

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

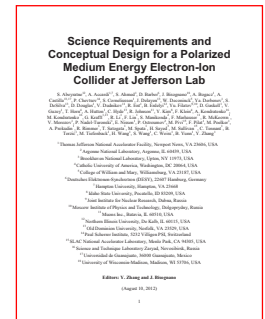
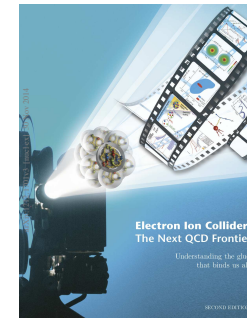
II) Color fields in nuclei

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 $\sqrt{s}_{eN} \sim 20\text{--}70/100$ GeV



- 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

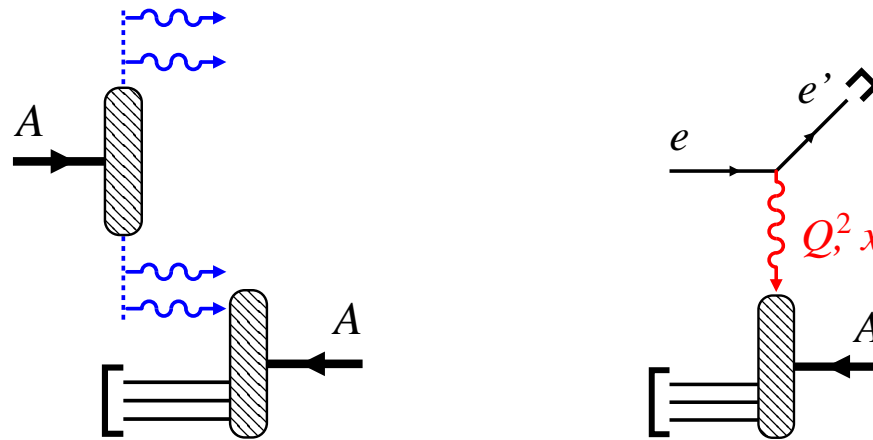
- Nucleon structure beyond PDFs

Transverse spatial distributions and GPDs from exclusive processes

Quantum fluctuations from diffractive dissociation

Nucleon fragmentation

- Unitarity limit: Black-Disk Regime



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

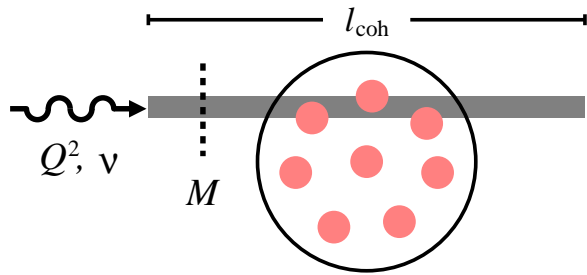
comparable

comparable

- UPC: Highest energies, limited control of hard process kinematics
Baltz et al. [arXiv:0706:3356](https://arxiv.org/abs/0706.3356). Talks Adam, Kryshen, Murray, Angerami
- EIC: Limited energy, hard process kinematics controlled by electron:
Inclusive/semi-inclusive measurements; Q^2 evolution at fixed x, p_T, \dots

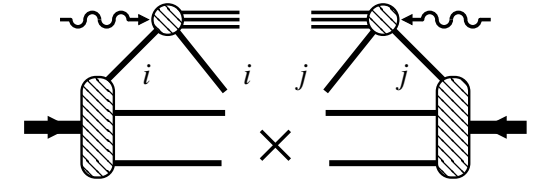
Nuclear shadowing: Basics

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

impulse app



shadowing

- Shadowing in high-energy scattering

Gribov 70's. Talk Guzey

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

Diffractive scattering enables interference

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

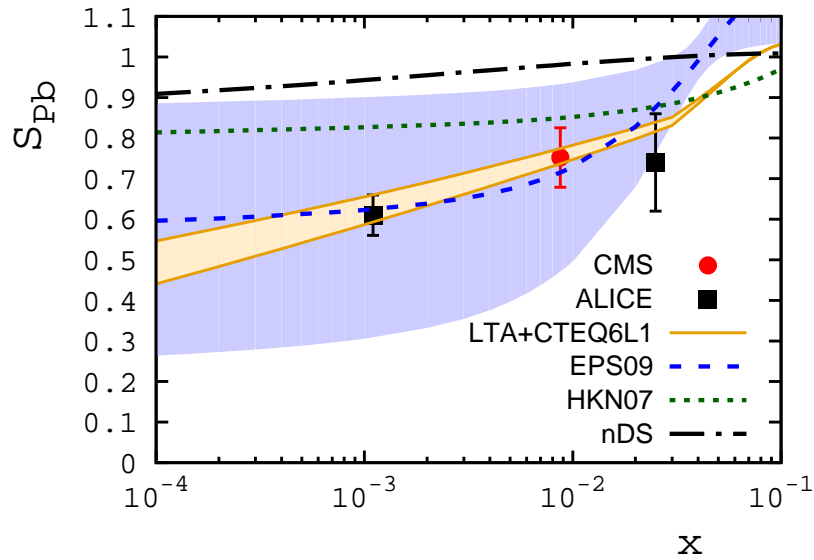
- Hard processes

Frankfurt, Strikman, Guzey 12

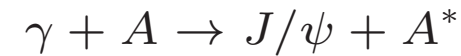
Leading-twist shadowing: Gluons attached to different nucleons

2-body correction calculable in terms of diffractive PDFs

Higher-twist shadowing also possible



- J/ψ photoproduction data show significant nuclear suppression
[Experimental talks](#)



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

- Questions

Demonstrate/confirm interference mechanism?

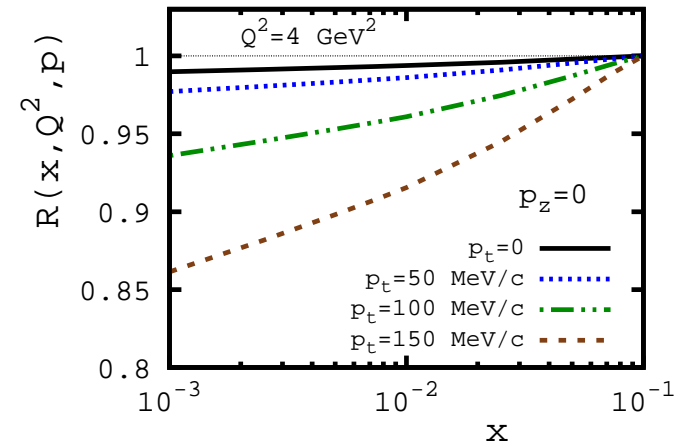
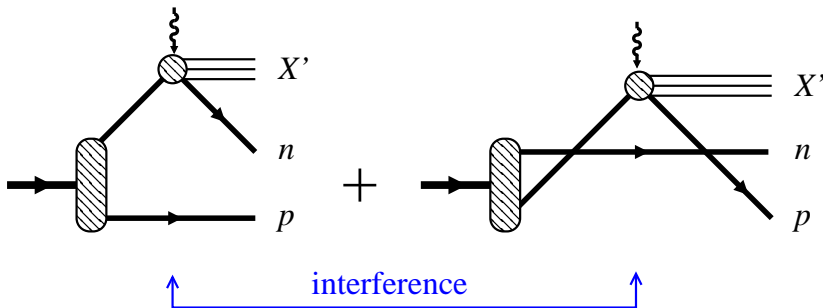
3-body and higher corrections?

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

$$ed \rightarrow e' + p + X \text{ (single-tagged)} \quad \text{or} \quad ed \rightarrow e' + p + n + X' \text{ (double-tagged)}$$

Large shadowing effect in recoil momentum dependence

Guzey et al., in progress

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

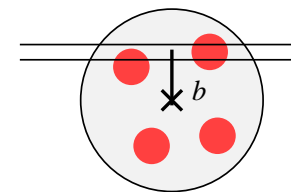
Possible with forward p/n detector: Design, simulations

- $N = 3$ shadowing from other light ions: ${}^3\text{He}$, ${}^4\text{He}$, ...

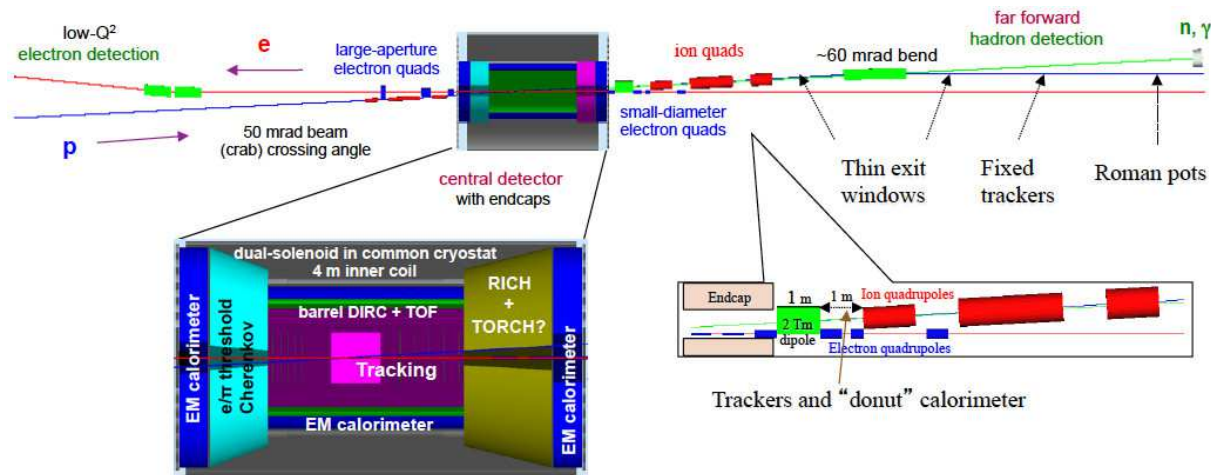
“Fringe effect” enhanced compared to heavy ions

- 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

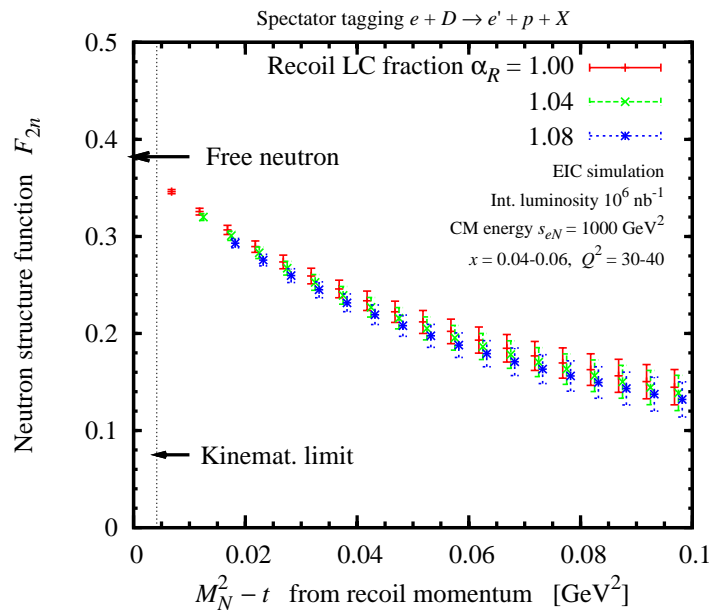
Resolution $dp/p \sim 10^{-3}$, angular $\delta\theta \sim 0.2$ mrad

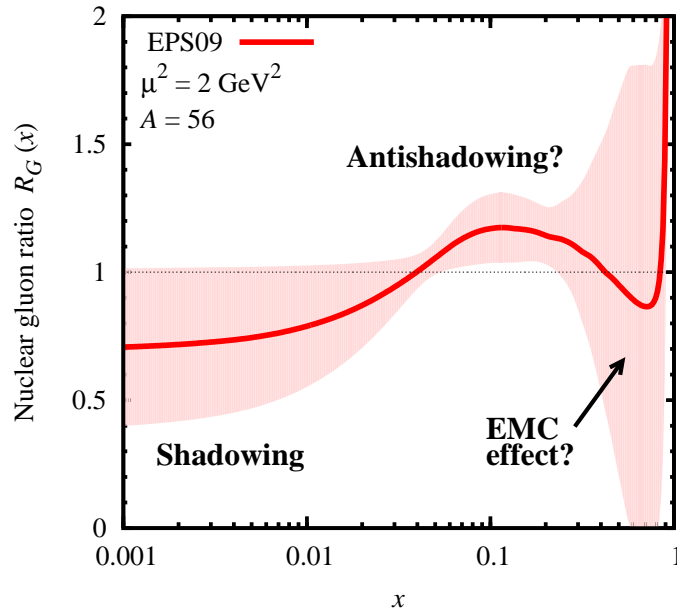
- Simulations tagged DIS $ed \rightarrow e' + p + X$

Neutron structure from on-shell extrapolation

Polarized deuteron for spin structure

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





- Gluon antishadowing at $x \sim 0.1$?

Momentum sum rule:
Shadowing \rightarrow antishadowing

Gluonic structure of NN interaction?

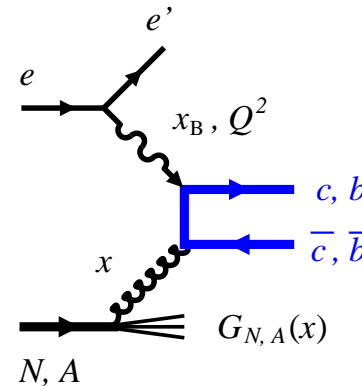
- Gluonic EMC effect at $x > 0.3$?

Modified nucleon structure, non-nucleonic DoF?

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

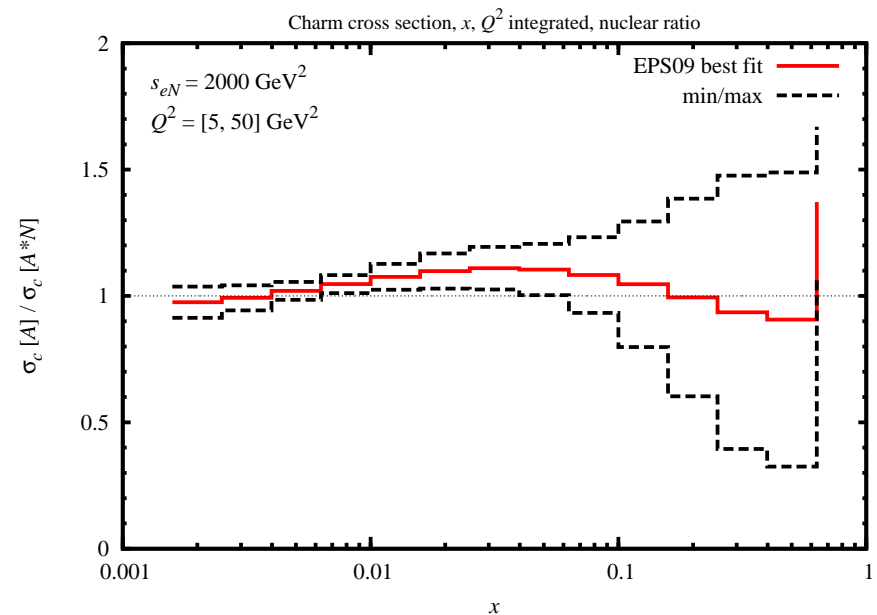
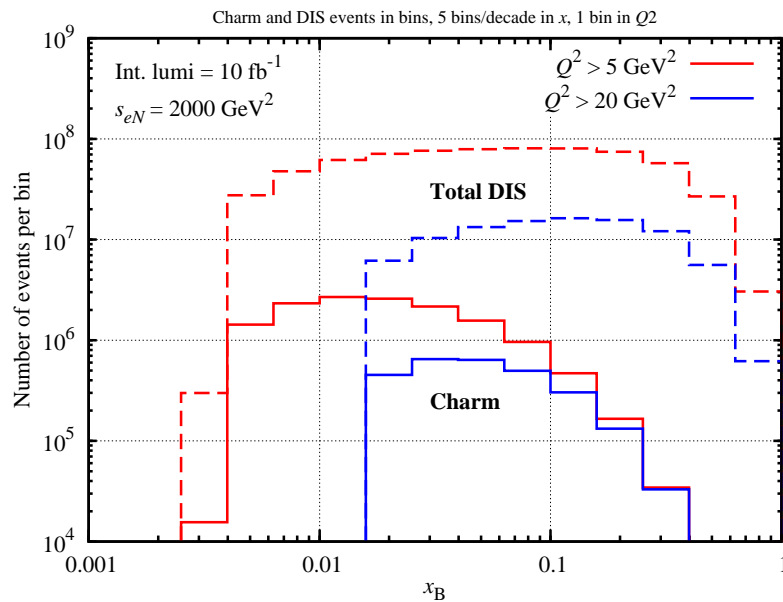
- Heavy quark production as direct probe

Gluon density sampled at $x > x_B$



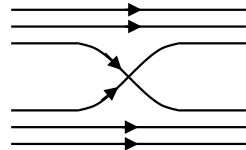
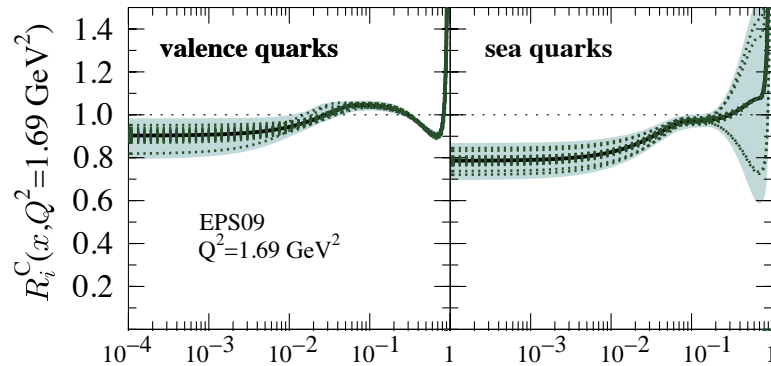
Nuclear gluons: Open charm with EIC

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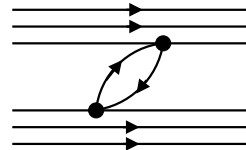


- Charm rates $O(10^6)$ at $x_B \sim 0.1$ with 10 fb^{-1} int lumi
- Charm reconstruction with $\sim 10\%$ efficiency seems feasible: PID + vertex, exclusive channels $D \rightarrow \pi^\pm K^\pm$, inclusive modes
- Medium-energy collider $10 \times 50 / 100 \text{ GeV}$ ideal for large- x charm detection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

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

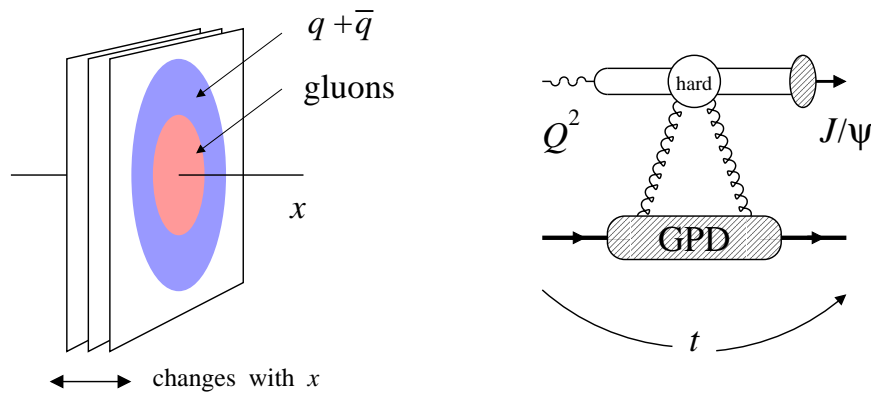


quark exchange



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

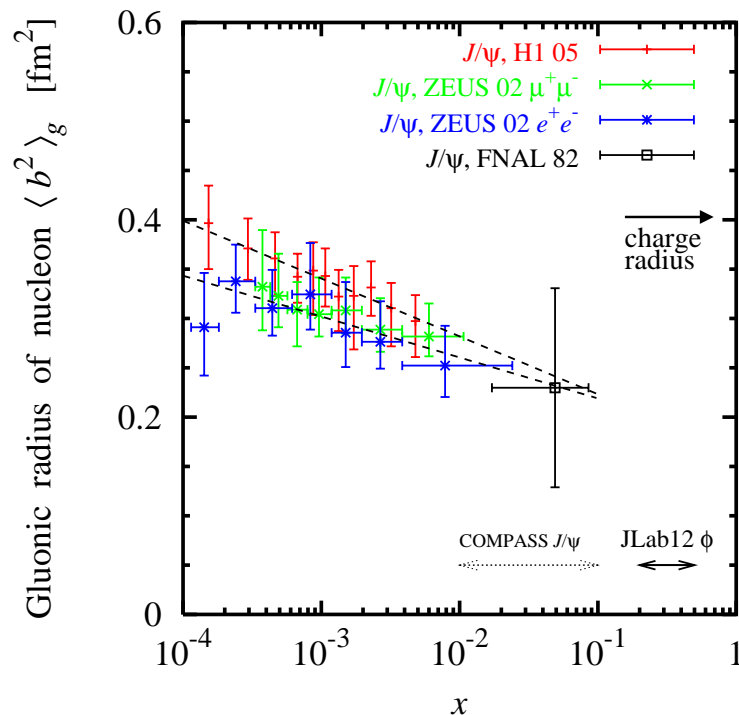


- Gluon distribution in transverse space

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



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

Gluonic form factor of nucleon: GPD

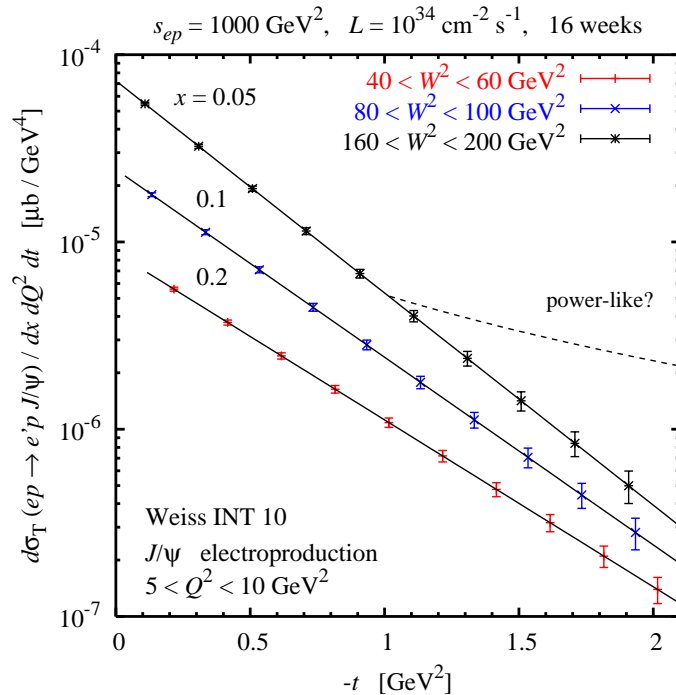
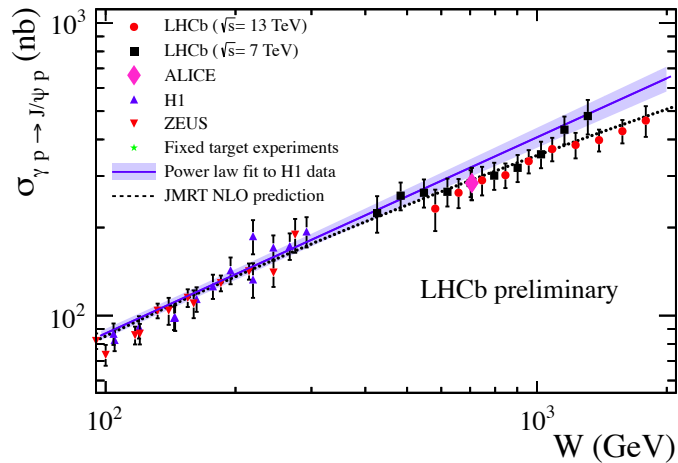
QCD mechanism tested at HERA

- Questions

Large x : Valence-like gluons?

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

Transverse distribution of quarks?



- 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 $J/\psi, \phi$: Mechanism

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

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

Medium-energy collider ideal

- EIC: Quark imaging

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

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

- VM production with diffractive dissociation $e + N \rightarrow e' + V + X$ (low-mass)

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

- Nucleon fragmentation in DIS: Conditional PDFs

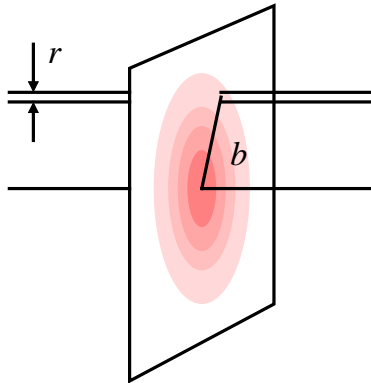
Trentadue, Veneziano 93; Collins 97

$x < 10^{-2}$: 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



- High-energy scattering of small-size color dipole

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

$\Gamma(b) \rightarrow 1$ 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

- 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 $\sqrt{s_{eN}} \sim 20\text{--}70$ GeV
- Make full use of next-generation detector capabilities
 - Forward detection of protons/neutrons/nuclear fragments
 - PID and vertex detection