Nuclear gluons with charm at EIC

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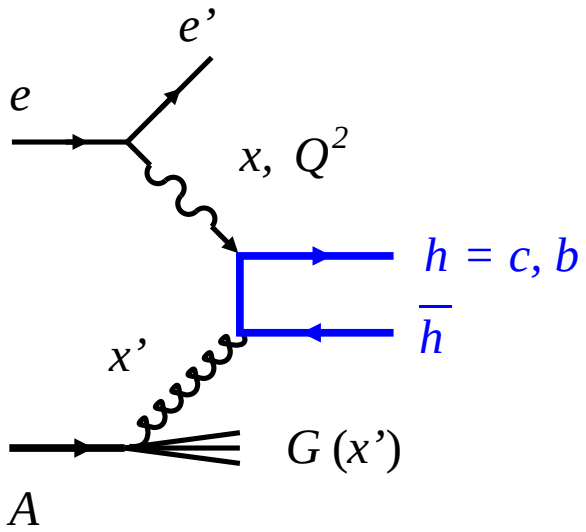
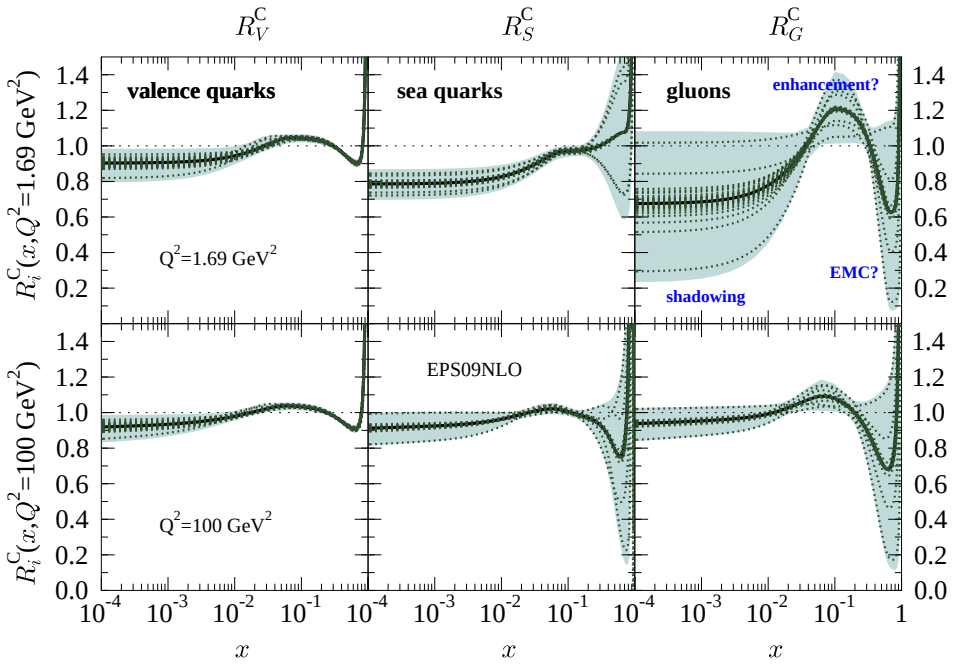
JLab FY16 LDRD Project LD1601

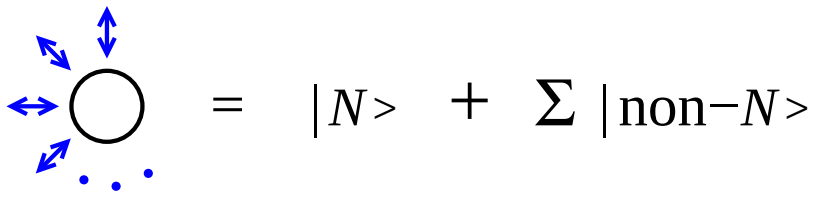
Aim: Investigate feasibility of direct measurements of nuclear gluons at $x \gtrsim 0.1$ using heavy quark probes — open charm, beauty — with EIC

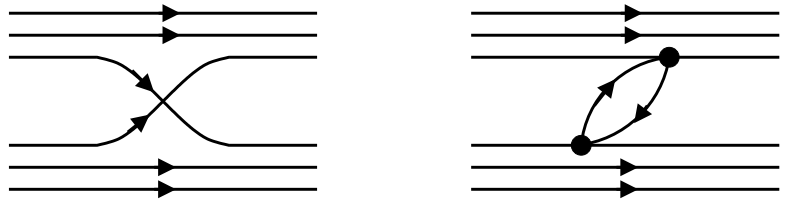


- Nuclear modification of gluons
- Open charm as direct probe
- Simulation tools and methods
- EIC simulations (first results)

Nuclear modification of partonic structure







quark exchange meson exchange

- Seen in inclusive DIS
  JLab 6 & 12 GeV: Valence quark EMC effect
- Gluonic EMC effect at $x > 0.3$?

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

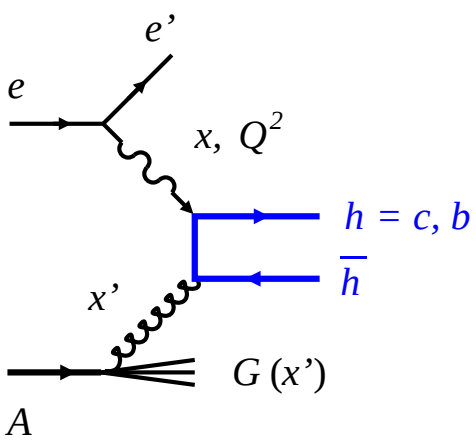
  QCD structure of NN interaction

  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



- Heavy quark production in DIS

  Calculated in QCD at LO, NLO; theory uncertainties quantified
  Laenen, Riemersma, Smith Van Neerven, Harris 93+. Kawamura et al. 12
  Alekhin, Moch et al. 93+

  Probes gluons at $x' > \dfrac{4M_h^2 + Q^2}{W^2}$ $\qquad (W^2 \gg Q^2)$

  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^*

  Single D, B mesons through vertex detection by track reconstruction or vertex detector

  Double heavy quark detection, e.g. $\bar{D} + D$ or $\Lambda_c + D$?

- Observables for analysis

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

  Inclusive charm structure function F_{2c}

Open charm experiments

- 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, marginal statistics
  Adolph et al. 2012/13

- Charm production in e^+e^-, photon–hadron, hadron–hadron

Simulation tools

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

- $F_2^{c\bar{c}}$ code: QCD–based parametrization for inclusive charm structure function
  Riemersma, Smith, van Neerven 94

R&D plan for EIC

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

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

  (1) Estimate charm production rates based on **generic assumptions about overall charm reconstruction efficiency at EIC.**

  (2) Simulate **"idealized" charm reconstruction at EIC,** using PYTHIA to generate the hadronic final state, including acceptance, background, angular distributions, but assuming idealized charm reconstruction parameters

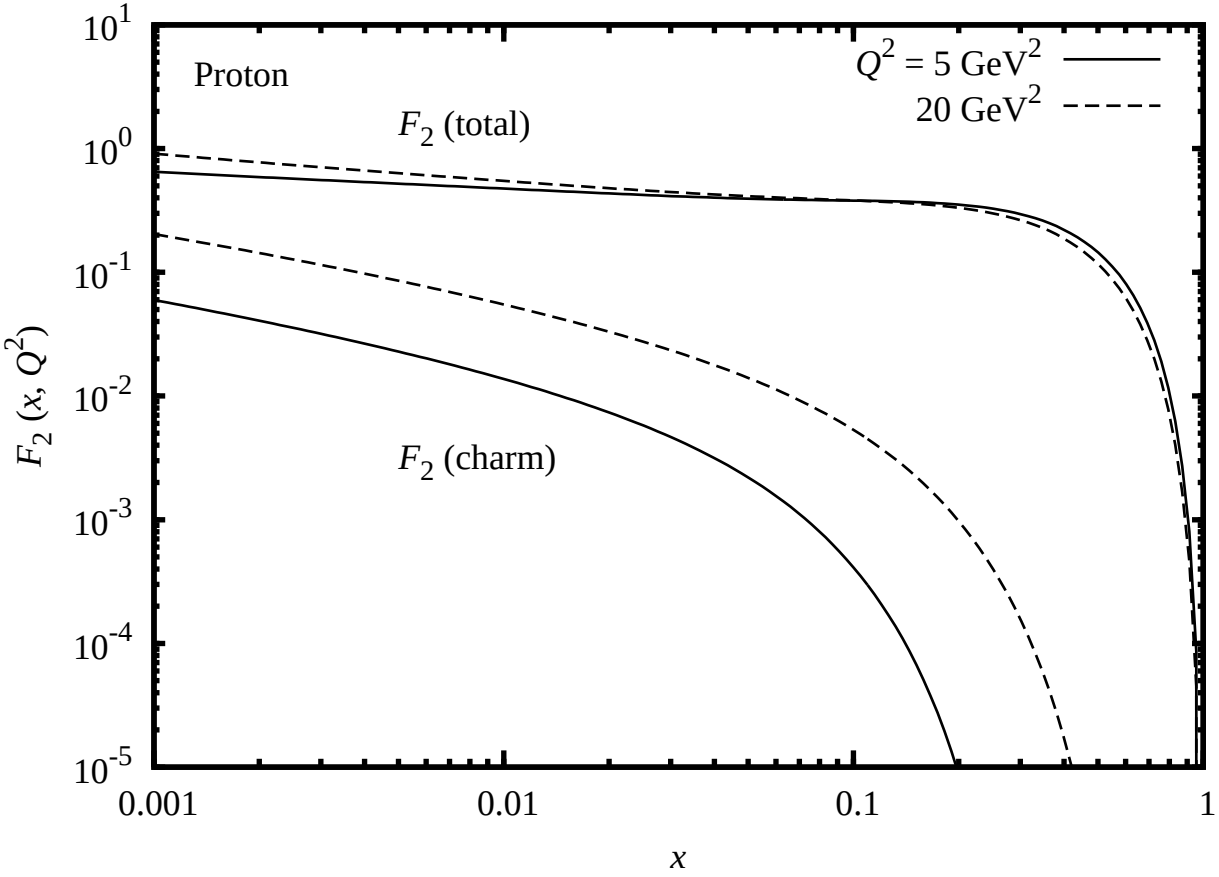
  (3) Simulate **"realistic" charm reconstruction at EIC,** using the same setup as in (2) but including also the momentum reconstruction resolution from detector specifications.
  Requires model of generic detector resolutions, to be developed as part of the project.

- Assess prospects for nuclear ratio measurements with EIC

  Stat and sys errors, luminosity elimination, optimal choice of kinematics

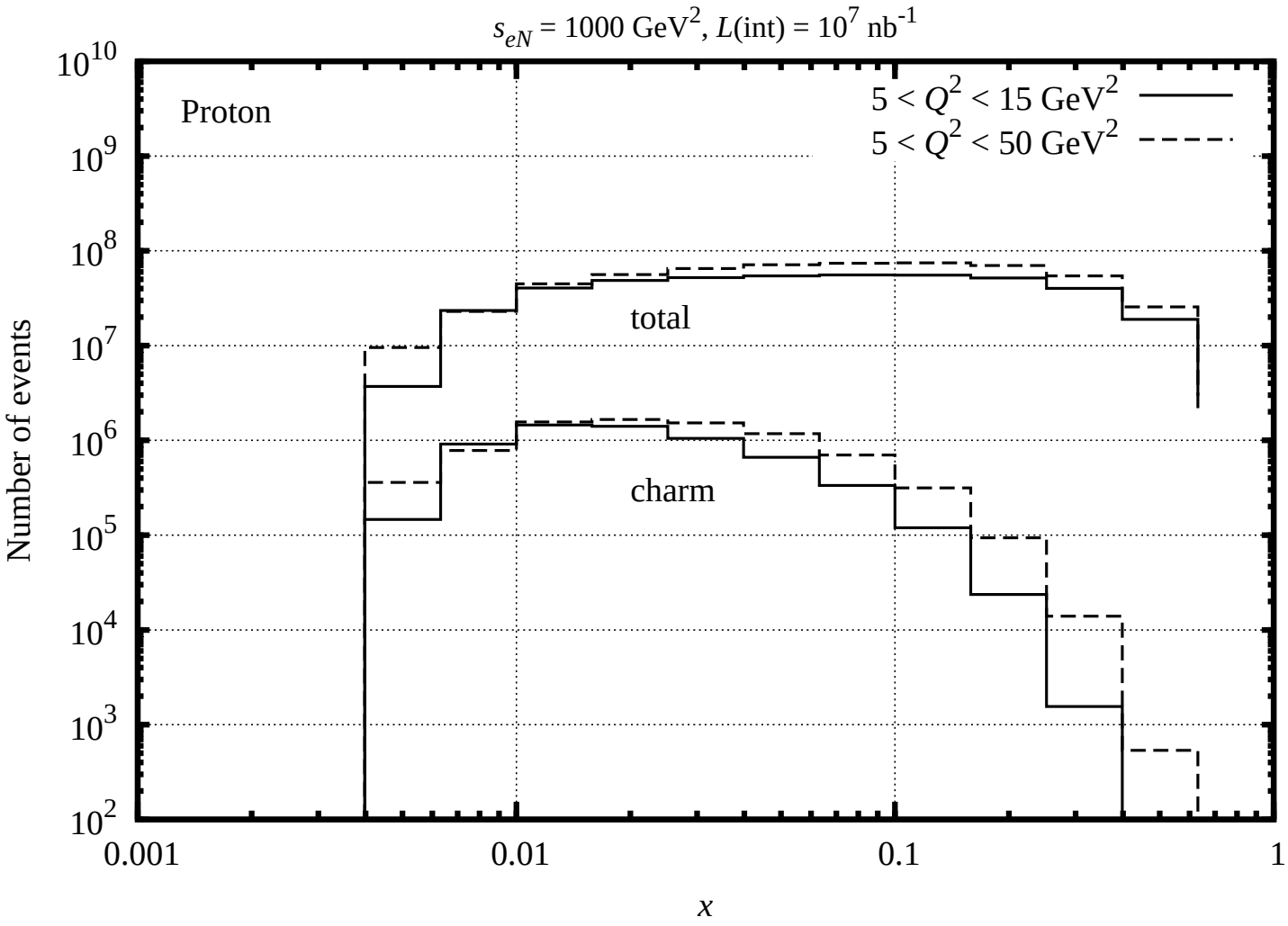
  Specifics of large $x \gtrsim 0.5$? Using beauty?

Results: Charm structure function F_2^c



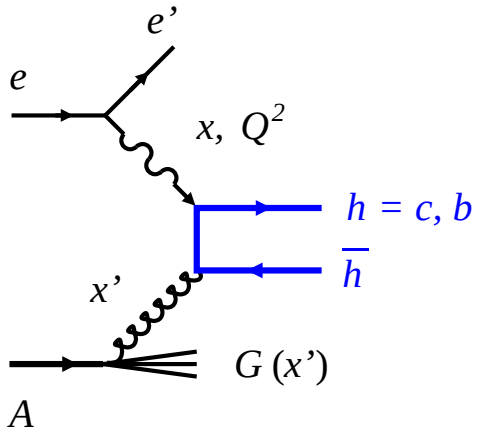
- F_2^c and ratio F_2^c/F_2 decrease rapidly with x
- Strong Q^2 variation of F_2^c at fixed x: Kinematic effect

Results: Total charm rate at EIC



- Here 5 bins per decade in x, single wide bin in Q^2
- Rates drop rapidly at large x
- Nuclear rates comparable: Structure function $F_{2A}^c \sim AF_{2N}^c$, but luminosity $L_A \approx L_N/A$

Results: Sensitivity to large–x' gluons

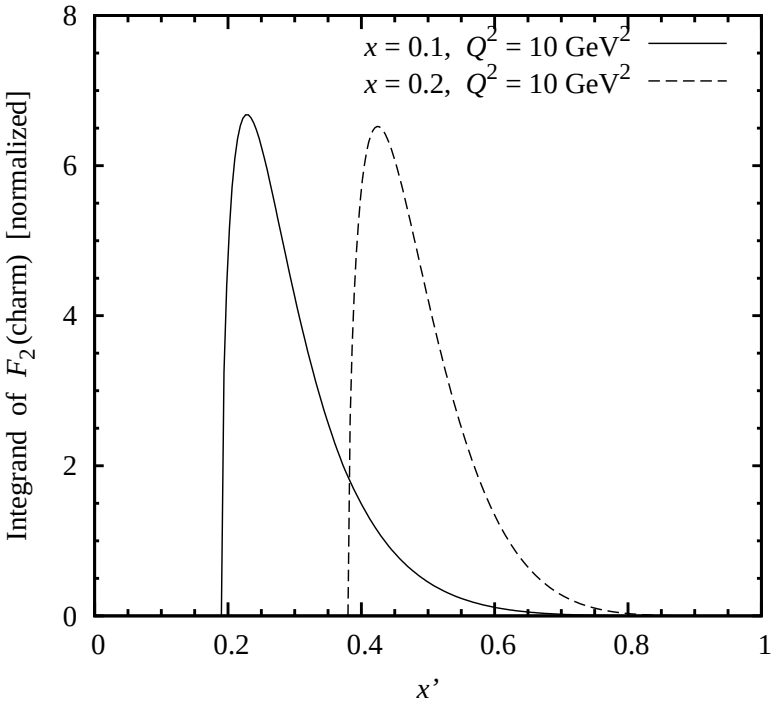


$$F_2^h(x,Q^2) \;=\; \int_{ax}^{1} \frac{dx'}{x'}\, x'G(x')\; \hat{F}_g^h(x/x',\, Q^2,\, m_h^2,\, \mu^2)$$

coefficient function

$$a \;=\; 1 + \frac{4m_h^2}{Q^2}$$

sets limit of x' integral



- Integrand localized in x' around lower limit ax
- Heavy quark production probes large–x' gluons "almost locally"

Theoretical accuracy and physics impact

- Final–state interaction in heavy meson production on nuclei

  Initial–state modifications saturate above $A \sim 12$

  Final–state interactions continue to grow as $A^{1/3}$

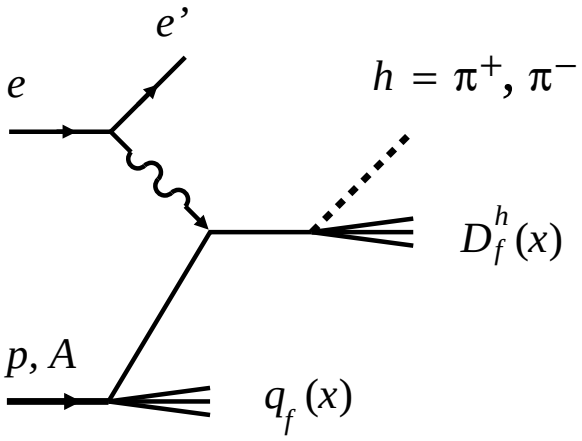
  Separate effects empirically

- L/T ratio of nuclear cross sections

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

- Impact of EIC pseudodata on PDF fits: Bayesian reweighting

Flavor separation of nuclear quarks 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

Summary

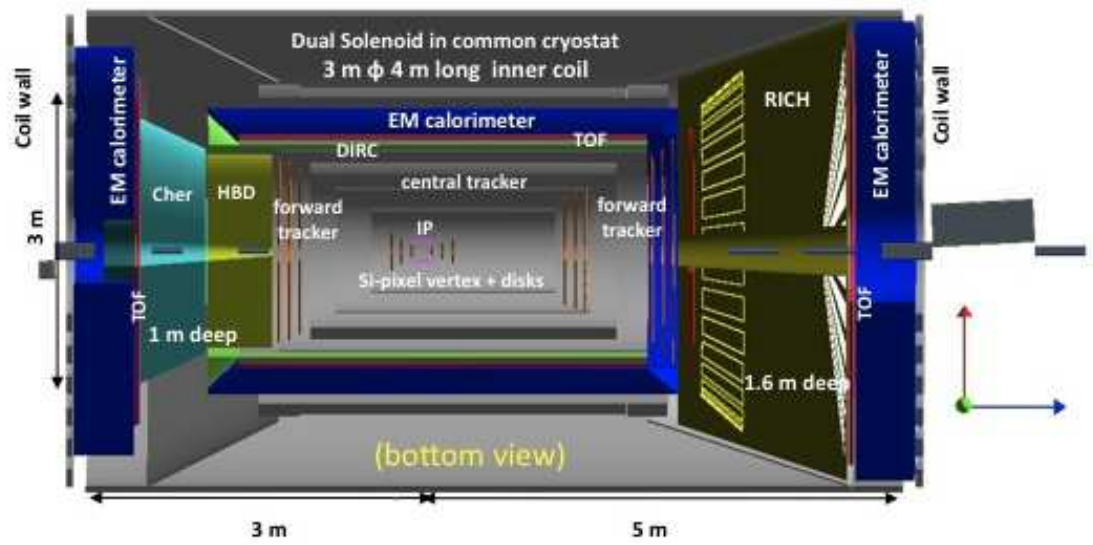
- Prospect of direct measurements of nuclear gluons using heavy quark production
- Further R&D to implement realistic charm reconstruction with EIC and quantify detector requirements
- Measurements of open charm at $x > 0.2$ will likley be limited by luminosity
- Open charm can definitely be used for nuclear gluons at small x (shadowing); question is about the limits at large x (EMC effect) and systematic errors

Further information

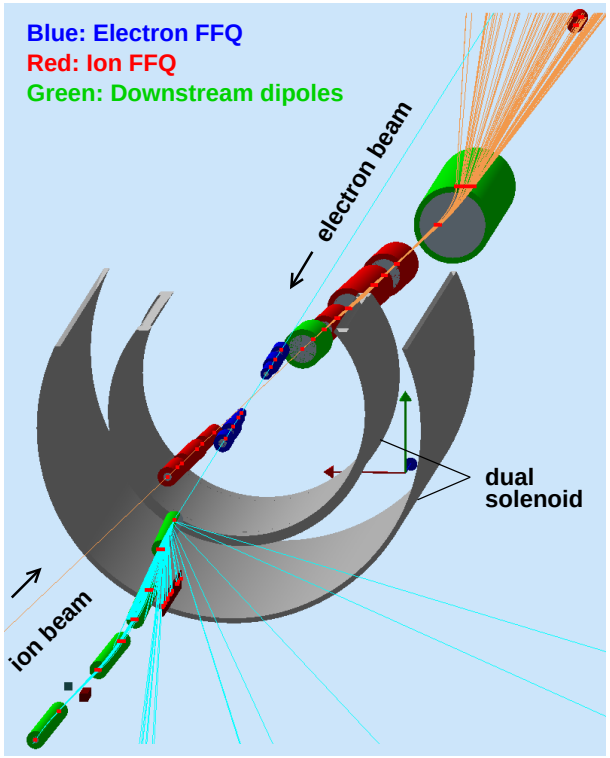
- Public Wiki at `https://wiki.jlab.org/nuclear_gluons/`
  Simulation tools, results, materials, references
- Tools & results can be used for follow-up studies
  Please contact investigators!

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/`