Search for Supersymmetric Neutral Higgs Bosons at the Tevatron

Tim Scanlon [a,b]

Imperial College London, Blackett Laboratory, Physics Department, Prince Consort Road, London SW7 2AZ, United Kingdom.

Abstract. Recent preliminary results obtained by the CDF and DØ 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 1 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 (CL) are presented.

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1 Introduction

The search for Higgs bosons is one of the main challenges for particle physics and as such a high priority for the upgraded CDF and DØ detectors at Run II of the Tevatron. Higgs boson production cross sections in the Standard Model (SM) are small at the Tevatron. However many models beyond the SM, including Supersymmetry, predict larger Higgs production cross sections, some within reach even with the present data sets.

The Minimal Supersymmetric extension of the SM (MSSM) [1] introduces two Higgs doublets and so contains five physical Higgs bosons. Two of them are CP-even scalars, h and H, of which h is the lighter and SM like. The other three consist of a charged Higgs pair, $H^{\pm}$, and a CP-odd scalar, A, the mass of which (m_A) is one of the two free parameters of the model 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, tanβ, the ratio of the two vacuum expectation values of the Higgs doublets. Large values of tanβ thus result in significantly increased production cross sections compared to the SM. Moreover, in the large tan β limit one of the CP-even scalars and the CP-odd scalar are degenerate in mass, leading to a further cross section enhancement. The main production mechanisms for such neutral Higgs bosons are the $gg, b\bar{b} \rightarrow \phi$ and $gg, q\bar{q} \rightarrow \phi + b\bar{b}$ processes, where $\phi = h, H, A$. The branching ratio of $\phi \rightarrow b\bar{b}$ is around 90% and $\phi \rightarrow \tau^+\tau^-$ is around 10%. The overall experimental sensitivity is however similar for the two channels, due to the lower background in the τ channel.

[a] *Email: tim.scanlon@imperial.ac.uk*

[b] *On behalf of the CDF and DØ Collaborations.*

Other extensions to the SM such as Top-color [2] or Fermiophobic Higgs models [3] also lead to enhanced decays of Higgs $\rightarrow \gamma\gamma$ which is negligible in the SM.

There are consequently a number of non-SM Higgs searches already being actively pursued with the first fb^{-1} of data collected during Run II. This note summarises these analyses. All results are preliminary and more information is available from the public pages of CDF and DØ [4,5].

2 Limits on neutral SUSY Higgs at high tanβ

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

The main background sources in this channel are $Z \rightarrow \tau^+\tau^-$ (irreducible), $W+$ jets, $Z \rightarrow \mu^+\mu^-/e^+e^-$ with multi-jet and di-boson events also contributing. DØ has performed a search in the channel where one of the τ leptons decays to a μ. The event selection requires only one isolated muon, separated from the hadronic τ with opposite sign. The τ identification is performed with a neural network. A 20 GeV cut on M_W, the reconstructed W boson mass, removes most of the remaining W background. The final separation of signal from background is achieved with a set of neural networks, optimized for different Higgs masses and trained on the visible mass, m_{vis}, and τ and μ kinematics. The data are found to be in good agreement with the background-only expectation. Fig. 1 shows the resulting 95 % CL exclusion in the tan$\beta - m_A$ plane.

CDF has performed a similar search, including channels where one τ lepton decays to an electron. The event selection includes an isolated electron/muon, τ identification with a variable cone-size algorithm and

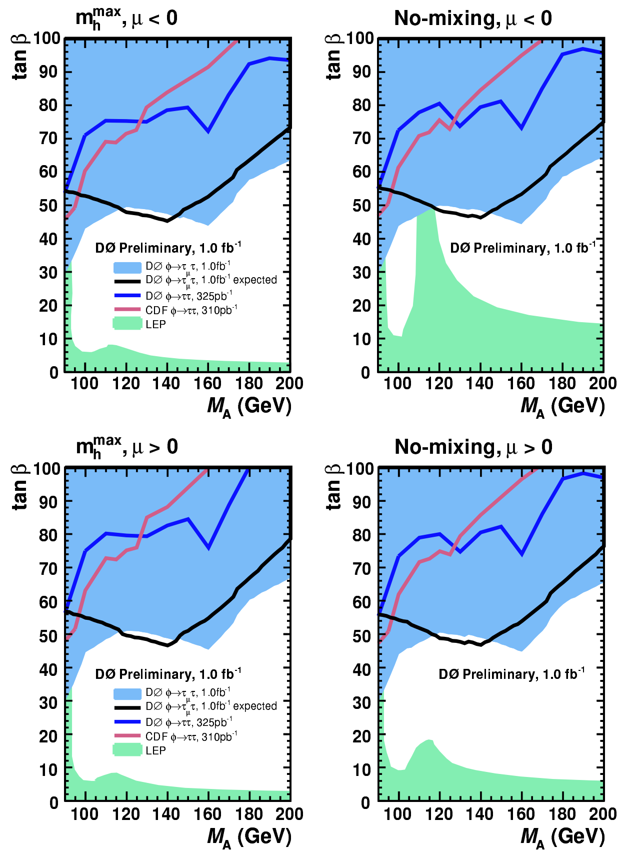

Fig. 1. Excluded region in the $\tan\beta - m_A$ plane from DØ for a negative (upper) and positive (lower) mass parameter (μ) in the m_h^{max} (left) and no-mixing (right) scenarios, along with the LEP limit [6] and the previous CDF [7] and DØ [8] results for $\phi \to \tau\tau$. These two scenarios are defined by the MSSM parameters in Fig. 2.

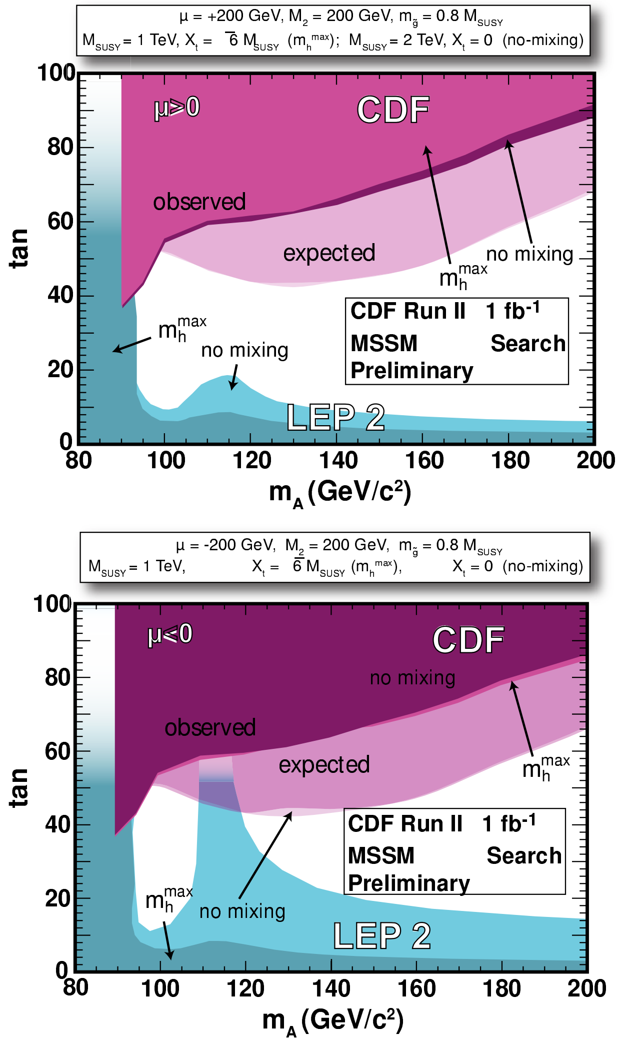

Fig. 2. Excluded region in the $\tan\beta - m_A$ plane from CDF in the m_h^{max} and no-mixing scenarios for the cases of a positive (upper) and negative (lower) mass parameter, along with the LEP limit [6].

jet background suppression with a cut on the scalar sum of the lepton transverse momentum (p_T), muon p_T and missing transverse energy ($\not\!\!E_T$). Most of the W background is removed by cuts on the relative directions of the visible τ decay products and the missing $\not\!\!E_T$. Limits on cross section times branching ratio and exclusion regions are derived from the m_{vis} distribution, the latter is shown in Fig. 2 in the $\tan\beta - m_A$ plane. Due to a small excess in the region of 130 GeV $< m_{vis} <$ 160 GeV, the limits are weaker than expected. However, when all channels ($e\tau, \mu\tau, e\mu$) and possible search windows are considered the significance of the observed excess is found to be less than two standard deviations.

2.2 Higgs $+ b \to b\bar{b}b$

DØ has carried out a search in this channel using a multi-jet event sample corresponding to an integrated luminosity of 0.9 fb^{-1}. Candidate events are required to contain at least three jets with $p_T > 15$ GeV, the leading jet must further be above 40 GeV and the second jet above 25 GeV. At least three jets must be identified as b-jets by the standard DØ neural network b-tagging algorithm [9]. A signal is searched for in the invariant mass spectrum of the two leading b-tagged jets. The simulation of signal and background is performed with PYTHIA [10] or ALPGEN [11] interfaced with PYTHIA and passed through the detailed detector simulation. The dominant background is multi-jet production and is estimated from the data outside the signal search region. The signal acceptance is found to be 1.7-2.6% depending on the Higgs mass. As no significant excess is observed, limits are set. Cross sections down to 20 pb are excluded for Higgs masses up to 170 GeV.

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

A single muon event sample collected by DØ, corresponding to an integrated luminosity of 0.3 fb^{-1}, is used to search for the final state where one τ decays hadronically and the other to a μ. Candidate events are required to have one μ with a $p_T > 12$ GeV, a hadronic τ with an opposite sign to the μ, which is identified by using a neural network, and at least one b-jet with $p_T > 15$ GeV, identified using an impact parameter b-tagging tool. The three major backgrounds are QCD multi-jet production, $Z + jets \to \mu\tau + jets$ and $t\bar{t} \to b\bar{b}\mu\tau$. The QCD multi-jet and Z+jets backgrounds are estimated from data and the other backgrounds are simulated using ALPGEN interfaced with PYTHIA. The signal is simulated using PYTHIA. After b-tagging the largest contribution is from $t\bar{t}$ events, which are removed using a neural network based upon kinematic variables. In the absence of any excess limits are set using the invariant mass distribution, calculated from the 4-vectors of the μ, hadronic τ and missing E_T. Fig. 1 shows the resulting 95 % CL exclusion in the tan$\beta - m_A$ plane.

3 Limits on non-SM Higgs $\to \gamma\gamma$

Though the Higgs to photon branching ratio is negligible in the SM, some extensions predict a significantly larger value. A fermiophobic Higgs does not couple to fermions at all and a Top-color Higgs has zero coupling to all fermions except the top quark. Such models would hence result in an enhanced rate of Higgs bosons decaying to photons.

DØ has searched for Higgs bosons in $3\gamma + X$ final states in data corresponding to an integrated luminosity of 0.8 fb^{-1}. The event selection includes three isolated photons with $E_T > 15$ GeV within $|\eta| < 1.1$ (central calorimeter). The combined transverse momentum of the three photons is further required to be larger than 25 GeV. 0 events are selected with a total expected background of 1.1$\pm$0.2 events. The background is dominated by direct triple photon production with a small contribution from QCD and $Z/W+X$ processes. No excess is observed and hence excluded fermiophobic Higgs masses are calculated. This search excludes a fermiophobic Higgs below 80 GeV for a charged Higgs mass below 100 GeV and tan$\beta = 30$.

4 Conclusions

The preliminary results presented at this conference by the CDF and DØ collaborations, together with the recent performance of the experiments and the Tevatron, are very encouraging for the Higgs searches at Run II. The 1 fb^{-1} searches for Higgs bosons beyond the SM, in the MSSM scenario and other extensions, show very promising sensitivity and have already produced new powerful limits on $h/H/A \to \tau\tau/b\bar{b}$ and $h \to \gamma\gamma$. New MSSM results can be expected from both experiments shortly, with both more data and improvements to the analyses themselves. Work will also focus on combining the complimentary results from the different channels and from both experiments.

Having successfully accomplished analyses of the first fb^{-1} of Run II data, CDF and DØ are confidently looking forward to exploring the almost 3 fb^{-1}

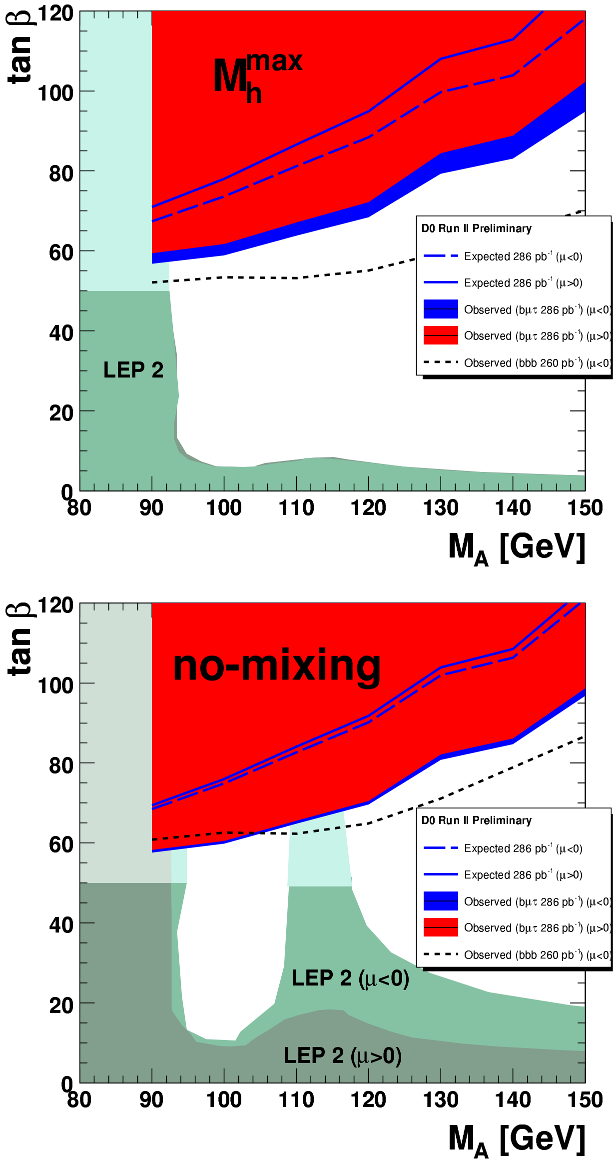

Fig. 3. Excluded region in the tan$\beta - m_A$ plane in the m_h^{max} (upper) and no-mixing (lower) scenarios along with the LEP limit [6] and previous DØ [12] limits for $\phi b \to b\bar{b}b$. The two scenarios are defined by the MSSM parameters in of Fig. 2.

of data per experiment which has already been written to tape, and the ∼8 fb^{-1} total per experiment expected by the end of Run II.

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