Higgs Searches at the Tevatron

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1 Introduction

The standard model (SM) of the particle physics has been achieving quite successful outcomes in terms of not only explanation of the already measured physics framework but also prediction of the variables to be measured. However, the key element of the SM, the higgs boson, has not been discovered yet, which is indispensable for generating masses of particles and keeping the theory renormalizable at the electroweak scale. Since it is also clear that the SM is not self-contained, that is, not enough to tell its framework without any given parameters, we expect the existence of the physics beyond the SM. Among a number of physics models beyond the SM, the simplest one is the minimal supersymmetric extension of the standard model (MSSM). Along with the above theoretical guidance, searches for the SM and MSSM higgs bosons are being preformed and/or being prepared with the worldwide collaborations. Here we present the recent results of the higgs searches at the Tevatron, which is the only one facility where the higgs searches are undergoing at of this moment in the world.

2 The Tevatron collider and the CDF detector

The Tevatron is a collider accelerator which provides $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. As of January 2006, the typical peak luminosity and the weekly integrated luminosity is $1.5 \sim 1.7 \times 10^{32}$ cm^{-2}s^{-1} and $15 \sim 20$ pb^{-1} respectively. 1540 pb^{-1} has been delivered to the collision hall, 1230 pb^{-1} has been recorded to the data tapes, and about 360 pb^{-1} has been analyzed. The CDF detector is a general-purpose detector for the collider experiment. The schematic view of the CDF detector is shown in Figure 1. Silicon strip detectors and a cylindrical drift chamber are placed inside the solenoid magnet which provides the field strength of 1.4 T. On the other hand, electro-magnetic and hadron calorimeters are located outside the magnet. Muon chambers are installed in the outermost region. The details on the CDF detector can be found in [1].

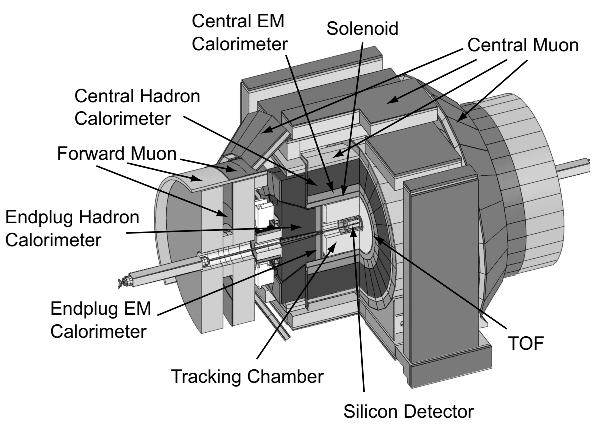

Figure 1: The schematic view of the CDF detector.

3 SM higgs boson searches

The SM higgs boson is dominantly produced via the gluon fusion ($gg \to h$) and the vector-boson associated process ($q\bar{q}^{(\prime)} \to Wh/Zh$) at the Tevatron energy. The cross sections of $gg \to h$, $q\bar{q}' \to Wh$ and $q\bar{q} \to Zh$ are 1.0 pb, 0.15 pb and 0.091 pb for the higgs mass (M_h) of 120 GeV/c^2, and 0.43 pb, 0.050 pb and 0.033 pb for $M_h = 160$ GeV/c^2 according to the NNLO calculation [2]. The search channels are roughly grouped into two by means of the decay modes of which branching fraction depends on the higgs mass, namely $h \to b\bar{b}$ and $h \to WW$. The former one is promising for the light higgs ($M_h < 130$ GeV/c^2) with the combination of the vector-boson associated production, while the latter one is suitable for the high mass higgs ($M_h > 130$ GeV/c^2). The important thing is that we need at least one high-p_{T} lepton from W/Z and/or higgs itself for event triggering due to the quite large QCD background.

As the recent results from the CDF experiment, the following four higgs search channels are presented here. Firstly, we describe the analysis of $q\bar{q}' \to Wh \to \ell\nu b\bar{b}$. The signature is high p_{T} isolated lepton + missing E_{T} (> 20 GeV/c^2) + two jets. We required at least one b-tagged jet. The major components of the background are W + heavy flavours and top quark production. Since we did not see any significant excess in the dijet invariant mass distribution, the upper limits on the production cross section times branching ratio ($\sigma(p\bar{p} \to Wh) \times Br(h \to b\bar{b})$) was calculated to be $3 \sim 10$ pb for the higgs mass range between 110 GeV/c^2 $\sim$ 150 GeV/c^2 at 95% confidence level (C.L.) with the integrated luminosity of 320 pb^{-1} [3]. Secondly we show the result on $q\bar{q} \to Zh \to \nu\bar{\nu}b\bar{b}$. This is the most sensitive channel in the Tevatron Run I search and also recent analyses at CDF. The signature of this channel is two jets and large missing E_{T} coming from two neutrinos in the final state. We required jets to be at least one b-tagged, and missing E_{T} to be larger than 70 GeV. We found the events passing the above cuts were consistent with the SM prediction which was dominated by QCD + mistag events and W/Z diboson production. We set the upper limits on the production cross section times branching ratio ($\sigma(p\bar{p} \to Zh) \times Br(h \to b\bar{b})$) to be $4 \sim 6$ pb for the higgs mass range between 90 GeV/c^2 $\sim$ 130 GeV/c^2 with 95% C.L. The integrated luminosity of 289 pb^{-1} was used for this channel. Thirdly we investigate the high mass higgs via $gg \to h \to WW$. The advantage of this channel is the large cross section of the higgs production through the gluon fusion. The signature is high p_{T} opposite-sign dilepton from $W^+W^- \to \ell^+\ell^-\nu\bar{\nu}$ and large missing E_{T}. Also since the scalar nature of the higgs boson results in the angular alignment between the final state leptons unlike those from diboson production which is the main component of the background, we utilized it to search for excess in spectra of the dilepton invariant mass and dilepton azimuthal separation. From the result of no excess against the SM prediction, the 95% C.L. upper limits on the production cross section times branching ratio ($\sigma(gg \to h) \times Br(h \to WW)$) was obtained to be $4 \sim 9$ pb for the higgs mass range from 110 GeV/c^2 to 200 GeV/c^2 using the integrated luminosity of 360 pb^{-1}. The fourth channel is $q\bar{q}' \to Wh \to WWW$. This process provides us with a like-sign dilepton as a final state resulting from $WWW \to \ell^{\pm}\nu\ell^{\pm}\nu X$. Since the like-sign dilepton event is quite rate in the SM events, this should be a good signature to discriminate the non-higgs SM events. Therefore, the background is dominated by events such as fake leptons and conversion electrons which are not able to be estimated by the simple Monte Carlo simulation. After understanding effects of the fake leptons and conversion electrons, no significant excess indicating higgs production was found in the 193.5 pb^{-1} data. We set the upper limits on the product of the production cross section and the branching ratio ($\sigma(p\bar{p} \to Wh) \times Br(h \to WW)$) to be around 10 pb at 95% C.L. for the higgs range from 90 GeV/c^2 to 200 GeV/c^2. The summary of the above results on the SM higgs searches are presented in Figure 2.

The SM higgs mass is also strongly correlated with masses of a W boson (M_W) and a top quark (M_t) via the radiative correction. Recently a new result of M_t was given by CDF and

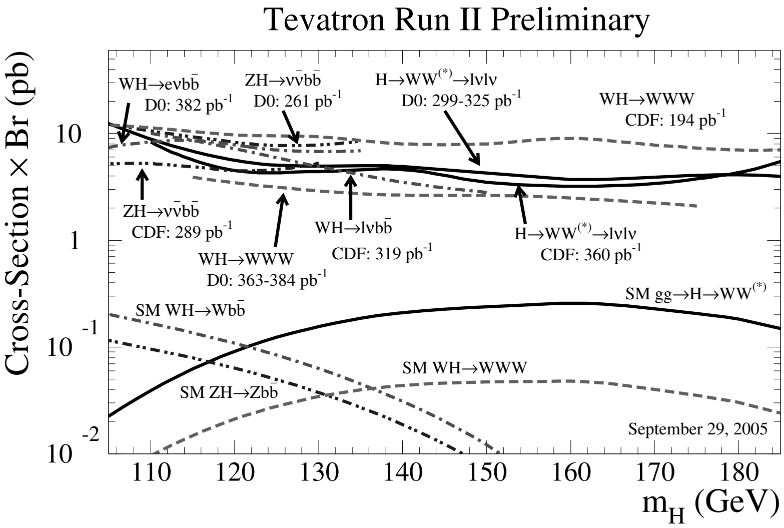

Figure 2: Summary of the SM higgs search results at the Tevatron. All experimental results represent the 95% C.L. upper limits.

DØ with higher precision to be 172.7 ± 2.9 GeV/c^2 [4]. Using this result and the current world average of M_W $(= 80.410 \pm 0.032$ GeV/$c^2)$, the 95% C.L. upper limit on the SM higgs mass was set to be 186 GeV/c^2 by means of the electroweak global fit [5].

4 MSSM higgs boson searches

As mentioned in the introduction, the simplest and the most natural extension of the SM is the MSSM. Two higgs field doublets which appears in the MSSM framework provide five physical higgs bosons, namely three neutral higgs $h^0/H^0/A^0(= \phi)$ and two charged higgs $H^\pm$.

We begin with showing the result on the neutral higgs search through $gg/b\bar{b} \to \phi \to \tau\tau$. The well-developed algorithm of τ identification enabled a study of this channel. A pair-created $\tau^+\tau^-$ was identified with a signature having one lepton resulting from leptonic decay of τ and one isolated narrow jet resulting from hadronic decay of the other τ. We require the lepton E_{T} or p_{T} to be greater than 10 GeV, and the isolated narrow jet to include odd number tracks, which indicate for them to be originated from one charged track. This τ identification scheme was validated using $Z \to \tau\tau$ events, and we obtained a quite good agreement between the Monte Carlo simulation and data. In consequence of no significant excess in the visible mass distribution, the upper limits on the production cross section were calculated. From a phenomenological point of view, the MSSM framework can be expressed by a mass of A^0 (M_A) and a ratio of vacuum expectation value of two higgs doublets (β). The regions excluded by this analysis on the M_A and $\tan\beta$ plane are shown in Figure 3 for two benchmark cases. Please see [6] for more details on this analysis.

Next we describe the charged higgs search. When the charged higgs mass $(M_{H^\pm})$ is smaller than the sum of the top quark mass (M_t) and the bottom quark mass (M_b), a top quark can decay to a charged higgs through $t \to H^\pm b$ followed by $H^\pm \to \tau\nu, cs, Wb\bar{b}$. Existence of these additional decay channels of a top quark would provide anomaly in the top cross section and the final state components. However, no anomaly was found with the data of 193 pb^{-1}. This result was interpreted as constraints of $M_{H^\pm}$ and $\tan\beta$. Figure 4 shows excluded regions for the two benchmark scenarios of the MSSM. More details can be found in [7].

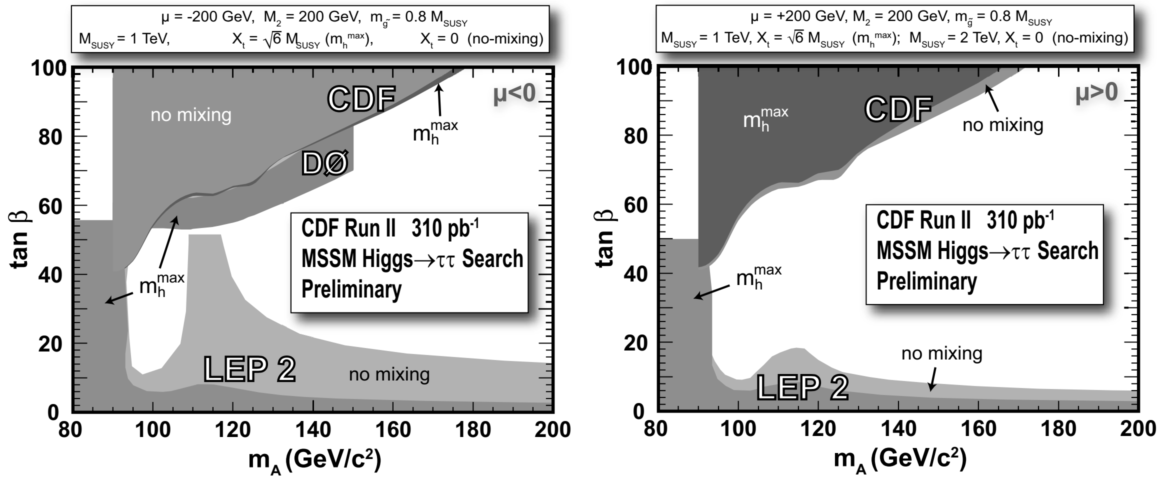

Figure 3: The excluded regions on the M_A - $\tan\beta$ plane for two MSSM benchmark cases.

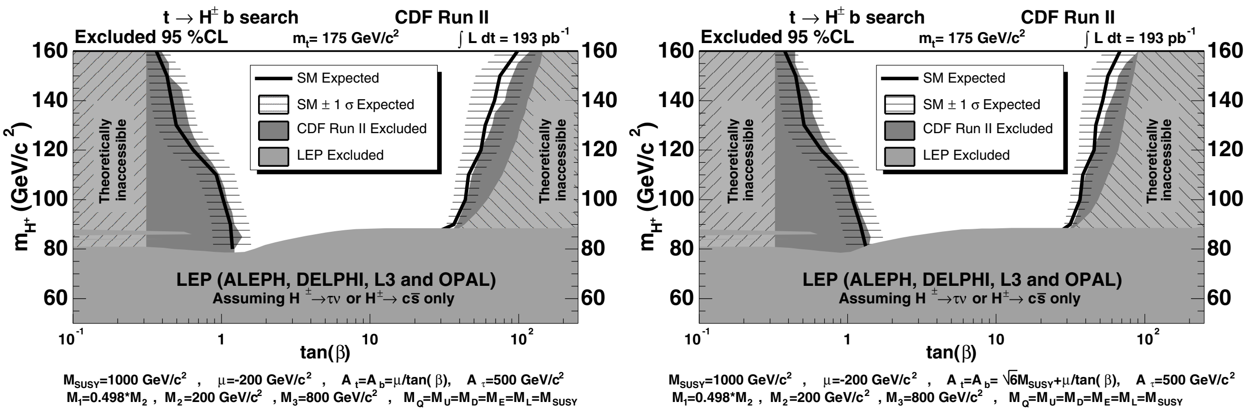

Figure 4: The excluded regions on the $M_H^{\pm}$ - $\tan\beta$ plane for two MSSM benchmark cases.

5 Future Prospects

The most important key for success of collider experiments is luminosity. As mentioned previously, we are receiving the typical luminosity of $1.5 \sim 1.7 \times 10^{32}$ cm^{-2} s^{-1} as a peak value and $15 \sim 20$ pb^{-1} as weekly integration. In order to make a realistic estimation of the luminosity accumulation, a practical strategy for luminosity upgrade was made by the Fermilab accelerator division in FY04, and they set a "base plan" as a simple extrapolation as of the end of FY04 and a "design plan" as a case all technical challenges are succeeded. The luminosity estimation based on the above study is 4.1 fb^{-1} at the end of FY09 for the base plan and 8.2 fb^{-1} for the design plan. It should be noted that we are on the track of the design plan as of January 2006. On the other hand, we have sensitivities of 95% C.L. exclusion with 2 fb^{-1} and 3σ evidence with 4 fb^{-1} for the SM higgs boson of $M_h = 120$ GeV/c^2 as a result of the precise Monte Carlo simulation. With respect to the MSSM higgs bosons, although it is not easy to tell sensitivities in detail due to many SUSY parameters, we can say that large region of $\tan\beta > 30$ on the M_A - $\tan\beta$ plane could be explored with $4 \sim 8$ fb^{-1}.

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