring at least one b-tagged jet removes over 50% of the signal, but only 30% of the $t\bar{t}$ background.

8 Results

Figures 8, 9, 10 and Table 1 show the results of the cuts suggested in the previous sections.

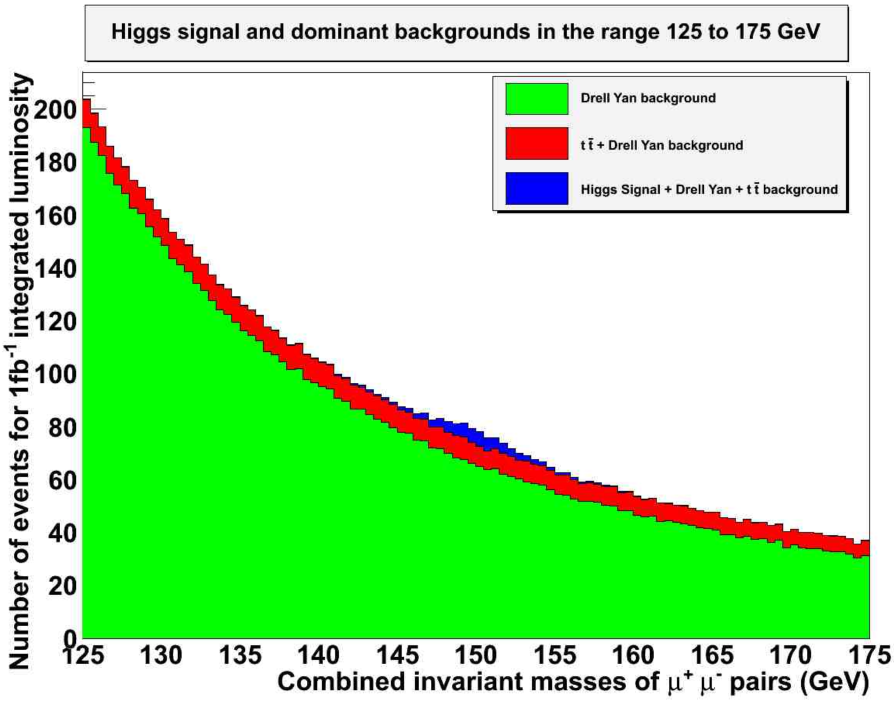

Figure 8: Signal and background with no cuts

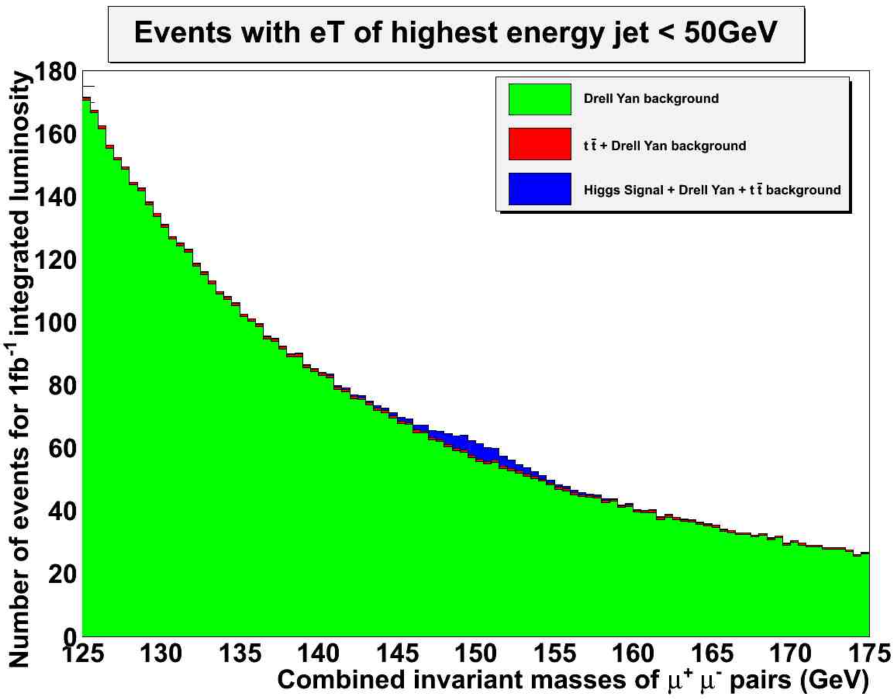

Figure 9: Signal and background with the E_T jet cut

Approximate number of events between 140 and 160 GeV for $1fb^{-1}$ integrated luminosity	Higgs Signal	Drell Yan	$t\bar{t}$
No cuts	74	2712	316
E_T of highest energy jet < 50GeV	65	2346	27
At least one b-tagged jet, and E_T of highest energy jet < 50GeV	28	51	19

Table 1: Table showing the effects of cuts on the number of events for $1fb^{-1}$ integrated luminosity

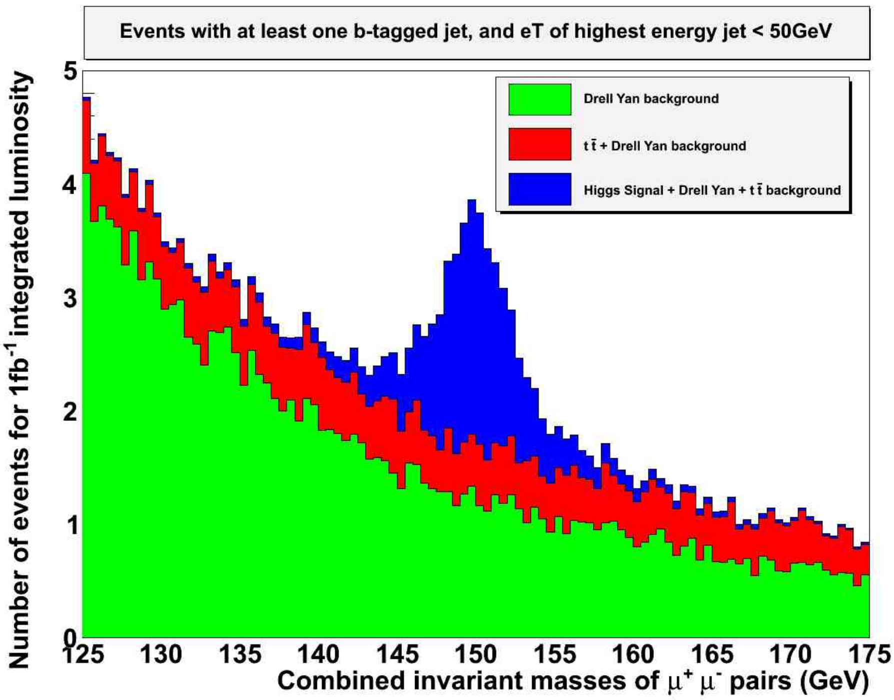

Figure 10: Signal and background with the E_T jet and b-tagging cuts

9 Conclusion

The cuts chosen, E_T of highest energy jet < 50GeV and at least one b-tagged jet, were sucessful in reducing the $t\bar{t}$ background by 94% and the Drell-Yan by 99% while the signal fell by 62%. Improvements in b-tagging algorithms, particularly for jets with high pseudorapidity, are one of the most promising ways to further improve the signal to background ratio. This study only took into account the two largest background processes, and for completeness minor background contributions such as diboson processes should also be considered.

10 Acknowledgments

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