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SEARCH FOR LOW MASS HIGGS AT THE TEVATRON

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We present CDF and DØ searches for a Standard Model Higgs boson produced associatively with a W or Z boson at $\sqrt{s} = 1.96$ TeV using up to 1 fb^{-1} of analyzed Tevatron data collected from February 2002 to February 2006. For Higgs masses less than 135 GeV/c^2, as is favored by experimental and theoretical constraints, $W^{\pm}H \rightarrow l^{\pm}\nu b\bar{b}$, $ZH \rightarrow l^{+}l^{-}b\bar{b}$, and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ are the most sensitive decay channels to search for the Higgs boson. Both CDF and DØ have analyzed these three channels and found no evidence for Higgs production, and therefore set upper limits on the Higgs production cross-section. While the analyses are not yet sensitive to Standard Model Higgs production, improvements in analysis techniques are increasing sensitivity to the Higgs much faster than added luminosity alone.

Keywords: Higgs; CDF; DØ ; Tevatron; associative.

1. Introduction

The Higgs boson is the only particle predicted by the Standard Model which has not yet been detected. It holds a special place in the Standard Model as the only scalar boson and as the particle which gives mass to the fermions, its coupling strength increasing as a function of their mass. Its predicted couplings to other Standard Model particles has allowed its mass to be indirectly constrained by precision electroweak data, most importantly the top quark mass and the W mass. The new combined Tevatron top quark mass of 171.4 ± 2.1 GeV/c^2 [1] and the new combined W boson mass of 80.376 ± 0.033 GeV/c^2 [2] have indirectly constrained m_H to 85 $+^{39}$ $-_{28}$ GeV/c^2, yielding a 95% CL upper limit of 166 GeV/c^2 [3]. Direct searches for the Higgs at LEP have excluded the Higgs up to 114.4 GeV/c^2 [4]. There is then clear motivation for searching for a low mass Higgs just above 114.4 GeV/c^2.

CDF and DØ at the Tevatron are currently the only experiments capable of searching for the Higgs boson. Above 135 GeV/c^2, $H \rightarrow W^{+}W-$ is the dominant Higgs decay mode, while below 135 GeV/c^2, the focus for this proceeding, Higgs decays predominantly $H \rightarrow b\bar{b}$. The dominant mode of production at the Tevatron is directly via $p\bar{p} \rightarrow H$ ($\sigma = 0.8$ pb) which is about four and seven times larger than the associative modes of $p\bar{p} \rightarrow W^{*} \rightarrow WH$ and $p\bar{p} \rightarrow Z* \rightarrow ZH$ for $M_H = 115$ GeV/c^2. The direct production signature of $H \rightarrow b\bar{b}$ is overwhelmed by QCD dijet backgrounds. The associative modes are most sensitive for discovering a low mass Higgs since the background rate is much smaller due to the reconstruction of the Z or W.

CDF and DØ have searched for the low mass Higgs in three associative channels, $W^{\pm}H \rightarrow l^{\pm}\nu b\bar{b}$, $ZH \rightarrow l^{+}l^{-}b\bar{b}$, and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$, where l can be an electron or a muon.

2. Identifying b quarks from Higgs decay

Each of the three low mass searches share the decay $H \rightarrow b\bar{b}$ which has a branching ratio of 73% for $m_H = 115$ GeV/c^2. Therefore, b-quark identification is a key element in event selection. Jets originating from b quarks can be "b-tagged" by identifying the b decay vertex, which is displaced from the collision vertex due to the large b lifetime. At CDF, the b-tag is 42 % efficient for jets within $\eta < 1.0$

and with $E_T > 15$ GeV. The "mistag" rate for light-quark jets to be b-tagged is about 1%. Since the probability of two mistags is small, and $H \to b\bar{b}$ has two possible b-tags, both CDF and DØ divide events into two separate samples by the number of b-tags for maximal signal to background sensitivity. At CDF a Neural Network is used in the WH analysis to further divide b-tagged jets into those most likely coming from b's, c's, and mistags.

A benchmark for Higgs searches is reconstructing $b\bar{b}$ resonances from b-tagged events. DØ finds evidence for a $Z \to b\bar{b}$ signal of 1168 events from a QCD background of almost a million events, measuring $M_Z = 81.0 \pm 2.2$ GeV/c^2, compared to an expected measured value from pseudo-data of 83 ± 2 GeV/c^2 (Figure 1).

3. Higgs Search in $W^{\pm}H \to l^{\pm}\nu b\bar{b}$

The signature from $W^{\pm}H \to l^{\pm}\nu b\bar{b}$ of a high transverse momentum (P_T) lepton, missing transverse energy ($\not{E}_T$) from the neutrino, two or more high transverse energy (E_T) jets, and one or more b-tags, is well understood since it is almost the same channel in which CDF and DØ measure $t\bar{t}$ production. The main difficulties for the WH analysis are estimating the dominant W plus heavy flavor jets background which can be seen in the dijet mass distributions that are used to search for the Higgs resonance in Figures 2 and 3.

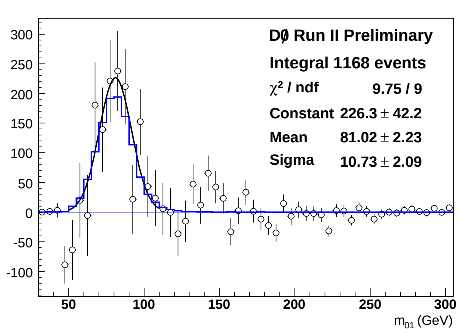

Fig. 1. The extracted $Z \to b\bar{b}$ mass peak in single b-tagged events from DØ .

4. Higgs Search in $ZH \to \nu\bar{\nu}b\bar{b}$

The $ZH \to \nu\bar{\nu}b\bar{b}$ signature of two high E_T jets with at least one b-tag recoiling against $\not{E}_T$ from Z decays to neutrinos is the most sensitive signature to low mass Higgs produc-

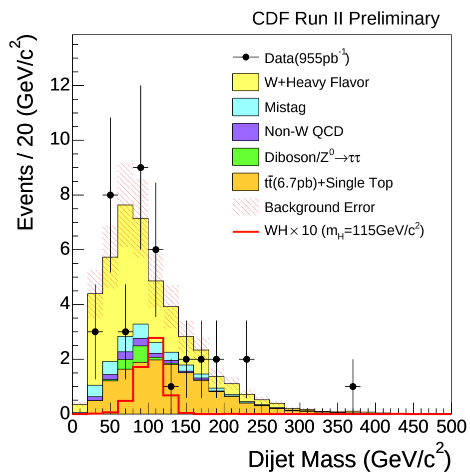

Fig. 2. The CDF analysis of $WH \to l\nu b\bar{b}$ showing the dijet mass distribution used to search for the higgs resonance.

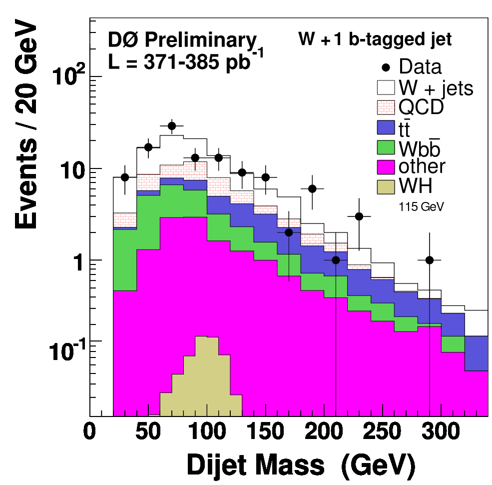

Fig. 3. The DØ analysis of $WH \to l\nu b\bar{b}$ showing the dijet mass distribution used to search for the higgs resonance.

tion at the Tevatron. At CDF, the search in the $\not\!\!E_T$ + jets channel includes WH events which did not pass lepton identification requirements. At DØ , a separate search for WH in the $\not\!\!E_T$ + jets channel is made. The largest backgrounds are due to jet energy mismeasurements of heavy flavored dijet QCD production, as well as W+jets and Z+jets where either the neutrinos or leptons are not reconstructed and yield $\not\!\!E_T$. Checks are made to verify the modeling of these backgrounds in two control regions sensitive to these QCD and electroweak backgrounds. The dijet mass distributions in the signal region for CDF and DØ are shown in Figures 4 and 5.

5. Higgs Search in $ZH \rightarrow l^+l^-b\bar{b}$

The $ZH \rightarrow l^+l^-b\bar{b}$ channel has the smallest event yield, but requiring two identified leptons to reconstruct the Z mass results in the cleanest signal. The DØ analysis uses the dijet mass to discriminate signal from the backgrounds dominated by Z+ jets (Figure 6). The CDF analysis uses a two dimensional Neural Network discriminant based on nine kinematic variables in order to maximize signal discrimination from Z+ jets and subdominant $t\bar{t}$ background (Figure 7).

6. Summary of Search Results

No significant signal excess was measured in any of the CDF and DØ channels and therefore upper limits are set on Higgs production. These limits are summarized in Table 1. Note that CDF combines its ZH and WH signals in the $\not\!\!E_T$ + jets channel, while DØ has separate $\not\!\!E_T$ + jets results for each signal. Also, DØ reports $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ as separate analyses while CDF does a combined fit in both channels.

These results are combined according

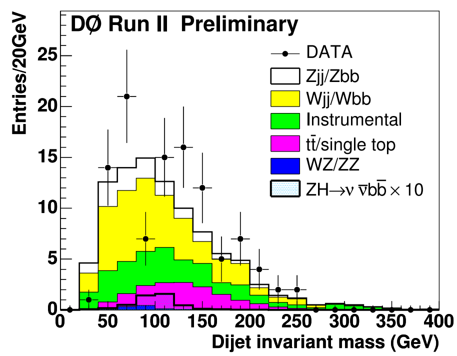

Fig. 5. The DØ analysis of $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ showing the dijet mass distribution used to search for the higgs resonance.

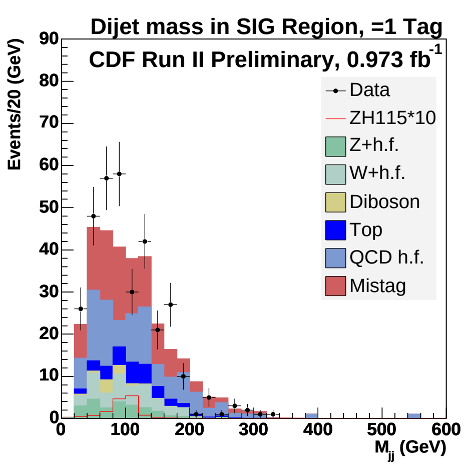

Fig. 4. The CDF analysis of $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ showing the dijet mass distribution used to search for the higgs resonance.

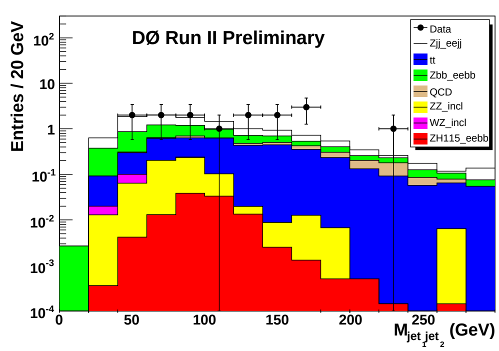

Fig. 6. The DØ analysis of $ZH \rightarrow l^+l^-b\bar{b}$ (ee) showing the dijet mass distribution used to search for the higgs resonance.

to their statistical and systematic correlations into an upper limit on Higgs production as a function of mass. At 115 GeV/c^2, the observed (expected) upper limit is 10.4 (7.6) times larger than the Standard Model prediction[5]. With the full DØ 1 fb^{-1} dataset, these expected limits would be 25% better.

7. Conclusions

The prospects for Higgs discovery or exclusion at the Tevatron depend on large integrated luminosity, advanced techniques for extracting Higgs candidates from background, and the timing of the transition to quality physics results at the LHC.

The Tevatron is well on its way to delivering the design goal of 8 fb^{-1}, after delivering more than 1.6 fb^{-1} of data, and recently surpassing the integrated luminosity rate necessary for delivering 4 fb^{-1}.

In this proceeding, we reported for the first time the addition of the CDF and DØ $ZH \to l^+l^-b\bar{b}$ channels to the combined Higgs search. We also report for the first time the updated 1 fb^{-1} results for CDF's $W^\pm H \to l^\pm \nu b\bar{b}$, and $ZH \to \nu\bar{\nu}b\bar{b}$.

With 1 fb^{-1} of data, the Tevatron is about a factor of 6 away from the Standard Model in terms of expected limits for a low mass Higgs. As new data are accumulating, Higgs analysis techniques are also becoming more advanced, making use of Neural Networks for b-tagging as well as kinematic separation of signal from background.

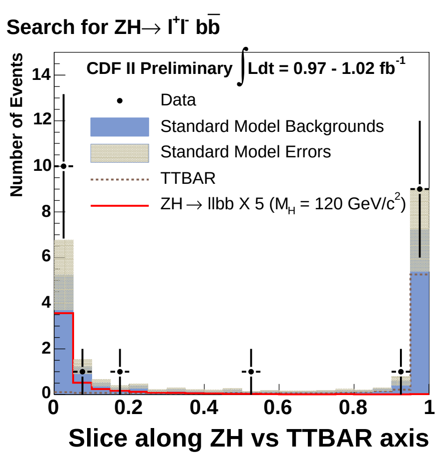

Fig. 7. The CDF analysis of $ZH \to l^+l^-b\bar{b}$ (ee,$\mu\mu$) showing a slice of the 2-D Neural Network discriminant used to search for the higgs resonance along the ZH vs $t\bar{t}$ axis.

Table 1. Summary of CDF and DØ Higgs upper limits for $M_H = 115$ GeV/c^2. L/SM is the measured upper limit of σ_{ZH} or σ_{WH} divided by its Standard Model NLO Cross-Section.

Expt	Channel	$\mathcal{L}$ (fb^{-1})	L/SM
CDF	$WH \to l\nu b\bar{b}$	1	25
DØ	$WH \to l\nu b\bar{b}$	0.38	18
CDF	$Z/WH \to \not{E}_T b\bar{b}$	1	14
DØ	$ZH \to \not{E}_T b\bar{b}$	0.26	41
DØ	$WH \to \not{E}_T b\bar{b}$	0.26	55
CDF	$ZH \to llb\bar{b}$	1	28
DØ	$ZH \to eeb\bar{b}$	0.39	100
DØ	$ZH \to \mu\mu b\bar{b}$	0.32	139
Comb	All	0.3-1.0	10.4

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