Snowmass 2021 Letter of Interest: Jet Physics at the Electron Ion Collider

The EICjets Community[1]

Jet studies have played a key role in the exploration of QCD since its conception [1]. With the advances in experimental techniques, and theory development over time, jets have become powerful tools for exploring the fundamental properties and regimes of QCD, and when searching for unexpected phenomena in high-energy collisions [2,3]. This has pushed jet physics to the forefront of phenomenology at the LHC and RHIC. In this document, we advocate that jet physics will play a central role at the future Electron Ion Collider (EIC).

The future EIC, a one-of-a-kind US flagship facility, smashes electrons into protons and heavier atomic nuclei to elucidate the mysteries of QCD [4]. The EIC is set to push the envelope building on the HERA discovery of the role of gluons in the structure of the proton. The advent of the EIC with its high luminosity (~1000 times higher than HERA) and polarized hadron beams will produce the first-ever jets in polarized electron-hadron scattering, and will unlock the full potential of jets as novel tools for probing the structure of nucleon and nuclei.

While jets are familiar in high-energy physics analyses, and appear in many different guises, jets at the EIC can add important pieces of the puzzle[2] on top of insights gained at hadron-hadron machines: Jets at EIC are naively expected to be very “clean”, i.e. little energy is not associated with the jets. However, the jets themselves contain relatively few particles, and the particles have moderate energies. This offers unique challenges and opportunities: Every particle is precious and differences between jet algorithms or substructure methods can become very apparent, while at the same time, underlying event contamination (that continues to be a major challenge at the LHC) will be much smaller. This already makes an assessment of jet properties at EIC an exciting theoretical and experimental prospect. On top of that, non-perturbative contributions from fragmentation are more pronounced at lower jet masses, which makes EIC jets a stress test for the universality of jet-based methods in high-energy physics. In addition, because of its polarization capability and unmatched versatility, the EIC will surely serve as a venue for developing new jet-based observables that exploit the spin. Thus, dedicated studies of jet substructure at the EIC are critical in order to realize the full

[1] See the last page for the complete author list.

[2] The topic has generated significant interest and many ideas in the very recent past. Presentations at the recent workshop on "Jet Observables at the Electron-Ion Collider" [5] might serve as a snapshot of this budding field.

potential of the EIC in jet physics. This study could draw from diverse backgrounds: Expertise in QCD theory[3], and in Monte Carlo simulations[4] can help facilitate this study.

A variety of key measurements include (but are not limited to):

- Jet substructure (such as jet shape, jet mass, jet angularity, etc) in electron-proton collisions as powerful probes for QCD dynamics
- Jet-based observables and event shapes (such as 1-jettiness) as precision probes for extraction of fundamental QCD parameters, notably the strong coupling constant and its running
- Jets for studies of flavor and spin structure of the nucleon, in particular three-dimensional (3D) imaging of the nucleon and even 5D Wigner distribution
- Modification of jets and jet substructure from e+p to e+A collisions for studying the transport of partons through nuclear matter

During the Snowmass 2021 process, we will make this connection between the EIC and LHC jet communities. This Letter of Interest aims to tackle these exciting topics, with methods that include, but need not be limited to:

1. New theory studies and developments for jets and jet substructure at the EIC
    a. pQCD and effective field theory techniques for jets
    b. Novel jet definitions and jet substructure observables
    c. Jets for precision measurements of standard model parameters such as strong coupling constant
    d. Novel opportunities to connect experiment and lattice QCD calculations
    e. Modification of jets in electron-nucleus collisions
    f. Probing the photon structure with jets
2. Monte Carlo simulation
    a. Incorporating 3D kinematics and spin into the event generator
    b. Resummation of large logarithms in perturbation theory
    c. Parton showers
3. Computing and detector simulation
    a. Fast simulation with machine learning techniques
    b. Event reconstruction with experiment-independent software

[3] A reasonably complete list of recent pQCD developments is given in the introductions of recent Les Houches SM working group reports [6].

[4] For MC developments and challenges for LHC physics, see [7]. For a reasonably inclusive set of references regarding pQCD and MC developments for LHC physics, Les Houches SM working group reports [6] can serve as a starting point.

References

[1] A. Ali and G. Kramer, “Jets and QCD: A Historical Review of the Discovery of the Quark and Gluon Jets and its Impact on QCD”, Eur. Phys. J. H 36, 245 (2011).

[2] A. J. Larkoski, et.al., “Jet Substructure at the Large Hadron Collider: A Review of Recent Advances in Theory and Machine Learning”, Phys. Rept. 841, 63 (2020).

[3] S. Marzani, G. Soyez, M. Spannowsky, “Looking inside jets: an introduction to jet substructure and boosted-object phenomenology”, Lect. Notes Phys. 958 (2019).

[4] A. Accardi, et.al., “Electron Ion Collider: The Next QCD Frontier”, Eur. Phys. J. A. 52, 268 (2016).

[5] M. Arratia, et.al., "Jet Observables at the Electron-Ion Collider", RIKEN BNL Research Center Workshop, July 27–29, 2020, see https://indico.bnl.gov/event/7200/.

[6] S. Amoroso, et.al., Les Houches 2019: Physics at TeV Colliders: Standard Model Working Group Report, e-Print: 2003.01700 [hep-ph], and J.R. Andersen, et.al. Les Houches 2017: Physics at TeV Colliders Standard Model Working Group Report, e-Print: 1803.07977 [hep-ph].

[7] HSF Physics Event Generator WG, Challenges in Monte Carlo event generator software for High-Luminosity LHC, e-Print: 2004.13687 [hep-ph] , and A. Buckley, et.al., Monte Carlo event generators for high energy particle physics event simulation, e-Print: 1902.01674 [hep-ph].

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