EIC and UPC physics

C. Weiss (JLab), INT17-65W Photon-Nucleus Interactions, INT Seattle, 13-17 Feb 2017

I) 3D nucleon structure in QCD

Sea quark and gluon polarization
Spatial distributions, orbital motion
Multiparton correlations

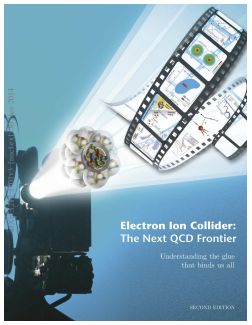
II) Color fields in nuclei

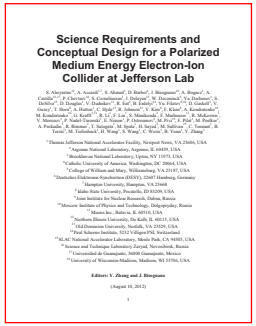
Nuclear quark/gluon densities
Color transparency, opacity
Shadowing, coherent processes
Nonlinear effects, saturation

III) Hadrons from color charge

Fragmentation and hadronization
Color propagation in matter

- Focus on phenomena & structures with clear UPC-EIC connection
- Highlight complementarity and synergies
- Generic EIC $\sqrt{s}_{eN} \sim$ 20–70/100 GeV




Science Requirements and Conceptual Design for a Polarized Medium Energy Electron-Ion Collider at Jefferson Lab

EIC and UPC: This presentation

- Nuclear shadowing

  Interference mechanism, leading vs. higher twist, effects beyond $N = 2$

- Nuclear quarks and gluons

  Gluons at large x: antishadowing, EMC effect

  Valence quark shadowing, antishadowing

- Nucleon structure beyond PDFs

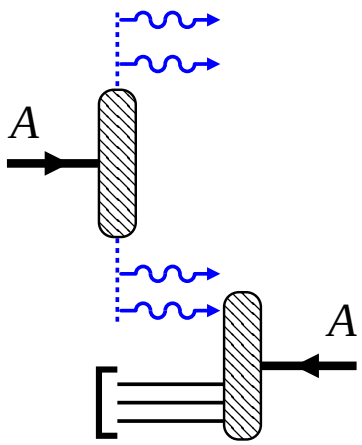
  Transverse spatial distributions and GPDs from exclusive processes

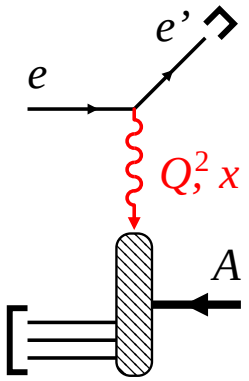
  Quantum fluctuations from diffractive dissociation

  Nucleon fragmentation

- Unitarity limit: Black-Disk Regime

EIC and UPC: Characteristics



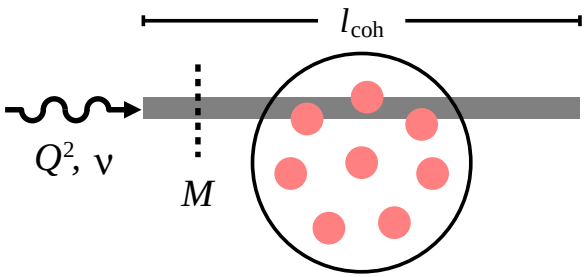


γN CM energy W	$\sim 500 - 1800$ GeV	$\sim 20 - 70$ GeV
rest frame energy ν	$\sim 10^6$ GeV	
hard processes kinematics	final state p_T^2, M^2	initial and/or final state x, Q^2 and/or p_T^2, M^2
Photon flux kdN/dk	comparable	comparable

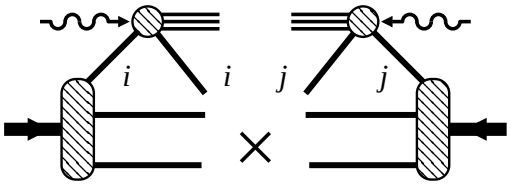
- UPC: Highest energies, limited control of hard process kinematics
  Baltz et al. arXiV:0706:3356. Talks Adam, Kryshen, Murray, Angerami

- EIC: Limited energy, hard process kinematics controled by electron: Inclusive/semi-inclusive measurements; Q^2 evolution at fixed x, p_T, . . .

Nuclear shadowing: Basics



$$\sigma = \sum_i \sigma_i + \sum_{i,j}$$



impulse app shadowing

- Shadowing in high-energy scattering

  Gribov 70's. Talk Guzey

  Coherence length $l_{\rm coh} = \nu/(M^2 + Q^2) \sim$ nuclear size

  Diffractive scattering enables interference

  Effect calculable: 2-body + 3-body + ...

- Hard processes

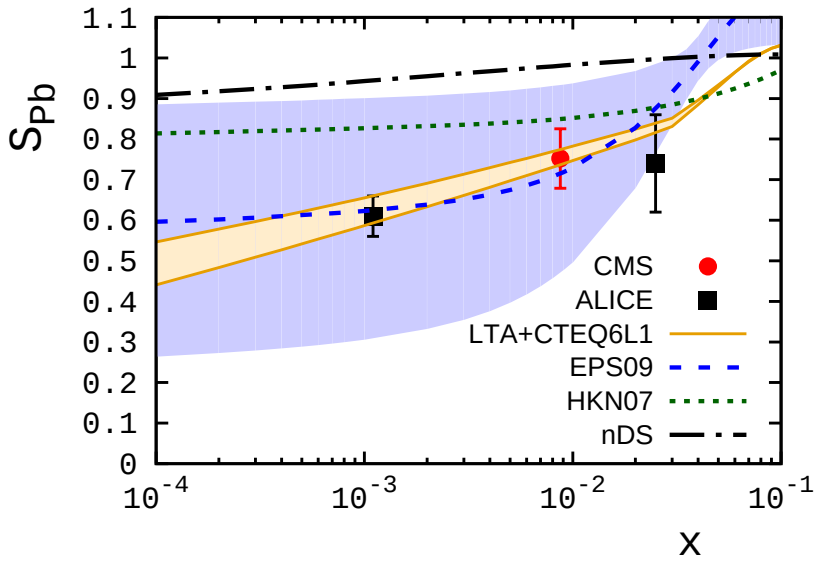
  Frankfurt, Strikman, Guzey 12

  Leading-twist shadowing: Gluons attached to different nucleons

  2-body correction calculable in terms of diffractive PDFs

  Higher-twist shadowing also possible

Nuclear shadowing: UPC



- J/ψ photoproduction data show significant nuclear suppression
  Experimental talks

$$\gamma + A \to J/\psi + A^*$$

- Consistent with large LT gluon shadowing predicted at $x < 10^{-2}$: On-going discussion
  Talk Guzey

- Questions

  Demonstrate/confirm interference mechanism?

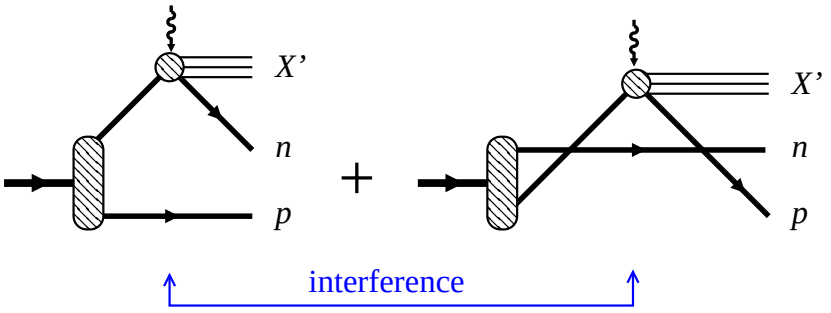
  3-body and higher corrections?

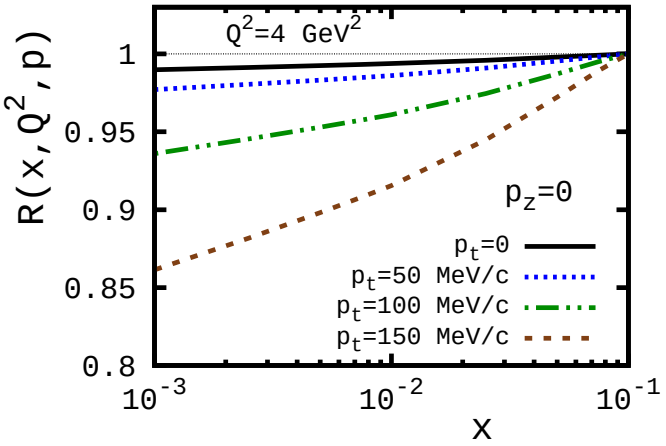
  Leading vs. higher-twist shadowing in VM production and DIS?

  Impact on large-x nuclear gluons: antishadowing?

  Shadowing of quarks?

Nuclear shadowing: EIC





- Shadowing in diffractive DIS on deuteron

  $ed \to e' + p + X$ (single-tagged) or $ed \to e' + p + n + X'$ (double-tagged)

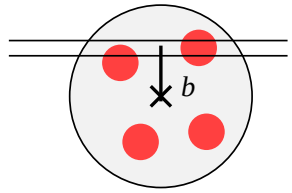
  Large shadowing effect in recoil momentum dependence — Guzey et al., in progress

  Detailed test of interference mechanism in $N = 2$ system

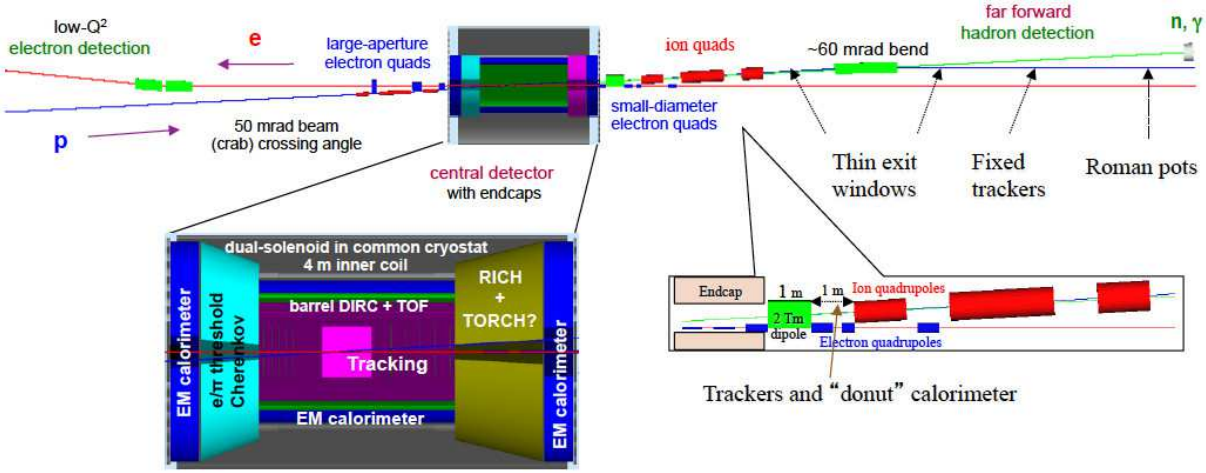
  Possible with forward p/n detector: Design, simulations

- $N = 3$ shadowing from other light ions: ^{3}He, ^{4}He, ...
  "Fringe effect" enhanced compared to heavy ions

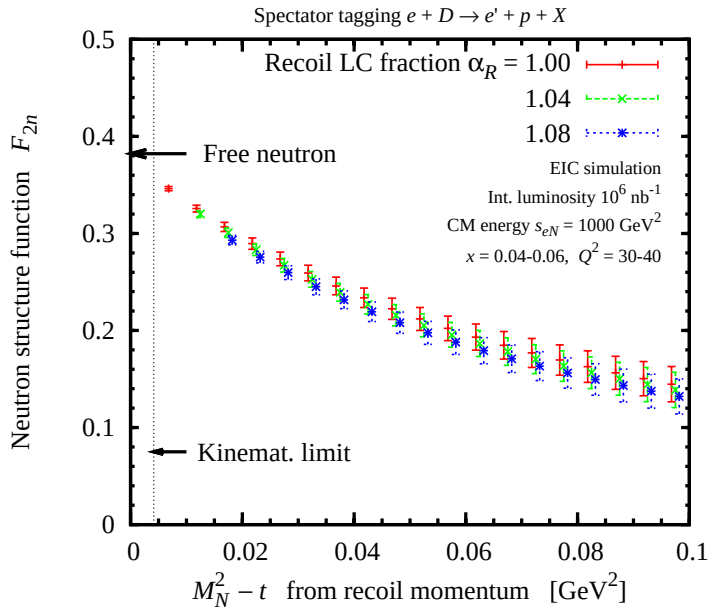
- Shadowing in coherent scattering:
  Impact parameter dependence
  Guzey et al., Kowalski, Caldwell 10



JLEIC forward detector, simulations



P. Nadel-Turonski et al.



- JLEIC forward detector design

  Acceptance for elastic recoil (99.5% mom, 2 mrad) and fragments/spectators

  Resolution $dp/p \sim 10^{-3}$, angular $\delta\theta \sim 0.2$ mrad

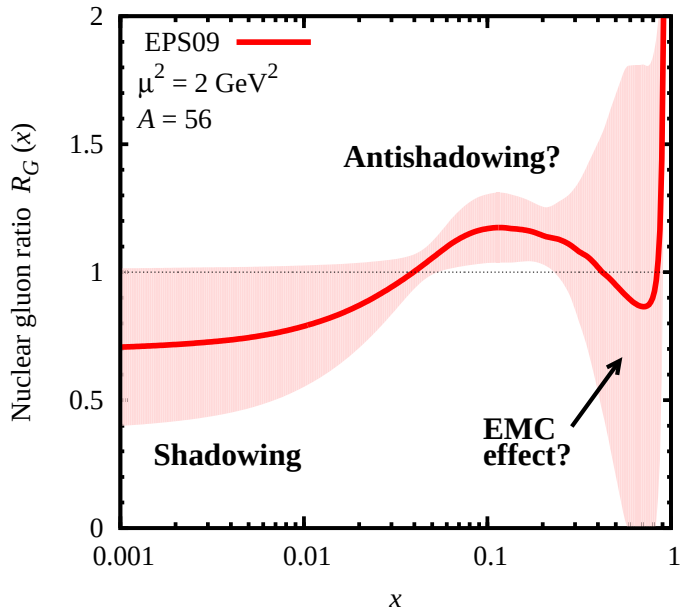
- Simulations tagged DIS $ed \to e' + p + X$

  Neutron structure from on-shell extrapolation

  Polarized deuteron for spin structure

  JLab LDRD 14/15. Further information:
  https://www.jlab.org/theory/tag/

Nuclear gluons: Large x with EIC



- Gluon antishadowing at $x \sim 0.1$?

  Momentum sum rule:
  Shadowing $\rightarrow$ antishadowing

  Gluonic structure of NN interaction?

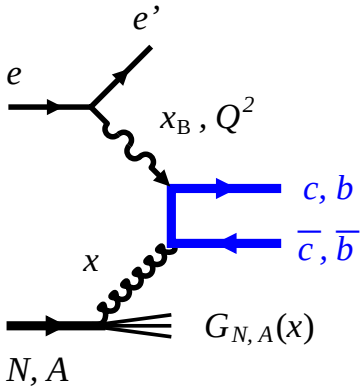
- Gluonic EMC effect at $x > 0.3$?

  Modified nucleon structure, non-nucleonic DoF?

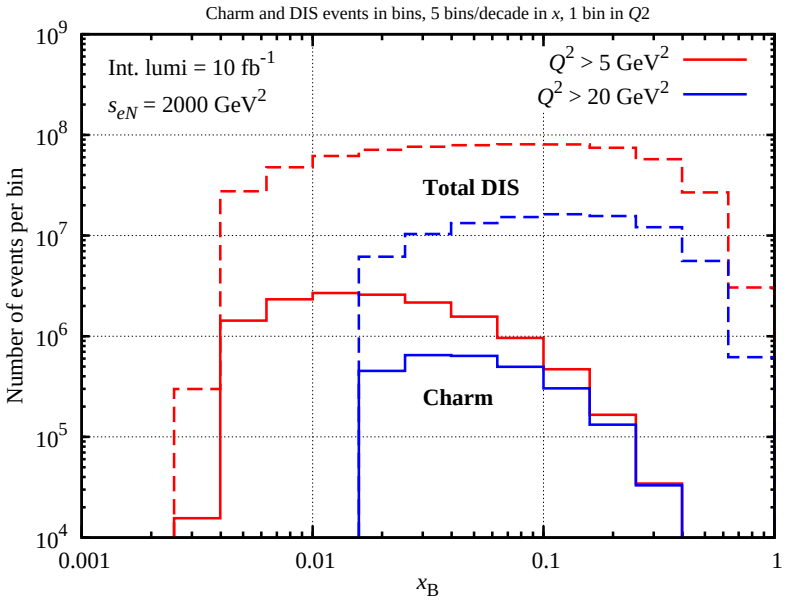
- Inclusive F_{2A}, F_{LA} + DGLAP
  EIC White Paper. Talk Aschenauer

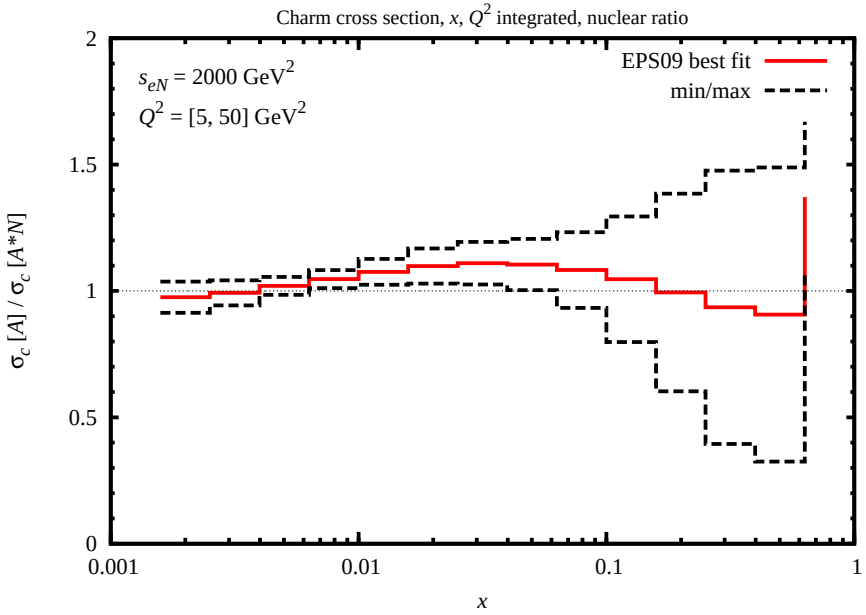
- Heavy quark production as direct probe

  Gluon density sampled at $x > x_B$



Nuclear gluons: Open charm with EIC

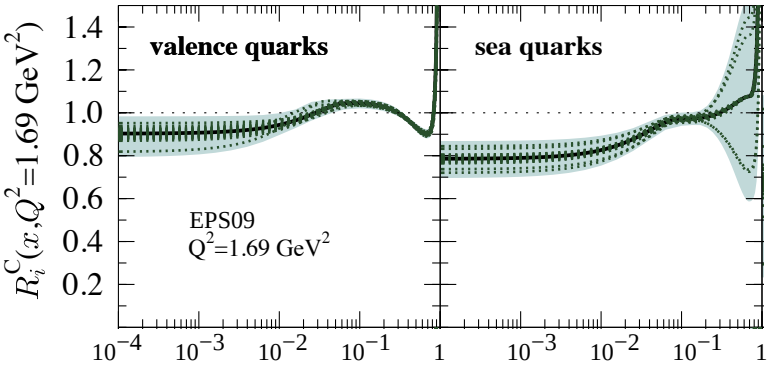


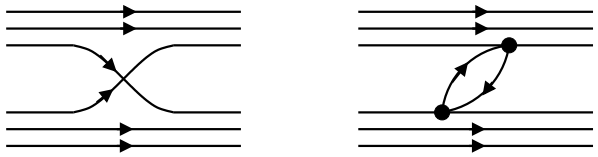


- Charm rates $O(10^6)$ at $x_B \sim 0.1$ with 10 fb^{-1} int lumi
- Charm reconstruction with ∼10% efficiency seems feasible: PID + vertex, exclusive channels $D \to \pi^{\pm} K^{\pm}$, inclusive modes
- Medium-energy collider 10×50/100 GeV ideal for large–x charm detection
- Excellent sensitivity to nuclear gluons at $x > 0.1$

JLab LDRD 16/17. Further information: https://wiki.jlab.org/nuclear_gluons/

Nuclear quarks: Valence, sea, flavor with EIC





quark exchange meson exchange

- Quark shadowing at $x < 10^{-2}$?

  Diffractive mechanism? Valence/sea DPDFs?

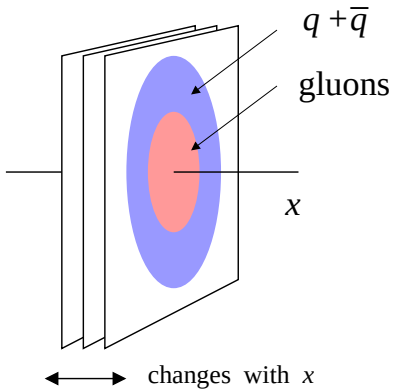
  Baryon number sum rule for valence quarks

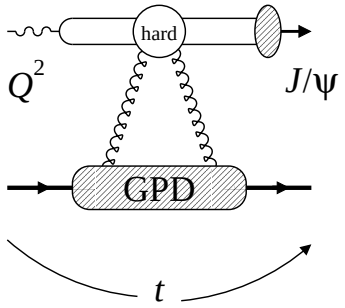
- Quark enhancement at $x \sim 0.1$?

  QCD structure of NN interaction

- EIC: Identify leading-twist nuclear modifications at $x > 10^{-2}$
- Separate valence/sea with inclusive DIS + DGLAP
- Separate valence/sea and flavor with semi-inclusive DIS $\pi^+ \pm \pi^-$
  New method; simulations in progress. Strikman, CW, Zhihong Ye.
- Explore spin-dependent nuclear modifications

Nucleon structure: Transverse distributions



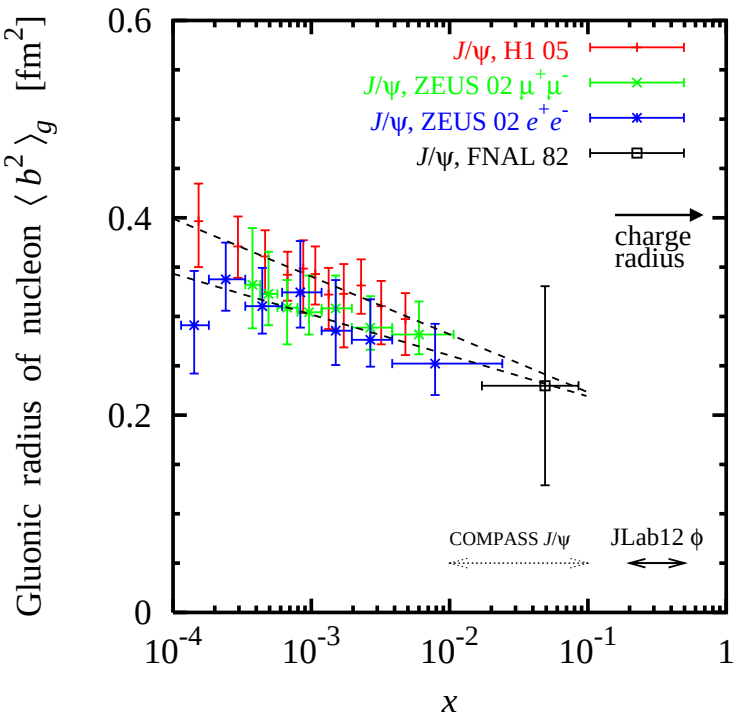


- Gluon distribution in transverse space

  Gluonic size and shape of nucleon

  Distribution changes with x:
  Diffusion $\leftrightarrow$ Regge dynamics, DGLAP

  Input for saturation models, MPI,
  geometric correlations in pp@LHC



Frankfurt, Strikman, CW 10

- Exclusive processes $\gamma^{(*)}+N \to J/\psi+N$

  Gluonic form factor of nucleon: GPD

  QCD mechanism tested at HERA

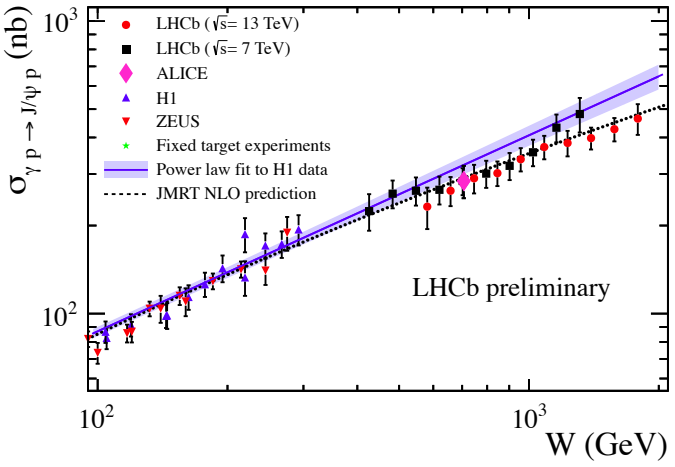
- Questions

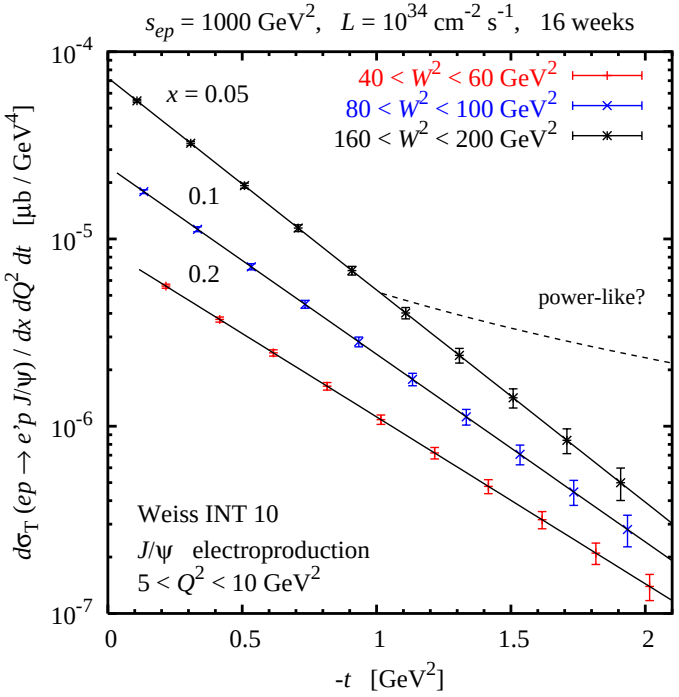
  Large x: Valence-like gluons?

  $x < 10^{-4}$: Energy dependence, diffusion,
  approach to BDR?

  Transverse distribution of quarks?

Nucleon structure: Transverse distributions





- UPC: Exclusive J/ψ photoproduction
  Experimental talks

  Mechanism at high energies: Discussion

  t–dependence will give transverse profile

- EIC: Gluon imaging at $x > 10^{-3}$

  Electro/photoproduction J/ψ, ϕ: Mechanism

  Forward detector: Exclusivity, accurate t measurements, coverage up to $t > 1$ GeV^2

  Access to valence-like gluons at $x > 0.1$

  Medium-energy collider ideal

- EIC: Quark imaging

  DVCS $\gamma^* N \to \gamma N$: Extensive program, polarization observables

  Non-singlet mesons $\pi^{\pm}$, π^0, $\rho^{\pm}$, K

Nucleon structure: Further topics

- VM production with diffractive dissociation $e + N \to e' + V + X(\text{low-mass})$

  Quantum fluctuations of nucleon's gluon density $\omega_g = \dfrac{\langle G^2 \rangle - \langle G \rangle^2}{\langle G \rangle^2}$
  Frankfurt, Strikman, Treleani CW 08

- Nucleon fragmentation in DIS: Conditional PDFs
  Trentadue, Veneziano 93; Collins 97

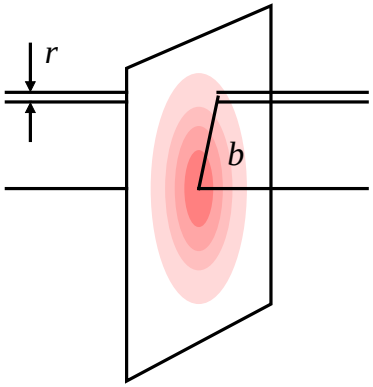
  $x < 10^{-2}$: Diffractive PDFs, Regge-type dynamics

  $x > 0.1$: Hadronization of nucleon with color charge removed, spin effects

  New information on nucleon structure

  Input for calculations/modeling of nuclear breakup in DIS

Unitarity limit



- High-energy scattering of small-size color dipole

  Scattering amplitude represented by profile function $\Gamma(b)$

  $\Gamma(b) \to 1$ total absorption of incoming wave, "black disk"

  Criterion independent of dynamics, small–x evolution, ...

- General strategy

  1) Verify dominance of small-size dipoles in given hard scattering process

  2) Identify signatures of approach to BDR at high energies

- LHC $pA/\gamma A$ forward hadron/jet production will see **whether** it is there:
  Highest energy/smallest x, final-state signatures

- Medium-energy EIC $eA/\gamma A$ can explain **how** it happens:
  Shadowing, transverse geometry, initial condition of small–x evolution

Summary

- UPCs and EIC complementary

  Highest energy $\leftrightarrow$ control of hard-process kinematics

- Concrete possibilities for "joint" studies

  Mechanism of nuclear shadowing
  Nuclear quarks/gluons at larger x
  Transverse nucleon structure
  Unitarity limit in hard interactions

- Can be done with medium-energy EIC $\sqrt{s_{eN}} \sim$ 20–70 GeV

- Make full use of next-generation detector capabilities

  Forward detection of protons/neutrons/nuclear fragments
  PID and vertex detection