Higgs plus two jet production at LHC and VLHC

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We consider gluon-fusion and weak-boson fusion production of Higgs plus two jets in pp collisions at $\sqrt{s} = 14$ TeV (LHC) and $\sqrt{s} = 50, 100, 200$ TeV (VLHC). We give cross sections for Higgs masses between 115 GeV and 200 GeV, and discuss the experimental cuts that should be applied in order to enhance the weak-boson fusion contribution with respect to the gluon-fusion background.

1. Introduction

Gluon fusion and weak-boson fusion (WBF) are expected to be the most copious sources of Higgs bosons in pp collisions at the Large Hadron Collider (LHC) and a future Very Large Hadron Collider (VLHC). Beyond representing the most promising discovery processes [1, 2, 3], these two production modes are also expected to provide a wealth of information on Higgs couplings to gauge bosons and fermions [4]. The extraction of Higgs boson couplings, in particular, requires precise predictions of production cross sections.

A key component of the program to measure Higgs boson couplings at a pp collider is the WBF process, $qq \to qqH$ via t-channel W or Z exchange, characterized by two forward quark jets [3, 4]. QCD radiative corrections to WBF are known to be small [5] and, hence, this process promises small systematic errors. $H + 2$ jet production via gluon fusion, while part of the inclusive Higgs signal, constitutes a background when trying to isolate the HWW and HZZ couplings responsible for the WBF process.

In two recent papers [6] we presented the details of the calculation and some results for the real-emission corrections to gluon fusion which lead to $H + 2$ parton final states, at order α_s^4, at LHC energies. The contributing subprocesses include quark-quark scattering which involves top-quark triangles, quark-gluon scattering processes which are mediated by top-quark triangles and boxes, and $gg \to Hgg$ which requires pentagon diagrams in addition. In these papers we investigated the validity of the large top-mass limit ($m_t \to \infty$) by comparing a few distributions computed using the heavy-top effective Lagrangian [7] with the corresponding ones computed keeping m_t finite. In addition, we studied the renormalization and factorization scale-dependence of the resulting $H + 2$ jet cross section, and discussed some phenomenologically important distributions at the LHC.

In this contribution, we extend the analysis to the higher energy pp collisions of a VLHC, at center of mass energies $\sqrt{s} = 50,\ 100$ and 200 TeV. In particular, we investigate the cuts that need to be applied in order to enhance WBF signals with respect to gluon fusion contributions.

2. H+2 jet production at LHC and VLHC

The gluon-fusion processes at $\mathcal{O}(\alpha_s^4)$, together with weak-boson fusion, are expected to be the dominant sources of $H + 2$ jet events at the LHC and VLHC. The relative size of the two contributions decides the impact which gluon-fusion will have on the study of WBF processes. The gluon-fusion cross sections diverge as the final-state partons become collinear with one another or with the incident beam directions, or as final-state gluons become soft. A minimal set of cuts on the final-state partons is required to define a finite $H + 2$ jet cross section, and these cuts should at the same time anticipate detector capabilities and jet finding algorithms.

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Table I Total cross section, in picobarn, for $H + 2$ jet production, in pp collisions at LHC ($\sqrt{s} = 14$ TeV) and VLHC ($\sqrt{s} = 50, 100, 200$ TeV) for three different values of the Higgs mass m_H. Results are shown for gluon fusion (GF) and WBF, using the inclusive cuts of Eq. (1) and the WBF cuts of Eqs. (1) and (3) for LHC, and the inclusive cuts of Eq. (2) and the WBF cuts of Eqs. (2) and (4) for VLHC.

σ [pb]	INCLUSIVE CUTS								WBF CUTS							
	14 TeV		50 TeV		100 TeV		200 TeV		14 TeV		50 TeV		100 TeV		200 TeV	
	GF	WBF	GF	WBF	GF	WBF	GF	WBF	GF	WBF	GF	WBF	GF	WBF	GF	WBF
$m_H = 115$ GeV	9.9	3.3	66.2	16.8	210	38.5	635	78.6	0.57	1.4	0.71	2.5	3.7	7.3	15.1	16.6
$m_H = 160$ GeV	7.9	2.4	55.3	13.1	189	30.6	559	63.3	0.50	1.2	0.68	2.3	3.6	6.8	14.8	15.8
$m_H = 200$ GeV	6.8	1.8	51.2	10.8	170	25.5	524	53.3	0.44	1.0	0.65	2.1	3.5	6.3	14.4	14.4

We consider two broadly defined sets of cuts: a selection for generic $H + 2$ jet events (called "inclusive cuts") and a more stringent selection which is typical for WBF studies ("WBF cuts"). In going from LHC to the higher VLHC energies, harder jet cuts will have to be imposed, in particular on the jet transverse momentum, p_{Tj}. We distinguish between LHC and VLHC specific cuts:

- Inclusive cuts

$$\text{LHC}: \quad p_{Tj} > 20 \text{ GeV}, \qquad |\eta_j| < 5, \qquad R_{jj} > 0.6, \tag{1}$$

$$\text{VLHC}: \quad p_{Tj} > 30 \text{ GeV}, \qquad |\eta_j| < 6, \qquad R_{jj} > 0.6, \tag{2}$$

- WBF cuts: previous inclusive cuts plus [3]

$$\text{LHC}: \quad |\eta_{j_1} - \eta_{j_2}| > 4.2, \qquad \eta_{j_1} \cdot \eta_{j_2} < 0, \qquad m_{jj} > 600 \text{ GeV}, \tag{3}$$

$$\text{VLHC}: \quad |\eta_{j_1} - \eta_{j_2}| > 5, \qquad \eta_{j_1} \cdot \eta_{j_2} < 0, \qquad m_{jj} > 3 \text{ TeV}. \tag{4}$$

In general, the gluon fusion differential cross section tends to peak for central jets and and at a relatively small invariant mass, m_{jj}, of the dijet system. This is because final-state gluons tend to be soft and the energy of initial gluons is restricted due to the rapid fall-off of the gluon distribution, $g(x, \mu_f)$, with increasing x. The WBF cuts then enhance the WBF contribution with respect to gluon fusion. For the inclusive cuts, which allow soft events, the gluon fusion cross section dominates over WBF by a factor 3–10. The WBF cuts force the two tagging jets to be well separated in pseudorapidity, η, they must reside in opposite detector hemispheres and they must possess a large dijet invariant mass. The combination of these requirements forces the gluon fusion cross section below the WBF rate for all machine energies.

This is demonstrated in Table I, where the expected $H + 2$ jet cross sections are shown for Higgs masses of 115, 160, and 200 GeV, and for the two sets of cuts introduced previously. The gluon fusion cross sections depend only weakly on the Higgs mass. Cross sections correspond to the sum over all Higgs decay modes: finite Higgs width effects are included. We use CTEQ4L parton-distribution functions [8]. The factorization scale was set to $\mu_f = \sqrt{p_{T1}\, p_{T2}}$ and we fix $\alpha_s = \alpha_s(M_Z) = 0.12$. Different choices for the renormalization and factorization scales have been discussed in Ref. [6], where a strong dependence on the renormalization scale was found for the gluon fusion cross section.

It is instructive to consider the dijet invariant mass distributions for our two sources of $H+2$ jet events. Within the WBF cuts (but without the m_{jj} constraint) they are shown in Fig. 1. At machine energies below 100 TeV, WBF soon dominates the m_{jj} distribution: a relatively modest m_{jj} requirement (500 GeV at the LHC, 1 TeV at a 50 TeV machine) will suffice, while retaining most of the WBF signal. At higher collision energies WBF only dominates at very large dijet invariant masses, and cuts at 2 or 4 TeV will come at a huge cost of WBF cross section. In addition, since the jet transverse momenta in WBF events are tied to the weak boson masses, such cuts leave us with dijet systems with very large rapidity separation. Containing such events will require superior rapidity coverage of VLHC detectors, up to $|\eta| = 7$.

3. Conclusions

As the center-of-mass energy is increased at very high energy hadron colliders, the mix of $H + 2$ jet events shifts more and more to gluon fusion induced events, even with cuts geared

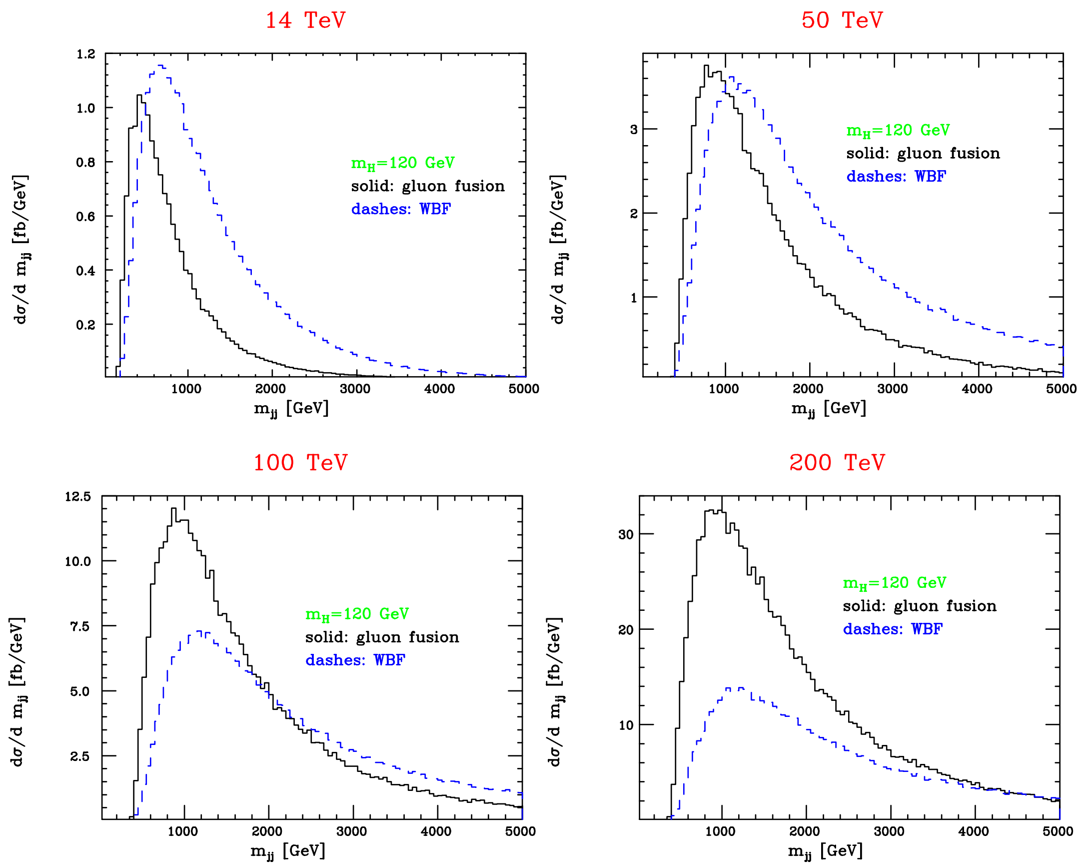

Figure 1: Dijet invariant-mass distribution of the two final jets for gluon-fusion (solid) and WBF (dashes) processes at LHC, $\sqrt{s}$ = 14 TeV, and VLHC, with center-of-mass energies of 50, 100 and 200 TeV. The mass of the Higgs was fixed at m_H = 120 GeV. Cross sections are for WBF cuts as discussed in the text, without the m_{jj} constraint.

towards the enhancement of weak boson fusion. A separation of the two sources is partially possible with the rapidity and invariant mass cuts discussed above. However, other distinguishing characteristics will have to be exploited. Chief among these will be the different color structure of the events: t-channel color singlet exchange for WBF, t-channel color octet exchange for gluon fusion. The resulting suppression of soft jets in the central region for WBF events [3, 9] will need to be studied in detail to prepare tools for the isolation of WBF events at a VLHC.

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