Search for Low Mass Standard Model Higgs Boson at Tevatron Run II

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The data delivered by the 1.96 TeV $p\bar{p}$ collider Tevatron provides the opportunity to search for the production of the Standard Model Higgs boson. Both experiments, CDF and DØ have analyzed so far up to 2.4 fb^{-1} to search for this particle. No significant excess is observed in the various channels so that limits on the Higgs boson production rates are set. This proceedings presents the status of the search for Higgs boson in the range $110 < m_H < 130$ GeV.

1 Introduction

The electroweak symmetry breaking mechanism in its simpler form, described within the Standard Model (SM), predicts the existence of a scalar particle, the Higgs boson. The only free parameter of the Higgs sector is the Higgs boson mass. It is actually constrained by the direct searches for Higgs production conducted at the electron-positron collider LEP (1989-2000) which conclude its mass should be heavier than 114.4 GeV [2]. Indirect constraints are obtained when accounting for the Higgs boson's quantum effects in various electroweak measurements. This yields an upper bound of 190 GeVat 95% Confidence Level [3].

At the present time, finding the Higgs is one of the most topical goals of particle physics. Thus it is also a primary objective of the CDF and DØ experiments, which analyze the $p\bar{p}$ collisions from the Tevatron, at center-of-mass energy of 1.96 TeV. Indeed direct and indirect constraints define a range of mass of $110 < m_H < 200$ GeV to look for the Higgs boson, perfectly suitable for the Tevatron energy reach.

The Run II of the Tevatron started in spring 2001. As of spring 2008, both experiments have recorded an integrated luminosity $\mathcal{L} \simeq 3$ fb^{-1} of high quality data for physics analysis, which is roughly 25 times more than during Run I (1992-1996). This proceedings presents the status of the search for Higgs boson at low mass, namely $110 < m_H < 130$ GeV, in the different channels of interest. All limits hereafter are given at 95% Confidence Level.

2 Higgs boson production and decay channels

The production cross-sections of Higgs bosons at Tevatron are well defined theoretically. A leptonic or missing transverse energy ($\not{E}_T$) signature is required to search for a rare process at a hadronic collider because of the overwhelming QCD background. Given that, the dominant decay mode is $H \to b\bar{b}$ ($\simeq 80$ %) for $m_H < 130$ GeV, the associated production with gauge bosons decaying to leptons or missing energy provide the best channels to search for Higgs bosons at low mass.

The dominant production mode, the gluon fusion, $gg \to H$, plays a crucial role a high mass ($m_H > 140$ GeV) for which the Higgs boson decays mainly into a pair of W bosons. This is discussed elsewhere in this proceedings [4].

3 b-jet tagging

The channels presented hereafter rely on the ability to tag b-quark jets thanks to their properties. As B-hadrons are massive, long-lived particles that can decay semi-leptonically, it is possible to build jet observables characterizing b-jets: high impact parameters of tracks, probability to be a light jet based on the track impact parameters (JP), presence of secondary vertex (ST), lepton tag, jet kinematics. Combining the observables with multivariate techniques such as a Neural Network (NN) gives an even better discrimination over light jets. The typical b-tagging efficiency with a NN is $\varepsilon = 50\%$ for a mis-tag rate of 0.5% for $p_T = 50$ GeV.

4 Associated production with a W vector boson: the $Wb\bar{b}$ channel

The $Wb\bar{b}$ signature consists of one high p_T, isolated lepton (electron or muon), a large $\not\!\!E_T$, and the presence of two b-tagged jets. The transverse mass of the (lepton, $\not\!\!E_T$) system ($M_T(W)$) has also to be compatible with the expected W transverse mass spectrum. The scalar sum of E_T of the different objects in the event, H_T has also to be large. The background is made of W+jets events,W+heavy flavor jets, QCD events with a fake isolated lepton, and top production.

CDF has analyzed 1.9 fb^{-1} of data in both electron and muon channels. The lepton has to be isolated with $p_T > 20$ GeV, while $\not\!\!E_T > 20$ GeV and $M_T(W) > 20$ GeV. Exactly two jets with $E_T > 15$ GeV and $|\eta| < 2$ have to be reconstructed, events with other jet multiplicities are control samples for the background level. One of the latest improvement in this channel is the inclusion of forward electron, increasing the acceptance by $\simeq 10\%$.

DØ has analyzed 1.7 fb^{-1} of data. The same kind of preselection as in CDF is applied: p_T(lepton) > 15 GeV, $\not\!\!E_T > 20$ GeV, $H_T > 60$ GeV and 2 jets with momenta higher than 20, 25 GeV are demanded. The electron acceptance, $|\eta| < 1.1$ is lower than the muon acceptance $|\eta| < 2$. The recent combination of all possible triggers in the muon channel yields an increase of its acceptance by $\simeq 35\%$.

The b-jet content of the events is used to discriminate the signal against the background. CDF performs the combination of three exclusive channels: 1 b-tag (NN), 2 b-tag (ST+ST) and 2 b-tag (ST+JP). DØ combines a channel with 2 loose NN b-tagged jets and a channel with only one tightly NN b-tagged jet.

Both CDF and DØ use a NN to combine the kinematic information of the events (including the di-jet invariant mass) and discriminate signal against background. As no significant excess of events is observed with respect to the expectation limits on the Higgs production are set. Those limits (reported to the SM yield) read for $m_H = 115$ GeV: $\sigma_{95}/\sigma_{SM} = 8.2$ (7.3 expected), $\sigma_{95}/\sigma_{SM} = 9.1$ (11.1 expected) for respectively CDF and DØ.

5 Associated production with a Z vector boson: the $\ell\ell b\bar{b}$ channel

The $H\ell\ell$ signature consists of two high p_T leptons, their invariant mass being close to 91 GeV, and the presence of two high p_T b-jets. The expected absence of $\not\!\!E_T$ is a further constraint that CDF employs to improve the di-jet mass resolution, thus increasing the signal to background ratio.

Two exclusive samples are defined both at CDF and DØ: either 2 loosely b-tagged jets or 1 tightly b-tagged jet, to improve the signal over background discrimination. Employing a NN based on the kinematics further reduces the impact of the background which consists of Z+jets, Z+heavy flavor jets, top production and QCD events. As no excess is observed in the 1 fb^{-1} of analyzed data, limits are set on the Higgs production rate: for $m_H = 115$ GeV: $\sigma_{95}/\sigma_{SM} = 16$ (16 expected), $\sigma_{95}/\sigma_{SM} = 17.8$ (20.4 expected) for respectively CDF and DØ.

5.1 Missing energy channel

The missing energy signature arises either from the ZH production followed by the decay $Z \rightarrow \nu\bar{\nu}$, or to some significant extent from the WH production followed by the decay $W \rightarrow \ell\nu$ for which the lepton is undetected. It is characterized by two high p_T b-jets and a large $\not{E}_T$. Triggers based on on-line measurement of $\not{E}_T$ had to be developed to be sensitive to this channel.

In 1.7 fb^{-1} of data CDF demands 2 jets of $E_T > 45,\ 25$ GeV, $\not{E}_T > 50$ GeV and perform the analysis in two exclusive sample: 2 b-tagged jets either by (ST+ST) or by (ST+JP). In 2.1 fb^{-1} of data DØ demands two NN b-tagged jets (loose+tight) with $E_T > 20$ GeV, $\not{E}_T > 50$ GeV.

The main backgrounds arise from top production, Z+jets and W+jets process. The most difficult background consists of QCD events for which one jet has been mis-measured yielding presence of $\not{E}_T$. To suppress and control those events, both experiments exploit the difference between a charged track based $\not{E}_T$ and the usual calorimeter based $\not{E}_T$.

In this channel multivariate techniques based on the kinematics of the events also increase the signal over background ratio. As no excess of events is observed limits are set on the Higgs production rate: for $m_H = 115$ GeV: $\sigma_{95}/\sigma_{SM} = 8.0$ (8.3 expected), $\sigma_{95}/\sigma_{SM} = 7.5$ (8.4 expected) for respectively CDF and DØ.

6 $\tau\tau$ + 2 jets channel

This spring, CDF has for the first time released results searching for the SM Higgs based on its decay to tau leptons, which are at the level of $\simeq 8\%$ for $m_H = 115$ GeV. Several production mechanisms are actually involved to search for a $\tau\tau$+2 jets signature: gluon fusions with initial state radiation, associated production with vector boson and vector boson fusion. One of the tau has to decay leptonically while a hadronic signature is required for the second one. In this analysis performed on 2 fb^{-1}, three NN exploit the kinematic observables to discriminate against the three main backgrounds: Z+jets, top pair production and QCD events. No excess of events is observed and limits are set. This gives $\sigma_{95}/\sigma_{SM} = 30.5$ (25 expected) for $m_H = 115$ GeV.

7 H to $\gamma\gamma$

Contrary to LHC, the decay to photons plays a minor role in the search for Higgs at Tevatron. However this channel is interesting to search for more exotic Higgs models. DØ has analyzed 2.3 fb^{-1} of data, demanding NN-identified high p_T photon ($p_T > 25$ GeV). No excess of events is observed in the invariant mass spectrum of the photon pair, when accounting from the presence of background events: Drell-Yan, direct photon production and photon+jet production. The limit reads for $m_H = 120$ GeV, $\sigma_{95}/\sigma_{SM} = 53$ (43 expected).

8 Tevatron combined limits

The combination of all channels accounts for systematic uncertainties, their correlations between signal and background and between the channels [5]. The combined limits on the Higgs yield as a function of its mass are shown in Fig. 1. The limits are for $m_H = 115$ GeV: $\sigma_{95}/\sigma_{SM} = 3.7$ (3.3 expected) and for $m_H = 130$ GeV: $\sigma_{95}/\sigma_{SM} = 5.7$ (4.2 expected).

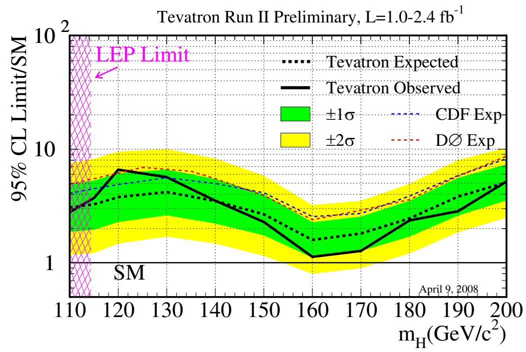

Figure 1: Tevatron combined limits in term of Higgs yield relative to the SM yield. If the observed curve was below 1, then a range of SM Higgs boson mass would be excluded.

9 Conclusion and prospects

Most channels of the search for SM Higgs are covered by the DØ and CDF experiments, with roughly 2 fb^{-1} of analyzed data. The first channels with taus have also been included recently. The sensitivity to a low mass Higgs boson is roughly 3.5 times the SM yield.

Naively, one expects such a number to scale down with integrated luminosity like $\frac{1}{\sqrt{\mathcal{L}}}$. By 2009 or 2010, 6 to 7 fb^{-1} of physics quality data per experiment should have been recorded, which does not seem to be enough to explore the low mass region.

But in the last few years, both CDF and DØ have demonstrated that their Higgs sensitivity was improving faster than $\frac{1}{\sqrt{\mathcal{L}}}$, thanks to analysis improvements. Further improvements are actually foreseen and in development. This includes a better di-jet mass resolution, an increased lepton acceptance, improved trigger acceptances, a better b-tagging, the addition of more tau channels... If the Tevatron experiments keep improving their analyzes, they will be able to exclude the low mass range $[110, 125]$ GeV by the end of Run II. Observing a 3-sigma evidence of the production of a Higgs boson is also a possibility.

References

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