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STANDARD MODEL HIGGS SEARCHES AND PERSPECTIVES AT THE TEVATRON

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Abstract

The status and perspectives of Standard Model Higgs searches at the Tevatron experiments CDF and DØ are discussed.

1 Introduction

In the Standard Model (SM) the Higgs mechanism is responsible for breaking the electroweak symmetry, thereby giving mass to the 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 SM. The Tevatron experiments, DØ and CDF, constrain the mass of the SM Higgs bosons indirectly through electroweak precision measurements. The main contribution to these indirect constraints from the Tevatron are the measurements of the W and top masses [1]. The dependence of the Higgs mass on these measurements is shown in Figure 1 together with the Higgs mass dependence on the measured electroweak precision parameters. The SM fit yields a best value of $m_H = 85^{+39}_{-28}$ GeV [2].

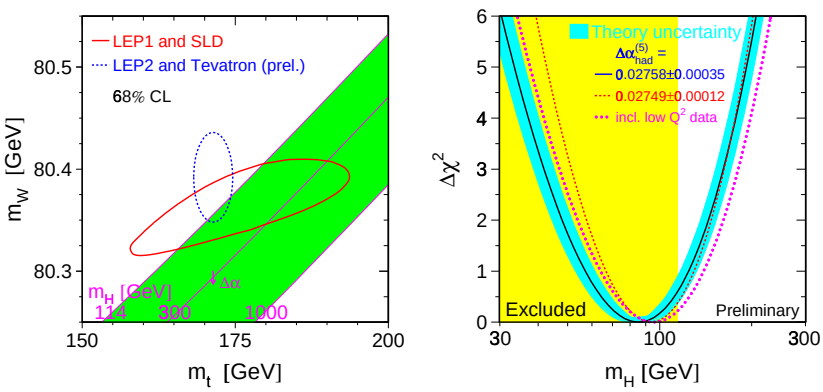

Figure 1: Dependence of the Higgs mass on the measured W and top masses (left). $\Delta\chi^2$ curve derived from precision electroweak data as a function of Higgs mass (right) [2].

The direct mass limit from LEP is 114.4 GeV at 95% Confidence Level (CL) [3]. The Tevatron experiments search for direct Higgs boson production in the mass range above the LEP limit using associated Higgs production ($p\bar{p} \to WH$, $p\bar{p} \to ZH$) and gluon fusion ($gg \to H$). The main tools are jet reconstruction, b tagging and lepton identification. The tagging of b jets from Higgs decays is usually performed by requiring tracks with large impact parameters or by reconstructing secondary vertices. More advanced analyses will combine these and other variables in Neural Nets. Events with neutrinos in the

final state are identified using missing transverse energy. The reconstruction of all these variables require excellent performance of all detector components.

There are different types of background to the Higgs search. An important source of background are multi-jet events (QCD background). This background and the instrumental background due to mis-identified leptons or b-jets is not very well simulated by Monte Carlo. Its shape and normalisation is therefore taken from data using control samples. Electroweak background processes such as $VV(V = W, Z)$ or $t\bar{t}$ pair production often dominate at the final stages of the selection; these are simulated using Monte Carlo programs.

At the time of writing these proceedings, the two Tevatron experiments have each recorded about 1.5 fb^{-1} of luminosity. Most results presented here are based on data corresponding to about 0.3 fb^{-1}. The preliminary results of the two collaborations are accessible through their web pages [4].

2 Low Mass Higgs Searches

In the Higgs mass region below 135 GeV the most important search channels are the associated production of a Higgs and a W or Z boson. The largest production cross-section is due to the process $gg \to H$, it is about 0.7 pb for a Higgs mass of 115 GeV. However, the Higgs boson predominantly decays into b quarks in this mass range and the QCD background is too large in this final state. The process $gg \to H$ is therefore not a viable search channel. The WH and ZH channels with the vector boson decaying into leptons have much lower cross-sections but the lepton tag and cuts on missing transverse energy help to reduce the background significantly.

2.1 $WH \to \ell\nu b\bar{b}$

This final state consists of two b jets from the Higgs boson and a charged lepton (electron or muon) and a neutrino from the W boson. DØ therefore selects events with one or two tagged b-jets, one isolated lepton with a transverse momentum $p_T > 20$ GeV and missing transverse energy $E_T^{\rm miss} > 25$ GeV. The main backgrounds are W production in association with two heavy flavour jets and $t\bar{t}$ production. This search yields an upper limit on the WH production cross-section in the range 2.4 pb to 2.9 pb for Higgs masses between 105 GeV and 145 GeV. The average integrated luminosity is 378 pb^{-1}.

CDF performed a similar analysis requiring one or two tagged b-jets with $E_T > 15$ GeV, an electron or a muon with $p_T > 20$ GeV and $E_T^{\rm miss} > 20$ GeV [5]. This search has recently been updated to include data with an integrated luminosity of 955 pb^{-1}, yielding limits on the cross-section $\sigma(p\bar{p} \to WH)\mathrm{BR}(H \to b\bar{b})$ between 3.9 pb and 1.3 pb for the mass range 110 GeV to 150 GeV [6].

2.2 $ZH \to \nu\nu b\bar{b}$

This channel has very good sensitivity because of the large branching ratios for $Z \to \nu\nu$ and $H \to b\bar{b}$ decays. Since the two b-jets are boosted in the transverse direction, the signature for the final state are acoplanar di-jets in contrast to most QCD di-jet events which are expected to be back-to-back in the transverse plane. In addition, large missing transverse energy (DØ : $E_T^{\rm miss} > 50$ GeV, CDF: $E_T^{\rm miss} > 75$ GeV) is required. Main background sources are W/Z production in association with heavy flavour jets, QCD events and $t\bar{t}$ pairs. A search in 260 pb^{-1} of data has been published by DØ [7] giving a limit on $\sigma(p\bar{p} \to ZH)\mathrm{BR}(H \to b\bar{b})$ of 3.4-2.5 pb for masses 105-135 GeV. The most recent preliminary CDF result includes 973 pb^{-1} of data [6].

2.3 $ZH \to \ell\ell b\bar{b}$

In this channel the Z boson is reconstructed by its decay into two high-p_T isolated muons or electrons. The reconstructed Z and two b-tagged jets are then used to select the Higgs signal. The main background sources are Z plus heavy jets and $t\bar{t}$ production. DØ measured a limit on $\sigma(p\bar{p} \to ZH)\mathrm{BR}(H \to b\bar{b})$ between 6.1 pb and 4.7 pb in the Higgs mass range 115-145 GeV using 320-389 pb^{-1} of data. CDF performed a similar analysis using about 1 fb^{-1} of data and obtained a limit of 2.0-1.1 pb in the mass range 110-150 GeV [6].

3 High Mass Higgs Searches

The dominant decay mode for higher Higgs masses is $H \to WW^{(*)}$. Leptonic decays of the W bosons are therefore used to suppress QCD background.

3.1 $H \to WW^{(*)} \to \ell\ell$

The signature of the $gg \to H \to WW^{(*)}$ channel is two high-p_T isolated leptons with 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 Z decays are predominantly back-to-back in $\phi_{\ell\ell}$. The experiments currently use the W decays into electrons or muons for this search. The CDF limit on $\sigma(p\bar{p} \to W)\mathrm{BR}(H \to WW)$ using 360 pb^{-1} is between 5.5 pb and 3.2 pb for Higgs masses from 120 to 200 GeV [8]. DØ has recently updated a published analysis with 300-325 pb^{-1} [9] using 950 pb^{-1}. The resulting limits are 6.3-1.9 pb for Higgs masses in the range 120-180 GeV [6].

3.2 $H \to WWW^* \to \ell\nu\ell'\nu q\bar{q}$

Here the Higgs boson is produced in association with a W boson. DØ has performed an analysis with data corresponding to 360-380 pb^{-1}, requiring two opposite sign isolated leptons (e, μ) with $p_T > 15$ GeV, one originating from the $H \to WW$ decay and one from the associated W boson, and $E_T^{\rm miss} > 20$ GeV [10]. This opposite sign charge requirement is very powerful in rejecting background from Z production. The remaining background is either due to di-boson production or due to charge mis-measurements. The upper limit on the cross-section $\sigma(p\bar{p} \to W)\mathrm{BR}(H \to WW^*)$ is between 3.2 pb and 2.8 pb for Higgs masses from 115 GeV to 175 GeV. A similar analysis was performed by CDF with an integrated luminosity of 194 pb^{-1}.

4 Combined Tevatron Limit

The data of both experiments have been combined using the full set of analyses with luminosities in the range 0.2-1 fb^{-1} [11]. The 95% Confidence Level (CL) upper limits are a factor of 10.4 (3.8) higher than the expected SM cross-sections for Higgs masses of 115 (160) GeV. The difference between the expected

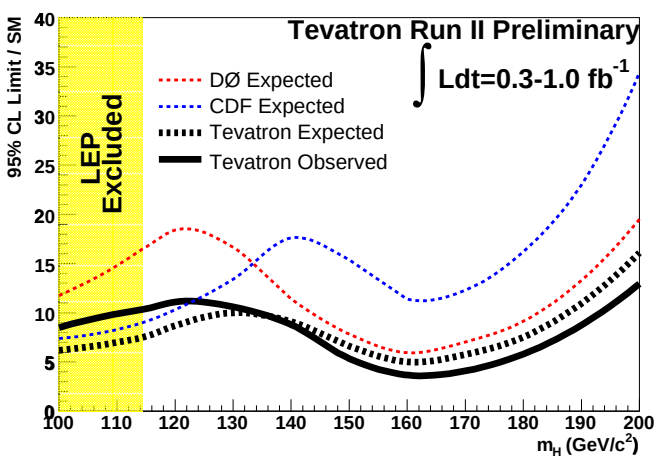

Figure 2: Expected and observed 95% CL cross-section ratios for the combined CDF and DØ analyses. The expected 95% CL ratio for both experiments are also shown.

limits for CDF and DØ is mainly due to the different size data samples that

have been analysed in the low and high mass high region, The overall sensitivity shown is therefore closer to the sensitivity of a single experiment with 1 fb^{-1}.

5 Summary and Perspectives

The CDF and DØ experiments at Fermilab's Tevatron have searched for the SM Higgs boson in a variety of channel, using data corresponding to integrated luminosities between 0.2 fb^{-1} and 1 fb^{-1}. The cross-section limits are about a factor ten above the SM expectation for a Higgs boson mass of 115 GeV. A long list of improvements - in addition to adding more data - are expected to lead to a significant increase in the sensitivity. The most important improvements are better b tagging using Neural Net algorithms, improvements of the di-jet mass resolution to separate the Higgs signal from the background, the inclusion of new channels such as $WH \rightarrow \tau(\rightarrow \text{hadrons})\nu b\bar{b}$ and the use of advanced analysis techniques such as Neural Nets. This and more data will give the Tevatron experiments a good chance to exclude a SM Higgs boson (or find indications for its existence) in the low mass region above the LEP limit of 114.4 GeV.

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