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HIGGS SEARCHES AT THE TEVATRON RUN 1 RESULTS AND RUN 2 PROSPECTS

M. ROCO
Fermi National Accelerator Laboratory, Batavia, IL. USA
E-mail: roco@fnal.gov

This report summarizes the results of recent Higgs searches in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Tevatron using $\approx$100 pb^{-1} of integrated luminosity from Run 1. We also present estimates of the Higgs discovery and exclusion reach in Run 2 based on a study by the Fermilab Higgs working group [1].

1 Run 1 Results

1.1 SM Higgs Searches

The CDF and DØ experiments have searched for the Standard Model (SM) Higgs boson produced in association with a vector boson. The searches are restricted to a Higgs mass below 140 GeV/c^2 where $H \to b\bar{b}$ dominates. Results for $p\bar{p} \to WH \to \ell\nu b\bar{b}$ ($\ell = e, \mu$) and $p\bar{p} \to VH \to q\bar{q}b\bar{b}$ ($V = W, Z$) were published earlier by CDF [2]. Recently the channels $ZH \to \nu\bar{\nu}b\bar{b}$ and $ZH \to \ell^+\ell^-b\bar{b}$ ($\ell = e\mu$) have also been investigated.

The search for $\nu\bar{\nu}b\bar{b}$ events requires a large missing transverse energy $\not\!\!E_T \geq 40$ GeV, a lepton veto and 2 or 3 jets, at least one jet has to be b-tagged. The main backgrounds are QCD events with $\not\!\!E_T$ from jet energy mismeasurements, $W/Z+$ jets, $t\bar{t}$ and single top events and diboson production. A total of 40 (4) events is observed with 39 ± 4 (3.9 ± 0.6) expected from the single (double) tagged sample.

For the $\ell^+\ell^-b\bar{b}$ search, two leptons are required with a dilepton invariant mass consistent with the Z mass, and 2 or 3 jets with at least one jet b-tagged. There are 5 events observed in the data consistent with 3.2 ± 0.7 events expected from background consisting of $Z+$ heavy flavors, diboson production, and $t\bar{t}$ and single top events.

The 95% confidence level (CL) limit on the $p\bar{p} \to VH$ production cross section times the branching ratio BR($H \to b\bar{b}$) for the individual channels discussed above as well as the combined limit are shown in Figure 1 as a function of the SM Higgs mass. These limits are more than an order of magnitude above the expected SM Higgs associated production cross section in $p\bar{p}$ collisions therefore no mass limits can be set.

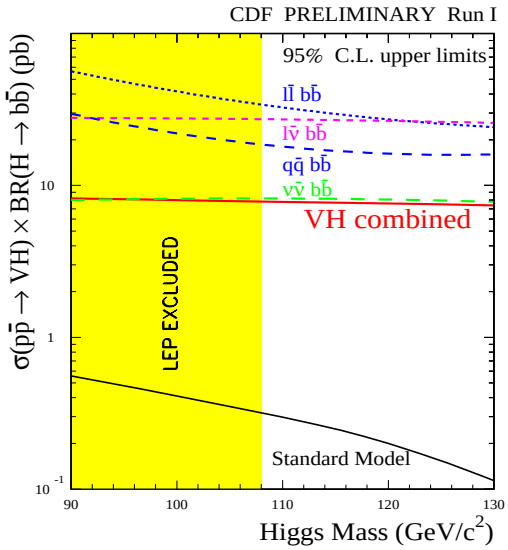

Figure 1. Run 1 individual and combined 95% CL limits on $\sigma(p\bar{p} \to VH) \times \mathrm{BR}(H \to b\bar{b})$ as a function of the SM Higgs mass.

1.2 SUSY Higgs Searches

The Higgs sector in supersymmetric (SUSY) extensions to the Standard Model includes at least five physical Higgs bosons: two CP-even scalars (h and H, with $m_h < m_H$), one CP-odd scalar A and a charged Higgs pair ($H^\pm$).

At tree-level all Higgs masses can be computed in terms of two parameters typically chosen to be m_A (or m_h) and $\tan\beta = v_u/v_d$, where v_u and v_d describe the Higgs coupling to *up*-type and *down*-type fermions, respectively. CDF has performed a search for the process $p\overline{p} \to b\overline{b}\phi \to b\overline{b}b\overline{b}$ ($\phi = h, H, A$) in Run 1. This channel becomes important at large $\tan\beta$ values due to the strongly enhanced Yukawa couplings between the Higgs scalars and the b quarks leading to production rates roughly a factor of $\tan^2\beta$ larger than the SM expectations.

The $b\overline{b}b\overline{b}$ final state is characterized by two clear signatures, the four-jet topology and a high b-quark content. The selection requires four or more high p_T jets, at least three should be tagged as b jets. Figures 2 and 3 show the 95% CL excluded regions in the $\tan\beta$ vs M_h and M_A plane, respectively. Results are shown for a SUSY mass scale of 1 TeV using two stop mixing scenarios, no mixing and maximal mixing. By convention, maximal mixing refers to a choice of SUSY parameters which gives the largest predicted value for the Higgs mass.

Recently DØ and CDF have published results on searches for charged Higgs bosons in decays of top quark pairs [3]. A charged Higgs boson lighter than the top mass could allow a large BR($t \to H^+b$) which competes with the SM prediction requiring the top quark to decay almost exclusively via $t \to W^+b$.

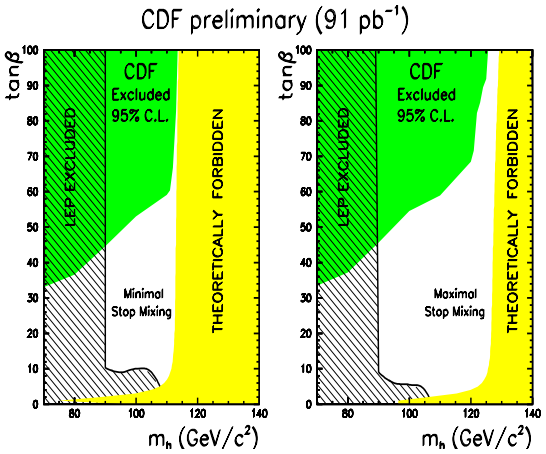

Figure 2. 95% CL exclusion regions in the $\tan\beta$ vs M_h plane. Also shown are the present LEP exclusion and theoretically forbidden regions.

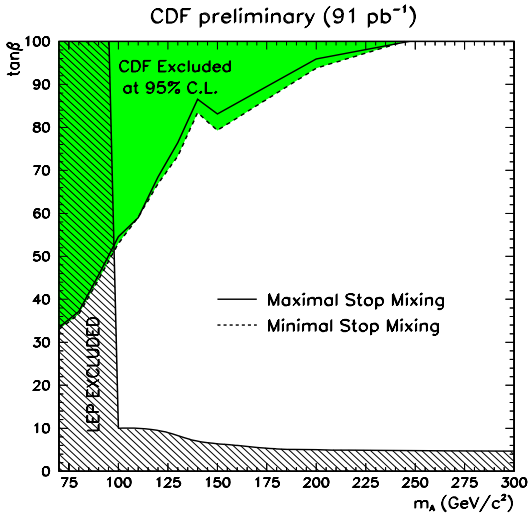

Figure 3. 95% CL exclusion regions in the $\tan\beta$ vs M_A plane. Also shown is the present LEP exclusion region.

2 Run 2 Prospects

With a center of mass energy $\sqrt{s} = 2$ TeV and instantaneous luminosities $\mathcal{L} = 2 \times 10^{32}\ cm^{-2}s^{-1}$ the next collider run, scheduled to begin in March 2001, promises an exciting physics program. To estimate the Higgs discovery and exclusion reach of the Tevatron in Run 2 an extensive study was performed by the Fermilab Higgs working group. This study extends previous Tevatron results by including additional SM Higgs decay modes in the previously explored Higgs mass region, considering the production of high mass Higgs bosons, systematically combining results from all possible search channels and considering additional decay modes arising from SUSY Higgs production. In addition, a detector simulation program based on parameterized calorimeter resolu-

tions and particle identification efficiencies was developed to provide a realistic estimate of the geometric and kinematic acceptances of the upgraded detectors. Results are presented as the integrated luminosities required to exclude a Higgs boson at 95% CL, or to establish either 3σ or 5σ excesses over the predicted SM backgrounds.

2.1 SM Higgs Searches

Searches for Higgs masses below 135 GeV focused on associated Higgs production with final states determined by the decay mode of the accompanying W or Z: (1) $p\bar{p} \to WH \to \ell\nu b\bar{b}$, (2) $p\bar{p} \to ZH \to \ell^+\ell^- b\bar{b}$, (3) $p\bar{p} \to ZH \to \nu\bar{\nu}b\bar{b}$, or (4) $p\bar{p} \to WH/ZH \to q\bar{q}b\bar{b}$. Similar criteria as in the previous Run 1 analyses were used. A multivariate analysis using neural network techniques was performed for the leptonic modes resulting in significantly improved sensitivities [4].

For masses above 135 GeV the decay mode $H \to WW^*$ dominates. Searches were performed in the following production modes where V represents either a W or Z boson: (1) $p\bar{p} \to VH \to \ell^\pm\ell^\pm jj$ (2) $p\bar{p} \to H \to \ell^+\ell^-\nu\bar{\nu}$ (3) $p\bar{p} \to VH \to \ell^\pm\ell^\pm\ell^\mp$ leading to final states with like-sign lepton pairs with jets, opposite-sign leptons with a large $\not\!\!E_T$ and trileptons, respectively. The main SM backgrounds are from vector boson pair production WW, WZ, ZZ as well as $W/Z + j$, $t\bar{t}$ production and multijet events with jets misidentified as electrons. After some initial selection cuts on the p_T of the leptons and $\not\!\!E_T$, additional requirements on angular correlations and the cluster mass $M_C \equiv \sqrt{p_T^2(\ell\ell) + m^2(\ell\ell)} + |\not\!\!E_T|$ were applied. Sensitivity is maximized by fine tuning these cuts and using likelihood methods as described in detail in [5].

The extraction of the Higgs signal from the large background depends critically on the resolution we can attain for the Higgs mass, reconstructed from the measured b jet energies. The final results shown in Figure 4 include a 30% improvement in the mass resolution. This level of improvement is possible by combining calorimeter-based energies with information from charged particle momenta measurements and shower maximum detectors.

Figure 4 gives the results for the low mass and high mass Higgs analyses, combining all the SM search channels and the data from both CDF and DØ experiments. The contours show the required luminosities for 95% exclusion, 3σ evidence and 5σ discovery as a function of the SM Higgs mass.

The statistical method to combine the channels uses a Bayesian approach based on calculating the joint likelihood for a given experimental outcome as a function of the Higgs cross section. Systematic errors on the background estimate for each channel is taken into account by including into the likelihood a relative uncertainty on the background which is the smaller of the 10% of the expected background or $1/\sqrt{\mathcal{L}B}$, where B is the expected background in 1 fb^{-1} and $\mathcal{L}$ is the integrated luminosity. The luminosity thresholds are between 30-50% smaller if these systematic errors are not included.

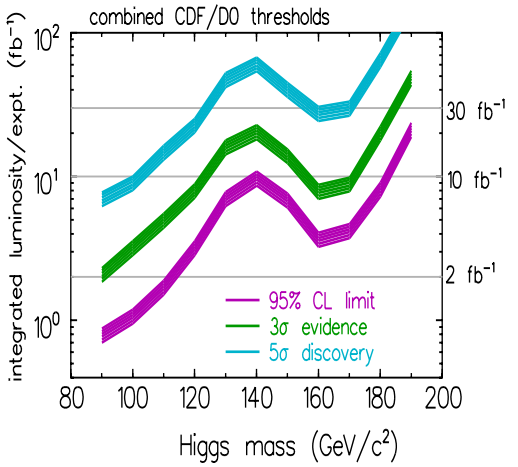

Figure 4. Integrated luminosity required to achieve 95% CL exclusion, 3σ evidence and 5σ discovery as a function of SM Higgs mass.

2.2 SUSY Higgs Searches

A study to evaluate the sensitivity reach for the neutral SUSY Higgs bosons via $p\bar{p} \rightarrow b\bar{b}\phi \rightarrow b\bar{b}b\bar{b}$ in Run 2 has been performed. Fig. 5 shows the 95% CL exclusion contours for one experiment in the $\tan\beta$ vs. m_A plane for several values of the integrated luminosities in the maximal mixing scenario. These results indicate that assuming $\tan\beta = 40$, the sensitivity reach is about 160 GeV/c^2 at 95% CL with an integrated luminosity of 2 fb^{-1}, extending up to 225 GeV/c^2 with 10 fb^{-1}.

The results of a study extending previous Run 1 searches [3] for charged Higgs bosons produced in top quark decays are shown in Figure 6 for a luminosity of 2 fb^{-1}.

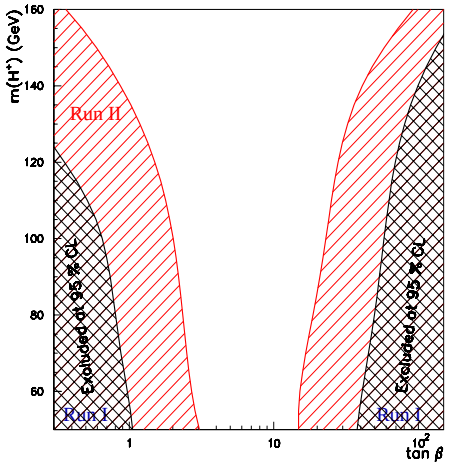

Figure 6. 95% CL exclusion regions in the M_H^+ vs $\tan\beta$ plane. for $m_t = 175$ GeV/c^2 and an integrated luminosity of 2 fb^{-1}.

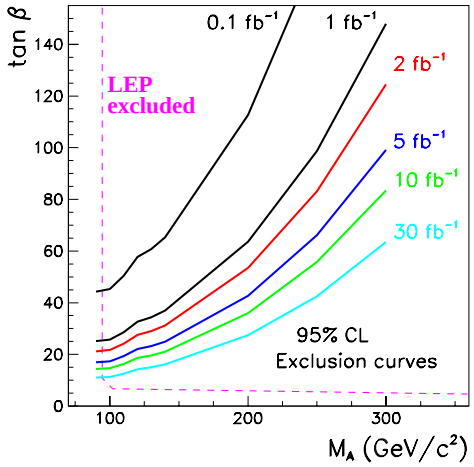

Figure 5. 95% CL exclusion curves for $p\bar{p} \rightarrow b\bar{b}\phi \rightarrow b\bar{b}b\bar{b}$ with $\phi = h, H, A$. The curves show the sensitivity reach for the MSSM neutral Higgs bosons in the $\tan\beta$ and m_A parameter space. The LEP excluded region is also shown for comparison. The results are shown for the maximal mixing scenario.

3 Summary

Recent results from searches for the SM and SUSY Higgs bosons in Run 1 at the Tevatron have been shown. The sensitivity of the present SM Higgs searches at the Tevatron is limited by statistics leading to a reach in $p\bar{p} \rightarrow VH$ production more than an order of magnitude higher than the SM prediction. The search for the neutral SUSY Higgs via $p\bar{p} \rightarrow b\bar{b}\phi \rightarrow b\bar{b}b\bar{b}$ excludes regions in the $\tan\beta$ vs M_A space which extend significantly those previously probed by LEP.

We have presented results from studies of the discovery and sensitivity reach for the Higgs bosons in Run 2. Combining all search channels and the data from both experiments a SM Higgs can be excluded at 95% CL over the full mass range $M_H < 190$ GeV with 15 fb^{-1}. The sensitivity to neutral SUSY Higgs production with $b\bar{b}$ has been shown. The $p\bar{p} \rightarrow b\bar{b}\phi \rightarrow b\bar{b}b\bar{b}$ channel serves as the most important mode for discovering or ruling out the MSSM Higgs at large $\tan\beta$.

References

1. http://fnth37.fnal.gov/higgs.html
   To be published in the Fermilab Higgs Working Group Final Report.
2. F. Abe et al., *Phys. Rev. Lett.* **79**, 3819.
   F. Abe et al., *Phys. Rev. Lett.* **81**, 5748.
3. B. Abbot et al., *Phys.Rev.Lett.* **82**, 4975.
   F. Abe et al., *Phys. Rev.* D **62**, 012004.
4. P. Bhat et al., *Fermilab-Pub-00-006.*
5. T. Han et al., *Phys. Rev.* D **59**, 093001.