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HIGGS SEARCHES AT THE TEVATRON

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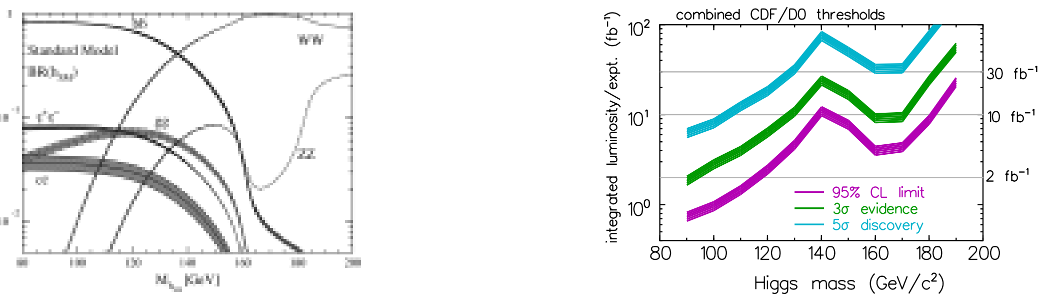
One of the highest priority physics goals for the upgraded Tevatron experiments, CDF and DØ, is the search for the Higgs boson. We present the initial results from both experiments, based on 40–90 pb^{-1} integrated luminosity, of Higgs searches in several final states, including WH and ZH, $H \to WW$, and doubly-charged Higgs.

1 Introduction

A major goal of Tevatron Run II is the search for the Higgs boson. Direct searches at LEP have excluded a Standard Model Higgs having a mass below 114.4 GeV at 95% confidence level, with a hint of an excess just above that. Indirect evidence from a global Standard Model fit to electroweak data can also be used to constrain the Higgs boson mass. The LEP Electroweak Working Group recently reported, that the global fit to LEP electroweak data gives a Higgs boson mass of 91^{+58}_{-37} GeV with an upper limit of 211 GeV at 95% C.L. [1]. These results suggest that the Higgs boson mass may not be very high and add urgency to Higgs boson searches at the Tevatron for Run II.

The Higgs boson production mechanism with the largest cross section, ~ 0.7pb for a Higgs mass of 120 GeV, is gluon fusion [2]. Unfortunately the background in this mode is very large. The most promising Standard Model Higgs discovery channels at the Tevatron is through associated production with W/Z, where W/Z decays leptonically. The Higgs boson production cross-section is ~ 0.16 pb for WH and ~ 0.1 pb for ZH, for a Higgs boson mass of 120 GeV. It is worth to mention that although the ZH cross section is roughly a factor of two lower over the same Higgs mass range than the WH production cross section, the Z decays to neutrino pairs give a larger cross section times branching ratio than a single lepton W decays. The QCD corrections to $\sigma(q\bar{q} \to WH \mathrm{or} ZH)$ coincide with those of the Drell-Yan process and increase the cross section by about 30% [3,4,5]. In order to discover a Higgs signal in this channel at the Tevatron, the main



a) b)

Figure 1: a) Branching ratios of the dominant decay modes of the SM Higgs boson, b) the integrated luminosity required per experiment, to either exclude a SM higgs at 95% C.L. or discover it at 3σ or 5σ level.

challenge is to be able to separate the signal from an irreducible Standard Model $Wb\bar{b}$ or $Zb\bar{b}$ background.

The branching ratios for the dominant decay modes of a Standard Model Higgs boson are shown as a function of Higgs boson mass in Fig. 1 a). For Higgs boson masses below about 135 GeV, the decay of $H \to b\bar{b}$ is dominant. For Higgs masses above 135 GeV, $H \to WW^*$ becomes the dominant mode.

Using Run I data, CDF has searched for WH and ZH in different channels, including Z decaying to dileptons, W decaying to leptons or hadrons, with Higgs decay to $b\bar{b}$. The result from combining these channels gives

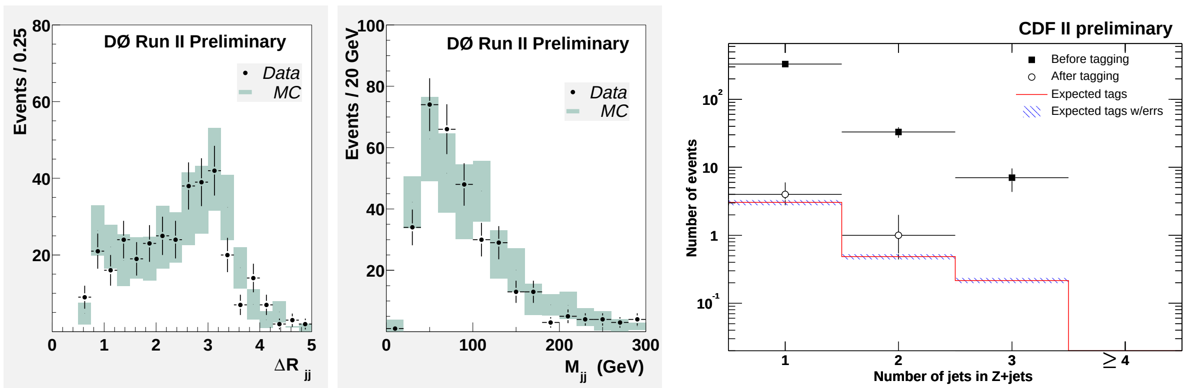
$$\sigma(p\bar{p} \to VH) * Br(H \to b\bar{b}) < 7.4\text{pb} \qquad \text{at } 95\% \text{ C.L.}$$

A few years ago, a Tevatron Higgs Working Group's study evaluated the Higgs discovery potential for the Tevatron Run II. This was a joint effort of theorists and experimentalists from both CDF and DØ experiments. The study was based on a parameterized detector simulation. The main conclusions [2] are that to maximize the Higgs discovery at the Tevatron, one must combine data from both experiments, CDF and DØ; must combine all channels, and must improve the understanding of signal and background processes as well as improve the detector performance. Figure. 1 b) shows the integrated luminosity per experiment for a 95% C.L. exclusion of a SM Higgs boson or a 3σ or 5σ discovery. Recently a new group, the Higgs Sensitivity Group, has been formed which is reevaluating the Tevatron Run II sensitivity using more realistic simulations.

2 Tevatron and Detector upgrades

The Tevatron in Run II is the world's highest energy accelarator. With the Tevatron upgrades, a new Main Injector, this machine can deliver to the experiments an order of magnitude more instantaneous luminosity, as compared with Run I. This greatly enhances the discovery potential for the Higgs boson, since the discovery reach is limited by the integrated luminosity. In Run I the CDF and DØ experiments each collected data corresponding to about 0.1 fb^{-1} of integrated luminosity. In Run II we expect to collect 5 fb^{-1}, with the possibility of 10 fb^{-1} if we run efficiently through the end of the decade. So far, each experiment has recorded about 100 pb^{-1} data, with a recent peak luminosity of $4.0 \times 10^{31}/\text{cm}^2/\text{sec}$. In Run II the machine energy is increased from 1.8 TeV to 1.96 TeV in the $p\bar{p}$ center of mass; this typically increases physics cross sections by about 30–40%.

Both CDF and DØ have upgraded their detectors. CDF has a new central drift chamber and silicon tracker, new forward calorimeters covering the psuedorapidity range from 1 to 3, new time of flight detector, extended muon coverage, and an improved tracking and secondnary vertex trigger. DØ has a new silicon and fiber tracker in 2 Telsa magnetic field, added preshower



a) b) c)

Figure 2: a) and b) are ΔR_{jj} and M_{jj} distributions for DØ W+jets sample. The dots are data and the shaded bands are Pythia MC, including systematic errors. c) is jet multiplicity distribution for CDF Z+jets sample, before and after b-tagging.

detectors in front of the calorimeter, a much improved muon system, and a new data aquisition and trigger systems. The upgrades of the detectors enhance the ability to make sensitive searches.

3 Run II Analyses and Results

3.1 WH and ZH analyses

The first step towards the $WH \to \ell\nu + bb$ and $ZH \to \ell\ell + b\bar{b}$ searches is to study the $W+$jets and $Z+$jets samples, which are the major backgrounds for these analyses. The basic event selections for DØ's $W+$jets and $Z+$jets are: one or two isolated high p_T leptons with large missing E_T (for W), and two jets with $p_T > 20$ GeV and $|\eta| < 2.5$. Figure 2 a) and b) show the $\Delta R_{\rm jj}$ and dijet mass distributions from the DØ W+jets sample, based on a intergrated luminosity of 35 pb^{-1}. The spectra are normalized to the same total yield. There is good shape agreement between data and Monte Carlo. We are working to understand the uncertainties of the theoretical prediction of the total yield. Figure 2c) shows jet multiplicity distribution from the CDF Z + jets sample, based on a intergrated luminosity of 57 pb^{-1}, for jet $E_T > 15$ GeV and $|\eta| < 2$, with and without b-tagging (secondary vertex tag). There is a good agreement between observed and expected number of b-tagged jets.

3.2 $H \to WW^*$ searches

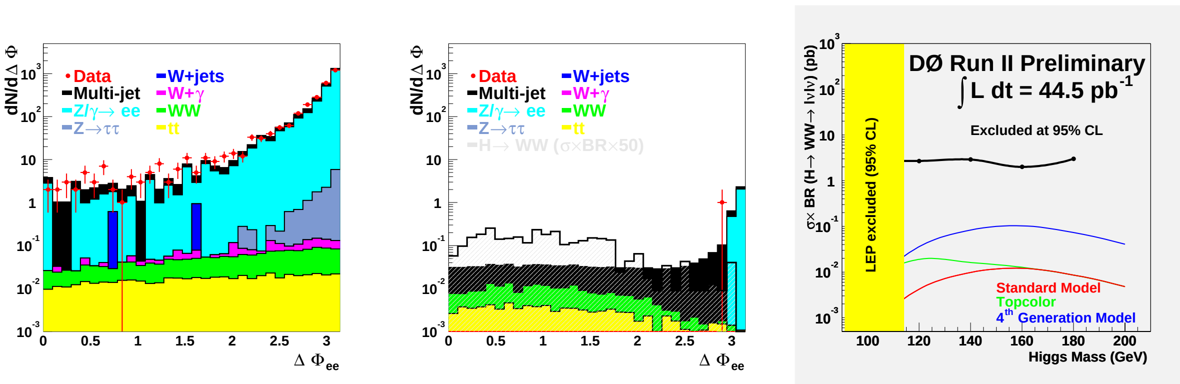
In the SM $H \to WW^*$ is the dominant decay channel if the Higgs mass is greater than 135 GeV. The cross section times branching ratio is largest for Higgs mass around 160 GeV. A fourth generation fermion family would enhace the Higgs cross section by about factor of 8.5 relative to the SM for a Higgs boson mass range of 100-200 GeV [6]. In fermiophobic/Topcolor Higgs models the coupling to fermions is suppressed, so these models give a larger branching ratio to boson pairs [7]. The cleanest diboson decay channels are those where both W's decay leptonically.

The main backgrounds for diboson Higgs searches are Z/γ^*, WW, $t\bar{t}$, W/Z+jets, and QCD multijet productions. Requiring large missing tranverse energy can remove much of the Z/γ^* background. Another useful discriminant variable is the opening angle between the two charged leptons, $\Delta\phi_{\ell\ell}$. The two charged leptons from Higgs decay tend to move parallel due to spin correlations in $H \to WW^*$ decay products thus these $H \to WW$ events have smaller $\Delta\phi_{\ell\ell}$ than background events.

The data used for DØ analysis of $H \to WW^* \to e\nu e\nu$ search was collected from Sept. 2002 to Jan. 2003, corresponding to an intergrated luminosity of 44.5 pb^{-1}. Table 1 shows the event

Table 1: Data and Expected background as a function of cuts in the DØ $H \to WW^* \to e\nu e\nu$ analysis. The cuts are optimized for $M_H = 120$ GeV.

Event Selection	Expected Background	Data
Lepton ID, $p_T > 10, 20$ GeV	$2748 \pm 42 \pm 245$	2753
$M_{ee} < M_H/2$	$264 \pm 18.6 \pm 4.3$	262
missing $E_T > 20$ GeV	$12.3 \pm 2.5 \pm 0.7$	11
$M_T > M_H + 20$ GeV	$3.6 \pm 1.4 \pm 0.2$	1
$\Delta\phi_{ee} < 2.0$	$0.7 \pm 1.4 \pm 0.1$	0



a) b) c)

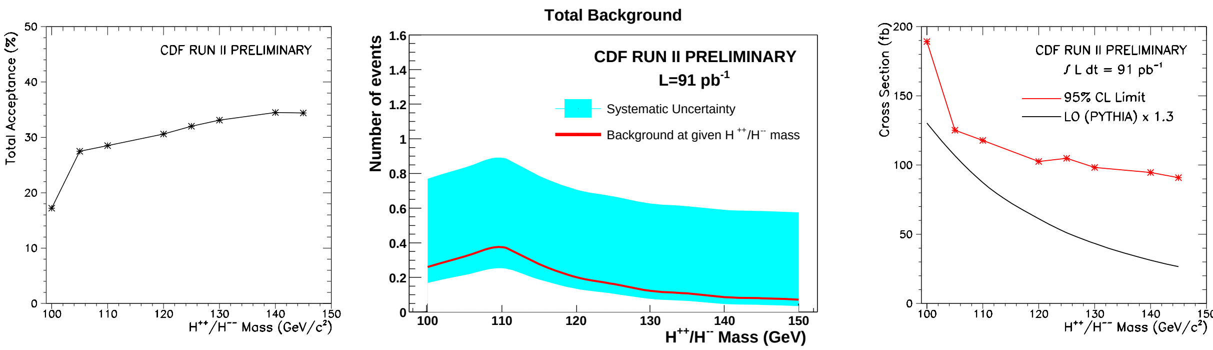
Figure 3: a) and b) are $\Delta\phi_{ee}$ distributions for data and backgrounds for $H \to WW^* \to e\nu e\nu$ searches, a) is after basic kinematic cuts and b) is after selection cuts. c) is the cross section times branching ratio of $H \to WW \to l\nu l\nu$ versus Higgs mass.The black line is the DØ upper limit at 95% C.L.; the color lines indicate expectations from various models.

selection optimized for $M_H = 120$ GeV. The efficiency for this selection is about 8%. Figure 3 a) shows the $\Delta\phi_{ee}$ distribution for data and background processes after basic kinematic cuts, which mainly are lepton identification and lepton E_T requirements. The data and background shown in Fig. 3 a) are in agreement in rate and shape. Figure 3 b) shows the $\Delta\phi_{ee}$ distributions after all selection cuts listed in Table 1 except the $\Delta\phi_{ee}$ cut. There is only one event from data in this plot, which is removed by the $\Delta\phi_{ee}$ cut. Fig.3c) shows the $\sigma(p\bar{p} \to H) \times Br(H \to WW)$ limit at 95% C.L. from current data, along with the expectations from the standard model, Topcolor, and fourth generation model.

3.3 Searches for Double Charged Higgs

Doubly-charged Higgs bosons appear in exotic Higgs representations such as found in left-right symmetric models[8]. At the Tevatron the doubly-charged Higgs can be produced in pairs through $p\bar{p} \to Z\gamma X \to H^{++}H^{--}X$, or produced singly through WW fusion. CDF searched for doubly-charged Higgs by looking at leptonic decays of H^{++}, using same-sign electron pairs. The search region is above 100 GeV. The search is performed in an invariant mass window of $\pm 10\%$ of a given H^{++} mass, which is about 3σ of the detector resolution. The main backgrounds are from Z's, QCD, and W+jets.

In the 80-100 GeV mass range the instrumental background from Z production is dominant. The background occurs when one of the electrons from Z radiates a photon, which subsequently converts. When the wrong sign conversion track is associated with the electron cluster, the event is reconstructed with two same-sign electrons. The Z background is estimated using the data in the 80-100 GeV mass range and the search covers the region above 100 GeV. The mass region



a) b) c)

Figure 4: a) The CDF total acceptance for doubly-charged Higgs, using the Pythia event generator and a GEANT-based detetctor simulation, b) the total background as function of the Higgs mass, and c) the production cross section and 95% C.L. upper limit.

of 100–130 GeV is dominated by the high-mass tail of the Z; above 130 GeV, QCD and Z production processes are expected to contribute equally to the background. Figure 4 a) and b) show the acceptance and background for doubly-charged Higgs as a function of Higgs mass. The large upper band in Fig. 4 b) for the systematic uncertainty arises from the W+jets background, for which CDF predicts 0.0 +0.5 −0.0 events.

The low mass region ($<$ 80 GeV) is used as a test of the background prediction. CDF predicts 0.6 events in this region and observes 0 events. In the search region ($>$ 100 GeV), CDF also observes 0 events. The Fig.4 c) shows the 95% C.L. cross section upper limit for pair-production of doubly-charged Higgs, based on an intergrated luminosity of 91 pb^{-1}.

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