# MSSM Higgs Boson Production via Gluon Fusion

*Margarete Mühlleitner*[1], *Heidi Rzehak*[1]*, *Michael Spira*[2]

[1]KIT, ITP, Wolfgang-Gaede-Str. 1, 76128 Karlsruhe, Germany
[2]Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

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One major task at the LHC is the search for Higgs bosons. In the Minimal Supersymmetric Standard Model (MSSM), the cross section of the production process of Higgs bosons via gluon fusion, $gg \to h, H$, yields the largest values for a wide range of the MSSM parameters. This process is loop-induced where, in the MSSM, the coupling of the Higgs boson to the gluons is not only mediated by top and bottom quark loops as in the Standard Model (SM) but also by the corresponding squark loops (see Fig. 1). For large $\tan\beta$, which denotes the ratio of the two vacuum expectation values of the two complex Higgs doublets introduced in the MSSM, the coupling of bottom quarks to the Higgs bosons is enhanced. Therefore, for large $\tan\beta$, also bottom quark as well as bottom squark loops contribute sizeably to the gluon fusion cross section.

### Pure QCD and Supersymmetric QCD Contributions

The pure QCD corrections to quark and squark loops (see Fig. 1 (b)) have been calculated at next-to-leading order taking into account the full mass dependence [1]. An increase of the cross section by up to 100% has been found. Theses corrections can be approximated by the limit of very heavy top quark and squarks with an accuracy of 20% − 30% for small $\tan\beta$ [2] (for large $\tan\beta$ also bottom quark and squark loops have to be taken into account). In the heavy top quark mass limit — without squark effects — the next-to-next-to-leading order (NNLO) QCD corrections have been calculated which resulted in an increase of 20% − 30% of the cross section [3]. At NNLO finite top quark mass effects (no squarks) have been discussed and found to be below the scale uncertainty [4]. Estimates of the next-to-next-to-next-to-leading order ($\mathrm{N^3LO}$) corrections indicate an improved convergence [5].

The supersymmetric (SUSY) as well as the pure QCD contributions, taking into account gluino as well as gluon contributions (see Fig. 1 (c) as well as (b)), have been calculated in the heavy top quark, top squark and gluino limit [6]. The size of the next term in the mass expansion indicates that this is a good approximation for the lightest MSSM Higgs boson for small and moderate $\tan\beta$ values. Most recently, also the pure and the SUSY QCD contributions to the bottom quark and squark loops have been calculated based on an asymptotic expansion in the squark and gluino masses which are assumed to be much heavier than the bottom quark and the Higgs boson [7].

The pure and the SUSY QCD corrections have been calculated including the mass dependence of all particles and also the bottom quark and squark contributions [8]. This calculation

*Speaker

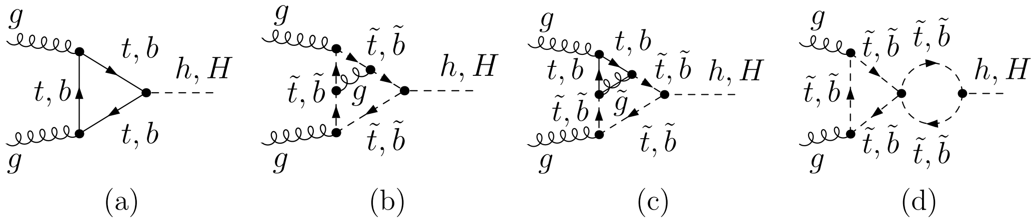


Figure 1: Sample diagrams which contribute to the gluon fusion process at (a) leading order and (b), (c), (d) next to leading order.

has shown that the heavy mass limit is a good approximation for small and moderate $\tan\beta$. Also, it was pointed out that the contributions from the squark quartic couplings (see Fig. 1 (d)) as well as from the gluinos can be sizeable.

This leads us to a conceptional problem: On the one hand if the supersymmetric relations between the parameters are kept intact the gluinos do not decouple. To be more precise, for heavy gluinos, the results of the form factors depend logarithmically on the gluino mass $M_{\tilde{g}}$. On the other hand the decoupling theorem says that heavy fields decouple at low momenta (except for renormalization effects) [9].

### Decoupling of the Gluinos

Assuming vanishing squark mixing, for scales *above* the gluino mass, the coupling of the light CP-even Higgs boson to quarks $\lambda_Q$ and the coupling of the same Higgs boson to squarks $\lambda_{\tilde{Q}}$ can be expressed as

$$\lambda_Q = g\,\frac{m_Q}{v} \quad \text{and} \quad \lambda_{\tilde{Q}} = 2\,g\,\frac{m_Q^2}{v} \tag{1}$$

where $v = (v_1^2 + v_2^2)^{\frac{1}{2}} \approx 246$ GeV and $v_i$ is the i$^{\text{th}}$ Higgs vacuum expectation value. $m_Q$ denotes the top quark mass and $g$ is a normalization factor of the Higgs coupling to a quark pair with respect to the SM. Obviously, the symmetry relation between $\lambda_Q$ and $\lambda_{\tilde{Q}}$ in Eq. 1 is intact. For the evaluation of $\lambda_Q$ and $\lambda_{\tilde{Q}}$ at a different scale the corresponding renormalization group equations (RGE) can be used. In the assumed case of scales *above* the gluino mass, the RGE for $2\,\frac{v}{g}\,\lambda_Q^2$ and for $\lambda_{\tilde{Q}}$ are the same.

For scales *below* the gluino mass, the gluino decouples from the RGE and the RGE for $2\,\frac{v}{g}\,\lambda_Q^2$ and for $\lambda_{\tilde{Q}}$ differ. The symmetry relation between $\lambda_Q$ and $\lambda_{\tilde{Q}}$ is broken.

At the scale of the gluino mass the proper matching yields a finite threshold contribution for the evolution from the gluino mass scale to smaller scales. The logarithmic behaviour of the matching relation is given by the solution of the RGE for smaller scales.

If the decoupling of the gluino is taken into account in the RGE the gluino also decouples from the theory as it should according to the decoupling theorem (for more details, see [10]).

### Genuine SUSY QCD Contributions

In Fig. 2, first results of the calculation of the genuine SUSY QCD contributions to the bottom quark and squark amplitudes are shown in terms of the form factor $C^b_{\text{SUSY}}$ normalized to the bottom quark form factor $A_b^{\rm Higgs}$:

$$A_b^{\rm Higgs}(1 + C^b_{\rm SUSY}\frac{\alpha_s}{\pi}) \,. \qquad (2)$$

The parameters are chosen as follows: The sfermion mass parameter $M_{\rm SUSY} = 800$ GeV, the gluino mass $M_{\tilde{g}} = 1.0$ TeV, the gaugino mass parameter $M_2 = 500$ GeV, the Higgs superfield mixing parameter $\mu = 2.0$ TeV, $\tan\beta = 30$ and the trilinear coupling chosen in the $\overline{\rm MS}$ scheme as $A_b = -1.133$ TeV. The SUSY QCD contributions with the full mass dependence (solid lines) are sizeable and can be roughly approximated using a correct bottom Yukawa coupling. This approximation is referred to as $\Delta_b$ approximation (dashed lines). It is important to choose the renormalization carefully. Using the trilinear coupling $A_b$ in the $\overline{\rm MS}$ scheme is one reasonable choice (for further details, see [11]).

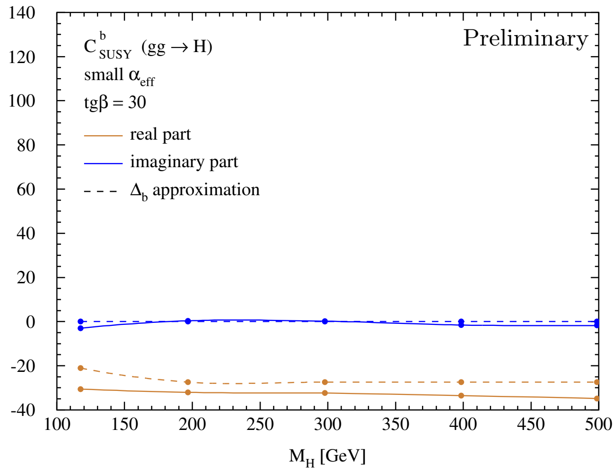


Figure 2: The genuine SUSY QCD contributions in terms of the form factor $C^b_{\rm SUSY}$ normalized to the bottom quark form factor: Real part in orange (light gray), imaginary part in blue (dark gray). The result with the full mass dependence (solid) is compared to the one in the $\Delta_b$ approximation (dashed).

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