A First Look at Event Kinematics in ttbar Production with Herwig 7

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(With the real work done by the Herwig Collaboration)

Herwig7 Overview

Herwig 7 is the latest version of the Herwig Monte Carlo program. It is a highly configurable, general purpose Monte Carlo program which includes:

- Interfaces to many Matrix Element Generators as well as Les Houches Accord Event Files
- Implementations of the POWHEG and MCatNLO methods for NLO Matrix Element + Parton Shower simulations
- Implementations of Angular Ordered and Seymour-Catani Dipole Showering algorithms
- Configurable options for scale choices, hadronization parameters, Multiple Parton Interaction handling, grid sampling etc….

Source and Tutorials available at:

https://herwig.hepforge.org/index.html

The customizable nature of Herwig7 allows for coherent studies of many event generation options. The effects of a given parameter or algorithm can be studied by systematic variations within Herwig. This facilitates “apples to apples” comparisons which isolate the effects of interest.

- Studies of theoretical parameter uncertainties (e.g. mass parameters, value of a renormalized coupling at a given scale)
- Studies of algorithmic differences
- **Studies of perturbative truncation uncertainties**

Members of the Herwig collaboration have already produced a paper with a careful systematic approach to understanding uncertainties in LO processes with focus on examples from Higgs and Z production:
http://arxiv.org/pdf/1605.01338v1.pdf

This serves as a very nice starting point for similar studies at NLO and with a wider range of processes.

Event Generation Overview

Present preliminary results of ttbar Monte Carlo event generation with Herwig 7. More in depth and comprehensive exploration is underway.

→ Focus on “Out of the Box” Herwig Matchbox. Full event simulation (with hadronization and Multiple Parton Interactions).
→ Leading Order, Leading Order + Decay Matrix Element Corrections and Next To Leading Order Matrix Elements
→ MCatNLO and POWHEG methods. **Note: Using default tunes! i.e. parameters for the two methods are not identical, differences should not be considered inherent to the methods.**
→variations of three scales relevant to event generation:

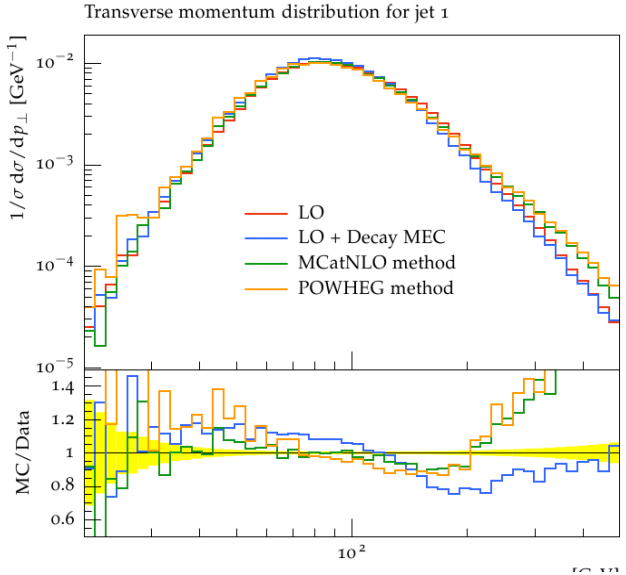
I. The renormalization and factorization scale used in the hard process, $\mu_{R/F}$
II. The veto scale, limiting the hardness of emissions Q
III. The shower scale, argument of the couplings in the PDFs and Parton Shower, μ_s

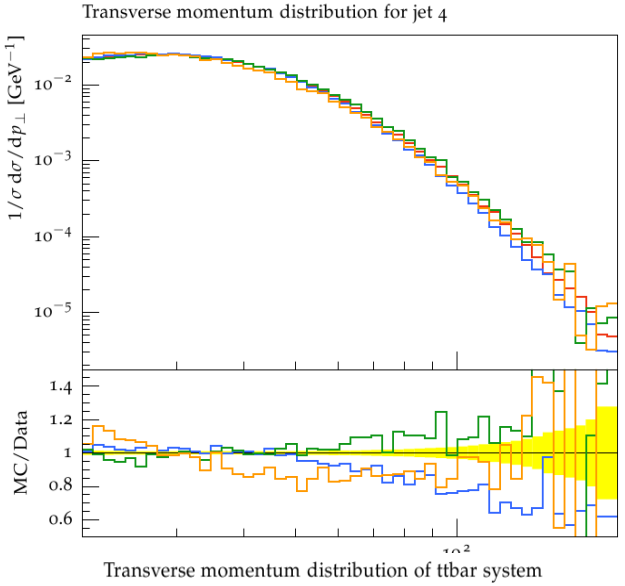
More Event Generation and Plot Details

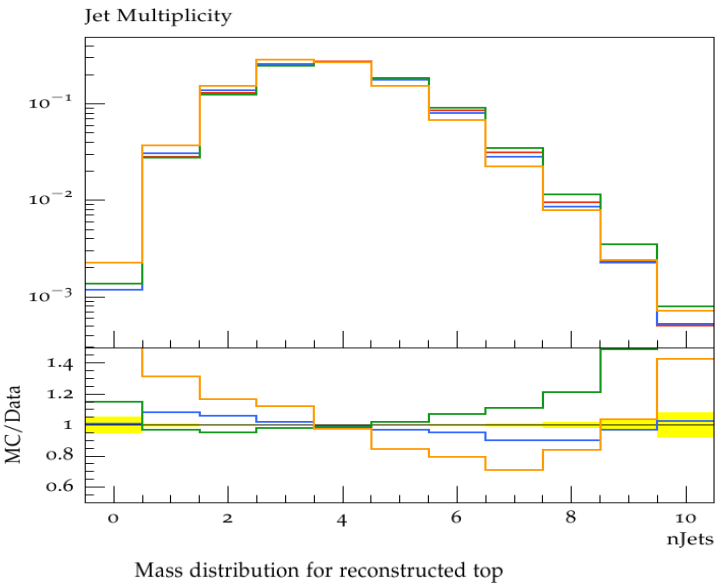
- No Generator level cuts being applied, analysis cuts require exactly one charged lepton, two b-tagged jets (perfect tagging) and >30 GeV MET
- All Events are generated using matrix elements for stable tops, which are then decayed by Herwig. The LO + Decay Matrix Element Correction event generation uses the same shower settings as the MCatNLO method for comparison between LO and NLO matrix elements.
- "Nominal" renormalization scale set to the top pair mass, the veto scale is set to the renormalization scale, and the shower scale is set to the average transverse mass of the objects in the hard scatter
- Herwig also includes a hard scale profile which defaults to theta function. For the MCatNLO and LO + Decay MEC method the so-called resummation profile is being used (see LO paper for more details).

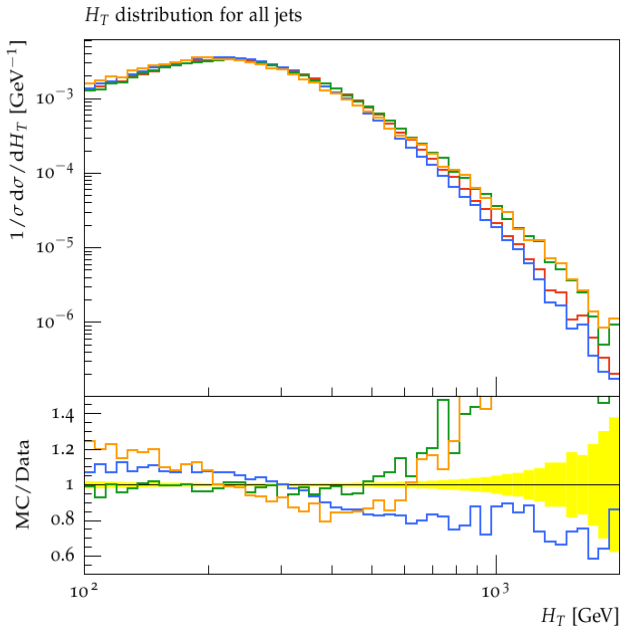
ttbar event generation with herwig LHC-Matchbox “almost default” settings

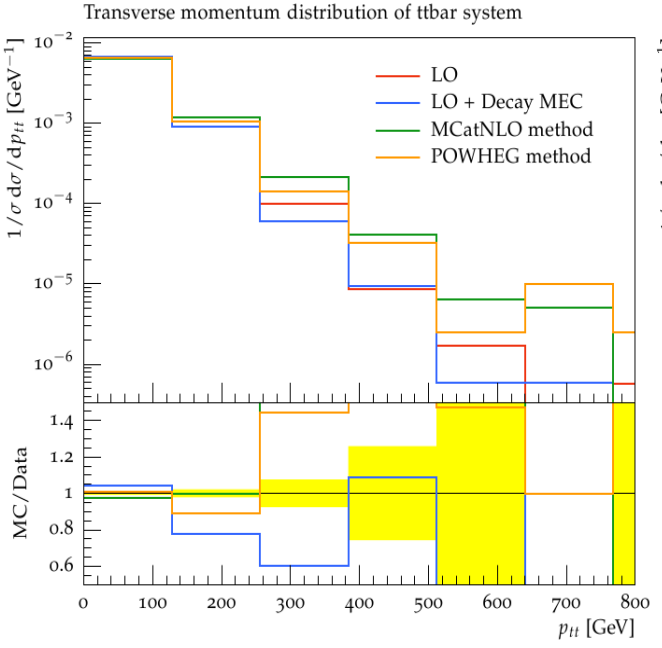
Event generation at LO and NLO with various matching schemes, using Herwig’s LHC-Matchbox default setting for each of the schemes with angular ordered showers. The agreement between the various schemes is quite good, with expected deviations in high transverse momentum regions.

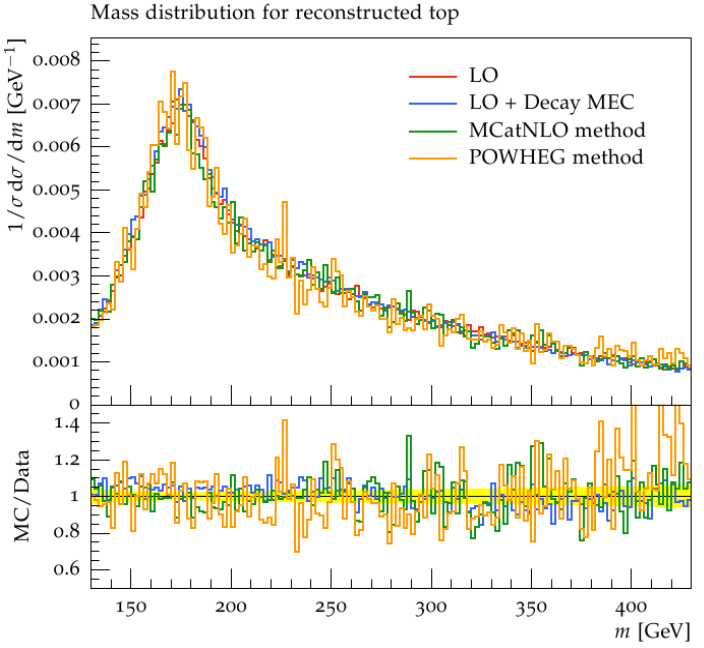






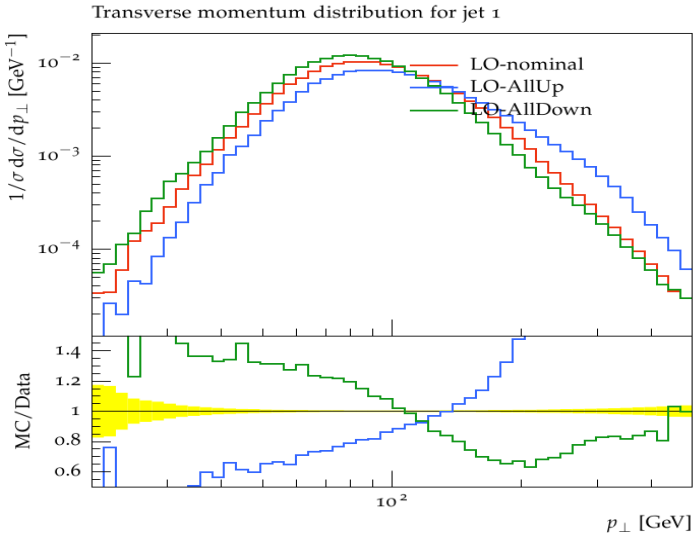




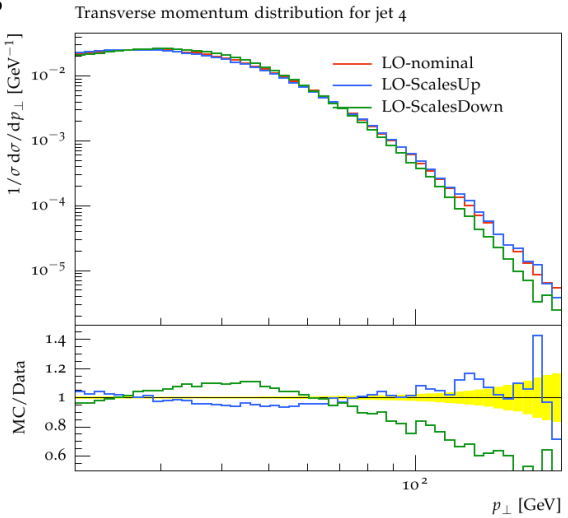


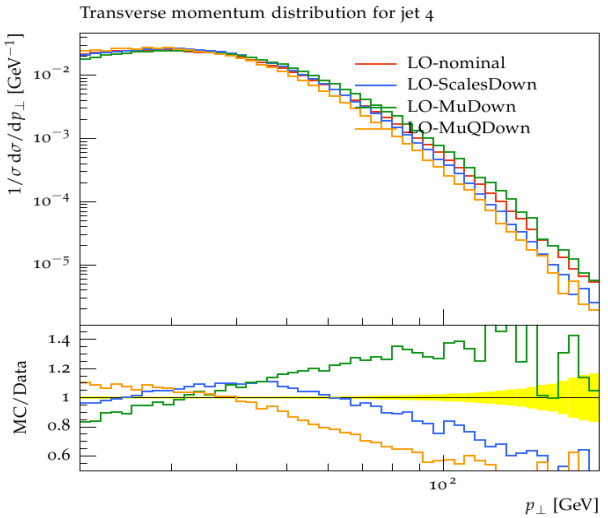
LO Matrix Element With Angular Ordered Showers and Scale Variations

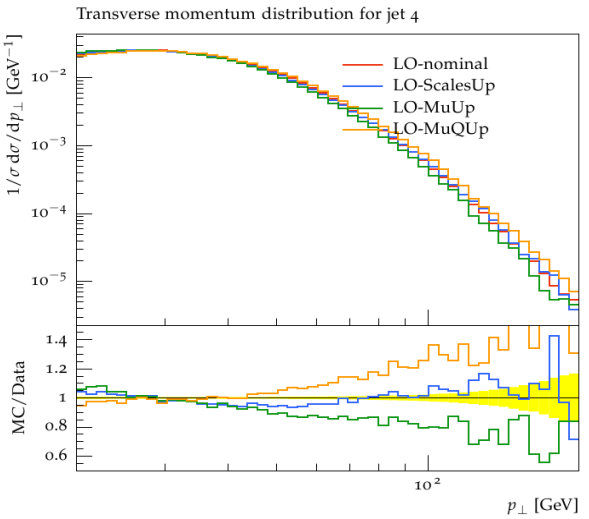
Can use scale variations to understand the perturbative uncertainties.
Variations in the Hard Process scale, the veto scale and shower scale



Full understanding of scale dependence requires the full envelope of variations, covering correlations between choices. Example: varying the hard process scale and veto scale has opposite effects in some cases

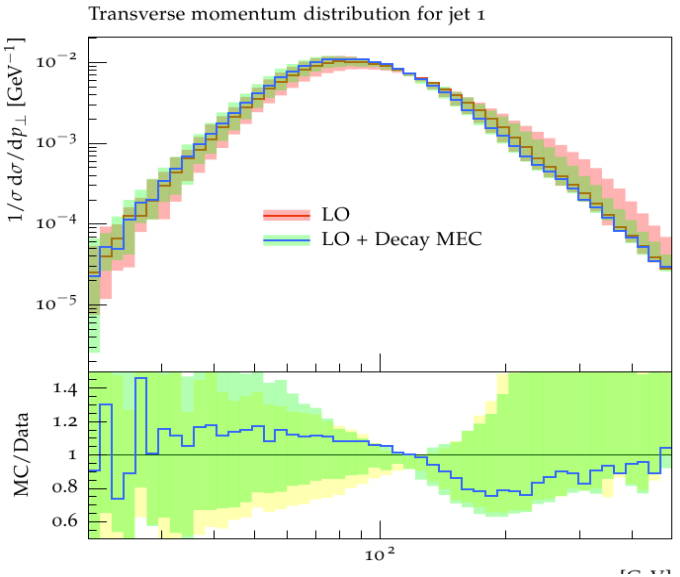


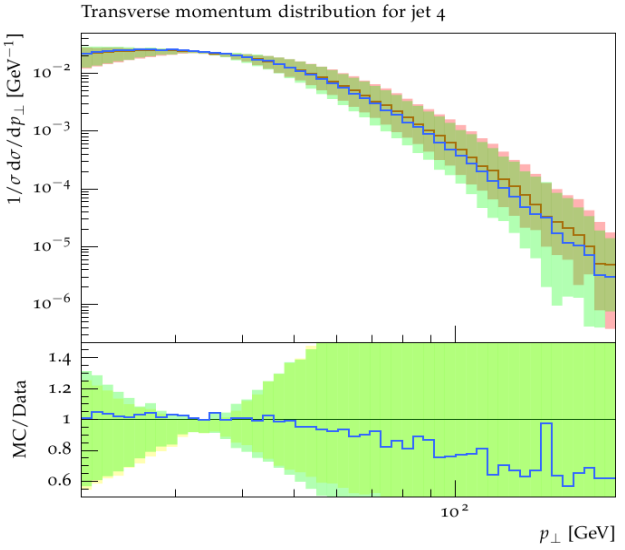


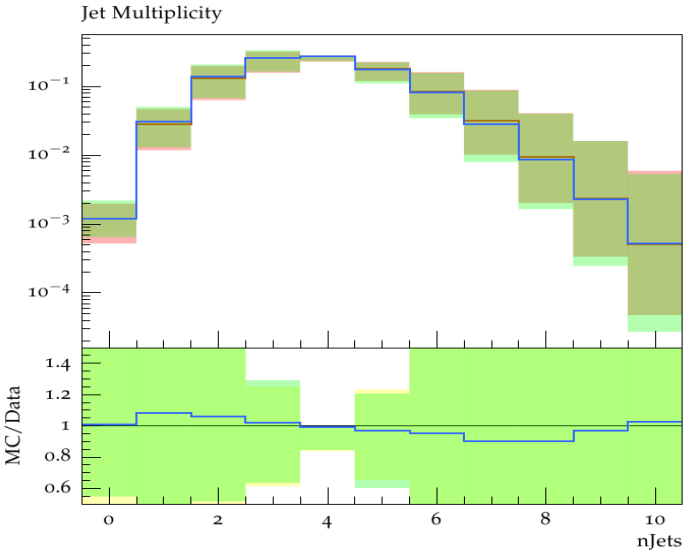


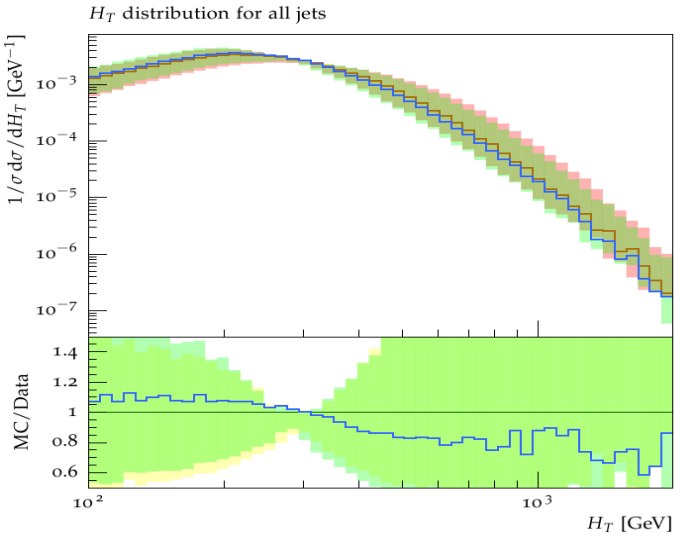
LO with Angular Ordered Showers

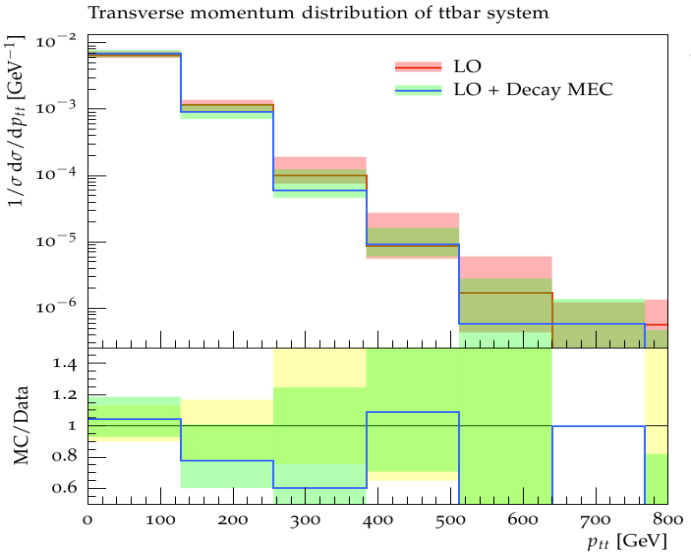
Plots of Leading Order Event Generation, with Angular Ordered showers and no Matrix Element correction compared with LO and a DecayMatrix Element correction. Central values are produced with the nominal scale choices and partial scale bands are produced by variations of the hard process scale and the hard veto scale up and down by factors of 2

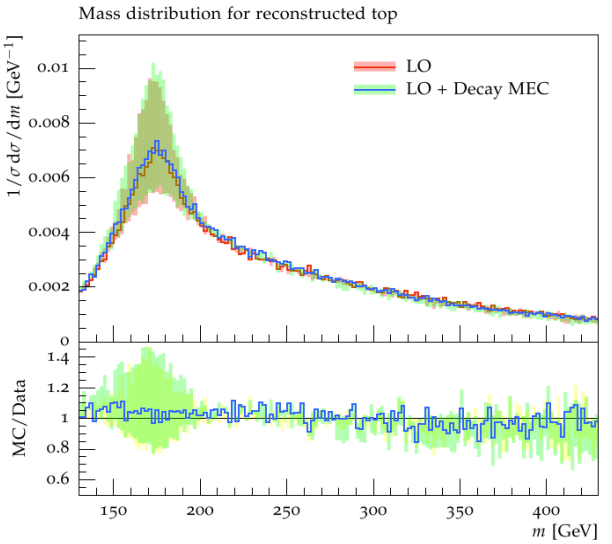






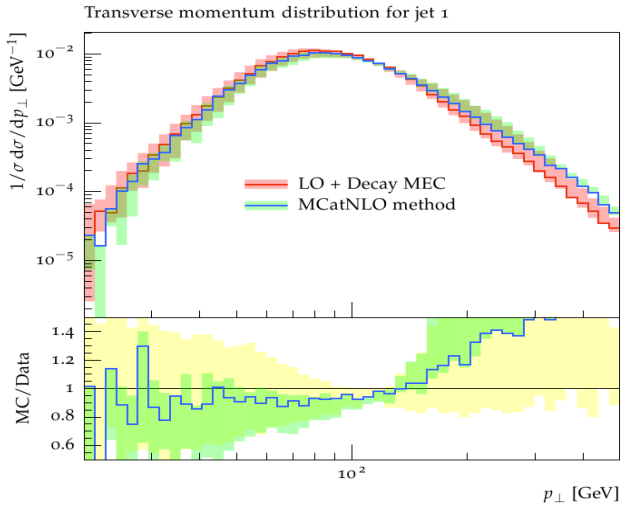


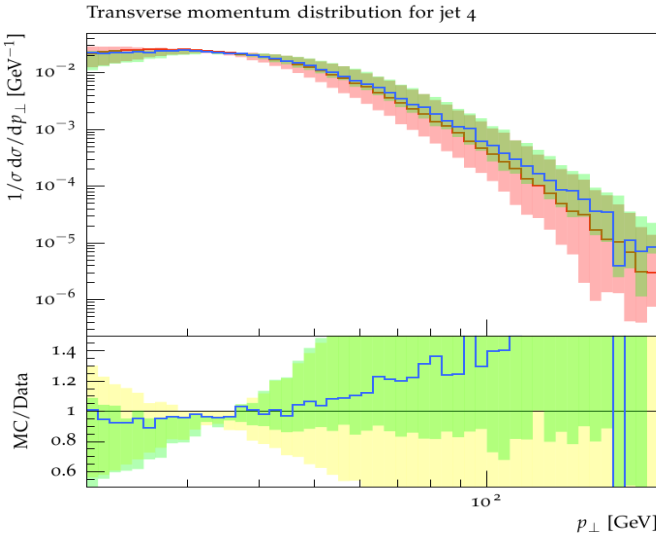


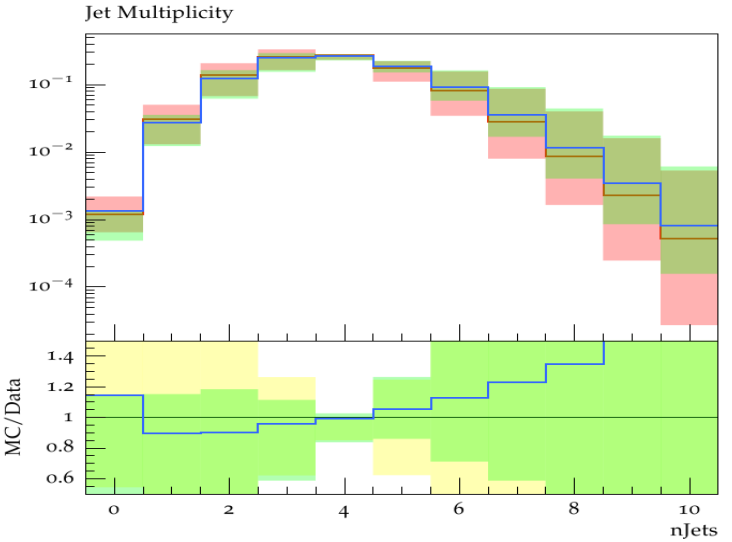


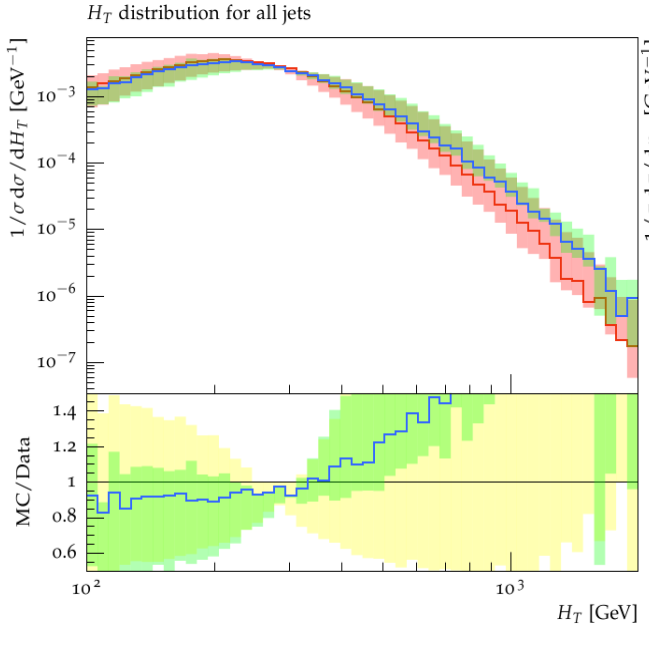
LO vs McatNLO comparison

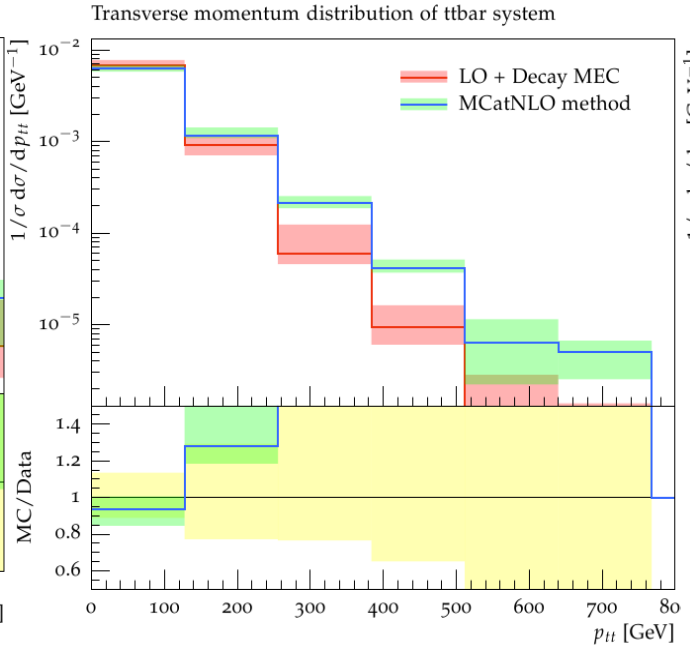
Plots of ME + Angular Ordered showers comparing LO Matrix Element to NLO Matrix Element matched with a McatNLO method. Central values are produced with the nominal scale choices and partial scale bands are produced by variations of the hard process scale and the hard veto scale up and down by factors of 2 the hard veto scale up and down by factors of 2

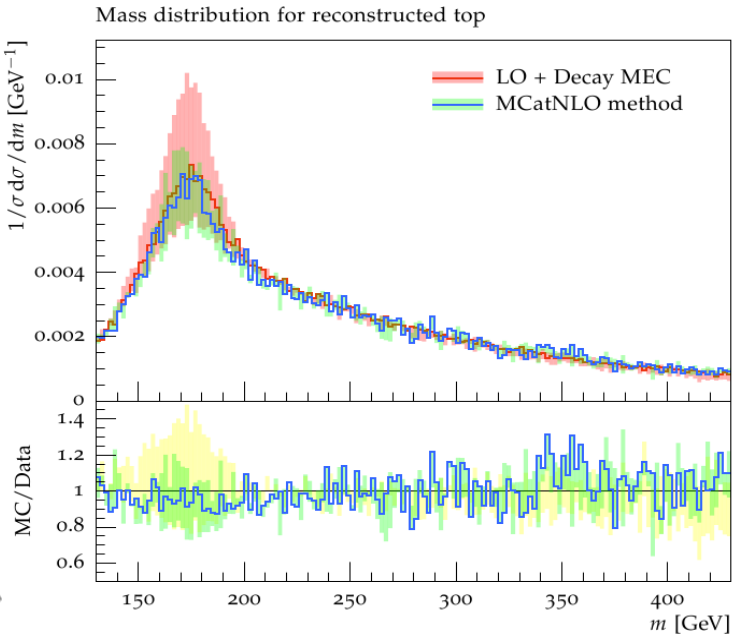






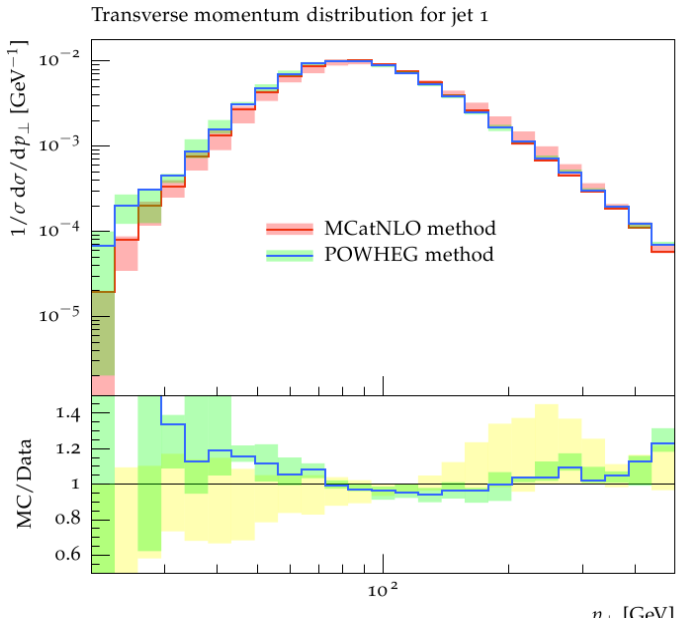


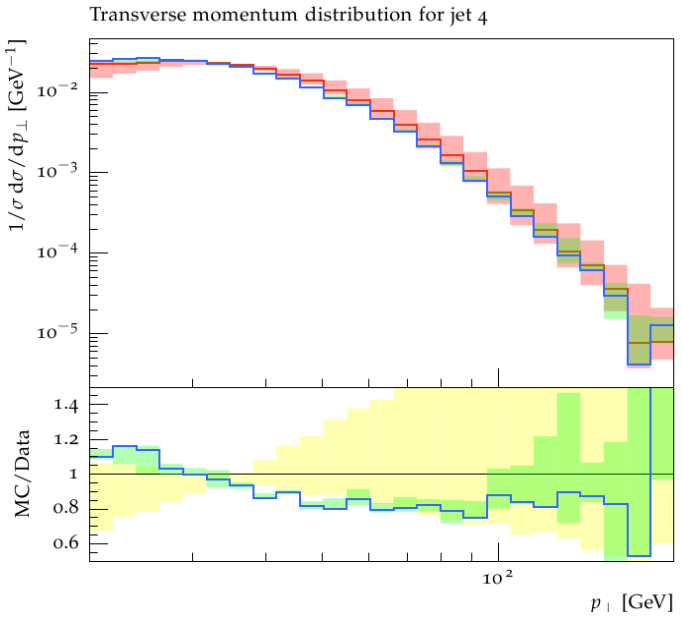


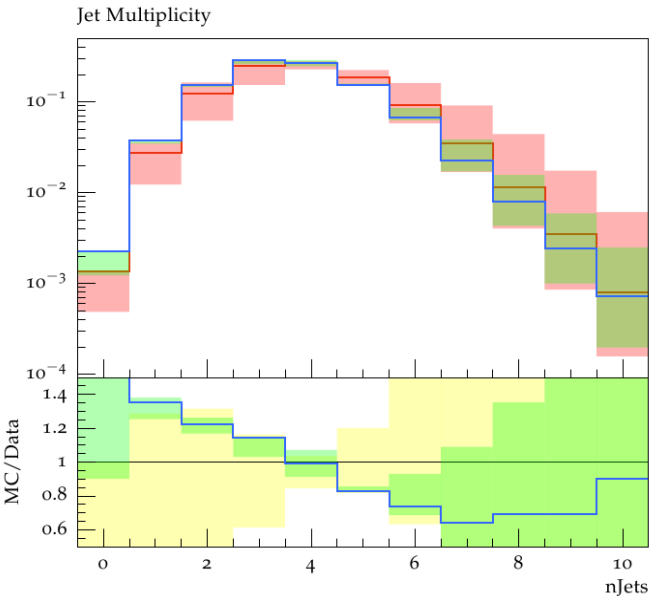


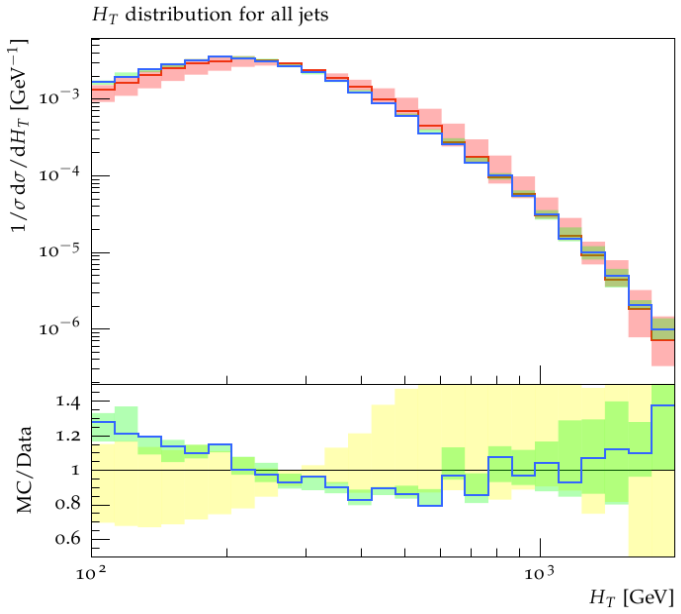
POWHEG and MCatNLO

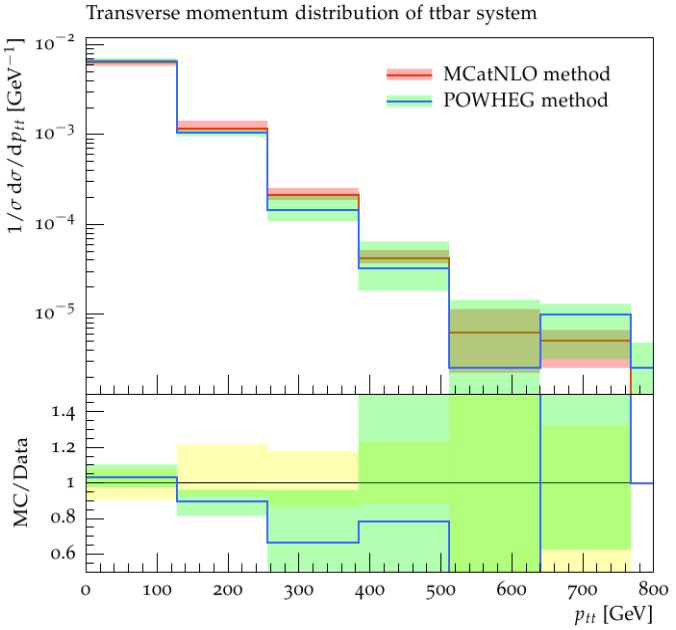
POWHEG and MCatNLO methods with angular ordered showering. Central values are produced with the nominal scale choices and partial scale bands are produced by variations of the hard process scale and the hard veto scale up and down by factors of 2 the hard veto scale up and down by factors of 2. Overlap between the two sets of curves indicates agreement within a partial uncertainties band.

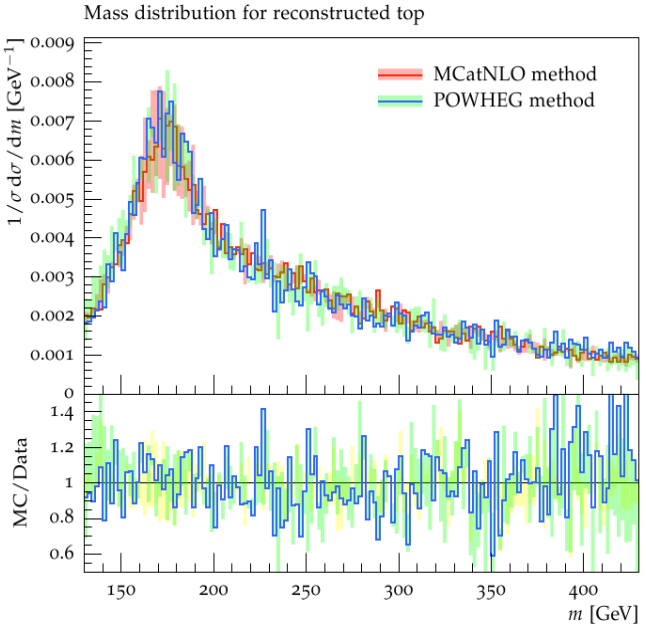








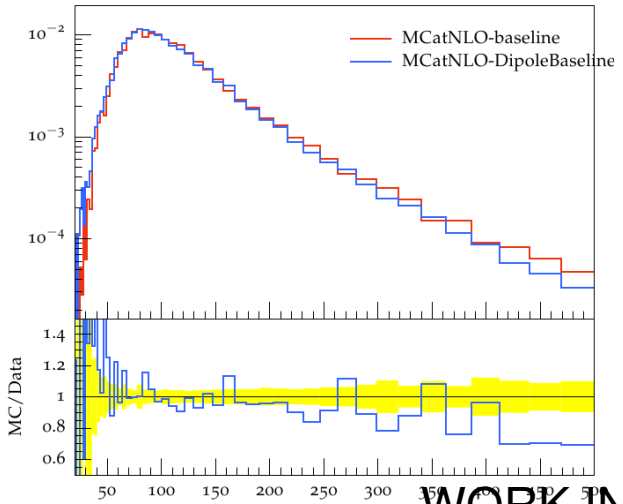


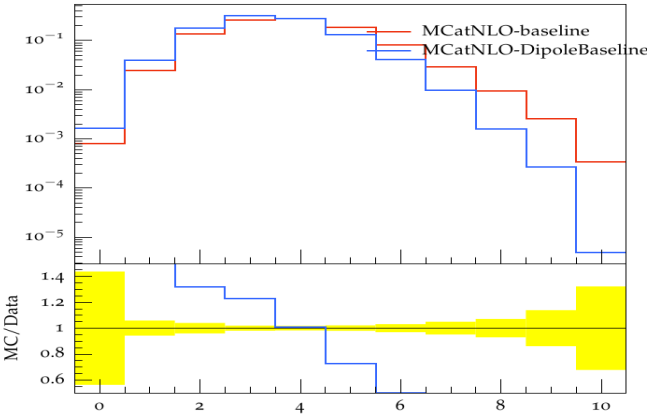


MCatNLO method withAngular and Dipole Showers, no MPI, no hadronization

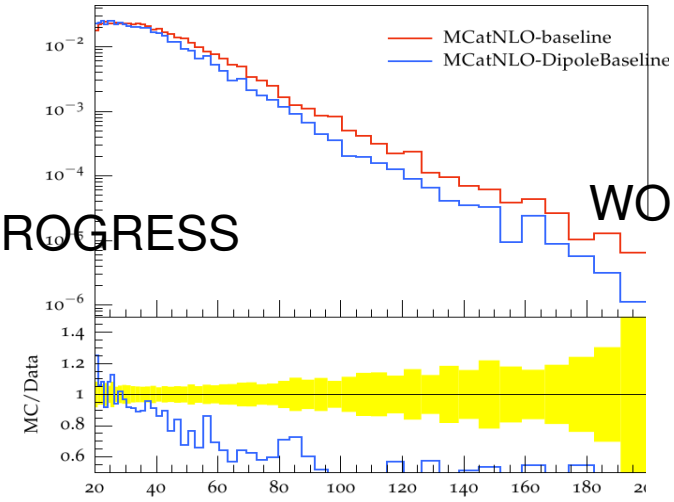
For the purposes of comparing different methods directly, it is interesting to remove multiple parton interactions, and hadronization and set common parameters to the same values, work in this direction is now underway...

Plots of unobservable, but instructive parton level distributions





WORK IN PROGRESS



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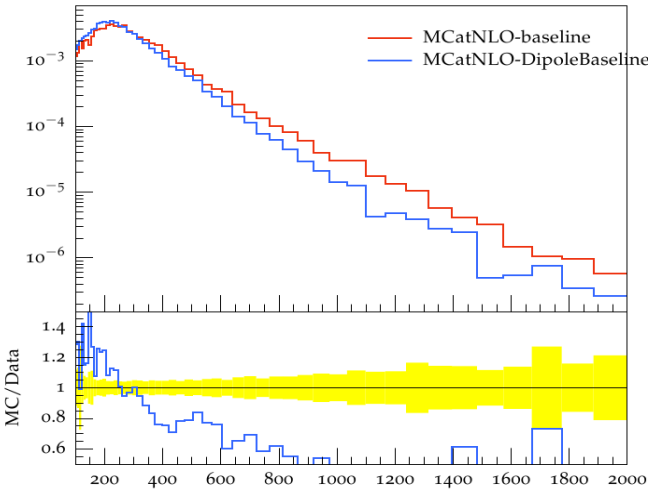

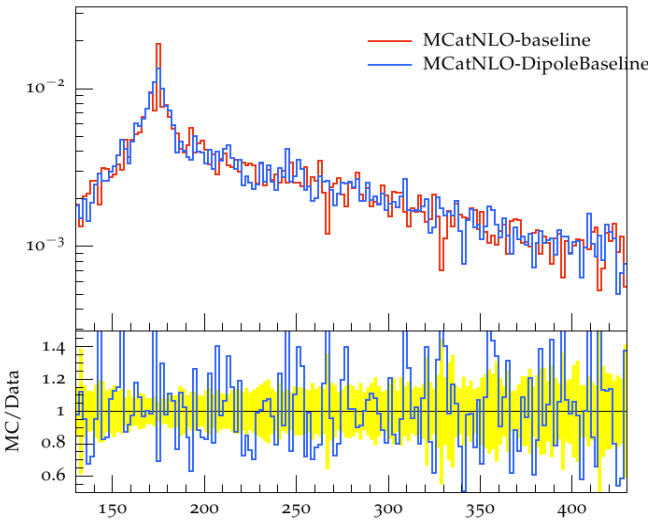

Conclusions and Future Work

- “Out of the Box” Herwig 7 Matchbox provides a variety of options for ttbar event generation. Differences due to the Matrix Element and Showering choices investigated so far appear as expected and are consistent with uncertainties due to the choice of scale.
- Studies are underway to comprehensively study the uncertainties in Herwig 7 ttbar event generation. A partial look at the sensitivity of the event kinematics to scale variations has been performed and the full envelope for all combinations of matching and shower prescriptions will follow. Further studies will include the effects of the veto scale profile shape, dipole showering and more.
- Studies of more observables, including boosted tops and top tagging related observables to come...