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Searching for charged Higgs bosons with boosted top and boosted bottom jets

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Abstract. At moderate values of $\tan\beta$, a supersymmetric charged Higgs boson $H^{\pm}$ is difficult to find due its small cross section and large backgrounds. Using realistic boosted tagging rates, we present preliminary predictions for the reach for TeV-scale charged Higgs bosons at 14 TeV and 100 TeV colliders in top-Higgs associated production. We conclude that moderate values of $\tan\beta$ will be possible to probe at a 100 TeV collider.

1 Introduction

After the discovery of a 126 GeV Higgs-like boson at the Large Hadron Collider at CERN, the emphasis has shifted to whether this is *the* Higgs boson of the Standard Model, or if it is merely one degree of freedom in a larger model like supersymmetry (SUSY). SUSY, like other two Higgs-doublet models, contains additional neutral (H^0, A^0) and charged ($H^{\pm}$) Higgs states. Experiment already constrains SUSY models to be in the "alignment limit," where the masses of these new Higgs states are nearly degenerate. Hence, the $H^{\pm}$ bosons couple almost exclusively to third generation quarks.

Given the strength of the $tbH^{\pm}$ Yukawa coupling, the dominant production mode for charged Higgs bosons at the LHC is in association with a top quark, where the Higgs decays to a boosted top jet and boosted bottom jet final state. Last winter, excitement was generated by a claim [1] that the "wedge region" in $\tan\beta$ ($\tan\beta \sim 6$ where the h^0 shares equal coupling to top and bottom at leading order) could be explored up to 2 TeV in $H^{\pm}$ mass at a 14 TeV LHC through the channel $tbH^{\pm} \to tb(tb)$. On the other hand, a previous paper [2] found that even a mass of 500 GeV could not be probed at the LHC. Here we utilize our new boosted bottom jet tag [3, 4] to examine whether the ~ 2 TeV limit can be reached in the SUSY wedge region at the LHC or at a future 100 TeV pp collider.

2 Analysis

Charged Higgs boson-top quark associated production has two distinguishable final states (ttb and $ttbb$ as depicted in Fig. 1). The dominant measurable cross section is ttb, where the top and bottom quark from the Higgs boson hadronize into boosted jets, and the associated top quark decays to a lepton plus missing energy and a low energy b jet. Technically a higher-order QCD correction, the $ttbb$ final state adds an additional low energy b jet, and 65% to the measurable cross section. Since the measurement is signal constrained, we consider the $ttb + X$ inclusive measurement.

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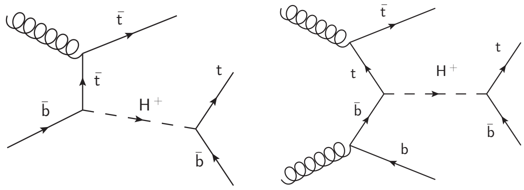

Figure 1. Feynman diagrams for $H^+\bar{t}$-associated production. (Left) The dominant cross section $g\bar{b} \to \bar{t}H^+ \to \bar{t}(t\bar{b})$ has a boosted-top jet, a boosted-bottom jet, and a low energy top quark. (Right) Part of the higher-order correction $gg \to \bar{t}bH^+ \to \bar{t}b(t\bar{b})$ adds a taggable low energy b jet.

We model the signal and backgrounds using MadEvent 5 [5] and CTEQ 14 PDFs [6], perform showering with PYTHIA 8 [7, 8], and use the DELPHES 3 [9] detector simulation. The dominant backgrounds to this process are from boosted jets faking top or bottom jets in Standard Model $t\bar{t}j + X$ production. Direct $t\bar{t}b\bar{b}/t\bar{t}c\bar{c}$ increase the background by 20%. In order to correctly model the fake rates we use the top tagging (and fake) rates provided by the CMS Collaboration [10], and the μ_x boosted b algorithm [3, 4] with code provided by Ref. [11].

The search strategy for a charged Higgs boson consists of reconstructing the boosted top and boosted bottom jet invariant mass $M_{H^\pm}$, and looking for a peak above background in a window $[0.9, 1.15] \times M_{H^\pm}$. We first reconstruct the boosted top with a Cambridge-Aachen algorithm and $R = 0.8$, and all other jet candidates use anti-k_T jets with $R = 0.4$ in FastJet [12]. We require both boosted jets to have $p_T > 350$ GeV, and other jets to have $p_{Tj} > 20(40)$ GeV and $|\eta| < 2.1(3)$ at a 14(100) TeV pp collider. We suppress backgrounds by identifying exactly one isolated lepton with $p_{Tl} > 15(25)$ GeV, and at least one low-energy b tag that satisfies $70\,\text{GeV} < m_{bl} < 180\,\text{GeV}$; we cannot fully reconstruct the low energy top quark because the missing energy is poorly constrained in this system.

After all cuts, the signal to background is 1:2(~1:20) at 14(100) TeV. The 95% confidence level (C.L.) exclusion reach at leading order in QCD is shown for both collider energies in Fig. 2. Unfortunately, the production cross section a moderate $\tan\beta$ (the "wedge region") is simply too small to observe at 14 TeV for masses of the charged Higgs boson above 1 TeV. This result looks like a continuation of Fig. 20 of Ref. [2] (which stops at 1 TeV), and hence a charged Higgs boson is very unlikely to be observable at the LHC. In contrast, at a 100 TeV collider it should be possible to exclude charged Higgs bosons up to 2 TeV for all values of $\tan\beta$, and have significant reach up to 6 TeV.

3 Conclusions

At ISMD this year we presented the results of an analysis to find the reach for TeV-scale charged Higgs bosons at the LHC and at a future 100 TeV collider. Given current measurements of the lightest neutral Higgs boson, a charged Higgs boson would be produced in association with a low energy top quark, and the charged Higgs boson will decay to a boosted top and boosted bottom quark. Despite promising hints [1] that t–$H^\pm$ associated production could be identified at the LHC for moderate values of $\tan\beta = 1$–10, our more complete analysis suggests that the LHC will have very little sensitivity to charged Higgs bosons with mass above 1 TeV. However, we find strong motivation for a 100 TeV collider in that charged Higgs bosons up to 6 TeV can probed for nearly all values of $\tan\beta$.

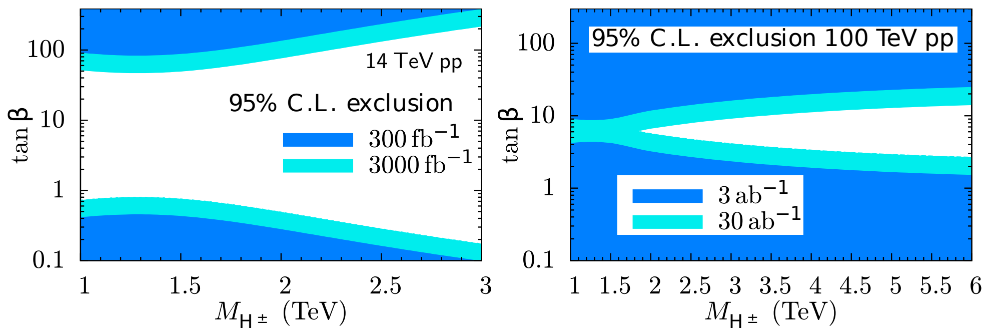

Figure 2. 95% confidence level exclusion limits obtainable at a (left) 14 TeV LHC or (right) 100 TeV pp collider, for $\tan\beta$ vs. charged Higgs boson $H^{\pm}$ mass.

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