Probing nuclear gluons with heavy flavors at an Electron-Ion Collider

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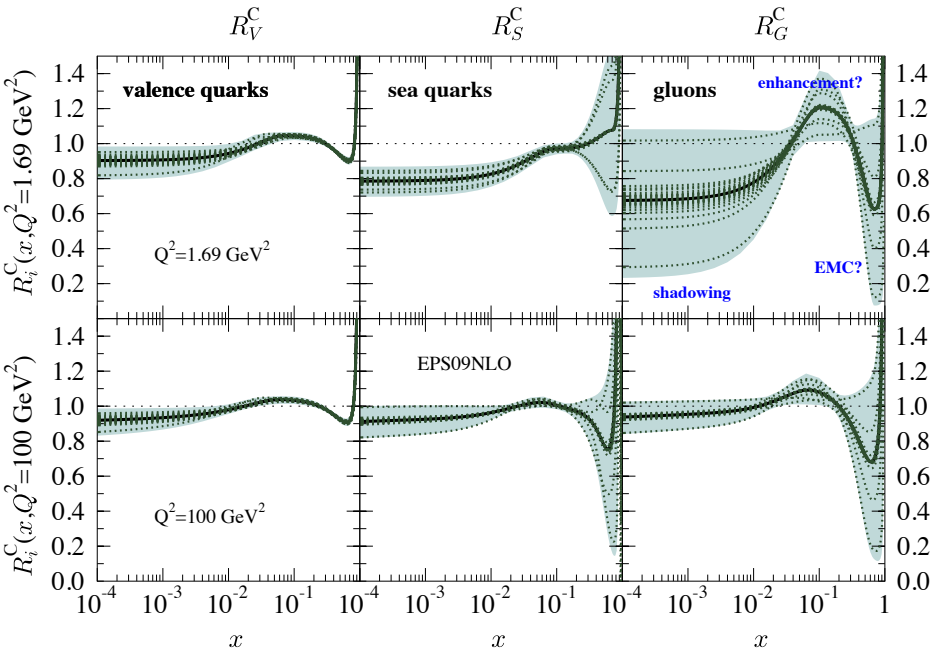
AIM: Study feasibility of direct measurements of nuclear gluons at $x \gtrsim 0.1$ using heavy quark probes with a future Electron-Ion Collider

OUTLINE

- Nuclear modification of gluons
- Open charm/beauty as direct probe
- Simulation tools and methods
- EIC simulation results

Nuclear modification of gluons



Nuclear PDF parametrization EPS09 Eskola et al. 2009

- Nucleon's partonic structure is modified in nucleus

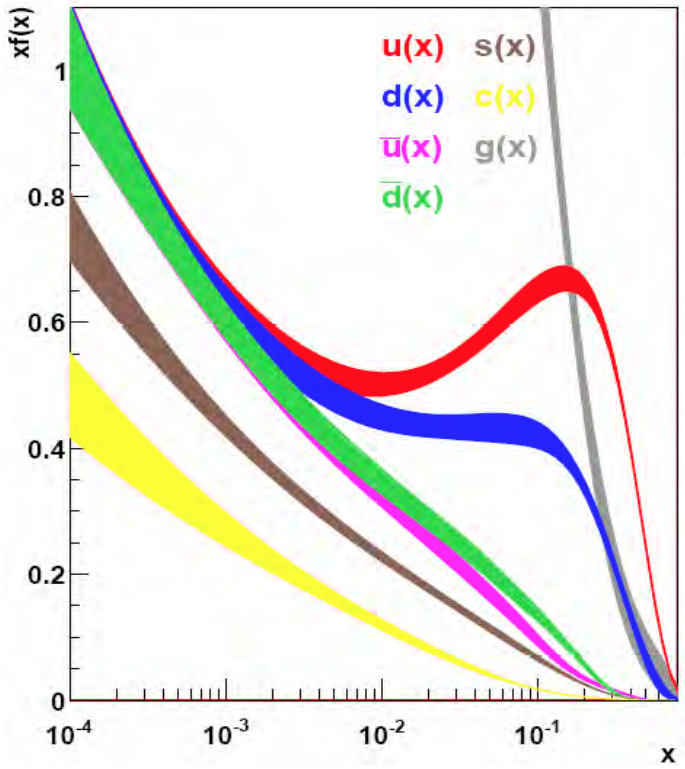
- Open questions concerning gluons:

1. Is the nuclear gluon density suppressed at $x > 0.3$ (EMC effect) ?

2. Are gluons enhanced at $x \sim 0.1$ (antishadowing) ?

- Strong gluon shadowing at $x < 0.01$ observed in the LHC Alice AA data suggests compensating antishadowing at $x \sim 0.1$

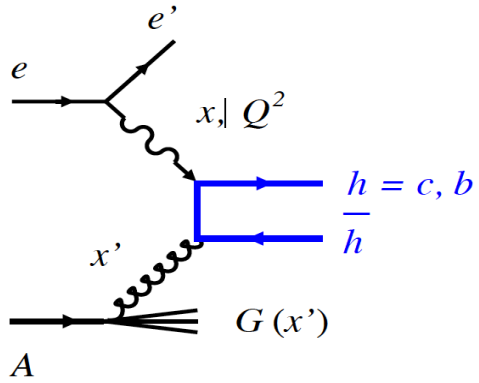
Nuclear gluons: Why large x



CTEQ6 nucleon PDF parametrization

- ~50% of gluon momentum sum rule from region $x > 0.1$
- $g(x) \approx d(x)$ quarks at $x \geq 0.3$ within errors
- Physics interest: NN interactions, non-nucleonic degrees of freedom

Open charm/beauty as direct probe



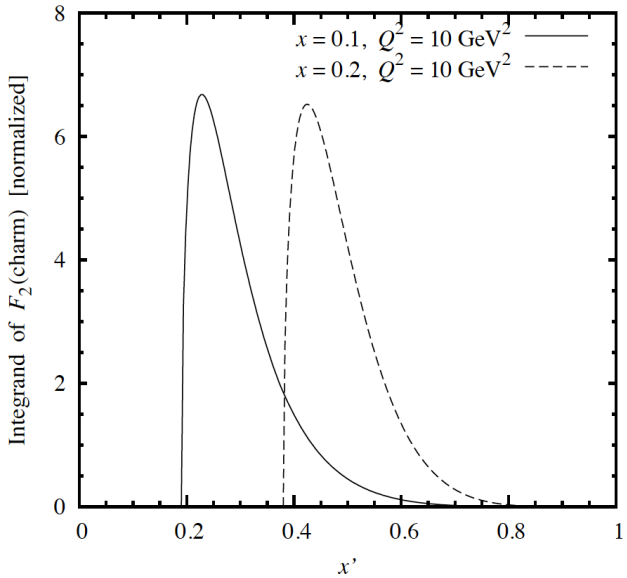
Boson (photon) Gluon Fusion (BGF)

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

coefficient function

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

sets limit of x' integral

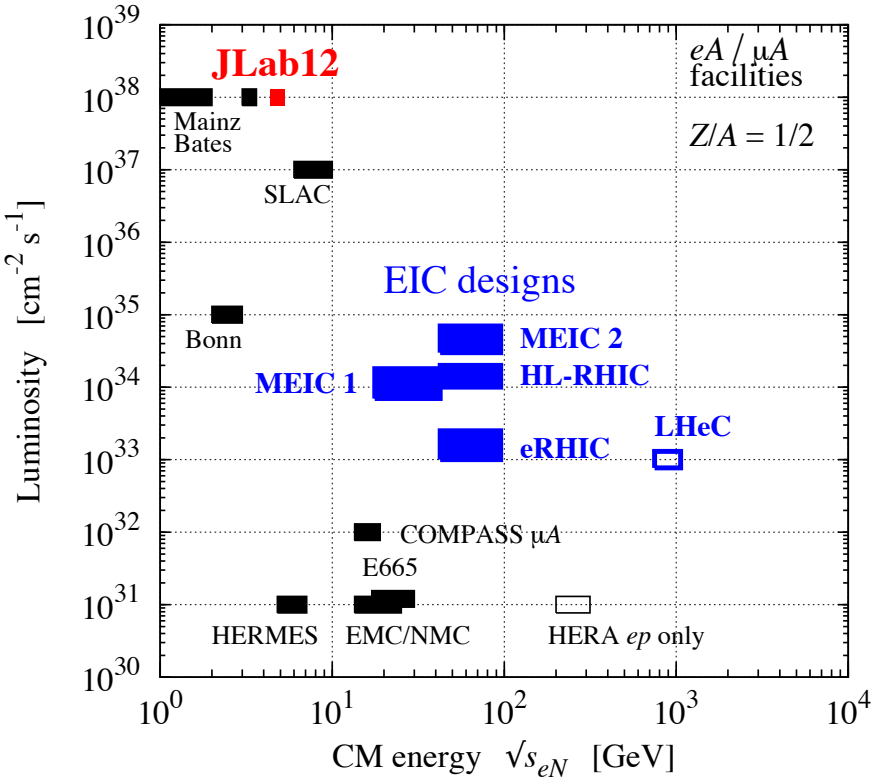


- Heavy quark production probes large-x′ gluons "almost locally" at x′ > x

- NLO corrections calculated, theory uncertainties quantified

Laenen, Riemersma, Smith, Van Neerven 93+, Kawamura et al. 12, Alekhin, Moch et al. 93+

Electron-Ion Collider (EIC)



eA/μA facilities, luminosity vs CM energy

- CM energy 20-70 GeV (eN) ideal for DIS at x = 0.01-0.1
- Luminosity ~10^34 /cm^2/s (~1000 times HERA!) for study of low-rate processes
- Wide range of nuclear beams (A = 2-208), including polarized light nuclei
- Next-generation detector concepts: Central (tracking, PID), forward

Nuclear gluons with HQ at EIC: R&D

JLab 2016/17 LDRD Project LD1601

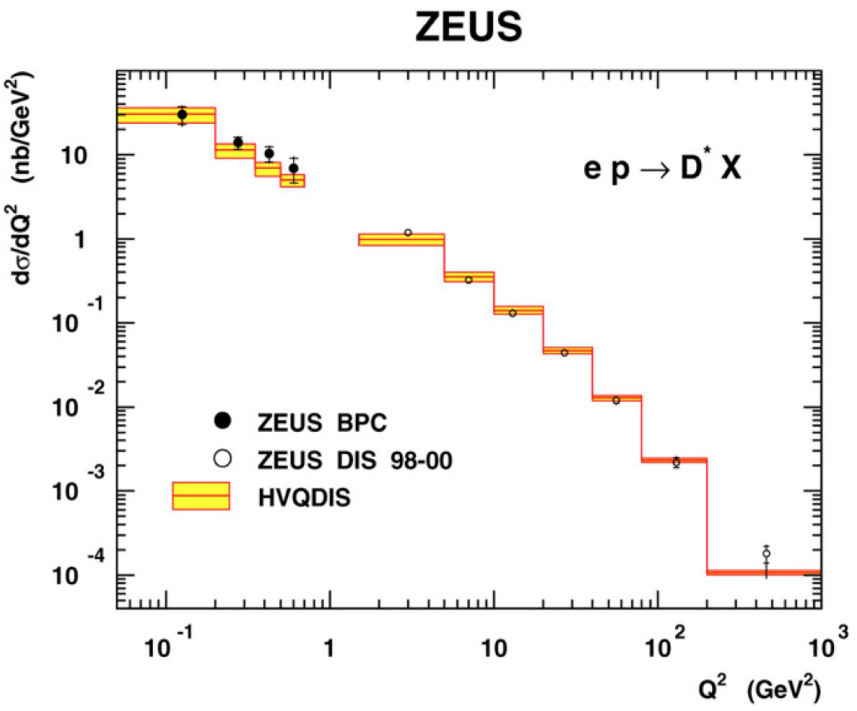
- Adapt HQ simulation tools (HVQDIS, F2c) to eN at EIC
- Assess experimental conditions for open charm/beauty production in eN at EIC, using different reconstruction methods

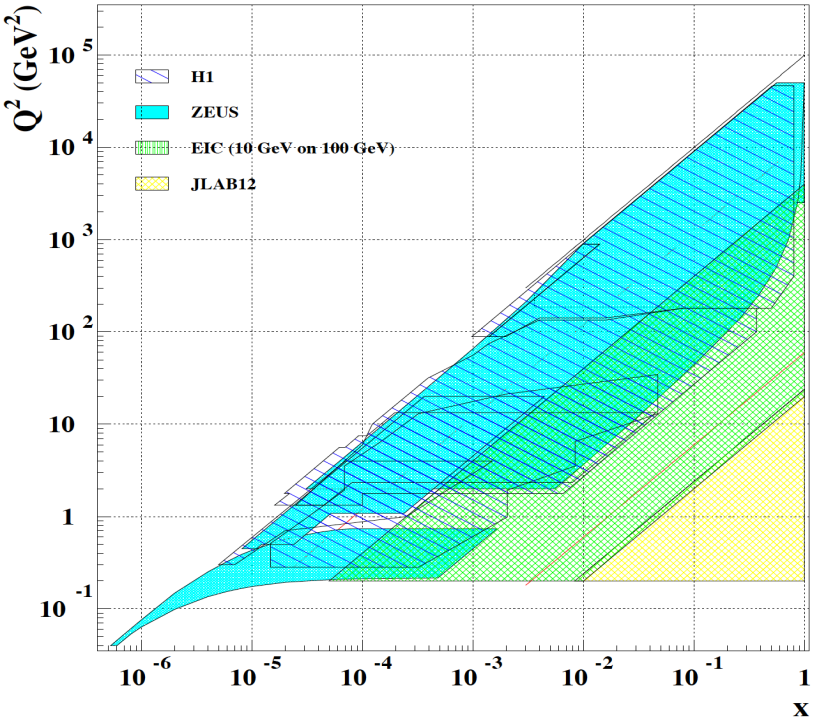
  Stage 1: Generic assumptions about HQ reconstruction
  Stage 2: Idealized simulations of HQ reconstruction with PYTHIA, including acceptance, background
  Stage 3: Realistic simulations including resolution from detector specs

- Simulate nuclear ratio measurements: Stat/sys errors, impact on nuclear PDFs

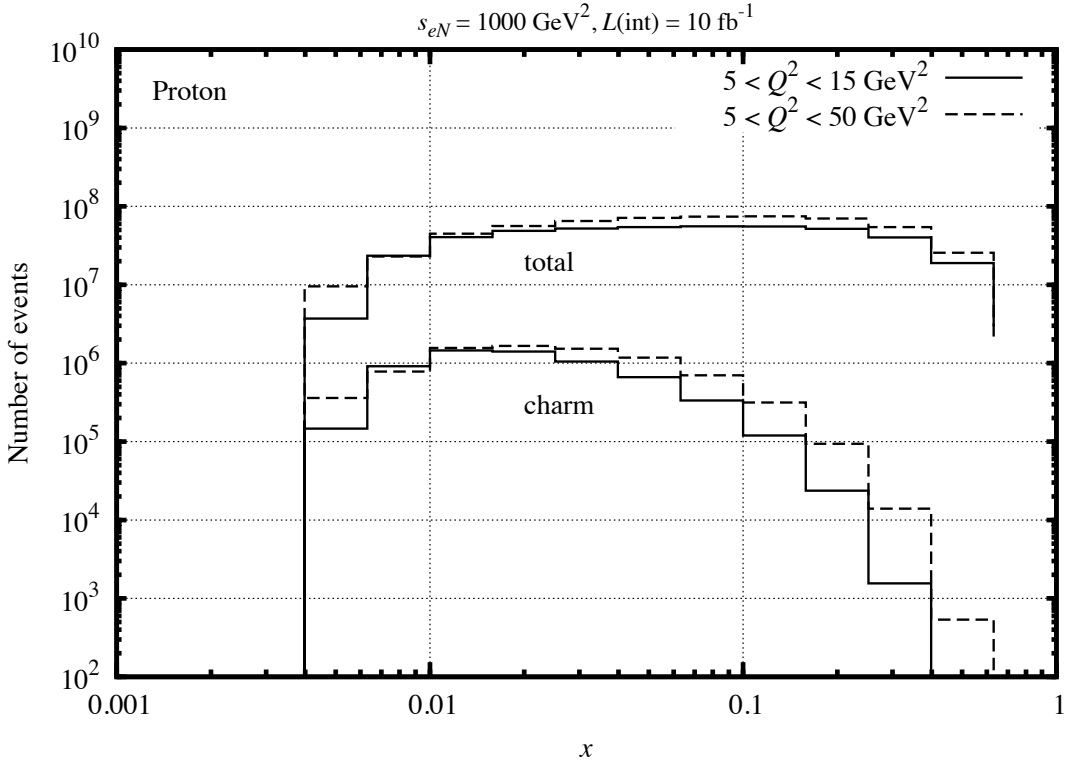
Simulation tools: HVQDIS

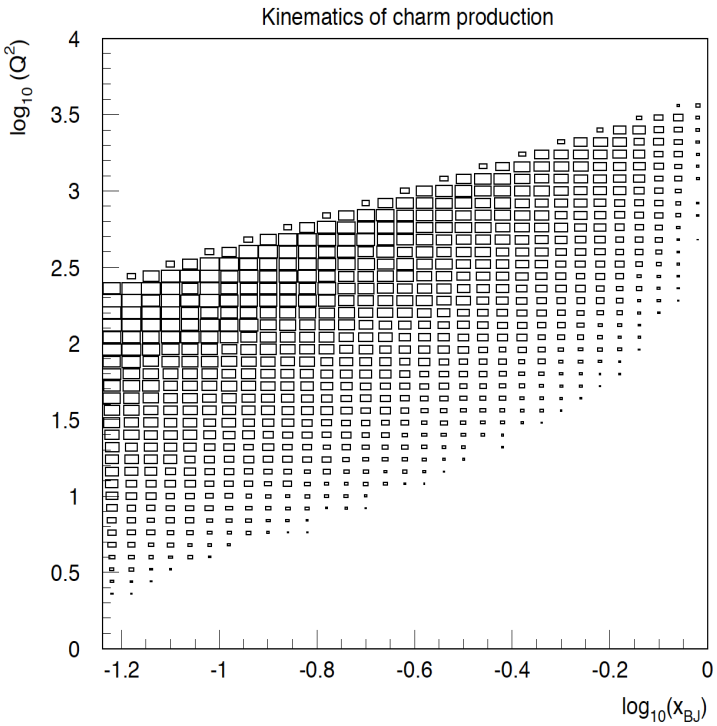
- NLO QCD describes HERA data over wide range in Q2
- HVQDIS and F2c codes can be used for EIC simulations





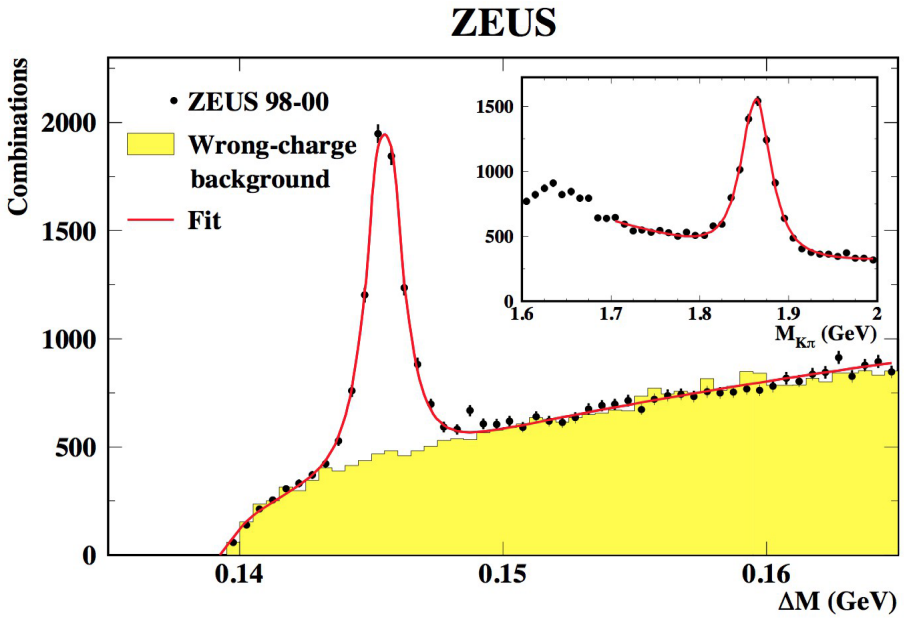
Open charm rates at EIC



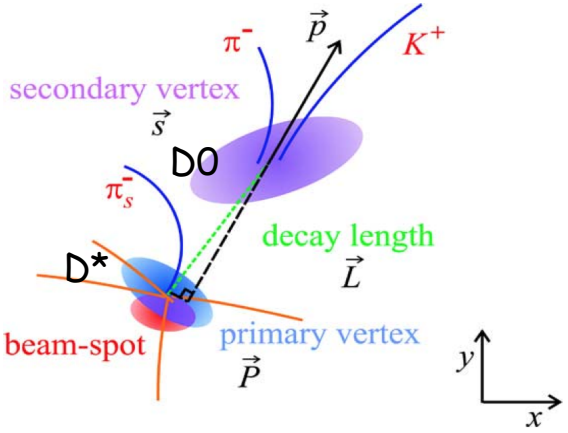


- Charm rates drop rapidly at x > 0.1
- Charm/background ratio largest at high Q2 — favorable
- Aim for overall charm reconstruction efficiency of ~few% — challenge!

Charm reconstruction: D*



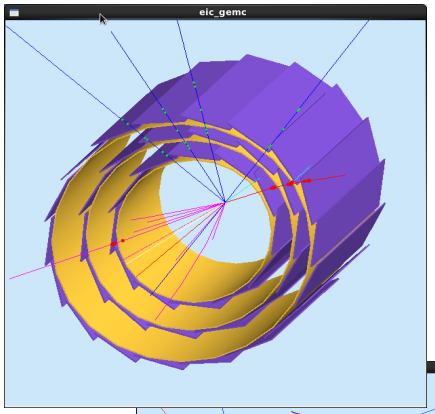
$D^{*+} \rightarrow D^o \pi_s^+ \ , \ D^o \rightarrow K^- \pi^+$



- Fragmentation c -> D* with probability ~20%
- D* identified through decays D*+ -> π+(slow) + D0 (68%) and D0 -> K- + π+ (4%)
- Extensively used at HERA; does not require vertex detection
- Overall efficiency ~< 1%

EIC can add other reconstruction methods: Vertex detection!

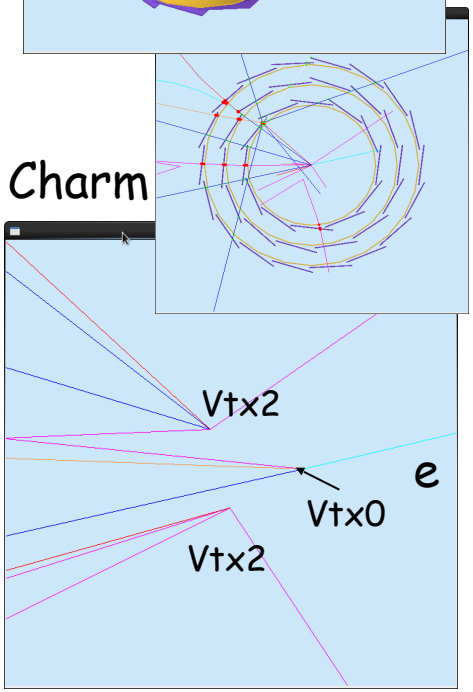
Charm reconstruction: Vertex detector

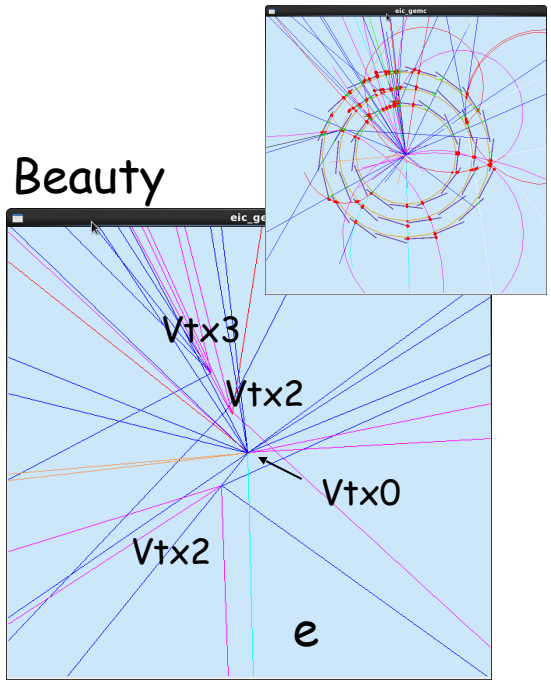


- Need vertex cut and good PID to reduce combinatorial background
- Increase overall reconstruction efficiency to ~few percent

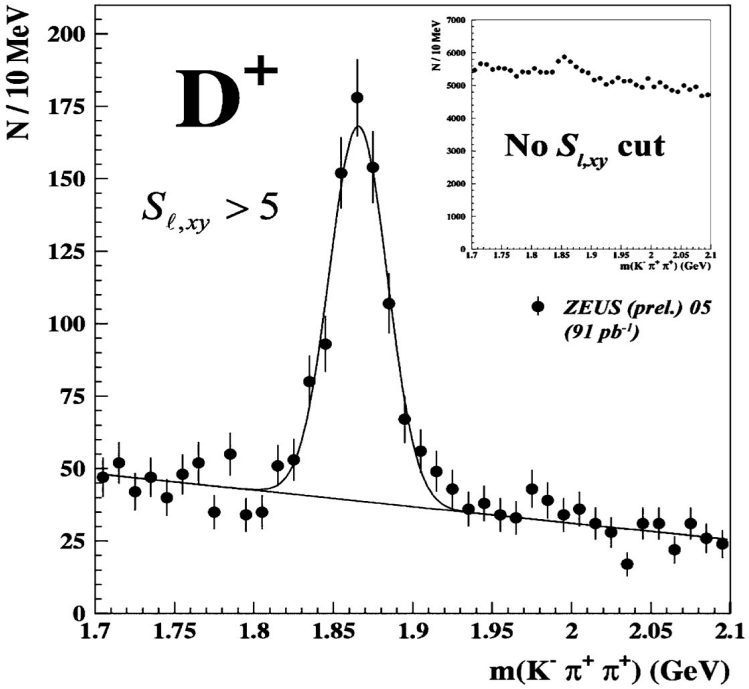
c-> D+ ->K-π+π+

c-> D^+ (20%)
D^+ ->K-π+ π+ (9.13%)



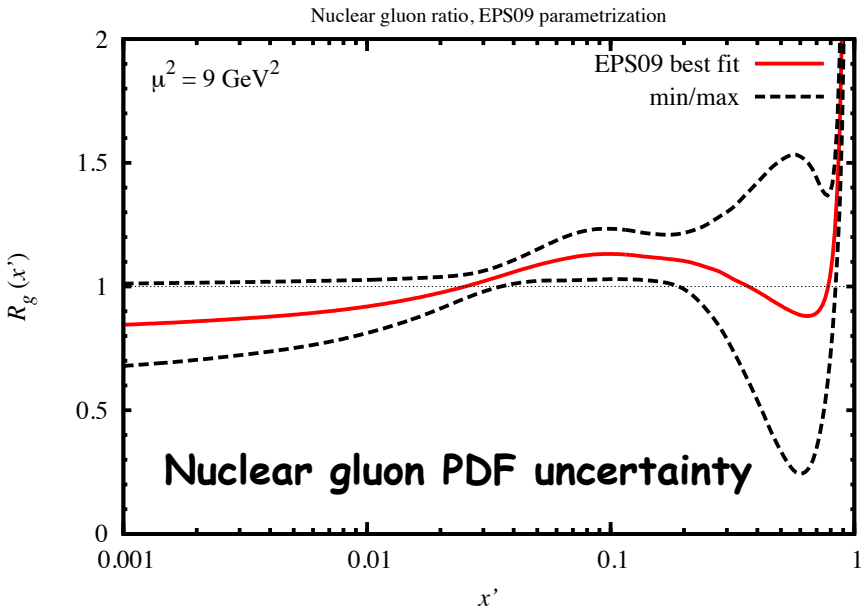


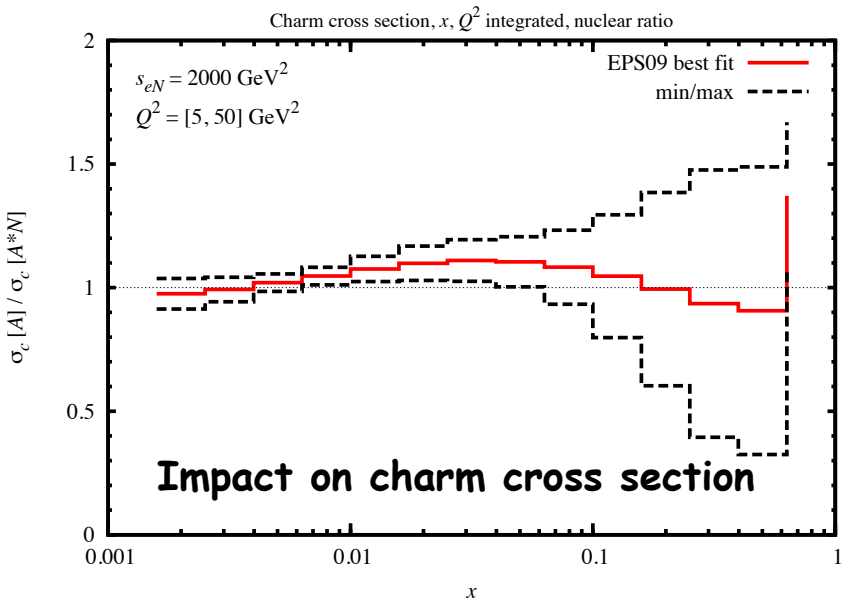
Reconstruction of D+ with/without microvertex



N. Coppola, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 54, NO. 5, OCTOBER 2007

Open charm sensitivity to nuclear gluons





- Good sensitivity of charm cross section at x ~ 0.1 to nuclear modification of gluon PDF
- Measurement of σ(charm) with ~10% accuracy would already reduce gluon PDF uncertainty

Summary

- Prospect of direct measurements of nuclear gluons at x >~ 0.1 using heavy quark production at EIC
- Reasonable charm production rates at x >~ 0.1 with EIC luminosity ~10^34 /cm^2/s
- Challenge to identify charm/beauty with overall efficiency of ~few%
- High-resolution vertex detector can significantly improve overall charm reconstruction efficiency and should be integrated into EIC detector design
- Studies of charm reconstruction and physics impact in progress

Further information

- Public Wiki at: https://wiki.jlab.org/nuclear_gluons/
- Tools & results can be used for follow-up studies