Searching for the Higgs at CDF

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The CDF experiment at the Fermilab Tevatron has performed direct searches for the Standard Model Higgs boson. There are two main search channels, each sensitive to different Higgs mass ranges. For a light mass Higgs boson ($m_H < 135$ GeV/c^2) we search for a Higgs decaying into two b-jets, produced in association with a vector boson. For heavier Higgs boson masses ($135 < m_H/\mathrm{GeV}c^{-2} < 200$) we search for a Higgs decaying into two W-bosons. No evidence for Higgs production is found. At the most sensitive mass, the excluded cross section is a factor of 3.4 higher than the predicted Standard Model cross section.

1 Introduction

The Higgs boson (H) is the only Standard Model particle for which we have no direct evidence. Direct searches for the Higgs in the process $e^+e^- \to ZH$ at LEP provide a lower limit on the Standard Model Higgs boson mass of $m_H > 114.4$ GeV/c^2 at 95% confidence level (CL) [2]. An upper limit on m_H can be calculated through radiative corrections to various electroweak processes. Using the most recent measurement of the top quark mass from the Tevatron, $m_t = 170.9 \pm 1.1(\mathrm{stat}) \pm 1.5(\mathrm{syst})$ GeV/c^2 [3], and the improved accuracy of the mass W-boson, the upper limit on the Higgs boson mass is $m_H < 182$ GeV/c^2 at 95% CL [4].

2 Higgs production and decay at the Tevatron

This talk outlines searches at the CDF experiment for evidence of direct Higgs boson production.

The Fermilab Tevatron collides protons and anti-proton at centre of mass energies of 1.96 TeV. The main mechanisms for producing Higgs bosons are through gluon-gluon fusion $gg \to H$ and associated production with a gauge boson: ZH or WH. The cross section for the associated production is roughly a factor of 10 smaller than for the gluon fusion. The cross sections decrease as m_H increases, from around 1 pb at $m_H = 115$ GeV/c^2 to around 0.2 pb at $m_H = 200$ GeV/c^2. For masses less than 135 GeV/c^2 the Higgs decays primarily as $H \to b\bar{b}$. For higher masses the dominant decay mode is into two W-bosons: $H \to WW^{(*)}$.

Typical events in 1 fb^{-1} for m_H (GeV/c^2)	$ZH \to \ell^+\ell^- b\bar{b}$ 115	$ZH \to \nu\bar{\nu}b\bar{b}$ 115	$WH \to \ell\nu b\bar{b}$ 115	$H \to WW^{(*)} \to \ell\nu\ell\nu$ 160
Signal produced	5	15	30	20
Signal accepted	1	2	3	4
Backgrounds	100	300	500	300

Table 1: Number of signal and background events for main Higgs search channels. ℓ here refers to an electron or muon.

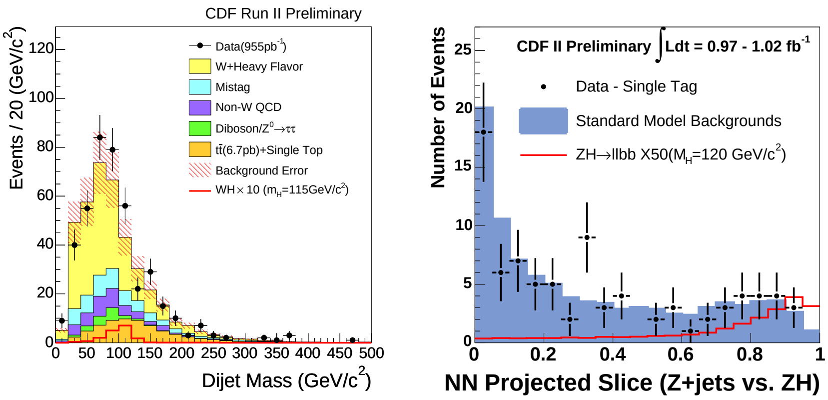

Figure 1: Left: From the $WH \to \ell\nu b\bar{b}$ search, the reconstructed di-jet mass for events where only one of the jets is tagged as a b-jet. Right: The output of the Neural Net tuned to find ZH events in the $ZH \to \ell^+\ell^- b\bar{b}$ analysis.

We therefore employ two different search strategies for the Higgs boson, each sensitive to a different range of m_H. For relatively low Higgs boson masses ($115 < m_H/\mathrm{GeV}c^{-2} < 135$) we search for a Higgs decaying into two b-jets produced in associated with a W or Z boson decaying leptonically. (The enormous background from di-jet production makes the search for non-associated production: $gg \to H \to b\bar{b}$ unfeasible.) For a higher Higgs boson masses ($135 < m_H/\mathrm{GeV}c^{-2} < 200$) we search for Higgs decaying into two W-boson, where both of the W-bosons decay into either an electron or muon plus associated neutrino. Table 1 shows the typical number of events expected in each 1 fb^{-1} of data.

3 Low-Mass Higgs Searches

For low mass Higgs searches b-jet tagging and the di-jet mass resolution are crucial for the Higgs search. CDF have made improvements to their b-jet tagging algorithms over the past year. For recent analyses, finding one b-tag improves the signal to background from 1:1000 to 1:100; finding two b-tag improves this to 1:50. The b-jet energy response is calibrated using simulated events. We cross check this calibration using reconstructed $Z \to b\bar{b}$ events.

To search for $WH \to \ell\nu b\bar{b}$, we select events with an isolated, high-p_T electron or muon, two high-E_T jets, with at least one tagged as a b-jet and large missing transverse energy ($\not\!\!E_T$) due to the unidentified neutrino. We plot the di-jet mass, as shown in Figure 1. The observed distribution of events can be accounted for by the backgrounds, which are dominated by top quark pair and direct W+heavy flavour production. We therefore set a limit on Higgs boson production. The observed limit and the expected limit are given in Table 2 [5].

The signature of $ZH \to \nu\bar{\nu}b\bar{b}$ is two high-E_T jets and large $\not\!\!E_T$ from the two neutrinos. We veto events containing an isolated charged lepton and we apply optimised kinematic cuts to reduce the huge background from QCD jet production. As before, we calculate the di-jet mass and compare this distribution expected from background events. No evidence for the Higgs is observed and we again set a limit on the Higgs cross section, given in Table 2 [6].

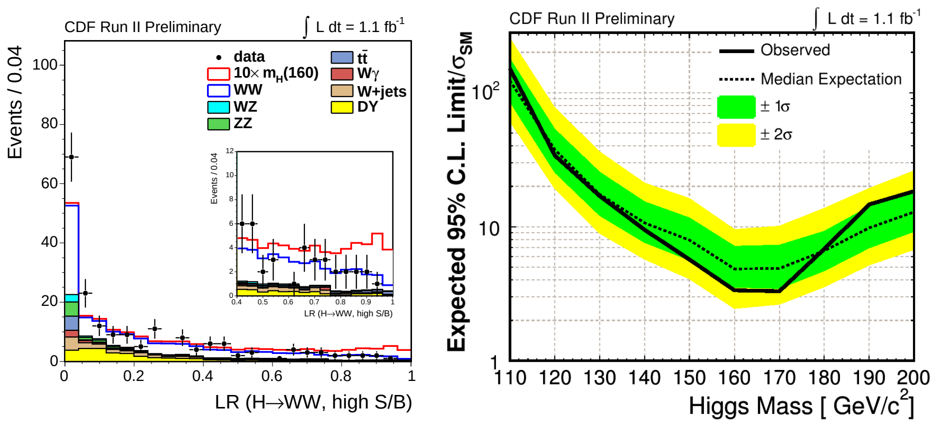

Figure 2: $H \to WW^{(*)}$ search using the likelihood ratio method. Left: The LR variable for the selected events. Right: Limit on the Higgs production cross section as a function of m_H.

Low mass searches: $m_H = 115$ GeV/c^2	exp.	obs.
$\sigma(WH \to \ell\nu b\bar{b})/\sigma(\mathrm{SM})$	17	26
$\sigma(ZH \to \nu\bar{\nu}b\bar{b})/\sigma(\mathrm{SM})$	15	16
$\sigma(ZH \to \ell^+\ell^- b\bar{b})/\sigma(\mathrm{SM})$	16	16

Higgs mass searches: $m_H = 160$ GeV/c^2	exp.	obs.
$\Delta\phi$ anal: $\sigma(H \to WW \to \ell^+\ell^-\nu\bar{\nu})/\sigma(\mathrm{SM})$	6.0	9.2
LR anal: $\sigma(H \to WW \to \ell^+\ell^-\nu\bar{\nu})/\sigma(\mathrm{SM})$	4.8	3.4

Table 2: The expected (exp.) and observed (obs.) limits on Higgs production cross section at 95 % CL at two values of m_H. σ(SM) is the Standard Model cross section.

The search for $ZH \to \ell^+\ell^- b\bar{b}$ begins by selecting events with two electrons or muons and two jets, of which at least one must be tagged as a b-jet. In the 1 fb^{-1} of data used for this search, these cuts selects around 100 events. One only of these events is expected to be from Higgs production. To improve the signal to background ratio we use a two-dimensional Neural Net (NN). Both NNs are each tuned to separate one background channel (either $t\bar{t}$ or $Zb\bar{b}$) from the signal. An illustation of the output is shown in Figure 1. Making appropriate cuts on the NN output improves the sensitivity of the search by a factor of 2.5. Again, no evidence for Higgs production is observed and limits are set as given in Table 2 [7].

4 High-Mass Higgs Searches

For Higgs boson masses above around 135 GeV/c^2 we search for $H \to WW^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$ events. Through intensive study of the detector we have increased acceptances for electron and muons, mainly by incorporating regions of the detector not previously well understood [8]. The improvement in lepton acceptance increases the expected yield of $m_H =$ 160 GeV/c^2 Higgs events from 2.5 to 4 events.

Due to the two neutrinos in the final state, it is impossible to reconstruct the Higgs mass directly. Instead, we exploit of the spinless nature of the Higgs boson and examine the polar angle difference between the two charged leptons, $\Delta\phi$. For Higgs production $\Delta\phi$ peaks at lower values than for direct WW production, the main background to this search. Again we find no evidence for Higgs events contributing to the observed $\Delta\phi$ distribution and we set a limit on the Higgs production cross section, as given in Table 2.

A more sensitive search for $H \to WW^{(*)}$ events is performed using a matrix element technique. In terms of the probability, $P(\vec{x})$, to observe an event with kinematic properties $\vec{x}$, we define the likelihood ratio (LR) to observe a given event as:

$$\mathrm{LR}(\vec{x}_{\mathrm{obs}}) = \frac{P_H(\vec{x}_{\mathrm{obs}})}{P_H(\vec{x}_{\mathrm{obs}}) + \Sigma_{\mathrm{backg}} P_i(\vec{x}_{\mathrm{obs}})} \tag{1}$$

Where P_H is the probability to observe Higgs production and P_i is the probability to observe one of the backgrounds. LR gives the most discriminating power between the signal and background. Figure 2 shows the distribution of LR observed, along with the expectation for Higgs production and the backgrounds. The observed distribution is compatible with the expected backgrounds and therefore we set a limit on the Higgs cross section as a function of m_H, also shown in Figure 2 [9].

5 Conclusions

In conclusion, using 1 fb^{-1}, CDF sees no evidence for Standard Model Higgs production. Recent improvements in b-jet tagging, di-jet mass resolution, triggers and acceptances along with the use of more advanced analysis techniques have been critical in improving the sensitivity of the Higgs searches presented. Coupled with these searches, precision measurements from the Tevatron also constrain the mass of the Higgs boson within the Standard Model.

CDF has around two-and-a-half times more data on tape and the Tevatron is projected to deliver a total integrated luminosity of 4 fb^{-1} by the end of 2007. Further improvements to the analyses are also being incorporated, therefore we can expect substantial improvements compared to the limits presented in this talk. If the Tevatron continues to deliver improvements to the instantaneous luminosity, if the CDF and DØ experiments collaborate on combining analyses, and if the Higgs boson has a mass less than about 200 GeV/c^2 then the Tevatron does have a *chance* to observe direct evidence for the Higgs boson.

I thank the organisers of the workshop for a productive and interesting meeting and, in particular, for the opportunity to get up close and personal with a Nasenbär!

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