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HIGGS SEARCHES AT THE TEVATRON

L. MONETA
(for the CDF and DØ Collaborations)
University of Geneva, DPNC
CH-1211 Geneva, Switzerland

This paper describes the searches for the Higgs boson performed by the CDF and DØ collaborations at the Tevatron $p\bar{p}$ Collider using the data collected in the 1992-95 run. Searches for standard model Higgs and as well for neutral and charged minimal SUSY Higgs bosons are also presented. No signal has been observed and limits are set for production cross sections.

1 Introduction

The Standard Model (SM) predicts the existence of the Higgs boson which is responsible of the electroweak symmetry breaking. The mass is not predicted by the theory but precision electroweak measurements constraint the Higgs mass below 212 GeV/c^2 [1](at 95% CL). Direct searches at LEP [2] exclude $<$ 113.5 GeV/c^2. In addition, an excess of events consistent with a Higgs boson with mass of 115 GeV/c^2 is observed at LEP [2], but it is not statistically conclusive.

In the minimal supersymmetric extension of the SM (MSSM), the electroweak symmetry breaking of the Higgs sector requires the presence of three neutral (h, H and A) and two charged ($H^{\pm}$) scalar Higgs bosons. The mass of the lightest Higgs, h, is constrained by the model to $M_h \leq 130$ GeV/c^2, while the other masses are expected to be larger.

2 Searches for the Standard Model Higgs

The dominant Higgs production processes at Tevatron are the gluon fusion, $gg \to H$, and associated production with a W or Z boson, $q\bar{q} \to W/ZH$. The gluon fusion has higher cross sections but it is very difficult to distinguish from the overwhelming QCD background in the light mass region ($m_H \leq 130$ GeV/c^2), when $H \to b\bar{b}$ is the dominant decay channel. In the case of associated production, the vector boson provides a handle to suppress the background, but the cross section, $\sigma(p\bar{p} \to W/ZH) \approx 300$ fb for $m_H = 110$ GeV/c^2, is approximately 20 times smaller than the $t\bar{t}$ cross section. According to the decay mode of the vector bosons, four different signatures are considered: $\ell\nu b\bar{b}$, $\nu\nu b\bar{b}$, $\ell^+\ell^- b\bar{b}$ and $jjb\bar{b}$ ($\ell = e, \mu$).

The search strategy is similar for all decay channels. After identifying the W or Z through its decay, at least two extra jets from the $H \to b\bar{b}$ decay are required and, depending on the analysis, one or both jets, must be tagged as b jets. Two b-tagging techniques, have been developed and applied successfully by CDF and DØ in the discovery of the top quark. The first methods look for leptons within a jet (soft lepton tagging) exploiting the semileptonic decays of the b hadrons. The second method (secondary vertex or jet probability) is more powerful and is based on the presence of the displaced decay vertex within the jet, arising from the relative long B lifetime. Only CDF, equipped in the past run with a silicon vertex detector, could use this second technique. The Higgs mass is reconstructed using the two b tagged jets or the two most energetic jets. Jet energy resolution plays as well a major role to discriminate signal against background.

Both CDF [3] and DØ [4] search for the SM Higgs in the $WH \to \ell\nu b\bar{b}$ channel. These events are reconstructed by requiring one isolated electron and muon with $p_T > 20$ GeV/c, transverse missing energy $\not{E}_T > 20$ GeV and two jets with $E_T > 15$ GeV and $\eta < 2$. CDF distinguishes when one or both jets are identified as b jets using the secondary vertex and the soft lepton tag, while DØ requires at least one soft muon b tagged jet. Major remaining sources of background are W produced in association with heavy flavours ($Wb\bar{b}$, $Wc\bar{c}$), fake b tags, and top events.

A preliminary search in the $ZH \to \nu\nu b\bar{b}$ channel is performed by CDF. The signature consists in the presence of large missing transverse energy ($\not{E}_T > 40$ GeV), no charged lepton and two or three jets. QCD background from mismeasured $\not{E}_T$ is reduced by requiring $\Delta\Phi_{min}(\not{E}_T, jet) > 60^0$ and background from QCD dijet events is reduced with a cut on $\Delta\Phi(jet_1, jet_2) < 120^0$. Independent analyses with single and double b-tag are performed. After b-tagging, the remaining backgrounds are QCD, $Wb\bar{b}$, $Wc\bar{c}$ top and dibosons productions.

The $ZH \to \ell^+\ell^- b\bar{b}$ channel is the cleanest given the presence of two leptons with the possibility of applying the Z mass constraint but it is limited by the low $BR(Z \to \ell^+\ell^-)$. CDF has performed a preliminary search looking for two high p_T electrons or muons ($p_T > 20, 10$ GeV/c) with invariant mass, $76 < M_{\ell\ell} < 106$ GeV/c^2. Two or three jets are required, and at least one must be b-tagged. The remaining backgrounds are $Zb\bar{b}$, $Zc\bar{c}$ and fake tags.

The $Z/WH \to q\bar{q}b\bar{b}$ channel contributes to ~ 50 % of all decays, but suffers from the high QCD multi jet production. The CDF search [5] starts by accepting events with 4 or more jets, among which at least two are tagged as b-jets by the secondary vertex algorithm. In addition, the p_T of the two b-jets system is required to be $p_T(b\bar{b}) > 50$ GeV/c. The background is dominantly QCD, but contributions from fake b-tags, top and $Z+$ jets are also present.

The results of the CDF searches are summarised in table 1, where the estimated acceptance for each channel and the number of events observed in the data are reported together with the total background predictions after the $W/Z + b\bar{b}$ selection. The observed events are consistent with the expectations and 95% CL limits on the production cross section times branching ratio are derived from a maximum likelihood fit to the dijet mass distributions. Figure 1 shows the results for each channel and their combination.

3 Search for MSSM Neutral Higgs

CDF has searched for a neutral MSSM Higgs (ϕ) produced in association with $b\bar{b}$, process $p\bar{p} \to b\bar{b}\phi \to b\bar{b}b\bar{b}$, using 91 pb^{-1} of data [6]. This process can be particularly important in the MSSM parameter region when the Yukawa couplings between the Higgs scalars and the b quarks are enhanced with respect to the SM. Events are selected by requiring four jets with at least three of them b tagged and imposing Higgs mass dependent E_T cut. In addition, a

Table 1: Table summarising the results for the SM Higgs searches showing for each channel the corresponding luminosity, branching ratio × acceptance, expected background and observed events.

Channel	b-tags	Experiment	$\int \mathcal{L}$ (pb^{-1})	BR × Accept.(%) for M_H (GeV/c^2) 90	110	130	Expected background	Observed events
$\ell\nu b\bar{b}$	1	CDF[3]	106	$.55 \pm .14$	$.74 \pm .18$	$.89 \pm .22$	30 ± 5	36
$\ell\nu b\bar{b}$	2	CDF[3]	106	$.23 \pm .06$	$.29 \pm .07$	$.34 \pm .09$	3.0 ± 0.6	6
$\ell\nu b\bar{b}$	1	DØ[4]	106	$.30 \pm .02$	$.36 \pm .02$	$.44 \pm .03$	25.5 ± 3.3	27
$\nu\nu b\bar{b}$	1	CDF	88	$.59 \pm .12$	$.69 \pm .14$	$.86 \pm .17$	39.2 ± 4.4	40
$\nu\nu b\bar{b}$	2	CDF	88	$.37 \pm .08$	$.44 \pm .11$	$.53 \pm .11$	3.9 ± 0.6	4
$\ell\ell b\bar{b}$	1	CDF	106	$.14 \pm .03$	$.20 \pm .04$	$.19 \pm .04$	3.2 ± 0.7	5
$q\bar{q}b\bar{b}$	2	CDF[5]	91	$1.3 \pm .4$	$2.2 \pm .6$	$3.1 \pm .8$	594 ± 30	589

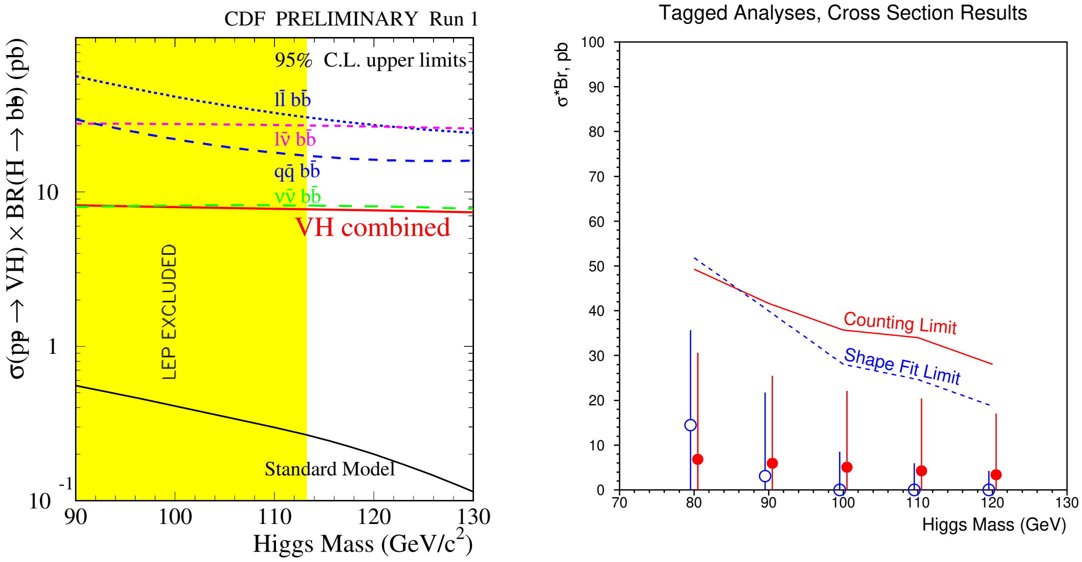

Figure 1: 95% CL upper limits on production cross section times branching ratios as function of Higgs mass from CDF (left) and DØ (right). The combined CDF limit is calculated by fitting the product of the individual likelihood for each channel, taking into account correlation between systematic uncertainties.

cut on the b-tagged dijet angular distribution reduces the QCD background with $g \to b\bar{b}$. The observed number of events is in agreement with SM contributions, consisting mainly of QCD heavy flavours, mistags, top and Zjj events. Excluded regions are set in the $\tan\beta$ vs M_h and m_A plane, for two stop mixing scenario (no mixing and maximal mixing) and for a SUSY mass scale of 1 TeV. As shown in figure 2, the CDF limits probe a region of parameter space, for $\tan\beta$ larger than 35, which could not be accessible at LEP.

4 Search for charged Higgs from the decay of the top quark

Searches for charged Higgs are performed by CDF and DØ looking for top quark decay to charged Higgs ($t \to H^+ b$), when $m(H^+) < m_t - m_b$. This search is sensitive only for low and large $\tan\beta$ values, when the $BR(t \to H^+ b)$ dominates. The charged Higgs decays almost 100% in $\tau\nu$ for $\tan\beta > 1$ and hadronically in cs for low $\tan\beta$ values. Direct searches from CDF [7] look for $H^+ \to \tau\nu$ using τ identification via its hadronic decays and they are thus sensitive only in the large $\tan\beta$ region. Indirect searches, performed by CDF and DØ [8], are more powerful and look for suppression of SM $t\bar{t}$ decays, caused by $t \to H^+ b$ decays. Observed rates of dilepton

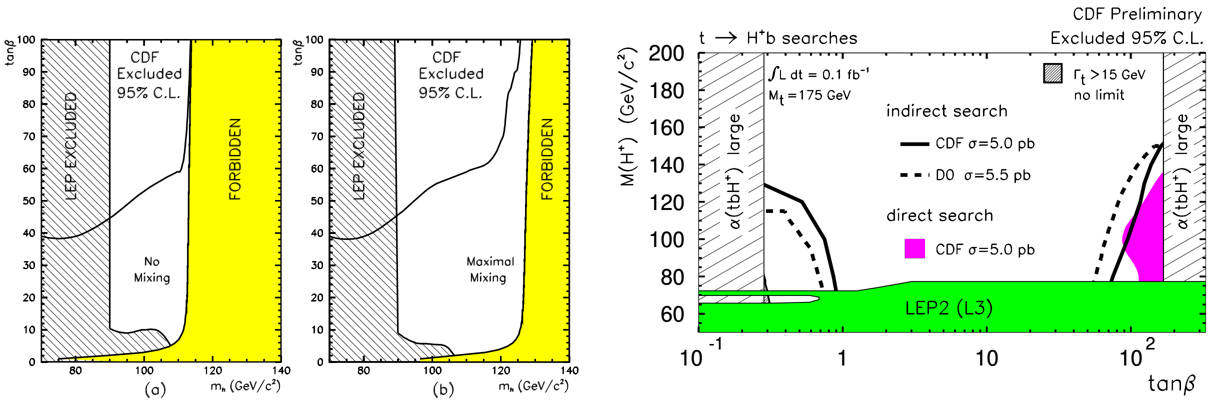

Figure 2: 95% CL exclusion region in the $\tan\beta$ vs M_h plane from the CDF MSSM neutral Higgs search (left) and exclusion region in $\tan\beta$ vs $M_{H^\pm}$ plane for the charged Higgs searches(right) from CDF and DØ.

and lepton + jets events in the top sample depends on $BR(t \to H^+ b)$, while the SM predictions for $\sigma_{t\bar{t}}$ are independent $H^\pm$ production. Exclusion regions in the $M(H^+)$ vs $\tan\beta$ plane have been then derived with sensitivity in both low and high $\tan\beta$ region as shown in figure 2.

5 Conclusion

Results on Higgs searches from the data collected at Fermilab during 1992-95 have been reported. No evidence of signal has been found and 95% CL limit have been derived. Searches for the SM Higgs boson are presently limited by statistics at approximately < 8 pb, 30 times higher than the SM values. These searches are however the starting points for the analyses of the next run. The increased integrated luminosity and the detector upgrades will allow the possibility of discovering the Higgs bosons in the intermediate mass range [9]. Results on searches for MSSM neutral Higgs, via $p\bar{p} \to b\bar{b}\phi \to b\bar{b}b\bar{b}$, and charged Higgs produced from top quark decays, are also presented. Limits are derived as function of the MSSM parameters, probing region inaccessible at LEP.

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