Nuclear gluons with charm at EIC

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Project period: 2 years

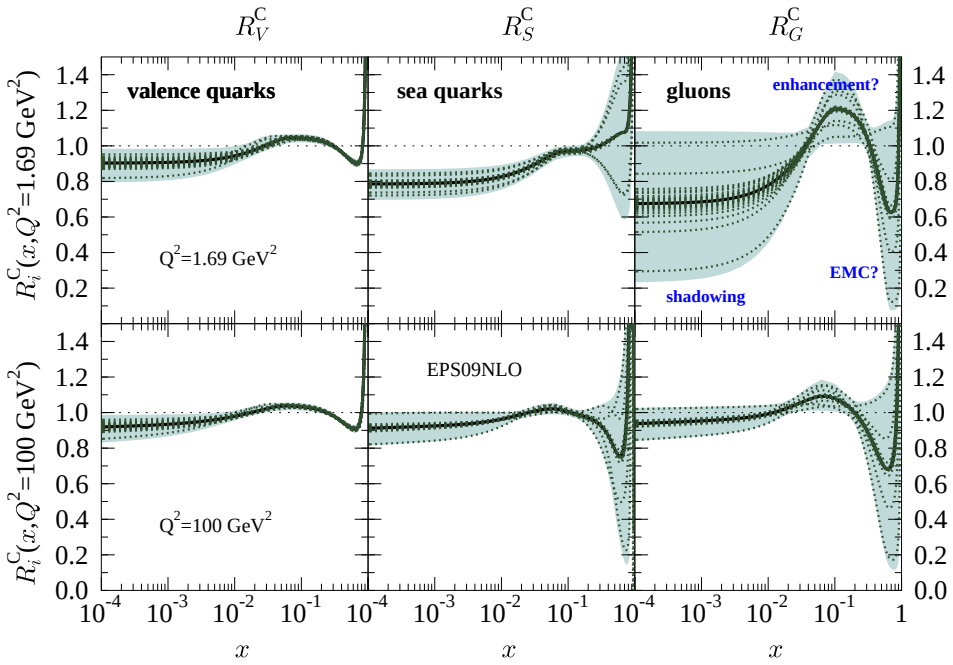
Welcome!

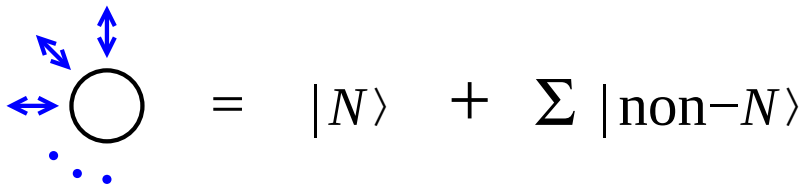
Aim: Demonstrate feasibility of direct probes of nuclear gluons & quarks with EIC:
Gluons at $x \gtrsim 0.05$ with heavy quarks — open charm, beauty;
Quark flavor decomposition with semi-inclusive DIS.

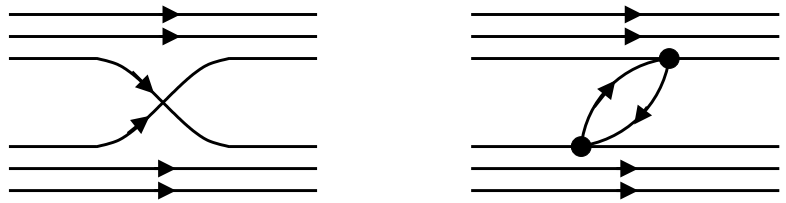
Tasks

- Adapt simulation tools for heavy quark production in ep (HVQDIS, F_{2c} code) to eA at EIC, with schematic modeling of charm detection/reconstruction, simple $\rightarrow$ more detailed
- Adapt MC tool for ep semi-inclusive DIS to eA at EIC
- Simulate nuclear ratio measurements of open charm production and semi-inclusive DIS at EIC
- Assess systematic and theoretical accuracy of nuclear ratio measurements at EIC and quantify physics impact

Nuclear modification of partonic structure







quark exchange meson exchange

- Seen in inclusive processes
  PDF fits: EPS, DSZS, FGS, ...
- Gluonic EMC effect at $x > 0.3$?

  Non-nucleonic DOF in nucleus
- Quark and gluon enhancement at $x \sim 0.1$ (antishadowing)?

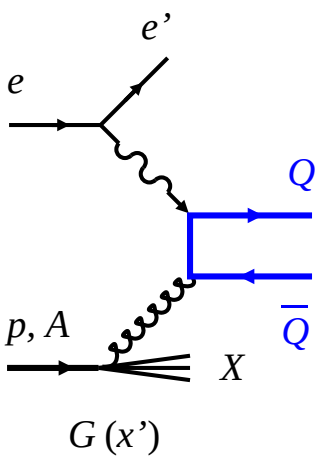
  QCD structure of NN interaction

  Flavor structure of quark enhancement?

  Gluon enhancement?

  Strong gluon shadowing observed at $x < 0.01$ suggests compensating antishadowing at $x \sim 0.1$
  LHC ALICE J/ψ in ultraperipheral AA
- Need **direct probes!**

Gluons with open charm: Methods



- Heavy quark production in DIS

  Calculated in QCD at LO, NLO; estimates beyond NLO
  Laenen, Riemersma, Smith Van Neerven, Harris 93+. Kawamura et al. 12

  Theoretical uncertainties studied: Scheme dep, quark mass
  Alekhin, Moch et al. 93+

  Probes gluons at $x' > x(1 + 4M_Q^2/Q^2)$, mostly $x \sim x'$

  Good sensitivity to gluons even at $x \gtrsim 0.1$

- Experimental identification

  Single D, B mesons through distinctive leptonic or hadronic decays, e.g. D^*

  Vertex detection through track reconstruction or vertex detector

  (Double detection, e.g. $\Lambda_c + D$?)

- Observables for analysis

  Differential cross section $d^4\sigma/dQ^2 d\eta d^2p_T$

  Inclusive charm structure function F_{2c}

Gluons with open charm: Simulation tools

- Experimental results

  ep HERA H1 & ZEUS: extensive measurements, various identification methods, detailed comparison with QCD calculations
  Latest analysis: Aaron et al. 2011, Abramowicz et al. 2014

  μN COMPASS: polarized target
  Adolph et al. 2012/13

  e^+e^-, photon–hadron, hadron–hadron

- Simulation tools

  HVQDIS code: Calculates differential D–meson production cross section using NLO QCD approximation, heavy quark fragmentation functions, and nucleon PDFs. Permits MC integration over phase space.
  Harris, Smith 98

  $\boldsymbol{F}_2^{c\bar{c}}$ **code:** QCD–based parametrization for inclusive charm structure function
  Riemersma, Simth, van Neerven 94

  Still current? Updates? Recent developments?

Gluons with open charm: EIC

- Adapt simulation tools (HVQDIS, F_{2c} codes) to eN in EIC kinematics

  Specifics of $x > 0.1$? Check approximations!

- Assess experimental conditions for heavy quark production in eN at EIC in three stages

(1) Estimate charm production rates with the HVQDIS inclusive cross sections and **generic assumptions about overall charm reconstruction efficiency at EIC.** First orientation regarding rates, kinematic dependencies, and potential sensitivity to gluons in proton.

(2) Simulate **"idealized" charm reconstruction at EIC,** using PYTHIA to generate the full hadronic final state (heavy meson decay and other hadrons), and including effects of acceptance, background, angular distributions, but assuming simple idealized reconstruction and vertex parameters

(3) Simulate **"realistic" charm reconstruction at EIC,** using the same setup as in (2) but including also the momentum reconstruction resolution from detector specifications.
Requires model of generic detector resolutions, to be developed as part of the project.

(GEANT4 simulations at the "hit" level, including material properties and signal processing, requires full detector design and are outside of scope of present project)

Gluons with open charm: Nuclear ratios

- Assess prospects for constraining nuclear gluons through nuclear ratio measurements $(A/p, A/D)$ of open charm production at EIC

  Stat and sys errors: QCD uncertainties and charm reconstruction efficiencies partly cancel in ratio. How far can we push overall errors (stat $\approx$ sys)?

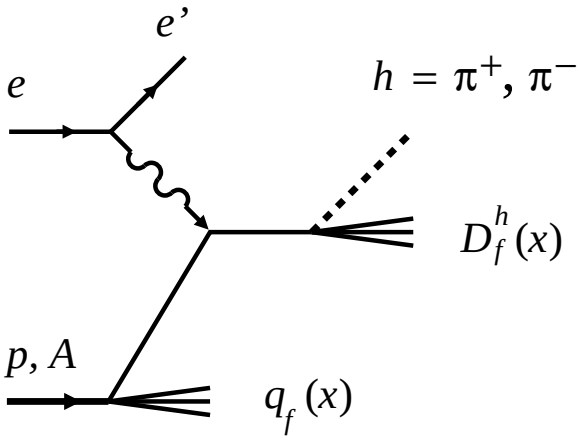
  Luminosity elimination: Normalize open charm production ratios with well-known inclusive rations F_{2A}/F_{2p} or F_{2A}/F_{2D} at $x \sim 0.2 - 0.3$ (double ratios)

  Optimal kinematics: Rapidity ranges?

  Specifics of large $x \gtrsim 0.5$: QCD processes? Charm reconstruction in different event geometry? Exclusive channels $\Lambda_c + D$?

  Using beauty: Probes larger x' than charm. Comparison with charm?

Flavor separation with SIDIS



- Semi-inclusive hadron production

  Standard method for charge/flavor separation of quark PDFs
  HERMES, COMPASS, JLab 6 + 12 GeV

  LO, NLO implementation available

- Simulation tools available: HERMES, JLab CLAS/Hall C

- Adapt to eA at EIC

- Apply to nuclear ratios at $x \sim 0.1$

  Separate charge/isospin combinations with $N(\pi^+ \pm \pi^-)$

  Fragmentation functions cancel in nuclear ratio. NLO effect?

  Estimate final-state interactions by measuring on different nuclei and using A–dependence

Theoretical accuracy and physics impact

- Address specific theoetical issues in nuclear ratio measurements at $x > 0.1$ and quantify physics impact

- Final–state interaction in heavy/light meason production on nuclei

  Initial–state modifications saturate above $A \sim 12$
  Final–state interactions continue to grow as $A^{1/3}$
  Develop empirical method

- L/T ratio of nuclear cross sections

  Early data indicate small nuclear modification $\Delta R/R < 0.1$ Gousset, Pirner 96

  Revisit analysis with current data

- Impact of EIC pseudodata on PDFs

  Bayesian reweighting: Efficient, avoids refitting

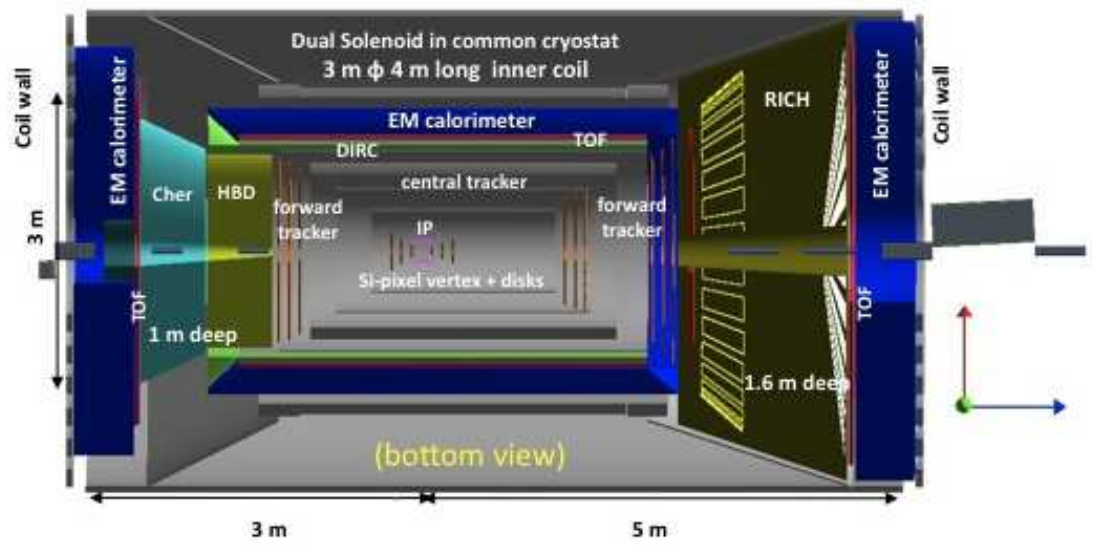
First steps

- Inspect HVQDIS and begin adapting to EIC eN Sergey
- Inspect available SIDIS generators and decide which one to adapt/use for nuclear ratios Doug
- Prepare analytic estmates of heavy quark production rates for quick orientation and check of MC integration (LO) Christian

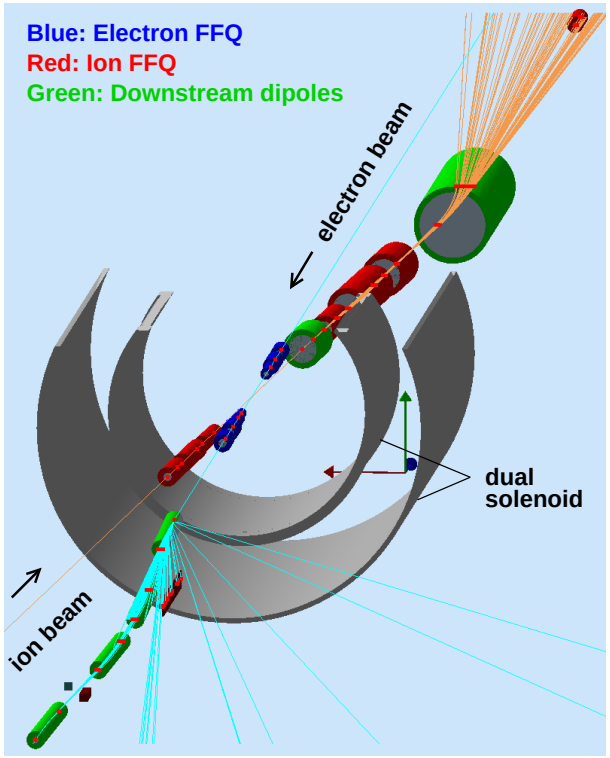
Next meeting

- EIC detector overview and charm reconstruction capabilities Charles
- HVQDIS demonstration (?) Sergey
- Summary HERA charm/beauty results (?) NN
- Please suggest other topics!

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/`

Supplementary material

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