QCD and Electroweak Interference in Higgs production by Gauge Boson Fusion

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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.

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 $gg \rightarrow H$, 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 and QCD origin. Calculations of the $O(\alpha_s)$ 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 quark loop can be described accurately by an effective vertex which case the gluon-gluon-Higgs fusion 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 and QCD origin. Calculations of the $O(\alpha_s)$ 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.

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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. (b). This process is considered a pollutant in the study of the dynamics of the electro-weak symmetry breaking through the coupling

$$V_{WWH}(p^\mu, k^\nu) = V_{ZH}(p^\mu, k^\nu) \cos^2 \theta_w = g_w M_W g^{\mu\nu},$$

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which contributes to $Hjj$-production at tree level through the diagram in Fig. (b). Higher order corrections from QCD are considered separately for the two processes, and have been calculated for the gluon fusion process to order $\alpha_s^3$ in the limit of infinite top mass, and to order $\alpha^3 \alpha_s$ for weak boson fusion (WBF). Since higher order corrections to WBF are found to be small (on the order of $3\% - 10\%$ in the relevant kinematic region) 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

$$V_{WWH}^A(p^\mu, k^\nu) = g_w M_W (a_1(p, k)) g^{\mu\nu} + a_2(p, k) [g^{\mu\nu} p \cdot k - p^\nu k^\mu] + a_3(p, k) \varepsilon^{\mu\nu\rho\sigma} q_1 q_2 q_{2\sigma},$$

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

$$R_{jj} > 0.6 \quad \eta_{jj} < 0 \quad \|\eta_j - \eta_j\| > 4.2$$

$$p_{T,jj} > 20 \text{ GeV} \quad \|\eta_j\| \leq 5 \quad s_{jj} > (600 \text{ GeV})^2.$$

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 contribu-
tions 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 kinematic-
al suppression arising from the crossing. For the $ZZH$
fusion process, the channels with identical quarks con-
tribute a third of the cross section, but the crossed term
suffers the suppression of a further 4 orders of magni-
tude 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 di-
agrams 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 be-
tween the QCD and electro-weak generated Higgs
production, we find that the $(\alpha_w \sqrt{\alpha_w \alpha_s^2})$–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 obvi-
uously different from either of the pure electro-weak and
the pure QCD terms, and so the applied cuts do not sup-
press 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 effect-
ive $ggH$–coupling could be mistaken for an anomalous
contribution to the $ZZH$–coupling, since such contribu-
tions are not present in the available NLO calculations
of this process.

Most importantly though, higher order QCD correc-
tions, 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 per-
mit interference effects in all channels. The indicated
one-loop process is the leading order mechanism for pro-
cesses 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 re-
ported 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 contribu-
tion 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 re-
ported in Ref. [8, 15, 16]. This effect could then have im-

**FIG. 2:** Diagrams contributing to QCD and electro-weak in-
terference terms of order $\alpha_w \sqrt{\alpha_w \alpha_s^2}$ 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 interfer-
ence term has a different kinematical dependency 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 or-
der $\alpha_s^3 \alpha_w \sqrt{\alpha_w}$ could be as important as the one-loop
corrections of order $\alpha_s \alpha_s^3$ and $\alpha_s^5$ already calculated in
the literature.

It should be noted that the ideas of interference effects
between electro-weak and QCD generated processes dis-
cussed 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].

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