Nuclear gluons with charm at EIC

Jefferson Lab

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FY17 LDRD Project, continuing 2nd year

Aim: Demonstrate feasibility of novel direct measurements of nuclear gluons and quarks/antiquarks with JLEIC

Nuclear gluons with heavy quark probes – open charm, beauty

Nuclear quarks/antiquarks with flavor tagging

Tasks

- Assemble simulation tools: Physics models, generators, analysis tools
- Simulate measurements with schematic JLEIC detector model $\leftrightarrow$ JLEIC effort, Yu.F.
- Quantify physics impact, interpret results, optimize setup

Nuclear gluons: Accomplished so far

- Assembled/tested simulation tools: QCD charm codes, HVQDIS MC (HERA), PYTHIA/HERWIG for hadronic final states

- Calculated charm rates at large x, kinematic dependences, DIS background

- Mapped momentum and angular distributions of $c\bar{c} \to D, \bar{D} \to \pi, K$

- Assessed potential of charm reconstruction methods with JLEIC

Recent progress

← **this update**

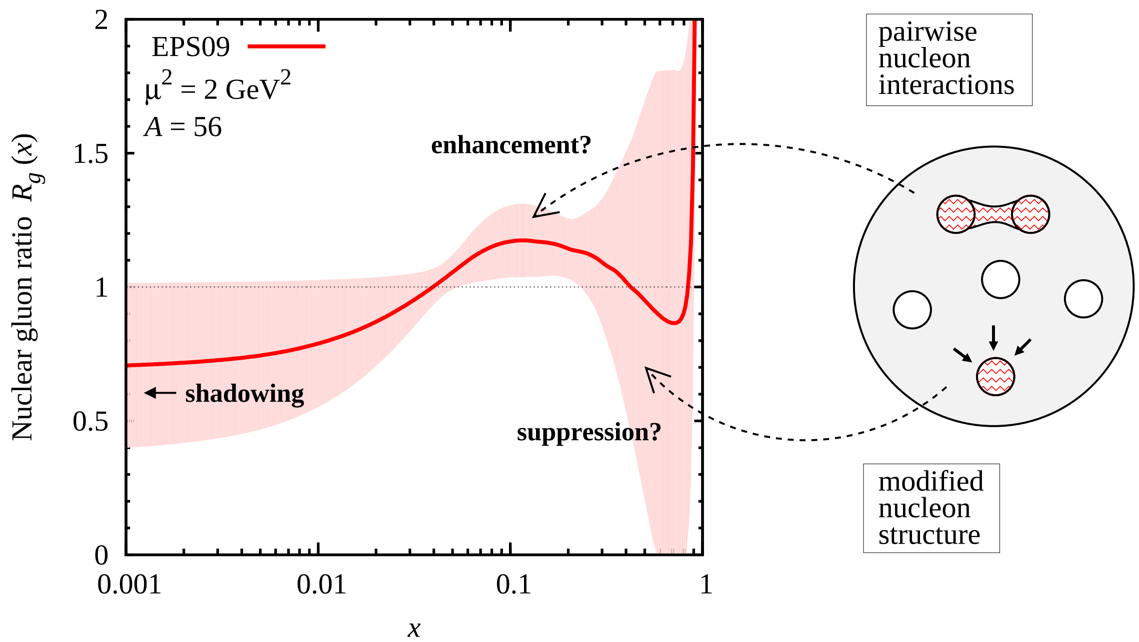
- Simulated charm reconstruction using exclusive and inclusive D-meson decays

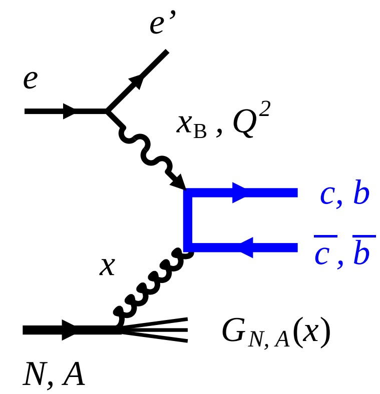
- Implemented analysis chain with tracking and vertexing based on schematic JLEIC detector model

- Quantified impact of charm pseudodata on gluon PDF fits

Materials publicly available on Wiki: `https://wiki.jlab.org/nuclear_gluons/`
E. Chudakov et al., BEACH 2016 Proceedings [arXiv:1610.08536]
E. Chudakov et al., DIS 2016 Proceedings [arXiv:1608.08686]
Presentations at POETIC 2016, DIS2017 (R. Yoshida) and QCD Evolution 2017

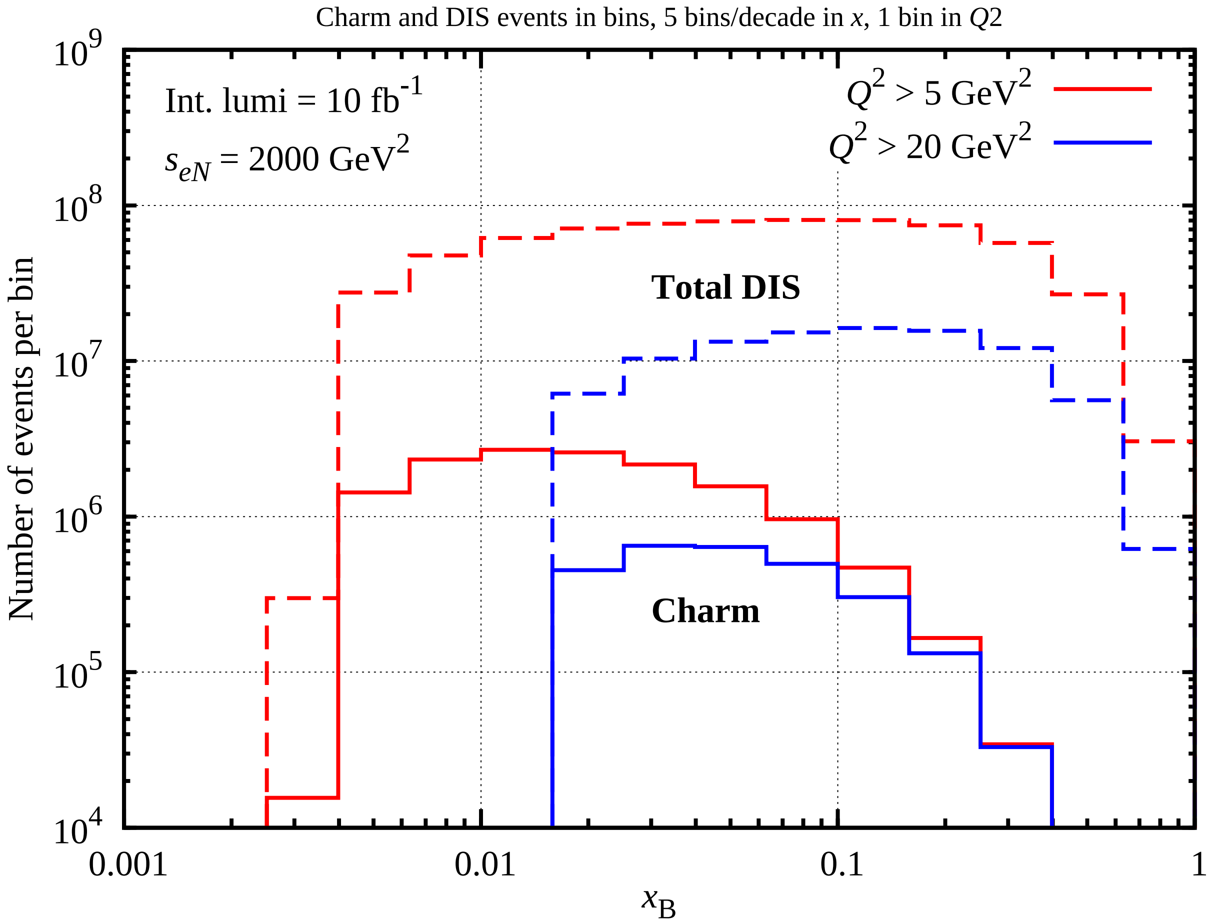
Nuclear gluons at large x





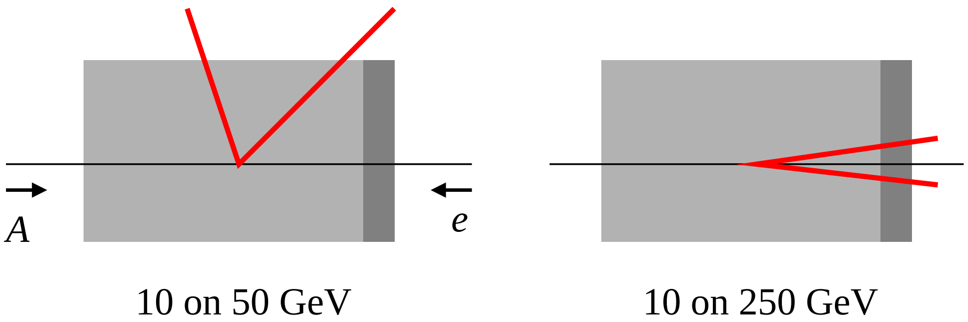
- Nuclear modification of gluons gives insight into NN interactions in QCD
  $x > 0.3 \leftrightarrow$ modified single-nucleon structure, $x \sim 0.1 \leftrightarrow$ pairwise NN interactions
- Nuclear modification at large x poorly constrained by present data
- EIC: Limited information from inclusive F_{2A}, F_{LA}
- EIC: Heavy quark production as direct probe

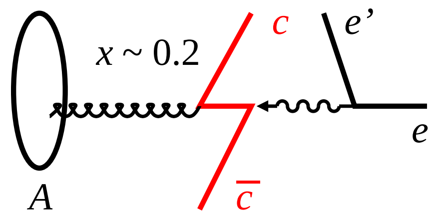
Charm production rates at large x



- Charm production rates drop rapidly at large x
- Charm production rates $\sim 10^5$ at $x \sim 0.1$ (int. lumi 10 fb^{-1})
  Defines charm reconstruction efficiency needed for physics at $O(10\%)$
- Charm/DIS ratio $\sim$ 2–3 % at $x \sim 0.1$
  Defines charm reconstruction environment

Charm angle and momentum distributions





- Large-x $c\bar{c}$ pairs produced almost at rest in low-ratio collider

  Example: Gluon with $x = 0.2$ and 10×50 GeV$/N$

  Contrast with high-ratio collider!

- π/K produced at large angles, with typical momenta $\lesssim 5$ GeV

  Favorable situation!

- Good PID and momentum resolution available in central detector

  Enables "new" methods of charm reconstruction

Charm reconstruction: Methods

- Exclusive D-meson decays
- Inclusive decays with displaced vertex

Questions

How well do the methods work at large x?

What are the overall efficiencies and uncertainties?

What detector performance is required?

Simulations at different levels

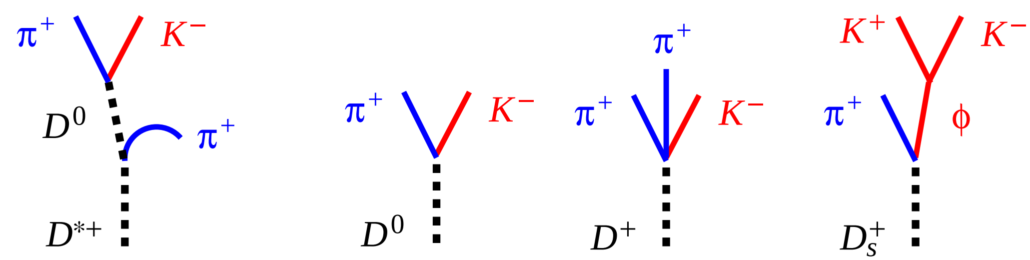
1) Theoretical estimates of reconstruction efficiency

2) Model acceptance and PID performance, describe resolution effects through smearing of vertex and momentum distributions

3) Tracking and vertexing based on schematic JLEIC detector model

Charm reconstruction: Exclusive D decays

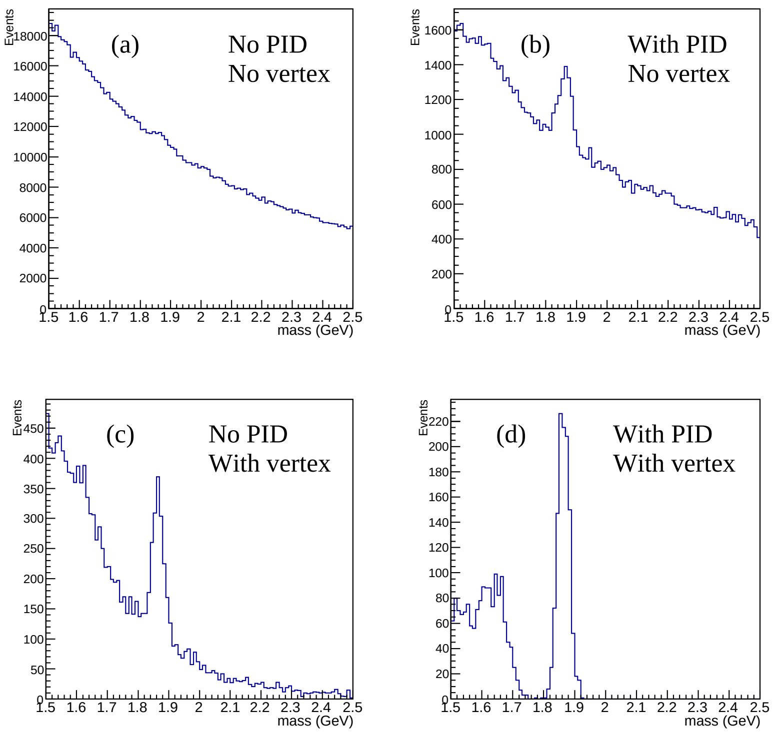
h_c	f	Decay	BR
D^0	59%	$K^-\pi^+$	3.9%
		$K^-\pi^+\pi^+\pi^-$	8.1%
D^+	23%	$K^-\pi^+\pi^+$	9.2%
D^{*+}	23%	$(K^-\pi^+)_{D0}\ \pi^+_{\rm slow}$	2.6%
		$(K^-\pi^+\pi^+\pi^-)_{D0}\ \pi^+_{\rm slow}$	5.5%
D_s^+	9%	$(K^+K^-)_\phi\ \pi^+$	2.3%
Λ_c^+	8%	$pK^-\pi^+$	5.0%

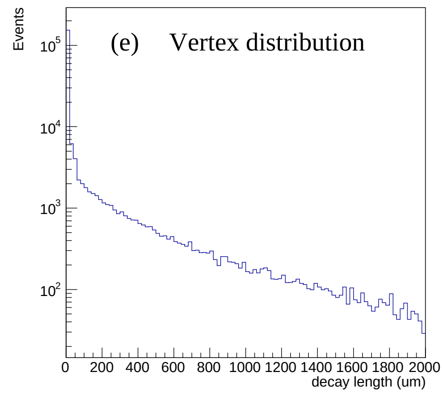


- $D^{*+} \to \pi^+(\text{slow}) + (K^-\pi^+)_{D0}$ used at HERA w/o PID, efficiency $< 1\%$.
- EIC PID + vertex detection allow use of other exclusive channels D^0, D^+, D_s^+
- Theoretical efficiency $\sim 10\%$ summed over channels

  Fragmentation ratio f $\times$ Branching ratio BR

Charm reconstruction: Exclusive D decays





Invariant mass spectrum of two charged tracks/mesons in sample of charm events with $Q^2 > 10$ GeV^2 and $x_B > 0.05$. PYTHIA 6 simulation, arbitrary normalization of event sample, no DIS background, vertex cut 100 μm.

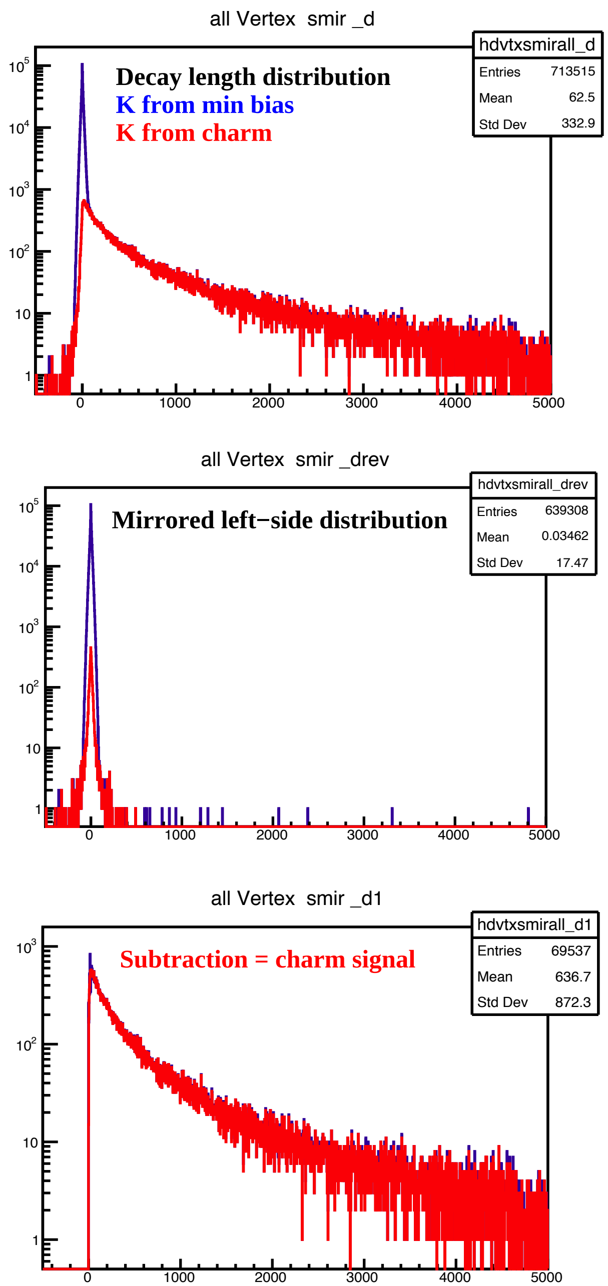
- Example: D^0 meson reconstruction using exclusive decay $D^0 \to K^-\pi^+$

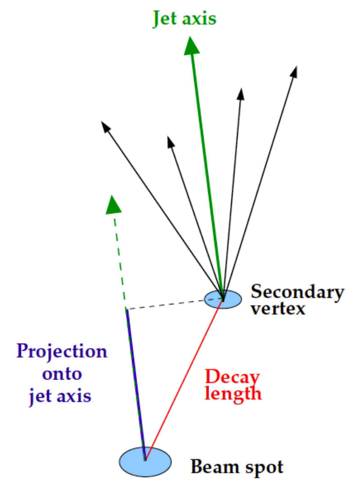
  Level-2 simulation with mass/momentum and vertex smearing

  Also other channels

- Impact of PID and vertex cuts

Charm reconstruction: Inclusive D decays





- Decay length significance distribution

  Establish secondary vertex

  Project decay length on jet axis, positive/negative

  Identify D-meson decays through positive projection

- Used at HERA with vertex detector

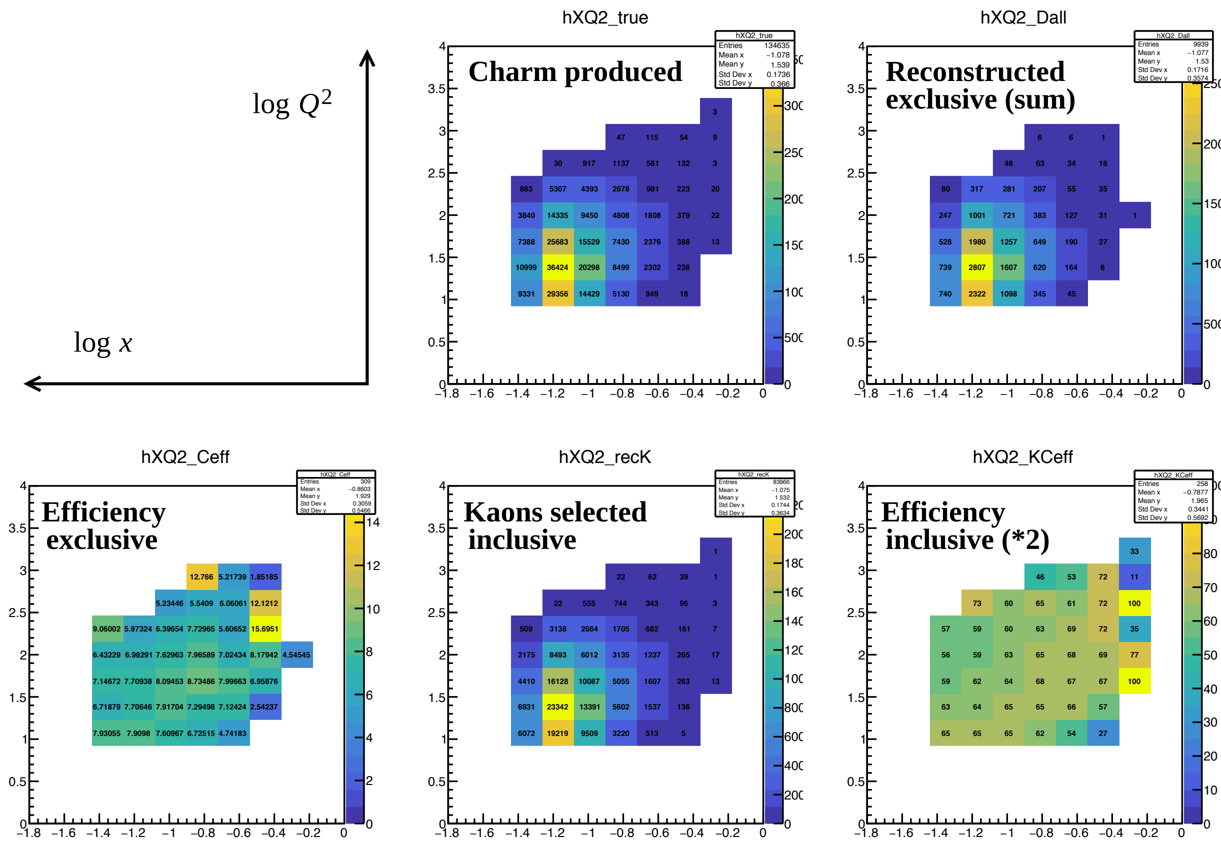
- Use for charm at JLEIC

  Level-2 simulations with vertex smearing

  Identified K from PID

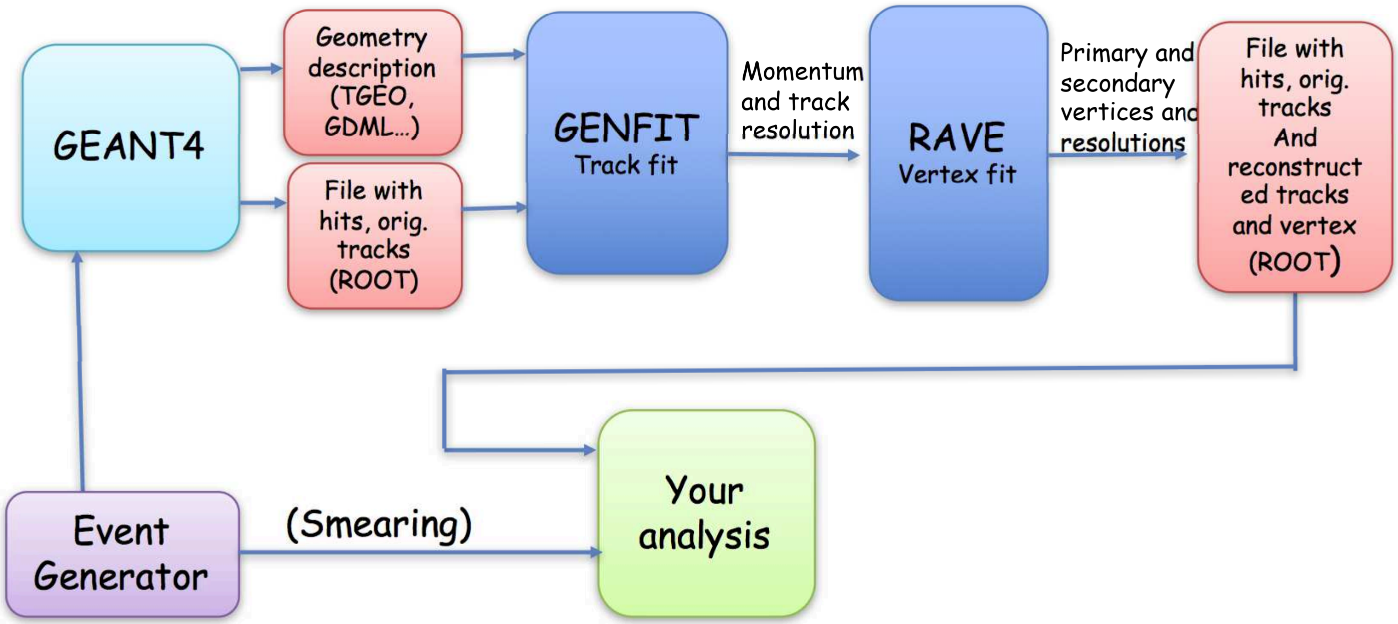
  Efficiency up to $\sim$ 30%

Charm reconstruction: Summary



- Total efficiency estimated ∼5-7% exclusive, ∼30% inclusive
- Little kinematic variation in (x, Q^2) region of interest
- Systematic uncertainties? HERA $\lesssim 10\%$
- Both vertex detection and PID are essential for charm reconstruction

Tracking and vertexing with JLEIC



- Analysis chain for tracking and vertexing with JLEIC — Yulia, Sergey

  Model of vertex detector and outer tracker/endcap geometry

  Based on GEANT4/Root, uses available tools GENFIT, RAVE

- Can be used in two ways

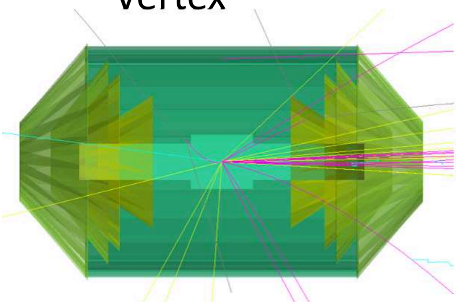
  Verify smearing parameters of Level-2 simulations

  Full event reconstruction

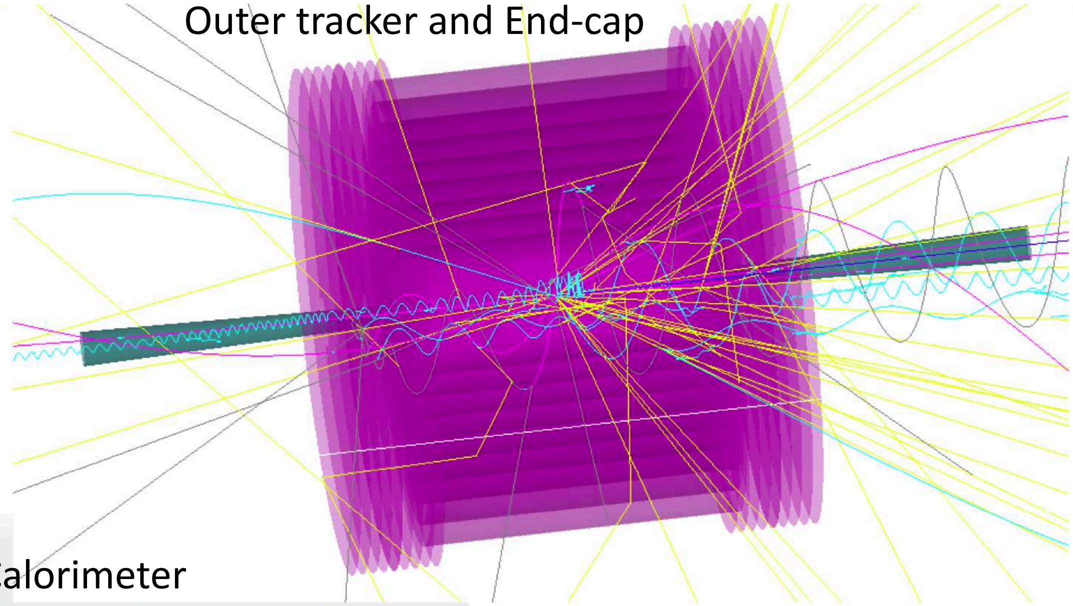
Tracking and vertexing with JLEIC

GEANT4

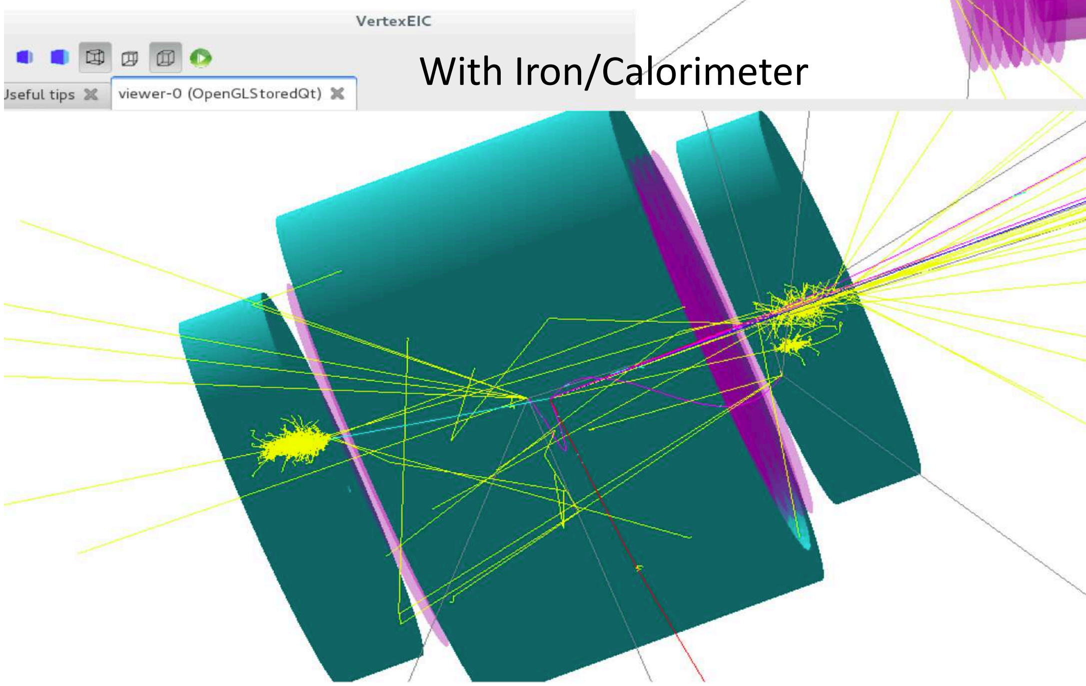
Vertex



Outer tracker and End-cap



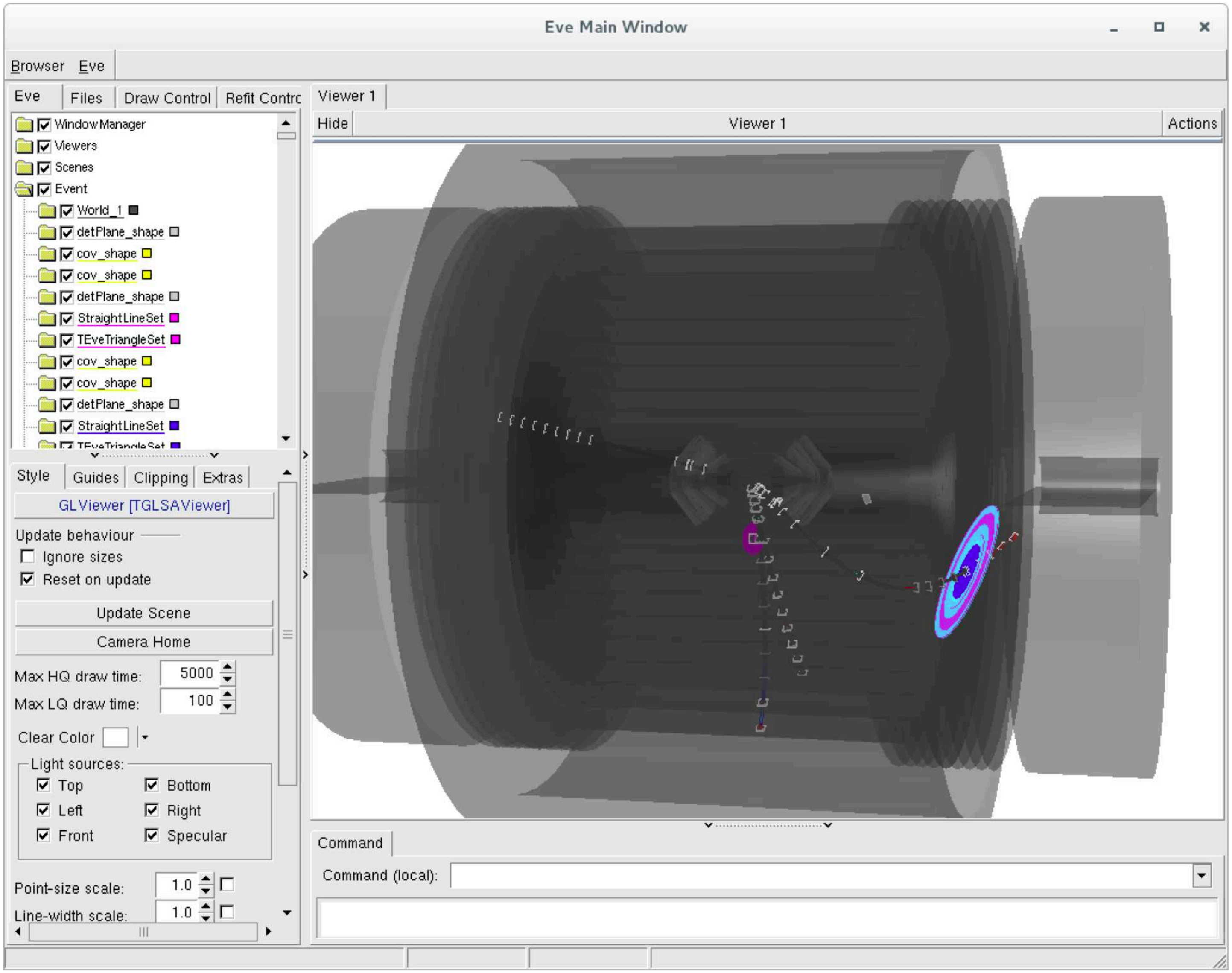
With Iron/Calorimeter



Yulia Furletova

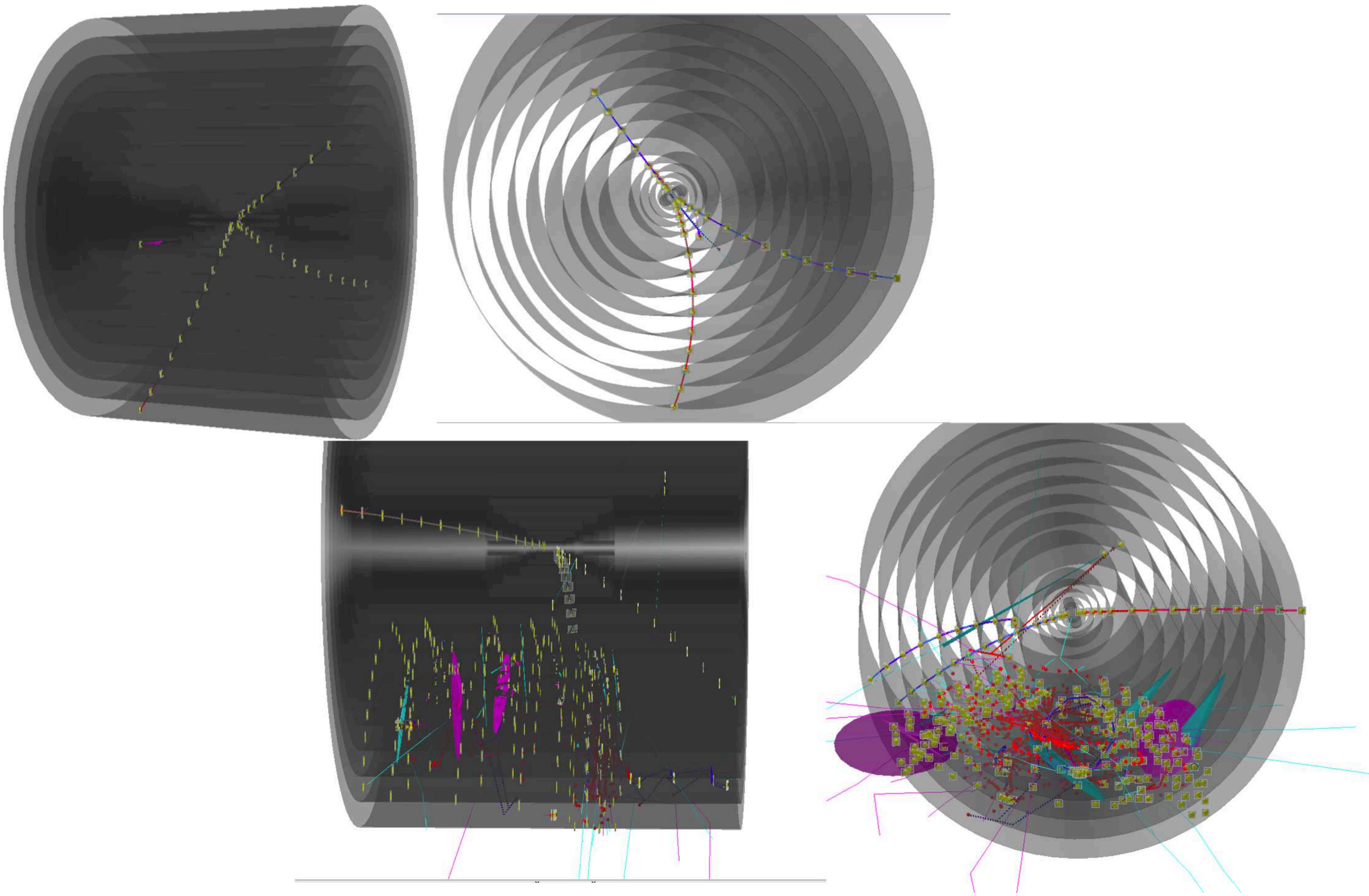
Tracking and vertexing with JLEIC

GENFIT/EVE EVENT DISPLAY



Tracking and vertexing with JLEIC

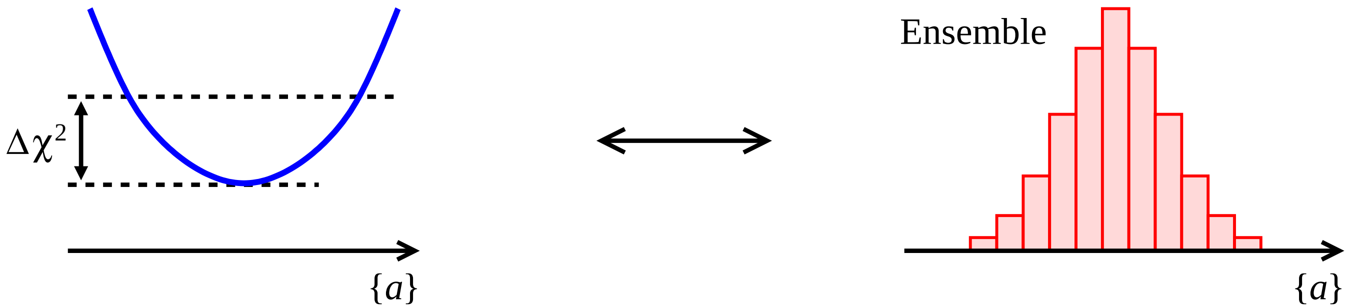
GENFIT/EVE EVENT DISPLAY



Tracking and vertexing with JLEIC

- Setup almost complete; can start simulations
- Preliminary results support the vertex smearing parameters used in previous Level-2 simulations
  Confirmed using tools of LBNL group: S. Klein, M. Lomnitz
- Detector model can be updated
  Parametric model of PID performance: Ch. Hyde, LDRD
- Setup could be used for other applications
  Synergies with JLEIC Software effort: M. Diefenthaler, Yu. Furletova, R. Yoshida

Charm impact on large–x nuclear gluons



- PDF reweighting

  Method for quantifying impact of new (pseudo-) data on existing global fit

  Represents existing fit as statistical ensemble, uses Bayes' theorem

  Avoids costly re-fitting

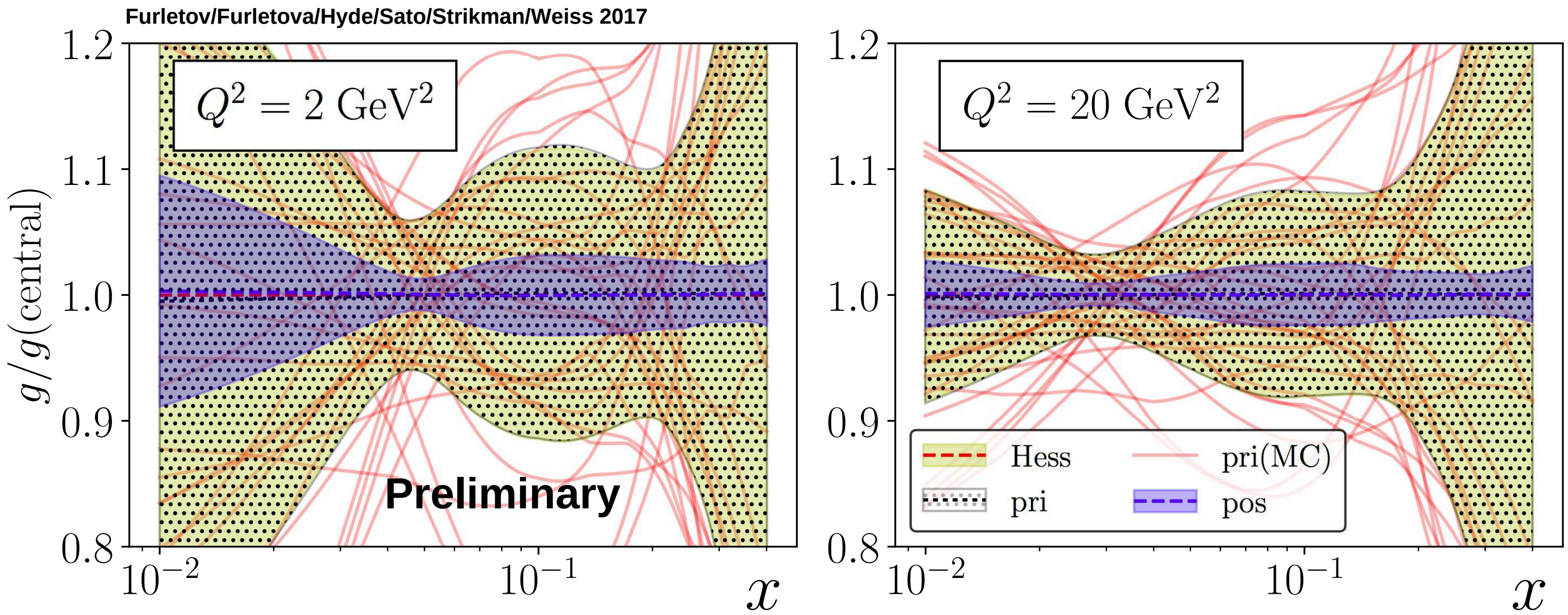
  Widely used in PDF analysis, HEP
  Review: Paukkunen, Zurita JHEP 1412 (2014) 100 [INSPIRE]

- Implemented for charm pseudodata from EIC N. Sato, C. Weiss

  Presently F_{2c}, can be extended to other observables

  Python code package, on github: `https://github.com/JeffersonLab/F2c`

Charm impact on large–x nuclear gluons



- Here: Assumed 10% total error, dominated by systematics, point-to-point
- Substantial impact on large–x nuclear gluons
- Will be updated/refined
- Possible to constrain large–x nuclear gluons with charm at EIC!

Next steps

- All elements of “chain” in place, can begin next-level simulations
- Gluon PDF impact of realistic charm pseudodata
- Documentation and publication of results
- Charge/flavor separation of nuclear quarks with semi-inclusive pions
  Zhihong Ye, F. Hauenstein