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SEARCH FOR LOW MASS SM HIGGS AT THE TEVATRON

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Abstract

The only place in the world where at this time standard model Higgs bosons can be produced and detected is the Tevatron at Fermilab. In this contribution, the most recent results on the search for a low mass Higgs boson are presented, using datasets of up to $1.9\,\mathrm{fb}^{-1}$. In the absence of signal, the combined Tevatron cross section limit at a Higgs boson mass of 115 GeV is determined to be 6.2 (4.3 expected) times the standard model (SM) expectation, at 95% confidence level. The expected gain in sensitivity from the forthcoming larger dataset and improved analysis methods will likely make an exclusion or observation at low mass possible in the near future.

1 Introduction

The standard model of particle physics as we know it has been very successful. Many precision measurements have given excellent agreement with the model, and many processes predicted by the standard model have been observed. However, the success of the standard model depends on a mechanism to break the electroweak symmetry. Without that, the W and Z bosons would remain massless.

The Higgs mechanism is the most promising way to break the electroweak symmetry. It gives mass to the electroweak bosons and it leaves the photon massless. The same Higgs field can be used to give mass to the quarks and leptons. An essential prediction of the Higgs mechanism is the existence of a yet unobserved particle: the Higgs boson (H).

Through radiative corrections, the mass of the top quark and the mass of the W boson depend on the mass of the Higgs boson. Precision measurements of these parameters, and many others, at LEP, SLD and the Tevatron can thus be interpreted in the standard model as a prediction for the mass of the Higgs boson. At the time of this meeting, the central value for this prediction [1)] was $m_{\mathrm{H}} = 76^{+33}_{-24}$ GeV, leading to an upper limit [1] of 144 GeV. Including the direct Higgs mass limit from LEP [2)] of 114.4 GeV raises this upper limit to 182 GeV. The Higgs boson is thus expected to have a relatively low mass, within reach of the Tevatron experiments.

2 Low mass Higgs and the Tevatron

The Tevatron is a $p\bar{p}$ collider at Fermilab, near Chicago, running at a centre-of-mass energy of 1.96 TeV. The two general-purpose experiments D0 and CDF have collected a data sample corresponding to an integrated luminosity of about $3.7\,\mathrm{fb}^{-1}$. The results shown in the following are based on datasets of up to $1.9\,\mathrm{fb}^{-1}$.

At the Tevatron, the dominant production mode for a low mass Higgs boson ($m_{\mathrm{H}} \lesssim 140$ GeV) is the gluon fusion process. The dominant decay mode for the Higgs boson is to the kinematically allowed heaviest particle, in this case to a $\mathrm{b\bar{b}}$ quark pair. Experimentally the combination of gluon fusion and $\mathrm{b\bar{b}}$ decay is unfeasible due to the enormous background from dijet production. The next most dominant production modes are those where the Higgs is produced in association with a W or Z boson. In this case the $\mathrm{H} \rightarrow \mathrm{b\bar{b}}$ decay mode is accessible, using the leptonic or invisible decay modes of the W and Z bosons.

The search for a low mass Higgs boson at the Tevatron is thus a search for a pair of jets originating from b-quarks in association with a leptonic or

[1] All limits quoted in this contribution are given at 95% C.L.

invisible W or Z signature. For WH $\rightarrow \ell\nu b\bar{b}$, the expected cross section times branching ratio (for one lepton flavour) is of the order of 20 fb at a Higgs mass of 105 GeV down to 4 fb at 140 GeV. The same quantity for ZH production with the Z decaying invisibly to neutrinos is essentially the same as that for WH for one lepton flavour. ZH production with the Z decaying to an e, μ, or τ pair is about a factor of five below that.

Tagging a jet as originating from a b-quark is an important ingredient of this search. Both experiments use combinations of variables sensitive to the presence of B-mesons, such as a reconstructed secondary vertex, large track impact parameters with respect to the primary vertex and the secondary vertex mass, to obtain efficient b-tagging algorithms. As an example, D0's neural net tagger [3] obtains a 50% b-tag efficiency for a mis-tag rate of 0.5% ("tight" tag) and 74% efficiency at 5% mis-tag rate ("loose" tag). Typically, in analyses either two loose b-tags or one tight b-tag are required (exclusively).

3 Low mass Higgs searches at the Tevatron

In the following sections, the current state of the various low mass Higgs searches at D0 and CDF is described. Common to all analyses is the clean signature of the decay of a Z or W boson as one or two high momentum leptons (only electrons and muons are considered; leptonic τ decays are typically included) and/or large missing transverse energy due to undetected neutrinos. The Higgs boson decay has the signature of two or more (due to initial or final state radiation) jets.

Background sources include production of a W or Z boson in association with jets (including b-quark jets), production of top-quark pairs or a single top, and diboson production (WW, WZ, ZZ). The amount of background from these processes is estimated from Monte Carlo simulation of the physics process (with generators like ALPGEN, PYTHIA and HERWIG) and the detector response. Another source of background is that where a jet in a multijet event, which are abundantly produced, is misidentified as a lepton from a W or Z boson decay, and where energy mismeasurements lead to missing transverse energy. This source of background is typically estimated from the data itself.

3.1 Two charged leptons: ZH $\rightarrow \ell\ell b\bar{b}$

The event signature of ZH $\rightarrow \ell\ell b\bar{b}$ production is very clean: two isolated leptons with an invariant mass close to the Z boson mass, and two jets. Both D0 and CDF have analyzed datasets corresponding to $\simeq 1\,\mathrm{fb}^{-1}$ of integrated luminosity. No updates were made recently.

The CDF collaboration applies a constrained fit using the measured jet energies and missing transverse energy to improve the jet energy measurement.

To gain acceptance, D0 has rather low transverse momentum cuts on the leptons. In spite of these differences between the analyses, the final sensitivity to a Higgs boson signal is similar. Both collaborations use neural networks to improve the sensitivity over that obtained using the dijet invariant mass.

The dijet mass distribution found by D0, after requiring both jets to be b-tagged is shown in fig.1 (left). The expected Higgs boson mass peak is clearly visible, but the amount of background, in particular from Z+b$\bar{\text{b}}$ production is large. CDF uses a two dimensional neural network, trained against Z+jets and top-quark pair production. A slice of the final CDF neural network output distribution is shown in fig.1 (right). The Higgs boson signal clearly peaks towards large output values.

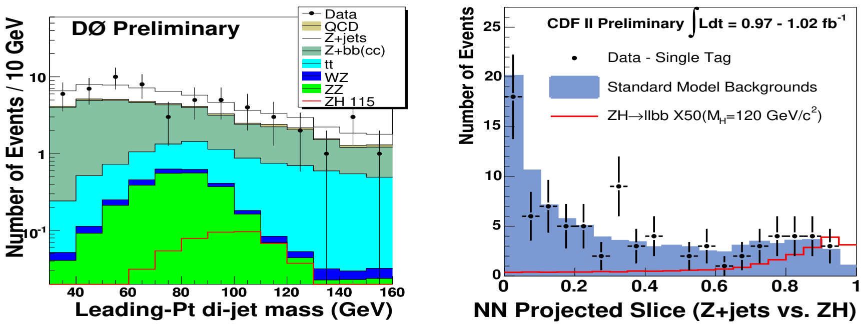

Figure 1: Dijet mass distribution obtained by D0 in the ZH $\to \ell\ell b\bar{b}$ analysis after requiring two b-tags in the event (left) and a slice of CDF's neural network output in the same search channel (right).

Neither D0 nor CDF finds an excess, and the data agree well with the background model. The neural network distributions are then used to derive limits on the Higgs boson production cross section. At a Higgs mass of 115 GeV, D0 finds a limit of 18 (20 expected) times the expected standard model cross section times branching ratio of H $\to b\bar{b}$, whereas CDF finds 16 (16 expected).

3.2 One charged lepton: WH $\to \ell\nu b\bar{b}$

Removing a lepton from the final state described in the previous section, and instead requiring some missing transverse energy leads to the final state corresponding to WH $\to \ell\nu b\bar{b}$ decays.

In this channel, D0 has analyzed a data set corresponding to an integrated luminosity of 1.7 fb^{-1}. Fig.2 (left) shows an example of the total background levels and the contribution from multijet production, in events with a W boson candidate and two jets. For an expected WH signal contribution ($m_{\mathrm{H}} = 115$ GeV) of 9.9 events, a background of 33.5k events is expected. The dominant background source is production of a W boson in association with jets (white histogram), and the next most significant background source is that of multijet production (red histogram). The final discriminant variable in the D0 analysis is the output of a neural network, trained to separate Higgs boson signal from background. The distribution is shown in fig.2 (right), for events where both jets are b-tagged. At this analysis stage, the expected number of signal events is 2.3, with a background of 204 events.

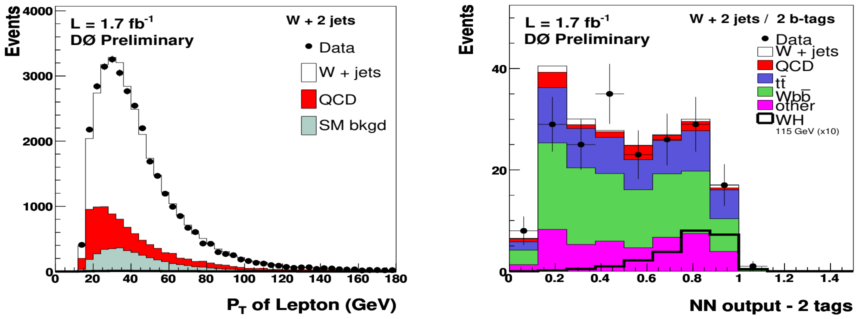

Figure 2: Distribution of the transverse momentum of the lepton in the D0 WH $\rightarrow \ell\nu b\bar{b}$ analysis, before b-tagging requirements are applied to the two jets (left), and the final neural network output distribution for events where both jets are b-tagged (right).

The CDF collaboration has released new results in this search channel with a slightly larger integrated luminosity ($1.9\,\mathrm{fb}^{-1}$). The b-tagging classification was extended to two double-tag and one single tag category (all exclusive). Moreover, CDF has already included the forward-going electrons ("plug" electrons) in the analysis. An example of that is shown in fig.3 where on the left the final neural network output distribution is shown for the events with a "central" electron or muon, and on the right that for events with a "plug" electron. The expectation is to find 0.09 WH events in the plug region (electron only), to be compared to 0.94 in the central region (electron and muon combined). This 10% increase in signal acceptance comes at the cost of larger relative background levels (14.2 events in the plug region versus 80.4 in the central region).

Again, both D0 and CDF find good agreement between the data and the expected background, without any sign of a Higgs boson signal. Therefore, cross section limits for Higgs boson production are derived using the final neural network output distributions. D0 finds, at an assumed Higgs mass of 115 GeV,

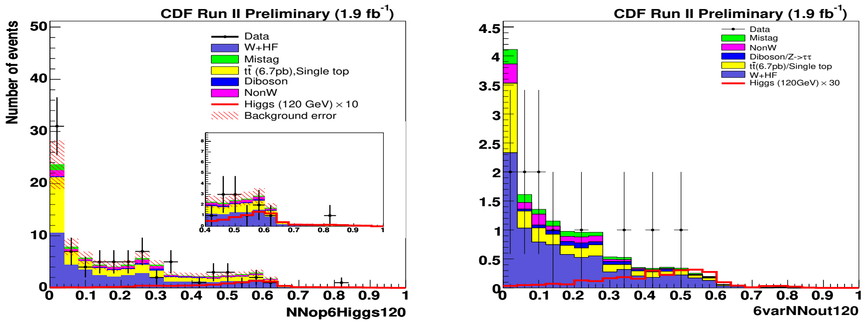

Figure 3: Neural network output distributions obtained by CDF in the WH $\rightarrow \ell\nu b\bar{b}$ analysis for central electrons and muons (left) and forward going electrons (right).

a limit of 11.1 (9.1 expected) times the standard model expectation, and CDF find 8.2 (7.3 expected). The CDF result is better than the current D0 result, but an improved analysis from D0, using forward electrons, three-jet events and an improved neural network, will be finalized in the near future.

3.3 No charged leptons: ZH $\rightarrow \nu\nu b\bar{b}$

Removing the lepton from the final state described in the previous section leads to the signature of ZH $\rightarrow \nu\nu b\bar{b}$ events.

In this case, the multijet background in the analysis is caused by events in which the energy of the jets is mismeasured, leading to missing transverse energy. The level of this background contribution can be estimated by using the fact that if the energy of one jet is mismeasured, the missing transverse energy will point in the jet direction. Also, the missing energy calculated using tracks will be different from the calorimeter based missing energy in the case of a calorimeter mismeasurement. The D0 collaboration also uses the asymmetry between missing energy calculated with all calorimeter information and missing energy using the reconstructed jets as a measure of multijet production (as shown in fig.4 (left)). CDF has used a dedicated neural network to separate the multijet background from others (shown in fig.4 (right)).

Both D0 and CDF train a neural network to improve the sensitivity of the analysis, as compared to considering the dijet mass distribution only. In the absence of a signal excess, D0 finds a cross section limit at a Higgs boson mass of 115 GeV of 13 (12 expected) times the standard model expectation, using a relatively small dataset of $0.9\,\mathrm{fb}^{-1}$. A new analysis from the CDF collaboration, using an integrated luminosity of $1.7\,\mathrm{fb}^{-1}$, leads to a limit of 8.0 (8.3 expected) times the standard model expectation.

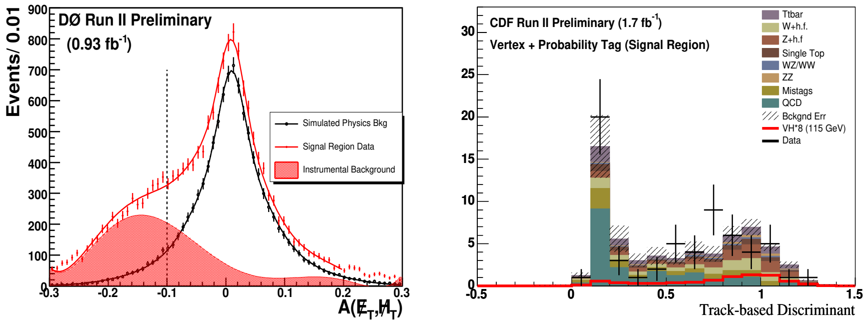

Figure 4: Distribution of the missing transverse energy asymmetry as defined by D0 in the ZH $\rightarrow \nu\nu b\bar{b}$ analysis, before b-tagging (left) and distribution of the neural network output used by CDF to isolate multijet production, after b-tagging (right).

3.4 Tevatron combination

All analyses presented in the preceding sections specifically search for a standard model Higgs boson (at low mass). For optimal sensitivity, the individual search results of the two experiments can then be combined, assuming standard model branching ratios and cross sections. At the time of this meeting, the new CDF results in the WH $\rightarrow \ell\nu b\bar{b}$ and ZH $\rightarrow \nu\nu b\bar{b}$ channels were not included yet in the most recent Tevatron combination [4)].

The log-likelihood-ratio test statistic of the Tevatron combined Higgs boson search is shown in fig.5 (left), for both a pure-background hypothesis (black dashed line) and a signal-plus-background hypothesis (red dashed line). The separation between these two gives a measure for the sensitivity, and from the figure it becomes clear that the sensitivity of the low mass Higgs boson searches is smaller than that for a high mass Higgs boson. This is mostly due to the different production and decay processes, and consequently background levels for low and high mass searches. In fig.5 (right) the combined cross section limit is given, as a ratio to the expected standard model cross section. At a Higgs boson mass of 115 GeV, the combined limit is a factor 6.2 (4.3 expected) times the standard model cross section.

4 Conclusion and outlook

In spite of extensive searches the Higgs boson has not been observed yet by the Tevatron experiments CDF and D0. However, the combined cross section limit for a Higgs boson mass of 115 GeV is only a factor 6.2 (4.3 expected) away from the cross section predicted by the standard model.

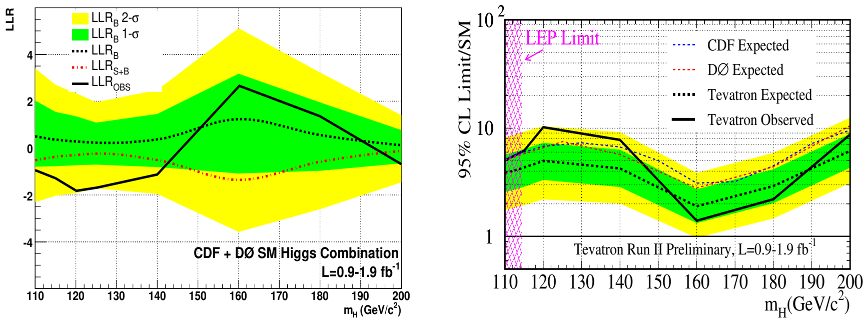

Figure 5: Tevatron combined Higgs boson search result given as the measured and expected log-likelihood-ratio test statistic (left), and as the cross section limit divided by the expected standard model cross section (right).

The prospects for an exclusion of the existence, or even an observation of the Higgs boson over a wide mass range are very good. The data sample accumulated by 2010 is expected to have a size of 7 to 9 fb^{-1}, which is a factor four to eight more than what was used for the results presented here. Also, the improvements of the analyses over the last few years have shown an increase in sensitivity proportional to the accumulated integrated luminosity. For the near future, this trend is expected to continue, with additional improvements in, e.g., b-tagging, jet energy resolution, multivariate techniques and lepton identification.

5 References

References

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