BSM Higgs and other Bump Searches at the Tevatron

Émilien Chapon[1] on behalf of the CDF and DØ collaborations

[1]CEA, F91191 Gif-sur-Yvette, France

DOI: `http://dx.doi.org/10.3204/DESY-PROC-2012-02/279`

In Beyond Standard Model (BSM) theories such as supersymmetry, the electroweak symmetry breaking mechanism predicts one or several Higgs bosons with different masses and couplings to other particles compared to the Standard Model (SM) one. We present the constraints on BSM theories originating from searches for exotic Higgs bosons from the CDF and D0 collaborations at the Tevatron. In addition, searches for excesses in other channels will also be presented, such as in the dijet mass spectrum in W+2jets events.

The Minimum Supersymmetric Standard Model (MSSM) requires two Higgs doublets, which couple to respectively up-type and down-type quarks, with vacuum expectation values (vev) of respectively v_u and v_d. The ratio of the two vevs is denoted $\tan\beta = \frac{v_u}{v_d}$. It is worth noting that large values of $\tan\beta$ look natural, as for instance $\tan\beta \approx \frac{m_t}{m_b} \approx 35$.

In the MSSM, there are five physical Higgs bosons: three neutral (denoted H, h and A) and two charged (H^+ and H^-). The three neutral Higgs bosons are collectively denoted ϕ.

A nice feature of the coupling of the Higgs boson to b quarks is that it is enhanced with $\tan\beta$, which leads to an enhanced production cross section $\sigma(p\bar{p} \to \phi)$ compared to the Standard Model. In addition to this effect, two of the three neutral Higgs bosons become degenerate in mass, which effectively doubles the production cross-section. Finally, the branching ratio is also modified: at high $\tan\beta$, we have $\mathcal{B}(\phi \to b\bar{b}) \approx 90\%$ and $\mathcal{B}(\phi \to \tau^+\tau^-) \approx 10\%$, while other decay modes are suppressed compared to the SM.

At tree level, the MSSM Higgs sector is fully described by two parameters: $\{m_A, \tan\beta\}$. However, radiative corrections make it more model-dependent for the $\phi \to b\bar{b}$ decay mode.

1 MSSM

Searches for a MSSM neutral Higgs boson are performed by both the CDF and DØ experiments in its main decay channels.

$\phi \to \tau\tau$ **(inclusive):** An inclusive $\phi \to \tau\tau$ search has been performed by both the CDF (in the $\tau_\mu\tau_{\rm had}$, $\tau_e\tau_{\rm had}$, $\tau_e\tau_\mu$ final states [1]) and DØ (in the $\tau_e\tau_\mu$, $\tau_\mu\tau_{\rm had}$ [2] and $\tau_\mu\tau_{\rm had}$ [3] final states) experiments. Both experiments did not find any excess in the visible mass spectrum $M_{\rm vis} = \sqrt{(P_{\tau_{\rm h}} + P_{\tau_\mu} + \not{E}_T)^2}$. The dominant backgrounds are Z+jets, but also multijet and $t\bar{t}$.

$b\phi \to b\bar{b}b$ **(associated production):** At high $\tan\beta$, the coupling of the Higgs boson to b quarks is such that $\mathcal{B}(\phi \to b\bar{b}) \approx 90\%$. However, despite of this large branching ratio, and hence relatively large signal, this channel suffers from a very large multijet background, which is also challenging to model because of the large theoretical uncertainties on multijet processes cross sections. To make this analysis possible, both CDF [4] and DØ [5] experiments actually look for the associated production of the MSSM Higgs boson with a b quark (respectively with $2.6\,\mathrm{fb}^{-1}$ and $5.2\,\mathrm{fb}^{-1}$ of data), so that the experimental signature is three to four jets with high transverse momentum p_T, out of which at least three must be b-tagged. The flavor composition of the multijet background is fit using data.

Both experiments use the invariant mass of two of the b-tagged jets to set limits on the production cross section times branching ratio $\sigma(p\bar{p} \to \phi + b_{\mathrm{jet}}) \times \mathcal{B}(\phi \to b\bar{b})$. CDF chooses to consider the two jets with the highest transverse momentum, while DØ uses a likelihood to discriminate signal from background and choose the pair which most likely comes from a Higgs boson decay.

Both experiments see an excess, CDF around 120 GeV with a local significance of $2.0\,\sigma$ and DØ with a local significance of $1.9\,\sigma$. In order to further investigate this excess, a Tevatron combination is in progress, as well as updates to these analyses.

$b\phi \to b\tau\tau$ (associated production): There are several motivations for performing a search for $b\phi \to b\tau\tau$. Compared to $b\phi \to b\bar{b}b$, the results obtained are much less sensitive to model parameters. Moreover this final state benefits from a lower $Z \to \tau\tau$ background compared to the inclusive $\phi \to \tau\tau$ search, thanks to the use of b-tagging.

For these reasons the DØ experiment has performed this analysis in the $\tau_e\tau_{\mathrm{had}}$ ($3.7\,\mathrm{fb}^{-1}$, Preliminary) and $\tau_\mu\tau_{\mathrm{had}}$ ($7.3\,\mathrm{fb}^{-1}$ [6]) final states. To get the best sensitivity from data, the analyzers use multivariate techniques: the multijet and $t\bar{t}$ backgrounds are rejected using two dedicated discriminants, while, because no excess over background is found, limits are set using a final discriminant.

Combination: The DØ experiment has done a combination of different MSSM Higgs searches [3], combining $b\phi \to b\bar{b}b$ ($5.2\,\mathrm{fb}^{-1}$), $b\phi \to b\tau_\mu\tau_{\mathrm{had}}$ ($7.3\,\mathrm{fb}^{-1}$) and $\phi \to \tau_\mu\tau_{\mathrm{had}}$ ($7.3\,\mathrm{fb}^{-1}$).

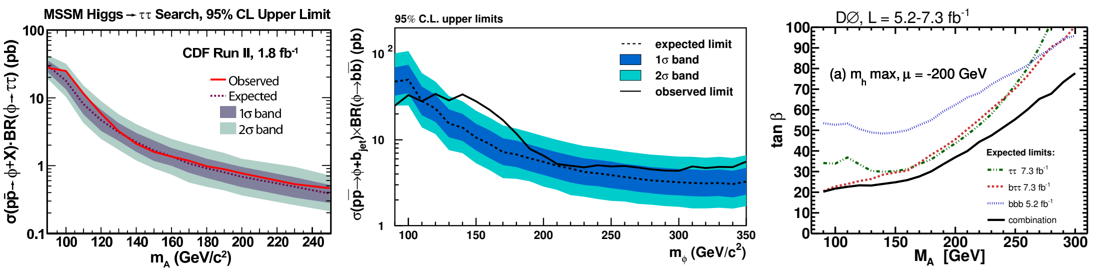

Figure 1: Left: Expected and observed limits on $\sigma(p\bar{p} \to \phi + X) \times \mathcal{B}(\phi \to \tau\tau)$ from CDF [1]. Middle: Expected and observed limits on $\sigma(p\bar{p} \to b + \phi) \times \mathcal{B}(\phi \to b\bar{b})$ from CDF [4]. Right: expected limits on MSSM parameters in the $(m_A, \tan\beta)$ plan from DØ [3]. The contributions from the channels entering the combination are also shown.

2 Looking for excesses in other channels

Analyzers have also looked for resonances predicted by other models.

Hidden Valley: The CDF experiment has looked for Hidden Valley particles ($5.8\,\mathrm{fb}^{-1}$, Preliminary [7]), denoted HV. These are long-lived heavy particles ($c\tau \approx 1\,\mathrm{cm}$), which decay into a pair of b quarks: HV $\to b\bar{b}$. Displaced vertex variables are used, relying on the b-jets impact parameter and the reconstructed HV particle decay length. No excess is found and limits are set on the production cross section.

Doubly-charged Higgs: The models implementing two Higgs triplets predict doubly-charged Higgs bosons, which have been considered by the DØ experiment [8] using up to 7.0 fb^{-1} of data. The branching ratio of such particle depends on the model, but the analysis requires two hadronic taus and one muon in the final state, making it the first analysis looking for $H^{\pm\pm} \to \tau_{\text{had}}\tau_{\text{had}}X$ at a hadronic collider. The analysis is split into four channels, depending on the nature of the two same-sign leptons and on the presence or not of additional leptons. No evidence for signal has been found.

Fermiophobic Higgs search: Various models predict a Higgs boson with reduced, or even forbidden, couplings to fermions. In particular, assuming no coupling to fermions the gluon fusion mode $gg \to H_f$ is forbidden, because of the absence of coupling to heavy quarks. Another feature is that only decays to bosons are allowed (there is no $H_f \to ff$ decay), and hence the branching ratio $\mathcal{B} \to \gamma\gamma$ is greatly enhanced, making this channel dominate the exclusion.

Both the CDF and DØ experiments have released a preliminary result [9, 10] in this model in the $\gamma\gamma$ final state using the full Tevatron dataset (9.7-10 fb^{-1}). DØ uses a decision tree to set limits, and models the background using Monte-Carlo simulations. CDF uses the invariant mass $M_{\gamma\gamma}$ of the two photons to set limits, and estimates the background via a sideband fitting, with a sliding window shadowing the signal region. No excess is found and the Tevatron combination [11] excludes a fermiophobic Higgs mass below 119 GeV/c^2 at 95% C.L.

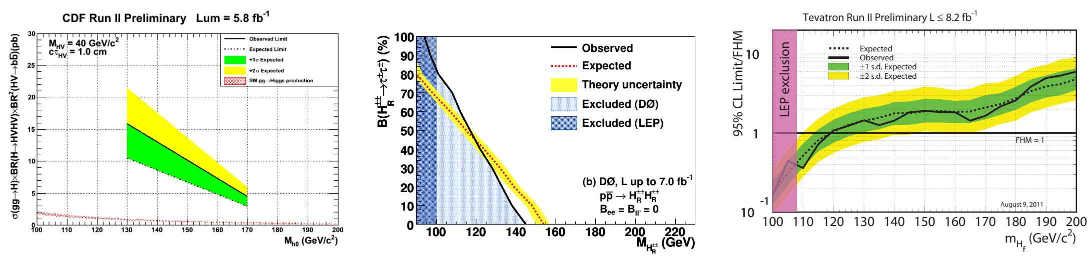

Figure 2: Left: limits on $\sigma gg \to H \times \mathcal{B}(H \to \text{HVHV}) \times \mathcal{B}^2(\text{HV} \to b\bar{b})$ as a function of M_{h_0} as measured from CDF. Middle: limits on $\mathcal{B}(H_R^{\pm\pm} \to \tau^\pm\tau^\pm)$ as a function of M_H, from DØ [8]. Right: Combined Tevatron limits [11] on the fermiophobic Higgs production cross-section, divided by the prediction of the fermiophobic Higgs model, as a function of m_{h_f}.

Dijet mass spectrum in $W + jj$ events: The CDF experiment has found an excess in the dijet mass spectrum in $W + jj$ events, published with 4.3 fb^{-1} [12] and updated to 7.3 fb^{-1}, which they can fit by a Gaussian resonance with cross section $\sigma = 3.1 \pm 0.8$ pb. The DØ experiment, however, has done the same analysis [13] and has excluded the presence of a resonance in this final state that would have a cross-section greater than 4 pb.

Despite many studies, this disagreement between both experiments has not been fully understood yet. CDF is performing several independent analyses with the full dataset to make a final statement on the subject. If the excess is confirmed, DØ will also update its result with the full dataset.

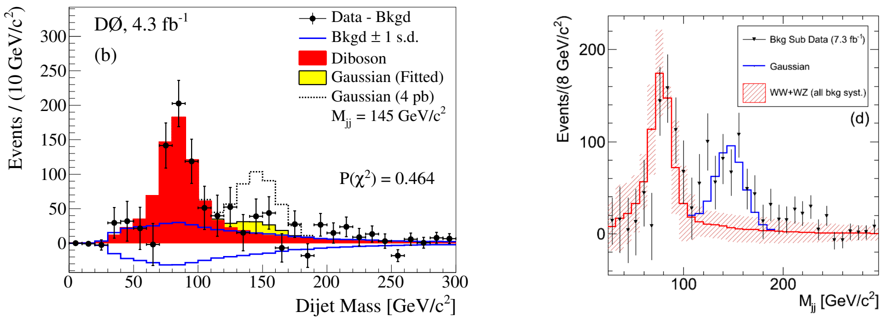

Figure 3: Left: background-subtracted dijet mass spectrum measured by DØ in $W + jj$ events [13], showing the diboson contribution in red. The contribution from a Gaussian signal, which cross-section times branching ratio is either fitted to the data or fixed to 4 pb, is also shown. Right: similar plot from CDF [12], with the fitted contribution from the Gaussian signal.

Conclusion

We have reported selected results from the CDF and DØ BSM Higgs searches. The Higgs sector is a good place to look for new physics, because BSM theories predict Higgs bosons with different properties than the Standard Model one. In the case of the MSSM, analyzers look for its main decay channels at high $\tan\beta$, i.e. $\phi \to b\bar{b}$ and $\phi \to \tau^+\tau^-$. The results from these different analyses can be combined in order to obtain the best sensitivity possible. We have also presented the results in other BSM theories: Hidden Valley, doubly-charged Higgs and fermiophobic Higgs. At last, we have reported the status of the bump search in the dijet mass spectrum of $W + jj$ events.

Most of these results will be legacy results from the Tevatron. However there are still updates to come, for instance from the $b\phi \to b\bar{b}b$ analysis or from a fermiophobic Higgs Tevatron combination with the full Run II dataset.

References

[1] CDF Collaboration, Phys. Rev. Lett. **103** (2009) 201801.
[2] DØ Collaboration, Phys. Lett. **B707** (2011) 323.
[3] DØ Collaboration, Phys. Lett. **B710** (2012) 569.
[4] CDF Collaboration, Phys. Rev. **D85** (2012) 032005.
[5] DØ Collaboration, Phys. Lett. **B698** (2011) 97.
[6] DØ Collaboration, Phys. Rev. Lett. **107** (2011) 121801.
[7] CDF Public Note 10356.
[8] DØ Collaboration, Phys. Rev. Lett. **108** (2012) 021801.
[9] CDF Public Note 10731.
[10] DØ Conference Note 6297-CONF.
[11] Tevatron New Phenomena & Higgs Working Group, `hep-ex/1109.0576`
[12] CDF Collaboration, Phys. Rev. Lett. **106** (2011) 171801.
[13] DØ Collaboration, Phys. Rev. Lett. **107** (2011) 011804.