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Searches for the Standard Model Higgs at the Tevatron

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The CDF and DØ experiments at the Tevatron are currently the only capable of searching for the Standard Model Higgs boson. This article describes their most sensitive searches in the expected Higgs mass range, focusing on advanced methods used to extract the maximal sensitivity from the data. CDF presents newly updated results for $H \to W^+W^-$ and $ZH \to l^+l^-b\bar{b}$. DØ presents two new searches for $WH \to l\nu b\bar{b}$. These new analyses use the same 1 fb^{-1} dataset as previous searches, but with improved techniques resulting in markedly improved sensitivity.

1 Introduction

The Higgs boson is the last remaining Standard Model particle to be discovered, and the one responsible for generating the W and Z gauge boson masses. Direct searches at the LEP experiments have excluded a Higgs boson with mass less than 114.4 GeV/c^2 at 95% Confidence Level (CL) in the production mode $e^+e^- \to ZH$ [1]. Experimental measurements of the top quark and W boson masses provide the strongest indirect constraints on m_H. Considering the newest CDF and DØ combined top mass measurement of $m_t = 170.9 \pm 1.8$ GeV/c^2, and the newest CDF W mass measurement of $m_W = 80.398 \pm 0.025$ GeVc^2, in addition to other precision electroweak other observables from LEP and SLD, the Higgs boson mass is expected to be less than 144 GeV/c^2 at 95% CL [2].

The Tevatron at Fermilab provides 1.96 TeV center-of-mass energy from proton-antiproton collisions in the two multi-purpose detectors, CDF and DØ . Gluon fusion is the highest cross-section process for producing a Higgs boson, but because of high backgrounds at lower masses, this production process is sensitive to Higgs mainly for $m_H > 135$ GeV/c^2, where BR($H \to W^+W^-$) starts at 68 % and increases up to 90% for $m_H = 160$ GeV/c^2. For $H \to W^+W^-$ in this mass range, the most sensitive final state topology is two charged leptons with large missing transvere energy ($\not{E}_T$). For $114 < m_H < 135$ GeV/c^2, quark annhilation into an offshell W or Z boson, which then emits a Higgs boson, provides the best opportunity for discovery. At this mass range, the Higgs decays predominantly $H \to b\bar{b}$. CDF and DØ have previously done 1 fb^{-1} searches for $H \to W^+W^- \to l^+\nu l^-\bar{\nu}$, $WH \to l\nu b\bar{b}$, $ZH \to l^+l^-b\bar{b}$, and $ZH \to \nu\bar{\nu}b\bar{b}$, where $l = e, \mu$. Because of the small expected Higgs signals, to maximize search sensitivity over the allowed Higgs mass range, it is necessary to combine all searches from both the CDF and DØ experiments, as well as improve analysis techniques.

This proceeding outlines updates to searches in several of these channels, focusing mainly on improvements in analysis techniques. New CDF searches for $ZH \to l^+l^-b\bar{b}$ and $H \to W^+W^- \to l^+\bar{\nu}l^-\nu$ are presented for the first time, as well as two new DØ searches in the $WH \to l\nu b\bar{b}$ channel.

2 $H \to W^+W^- \to l^+\nu l^-\bar{\nu}$

CDF presents a new search in the $H \to W^+W^- \to l^+\nu l^-\bar{\nu}$ channel. One improvement in this analysis is the increasing of geometric lepton acceptance by defining new, less stringent lepton types for regions of the detector without complete instrumentation, such as leptons not identifiable as electrons or muons since they are not fiducial to calorimeters or muon chambers. Such lepton types were successfully used in CDFs observaton of WZ production [3]. The number of Higgs signal events expected in the data for $m_H = 160$ Gev/c, increases from 2.5 to 4.0 events with this new selection, as compared to the previous CDF analysis with the same dataset. The new analysis also improves upon the technique for extracting the signal from the data. The previous search had performed a likelihood fit for the Higgs signal using the distribution of $\Delta\Phi$ between the two leptons which is sensitive to the angular correlations from WW produced by a scalar Higgs boson. The newest CDF measurement is done by constructing matrix element probabilties using the observed lepton four-vectors and $\not{E}_T$ for the processes $H \to WW$, WW, ZZ, $W + \gamma$, and W+parton. A likelihood ratio (LR) is formed for each event by dividing the signal probability by the sum of the signal and background probabilities. LRs are constructed for different processes specified as signal in order to validate background modeling. Figure 1 shows the $H \to WW$ LR distribution for $m_H = 160$ GeV/c^2, which is used to search for an excess consistent with Higgs signal for a range of masses. No significant excess is measured, and limits are set such that the observed (expected) upper limit is 5 (3.5) times larger than the Standard Model expected cross-section for the most sensitive Higgs mass of $m_H = 160$ GeV/c^2 [4].

3 $ZH \to l^+l^-b\bar{b}$

CDF also presents a new result in the $ZH \to l^+l^-b\bar{b}$ channel. Previous results first presented at ICHEP 2006 [5] demonstrated the use of a two-dimensional neural network trained to separate $ZH \to l^+l^-b\bar{b}$ from the dominant background of $Z+ >= 2$ jets production and $t\bar{t} \to WbWb \to l\nu bl\nu b$. The new result uses the same dataset but makes several improvements which result in improved sensitivity. One technique is in the identification of b hadrons from $H \to b\bar{b}$ using secondary vertex finders or "b-tagging" algorthms. The previous ZH analysis selected events with $>= 1$ "b-tag", using tight requirements for the secondary vertex significance (40% efficient). Since S:B is 200:1 for events with one b-tag (40% efficient), but 50:1 for events with two looser b-tags (each 50% efficient), there is an improvement in Higgs sensitivity by fitting these classes of events separately. Another new technique is to improve the resolution of the $H \to b\bar{b}$ dijet mass distribution, which is one of the most important Neural Network inputs. Since the main cause of $\not{E}_T$ in $ZH \to l^+l^-b\bar{b}$ events is from jet energy mismeasurement, a correction is applied which corrects the leading two jets independently according to their projection onto the $\not{E}_T$ direction. The effect is to reduce the dijet mass resolution from 14% to 9% for events with two

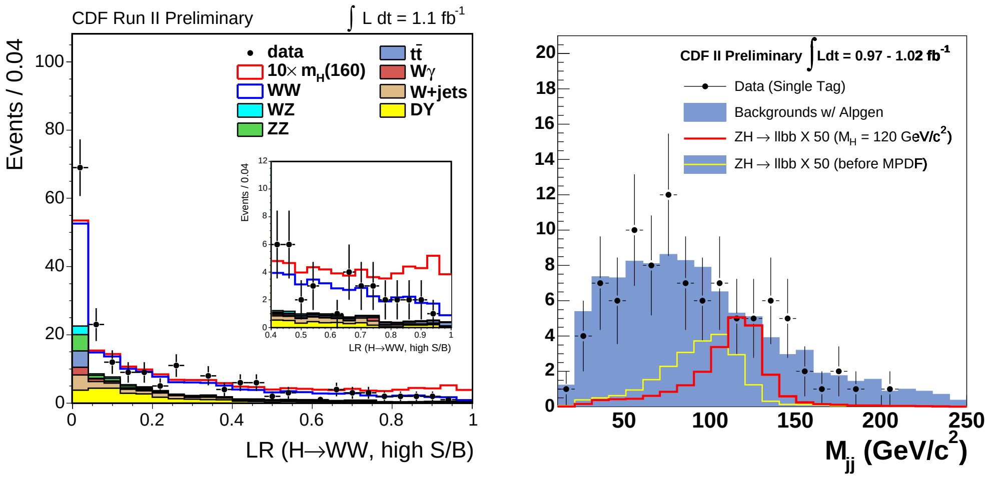

Figure 1: New CDF analyses. Left plot shows the $H \to WW$ discriminant, comparing data with Standard Model and with a 10 times expected $H \to WW$ signal. Right, dijet mass improvement in the ZH analysis shown before and after the Met Projection Dijet Fitter (MPDF) is used to improve the resolution of the dijet mass distribution, which is then input into the 2D Neural Network discriminant used to fit the ZH signal.

b-tags. With these two enhancements, the analysis improves its Higgs search sensitivity by a factor of two in terms of an effective luminosity increase as compared to the previous version of the analysis with the same dataset. For $m_H = 115$ GeV/c^2, the observed (expected) upper limits for σ_{ZH} are 16 times that of the Standard Model [6].

4 $WH \to l\nu b\bar{b}$

DØ presents two new searches in the $WH \to l\nu b\bar{b}$ channels. The first analysis improves over previous analyses by using multiple muon triggers in order to retain 100% muon acceptance for $WH \to \mu\nu b\bar{b}$. This results in 50% more signal than previous techniques. The b-tagging selection is optimized to separate events into one tight b-tag and two loose b-tags as is described in Section 3. But in addition, making use of a neural network b-tagging algorithm which uses variables in addition to the secondary vertex displacement to identify b-quarks, the b-tagging efficiency is increased to 50% for tight b-tags and 70% for loose b-tags, with misidentification rates of 0.5% and 4.5%, respectively. The discriminant used to search for the Higgs signal is the dijet invariant mass (Figure 2), and the combined limit from both single and double b-tagged events is expected (observed) to be less than 9 (10) times the Standard Model expectation [7].

The second analysis makes use of a matrix element technique similar to the one described in Section 2. This matrix element technique was developed originally in the context of the DØ single-top analyses which established 3-σ evidence for single-top production [8]. By fitting the matrix element discriminant for WH (Figure 2), DØ obtains expected (observed) limits of 9 (13) times the Standard Model expectation [9]. However, this analysis does not make use of the improved muon acceptance and optimized b-tagging used in the first analysis. Incorporating these improvements into the matrix element approach is expected to yield 30% better expected sensitivity.

5 Conclusions

CDF and DØ are improving analysis techniques in order to make gains in Higgs sensitivity which scale much faster than increasing statistics alone. New results in $H \to WW$, ZH, and WH rely on improved lepton acceptance and triggers, higher efficiency b-taggers, and dijet mass

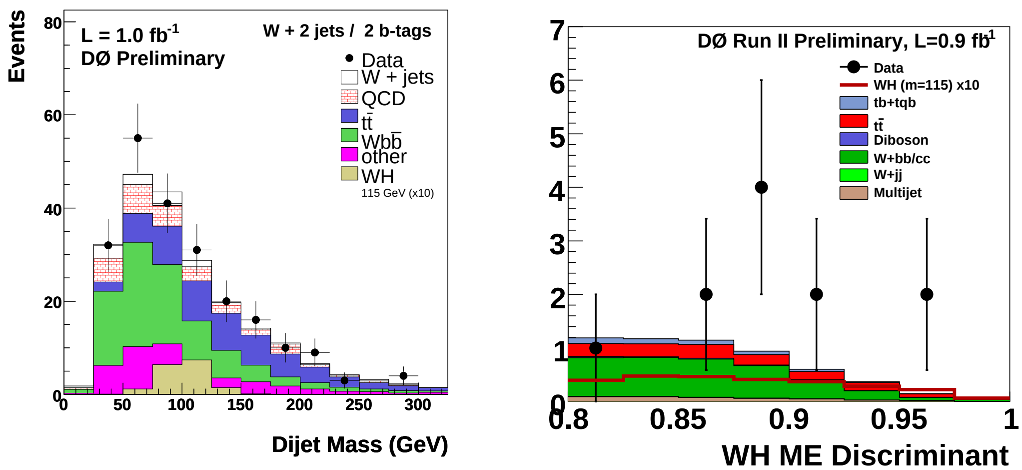

Figure 2: New DØ analyses. Left, dijet mass distribution for WH dijet mass fit analysis, and right, discriminant for WH matrix element analysis.

resolution improvements. The new WH and $H \to WW$ results are better in their most sensitive mass ranges than the combined results of all CDF and DØ channels presented a year ago.

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