Search for the MSSM Higgs boson in $p\bar{p}$ collisions at D0

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Abstract. We present searches for neutral Higgs bosons (ϕ) in the framework of the minimal supersymmetric extension of the standard model (MSSM) using up to 5.2 fb^{-1} of data collected with the D0 detector in proton-antiproton collisions at a center of mass energy of 1.96 TeV at the Fermilab Tevatron collider. Within the MSSM the production of Higgs bosons can be significantly enhanced compared to the standard model (SM) and there is a significant branching ratio to third generation fermions (pairs of b quarks and τ leptons) at all masses. In addition to gluon fusion ($gg \rightarrow \phi$), we also investigate associated production with a b quark ($bg \rightarrow b\phi$) and present results for final states involving three or four b jets, τ pairs and τ pairs produced in association with a b quark. We interpret our result in the framework of the MSSM.

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INTRODUCTION

The search for Higgs bosons is one of the main challenges for particle physics and as such a high priority for the upgraded D0 detector at Run II of the Tevatron. Higgs boson production cross sections in the SM are small at the Tevatron. However some models beyond the SM, among these supersymmetry, predict larger Higgs cross sections and cleaner search channels. The MSSM [1] contains two Higgs doublets which after electroweak symmetry breaking result in five physical Higgs bosons, h, H, A and $H^{\pm}$. The data collected by the D0 experiment can be probed for these and in the absence of an observed excess used to constrain the MSSM. The latest results from searches for neutral MSSM Higgs bosons are presented here. More information on these searches and the most recent results can be found on the public results web-page of the D0 experiment [2].

LIMITS ON NEUTRAL MSSM HIGGS BOSONS AT HIGH TANβ

In the MSSM the mass of the CP-odd pseudoscalar, A, is a free parameter at tree level. The neutral Higgs production cross section in the MSSM is proportional to the square of the second free parameter of the model, tanβ, the ratio of the vacuum expectation values of the Higgs doublets, v_u and v_d. A large value of tanβ could result in significantly

[1] For the D0 collaboration.

increased Higgs cross sections. Moreover, at the large tanβ limit A and one of the CP-even scalars, h and H (of which h is the lighter and SM like), are degenerate in mass, leading to a further enhanced cross section. The main production mechanism for neutral Higgs bosons in the MSSM would be through diagrams like $gg, b\bar{b} \to \phi$, $gb \to \phi + b$, 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 experimental sensitivity is however similar for the two decay channels, due to lower background in the τ channel. Searches for $h/H/A$ in final states with τ leptons or b quarks are therefore well motivated.

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

The main background sources in this channel are $Z \to \tau^+\tau^-$ (irreducible), $W+$ jets, and $Z \to \mu^+\mu^-/e^+e^-$ with multijet and diboson events also contributing. Searches have been performed using 1 fb^{-1} of data in the channels where one of the τ leptons decays to a muon or electron [3]. The muon channel search has 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 hadronic τ identification is performed with a neural network and the $W+$ jet background is reduced with cuts on the transverse mass. The multijet background is modeled from data and other backgrounds are modeled with PYTHIA [4]. The normalization of the $W+$ jet contribution is obtained from a data sample. 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 distribution of the visible mass, i.e. the invariant mass of the visible τ products and the missing transverse energy. The model independent 95% C.L. upper limit on the cross section times branching ratio is shown in Figure 1.

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

A search has been performed using 2.7 fb^{-1} of Run II data in the channel where one τ lepton decays to a muon [5]. This analysis has recently been updated using 4.3 fb^{-1} of data and complemented with a search in the channel where one τ lepton decays to an electron using 3.7 fb^{-1} of data. Events are selected by requiring an isolated muon or electron separated from a hadronic τ of opposite sign, along with a b jet. The dominant backgrounds are $Z+$ jets, $t\bar{t}$, and multijets. The multijet background is estimated from data and the $Z+$ jets and $t\bar{t}$ backgrounds are modeled using ALPGEN [6] interfaced with PYTHIA [4]. Both the hadronic τ and b-jet identification are performed with neural networks. The b-jet identification criteria are used to reduce the $Z+$ jet events and $t\bar{t}$ and multijet events are separated from signal using different multivariate (MVA) classifiers based on kinematic variables. The MVA distributions are used to derive limits on cross section times branching ratio and exclusion regions in the MSSM parameter space. Figure 1 shows the model independent limit for the $\tau_\mu \tau_{had} b$ channel.

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

A multijet event sample, corresponding to an integrated luminosity of 5.2 fb^{-1}, is used in the published analysis in Ref. [7]. Candidate events are required to contain at least three jets with transverse momenta, $p_T > 20$ 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 algorithm. The composition of the background, dominated by heavy flavor multijet events, is estimated from a fit of distributions from simulated events to data over several different b-identification criteria. A likelihood based on kinematic variables is used to remove background events separately in the three and four-jet channels and the invariant di-jet mass distributions are used to search for a signal. No indication of a signal is detected and instead preliminary exclusion limits at 95% C.L. are calculated. The model independent 95% C.L. upper limit on the cross section times branching ratio is shown in Figure 1.

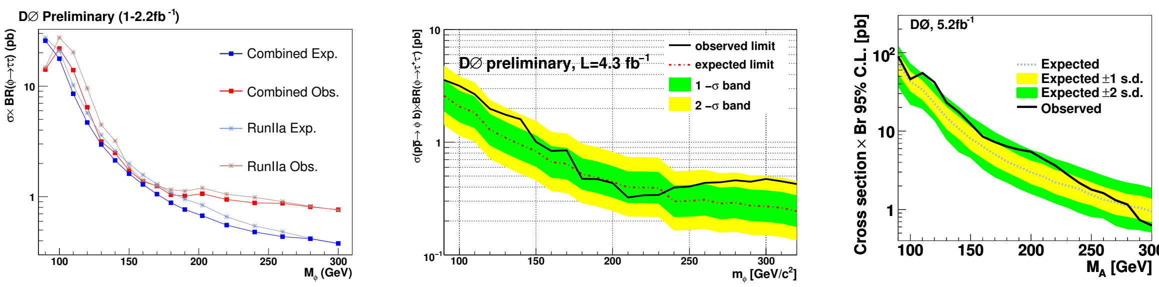

FIGURE 1. Expected and observed model independent 95% C.L. upper limits on the cross section times branching ratio from different MSSM Higgs channels. Left) The 1 fb^{-1} ("RunIIa") and 2.2 fb^{-1} ("Combined") $\phi \rightarrow \tau^+\tau^-$ analyses. Middle) The 4.2 fb^{-1} $\phi b \rightarrow \tau_\mu \tau_{had} b$ analysis. Right) The 5.2 fb^{-1} $\phi b \rightarrow b\bar{b}b$ analysis. The colored bands show the one and two standard deviation regions around the expected limits.

Combined limits

To improve the sensitivity, combined limits are produced from the three complementary neutral MSSM Higgs channels. Using earlier versions of the $\tau^+\tau^- b$ and $b\bar{b}b$ analyses, in total nineteen sub-channels with between 1.0 and 2.6 fb^{-1} of data are included. Figure 2 shows the excluded region at 95% C.L. in one MSSM benchmark scenario [8]. A combined limit with the results from the other Tevatron experiment, CDF, in the $\phi \rightarrow \tau\tau$ channel [9] is also shown in Figure 2.

CONCLUSIONS

The results using up to 5.2 fb^{-1} of data presented by the D0 collaboration at this workshop together with the continued good performance of the experiment and the Tevatron, are very encouraging for the MSSM Higgs searches at Run II. The more than 9.5 fb^{-1} of data which have already been written to tape are now being explored

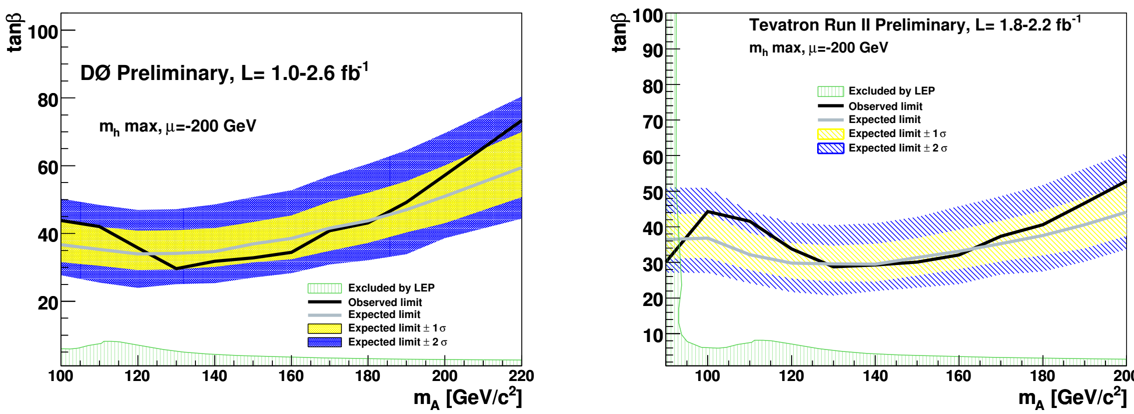

FIGURE 2. Left) Excluded region in the $\tan\beta - m_A$ plane for a negative mass parameter μ in the m_h^{max} scenario [8]. Right) The excluded region in the same scenario from the combined Tevatron search in the $\phi \rightarrow \tau\tau$ channel. Also shown is the limit from LEP [10].

with refined and improved analysis techniques. New MSSM results probing extremely interesting regions can be expected shortly and the focus is also on combining the results from the different channels and with CDF to gain maximum sensitivity.

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