SEARCHES FOR HIGGS AT CDF

CHRISTOPHER NEU
on behalf of the CDF Collaboration
Department of Physics
The Ohio State University
Columbus, OH 43210 USA
E-mail: neu@fnal.gov

The Higgs boson is predicted to play a crucial role in the dynamics of electroweak symmetry breaking. The search for this yet-unseen state is an important part of the Run 2 physics program at the Tevatron. Herein is offered a brief description of the latest Run 1 Higgs results from CDF, as well as an early Run 2 result.

1. Introduction and Motivation

In the standard model (SM), it is the Higgs mechanism that is responsible for electroweak symmetry breaking. This framework predicts the existence of a physically observable neutral scalar particle, the Higgs boson, for which no direct experimental evidence yet exists. The combined results of the LEP experiments place the best limit on the standard model Higgs mass: $M_H > 114.4\ GeV/c^2$ at 95% CL [1]. The Higgs mechanism in supersymmetric extensions of the standard model similarly predicts several new states.

The Collider Detector at Fermilab (CDF) is described in detail elsewhere [2]. This general purpose detector is well-suited for Higgs searches in a variety of channels. Several Run 1 (1992-1995) searches were performed, and a rich Higgs physics program is planned for Run 2, presently underway.

2. Run 1 Standard Model Higgs Searches

There are several predicted SM Higgs production mechanisms at the Tevatron (see Figure 1.a). The production process with the largest cross section is $gg \to H$; however because of formidable backgrounds to this process, most of the Run 1 CDF Higgs searches focused on associated Higgs production, $p\overline{p} \to VH$ where $V = W$ or Z. The production cross section for these associated Higgs channels varies between 0.08 and 0.2 pb for Higgs masses up to 150 GeV/c^2 (for comparison, the $t\bar{t}$ Run 1 cross section is ~ 7 pb).

As seen in Figure 1 the decay $H \rightarrow b\bar{b}$ dominates in the range $M_H < 135$ GeV/c^2. In Run 1 CDF exploited the relatively long lifetime of the b quark to develop b identification tools that identified secondary vertices indicative of B-hadron production and subsequent decay, so-called "b tagging". A jet is tagged as a b-jet if it has a secondary vertex at least 3σ away from the event vertex in the direction of the jet-axis. Longer-lived light flavor hadrons, such as K_0 and Λ, are vetoed. We describe below several Run 1 SM Higgs searches that relied on this technique in the low mass regime.

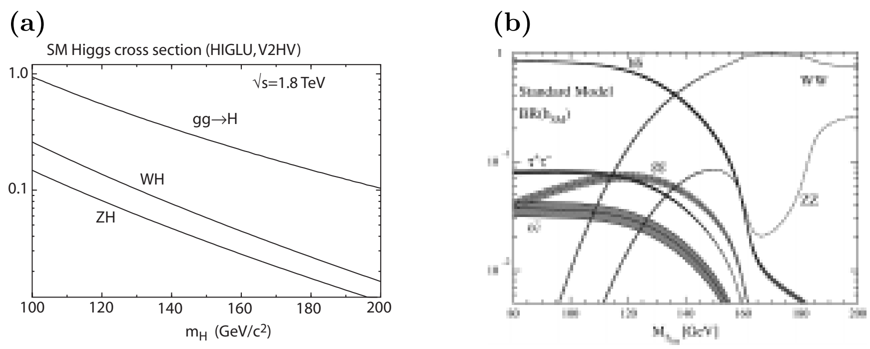

Figure 1. SM Higgs production cross sections for $\sqrt{s} = 1.8\ TeV$ and decay modes as a function of M_H.

2.1. *Combined Limit from Four VH Searches*

Four analyses searching for associated Higgs production were performed in the low Higgs mass range 90 $GeV/c^2 < M_H <$ 130 GeV/c^2 . Each analysis focused on one of the following final states: $\ell\nu b\bar{b}$, $\ell\ell b\bar{b}$, $\nu\nu b\bar{b}$, and $q\overline{q'}b\bar{b}$. The leptonic decay of the W and Z is exploited in three of these four searches by providing highly efficient event triggering. In the $\ell\nu b\bar{b}$ and $\nu\nu b\bar{b}$ cases, the neutrinos escape the CDF detector without interacting; their presence however is inferred by an energy imbalance measured in the transverse plane (missing E_T, denoted $\not{E}_T$) in the detected event objects. The searches relying on the leptonic W and Z decays were restricted to events with 2 jets which we expect to be produced in the decay $H \rightarrow b\bar{b}$. Signal content in the selected events is enhanced by requiring that at least one of the 2 jets be b-tagged. In the case of the $q\bar{q}b\bar{b}$ the jet multiplicity is expected to be higher. Therefore events in this analysis were demanded to have four jets, among which at least two were similarly required to have a b tag.

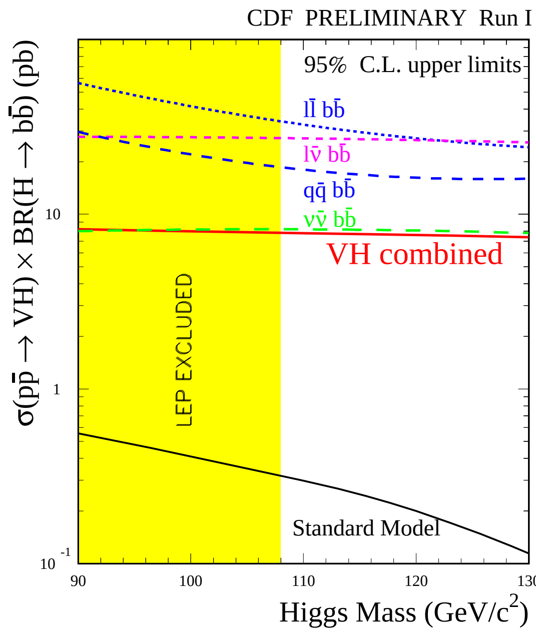

Figure 2. Upper limit on the SM VH cross section as a function of M_H.

Single and double tag results from these searches in the four final states were combined into one cross section limit [3]. Figure 2 shows the combined upper limit as a function of M_H. Note that the combined limit from these four analyses is an order of magnitude larger than the standard model theory prediction; thus no exclusion beyond those provided by LEP experiments was possible.

2.2. *Optimized $\ell\nu b\bar{b}$ Analysis*

A new $WH \to \ell\nu b\bar{b}$ analysis in the low Higgs mass regime was recently completed that sought to optimize the search technique [4]. Like the previous $\ell\nu b\bar{b}$ search, the selection criteria required events to have a high p_T lepton, large missing energy and 2 jets, one of which is required to be b-tagged. This analysis refined the standard event selection by employing a neural network to discriminate signal from background. The network was designed to classify each event passing the standard selection into one of the five classes that were constructed (four background and one signal class).

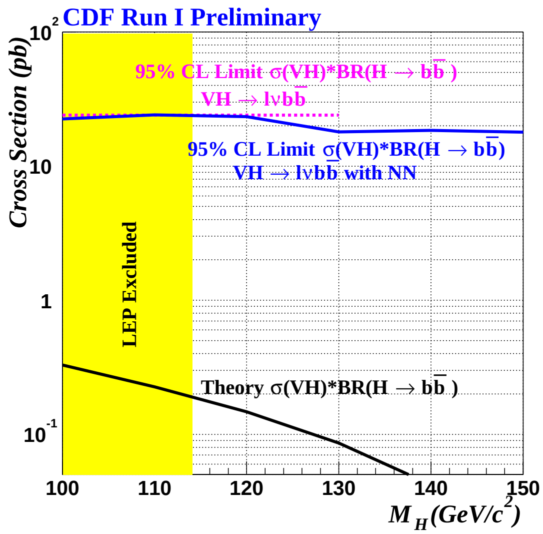

Figure 3. Upper limit on the $VH \to \ell\nu b\bar{b}$ cross section from optimized search compared to standard analysis in this channel. Note that the limit from the standard analysis only goes out to 130 GeV/c^2.

Improved sensitivity with the neural network was demonstrated in Monte Carlo studies; for example, for $M_H = 120\ GeV/c^2$, it was shown that the optimized technique yielded a 34% increase in signal sensitivity $(N_{Signal}/\sqrt{(}N_{Background})$. Figure 3 shows the new cross section limit from this $\ell\nu b\bar{b}$ as a function of M_H.

The Run 1 analyses gave a 2-3σ excess of observed events over the expected background. The ability to characterize the phenomena contributing to the excess will benefit from the increased statistics in Run 2. Future standard model Higgs searches will also benefit from optimized search techniques like the one described above.

3. Run 1 MSSM Higgs Searches

Run 1 searches at CDF were not limited just to the standard model Higgs. The minimal supersymmetric extension to the standard model (MSSM) predicts two Higgs doublets, which correspond to five new physical states: two neutral CP-even states h, H; a neutral CP-odd state A; and two charged states H^+ and H^-. The masses of the different Higgs bosons are often given in terms of two free MSSM parameters, M_A and $\tan\beta$. Couplings between members of the MSSM Higgs spectrum to weak isospin fermions, like b quarks and τ leptons, are proportional to $\tan\beta$. By virtue of $\tan\beta$ being a free parameter, then, there are regions of phase space in which the couplings to b quarks and the like are very large.

A search was performed for the process $gg \to b\bar{b}\phi \to b\bar{b}b\bar{b}$ [5]. The four b quark final state is exceptional and somewhat clean given CDF's b identification abilities. The search criteria required events to contain four well-separated jets, with three b-tags among the jets. Major backgrounds included QCD multijet production, all hadronic $t\bar{t}$ and W+jets.

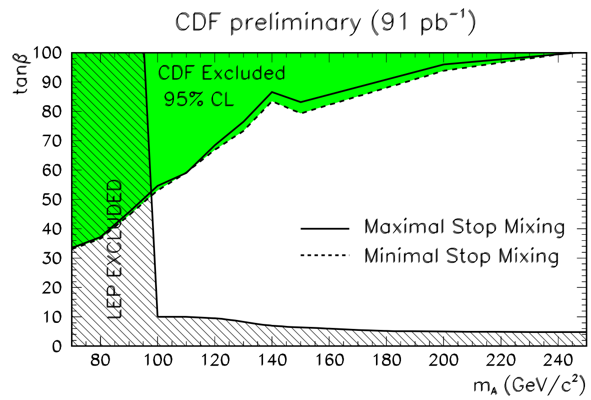

Figure 4. Limits in the $\tan\beta$ versus M_A plane from the $b\bar{b}b\bar{b}$ analysis.

From Figure 4 one can see that a large portion of the M_A versus $\tan\beta$ plane was excluded by the Run 1 search, exceeding LEP sensitivity in the large $\tan\beta$ region.

4. Run 2 Doubly Charged Higgs Search

Although much of the Run 2 Higgs physics program at the Tevatron relies on the collection of large amounts of integrated luminosity, the results of one Run 2 search have already improved previous Higgs limits from LEP. Doubly charged Higgs bosons, $H^{\pm\pm}$ arise in several left-right symmetric models. In particular, SUSY LR models predict a low mass doubly charged Higgs, $M_{H^{\pm\pm}}$ between 100 GeV/c^2 and 1 TeV/c^2 . Doubly charged Higgs bosons can be produced in pairs at the Tevatron in Z/γ^* decays. The decay $H^{\pm\pm} \to \ell^\pm\ell^\pm$ is considered; the same sign dilepton final state is particularly attractive experimentally because of high lepton identification efficiency and very low backgrounds. The search was performed in both the dielectron and dimuon channels [6]. Backgrounds to the same-sign dielectron state include

Z production, QCD jet production, W+jets and WZ production. Z events that contribute to the background in the ee channel come from conversions, therefore this background is not as critical in the dimuon analysis. From Figure 5 one can see that the dimuon search is able to exclude the doubly-charged Higgs at masses below $\sim$110 GeV/c^2; the previous lower limit from LEP was 100 GeV/c^2.

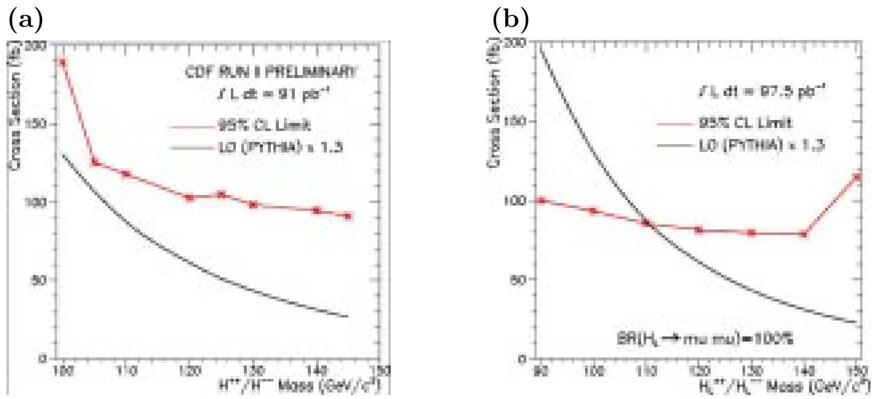

Figure 5. Doubly charged Higgs production cross section upper limits in the dielectron and dimuon analyses as a function of $M_{H^{\pm\pm}}$

5. Summary

CDF performed several Run 1 Higgs searches, each with limited reach. The search for the Higgs will be an important part of Run 2 at the Tevatron; Higgs searches will benefit in Run 2 by increased luminosity and optimized search techniques. Run 2 will be an exciting time to extend our understanding of Higgs physics before the LHC era.

References

1. "Search for the Standard Model Higgs Boson at LEP", LEP Higgs Working Group CERN-EP/2003–011
2. F. Abe *et al.*, Nucl. Inst. Meth. Phys. Res. Sect. A **271**, 387 (1988)
3. M. Kruse, for the CDF Collaboration. hep-ex/0310057.
4. C. C. Neu, "A Search for the Higgs boson in proton - antiproton collisions at 1.8 TeV," FERMILAB-THESIS-2003-32
5. T. Affolder, *et al.*, PRL 86,4472(2001).
6. CDF Collaboration, CDF Notes 6342, 6457.