Snowmass 2021 LOI
Precision resummation for jet cross sections

Xiaohui Liu[1,2] and Felix Ringer[3]

[1] *Center of Advanced Quantum Studies, Department of Physics, Beijing Normal University, Beijing 100875, China*
[2] *Center for High Energy Physics, Peking University, Beijing 100871, China*
[3] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*

High precision calculations and jet physics are at the forefront of phenomenological studies at the LHC. In the recent years, the precision frontier at the LHC has been pushed beyond next-to-leading order (NLO) accuracy, where many phenomenologically important processes, such as ggH, Drell-Yan, top quark production, $H/Z/W+$jet and inclusive jet production [1, 2] are predicted differentially at next-to-next-to-leading order (NNLO) and even beyond. The rapid progress of precision predictions benefits from the development of the modern multi-loop techniques, infrared subtraction schemes and resummation frameworks [3]. Besides high precision, driven by the infrared structures of pQCD, various jet substructure and global jet observables were developed which allow for a deeper exploration of LHC phenomena.

Specifically, we want to emphasize the tremendous influence of high precision jet physics for deciphering the internal structure of hadrons. These studies include for example the global extraction of the collinear parton distribution functions (PDFs) [4], which arise in the factorization $\sigma = \int \mathrm{d}x_1 \mathrm{d}x_2 \, \hat{\sigma}_{ij}(x_1, x_2) \, f_i(x_1) f_j(x_2)$. The PDFs $f_i(x)$ are constrained through global fits to experimental data, given the knowledge of the partonic cross sections $\hat{\sigma}_{ij}$. *Any uncertainty of $\hat{\sigma}$ will propagate to the errors of the extracted PDFs.* Jet observables allow for scans over different values of Bjorken-x and possible selections of the parton flavors. State of the art precision calculations provide the most reliable determination of $\hat{\sigma}$ from first principles in QCD with unprecedented well-controlled theoretical uncertainties. *It is this level of precision of $\hat{\sigma}_{ij}$ which makes PDFs one of the most well-constrained non-perturbative objects.*

With the advent of the Electron Ion Collider [5], arguably the only foreseeable new collider which will be built in the U.S., new efforts have to be made to migrate the theoretical tools developed at the LHC to the EIC. In particular, jet observables have attracted attention and opened up novel opportunities to probe the 3D structure of hadrons, hot/cold QCD medium effects and gluon saturation phenomena. Pioneering work along these lines can be found in [6, 7, 8, 9, 10, 11]. Following a similar approach to PDFs, by comparing theoretical predictions $\mathrm{d}\hat{\sigma} \otimes \mathcal{F}$ to future EIC data, the non-perturbative quantities $\mathcal{F}$ can be extracted. *The more accurately $\hat{\sigma}$ can be predicted, the better constraints on the $\mathcal{F}$ will be obtained.*

Given the small projected experimental errors at the EIC [5, 10], which in some cases are of order $\mathcal{O}(10^{-3})$, many current theoretical predictions cannot achieve the targeted EIC error budget. The uncertainty of many NLO and next-to-leading logarithmic (NLL) predictions can easily be of order $\mathcal{O}(0.1)$ at low energies, see for instance [12, 13]. *Therefore, we would like to draw attention to the development of the precision machinery which is central to the entire EIC program, especially for jet associated processes.*

A list of possible directions that can be explored during the Snowmass 2021 process with connections to other frontiers such as EF05-EF07, include (but are not limited to)

- TMD and spin physics. The subject has a close connection to the q_T-distribution of the Drell-Yan/ggH process at the LHC, especially the TMD Sudakov evolution. Currently N^3LO QCD [12] and N^2LO QCD+QED [13] predictions are available for single jet production in unpolarized DIS. In addition, NLO [14] and NNLO [15] results are now known for the longitudinally polarized case. However, for transversely polarized DIS, predictions beyond LO are still not available. This direction also has overlap with the QCD/SCET power correction program.

- Small-x and forward scattering physics. Gluon saturation phenomena and its on-set is one of the central question which is expected to be answered by the EIC. The so-called color glass condensate (CGC) formalism predicts a dynamic saturation scale $Q_s \sim \mathcal{O}(3-5)$ GeV $\gg \Lambda_{\mathrm{QCD}}$ when the Bjorken-x variable is sufficiently small and thus pQCD calculations can be applied within the CGC framework. At the moment, most predictions are made at LO using light-front-perturbation theory (LFPT) within the CGC. However, higher order corrections are expected to be very large due to the relatively small scale Q_s. Attempts to go beyond LO have encountered various problems such as negative cross sections, the need of cut-offs that need to be put in by hand and possibly missing kinematic constraints. Recent studies propose to use power counting techniques and coupling SCET to the CGC formalism as a systematic solution to those problems [16, 17]. A more systematic treatment using effective field theory techniques for small-x physics needs to be developed and its application to EIC forward scattering can be studied.

- Heavy ion physics. Jets are frequently used to study medium effects in heavy ion collisions. For this purpose, a new approach was recently developed where jet functions in the vacuum are convolved with a non-perturbative model accounting for jet-medium interactions. This allows for the extraction of medium effects using the tools of global analyses [18]. In some circumstances, jet-medium interactions can be well modeled through the instantaneous exchange of gluons which is calculable in pQCD. Therefore it will be interesting to develop a pQCD framework to better control the perturbative part of the jet-medium interactions. This is also a main goal of the EIC science program where the focus is on cold nuclear matter effects [5].

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