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Prospects for Higgs Discovery at the Tevatron

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Abstract

This report presents the results of a Fermilab study of the sensitivity for Higgs boson production at the upgraded Tevatron in Run II. The study extends previous Tevatron results by combining all possible search channels, considering the production of higher mass Higgs bosons and interpreting the results in the context of supersymmetric Higgs production as well as Standard Model production.

1. Introduction

The success of the Standard Model (SM) as the theory of elementary particles and their interactions is remarkable. For the past 25 years, its predictions have been verified by experimental data with amazing precision. One of its most important predictions, which has not yet been confirmed despite intensive searches, is the existence of a neutral scalar Higgs boson‡. The Higgs formalism was introduced in the SM to account for the electroweak symmetry breaking. Although the Higgs mass is not predicted by the theory, precise measurements of electroweak observables at LEP and the Tevatron have greatly improved indirect constraints on the Higgs mass. In the next few years the Tevatron Run II promises an exciting physics program, with a good discovery potential for the Higgs in the intermediate mass range up to 120 GeV.

This report§ present the results of a study performed by the Fermilab Higgs working group [1] to estimate the Higgs discovery and exclusion reach at the Tevatron in Run II. The 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, interpreting the results in the context of minimal Supersymmetry (SUSY) and considering additional decay modes arising from SUSY Higgs production. In addition, a detector simulation program based on parameterized calorimeter resolutions and particle identification efficiencies was developed to provide a realistic estimate of the geometric and kinematic acceptances of the upgraded detectors. The results are presented as the integrated luminosities required to exclude a Higgs boson at 95% confidence level, or to establish either 3σ or 5σ excesses over the predicted SM backgrounds.

Figure 1 shows the cross sections [2] for various SM Higgs production modes at the Tevatron with

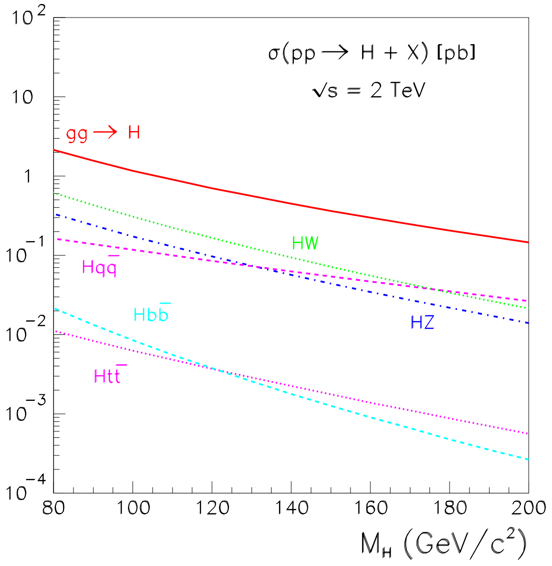

Figure 1. SM Higgs production cross sections as a function of the Higgs mass.

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‡ A more complicated spectra of Higgs bosons are predicted by extensions of the Standard Model based on Supersymmetry.

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$\sqrt{s} = 2$ TeV center-of-mass energy. The leading production mechanism for SM Higgs production is the gluon fusion process $p\bar{p} \to gg \to H$. However, for the lower Higgs mass range, this mode offers little sensitivity due to the overwhelming background arising from QCD dijet production. Associated Higgs production modes with $p\bar{p} \to WH$ and $p\bar{p} \to ZH$, with the W or Z decaying to leptons, play a significant role in the SM Higgs searches.

2. Standard Model Higgs Searches

The Higgs boson decays mainly via $H \to b\bar{b}$ for Higgs masses $M_H < 135$ GeV. For $M_H > 135$ GeV, the dominant decay mode is $H \to WW^*$ where one of the W's may be off its mass shell. Searches for the SM Higgs divide into two mass regions defined by the Higgs decay mode.

2.1. Low Mass Higgs Searches

Searches for Higgs masses below 135 GeV have concentrated on associated Higgs production. The final states are 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) $p\bar{p} \to WH/ZH \to q\bar{q} b\bar{b}$. Primary backgrounds include $W+b\bar{b}$ and $Z+b\bar{b}$ with the $b\bar{b}$ pair from gluon radiation, single top and top quark pair production.

For the $WH \to \ell\nu b\bar{b}$ channel, the selection criteria demands an e or μ with $E_T > 20$ GeV, missing transverse energy $\not{E}_T > 20$ GeV and two b-tagged central jets. Similar criteria are used for the other channels. A multivariate analysis using neural network techniques has been performed for the leptonic modes resuting in significantly improved sensivities for the $\ell\nu b\bar{b}$ channel.

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 2 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.

2.2. Higher Mass Higgs Searches

For Higgs 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 missing transverse energy 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 missing transverse energy, additional requirements on angular correlations and the cluster mass $M_C \equiv \sqrt{p_T^2(\ell\ell) + m^2(\ell\ell)} + |\not{E}_T|$ are applied. Sensitivity is maximized by fine tuning these cuts and using likelihood methods as described in detail in [3].

2.3. Combined SM Higgs Results

Figure 2 gives the results for the low mass and high mass Higgs analyses, combining all the SM search channels from both 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 $1/\sqrt{LB}$, where B is the expected background in 1 fb^{-1} and L is the

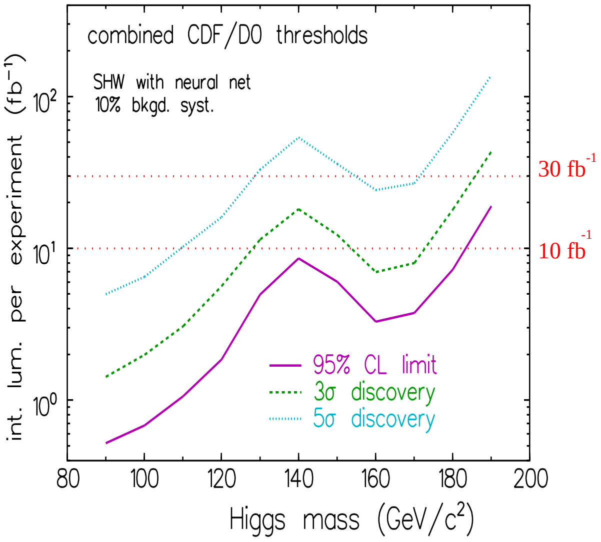

Figure 2. Integrated luminosity required to achieve 95% confidence level exclusion, 3σ evidence and 5σ discovery as a function of Higgs mass.

integrated luminosity. The integrated luminosity thresholds are between 30-50% smaller if these systematic errors are not included.

3. Searches for Neutral SUSY Higgs Bosons

The Higgs sector in supersymmetric 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 fermions and *down*-type fermions, respectively. Prospects of detecting one or more of the neutral SUSY Higgs bosons via $p\overline{p} \to b\overline{b}\phi \to b\overline{b}b\overline{b}$ ($\phi = h, H, A$) at the Tevatron [4] have been evaluated. The $p\overline{p} \to b\overline{b}\phi \to b\overline{b}b\overline{b}$ channel becomes important at sufficiently large $\tan\beta$ values due to the strongly enhanced $b\overline{b}\phi$ couplings leading to production rates roughly a factor of $\tan^2\beta$ larger than the Standard Model expectations. Results on neutral and charged SUSY Higgs searches using the Tevatron Run I data are reported in [5].

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. These properties are the main handles for suppressing the enormous QCD multi-jet backgrounds. The selection requires at least four high p_T jets, three of which have been tagged as b jets. All possible mass combinations of the tagged b jets are computed, and the resulting distribution is examined for a peak near the generated Higgs mass.

Fig. 3 shows the 95% confidence level exclusion contours in the $\tan\beta$ vs. m_A plane for several integrated luminosities. These results were obtained assuming maximal mixing, where SUSY parameters are chosen to give the largest predicted value for the Higgs masses.

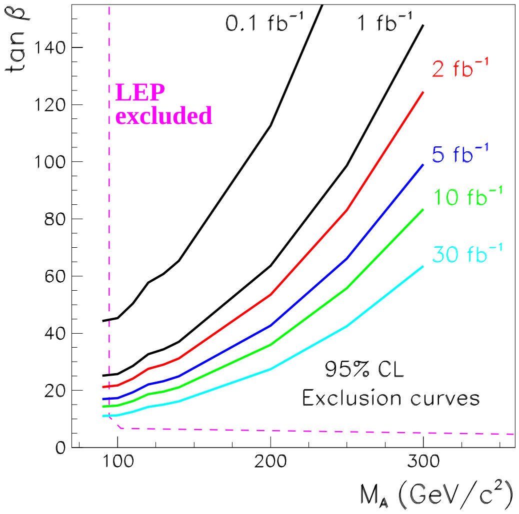

Figure 3. 95% confidence level exclusion curves for $p\overline{p} \to b\overline{b}\phi \to b\overline{b}b\overline{b}$ with $\phi = h, H, A$. The curves show the sensitivity reach for the MSSM neutral Higgs bosons in the $\tan\beta$ and m_A parameter space. The LEP excluded region ($m_A < 90$ GeV/c^2) is also shown for comparison. The results are shown for the case of maximal mixing where SUSY parameters are chosen to give the largest predicted value for the Higgs mass.

4. Conclusions

One of the primary goals of Run II of the Tevatron is the search for the Higgs. Studies to determine the experimental sensitivity to SM and SUSY Higgs production in Run II have been performed by the Higgs Working Group at Fermilab. Results on the exclusion and discovery limits have been presented in this report. Combining all search channels and the data from both experiments a SM Higgs can be excluded at 95% confidence level over the full mass range $M_H < 190$ GeV with 15 fb^{-1}. Discovery at the 5σ level beyond a Higgs mass of 120 GeV or evidence at the 3σ level beyond 140 GeV requires substantially more luminosity. The sensitivity to neutral SUSY Higgs production with $b\overline{b}$ has also been shown. This search represents the most important mode for discovering or ruling out the MSSM Higgs at large $\tan\beta$.

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