Standard Model Higgs Searches at the Tevatron

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We present results from the search for a standard model Higgs boson using data corresponding up to 10 fb^{-1} of proton-antiproton collision data produced by the Fermilab Tevatron at a center-of-mass energy of 1.96 TeV. The data were recorded by the CDF and D0 detectors between March 2001 and September of 2011. A broad excess is observed between $105 < m_H < 145$ GeV/c^2 with a global significance of 2.2 standard deviations relative to the background-only hypothesis.

1 Introduction

The Higgs boson is the only standard model (SM) particle yet to be found. Within the SM, it is the particle responsible for giving the W and Z bosons and fermions their masses [1]. Although the value of the Higgs mass is a parameter, and is therefore formally unconstrained, measurements of electroweak observables such as m_W and m_t, indirectly constrain it to be less than roughly 150 GeV/c^2 at 95% confidence level (C.L.).

In December of 2011, the CMS and ATLAS collaborations released results indicating excesses in the $H \to \gamma\gamma$ channel relative to the background-only hypothesis. Along with the $H \to \gamma\gamma$ channel, the $H \to W^+W^-$ and $H \to ZZ$ diboson channels have the most sensitivity to Higgs production [2, 3]. On the other hand, the sensitivity to the Higgs through the $H \to b\bar{b}$ channel is a bit less — as of the Moriond 2012 conference, the expected sensitivities to the $H \to b\bar{b}$ final states were roughly $4.3 \times \sigma_{\text{SM}}$ [4] and $3.5 \times \sigma_{\text{SM}}$ [5], respectively, for the CMS and ATLAS Higgs searches. In contrast, the expected sensitivities at the Tevatron at low-mass are predominantly through the $H \to b\bar{b}$ associated production modes, and on the order of $1.7 \times \sigma_{\text{SM}}$ [6] and $2.2 \times \sigma_{\text{SM}}$ [7], respectively, for the CDF and D0 searches. The low-mass Higgs searches at the Tevatron and LHC are therefore complementary. The $H \to b\bar{b}$ searches at the Tevatron are therefore the focus of this presentation.

2 Low-Mass Higgs Searches at the Tevatron

Low-Mass Higgs searches use a typical analysis selection, summarized in Table 1. Requiring the two leading jets in the event to be b-tagged substantially reduces the background relative to the Higgs signal. Additional sensitivity can be gained by also considering events where one but not both leading jets are tagged. Note that analyses that have zero and one leptons in the final state are also sensitive to $\ell\nu b\bar{b}$ and $\ell^+\ell^- b\bar{b}$ final states, respectively, due to losing a lepton from detector inefficiencies. Multivariate techniques are implemented to separate signal from QCD and electroweak backgrounds.

To obtain the best expected sensitivities to SM Higgs production, the b-tagging and lepton identification algorithms must be optimized. Also, variables that discriminate between signal and background processes can be improved, such as the dijet invariant mass m_{jj}, which improves the ability of multivariate discriminants to separate the Higgs signal from background processes.

Analysis Channel	No. of Leptons	$\not\!\!E_T$	No. of b-jets
$ZH \to \nu\bar{\nu}b\bar{b}$	0	Yes	2
$WH \to \ell\nu b\bar{b}$	1	Yes	2
$ZH \to \ell^+\ell^- b\bar{b}$	2	No	2

Table 1: Basic selection for $H \to b\bar{b}$ final states produced in association with a W or Z boson.

2.1 Analysis Improvements

The results presented here are given in Ref. [8] and the references therein. Many Higgs analyses at CDF and D0 have implemented several improvements, consisting of increased luminosity (roughly 10% gain in sensitivity), improved b-tagging, improved m_{jj} resolution, and various improvements in analysis methods. At CDF, an improved b-tagging algorithm called HOBIT [9] was used in most of the mainstream $H \to b\bar{b}$ search channels. This multivariate algorithm, trained on $H \to b\bar{b}$ events for a Higgs mass of $m_H = 120$ GeV/c^2, increased Higgs sensitivity by roughly 10% for a given search channel. Various analysis improvements were made by the D0 searches, including increasing signal acceptance by relaxing some of the variable definitions.

3 Tevatron Combinations

To determine upper limits on SM Higgs production at 95% C.L., two approaches are taken: a frequentist profile likelihood approach where the minimum of the likelihood is used to determine the nuisance parameters; a modified frequentist (or Bayesian) approach where the nuisance parameters are integrated out to determine posterior probabilities. Both approaches yield agreement better than 10% for all Higgs mass hypotheses in the range $100 < m_H < 200$ GeV/c^2, and better than 1% on average. The Bayesian limits are adopted as the Tevatron results.

Systematic uncertainties such as the jet-energy scale, luminosity, and pdf's are incorporated as nuisance parameters. Care is taken to ensure that all appropriate correlations are taken into account between the CDF and D0 experiments.

3.1 All Channels

The complete list of channels that goes into the Higgs Tevatron combination is given in Ref. [8], along with a complete description of the limit-setting procedure and handling of systematic uncertainties. The 95% C.L. limits on Higgs production are shown in Fig. 1, along with the best-fit value assuming the existence of signal in the data. The expected upper limit is better than $1.15 \times \sigma_{\rm SM}$ across the entire Higgs mass range. The expected exclusion regions are $100 < m_H < 119$ GeV/c^2 and $141 < m_H < 184$ GeV/c^2, whereas the observed exclusion regions are $100 < m_H < 106$ GeV/c^2 and $147 < m_H < 179$ GeV/c^2. A broad excess is observed in the mass range $105 < m_H < 145$ GeV/c^2, where the minimum local p-value (p_0) at $m_H = 120$ GeV/c^2 corresponds to a 2.7-standard-deviation departure from the background-only hypothesis. Assuming a jet-energy resolution of about 10%, the estimated correction from the look-elsewhere effect gives $p_{\rm global} \approx 4 \times p_0$, which corresponds to a 2.2 standard-deviation

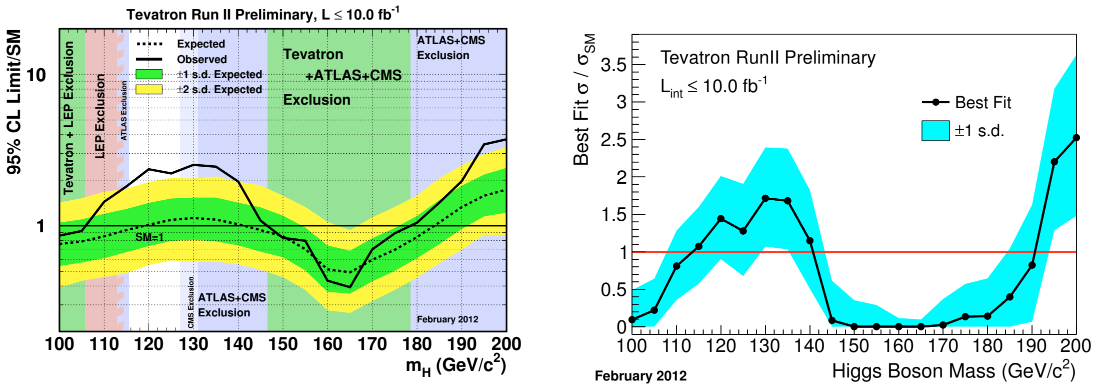

Figure 1: (Left) Upper limits on SM Higgs production at 95% C.L. assuming the background-only hypothesis. (Right) Best fit value for SM Higgs production, assuming the signal plus background hypothesis.

effect relative to the background-only hypothesis. The best-fit value of the Higgs production cross-section is consistent with the SM prediction in the mass region $110 < m_H < 140$ GeV$/c^2$.

3.2 $H \to b\bar{b}$ Channels

Upper limits on SM Higgs production have also been obtained by looking at only $H \to b\bar{b}$ final states. The 95% C.L. limits, and associated best-fit value for Higgs production are shown in Fig. 2.

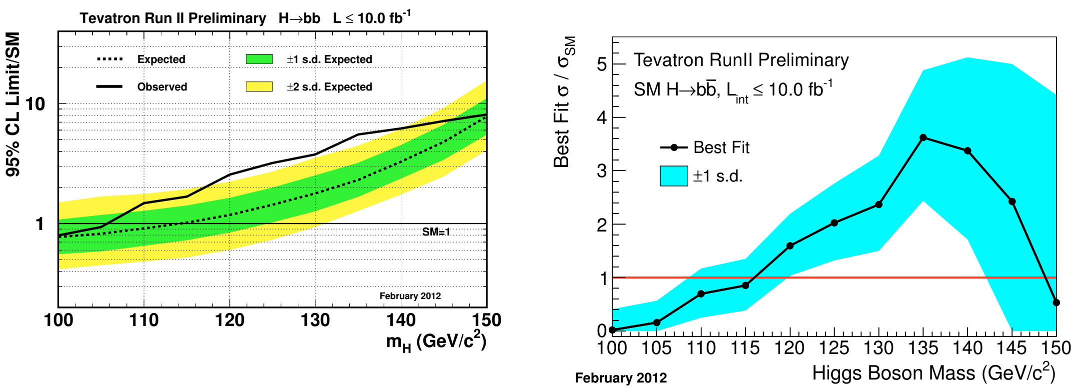

Figure 2: (Left) Upper limits on $H \to b\bar{b}$ production at 95% C.L. assuming the background-only hypothesis. (Right) Best fit value for $H \to b\bar{b}$ production, assuming the signal plus background hypothesis.

The broad excess in the low-mass range results in a minimum p-value of 2.8 standard deviations away from the background-only hypothesis at a Higgs mass of $m_H = 135$ GeV/c^2. Using a look-elsewhere effect correction of 2 (based on the assumed jet-energy resolution), the global p-value is diluted to a 2.6 standard-deviation effect. The best-fit value is consistent with the SM prediction in the region $110 < m_H < 120$ GeV/c^2. The significant departure from the SM prediction in the region $120 < m_H < 145$ GeV/c^2 results from the signal component of the fit needing to compensate for the excess of data events relative not only to the background-only prediction, but also to the signal-plus-background prediction.

4 Conclusions

The CDF and D0 collaborations have combined their results to give a Tevatron-wide combination of the upper limits of the SM Higgs production at 95% C.L. After combining all channels across the range $100 < m_H < 200$ GeV/c^2, a broad excess is observed in data relative to the background-only hypothesis, corresponding to a 2.2 standard-deviation effect. Considering only the $H \to b\bar{b}$ search channels yields an excess in data, corresponding to a 2.6 standard-deviation departure from the background-only prediction. An update of the Tevatron combination is expected in the summer of 2012.

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