Heavy Flavor at the EIC

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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 TMDs, e.g.: 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
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
EIC Simulation Setup

• Pythia6 EIC tune
• All-silicon tracker design composed of MAPS sensors
• 3x2 barrel layers within \(|\eta| < 1\); five disks in forward and backward regions each, with coverage 1<\(|\eta|<3
• Tracking specifications as in EIC YR Det.Matrix: arXiv:2102.08337

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

\[ \sigma_T^{c\bar{c}}(x_B, Q^2) = F_{2}^{c\bar{c}}(x_B, Q^2) - \frac{y^2}{Y + F_L^{c\bar{c}}(x_B, Q^2)} \]

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

Important to constrain shadowing, anti-shadowing and at high $x$, possible gluonic EMC effects

For more details see: Phys. Rev. D 104, 054002 (2021)
Impact of Intrinsic Charm in Proton

- Question of intrinsic charm in proton still an open one, different models
- EIC charm data will have sufficient precision to distinguish between different scenarios

For more details see: Phys. Rev. D 104, 054002 (2021)
Impact on Gluon Helicity

- Access to $\Delta g/g$ over a broad kinematic range
- Impact on gluon helicity distributions evaluated through pdf reweighing

$$A_1^c \equiv \frac{1}{D(y)} A_{LL}^{e+\bar{p}\rightarrow e'+D^0+X} = \frac{1}{D(y)} \frac{1}{P_e P_p} N++-N+- \propto \hat{a}_{LL} \frac{\Delta g}{g}$$

For more details see: Phys. Rev. D.104.114039 (2021)
Also EIC YR: arXiv:2103.05419
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
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
Heavy Flavor Tagging Performance

- 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%
• 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

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<th>η Region</th>
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<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

![Graph showing D^0 topological efficiency vs. p_T (GeV/c)]
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...