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Scalar and pseudoscalar Higgs production in association with a top–antitop pair

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ABSTRACT

We present the calculation of scalar and pseudoscalar Higgs production in association with a top–antitop pair to the next-to-leading order (NLO) accuracy in QCD, interfaced with parton showers according to the MC@NLO formalism. We apply our results to the cases of light and very light Higgs boson production at the LHC, giving results for total rates as well as for sample differential distributions, relevant to the Higgs, to the top quarks, and to their decay products. This work constitutes the first phenomenological application of aMC@NLO, a fully automated approach to complete event generation at NLO in QCD.

1. Introduction

Establishing evidence for the Higgs boson(s), i.e., the scalar remnant(s) of the Englert–Brout–Higgs mechanism [1–3] in the standard model and in extensions thereof, is among the most challenging goals of the LHC experiments. A coordinated theoretical/experimental effort in the last years has led to a number of remarkable achievements in the accuracy and usefulness of the available theoretical predictions, and in the role these play in current analysis techniques [4].

Depending on mass and couplings, Higgs bosons are produced and eventually decay in a plethora of different ways, leading to a wide range of signatures. In most cases, signals are difficult to identify because of the presence of large backgrounds, and reliable predictions are necessary firstly to design efficient search strategies, and secondly to perform the corresponding analyses. A particularly challenging scenario at the LHC is that of a standard-model light Higgs, $m_H \lesssim 130$ GeV. In this case, the dominant decay mode is into a $b\bar{b}$ pair, which is however completely overwhelmed by the irreducible QCD background. A possible solution is that of considering the Higgs in association with other easier-to-tag particles. An interesting case is that of a top–antitop pair, since the large Yukawa coupling ttH, and the presence of top quarks, can be exploited to extract the signal from its QCD multi-jet backgrounds. Unfortunately, this production mechanism is also plagued by large backgrounds that involve a $t\bar{t}$ pair, and hampered by its rather small rates, and thus turns out to be difficult to single out. Several search strategies have been proposed, based on different decay modes: from $b\bar{b}$ which leads to largest number of expected events, to the more rare but potentially cleaner $\tau\tau$ [5], $WW^{(*)}$ [6] and $\gamma\gamma$ [7] final states. All of them are in fact very challenging, and dedicated efforts need be made. For example, recently it has been argued that in the kinematical regions where the Higgs is at quite high transverse momentum the $b\bar{b}$ pair would be merged into one "fat" jet, whose typical structure could help in discriminating it from QCD backgrounds [8,9] (boosted Higgs scenario).

It is then clear that accurate and flexible simulations, for both signals and backgrounds, can give a significant contribution to the success of any given analysis. Predictions accurate to NLO in QCD and at the parton level for $t\bar{t}H$ hadroproduction have been known for some time [10–15], and recently confirmed by other groups [16,17]. As for the most relevant background processes to the Higgs decay mode into $b\bar{b}$, NLO calculations for $t\bar{t}b\bar{b}$ [18–20] and $t\bar{t}jj$ [21] are available in the literature. In this work, we extend the results for the signal to computing the associated production $t\bar{t}A$ of a pseudo-scalar Higgs boson. All aspects of the calculations we present here are fully automated. One-loop contributions have been evaluated with MadLoop [17], that uses the OPP integrand

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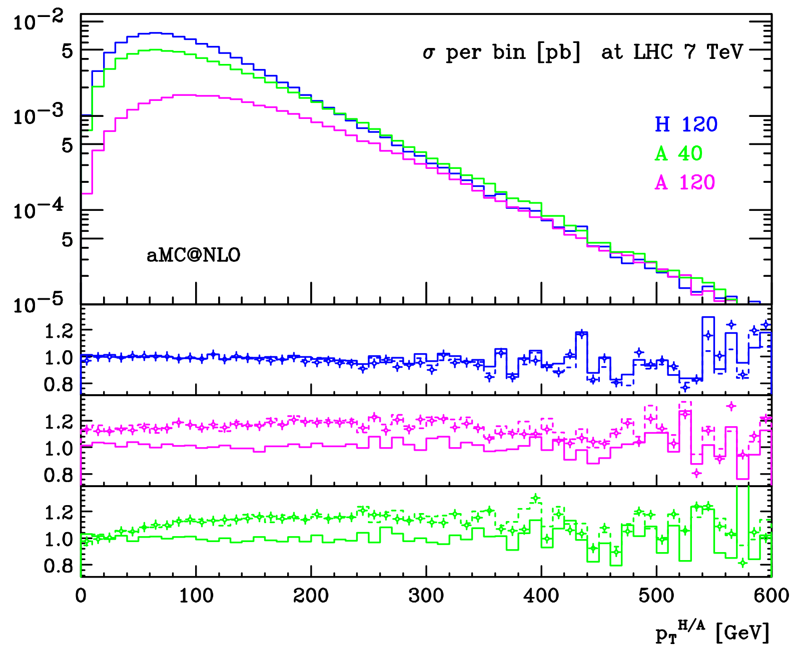

Fig. 1. Higgs transverse momentum distributions in $t\bar{t}H/t\bar{t}A$ events at the LHC ($\sqrt{s}=7$ TeV), with aMC@NLO in the three scenarios described in the text: Scalar (blue) and pseudoscalar (magenta) Higgs with $m_{H/A}=120$ GeV and pseudoscalar (green) with $m_A=40$ GeV. In the lower panels, the ratios of aMC@NLO over LO (dashed), NLO (solid), and aMC@LO (crosses) are shown for each scenario. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

reduction method [22] as implemented in CutTools [23]. The other matrix-element contributions to the cross sections, their phase-space subtractions according to the FKS formalism [24], their combinations with the one-loop results, and their integration are performed by MadFKS [25]. The validation of MadLoop and MadFKS in the context of hadronic collisions has been presented in Ref. [17]. For the sake of the present work, we have also performed a dedicated comparison with the results of Ref. [4] for the total $t\bar{t}H$ cross section, and found agreement at the permille level for several Higgs masses.

We have also matched our NLO results with parton showers using the MC@NLO method [26]. This matching procedure has also been completely automated, and this work represents the first application of the MC@NLO technique to non-trivial processes which were previously available only at fixed order and at the parton level – in other words, to processes not already matched to showers by means of a dedicated, final-state-specific, software. What said above also implies that our results are the first example of NLO computations matched to showers in which *all* ingredients of the calculation are automated, and integrated in a unique software framework.

We remind the reader that the structure of the MC@NLO short-distance cross sections is the same as that of the underlying NLO computation, except for a pair of extra contributions, called MC subtraction terms. These terms have a factorised form, namely, they are essentially equal to the Born matrix elements, times a kernel whose main property is that of being process-independent. This is what renders it possible the automation of the construction of the MC subtraction terms, and ultimately the implementation of the MC@NLO prescription. We call aMC@NLO the code that automates the MC@NLO matching, and we defer its detailed presentation to a forthcoming paper [27]. aMC@NLO uses MadFKS for phase-space generation and for the computation of the pure-NLO short distance cross section of non-virtual origin, and on top of that it computes the MC subtraction terms. One-loop contributions may be taken from any program which evaluates virtual corrections and is compatible with the Binoth–Les Houches format [28]; as was said before, we use MadLoop for the predictions given in this work. The resulting MC@NLO partonic cross sections are integrated and unweighted by MINT [29], or by BASES/SPRING [30].[1] aMC@NLO finally writes a Les Houches file with MC-readable hard events (which thus includes information on particles identities and their colour connections).

Table 1
Total cross sections for $t\bar{t}H$ and $t\bar{t}A$ production at the LHC ($\sqrt{s}=7,14$ TeV), to LO and NLO accuracy. The integration uncertainty is always well below 1%. Scale choices and parameters are given in the text.

Scenario	Cross section (fb)					
	7 TeV			14 TeV		
	LO	NLO	K-factor	LO	NLO	K-factor
I	104.5	103.4	0.99	642	708	1.10
II	27.6	31.9	1.16	244	289	1.18
III	69.6	77.3	1.11	516	599	1.16

2. Results at the LHC

We present selected results for total cross sections and distributions relevant to $t\bar{t}H/t\bar{t}A$ production at the LHC in three scenarios:

I. Scalar H, with $m_H=120$ GeV;
II. Pseudoscalar A, with $m_A=120$ GeV;
III. Pseudoscalar A, with $m_A=40$ GeV;

where the Yukawa coupling to the top is always assumed SM-like, $y_t/\sqrt{2}=m_t/v$.

The three scenarios above allow one to compare the effects due the different parity of the Higgs couplings on total rates as well as on differential distributions. In this respect, it is particularly interesting to consider the situation in which the Higgs boson is light

[1] These integrators have been modified by us, in order to give them the possibility of dealing with both positive- and negative-weighted events.