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Searches for Higgs Boson(s) at the Upgraded Tevatron

Gregorio Bernardi
(for the CDF and DØ Collaborations)
LPNHE - Paris VII and VII, and Fermi National Accelerator Laboratory,
gregorio@in2p3.fr

We summarize the status of Higgs boson searches at the upgraded Fermilab Tevatron performed by the DØ and CDF collaborations. We report on three categories of searches, namely the search for the Standard Model Higgs boson ($p\bar{p} \to H$, WH or ZH, with $H \to WW^*$ and/or $H \to b\bar{b}$), the search for the minimal supersymmetric Higgs boson using $p\bar{p} \to hb\bar{b} \to b\bar{b}b\bar{b}$ and $p\bar{p} \to hX \to \tau\tau X$, and the search for doubly charged Higgs boson.

1 The Standard Model Higgs Boson

The Higgs boson is the only scalar elementary particle expected in the standard model (SM). Its discovery would be a major success for the SM and would provide new experimental insights into the electroweak symmetry breaking mechanism. Direct measurements at LEP have excluded a SM Higgs boson with a mass $m_H < 114.4$ GeV at 95% C.L. but constraints from precision measurements nevertheless favor a Higgs boson sufficiently light to be accessible at the Fermilab Tevatron Collider. The current preferred mass value, as deduced from a fit to electroweak measurements by the LEP, SLD, CDF, and DØ experiments [1] shown in Fig. 1a, is 126^{+73}_{-48} GeV. At the Tevatron, indirect searches involve precision measurements of the top quark and the W mass, while direct searches require high luminosity samples for discovery or exclusion in the $115 - 185$ GeV mass range, as shown in Fig. 1b. Although the expected luminosity necessary for its discovery at the Tevatron is higher than obtained thus far, the special role of the Higgs boson in the SM justifies extensive searches for a Higgs-like particle independent of expected sensitivity. The chances for discovery are better in supersymmetric (SUSY) extensions of the SM [2], since the SUSY Higgs production cross-section is generally predicted to be larger than that of the SM.

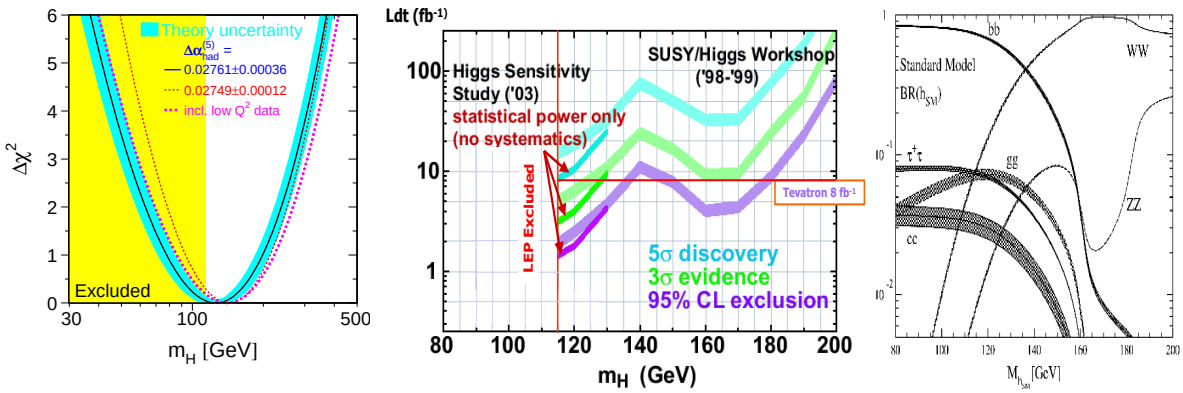

Figure 1: a) Constraints on the Higgs mass from a fit to Electroweak measurements; b) Expected sensitivity to the Higgs boson at the Tevatron; c) Branching ratios (BR) of the Higgs boson as a function of m_H, in the SM.

2 Searches for SM Higgs Production at the Upgraded Tevatron

At the Tevatron $p\overline{p}$ collider ($\sqrt{s}$=1.96 TeV), the two dominant mechanisms for Higgs production are gluon fusion, and associated production with a W or a Z: $gg \rightarrow H$, $q\overline{q} \rightarrow W/Z + H$. Although the gg process has the largest cross section, $\sim$ 1 pb at m_H=115 GeV, it is the most sensitive production mode only at relatively high mass Higgs boson, ($m_H \gtrsim$130 GeV) where it has a significant branching ratio in WW^*, as shown in Fig. 1c. At lower masses, the dominant decay $H \rightarrow b\bar{b}$ is swamped by multijet background, so only the search for a Higgs produced in assocation with a vector boson has enough sensitivity. The WH and ZH channels, would give a clear signal with lepton(s), neutrino(s), and 2 b-jets: $q\overline{q} \rightarrow W/Z + H \rightarrow l\nu/ll/\nu\nu + b\overline{b}$.

Two main studies have been performed on the sensitivity of the Tevatron experiments to SM Higgs physics. The first one, in 98-99 [4], explored the whole mass range available with some approximation of the detector response, while the second one, in '03, was restricted to the low mass region [3] and was using a more realistic simulation, since first data of Tevatron Run II had become available. The most recent study essentially confirmed the findings of the original study, and both results are summarized in Fig. 1b, after combination of all channels of both experiments. The amount of integrated luminosity needed for a Higgs discovery at m_H = 115 GeV is approximately 8 fb^{-1}. A 3 σ evidence might be found with $\gtrsim 3-4$fb^{-1}, while most of the Higgs mass region below $\sim$185 GeV could be excluded at 95% CL with $\sim$ 8 fb^{-1}.

These searches are crucially dependent on the performance of the Tevatron. After a "slow" start, the machine is performing very well since the end of 2003, with larger than designed delivered luminosities. Currently about 1 fb^{-1} has been delivered as shown in Fig. 2a, with weekly integrated luminosity which have reached over 20 pb^{-1}. Since this figure is the terminal value assumed in the minimal (base) luminosity expectation (cf Fig. 2b), the current performance ensure that, barring accident, a minimal integrated luminosity of 4 fb^{-1} will be achieved by the end of 2009, as shown in Fig. 2c. If the accelerator keeps following the designed luminosity evolution, a luminosity of 8.2 fb^{-1} will be achieved, rendering the potential for a Higgs discovery significant at the Tevatron.

2.1 Search for Higgs Production in Association with a W boson, in the $Wb\bar{b}$ Final State

CDF and DØ have studied the $Wb\bar{b}$ final state, in which WH production could be observed. The DØ analysis, based on 174 pb^{-1} of data, requires two b-tagged jets with $p_T > 20$ GeV and $\eta < 2.5$, large transverse missing energy ($\not\!\!E_T >$ 25 GeV) and an isolated electron with $p_T > 20$ GeV. The measured dijet mass distribution is well described by the expectation, both before

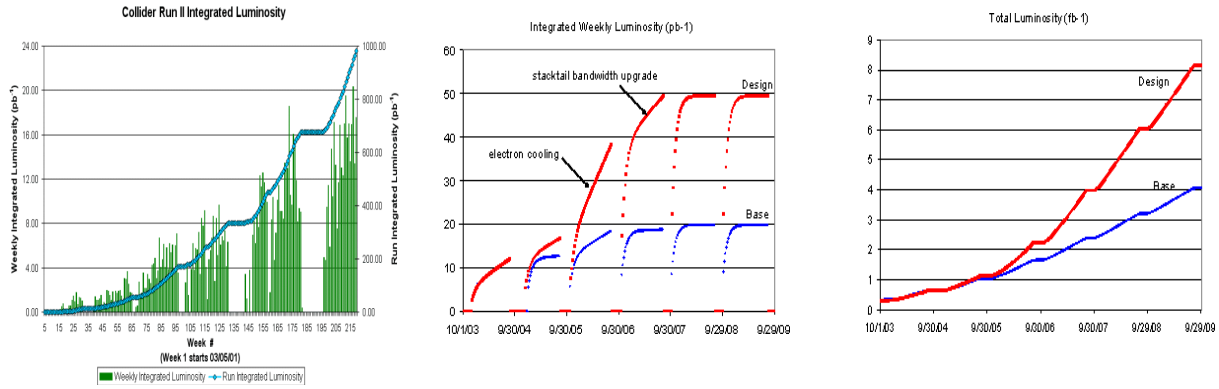

Figure 2: Current and expected performance of the Tevatron: a) integrated luminosity and weekly delivered luminosity since the beginning of Run II; b) Expected weekly delivered luminosity; c) Expected integrated luminosity.

(not shown) and after single b-tagging (shown in Fig. 3a). The number of observed events is reduced from 76 (2 jets including at least 1 b-tagged jet), to 6 events when requesting 2 b-tagged jets (Fig. 3b). The number of expected events being 4.4, a 95% C.L. upper cross section limit of 6.6 pb is set on $Wb\bar{b}$ production for $p_T^b > 20$ GeV and an $\eta - \varphi$ separation between b-jets > 0.75. By restricting the selection to a ± 25 GeV window around the searched Higgs masses, DØ has established a 95% C.L. limit on WH production of 9−12.2 pb for m_H between 105 and 135 GeV [5], as shown in Fig. 3c.

Although this limit is still significantly above the expected SM cross section, the difference in sensitivity compared to the '03 prospective study, shown in Fig. 1b, is "only" a factor 2.4, when taking into account the current luminosity and this specific channel only. This factor is understood for the major part of it, since i) the current analysis is temporarily restricted to "central" electron ($\eta < 1.1$), while the final coverage, up to 2.5, was used in Ref. [3]; ii) a "tight" b-tagging algorithm is currently applied, while new developments show that a significant gain can be achieved in b-tagging efficiency by loosening it; iii) several other efficiencies (trigger, lepton-id) can be improved. We expect thus that after implementing the analysis improvements mentioned above, the sensitivity prospects will be met.

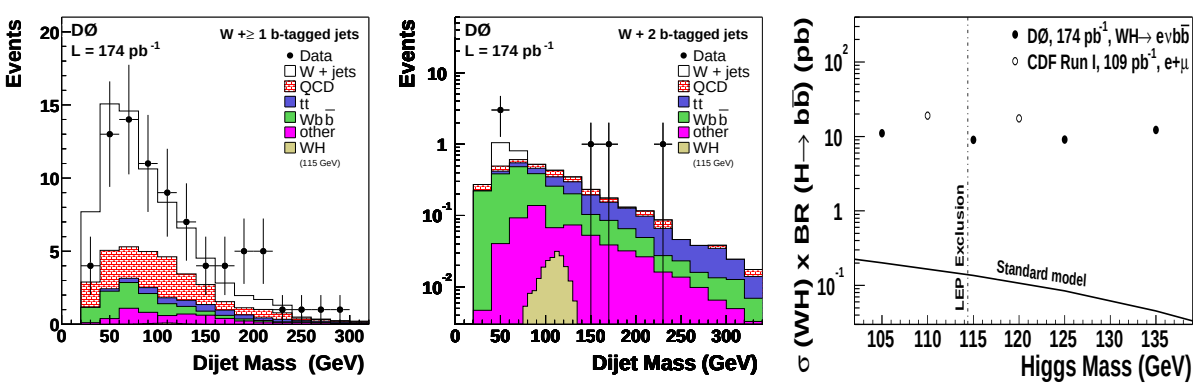

Figure 3: WH results at DØ. a) Distribution of the dijet invariant mass in the $W+2$ jets sample after requiring at least one b-tagged jet b) Same distribution, after requiring that the 2 jets are b-tagged. The expectation obtained from a 115 GeV Higgs is also shown. c) Limit on $WH \times BR(H \to b\bar{b})$ cross section, as a function of m_H.

CDF has done a similar search on 162 pb^{-1} of data, using a sample with one electron or muon ($p_T > 20$ GeV), 2 jets ($p_T > 15$ GeV, $\eta < 2$), $\not{E}_T > 20$ GeV, but requiring only one

jet to be b-tagged. The number of observed events goes from 2072 in the $W+2$ jets sample (Fig. 4a) to 62 events when requiring at least 1 b-tagged event (Fig. 4b). The search for the Higgs is performed in a mass window on this distribution, normalizing the background to the data outside the window. The resulting 95% limit is 5-6 pb in the 105-135 GeV range.

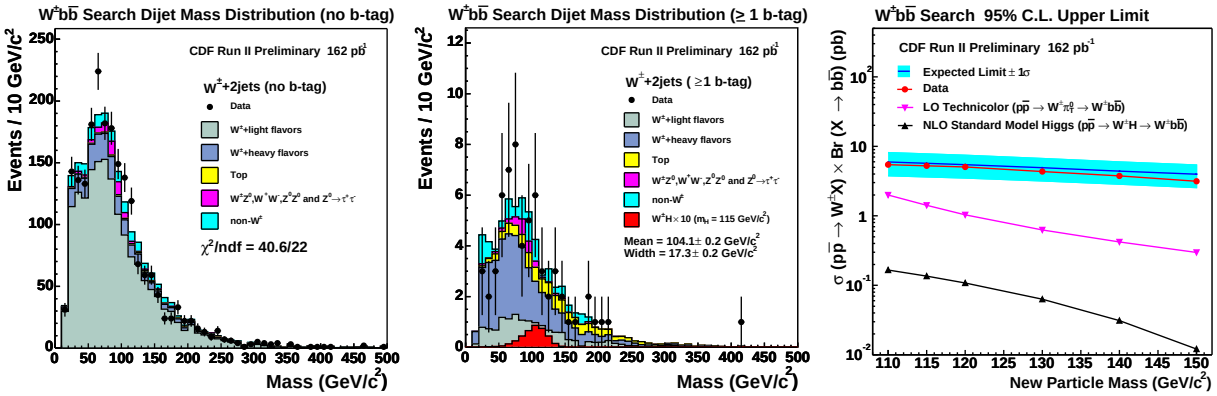

Figure 4: WH results at CDF: a) Distribution of the dijet invariant mass in the $W+$ 2 jets sample; b) Same distribution, after requiring that at least one jet is b-tagged. The expectation obtained ($\times 10$) from a 115 GeV Higgs is also shown. c) Limit on $WH \times BR(H \to b\bar{b})$ cross section, as a function of m_H.

2.2 Search for Higgs Production in Association with a Z boson, in the $\nu\bar{\nu}b\bar{b}$ Final State

DØ has studied the $\not\!\!E_T + b\bar{b}$ final state, in which $ZH(\to \nu\bar{\nu}b\bar{b})$ production could be observed [a]. The analysis is based on 261 pb^{-1} of data, obtained using a dedicated trigger selecting events with acoplanar jets and $\not\!\!E_T$. The final selection which requires two b-tagged jets with $p_T > 20$ GeV and $\eta < 2.5$, large transverse missing energy ($\not\!\!E_T >$ 25 GeV), no back-to-back topology, and no isolated tracks allows to reject multijet background and "leptonic" $W+$ jets or $Z+$ jets events in which the leptons escaped detection. The requirement $H_T < 200$ GeV, where H_T is defined as the scalar sum of the p_T of the jets, allows to reject $t\bar{t}$ events. Further rejection of the multijet background is obtained by putting requirements on the correlations between different ways of calculating $\not\!\!E_T$ (using calorimeter cells, tracks, or jets) which must be highly correlated in the case of the clean $\nu\bar{\nu}b\bar{b}$ topology. The measured dijet mass distribution is well described by the expectation, as shown after single b-tagging in Fig. 5a. The number of observed events is reduced from 132 (2 jets including at least 1 b-tagged jet), to 9 when requesting 2 b-tagged jets (Fig. 5b), for respective SM expectations of 144.7 and 6.4 events. The dominant systematic uncertainties on the signal are due to the b-tagging efficiency ($\sim 22\%$) and to the jet reconstruction/energy scale ($\sim 11\%$). By restricting the selection to a ± 25 GeV window around the searched Higgs masses, DØ has established a 95% C.L. limit on the $ZH \times BR(H \to b\bar{b})$ production cross section, between 12.2 and 8.5 pb for m_H between 105 and 135 GeV, as shown in Fig. 5c. The corresponding expected limits (8.8–6.5 pb) are also shown.

This limit is, as expected, still significantly above the expected SM cross section. For this channel and the current luminosity, the sensitivity of this analysis due to the trigger/reconstruction efficiencies compared to the '03 prospective study, is approximately a factor 3 lower. As in the WH case, work is in progress to approach the performance assumed in the sensitivity study.

2.3 Search for the SM Higgs Boson $H \to WW^* \to l^+\nu l'^-\overline{\nu}$

At higher Higgs masses, the search is best performed in the $H \to WW^*$ channel. After measuring the WW^* production cross section [6,7], which is well reproduced by Next-to-Leading Order

[a] This result became public after this conference (on 11/4/2005), but is reported here for completeness.

calculations, CDF and DØ have searched for the SM Higgs decaying into WW^* decaying leptonically (ee, $e\mu$ and $\mu\mu$ channels). The event selection requires 2 high p_T leptons of opposite charge, with an invariant mass incompatible with the Z mass and constrained by the searched Higgs mass, and a significant $\not\!\!E_T$. Further requirements are based on the sum of $\not\!\!E_T$ and p_T of the leptons, and on the φ separation between leptons which are not back-to-back in Higgs decays due to spin correlations, as visible in the CDF $\Delta\varphi$ distribution, Fig. 6a.

For CDF, on 184 pb^{-1} of Data, 8 events are observed, for an expectation of 9.1 events. The 95% C.L. upper limit on the cross-section times $BR(H \to WW*)$ is measured for masses between 140 and 180 GeV and shown in Fig. 6b. For $m_H = 160$ GeV, the limit is 5.6 pb i.e. about an order of magnitude above the SM prediction.

For DØ on 320 pb^{-1} of Data, 20 events are observed, for an SM expectation of 17.7 events. In Fig. 6c is shown the corresponding limit which is 5.3 pb for m_H=160 GeV. Models assuming a 4th generation could be excluded in the near future, if m_H is approximately 160 GeV.

2.4 Search for the SM Higgs Boson in the $WH \to WWW^*$ channel

CDF has searched for W Higgs production, in which $H \to WW^*$, using high-p_T isolated like-sign dilepton events in 193.5 pb^{-1} of data. The background components is studied in a like-sign sample selected by requiring the leading lepton $p_T > 20$ GeV and the second lepton $p_T > 6$ GeV. The entire sample is consistent with the background expectation as shown in Fig. 7 for 2 typical distributions. The signal region is determined in the plane of the second lepton p_T ($p_{T,2}$) versus the vector sum of p_T's of the two leptons($p_{T,12}$): $p_{T,2} > 16$ (18) GeV and $p_{T,12} > 35$ GeV for Higgs masses < 160 GeV (> 160 GeV). No event is found, while the total background is expected to be 0.95 ± 0.64 events. The expectation for a 110 GeV bosophilic Higgs is about 0.06 events assuming the same production cross section as the Standard Model Higgs, and for $m_H = 160$ GeV, the SM Higgs expectation is about 0.03 events. For this mass, the cross section upper limits $\sigma(WH) \times BR(H \to WW^*)$ is ~ 8 pb, as shown in Fig. 7c.

3 Searches for Supersymmetric Higgs Bosons

Searches for non-SM Higgs bosons are also performed at the Tevatron. CDF and DØ have started searching for exotic Higgs bosons including SUSY Higgs bosons and doubly charged Higgs bosons. In the case of SUSY, the efforts have concentrated so far on the minimal supersymmetric standard model (MSSM) Higgs bosons.

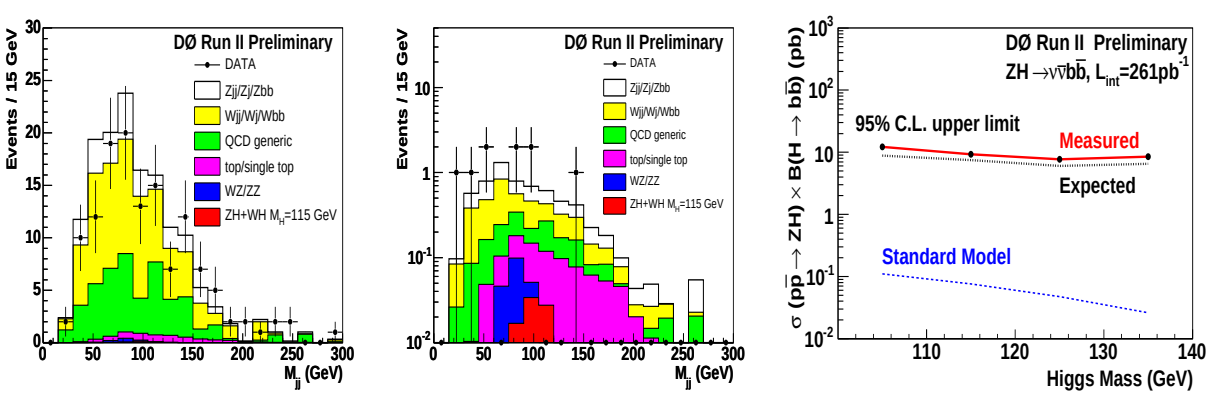

Figure 5: ZH results at DØ. a) Distribution of the dijet invariant mass in the $Z+$ 2 jets sample after requiring at least one b-tagged jet b) Same distribution, after requiring that the 2 jets are b-tagged. The expectation obtained from a 115 GeV Higgs is also shown. c) Limit on $ZH \times BR(H \to b\bar{b})$ cross section, as a function of m_H.

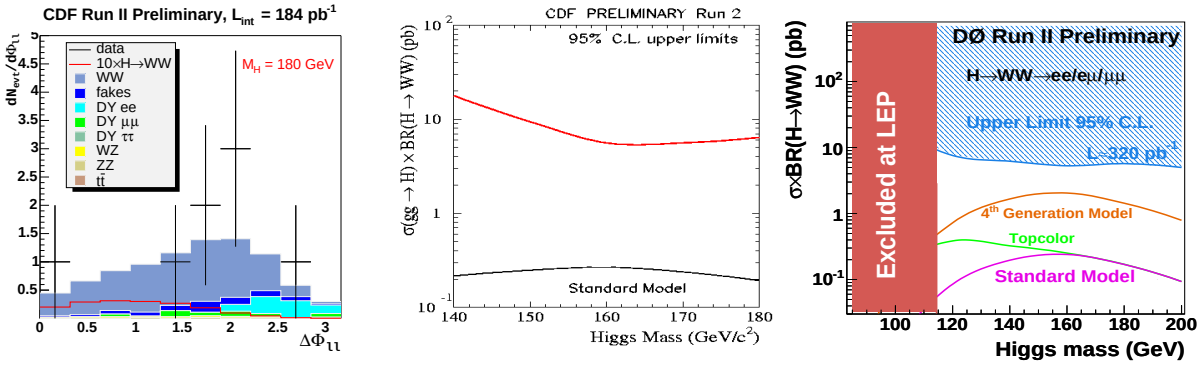

Figure 6: WW^* results at CDF and DØ. a) Distribution of $\Delta\varphi$ between the 2 leptons. The WW^* signal tend to be at lower $\Delta\varphi$ values. Limits on WW^* production $\times$ $BR(H \to WW^*)$ at CDF (b) and at DØ (c).

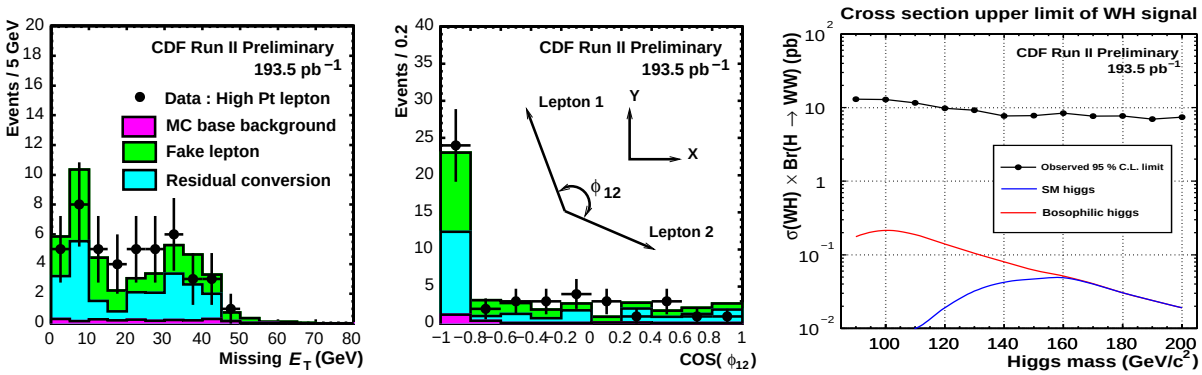

Figure 7: WWW^* results at CDF. Distributions of $\not{E}_T$ (a) and $\cos\varphi_{12}$ (b) in the control sample (see text); c) 95 % CL limit obtained on WWW^* production, compared to the SM expectation, and to the beyond the SM scenario of a bosophilic Higgs.

In two Higgs-doublet models of electroweak symmetry breaking, such as in the MSSM [2], there are five physical Higgs bosons: two neutral CP-even scalars, h and H; a neutral CP-odd state, A; and two charged states, $H^{\pm}$. The ratio of the vacuum expectation values of the two Higgs fields is defined as $\tan\beta = v_2/v_1$, where v_2 and v_1 refer to the Higgs fields that couple to the up-type and down-type fermions, respectively. At tree level, the coupling of the A boson to down-type quarks, such as the b quark, is enhanced by a factor of $\tan\beta$ relative to the standard model (SM), and the production cross section is therefore enhanced by $\tan^2\beta$ [8].

LEP experiments have excluded at 95% C.L. a light Higgs boson with mass $m_h \leq 92.9$ GeV [9], independent of $\tan\beta$, and at higher masses for $\tan\beta$ below 10–20. The Tevatron is currently sensitive to $\tan\beta$ values between ~ 50 and ~ 100. In this region of $\tan\beta$, the A boson is nearly degenerate in mass with either the h or the H boson, and their widths are small compared to the dijet mass resolution. Since we cannot distinguish between the h/H and the A, the total cross section for signal is assumed to be twice that of the A boson.

The major decay modes of h are a b quark pair production($\sim$ 90%) and τ lepton pair production($\sim$ 8%). The $p\bar{p} \to hb\bar{b}$ with $h \to b\bar{b}$ or the gluon-gluon higgs production with $h \to \tau\tau$ decay are the most promising channels at the Tevatron.

3.1 Search for MSSM Higgs Bosons in the $hb\bar{b}$ Channel

DØ has searched for the MSSM Higgs in the $hb\bar{b}$ channel using 260 pb^{-1} of data, with a dedicated trigger based on high (≥ 3) jet multiplicity, designed for maximizing signal acceptance while providing acceptable trigger rate. Events with up to five jets were initially selected, while the signal was searched as a mass resonance in the subsample having at least 3 $b-$tagged jets. Jets containing b quarks were identified using a secondary vertex (SV) tagging algorithm. The b tagging efficiency is $\approx 55\%$ for central b-jets of p_T>35 GeV with a light quark (or gluon) mistag rate of about 1%.

The $b\bar{b}h$ signal events, with $h \to b\bar{b}$, were generated for Higgs boson masses from 90 to 150 GeV using PYTHIA event generator [10]. The p_T and rapidity spectra of the Higgs bosons from PYTHIA were normalized to those from NLO calculation [11]. The multijet production is the largest background and is determined from data but is also verified using the ALPGEN [12] event generator. All other backgrounds are expected to be small and are simulated with PYTHIA.

There are two main categories of multijet background. One contains genuine heavy-flavor jets, while the other consists of light-quark or gluon jets that are mistakenly tagged as b-quark jets, or correspond to gluons that "split" into nearly collinear $b\bar{b}$ pairs. Using the selected data sample, before the application of b-tagging requirements, the probability to b-tag a jet ("mistag" function) was measured as a function of its p_T and $|\eta|$. The mistag function was corrected by subtracting heavy-flavor contributions. and used to estimate the instrumental background, by applying them to every jet reconstructed in the full data sample. The triple b-tagged data were compared with this background expectation, as shown in Fig. 8a. No evidence for signal was found in mass windows centered around the searched Higgs masses. The expected dijet mass distribution originating from a 120 GeV MSSM Higgs boson is also shown in the figure.

Figure 8b shows the expected MSSM Higgs boson production cross section as a function of m_A for $\tan\beta = 80$. The MSSM cross section shown in Figure 8 corresponds to no mixing in the scalar top quark sector [13], or $X_t = 0$, where $X_t = A_t - \mu\cot\beta$, A_t is the tri-linear coupling, and the Higgsino mass parameter $\mu = -0.2$ TeV. The results are also interpreted in the "maximal mixing" scenario with $X_t = \sqrt{6} \times M_{SUSY}$, where M_{SUSY} is the mass scale of supersymmetric particles, taken to be 1 TeV. Results for both scenarios of the MSSM are shown in Figure 8c as limits in the $\tan\beta$ versus m_A plane. The present DØ analysis excludes a significant portion of the parameter space, down to $\tan\beta = 50$, depending on m_A and the MSSM scenario assumed.

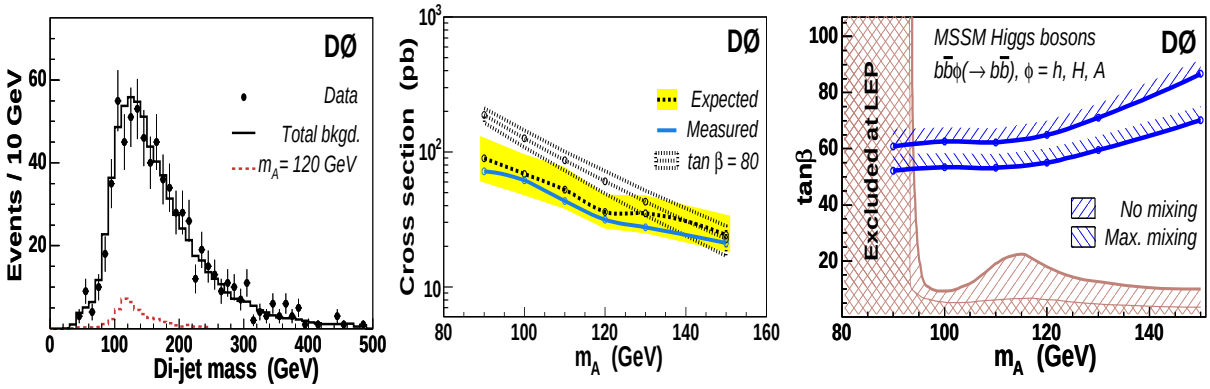

Figure 8: $hb\bar{b}$ results at DØ. a) Dijet mass distribution obtained from the 2 leading b-tagged jets in multijet events with at least 3 b-tagged events. b) Upper limits on the signal cross section as a function of Higgs boson mass. c) 95% C.L. upper limit on $\tan\beta$ as a function of Higgs boson mass (right).

3.2 Search for MSSM Higgs Bosons in the $gg \rightarrow hX \rightarrow \tau\tau X$ Channel

Using an integrated luminosity of about 200 pb^{-1}, CDF has searched for a MSSM Higgs in the $gg \rightarrow hX \rightarrow \tau\tau X$ channel The signal consists of a tau pair in which one of the taus decays to hadrons and a neutrino (τ_h) while the other decays to an electron (τ_e) or a muon (τ_μ) and two neutrinos. The data were collected with a set of dedicated τ-triggers which select a lepton (e or μ) candidate with $p_T > 8$ GeV and an isolated track from τ_h decay. The τ lepton decaying into hadrons, was identified/reconstructed by the charged tracks and the neutral pions lying inside a narrow cone. The invariant mass and the track multiplicity of the τ_h were required to be less than 1.8 GeV and equal to 1 or 3, respectively. Further selections were done on the event topology using missing transverse energy ($\not\!\!E_T$) and the p_T of the taus. An example is the scalar sum $\hat{H}_T = |p_T^{vis}(\tau_1)| + |p_T^{vis}(\tau_2)| + \not\!\!E_T$, where $p_T^{vis}(\tau)$ is the visible transverse momentum of the tau decay products not including the neutrinos. Requiring $\hat{H}_T$ >50 GeV leads to significant background reduction with small signal loss.

The signal processes $gg \rightarrow h$ and $b\bar{b} \rightarrow h$ were simulated using PYTHIA. Higgs masses between 115 GeV and 200 GeV were generated for $\tan\beta$=30. The backgrounds from $Z \rightarrow l^+l^-$, (l=e,μ,or τ), di-boson production, and $t\bar{t}$ production were estimated using Monte Carlo samples. The backgrounds from jet to τ misidentification were estimated using a fake rate function obtained from independent jet samples, as a function of the jet energy, pseudorapidity, and track multiplicity. The biggest source of background is $Z \rightarrow \tau\tau$ events, which can only be distinguished from the Higgs signal by the di-τ mass. A mass-like discriminating variable, $m_{vis}(l,\tau_h^{vis}, \not\!\!E_T)$, was constructed using the four-momentum of the lepton (e or μ), the four-momentum of the visible decay products of the $\tau_h(\tau_h^{vis})$ and $\not\!\!E_T$ (also treated as a four vector). After combining the $\tau_e\tau_h$ and $\tau_h\tau_\mu$ channels, a binned likelihood fit of the $m_{vis}(l,\tau_h^{vis}, \not\!\!E_T)$ distribution was done to search for the Higgs signal. In Fig. 9 is shown the $m_{vis}(l,\tau_h^{vis}, \not\!\!E_T)$ distribution for data and various backgrounds. The limits on Higgs production cross section times branching ratio at 95 % C.L. are presented in Fig. 9.

4 Searches for Doubly Charged Higgs Bosons

Several models like the left-right symmetric model [14] require a Higgs triplet leading to an observable doubly-charged Higgs boson ($H^{\pm\pm}$), which could be light in the minimal supersymmetric left-right model. The dominant production mode at the Tevatron is expected to be $p\bar{p} \rightarrow \gamma^*/Z + X \rightarrow H^{++}H^{--}$. The partial width in the leptonic decay mode is proportional to the coupling to the lepton and to the Higgs mass. DØ and CDF have already published mass

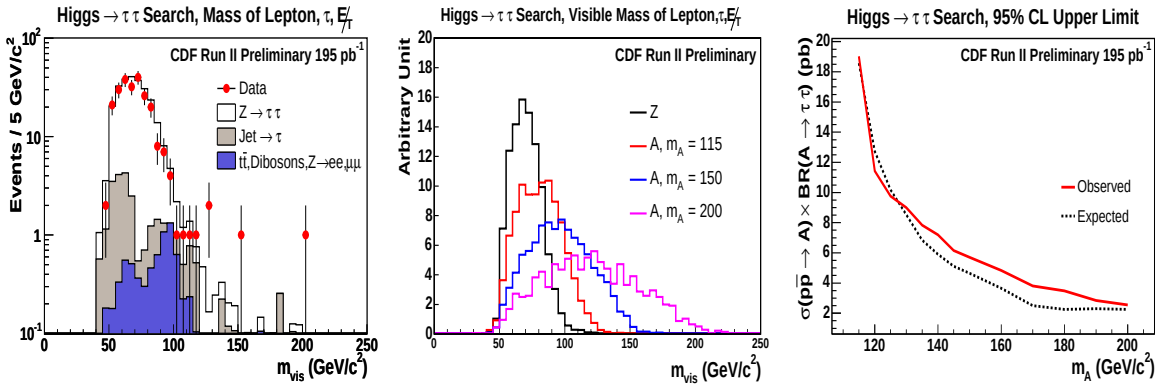

Figure 9: $A \to \tau\tau$ results at CDF. a) Observed visible invariant mass $m_{vis}(l,\tau_h^{vis}, \not{E}_T)$ distribution compared to the sum of various backgrounds; b) comparison of $m_{vis}(l,\tau_h^{vis})$ reconstructed with τ's originating from Z or A decay; c) 95% CL upper limit on $\sigma(p\bar{p} \to h) \times B(A \to \tau\tau)$ as a function of m_H.

limits from direct searches in the di-lepton decay channels for the short lived $H^{\pm\pm}$ [15, 16], as shown in Fig. 10a. The LEP experiments exclude $m_{H^{\pm\pm}} <\sim 99.5$ GeV at 95% C.L. for $H^{\pm\pm}$ bosons with couplings to left- or right-handed leptons.

If the $H^{\pm\pm}$ boson is long-lived ($c\tau$ >3 m), it can decay outside the detector. CDF has performed such a search on 292 pb^{-1} of data [17], using an inclusive muon trigger which requires a track with $p_T > 18$ GeV, and a match in the muon chamber. The event selection requires two tracks, each with p_T >20 GeV, and at least one of them must have a matching muon. Since the charge collected by the drift chamber is proportional to the ionization deposited by the particle per unit length(dE/dx), an $H^{\pm\pm}$ boson would deposit a dE/dx four times larger than a single charge tracks like an isolated μ. The $H^{\pm\pm}$ boson charge deposit is modelled by quadrupling the dE/dx of cosmic ray muons, while the dE/dx for low momentum protons are used as a controlled sample, see Fig. 10b.

Since no events remained after selecting large dE/dx, 95% C.L. upper limits on the $H^{\pm}$ pair production cross section were set, as shown in Fig. 10c. The theoretical cross sections are computed separately for $H^{\pm\pm}$ bosons that couple to left- and right-handed particles ($H_L^{\pm\pm}$ and $H_R^{\pm\pm}$). Long-lived $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$ bosons were excluded below a mass of 133 GeV and 109 GeV, respectively. When the two states are degenerate in mass, the exclusion limit becomes $H^{\pm\pm}$ <146 GeV.

5 Conclusion

We reported on searches for SM and beyond SM Higgs bosons. No evidence for Higgs signal has been found yet, but the evolution of the Tevatron luminosity indicates that a light SM Higgs is within reach for CDF and DØ by the years 2008-2009. To achieve this difficult goal, all channels will have to be exploited and combined, and the first results obtained by the two collaborations allow to be optimistic. A significant improvement of sensitivity in the BSM Higgs searches is also taking place, as the first Tevatron Run II results are demonstrating.

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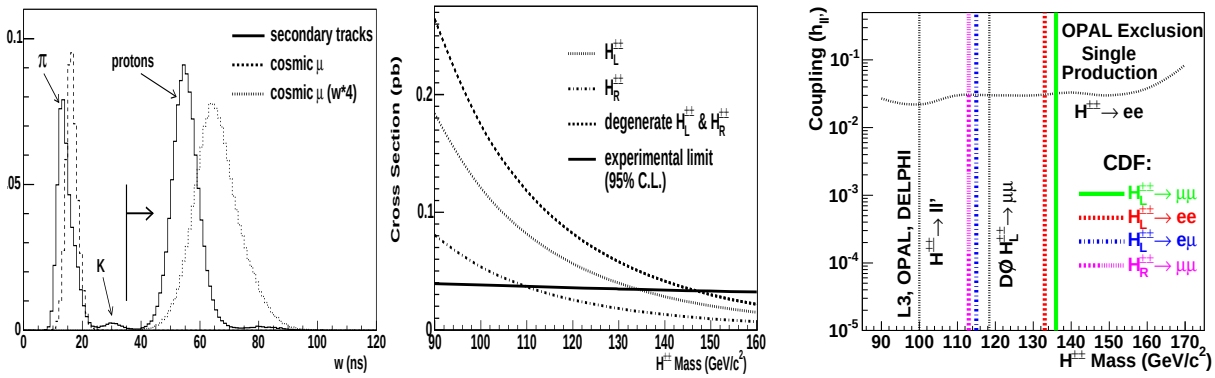

Figure 10: $H^{\pm\pm}$ results at CDF and DØ. a) Distribution of the CDF tracking detector dE/dx variable w for positively-charged secondary tracks with p_T of 300 -350 MeV/c (solid), for high-pT cosmic ray muons (dashed), and the expectation for H tracks (dotted); b) comparison of the CDF experimental cross section upper limit with theoretical NLO cross section for pair production of long-lived $H^{\pm\pm}$ bosons, with left-handed ($H_L^{\pm\pm}$) and right-handed ($H_R^{\pm\pm}$) couplings, and summed for the degenerate mass case; c) comparison of the CDF and DØ experimental cross section upper limit with theoretical NLO cross section for pair production of short-lived $H^{\pm\pm}$.

Suyong Choi, Beate Heinemann, Avto Kharchilava and Makoto Tomoto.

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