EIC physics from the JLab12 perspective: Concepts and measurements

C. Weiss (JLab), INT Workshop "Gluons and the quark sea," Seattle, 16–Nov–10

Dynamics of color fields in nuclei

nuclear gluons, shadowing
saturation, strong color fields
fluctuations, diffraction

3D quark/gluon structure of the nucleon

ΔG and polarized sea
transverse distributions, orbital motion
parton correlations

Emergence of hadrons from color charge

fragmentation, "timelike QCD"
radiation/energy loss in matter

Electroweak → Talk McKeown

- Conceptual framework

  Unifying perspective JLab12 ↔ EIC

  Focus on physical system,
  not formal descriptors

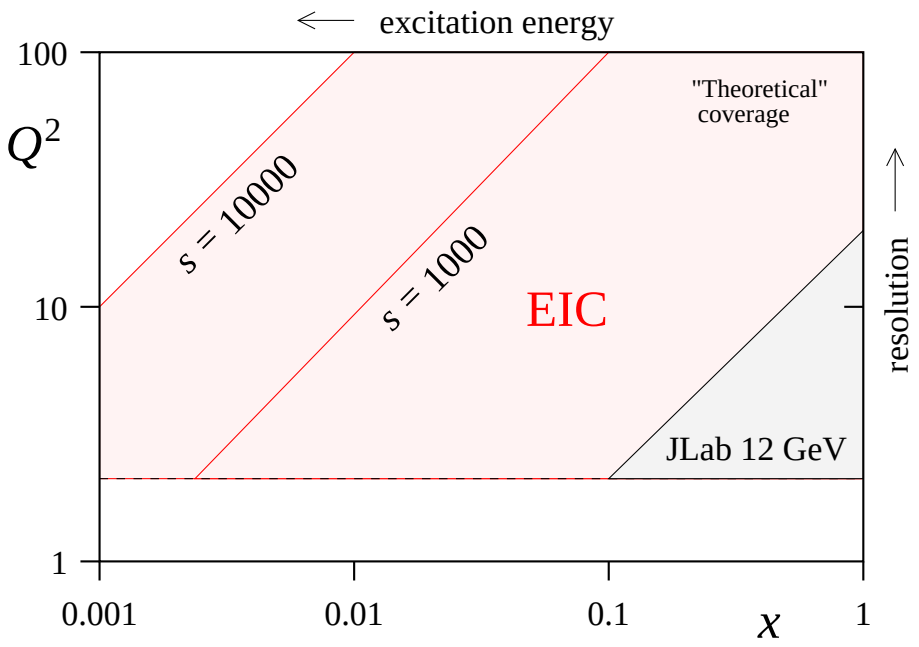
- EIC measurements "Qualitatively new"

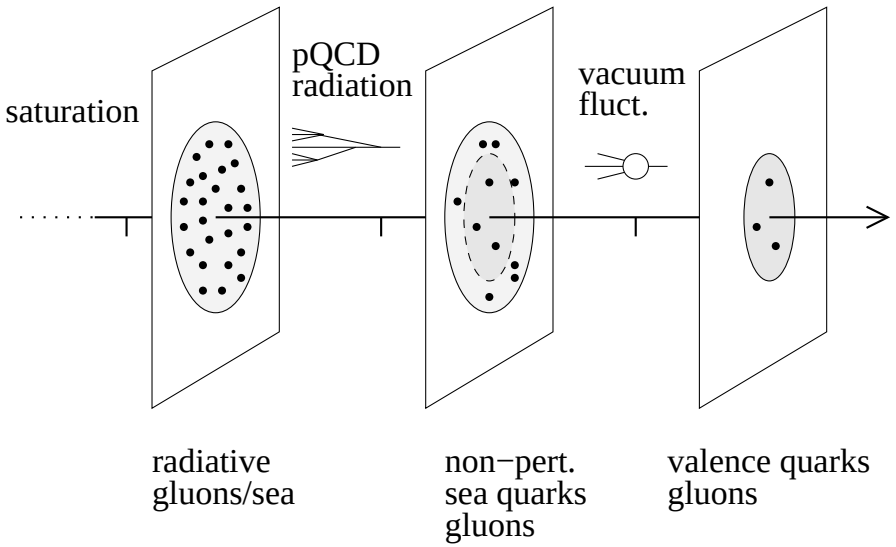
  Gluon/sea imaging with excl. mesons
  Orbital motion and target fragmentatn
  Toward parton correlations

  Color transparency
  Gluons/sea in nuclei
  Shadowing, coherent effects

Disclaimer: Emphasizes "evolutionary" aspects. No attempt at completeness. Results of other facilities folded into considerations: COMPASS, HERMES, HERA, RHIC, LHC

Nucleon structure: Physical system





- Nucleon in QCD many–body system

  Different components of wave function, particle number, effective dynamics

  "Face" changes with excitation energy and resolution scale!

- Components probed in ep

JLab 12 GeV	Valence quarks: Source, quantum numbers **few–body**
EIC	Sea quarks, gluons, Q^2 dependence **many–body**

- Physical properties

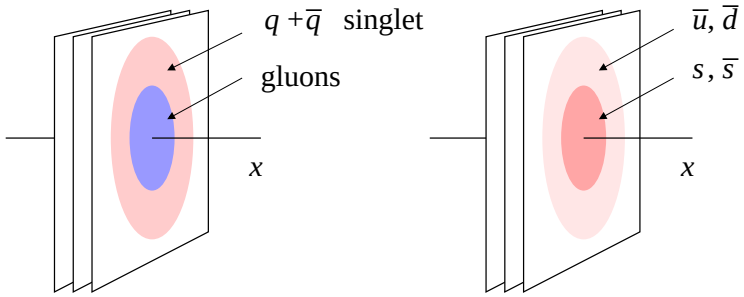
  Parton densities

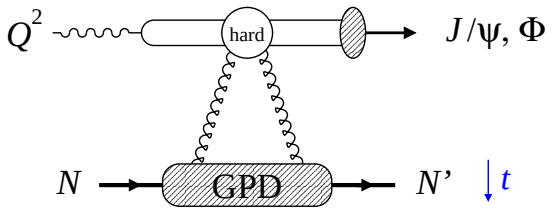
  Transverse spatial distributions

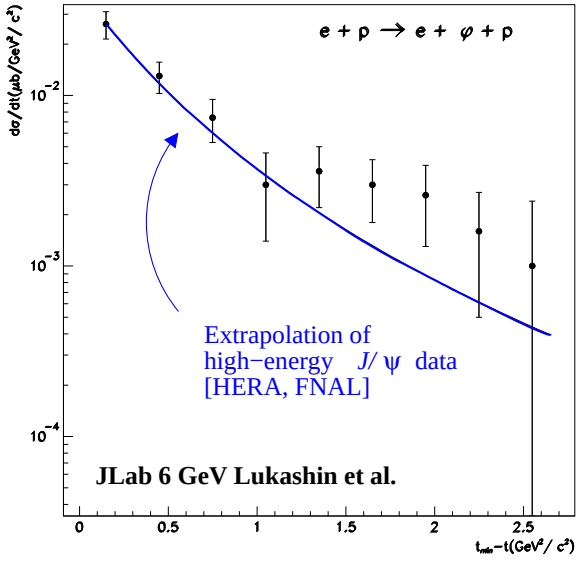
  Orbital motion, angular momentum

  Correlations

Nucleon structure: Transverse imaging







- Map transverse distribution of partons and its change with x

  Fundamental: Twist–2, lattice
  Dynamics: Diffusion, vacuum structure
  Essential for pp@LHC, multiparton processes

- Hard exclusive processes

$J/\psi, \phi$	gluons selective!
γ, ρ^0	gluons + singlet quarks
ρ^+, K^*, π, K	non-singlet quarks

  Finite–size effects interesting, under exp. control
  HERA: $Q^2 \sim 10\,\mathrm{GeV}^2$ for small–size regime

- JLab12: Valence quarks with DVCS

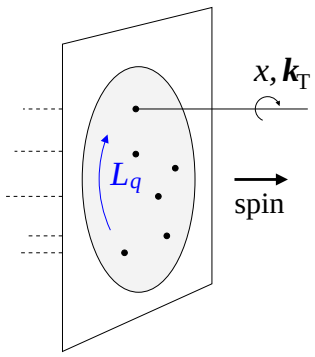
  Meson production: Precise data incl. L/T, but difficult to control reaction mechanism

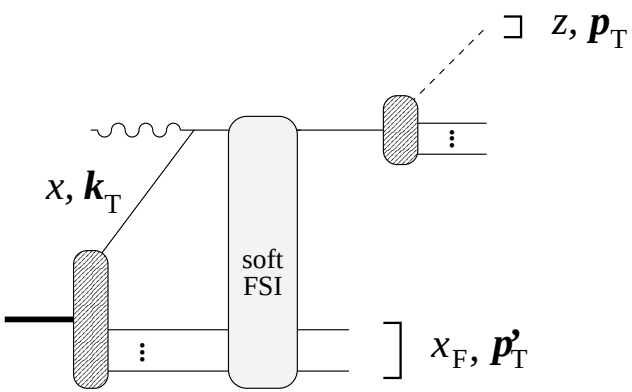
  Gluon imaging with exclusive ϕ: Much interest!
  6 GeV results consistent with high-energy t–dependence

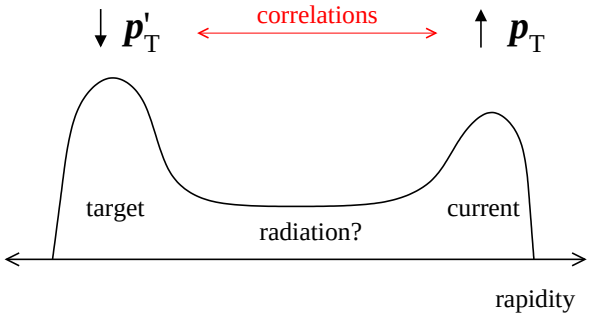
- EIC: Imaging gluons and sea quarks with meson production

  Detailed simulations available → Diehl, Burkardt, Guzey, Sabatie

Nucleon structure: Orbital motion







- Explore quark/gluon orbital motion and its polarization dependence

  Non-pert. dynamics: Confinement, spin-orbit forces
  Orbital angular momentum → large–x PDFs, form factors

- Semi-inclusive DIS p_T dependence

  Cannot separate intrinsic k_T in WF from soft final–state interactions and fragmentation
  TMDs combine intrinsic k_T and FSI

  New insight from p'_T of target fragments:
  Origin of FSI? QCD radiation?

- JLab12: Polarized SIDIS in valence region

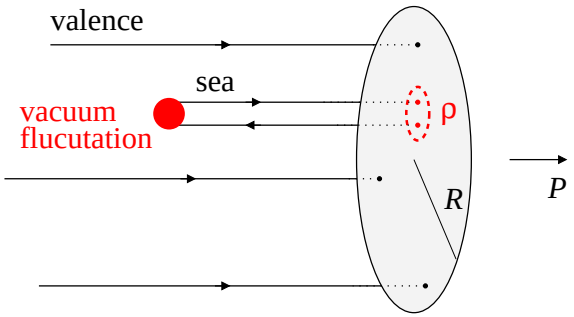
  Limited phase space for fragmentation,
  separation target ↔ current region

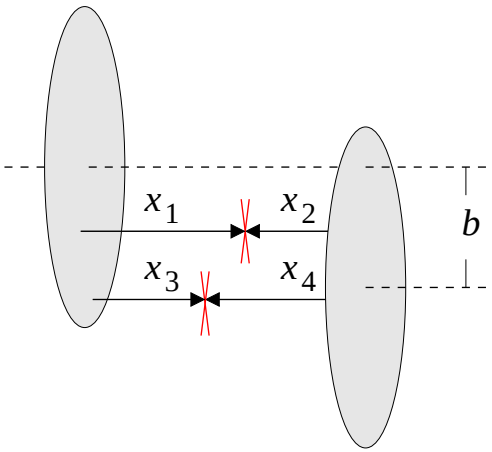
- EIC: Wide kinematic range, low ↔ high p_T

  Aim for current–target correlation measurements!

  OAM: Comprehensive approach based on TMDs, form factors, GPDs . . . model–dependent!
  Needs JLab12 and EIC for data + interpretation

Nucleon structure: Correlations





- Explore correlations in nucleon's partonic WF

  Next step after one–body densities

  QCD vacuum structure, non-pert. scale $\rho \ll R_{\rm had}$

  Cf. short–range NN correlations in nuclei JLab Hall A, CLAS

- Multiple hard processes in pp indicate substantial correlations

  CDF 3 jet + gamma consistent with $\rho \sim 0.3\,\mathrm{fm}$

  LHC: High rates for multijets events, great interest
  New field of study! Background to new physics

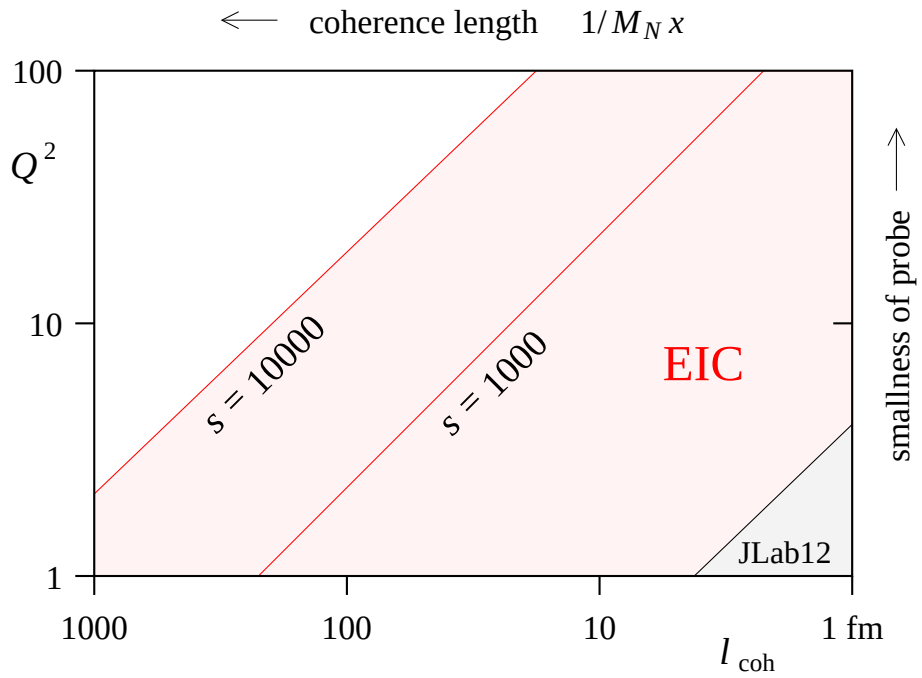
- JLab12: Higher twist in incl. DIS g_1, g_2, F_2, F_L

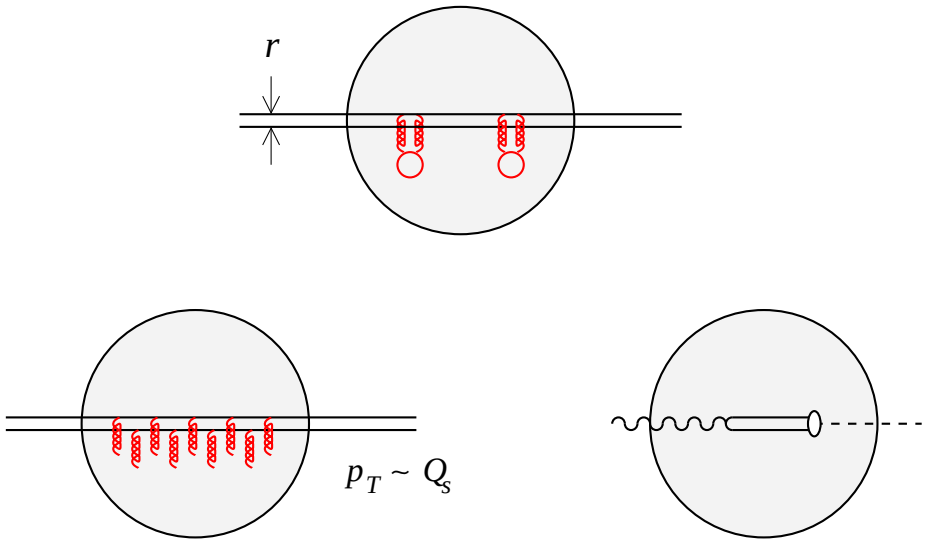
- EIC: Several possibilities Need to think!

  Transverse distributions essential input to pp analysis

  GPDs in ERBL region from Re(DVCS):
  Distribution amplitude for $q\bar{q}$ pair in nucleon
  Twist–2, lattice results. Information on number of pairs, not ρ

Color fields in nuclei: Physics





- Explore dynamics of color fields in nuclei

  Fields change with energy!
  QCD radiation, self–interaction
  Coherence effects $A \neq \sum N$

  Interaction of small–size high–energy probe with nucleus

- QCD phenomena

  Color transparency: Gauge theory

  Gluon shadowing: QM coherence

  Saturation: Strong gluon fields,
  new dynamical scale Q_s,
  "black disk regime"

  Diffraction: Quantum fluctuations

Color fields in nuclei: Measurements

- Color transparency

  JLab12: Onset of CT in meson electroproduction $A(e, e'M)X$
  Formation length $\sim 1 - 2\,\mathrm{fm}$, expansion/hadronization inside nucleus
  CLAS 6 GeV ρ^0 data Hafidi et al.

  EIC: Definitive tests of CT through vector meson production
  Wide range of coherence lengths $l_{\mathrm{coh}} \gg R_A$ and Q^2
  Fundamental QCD prediction! Necessary to establish transparency before studying opacity/blackness

- Nuclear gluon densities and shadowing

  JLab12: EMC effect in valence region

  EIC: Nuclear gluon from Q^2 dependence,
  Leading $\leftrightarrow$ higher–twist mechanisms of nuclear shadowing
  Fundamental quantum–mechanical coherence effect!
  Necessary input for saturation in eA, hard processes in AA at RHIC, LHC

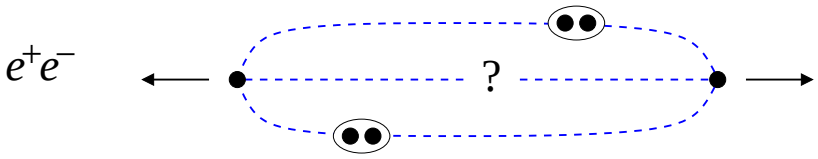
- Gluon radii of light nuclei

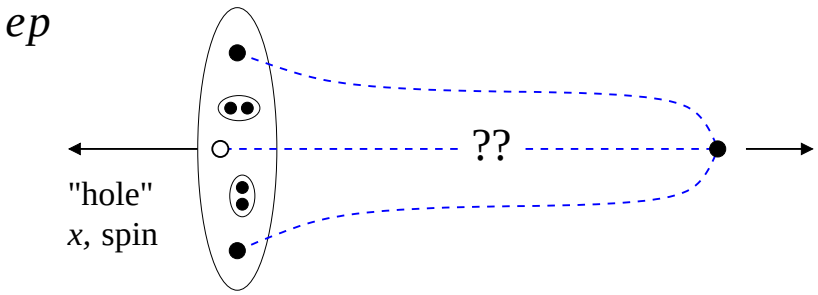
  JLab12: Quark matter radius of $^4\mathrm{He}$ with coherent DVCS

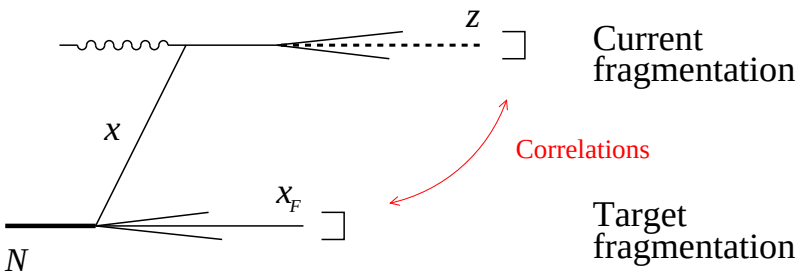
  EIC: Gluonic radii of light nuclei with exclusive J/ψ
  Fundamental QCD characteristic! QM coherence effect

- Saturation $\rightarrow$ Talks Kovchegov, Dumitru, Accardi, Lamont, Marquet

Emergence of hadrons: Physics







- Understand emergence of hadrons from color charge in QCD

  Conversion energy $\rightarrow$ matter

  Dynamical mechanisms: QCD radiation, pair creation by soft fields

  Vacuum structure: $q\bar{q}$ condensate

- e^+e^-: Fragmentation functions

  Essential input to SIDIS

  Many puzzles: $s\bar{s}$, kaons, baryons

- ep: Target fragmentation

  How does nucleon with "hole" materialize? x, spin dependence

  Correlations current–target, e.g. K–Λ

  Unfavored fragmentation functions, charge separation

New, unexplored! Many applications. Unique for EIC

Summary

- Emerging physics narrative for main themes of EIC program

  Focus on dynamical system at the center:
  Degrees of freedom, spatial extent, motion, interactions
  Connect with condensed matter, low-energy nuclear, and astrophysics. Needs further development!

- Qualitatively new probes available with EIC

Exclusive meson production	gluon imaging $x > 0.01$, sea quarks
Target fragmentation	k_T dependence, correlations, nucleon breakup
High-energy nuclear scattering	nuclear gluons, shadowing, saturation

- JLab12 and EIC — complementary and interdependent

  EIC can establish reaction mechanism and QCD description of exclusive and semi-inclusive processes. JLab12 will provide precise data in valence region.
  Both needed for orbital angular momentum, spin–orbit interactions, imaging of valence–like gluons