All Orders QCD Predictions for Event Shape Observables

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As the Large Hadron Collider (LHC) pushes for higher luminosities, more analyses are limited by the uncertainties of theoretical predictions. More precise predictions will not only allow to reduce these uncertainties, but also allow for more precise tests of the Standard Model (SM). Quantum chromodynamics (QCD) dominates LHC events and is therefore of particular interest.

From a QCD perspective lepton colliders provide a very clean experimental environment, as there are no hadrons involved in the initial state. Proton (anti-)proton colliders have an abundance of hadronic events, but multiple parton interactions (MPI) make it difficult to study hadronic final states. Deep inelastic scattering (DIS) offers a middle way with hadronic events that produce less secondary radiation. Altough the HERA experiment stopped taking data in 2007, new methods that were not developed at that time can be challenged by old data. The knowledge gained can also be used in future colliders such as the Electron-Ion Collider (EIC) or the Large Hadron-Electron Collider (LHeC).

Typical events in QCD are dominated by a large number of soft and collinear emissions. We restrict ourselves to observables whose value v is not changed much by such emissions. The emissions are logarithmically enhanced by $L = \ln(1/v)$. For n emissions, the largest contributions for small v in the perturbative calculations scale as $\alpha_S^n L^{2n}$. Fixed order (FO) calculations do not account for these terms and therefore give inaccurate predictions for small v. Resummed calculations take into account the highest logarithmical contributions in all orders in α_S and is therefore more accurate for small v, for large v FO calculations are more accurate. For accurate predictions over the whole v range, resummation and FO calculations must be matched. After matching, the prediction includes all terms of the resummation and FO calculations without double counting. Since these calculations give predictions for the parton level (PL) non-perturbative (NP) corrections must be employed to transition the predictions to hadron level (HL) and be able to compare to data.

I worked with the implementation of the semi-analytic resummation formalism CAESAR [1] in SHERPA-3.0 [2, 3], where we extract NP corrections from PL and HL simulations with SHERPA and convolute the resummed predictions with transition matrices like the one in Fig. 1. Comparisons of matched resummed predictions including NP corrections against hadronic SHERPA predictions and H1 data can be found in Fig. 1 and have been published in Refs. [4, 5]. I am currently working to upgrade the implementation to higher logarithmic precision, following the ARES description [6].

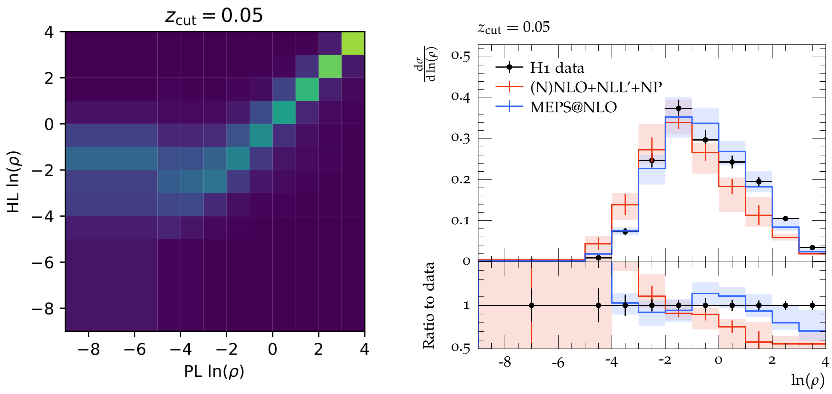

Figure 1: Left: Transition matrix used to migrate parton level resummed predictions to hadron level.
Right: Matched resummed predictions and SHERPA generated hadronic predictions against H1 data.

References

[1] Andrea Banfi, Gavin P. Salam, and Giulia Zanderighi. "Principles of general final-state resummation and automated implementation". In: *Journal of High Energy Physics* 2005.03 (Mar. 2005). DOI: 10.1088/1126-6708/2005/03/073.

[2] Enrico Bothmann et al. "Event Generation with Sherpa 2.2". In: *SciPost Phys.* 7.3 (2019), p. 034. DOI: 10.21468/SciPostPhys.7.3.034.

[3] The SHERPA-3.0.0 code can be obtained from: https://sherpa-team.gitlab.io/changelog.html.

[4] Max Knobbe et al. "Precision calculations for groomed event shapes at HERA". In: *31st International Workshop on Deep-Inelastic Scattering and Related Subjects.* July 2024. arXiv: 2407.02456 [hep-ph].

[5] V. Andreev et al. "Measurement of groomed event shape observables in deep-inelastic electron-proton scattering at HERA". In: *Eur. Phys. J. C* 84.7 (2024), p. 718. DOI: 10.1140/epjc/s10052-024-12987-0.

[6] Andrea Banfi et al. *A general method for the resummation of event-shape distributions in e^+e^- annihilation.* 2017. arXiv: 1412.2126 [hep-ph].