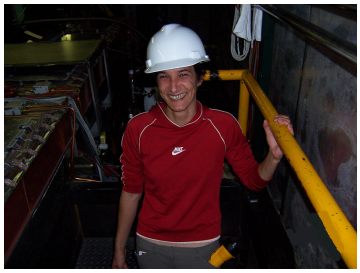
SEARCHES FOR HIGGS BOSONS BEYOND THE STANDARD MODEL AT THE TEVATRON

C. BISCARAT
(For the CDF and DØ Collaborations)

Department of Physics, Lancaster University, Bailrigg, Lancaster, UK, LA1 4YW



Preliminary results from the CDF and DØ Collaborations on the searches for Higgs bosons beyond the Standard Model at the Run II Tevatron are reviewed. These results are based on datasets corresponding to an integrated luminosity of 100-200 pb^{-1} collected from proton anti-proton collisions at a center of mass energy of 1.96 TeV. No evidence of signal is observed and limits on Higgs bosons production cross sections times branching ratio, couplings and masses from various models are set.

1 Introduction

The Standard Model (SM) predictions has been extensively tested by experiments over the past decades. All the SM particles have been discovered, except the Higgs boson predicted in the minimal version of the SM. Despite many successes, the SM suffers from theoretical drawbacks. For example, it does neither explain the origin of the electroweak symmetry breaking, nor include gravity. Hence, several extensions of the minimal SM have been proposed. Some of them, such as Supersymmetry, left-right symmetric models, or other exotics models, lead to the prediction of Higgs bosons with properties different from the SM one. At the Run II Tevatron, a proton anti-proton collider running at the center of mass energy of 1.96 TeV, one of the major physics objectives is to search for Higgs bosons predicted in theories beyond the Standard Model. In this report, preliminary results from the CDF and DØ Collaborations are presented. In the following, limits are given at the 95% Confidence Level.

2 Search for MSSM neutral Higgs bosons

After symmetry breaking, the Minimal Supersymmetric extension of the Standard Model [1] (MSSM) predicts five physical Higgs bosons. Three are neutral: h, H and A. Generally, their couplings to the down type fermions are enhanced by a factor of tanβ (the ratio of the vacuum expectation values of the two Higgs doublets) compared to the SM Higgs boson ones, thus the cross-sections of some production processes scale as $\tan^2\beta$. The neutral Higgs bosons mostly decay to a bottom quark pair (90%) and to a tau lepton pair. At the Tevatron, the main production mechanisms $\mathrm{gg, b\bar{b}} \to \phi$ (ϕ= h, H, A) lead to topologies that are difficult to extract from the overwhelming background unlike the associated production $\mathrm{gb} \to \mathrm{b}\phi$ and $\mathrm{gg, q\bar{q}} \to \mathrm{b\bar{b}}\phi$.

2.1 Search for MSSM neutral Higgs bosons decaying to bottom quark pairs

DØ searches for a neutral Higgs boson in the channel $\phi\mathrm{b\bar{b}} \to \mathrm{b\bar{b}b\bar{b}}$. The h/H and A bosons can not be distinguished due to either the di-jet mass resolution or the Higgs boson width and since they are nearly mass degenerate. This topology is a potential discovery channel for Supersymmetric Higgs bosons if tanβ is large. This channel suffers from multi-jet events background (4j, 2b+2j, 2b, Z+jets and $\mathrm{t\bar{t}}$) which is reduced by selecting events with at least three b-tagged jets and by applying kinematical cuts on the leading jets, optimized for each Higgs boson mass hypothesis, studied in the range 90-150 GeV/c^2. The background is predicted from a two b-tagged sample by applying fake tag rate. Typical acceptances are at the percent level. Dominant systematics effects come from the b-tagging modelling. In a multi-jet trigger dataset ($\mathcal{L}_{int}$=131 pb^{-1}), the signal is searched for as a peak in the invariant mass distribution of the two leading jets. In the absence of a signal the limits are set on tanβ values in the range 80-120, depending on $\mathrm{m_A}$, as shown in Fig. 1.

2.2 Search for MSSM neutral pseudoscalar Higgs boson A decaying to tau pairs

CDF searches for evidence of Higgs boson production via the $\mathrm{gg, b\bar{b}} \to \mathrm{A}$ process in the $\mathrm{A} \to \tau^+\tau^-$ decay channel with one tau decaying hadronicaly and the other decaying leptonicaly (electron or muon produced with two neutrinos). This channel is an important addition to the well known Wh and Zh associated production ones. The data ($\mathcal{L}_{int}\sim$200 pb^{-1}) was collected with dedicated Run II triggers which select one lepton, e or μ, and one isolated track. The events selection starts with the tau-jet identification (the main source of systematics uncertainties), based both on calorimetry and tracking isolation as well as the number of associated tracks. Background events (multi-jet, $\mathrm{W} \to \ell\nu$ and $\mathrm{Z} \to \ell\ell$) are further reduced by applying requirements on the tau decay products topology. The signal detection efficiency is less than 1%. The remaining background consists mainly of $\mathrm{Z} \to \tau\tau$ events. Thus, CDF searches for signal in a "pseudo"-mass distribution as shown in Fig. 1. No signal is observed and an upper limit is set on the production cross-section times branching fraction as a function of $\mathrm{m_A}$: from 19 pb to 3 pb in the mass range 115-200 GeV/c^2.

3 Search for light Higgs boson decaying to photon pairs

The SM Higgs boson decays dominantly to heavy particles and the branching fraction to photon pair is tiny, 10^{-3}-10^{-4}. Thus the search for $\mathrm{h} \to \gamma\gamma$ can not probe the SM Higgs at the Tevatron. However, some non-SM models predict enhanced $\mathrm{h} \to \gamma\gamma$ rate. At DØ, two scenarios are investigated: the Fermiophobic Higgs [2] (no coupling to fermions are allowed) and the Topcolor Higgs [3] (the Higgs boson couples to the top quark only). The dataset ($\mathcal{L}_{int}$=191 pb^{-1}) was collected by triggering on two energetic electromagnetic objects. The signal suffers mainly from the di-jet background that is reduced by requiring the transverse momentum ($\mathrm{p_T}$) of the di-photon system

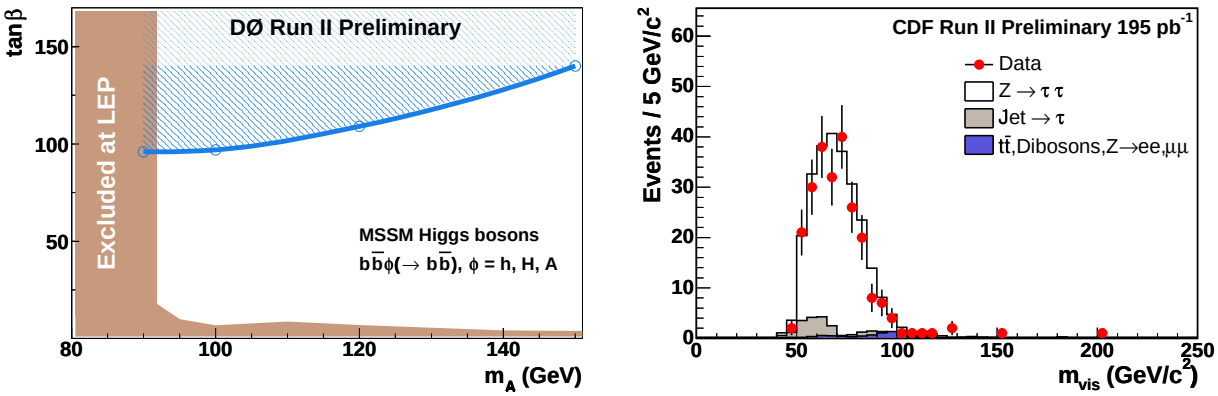


Figure 1: Left: DØ lower limit on tanβ as a function of m_A (thick blue curve; the dashed area is excluded). Right: Observed "pseudo"-mass (lepton, τ, missing transverse energy) distribution and background predictions in CDF.

to be high. The γ mis-identification is the largest source of background systematic uncertainties. The $\gamma\gamma$ invariant mass spectrum observed in data is in agreement with the SM background predictions (di-jet, $\gamma^\star/Z \rightarrow ee$ and direct di-photon events). Upper limits on the Higgs boson branching fraction to a photon pair are set to $\sim$0.8, in both scenarios, over the m_h range of 60-150 GeV/c^2.

4 Search for doubly-charged Higgs bosons

Many extensions of the SM predict the existence of doubly-charged Higgs bosons, $H^{\pm\pm}$. For example, the left-right symmetric model[4] suggests a low mass $H^{\pm\pm}$, $\mathcal{O}(100$ GeV/c$^2)$, and motivates its search at the Tevatron. The $H^{\pm\pm}$ are mainly produced in pairs via the Drell-Yan process $q\bar{q} \rightarrow \gamma^\star/Z \rightarrow H^{++}_{L,R}H^{--}_{L,R}$, the left handed states cross-section being twice larger than the right handed states. They dominantly decay into like-charge lepton pairs. The Yukawa coupling of the $H^{\pm\pm}$ to leptons ($h_{\ell\ell'}$) has no lower limit. Thus two types of search are performed: assuming the decay of the Higgs bosons within the detector or assuming long lived particles.

4.1 Doubly-charged Higgs bosons decaying promptly

The sensitivity is increased by searching for any of the two $H^{\pm\pm}$ produced. The main background comes from hadrons decaying to leptons, weak bosons production and cosmic rays.

The first search for $H^{\pm\pm}$ decaying to lepton pairs at hadron colliders has been carried out by the DØ Collaboration. It assumes decays to muons exclusively and $h_{\mu\mu} > 10^{-7}$. An inclusive di-muon dataset ($\mathcal{L}_{int}$=113 pb^{-1}) is analyzed. Events with at least two energetic, isolated, like-sign muons are selected. If only two muons are identified in an event, they are required to be relatively close in azimuth. Such muon pairs are considered as $H^{\pm\pm}$ candidates. The total signal efficiency is typically about 47%, independantly of $m_{H^{\pm\pm}}$. Although the Monte Carlo modelling is carefully controlled, it represents the major source of systematic uncertainties. The final di-muon invariant mass is shown in Fig. 2. Three candidates are observed while the expected number of background events is 1.5±0.4, the majority being $b\bar{b}$ events. Mass limits are derived: $m_{H^{\pm\pm}_L} > 118.4$ GeV/c^2 and $m_{H^{\pm\pm}_R} > 98.2$ GeV/c^2. They improve previous LEP limits as can be seen in Fig. 2.

Doubly-charged Higgs bosons decaying exclusively to ee, $\mu\mu$ and eμ are considered by the CDF Collaboration. The range $10^{-5} < h_{\ell\ell'} < 0.5$ is probed. The ee sample ($\mathcal{L}_{int}$=235 pb^{-1}) is selected using a di-electron trigger and requiring an energetic central electron and a track. The $\mu\mu$ sample ($\mathcal{L}_{int}$=242 pb^{-1}) is selected using a single muon trigger. Additional requirements

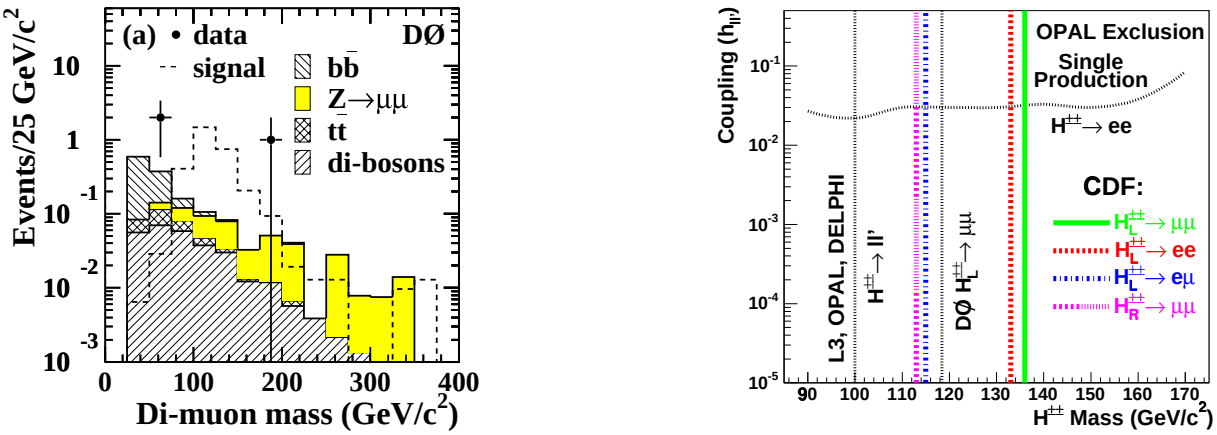


Figure 2: Left: Di-muon mass for the two leading like-sign muons after all selections (the open histogram shows a $H_L^{\pm\pm}$ of 120 GeV/c^2 mass). Right: Lower limits on $m_{H^{\pm\pm}}$ assuming exclusive decay to a given lepton pair.

(minimum ionizing high p_T tracks, calorimeter isolation, consistency with beam line outgoing muons) reduce the backgrounds. The eμ sample ($\mathcal{L}_{int}$=240 pb^{-1}) is selected using a single electron trigger and requiring a central electron and a track matched to a muon. In the di-lepton mass search region ($m_{\ell\ell'}$ >100, 80, 80 GeV/c^2 for the ee, $\mu\mu$ and eμ channels respectively) the acceptances are: ~34% for the ee and $\mu\mu$ samples and ~ 18% for the eμ sample. No candidates are observed in the search regions and lower limits on $m_{H^{\pm\pm}}$ are derived: 133 GeV/c^2, 136 GeV/c^2, 115 GeV/c^2 for $H_L^{\pm\pm}$ decaying to ee, $\mu\mu$ and eμ, respectively, and 113 GeV/c^2 for $H_R^{\pm\pm}$ decaying to $\mu\mu$. These results are compared to previous ones in Fig. 2.

4.2 Quasi-stable doubly-charged Higgs bosons

Since stable charged massive particles lose significant energy due to ionization, the passage of any long lived doubly-charged particle through the detector leads to a characteristic signature free of physics SM background: only highly ionizing leptons and jets mimic the signal.

The data were collected by CDF with an inclusive muon trigger ($\mathcal{L}_{int}$=206 pb^{-1}). Events with one isolated muon and a second high p_T track are selected. These two objects are required to be highly ionizing, combining the dE/dx measurements in the calorimeters and in the tracker. The signal efficiency is ~3% on the studied $m_{H^{\pm\pm}}$ range of 90-160 GeV/c^2. The expected background is dominated by mis-identified jets, reduced to the level of 10^{-5}. The major source of systematic uncertainties comes from identification efficiencies. No events are observed and a lower limit on $m_{H^{\pm\pm}}$ is set to 134 GeV/c^2, to be compared with the previous limit set by the DELPHI Collaboration at 97.3 GeV/c^2.

5 Conclusion

Both CDF and DØ Collaborations are probing the Higgs sector of theories beyond the Standard Model. Present results are competitive with the LEP ones. Moreover, the Tevatron accelerator is performing well and an exciting era regarding to the quest for Higgs bosons is ahead of us.

References

1. See, for example, H. P. Nilles *Phys. Rep* **110**, *1 (1984).*
2. *M. Carena et al (Higgs Working Group Report), hep/ph0010338.*
3. *C.T. Hill,* Phys. Lett. *B* **266**, *419 (1991);* Phys. Lett. *B* **345**, *483 (1995).*
4. *J. C. Pati and A. Salam,* Phys. Rev. *D* **10**, *275 (1974)*