SEARCHES FOR THE STANDARD MODEL HIGGS AT THE TEVATRON

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Preliminary results obtained by the CDF and DØ Collaborations on the Standard Model Higgs searches at the Tevatron Run II are discussed. The data that correspond to an integrated luminosity of $\gtrsim$ 150 pb^{-1} are compared to theoretical expectations. Various final states involving the W and Z bosons production are examined, and new limits are set on the $\sigma[W(\to e\nu/\mu\nu)H(\to b\bar{b})]$ and $\sigma[H(\to WW^{(*)})]$ cross sections.

1 Introduction

One of the main physics objectives at the upgraded Tevatron Run II is to search for the Standard Model (SM) Higgs boson. Prospects for the discovery are not slim thanks to the recent improvements in the accelerator performance, and due to indirect constraints on the mass that favor a light Higgs boson of 117 GeV with an upper limit at 251 GeV [1]. The direct searches at LEP have already excluded the SM Higgs boson below 114.4 GeV [2].

In this range of masses, the Higgs boson production cross sections at Tevatron energies are small, of the order of 1 - 0.1 pb depending on its mass and the production mechanism. The rate is largely dominated by the gluon fusion, $gg \to H$. At low masses ($m_H \lesssim$ 135 GeV) however, when $H \to b\bar{b}$ decays are dominant, this mechanism suffers from the overwhelming QCD background. Instead, the WH and ZH associated production can be explored with vector bosons decaying leptonically to handle the background. At higher masses, $m_H \gtrsim$ 135 GeV, the $H \to WW^{(*)} \to \ell\nu\ell\nu$ ($\ell = e, \mu$) decays are promising to look at, although the Higgs boson cannot be reconstructed explicitly due to presence of neutrinos in the final states.

While to discover, or rule out, the SM Higgs boson at the Tevatron would require several fb^{-1} of data [3], the modest luminosities of $\gtrsim$ 150 pb^{-1} that have been collected and analyzed so far by CDF and DØ allow to optimize detector performance, study the background processes, and extend the previous limits on the Higgs boson production.

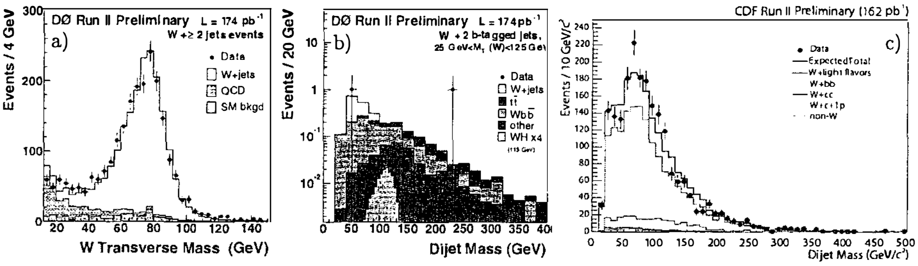

Figure 1: a) The W transverse mass distribution obtained by DØ in $e + \not{E}_T + jets$ final states. b) The di-jet mass spectrum when both jets are tagged as b's by DØ; light gray (brown) histogram corresponds to 4 times the expected Higgs signal of 120 GeV. c) Un-tagged di-jet mass distribution in $e/\mu + \not{E}_T + jets$ final states by CDF.

2 WH associated production

The first step of the search strategy is to identify the W production through its decay to a charged lepton and a neutrino. In addition, two jets in the event are required with at least one of them tagged as a b-jet. DØ has analyzed 174 pb^{-1} of data and observed nearly 2,600 $W(\rightarrow e\nu)+ \geq 2jets$ candidates. These events are selected by requiring a central, isolated electron with $p_T > 20$ GeV, missing transverse energy of $\not{E}_T > 25$ GeV and jets with $p_T > 20$ GeV in a pseudorapidity region $|\eta| < 2.5$. A good agreement between data and MC has been obtained for various kinematic properties of the event. An example of the W transverse mass distribution is shown in Fig. 1a. The $W + 2jets$ processes are simulated by ALPGEN [4] parton generator interfaced with PYTHIA[5], but the cross sections are normalized to NLO calculations[6]. The QCD background is evaluated from the data, while other SM processes are generated with PYTHIA. Only two jet events are retained in the analysis (to suppress the $t\bar{t}$ background) with both tagged as b-jets. Figure 1b shows the di-jet invariant mass distribution in the final sample. Two events are observed in data while 2.5 ± 0.5 events are expected from simulations. The background is dominated by the $Wb\bar{b}$ production (1.4 ± 0.4) with a non-negligible contribution from the $Wc\bar{c}/jj$ (0.4 ± 0.3), $t\bar{t}$ and single top processes (0.6 ± 0.2). An upper limit on the WH associated production cross section, $\sigma[W(\rightarrow e\nu)H(\rightarrow b\bar{b})] < 12.4$ pb, has been set at 95% C.L. by DØ for a Higgs mass of 115 GeV.

CDF uses both, electron and muon decay modes of W, to effectively double the size of the initial data sample which corresponds to an integrated luminosity of 162 pb^{-1}. The di-jet sample is selected by requiring central, isolated electron/muon with $p_T > 20$ GeV, $\not{E}_T > 20$ GeV, two jets with $E_T > 15$ GeV in $|\eta| < 2$, and vetoing extra jets or isolated leptons in an event. Figure 1c compares the di-jet mass distribution in data (about 2,100 events in total) with ALPGEN plus HERWIG [7] simulations. At least one b-jet is then required that leaves 62 events in data with 61 ± 5 events expected in MC. The background is dominated by fake tags in Wjj events (14), contribution from $Wc\bar{c}/b\bar{b}$ (13/12), QCD (10) and top production (9). Figure 2a shows the di-jet mass distribution in these events indicating a good agreement between data and MC. It also shows simulated Higgs signal with a mass of 115 GeV, but 100 times the expected rate. In the absence of a signal, CDF sets upper limits on the WH production, $\sigma[W(\rightarrow e\nu/\mu\nu)H(\rightarrow b\bar{b})] \lesssim 5$ pb at 95% C.L. that are shown in Fig. 2b as function of the Higgs boson mass. Both, CDF and DØ results discussed here are superior to similar Run I measurements [8].

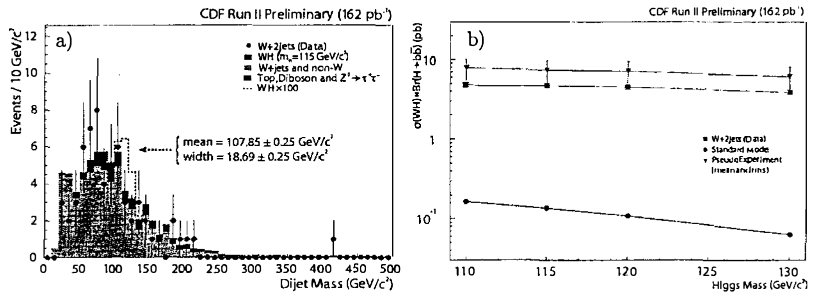

Figure 2: a) Di-jet mass spectrum in $\ell + \not{E}_T + jets$ events with at least one b-jet obtained by CDF. b) Limit on the WH production cross section as function of the Higgs boson mass; dots indicate the SM expectations.

3 Measurement of the $\sigma[Z + b\text{-}jet]/\sigma[Z + jet]$ cross section ratio

The Z boson production in association with b-jet(s) is an important process to study for several reasons: it probes the b-quark content of the proton parton distribution functions, it is a dominant background to the ZH associated production and a benchmark process for non-SM Higgs searches in $bh/b\bar{b}h$ associated production. DØ has analyzed electron and muon decays of Z and presented results on $\sigma[Z + b\text{-}jet]/\sigma[Z + jet]$, since in the ratio many systematic uncertainties cancel. The event selection requires two isolated leptons with $p_T > 15$ GeV in $|\eta| < 2.5$ (electron channel) or $p_T > 20$ GeV, $|\eta| < 2$ (muon channel). Z peak is selccted for signal events while the side bands are used for the background evaluations. Events are required to have a jet with $E_T > 20$ GeV in $|\eta| < 2.5$. Since the b-tagging algorithm cannot distinguish between b- and c-jets, their relative content in $Z + jet$ sample is taken from the NLO calculations [9], while the total rate (including light quarks/gluon jets) is normalized to data. This leaves one unknown quantity to measure – the fraction of events with one b-tagged jet provided the (mis-)tagging rates for light quarks and b-/c-jets are known; these rates are in fact measured in data.

Preliminary result on the cross section ratio is $0.024 \pm 0.005(stat.)^{+0.005}_{-0.004}(syst.)$ as compared to ~ 0.02 predicted in theory [9]. The systematic errors include uncertainties due to the jet tagging efficiency (16%), the jet energy scale (11%), background estimations (6%) and assumtions on the relative fraction of b- and c-jets (3%). This measurement by DØ is the first of its kind.

4 Higgs searches in $H \to WW^{(*)} \to \ell^+\nu\ell^-\bar{\nu}$ final states

At higher Higgs boson masses, $m_H \gtrsim 135$ GeV, when the $WW^{(*)}$ decay mode becomes kinematically accessible, one can explore leptonic decays of W to handle various backgrounds. The signal signature is: two isolated, opposite charge leptons accompanied by a large missing E_T. The background processes include the $Z/\gamma^*(\to \ell^+\ell^-) + jets$ ($\ell = e, \mu, \tau$), WW, WZ, $W + jets$, $t\bar{t} \to b\ell^+\nu\bar{b}\ell^-\bar{\nu}$ and QCD production.

DØ has analyzed $\sim$ 180, 160 and 150 pb^{-1} of data in ee, $e\mu$ and $\mu\mu$ final states, respectively. Selected events must have two leptons with $p_T > 12$, 8 GeV ($ee/e\mu$ channels), $p_T > 20$, 10 GeV ($\mu\mu$), $\not{E}_T > 20$ GeV ($ee/e\mu$), $\not{E}_T > 30$ GeV ($\mu\mu$), no Z candidates and energetic jets. Simulations are done with PYTHIA except for the QCD contributions which are evaluated from the data. A good agreement between data and MC is obtained at each step of the event selection. As an example, Fig. 3a shows the $\not{E}_T$ spectrum in di-muon final states after event pre-selection (p_T and isolation criteria). Figure 3b shows the azimuthal opening angle distribution between electron and muon after all cuts have been applied. This variable has a strong discriminating power

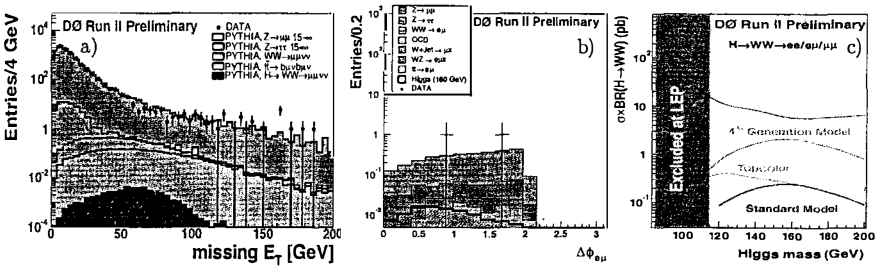

Figure 3: a) The missing transverse energy distribution in di-muon sample after event pre-selection. b) Distribution of the azimuthal opening angle between electron and muon; dark (blue) histograms in both plots correspond to the Higgs signal of 160 GeV. c) Excluded cross section times branching ratio to W-pairs, $\sigma \times BR(H \rightarrow WW^{(*)})$, along with the expectations from the SM Higgs boson production and alternative models.

against, e.g. non-resonant WW production, since leptons in signal events tend to be collinear due to the spin correlations between the Higgs boson decay products.

Final data samples of ee, $e\mu$ and $\mu\mu$ final states contain 2, 2 and 5 events, respectively, while 2.7 ± 0.4, 3.1 ± 0.3 and 5.3 ± 0.6 events are expected in MC. The background is dominated by the WW production. In the absence of a signal, the limits are set at 95% C.L. on the Higgs boson production cross section times branching ratio into W bosons as illustrated in Fig. 3c.

5 Conclusions

New measurements done by the CDF and DØ Collaborations for the SM Higgs boson searches at the Tevatron Run II, as well as the recent improvements in accelerator performance are very encouraging. Limits set on the WH and $H \rightarrow WW^{(*)}$ production processes are unmatched or superior to Run I results. To conclude – the hunt for Higgs boson(s)[a] in Run II has begun, and this searches will form a central part of the physics program at the Tevatron.

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[a]Searches for non-SM Higgs bosons at the Tevatron have been discussed in a separate talk [10]