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Search for charged Higgs Bosons at D0

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Abstract. In both Supersymmetry and in generic Two Higgs Doublet models (2HDM), the charged Higgs boson $H^{\pm}$ exhibits a unique phenomenological signature. We report on a search for charged Higgs bosons, performed using 0.9 fb^{-1} of data collected with the D0 detector at the Fermilab Tevatron $p\bar{p}$ collider with a center-of-mass energy of $\sqrt{s} = 1.96$ TeV. No evidence for a charged Higgs boson is found and we set limits on its production cross section or the branching fraction.

Keywords: charged Higgs, single top, top quark
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INTRODUCTION

In the Standard Model (SM) of particle physics one SU(2) doublet is needed to induce electroweak symmetry breaking, leading to one observable particle called the Higgs boson. So far no hint for the Higgs boson has been observed experimentally. Furthermore, there is no reason to believe that the electroweak symmetry breaking is caused by only one Higgs field. A second SU(2) doublet is introduced in two-Higgs-doublet models (2HDM). This leads to five physical Higgs bosons, three of which are neutral (h^0, A^0 and H^0) and the other two carry electric charge ($H^{\pm}$).

In the 2HDM models, the coupling of fermions to the Higgs fields is not specified by the theory. The only requirement is to avoid flavor-changing neutral currents (FCNC). Three types of 2HDM are considered [1, 2]. In Type I 2HDM, only one Higgs doublet couples to fermions, in Type II one doublet couples to up-type, the other to down-type fermions. In Type III models, both doublets couple to fermions and additional methods are introduced to suppress FCNCs, for example, by exploiting the small mass of first and second generation quarks. A very prominent candidate for physics beyond the SM is Supersymmetry (SuSy). In SuSy, and in the simplest sypersymmetric extension of the SM, the Minimal Supersymmetric Standard Model (MSSM), only Type II 2HDM models can be realized. At tree-level MSSM two parameters are relevant: the mass of the $H^{\pm}$ and $\tan\beta$, the ratio of the vacuum expectation values of the two Higgs fields.

We present two searches for charged Higgs bosons in the top quark sector. The top quark, the fermion with the highest mass, has the strongest coupling to the Higgs sector of all known particles. In the first analysis we search for a charged Higgs boson heavier than the top quark in the single top production channel [3]. The second search explores the production of $H^{\pm}$ lighter than the top quark in the top quark pair ($t\bar{t}$) production channel.

A SEARCH FOR HEAVY CHARGED HIGGS BOSONS

In 2006, the first evidence for single top quark production was reported by D0 [3]. While for this measurement the s- and t-channels were considered together, it is worth to study both production mechanisms separately [5], especially since the s- and t-channel show different sensitivity to new physics. For example, searches for W' bosons [6], anomaleous Wtb couplings [7] or the search for charged Higgs bosons [8] are performed in the s-channel, the latter search being presented here.

The branching fraction $\mathscr{B}(H^+ \to t\bar{b})$ is close to unity for a large range of $\tan\beta$. We study the cross section times branching fraction $\sigma(q\bar{q}' \to H^+) \times \mathscr{B}(H^+ \to t\bar{b})$ (referred to as $\sigma \times \mathscr{B}$) in the s-channel (Fig. 1 left). The t-channel (Fig. 1 right) is not relevant due to the small couplings of H^+ to light quarks.

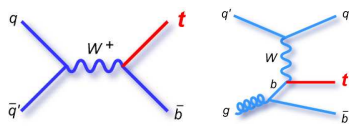

FIGURE 1. s- and t-channel diagram of single top quark production.

In the s-channel, the decays $H^+ \to t\bar{b}$ and $W^+ \to t\bar{b}$ result in the same final state. Therefore the same event selection as for the single top production cross section measurement is used for the H^+ search. While for the latter subsamples with jet multiplicities of 2, 3 and 4 jets are considered, only events with exactly two jets are con-

sidered for the H^+ search. This is the subsample with the highest sensitivity for s-channel single top quark production. Events where exactly one isolated electron (muon) with $E_T > 15$ GeV ($E_T > 18$ GeV) and pseudorapidity $|\eta| < 1.1$ ($|\eta| < 2.0$) and transverse missing energy $\not{E}_T$ of 15 GeV $< \not{E}_T <$ 200 GeV are selected. Additionally, one jet has to fulfil $p_T > 25$ GeV and $|\eta| < 2.5$, the other $p_T > 20$ GeV and $|\eta| < 3.4$ requirements. At least one of the jets must be identified as a b-jet.

The b-jet identification is done using a neural-network tagging algorithm [9]. It combines variables characterizing the presence and properties of tracks with high impact parameter and seconday vertices inside a jet. In the simulation, the events are weighted by a probability for each jet to be b-tagged, derived from data control samples.

The simulation of the charged Higgs signal is performed by setting the couplings such that pure chiral samples are produced. The combination of different proportions of purely left and right-handed samples is used to simulate the three different 2HDM types, as the chriality and up/down-type fermions are correlated.

In order to discriminate charged Higgs production from SM processes, the region of charged Higgs masses, $m_{H^+} > m_t$, is explored. We build the reconstructed invariant mass of the two jets and the W-boson $M(\text{jet1}, \text{jet2}, W)$ for all Monte Carlo and data samples. A binned likelihood in the invariant mass is constructed.

No excess of data over the SM prediction can be observed. Therefore, we set upper limits on $\sigma \times \mathscr{B}$ in all three 2HDM models using Bayesian statistics with a flat prior in the signal cross section. The limits can be parametrized as a function of m_{H^+} and $\tan\beta$ in case of the Type I and Type II 2HDM, and as function of m_{H^+} and the top-charm quark mixing parameter ζ in the Type III 2HDM. The expected and observed limits come out close to each other.

The limits are compared to the expected signal cross section in the different 2HDM models. Figure 2 shows the expected and observed limits together with the theoretical predictions for the Type II (left) and Type I and Type III models (middle). In Type I, charged Higgs masses between 180 and 184 GeV can be excluded in the ($\tan\beta$, m_H^+) parameter space, as shown in Fig. 2 (right). In the Type II and Type III models, the analysis sensitivity is not sufficient yet to exclude regions in the (m_{H^+}, $\tan\beta$) or (m_{H^+}, ζ) parameter space, respectively.

A SEARCH FOR LIGHT CHARGED HIGGS BOSONS

The $t\bar{t}$ production cross section at next-to-leading order is 6.8 ± 0.6 pb at a top quark mass of 175 GeV at the Tevatron [10]. This yields several thousands of top quark pairs with the current integrated luminosity, large $t\bar{t}$ yields after selection cuts enabling precision measurements and searches for new physics in the top quark sector.

In the SM, the top quark decays into a W boson and a b-quark. Different final states are classified according to the decay of the two W bosons in the $t\bar{t}$ system. The final state in which both W's decay into a lepton (electron or muon) is called a dilepton channel. If one W boson decays into electron or muon and one into quarks, the final state is called lepton plus jets (ℓ+jets).

Requiring at least four jets with at least one of them b-tagged in the ℓ+jets channel, the $t\bar{t}$ cross section is measured with about 1 fb^{-1} of data at a top quark mass of 175 GeV as [11]

$$\sigma(t\bar{t})_{\ell+\text{jets}} = 8.27^{+0.96}_{-0.95}\ (\text{stat} + \text{syst}) \pm 0.51\ (\text{lumi})\ \text{pb}\,.$$

In the dilepton final state we obtain [11]

$$\sigma(t\bar{t})_{\text{dilepton}} = 6.8^{+1.2}_{-1.1}\ (\text{stat})^{+0.9}_{-0.8}\ (\text{syst}) \pm 0.4\ (\text{lumi})\ \text{pb}\,.$$

The requirement of at least four jets in the ℓ+jets channel is chosen to minimize the overlap between dileptonic and semileptonic final states.

In the presence of a charged Higgs boson lighter than the top quark, the decays $t \to Wb$ and $t \to H^+b$ can compete. Depending on the H^+ decay mode, for example a pure decay into $\tau\nu$ or $c\bar{s}$, the expected yields in the various final states of a $t\bar{t}$ pair can significantly deviate from the SM expectation.

Since a new decay mode of the top quark can change the measured cross section, the ratio of the cross sections measured in the ℓ+jets and dilepton channels

$$R_\sigma = \frac{\sigma(t\bar{t})_{\ell+\text{jets}}}{\sigma(t\bar{t})_{\text{dilepton}}}$$

can be used to explore alternative models beyond the SM [11]. By generation of pseudo-experiments taking into account the systematic uncertainties and their correlations we derive $R_\sigma = 1.21^{+0.27}_{-0.26}$ (stat + syst).

Any deviation from the SM value of $R_\sigma = 1$ can be a hint for new physics. For example, the branching ratio $\mathscr{B}(t \to bX)$ with X being any particle but the W boson can lead to R_σ different from one. In case of $X := H^+$, the ratio of cross sections can be used to search for light charged Higgs bosons.

We study a simple model in which $\mathscr{B}(H^\pm \to cs)$ is 100 %, the charged Higgs boson mass is close to the W mass, and therefore a similar event kinematics of the $t \to bW$ and $t \to bH^+$ decays can be assumed. This leptophobic charged Higgs model is interesting at low $\tan\beta$ in the MSSM for scenarios with large suppression of the tauonic decay, for example, from SuSy-breaking effects [12]. Furthermore, in general multi-Higgs-doublet

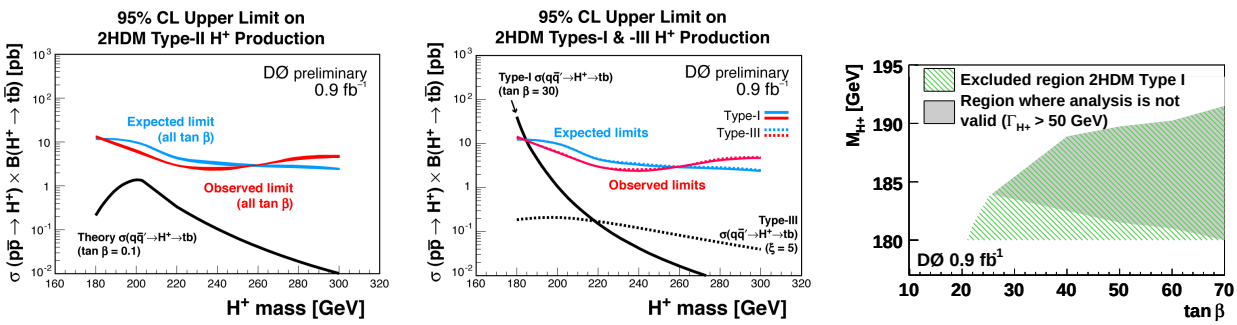

FIGURE 2. Expected and observed limtis for Type II (left) and Type I and III (middle) 2HDM models. The right plot shows the 95 % Cl. L. exclusion region in the ($\tan\beta$, m_H^+) space for the Type I 2HDM model.

models (MHDM), a leptophobic decaying charged Higgs is possible for the full $\tan\beta$ range [13]. For a $H^\pm$ mass of 80 GeV and $\tan\beta < 3.5$, such a leptophobic charged Higgs boson could lead to noticeable effects at the Tevatron [14].

As R_σ shows no deviation from one within its uncertainty, we set upper limits on $\mathscr{B}(t \to H^+b)$ for a leptophobic decaying charged Higgs boson with a mass of 80 GeV. We use a frequentist method from Feldman and Cousins [15], resulting in an upper observed limit of $\mathscr{B}(t \to H^+b) < 0.35$ at 95 % C.L., and an expected limit of $\mathscr{B}(t \to H^+b) < 0.25$ at 95 % C.L.

The earlier measurement of the ratio $1/R_\sigma$ from CDF with 200 pb^{-1} yields $1/R_\sigma = 1.45^{+0.83}_{-0.55}$ and a limit on $\mathscr{B}(t \to Xb)$ of less than 0.46 at 95 % C.L. [16] under the assumption of the same acceptance for $t \to bW$ and $t \to bH^+$ decays.

A dedicated search for light charged Higgs bosons between 80 and 155 GeV has been released by D0 recently [17], where the yields in the dilepton, ℓ+jets and τ+lepton channels are used to search for the charged Higgs. Limits on a purely tauonic and a leptophobic charged Higgs model have been set, resulting in $\mathscr{B}(t \to H^+b) < 0.2$ in the tauonic model and $\mathscr{B}(t \to H^+b) < 0.26$ in the leptophobic model for charged Higgs masses between 80 and 15 GeV. The procedure is complementary to the consideration of the cross section ratio.

CONCLUSION AND OUTLOOK

We presented searches for charged Higgs bosons in single top and top pair events at D0, with about 1 fb^{-1} of integrated luminosity. In the single top channel we searched for heavy charged Higgs bosons, interpreted in terms of upper limits on $\sigma \times \mathscr{B}$ for Type I, II and III 2HDM models. First exclusion limits have been set in the ($m_{H^\pm}$, $\tan\beta$) space for Type I models.

In the $t\bar{t}$ production mode, we derived the ratio R_σ of the cross sections measured in the ℓ+jets and dilepton channels and interpreted in terms of charged Higgs decays of the top quark, resulting in an upper limit on $\mathscr{B}(t \to H^+b)$ for a leptophobic charged Higgs model.

With higher luminosity and ever improving techniques, the SM $t\bar{t}$ and single top sector can be explored more and more precisely. Until the end of Tevatron's Run II about $6-8$ fb^{-1} of data are expected, yielding a lot of opportunities to search for new physics.

REFERENCES

1. J. Gunion *et al.*, Frontiers in Physics (Addison-Wesley, Redwood City, CA, 1990)
2. H.-J. He and C.-P. Yuan, Phys. Rev. Lett. **83**, 28 (1999)
3. D0 Collaboration, V. Abazov *et al.*, Phys. Rev. Lett. **98**, 181802 (2007).
4. D0 Collaboration, V. Abazov *et al.*, Nucl. Instrum. and Methods A **565**, 463 (2006).
5. D0 Collaboration, V. Abazov *et al.*, Phys. Rev. D **78**, 012005 (2008).
6. D0 Collaboration, V. Abazov *et al.*, Phys. Rev. Lett. **100**, 211603 (2008).
7. D0 Collaboration, V. Abazov *et al.*, submitted to Phys. Rev. Lett., arXiv:0807.1692v1 [hep-ex] (2008).
8. D0 Collaboration, V. Abazov *et al.*, submitted to Phys. Rev. Lett., arXiv:0807.0859v1 [hep-ex] (2008).
9. T. Scanlon, Ph.D. thesis, University of London, 2006.
10. N. Kidonakis and R. Vogt, Phys. Rev. D **68**, 114014 (2003); M. Cacciari *et al.*, JHEP **404**, 68 (2004).
11. D0 Collaboration, D0 note 5466-CONF
12. M. S. Carena, S. Mrenna and C. E. M. Wagner, Phys. Rev. D **62**, 055008 (2000).
13. Y. Grossman, Nucl. Phys. B **426**, 355 (1994).
14. A. G. Akeroyd, hep-ph/9509203 (1995).
15. G. Feldman and R. Cousins, Phys. Rev. D **57**, 3873 (1998).
16. K. Bloom, FERMILAB-CONF-04-071-E, May 2004, hep-ex/0405020
17. D0 Collaboration, D0 note 5715-CONF