Letter of Interest: Heavy Flavor at the EIC

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Theory

- ***Role of heavy quarks in hadronic and nuclear structure***

Many ambiguities remain regarding the possible role of heavy quarks -particularly charm - in hadronic and nuclear structure. A prime example of this is the issue of the nonperturbative or intrinsic charm contribution to the proton wave function. Numerous attempts to model or constrain the proton's intrinsic charm component in QCD global analyses have been made over the years, but, aside from the disputed 1983 EMC F^c_2 data, there is nearly a complete lack of measurements with direct sensitivity to nonperturbative charm in the nucleon. The ideal measurement would involve charm structure-function data in the high-x (x >0.1) and intermediate-Q (Q ~ 10 GeV) region, which the EIC will be poised to extract with considerable precision. Similarly, the EIC will be well-positioned to not only constrain/isolate the presence of intrinsic charm but also to potentially determine its detailed origins in QCD. This will involve disentangling the intersecting notions of intrinsic and "fitted" charm that have emerged in recent years in the literature on this subject. The EIC could shed light on this subject through a detailed exploration of the scale dependence of the nucleon's charm component. More broadly, there is a possible role to be played by charm-jet production in this area as well.

- ***Improvement of theoretical tools and complementarity with other experiments***

Status review of the tools/theory to predict open and hidden heavy-flavor at the EIC is needed. In particular, are the available tools/theory predictions accurate enough to extract valuable info from future data, which issues/uncertainties come from the modelling of the nucleus, which cold nuclear matter effects still need to be incorporated or are already incorporated in the present tools, and how can we distinguish between different cold nuclear matter effects (i.e. how to distinguish nPDF effects from other CNM effects through the analysis of EIC data)? The complementarity between the data at the EIC (and other future experiments), the data on heavy-flavor production at HERA, and the data on heavy-flavor production at LHC must be explored. It will help better constrain gluon and sea quark PDFs at both low and large x and charm and bottom masses. On constraints on PDFs from HERA+LHC present data on open heavy flavor community members have been active through the PROSA collaboration.

- ***Open heavy flavor production***

To address some specific needs of open heavy flavor theory. Status review of the tools/theory to predict open and hidden heavy-flavor at the EIC is needed. The impact of flavor number schemes - fixed-flavor number (FFN) scheme and variable-flavor-number (VFN) scheme – on charm and bottom distributions in deep-inelastic scattering needs to be studies and understood. As heay quarks introduce a new mass scale, the evolution of heavy quarks distributions has to be understood better.

- ***TMD Physics with heavy quarks***

Compared to the quark TMDs, our knowledge of the gluon TMDs is much less advanced. Heavy flavor production at the future EIC plays an irreplaceable role in probing gluon TMDs inside unpolarized and polarized nucleons, which we are particularly interested. The community is interested in using heavy flavor production to study gluon TMDs via spin asymmetries. Processes like open or hidden heavy meson production are induced by photon-gluon fusion at the lowest order, and thus provide opportunities to measure the gluon TMDs. We are interested in studying the QCD effects in these processes, as well as their impact on the size of asymmetry.

- ***Effects of matter and mass on parton showers***

An exciting and cross-cutting field that must be further explored is the theory of dense QCD. Comparative studies of light and heavy meson production on e+p and e+A collisions can shed light in the process of hadronization, the time scales involved and the magnitude of non-perturbative effects. Modern effective field theories of QCD, such as soft-collinear effective theory, have allowed us to include effects of nuclear matter on the formation of parton showers and to combine those with heavy quark mass effects. Theoretical developments in the past several years have shown that evolution in the nuclear medium can amplify the impact of charm and bottom mass on heavy flavor observables and can constrain the transport properties of large nuclei. This physics is most easily accessible in the forward proton/nucleus going direction.

Experiment

- ***Open heavy flavor***

Heavy flavor quarks are produced in initial collisions due to their heavy masses ($m_{c/b} >> \Lambda_{QCD}$). They serve as an ideal probe to study the nuclear medium impacts on initial-state and final-state observables. Unlike heavy ion experiments at Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC), these asymmetric collisions at the EIC have no multiple interactions of the electron with the nucleus. Therefore, heavy flavor production at the EIC can precisely study the initial state nPDFs especially in the large x_B This includes gluon nuclear parton distribution functions at Bjorken-x > 0.001, and the charm and bottom distributions themselves. Fully reconstructed D-mesons and B-mesons with high statistics in both e + p and e + A collisions at the EIC will provides strong discriminating power to separate different model calculations on the hadronization in the vacuum and in the medium. Parton fragmentation in the presence of a nuclear medium can be constrained much better in comparison to light hadron measurements alone. Heavy flavor jets that contain at least one fully reconstructed heavy flavor meson inside their cone will be a key to improving our knowledge of flavor dependent hadronization processes.

- ***Open heavy flavor in polarized reactions***

The polarized electron+nucleon/nucleus collisions at the future EIC will provide opportunities to further explore the nucleon/nucleus spin structure such as the gluon Sivers effects through heavy flavor measurements as well. Specifically, constraints on the gluon transverse momentum distributions (TMDs) from measurements of charm hadron pairs. EIC experiments will further access gluon polarization by doing longitudinally double spin asymmetry measurements in the heavy flavor production. Measurements of azimuthal distribution of the charm hadron pair momentum in unpolarized electron-proton collisions are also of interest to compare to the polarized measurements.

- ***Opportunity with charm jets***

A primary source of information in contemporary determinations of the strange PDF is supplied by fixed-target neutrino DIS experiments involving heavy nuclear tar- gets. The interpretation of data from these experiments is complicated by a subtle interplay of effects arising from nuclear, target-mass, and other power-suppressed corrections, as well as potential contamination from target fragmentation. EIC presents the opportunity specifically focus on charm-jet production in CC DIS and its potential sensitivity to the strange quark sea. Heavy flavor jet substructure at the EIC is also investigated to understand heavy quark mass effects on hadronization.

- ***Quarkonia and exotics***

Heavy quark states that are produced in eA collisions at the EIC are subject to disruption via interactions with partons inside the nucleus. Since these interactions are expected to depend on the size and binding energy of the state, measurements of quarkonia suppression at the EIC can provide information on the structure of the heavy quark states. This offers a new method to discriminate between compact tetra- and pentaquark versus hadronic molecule models of exotic quarkonia structure.

- ***Gluon saturation with quarkonia***

It has been suggested that the Color Glass Condensate (CGC) of Quantum Chromodynamics (QCD) has universal properties common to nucleon and all nuclei. Study of heavy flavor production in e+A collisions at the Electron Ion Collider with various nuclear species could provide an access to the saturation regime. The measurements are possible in two modes, exclusive and inclusive. The energy range for e+A collisions at EIC allows the study both productions of the charmonium and the bottomonium states, which increases the reliability of the searches.

- ***Detector developments***

Heavy flavor physics at the EIC requires advances in detector development. Ability to reconstruct heavy flavor hadron decays with good signal significance is crucial for most of the proposed physics measurements. Micro vertexing and good momentum resolution, combined with low material budget are important requirements for this program. Collisions at the EIC are asymmetric and, while many of the heavy flavor decay daughters fall in the pseudorapidity region $|\eta| < 3$, the pattern if hadron production is skewed in the forward proton/nucleus going direction. The community is working on tracker designs including an all silicon detector and a forward silicon tracker optimized to extend forward rapidity coverage. Physics simulations are essential to back up these design efforts.