Exploring nuclear interactions with DIS at mid-x

Jefferson Lab

Nuclear modifications of partonic structure $\leftrightarrow$ nucleon interactions in QCD

"Large" $x \gtrsim 0.3$ short distance interactions, SRCs

"Intermediate" $x \sim 0.1$ average distance interactions, nuclear mesons $\rightarrow$ *Physics narrative*

Nuclear DIS measurements at $x \sim 0.1$ and impact

Inclusive DIS, semi-inclusive DIS, heavy flavor production

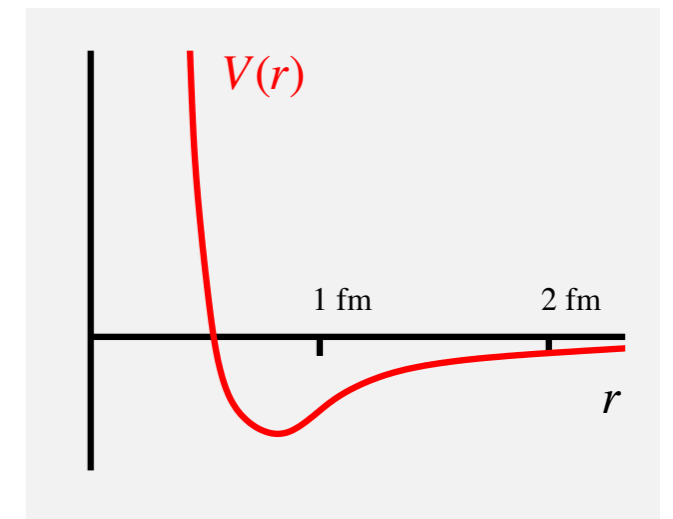EIC and/or fixed-target 24 GeV $\rightarrow$ *Experimental program*

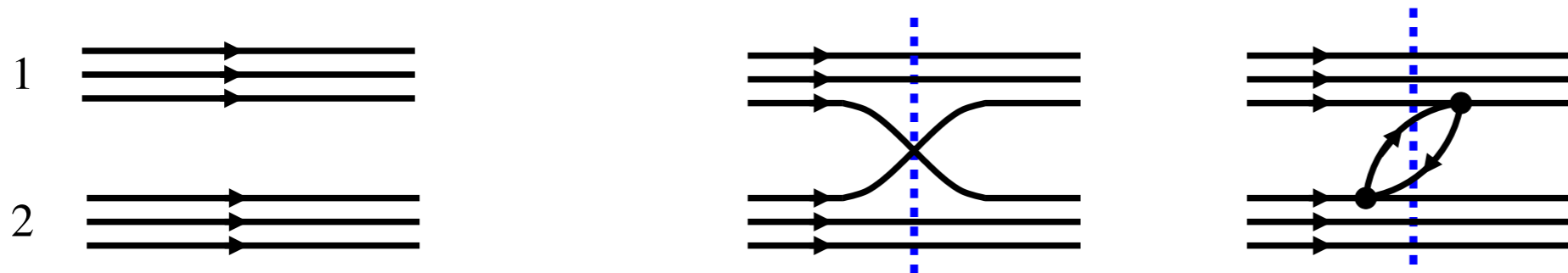Interactions involve non-nucleonic degrees of freedom: QM + relativity

Low-energy nuclear structure and reactions ($k \sim$ few 10 MeV) does not resolve intermediate states: NN potential, EFT contact interactions

High-energy processes can resolve intermediate states: "Origin" of interactions

$$|N\rangle = \sum_{\text{configs}} |qqq \ldots q\bar{q} \ldots g \ldots\rangle \quad \text{coherent superposition}$$

$$|N_1 N_2\rangle = (\ldots)_1 (\ldots)_2 + \text{other configs}$$

NN interactions change superposition of quark/gluon configurations
compared to free nucleons ($\leftrightarrow$ non-nucleonic DoF)

High-energy short-distance process on nuclei (DIS etc.)
can give insight into QCD origin of NN interactions
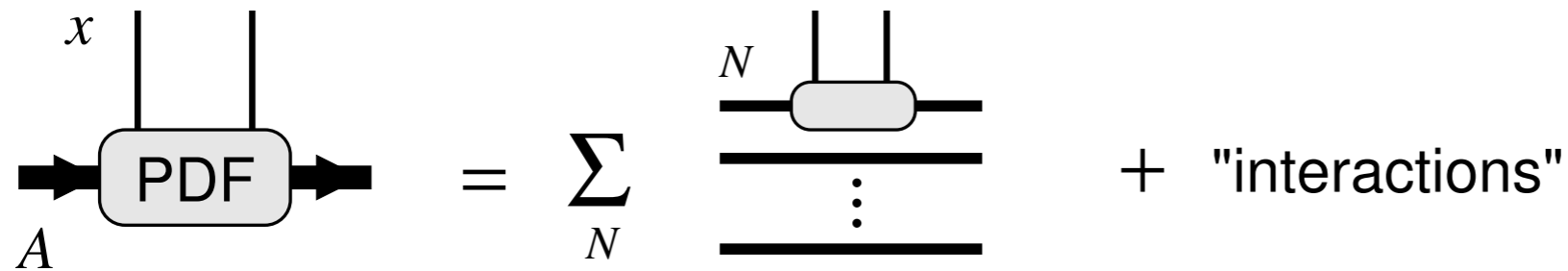
DIS on nucleus: QCD factorization, measures nuclear PDF $\langle A | \hat{\mathcal{O}}_{\text{QCD}}(\mu^2) | A \rangle$

Compare nuclear PDF with sum of nucleons $\times$ Fermi motion $\to$ interactions

Systematic organization using EFT methods: 1-nucleon, 2-nucleon operators

Physical questions

- What are the modifications of quarks/antiquarks/gluons at different x?

- What are the relevant distances in the nucleon interactions?

- What are the relevant non-nucleonic configurations/states?

  Different interactions & configurations are at work at different x

Eskola, Paakkinen, Paukkunen, Salgado 2022
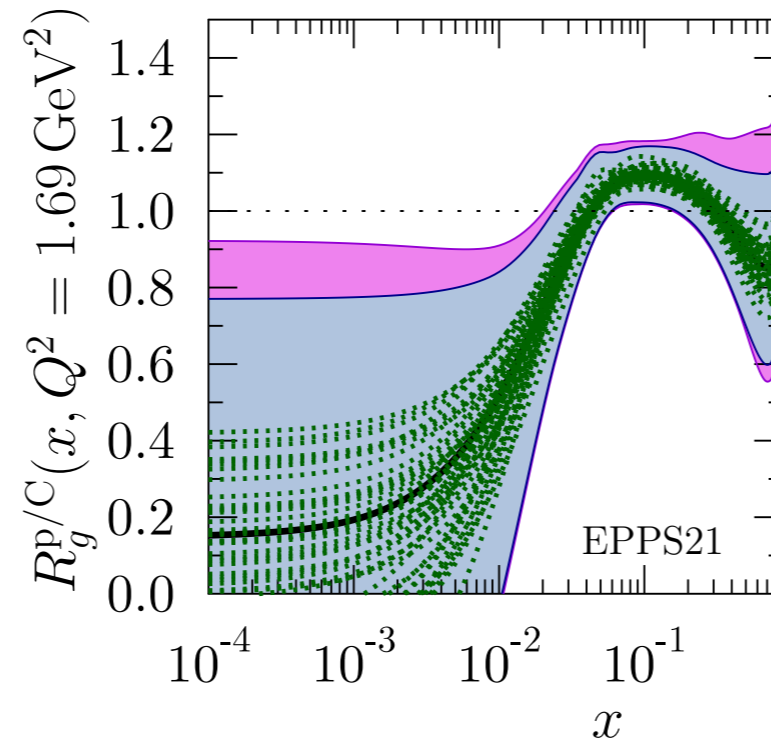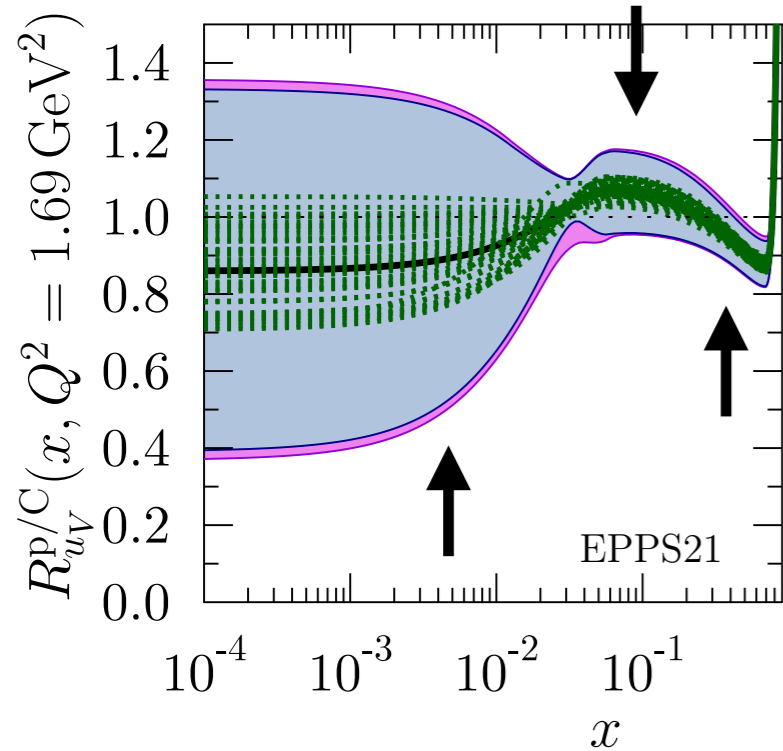
[→Talk Olness]

Basic properties still unknown: Isospin, spin depende...
Gluons? Momenta/distances of interacting configs?

Dedicated experiments at JLab12 and EIC: Mirror nuc...
polarization, gluons with heavy flavor production, tag...
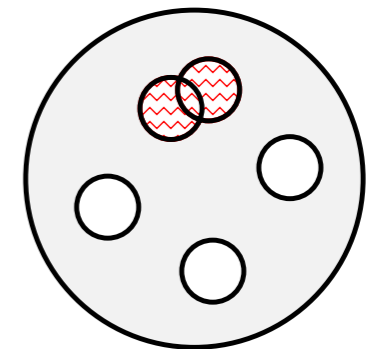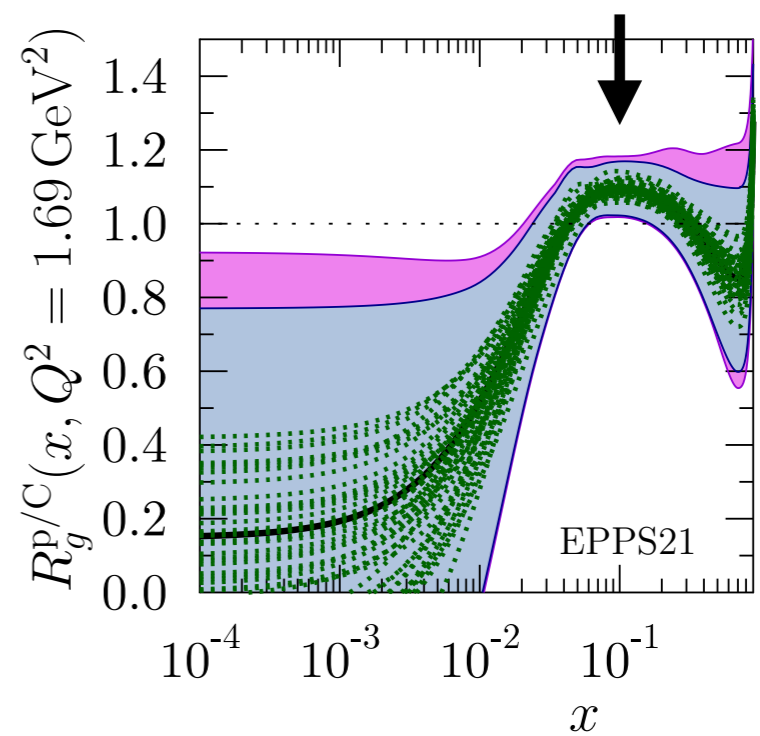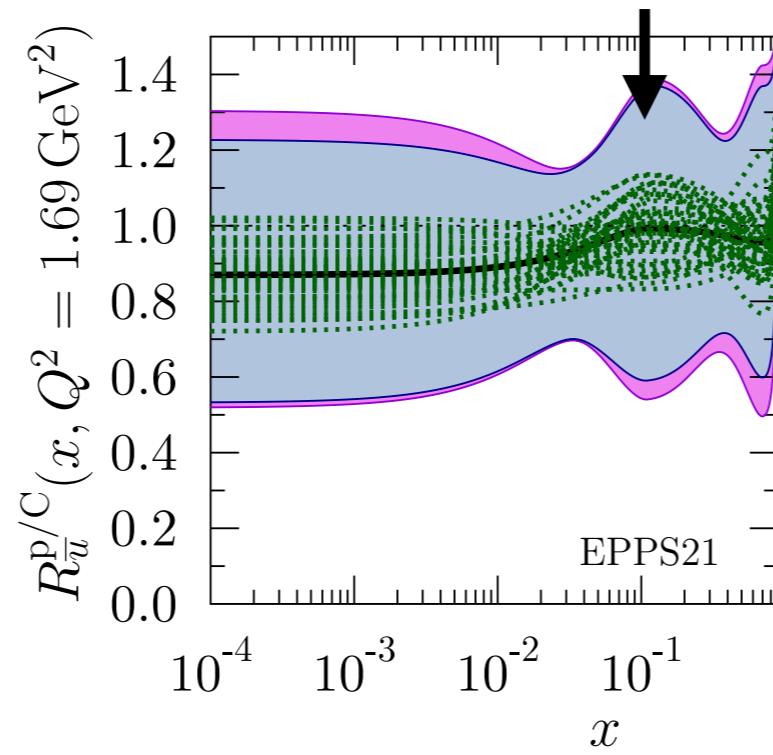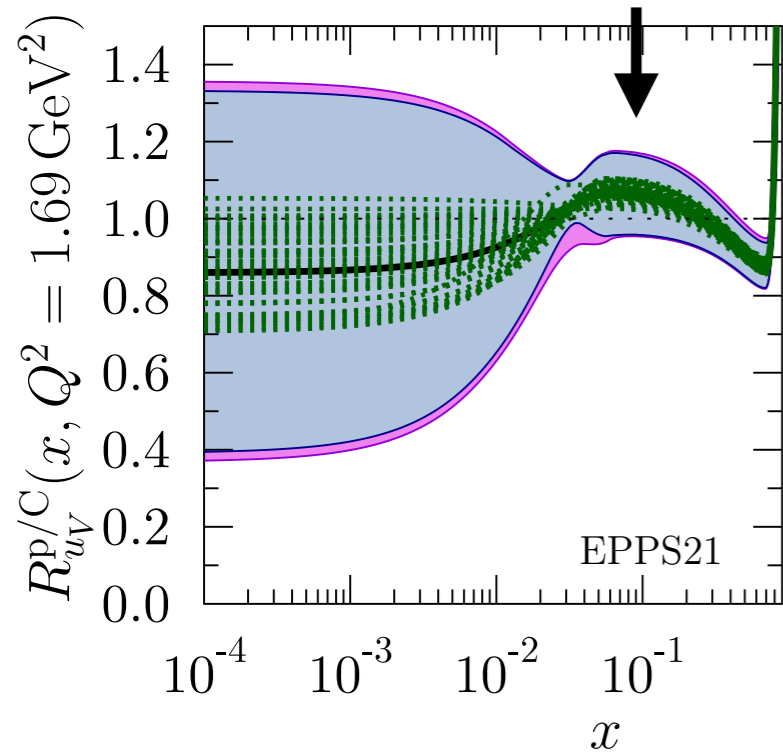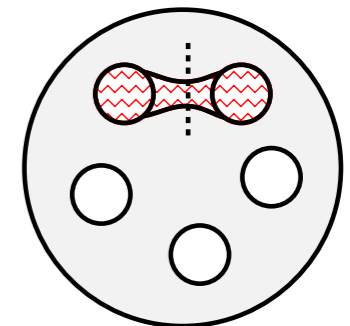
Gluon enhancement? Gluon shadowing at $x \ll 0.1$ ...
compensating antishadowing for momentum sum ru...
Large gluon shadowing observed in ultraperipheral AA collisions at...

NMC 1995

F_2^A/F_2^D vs x, panels labeled C/D and Ca/D
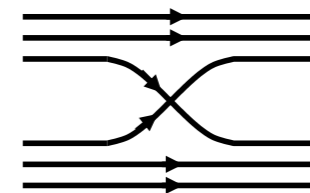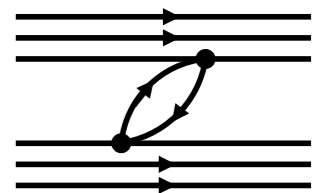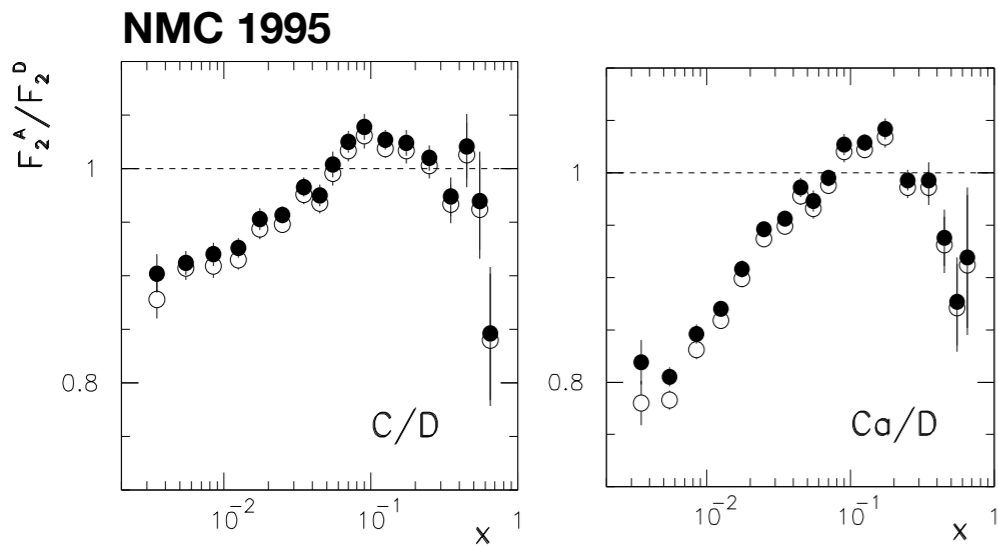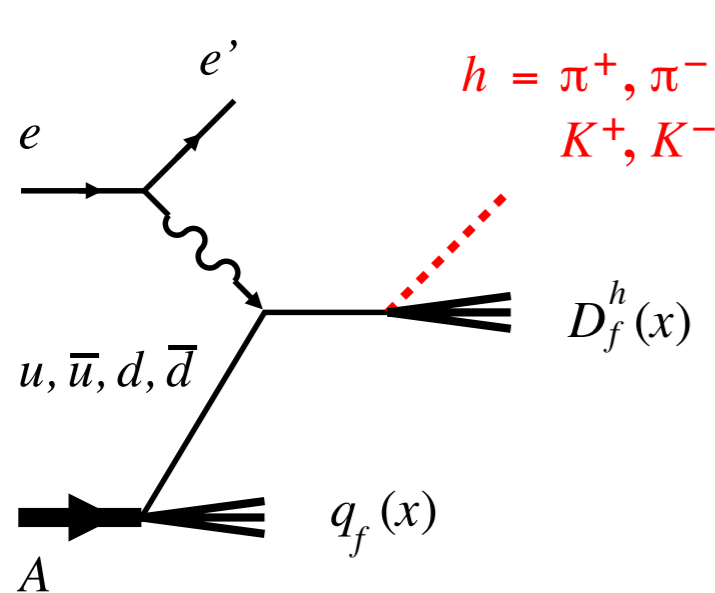
Inclusive DIS

Measured in μA EMC/NMC, eA SLAC, νA CHORUS

Nuclear modification $\lesssim 5\%$ at $x \sim 0.1$ [→Talk Niculescu]

Limited motivation for re-measuring

Semi-inclusive DIS

Could separate $q \leftrightarrow \bar{q}$, constrain nuclear sea

Need good control of $q \to \pi, K$ fragmentation process and nuclear final-state interactions

EIC: Large phase space for fragmentation $W \sim$ 10-100 GeV, strategies for controlling/estimating nuclear FSI

Fixed-target 24 GeV: Limited phase space, fragmentation poorly understood (esp. unfavored), nuclear FSI present HERMES results + experience [→Talk Kinney]

Could perhaps reduce uncertainties in $\bar{u}, \bar{d}$ PDFs. Impact on NN interaction would require accuracy $< 5\%$ percent… unlikely to be achieved
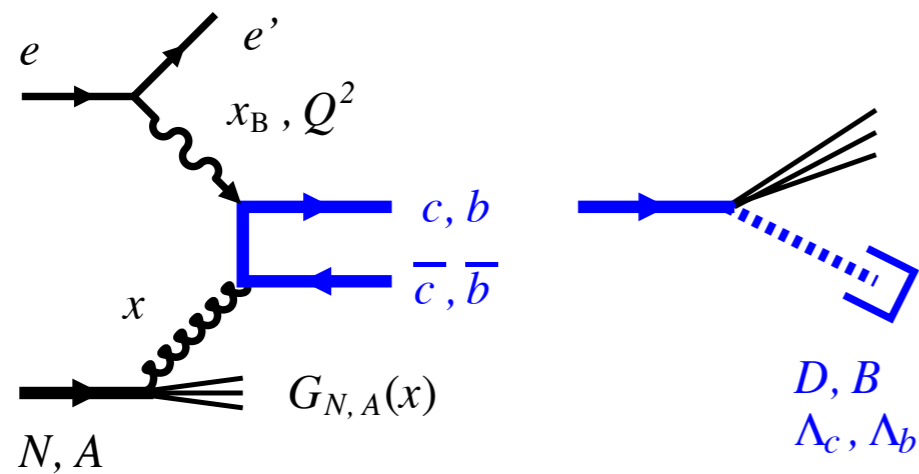
A. Casas, N. Sato, C. Weiss, from EIC pseudodata
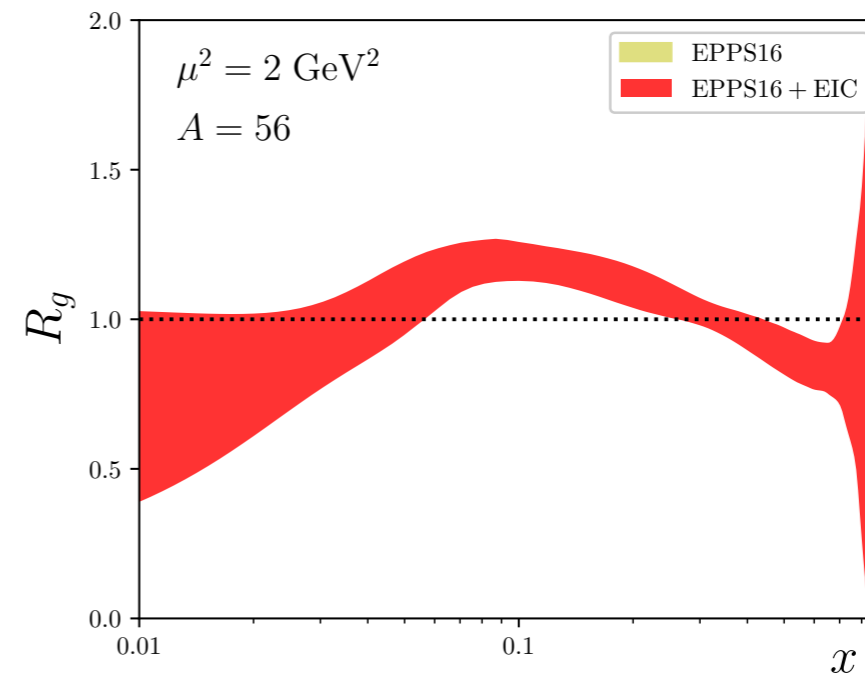
Open heavy flavor production

Direct probe of nuclear gluons, good theoretical control

EIC: Physics & detector simulations [JLab LDRD 2016/17 Weiss et al]
High charm production rates & reconstruction efficiency
Impact on nuclear gluons at $x \sim 0.1$

[Furletova, Sato, Weiss; 2020 INT Report, arXiv:2002.12333; Aschenauer et al. PRD 96 114005 (2017)]

Fixed-target 24 GeV: Above $D\bar{D}$ threshold, but fragmentation effects and hadronic FSI significant
Needs theoretical modeling

- QCD origin of nucleon interactions as unifying physics perspective

  Large x short distance interactions, SRCs

  Intermediate x average distance interactions, nuclear mesons

- Overall nuclear modfication at $x \sim 0.1$ is $\lesssim 5\,\%$.
  Physics impact requires $q \leftrightarrow \bar{q}$ and gluon determination with comparable accuracy

- EIC: $q \to \bar{q}$ from SIDIS, g from heavy flavor production.
  Impact on nuclear interactions expected

- Fixed-target 24 GeV: Non-inclusive measurements limited by phase space — fragmentation, nuclear final state interactions. Impact on nuclear interactions unlikely

[• Open questions in nuclear structure at large x that could/should be answered with 24 GeV:
  Q^2 dependence of EMC effect — leading vs. higher twist
  Scaling and power corrections in $x > 1$ structure functions, plateaus in ratios
  Can only be answered with high-intensity fixed-target experiments!]