PROCEEDINGS OF SCIENCE

Searches for non-SM Higgs at the Tevatron

Per JONSSON[*†]
Imperial College London, Blackett Laboratory, Physics Department, Prince Consort Road, London SW7 2AZ, United Kingdom
E-mail: jonsson@fnal.gov

Recent results obtained by the CDF and D0 Collaborations on searches for Higgs bosons beyond the Standard Model at Run II of the Tevatron are discussed. The data, corresponding to integrated luminosities of up to 4.2 fb^{-1}, are compared to theoretical expectations. No significant excess of signal above the expected background is observed in any of the various final states examined, and so limits at 95% Confidence Level (C.L.) are presented.

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[*] Speaker.
[†] For the CDF and D0 collaborations.

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1. Introduction

Higgs boson production cross sections in the Standard Model (SM) are small at the Tevatron. However some models beyond the SM predict larger Higgs cross sections and cleaner search channels. The Minimal Supersymmetric extension of the SM (MSSM) [1] contains five physical Higgs bosons, h, H, A and $H^{\pm}$. The mass of A is a free parameter at tree level. The production cross section of the Higgs in the MSSM is proportional to the square of the second free parameter of the model, $\tan\beta$, the ratio of the vacuum expectation values of the Higgs doublets, ν_u and ν_d. A large value of $\tan\beta$ could result in significantly increased Higgs cross sections. Moreover, at the large $\tan\beta$ limit A and one of h and H are degenerate in mass, leading to a further enhanced cross section. Searches for $h/H/A$ in final states with τ leptons or two b-quarks are therefore well motivated. $H^{\pm}$ can be pursued in searches for deviations of the SM expectations in top decays. Other possible extensions to the SM such as next-to-MSSM [2] or hidden-valley (HV) models [3], could lead to decays of Higgs bosons to experimentally challenging signatures, which could escape detection by the standard reconstruction algorithms. There is consequently a wide range of Higgs searches beyond the SM being actively pursued with the more than 5 fb^{-1} of data collected during Run II.

2. Limits on neutral SUSY Higgs at high tanβ

The main production mechanism for neutral Higgs bosons in the MSSM would be through diagrams like $gg, b\bar{b} \to \phi$ and $gg, q\bar{q} \to \phi + b\bar{b}$, where $\phi = h, H, A$. The branching ratio of $\phi \to b\bar{b}$ is around 90% and $\phi \to \tau^+\tau^-$ is around 10%. The overall experimental sensitivity is however similar for the two channels, due to lower background in the τ channel.

2.1 Higgs $\to \tau^+\tau^-$

The main background sources in this channel are $Z \to \tau^+\tau^-$ (irreducible), $W+$ jets, $Z \to \mu^+\mu^-/e^+e^-$ with multijet and di-boson events also contributing. D0 has performed searches in the channels where one of the τ leptons decays to a μ or electron [4]. The μ channel has recently been updated to 2.2 fb^{-1} of data. The event selection requires one isolated muon or electron, separated from the hadronic τ or other lepton with opposite sign. The τ identification is performed with a neural network. CDF has performed a similar search [5]. The event selection includes an isolated electron/muon and τ identification with a variable cone-size algorithm. Both experiments find that the data are in good agreement with the background only expectation. Limits on cross section times branching ratio and exclusion regions in the MSSM parameter space are derived from the visible mass distribution.

2.2 Higgs $+b \to \tau^+\tau^- b$

D0 has performed a recent search using 1.2 fb^{-1} of Run IIb data in the channel where one tau lepton decays to a μ. The dominant backgrounds are $t\bar{t}$ and multijets. The multijet background is estimated from data and the $t\bar{t}$ background is modeled using ALPGEN [6] interfaced with PYTHIA [7]. $t\bar{t}$ events are removed using a neural network based on kinematic variables. Multijets are removed using an unbinned log-likelihood ratio. The likelihood and $t\bar{t}$ neural network distributions are used to derive limits on cross section times branching ratio and exclusion regions in the MSSM parameter space.

2.3 Higgs $+b \rightarrow b\bar{b}b$

D0 is using a multijet event sample, corresponding to an integrated luminosity of 2.6 fb^{-1} in a recent update to the analysis in Ref. [8]. Candidate events are required to contain at least three jets with $p_T > 20$ GeV, the two leading jets must further be above 25 GeV. At least three jets are required to be identified as b-jets by a neural network b-tagging algorithm. A likelihood based on kinematic variables is used to remove background events and the invariant di-jet mass distribution is used to search for a signal. The CDF search, based on 2.0 fb^{-1}, requires exactly 3 jets, with $p_T > 20$ GeV and $|\eta| < 2$. All three jets must be tagged by the standard CDF secondary vertex algorithm. Neither of the experiments detects any indication of a signal and instead preliminary exclusion limits at 95% C.L. are calculated.

2.4 Combined limits

D0 has produced combined limits from the three neutral MSSM Higgs searches. In total nineteen sub-channels with between 1.0 and 2.6 fb^{-1} of data are included. Fig. 1 shows the excluded region at 95% C.L. in one MSSM benchmark scenario [9]. This is the strongest limit on neutral MSSM Higgs in the tan$\beta - m_A$ plane to date at a hadron collider.

3. Charged Higgs bosons

CDF has carried out a search for H^+ using 2.2 fb^{-1} of data in the low tanβ region which is dominated by the decay $H^+ \rightarrow c\bar{s}$ [11]. The search is conducted in the lepton+jets $t\bar{t}$ channels. Mass templates for H^+ and W^+ are fit to the dijet mass distribution in data to derive uppper limits on the branching ratio of $t \rightarrow H^+b$. The dominant background is $t\bar{t}$ which is modeled with PYTHIA. The upper limits on the branching ratio, Br($t \rightarrow H^+b$), shown in Fig. 1, range from 0.3 to 0.1 depending on the H^+ mass. D0 has carried out charged Higgs searches with 1.0 fb^{-1} of data in the $H^+ \rightarrow c\bar{s}$, $H^+ \rightarrow \tau^+\nu$ and $H^+ \rightarrow t\bar{b}$ channels [12].

4. Next-to-MSSM and neutral long-lived particles

In the nMSSM [2] the branching ratio of Higgs$\rightarrow b\bar{b}$ is greatly reduced. Instead the Higgs predominantly decays to a pair of lighter neutral pseudoscalar Higgs bosons, a. D0 has conducted two searches with 4.2 fb^{-1} of data [13]. Firstly for the case with $2M_\tau < M_a \leq 3M_\pi$ where a dominantly decays to two muons. Secondly, for the case where $2M_\tau < M_a \leq 2M_b$ and a predominantly decays to a pair of tau leptons. No excess is observed and limits are calculated on the cross section times branching ratio, see Fig. 1. D0 has also performed a search for pairs of displaced secondary vertices at distances of 1.6-20 cm from the beam axis with 3.6 fb^{-1} of data [14]. No significant excess over the expected background is found. This search can be interpreted as a limit on the SM Higgs decaying to a pair of neutral and long-lived HV particles, each decaying to a pair of b quarks.

5. Conclusions

The results presented at this conference by the CDF and D0 collaborations, together with the recent performance of the experiments and the Tevatron, are very encouraging for the Higgs

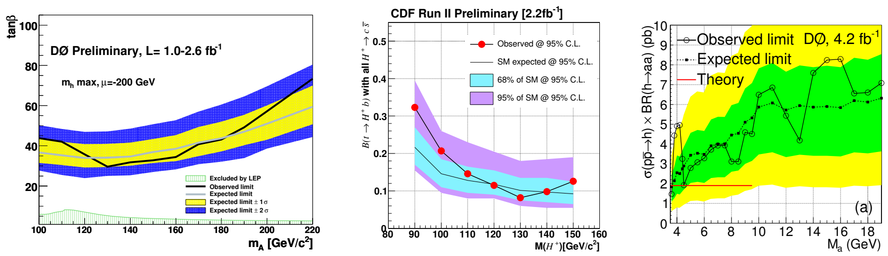

Figure 1: Left) Excluded region in the $\tan\beta - m_A$ plane from D0 for a negative mass parameter μ in the m_h^{max} scenario [9]. Also shown is the limit from LEP [10]. Center) The expected and observed 95% C.L. upper limit on the branching ratio, Br($t \to H^+ b$) from CDF. Br($H^+ \to c\bar{s}$) is assumed to be 100%. Right) The expected and observed limits and $\pm$ 1 and 2 s.d. bands for $\sigma(p\bar{p} \to h + X) \times$ BR($h \to aa$) and $M_h = 100$ GeV.

searches at Run II. We are confidently looking forward to exploring the more than 5 fb^{-1} of data per experiment which has already been written to tape. New MSSM results can be expected shortly and the focus is also on combining the results from the different channels of both experiments to gain maximum sensitivity.

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