Combinations of Searches for SM Higgs at the Tevatron

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We present the recent results from combinations of searches for a standard model (SM) Higgs boson (H) by the CDF and D0 experiments at the Tevatron $p\bar{p}$ collider at $\sqrt{s} = 1.96$ TeV. The data correspond to an integrated total luminosity of 2.0-4.8 (CDF) and 2.1-5.4 (D0) fb^{-1} of $p\bar{p}$ collisions. No excess is observed above background expectation, and resulting limits on Higgs boson production exclude a standard-model Higgs boson in the mass range 162–166 GeV/c^2 at the 95% C.L. The absence of $gg \to H \to WW$ also constrains some new physics such as 4^{th} generation models. Assuming the presence of a fourth sequential generation of fermions with very large masses, we exclude a standard-model-like Higgs boson with a mass between 131 and 204 GeV/c^2.

1 Introduction

The search for the standard model(SM) Higgs boson has been a major goal of HEP for many years, and is a central part of Tevatron physics program. Recent observations of single top production [1] and diboson production [2] in semileptonic decayss have paved the way for Tevatron to probe the production process with cross section at sub-pb level. Direct search from LEP and global fit of precision electroweak data constrains the Higgs mass between 114.4 GeV/c^2 and 186 GeV/c^2 at 95% C.L., which therefore places the SM Higgs boson within the Tevatron reach. In this note, we present the recent results from the combination of multiple direct searches for the SM Higgs boson at the Tevatron [3]. The analyses that are combined seek signals of Higgs bosons produced in associated with vector bosons ($q\bar{q} \to W/ZH$), through gluon-gluon fusion ($gg \to H$), and through vector boson fusion (VBF) ($q\bar{q} \to q'\bar{q}'H$) corresponding to integrated luminosities ranging from 2.0 to 4.8 fb^{-1} at CDF and 2.1 to 5.4 fb^{-1} at D0.

1.1 Higgs Search Strategies

The Higgs search strategies are quite similar for the corresponding CDF and D0 analyses. Based on Higgs decay, we divide the searches into many different channels. The Higgs signature can be either $H \to b\bar{b}$ at low mass, $H \to W^+W^-$ at high mass, $H \to \tau^+\tau^-$, or $H \to \gamma\gamma$. Both CDF and D0 empolyed "no channel too small" strategies to gain signal acceptances while reducing the background with advanced multivariate analysis techniques, such as neural network(NN), matrix element(ME), and boosted decision tree(BDT). There are in total 90 mutually exclusive final states, 54 channels from D0 and 36 channels from CDF. All analyses provide binned histograms of the final discriminant for signal and background predictions itemized separately for each source, and the data. More details for the low and high-mass SM Higgs searches can be found in these talks [4].

We use the most recent high-order calculations of the SM Higgs production cross section and decay branching ratio to normalize the signal event yield in each individual channel. So we can combine them statistically.

1.2 Combination Procedures

To gain confidence that the final result does not depend on the details of statistical method, we perform two types of combinations, using Bayesian and Modified Frequentist approaches, which yield results that agree within 10%. Both methods rely on distributions of final discriminants, not just on events counts. Systematic uncertainties are treated as nuisance parameters with truncated Gaussian. Both methods use likelihood calculations based on Poisson probabilities. There are two types of systematic uncertainties that affect the rate and shape of estimated signal and background in a correlated way. The rate systematic only affects overall normalization while the shape systematic is changing differential distribution due to the jet energy scale(JES) and Monte Carlo(MC) modeling.

CDF and D0 share common systematic uncertainties on luminosity, the theoretical cross sections, and some scale and PDF veriations, which are treated as correlated. Other sources of systematic are experiment dependent, treated uncorrelated between experiments, but correlated within the experiment, such as lepton identification, b-tagging efficiency, JES, detector effects and instrumental backgrounds.

In order to check the consistency between data and expectations, we rebin the final discriminant from each channel in terms of signal to background ratio (s/b) and the data with similar s/b may be added without loss in sensitivity. Figure 1 show the data after background subtraction, compared to the expected signal as function of log(s/b) for m_H = 115 and 165 GeV/c^2, respectively. There is no significant excess of events observed in the higest s/b bins.

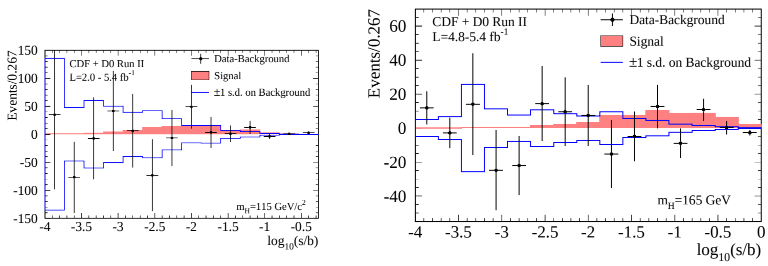

Figure 1: Background-subtracted data distributions for the discriminant histograms, summed for bins with similar s/b, for m_H = 115 GeV/c^2 (left) and m_H = 165 GeV/c^2 (right).

2 Combined Tevatron Searches for SM Higgs

Before extracting the combined results, we check the search sensitivity using log-likelihood ratio(LLR) for different hypotheses to quantify the expected sensitivity across the mass range tested. Figure 2 (left) shows the combined distributions of the log-likelihood ratio as function of Higgs mass. The black dot curve is for the background-only hypothesis, the red dot curve is for signal-plus-background hypothesis, and the solid curve is for the observed data. The sizes of one and two sigma bands indicate the width of the LLR background-only distribution. The separation between the background-only and signal-plus-background hypotheses provides a measure of the search sensitivity, which is about one sigma at low mass and slightly more than 2 sigma at m_H = 165 GeV/c^2.

Figure 2 (middle) shows the ratio of the 95% C.L. expected and observed limit to the SM Higgs cross section times branching ratio at the Tevatron after combining CDF and D0 searches together using the results presented at HCP 09 [3]. We obtain the observed limit of 2.70 with expected 1.78 for $m_H = 115$ GeV/c^2 and 0.94 with expected 0.89 for $m_H = 165$ GeV/c^2.

Since then we have combined searches using $H \to W^+W^-$ only and have published the first joint CDF and D0 publication [5]. For the first time, the Tevatron set mass exclusion in the mass range between 162 and 166 GeV/c^2 with expected $159 < m_H < 169$ GeV/c^2 at 95% C.L. as shown in Figure 2(right).

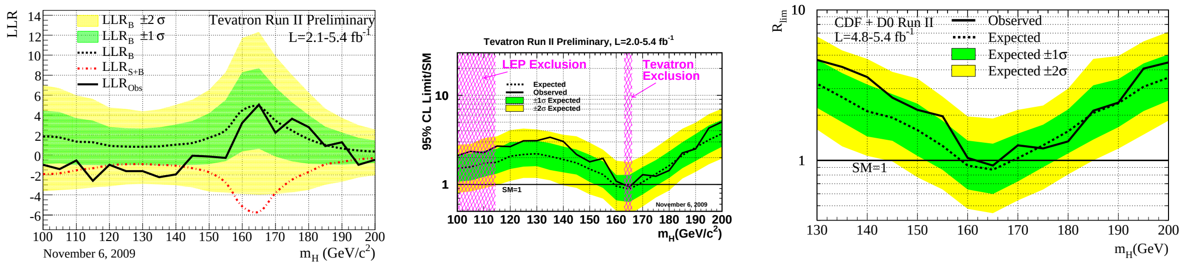

Figure 2: Distributions of the log-likelihood ratio (left), observed and expected 95% C.L. upper limits on the ratio to the SM prediction for the full Higgs mass range (middle), and the corresponding observed and expected limits in the $H \to W^+W^-$ decay (right). The bands indicate the 68% and 95% probability regions where the limits can fluctuate, in the absence of signal.

3 Constraints on Fourth-Generation Fermion Models

With the absence of $H \to WW$ signal, we can constrain some new physics models such as 4^{th} generation, which may exist in nature if the masses are much higher than the current experiment limit. In this scenario $gg \to H$ coupling is enhanced by a factor of $K = 3$ with additional heavy quarks in the triangle loop. The production cross section then is enhanced by a factor of K^2 and K for the heavy quark and the electro-weak contributions, respectively. The Higgs decay is also modified due to the presence of 4^{th} generation, in particular, the partial decay width for $H \to gg$ is enhanced by the same factor as production cross section. Two 4^{th} generation scenarios are considered in this study:

- high-mass scenario: set $m_{\nu_4} = m_{l_4} = 1$ TeV/c^2;
- low-mass scenario: set $m_{\nu_4} = 80$ GeV/c^2, $m_{l_4} = 100$ GeV/c^2, just above the current limit.

The analysis strategy [6] is similar to the one used in the SM Higgs case, except we consider $gg \to H \to WW$ signal only by ignoring contributions from WH, ZH, and VBF; loosen the $\delta\phi < 2.5$ cuts for D0 analysis to gain acceptance for large m_H; extending the Higgs mass from 110 to 300 GeV/c^2.

Keeping the same background predictions, we use the same combination procedure to set the limit on $\sigma(p\bar{p} \to H) \times B(H \to W^+W^-)$ as function of Higgs mass. The combined limit is shown in Figure 3(left) along with the 4^{th} generation theory predictions [7] for the high-mass scenario, as well as for the low-mass scenario.

In order to set limits on m_H in these two scenrios, we perform a second combination on the limit relative to the model prediction, including the uncertainties on the prediction due to scale and pdf uncertainties at each Higgs mass tested.

Figure 3 (right) shows the 95% C.L. limit over the model prediction as a function of Higgs mass. In the low-mass scenario, we exclude a SM-like Higgs boson with a mass in the range 130-210 GeV/c^2, with an expected exclusion of 125-218 GeV/c^2.

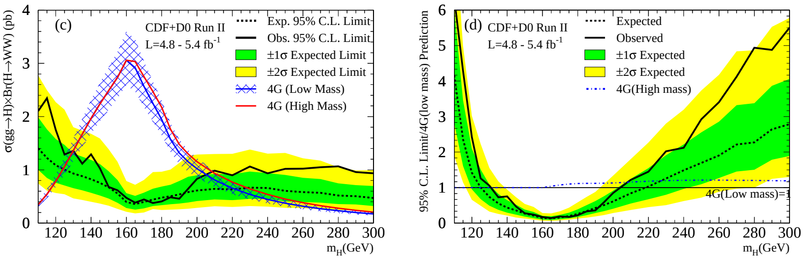

Figure 3: The combined observed (solid black lines) and expected (dashed black lines) 95% C.L. upper limit on $\sigma(p\bar{p} \to H) \times B(H \to W^+W^-)$ are shown(left) and the ratio of 95% C.L. combined limit relative to the theoretical predictions(right).

4 Conclusions and Future Prospects

We present recent results from combinations of searches for a standard model (SM) Higgs boson (H) by the CDF and D0 experiments at the Tevatron $p\bar{p}$ collider at $\sqrt{s} = 1.96$ TeV. The data correspond to an integrated total luminosity of 2.0-4.8 (CDF) and 2.1-5.4 (D0) fb^{-1} of $p\bar{p}$ collisions. No excess is observed above background expectation, and resulting limits on Higgs boson production exclude a standard-model Higgs boson in the mass range 162–166 GeV at the 95% C.L. The absence of $gg \to H \to WW$ can also constrain some new physics such as 4^{th} generation models. Assuming the presence of a fourth sequential generation of fermions with very large masses, we exclude a standard-model-like Higgs boson with a mass between 131 and 204 GeV/c^2.

The Tevatron is doing remarkably well and has delivered an integrated luminosity close to 9 fb^{-1}. Both CDF and D0 continue to add additional Higgs sensitivity with "no channel too small" strategies. By this summer, we aim to publish the combined searches in full mass region and each experiment should reach individual exclusion sensitivity near $m_H = 165$ GeV. With 12 fb^{-1} by 2012, the Tevatron would either find some evidence for the SM Higgs boson or exclude it up to $m_H < 180$ GeV/c^2 at 95% conference level.

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