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Search for Beyond the Standard Model Higgs Bosons at DØ

Ingo Torchiani on behalf of the DØ Collaboration

Physikalisches Institut, Universität Freiburg, Herrman-Herder-Str. 3, 79104 Freiburg, Germany

Abstract. Recent searches by the DØ collaboration for Higgs bosons in extensions of the Standard Model at the Tevatron are reported with emphasis on neutral Higgs bosons in supersymmetry.

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INTRODUCTION

Despite its tremendous success in describing the available high energy physics data to high precision, the standard model (SM) of particle physics is known to be incomplete. The most popular extension of the SM is supersymmetry. It provides elegant solutions to various problems of the SM, e.g. the fact that in the SM the mass of the Higgs boson is sensitive to large radiative corrections driving its mass to the Planck scale.

The reported results are based on data samples of proton-antiproton collisions at a center-of-mass energy of $\sqrt{s} = 1.96$ TeV provided by the Tevatron. The analyzed data is recorded by the DØ detector [1]. All reported limits are calculated at the 95% confidence level (CL) based on the modified frequentist approach [2].

NEUTRAL HIGGS BOSONS

The minimal supersymmetric SM (MSSM) contains two complex Higgs doublets leading to two neutral CP-even (h,H), one CP-odd (A) and a pair of charged $(H^{\pm})$ Higgs bosons. At tree level, all Higgs masses can be expressed by two parameters, generally chosen to be m_A and the ratio of the vacuum expectation values of the two Higgs doublets, $\tan\beta$. At large values of $\tan\beta$, A is nearly mass degenerate with either h or H, and the coupling of the neutral Higgs bosons to down-type quarks and leptons are strongly enhanced resulting in sizeable production cross sections and an increased branching ratio (BR) to tau leptons ($\approx 10\%$) and bottom quarks ($\approx 90\%$). In the following, the neutral Higgs bosons will be referred to as Φ. The results are interpreted in two benchmark scenarios: the $m_h^{\max}$ scenario (characterized by a mass of the lightest neutral Higgs boson which is close to the maximal possible value) and the no-mixing scenario (vanishing mixing in the stop-sector) [3, 4]. Some of the analyses consider the two scenarios for two choices of the Higgs mass parameter: $\mu = \pm 200$ GeV.

$\Phi \rightarrow \tau^+\tau^-$. The disadvantage of the relative small $\mathrm{BR}(\Phi \rightarrow \tau^+\tau^-)$ is compensated by the advantage of a clean signal signature consisting of two oppositely charged high-p_T tau leptons. The inclusive search is therefore sensitive to the production mode $gg \rightarrow \Phi$. Considering the three final states $e\tau_h$, $\mu\tau_h$, and $e\mu$ covers approximately half of the total $\mathrm{BR}(\Phi \rightarrow \tau^+\tau^-)$ (τ_h indicates a hadronically decaying tau; neutrinos are not indicated). The identification of hadronically decaying taus, characterized by narrow isolated jets, is based on artificial neutral networks. The analysis relies on electron/muon triggers and uses a data set of 1 fb^{-1}. All SM backgrounds are estimated using Monte Carlo (MC) simulation except the multi-jet background which is estimated from data. The signal is expected to stand out as an enhancement over SM backgrounds in the distribution of the *visible mass* calculated as the invariant mass of the visible tau decay products and the missing momentum four-vector $\not{p}$ approximated by $\not{p} = \left(\sqrt{\not{E}_x^2 + \not{E}_y^2}, \not{E}_x, \not{E}_y, 0\right)$ (Fig. 1). No significant excess is observed and limits on $p\bar{p} \rightarrow \Phi \rightarrow \tau^+\tau^-$ are set taking into account shape uncertainties due to the tau energy measurement. The interpretation in two benchmark scenarios is shown in Fig. 2. The impact of the increasing Higgs width with $\tan\beta$ was studied in detail and found to be negligible in the considered scenarios [5].

$b(\bar{b})\Phi \rightarrow b\bar{b}b(\bar{b})$. Due to the overwhelming multi-jet background from QCD production, the decay $\Phi \rightarrow b\bar{b}$ can not be observed inclusively. Instead, the process is considered where the Higgs boson is radiated off an initial b quark. The analyzed data (1 fb^{-1}) is recorded by 3-jet and b-jet triggers. An artificial neural network b-tagging algorithm [6] based on life-time information is used to select events which contain at least three b-tagged jets with transverse momenta larger than 20 GeV. Two likelihood discriminators (one for light and one for heavy Higgs masses, with a split at 130 GeV) are employed to suppress remaining background contributions from QCD multi-jet events (Fig. 3). They exploit the different kine-

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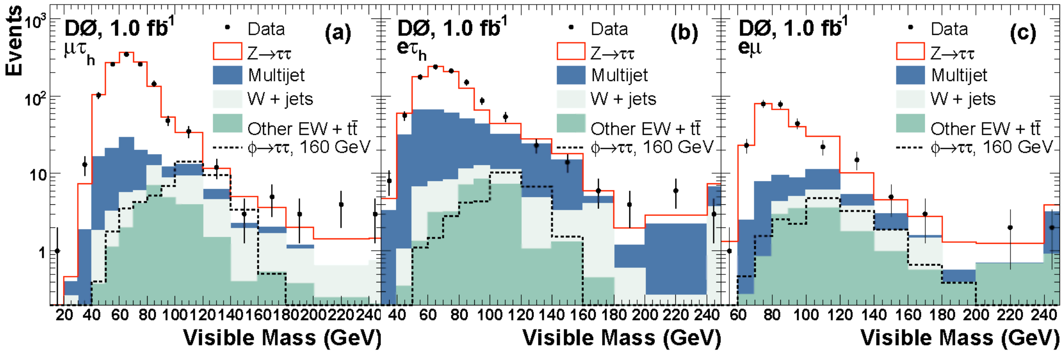

FIGURE 1. Visible mass distribution in the three channels considered in the search for $\Phi \to \tau^+\tau^-$.

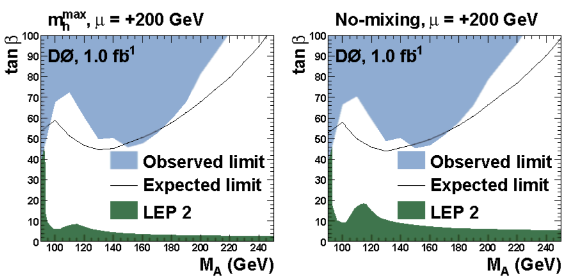

FIGURE 2. Excluded regions in the $(m_A, \tan\beta)$ plane for the $m_h^{\rm max}$ and no-mixing scenario for positive μ by the search for $\Phi \to \tau^+\tau^-$.

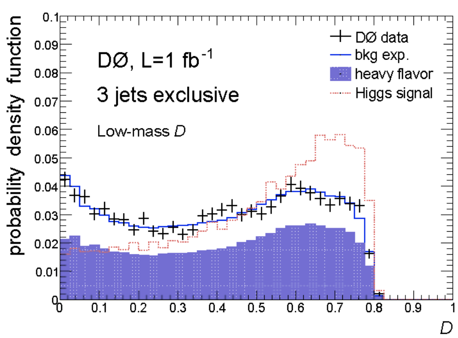

FIGURE 3. Distribution of the low-mass kinematic likelihood from the search for $b(\bar{b})\Phi \to bb\bar{b}(\bar{b})$.

matic properties of signal and SM background events. The three b-tag background is estimated using two b-tag data and shape information from MC simulation. Since no excess over the expected SM background is observed, upper limits on the process $b(\bar{b})\Phi \to bb\bar{b}(\bar{b})$ are set based only on the shape differences of signal and background in the distribution of the invariant mass of the two leading b-jets. Higgs width effects are taken into account in the interpretation as an upper limit on $\tan\beta$ as a function of the Higgs mass m_A (Fig. 4) [7].

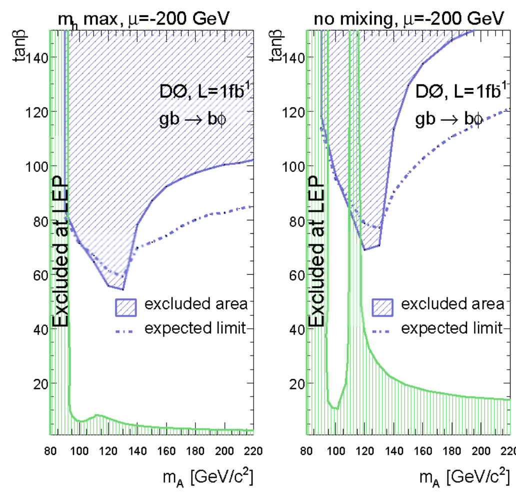

FIGURE 4. Regions excluded in the $m_h^{\rm max}$ and no-mixing scenario for negative μ by the search for $b(\bar{b})\Phi \to bb\bar{b}(\bar{b})$.

$b\Phi \to b\tau^+\tau^-$. The DØ collaboration performed a search for $b\Phi \to b\tau^+\tau^-$ in the $b\mu\tau_h$ final state based on a data set corresponding to an integrated luminosity of 0.3 fb^{-1} [8]. It has been updated recently using a data set of 1.2 fb^{-1}, leading to upper bounds on $\tan\beta$ in the two benchmark scenarios [9].

As can be seen from Figs. 2 and 4, the reported results are complementary to existing bounds from the LEP experiments.

DOUBLY CHARGED HIGGS BOSONS

Doubly charged Higgs bosons $H^{\pm\pm}$ appear e.g. in left-right symmetric models. The DØ collaboration searched in a 1.1 fb^{-1} dataset for the process $p\bar{p} \to Z/\gamma^* \to H^{++}H^{--}$ with both Higgs bosons decaying to muons, $H^{\pm\pm} \to \mu^\pm\mu^\pm$ [10]. After requiring three isolated high-p_T muons out of which two have the same charged assigned and imposing further selection criteria, three

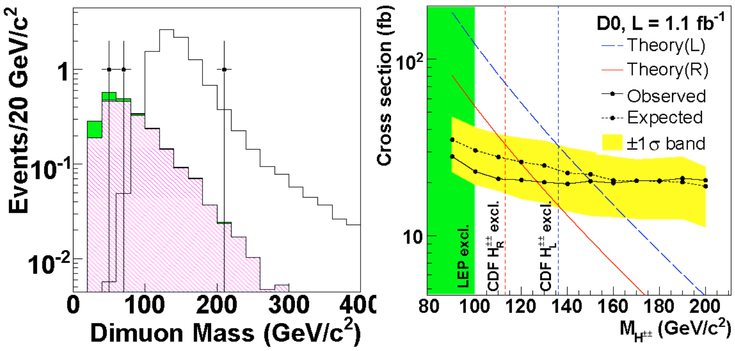

FIGURE 5. Left: Invariant $\mu^\pm\mu^\pm$ mass distribution after applying all selection criteria optimized for $H^{\pm\pm} \to \mu^\pm\mu^\pm$ (hatched (filled) histogram: simulated WZ/ZZ (from data estimated multi-jet) background; open histogram: expected signal for a Higgs mass of 140 GeV). Right: Upper limit on the doubly charged Higgs boson production cross section as a function of the Higgs mass.

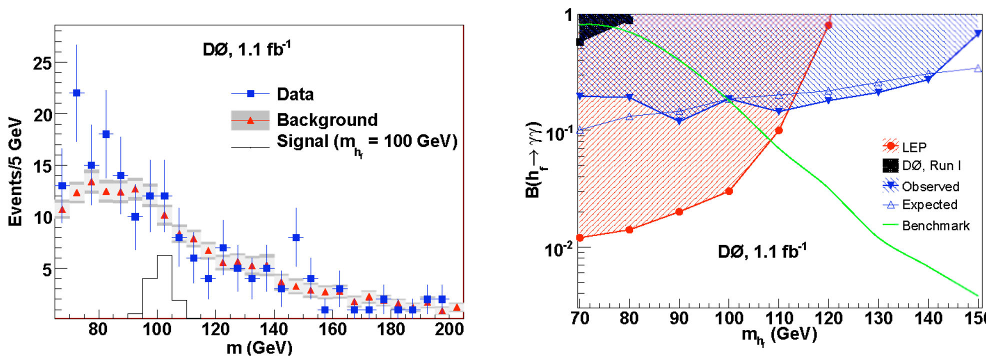

FIGURE 6. Left: Invariant di-photon mass distribution after applying all selection criteria optimized for $h_f \to \gamma\gamma$. Right: Resulting upper limit on BR($h_f \to \gamma\gamma$) as a function of the Higgs mass.

events are observed in data, which is consistent with the SM background expectation of 2.1 ± 0.2 events (dominated by WZ and ZZ production). Lower limits on the mass of $H^{\pm\pm}$ are set at 150 GeV (127 GeV) for left-handed (right-handed) $H^{\pm\pm}$ (Fig. 5).

FERMIOPHOBIC HIGGS BOSONS

In fermiophobic models where all Higgs-fermion couplings are suppressed but the Higgs-gauge boson couplings are unchanged compared to the SM, the decay $h_f \to \gamma\gamma$ dominates for light Higgs bosons, $m_h \lesssim 100$ GeV. The DØ collaboration selects di-photon events ($p_T^\gamma > 25$ GeV) in a 1.1 fb^{-1} data set [11]. SM background from direct photon production and from jets misreconstructed as photons are suppressed by requiring the di-photon transverse momentum to be larger than 35 GeV. In the described scenario a lower limit on the Higgs mass is obtained at $m_h > 100$ GeV. The search extends the parameter region probed by the LEP experiments in the case of large BR($h_f \to \gamma\gamma$) (Fig. 6).

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REFERENCES

1. DØ Collaboration, *Nucl. Instrum. Meth.* **A565**, 463 (2006).
2. T. Junk, *Nucl. Instrum. Meth.* **A434**, 435 (1999).
3. M. Carena, S. Heinemeyer, C. Wagner, and G. Weiglein, *Eur. Phys. J.* **C26**, 601 (2003).
4. M. Carena, S. Heinemeyer, C. Wagner, and G. Weiglein, *Eur. Phys. J.* **C45**, 797 (2006).
5. DØ Collaboration, *Phys. Rev. Lett.* **101**, 071804 (2008).
6. T. Scanlon, FERMILAB-THESIS-2006-43 (2006).
7. DØ Collaboration, arXiv:0805.3556 [hep-ex] (2008), submitted to Phys. Rev. Lett.
8. DØ Collaboration, DØ Note 5246-CONF (2006).
9. DØ Collaboration, DØ Note 5727-CONF (2008).
10. DØ Collaboration, *Phys. Rev. Lett.* **101**, 071803 (2008).
11. DØ Collaboration, arXiv:0803.1514 [hep-ex] (2008), accepted by Phys. Rev. Lett.