Higgs production in the (complex) MSSM via vector boson fusion

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Outline

The MSSM Higgs sector

- In the MSSM, the Higgs sector needs to contain two Higgs doublets, which leads to 5 physical Higgs states:

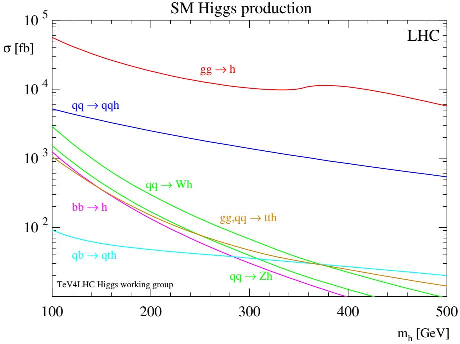
$$h, H, A, H^+, H^-$$

- In general, several of the parameters of the MSSM can be complex, which can lead to some interesting (and non-excluded) phenomenology
- Complex phases allow mixing between all three neutral Higgs bosons

$$M(p^2) = \begin{pmatrix} m_h^2 - \hat{\Sigma}_{hh}(p^2) & -\hat{\Sigma}_{hH}(p^2) & -\hat{\Sigma}_{hA}(p^2) \\ -\hat{\Sigma}_{hH}(p^2) & m_H^2 - \hat{\Sigma}_{HH}(p^2) & -\hat{\Sigma}_{HA}(p^2) \\ -\hat{\Sigma}_{hA}(p^2) & \hat{\Sigma}_{HA}(p^2) & m_A^2 - \hat{\Sigma}_{AA}(p^2) \end{pmatrix}$$

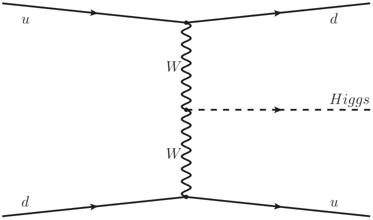
Vector boson fusion

Vector boson fusion is expected to be an important Higgs production channel at the LHC



From: **hep-ph/0607308**, T Hahn, S Heinemeyer, F Maltoni, G Weiglein, S Willenbrock

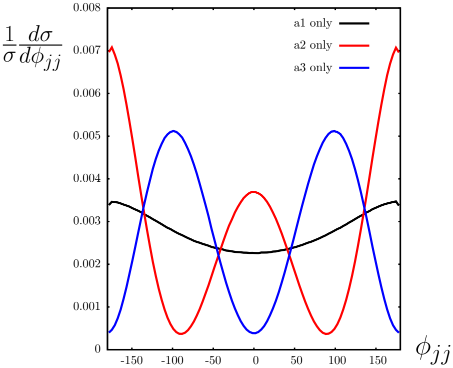
$$q + q \rightarrow q + Higgs + q$$



The Higgs – weak boson coupling

The most general *HVV* coupling is:

$$T^{\mu\nu}(q_1, q_2) =$$
$$a_1(q_1, q_2)\, g^{\mu\nu} +$$
$$a_2(q_1, q_2)\left(q_1 \cdot q_2 g^{\mu\nu} - q_2^\mu q_1^\nu\right)$$
$$+\, a_3(q_1, q_2)\, \epsilon^{\mu\nu\rho\sigma} q_{1\sigma} q_{2\rho}$$



VBFNLO

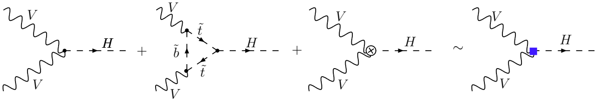
VBFNLO* is a public Monte Carlo program that produces predictions and distributions for VBF. The next release will include:

- SUSY parameters set by the user
  - FeynHiggs** is used to evaluate the Higgs sector
- Production of any of the neutral Higgs bosons
- Electroweak loop corrections and approximations
  - FeynArts, FormCalc, and LoopTools** were used to calculate these corrections
- LO parametrised by $\alpha(0)$, $\alpha(M_Z)$ or G_F
- Propagator-type corrections

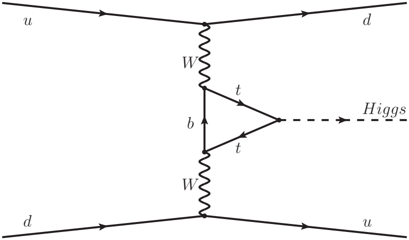
* **hep-ph/0811.4559**, K. Arnold, M. Bahr, G. Bozzi, F. Campanario, C. Englert, T. Figy, N. Greiner, C. Hackstein, V. Hankele, B. Jager, G. Klamke, M. Kubocz, C. Oleari, S. Platzer, S. Prestel, M. Worek, D. Zeppenfeld
*Available at **http://www-itp.particle.uni-karlsruhe.de/∼vbfnloweb/***

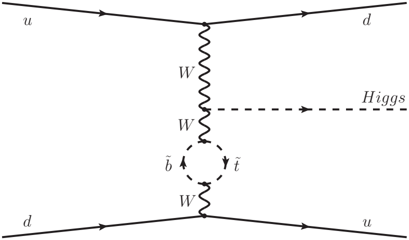
Programs available at **www.feynarts.de** and **www.feynhiggs.de

Higgs Formfactors

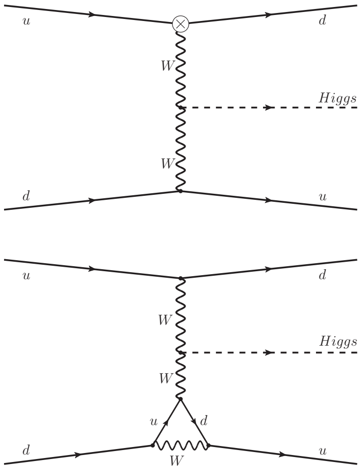


Higgs vertex contributions and weak boson self energies are incorporated into an effective coupling $T^{\mu\nu}$



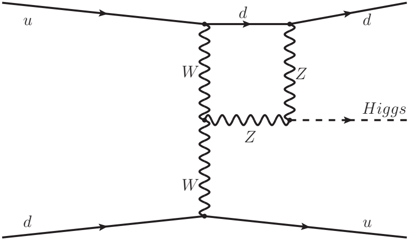


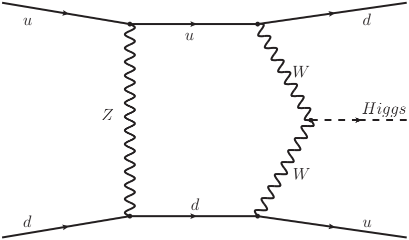
Effective couplings



The corrections to the qqV vertex are included by calculating an effective qqV coupling which includes the loop contributions

Boxes and pentagons

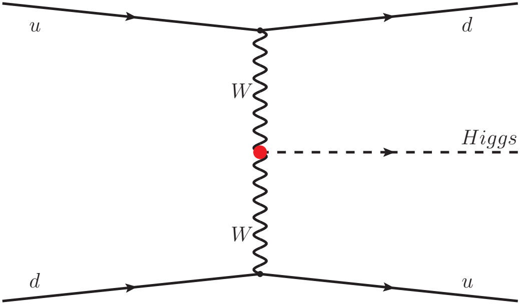




Box and pentagon loop diagrams are included by calculating the full 2→3 matrix element

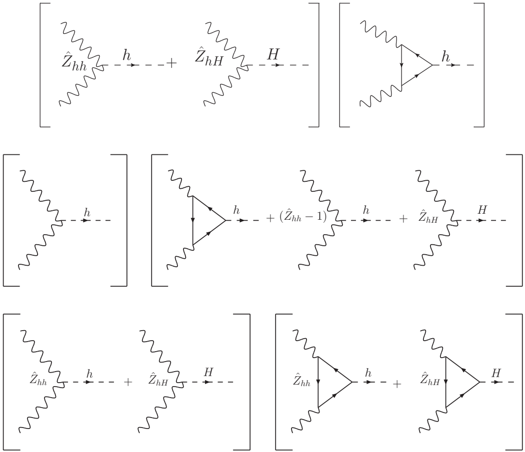
Higgs propagator corrections I

- Finite wavefunction normalisation factors are used to give outgoing Higgs bosons the correct on-shell properties to take mixing into account
- These corrections can be extremely important numerically



$$\begin{pmatrix} \hat{\Gamma}_1 \\ \hat{\Gamma}_2 \\ \hat{\Gamma}_3 \end{pmatrix} = \hat{Z} \begin{pmatrix} \hat{\Gamma}_h \\ \hat{\Gamma}_H \\ \hat{\Gamma}_A \end{pmatrix}$$

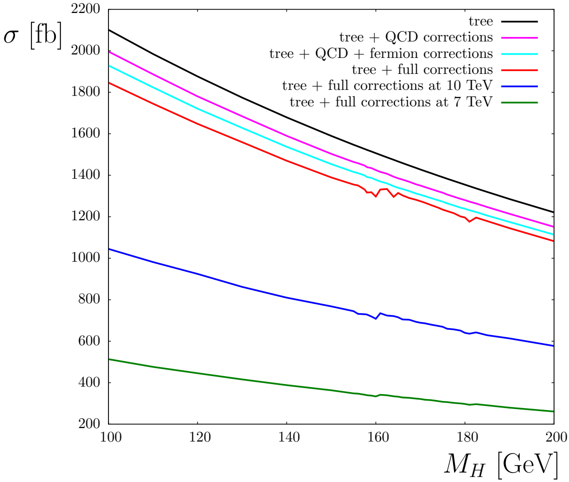
Higgs propagator corrections II



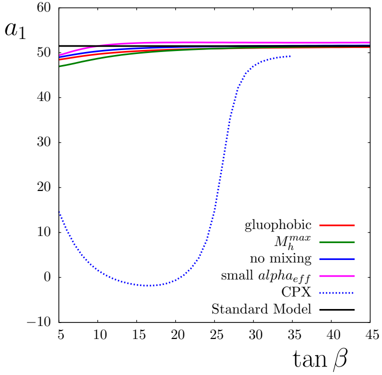
- Improved Born Approximation
- Propagator corrections treated as a loop correction
- Propagator corrections applied at LO and NLO

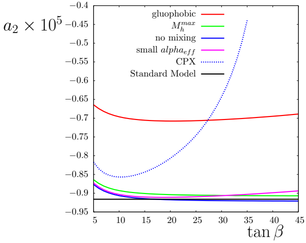
Results in the SM

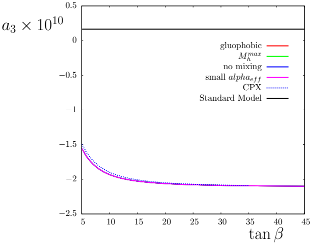
- QCD corrections are $\sim -5\%$
- Electroweak corrections are also $\sim -5\%$



Formfactors in the MSSM

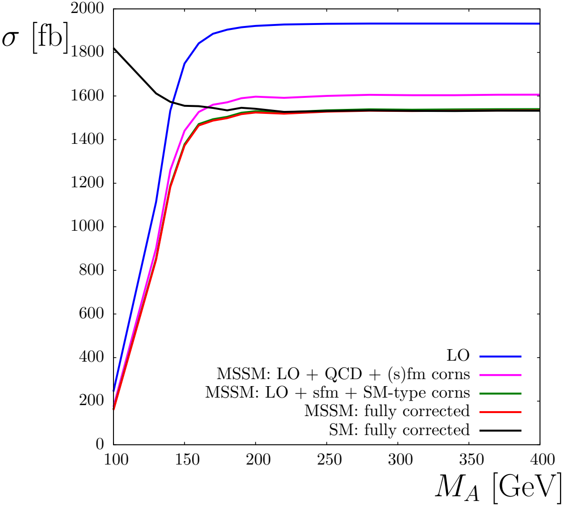






Formfactor calculations can be used in order to perform fast parameter scans

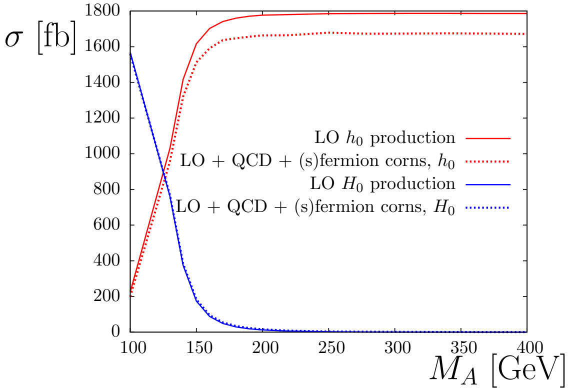
The MSSM with real parameters



The contribution from charginos/neutralinos is negligible in this scenario, and the MSSM cross section approaches the SM cross section in the decoupling limit.

M_h^{max} scenario
$\tan\beta = 10$

The MSSM with real parameters

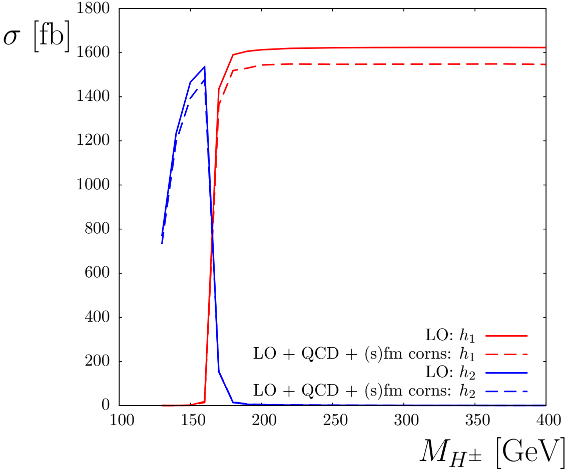


As expected, at low values of M_A, production of the heavy neutral Higgs boson is dominant

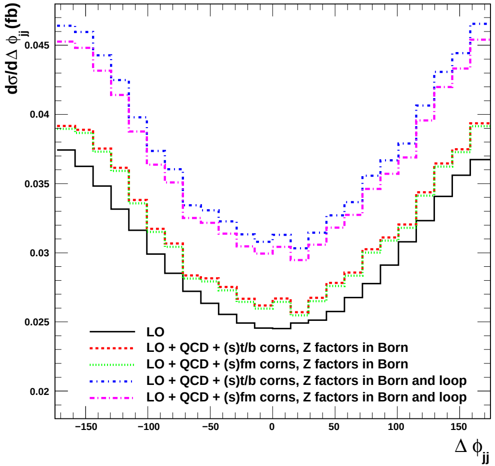
The MSSM with complex parameters

In the CPX scenario, the production of the lightest neutral Higgs decreases very rapidly below $M_{H^\pm} \sim 170$ GeV, as it becomes dominated by the CP-odd component

CPX scenario
$\tan\beta = 10$



The MSSM with complex parameters



Even in the CPX scenario, the azimuthal angle distribution is very similar to that in the SM

h_1 production, $\tan\beta = 10$, $M_{H^\pm} = 160$ GeV

Summary

- Weak boson fusion is important as a
  - Higgs discovery channel
  - Study of electroweak symmetry breaking and BSM
- The electroweak corrections – in both the SM and the MSSM – are significant ($\mathcal{O}(5\%)$), and should be taken into account when studying this process at the LHC
- `VBFNLO` is a fast, simple tool that can study production of the neutral Higgs bosons in the SM and (complex) MSSM including
  - One-loop electroweak corrections
  - Propagator type corrections