THE SUPERSYMMETRIC HIGGS BOUNDS AT THE TEVATRON AND THE LHC

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MSSM Higgs bosons are the most promising way to discover Higgs physics at hadronic colliders since their cross section is enhanced compared to that of the Standard Model. We will present theoretical predictions for their production and decay in the Higgs$\to \tau\tau$ channel at the Tevatron and the LHC, focusing on the theoretical uncertainties that affect them. The inferred SUSY Higgs bounds on the $[\tan\beta; M_A]$ plane and the impact of these uncertainties will also be discussed.

1 Introduction

The search for the Higgs bosons which are a trace of the electroweak symmetry breaking[1,2] is the main goal for current high–energy colliders. In the minimal supersymmetric extension of the Standard Model (SM), one of the most attractive solutions of the hierarchy problem in the SM[3], two Higgs doublets are required to cancel anomalies, which then lead to five Higgs states: the CP–even h, H, the CP–odd A and the two charged Higgs bosons $H^{\pm}$.

At tree–level two parameters in the Minimal Supersymmetric Standard Model (MSSM) describe the Higgs sector: the vacuum expectation values (vev) ratio between the two Higgs doublets $\tan\beta = \dfrac{v_1}{v_2}$ and the CP–odd Higgs mass M_A.

At high $\tan\beta$ values, $\tan\beta \gtrsim 10$, either h or H is SM–like and its couplings to other particles are the same as those of the SM Higgs boson, while the other CP–even state behaves as the CP–odd A: same couplings and almost same mass. We will denote these two states as Φ in the next sections. This behaviour occurs in current MSSM Higgs benchmarks scenarios[4] which are considered at the Fermilab Tevatron[5] and the CERN LHC[6,7] colliders.

b–processes are dominant as they are proportionnal to $\tan\beta$ contrary to that of the top–loop. We will thus consider the gluon–gluon fusion Higgs production through bottom quark loop[8,9] and the $b\bar{b}$ fusion channel[10,11,12,13], followed by the Higgs$\to \tau^+\tau^-$ desintegration. Squark loops can be safely neglected while SUSY Δ_b corrections to the $\Phi b\bar{b}$ coupling nearly cancel out in the production cross section times branching ratio calculation[14].

We will present numerical results at the Tevatron and the lHC (LHC at 7 TeV) for $\tan\beta = 1$, which means that we have to multiply by $2\tan^2\beta$ for actual values. Theoretical uncertainties will also be presented and their implications on the MSSM parameter space limits will be discussed. A more detailed discussion can be found in Refs.[14,15,16]

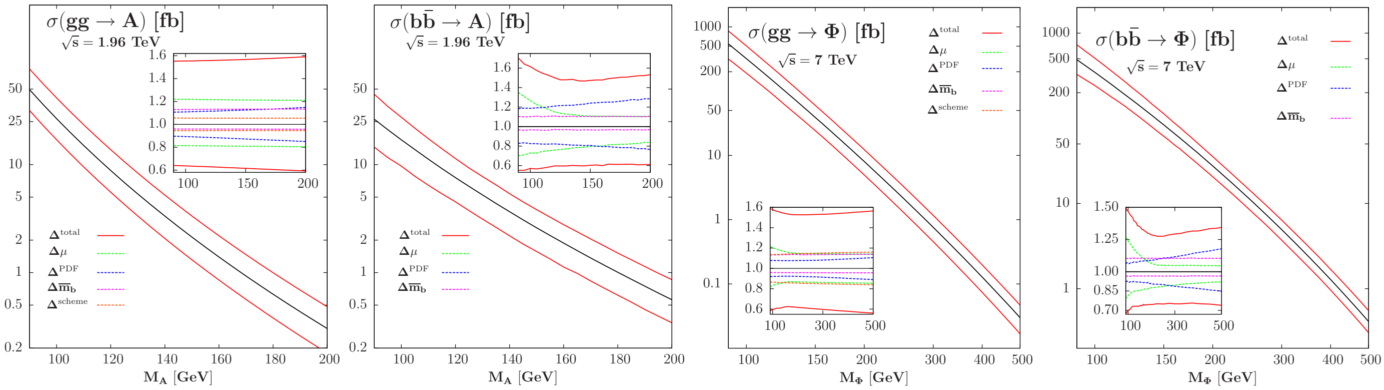

Figure 1: $\sigma^{\rm NLO}_{gg\to\Phi}$ and $\sigma^{\rm NNLO}_{b\bar{b}\to\Phi}$ central cross sections using MSTW 2008 PDFs and $\Phi b\bar{b}$ unit couplings together with total uncertainties at the Tevatron (left) and at the lHC (right). In the insert are shown the individual sources of uncertainties normalised to the central cross section.

2 SUSY Neutral Higgs production at the Tevatron and the lHC

2.1 $gg \to \Phi$ channel

The Higgs bosons in the gluon–gluon fusion channel is produced through top and bottom quarks loops. At $\tan\beta \gtrsim 10$ values the top loop is strongly suppressed because $\Phi t\bar{t}$ is inversely proportionnal to $\tan\beta$ contrary to the $\Phi b\bar{b}$ coupling. Although the top loop is known up to next–to–next–to–leading order (NNLO) in QCD, the b–loop is known up to next–to–leading order (NLO) only[9]. We will use NLO MSTW 2008 parton distribution functions (PDF) set[17]. We consider the standard QCD theoretical uncertainties that have been discussed in Refs.[14,15,16].

It is customary to estimate the uncertainty due to the missing higher order terms in a perturbative calculation by varying the renormalisation scale μ_R and the factorisation scale μ_F around a central scale μ_0: $\frac{\mu_0}{\kappa} \leq \mu_R, \mu_F \leq \kappa\mu_0$. We take $\mu_0 = \frac{1}{2} M_\Phi$ as the central scale in order to be consistent with the SM calculation[18], as one of the CP–even Higgs is SM–like. We use $\kappa = 2$ in the gluon–gluon fusion channel and obtain $\Delta\sigma/\sigma \simeq \pm 20\%$ at the Tevatron ($\pm 15\%$ at the lHC).

The next source of uncertainties is due to the combined uncertainty from the PDF and α_S coupling. We use MSTW collaboration scheme[19] and calculate the PDF+$\Delta^{\rm exp+th}\alpha_S$ 90% CL uncertainty which is equivalent to the MSTW PDF4LHC recommandation[20] and we obtain $\Delta\sigma/\sigma \simeq \pm 10\%$ both at the Tevatron and the lHC.

The last important uncertainty is specific to the MSSM case, and deals with the m_b mass. There are two types of uncertainties: the experimental errors on the $\overline{\rm MS}$ $\bar{m}_b(\bar{m}_b)$ value and the uncertainty due to the scheme choice for the renormalisation of the b–mass. The first uncertainty will cancel out in the production cross section times branching ratio (see below) but not the other one. We obtain $\Delta\sigma/\sigma \simeq \pm 15\%$ at both colliders due to these b–quark issues.

All these individual sources of uncertainties are shown in Fig.1 in the insert. We also display the total uncertainty on the cross section when combining the uncertainties according to the procedure developed in Ref.[15]. We obtain $\Delta\sigma/\sigma \simeq +58\%, -40\%$ at the Tevatron and $\Delta\sigma/\sigma \simeq +53\%, -38\%$ at the lHC.

2.2 $b\bar{b} \to \Phi$ channel

The bottom quark fusion channel is strongly enhanced because of the $\tan\beta$ effect in b–quark processes. This channel is known in the SM up to NNLO in QCD[13] and we rescale the predictions with the MSSM $\Phi b\bar{b}$ coupling to obtain a NNLO MSSM prediction. We use the same PDF set as for gluon–gluon fusion and consider the same set of theoretical uncertainties.

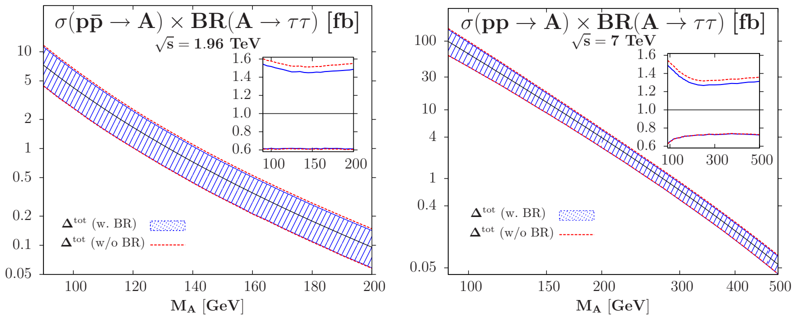

Figure 2: $\sigma(p\bar{p} \to A) \times \mathrm{BR}(A \to \tau^+\tau^-)$ as a function of M_A at the Tevatron (left) and at the lHC (right), together with the associated overall theoretical uncertainty; the uncertainty when excluding that on the branching ratio is also displayed. In the inserts, shown are the relative deviations from the central values.

For the scale uncertainties we consider here $\kappa = 3$ instead of $\kappa = 2$ in $gg \to \Phi$. Indeed this is well known that either four or five active flavours schemes can be used for the calculation. The two predictions differ significantly[21] and one way to reconcile them is to allow such a scale interval. Furthermore this also allows the inclusion of the b–mass scheme uncertainty that was obtained separately in the gluon–gluon fusion calculation. We obtain in the end $\Delta\sigma/\sigma \simeq 30\%$ for low masses at the Tevatron ($\pm 25\%$ at the lHC).

The combined PDF+α_S uncertainty is calculated exactly as in the gluon–gluon fusion case. We obtain in the bottom quark fusion $\Delta\sigma/\sigma \simeq \pm 20\%$ for low masses and $\simeq \pm 30\%$ for high masses at the Tevatron ($\simeq 10\%$ at low masses and $\simeq \pm 20\%$ at high masses at the lHC).

The last uncertainty involves only the experimental b–mass error. We obtain a $+10\%, -4\%$ uncertainty at the Tevatron (nearly the same at the lHC), which as discussed in the next section will cancel out in the cross section times branching ratio calculation.

All the uncertainties are displayed in Fig.1. The overall total uncertainty is $\Delta\sigma/\sigma \simeq +50\%, -40\%$ at the Tevatron ($+40\%, -30\%$ at the lHC).

2.3 Combinaison with the $\Phi \to \tau\tau$ branching ratio

We finally evaluate the combinaison of the two production channels together with the branching ratio $\Phi \to \tau^+\tau^-$. The issue is how to combine the uncertainties and we proceed as stated in Refs.[16,15]: the cross section uncertainties are weighted according to their importance and we add linearly the decay branching ratio uncertainty which is $\simeq +4\%, -9\%$ on $\mathrm{BR}(\Phi \to \tau^+\tau^- \simeq 10\%)$[16]. In this procedure, as the uncertainties due to the experimental errors on b–mass are anti-correlated in the production and decay, they cancel out.

We then obtain $\Delta(\sigma \times \mathrm{BR})/(\sigma \times \mathrm{BR}) \simeq +50\%, -39\%$ at the Tevatron and $\simeq +35\%, -30\%$ at the lHC, as shown in Fig.2.

3 Higgs bounds on the MSSM parameter space

We are left to evaluate the impact of the theoretical uncertainties calculated above on the 95% CL limits in the $[\tan\beta; M_A]$ plane using the experimental results at the Tevatron and the lHC. The results presented above are quite model independant as they do not depend on the details of the MSSM model as long as we have a degeneracy in the $h/H, A$ spectrum. We apply the limit on the minimal cross section times branching ratio instead of the central prediction in order to take into account the theoretical uncertainties.

The result is shown in Fig.3 and the theoretical uncertainties are extremely important. We obtain $\tan\beta > 45$ at the Tevatron, which thus reopens a large part of the parameter space excluded by CDF/D0[5]. The comparaison with CMS results at the lHC shows a slight reduction

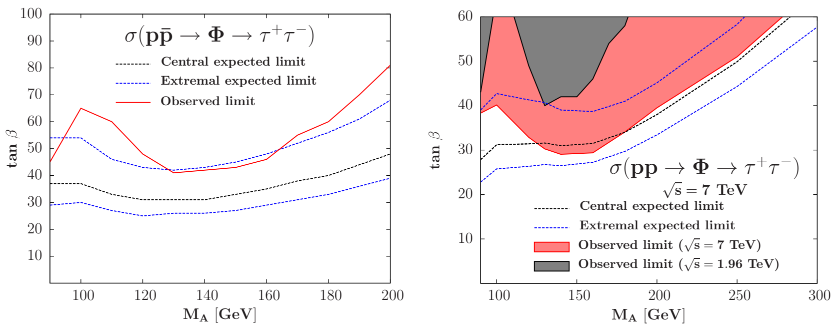

Figure 3: Contours for the expected $\sigma(p\bar{p} \to \Phi \to \tau^+\tau^-$ rate at the Tevatron (left) and at the lHC (right) in the $[M_A; \tan\beta]$ plane with the associated theory uncertainties, confronted to the 95% CL exclusion limit obtained by CDF/D0 and CMS.

of the exclusion limit as we obtain $\tan\beta > 29$ to be compared with $\tan\beta > 23$. The result is comparable to what can be obtained with the theory uncertainty quoted by CMS[7].

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