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Search for the Standard Model Higgs Boson in Final States with Photons or Taus at the Tevatron

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Although the sensitivity to a low mass Standard Model Higgs boson at the Fermilab Tevatron is highest for channels involving the $H \to b\bar{b}$ decay, other channels contribute significantly to the combined Higgs search. We report the results of searches for the Higgs boson in the diphoton and ditau final states using up to 8.5 fb^{-1} of integrated luminosity collected by the CDF and D0 detectors at $\sqrt{s} = 1.96$ TeV. Both gluon fusion and associated production processes are exploited. The diphoton and ditau channels contribute appreciably to the overall Higgs sensitivity at the Tevatron, despite the small branching ratio to the diphoton final state in the SM.

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1. Introduction

The Higgs boson (H) is the last particle of the standard model (SM) of particle physics that remains to be observed in nature. In electroweak theory, the Higgs boson serves both to give the W and Z bosons their masses and to give the fermions mass. It is thus a vital part of the theory. In the SM the couplings of the Higgs boson to other particles is completely specified and is a function of the mass of the Higgs boson (m_H), which itself is unspecified. Direct searches at LEP give a lower limit on m_H of 114.4 GeV/c^2 [1]. Indirect constraints from precision electroweak measurements indicate that the Higgs mass is likely less than 160 GeV/c^2 [2].

For the diphoton channel, the event selection in CDF and D0 is designed in order to reduce backgrounds such as jets faking photons and Dalitz decay. Therefore, EM energy deposition, EM isolation, and the absence of high-p_T tracks associated with the EM cluster are the main criteria in event selection.

Tau leptons are short-lived particles that can be detected only through their visible decay products. For hadronic decays, denoted as τ_h, the corresponding B.R. is about 65%. The remaining channels are represented by leptonic decays into muons (τ_μ) or electrons (τ_e). The visible four-momentum, sum of track p_T and π^0's, is used to describe the energy of the decay products of τ's.

2. Motivation

In recent years, the CDF and D0 experiments have increased the sensitivity of their Higgs searches [3]. This was partially achieved by including challenging secondary channels. The diphoton channel and tau lepton final-state channel are examples of those secondary channels and will be main topic of this paper.

The SM prediction for the Higgs boson branching ratio into diphotons ($H \to \gamma\gamma$) is extremely small. However, the diphoton final state contributes significantly to the Tevatron Higgs searches in a mass region between 100 and 150 GeV/c^2 due to better mass resolution and detector acceptance relative to dominant decay modes involving b-quark final states. In addition, in so called "fermiophobic" models [4], where the coupling of the Higgs boson to fermions is suppressed, the diphoton decay can be greatly enhanced.

The $H \to \tau\tau$ process is a promising channel to improve search sensitivity in the low mass region. This is because the branching ratio of the SM Higgs boson to a pair is the second highest (6.9% at M_H = 120 GeV/c^2). Also, the main background of this process is $Z \to \tau\tau$, which has a well estimated production rate and well modeled kinematic shape compared with QCD processes.

3. Diphoton Channel

The D0 experiment decomposes the backgrounds and uses a boosted decision tree (BDT) as final discriminant based on five kinematic inputs. Meanwhile, the CDF experiment uses a data-driven background model. The BDT output for the SM is shown in Figure 1 (left). Moreover, The fits for the central channel are shown in Figure 1 (center and right) for the whole $p_T^{\gamma\gamma}$ region used in the SM search and for each of the three $p_T^{\gamma\gamma}$ regions used in the fermiophobic search. In Figure 2, limits from D0 and CDF are shown for the SM interpretation (left two plots) and the fermiophobic interpretation (right two plots). More details can be found in [5] and [6].

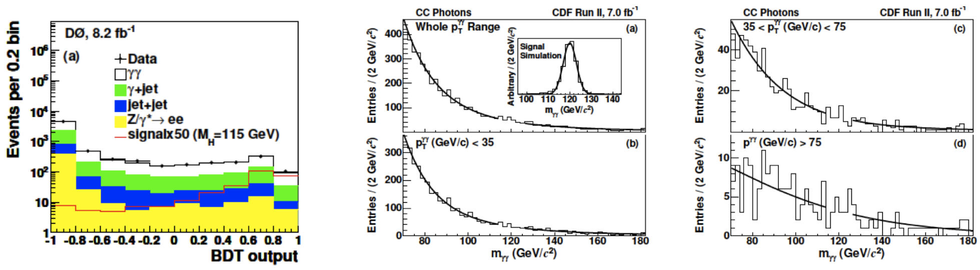

Figure 1: The BDT output distributions for the SM (left). The invariant mass distribution of central-central photon pairs (center and right): (a) the entire $p_T^{\gamma\gamma}$ region used for the SM Higgs boson search and three separate $p_T^{\gamma\gamma}$ regions in (b) $p_T^{\gamma\gamma} < 35$ GeV ,(c) $35 < p_T^{\gamma\gamma} < 75$ GeV, and (d) $p_T^{\gamma\gamma} > 75$ GeV.

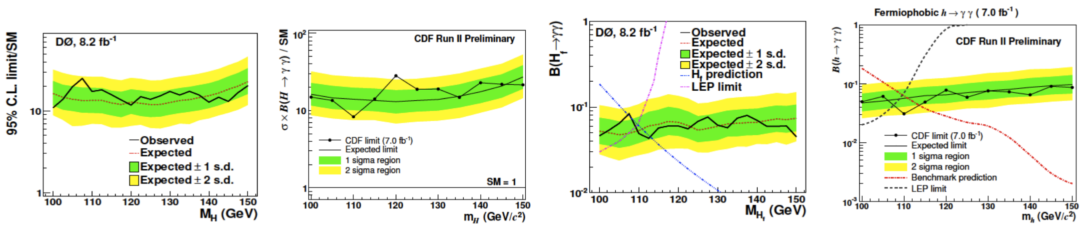

Figure 2: (from left to right) Observed and expected 95% CL upper limits on $\sigma \times \mathrm{Br}(H \to \gamma\gamma)$ relative to the SM prediction, as a function of the SM Higgs boson mass for D0 and CDF (left two plots). Similarly for the femiophobic Higgs model, the limits on $\mathrm{Br}(H \to \gamma\gamma)$ are shown (right two plots). The shaded regions represent the probability of fluctuations of the observed limit away from the expected limit based on the distribution of simulated experimental outcomes under the background-only hypothesis.

4. Tau lepton Channels

In this paper, we show results on $H \to \tau\tau+$ jets from both D0 and CDF. Multivariate techniques are used to maximally exploit the kinematic differences between the $H \to \tau\tau$ signal and backgrounds as shown by the BTD for D0 and CDF in Figure 3 (left and center), and Support Vector Machine (SVM) in Figure 3 (right). The limits are shown in Figure 4. In this channel, CDF observes a 95% C.L. limit of 14.7 $\times$ SM prediction ($m_H = 115$ GeV/c^2), while expecting 15.2. For the same test mass, D0 observes a limit of 32.8 $\times$ SM, while expecting 12.8. Moreover, A recent search from CDF in the $ll\tau_h$ final state, with a combination of all lepton channels, observes 18.5 and expects 17.3. More details can be found in [7] and [8].

5. Conclusions

These $H \to \gamma\gamma$ results significantly extend the sensitivity of the separate D0 and CDF limits on the SM Higgs production process obtained from Tevatron data. In the fermiophobic interpretation,

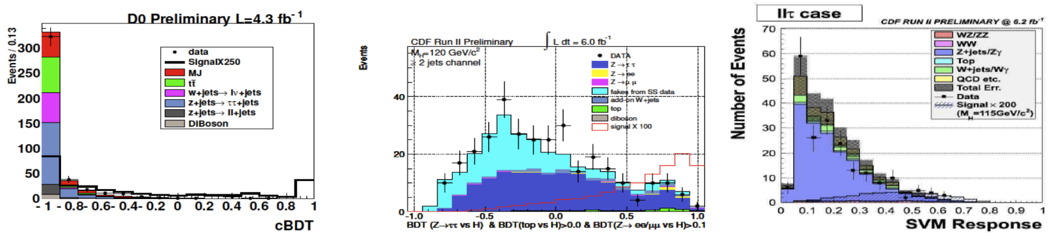

Figure 3: Final BDT discriminant in the $\mu - \tau$ channel (left). Final discriminant in the 2-jets channel at CDF (center). Comparison between the background model of the final discriminant and the data distribution in the $ll\tau_h$ channel (right).

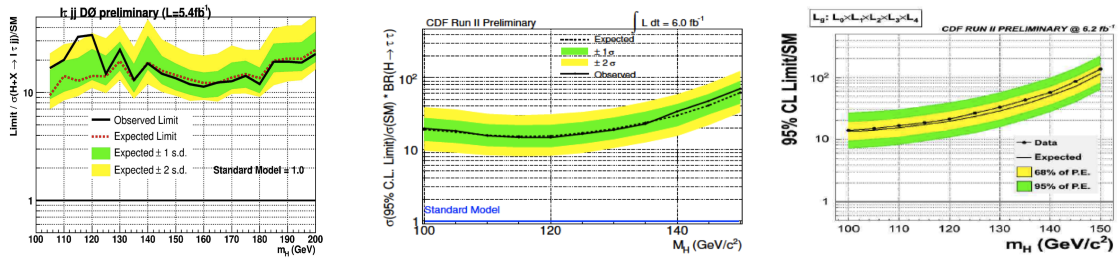

Figure 4: 95% C.L. limit on Higgs boson production rate times branching ratio over the SM expection as a function of the Higgs boson mass at D0 (left) and CDF (center). Similarly for a combination of all $ll\tau_h$ channels, the limits are shown in right plot.

the D0 (CDF) data set a lower limit on on the fermiophobic Higgs boson mass of 112.9 (114) GeV/c^2 at 95% C.L. Each experiment alone, therefore, produces more stringent lower limits than that of 109.7 GeV/c^2 obtained from combined searches at LEP. Despite the fact that Higgs searches using τ final states are very challenging, these channels set limits on the Higgs boson production cross section on the order of $10 \times$ SM expectation, and their contribution to the potential sensitivity at the Tevatron is very crucial.

References

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