Exclusion Limits for Charged Higgs Bosons

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The existence of charged Higgs bosons is a consequence of models with two or more Higgs doublets. Their existence would provide evidence for physics beyond the Standard Model. The goal of this research is to determine if some models of a heavy charged Higgs can be excluded using ATLAS data from the Large Hadron Collider experiment. This was done by taking the cross sections predicted by Monte Carlo models of different Higgs production channels. These were compared to the ATLAS exclusion limits [1] on heavy resonances decaying to dijets in events with leptons. Monte Carlo events with charged Higgs were created by setting its mass and tan(β) value and performing this exclusion limits comparison. Any mass and tan(β) with cross section above the limits could be excluded from the model. Using these values, a region was determined where all values of mass and tan(β) could be excluded. This region was calculated with data corresponding to a luminosity of 79.8 fb^{-1} [1].

As more data is collected by the LHC, the luminosity increases, and the exclusion limits would change. Predictions of how the limits would change can be made using background Monte Carlo models for higher luminosities. This dependence could be used to approximate the ATLAS exclusion limits for higher luminosity. New exclusion regions were calculated for 200, 1000, and 3000 fb^{-1}. These regions got larger as luminosity increased so, as higher luminosity is reached, the larger parameter space that could be excluded.

I. Introduction

The discovery of the Higgs boson at the LHC in 2012 was remarkable as it's properties agreed with those predicted by the Standard Model. Models such as the two-Higgs-doublet model (2HDM) predict that, in addition the Standard Model Higgs, there is also a charged Higgs boson. The 2HDM states that there are five Higgs scalars in the Higgs sector. The discovered Higgs would be one of two CP-even neutral scalars. In addition, there is a CP-odd neutral scalar and two oppositely charged scalars [2]. The existence of a charged Higgs would prove that the Higgs sector contains more than just the Standard Model Higgs. It also would provide evidence that there is more physics beyond the Standard Model. However, even if charged Higgs are commonly produced, they may be rather difficult to detect [3].

In this paper, several properties of the charged Higgs are discussed. They include its tan(β) value and mass. The tan(β) value is the ratio of vacuum expectation values of the doublets. Models with heavy charged Higgs were examined, which correspond a mass greater than 500 GeV.

II. Methods

Monte Carlo simulations were run of four different decay paths of the charged Higgs. These were the following:

$$H^+W \rightarrow hWW \rightarrow bbWW \quad (1)$$

$$H^+W \rightarrow tbW \quad (2)$$

$$H^+t \rightarrow hWt \rightarrow bbWt \quad (3)$$

$$H^+t \rightarrow tbt \quad (4)$$

For each path, mass of the charged Higgs' mass was varied between 500 and 5000 GeV with increments of 500 GeV. The branching ratio for $H^+ \rightarrow tb$ and $H^+ \rightarrow hW$ was set to 100%. The tan(β) value was varied between 1 and 7 with increments of 1. The cross section for each combination of mass and tan(β) was calculated and stored in a text file. Monte Carlo event samples were created using the Madgraph5 Monte Carlo. Parton showering and hadronization were performed by the Pythia8 generator. The event samples are publicly available from the HepSim event repository [4]. Particle event record from the Monte Carlo events stored in HepSim were processed with the FastJet program that reconstructs antiKT jets with a size 0.4. The events should contain at least one lepton (electron or muon) with transverse momentum above 60 GeV. The lepton is expected to be produced from associated W or t, while jets that are used for calculation of dijet invariant masses are expected to be produced by charged Higgs in hadronic decays modes (H+ -> tb and HW) in the boosted regime.

Histograms of the charged Higgs mass after jet reconstruction were also produced for each mass tested. Despite the Higgs mass being a delta function, the reconstruction of the jets causes it to spread out. These histograms were fitted to a Gaussian function and the standard deviation, or width, was stored in another text file for each mass. This was necessary since the width to depend on the mass. As shown in Table 1, the width of the dijet mass decreased as the mass increased for every decay path. The dijet mass widths were used to determine which exclusion limits to use. A program would take the width for each mass and determine which of the ATLAS exclusion limits [1] to use. This creates even more accurate exclusion limits rather than just picking a single width to use for the entire boundary.

Cross section versus mass plots were made for each decay channel showing each tan(β) value and the exclusion limits. This is used to visualize what region could be excluded. To get a better approximation of where the cross section intersects the exclusion limits, the cross sections for each mass were fit to a function of tan(β). This function was of the form:

$$y = A * e^{B * x^{C}} \qquad (5)$$

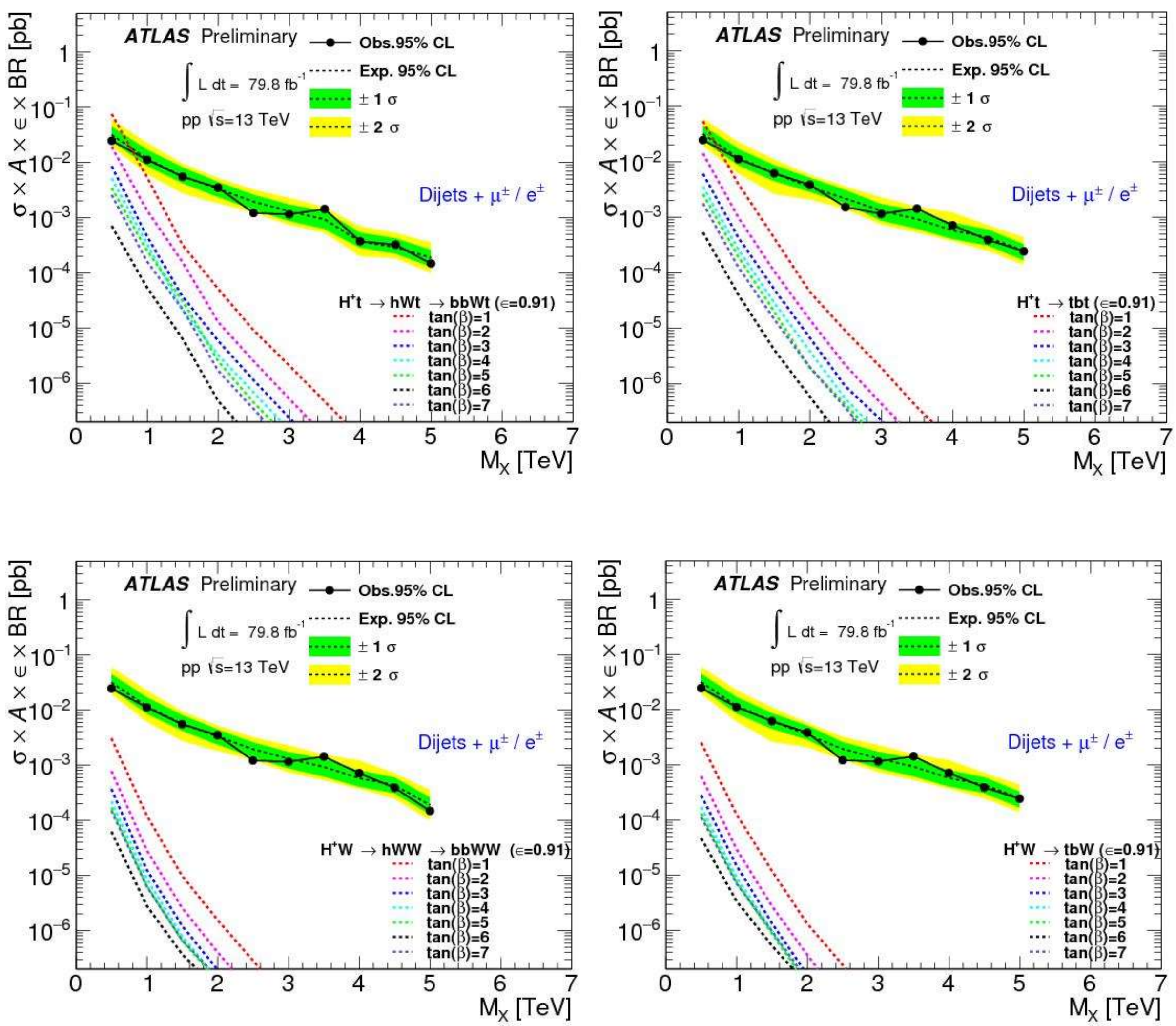
where A, B, and C are constants determined by fitting the points for each mass. In this case *y* would represent the cross section and *x* would be the value of tan(β). This function was used to determine more accurately what values of tan(β) could be excluded. The intersections of the calculated functions and the exclusion limits were computed and plotted to give a parameter space of exclusion limits.

These limits were specific to a luminosity of 79.8 fb^{-1}. To get an approximation for limits for higher luminosity, exclusion limits for a background Monte Carlo with luminosity up to 3000 fb^{-1} were used. These limits were fit to a function of luminosity of the same form as Equation 5 with *y* in this case being exclusion limits and *x* being luminosity. These functions were then used to extrapolate the exclusion limits for charged Higgs to higher luminosity. It was assumed that the Higgs limits would follow the same type of function that the background limits followed. This allowed the limit to be extended to 200, 1000, and 3000 fb^{-1}. Once the new exclusion limits were calculated, new parameter spaces were calculated using the same process as before with the new limits.

III. Results

Gaussian Width of Dijet Masses after Jet Reconstruction				
Mass [TeV]	$H^+W \rightarrow hWW \rightarrow bbWW$	$H^+W \rightarrow tbW$	$H^+t \rightarrow hWt \rightarrow bbWt$	$H^+t \rightarrow tbt$
0.5	0.2611	0.2477	0.3246	0.2603
1.0	0.3926	0.2512	0.4150	0.2587
1.5	0.0975	0.2201	0.1129	0.4167
2.0	0.0755	0.1077	0.0790	0.1191
2.5	0.0664	0.0879	0.0717	0.1054
3.0	0.0609	0.0827	0.0658	0.0898
3.5	0.0583	0.0772	0.0611	0.0863
4.0	0.0548	0.0846	0.0570	0.0869
4.5	0.0534	0.0738	0.0531	0.0758
5.0	0.0499	0.0734	0.0548	0.0766

Table 1: This table shows all the widths of the dijet mass after jet reconstruction. As the mass increases, the width decreases. This dependence on mass is why a single width could not be used for every mass and for every decay channel.



Figures 1-4: Each graph shows the cross section versus mass for a different decay channel. The green-yellow band is the ATLAS exclusion limits. Any part of a tan(β) line found above the band can be excluded. Not every decay channel has values that can be excluded. In fact, only the H^+t channels have points that lie above the exclusion limits.

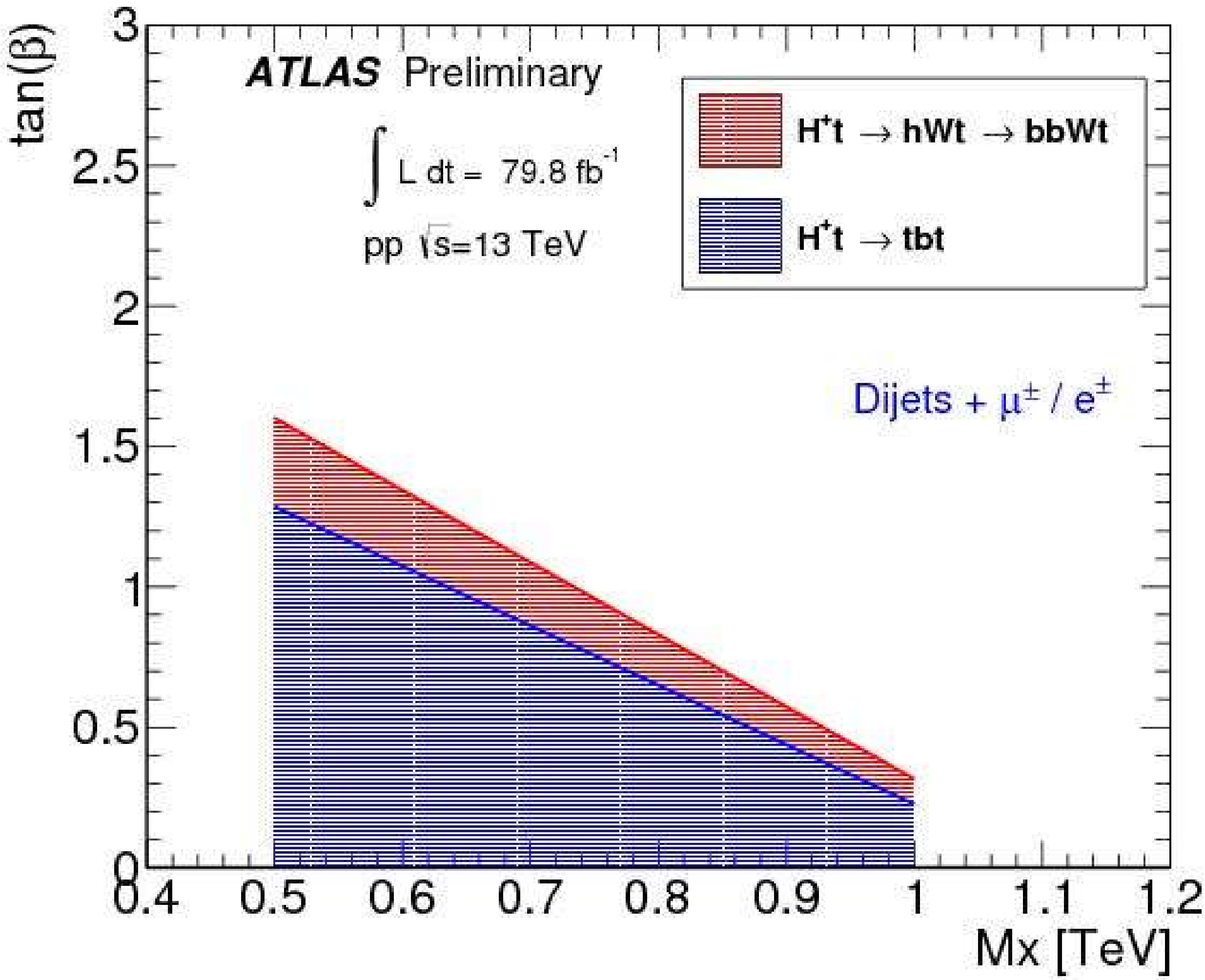


Figure 5: This is the parameter space of mass and tan(β) that can be excluded based on limits at 79.8 fb^{-1} for both channels that had point that could be excluded. Only the $H^{+}t$ processes are shown because they are the only channels that had high enough cross sections to exclude.

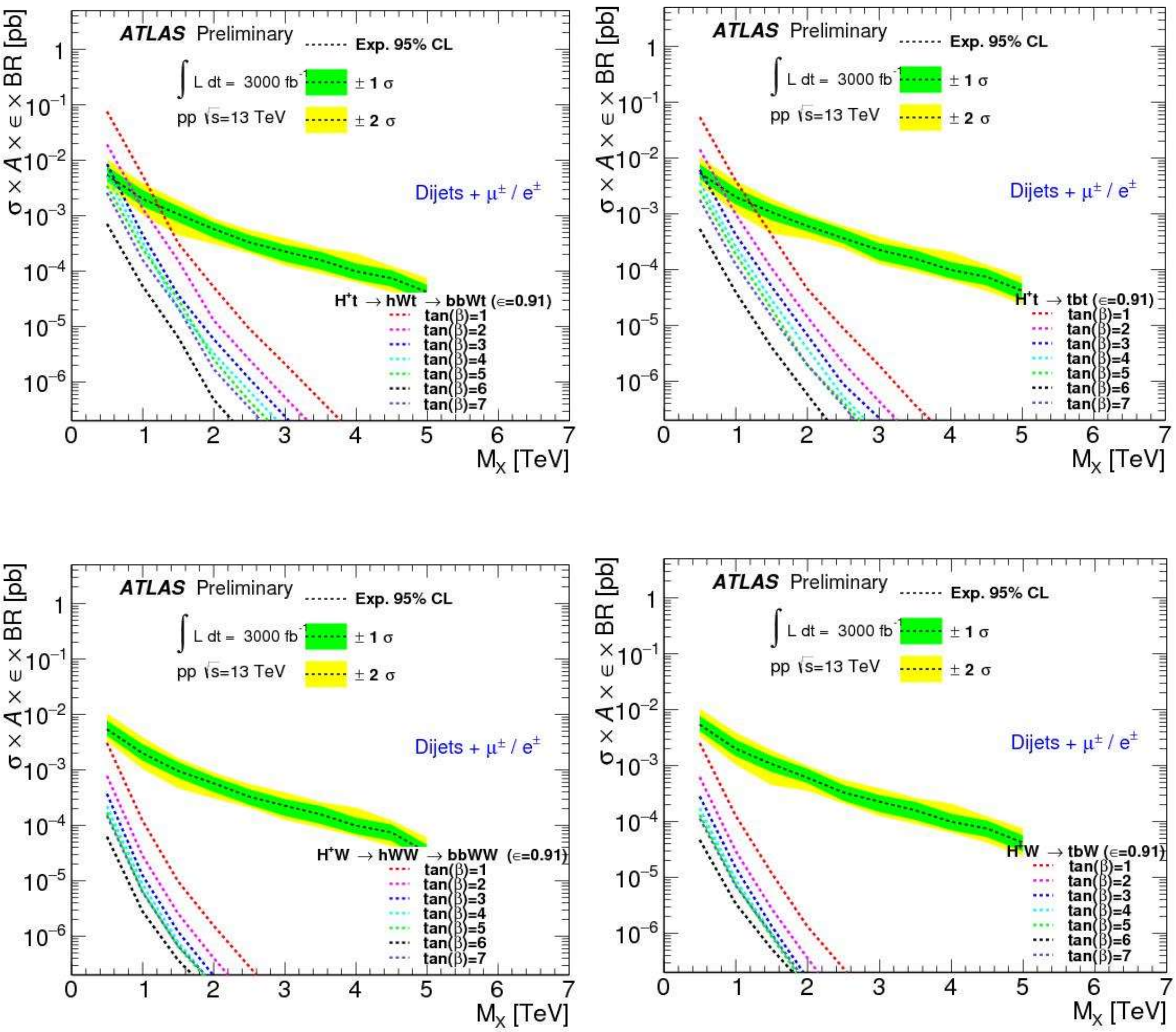
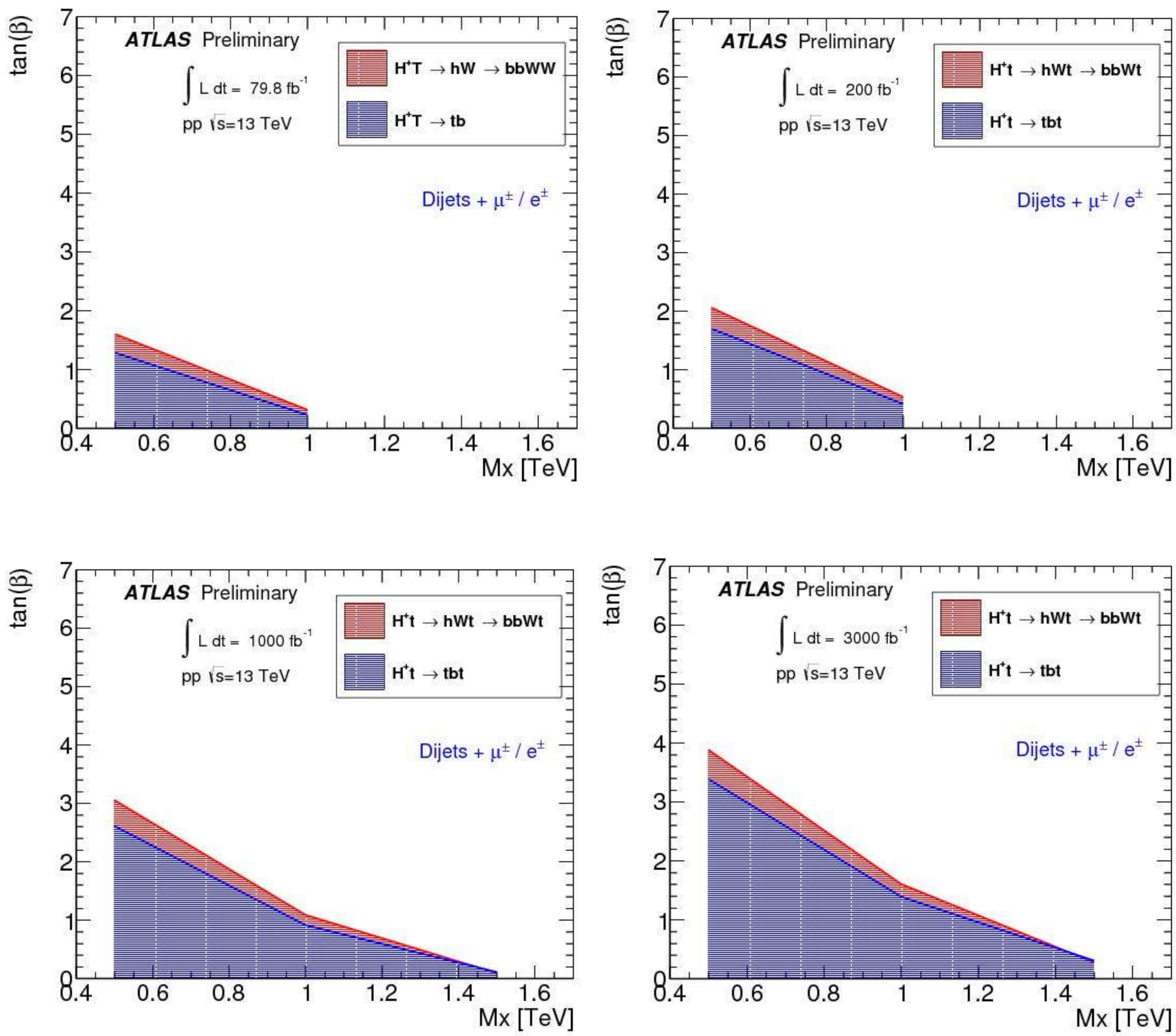


Figure 6-9: These graphs show the exclusion limits at a much higher luminosity of 3000 fb^{-1}. They are shifted downward which would allow for more points to be excluded. However, still not all channels have points that are able to be excluded. Some still have cross sections far too low to exclude anything. However, the regions that can be excluded would expand significantly at this higher luminosity.



Figures 10-13: Each graph is the parameter space for different luminosity. Figure 6 is the same graph as figure 5 with different bounds for better comparison with the other regions. As the luminosity increases, the region that can be excluded gets larger. This is due to the exclusion limits (green-yellow band) shifting downward at higher luminosity. Despite this, none of the decay channels that involved H^+W had high enough cross sections to be excluded. This is why only the H^+t paths are still the only channels shown.

IV. Conclusion

In conclusion, a significant region of the parameter space charged Higgs mass-tan(β) that can be excluded by the existing ATLAS data. Such exclusions can be considered as upper limits since branching ratios were set to 100%. As higher and higher luminosity are reached, a larger parameter space can be excluded. By the end of 2018, luminosity of 150 fb^{-1} are expected to be reached. The 200 fb^{-1} exclusion plot generated is very realistic for what could be obtained by the end of this year. All of which was done solely with Monte Carlo simulations and existing ATLAS data.

V. Acknowledgments

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