SEARCHES FOR BSM HIGGS AT THE TEVATRON

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In this paper, we present the latest results of the searches for beyond standard model Higgs boson production at the Tevatron collider of Fermilab. Analyses have been carried out on samples of about 1-4 fb$^{-1}$ of data collected by the CDF and DØ detectors. In particular, Higgs bosons in supersymmetric models and fermiophobic scenario have been investigated, and limits on production cross sections and theory parameters have been established.

1 Introduction

The CDF and DØ experiments are finally reaching sensitivity to a standard model Higgs boson production in $p\bar{p}$ collisions at the Tevatron. Nevertheless, no hint for Higgs has been observed yet. Moreover, the experiments can not still probe the low mass region $M_H < 160$ GeV/c$^2$ which is favorite by the fit to the electroweak observables.

Searches for Higgs boson production in the context of beyond standard model theories are then well motivated and have been carried out both from CDF and DØ collaborations. We will summarize here the latest results, by focusing on four different scenarios: neutral Higgs bosons in the minimal supersymmetric standard model (MSSM), charged Higgs bosons, Higgs in the next to minimal supersymmetric standard model (nMSSM), and fermiophobic Higgs bosons.

2 Neutral Higgs Bosons in the MSSM

The MSSM requires the existence of two isodoublets of Higgs fields, which couple to up-type and down-type fermions respectively. Out of the eight degrees of freedom, three are absorbed by the masses of the $Z$ and $W$ bosons, and five are associated to new scalar particles: three neutral Higgs bosons ($h$, $H$, $A$) and two charged ones ($H^{\pm}$). At tree level, Higgs phenomenology in the MSSM is described by two parameters: the ratio $\tan \beta$ of the vacuum expectation values of the Higgs doublets, and the mass $m_A$ of the pseudoscalar boson $A$.

The couplings of neutral Higgs bosons to bottom quark $b$ and tau $\tau$ (down-type fermions) scale as $\tan \beta$ with respect to standard model value. For $\tan \beta \sim 1$, therefore, limits on standard model Higgs production apply to neutral Higgs in MSSM too. At high values of $\tan \beta$, production processes involving $b$ quarks are enhanced of a factor $\tan^2 \beta$. Moreover, the pseudoscalar boson $A$ becomes degenerate with either one of the other neutral Higgs particles, which provides a further enhancement of the searched signal. Finally, in the high $\tan \beta$ region the neutral Higgs bosons decay dominantly into $b\bar{b}$ ($\text{Br} \sim 90\%$) or $\tau^+\tau^-$ ($\text{Br} \sim 5-13\%$) pairs.
The CDF and DØ collaborations looked for signal of MSSM neutral Higgs boson production both inclusively and in association with a bottom quark. While offering a higher cross section, the inclusive production can only be exploited in the decay mode to taus, due to the high background from QCD processes which can mimic a $b\bar{b}$ signal. Associated production has been instead investigated both in the $\tau^+\tau^-$ and $b\bar{b}$ decay channels. The reconstruction of the hadronic decays of the tau and the identification of jets coming from b quark hadronization are key ingredient of these searches. Upper limits on production cross sections can be interpreted as exclusion regions in the plane $m_A$-$\tan \beta$. Since at higher order other parameters of the MSSM become important for Higgs phenomenology, a particular set (benchmark scenario) for their values have to be considered when drawing the exclusion regions. Fig. 1 shows the results for the maximum Higgs mass and the no-mixing scenarios, and for Higgs mixing parameter $\mu = \pm 200$ GeV.

3 Charged Higgs Bosons

Searches for charged Higgs bosons $H^\pm$ have been carried out at the Tevatron experiments by looking in top quark samples. In particular, the CDF collaboration looked for the decay of top quark into charged Higgs and bottom quark in $tt$ pair production events. In order to reduce background, the other top was required to decay in a W boson which then decay to leptons, and the bottom quarks are required to be tagged. The charged Higgs is assumed to decay exclusively to quarks. This search is sensitive to MSSM production for $\tan \beta < 1$ and $M^\pm_H < 130$ GeV/c$^2$. By fitting the observed dijet mass distribution to $H^\pm \rightarrow q\bar{q}'$, $W^\pm \rightarrow q\bar{q}'$ and background templates, an upper limit on the branching ratio of the $t \rightarrow H^+b$ decay has been set as a function of the Higgs boson mass (see Fig. 2).

The DØ experiment searched for charged Higgs boson by using a different approach, which consists in computing the effects that a $t \rightarrow H^+b$ decay would have on the yields of events in the different $tt$ decay channels, and then comparing the expectations to the observed number of events to set limit on the branching ratio of top quark decay to charged Higgs boson. Fig. 3 shows the results in two scenarios for the Higgs decay: a tauonic model where the Higgs decays exclusively into tau and neutrino (which is equivalent to the MSSM for very high values of $\tan \beta$), and a leptophobic model assuming $\text{Br}(H^+ \rightarrow c\bar{s})= 100\%$ (realized by a general multi-Higgs-doublet model).
4 Higgs Bosons in the nMSSM

The nMSSM[6] adds a singlet superfield to the MSSM, allowing the theory to generate dynamically the mixing term $\mu H_u H_d$ in the Higgs sector, and solving in this way the $\mu$ problem. It also turns out to be the simplest supersymmetric model in which the electroweak scale originates only from the scale of supersymmetry breaking.

Two additional Higgs boson states appear in the nMSSM: a neutral CP-even Higgs $s$ and a CP-odd Higgs $a$. While the lightest CP-even Higgs boson $h$ remains SM-like in the nMSSM, its dominant decay may not be necessarily into a $b\bar{b}$ pair, since the mass of the new state $a$ is allowed to be small enough for the decay $h \rightarrow aa$ to become dominant. LEP limits on the mass of the $h$ boson can then be avoided if $M_a < 2m_b$, obtaining in this way a theory free from fine-tuning problems.

The DØ collaboration searched for the nMSSM process $h \rightarrow aa$. At low $M_a < 2m_\tau$, a 4 muon signature is required, and upper limits on $\sigma(p\bar{p} \rightarrow hX) \times \text{Br}(h \rightarrow aa) \times \text{Br}(a \rightarrow \mu^+\mu^-)^2$ at about 10 fb have been set. Assuming $\text{Br}(h \rightarrow aa) \approx 100\%$ and $M_h = 120 \text{ GeV}/c^2$, which correspond to a production cross section of 1000 fb within the SM, it should be $\text{Br}(a \rightarrow \mu^+\mu^-) \lesssim 10\%$ to avoid detection, while the nMSSM predicts a branching ratio for the decay $a \rightarrow \mu^+\mu^-$ greater than 10% for a boson mass up to $2m_c$, and, depending on the branching ratio of $a$ to charm quarks, possibly even up to $2m_\tau$. For $M_a > 2m_\tau$, the decay channel to $\mu^+\mu^-\tau^+\tau^-$ has been investigated and the limits set on Higgs production are still a factor of $\sim 4$ larger than predictions.

5 Fermiophobic Higgs Bosons

A fermiophobic Higgs boson would greatly enhance the sensitivity of the Tevatron experiments to Higgs production in the low mass region ($M_H \lesssim 130 \text{ GeV}/c^2$), where the dominant SM decay to $b\bar{b}$ provides a difficult signature due to the background from QCD processes. Theoretically, null (or highly suppressed) coupling of the Higgs boson to fermions could indicate a different origin for fermion and boson masses.

The benchmark fermiophobic model assumes the same Higgs couplings to gauge boson as in the SM, and no couplings to fermions. In such a scenario, Higgs direct production is forbidden, and productions in association with a $W$ or a $Z$ boson and via vector boson fusion become the dominant mechanisms.

The CDF and DØ collaborations looked for $WH \rightarrow WWW^*$ production in events with two leptons (electrons or muons) with the same charge. Observed limits on the production...
Figure 4: CDF and DØ upper limits on the Higgs associated production with a W boson times the branching ratio of Higgs decays to $W^+W^-$. Also shown are the predictions from the standard model and the benchmark fermiophobic model.

Figure 5: CDF upper limits on the production cross section times branching ratio for a fermiophobic Higgs boson decaying into photons, compared with benchmark model predictions.

cross section times the branching ratio for the decay $H \rightarrow W^+W^-$ are compared to SM and fermiophobic model predictions in Fig. 4.

Inclusive production of a Higgs boson decaying to photons has also been searched by the two experiments by exploiting the high resolution (about 3%) on the reconstructed mass of the diphoton system provided by their calorimeters. When comparing the observed limits on the production cross section to the benchmark model expectations, a lower limit on the mass of a fermiophobic Higgs boson is set at 106 GeV/c² (see Fig. 5).

6 Conclusions

The CDF and DØ collaborations looked actively for Higgs bosons in the context of physics beyond the standard model in about 1-4 fb⁻¹ of $p\bar{p}$ collisions at the Tevatron collider. Advanced techniques have been established and several limits on relevant parameters for different theories have been set, but no Higgs production signal has been observed yet.

Lot of improvements are to come: increased statistics (both experiments already have 5 fb⁻¹ of data on tape) and combination of different search channels and experiment results will enhance the sensitivity to Higgs production, eventually leading to new insights on the mechanism of electroweak symmetry breaking.

References

1. D. Acosta et al, PRD 71, 032001 (2005).
2. V. Abazov et al, Nucl. Instrum. Methods Phys. Res. A 565, 463 (2006).
3. arXiv:0903.4001v1 [hep-ex].
4. M. Carena et al, Eur. Phys. J. C 26, 601 (2003).
5. Y. Grossman, Nucl. Phys. B 426, 355 (1994).
6. U. Ellwanger et al, Nucl. Phys. B 492, 21 (1997).