HIGGS BOSON SEARCHES AT CDF

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A summary of the latest results on the searches for the Standard Model and MSSM Higgs bosons at CDF is presented. These analyses were performed with a data sample corresponding to an integrated luminosity of up to 2.4 fb^{-1} of proton-antiproton collisions provided by the Tevatron Run II. Multivariate techniques and increased event acceptance have translated into significant improvements in the sensitivity of these searches in the different detections modes.

1. Introduction

Higgs bosons searches have become central in the physics program of the CDF collaboration.The experiments at LEP reported a 95% confidence level (CL) lower limit on the mass of the SM Higgs boson of 114.4 GeV/c^2 as a result of a full set of direct searches. Moreover, gobal fits to precision electroweak measurements indicate that the mass of the Higgs boson should be below 144 GeV/c^2 at a 95% CL. Actually, the result of these fits point to a prefered value of 76^{+33}_{-24} GeV. These precision electroweak data include the CDF measurements of the mass of the W boson and the top quark.

In the Minimal Supersymetric extension of the SM (MSSM) scenario, two complex doublets are used to break the electroweak symmetry, originating five physical states, instead of the single Higgs boson of the SM. The MSSM Higgs bosons include two neutral scalars (h and H), one pseudoscalar (A) and two charged scalars ($H^{\pm}$). The Higgs sector is characterized at tree level with two parameters, usually chosen to be the mass of the pseudoscalar, m_A, and $\tan\beta$, the ratio of the vacuum expectation values of the doublets. For large values of $\tan\beta$, the pseudoscalar A is almost

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degenerate in mass with H (h) above (below) the threshold of the Z mass pole.

2. Standard Model Higgs Boson Searches

Gluon fusion, gg→H, is the predicted dominant production mechanism of the Higgs boson at the Tevatron, with a total cross section ($\sigma_{\rm SM}$) ranging from 1 $\rm pb^{-1}$ to 0.1 $\rm pb^{-1}$. In the low mass range, $m_H < 140$ GeV, the main decay channel is $H \to b\bar{b}$. However, the environment in a hadron collider like the Tevatron prevents probing direct production due to the large QCD background. Therefore, alternative production mechanims (associated production with a vector boson) have to be investigated. When the vector bosons decay leptonicaly, these decay products can be used for triggering and reducing the backgrounds. For a high mass Higgs, $m_H > 140$ GeV, the H→WW decay channel dominates. Requiring leptonic decays of the W bosons rejects backgrounds to a low enough level that allows the study direct production.

2.1. $ZH \to \nu\bar{\nu}b\bar{b}$

The search for the Higgs boson in this channel was performed with a dataset corresponding to an integrated luminosity of 1.7 $\rm fb^{-1}$, triggered on missing transverse energy ($\not\!\!E_{\rm T}$). The event signature contains a b-quark pair (from an eventual Higgs boson) and $\not\!\!E_{\rm T}$, produced by the neutrinos coming from the Z boson.This detection mode also benefits from the Higgs production mode in association with a W boson, when it decays leptonically and the lepton goes undetected.

Two separate artificial neural networks (NN) have been developed for this analysis. The first one focuses on separating signal from QCD multi-jet events. This discrimination relies in the measurement of the $P_{\rm T}$ of all the charged particles by the tracker. The second NN is used as a discriminant for signal extraction.

A binned maximum likelihood technique is used to calculated 95% CL upper limits on the cross section using the output of the second NN. The final event yield is divided in two samples according to the features of b-jet identification, but fitted simultaneously. The expected limit for a Higgs of a 115 GeV/c^2 is 8.3 times the $\sigma_{\rm SM}$ while the observed limit set by this search is 8.0 times the $\sigma_{\rm SM}$.

2.2. $ZH \to l^+l^-b\bar{b}$

This search focuses on the same production mechanism as in Section 2.1, but with the Z boson decaying to pairs of electrons of muons. The branching ratio of the Z boson to charged leptons is smaller than to neutrinos, but provides a cleaner experimental signature.

Both electron and muon pair final states are investigated, with a data sample corresponding to a total integrated luminosity of 1 fb^{-1}. The backgrounds to this process are small, mainly Z+jets events, due to the requirement of two leptons consistent with the mass of the Z boson. In order to increase acceptance, the identification requirements for leptons have been relaxed when possible for one of the candidates.

Two NN were implemented, one for improving the energy resolution of the two candidate Higgs jets and a second one for signal to background discrimination. Energy resolution of the jets is improved by taking into consideration the $\not{E}_{\mathrm{T}}$ of the event and relative azimuthal angles to the jets. A two-dimensional NN is trained to distinguish signal events from the main backgrounds, Z+jets in one dimension and $t\bar{t}$ in the other.

The selected events are divided in two samples depending on their b-jet identification features. Limits are extracted with a likelihood based procedure in a Bayesian approach for both samples. The final 95% CL upper exclusion limits on the cross section are plotted as a function of the Higgs mass and normalized to the σ_{SM}. Both the expected and the observed 95% CL limits for a Higgs mass of 115 GeV/c^2 are 16 times the predicted σ_{SM}.

2.3. $WH \to l\nu b\bar{b}$

The SM Higgs boson is also produced in association with a $\mathrm{W}^{\pm}$ boson that, when decaying leptonically, provides an electron or a muon that can be used for triggering and rejecting backgrounds. CDF searches in this mode used a dataset corresponding to a total integrated luminosity of 1.9 fb^{-1}. Leptons from the central and forward regions of the detector were used and at least two jets are needed with at least one of them identified as a b-jet. Some additional event level cuts are applied for removing QCD-like contamination. This cuts include angular correlations between $\not{E}_{\mathrm{T}}$ and the jets, high transverse mass and large $\not{E}_{\mathrm{T}}$ significance.

An artificial NN has been trained to discriminate signal events from background sources. The output of the NN is used for limit calculation with a binned maximum likelihood technique. Events are divided into different sample according to the number of identified b-jets and the algorithm used. The expected 95% CL upper exclusion limit for this analysis is about 7 times the σ_{SM} while the observation stays at 8 times.

2.4. $H \to W^+W^- \to l^+l^-\nu\bar{\nu}$

This is the most sensitive channel for possible Higgs bosons with a mass above 140 GeV/c^2. A data sample corresponding to an integrated luminosity of 2.4 fb^{-1} was used for this search. The event acceptance has been increased by using all possible final state lepton combinations (e^+e^-, $\mu^+\mu^-$ and $e^\pm\mu^\mp$), and as much lepton categories (detection modes) as available: two for electrons, four for muons and also tracks that are not fiducial to the calorimeter. All leptons are required to be isolated in the calorimeter and fulfill quality conditions.

The main backgrounds to this final state are Drell-Yan events, diboson production (WZ, WW), W boson production associated with a photon or jets and top quark pair production. This background sources are modeled with Monte Carlo simulation samples except W+jets that is estimated with an isolation-based technique in data.

Signal extraction combines a matrix elements approach with an NN. A binned likelihood is build on the NN output templates. The expected 95% CL upper exclusion limit for this analysis is about 2.5 times the σ_{SM} while the observed limit is 1.6 times the σ_{SM}.

3. MSSM Higgs Bosons Searches

In the context of the MSSM, searches for the Higgs sector attempt to detect the decay products of the massive bosons: the pseudoscalar A and the scalar H. The main production mechanisms are $b\bar{b} \to$H/A+($b\bar{b}$) and gg→H/A, and the cross section of these processes is enhanced by a factor $\tan^2\beta$ with respect to the Standard Model.

The dominant decay modes are b-quark pairs and tau lepton pairs. The branching ratios are almost constant for the relevant values of $\tan\beta$ and m_A, being about 90% for the b-quark channel and 10% for the tau channel.

3.1. $A \to \tau^+\tau^-$

Only three of the possible final states are studied in this analysis: τ_e+τ_h, τ_μ+τ_h and τ_e+τ_μ. These three channels are selected because they offer the best signal to background rejection. Overall, they account for 50% of the

$\tau\tau$ events. Even if the event yield in this decay channels could be smaller than the corresponding in the b-quark pair channel, the leptons in the final state provide a very good handle for efficient triggering and background rejection. For this reason, both production mechanisms can be probed.

The sum of the four-vectors of both tau decay products and $\not\!\!E_{\rm T}$ defines the visible momentum. The mass of this four-vector is used a discriminant variable, the visible mass m_{vis}. Templates for each background contribution and each final state are produced and fitted using a maximum-likelihood profiling techinque. The systematic uncertainties are introduced as gaussians constrains in the fit and 95% CL upper limits on the cross sections times branching ratio are extracted. These results are then translated into the MSSM parameter space, $\tan\beta$ vs m_A plane.

3.2. $A \rightarrow b\bar{b}b(b)$

Due to the large QCD-like background present in the Tevatron, the $b\bar{b}$ decay channel can not be explored in direct production, gg→H/A. Only the $b\bar{b}$ →H/A production mechanism can be probed because the extra quarks in the event might be used to impose a tighter event selection. This search uses 1.9 fb^{-1} of data collected on a trigger that requires at least three energetic clusters in the calorimeter, each of them matching to a track.

The signal discriminant is built with two variables: the invariant mass of the leading jets in the event and x_{tag}, a variable related to the masses of each of the three jets. A binned maximum-likelihood fit in these two dimensions is used for limit calculation, following the CL$_s$ prescription. Then, the limits are translated into the MSSM parameter space.

4. Conclusions

Searches for the Higgs bosons in all the different channels have shown increased sensitivity to possible Higgs signals but no observation has been reported yet. The combination of all the CDF Standard Model Higgs searches results an exclusion limit that is approaching the predicted cross sections.The effort in the MSSM Higgs sector has also been able to exclude a vast region of the parameter space.

References

1. Higgs Discovery Group at CDF *http://www-cdf.fnal.gov/physics/new/hdg/hdg.html.*