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

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We search for associated Higgs boson production in the process $p\bar{p} \rightarrow$WH$\rightarrow$WWW$^* \rightarrow l^\pm\nu\ l'^\pm\nu\ q\bar{q}$ in the ee, $e\mu$, and $\mu\mu$ channels. The search is based on DØ Run II data samples corresponding to 384 pb^{-1} (ee), 368 pb^{-1} ($e\mu$), and 363 pb^{-1} ($\mu\mu$). We require two like sign isolated leptons (electrons or muons) with p_T >15 GeV plus additional selection cuts. We observe 1 event in the ee channel, 3 events in the $e\mu$ channel, and 2 events in the $\mu\mu$ channel which are in agreement with the predicted Standard Model background. We set 95% C.L. upper limits on σ(WH)$\times$Br(H$\rightarrow$WW*) between 3.9 and 2.1 pb for Higgs masses from 115 to 175 GeV.

Preliminary Results for Summer 2005 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$\rightarrow$WW*) may be close to 100% for Higgs masses down to $\sim$100 GeV [2]. In this scenario, it is worth considering the $p\bar{p}$ $\rightarrow$WH$\rightarrow$WWW* $\rightarrow$ $l^{\pm}\nu$ $l'^{\pm}\nu$ $q\bar{q}$ 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$\rightarrow$WW*, where the two leptons from W decays have opposite signs, implying large Standard Model backgrounds (Z/γ^*, WW, and $t\bar{t}$ production). 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$\rightarrow$ $l\nu ll$ production where one of the leptons from the Z is lost.

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.

The present analysis uses data collected by the DØ experiment between August 2002 and August 2004. The data samples correspond to total integrated luminosities of 384 pb^{-1} (ee), 368 pb^{-1} ($e\mu$), and 363 pb^{-1} ($\mu\mu$).

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. EVENT SELECTION

The analysis starts from data samples collected using dilepton triggers that require 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 minimum distance to the closest jet in the event $\Delta R(\mu j)$ >0.5 and a maximum sum of transverse momenta of all tracks in the cone R <0.5 around the muon track $\sum_{R<0.5} p_T^{tr}$ <4 GeV, where $R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$ and φ is the azimuthal angle. Neither the muon nor the electron candidates are allowed to share their central tracks with other lepton candidates in the event. We also impose a veto on events with a third high p_T isolated lepton in the event, to suppress the unlike sign production background.

An additional set of track quality cuts includes requirements on a maximum distance between two lepton tracks at the vertex, a maximum distance of closest approach to the beam axis, 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). We found that by requiring the lepton tracks to have at least two SMT measurements, the charge flip rate decreases by a factor of 2 for electrons and 5 for muons. The minimum number of 5 CFT measurements is chosen as a compromise between the charge flip rate reduction and the decrease in selection efficiency.

Finally, the missing transverse energy cut $\not{E}_T$ >20 GeV is imposed (see Fig. 1), where in case of $e\mu$ and $\mu\mu$, the $\not{E}_T$ value is computed ignoring the lepton momenta/energies. After all cuts, the number of remaining events is 1 in the ee channel, 3 in the $e\mu$ channel, and 2 in the $\mu\mu$ channel.

IV. SIGNAL EFFICIENCY

The efficiency for the signal to pass the selection is estimated using the Pythia 6.2 [4] event generator followed by a detailed GEANT-based [5] simulation of the detector. All trigger efficiencies are derived from data, and dis-

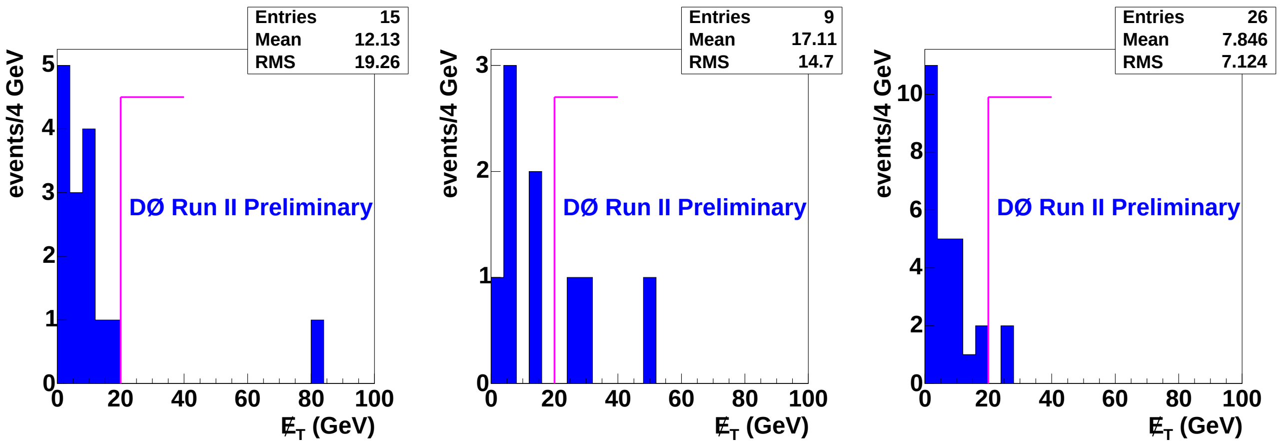

FIG. 1: The $\not\!\!E_T$ distributions for like sign ee (left), $e\mu$ (center), and $\mu\mu$ (right) data before the $\not\!\!E_T$ cut (shown with light vertical lines).

TABLE I: Overall detector efficiency for WH→WWW* $\rightarrow l^{\pm}\nu\ l'^{\pm}\nu\ q\bar{q}$ events, $\times 10^{-3}$.

	ee	$e\mu$	$\mu\mu$
$M_H = 115$	0.86±0.06	1.90±0.15	1.18±0.14
$M_H = 135$	1.10±0.06	2.63±0.18	1.90±0.21
$M_H = 155$	1.17±0.06	2.81±0.19	2.01±0.22
$M_H = 175$	1.50±0.08	3.45±0.22	2.35±0.25

crepancies between the data and Monte Carlo simulation are taken into account. The overall detection efficiency for WH→WWW* $\rightarrow l^{\pm}\nu\ l'^{\pm}\nu\ q\bar{q}$ events for four chosen Higgs mass points is summarized in Table I.

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→ $l\nu ll$ production. This background is estimated from the known theoretical cross section [6], taking into account the relevant branching ratio, trigger efficiency, 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. For the same lepton flavor channels (ee and $\mu\mu$) and before the $\not\!\!E_T$ cut, this background is dominated by $Z/\gamma^* \rightarrow ll$.

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→ $l\nu l\nu$ production where one lepton is mismeasured. $t\bar{t} \rightarrow ll$ 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). $t\bar{t} \rightarrow l$+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 number of background events due to charge flips N^{sel}_{flip} is estimated from the number of events in the unlike sign sample $N^{us\ sel}$ as

$$N^{sel}_{flip} = N^{us\ sel} P_{flip}$$

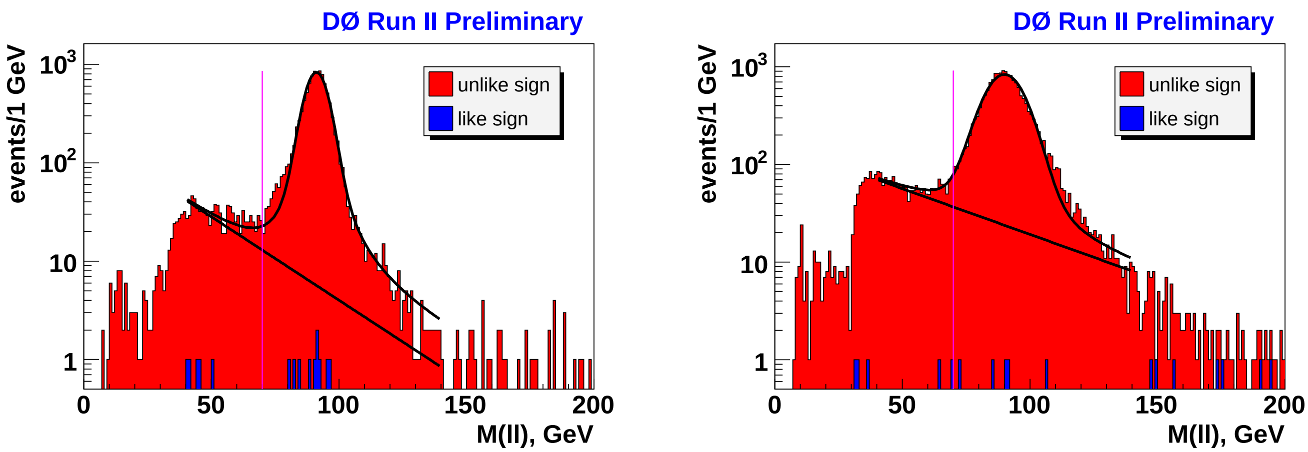

FIG. 2: The invariant mass of two leptons in unlike sign and like sign events before the $\not\!\!E_T$ cut in the ee (left) and $\mu\mu$ (right) channel. The light vertical lines indicate boundaries for regions 1 and 2.

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

	ee	$e\mu$	$\mu\mu$
observed data	1	3	2
WZ	0.43±0.03	0.33±0.03	0.16±0.03
charge flips	0.20±0.06	0.05±0.01	3.40±0.73
W/QCD	0.07±0.04	3.94±0.23	0.16±0.18
total background	0.70±0.08	4.32±0.23	3.72±0.75

where the probability for the lepton charge mismeasurement P_{flip} is calculated for events before the $\not\!\!E_T$ cuts. As the $\not\!\!E_T$ cuts do not depend on values measured in the central tracker, they do not modify P_{flip}.

The charge flip probability in events before the $\not\!\!E_T$ cuts is estimated by splitting the data sample into two parts according to the invariant mass of two leptons M_{ll} (Fig. 2): events with M_{ll} <70 GeV (region 1, dominated by QCD) and events with M_{ll} >70 GeV (region 2, dominated by charge flips). The P_{flip} value is determined from the ratio of like to unlike sign events in region 2, and the excess of events in region 1 above the estimated number of charge flips is attributed to QCD. The charge flip probability per event is measured from data to be P_{flip} =(9.7±3.1)$\times10^{-4}$ in ee and P_{flip} =(11.7±2.6)$\times10^{-4}$ in $\mu\mu$.

In the $\mu\mu$ case the method used could be biased, since M_{ll} for mismeasured muons is incorrect. Hence the result is cross checked with a different method that relies on two independent measurements of the muon charge in the central tracker and in the muon spectrometer. The value obtained with this alternative method is P_{flip} =(12.4±3.8)$\times10^{-4}$, in agreement with the above value.

The number of QCD events after the $\not\!\!E_T$ cut is extrapolated from the number of QCD events before the cut as

$$N^{sel}_{QCD} = N_{QCD}\ \varepsilon^{sel}_{QCD}.$$

The probability $\varepsilon^{sel}_{QCD}$for a QCD event to pass the $\not\!\!E_T$ cut is determined from the sample with reverse isolation (muons) or likelihood (electrons) cuts. Only events from region 1 are taken into account in order to reduce the background from Z→ ll. The resulting ε^{sel}_{QCD} values are 0.019±0.011 for ee, 0.511±0.028 for $e\mu$, and 0.292±0.024 for $\mu\mu$.

The number of predicted and observed events after all selections is summarized in Table II. It turns out that the background composition is different in different channels. In ee, where $\not\!\!E_T$ is better measured compared to other channels, the $\not\!\!E_T$ cut is very effective against QCD and charge flip contributions, and hence the background is dominated by physics sources. In contrast, in $e\mu$ and $\mu\mu$ channels, the background is primarily of instrumental origin. Since the number of unlike sign events in the $e\mu$ channel is two orders of magnitude smaller than in $\mu\mu$ (due to large $Z/\gamma^* \rightarrow \mu\mu$ production), the $\mu\mu$ background is dominated by charge flips, and in $e\mu$, the largest contribution comes from QCD. In all channels, the observed number of events is in agreement with the predicted background.

TABLE III: Observed upper limits on σ(WH)×Br(H→WW*) at the CL=95% (pb).

	ee	$e\mu$	$\mu\mu$	combined
M_H =115	13.04	6.99	10.18	3.88
M_H =135	10.11	5.06	6.29	2.73
M_H =155	9.44	4.73	5.95	2.58
M_H =175	7.40	3.84	5.06	2.09

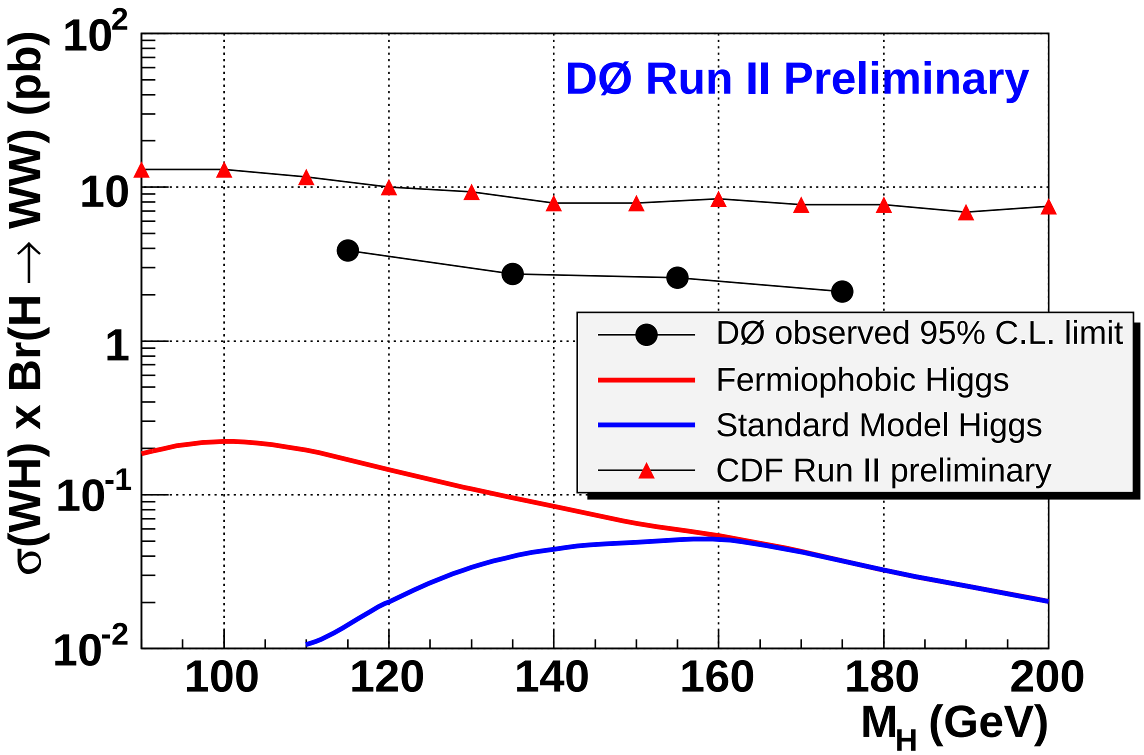

FIG. 3: Observed upper limits on σ(WH)×Br(H→WW*) at the CL=95% (pb).

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 [7]. The results of these calculations are summarized in Table III. Fig. 3 shows observed upper limits together with the theoretical prediction for the Standard Model, the theoretical prediction for a fermiophobic Higgs, and the CDF Run II result obtained with 193.5 pb^{-1} [8].

VII. CONCLUSIONS

A search has been performed on the process $p\bar{p}$ →WH→WWW* $\rightarrow l^{\pm}\nu\ l'^{\pm}\nu\ q\bar{q}$ in the ee, $e\mu$, and $\mu\mu$ channels. After the selection, 1 event in the ee channel, 3 events in the $e\mu$ channel, and 2 events in the $\mu\mu$ channel have been observed, in agreement with the predicted Standard Model background. The upper limits set on σ(WH)×Br(H→WW*) for the combination of all three channels vary from 3.9 to 2.1 pb as the Higgs mass varies from 115 to 175 GeV.

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