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HIGGS PRODUCTION IN ASSOCIATION WITH TWO JETS AT THE LHC*

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The Higgs boson is a keystone of the mechanism of ElectroWeak Symmetry Breaking (EWSB) in the Standard Model of particles. Besides the Higgs boson discovery, which will be widely pursued at the Large Hadron Collider (LHC) at CERN, in order to analyse EWSB it will be crucial to study the Higgs couplings. A key component of the programme to measure the couplings, and in particular the ones of the Higgs to the W- or Z-bosons, will be the vector-boson fusion (VBF) process, characterised by the production of a Higgs boson plus two jets. However, Higgs + 2-jet production occurs mostly via gluon fusion, which, while part of the Higgs signal, constitutes a background when trying to isolate the gauge couplings of the VBF process. We give an overview of Higgs production, and analyse some distributions, in particular the azimuthal correlation between the jets, which may distinguish the VBF process from gluon fusion.

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1. Introduction

The mechanism that governs the ElectroWeak Symmetry Breaking (EWSB) is at present the largest mistery in the Standard Model (SM) of elementary particle physics. The canonical mechanism, the Higgs model, is a keystone of the SM and its supersymmetric extensions. However, it is based on the existence of a CP-even scalar particle, the Higgs boson, which has not been detected yet and is the most wanted particle of Fermilab's Tevatron and CERN's Large Hadron Collider (LHC) physics programmes. In fact, one of the main objectives of the LHC is to investigate the dynamics of the EWSB, and thus to search for the SM Higgs boson or for multiple Higgs resonances in extended models, and to measure the Higgs couplings.

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The direct search in the $e^+e^- \to ZH$ process at the CERN LEP2 collider has posed a lower bound of 114.1 GeV on the SM Higgs mass, m_H [1–5]. LEP2 also posed lower bounds of 91.0 GeV (91.9 GeV) on the CP-even (CP-odd) Higgs bosons of the minimal supersymmetric extension of the Standard Model (MSSM) [6].

Two processes dominate the production of a SM-like Higgs boson at the LHC, gluon fusion and vector boson fusion (VBF). The largest production mechanism over the entire Higgs mass range relevant for LHC is via gluon fusion $gg \to H$, mediated by a heavy quark loop. The leading contribution comes from the top quark, the contributions from other quarks being at least smaller by a factor $\mathcal{O}(m_b^2/m_t^2)$. Since the Higgs boson is produced via a heavy quark loop, a calculation of the production rate is quite involved, even at leading order in α_s. The production rate for $gg \to H$ has been computed at next-to-leading order (NLO) in α_s, including the heavy quark mass dependence [7,8] (which required an evaluation at two-loop accuracy). The NLO QCD corrections are large and increase the production rate by up to 80%. However, the coupling of the Higgs to the gluons via a top-quark loop can be replaced by an effective coupling [9,10], called the *large m_t limit*, if the Higgs mass is smaller than the threshold for the creation of a top-quark pair, $m_H < 2m_t$. That simplifies calculations tremendously, because it effectively reduces the number of loops in a given diagram by one. It has been shown that adding the NLO QCD corrections in the large m_t limit to the leading order calculation with the top quark mass dependence approximates the full NLO QCD corrections within 10% up to 1 TeV [11] covering the entire Higgs mass range at the LHC. The reason for the quality of this approximation is that the QCD corrections to $gg \to H$ are dominated by soft gluon effects, which do not resolve the top-quark loop mediating the coupling of the Higgs boson to the gluons. The next-to-next-to-leading order (NNLO) corrections to the production rate for $gg \to H$ have been evaluated in the large m_t limit [12–14] and display a modest increase with respect to the NLO evaluation. The dominant part of the NNLO corrections comes from the gluon and collinear radiation [15, 16], in agreement with what already observed at NLO. The threshold resummation of soft gluon effects [11, 17] enhances the NNLO result by less than 10%, showing that the calculation stabilises at NNLO. In addition, a fully differential cross section for gluon fusion at NNLO, which thus accepts any acceptance cuts, has been computed in Ref. [18–20]. Furthermore, Higgs production from gluon fusion has been included [21] into MC@NLO [22], a code that interfaces the parton-level NLO calculation to a parton-shower Monte Carlo event generator.

2. Higgs + 2-jet production

The second largest production mechanism of a SM-like Higgs boson is VBF. Most of the times, this is characterised by two forward tagging jets separated by a large rapidity interval, a feature that is very helpful to suppress backgrounds. Higgs + 2-jet production via VBF has been computed at NLO accuracy [23, 24], which shows quite a modest increase, of about 10%, with respect to the leading order estimate. Of course also gluon-fusion processes give rise to Higgs + 2-jet production, which has been computed at leading order in α_s including the heavy-quark mass dependence [25, 26]. In this case, the large m_t limit provides a good approximation to the exact calculation as long as $m_H < 2m_t$, and the transverse energies of the Higgs boson and the jets are smaller than the top-quark mass [27]. Accordingly, Higgs + 2-jet production via gluon fusion has been evaluated at NLO accuracy in the large m_t limit [28].

For a measurement of Higgs couplings [29–31] it is important to distinguish gluon fusion from VBF. Fortunately, the distributions of the two tagging jets, as well as their correlations, are markedly different for gluon fusion and VBF. For example, the dijet invariant mass distribution of the two leading jets in gluon fusion is substantially softer than in VBF. This is due to the different shape of the PDF's of the partons initiating the hard scattering: in VBF the scattering occurs mostly through valence quarks, in gluon fusion through gluons.

3. The azimuthal correlation

A second characteristic difference emerges in the azimuthal correlations of the two tagging jets [26]. The distribution of the azimuthal angle $\Delta\phi_{jj}$ between the jets directly reflects the tensor structure of the coupling of the Higgs boson to weak bosons or gluons [32, 33]. The SM gauge couplings of the Higgs boson to the electroweak vector bosons lead to a fairly flat $\Delta\phi_{jj}$ distribution. In contrast, the loop induced effective Hgg coupling, which, in the large top-mass limit, can be written as a CP-even effective Lagrangian produces a dip in the $\Delta\phi_{jj}$ distribution at 90 degrees. The same correlation and similar dynamical properties were used in Refs. [32, 33] to discriminate between the SM gauge coupling and anomalous (New Physics) couplings between the Higgs and electroweak vector bosons.

The analyses of Refs. [26,32,33] were done at the parton level only. Previous experience with the azimuthal correlation between two jets at large rapidity intervals in dijet production in $p\bar{p}$ collisions, analysed at the parton level [34–38] and with parton showers and hadronisation [39, 40], and measured at the Tevatron [41], leads us to expect that a certain amount of de-correlation between the jets will be induced by showering and hadronisation. That reduces the correlation induced by the dynamical properties of Higgs + 2-jet production at the parton level. Indeed, a much weaker correlation between the tagging jets in Higgs + 2-jet production via gluon fusion was found after showering and hadronisation [42]. The analysis of Ref. [42] did not allow, though, for a direct comparison with the result of Ref. [26], because in Ref. [42] the two tagging jets associated to the Higgs production were generated by the parton shower and not by the matrix element. Thus, it was not possible to distinguish the decorrelation due to showering and hadronisation from an inherent lack of correlation between the two tagging jets caused by the approximations in the parton-shower generation.

In Ref. [43] we addressed the shortcomings of either a purely hard matrix element calculation or of a purely parton-shower approach. By using ALPGEN [44,45] to calculate the matrix elements for emission of hard partons and HERWIG [40] to then evolve the parton-level events through the shower and hadronisation phases, we considered the azimuthal correlation between the two tagging jets and a veto on the jet activity in the rapidity interval between the tagging jets. In the case of the azimuthal correlation, we found that the dip at $\Delta\phi_{jj} = \pi/2$, characteristic of a CP-even Higgs boson produced via gluon fusion [26,32], is slightly filled by the parton shower, but not as much as one would find by generating the tagging jets through the parton shower [42]. This feature is shown in Fig. 1, where the dot-dashed line gives the parton-level leading order prediction, while the solid line represents the distribution including also shower evolution effects. As a reference, the dashed histogram shows the $\Delta\phi_{jj}$ distribution for VBF, where the effects of parton showering are almost indistinguishable from the parton level calculation. It is worth mentioning that the shower effects on the Δ_{jj} distribution are of the same order as the ones given by the NLO corrections [28].

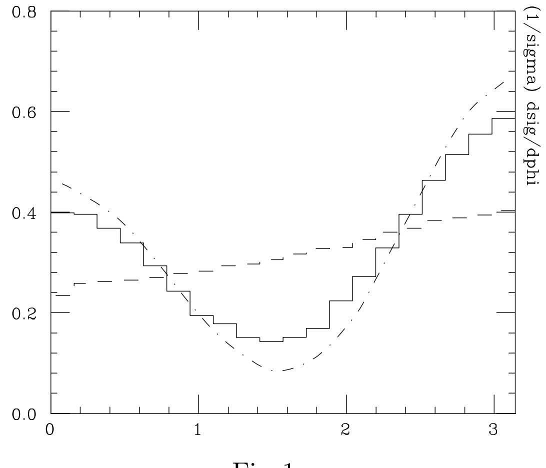

Fig. 1.

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