Study of the Powheg-bb4l generator including non-resonant and off-shell effects in comparison with other MC generator predictions

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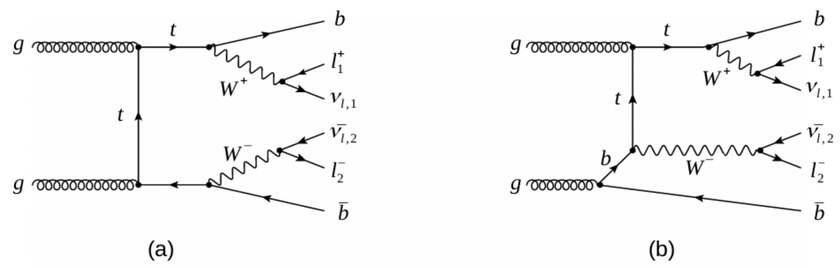
Abstract

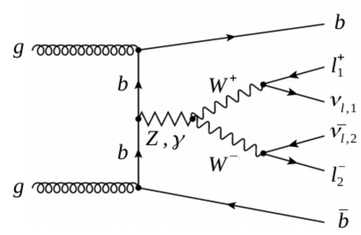
The precise simulation of $t\bar{t}$ processes is crucial for precision tests of the Standard Model and in the search for new physics at the Large Hadron Collider (LHC). The bb4l generator [1] is a next-to-leading order (NLO) matrix-element generator for $pp \to \ell^+\nu\ell^{-\prime}\bar{\nu}'b\bar{b}$ final states implemented in Powheg. It includes theoretical improvements in the simulation of $t\bar{t}$ processes, which allows the production of $t\bar{t}$ and tW events including interference and off-shell effects. The events simulated with the bb4l generator are interfaced with Pythia 8 for the simulation of the Parton Shower (PS) and hadronisation. They are compared to $t\bar{t}$ + tW samples produced with various NLO+PS setups and different top mass values , where different diagram-removal and diagram-subtraction methods [2] are used in the generation of the tW events.

Introduction

- At NLO, tW events are not well defined. tWb and $t\bar{t}$ events interfere due to having the same final state WWbb.
- For most ATLAS analyses, $t\bar{t}$ and tW events were produced separately. The overlap between the samples was removed using two different approaches [2]:
  - ***Diagram removal* (DR)** : all double resonant terms are removed
  - ***Diagram subtraction* (DS) :** a gauge invariant term is introduced to remove the $t\bar{t}$ contribution



- The **"bb4l"** generator is a MC generator for $pp \to \ell^+\nu\ell^{-\prime}\bar{\nu}'b\bar{b}$ production which takes into account the the interference between $t\bar{t}$ and tW, and implements the exact NLO treatment of spin correlations and off-shell effects.
  - Generated using **Powheg Box v2** with the **NNPDF3.NLO set** for the PDF and **h_{damp} = 1.5 x m_{top}**
  - Interfaced with the **Pythia 8** for the PS using the **NNPDF2.3LO set** for the PDF



- In all plots shown in this study, the scale variation in the matrix element and the parton shower (ISR and FSR) are combined in the red band for the ATLAS nominal sample $t\bar{t}$ + tW (DR).

Object definitions

Use only stable particles with $\tau > 30\ ps$

Electron and muon:

- Dressed leptons
- Originate from a W decay or from a Tau decay which itself originates from W decay
- p_T > 28 GeV and $|\eta|$ < 2.5

Jet:

- Reconstructed using the anti-k_t algorithm with R=0.4 , p_T > 25 GeV and $|\eta|$ < 2.5

B-jet:

- Identified using the ghost-association technique [5]

The bb4l sample only contains different flavor channels (ZZbb events are not yet included in this MC generator). A same-flavor cut is applied to all samples.

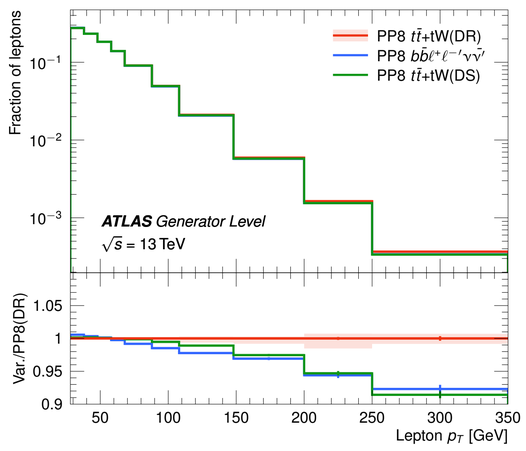
Event selection

Phase-space similar to phase-spaces used for the precision measurement of top properties in dilepton events at the LHC:

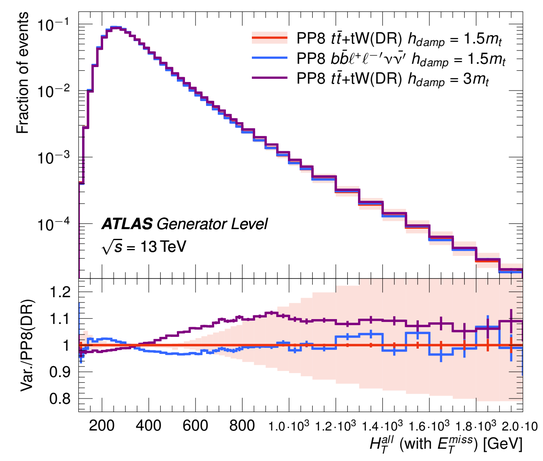
- Exactly 1 electron and 1 muon with OS
- At least 2 jets and exactly 2 b-jets

Lepton p_T

- The nominal and the bb4l samples show differences for the lepton p_T.
- Neither the scale variation nor the DS/DR uncertainties cover these differences for the lepton p_T smaller than 150 GeV.



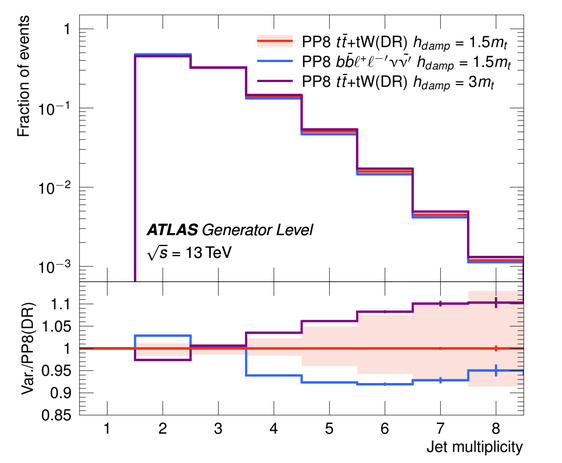
- The h_{damp} parameter controls the p_T of the first additional emission beyond the Born configuration. The choice of this parameter could affect the jet multiplicity and the jet p_T distribution.
- For the ATLAS nominal sample, its value is h_{damp} = 1.5 x m_{top}. The uncertainty in the choice of the h_{damp} parameter is taken as the difference between the nominal and the sample generated with h_{damp} = 3 x m_{top}.



- The H_T variable is defined as:

$$H_T = p_T^{b_1} + p_T^{b_2} + p_T^{l_1} + p_T^{l_2} + MET$$

- The nominal and the bb4l samples show differences in the bulk of the distribution, which are not covered by the h_{damp} and the scale variation uncertainties

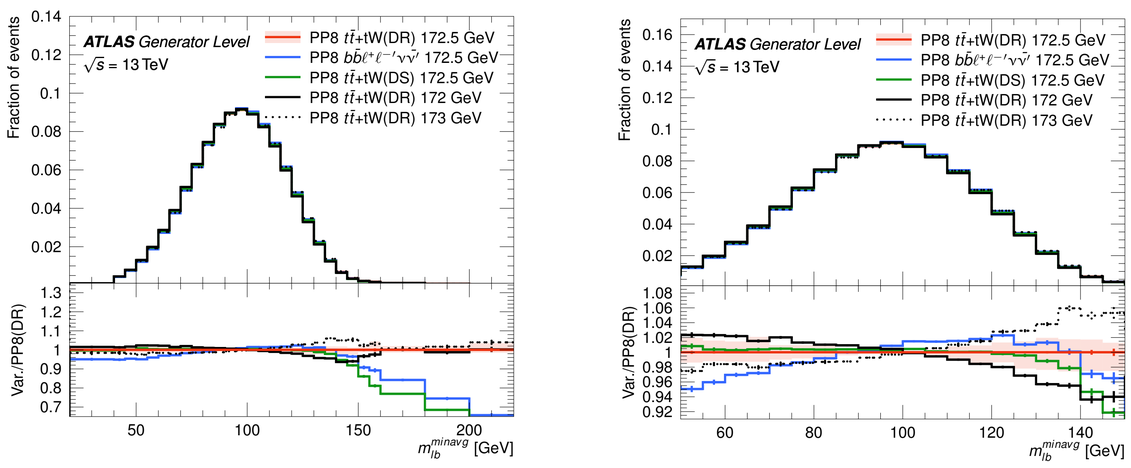


- The difference between the nominal and the bb4l samples for events with at most 6 jets is not covered by the h_{damp} and the scale variation uncertainties.

Observable used in top mass measurement

- The m_{lb} distribution, which is the invariant mass of the b-jet and the lepton system, is an observable widely used in the measurement of the top quark mass for example in the template method using the $t\bar{t}$ dilepton channel in ATLAS at 8 TeV [3].
- The following definition is used here:

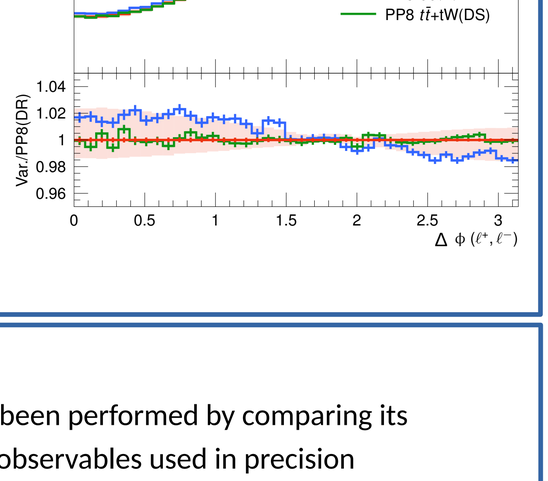
$$m_{lb}^{minavg} = min\left\{avg\left(m_{l_1b_1}, m_{l_2b_2}\right), avg\left(m_{l_1b_2}, m_{l_2b_1}\right)\right\}$$



- As expected, differences are seen between the nominal and bb4l generator in the off-shell region. The bb4l distribution has better agreement with the $t\bar{t}$ + Wt (DS) distribution.
- A clear shift towards higher values of m_{lb}^{minavg} is seen for the bb4l sample.
- Differences at lower values of m_{lb}^{minavg} are also observed.

Observable used in spin correlation measurement

- In the $t\bar{t}$ dilepton channel, the distribution of the azimuthal angle between the two charged leptons, $\Delta\phi$ (l^+, l^-), is different for a scenario with and without spin correlation between the top and anti-top quark.
- This quantity is used to extract the spin correlation in $t\bar{t}$ events [6].
- As expected, differences are seen between the nominal and the bb4l samples:
  bb4l: exact NLO treatment of the spin correlations
  Nominal: approximations are used to model the spin correlation



Conclusion

- Studies of the bb4l Monte Carlo event generator have been performed by comparing its prediction to the ATLAS $t\bar{t}$ + Wt samples for different observables used in precision measurements of top quark properties.
- Differences were seen between the bb4l and $t\bar{t}$ + Wt samples. In most cases these differences are not covered by the systematic uncertainties taken into account.

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[1] Eur.Phys.J.C 76 (2016) 12, 691
[2] Eur. Phys. J. C 71 (2011) 1547
[3] Physics Letters B 761 (2016) 350 – 371
[4] JHEP 04 (2007) 081
[5] JHEP 04 (2008) 005
[6] Phys. Rev. Lett. 108 (2012) 212001

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