PROCEEDINGS OF SCIENCE

Standard Model high mass Higgs search at CDF

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The CDF collaboration has analyzed almost 6 fb^{-1} of data collected at the Tevatron Collider at $\sqrt{s} = 1.96$ TeV to search for Standard Model Higgs boson through the decay into $\mathrm{W}^{+}\mathrm{W}^{-*}$. Starting from events with two leptons, advanced analysis techniques are applied to better discriminate signal from background. The Higgs sensitivity is maximized combining together analysis that exploit different event topologies. No significant excess over the expected background is observed and data is used to set a limit in units of Standard Model expectations. The limit plays a fundamental role in the Higgs search excluding the existence of this particle with mass between 158 and 175 GeV/c^2 when combined with D0, the other Tevatron experiment.

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1. Introduction

The search for the as-yet-unobserved Higgs boson is one of the most fashionable topic of the high energy particle physics. The Higgs field has been introduced in the Standard Model (SM) to explain the electroweak symmetry breaking and manifests itself through the Higgs particle. A SM Higgs boson with mass ($\mathrm{M_H}$) below 114.4 $\mathrm{GeV/c^2}$ or with $\mathrm{M_H}$ between 158 and 175 has been excluded at 95% confidence level in direct searches at LEP [1] and the Tevatron [2]. At the Tevatron, production of the Higgs boson is dominated by the direct production process $gg \to H$ and for $\mathrm{M_H} > 135\mathrm{GeV/c^2}$ the Higgs boson decays primarily to a pair of W bosons, $H \to \mathrm{W^+W^{-*}}$ [3]. Data, that brings to the results presented in this paper, has been collected by the CDF experiment in the last ten years and corresponds to about $6\mathrm{fb}^{-1}$.

2. The expected signal and background contributions

The experimental signature for the decay $H \to \mathrm{W^+W^{-*}} \to \ell\nu\ell\nu$ decay is two reconstructed leptons with opposite charge and a significant amount of transverse missing energy ($\not\!\!E_T$) from neutrino which escape the detector undetected. Here ℓ refers to electron or muon for the first lepton, the one that triggers the event and to electron, muon or tau for the second lepton depending on the analysis. There are several SM processes which result in a similar final state to $\mathrm{W^+W^{-*}}$ and constitute the background of this measurement. These are Drell-Yan ($Z/\gamma^* \to \ell^-\ell^+$) events that have no neutrino in the final state, but due to large production rates enter the signal sample via mismeasurements, the direct diboson production, WW, WZ, ZZ and $\mathrm{t\bar{t}}$ and single top production. The W+jets and Wγ events can be misinterpreted as signal events when a jet is reconstructed as a lepton or the γ converts in the detector material and it is reconstructed as a lepton. With the exception of the W+jets background, the acceptance and kinematic properties of the signal and background processes are determined by simulation. $\mathrm{W^+W^-}$ events are simulated at NLO using the `mc@nlo` generator [4]. The WZ, ZZ, $\mathrm{t\bar{t}}$ and Drell-Yan backgrounds are simulated with the `pythia` generator [5]. The Wγ background is determined using the generator described in Ref. [6]. The contributions to the Higgs signal production come from four sources. The dominant gluon fusion cross section has been calculated to NNLL [7] starting from NNLO calculations [8] Associated Higgs (WH and ZH) [9] and vector boson fusion (VBF) Higgs production [10] are also considered. The Higgs boson decay branching ratio predictions are calculated in `hdecay` [3].

3. The $H \to \mathrm{W^+W^{-*}}$ signal extraction

The signal to background separation is performed in two steps. Preliminary cuts are applied to reduce the background as low as possible while keeping integer the searched signal. A Neural Network technique is then used to discriminate signal against background with similar kinematic properties. The leading-lepton $\mathrm{p_T}$ is required to be above 20 GeV/c to satisfy the trigger requirements, while the second lepton is allowed to have a $\mathrm{p_T}$ as low as 10 GeV/c. A variant of $\not\!\!E_T$ used in selecting candidate events is defined as $\not\!\!E_{Tspec} = \not\!\!E_T \sin\Delta\phi$ when $\Delta\phi < \pi/2$, where $\Delta\phi$ is the azimuthal separation between the $\not\!\!E_T$ and the momentum vector of the nearest lepton candidate. If $\Delta\phi > \pi/2$, then $\not\!\!E_{Tspec} = \not\!\!E_T$. The $\not\!\!E_{Tspec}$ is designed to reject events where the apparent $\not\!\!E_T$ arises from the mismeasurement of lepton energy or momentum, and is required to be above 25 GeV to reduce the otherwise large Drell-Yan contamination. This requirement is lowered to 15 GeV for electron-muon events where contributions from Drell-Yan are inherently smaller. The W+jets and heavy flavor backgrounds are reduced by requiring that the invariant mass of the lepton pair, $M_{\ell\ell}$, be greater than 16 $\mathrm{GeV/c^2}$. Events which fail only the $M_{\ell\ell}$ requirement and have opposite charge are recovered with an *ad hoc* analysis optimization. With these cuts the signal-to-noise ratio is around 0.8, too low to perform a *counting experiment* measurement.

For this reason the analysis are then separated into channels by signal and background contributions: WW+0 jets, WW+1 jet, WW with 2 or more jets, WW$\rightarrow \ell\nu\tau\nu$, final states with same sign leptons and tri-leptons. For each channel a NeuroBayes® neural network (NN) is trained on a weighted combination of known signal and background events independently for each of the 19 Higgs mass points. The inputs of the neural network are set of physics variables that change going from one search channel to an other to optimize the signal sensitivity. The WW$\rightarrow \ell\nu\tau\nu$ channel is analyzed with the Boosted Decision Tree (BDT) as discriminant using tau identification observables and global event variables. When the NN or the BDT are trained, templates are created for signal and background that are used as final discriminant in calculating the 95% Confidence Level (CL) limits. The signal and background expectations are affected by systematic uncertainties. DY, WW, WZ and ZZ, $\mathrm{t\bar{t}}$ and single top Monte Carlo production cross section including contributions from higher-order effects have assigned errors ranging from 5% to 67%. Other uncertainties originating from lepton selection, trigger efficiency measurements, jet energy scale determination are within 30%. Background modeling, like Drell-Yan and W+jets have an additional systematic errors evaluated directly from data.

4. Results

A pure Bayesian method is adopted to estimate the upper limit at 95% C.L. on the Higgs production cross section as ratio to the SM prediction for the nineteen Higgs mass hypothesis considered. The method combines counting experiments performed in each bin of the NN output: a likelihood is built taking into account the expected signal and background together with the systematic uncertainties and the observed number of events. To estimate the sensitivity of the analysis before looking at data events, pseudo-experiments are generated in the background-only hypothesis by using pseudo-data randomly generated starting from the background expectations and including the systematic errors. The dotted line in figure 1 shows the expected limit as function of the Higgs mass with $\pm 1\sigma$ and $\pm 2\sigma$ variation indicated respectively by the green and yellow bands. The observed limit is represented by the solid line. CDF reached the SM sensitivity in the region [160-170] $\mathrm{GeV/c^2}$. The best sensitivity is for a Higgs mass of 165 $\mathrm{GeV/c^2}$ where the expected limit is at level of the SM. In table 4 are reported the observed and expected limits for the different analysis channels at $\mathrm{M_H = 165 GeV/c^2}$.

5. Conclusions

CDF has analyzed about $6\mathrm{fb}^{-1}$ of data to search for the decay $H \rightarrow \mathrm{W^+W^{-*}}$ and by combining together different $\mathrm{W^+W^{-*}}$ final states has reached the Standard Model sensitivity for

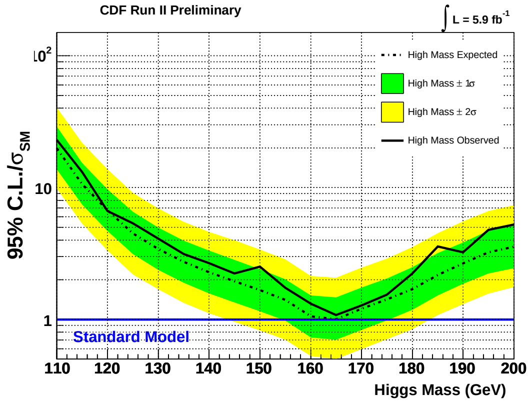

Figure 1: The observed (solid line) and the expected limit (dotted line) as function of the Higgs mass.

Final State	Observed Limit	Expected Limit
0-jets	1.67	2.39
1-jet	2.35	2.46
2+jets	3.16	6.14
Same Sign	4.86	5.92
tri-lepton-1	7.37	7.85
tri-lepton-3	9.16	10.4
tau	14.5	23.5
Low *M*	11.2	7.21
Combined	1.00	1.08

Table 1: Observed and expected limit for $\mathrm{M_H} = 165\mathrm{GeV}/\mathrm{c}^2$ for each analysis channels.

Higgs masses in a region around 165 GeV$/\mathrm{c}^2$. Work is in progress to obtain a better optimization of the analysis techniques. Moreover the ongoing data taking will provide CDF with a data sample large enough to allow an independent exclusion in a given mass window.

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