BEYOND THE SM SCALAR BOSON SEARCHES AT THE TEVATRON

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Recent results from the Tevatron are reported on Higgs boson searches in models beyond the standard model (SM). The models include fermiophobic Higgs bosons, the extension of the SM to a fourth generation of fermions, supersymmetric scenarios and heavy Higgs boson cascade decays.

1 Introduction

Recent results on Higgs boson searches beyond the standard model (SM) are presented on behalf of the CDF and D0 collaborations. The data were collected at the Tevatron, a proton-antiproton collider with 1.96 GeV center of mass energy, using two general purpose detectors. Both detectors had similar structure with different particular advantages. While the CDF detector [1] had a larger volume for tracking of the charged particles, the D0 detector [2] had a hermetic liquid argon calorimeter and a muon detector with larger coverage inside an iron toroidal magnet. The Tevatron operation stopped on September 2011 after 10 years of running, delivering about 12 fb^{-1} integrated luminosity per experiment providing about 10 fb^{-1} of analyzable data for each of the collaborations.

2 Higgs boson searches in the extension of the SM to a fourth generation of fermions

A fourth generation of fermions in the SM is an interesting possibility, since it is not ruled out by precision electroweak data and it opens up new sources of CP violation. Moreover, in this model (SM4) the production cross section of the Higgs boson is enhanced by a factor of about 9 due to the additional heavy quarks in the fermion loop of the gluon-gluon fusion (ggH) which becomes an overwhelmingly dominant production process. The CDF and D0 experiments used in this study the event selection designed for the SM Higgs boson searches in the WW and ZZ

final states[3] extending the Higgs boson mass range up to 300 GeV. In doing so, they reoptimized the separation of the signal from the background since, contrary to the SM Higgs boson search, here both the vector boson fusion (VBF) and the associate production of the Higgs particle with a vector boson (VH) are ignored.

Since no excess was observed above the background expectation, a limit was set on the cross section of the Higgs particle produced in ggH and decaying into a WW pair in the SM4 model, assuming that the ratio of the branching fractions $BR(H \longrightarrow WW)/BR(H \longrightarrow ZZ)$ is the same as in the SM. Two scenarios have been considered: in the low mass scenario the fourth generation charged and neutral lepton masses are close to their experimentally determined lower bounds: $m_{l4} = 100$ GeV and $m_{\nu 4} = 80$ GeV, whereas in the high mass scenario they are both equal to 1 TeV. In both cases the fourth generation quark masses are set to $m_{u4} = 450$ GeV and $m_{d4} = 400$ GeV. Figure 1 shows the combined observed and expected cross section times BR upper limits at 95% CL, expressed in units of the theoretical cross section of the low mass scenario. From there the following mass ranges can be excluded for the Higgs boson in the SM4 model: 120–224 GeV (observed), 118–274 GeV (expected) and 120–232 GeV (observed), 118–291 GeV (expected) in the low and high mass scenarios, respectively.

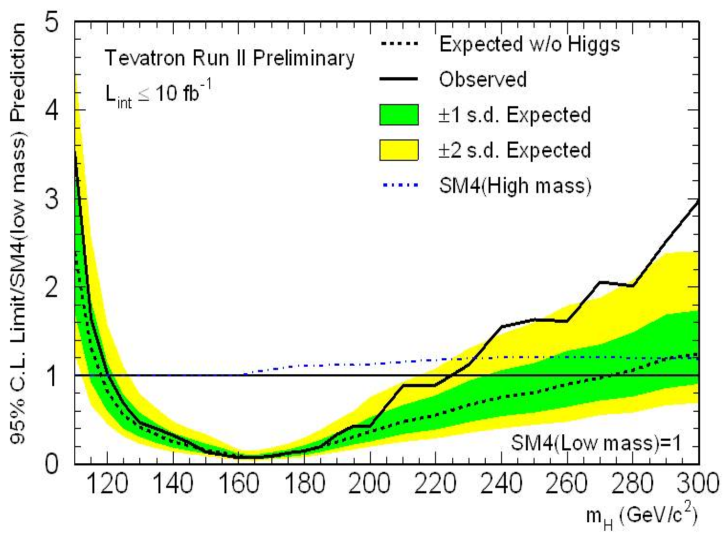

Figure 1: Observed (solid line) and expected (dotted line) 95% CL cross section times BR upper limits of the Higgs boson as a function of its mass, in the SM4 model. The limit is a combination of the CDF and D0 measurements on the full dataset, expressed in units of the theoretical cross section of the low mass scenario. Also shown is in the same unit the theoretical cross section of the high mass scenario (dash-dotted line). The green and yellow shaded area indicate the 68% and 95% probability regions where the limits can fluctuate, in the absence of signal.

3 Fermiophobic Higgs boson searches

In the Fermiophobic Higgs Model (FHM), one assumes that the coupling of the Higgs boson to fermions vanishes and all other couplings remain the same as in the SM. This scenario can arise in models with an extended Higgs sector like a two Higgs Doublet Model (2HDM) with parameters that make the lightest Higgs boson fermiophobic[4]. A fermiophobic Higgs boson is dominantly produced via VH and VBH. Moreover, its decay into two photons is largely enhanced, such that this decay mode provides the best search sensitivity for Higgs boson masses below 120 GeV. The CDF and D0 collaborations therefore reinterpreted the SM Higgs boson searches in the $\gamma\gamma$ and WW final states[3]. They reoptimized the signal separation from the background to account for the absence of the ggH production process. Figure 2 shows the combined observed and expected cross section times BR upper limits at 95% CL, in units of the FHM theoretical prediction. From there one can exclude 100–116 GeV (observed) and 100–132 GeV (expected) mass ranges for a fermiophobic Higgs boson.

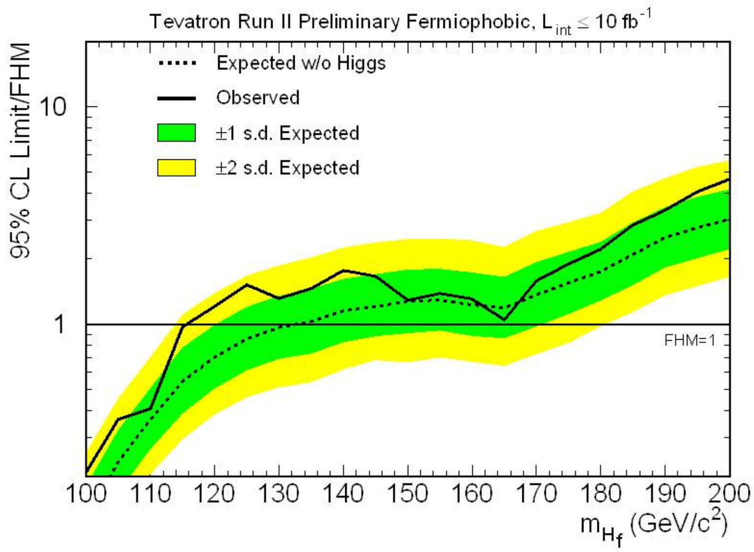

Figure 2: Observed (solid line) and expected (dotted line) 95% CL cross section times BR upper limits of the fermiophobic Higgs boson as a function of its mass. The limit is a combination of the CDF and D0 measurements on the full dataset, expressed in units of the FHM theoretical prediction. The green and yellow shaded area indicate the 68% and 95% probability regions where the limits can fluctuate, in the absence of signal.

4 Search for $\Phi \longrightarrow b\bar{b}$ in MSSM

In the minimal supersymmetric extension of the SM (MSSM) there are two complex Higgs doublet fields from which five Higgs bosons arise after the electroweak symmetry breaking: three neutrals (h, H, A), commonly denoted as Φ and two charged one ($H^{\pm}$). At tree-level, the model is fixed by two parameters: $\tan\beta$, the ratio of the vacuum expectation value of the two Higgs doublet fields and M_A, the mass of the CP-odd neutral Higgs boson. The other model parameters enter through radiative corrections. The mass of the lightest neutral Higgs boson, m_h has an upper bound. For $\tan\beta > 1$, the coupling of the Φ to down-type fermions becomes large and therefore it decays with about 90% branching fraction to a $b\bar{b}$ pair. Moreover, the associate production of the Φ with b quarks is enhanced by a large factor ($\sim 2\tan^2\beta$) with respect to the SM Higgs production. CDF and D0 therefore searched for the Φ boson as a resonant peak in the di-jet invariant mass distribution of events with 3 or 4 b-tagged jets.

Using 2.6 fb^{-1} of data, CDF selected ~11 500 events with 3 b-tagged jets. D0 analysed 5.2 fb^{-1} of data resulting in ~15 000 and ~11 000 events with 3 and 4 b-tagged jets, respectively. Both experiments used PYTHIA [5] to generate signal events subsequently weighted by MCFM [6], and estimated the multijet background from data. CDF enhanced the b-tagging algorithm by an additional flavour separator based on the invariant mass of the charged particles issued from the secondary vertex. D0 used a likelihood ratio discriminant to augment the separation of the signal from the background. Since no significant resonant peak was found by either experiment, a combined 95% CL upper limit of the Φ production cross section times BR was determined (Figure 3). No radiative corrections were taken into account and the width of the Φ boson was neglected. The local excesses seen in the observed limit at 120 GeV and 140 GeV correspond to 2 standard deviations after applying trial factors which take into account the number of

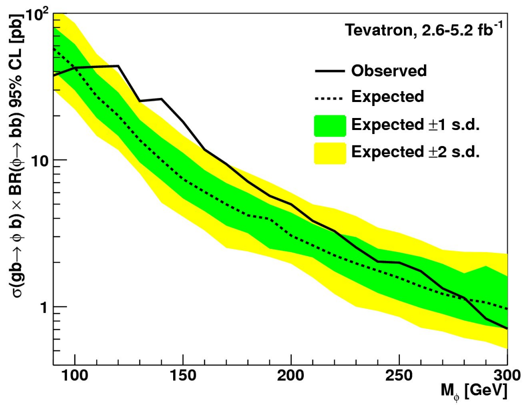

Figure 3: Observed (solid line) and expected (dotted line) 95% CL cross section times BR upper limits of the Φ boson as a function of its mass, produced in association with b quarks and decaying in $b\bar{b}$ quark pairs. The limit is a combination of the CDF and D0 measurements. The green and yellow shaded area indicate the 68% and 95% probability regions where the limits can fluctuate, in the absence of signal.

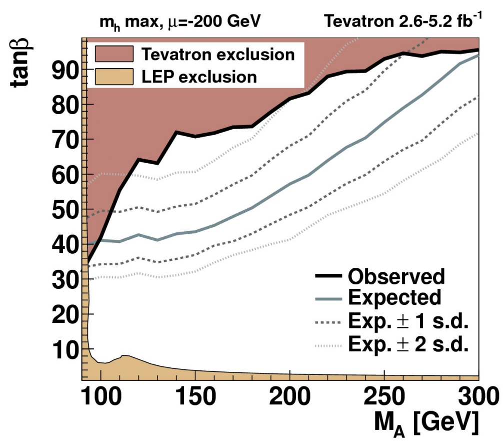

Figure 4: Excluded region in the $(M_A, \tan\beta)$ plane (dark shaded area) obtained in the m_h^{max} scenario. Also shown are the excluded region by the LEP experiments (light shaded area) as well as the median expected upper limits of $\tan\beta$ *vs* M_A (solid line). The dashed and dotted lines around the solid line enclose the 68% and 95% probability regions where the limits can fluctuate, in the absence of signal.

mass regions investigated. In addition, excluded regions in the $\tan\beta$ *vs* M_A were determined for different MSSM model parameters applying radiative corrections and taking into account the width of the Φ boson. Figure 4 shows the so-called m_h^{max} scenario, where the parameters were chosen to maximize the upper bound of m_h. These results were published in 2012 [7] and represented the best limits and excluded regions until the CMS collaboration has superseded it recently [8].

5 Search for heavy Higgs boson cascade decays

The CDF collaboration searched for a hypothetical heavy neutral Higgs boson (H^0) which would first decay to a medium heavy charged Higgs boson ($H^{\pm}$) and a W boson. The $H^{\pm}$ then would decay into a light neutral Higgs boson (h^0) of mass of 126 GeV and a second W boson. Finally, the h^0 would turn into a $b\bar{b}$ quark pair. This search is motivated by a possible existence of strongly coupled electroweak symmetry breaking sector in extended Higgs sectors, like 2HDM [11]. Since the final state is similar to a $t\bar{t}$ pair production, the same event selection was used as in the $t\bar{t}$ lepton+jets analyses. The signal was generated with MADGRAPH [9] interfaced with PYTHIA. The dominant backgrounds ($t\bar{t}$ and W+jets) were simulated with ALPGEN [10] interfaced with PYTHIA and the multijet background was estimated from data. The reconstruction of the decay chain started with the reconstruction of the W bosons from the untagged jet pairs, the signal is then searched in the invariant mass distribution of the b-tagged jet pairs (Figure 5). As

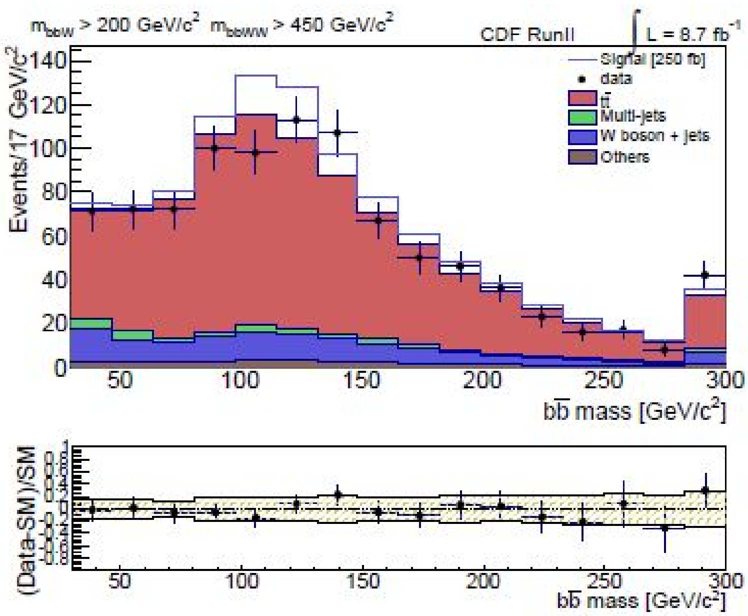

Figure 5: Invariant mass distribution of reconstructed b-tagged jet pairs for observed data and expected backgrounds. A signal hypothesis is shown, assuming a total cross section of 250 fb, 500 GeV and 300 GeV for the masses of H^0 and $H^{\pm}$, respectively. The lower panel shows the relative difference between the observed and expected distributions with the combined statistical and systematic uncertainties of the expected background.

no significant excess of the signal was seen in this distribution, upper limits for the production cross section times BR were determined as a function of the H^0 and $H^{\pm}$ masses. These limits, however, exceed the corresponding theoretical values, therefore no exclusion region could be derived for the masses of the heavy neutral and charged Higgs bosons. More details can be found in the public document [11].

6 Summary

Searches were presented for Higgs bosons beyond the SM, carried out by the CDF and D0 collaborations. No such signals have been observed. Mass ranges have been excluded for Higgs bosons assuming a fourth generation of fermions and for fermiophobic Higgs bosons, using the full available dataset collected at the Tevatron by the two experiments [12]. Upper limits have been derived and domains in the MSSM planes have been excluded for associate production of Higgs bosons with b quarks and decaying into $b\bar{b}$ quark pairs. Finally, upper limits for the production and cascade decay of a heavy Higgs boson were derived in a particular model.

More details can be obtained from the CDF and D0 public web pages:
http://www-cdf.fnal.gov/physics/new/hdg/Results.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Acknowledgments

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