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Search for low mass Higgs at the Tevatron (ZH and $H \to \gamma\gamma$)

Michele GIUNTA*
Fermilab, Kirk Road Batavia, IL 60510 USA
E-mail: michele.giunta@pi.infn.it

The Higgs search results at the Tevatron are described for the channels where the Higgs decays in two b-jets (SM) or two photons (Fermiophobic model) in the final state. The Tevatron, to date, is approaching the SM cross section sensitivity for low Higgs masses, while in the recent past it reached the SM sensitivity in the high mass domain. Results and techniques are reported.

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*Speaker.

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1. Introduction

The Standard Model (SM) provides the particle (bosons, fermions) masses by means of the Higgs mechanism. This is a well motivated hypothesis, but to date no experimental evidence of the Higgs boson was found. The mass of the undiscovered Higgs Boson is not provided by the SM, but constrains can be put on its mass making use of the measured masses of particles having a strong interaction with it, like the W boson or the top quark. The latest of such constraints is $M_H < 165\ GeV/c^2$ at 95% CL. There also are direct searches of this particle. The most tight limit before the Tevatron results was set by LEP, excluding SM Higgs with $M_H < 114\ GeV/c^2$.
Nowadays the Tevatron is the only accelerator being able to search for the Higgs in the $114 < M_H < 163\ GeV/c^2$ region. The Tevatron is an hadron collider where collisions of a proton and an antiproton beam collide at $\sqrt{s} = 1.96\ TeV$.
We report here the latest results in the Higgs boson searches at the Tevatron in three channels. Results come from the two experiments studying collisions provided by the Tevatron: CDF and D0. Both the experiments collected about 6 out the 7 fb^{-1} delivered by the Tevatron and are presently taking data.

2. Production and Decay

At the Tevatron energy, the most relevant SM Higgs production mechanisms are gluon-gluon fusion (two gluons interact via a top loop, resulting in an Higgs), Higgs-Strahlung (a W or Z boson from the initial state radiates an Higgs boson) and Vector-Boson fusion (VBF: each of the two quark in the initial state radiates an intermediate boson, the two of them interact giving an Higgs in the final state).
The Higgs production cross-section is expected to be $< 1\ pb$, while the background processes to the study of the relevant channels are several orders of magnitude larger. An efficient online selection is required to collect as more signal as possible. The study of an Higgs produced by gluon-gluon fusion is very cumbersome if associated to a $H \to b\bar{b}$ decay, because the multijet production largely overwhelms the signal. On the other hand, an associate production of an Higgs with a W or Z boson provides a good trigger whenever the W decays leptonically or the Z decays into a neutrino pair or an electron or muon pair.
An Higgs boson produced by VBS or Higgs-Strahlung and decaying into a photon pair is also affordable, in particular in the fermiophobic model context, because this model suppresses the gluon-gluon fusion production, but greatly enhances the $H \to \gamma\gamma$ branching ratio.

3. Analysis tools

At the Tevatron we apply a number of techniques to separate at best the large backgrounds from the tiny Higgs expected signals. First, we designed dedicated triggers for the online selection of events matching the expected signatures for the Higgs decays under study.
The offline studies enhance the signal acceptance by making use of a number of lepton categories of different quality and optimize the signal/background separation for each of them.
When two b-jets are present in the final state, CDF and D0 make use of b-tagging algorithms, devoted to the identification of heavy-favoured jets from the light ones. This is possible mainly by

searching for secondary vertices, which are typical of b-jets. The long-living B-hadron inside a b-jet, in fact, can fly hundreds of μm before hadronizing and produces an additional decay vertex which is often detectable. Flavor separator Neural Networks are also used to add kinematic informations to the secondary vertex ones and provide an efficient tool to identify b-jets.
Advanced multivariate techniques such Boosted Decision Trees (BDT) and Neural Networks (NN) are used as discriminators.

4. $ZH \rightarrow \nu\nu b\bar{b}$

The signature of this search has a large imbalance on the transverse energy (Missing E_t, $\not{E}_T$) and two b-jets in the final state. The production can be either an Higgs associated with a Z ($Z \rightarrow \nu\nu$) or with a W ($W \rightarrow \ell\nu$ when the lepton is not identified or escapes the detection). Events are triggered by an high-p_t electron or muon and a large $\not{E}_T$. The larger backgrounds are W/Z in association with jets and QCD activity with instrumental $\not{E}_T$. Both CDF and D0 analyzed to date 2.1 fb^{-1} of data and apply a pre-selection requiring two or three jets in the event and a large $\not{E}_T$.
CDF separates the events in three orthogonal b-tag samples [1] with different S/B ratios, then applies a NN trained to identify the QCD events. A cut on the output of the NN operates as a further selection before the events are examined by an additional NN whose output is used as a discriminant between signals and backgrounds.
D0, after the pre-selection, applies a flavor separator [2] to the events before applying a BDT technique to obtain the final discriminator.
There is no Higgs evidence in this channel, but a limit can be set by making use of the final discriminators provided by the analyses. The two experiments set limits on the SM Higgs production cross-section. For a number of Higgs hypothetical masses between 100 GeV and 150 GeV, the limit is given in units of the SM expected cross-section at 95% CL. In particular, for the mass of 115 GeV, CDF observes a limit of 6.9 and D0 a limit of 7.5.

5. $ZH \rightarrow \ell\ell b\bar{b}$

When the Higgs is produced in association with a Z boson and the $Z \rightarrow \ell^+\ell^-$, a clean signature is provided by the two electrons or muons in the final state. The two b-jets from the Higgs decay are then useful to suppress part of the background processes giving light jets in the final state. A trigger requiring high-p_t electrons or muons is used. Most of the background come from Z+jets, top quark production or dibosons. An useful feature of this channel is the presence of the two H and Z resonances allowing to fully reconstruct the final states. The sensitivity is improved by separating the leptons with tight and loose definitions in order to provide more accurate S and B comparisons.
CDF analyzed 2.7 fb^{-1} [3]. After the identification of the Z candidates, the data sample is divided into 6 subsamples depending on the b-tag definition and the S/B ratio. one 2-dimensional NN is trained for each subsample in order to simultaneously separate the signal from the Z+jets and the $t\bar{t}$ backgrounds. This technique allows to set a limit of 7.1 times the SM cross section for the 115 GeV Higgs mass.
D0 processes 4.2 fb^{-1} [4] and divides the data in 4 subsamples: events with electrons or muons

can be identified with tight and loose lepton definitions. Each event can then be assigned to a loose or a tight b-tag category. The 8 resulting subsamples are analyzed with a BDT. The combined limit set by D0 is 9.1 times the SM cross section for the 115 GeV Higgs mass.

6. $H \to \gamma\gamma$

Two photons provide the trigger to select candidate events from the processes $VBF \to qqH$ or $VH \to \ell\ell' H$ when $H \to \gamma\gamma$ (V=W,Z). The other objets in the final state are considered altogether by requiring $p_t(\gamma\gamma) > 75\ GeV$ (CDF) or 35 GeV (D0).
CDF analyzes 3.0 fb^{-1} [5] and models the background shapes by using the data (excluding a window around the probed Higgs mass), then compares the data $M_{\gamma\gamma}$ distribution with the simulated signal one. Under the fermiophobic hypothesis, the limit of $M_H > 106\ GeV$ is set.
D0 analyzes 4.2 fb^{-1} [6] and makes use of a NN trained to separate photons from jets. Using $M_{\gamma\gamma}$ distribution as a discriminant, the limit $M_H > 102\ GeV$ is set when using the fermiophobic theoretical cross sections. In the SM assumption, D0 computes a limit of 15.8 times the SM Higgs cross-section for the mass of 115 GeV [7].

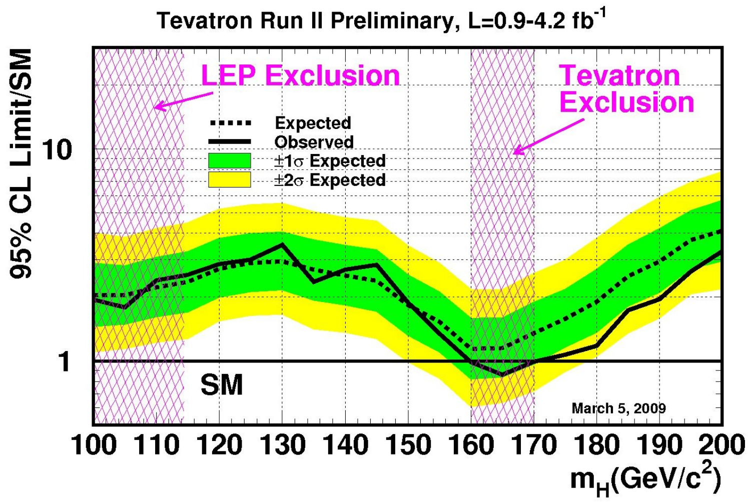

Figure 1: *Tevatron combination of limits on the SM Higgs cross-section. The limits are expresses in units of SM cross-section at 95% CL. The analyses reported here contribute to the limits in the* $[100;150]$ *GeV range together with the results from the* $WH \to \ell\nu b\bar{b}$.

7. Conclusions

No Higgs signals were found at the Tevatron in the low mass domain. Nevertheless, the two experiments CDF and D0 are approaching the sensitivity needed to probe cross sections as small as the expected ones for the studied Higgs channels (Figure 1) [8].
It was observed that the use of advanced techniques, as well as their fine tuning, is enhancing the analysis sensitivity faster than the bare data amount increase (faster than $\sqrt{\int L}$).

References

[1] CDF Public Note 9642

[2] D0 Public Note 5586

[3] CDF Public Note 9665

[4] D0 Public Note 5876

[5] arXiv:0905.0413 [hep-ex] 9 Jul 2009. Search for Fermiophobis Higgs Boson Decaying into Diphotons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96 TeV$

[6] D0 Public Note 5880

[7] D0 Public Note 5858

[8] CDF Public Note 9713 and D0 Public Note 5889; FERMILAB-PUB-09-060-E