

Merging of matrix elements and parton showers at NLO accuracy

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The merging of matrix elements and parton showers is an established calculational tool for the description of multi-jet final states at hadron colliders. These methods have recently been promoted to next-to-leading order accuracy in the description of hard well separated jets. This talk introduces such a method and discusses its application to phenomenologically relevant signal and background processes. The systematic assessment of its theoretical uncertainty is a prime focus.

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1. Introduction

Many experimentally important observables at recent and present particle colliders are dominated by final states of (multiple) large multiplicities of not necessarily well separated leptons, photons, hadrons and/or jets. Thus, achieving an accurate theoretical description of such observables necessitates not only matching higher terms in an expansion in terms of α_s , such as a next-to-leading order calculation, improving the description of short-distance physics, to a parton shower resummation, accurately describing parton evolution at small scales, for a process of fixed parton multiplicity, but also merging such matched calculations for subsequent multiplicities without the loss of their respective accuracies.

In the CKKW [1] type of formalisms a few approaches have been formulated recently [2, 3, 4, 5, 6] differing in their choice of tools and treatment of the overlap of the individual input calculations. The following reviews recent results with the implementation of this so-called MEPS@NLO method in the event generator SHERPA.

2. Recent results

In this section a few results obtained recently with the implementation of the MEPS@NLO method in the SHERPA [7] event generator are exhibited. They use SHERPA's tree-level matrix element generators AMEGIC++ [8, 9] and COMIX [10], its Catani-Seymour dipole subtraction implementation [11, 12] and SHERPA's CS-dipole shower, CSS, [13]. For all processes shown here, one-loop matrix elements were provided by BLACKHAT [14] or OPENLOOPS [15]. SHERPA further comprises modules to compute the effects of multi-parton interactions [16], hadronisation corrections [17], hadron decays and higher-order QED corrections [18].

The shown MEPS@NLO calculations are constructed from NLOPS calculations for the individual parton multiplicities, matched using the methods of [19]¹, according to the algorithm developed in [3, 4, 23, 24]. The MENLOPS technique – the presented results use an implementation according to [4, 25, 26] – is a special case of a MEPS@NLO calculation where only the lowest multiplicity is calculated at NLOPS accuracy and all higher multiplicities are merged at leading order accuracy.

Fig. 1 displays results obtained with the afore mentioned calculations for $pp \rightarrow W + \text{jets}$ production [3]. The $pp \rightarrow W$, $pp \rightarrow Wj$ and $pp \rightarrow Wjj$ contributions were calculated at NLOPS accuracy. Additionally, the processes $pp \rightarrow Wjjj$ and $pp \rightarrow Wjjjj$ were merged on top of that at leading-order accuracy. The results are compared to experimental data from the ATLAS collaboration [27]. Good agreement is found and, of equal importance, the theoretical uncertainty is reduced using next-to-leading order merging. Similar observations are made when comparing a MEPS@NLO simulation for $e^+e^- \rightarrow \text{jets}$ [4] to data taken by the ALEPH collaboration [28], as displayed in Fig. 2. This calculation computes $e^+e^- \rightarrow jj$, $e^+e^- \rightarrow jjj$ and $e^+e^- \rightarrow jjjj$ at next-to-leading order accuracy, again merging two more jets on top of that at leading order accuracy.

Finally, Figs. 3 and 4 show results for MEPS@NLO calculations for $pp \rightarrow \ell^+\ell^- + \cancel{E}_\perp + X$ production [24], merging $pp \rightarrow \ell^+\ell^- \nu\nu$ and $pp \rightarrow \ell^+\ell^- \nu\nu j$ at NLOPS accuracy. Included are also the loop-induced processes $gg \rightarrow \ell^+\ell^- \nu\nu$, $gg \rightarrow \ell^+\ell^- \nu\nu g$ and $gq \rightarrow \ell^+\ell^- \nu\nu q$. Emphasis here is put of course onto observables relevant for Higgs boson measurements as used by ATLAS and

¹The applicability of this method to processes of most general colour structures was demonstrated in [20, 21, 22].

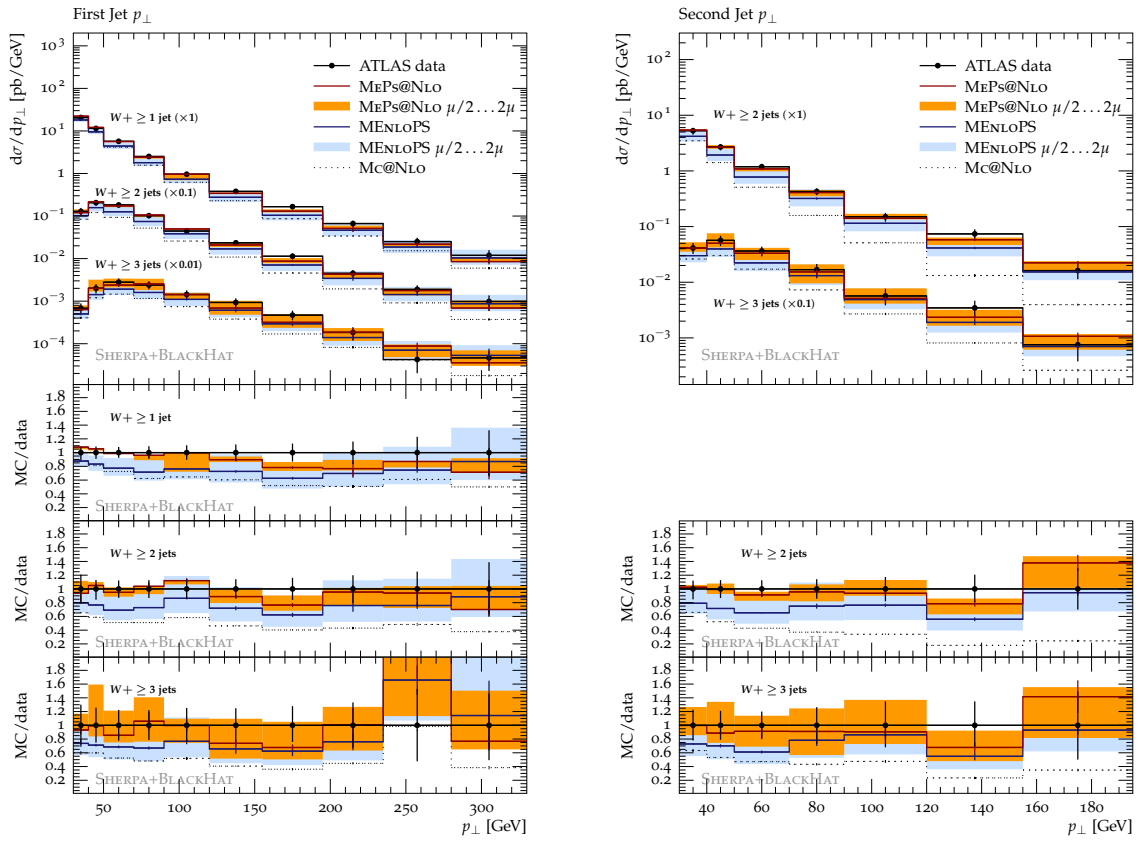


Figure 1: Transverse momentum of the leading (left) and subleading (right) jet in $pp \rightarrow W + \text{jets}$ events with at least one, two or three jets compared to ATLAS data [27]. Displayed are the results of a MEPS@NLO (red), MENLOPS (blue) and MC@NLO (black dotted) simulation of the inclusive process. For both multijet merged predictions the renormalisation and factorisation uncertainties are shown.

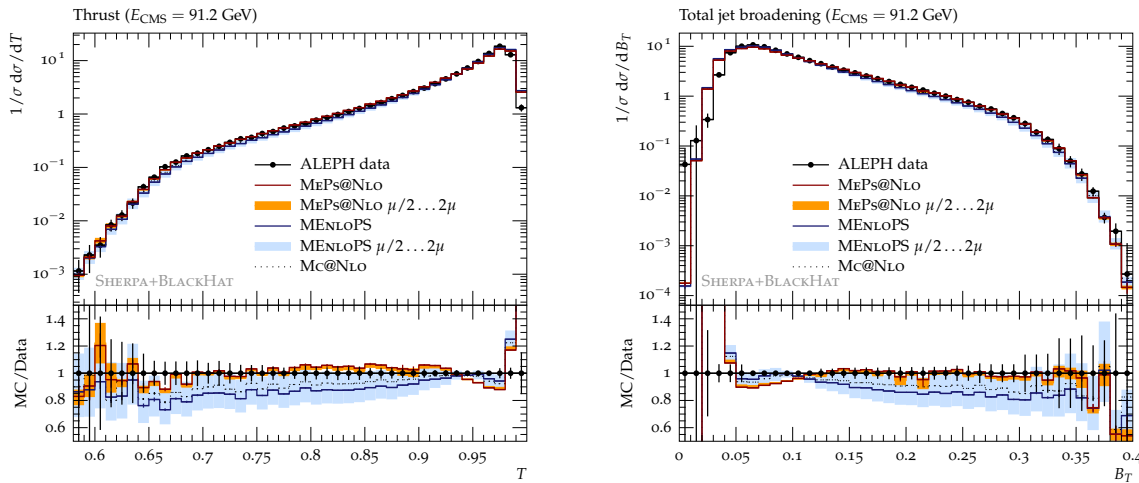


Figure 2: Thrust (left) and total jet broadening (right) in $e^+e^- \rightarrow \text{jets}$ events compared to ALEPH data [28]. Displayed are the results of a MEPS@NLO (red), MENLOPS (blue) and MC@NLO (black dotted) simulation of the inclusive process. For both multijet merged predictions the renormalisation and factorisation uncertainties are shown.

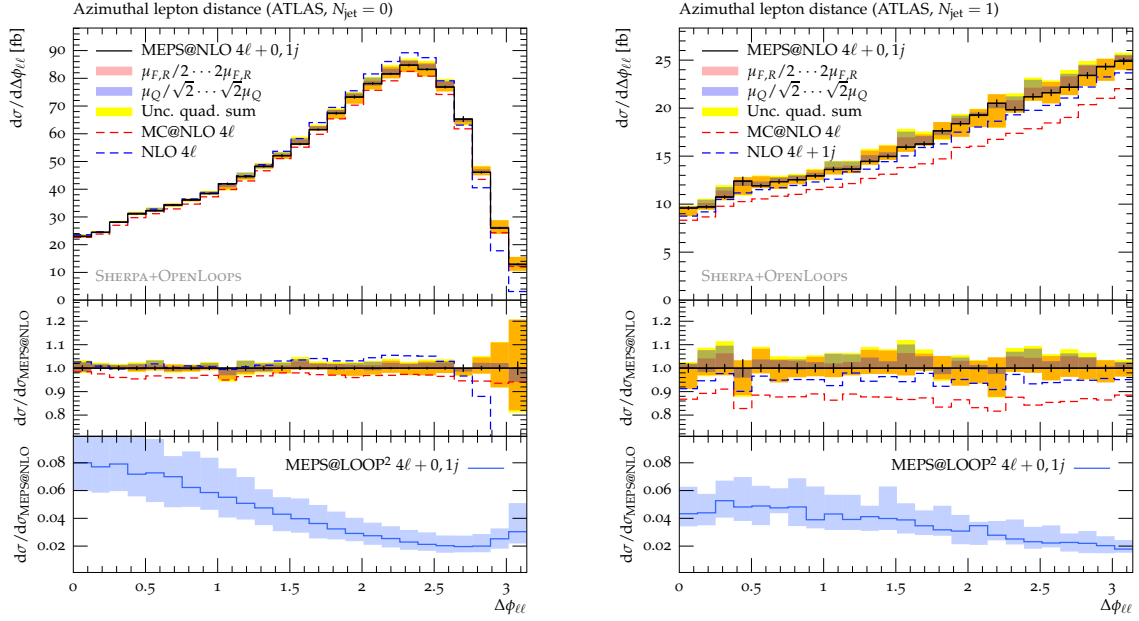


Figure 3: Azimuthal separation of the lepton pair in $pp \rightarrow \ell^+ \ell^- + \cancel{E}_\perp + X$ in the exclusive zero (left) and one (right) jet selection under typical cuts used in Higgs searches. Displayed are the MEPS@NLO (black) prediction, with its associated renormalisation and factorisation scale uncertainties as well as the resummation scale uncertainty, the inclusive MC@NLO prediction and the fixed-order NLO prediction. The lower panel shows the contribution of loop induced processes to the total result.

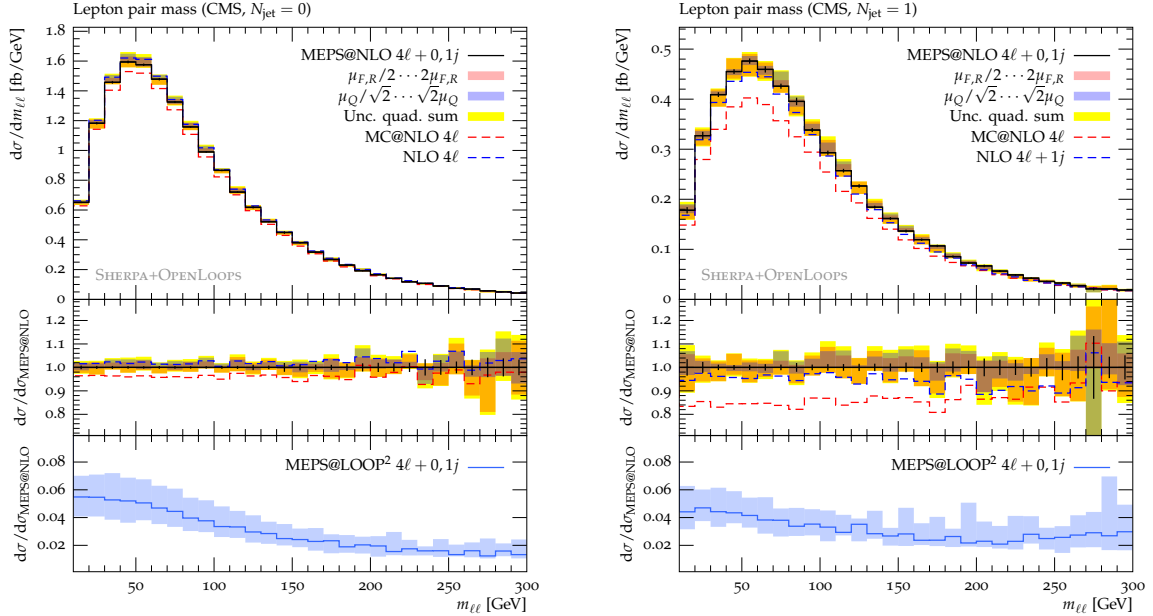


Figure 4: Invariant mass of the lepton pair in $pp \rightarrow \ell^+ \ell^- + \cancel{E}_\perp + X$ in the exclusive zero (left) and one (right) jet selection under typical cuts used in Higgs searches. Displayed are the MEPS@NLO (black) prediction, with its associated renormalisation and factorisation scale uncertainties as well as the resummation scale uncertainty, the inclusive MC@NLO prediction and the fixed-order NLO prediction. The lower panel shows the contribution of loop induced processes to the total result.

CMS, as usual divided into bins of exclusive jet multiplicity. The distributions show that both an improved central value and a small theoretical uncertainty, as compared to pure fixed-order NLO or an inclusive MC@NLO (generated according to [19]), can be achieved.

3. Conclusions

The method for merging multiple matrix elements of successive jet multiplicities at next-to-leading order accuracy implemented in the SHERPA event generator is a versatile tool that has been shown to be applicable to a multitude of processes. It describes the respective jet multiplicities at next-to-leading order accuracy which is reflected not only in a improved central value but also in smaller theoretical uncertainties. At the same time it also preserves the resummation of emission scale hierarchies provided by the parton shower. This allows to use the SHERPA Monte Carlo event generator to calculate inclusive multijet observables and study their uncertainty due to the truncation of the perturbative series in a systematic way.

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