**Searches for High-Mass Standard Model Higgs Boson at the Tevatron**

Ralf Bernhard
*on behalf of the DØ and CDF collaborations*
*Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Germany*

Searches for the Standard Model Higgs boson at a center-of-mass energy of $\sqrt{s}$ =1.96 TeV, using up to 5.4 fb$^{-1}$ of data collected with the CDF and DØ detectors at the Fermilab Tevatron collider in the mass range around 160 GeV/c$^2$ are presented. As no significant excess is observed, limits on standard-model Higgs boson production are set.

## 1 Introduction

In the standard-model of particle physics the Higgs mechanism is responsible for breaking electroweak symmetry, thereby giving mass to the $W$ and $Z$ bosons. It predicts the existence of a heavy scalar boson, the Higgs boson, with a mass that can not be predicted by the standard-model . Direct searches for the Higgs Boson were performed at the LEP experiments and yielded a direct mass limit of $m_H > 114.4$ GeV/c$^2$ [1] at the 95% confidence level (CL) [a].

Indirect limits have been placed on the Higgs boson mass by the LEP, SLD and Tevatron experiments from electroweak precision measurements [2]. The main contribution to these indirect constraints from the Tevatron experiments are the measurements of the $W$ Boson and top quark masses [2]. The standard-model fit yields a best value of $m_H = 87^{+35}_{-26}$ GeV/c$^2$ [3]. The upper limit on the Higgs mass at 95% CL is $m_H < 157$ GeV/c$^2$. If the direct mass limit is also taken into account this limit is increased to $m_H < 186$ GeV/c$^2$.

At the Tevatron CDF and DØ search for direct Higgs boson production in the mass range above the LEP limit using $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. The relevant processes at these energies are associated Higgs production (qq$'$ → WH, q$\bar{\text{q}}$ → ZH) and gluon fusion (gg → H).

The main focus here is for masses above $m_H$ = 140 GeV/c$^2$ (high mass region) where the Higgs boson will predominantly decay into WW boson pairs. Leptons from the decays of the W bosons and the missing transverse energy are used to reject background. In order to take

[a] All limits given in this paper are at 95% CL

advantage of the maximum potential signal acceptance, also the associated production with a W or Z boson and Higgs boson production via vector boson fusion is considered.

## 2 $\mathbf{H \to WW^{(*)} \to \ell\nu\ell'\nu'}$

The dominant decay mode for higher Higgs boson masses is $\mathrm{H} \to \mathrm{WW}^{(*)}$. The leptonic decays of the W bosons are used to suppress the QCD background. The signature of the $\mathrm{gg} \to \mathrm{H} \to \mathrm{WW}^{(*)}$ channel is two high-$p_T$ opposite signed isolated leptons with a small azimuthal separation, $\Delta\phi_{\ell\ell}$, due to the spin-correlation between the final-state leptons in the decay of the spin-0 Higgs boson. In contrast, the lepton pairs from background events, mainly WW events, are predominantly back-to-back in $\Delta\phi_{\ell\ell}$. This is shown in Figure 1 (left) for a preselected CDF data sample with zero reconstructed jets. An additional selection requires $E_T^{\mathrm{miss}} > 25$ GeV for CDF and

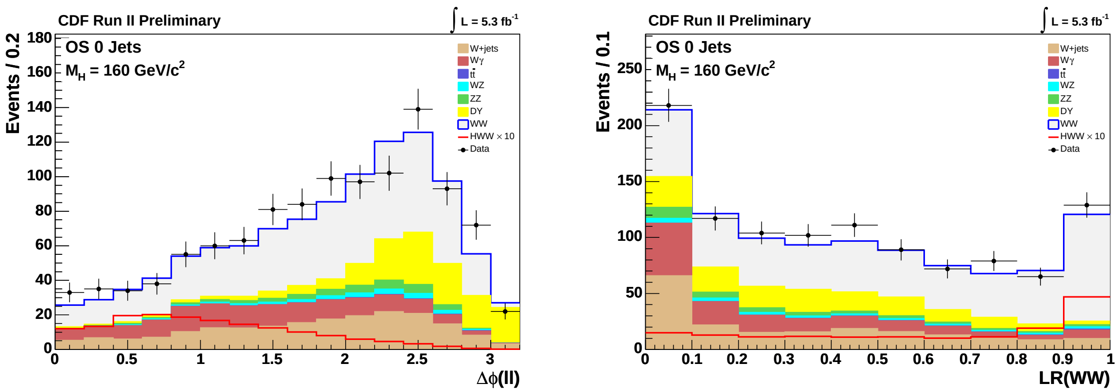


Figure 1: CDF $\mathrm{H} \to \mathrm{WW}^{(*)}$ channel: The azimuthal angle between the two leptons in the $\mathrm{H} \to \mathrm{WW}^{(*)}$ search. Due to spin correlations, the signal is at low $\Delta\phi_{\ell\ell}$, whereas the background is at high $\Delta\phi_{\ell\ell}$.

$E_T^{\mathrm{miss}} > 20$ GeV for DØ to account for the neutrinos in the final state. DØ defines three final states ($e^+e^-$, $e^\pm\mu^\mp$, and $\mu^+\mu^-$) [4]. CDF separates the $\mathrm{H} \to \mathrm{WW}^{(*)}$ events into five non-overlapping samples, first by separating the events by jet multiplicity (0, 1 or 2), then subdviding the 0 and 1 jet samples in two, one having a low signal/background (S/B) ratio, the other having a higher one. In these analyses, the final discriminants are neural-network outputs based on several kinematic variables. These include likelihoods constructed from matrix-element probabilities as input to the neural network for CDF and is shown on the right side of Figure 1. The NN distribution for DØ is shown in Figure 2 on the left side and the background subtracted NN distribution in the center of Figure 2. The expected yields for CDF in this five channels are

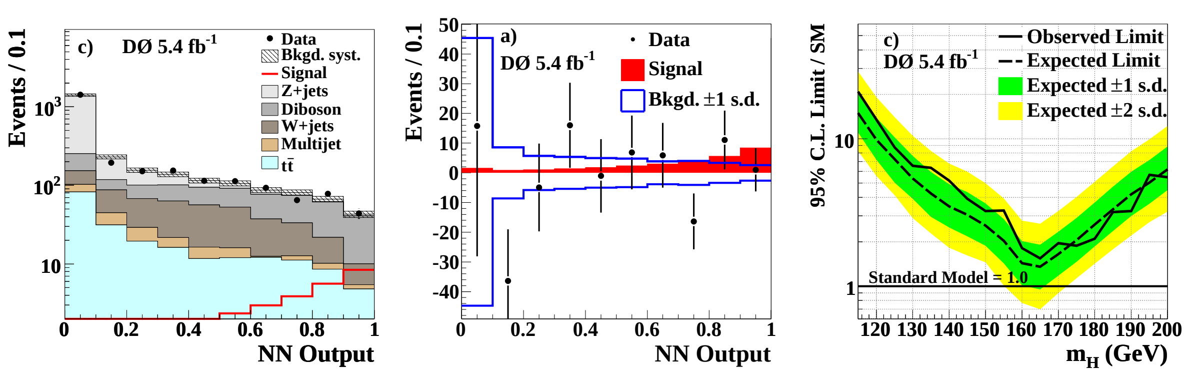


Figure 2: DØ $\mathrm{H} \to \mathrm{WW}^{(*)}$ channel: The NN distribution (left) and background subtracted distribution of the NN (center) and the obtained median observed and expected limits on the production cross-section (right).

32 signal events and 1840 background events in 5.3 fb$^{-1}$ of data and for DØ in the three search channels 30 signal events and 2445 background events in 5.4 fb$^{-1}$ of data.

## 3 Additional Acceptance

Additional signal acceptance is gained by including events with low dilepton invariant mass as a separate search region and the search for associated Higgs production in events with same-sign dileptons and trileptons in the final state. For each of the search channels a neural network is trained on a weighted combination of known signal and background events from Monte Carlo independently for each of the Higgs mass hypothesis.

### *3.1 Low Dilepton Invariant Mass*

To increase signal acceptance, events with low dilepton invariant mass ($M_{ll} < 16$ GeV/c$^2$) of the opposite-sign signal region selection are analyzed at CDF separately. In this case only events with zero or one jets are considered. Heavy flavor contributions (J/$\psi$, $\Upsilon$) are effectively removed by the missing transverse energy requirements. The primary background in this selection region are W$\gamma$ events, where the photon is misidentified as a lepton. The modeling of this background is tested with a control sample of the same selection but two same-sign leptons which is composed primarily of W$\gamma$ events. The expected yield of this selection is about one signal event and 100 background events.

### *3.2 Same-Sign Dileptons*

To further increase the sensitivity, also searches for Higgs signal in like sign, or same-sign (SS), dileptons are performed. These occur naturally in VH $\rightarrow$ VWW production, when the vector boson (Z or W) and one of the W bosons from the Higgs decay leptonically. The primary backgrounds in this search are from charge misidentification of a real lepton and misidentification of a photon or jet as a lepton. At DØ the rate of charge mis-measurements for muons is determined by comparing the independent charge measurements within the solenoidal and in the toroidal fields of the detector. For electrons the charge mis-measurement rate is determined by comparing the charge measurement from the solenoid with the azimuthal offset between the track and the calorimeter cluster associated to the electron. The additional expected acceptance for CDF in this channel is 2.1 signal events and 81 background events in 5.3 fb$^{-1}$ of data and for DØ 1.1 events and 118 background events in 2.5 fb$^{-1}$ of data.

### *3.3 Trileptons*

CDF searches in addition for a potential Higgs signal in the trilepton final state. Trilepton events occur naturally in WH $\rightarrow$ WWW production, in the case where all three W bosons decay leptonically, and in ZH $\rightarrow$ ZWW production, where the Z boson and one of the W bosons from the Higgs decay leptonically while the second W boson decays hadronically. The gluon fusion and vector boson fusion production modes contribute to the trilepton final state only in cases where a photon or jet is misidentified as a lepton and are therefore not considered. The primary background in this search is WZ production. To allow better discrimination against the dominant WZ background, events are separated into two channels depending on whether or not there are two same-flavor opposite-sign leptons with an invariant mass of the Z-boson.

Trilepton events with a same-flavor opposite-sign dilepton pair in the Z-mass peak have a Higgs signal contribution predominantly from ZH production. These events are required to have missing transverse energy larger than 10 GeV only since ZH trilepton events will in most cases contain a single neutrino. The decay of the second W boson in ZH trilepton events most often results in the production of additional jets, so one or more reconstructed jets are required. The expected yields of this selection are 0.6 signal events and 24 background events in 5.3 $\text{fb}^{-1}$ of data. The output of the NN classifier is shown in Figure 3 on the left.

Trilepton events without a same-flavor opposite-sign dilepton pair in the Z-mass peak have a Higgs signal contribution predominantly from WH production. Because most WH trilepton events contain three neutrinos, they typically have high values of missing transverse energy (center of Figure 3), and these events are required to have missing transverse energy larger than 20 GeV. The expected yields of this selection are 0.8 signal events and 15 background events in 5.3 $\text{fb}^{-1}$ of data.

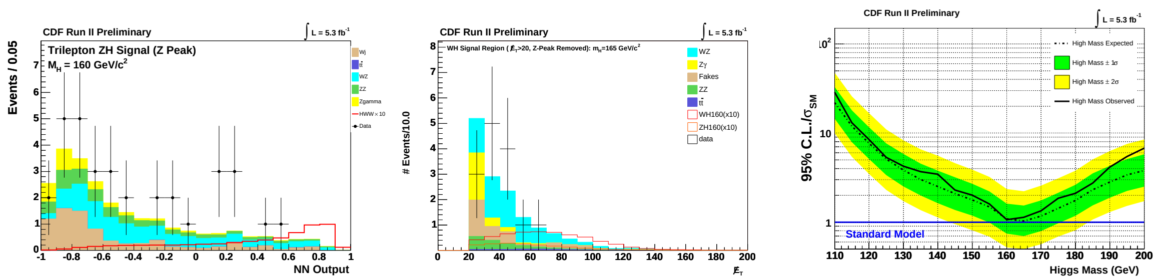


Figure 3: CDF: NN output classifier for the ZH trilepton events (left) and missing transverse energy for the WH trilepton search (center).

## 4 Results

No excess above the background expectation have been found neither by the CDF experiment nor the DØ experiment, therefore limits on the production cross-section of the Higgs boson can be set. The obtained limits of the combination of the orthogonal search channels for CDF on the production cross-section as a function of the Higgs boson mass are shown in Figure 3 on the right side. The best sensitivity is reached for a Higgs boson mass of 165 GeV/$c^2$ with an extracted median observed (expected) limit on the production cross-section of $\sigma_{95}/\sigma_{SM} = 1.13\,(1.03)$.

DØ uses the NN distribution (Figure 2 on the left) to extract median observed (expected) limits on the production cross-section of $\sigma_{95}/\sigma_{SM} = 1.55\,(1.36)$ for $m_H = 165$ GeV/$c^2$. The obtained limits on the production cross-section as a function of the Higgs boson mass are shown in Figure 2 on the right side.

A recent combination of the limits on Higgs boson production from the two Tevatron experiments excluded at the 95% CL a standard-model Higgs boson in the mass range 162–166 GeV [6,7].

## References


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