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Next-to-leading order QCD corrections to slepton pair production via vector–boson fusion

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Abstract

Slepton pairs can be produced in vector–boson fusion processes at hadron colliders. The next-to-leading order QCD corrections to the electroweak production cross section for $pp \to \tilde{\ell}^+\tilde{\ell}^- + 2$ jets at order $\alpha_s\alpha^4$ have been calculated and implemented in an NLO parton-level Monte Carlo program. Numerical results are presented for the CERN large hadron collider.

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1. Introduction

Among the primary goals of the CERN Large Hadron Collider (LHC) are the discovery of the Higgs boson, thus shedding light on the yet unexplored mechanism of electroweak (EW) symmetry breaking, and the search for physics beyond the Standard Model. Within the area of Higgs boson studies, vector–boson fusion (VBF) processes have emerged as being highly promising for revealing information on the symmetry breaking sector [1]. The prototypical process is $qq \to qqH$, which proceeds via t-channel W or Z exchange. The two scattered quarks emerge as forward and backward jets (called tagging jets) which provide a characteristic signature for VBF and allow to significantly suppress backgrounds. As a result, VBF searches are expected to lead to quite clean Higgs boson signals.

A natural question is whether vector boson fusion is a useful tool also for the study of other signals of new physics. Some recent work has indicated the effectiveness of VBF channels in the context of new physics searches, particularly for new particles that do not interact strongly. Perhaps the best example [2] is afforded by supersymmetric theories, wherein conventional search strategies for neutralinos and charginos may run into difficulty at the LHC, for a significant part of the parameter space. The possibility of a slepton search has been studied for vector–boson fusion as well [3]. A more recent study [4] on VBF slepton production using Smadgraph arrived at a substantially smaller cross section, however, which is partly caused by large cancellations among VBF-type diagrams and bremsstrahlung diagrams at the Born level.[1]

The discrepancies between these previous results lead us to a recalculation of the slepton pair-production cross section in VBF. The relevant Feynman graphs for this process are depicted in Fig. 1 for the tree level contributions. In this approximation, we confirm the new results of Ref. [4]. In addition, we also perform a calculation of the NLO QCD corrections to this VBF process. The NLO calculation closely follows previous calculations for Hjj and Zjj production in VBF in Refs. [5,6]. It uses the Catani–Seymour subtraction scheme [7] for implementing the real and virtual NLO contributions in the form of a fully flexible parton level Monte Carlo program.

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[1] Ref. [3] missed this contribution due to a programming error in the bremsstrahlung diagrams.

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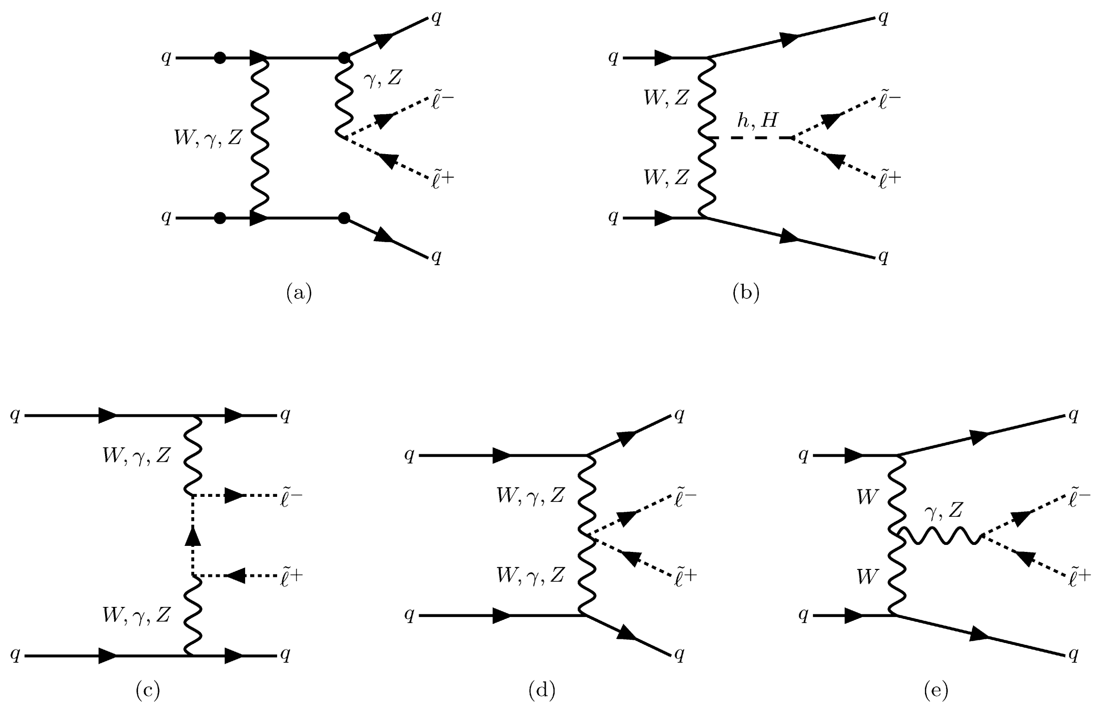

Fig. 1. Generic LO parton level diagrams leading to slepton pair-production through electroweak VBF at hadron colliders.

2. Calculation

The Feynman graphs contributing to $pp \to \tilde{\ell}^+\tilde{\ell}^- + 2$ jets at tree level are indicated in Fig. 1. Considering the possible choices of external quarks or anti-quarks, the subprocesses can be grouped into neutral-current (NC) processes, like $uc \to uc\tilde{\ell}^+\tilde{\ell}^-$, and charged-current (CC) processes, like $us \to dc\tilde{\ell}^+\tilde{\ell}^-$. For the purpose of calculating the virtual QCD corrections, the Feynman graphs are divided into Compton scattering type graphs, as in Fig. 1(a), and the VBF type graphs as in Fig. 1(b)–(e). The first class (Fig. 1(a) and three additional bremsstrahlung diagrams, with the vector boson radiated at the position of the blobs) corresponds to the emission of the external vector boson from one of the two quark lines. The VBF graphs represent $VV \to \tilde{\ell}^+\tilde{\ell}^-$. Here, V stands for a t-channel γ, Z or W boson. For selectron or smuon production one expects a negligible contribution from Fig. 1(b). We do include this Higgs exchange contribution for stau pair production, however, anticipating strong enhancements of the couplings to the Higgs bosons at large $\tan\beta$.

Contributions from anti-quark initiated t-channel processes such as $\bar{u}c \to \bar{u}c\tilde{\ell}^+\tilde{\ell}^-$, which emerge from crossing the above processes, are fully taken into account. On the other hand, two additional classes of diagrams which can appear in case of identical quark flavors, are simplified in our calculation. The first concern s-channel exchange diagrams, where both virtual vector bosons are time-like. These diagrams correspond to vector boson pair production with subsequent decay of one neutral vector boson to $\tilde{\ell}^+\tilde{\ell}^-$ while the other one decays into a quark–anti-quark pair. These contributions can be safely neglected in the phase-space region where VBF can be observed experimentally, with widely-separated quark jets of large invariant mass. The second class corresponds to u-channel exchange diagrams which are obtained by the interchange of identical final state (anti-)quarks. Their interference with the t-channel diagrams is strongly suppressed for typical VBF cuts and therefore neglected in our calculation. Color suppression further reduces any interference terms.

Throughout our calculation, fermion masses are set to zero and external b- and t-quark contributions are neglected. For the Cabibbo–Kobayashi–Maskawa matrix V_{CKM}, we use a diagonal form equal to the identity matrix. This yields the same results as a calculation using the exact V_{CKM} when the summation over all quark flavors is performed.

The computation of NLO corrections is performed in complete analogy to Ref. [6]. For the real-emission contributions, we consider the diagrams with a final-state gluon by attaching the gluon to the quark lines in all possible ways. As a result one obtains two distinct, non-interfering color structures which correspond to gluon emission off the upper or off the lower quark line in Fig. 1. Subprocesses with an initial gluon are obtained by crossing the final state gluon on a given quark line with the incident quark or anti-quark of this same quark line. As a result only one color structure exists for initial gluons. The other color structure would correspond to an s-channel process of the type $gq \to VVq$, which has been neglected also at Born level.

All amplitudes are evaluated numerically using the amplitude techniques of Ref. [8]. The calculation is simplified by introducing the leptonic tensors Γ_V^α and $L_{VV}^{\alpha\beta}$, which describe the effective polarization vector of the final state decay $V(q) \to \tilde{\ell}^-(p_1)\tilde{\ell}^+(p_2)$,

$$\Gamma_V^\alpha(p_1, p_2) = \frac{g_\tau^{V\tilde{\ell}}}{(p_1+p_2)^2 - m_V^2 + i m_V \Gamma_V}(p_1 - p_2)^\alpha, \qquad (1)$$