DØ Note 5485-CONF

Search for the Associated Higgs Boson Production $p\bar{p} \rightarrow WH \rightarrow WWW^* \rightarrow l^{\pm}\nu\ l'^{\pm}\nu' + X$ at $\sqrt{s}$ =1.96 TeV

The DØ Collaboration
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We search for associated Higgs boson production in the process $p\bar{p} \rightarrow WH \rightarrow WWW^* \rightarrow l^{\pm}\nu\ l'^{\pm}\nu' + X$ in the ee, $e\mu$, and $\mu\mu$ channels. The search is based on DØ Run II data samples corresponding to about 1 fb^{-1}. We require two like sign isolated leptons (electrons or muons) with p_T >15 GeV plus additional selection cuts. We observe 19 events in the ee channel, 15 events in the $e\mu$ channel, and 5 events in the $\mu\mu$ channel. In absence of an excess of observed number of events over the predicted Standard Model background, we set 95% C.L. upper limits on expected (observed) $\sigma(WH) \times Br(H \rightarrow WW^*)$ between 1.1(1.5) and 0.6(0.8) pb for Higgs masses from 120 to 200 GeV.

Preliminary Results for Summer 2007 Conferences

I. INTRODUCTION

In the Standard Model, the Higgs boson predominantly decays to a WW^* pair for Higgs masses above 135 GeV [1]. Furthermore, in some models with anomalous couplings ("fermiophobic Higgs"), the branching ratio $Br(H \to WW^*)$ may be close to 100% for Higgs masses down to ∼100 GeV [2]. In this scenario, it is worth considering the $p\bar{p} \to WH \to WWW^* \to l^{\pm}\nu\ l'^{\pm}\nu' + X$ process that provides a unique experimental signature with two like sign leptons from W decays. This channel is advantageous over the direct Higgs production, $H \to WW^*$, where the two leptons from W decays have opposite signs, implying large Standard Model backgrounds (Z/γ^*, WW, and $t\bar{t}$ production). For the WWW^* channel, the irreducible physics background of non-resonant triple vector boson production (VVV, $V = W, Z$) has very low cross section, as does $t\bar{t} + V$. The main physics background appears to be $WZ \to l\nu ll$ production.

As the channel involves two neutrinos in the final state, the reconstruction of the Higgs mass in the candidate events does not seem feasible. The potential Higgs signal appears as an excess in the number of observed events with two like sign leptons over predicted Standard Model background. In the absence of such excess, upper cross section limits are set. These limits vary with the Higgs mass as do the event selection efficiencies.

II. THE DØ DETECTOR

The DØ detector has a central-tracking system, calorimeters, and a muon spectrometer [3]. The central-tracking system includes a silicon microstrip tracker (SMT) and a central fiber tracker (CFT) embedded in 2 T solenoidal magnetic field, and provides tracking in the pseudorapidity range of $|\eta| < 3$. The uranium/liquid argon calorimeter consists of a central section (CC) covering pseudorapidities $|\eta|$ up to ≈ 1.1, and two end calorimeters (EC) that extend coverage to $|\eta| \approx 4.2$. The outer muon spectrometer surrounds the calorimeters and allows for detection of muons at pseudorapidities $|\eta| < 2$. Luminosity is measured from the $p\bar{p}$ inelastic collision rate using plastic scintillator arrays.

III. DATA AND MONTE CARLO SAMPLES

The present analysis uses data collected by the DØ experiment between August 2002 and February 2006. The data samples correspond to total integrated luminosities of about 1 fb^{-1}.

The signal and background processes have been generated with Pythia 6.323 [4] using CTEQ6L1 PDFs, followed by a detailed GEANT based simulation of the DØ detector. The signal cross section is calculated at NLO using HDECAY [5] and HIGLU [6]. The integrated luminosity for the data samples is obtained by normalizing the number of events in the $Z \to ll$ peak to the theoretical cross section (242±8 pb), which is calculated with CTEQ6.1M PDFs using the NNLO to LO K-factor according to [7]. The NLO diboson production cross sections are taken from [8].

IV. EVENT SELECTION

The analysis starts from data samples with at least two electromagnetic energy (EM) clusters (ee), an EM cluster and a muon ($e\mu$), or two muons ($\mu\mu$). For electrons, we require an EM cluster in the central calorimeter region ($|\eta| < 1.1$) with p_T >15 GeV, matched to a central track. In addition, the electron candidate must pass a seven-variable likelihood based quality cut that selects isolated prompt electrons. For muons, we require an isolated muon candidate with p_T >15 GeV. The isolation is defined as a maximum sum of energy cells within a hollow cone $0.1 < \Delta R < 0.4$ around the muon track $\sum_{0.1<R<0.4} E_T^{cell}$ <2.5 GeV, and a maximum sum of transverse momenta of all tracks in the cone R <0.5 around the muon track $\sum_{R<0.5} p_T^{tr}$ <2.5 GeV, where $R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$ and φ is the azimuthal angle. Both leptons are required to have the same charge. We also impose a veto on events with a third high p_T isolated lepton, with an idea to consider the trilepton channels later.

An additional set of track quality cuts includes requirements on a maximum distance between the lepton tracks and the vertex (1 cm), a maximum distance of closest approach to the beam axis $dca < 0.02$ cm and its significance (value divided by its error) $|dca/\sigma(dca)| < 3$, $\chi^2/NDF < 4$ for the lepton track fit, and a minimum number of SMT and CFT measurements. The track quality cuts are aimed at reducing the charge flip probability (the probability of the lepton charge being mismeasured, derived in Section V). The minimum number of 12 CFT measurements is chosen as a compromise between the charge flip rate reduction and the decrease in selection efficiency.

For the final separation between the signal and background, the 2-dimensional likelihood discriminant is used which involves $\Delta\varphi_{ll}$ (opening angle between two leptons in transverse plane), m_{ll} (invariant mass of two leptons), $\not\!\!E_T$ (missing transverse energy, the ee, $e\mu$ channels only), $\Delta\varphi^{min}_{l\not{E}_T{}'}$ (minimum angle between a lepton and $\not{E}_T{}'$ in transverse plane, the $\mu\mu$ channel only), and $\not{E}_T{}'$ (hadronic missing transverse energy). The two dimensions separate the signal from the instrumental background and physics background, respectively.

V. EVENT SAMPLE COMPOSITION

The Standard Model backgrounds are conveniently split in two categories: physics and instrumental. The physics background (true like sign isolated high p_T leptons) is mainly due to $WZ \to l\nu ll$ production. This background is estimated from the known theoretical cross section, taking into account the relevant branching ratio and event selection efficiency.

In addition to the physics background, there are two types of instrumental backgrounds. One type, referred to as "charge flips", originates from the misreconstruction of the charge of one of the leptons, mostly from $Z/\gamma^* \to ll$ decays. Another source of background is like sign lepton pairs from multijet or W+jets production. In the case of muons, these can be real muons from semileptonic heavy flavor decays that pass isolation cuts, punch-through hadrons misidentified as muons, or muons from π/K decays in flight. In the case of electrons, the background originates from electrons from semileptonic heavy flavor decays, from hadrons misidentified as electrons, and from real electrons from γ conversions. This kind of background will be referred to as "QCD".

There are other processes that are included in these two background categories. In particular, charge flips include events due to $WW \to l\nu l\nu$ production where one lepton is mismeasured. $t\bar{t} \to ll$ may contribute to either charge flips (if one of the leptons is mismeasured) or QCD (if one lepton is lost and a lepton from semileptonic b-decay passes the lepton identification cuts). $t\bar{t} \to l$+jets with a lepton from b-decay may contribute to QCD.

In case of instrumental backgrounds, no attempt is made to calculate their rates based on known cross sections and detector simulation, as such a calculation may not be reliable. Instead, both charge flip and QCD rates are measured directly from data. Therefore, contributions from all the processes are naturally taken into account.

The contribution from the charge flips is estimated using two measurements of the same charge. The first one is the measurement of the track charge in the central tracker. In the case of muons, the second measurement is local muon charge in the muon system. In the case of electrons, the second measurement is the azimuthal offset of the EM cluster with respect to the track direction at the origin $\Delta\varphi(tr, EM)$. The second measurement is considered to be of much lower accuracy than the tracker measurement. The fraction of the charge flips is derived from the number of events where the two measurements give the same answer for both leptons (SS), agree for one lepton and disagree for another one (OS), or disagree for both leptons (OO). In the $e\mu$ channel, the number of charge flips is assumed to be small compared to the QCD contribution.

The number of like sign events due to QCD is calculated from the number of events without tight leptons (N_0) and with exactly one tight lepton (N_1), taking into account dependence of the QCD fake rate on the lepton momentum and admixture of real (non-QCD) leptons in the N_0 and N_1 samples. The number of QCD events in the $e\mu$ sample is estimated using the sample with a tight muon and any electron. The EM likelihood distribution in this sample is fitted using templates for true and fake electrons.

The number of predicted and observed events after all selections is summarized in Table I. In all channels, the observed number of events is in agreement with the predicted background. As an example, Fig. 1 shows the dilepton invariant mass distributions for the three channels before and after track quality cuts.

VI. RESULTS

In absence of an excess in the number of observed events over the Standard Model background, cross section upper limits have been calculated using the modified frequentist approach [9]. The results of these calculations are summarized in Table II. Fig. 2 shows observed and expected upper limits together with the theoretical prediction for the Standard Model, the theoretical prediction for a fermiophobic Higgs, the previous DØ result obtained with 0.4 fb^{-1} [10], and the CDF Run II result obtained with 0.2 fb^{-1}[11].

The main source of systematic uncertainty is uncertainty on instrumental background (15–30% on the QCD events, 30% on the number of charge flips in the ee channel, +290–100% on the number of charge flips in the $\mu\mu$ channel). Other sources of uncertainty include luminosity, lepton ID, and physics background cross section.

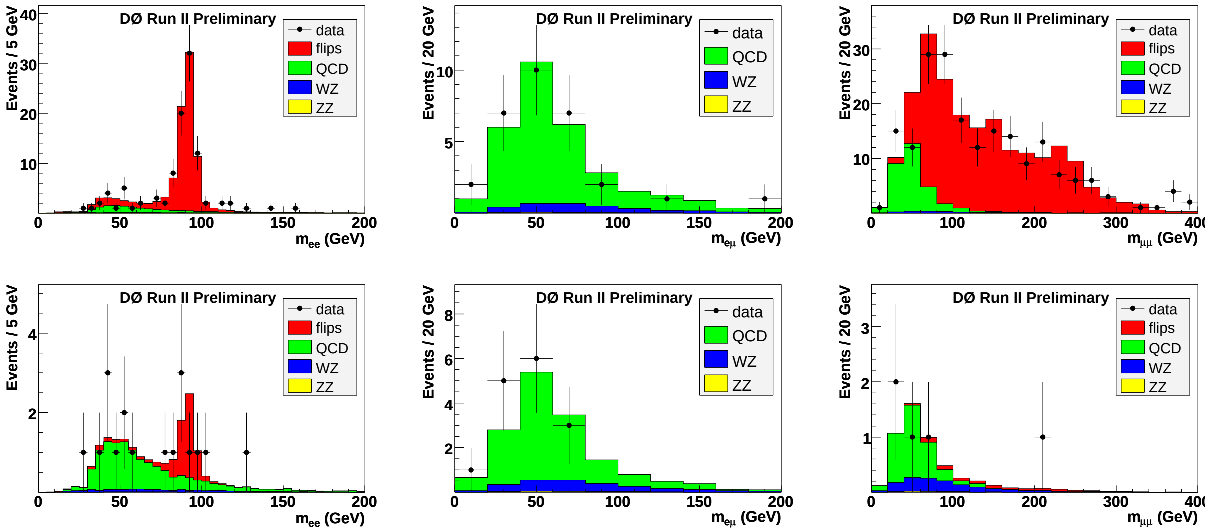

FIG. 1: The distribution of dilepton invariant mass in the ee (left), $e\mu$ (middle), and $\mu\mu$ (right) channel before track quality cuts (top row) and after all selection cuts (bottom row).

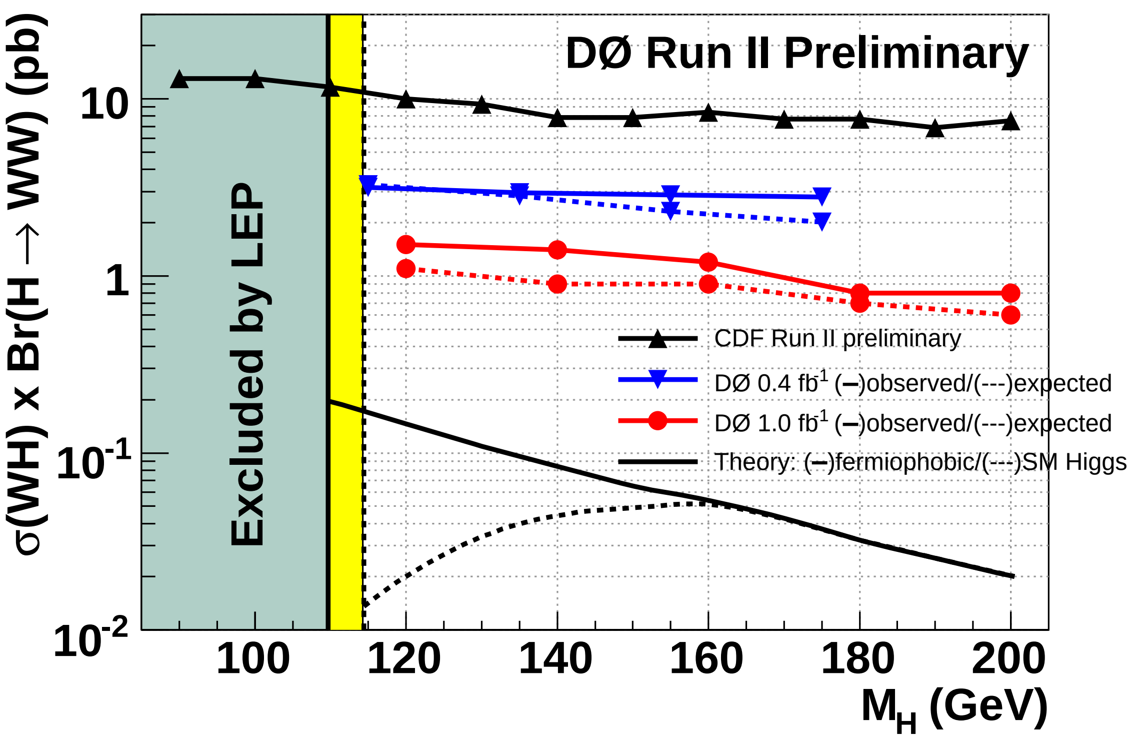

FIG. 2: Expected and observed upper limits on $\sigma(WH) \times Br(H \to WW^*)$ at the CL=95% (pb). Also shown are the previous DØ result obtained with 0.4 fb^{-1}, the CDF Run II result obtained with 0.2 fb^{-1}, and theoretical predictions (see references in the text).

TABLE I: The number of observed and predicted events after all selection cuts.

	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
$WZ \to l\nu ll$	1.18±0.17	2.46±0.34	1.29±0.18
$ZZ \to llll$	0.10±0.01	0.16±0.02	0.07±0.01
QCD	7.4±1.1	15.4±2.8	2.8±0.9
flips	11.9±3.8	0.04±0.02	0.8+2.3−0.8
total	20.6±4.0	18.0±2.8	5.0+2.5−1.2
$WH(120) \to lljj$	0.028	0.063	0.034
$WH(120) \to lll$	0.009	0.021	0.012
$WH(140) \to lljj$	0.067	0.143	0.069
$WH(140) \to lll$	0.018	0.043	0.024
$WH(160) \to lljj$	0.077	0.161	0.082
$WH(160) \to lll$	0.021	0.046	0.026
$WH(180) \to lljj$	0.056	0.108	0.060
$WH(180) \to lll$	0.014	0.031	0.017
$WH(200) \to lljj$	0.029	0.061	0.032
$WH(200) \to lll$	0.008	0.017	0.009
data	19	15	5

TABLE II: The expected (observed) upper limits on $\sigma(WH) \times Br(H \to WW^*)$ at the CL=95% (pb) for individual channels and the combination.

m_H (GeV)	120	140	160	180	200
ee	2.5(4.5)	2.3(4.1)	2.1(3.6)	1.9(2.7)	1.6(2.7)
$e\mu$	1.9(1.9)	1.6(1.6)	1.5(1.4)	1.3(1.1)	1.0(0.9)
$\mu\mu$	2.2(2.4)	2.0(2.5)	1.9(2.4)	1.6(1.9)	1.4(1.7)
combined	1.1(1.5)	0.9(1.4)	0.9(1.2)	0.7(0.8)	0.6(0.8)

VII. CONCLUSIONS

A search has been performed on the process $p\bar{p} \to WH \to WWW^* \to l^{\pm}\nu\ l'^{\pm}\nu' + X$ in the ee, $e\mu$, and $\mu\mu$ channels. After the selection, 19 events in the ee channel, 15 events in the $e\mu$ channel, and 5 events in the $\mu\mu$ channel have been observed, in agreement with the predicted Standard Model background. The expected (observed) upper limits set on $\sigma(WH) \times Br(H \to WW^*)$ for the combination of all three channels vary from 1.1(1.5) to 0.6(0.8) pb as the Higgs mass varies from 120 to 200 GeV.

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