Higgs boson production at the LHC: supersymmetric QCD corrections to gluon fusion

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The search for Higgs bosons and supersymmetric particles will be major tasks at the forthcoming experiments at the Large Hadron Collider (LHC). For reliable analyses of the experimental data accurate theoretical calculations of the production rates are necessary. We calculated the next-to-leading order corrections to the dominant Higgs production process via gluon fusion within supersymmetric Quantumchromodynamics (QCD). We find a large increase of the cross sections and sizeable mass effects compared to previous approximate calculations.

The Higgs mechanism

The Higgs mechanism is a cornerstone of the Standard Model (SM) and its supersymmetric extensions. The introduction of the fundamental Higgs field renders the standard electroweak theory weakly interacting up to high energy scales without violating the unitarity bounds for scattering amplitudes. Due to spontaneous symmetry breaking in the Higgs sector the electroweak gauge bosons W, Z and the fermions acquire masses through the interaction with the Higgs field. Since the gauge symmetry, though hidden, is still preserved, the theory of electroweak interactions is renormalizable. In the SM one weak isospin Higgs doublet is introduced and leads to the existence of one elementary Higgs particle after electroweak symmetry breaking.

Supersymmetry

Supersymmetric extensions of the SM are strongly motivated by the idea of providing a solution of the hierarchy problem in the Higgs sector. They allow for a light Higgs particle in the context of Grand Unified Theories (GUT), in contrast with the SM, where the extrapolation to high scales requires an unsatisfactory fine-tuning of the SM parameters. Supersymmetry is symmetry between fermionic and bosonic degrees of freedom and the most general symmetry of the S-matrix. The minimal supersymmetric extension of the SM (MSSM) yields a prediction of the Weinberg angle in agreement with present experimental measurements if embedded in a supersymmetric GUT. Owing to the large top quark mass supersymmetric GUTs develop electroweak symmetry breaking at the electroweak scale dynamically. The lightest supersymmetric particle offers a proper candidate for the Cold Dark Matter content of the universe. Finally, local supersymmetry enforces gravitational interactions.

The minimal supersymmetric extension

In the MSSM two isospin Higgs doublets have to be introduced in order to preserve supersymmetry. After electroweak symmetry breaking, three of the eight degrees of freedom are absorbed by the Z and W gauge bosons, leading to the existence of five elementary Higgs particles. These consist of two neutral scalar particles h,H, one neutral pseudoscalar particle A, and two charged particles $H^\pm$. At leading order the MSSM Higgs sector is fixed by two independent input parameters which are usually chosen to be the pseudoscalar Higgs mass M_A and $tg\beta = v_2/v_1$, the ratio of the vacuum expectation values of the two Higgs doublets.

Physical motivation

The dominant neutral MSSM Higgs production mechanisms for small and moderate values of $tg\beta$ are the gluon fusion processes $gg \to h,H,A$. These are mediated by quantum fluctuations (loops), which can be calculated perturbatively. In the SM case top and bottom loops contribute, but in the MSSM also stop and sbottom loops are important for the scalar Higgs bosons h,H, if the squark masses are below about 400 GeV. The QCD corrections to the quark loops are known in the heavy quark limit as well as including the full quark mass dependence. The QCD corrections to the squark loops were only known in the heavy squark limit and the full supersymmetric QCD

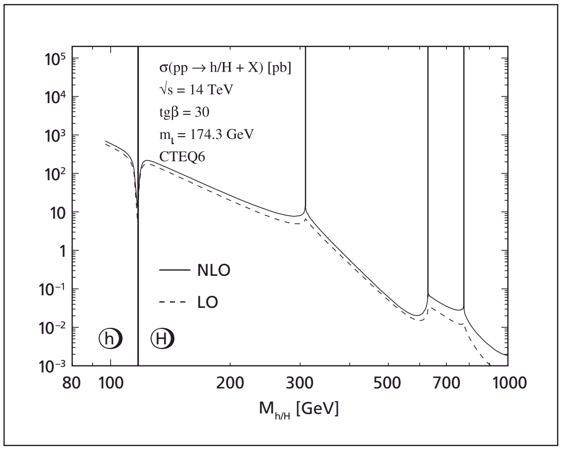

Figure 1: **Production cross sections of the scalar MSSM Higgs bosons via gluon fusion as functions of the corresponding Higgs masses for tgβ=30. The full curves include the QCD corrections, while the dashed lines are the leading-order predictions.**

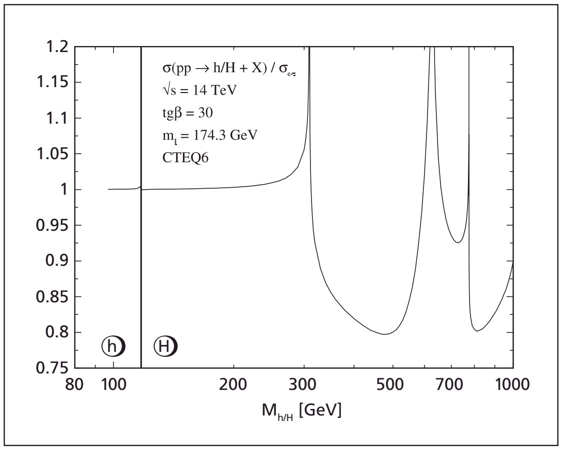

Figure 2: **Ratio of the QCD corrected production cross sections of the scalar MSSM Higgs bosons via gluon fusion including the full squark mass dependence and those in the heavy mass limit as functions of the corresponding Higgs masses for tgβ=30.**

corrections in the limit of heavy squarks and gluinos. Computations of the last two contributions including the full mass dependences were missing so far. The work of Ref. [1] presents the pure two-loop QCD corrections to the squark loops including the full squark and Higgs mass dependences as a first step towards a full supersymmetric QCD calculation at next-to-leading perturbative order.

Results

The cross sections at leading and next-to-leading perturbative order are shown in Figure 1. The spikes at next-to-leading order correspond to Coulomb singularities at the corresponding squark thresholds, which will be regularized by taking into account the finite widths of the virtual squarks. This is left for future work. The QCD corrections increase the gluon fusion cross sections by 10–100%, but can be significantly larger in regions of large destructive interferences between quark and squark loops. There is a strong dependence on the (unknown) value of tgβ, which is discussed in more detail in Ref. [1]. In spite of the large corrections the residual scale dependence is reduced from about 50% at leading order to ~20% at next-to-leading order, which indicates a significant stabilization of the theoretical predictions after including the QCD corrections. The theoretical uncertainties of our results can be estimated to less than about 20% except in the regions close to the Coulomb singularities, where the results are unreliable and require further improvements.

The squark mass effects are exemplified in Figure 2, where the ratios of the cross sections including the full mass dependence and of the approximate cross sections in the heavy squark mass limit are displayed. The squark mass effects modify the cross sections by up to about 20% and turn out to be larger than the corresponding quark mass effects. In addition they are larger than the residual theoretical uncertainties and cannot be neglected in realistic analyses. Since the gluino contributions are expected to be much smaller, the squark mass dependence obtained in Ref. [1] will be the dominant part of the differences between the heavy mass limits and a full MSSM calculation at next-to-leading perturbative order. These improved calculations will be important for the experimental search for supersymmetric Higgs bosons at the LHC and the Tevatron collider.

References

[1] M. Mühlleitner, M. Spira, hep-ph/0612254.