

Higgs and BSM at the Tevatron

Maiko TAKAHASHI^{1,2}

¹*University of Manchester, School of Physics and Astronomy, Schuster Lab,
Manchester M13 9PL, England, UK*

²*Eidgenössische Tech. Hochschule (ETH), Department of Physics,
ETH Honggerberg, CH-8093 Zurich, Switzerland*

The results from CDF and D0 experiments on direct searches for a standard model (SM) and beyond standard model (BSM) Higgs boson and other BSM signatures in $p\bar{p}$ collisions at the Fermilab Tevatron at $\sqrt{s} = 1.96$ TeV are presented. Hints of new physics observed in other SM measurements are also described.

§1. Introduction

The Tevatron collider (USA) has been providing proton — anti proton collisions with a centre of mass energy of $\sqrt{s} = 1.96$ TeV. In this article, results on searches for the Higgs boson as well as for the new physics performed by the two experiments, CDF and D0, using up to 9 fb^{-1} of integrated luminosity from the Tevatron Run II period (April 2002 – September 2011) are presented.

§2. Standard model Higgs boson searches

General search strategies for the Standard Model (SM) Higgs boson (and any other signatures) are: to maximise the selection of the Higgs boson signal, which is complimented by developing efficient object identification algorithms and by exploiting as many decay modes as possible; and to achieve the best discrimination against the backgrounds by improving the measurements of observables and the background modelling, by performing dedicated optimisation of selection and analysis methods for different sub-samples, and by employing multivariate techniques.

In the standard model (SM), the Higgs boson decays with a highest branching fraction to a $b\bar{b}$ pair when the Higgs boson mass is below ~ 135 GeV. At the Tevatron, the $b\bar{b}$ decay mode is exploited by searching for the Higgs boson production in association with a vector boson (W or Z) which gives rise to additional final state objects to identify the Higgs boson signal. The analysis is split into sub-channels defined by the number of leptons in the final state, either 0, 1 and 2 leptons, corresponding to $ZH \rightarrow \nu\nu bb$, $WH \rightarrow \ell\nu bb$ and $ZH \rightarrow \ell\ell bb$ processes, respectively. The identification of b-quark decay plays a crucial role and reduces the large background of dijet events, originating from W/Z boson production with jets or multijet production with fake lepton(s) and/or missing energy, by two orders of magnitudes. The higher mass Higgs boson search is driven by the inclusive analysis of a final state with dilepton which predominantly comes from the $gg \rightarrow H \rightarrow WW \rightarrow \ell\nu\ell'\nu'$ process. Dilepton samples are divided according to the lepton flavours and optimised sepa-

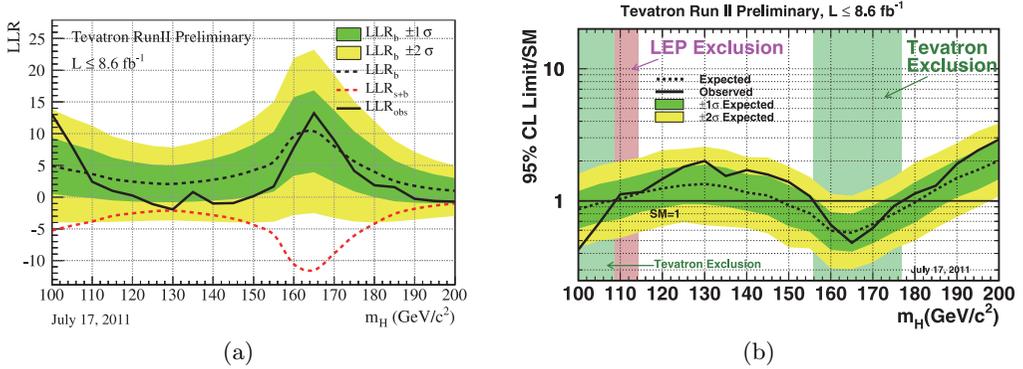


Fig. 1. (color online) The distribution of (a) log-likelihood ratios (LLR) and (b) upper limits on the SM Higgs boson production cross section as a function of the Higgs boson mass using up to 8.6 fb^{-1} of integrated luminosity analysed by the CDF and D0 experiments.

rately for events with 0, 1 and 2 jets which have different composition of the signal and background processes — e.g. the 0-jet events are dominated by non-resonant WW background whereas the 2-jet events are mostly from $t\bar{t}$ production.

Multivariate techniques, such as Neural Networks and Boosted Decision Trees, are used to combine all the discriminating kinematic variables and object quality variables in order to achieve maximum separation between the Higgs signal and the SM backgrounds. Dedicated multivariate discriminants are developed to remove one or two specific backgrounds, while the Higgs boson production cross section limit is derived using the distribution of a single multivariate discriminant trained to separate the signal and the total background.

Cross section limits are determined using the modified frequentist approach¹⁾ with a log-likelihood ratio (LLR) test statistics and using the Bayesian approach. The systematic uncertainty of the signal and background predictions are represented by a Gaussian distributed fluctuation of the expected yield, where correlations across different channels for any particular uncertainty are taken into account.²⁾ The Tevatron experiments have the sensitivity to the Higgs boson signal above the expected SM backgrounds and their uncertainties in a mass range around 165 GeV and also at lower masses, excluding the regions $156 < m_H < 177 \text{ GeV}/c^2$ and $100 < m_H < 108 \text{ GeV}/c^2$, using up to 8.6 fb^{-1} of integrated luminosity collected by each experiment²⁾ (Fig. 1).

§3. Beyond standard model Higgs boson searches

Some non-SM theories support a presence of a Higgs boson with different properties. In “fermiophobic” interpretation, Higgs boson’s couplings to all fermions are suppressed, eliminating the gluon fusion production (via top quark loop) and decays to $b\bar{b}$ and $\tau\tau$ which are dominant in the SM case. The Higgs boson decay channel to two photons has been reinterpreted in the fermiophobic scenario, setting an exclusion of masses below $119 \text{ GeV}/c^2$ ³⁾ (Fig 2(a)).

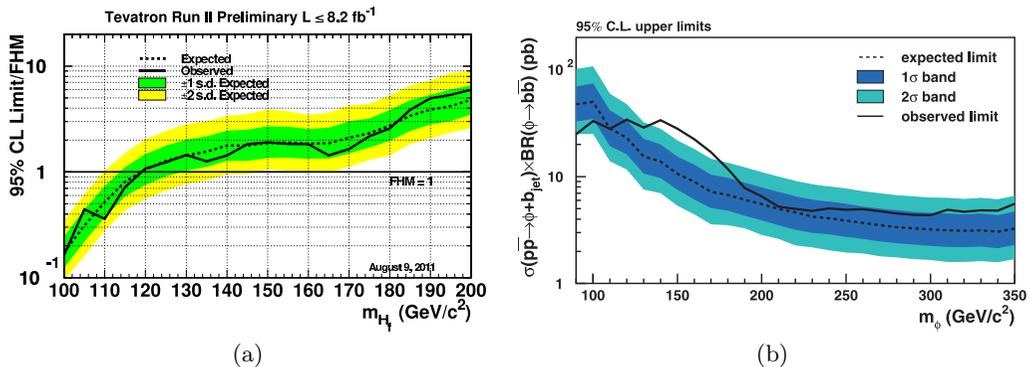


Fig. 2. (color online) (a) Upper limits on the production cross section of a fermiophobic Higgs boson in decays to two photons, and (b) for an MSSM Higgs boson produced in association with a b quark.

A final state with multiple hadronic b quarks is exploited in a search for a Higgs boson in the minimal supersymmetric standard model (MSSM), where a neutral Higgs boson is produced in association with a b and itself decays to a $b\bar{b}$ pair. In this channel, the observed limits on the production cross section of the MSSM Higgs boson showed some deviation from the expected limits within $\sim 2\sigma$ of the uncertainties at a mass around 150 GeV/c² (Fig. 2(b)), which is confirmed by both experiments.^{4),5)} An update including a larger dataset and a combination of the results are in progress.

§4. Hints of new physics

Some hints of new physics at the Tevatron came from measurements of SM parameters which showed deviations from the theoretical predictions.

In $p\bar{p}$ collisions at the Tevatron, the top or the anti-top quark prefers to go in the direction of the incoming quark or the anti-quark. The forward-backward asymmetry in $t\bar{t}$ production is defined by the number of events with positive or negative rapidity difference between top and anti-top, $A_{FB}^{t\bar{t}} = (N_{\Delta y > 0} - N_{\Delta y < 0}) / (N_{\Delta y > 0} + N_{\Delta y < 0})$, where $\Delta y = y^t - y^{\bar{t}}$. The value of $A_{FB}^{t\bar{t}}$ is expected to be zero at Leading-Order (LO), and \sim few percent at higher orders. After unfolding the detector effects, both CDF and D0 observe a significantly larger asymmetry with a deviation from the NLO prediction of 3-4 σ significance using approximately 5 fb⁻¹ of integrated luminosity^{6),7)} (Fig. 3(a)). The measurements are still statistically limited, and an updated results are expected with the full statistics of the Tevatron data.

The CP violation can be probed in semileptonic decays of $b\bar{b}$, where one of the B mesons from the b -decays, which may be B_d or B_s , oscillates and decays to a muon with the same electric charge as the other b -decay. The like sign dimuon charge asymmetry is defined using the number of semi-leptonically decayed $b\bar{b}$ events with both muons having positive or negative charges, $A_{sl}^b = (N_{bb}^{++} - N_{bb}^{--}) / (N_{bb}^{++} + N_{bb}^{--})$. In the SM, A_{sl}^b is very close to zero. A precise measurement of such quantity have been carried out by the D0 experiment where experimental uncertainties is

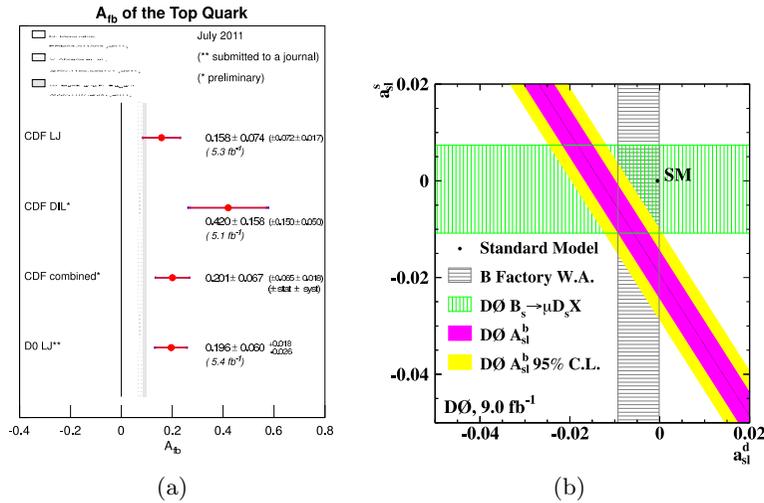


Fig. 3. (color online) (a) The forward-backward asymmetry in $t\bar{t}$ production, and (b) the charge asymmetry in semileptonic decays of $b\bar{b}$, both results showing significant deviations from the SM predictions.

reduced from the periodic change of the magnet polarities, effectively cancelling out the first order detector effects. The latest measurement of A_{sl}^b using 9.0 fb^{-1} of integrated luminosity showed 3.9σ deviation from the SM expectation, revealing an anomalously large CP violation⁸⁾ (Fig. 3(b)).

§5. Summary

Searches performed at the Tevatron by the CDF and D0 experiments for the SM and non-SM Higgs bosons as well as for a BSM physics are presented. The Tevatron measurements have set many of the first limits and revealed hints of new physics. Some areas remain unique and/or complimentary to the Large Hadron Collider results in the coming years. Final results using the full dataset are expected by summer 2012.

References

- 1) T. Junk, Nucl. Instrum. Methods A **434** (1999), 435.
- 2) The TEVNPH Working Group (for CDF and D0 Collaboration), arXiv:1107.5518.
- 3) The TEVNPH Working Group (for CDF and D0 Collaboration), arXiv:1109.0576.
- 4) CDF Collaboration, CDF Note 10414 (2011).
- 5) D0 Collaboration, Conference Note D0 Note 6227-CONF (2011).
- 6) CDF Collaboration, CDF Note 10584 (2011).
- 7) V. M. Abazov et al. (D0 Collaboration), Phys. Rev. D **84** (2011), 112005, arXiv:1107.4995.
- 8) V. M. Abazov et al. (D0 Collaboration), Phys. Rev. D **84** (2011), 052007; Phys. Rev. Lett. **105** (2010), 081801; Phys. Rev. D **82** (2010), 032001.