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Tevatron searches for Higgs bosons beyond the standard model *

Jason Nielsen (representing the CDF and DØ collaborations)
Santa Cruz Institute for Particle Physics
University of California, Santa Cruz, CA 95064, U.S.A.

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Abstract

Theoretical frameworks beyond the standard model predict a rich Higgs sector with multiple charged and neutral Higgs bosons. Both the CDF II and DØ experiments at the Tevatron have analyzed $1\,\mathrm{fb}^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$ in search of Higgs boson production. A complete suite of results on searches for neutral, charged, and fermiophobic Higgs bosons limit the allowed production rates and constrain extended models, including the minimal supersymmetric standard model.

1 Introduction

The standard model introduces a single complex scalar doublet which is manifested as a single physical Higgs boson after electroweak symmetry breaking. In contrast, many models beyond the standard model are two Higgs doublet models (2HDM) which predict three neutral Higgs bosons (h, H, A) along with charged Higgs bosons (H^+, H^-). Tevatron searches for Higgs bosons beyond the standard model all assume a CP-conserving Higgs sector, and nearly all interpret search results in the context of a minimal supersymmetric standard model (MSSM) [1].

2 Searches for neutral Higgs bosons

Even though the LEP2 experiments completely exclude A and h mass values $m_\phi < 93\,\mathrm{GeV}/c^2$ for low values of $\tan\beta$, the final search results are kinematically limited by the center-of-mass energy [2]. The Tevatron experiments are sensitive

*Presented at the Hadron Collider Physics Symposium 2007 in La Biodola, Elba, Italy to higher-mass Higgs boson production, especially for high $\tan\beta$ values which imply enhanced Higgs boson couplings to b quarks and τ leptons. Efficient τ lepton identification and b-jet tagging are therefore key elements of Higgs boson searches beyond the standard model.

Even though the light MSSM Higgs bosons decay predominantly to $b\bar{b}$ pairs, the single scalar production $gg \to \phi^0 \to b\bar{b}$ is indistinguishable above the large non-resonant $b\bar{b}$ background. Searches focused on associated Higgs production $\phi^0 b(b)$ benefit from a more favorable signal-to-background ratio. A DØ analysis of triple-b-tagged events in a $880\,\mathrm{pb}^{-1}$ dataset searches for resonant production in the invariant mass distribution of the two leading jets. [3]. The triple-tagged background is estimated by calculating a b-tagging rate from the large double-tagged sample and applying this rate to all events in the dijet mass distribution. This method of estimating background gives results consistent with predictions from Monte Carlo calculations. An overall background normalization factor is derived from fits to the sidebands, outside the sliding signal mass region for each Higgs boson mass hypothesis. The comparison of expected background and observed data (Figure 1) shows reasonable agreement, not worse than 2 standard deviations for all Higgs boson masses less than $170\,\mathrm{GeV}/c^2$. As a result, Higgs boson production rates greater than 20 pb are excluded in this channel. In the MSSM parameter space these rates correspond to $\tan\beta$ values greater than 50 or 80 for $m_A = 100\,\mathrm{GeV}/c^2$ or $150\,\mathrm{GeV}/c^2$, respectively.

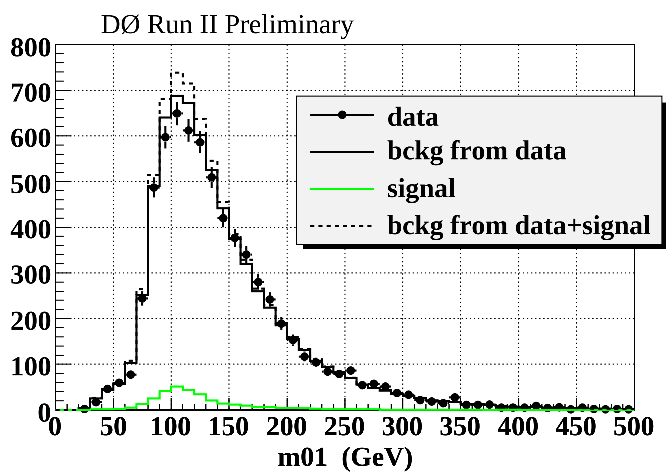

Figure 1: Invariant mass of two leading jets in triple-tagged DØ jet sample equivalent to $880\,\mathrm{pb}^{-1}$. Background contributions have been normalized to the data using sideband regions outside the expected signal contribution. The green line shows the expectation for a Higgs boson signal, assuming $m_\phi = 120\,\mathrm{GeV}/c^2$ and $\tan\beta = 60$.

Both CDF and DØ have also reported on searches for direct Higgs boson production with decays to tau lepton pairs [3, 4]. The CDF τ identification is based on track-based reconstruction using a double-cone isolation method, while the DØ analysis relies on a neural network τ filter operating on mini-jets. The Tevatron searches currently reconstruct a candidate visible mass from the visible τ components and missing transverse energy. (A full mass reconstrcution using missing E_T partitioning would require a subsample of back-to-back τ pairs and a corresponding loss of acceptance.) CDF observes an excess at the two standard deviation level in the $\tau \to \ell, \tau \to$ hadrons channel, consistent with $m_A = 160\,\mathrm{GeV}/c^2$ and $\tan\beta \approx 70$ (Fig. 2). However, this excess is narrower

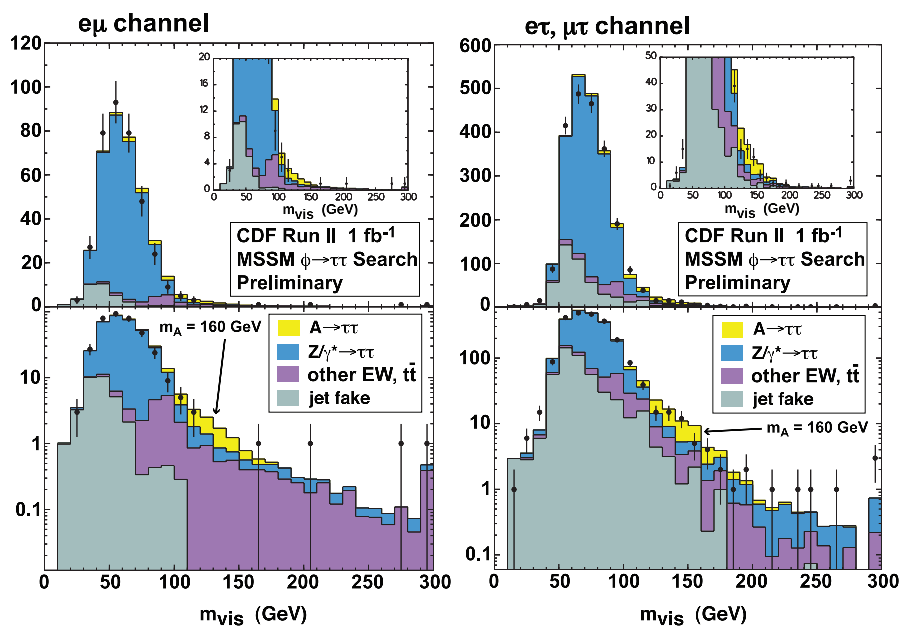

Figure 2: Visible mass in di-tau events from the CDF $\phi \to \tau^+\tau^-$ search. Separate distributions are shown for the fully leptonic final state (left) and the semi-hadronic final state (right).

than the expected di-tau mass resolution and is likely a statistical fluctuation. In fact, the DØ results for the $\phi^0 \to \tau\tau$ search using the same sample size show a deficit relative to the expected background at the same place in the visible mass distribution. As a result, DØ excludes any Higgs production interpretation of the CDF results at greater than 95% confidence level, as shown in Fig. 3.

Finally, DØ has searched for associated Higgs production with subsequent decay to tau lepton pairs $\phi^0 b \to \tau\tau b$ in a $344\,\mathrm{pb}^{-1}$ dataset [3]. This search complements the $bbb(b)$ analysis well, since the $\tau\tau$ decay channel may be enhanced for certain models in which the $b\bar{b}$ channel is suppressed. After a kinematic neural network filter removes $t\bar{t}$ dilepton events, only 6.3 ± 0.4 background events

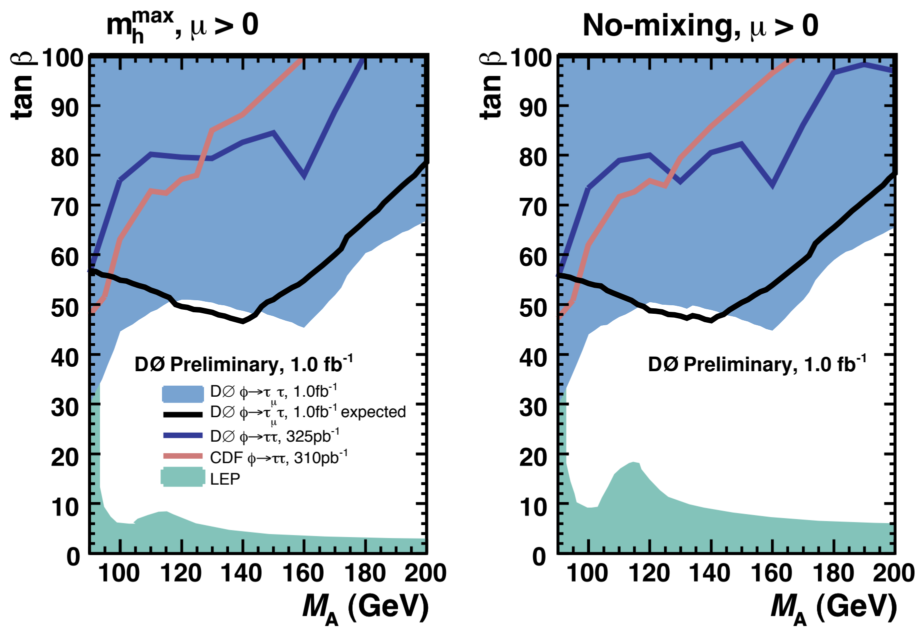

Figure 3: Interpretation of DØ $\phi^0 \to \tau^+\tau^-$ search results in the MSSM, assuming $\mu > 0$ with the extreme stop mixing scenarios defined in Ref. [5].

are expected. A slight deficit in the event count (3 events observed) yields an exclusion comparable to the $bbb(b)$ result in the same dataset.

3 Searches for charged Higgs bosons

If the charged Higgs boson is light enough, it may be produced in top quark decays $t \to bH^+$. Since the dominant H^+ decays are to $\tau\nu_\tau$ and cs, any such charged Higgs production can modify the relative final state ratios expected from standard model top quark production. For example, the relative ratio of τ leptons may be enhanced relative to the e/μ states, or the leptonic final states may be enhanced relative to the semileptonic states. A dedicated CDF analysis scans the MSSM parameter space to test the compatibility of the observed ratios between all final states with the expectation from charged Higgs production [6]. The results, shown in Fig. 4, extend the charged Higgs mass exclusion to $160\,\mathrm{GeV}/c^2$ for $\tan\beta$ values less than 0.5 or greater than 70.

CDF has also completed a direct search for $\ell\nu\tau\nu bj$ production in the $335\,\mathrm{pb}^{-1}$ dataset. The small allowed rate effectively limits the product $\mathcal{B}(t \to H^+b) \times \mathcal{B}(H^+ \to \tau\nu)$, excluding branching ratio products greater than 0.5 for $80 < m_{H^+} < 120\,\mathrm{GeV}/c^2$.

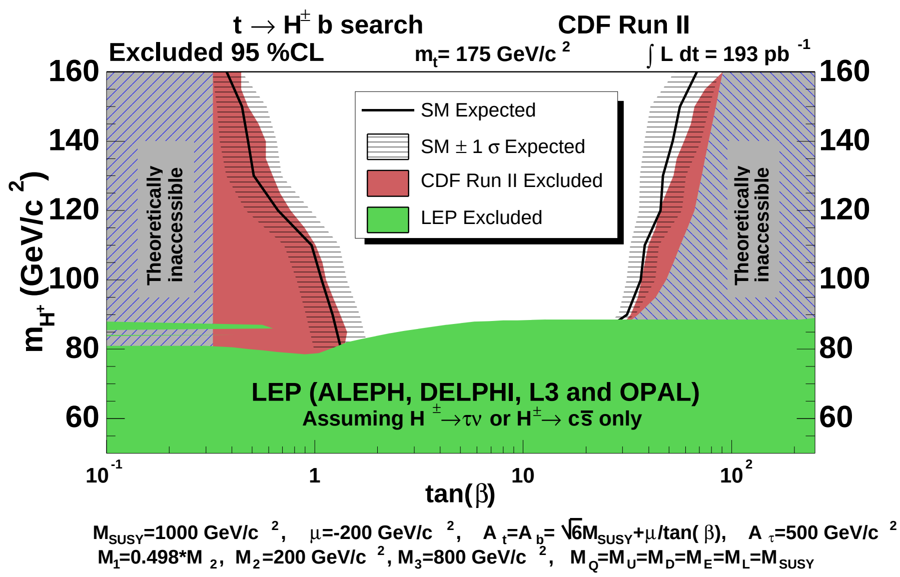

Figure 4: Charged Higgs mass exclusions obtained from compatibility scan of observed final states in top quark pair production and decay, interpreted in the "maximal mixing" scenario of the MSSM.

4 Search for fermiophobic Higgs bosons

Previous LEP2 results on fermiophobic Higgs boson production are weakened if the $h_f VV$ coupling is less than the standard model prediction. Light fermiophobic Higgs bosons may be observed in H^+ decays at the Tevatron via the process $p\bar{p} \to h_f H^+ \to h_f h_f W^+ \to \gamma\gamma\gamma(\gamma) + X$, a process unique to hadron colliders. The DØ collaboration have placed limits on 3γ production beyond the standard model expectation [3]. Dominant backgrounds for the 3γ final state are falsely-identified photons from $Z\gamma$ or $W\gamma\gamma$ production as well as direct diphoton production combined with an ISR/FSR photon. The latter is calculated using a rate $N_{3\gamma}/N_{2\gamma}$ determined from simulation, normalized to the observed 2γ data. The resulting exclusions translate to mass limits in a specific 2HDM for which $\mathcal{B}(h_f \to \gamma\gamma) \approx 1$ and $\mathcal{B}(H^+ \to h_f W^+) \approx 1$. Then $m_{h_f} \geq 50\,\mathrm{GeV}/c^2$ for $m_{H^+} \leq 150\,\mathrm{GeV}/c^2$, and $m_{h_f} \geq 80\,\mathrm{GeV}/c^2$ for $m_{H^+} \leq 100\,\mathrm{GeV}/c^2$, both for $\tan\beta = 30$.

5 Conclusion

There are no clear signs of Higgs boson production in any of the current Tevatron search results, although a couple of analyses show isolated excesses in the reconstructed mass distributions at the level of two standard deviations. The consequent rate exclusions can be used to constrain the Higgs sector of possible models, and future searches at the Tevatron with larger datasets should have increased sensitivity to Higgs boson production beyond the standard model.

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