Searches for Standard Model Higgs at the Tevatron

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A summary of the latest results of Standard Model Higgs boson searches from CDF and D0 presented at the DIS 2007 conference is reported in this paper. All analyses presented use 1 fb^{-1} of Tevatron data. The strategy of the different analyses is determined by the Higgs production mechanism and decay channel.

1 Introduction

The Higgs boson is the only Standard Model (SM) particle which remains unobserved. It is introduced in the spontaneous electroweak symmetry breaking mechanism, through which SM particles acquire mass. The Higgs mass is not predicted by the theory, however it can be constrained due to its predicted couplings to other particles. Global fits to precision electroweak data, which includes the latest mass measurements for W ($m_W = 80.398 \pm 0.025$ GeV [2] and top ($m_t = 170.9 \pm 1.8$ GeV [3]), favors a light Higgs with mass below 144 GeV [2]. Direct Higgs searches performed at LEP set a lower mass limit of 114 GeV. If this limit is included in the previous calculation, the upper mass limit increases to 182 GeV.

Both Tevatron experiments, D0 and CDF, have established the search for the SM Higgs as one of their highest priorities. Higgs sensitivity workshops at the Tevatron [4] show that the required luminosity to exclude a 115 GeV Higgs starts at around 2 fb$^-$1 per experiment. Both experiments have recorded approximately 1.7 fb^{-1} of data, although the analyses presented in this paper use 1 fb^{-1} of Tevatron data.

Higgs boson production cross sections in the SM are small at Tevatron energies, of the order or 1-0.1 pb depending on the production mechanism. Gluon fusion, $gg \rightarrow H$, is the dominant production mechanism. In the low mass region ($m_H < 135$ GeV) the highest branching ratio decay channel corresponds to $H \rightarrow b\bar{b}$, and the gluon fusion channel has an overwhelming QCD background. The most relevant production mechanism is therefore the associated production to a vector boson (W or Z). The main backgrounds are $t\bar{t}$, $Wb\bar{b}$, $Zb\bar{b}$ and dibosons. In the intermediate mass range ($135 < m_H < 200$ GeV), where the predominant decay channel is $H \rightarrow WW$, gluon fusion production has manageable backgrounds, the most relevant being dibosons, Drell-Yan, $t\bar{t}$ and single top.

Since the Higgs signal is 2 to 3 orders of magnitude below the backgrounds, optimal detector performance and analysis techniques are crucial. For discovery/exclusion one needs: better signal acceptances by improving the triggers and b-tagging efficiency; reduced backgrounds by improving the di-jet resolution and b-tagging algorithms; extraction of the signal from the enormous background by using sophisticated analysis techniques, such as multivariate techniques, Neural Networks (NN) or Matrix Element. No single improvement by itself will reach the sensitivity needed. All channels studied by both experiments must be combined, and as much data as possible must be analyzed.

2 Low Higgs mass region, $m_H < 135$ GeV

Here the strategy is to look for associated production of Higgs with a vector boson, with the Higgs decaying to $b\bar{b}$.

2.1 $WH \rightarrow l\nu b\bar{b}$

This channel is the golden channel at the Tevatron. The signature is a high transverse momentum, p_T, isolated lepton (e or μ), missing transverse energy ($\not{E}_T$) from the neutrino, and two or more high p_T jets with one or two jets identified as a b-jets. The main background is W+jets production, which is estimated from a combination of data and MC. Both experiments use very similar selection criteria. D0 [5] has significantly improved the sensitivity by increasing the muon trigger acceptances using a full coverage of the detector, and by dividing the sample into two categories of events, with one or two jets identified as a b (tagged jet). CDF has improved the b-jet identification by using an additional Neural Network to further reduce the c and light-quark content of tagged jets. Using ≈ 1 fb^{-1} of data, no excess is observed in the invariant mass distribution of the two tagged jets (see Fig 1), so upper cross section limits at 95% C.L. are set. For $m_H = 115$ GeV, D0 sets a limit of 1.3 pb (1.1 pb expected), and CDF sets a limit of 3.4 pb (2.2 pb expected).

D0 [7] also uses a Matrix Element approach to extract the signal from the background in this channel. This technique uses the LO Matrix Element to compute event probability densities for signal and background, creating a discriminant for each event, see Fig 2. This discriminant is a likelihood ratio constructed for each event by dividing the signal probabilities by the sum of the signal plus background probabilities. No excess is found and an upper limit of 1.7 pb (1.2 pb expected) is set for $m_H = 115$ GeV.
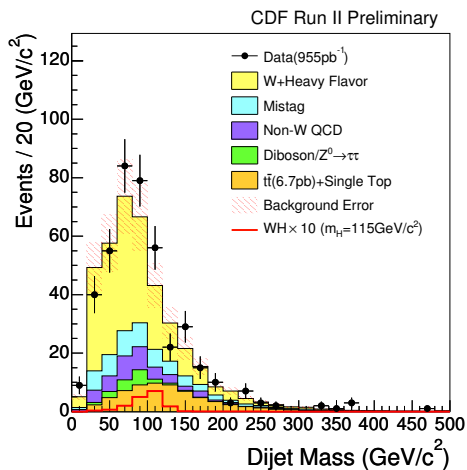

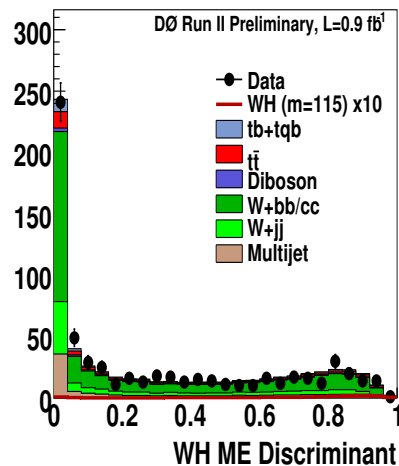Figure 1: CDF invariant mass distribution of the two tagged jets for the WH analysis.

Figure 2: D0 discriminant distribution for the Matrix Element WH analysis.

2.2 $ZH \rightarrow l^+l^-b\bar{b}$

The signature for this channel is two high p_T isolated leptons and two high E_T jets that could be identified as b jets. The main backgrounds come from Z+jets, $Zb\bar{b}$, Drell-Yan, dibosons and top. Although this channel has the smallest yield of events, the requirement of two identified leptons to reconstruct the Z mass results in the cleanest sample. D0 [8] uses the invariant mass of the two jets to discriminate signal from background. CDF use a two dimensional Neural Network discriminant based on eight variables to maximize signal over background. CDF [9] also improves the sensitivity further by using two different categories of events depending on the number of b-jets identified, and improving the energy resolution of the jets by applying an additional correction to the jet energy according to its projection onto the $\not{E}_T$ direction. This correction improves the di-jet mass resolution from 14% to 9% for the two identified b-jets category, see Fig 3. No excess is observed, so CDF sets a 95% C.L. cross section upper limit of 1.3 pb (1.3 pb expected) and D0 sets a limit of 1.9 pb (1.81 pb expected) for $m_H = 115$ GeV.

2.3 $ZH \rightarrow \nu\nu b\bar{b}$

The signature is two high E_T jets that could be tagged, and high $\not{E}_T$ due to the two neutrinos. The two jets must recoil against the $\not{E}_T$. The main backgrounds are Z+jets, $Zb\bar{b}/c\bar{c}$, dibosons and QCD, which are very challenging because of the heavy flavor modeling and jet mis-reconstructions. This channel has the advantage that it gains some acceptance from the WH when the lepton is lost. Both experiments use the special kinematics of this signature and b-identification to reduce the backgrounds. Checks are made to verify the modeling of the QCD and W/Z+jets backgrounds in control regions sensitive to them. A fit to the invariant mass distribution of the two jets, figures 4 and 5, shows that there is no excess, and upper limits are set 14 times over the SM cross-section prediction (10 times expected) for D0 [10] and 16 times for CDF [11] (15.4 expected).
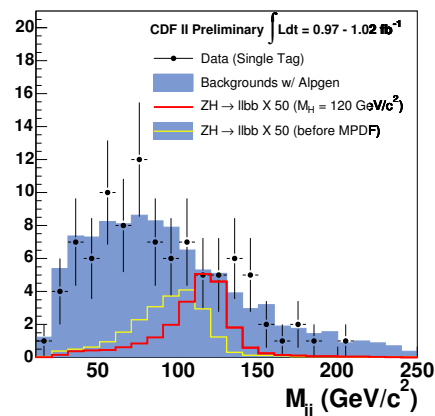

Figure 3: CDF invariant mass distribution of the two tagged jets for the ZH analysis. The red (yellow) histogram is the invariant mass distribution for the Higgs signal after (before) applying further jet energy corrections.

3 Intermediate Higgs mass region, $m_H > 135$ GeV

At higher Higgs masses, the decay mode to vector bosons is kinetically possible, allowing to use the gluon fusion production mode. This gives the biggest event yields. The $H \rightarrow WW^*$ decays with the subsequent electronic and/or muonic decays of the W's provide a promising search channels with manageable backgrounds.
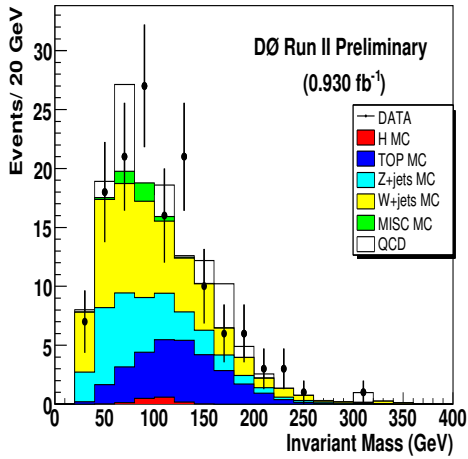
Figure 4: D0 invariant mass distribution of the two tagged jets for the ZH analysis.
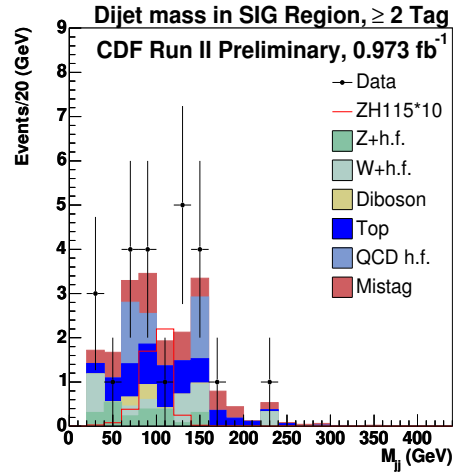

Figure 5: CDF invariant mass distribution of the two tagged jets for the ZH analysis.

3.1 $H \to WW^*$

The signature for this channel is two high p_T, isolated leptons with opposite charge and high $\not{E}_T$ due to the neutrinos. The main backgrounds are dibosons, $t\bar{t}$ and Drell-Yan. The Higgs mass cannot be directly reconstructed due to the neutrinos. The spin correlations between the decay products of the Higgs boson are used to suppress the backgrounds. The leptons from the Higgs tend to have small angles, while the leptons from other backgrounds are expected to be back-to-back. Both experiments have performed an analysis using this distribution to search for the Higgs boson [12], setting cross section upper limits. Using the same selection criteria CDF has used a Neural Network analysis based on two subsequent NN's, one to reduce the Drell-Yan background and one to separate signal from background. Using the NN the limit improves by a factor of 1.6. CDF [14] increases the geometric lepton acceptance by defining new lepton type categories, including regions of the detector without complete instrumentation. These leptons were used in CDF's observation of WZ production [13]. Using all the lepton categories, the expected sensitivity increases from 2.5 to 4 compared to the cut-based analysis. In addition, a Matrix Element technique is used to separate signal from background, similar to the one explained for the $WH \to l\nu b\bar{b}$ analysis, see Fig 6. The likelihood ratios are constructed for different signal hypothesis to validate the background modeling. No significant excess is observed, and an upper cross section limit of 3.5 times the SM prediction is set (5 times expected) for $m_H = 160$ GeV.

4 Combined Limits

Last summer, the first Tevatron Run II SM Higgs production cross section upper limits using 290-950 fb^{-1} were set [15]. The 95% C.L. upper limits were a factor of 10.4 (3.8) higher than the expected cross sections for m_H=115 (160) GeV/. These results have already been reached by the individual channels shown above, namely CDF's $ZH \rightarrow l^+l^-b\bar{b}$ and $H \rightarrow WW$ and D0's $WH \rightarrow l\nu b\bar{b}$. D0 has set cross section upper limits on Higgs production [16] for Higgs masses ranging from 100 to 200 GeV combining all the channels (WH, ZH and $H \rightarrow WW$) with approximately 1 fb^{-1} of data, see Fig 7.

5 Conclusions

New preliminary results have been presented at this conference, with very encouraging outcomes. Cross section limits are scaling much better than by just a luminosity factor. Both experiments, CDF and D0, have shown that improving analyses by increasing acceptances, improving jet energy resolution, b-tagging, and using advanced analysis techniques such as Matrix Element, Neural Networks, or Boosted Decision Trees can gain a sensitivity factor of ≈ 1.3 without adding data. The prospects for Higgs at the Tevatron depend also on a large integrated luminosity, but Tevatron is performing well and is on its way to deliver 8 fb^{-1} of data by 2009.

6 Acknowledgments

I would like to thank the members of the CDF and D0 collaborations for their work and effort in achieving the results presented in this report.
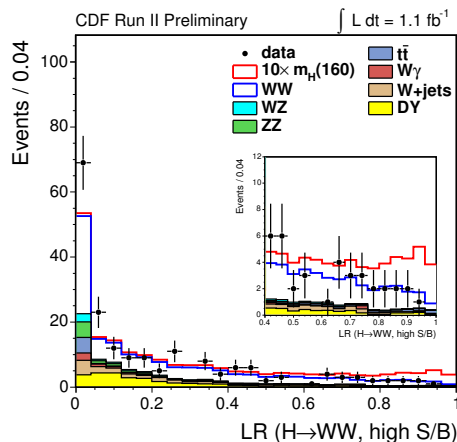

Figure 6: Likelihood ratio for the $H \rightarrow WW^*$ channel, using the Matrix Element technique and improved lepton acceptance.

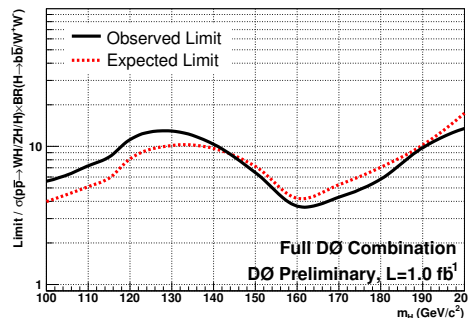Figure 7: D0 SM Higgs production cross section upper limits from the combination of all different channels using 1 fb^{-1} of data.

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