CDF/PUB/EXOTIC/PUBLIC/9468

Search for Standard Model Higgs Boson Production in Association with $W^{\pm}$ Boson at CDF with 2.7 fb^{-1}

The CDF Collaboration
URL http://www-cdf.fnal.gov

(Dated: August 1, 2008)

We present a search for Standard Model Higgs boson production in association with a $W^{\pm}$ boson. This search uses data corresponding to an integrated luminosity of 2.7 fb^{-1}. We select events matching the W + jets signature using leptons from both the central and forward regions of the detector. We futher require at least one jet to be identified as a b-quark jet. To further increase discrimination between signal and background, we use kinematic information in an artificial neural network. The number of tagged events and the resulting neural network output distributions are consistent with the Standard Model expectations, and we set an upper limit on the WH production cross section times branching ratio

$$\sigma(p\bar{p} \to W^{\pm}H) \times BR(H \to b\bar{b}) < 5.2 \text{ (expect 5.8)} \times \text{SM at } M_H = 115\ GeV/c^2$$

We set a limit that ranges from 3.6 to 61.1 times the Standard Model expectation for Higgs masses from 100 GeV/c^2 to 150 GeV/c^2 at 95% confidence level.

Preliminary Results for Summer 2008 Conferences

I. INTRODUCTION

The success of the Standard Model in explaining and predicting experimental data provides strong motivation for the existence of a neutral Higgs boson. Current electroweak fits combined with direct searches from LEP2 indicate the mass of the Higgs boson is less than $182\,\mathrm{GeV}/c^2$ at 95% confidence level [1, 2].

In proton-antiproton collisions of $\sqrt{s} = 1.96\,\mathrm{TeV}$ at the Tevatron, the Standard Model Higgs boson may be produced in association with a W boson [3]. For low Higgs masses (below $140\,\mathrm{GeV}/c^2$) the dominant decay mode is $H \to b\bar{b}$. The final state from the WH production is therefore $\ell\nu b\bar{b}$. We use complimentary high-p_T lepton and $\not\!\!E_T$ + jet triggers to maximize our signal acceptance.

The previously published WH search from CDF [4] was performed in a dataset with integrated luminosity equivalent to $955\,\mathrm{pb}^{-1}$. This analysis uses about 3 times more data and employs a neural network to improve discrimination between signal and background.

II. DATA SAMPLE & EVENT SELECTION

We use lepton and $\not\!\!E_T$ + jets triggered data collected through April 2008, corresponding to an integrated luminosity of $2.7\,\mathrm{fb}^{-1}$. The events are collected by the CDF II detector and classified according to their trigger type.

Central leptons event enter the analysis from high-p_T electron or muon triggers which have an 18 GeV threshold [5]. The electron or muon is further required offline to be isolated with E_T (or p_T) $> 20\,\mathrm{GeV}$. Central lepton events having the W+jets signature are confirmed with a missing transverse energy requirement ($\not\!\!E_T > 20\,\mathrm{GeV}$).

We select forward (plug) electron events with a trigger intended for W candidate events. The plug electron trigger requires both a plug electron candidate and missing transverse energy. Plug electrons events are futher required offline to have $E_T > 20\,\mathrm{GeV}$ and $\not\!\!E_T > 25\,\mathrm{GeV}$. We increase the purity of the sample by applying cuts intended to remove fake events from QCD processes. Our QCD veto consists of the following cuts:

- Linear cut on the $\not\!\!E_T$ and the azimuthal angle (ϕ) between the $\not\!\!E_T$ and the each of the jets ($\not\!\!E_T > 45-(30\cdot|\Delta\phi|)$).
- Large transverse mass of the reconstructed W ($M_T(W) > 20$)
- Large $\not\!\!E_T$ significance $\not\!\!E_T^{sig}$, where $\not\!\!E_T^{sig}$ is defined as ratio of $\not\!\!E_T$ to a weighted sum of factors correlated with mismeasurement, such as angles between the $\not\!\!E_T$ and the jet and amount of jet energy corrections.

We select $\not\!\!E_T$ + jet triggered events that have an identified loose (non-triggered) lepton. For trigger pre-selection, we require two jets with $E_T > 25$, $\Delta R > 1.0$, and at least on central jet with $\eta < 0.9$. The trigger requires 35 GeV of uncorrected missing transverse energy. We parameterize the trigger cut as a sigmoid turn-on in uncorrected $\not\!\!E_T$. We identify a single category of loose leptons called isolated tracks. We require isolated tracks to have $p_T > 20$ GeV and be isolated from other track activity in the event. As in the central leptons, events with the W+jets signature are confirmed with $\not\!\!E_T > 20$ GeV.

The events from all trigger types are classified according to the number of jets having $E_T > 20\,\mathrm{GeV}$ and $|\eta| < 2.0$. Because the Higgs boson decays to $b\bar{b}$ pairs, we employ b-tagging algorithms which relies on the long lifetime and large mass of the b quark. We require at least one of the jets in the event to be b-tagged. For events with exactly one b-tag, we reduce the contamination from events with a fake W's by applying cuts on the transverse mass and angular variables.

A. Bottom Quark Tagging Algorithms

To greatly reduce the backgrounds to this Higgs search, we require that at least one jets in the event be identified as containing b-quarks by one of two b-tagging algorithms. The secondary vertex tagging algorithm identifies b quarks by fitting tracks displaced from the primary vertex. This method has been used in other Higgs searches and top analyses [4, 6]. In addition, we add jet probability tagging algorithm that identifies b quarks by requiring a low probability that all tracks contained in a jet originated from the primary vertex, based on the track impact parameters [7]. We use three exclusive tagging categories: two secondary vertex tags, one secondary vertex tag and one jet probability tag, and exactly one secvtx tag.

CDF Run II Preliminary 2.7 fb^{-1} Number of Expected WH (M(H) = 120) Events	
Detector	Expected Number of WH events
One Tag	
cem	1.580
cmup	0.907
cmx	0.437
isotrk	0.723
Total	3.647
ST+ST Tag	
cem	0.656
cmup	0.374
cmx	0.167
isotrk	0.359
Total	1.556
ST+JP Tag	
cem	0.476
cmup	0.255
cmx	0.127
isotrk	0.232
Total	1.09

TABLE I: Expected number of WH events at a M(H)=120, shown broken down for tag categories and lepton types

B. Total WH Acceptance

The signal acceptance is measured in a sample of Monte Carlo events generated with the PYTHIA program [8]. The detection efficiency for signal events is defined as:

$$\epsilon_{WH\to l\nu b\bar{b}} = \epsilon_{Z0} \cdot \epsilon_{trig} \cdot \epsilon_{\mathrm{l}eptonid} \cdot \epsilon_{\mathrm{iso}} \cdot \epsilon^{MC}_{WH\to \ell\nu b\bar{b}} \cdot \left(\sum_{l'=e,\mu,\tau} Br(W \to \ell\nu) \right), \tag{1}$$

where $\epsilon^{MC}_{WH\to\ell\nu b\bar{b}}$ is the fraction of signal events (with $|z_0| < 60\,\mathrm{cm}$) which pass the kinematic requirements. The effect of the b-tagging scale factor in this fraction is considered by applying scale factor 0.95 ± 0.05. The quantity ϵ_{Z0} is the efficiency of the $|z_0| < 60$cm cut, ϵ_{trig} is the trigger efficiency; $\epsilon_{\mathrm{l}eptonid}$, is the efficiency to identify a lepton; ϵ_{iso} is efficiency of the energy isolation cut ; and $Br(W \to \ell\nu)$ is the branching ratio for leptonic W decay. For plug electrons, ϵ_{trig} is parameterized as a function of the trigger missing transverse energy and the E_T of the electron. For isolated tracks, ϵ_{trig} is parameterized as a function of the trigger missing transverse energy.

Table. I shows the central lepton acceptance for the single-tag and the double-tag categories as a function of Higgs mass. The acceptance for the double secondary vertex tagged category increases from (0.42±0.04)% for a Higgs mass of 110 GeV/c^2 to (0.51±0.05)% for a Higgs mass of 150 GeV/c^2. The acceptance of the secondary vertex plus jet probability category ranges from (0.36±0.04)% to (0.43±0.05)% over the same mass range. The acceptance of one neural network tagged category ranges from (0.91±0.05)% to (1.01±0.06)% over the same mass range.

Plug electrons increase the WH signal acceptance by 10%. Isolated tracks increase the signal acceptance by 25%.

These two categories of double-tagged events and one category of one neural network tagged events are defined exclusively, so the total acceptance is given by the sum of the acceptance for the three categories.

III. BACKGROUNDS

This analysis builds on the method of background estimation detailed in Ref. [6]. In particular, the contributions from the following individual backgrounds are calculated: falsely b-tagged events, W production with heavy flavor quark pairs, QCD events with false W signatures, top quark pair production, and electroweak production (diboson, single top).

We estimate the amount of falsely b-tagged events (mistags) from the number of pretag W + light flavor events. The amount of pretag W + light flavor is determined by a fit of the pretag $\not\!\!E_T$ distribution to W and non-W templates.

CDF Run II Preliminary 2.7 fb^{-1} Tight Lepton Background Predication and Event Yields Exactly One Secvtx Tag Events				
Process	2jets	3jets	4jets	5jets
All Pretag Candidates	38729	6380	1677	386
WW	41 ± 4.2	12 ± 1.2	2.9 ± 0.25	0.71 ± 0.055
WZ	14 ± 0.94	3.4 ± 0.23	0.93 ± 0.064	0.20 ± 0.015
ZZ	0.48 ± 0.037	0.19 ± 0.015	0.081 ± 0.0070	0.023 ± 0.0020
Top Pair Prod	100 ± 14	190 ± 26	180 ± 26	59 ± 8.8
Single Top s-Channel	24 ± 2.2	6.9 ± 0.67	1.5 ± 0.15	0.28 ± 0.030
Single Top t-Channel	43 ± 4.4	9.2 ± 0.94	1.6 ± 0.17	0.22 ± 0.024
Z+Jets	29 ± 3.4	8.7 ± 0.96	2.7 ± 0.29	0.52 ± 0.056
W+bottom	370 ± 111	91 ± 27	19 ± 5.7	4.0 ± 1.2
W+charm	360 ± 108	81 ± 24	17 ± 5.1	3.6 ± 1.1
Mistags	320 ± 42	84 ± 13	19 ± 5.1	3.8 ± 1.5
Non-W	110 ± 43	40 ± 17	17 ± 14	4.5 ± 4.4
Total Prediction	1400 ± 290	530 ± 75	270 ± 34	77 ± 11
Observed	1404	486	281	81

TABLE II: Background summary table for central leptons with one secondary vertex tag.

To estimate the amount of W + light flavor in the tagged sample, we apply a per-jet false tag rate parameterization (mistag matrix) to the pretag W + light flavor events. The mistag matrix is obtained from inclusive jet data.

The number of events from W + heavy flavor is calculated using information from both data and Monte Carlo programs. We calculate the fraction of W events with associated heavy flavor production in the ALPGEN Monte Carlo program interfaced with the PYTHIA parton shower code [8, 9]. This fraction and the tagging efficiency for such events are applied to the number of events in the original W+jets sample after correcting for the $t\bar{t}$ and electroweak contributions.

We use the $\not\!\!E_T$ shape difference between the non-w and the other background models to constrain the amount of QCD events. We perform a likelihood fit to the $\not\!\!E_T$ distribution to determine the total amount of QCD. We deduce the QCD fraction in the signal region by integrating the fitted distributions above our $\not\!\!E_T$ cut (25 GeV for plug electrons, 20 for all other leptons).We estimate the non-W contribution to the tagged sample by fitting the met distribution of the tagged events.

The summary of the background contributions to the central lepton selection are shows in Tables II to IV. The double secondary vertex tagged selection is given in Table IV, the summary in the case of secondary vertex plus jet probability tagged events is shown in Table III, and the summary in the case of one tag events is shown in Table II. Tables VIII through X show the background expecations for the plug electrons. Tables V through VII show the background expectations for isolated tracks.

Because the expected number of Higgs signal events is small in the 3-,4-, and 5-jet bins, the reasonable agreement between predicted backgrounds and observed data in the tables gives us confidence in our overall background estimate.

CDF Run II Preliminary 2.7 fb^{-1} Tight Lepton Background Predication and Event Yields One Secvtx Tag, One Jet Prob Tag Events				
Process	2jets	3jets	4jets	5jets
All Pretag Candidates	44723	7573	1677	386
WW	1.2 ± 0.53	0.85 ± 0.31	0.40 ± 0.13	0.16 ± 0.047
WZ	2.5 ± 0.42	0.78 ± 0.16	0.18 ± 0.043	0.052 ± 0.013
ZZ	0.098 ± 0.017	0.053 ± 0.0090	0.021 ± 0.0040	0.0050 ± 0.0010
Top Pair Prod	20 ± 4.2	64 ± 13	79 ± 16	30 ± 6.1
Single Top s-Channel	7.0 ± 1.1	2.5 ± 0.42	0.57 ± 0.10	0.13 ± 0.024
Single Top t-Channel	2.1 ± 0.64	1.7 ± 0.36	0.46 ± 0.091	0.076 ± 0.015
Z+Jets	1.8 ± 0.54	1.2 ± 0.35	0.34 ± 0.12	0.097 ± 0.032
W+bottom	49 ± 15	17 ± 5.1	4.9 ± 1.5	1.3 ± 0.4
W+charm	18 ± 5.4	7.9 ± 2.4	2.6 ± 0.8	0.67 ± 0.19
Mistags	5.8 ± 6.0	3.0 ± 3.4	1.0 ± 1.0	0.29 ± 0.37
Non-W	11 ± 5.3	6.6 ± 3.5	3.4 ± 3.4	1.5 ± 2.1
Total Prediction	120 ± 30	110 ± 19	93 ± 17	34 ± 6.6
Observed	126	108	102	36

TABLE III: Background summary table for central leptons with one secondary vertex tag and one jet probability tag.

CDF Run II Preliminary 2.7 fb^{-1} Tight Lepton Background Predication and Event Yields Two Secvtx Tag Events				
Process	2jets	3jets	4jets	5jets
All Pretag Candidates	44723	7573	1677	386
WZ	3.3 ± 0.37	0.94 ± 0.11	0.19 ± 0.024	0.039 ± 0.0050
ZZ	0.099 ± 0.011	0.073 ± 0.0080	0.019 ± 0.0020	0.0050 ± 0.0010
Top Pair Prod	26 ± 4.2	77 ± 12	100 ± 16	36 ± 5.9
Single Top s-Channel	9.6 ± 1.2	3.3 ± 0.41	0.72 ± 0.092	0.15 ± 0.020
Single Top t-Channel	2.2 ± 0.30	1.9 ± 0.26	0.53 ± 0.072	0.10 ± 0.014
Z+Jets	1.4 ± 0.20	0.95 ± 0.13	0.26 ± 0.038	0.085 ± 0.013
W+bottom	55 ± 16.5	18 ± 5.4	4.9 ± 1.5	1.2 ± 0.36
W+charm	4.9 ± 1.5	2.4 ± 0.72	0.94 ± 0.28	0.25 ± 0.08
Mistags	1.4 ± 0.39	0.93 ± 0.30	0.34 ± 0.12	0.10 ± 0.047
Non-W	9.0 ± 4.0	5.0 ± 2.0	0.74 ± 1.6	0.23 ± 1.5
Total Prediction	110 ± 25	110 ± 16	110 ± 17	38 ± 6.1
Observed	114	132	104	42

TABLE IV: Background summary table for central leptons with two secondary vertex tags

CDF Run II Preliminary 2.7 fb^{-1} Isolated Track Background Predication and Event Yields Exactly One Secvtx Tag Events				
Process	2jets	3jets	4jets	5jets
All Pretag Candidates	4253	1380	427	117
WW	6.4 ± 0.65	2.8 ± 0.25	0.75 ± 0.066	0.23 ± 0.019
WZ	2.4 ± 0.16	0.92 ± 0.061	0.19 ± 0.013	0.063 ± 0.0050
ZZ	0.13 ± 0.0090	0.052 ± 0.0040	0.0070 ± 0.0010	0.0060 ± 0.0010
Top Pair Prod	28 ± 3.8	58 ± 8.0	53 ± 7.6	17 ± 2.5
Single Top s-Channel	6.1 ± 0.58	1.9 ± 0.19	0.43 ± 0.044	0.078 ± 0.010
Single Top t-Channel	10 ± 1.0	2.3 ± 0.24	0.41 ± 0.045	0.068 ± 0.0070
Z+Jets	9.1 ± 1.0	3.3 ± 0.36	0.74 ± 0.077	0.16 ± 0.017
W+bottom	40 ± 12	18 ± 5.4	5.3 ± 1.59	$1.9 \pm .57$
W+charm	37 ± 11.1	16 ± 4.8	4.7 ± 1.41	1.5 ± 0.45
Mistags	43 ± 5.6	18 ± 2.34	4.8 ± 0.62	1.8 ± 0.23
Non-W	38 ± 15	22 ± 8.9	5.3 ± 4.2	2.1 ± 1.7
Total Prediction	220 ± 35	140 ± 19	76 ± 9.9	25 ± 3.4
Observed	208	150	78	31

TABLE V: Background summary table for isolated tracks with one secondary vertex tag .

CDF Run II Preliminary 2.7 fb^{-1} Isolated Track Background Predication and Event Yields One Secvtx Tag, One Jet Prob Tag Events				
Process	2jets	3jets	4jets	5jets
All Pretag Candidates	5149	1623	487	124
WW	0.20 ± 0.091	0.24 ± 0.092	0.10 ± 0.030	0.030 ± 0.010
WZ	0.51 ± 0.090	0.20 ± 0.041	0.048 ± 0.010	0.013 ± 0.0040
ZZ	0.032 ± 0.0060	0.021 ± 0.0050	0.0070 ± 0.0010	0.0020 ± 0.0010
Top Pair Prod	6.4 ± 1.3	20 ± 4.2	25 ± 4.9	9.0 ± 1.8
Single Top s-Channel	1.9 ± 0.31	0.74 ± 0.12	0.19 ± 0.034	0.043 ± 0.0090
Single Top t-Channel	0.53 ± 0.16	0.50 ± 0.11	0.12 ± 0.025	0.028 ± 0.0050
Z+Jets	0.61 ± 0.20	0.41 ± 0.13	0.13 ± 0.044	0.039 ± 0.013
W+bottom	6.0 ± 1.8	3.4 ± 1.0	1.4 ± 0.42	0.59 ± 0.18
W+charm	2.1 ± 0.63	1.6 ± 0.48	0.77 ± 0.23	0.34 ± 0.10
Mistags	0.80 ± 0.07	0.61 ± 0.05	0.27 ± 0.02	0.13 ± 0.01
Non-W	2.0 ± 0.79	1.4 ± 0.55	0.99 ± 0.79	0.37 ± 0.50
Total Prediction	21 ± 4.4	29 ± 5.2	29 ± 5.1	11 ± 2.0
Observed	21	30	32	12

TABLE VI: Background summary table for isolated tracks with one secondary vertex tag and one jet probability tag.

CDF Run II Preliminary 2.7 fb^{-1} Isolated Track Background Predication and Event Yields Two Secvtx Tag Events				
Process	2jets	3jets	4jets	5jets
All Pretag Candidates	5149	1623	487	124
WW	0.036 ± 0.0080	0.13 ± 0.021	0.067 ± 0.012	0.019 ± 0.0030
WZ	0.65 ± 0.072	0.24 ± 0.027	0.029 ± 0.0030	0.010 ± 0.0010
ZZ	0.045 ± 0.0050	0.025 ± 0.0030	0.010 ± 0.0010	0.0020 ± 0
Top Pair Prod	7.7 ± 1.2	23 ± 3.7	31 ± 5.1	11 ± 1.8
Single Top s-Channel	2.7 ± 0.34	0.91 ± 0.12	0.21 ± 0.027	0.045 ± 0.0060
Single Top t-Channel	0.58 ± 0.080	0.57 ± 0.077	0.18 ± 0.024	0.035 ± 0.0050
Z+Jets	0.51 ± 0.069	0.32 ± 0.045	0.093 ± 0.014	0.025 ± 0.0040
W+bottom	7.5 ± 2.25	3.6 ± 1.1	1.4 ± 0.42	0.53 ± 0.16
W+charm	0.68 ± 0.20	0.56 ± 0.17	0.26 ± 0.08	0.12 ± 0.04
Mistags	0.27 ± 0.02	0.20 ± 0.02	0.089 ± 0.01	0.052 ± 0.01
Non-W	1.8 ± 0.71	1.9 ± 0.76	6.5 ± 5.2	2.6 ± 2.1
Total Prediction	22 ± 4.0	31 ± 4.3	40 ± 7.3	15 ± 2.8
Observed	24	31	37	15

TABLE VII: Background summary table for isolated track events with two secondary vertex tags.

Njet	2jet	3jet	>=4jet
Pretag Events	5879	1010	202
Mistag	1.00±0.18	0.46±0.06	0.35±0.15
$Wb\bar{b}$	7.40±3.96	2.34±1.15	0.47±0.26
$Wc\bar{c}$	0.96±0.49	0.33±0.37	0.07± 0.03
$t\bar{t}$(6.7pb)	2.14±0.34	5.69±0.89	9.11± 1.43
Single top(s-ch)	0.69±0.10	0.22±0.03	0.06± 0.01
Single top(t-ch)	0.22±0.04	0.18±0.03	0.06± 0.01
WW	0.01±0.01	0.03±0.02	0.02± 0.01
WZ	0.58±0.06	0.12±0.02	0.04± 0.01
ZZ	0.00±0.00	0.00±0.00	0.00±0.00
$Z->\tau\tau$	0.00±0.00	0.00±0.00	0.00±0.00
nonW QCD	1.16±0.44	0.96±0.50	0.51±0.44
Total Bkg	14.18±4.03	10.32±1.58	10.67± 1.52
WH signal (120 GeV)	0.09±0.01	Control region	Control region
Observed Events	11	12	11

TABLE VIII: Background summary table for plug electron events with two secondary vertex tags.

Njet	2jet	3jet	>=4jet
Pretag Events	5879	1010	202
Mistag	3.18±0.49	1.71±0.33	0.74± 0.29
$Wb\bar{b}$	6.23±3.37	2.00±0.99	0.45±0.24
$Wc\bar{c}$	1.53±0.81	0.76±0.38	0.21± 0.11
$t\bar{t}$(6.7pb)	1.79±0.31	4.72±0.80	7.03± 1.19
Single top(s-ch)	0.51±0.08	0.16±0.03	0.04± 0.01
Single top(t-ch)	0.24±0.04	0.16±0.03	0.05± 0.01
WW	0.12±0.03	0.10±0.03	0.07± 0.02
WZ	0.42±0.05	0.13±0.02	0.03± 0.01
ZZ	0.01±0.00	0.00±0.00	0.00±0.00
$Z->\tau\tau$	0.01±0.00	0.01±0.00	0.01±0.00
nonW QCD	1.51±0.55	1.78±0.88	0.79±0.67
Total Bkg	15.54±3.56	11.53±1.63	9.43± 1.42
WH signal (120 GeV)	0.06±0.01	Control region	Control region
Observed Events	12	10	10

TABLE IX: Background summary table for plug electron events with one secondary vertex tag + Jet Probability tag

Njet	1jet	2jet	3jet	>=4jet
Pretag Events	39942	5879	1010	202
Mistag	91.19±8.32	28.47±3.30	6.48±1.20	0.78±0.60
$Wb\bar{b}$	98.10±50.81	43.09±12.33	10.74±3.10	1.79±0.62
$Wc\bar{c}$	116.9±49.6	33.37±9.55	7.90±2.28	1.21±0.42
$t\bar{t}$(6.7pb)	1.36±0.20	7.17±1.00	12.30±1.71	13.89±1.93
Single top(s-ch)	0.96±0.13	1.53±0.20	0.41±0.05	0.09±0.01
Single top(t-ch)	3.88±0.51	3.54±0.47	0.73±0.10	0.12±0.02
WW	1.23±0.12	3.00±0.20	0.74±0.09	0.14±0.04
WZ	1.38±0.08	1.62±0.09	0.43±0.04	0.08±0.02
ZZ	0.01±0.00	0.02±0.00	0.01±0.00	0.00±0.00
$Z->\tau\tau$	0.43±0.05	0.24±0.03	0.11±0.01	0.03±0.00
nonW QCD	18.76±6.98	18.34±5.54	5.54±2.59	3.18±2.53
Total Bkg	334.2±71.8	140.4±16.9	45.39±5.09	21.31±3.33
WH signal (120 GeV)	Control region	0.20±0.01	Control region	Control region
Observed Events	299	136	48	25

TABLE X: Background summary table for plug electron events with one secondary vertex tag with a NN tag.

Source	Uncertainty (%)		
	ST+ST	ST+JP	one tag
Trigger Lepton (Isotrk) ID	∼2% (8.85%)	∼2% (8.85%)	∼2% (8.85%)
Lepton (MET+Jets) Trigger	<1% (3%)	<1% (3%)	<1% (3%)
ISR/FSR	5.2%	4.0%	2.9%
PDF	2.1%	1.5%	2.3%
JES	2.5%	2.8%	1.2%
b-tagging	8.4%	9.1%	3.5%
Total (Isotrk)	10.6% (13.8%)	10.5% (14.0%)	5.6% (10.1%)

TABLE XI: Systematic uncertainty on the WH acceptance. "ST+ST" refers to double secondary vertex tagged events while "ST+JP" refers to secondary vertex plus jet probability tagged events. Effects of limited Monte Carlo statistics are included in these values.

IV. SYSTEMATIC UNCERTAINTIES

The uncertainties on the signal acceptance currently have the largest effect on the Higgs sensitivity. The b-tagging uncertainty is dominated by the uncertainty on the data/MC scale factor $S = 0.95 \pm 0.04$ (stat.+ sys.). The uncertainties due to initial state radiation and final state radiation are estimated by changing the parameters related to ISR and FSR, halving and doubling the default values. The difference from the nominal acceptance is taken as the systematic uncertainty. Other uncertainties on parton distribution functions, trigger efficiencies, or lepton identification contribute to a smaller extent to the overall uncertainty. For isolated tracks, the isolated track reconstruction uncertainty is dominated by varation of the data-MC scale factor in events with electrons reconstructed as isolated tracks and events with high occupancy. summary of these systematic uncertainties on the signal acceptance is given in Table XI.

V. ARTIFICIAL NEURAL NETWORK

To further improve signal to background separation we employ an artificial neural network. This neural network combines six kinematic variables into a single function with better discrimination between the Higgs signal and the background processes than any of the variables individually. To train the neural network, JETNET package [10]. The input variables are defined below:

Dijet invariant mass+: The invariant mass reconstructed from the two jets. If there are additional looser jets, the loose jet that is closest to one of the two jets is included in this invariant mass calculation.

Total System p_T: The vector sum of the transverse momenta of the lepton, the $\not\!\!E_T$, and the two jets.

p_T Imbalance: The scalar sum of the lepton and jet transverse momenta minus the $\not\!\!E_T$.

$\sum E_T$ (loose jets): The scalar sum of the loose jet transverse energy.

$M_{l\nu j}^{min}$: The invariant mass of the lepton, $\not\!\!E_T$and one of the two jets, where the jet is chosen to give the minimum invariant mass. The p_z of neutrino is ignored for this quantity.

ΔR (lepton-ν): The distance between the direction of lepton and neutrino in $\eta-\phi$ plane, where the p_z of the neutrino is taken from largest $|p_z|$ calculated from W mass constraint.

The training is defined such that the neural network attempts to produce an output as close to 1.0 as possible for Higgs signal events and as close to 0.0 as possible for background events. For optimal sensitivity, a different neural network is trained for each Higgs mass considered.

VI. RESULTS

We perform a direct search for an excess in the signal region of the neural network output distribution from single-tagged and double-tagged W+2 jet events. A binned maximum likelihood technique is used to estimate upper limits on Higgs production by constraining the number of background events to the estimates within uncertainties.

For optimal sensitivity, the search is performed simultaneously in the separate double secondary vertex tagged, the secondary vertex plus jet probability tagged samples and one neural network tagged samples. Our most sensitive search includes all lepton types, properly accounting for correlations.

For central lepton double secondary vertex tagged events, Fig. 2 shows the output distribution for the neural network trained for a Higgs mass of 120 GeV/c^2 in the data compared to the expectations from background. Fig. 3 and Fig. 4 shows the same distribution for the secondary vertex plus jet probability tagged events and one tag events, respectively. The agreement is reasonable, considering the uncertainties in the background distributions.

Figures 8 through 10 show the neural network output distributions for isolated track events in each b-tagging category. The agreement of the neural network output distributions with the background prediction is reasonable.

Figures 5 through 7 show the neural network output distributions for plug electron events in each b-tagging category. The agreement of the neural network output distributions is reasonable in each tag categoy. The large uncertainties on the data points are due to small number of observed events.

We perform a likelihood fit to set an upper limit on the cross section times branching ratio as a function of m_H. We combine all lepton and tag channels to maximize our sensitivity. Figure 1 shows the combined expected and observed limits as a function of m_H for isolated tacks, central leptons, and plug electrons. The limits on cross section times branching ratio are expressed as a ratio to the Standard Model. In general, the observed limits are in good agreement with the expectation. Table XII lists the expected and obsereved limits shown in Figure 1.

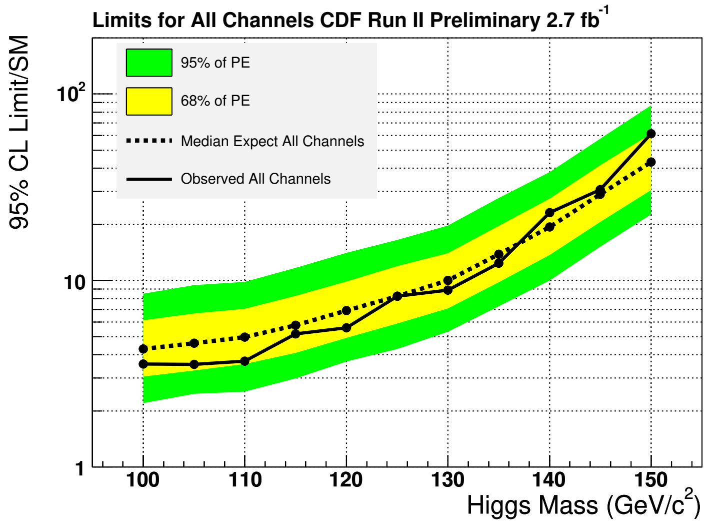

FIG. 1: Expected limits on Higgs production and decay for all lepton and tag categories combined, as a function of the Higgs mass hypothesis. The limits are expressed as a ratio to the Standard model.

VII. CONCLUSIONS

We have searched in a 2.7 fb^{-1} data set for evidence of Standard Model Higgs boson production associated with a W boson. We do not observe any such production in the $H \rightarrow b\bar{b}$ mode, and we set upper limits on the production rate times branching ratio. Total rates larger than $5.0 \times SM$ are excluded at 95% confidence level for the 115 GeV/c^2 Higgs mass hypothesis, with limits ranging from 3.6 to $61.1 \times SM$ for other mass values. These limits represent an improvement by a factor at M_H = 115 GeV/c^2 of approximately 17% over the previous limits obtained using the 1.9 pb^{-1} data set, which is close to the improvement expected from adding more luminosity. Despite the increase in luminosity, the result is still limited by the small number of expected Higgs events.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the

CDF Run II Preliminary 2.7 fb^{-1} Limits for Combined Lepton and Tag Categories		
M(H)	Observed Limit	Expected Limit
100	3.6	4.3
105	3.6	4.6
110	3.7	5.0
115	5.2	5.8
120	5.6	6.9
125	8.2	8.2
130	8.9	10.0
135	12.4	13.8
140	23.1	19.4
145	30.6	28.9
150	61.1	43.2

TABLE XII: Expected and observed limits as a function of Higgs mass for the combined search of Tight Lepton and Isotrk events, including all tag categories.

Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Science and Technology Facilities Council and the Royal Society, UK; the Institut National de Physique Nucleaire et Physique des Particules/CNRS; the Russian Foundation for Basic Research; the Ministerio de Educación y Ciencia and Programa Consolider-Ingenio 2010, Spain; the Slovak R&D Agency; and the Academy of Finland.

[1] LEP Electroweak Working Group, `http://lepewwg.web.cern.ch/LEPEWWG/`
[2] ALEPH, DELPHI, L3, OPAL. The LEP Working Group for Higgs Boson Searches, Phys. Lett **B565** 61 (2003).
[3] T. Han and S. Willenbrock, Phys. Lett. **B273** (1991) 167;
A. Djouadi, J. Kalinowski, and M. Spira, Comp. Phys. Commun. **108 C** (1998) 56.
[4] T. Aaltonen *et al.*, Phys. Rev. Lett. **100** 041801 (2008).
[5] F. Abe, *et al.*, Nucl. Instrum. Methods Phys. Res. A **271**, 387 (1988);
D. Amidei, *et al.*, Nucl. Instum. Methods Phys. Res. A **350**, 73 (1994);
F. Abe, *et al.*, Phys. Rev. D **52**, 4784 (1995);
P. Azzi, *et al.*, Nucl. Instrum. Methods Phys. Res. A **360**, 137 (1995);
The CDF II Detector Technical Design Report, Fermilab-Pub-96/390-E.
[6] A. Abulencia *et al.*, Phys. Rev. **D71**, 072005 (2005).
[7] D. Buskulic, *et al.* (ALEPH Collaboration), Phys. Lett. B **313**, 535 (1993);
F. Abe *et al.* (CDF Collaboration), Phys. Rev. D **53**, 1051 (1996);
A. Affolder *et al.* (CDF Collaboration), Phys. Rev. D **64**, 032002 (2001), Erratum-ibid: Phys. Rev. D **67**, 119901 (2003).
[8] P. Edén, C. Friberg, L. Lönnblad, G. Miu, S. Mrenna, E. Norrbin, and T. Sjöstrand, Computer Phys. Commun. **135** (2001) 238.
[9] M.L. Mangano *et al.*, JHEP 0307:001, 2003.
[10] L. Lönnblad, C. Peterson, and T. Rögnvaldsson, Comp. Phys. Comm. 81 (1994) 185.

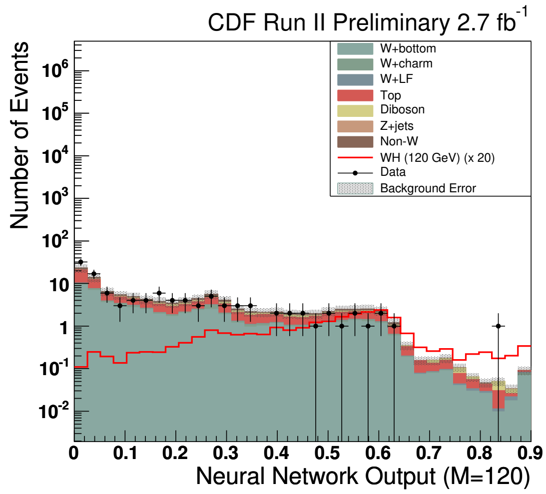

FIG. 2: Predicted and observed output for the neural network trained with a Higgs mass of 120 GeV$/c^2$ for double secondary vertex tagged events. The output for neural networks trained for other Higgs masses looks similar.

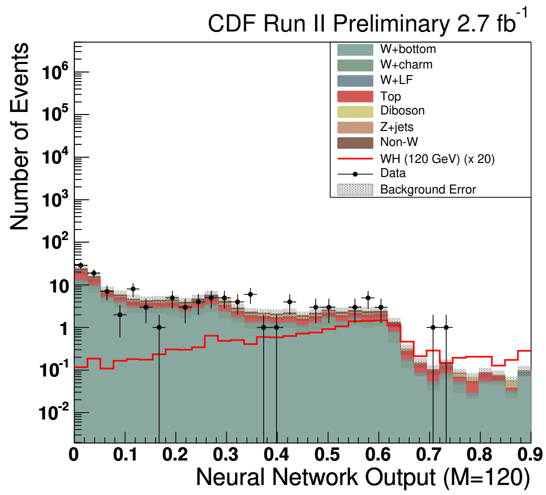

FIG. 3: Predicted and observed output for the neural network trained with a Higgs mass of 120 GeV$/c^2$ for secondary vertex plus jet probability tagged events. The output for neural networks trained for other Higgs masses looks similar.

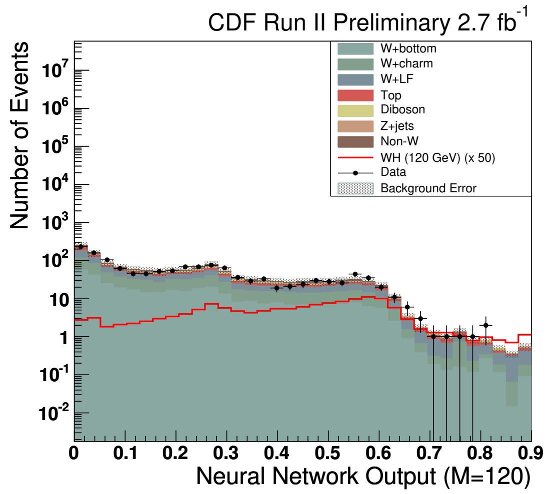

FIG. 4: Predicted and observed output for the neural network trained with a Higgs mass of 120 GeV/c^2 for one neural network tagged events. The output for neural networks trained for other Higgs masses looks similar.

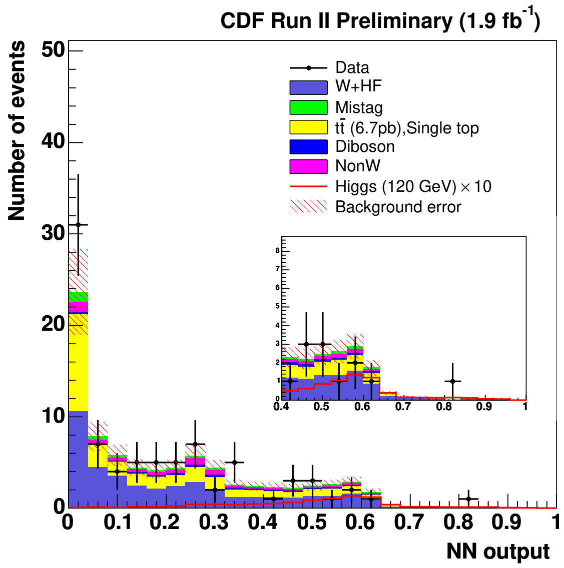

FIG. 5: Neural Network output for double secondary vertex tagged plug electron events.

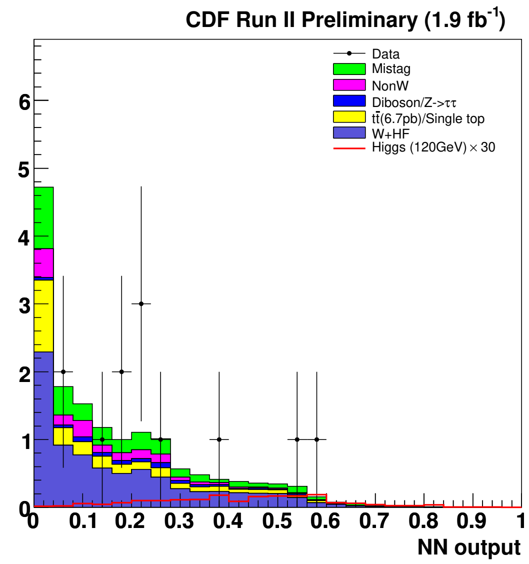

FIG. 6: Neural Network output for one secondary vertex tag and one jet probability tag plug electron events.

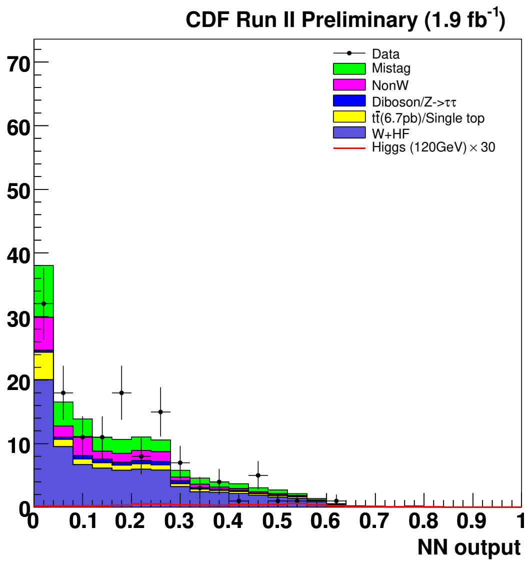

FIG. 7: Neural Network output for one secondary vertex tag with neural network flavor separation plug electron events.

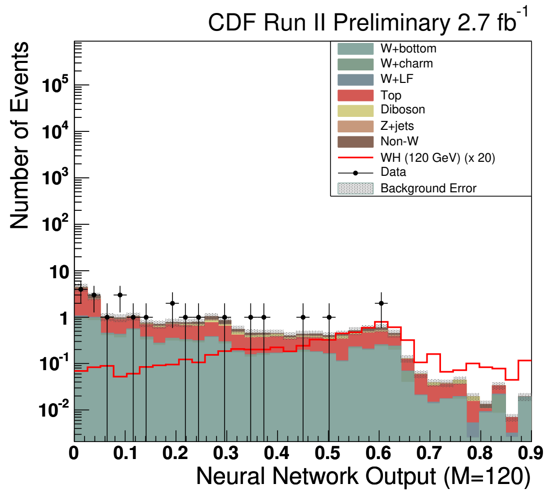

FIG. 8: Neural Network output for isolated track events with two secondary vertex tags.

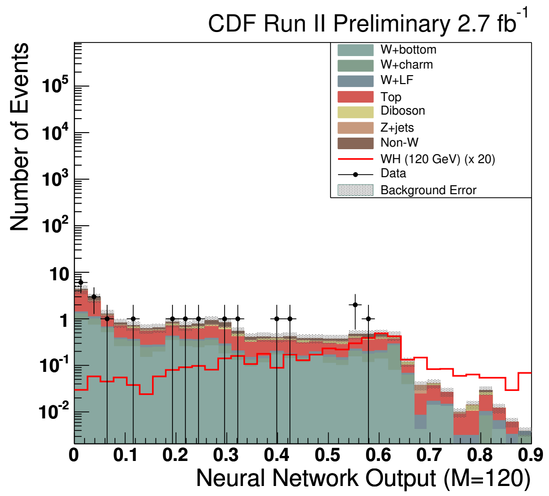

FIG. 9: Neural Network output for isolated track events with one secondary vertex tag and one jet probability tag.

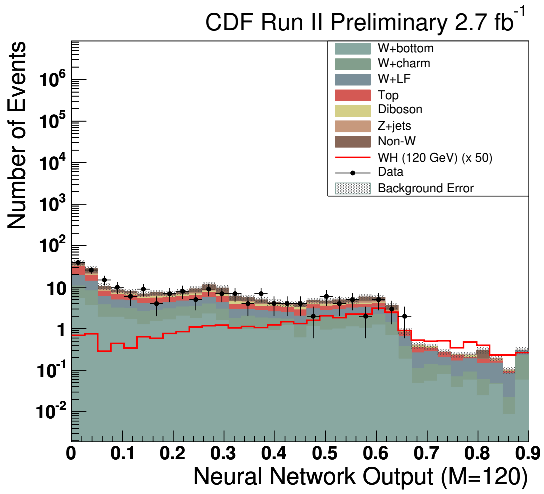

FIG. 10: Neural Network output for isolated track events with one secondary vertex tag .