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A Z-MONITOR TO CALIBRATE HIGGS PRODUCTION VIA VECTOR BOSON FUSION WITH RAPIDITY GAPS AT THE LHC

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We study central Z-boson production accompanied by rapidity gaps on either side as a way to gauge Higgs weak boson fusion production at the LHC. We analyse the backgrounds for the $b\bar{b}$-decay mode and show that these can be substantially reduced. Special attention is paid to the evaluation of the gap survival factor, which is the major source of theoretical uncertainty in the rate of H and Z central production events with rapidity gaps.

1 Introduction

Hunting the Higgs boson(s) is now the highest priority of the international high-energy physics programme. To ascertain whether a Higgs signal can be seen, it is crucial to show that the background does not overwhelm the signal. For instance, the major difficulty in observing inclusive production of the Higgs in the preferred mass range around 115 GeV via the dominant $H \to b\bar{b}$ mode is the huge $b\bar{b}$ QCD background. An attractive possibility to reduce the background is to study the central production of the Higgs in events with a large rapidity gap on either side. An obvious advantage of the rapidity gap approach is the clean experimental signature – hadron free zones between the remnants of the incoming protons and the Higgs decay products.

The cross section is large enough in the semi-inclusive case when the protons dissociate,

$$pp \to X + H + Y \tag{1}$$

where the plus sign denotes a large rapidity gap. A significant contribution to process (1) comes from Higgs production via WW/ZZ fusion, i.e. $qq \to qqH$. Since this process is mediated by colourless t-channel W/Z exchanges there is no corresponding gluon bremsstrahlung in the central region, and thus Sudakov suppression of the rapidity gaps does not occur. Another characteristic feature of the vector boson fusion Higgs production process is that it is accompanied by energetic quark jets in the forward and backward directions.

The most delicate issue in calculating the cross section for processes with rapidity gaps concerns the soft survival factor $\hat{S}^2$. This factor has been calculated in a number of models for various rapidity gap processes, see for example [1,2,3,4]. Although there is reasonable agreement between these model expectations, it is always difficult to guarantee the precision of predictions which rely on soft physics.

Fortunately, calculations of $\hat{S}^2$ can be checked experimentally by computing the event rate for a suitable calibrating reaction and comparing with the observed rate. As shown in [6,7] the appropriate monitoring process for the double-diffractive mechanism is central dijet production with a rapidity gap on either side. To date, such a check has been the prediction of diffractive dijet production at the Tevatron in terms of the diffractive structure functions measured at HERA [8]. The evaluation of the survival factor $\hat{S}^2$ based on the formalism of [1,2] appears to be in remarkable agreement with the CDF data. We expect that future measurements in Run II of the Tevatron will provide us with further detailed information on $\hat{S}^2$.

As was pointed out in [9,10], the survival factor for the gaps surrounding $WW \to H$ fusion can be monitored experimentally by observing the closely related central production of a Z boson with the same rapidity gap and jet configuration.

We develop these ideas further by considering the decays of both (light) Higgs and Z bosons into $b\bar{b}$ pairs, the dominant decay channel of the former. In each case we require two forward energetic jets, and rapidity gaps on either side of the centrally produced decay products. Both H (Fig 1) and Z (Fig 2) can be produced by electroweak vector boson fusion, for which gaps are 'natural', but the Z can also be produced via $\mathscr{O}(\alpha_S^2 \alpha_W)$ QCD processes (Fig 3), with both quarks and gluons exchanged in the t-channel. Finally, there is a large continuum $\mathscr{O}(\alpha_S^4)$ $b\bar{b}$ background (Fig 4).

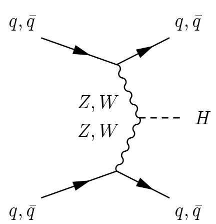
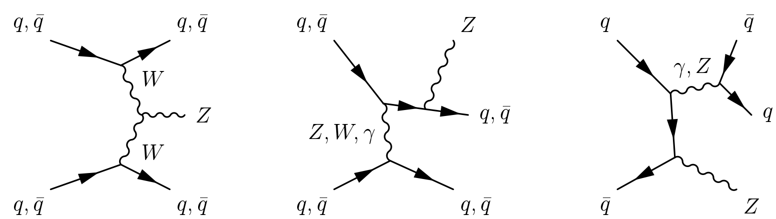


Figure 1: Higgs production via electroweak vector boson fusion.



(a) (b) (c)

Figure 2: The three topologies for $\mathscr{O}(\alpha_W^3)$ Zqq production.

2 Parton Level Signal and Background Rates

At the parton level, we define a set of selection cuts to pick out the 'natural' features of our two signals. Table 1 shows the effect of applying these cuts in sequence to the Higgs signal. p_{Tj} and η_j are the transverse momentum and rapidity of the forward jet partons. Of course, the depletion of the backgrounds is much greater. The rates are shown in Figure 6.

3 Gap Survival Probability

3.1 Parton Level

The QCD-induced $b\bar{b}$ background is still large after cuts, exceeding by two orders of magnitude the Z/H cross sections. Further suppression can be achieved by requiring a *completely clean*

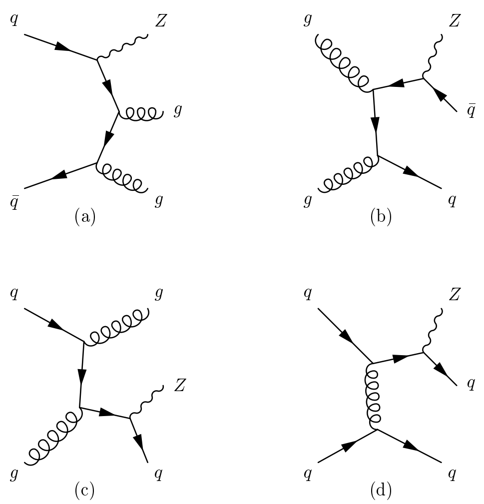


Figure 3: $\mathscr{O}(\alpha_s^2\alpha_W)$ Zqq production.

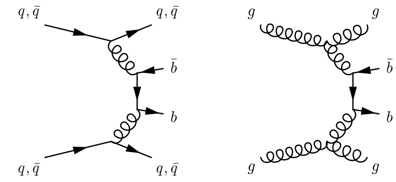


Figure 4: $\mathscr{O}(\alpha_s^4)$ backgrounds to $qq \to qq(H,Z)$, $(H,Z) \to b\bar{b}$.

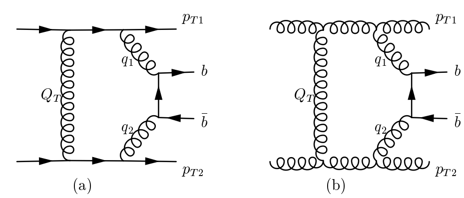


Figure 5: Screening of QCD dijet + $b\bar{b}$ production via gluon exchange.

Table 1: Loss of $qq \to qqH$ cross section at $\sqrt{s} = 14$ TeV with $M_H = 115$ GeV in applying selection cuts and the $b\bar{b}$ branching ratio.

Cut Imposed	Cross Section for $qq \to qqH$ at $p_{Tj} > 40$GeV	% of Initial Cross Section
	4.86pb	100%
Br($H \to b\bar{b}$)	3.49pb	71.9%
$\eta_1 \cdot \eta_2 < 0$	2.47pb	50.8%
$\Delta\eta_j > 6$	0.495pb	10.2%
$\lvert\eta_j\rvert > 3$	0.0990pb	2.04%
$\lvert\eta_b\rvert < 1.5$	0.0465pb	0.957%
$p_{Tb} > 10$ GeV	0.0463pb	0.953%

gap, i.e. without any soft hadrons. The only way to create a gap in a QCD induced event is to screen the colour flow across the gap by an additional gluon; that is, to consider graphs of the type shown in Fig. 5. Using a leading logarithmic approximation to this loop integral, one obtains the probability to screen out the octet colour flow

$$P_a = C_a \left(\int_{Q_0}^{p_{T\min}} \alpha_S(Q_T^2) \frac{dQ_T^2}{Q_T^2} \exp\left\{ -\frac{N_c \Delta\eta}{2\pi} \int_{Q_T}^{p_{T\min}} \alpha_S(Q'^2) \frac{dQ'^2}{Q'^2} \right\} \right)^2 = C_a \left(\frac{2\pi}{N_c \Delta\eta} \right)^2. \quad (2)$$

Numerically, this suppresses the backgrounds by a factor of ten.

Another point we must take into account is the fact that now the $b\bar{b}$-pair may be produced in a colour singlet state only, and the ordinary $gg \to b\bar{b}$ hard subprocess cross section (which includes both colour singlet and octet contributions) should be replaced by the pure colour singlet cross section. Numerically, this suppresses the background by a further factor of ten. Our arguments are further explained in a recent paper [5].

3.2 Hadron Level

We now require there to be no hadrons in the gaps at hadron level, i.e. we must take into account soft interactions of spectator partons. Using the formalism of Ref. [2] we obtain for our kinematics

$$\hat{S}_Z^2 = 0.31; \qquad \hat{S}_H^2 = 0.31; \qquad \hat{S}_{QCDb\bar{b}}^2 = 0.27. \quad (3)$$

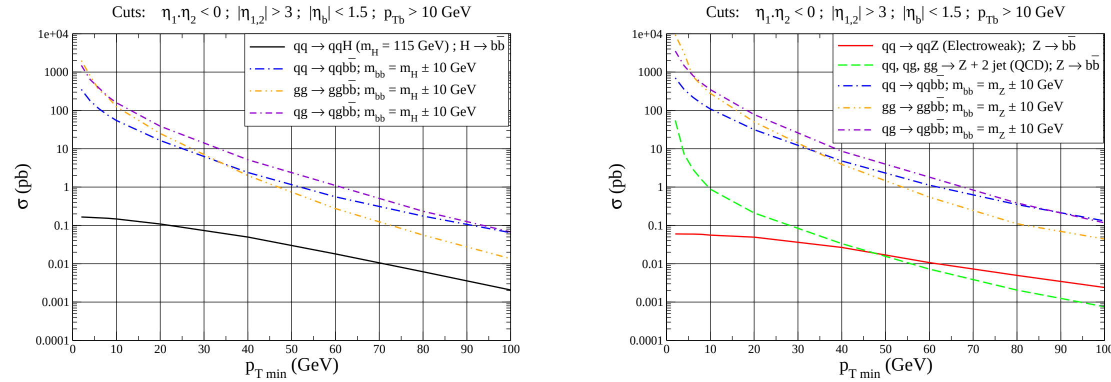


Figure 6: Parton level cross sections at $\sqrt{s} = 14$ TeV for H (left) and Z (right) production processes and backgrounds after application of cuts.

4 Results

Figure 7 summarises our results, which are based on the parton level cross sections after application of cuts (Fig. 6). The QCD-induced cross sections (both the QCD Z production of Fig. 3d and the direct QCD $b\bar{b}$ production of Fig. 4) are then multiplied by the probability to screen out the colour octet contribution for the relevant initial state (Eqn. 2). To take into account the fact that the $b\bar{b}$ pair in the background processes can only be produced in the colour singlet state the ordinary $gg \to b\bar{b}$ cross section is replaced by the pure singlet cross section. Finally both the signals and backgrounds are multiplied by the relevant soft survival probability of Eqn. 3.

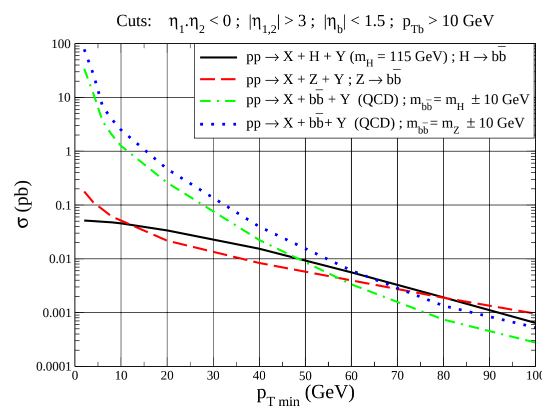


Figure 7: Hadron-level cross sections at $\sqrt{s} = 14$ TeV for inclusive Higgs and Z production with subsequent decay to $b\bar{b}$ and their respective QCD $b\bar{b}$ backgrounds. These are plotted as a function of the minimum p_T of the forward jets.

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