Charm and beauty production with EIC

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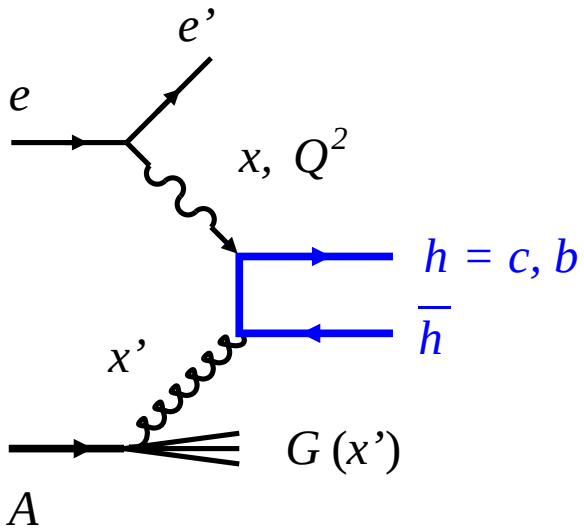
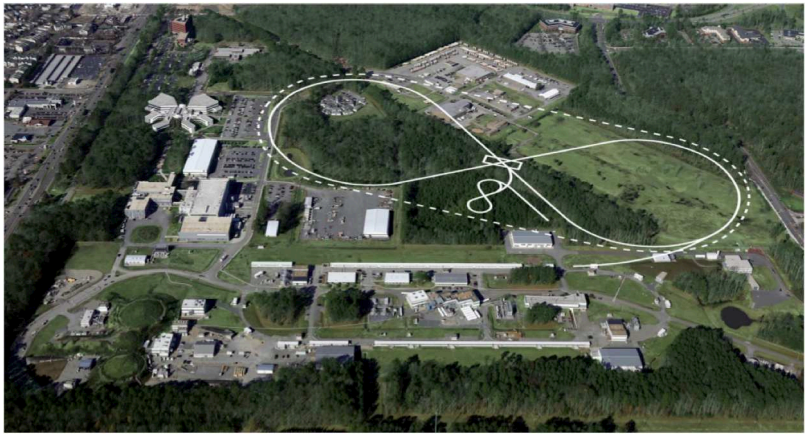
M. Stratmann, M. Strikman, C. Weiss∗, BEACH2016, George Mason U., June 12–18

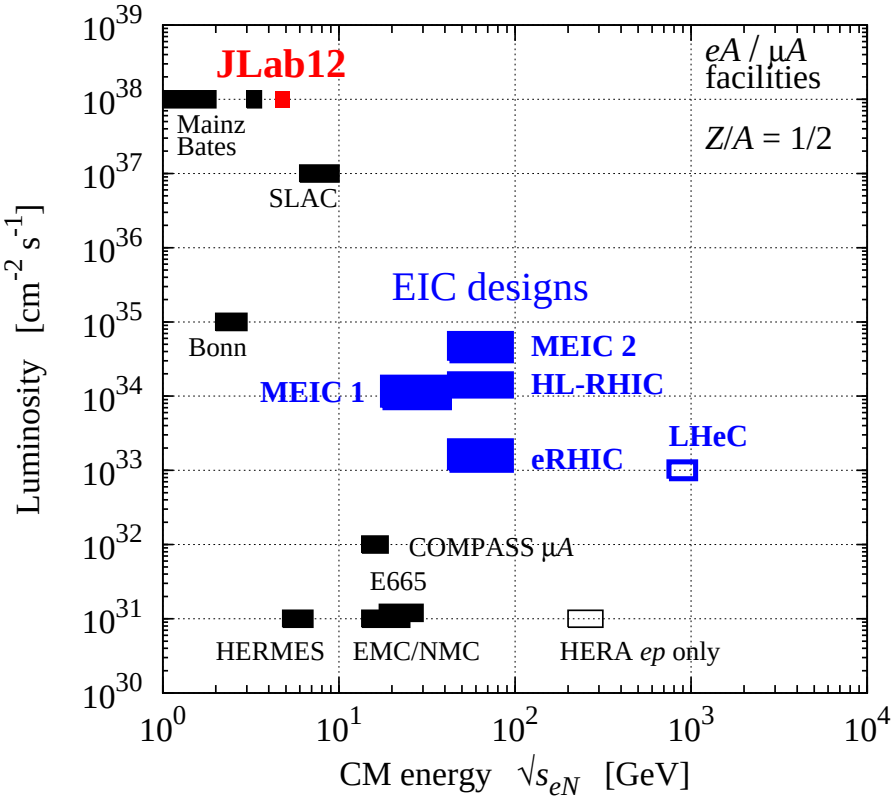
Jefferson Lab

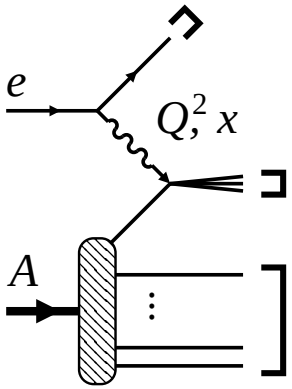




- Electron-Ion Collider
  - Energy, luminosity, detection
- Nuclear gluons at large x
  - Nucleon-nucleon interaction in QCD
  - Heavy quarks as direct probe
- Open charm/beauty with EIC
  - Rates and background
  - Charm identification
  - New methods using PID
- More heavy-quark physics
  - Exclusive $h\bar{h}$ production, Λ_h baryons

EIC: Energy, luminosity, detection





- CM energy $\sqrt{s_{eN}} \sim$ 20–100 GeV

  $Q^2 \sim$ few 10 GeV^2 for DIS

  $x \gtrsim 10^{-3}$: gluons, sea quarks

- Luminosity $\sim 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

  Rare processes, e.g. heavy quarks

  Multi-variable final states

  Polarization observables

- Proton and ion beams

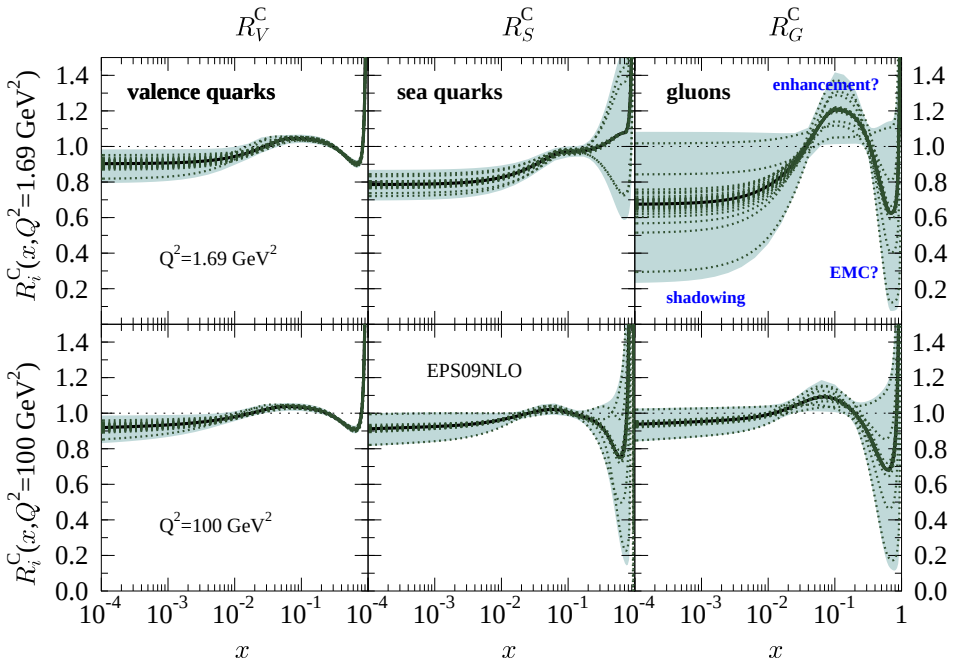
  Polarized proton, light ions

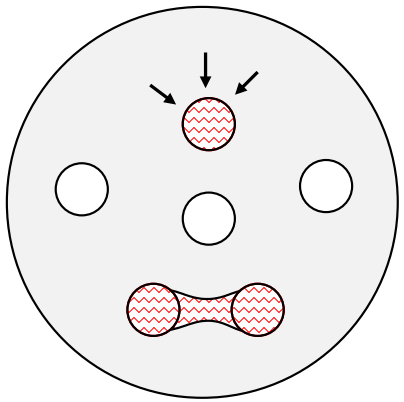
- Next-generation detector concepts

  Central: Tracking, particle ID

  Forward: Target fragments

Nuclear gluons: Physics





modified nucleon structure

pairwise NN interactions

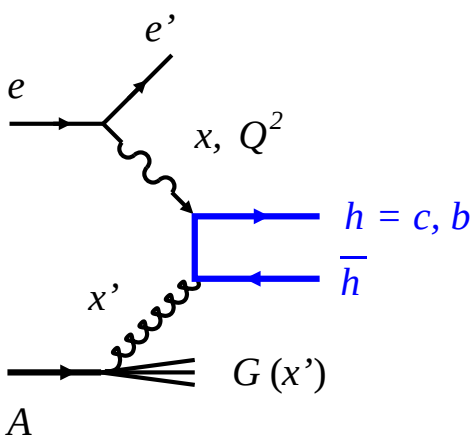
- Nucleon's partonic structure modified in nucleus
  Seen in inclusive DIS
- Gluons suppressed at $x > 0.3$? "Gluonic EMC effect"

  Modified nucleon structure?
- Gluons enhanced at $x \sim 0.1$? "Antishadowing"

  QCD structure of NN interaction?

  Strong gluon shadowing observed at $x < 0.01$ suggests compensating antishadowing at $x \sim 0.1$
  LHC ALICE J/ψ in ultraperipheral AA
- Limited information from Q^2 evolution. . . need direct probes!

Nuclear gluons: Heavy quark probes



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

  Excellent sensitivity to gluons even at $x' \gtrsim 0.1$

- Experimental identification of c, b through fragmentation into D, B mesons: Distinctive leptonic or hadronic decays (e.g. D^*), displaced vertex

- Observables: Differential cross section $d^4\sigma/dQ^2 d\eta d^2p_T$, inclusive F_{2c}

- Measured at HERA H1 & ZEUS in ep at $x < 0.01$: Extensive studies, various identification methods, comparison with QCD calculations
  Latest analysis: Aaron et al. 2011, Abramowicz et al. 2014

- Can we use it for eA at large x with EIC?
  New challenges, new tools!

EIC: R&D program

- Adapt simulation tools to eA at EIC: HVQDIS MC, F_{2c} codes

- Assess experimental conditions for heavy quark production at EIC

  Stage–1: Generic assumptions about HQ reconstruction

  Stage–2: Idealized simulations of HQ reconstruction including acceptance and background (PYTHIA)

  Stage–3: Realistic simulations including resolution from detector model

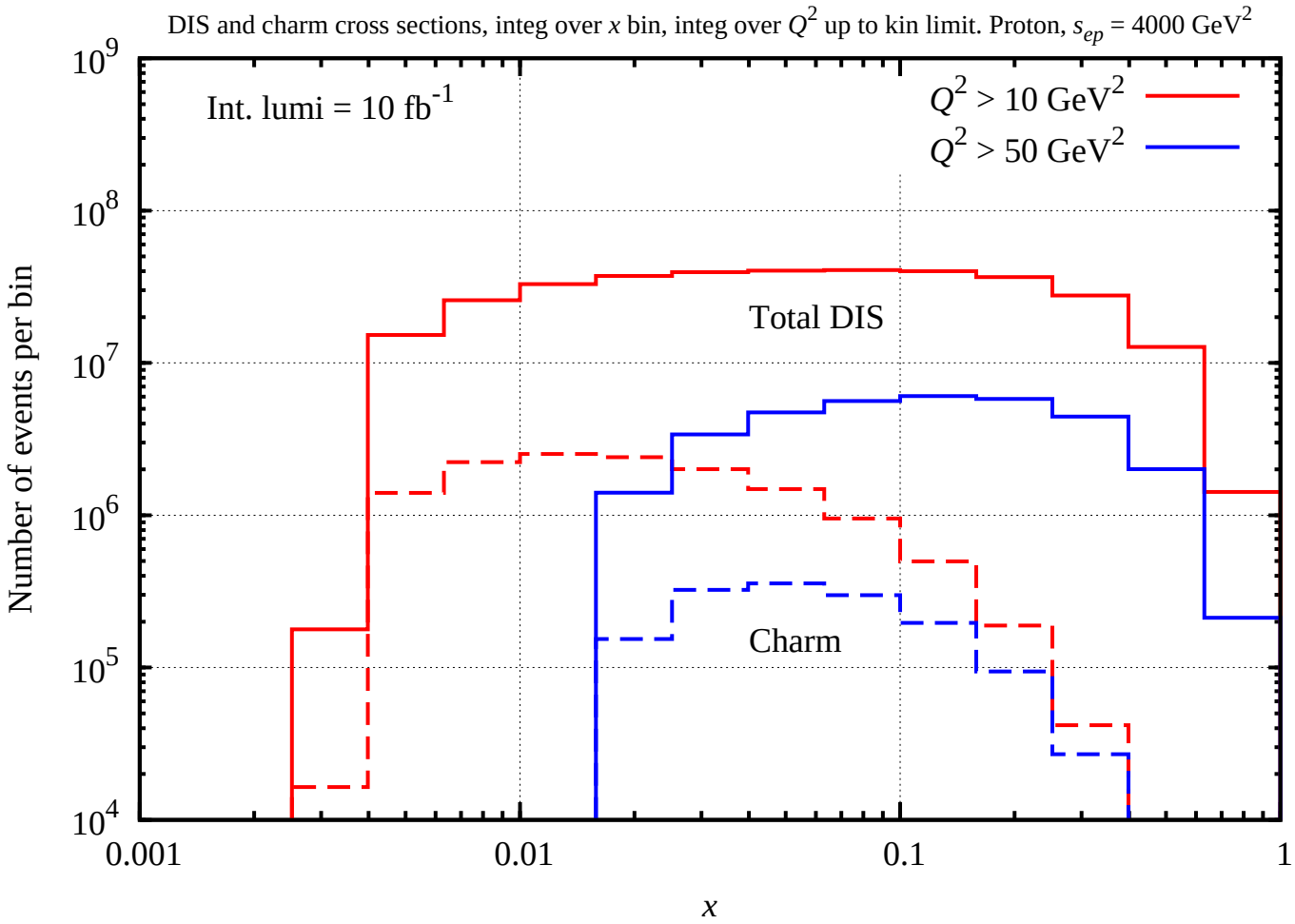
- Determine prospects for nuclear ratio measurements with EIC

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

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

LDRD Project LD1601 "Nuclear gluons with charm at EIC," https://wiki.jlab.org/nuclear_gluons/

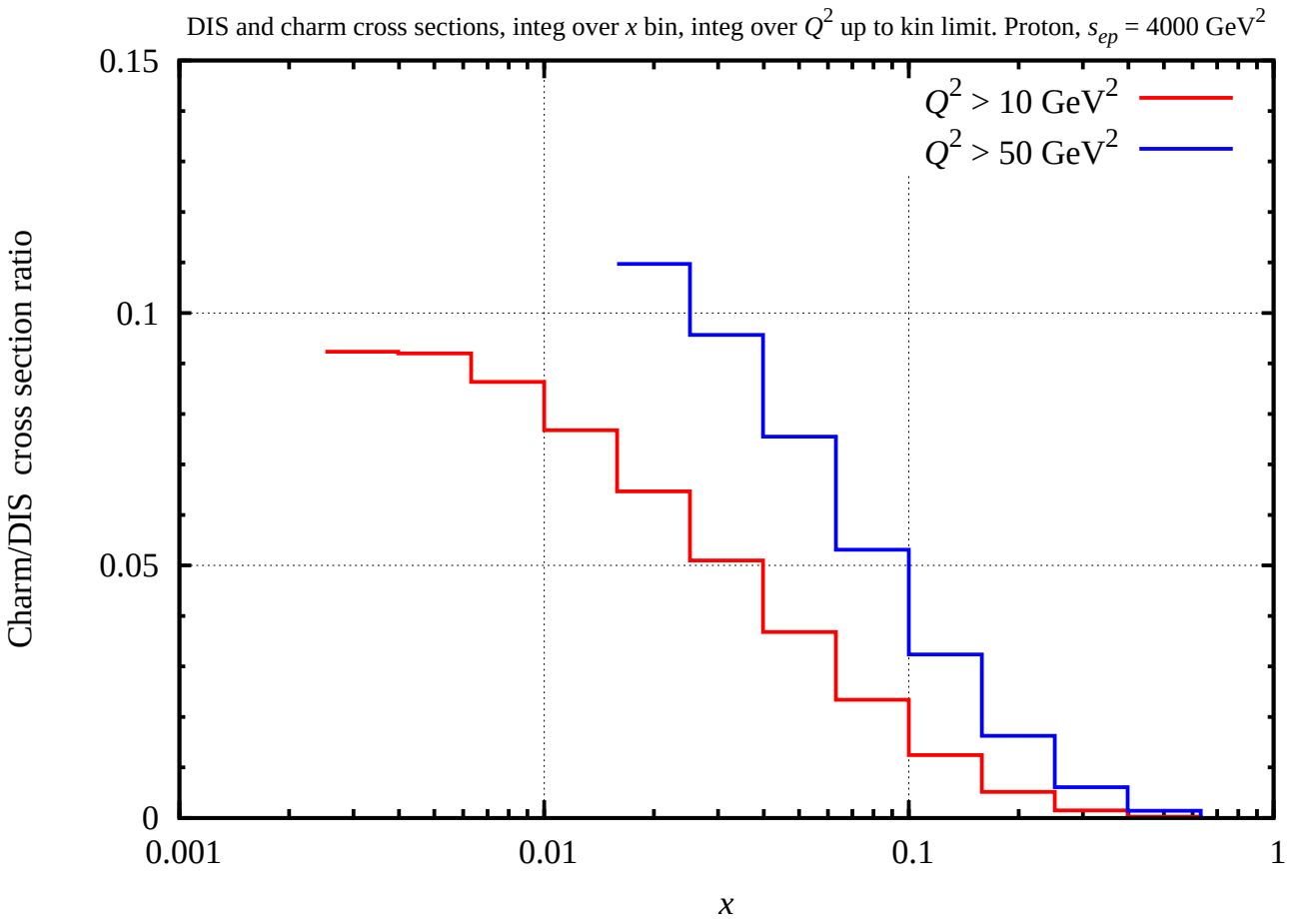
EIC: Charm and DIS rates



- Here 5 bins per decade in x, single bin in Q^2 (up to kinematic limit)
- Charm production rates drop rapidly at large x
- Charm production rates $\sim 10^5$ at $x \sim 0.1$ (integrated luminosity 10 fb^{-1})

- **Reasonable charm rates even at high x!**

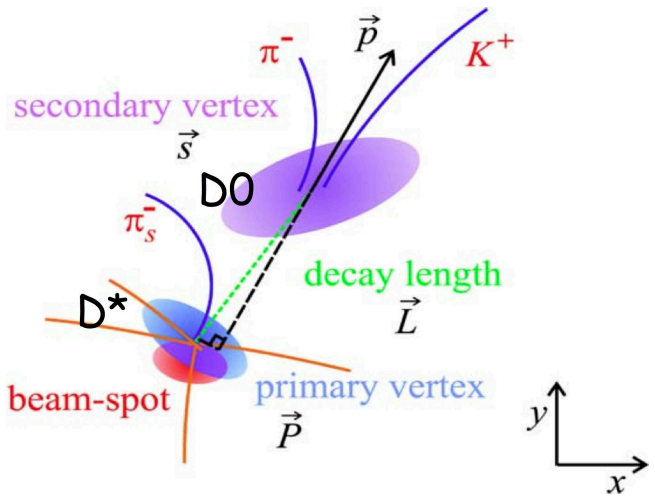
EIC: Charm to DIS ratio

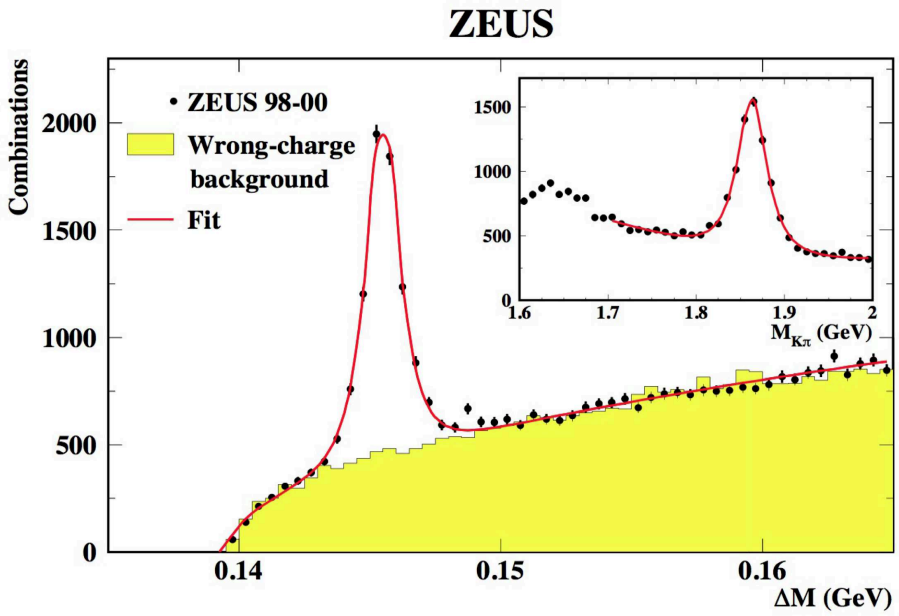


- Charm to DIS ratio at large x grows with Q^2
- Charm to DIS ratio $\sim 5\%$ at $x \sim 0.1$ for $Q^2 \sim$ several 10 GeV^2

- **High Q^2 improves charm/DIS ratio!**

EIC: Charm reconstruction with D^*

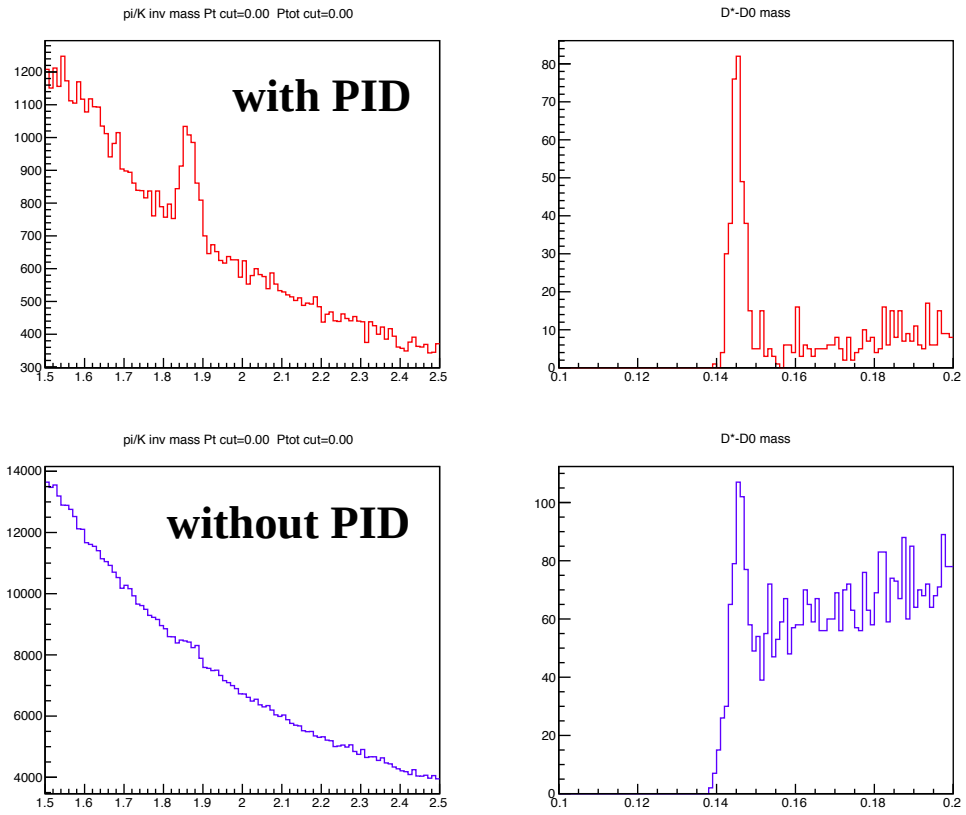




- Fragmentation $c \to D^*$ with probability ~20%
- Identified through decays $D^{*+} \to \pi^+(\text{slow}) + D^0$ and $D^0 \to K^- + \pi^+$
- Extensively used at HERA — does not require PID or vertex detection
- Overall efficiency $< 1\%$

- **Possible with EIC, but likely not sufficient at large x.**
  Explore other identification methods!

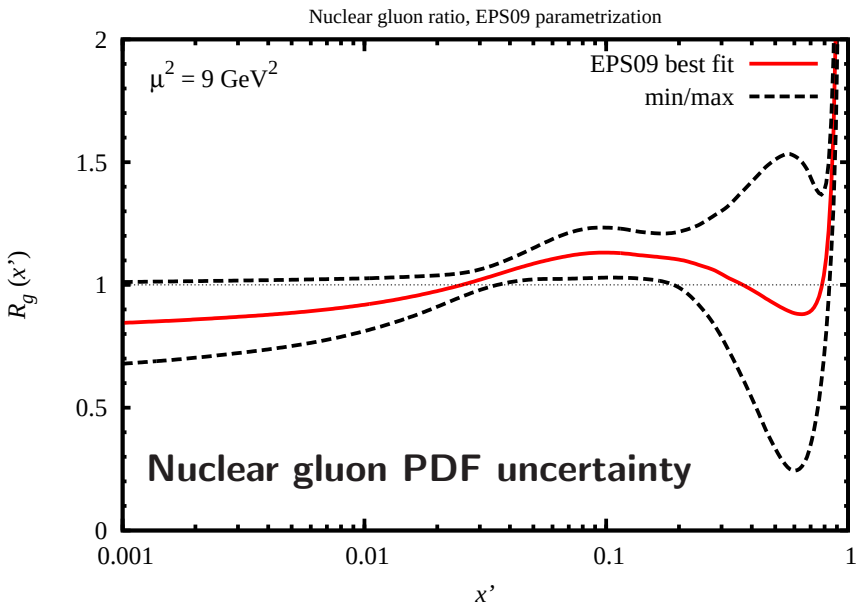
EIC: Charm reconstruction using PID

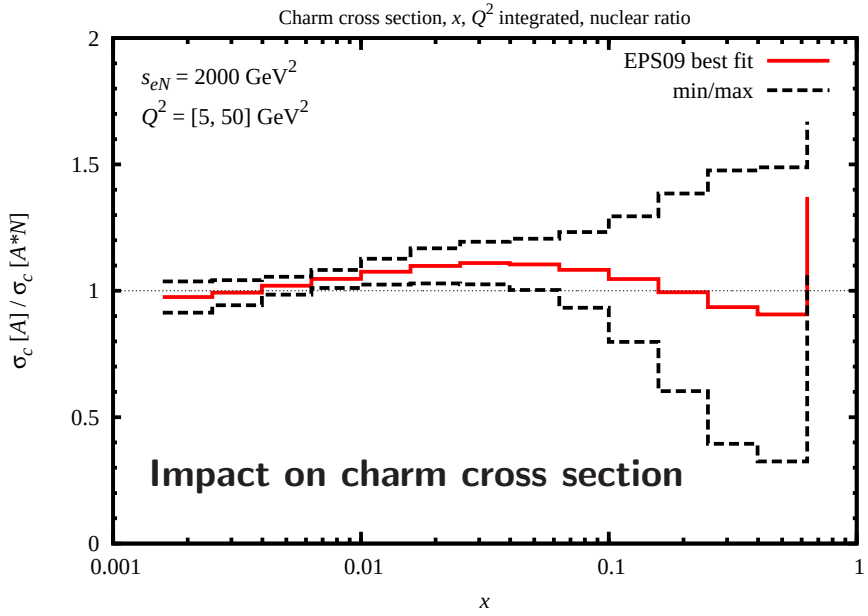


- Pion/kaon identification at EIC allows use of other $D \to K^{\pm}\pi^{\pm}$ decay channels
- Substantially reduces combinatorial background
  DIS bckground to be included
- Potential efficiency $\sim 10\%$
- Vertex detection can further improve signal/background, but reduces overall efficiency

- Simulations in progress
- **EIC enables new ways of charm reconstruction at large x!**

EIC: Sensitivity to nuclear gluons

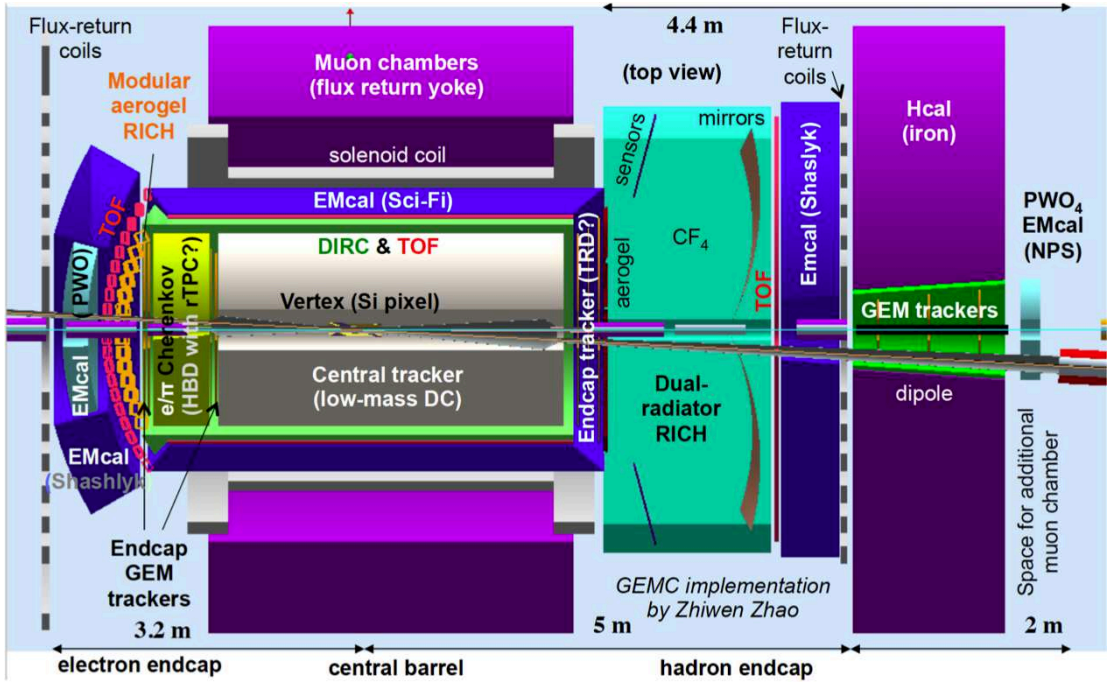




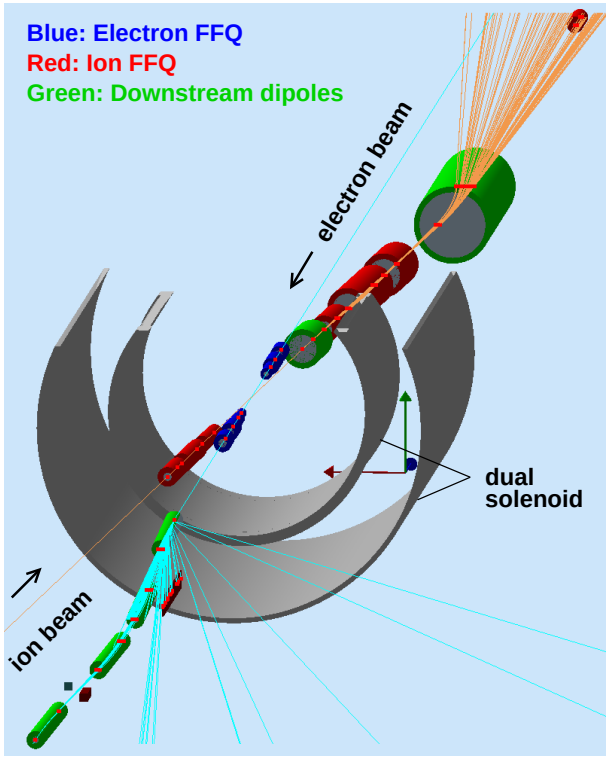
- Charm cross section at $x \sim 0.1$ shows good sensitivity to nuclear modification of gluon density at large x

- Measurement of σ(charm) with $\sim$10% accuracy would already reduce gluon uncertainty

JLEIC detector concept



JLEIC 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

- Energy ratio $E_e/E_p \sim$ 5–10 places large–x $c\bar{c}$ jets in central detector

Information on machine & detector design: `https://eic.jlab.org/wiki/`

More heavy-quark physics with EIC

- Exclusive production of heavy quarkonia $\gamma^{(*)} + p \to J/\psi + p$

  Measures transverse spatial distribution of gluons in proton:
  Generalized parton distribution (GPD)

  Quantifies color transparency of nuclear targets

- Heavy baryons in target fragmentation region $\gamma^{(*)} + p \to D + \Lambda_c + X$

  Limiting case of open charm production

  Structure and decays of charmed baryons

  Can be measured with JLEIC forward detectors

- Heavy meson spectroscopy

  Photo/electroproduction of XYZ states

  Quantum numbers CP

Summary

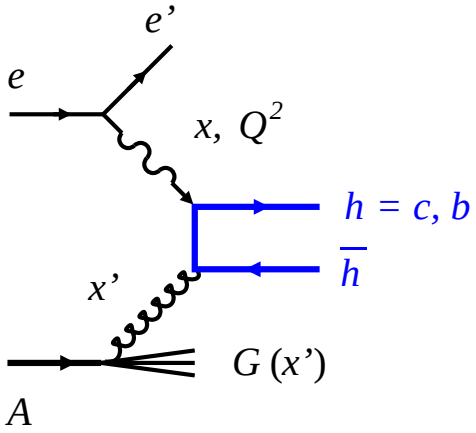
- Nuclear modification of large–x gluons reveals QCD origin of NN interactions
- Prospect of direct measurements of nuclear gluons using heavy quarks at EIC
- New methods of charm reconstruction using π/K ID promise efficiency $\sim$10%
- Luminosity $\sim 10^{34}$ cm^{-2} s^{-1} essential
- Other interesting heavy-quark physics with EIC

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

Sensitivity to gluon density

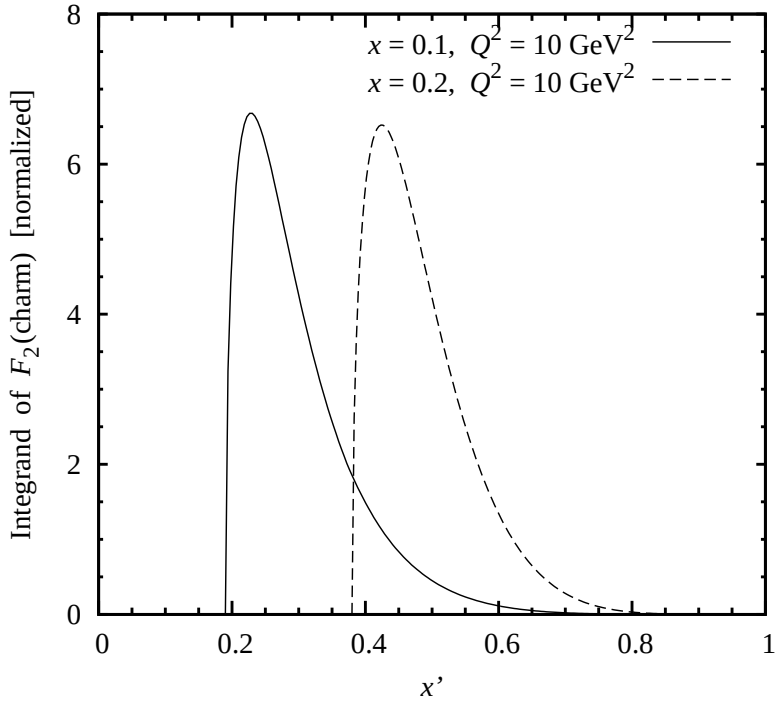


$$F_2^h(x,Q^2) \;=\; \int_{ax}^1 \frac{dx'}{x'}\, x'G(x')\; \hat{F}_g^h(x/x',\, Q^2,\, m_h^2,\, \mu^2)$$

coefficient function

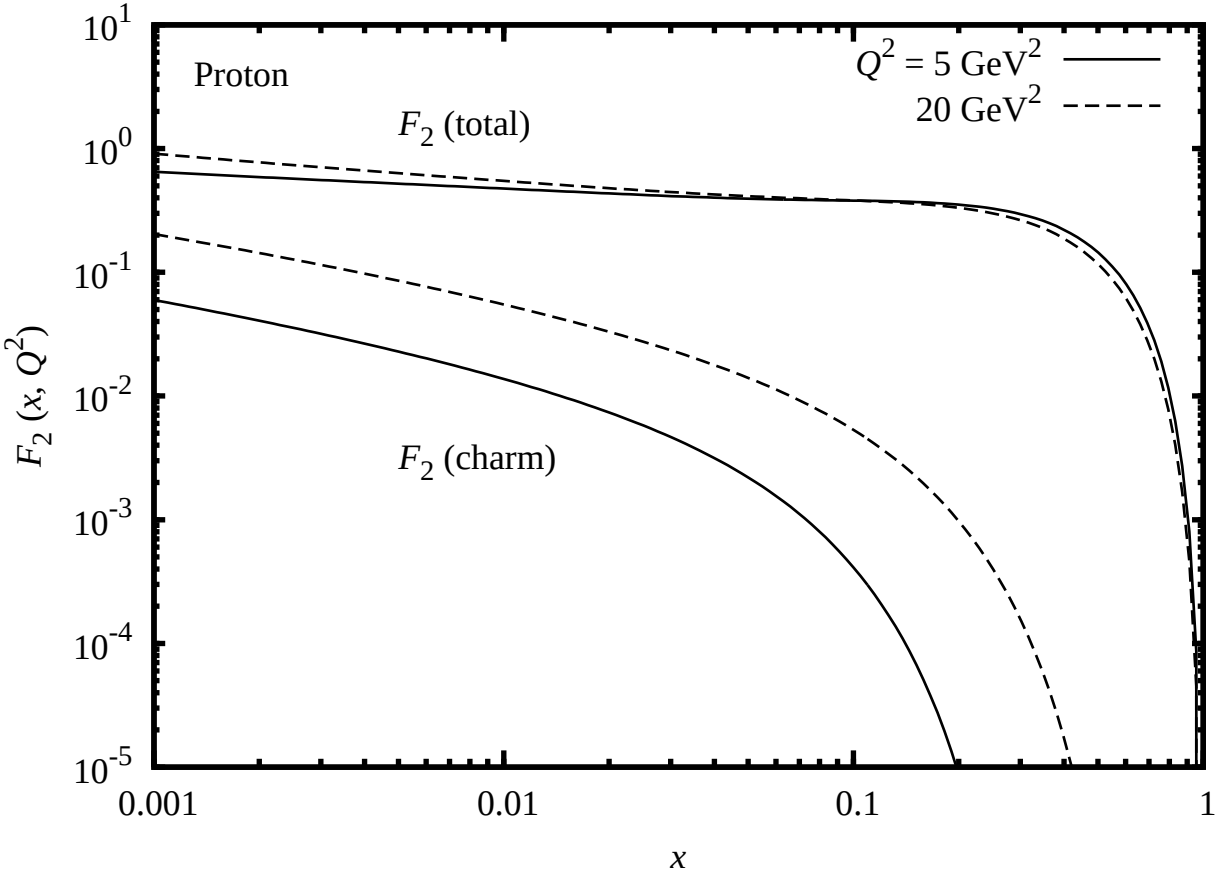
$$a \;=\; 1+\frac{4m_h^2}{Q^2}$$

sets limit of x' integral



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

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