QCD and Electroweak Interference in Higgs production by Gauge Boson Fusion

Jeppe R. Andersen* and Jennifer M. Smillie†
Cavendish Laboratory, University of Cambridge
JJ Thomson Avenue
CB3 0HE
Cambridge, UK

(Dated: February 2, 2008)

We explicitly calculate the contribution to Higgs production at the LHC from the interference between gluon fusion and Weak Vector Boson fusion, and compare it to the pure QCD and pure Electro-weak result. While the effect is small at tree level, we speculate it will be significantly enhanced by loop effects.

arXiv:hep-ph/0611281v2 1 May 2007

INTRODUCTION

One of the main tasks for the experimental and theoretical programme in connection with the CERN LHC is to determine whether the breaking of the electro-weak symmetry is due to the Higgs boson of the Standard Model. While the production of a Standard Model Higgs boson at the LHC is dominated by the process $gg \to H$, gluon fusion mediated through a top quark loop, the exact dynamics of the symmetry breaking can be more directly extracted by studying the production of the Higgs in addition to two jets. This process receives contributions from channels of both electro-weak[1, 2, 3] and QCD origin[4, 5]. Calculations of the $\mathcal{O}(\alpha_s)$ corrections to the electro-weak channel indicate that the higher order effects are very small, and since the QCD channel can be efficiently suppressed, it would seem that the Higgs coupling to electro-weak bosons can be cleanly studied.

The purpose of this letter is to explore mechanisms which could reduce the purity of the extraction of this HVV coupling from the Hjj process. We will further highlight the generality of one such observed mechanism.

HIGGS + 2 JETS IN THE STANDARD MODEL

We will consider the production of a Standard Model Higgs with a mass between 115 GeV and 200 GeV, in which case the gluon-gluon-Higgs fusion through a top loop can be described accurately by an effective vertex of the form[6, 7]

$$V(p_a^\mu, k_b^\nu) = -i\, \frac{\alpha_s}{3\pi v}\, \delta^{ab}\, (g^{\mu\nu}\ p\cdot k\ -\ p^\nu k^\mu), \qquad (1)$$

where v is the vacuum expectation value of the Higgs field, and a, b denote the colour index of the gluons. Within this approximation, a possible tree level process for Hjj production is shown in Fig. 1(b). This process is considered a pollutant in the study of the dynamics of the electro-weak symmetry breaking through the coupling

$$V_{\mathrm{WWH}}(p^\mu, k^\nu)\ = V_{\mathrm{ZZH}}(p^\mu, k^\nu)\cos^2\theta_{\mathrm{W}} = g_{\mathrm{W}} M_{\mathrm{W}} g^{\mu\nu}, \quad (2)$$

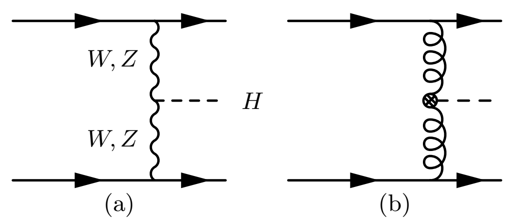

FIG. 1: Hjj production at tree level by weak boson fusion and gluon fusion (where the effective vertex from Eq. (1) is used).

which contributes to Hjj–production at tree level through the diagram in Fig. 1(a). Higher order corrections from QCD are considered separately[8] for the two processes, and have been calculated for the gluon fusion process to order α_s^5 [9, 10, 11, 12, 13] in the limit of infinite top mass, and to order $\alpha_{\mathrm{W}}^3\alpha_s$ for weak boson fusion (WBF)[14]. Since higher order corrections to WBF are found to be small (on the order of $3\% - 10\%$ in the relevant kinematic region [15, 16]) and the gluon fusion channel can be suppressed to the same level, it even becomes feasible to study possible anomalous couplings of the Higgs field to the weak bosons of the form [17]

$$\begin{aligned} V^A_{\mathrm{WWH}}(p^\mu, k^\nu)\ &=\ g_{\mathrm{W}} M_{\mathrm{W}}\big(a_1(p,k) g^{\mu\nu} \\ &+\ a_2(p,k)[g^{\mu\nu}\ p\cdot k - p^\nu k^\mu] +\ a_3(p,k)\varepsilon^{\mu\nu\rho\sigma} q_{1\rho} q_{2\sigma}\big), \end{aligned} \qquad (3)$$

where $a_1 = 1, a_2 = a_3 = 0$ corresponds to the Standard Model, and any deviation from this is anomalous.

The high purity of the Hjj sample in terms of WBF is obtained by imposing the following cuts, which are used in our numerical studies

$$\begin{aligned} &R_{jj} > 0.6 \quad \eta_{j_1}\cdot\eta_{j_2} < 0 \quad |\eta_{j_1} - \eta_{j_2}| > 4.2 \\ &p_{T,j} > 20\ \mathrm{GeV} \quad |\eta_j| \le 5 \quad s_{jj} > (600\ \mathrm{GeV})^2\,. \end{aligned} \qquad (4)$$

In this setting it is worth considering all standard model contributions which could mimic an anomalous coupling and destroy the pure extraction of the VVH vertex.

One such contribution, which has been ignored in the literature, is the interference between the QCD and electro-weak generated Higgs production. Usually (e.g. in the effective structure function approach), all contributions requiring a $t \leftrightarrow u$-channel crossing at tree level are neglected, since such effects only contribute to channels of identical quarks, and furthermore suffer a kinematical suppression arising from the crossing. For the ZZH fusion process, the channels with identical quarks contribute a third of the cross section, but the crossed term suffers the suppression of a further 4 orders of magnitude due to the kinematical effects in the crossing. It is therefore valid to ignore such contributions. Within this approximation, there is also no interference between diagrams of colour singlet and colour octet exchange, and therefore even the tree-level effects discussed in this letter are ignored.

However, by calculating explicitly the interference between the QCD and electro-weak generated Higgs production, we find that the $(\alpha_\mathrm{W}\sqrt{\alpha_\mathrm{W}}\alpha_\mathrm{s}^2)$–contribution from this crossed term is 15 times larger than the neglected contribution from ZZxZZ–interference, even though it suffers the same suppression effects from the requirement of a $t \leftrightarrow u$–crossing and identical quarks.

While this may seem like a small effect, it is about 1% of the quark initiated pure gluon fusion channel, and about 5%-10% of the NLO QCD corrections to the quark initiated Z fusion channel reported in Ref.[15, 16]. The kinematical dependence of the interference term is obviously different from either of the pure electro-weak and the pure QCD terms, and so the applied cuts do not suppress this term to the same extent as the pure QCD one. In fact, the relative impact of the tree level interference is increased by raising the cut on the transverse momentum of the jets.

More importantly, the Lorentz structure of the effective ggH–coupling could be mistaken for an anomalous contribution to the ZZH–coupling, since such contributions are not present in the available NLO calculations of this process.

Most importantly though, higher order QCD corrections, which take into account the exchange of a gluon between the quark lines as depicted in Fig. 2, will remove the requirement of a $t \leftrightarrow u$-crossing in the interference between the QCD and electro-weak processes, and permit interference effects in all channels. The indicated one-loop process is the leading order mechanism for processes not suppressed by crossing, and for all processes involving non-identical quarks, and quarks of different helicity configurations. The one-loop process is therefore not a higher order correction to the tree-level process reported above, and the size of the one-loop interference term is not indicated by the size of the calculated tree-level interference term. Rather, the size of the contribution from one-loop interference should be comparable to the size of the one-loop (in this case NLO) corrections to the weak boson fusion and gluon fusion processes reported in Ref.[9, 15, 16]. This effect could then have impact beyond the study of possible anomalous couplings.

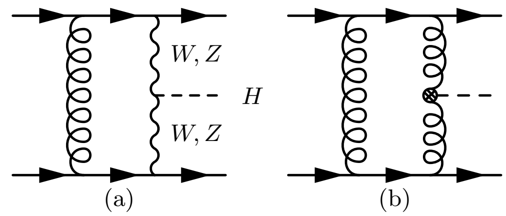

FIG. 2: Diagrams contributing to QCD and electro-weak interference terms of order $\alpha_\mathrm{W}\sqrt{\alpha_\mathrm{W}}\alpha_\mathrm{s}^3$ in the uncrossed channel for all assignments of quark flavours.

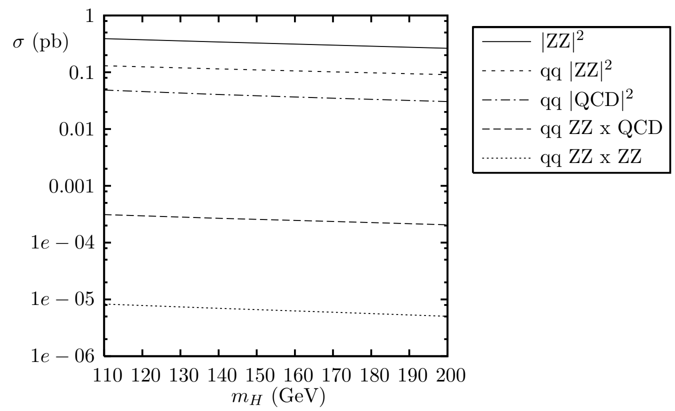

FIG. 3: The contribution to Hjj within the cuts of Eq. (4) from various tree level processes as a function of the mass of the Higgs boson. ZZxQCD and ZZxZZ denote $t \leftrightarrow u$-channel interference terms.

SUMMARY AND CONCLUSIONS

We have calculated the interference between colour octet gluon fusion and colour singlet weak boson fusion channels in Hjj–production at tree level. The interference term has a different kinematic dependence to other contributions previously investigated and is small (but still an order of magnitude larger than the ZZ interference term) only due to the tree level requirement of $t \leftrightarrow u$-channel crossing, which will be lifted at higher orders and could lead to a very significant interference effect. We speculate that the one-loop corrections of order $\alpha_\mathrm{s}^3\alpha_\mathrm{W}\sqrt{\alpha_\mathrm{W}}$ could be as important as the one-loop corrections of order $\alpha_\mathrm{s}\alpha_\mathrm{W}^3$ and α_s^5 already calculated in the literature.

It should be noted that the ideas of interference effects between electro-weak and QCD generated processes discussed in this letter obviously are not confined to Higgs masses in the studied range, nor indeed Higgs production itself. Similar effects were reported in Ref.[18].

We would like to acknowledge discussions with Alexander Sherstnev on the efficient use of CompHEP[19, 20].

* Electronic address: andersen@hep.phy.cam.ac.uk
† Electronic address: smillie@hep.phy.cam.ac.uk

[1] R. N. Cahn and S. Dawson, Phys. Lett. **B136**, 196 (1984).
[2] D. A. Dicus and S. S. D. Willenbrock, Phys. Rev. **D32**, 1642 (1985).
[3] G. Altarelli, B. Mele, and F. Pitolli, Nucl. Phys. **B287**, 205 (1987).
[4] R. P. Kauffman, S. V. Desai, and D. Risal, Phys. Rev. **D55**, 4005 (1997), hep-ph/9610541.
[5] V. Del Duca, W. Kilgore, C. Oleari, C. Schmidt, and D. Zeppenfeld, Nucl. Phys. **B616**, 367 (2001), hep-ph/0108030.
[6] S. Dawson, Nucl. Phys. **B359**, 283 (1991).
[7] A. Djouadi, M. Spira, and P. M. Zerwas, Phys. Lett. **B264**, 440 (1991).
[8] A. Djouadi (2005), hep-ph/0503172.
[9] J. M. Campbell, R. Keith Ellis, and G. Zanderighi, JHEP **10**, 028 (2006), hep-ph/0608194.
[10] V. Del Duca, A. Frizzo, and F. Maltoni, JHEP **05**, 064 (2004), hep-ph/0404013.
[11] S. D. Badger, E. W. N. Glover, and V. V. Khoze, JHEP **03**, 023 (2005), hep-th/0412275.
[12] L. J. Dixon, E. W. N. Glover, and V. V. Khoze, JHEP **12**, 015 (2004), hep-th/0411092.
[13] R. K. Ellis, W. T. Giele, and G. Zanderighi, Phys. Rev. **D72**, 054018 (2005), hep-ph/0506196.
[14] T. Han, G. Valencia, and S. Willenbrock, Phys. Rev. Lett. **69**, 3274 (1992), hep-ph/9206246.
[15] T. Figy, C. Oleari, and D. Zeppenfeld, Phys. Rev. **D68**, 073005 (2003), hep-ph/0306109.
[16] E. L. Berger and J. Campbell, Phys. Rev. **D70**, 073011 (2004), hep-ph/0403194.
[17] V. Hankele, G. Klamke, D. Zeppenfeld, and T. Figy, Phys. Rev. **D74**, 095001 (2006), hep-ph/0609075.
[18] S. Moretti, M. R. Nolten, and D. A. Ross, Phys. Rev. **D74**, 097301 (2006), hep-ph/0503152.
[19] A. Pukhov et al. (1999), hep-ph/9908288.
[20] E. Boos et al. (CompHEP), Nucl. Instrum. Meth. **A534**, 250 (2004), hep-ph/0403113.