Nuclear gluons with charm at EIC

Jefferson Lab

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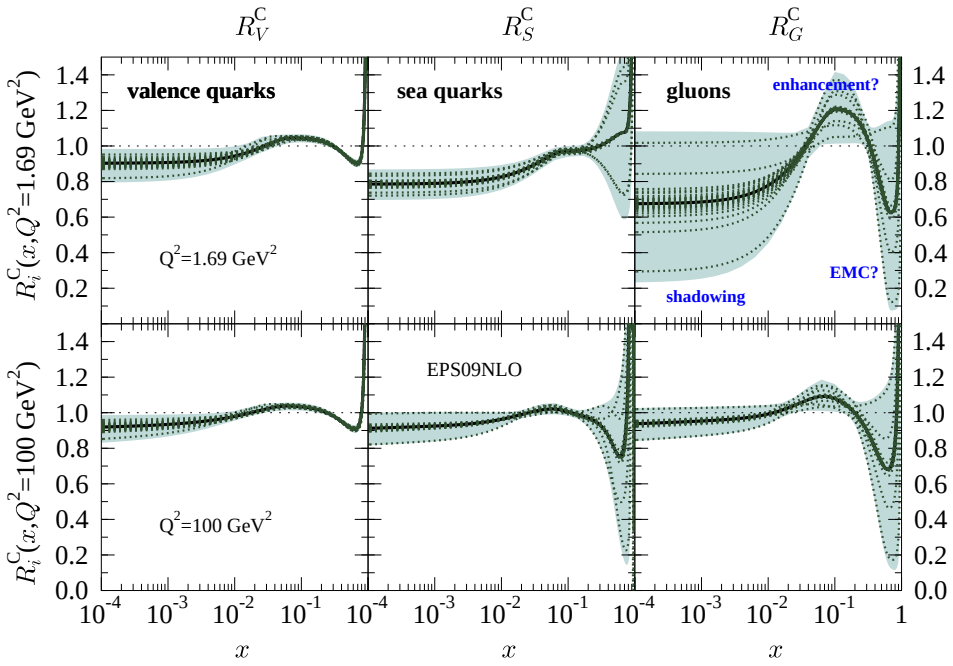
Collaborators: C. Hyde (ODU), M. Stratmann (Tübingen), M. Strikman (Penn State)
Two graduate students (UVA, MIT, at JLab)

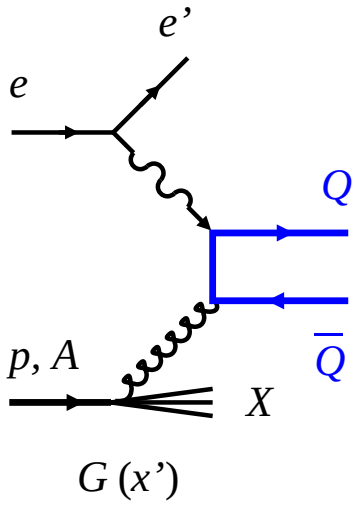
Duration: 2 years Budget: $340K

Aim: Demonstrate feasibility of **new direct probes of nuclear gluons & quarks** with MEIC and quantify physics impact: gluons with heavy quarks (open charm), quark flavor decomposition with semi-inclusive DIS.

- Fundamental nuclear physics questions identified in NSAC Long-Range Plan: QCD structure of nucleon-nucleon interaction, non-nucleonic degrees of freedom
- Novel approaches to nuclear gluons & quarks enabled by EIC, great potential
- Project plan updated in response to reviewers' suggestions: 2-year schedule, additional collaborators, increased depth & scope

Context and motivation





- Nuclear modification of gluons

  Gluonic EMC effect at $x > 0.3$?
  Non-nucleonic DOF

  Gluon enhancement at $x \sim 0.1$?
  NN interactions in QCD
  Strong gluon shadowing at $x < 0.01$ seen in recent LHC ALICE ultraperipheral AA data

- Open charm as direct probe

  Used in ep: Theory, MC tools, charm reconstruction methods
  HERA HVQDIS, H1/ZEUS data. Also pp at LHC

  Theoretical uncertainties cancel in nuclear ratio

- Nuclear modification of quarks: Flavor decomposition

  $x \sim 0.1$: NN interaction in QCD

  Semi-inclusive DIS as direct probe

Tasks

- Adapt existing ep heavy-quark MC tool HVQDIS to eA at MEIC, with schematic models of charm detection/reconstruction. Implement semi-inclusive DIS MC for eA at MEIC **Furletov, Hyde, Higinbotham, Weiss**

- Simulate nuclear ratio measurements of open charm production and semi-inclusive DIS at MEIC **Higinbotham, Students A/B, Furletov, Weiss**

- Quantify physics impact and interpret results **Stratmann, Strikman, Weiss**

Personnel

JLab staff investigators

Furletov 20% / 10%	Adapt HERA MC, unique expertise
Higinbotham 10%	Process simulations, supervising students
Weiss 20%	Project coordination, analytic modeling, testing, documentation
Chudakov 0%	Advisory, charm reconstruction methods

Graduate students in experimental physics

Student A 50%, 1 year	Support simulations/analysis open charm production
Student B 50%, 1 year	Support simulations/analysis semi-inclusive DIS

Supervised by senior investigators, based at JLab. Strong candidates identified (UVA, MIT)

Consultants

C. Hyde, 2 $\times$ 4 weeks	Develop/refine MEIC detector model for charm, π/K
M. Stratmann, 2 $\times$ 2 weeks	Production theory updates, impact on nuclear PDFs
M. Strikman, 2 $\times$ 2 weeks	Interpretation of nuclear ratios, analysis strategies

Schedule and milestones

Months	Tasks		Milestones
1-3	Adaptation open charm MC for EIC	Furletov/Weiss	
4-6	Testing open charm MC for EIC	Furletov/Weiss/Chudakov/Stud. A	
	Stage-1 simulations nuclear gluons		
	Development semi-inclusive π/K MC for EIC	Higinb./Weiss	Basic MC setup for nuclear gluons with charm at EIC
6-9	Stage-1 and 2 simulations nuclear gluons	Furletov/Higinb./Weiss/Student A	
	Testing semi-inclusive π/K MC	Higinb./Weiss	
	Theoretical strategy for nuclear ratios	Strikman 1 week	
9-12	Stage-2 simulations nuclear gluons	Student A/Higinb./Weiss	
	Development EIC detector model for charm	Hyde 4 weeks	MC simulations nuclear gluons, first physics assessment
	Theoretical update QCD description	Stratmann 2 weeks Strikman 1 week	MC setup for nuclear quarks with semi-inclusive pions/kaons
13-15	Stage-3 simulations nuclear gluons	Furletov/Higinb./Weiss	
	Simulations nuclear quarks	Student B/Higinb./Weiss	
16-18	Comprehensive assessment nuclear gluons	All	
	Optimization kinematics nuclear gluons	Strikman 1 week	
	Impact global PDF fits	Stratmann 2 weeks	
	Detailed simulations nuclear quarks		Comprehensive assessment nuclear gluons with heavy quarks
	Physics assessment nuclear quarks		
19-21	Publication nuclear gluons	All	
	Development EIC detector model semi-incl. π/K	Hyde 4 weeks	
	Optimization kinematics/strategy nuclear quarks	All	
	Comprehensive assessment nuclear quarks	Strikman 1 week	
21-24	Publication nuclear quarks	All	
	Overall assessment physics impact: NN interaction, non-nucleonic DOF		Comprehensive assessment nuclear quarks & gluons with EIC

Expected outcomes

1. **Simulation tool** (event generator, analysis scripts) for open heavy quark production in eA at EIC, adapted from HVQDIS for ep, implementing different methods of charm/beauty reconstruction, with a schematic model of the EIC detector performance (computer codes, documentation). Simulation tool for semi-inclusive pion/kaon production in eA at EIC, implementing a schematic model of particle identification.
2. **Demonstration of feasibility** of nuclear gluon distribution measurements at $x \gtrsim 0.1$ with heavy quark production at EIC, and optimization of experimental technique, based on detailed process simulations (technical report, summary plots). Demonstration of feasibility of flavor decomposition of nuclear quarks with semi-inclusive pion/kaon production at EIC.
3. **Quantitative assessment of theoretical accuracy and physics impact** of direct measurements of nuclear gluons and quark flavor decomposition with EIC (publications).

Broader impact

- Benchmarks for MEIC central detector development: Vertex detection, particle ID, resolution
- User involvement: Natural extension of 6/12 GeV nuclear physics program, great interest
- Outreach to heavy-ion physics: Nuclear gluons as input for AA, connection with LHC expts
- Future applications: Large–x gluons in proton with open charm (needs further theory input), hadronization of heavy quarks
- Training of young researchers

Updates in response to reviewers' suggestions

- **Two-year schedule:** Flexible scheduling of JLab staff effort (Furletov, Higinbotham); easier synchronization with student and visitor effort; increased depth and scope

- **Additional labor:** Two exp. graduate students (1-year contracts, 50% FTE); doubled consultant efforts (Hyde 2 $\times$ 4 weeks detector modeling; Strikman/Stratmann 2$\times$2 weeks theory)

- **Increased depth and scope:** Simulations of nuclear gluons through open charm with advanced MEIC detector model; flavor decomposition of nuclear quarks with semi-inclusive pions/kaons

Additional explanations

- The simulations of open charm production in eA at EIC will be performed with an adapted version of the HVQDIS MC code (HERA ep, publicly available, documented). Furletov has extensive experience with this code and can deliver a first working version with 2-3 weeks of total effort in the first 3-6 months of the project. No major physics or software development will be needed.

- The graduate students will assist with running the simulation code and analyzing the output (event generation, filtering/plotting of pseudodata, investigating specific questions as directed). These tasks can be performed with the students' existing nuclear physics and computer skills (from their work on 12 GeV experiments) and do not involve large–scale software development. The students' work will be synchronized with the the staff and visitor effort and supervised by the senior investigators.

- New MEIC–specific elements in the simulation tools will be an improved schematic model of the detector performance for charm/beauty detection, and for pion/kaon separation in semi-inclusive DIS, to be included in the advanced stages of the simulations. These elements will be developed by C. Hyde (consultant, 2 $\times$ 4 weeks summer work), who is actively participating in JLab's MEIC detector development.

Budget

Requested project funding Year 1

Labor of JLab staff (Weiss 20% FTE, Furletov 20% FTE, Higinbotham 10% FTE) 73,943
Consultants/Subcontractors (Student A 50% FTE, Hyde 1 month) 38,516
Travel visiting scientists (Stratmann 2 weeks, Strikman 2 weeks) 6,000
Total direct costs Year 1 118,459
Total LDRD request Year 1 (incl. G&A) 177,689

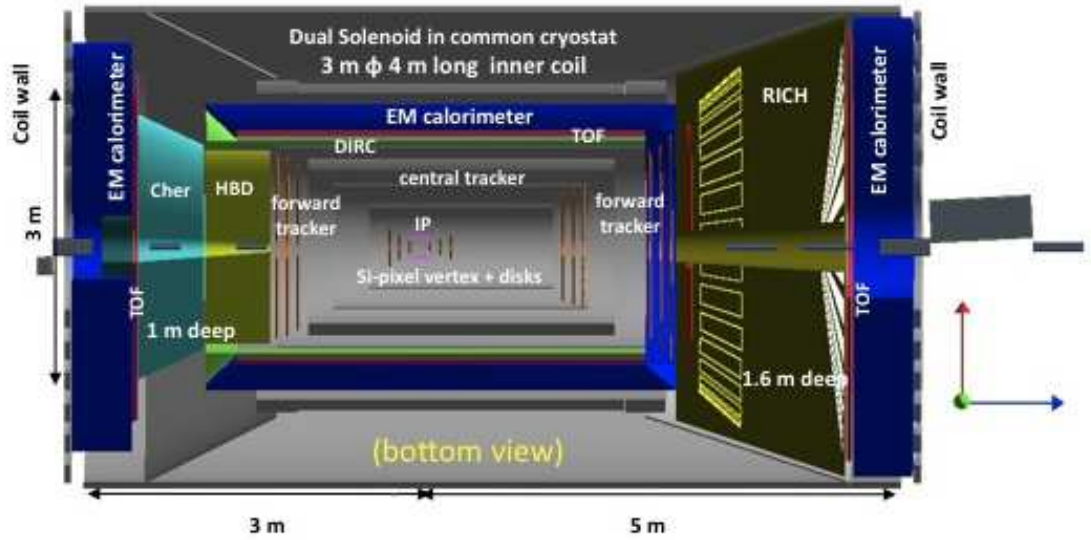
Requested project funding Year 2

Labor of JLab staff (Weiss 20% FTE, Furletov 10% FTE, Higinbotham 10% FTE) 63,163
Consultants/Subcontractors (Student B 50% FTE, Hyde 1 month) 39,215
Travel visiting scientists (Stratmann 2 weeks, Strikman 2 weeks) 6,000
Total direct costs Year 2 108,378
Total LDRD request Year 2 (incl. G&A) 162,567

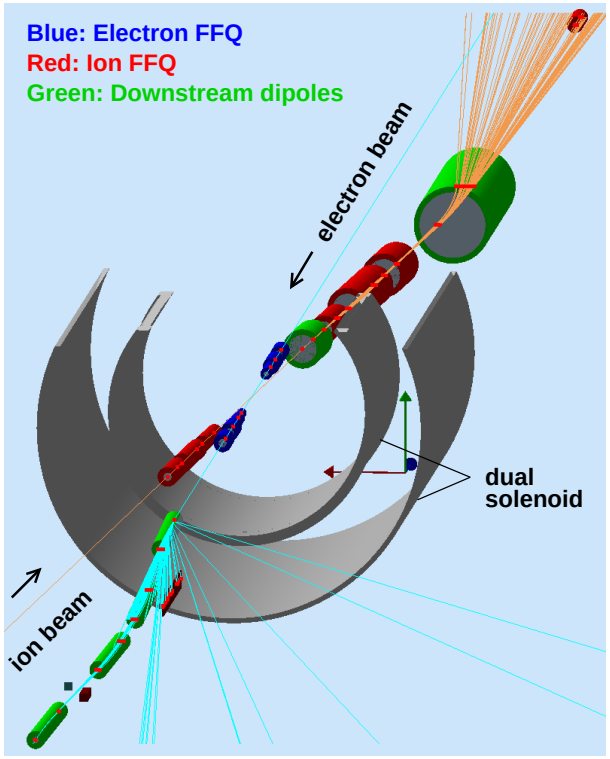
Total LDRD request Year 1 and 2 (incl. G&A) 340,256

Supplementary material

MEIC detector concept



MEIC central detector
Ion beam from left at 50 mrad
Electron beam from right



Central & forward detectors integrated with beam optics
Ion beam from lower left
Electron beam from upper right

Information on current MEIC machine/detector design at: `https://eic.jlab.org/wiki/`