Studying Gluon Distributions and Hadronization with Heavy Flavor Production at the Future Electron Ion Collider

Sooraj Radhakrishnan (for ATHENA Collaboration)
Kent State University/ Lawrence Berkeley National Laboratory
Heavy Quarks as Probes of Gluon Distributions

- Heavy quark production in DIS: leading order contribution from photon gluon fusion process
- Ideal to probe gluon distributions

- Can access heavy flavor production over a broad kinematic range at the EIC

- Will constrain gluon helicity, gluon nPDFs, gluon TMDs over a broad kinematic range, which are major focuses of EIC physics


Gluon TMDs and Hadronization

- Heavy flavor pair production ideal channel to probe gluon Sivers asymmetry, linearly polarized gluon TMDs
- Also, clean probes of gluon TMDs
- Study Hadronization through modification of fragmentation in presence of nuclear matter
Heavy Flavor Reconstruction at EIC

- Key for HF measurements: Tracking system with excellent track pointing resolution, good momentum resolution

- MAPS based inner tracking and vertexing system required for excellent track pointing and momentum resolutions

- Part of both ATHENA and ECCE proposals
- Both can provide resolutions satisfying YR requirements

Plots from EIC UG meeting August 2021
EIC Simulation Setup

- Pythia6 EIC tune
- All-silicon tracker design composed of MAPS sensors
- $3 \times 2$ barrel layers within $|\eta| < 1$; five disks in forward and backward regions each, with coverage $1 < |\eta| < 3$

- Signal significance improves greatly with vertexing cuts
Simulation Results
 Charm Cross-section and Gluon nPDF

For more details see: Phys. Rev. D 104, 054002 (2021)

- $x_B$ - $Q^2$ coverage and statistical uncertainty projections for charm cross-section at EIC
- Excellent precision over a broad kinematic range. Higher $x_B$ coverage with lower collision energies
Impact of EIC charm data evaluated by reweighting of pdfs

Significant reduction in uncertainties with EIC data, particularly at large $x_B$

Impact similar across different nPDF fits studied
Question of intrinsic charm in proton still an open one, different models

EIC charm data will have sufficient precision to distinguish between different scenarios
Impact on Gluon Helicity

- Access to $\Delta g/g$ over a broad kinematic range
- Impact on gluon helicity distributions evaluated through pdf reweighing
Heavy flavor hadron pair reconstruction gives access to gluon transverse kinematics — direct probes of gluon TMDs

Good signal to background ratio and signal significance for D meson pair reconstruction

Signal: Unlike sign Kπ pairs within 3σ of D⁰ mass peak

Background: Unlike sign Kπ pairs within 6 to 12σ on either side of D⁰ mass peak
Heavy Flavor Tagging

- Exclusive reconstruction suffers from low branching ratios, ~3% for $D^0 \rightarrow K\pi$
- Utilize HF hadron decay topology to tag heavy flavor hadrons

- Used Fastjet package for clustering, Anti-$k_T$ with $R = 1.0$
- Construct topological variables for jets from constituent tracks. Excellent signal to background separation
- Different jet variables combined using Boosted Decision Trees
- Truth tagging: if parent HF hadron momentum falls within jet cone, tag it HF jet
Heavy Flavor Tagging Performance

- About 60% purity at 10% signal efficiency for single jet tagging
- Good correlation between reconstructed jet and hadron momenta
• Purity for HF pair selection improves from 2% to 70% with topological selection
• Gains substantially in statistics
• Initial transverse SSA at gluon level is preserved at final hadron level and for tagged HF jet pairs. Dilution of signal, ~50%
Project Projections for gluon TMD measurements

- For gluon Sivers asymmetry:
  Statistical uncertainty projections for transverse SSA
  $A_{UT}$ with tagged HF pair:
  $\delta A_{UT}^{HF} = \delta A_{UT}^{measured}/\text{purity/}\text{Polarization}$

- Far improved (nearly an order of magnitude) improved precision for $A_{UT}^{HF}$ measurements with tagged HF compared to using DDbar

- Linearly polarized gluon TMD can also be measured using transverse anisotropy. Similar error bars, but without dilution from polarization

- Tagging can significantly help other measurements also: other gluon TMDs, interactions with nuclear matter etc
Study hadronization using HF hadrons

- Can study hadronization through modification of fragmentation in presence of nuclear matter
- Good precision for HF measurements

- Systematic study of production of charm baryon states to understand different hadronization schemes
Summary and Outlook

• Heavy quark production offers a clean channel to study gluon distributions at the EIC

• A MAPS-based silicon tracker experiment at EIC will enable precision measurements
  • Significantly improves constraints on gluon nPDFs, gluon helicity distributions, intrinsic charm PDF and gluon TMDs with EIC data

• Topological tagging of HF hadron decays can be done with good purity and efficiency
  • HF pair signal purity can be improved substantially, from ~2% to ~70%
  • Improves precision of gluon TMD measurements using HF substantially

• High precision for HF measurements allows study of hadronization through fragmentation modification and heavy flavor baryon measurements
Back Up
Fast Simulation Setup

- Detector responses implemented through a fast simulation with parametrized position and momentum resolutions - for sufficient statistics
- Parameterizations taken from the current EIC detector matrix
- Full simulation studies and fastsim validation: See Rey’s and Matt’s talks

<table>
<thead>
<tr>
<th>η Region</th>
<th>Detector Matrix (µm)</th>
<th>η Region</th>
<th>Resolution (%)</th>
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- Primary vertex resolution taken from full simulation

- Fast simulation performance was validated using full simulation
D Meson Topological Cut Efficiency
Correlations between Partonic and Hadronic Stages

- Hadronization doesn't cause much decorrelation in angular distributions
- Stronger dilution in PYTHIA going from initial gluon to ccbar - but not seen in events where PYTHIA doesn't split photon to