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Search for high mass Standard Model Higgs bosons at the Tevatron in the main channels

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Up to 8.2 fb^{-1} of data collected at the Tevatron experiments, CDF and DØ, have been analyzed to search for the Standard Model Higgs boson. We present here the results of the di-leptons + missing transverse energy channels, which probe the high mass range, $m_H > 135$ GeV, for the Higgs particle.

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1. Introduction

Electroweak symmetry breaking is a fact of nature, but the details of the mechanism are not yet fully explored and understood. In the Standard Model of particle physics, electroweak symmetry breaking is due to a single elementary scalar field doublet, which also yields a yet to be observed scalar particle, the Higgs boson. In this model the only unknown is the Higgs boson mass.

Direct searches for the Higgs has been conducted in the past at the LEP collider yielding the constraint $m_H > 114.4$ GeV [1]. Indirect constraints arising from precision measurements of electroweak observables give an upper bound of $m_H < 185$ GeV [2]. The narrow remaining mass range is suitable for searches at the Tevatron $p\bar{p}$ collider, at the center-of-mass energy of 1.96 TeV of Run II. Indeed, in early 2010 both Tevatron experiments, CDF and DØ, have extended the direct constraints on the Higgs boson by publishing the combined result of their searches [3]. Using up to 5.4 fb^{-1} of data they exclude the existence of a SM Higgs boson in the mass range $[163-164]$ GeV at 95% CL.

In summer 2011 a few months before the Tevatron final shutdown, up to 8.2 fb^{-1} of the final full dataset of approximately 10 fb^{-1} per experiment have been analyzed by the CDF and DØ collaboration to search for the Higgs boson. This proceedings presents the status of the search by the Tevatron collaborations for Higgs bosons at high mass, namely for $m_H > 135$ GeV, in the di-lepton+ missing transverse energy ($\not\!\!E_T$) channels. Other search modes at high mass are discussed elsewhere in this proceedings [4]. All limits hereafter are given at 95% CL.

2. Production, decays and search channels

The dominant Higgs boson production mode is the gluon fusion process, $gg \to H$, with a cross-section going from 1200 to 300 fb for the mass range $[115-180]$ GeV. An additional yield arises from the associated production modes $q\bar{q} \to WH$, $q\bar{q} \to ZH$, and also from the vector boson fusion process, $q\bar{q} \to Hq\bar{q}$, which are roughly one order of magnitude more seldom than $gg \to H$.

The high mass range is defined at Tevatron by $m_H > 135$ GeV. Above this mass, the decay to a pair of W bosons, $H \to WW$, is dominant and reaches almost 100% at 165 GeV. For mass lower than 135 GeV, the Higgs boson decays predominantly into a pair of b-quarks.

To search for the Higgs boson at high mass one has to look to the W decay products. The easiest signature arises from the simultaneous leptonic decays of both W bosons to electrons or muons. This gives rise to the opposite sign (OS) di-lepton + $\not\!\!E_T$ signature, which has actually a small chance to occur ($\simeq$ 6%), but presents the advantage of a clear signal.

Another di-lepton plus $\not\!\!E_T$ signature arises from the associated production of the Higgs and a W, followed by $H \to WW$. In this case it can be searched for two same sign (SS) leptons + $\not\!\!E_T$. This constitutes a very distinct kind of events.

3. Backgrounds

The main irreducible backgrounds to the di-lepton plus $\not\!\!E_T$ channel arise from the electroweak production of di-boson (WW, WZ, ZZ). Next to Leading Order calculations are employed to assess the rate of those backgrounds, and in particular to model the WW system p_T and the di-lepton opening angle.

The Drell-Yan process, Z/γ^*+jets, is also an important source of background as mismeasured jets or lepton momentum can yield $\not\!\!E_T$. Data based correction of the Z recoil are employed to simulate this background.

The W+jets and $W+\gamma$ production can also yield two observed leptons whenever the jets or γ fake a lepton. Data driven model are employed to assess their contributions to the total background.

Top-quark pairs decay into two W bosons and b-quarks. This can also produce two leptons and $\not\!\!E_T$. This background can be rejected because of its higher jet multiplicity and the presence of heavy flavors in the jets.

Finally, multijet (QCD) events, where the mismeasured jets fake leptons and creates $\not\!\!E_T$ are also present in the final selection of candidate events. Their contribution is assessed thanks to data control region.

4. Analysis in di-lepton +$\not\!\!E_T$ channels

The OS selection demands first two isolated, opposite sign, high p_T leptons. This requirement gets rid of most of the W+jets and QCD background. The measured $\not\!\!E_T$ and other $\not\!\!E_T$ based quantities are employed to suppress the Drell-Yan background. Close to the threshold of $H \to WW \to \ell\nu\ell\nu$ decay, as the Higgs is scalar at rest and, because of the V-A interaction, the final leptons tend to be collinear. This distinct topology allows to discriminate against the di-boson background.

The SS analysis follows a very similar selection. In addition, well measured tracks are demanded to ensure a good measurement of the charge and suppress the Drell-Yan and WW background. The presence of jets arising from the third vector boson in case of Higgs boson production is also a good way to enhance the discrimination against the background.

The general strategy consists in preselecting events with two isolated high p_T leptons, geting rid of the dominant Drell-Yan background, and then splitting the analysis into subchannels with different signal/background ratio to maximize the discriminating power of the analysis. Namely, the selections are split according to the lepton flavor (electron or muon) in DØ and the lepton reconstruction quality at CDF. Thus each subchannel has a different instrumental background, a different momentum resolution and a better sensitivity is achieved. The OS channels are further broken down into jet multiplicity bins, that each have a different dominant background (WW for the 0 jet case, WW and Z/γ for the 1 jet case, top pairs for the ≥ 2 jets case). The low di-lepton mass requirement, $M_{\ell\ell} < 16$ GeV, defines an additional subchannel for the OS final state at CDF, to which the $W+\gamma$ is the dominant background.

To further increase their sensitivity, the analyses also make use of multivariate techniques, boosted decision trees, artificial neural networks and matrix element computation. They combine into a single discriminant many pieces of information that describes the event topology, the lepton kinematics, the lepton quality, the jet activity and $\not\!\!E_T$ related variables, that gauge whether the $\not\!\!E_T$ is genuine or due to a mismeasured object. They are optimized for each subchannel and each tested Higgs boson mass hypothesis. These techniques may be used more than once per subchannel; for example, the DØ ee and $\mu\mu$ OS analysis employ specific decision trees to reject Drell-Yan events

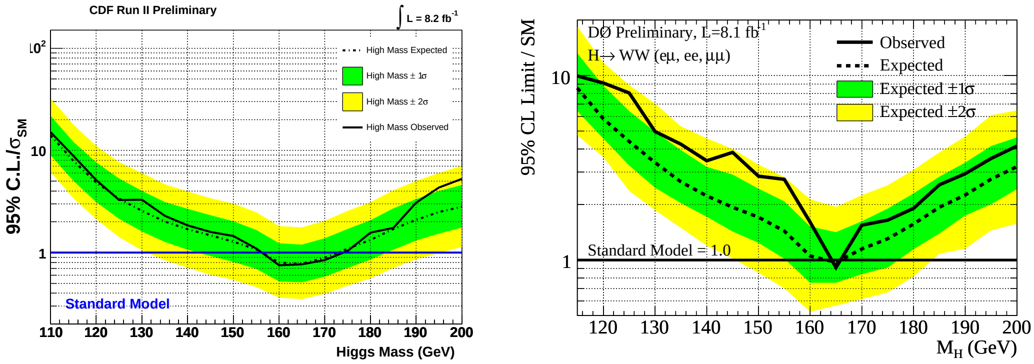

Figure 1: Limits on the Higgs boson yield obtained after combining all WW channels for CDF (left), or after combining the DØ di-lepton OS channels (right).

and then other decision trees to discriminate against the remaining backgrounds. At CDF, the matrix element calculation, which has the 4-vectors of the event reconstructed objects as inputs, is itself an input to the final neural network discriminant.

For all channels, a final multivariate discriminant is employed for the statistical analysis of the data. It gauges whether the data are signal-like or background-like and allows to derive limits on the Higgs boson yield in the case when no signal-like excess has been observed. This analysis accounts for the systematic uncertainties on both the signal and the backgrounds, their correlations and the way the uncertainties may modify the shape of discriminant variables. The systematic uncertainties degrade the sensitivity by 15 to 25%.

5. Results

The di-lepton+$\not\!\!E_T$ results benefit from several improvements compared to what was presented at the winter 2011 conferences. At CDF, the amount of analyzed data has increased from 7.1 to 8.2 fb^{-1}. The leptons acceptances have been enhanced thanks to additional lepton definitions and triggers. In addition a modified lepton isolation algorithm has been implemented to prevent self-spoiling of narrowly separated lepton pairs. At DØ, the same 8.1 fb^{-1} sample as for the winter conferences has been analyzed in the OS channel, but with modified selection cuts and systematic treatments in the $e\mu$ case. In addition, the 8.1 fb^{-1} 4^{th} generation interpretation has been finalized. Also the 5.3 fb^{-1} SS analysis has been released for publication [5].

As no significant excess has been observed in these channels limits are derived on the Higgs boson yield as a function of its mass [6, 7]. They are presented in Figure 1. These limits read $\sigma_{95}/\sigma_{SM} = 0.77$ (0.78 expected) for $m_H = 165$ GeV when using all WW channels at CDF. At DØ the limits are $\sigma_{95}/\sigma_{SM} = 0.78$ (0.90 expected) for the OS $ee + \mu\mu + e\mu$ combination at $m_H =$ 165 GeV.

As of 2011, thanks to refined techniques and the amount of data analyzed, both experiments have individually reached the sensitivity to exclude a range of mass around 165 GeV. For this conference, the expected range in exclusion are $[156-173]$ GeV for CDF and $[159-169]$ GeV for DØ.

The search for OS di-leptons can be re-interpreted within the framework of a 4th generation of heavy fermions. In this class of models the gluon-gluon-Higgs coupling is scaled by roughly a factor of 3 with respect to the Standard Model coupling and the $gg \to H$ process is enhanced by a factor of 9. As no significant excess of events have been found above the background expectations, CDF and DØ exclude respectively the Higgs boson mass range of $[123-215]$ GeV and $[140-240]$ GeV.

6. Conclusion

CDF and DØ presented updates of their searches for the Standard Model Higgs bosons and di-lepton $+\not\!\!E_T$ channels at high mass. Both experiments are individually sensitive to the production of the Higgs boson at mass around 165 GeV. These channels are part of the combined results presented by each collaboration and the full Tevatron combination discussed elsewhere in this proceedings [8, 9].

As the Tevatron has stopped taking collision data in September 2011, the sample of analyzed data will not grow much. CDF and DØ have to focus on analysis refinements to enhance the sensitivity to $H \to W^+W^-$. Combined with the Tevatron "low mass channels", the so called "high mass channels" have actually a significant role to play to help to cover the $[115-135]$ GeV mass ranges for the Higgs boson searches.

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