Searches for non-SM Higgs Bosons at the Tevatron

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Extensions of the Standard Model (SM) predict Higgs phenomenology which can be quite different from that expected within the SM. This contribution discusses the latest results from searches for Higgs bosons by the DZero and CDF experiments at the Tevatron in several non-SM scenarios: supersymmetry, left-right symmetric (Higgs-triplet), and fermiophobic.

1 Introduction

The Tevatron accelerator at Fermilab has performed very well in recent years, delivering over 3.5 fb^{-1} of data. The DZero and CDF experiments are using this data to study many questions at the forefront of high-energy physics. A central goal is the understanding of electro-weak symmetry breaking, which gives the W and Z bosons mass while leaving the photon massless. In the SM, electro-weak symmetry breaking is delivered via the Higgs mechanism, which predicts a single neutral spin-0 boson - the Higgs boson. Extensions to the SM, such as supersymmetry, predict different productions and/or decays of the Higgs boson and often a richer spectrum of multiple Higgs bosons.

We will discuss first the most anticipated extension to the SM, supersymmetry. Both DZero and CDF have specifically tuned searches for the new neutral Higgs boson(s) of supersymmetry, in the $bh \to bbb$, $h \to \tau\tau$, and $bh \to b\tau\tau$ channels. Next we show the results for left-right symmetric or Higgs-triplet models, which predict a doubly-charged Higgs boson, H^{++}. Finally, DZero has considered the case where the Higgs prefers not to decay to fermions, the so-called fermiophobic scenario, leaving open the $h \to \gamma\gamma$ channel as the main decay mode for a low-mass Higgs boson.

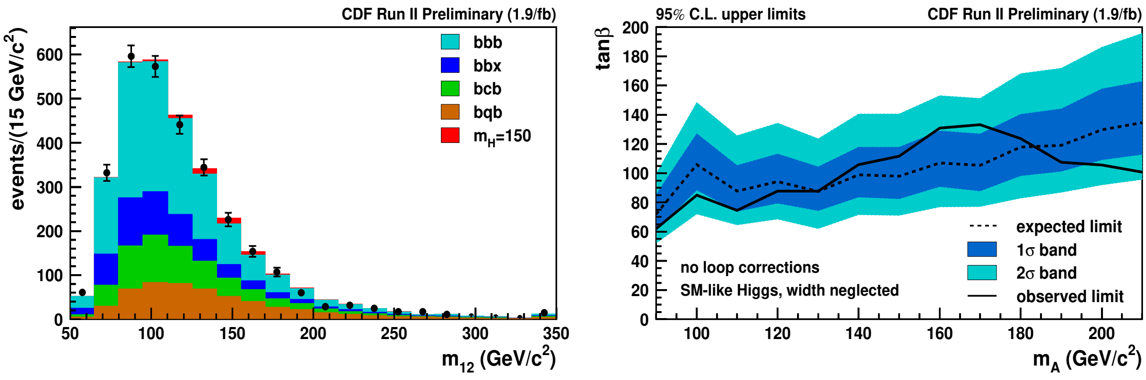


Figure 1: The di-jet invariant mass spectrum in bbb events and corresponding limits in the m_A - $tan\beta$ parameter space of the MSSM from the CDF $bh \rightarrow bbb$ analysis.

2 Searches in the MSSM at high $tan\beta$

In two-Higgs-doublet models of electro-weak symmetry breaking, such as the minimal supersymmetric extension of the standard model (MSSM) [1], there are five physical Higgs bosons: two neutral CP-even scalars, h and H, with H being the heavier state; a neutral CP-odd state, A; and two charged states, $H^{\pm}$. The ratio of the vacuum expectation values of the two Higgs fields is defined as $tan\beta = v_u/v_d$, where v_u and v_d refer to the fields that couple to the up-type and down-type fermions, respectively. At tree level, the coupling of the A boson to down-type quarks, such as the b-quark, is enhanced by a factor of $tan\beta$ relative to the SM, and the production cross section is therefore enhanced by $tan^2\beta$ [2]. At large $tan\beta$, this is also true either for the h or H boson depending on their mass. At high $tan\beta$, the h/H and A decay roughly 90% to bb and 10% to $\tau\tau$.

The dominant decay to bb is unfortunately drowned by QCD background, but due to the enhanced coupling to b-quarks the h/H and A are also produced in association with one or more b-quarks, opening the channel $bh \rightarrow bbb$. Both DZero and CDF have performed searches for an excess in the di-jet invariant mass spectrum of the bbb final state. CDF's latest results are shown in Figure 1, using 1.9 fb^{-1} of data. The dijet mass spectrum of the heavy flavor multi-jet background is derived from double-tagged data in a manner that accounts for tagging biases and kinematic differences introduced by the addition of the third tag. No excess is observed for any di-jet invariant mass window, so limits are placed in the Higgs mass vs. $tan\beta$ parameter space.

The subdominant decay of the h/H or A to $\tau\tau$ is much cleaner, so both DZero and CDF have searched for direct $h \rightarrow \tau\tau$ excesses, see Figures 2 and 3. The main background is from $Z \rightarrow \tau\tau$, which is essentially irreducible.

At DZero, a set of Neural Networks (NN) are trained to identify tau decays from jet backgrounds, for each of 3 tau types (charged pion-like, pion + EM shower-like, and 3-prong). One of the taus is required to decay to a muon, for triggering and to reduce QCD background. The QCD background is determined by comparing same-sign vs. opposite-sign candidates. Some loose selection cuts remove W backgrounds, such as requiring the visible W mass <20 GeV. Finally, a set of NN's (one for each tau type) is used to separate signal from backgrounds. Good agreement is seen between data and expected background at high NN output, so limits are placed on the signals' cross-sections and interpreted in the Higgs mass vs. $tan\beta$ parameter space. CDF has performed similar analyses, but using in addition the e+tau and e+mu decay channels, as well as more data. No NN separation is employed, however.

By adding the requirement that there be an associated b-quark in the production, followed by the clean di-tau decay, $bh \rightarrow b\tau\tau$ has the highest signal / background of any high $tan\beta$ MSSM

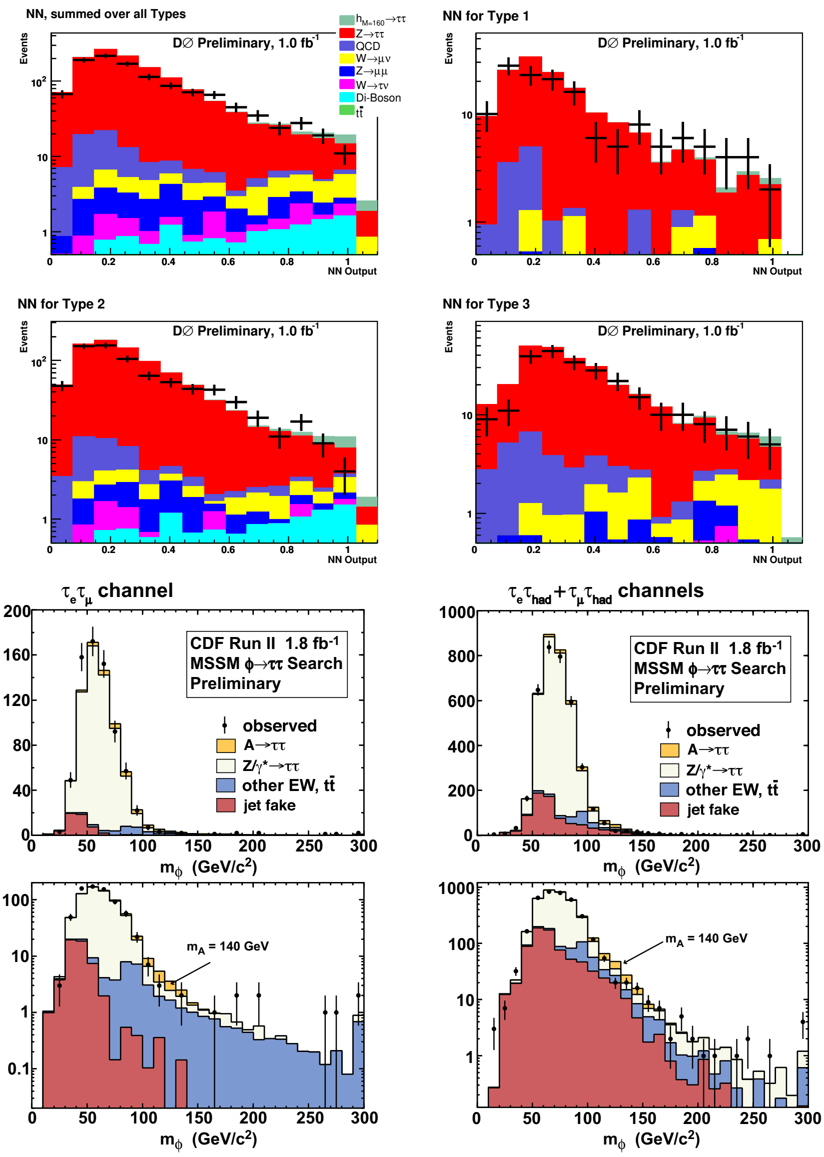


Figure 2: (top) NN outputs for all tau types (top left) and each tau type (see text) individually in the DZero $h \to \tau\tau$ analysis. (bottom) Visible mass distributions in the CDF $h \to \tau\tau$ analysis for the $e\mu$ and $lepton + \tau$ channels.

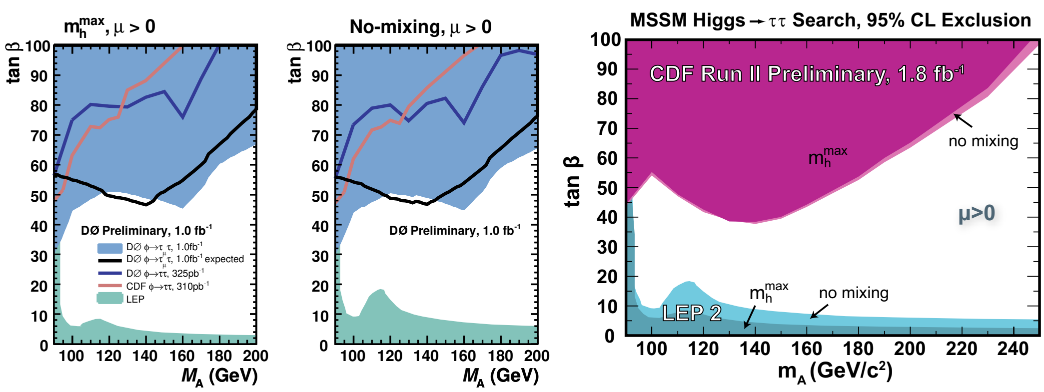


Figure 3: D0 (left) and CDF (right) limits in the m_A - $tan\beta$ parameter space of the MSSM from the $h \to \tau\tau$ analyses.

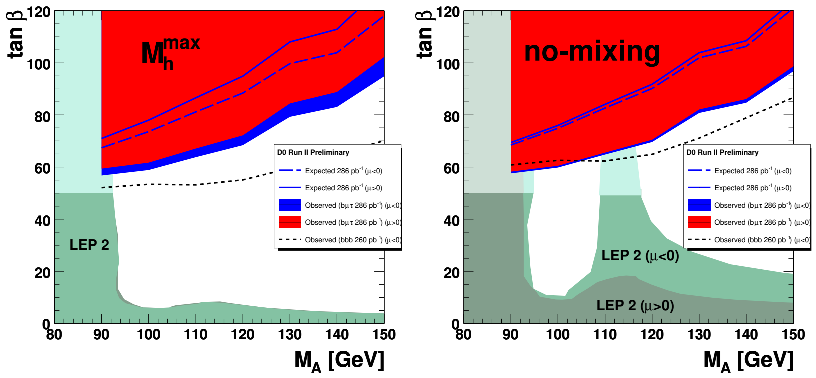


Figure 4: Limits in the m_A - $tan\beta$ parameter space of the MSSM from the DZero $bh \rightarrow b\tau\tau$ analysis.

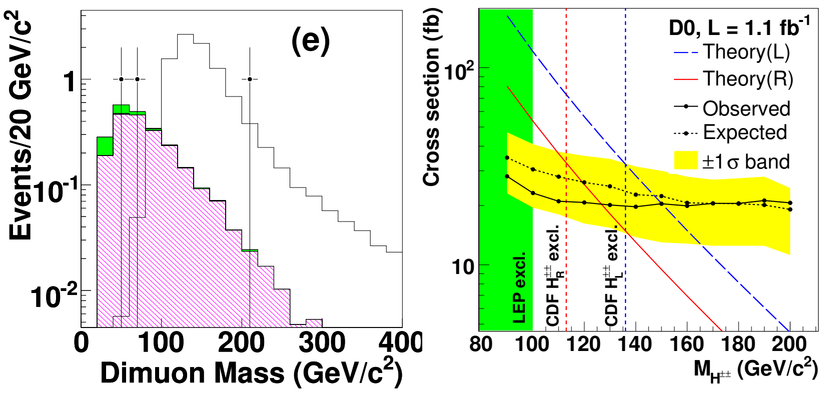
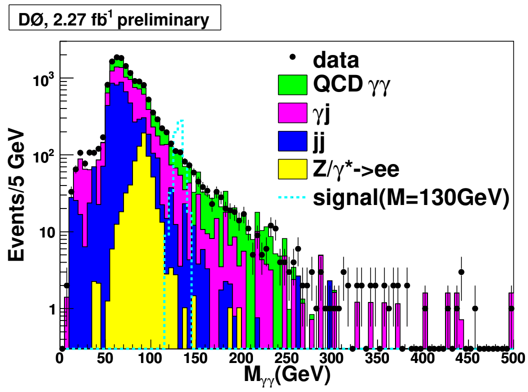


Figure 5: (left) Di-muon invariant mass spectrum in events with 3 muons. (right) Limits on the H^{++} mass for left- or right-handed Higgs bosons from the latest DZero search.

Higgs search. It also suffers from a low cross-section times branching ratio however. DZero has performed a search using just 344 pb^{-1} of data in this channel. Di-tau events are normalized to the $Z \rightarrow \tau\tau$ peak, and then an additional b-tagged jet is required with p_T >15 GeV. For a Higgs mass of 120 GeV and $tan\beta$=80, there are 5.3 signal events expected, with just 6.3 expected background events. Only 3 events are observed in data, and limits are placed in the Higgs mass vs. $tan\beta$ plane, as seen in Figure 4, competitive with the other channels.

3 Searches for $H^{++}H^{--}$

Many models of beyond-SM Higgs physics predict a doubly-charged Higgs boson, H^{++}, such as left-right symmetric models, Higgs-triplet models, and little-Higgs. DZero has recently updated its search for pair-produced $H^{++}H^{--}$, using 1.1 fb^{-1} of data. 3 muons are required, with p_T >15 GeV. At least one pair must have an invariant mass >30 GeV and $\Delta\phi$ <2.5 radians, to reduce backgrounds from QCD and Z decays. 3 events are observed in data, for an expectation of 3.1 events from backgrounds, and thus limits are set on the H^{++} mass as shown in Figure 5. Left-handed doubly-charged Higgs bosons, H_L^{++} have a larger production cross-section than right-handed, H_R^{++}, by about a factor of 2, due to their different coupling to the intermediate Z boson. Thus, the limit on the mass of H_L^{++} (>150 GeV) are higher than on H_R^{++} (>127 GeV).



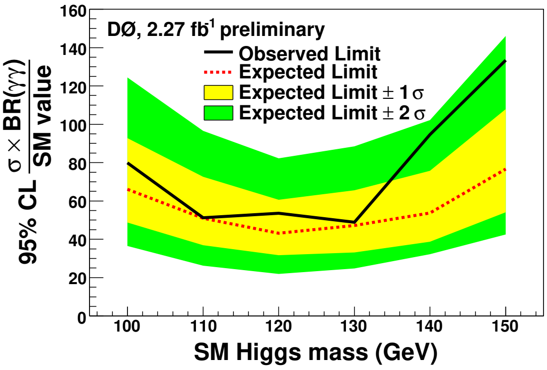


Figure 6: (left) Di-photon invariant mass spectrum and (right) limits on the $h \to \gamma\gamma$ cross-section in units of the SM cross-section from the latest DZero di-photon analysis.

4 Searches for $h \to \gamma\gamma$

Although the SM Higgs boson decays to the di-photon final state with a small branching ratio, this decay channel could be subject to a large enhancement in models where the Higgs does not couple strongly to fermions. In this case, fermion masses could arise from some other source. DZero has recently completed a search using 2.3 fb^{-1} of data for $h \to \gamma\gamma$. 2 isolated photons with p_T >25 GeV are required. QCD jets faking photons are estimated by looking at the calorimeter shower-shape correlations between the two photons in each event, and samples are divided into QCD di-jet, photon+jet, and di-photon backgrounds. $Z \to ee$ also contributes near the Z mass. Data agree very well with estimated backgrounds, and no significant excess is seen at any di-photon invariant mass range. Limits are therefore set on the cross-section times branching ratio for $h \to \gamma\gamma$ and are compared to the expected cross-section times branching ratio in the SM, as shown in Figure 6. The current analysis can exclude down to about 50 times the SM event rate at 120 GeV and in fact also contributes non-negligibly to the SM Higgs search.

5 Conclusions

CDF and DZero have searched for Higgs bosons in several models beyond the SM: the MSSM at high $tan\beta$ in b and τ channels, for doubly charged Higgs, and for fermiophobic Higgs. No significant excesses or deviations indicative of non-SM Higgs signatures have been seen so far. But the Tevatron experiments expect to more than double their data samples in the next two years, hone their search strategies, and enlarge the variety of models considered.

Acknowledgments

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References

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