Nuclear physics with JLab12 and EIC

C. Weiss (JLab), EIC Users Meeting, Stony Brook U., 24-Jun-2014 Jefferson Lab

Focus on physical system

Components probed at different energies

Unifying perspective large x — small x

Complementarity & synergies

Mutual benefits from broad coverage

Global questions: QCD evolution, angular momentum

- 3D nucleon structure

  Valence quarks $\longrightarrow$ sea quarks, gluons

  Spin/flavor densities

  Spatial distributions

  Orbital motion

- Color fields in nuclei

  Local properties $\longrightarrow$ coherent fields

  Quarks/gluons in bound nucleon

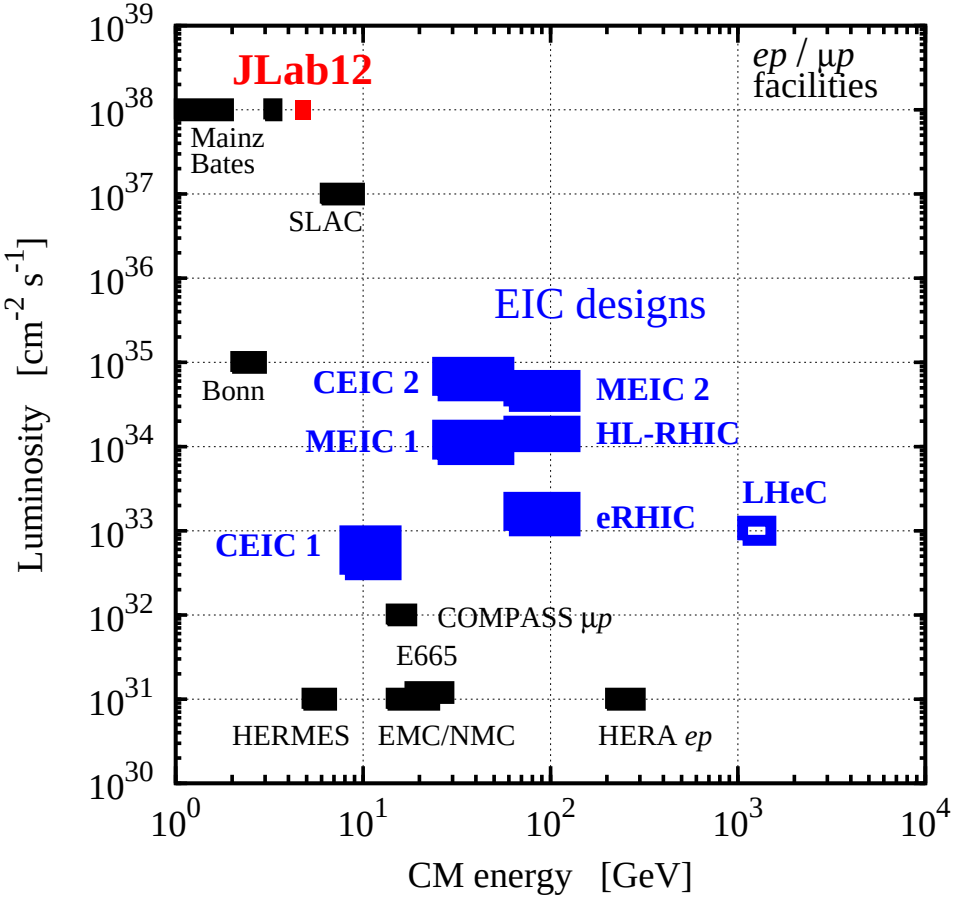
  Coherence, shadowing, saturation

- Other topics

  Hadrons from color charge: $\rightarrow$ Talk W. Brooks
  Fragmentation, medium effects

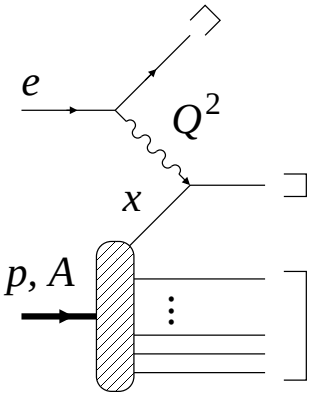
  Electroweak probes $\rightarrow$ Talk K. Kumar

Energy–luminosity frontier



[Summary plot M. Klein 4/2014]

JLab12 and **EIC** extend luminosity frontier in different energy regions



- Scattering energy

  Resolution scale $1/Q$

  Light-cone fraction x: Target configurations, types of constituents

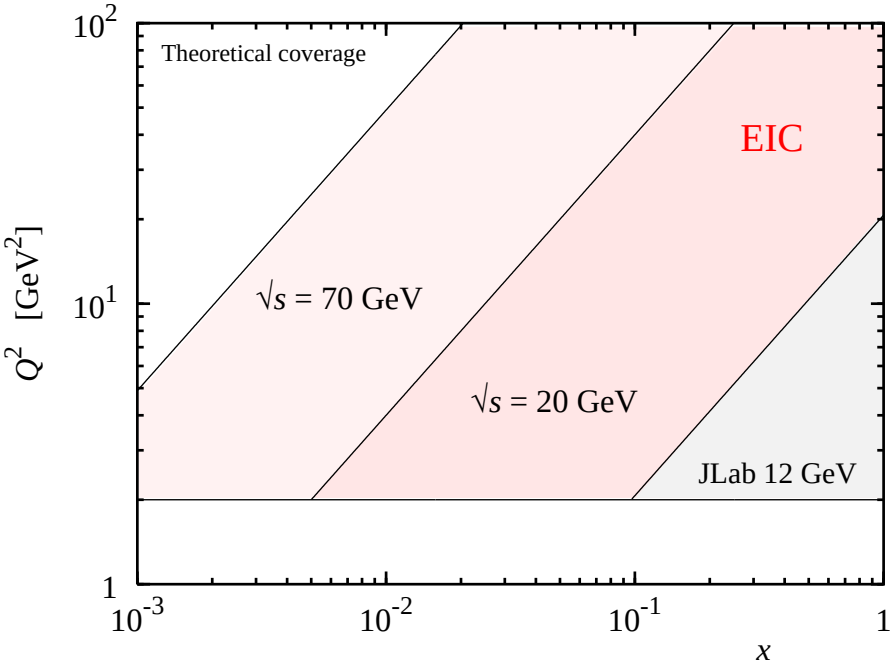
- Luminosity

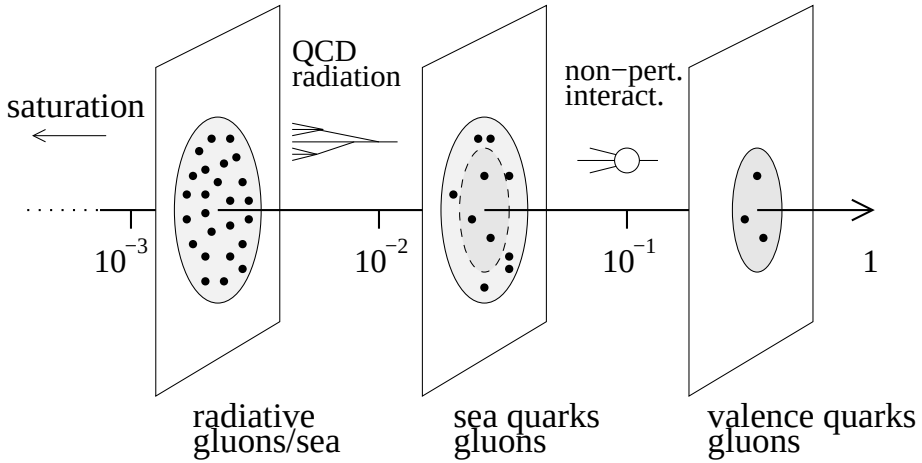
  Exceptional configurations, rare processes

  Multi-variable final states

  Polarization effects

Nucleon: QCD structure





- Relativistic many–body system

  Particle number changes with energy and resolution scale!

  JLab 12 GeV: Valence quark component, incl. $x \to 1$

  EIC: Sea quarks, gluons, scale dependence

- Physical charateristics

  Quark/gluon number densities, incl. spin and flavor dependence — PDFs

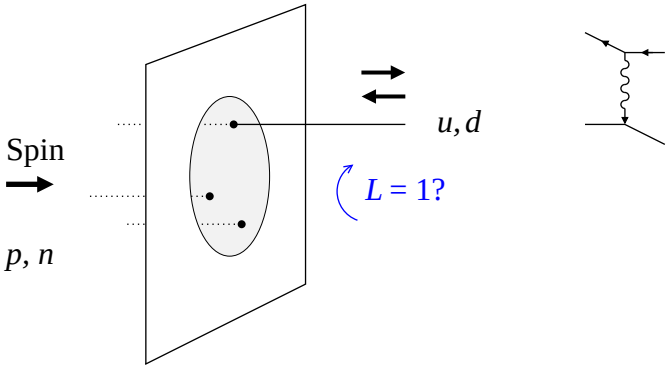
  Transverse spatial distributions — GPDs

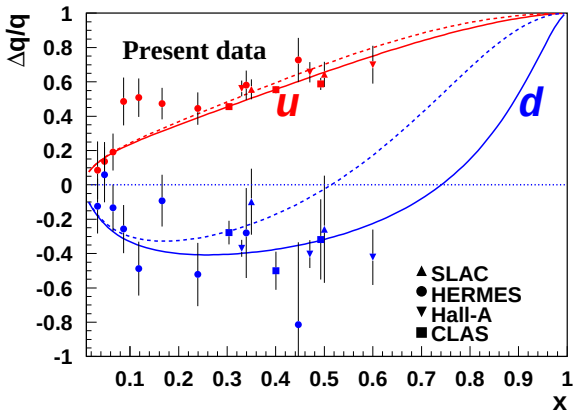
  Orbital motion — TMDs

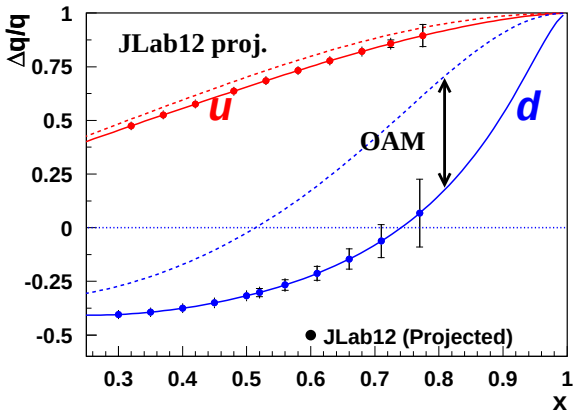
  Multiparticle correlations — GPDs, higher twist

Learn about dynamics!
Densities with operator definition $\langle N|\,\mathrm{QCD\text{–}Op}\,|N\rangle$
Calculable with non–perturbative methods, LQCD

Nucleon: Valence quark polarization







- How are valence quarks in nucleon polarized at $x \to 1$?

  Basic $3q$ component of nucleon wave fn

  Non–perturbative QCD interactions?

  Orbital angular momentum L $= 1$?

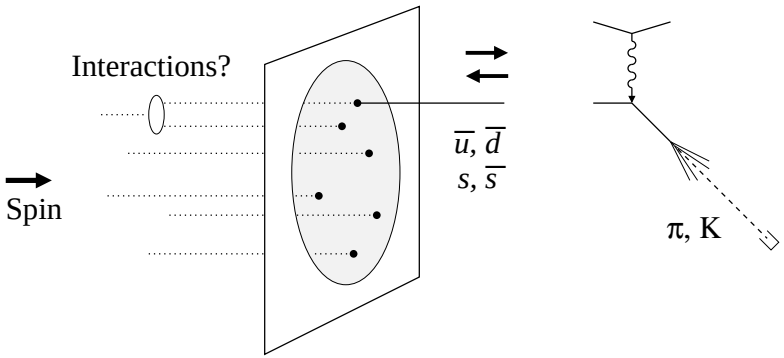
  Poorly constrained by present data
  SLAC, HERMES

- JLab12: Map u, d quark polarization precisely up to $x \sim 0.8$

  Inclusive DIS with p and n targets

  Combination of energy and luminosity!
  Many more applications: Spatial imaging, orbital motion

Nucleon: Sea quark polarization

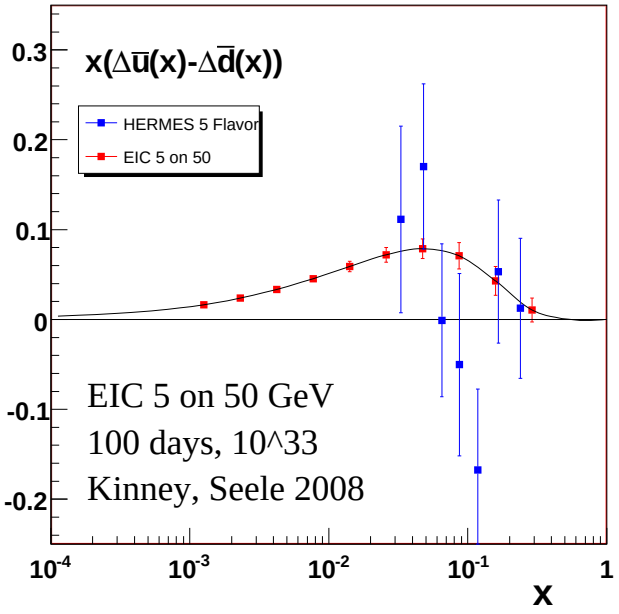


- How are sea quarks polarized?

  Non-perturbative QCD interactions connecting valence ↔ sea quarks?

  Flavor asymmetry related to mesonic degrees of freedom?
  "Pion cloud"

  First hints of $\Delta\bar{u} > \Delta\bar{d}$ from RHIC $W^{\pm}$



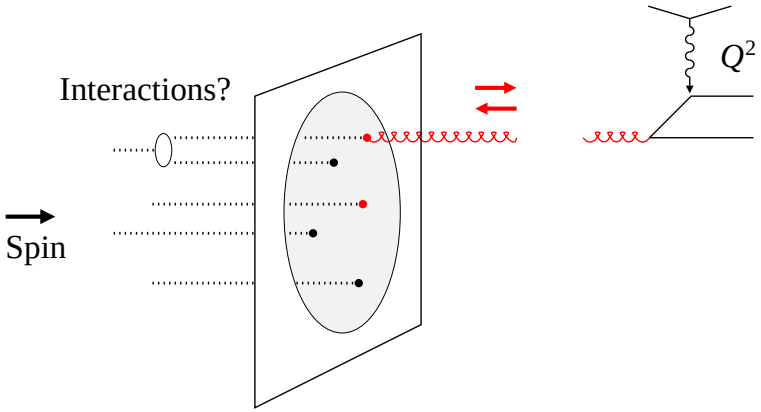
- EIC: Map sea quark spin/flavor distributions with semi-inlusive DIS
  → Talk X. Jiang

  Tag charge/flavor of struck quark

  High energy ensures independent fragmentation of struck quark; luminosity for multi-dimensional binning

  Measure also quark fragmentation functions: Unfavored vs. favored
  Universal, can be used also for large x

Nucleon: Gluon polarization

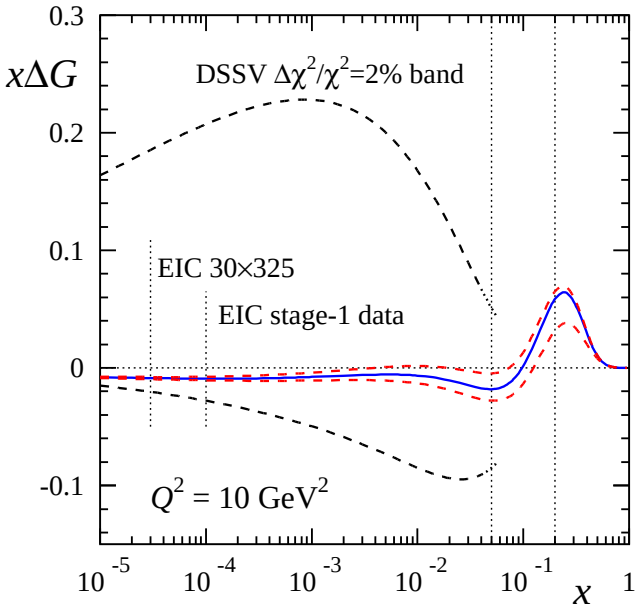


- How do gluons respond to nucleon spin?

  Origin of non-perturbative gluon fields?

  Gluon contribution to nucleon spin?
  Orbital angular momentum?

  Constrained by Q^2 dep. of $g_1(x, Q^2)$,
  hard processes in $\vec{p}\vec{p}$ EMC/SMC, SLAC,
  HERMES, COMPASS, JLab 6/12 GeV. RHIC Spin



M. Stratmann, INT Workshop 2010

- EIC: Definitive measurement of gluon polarization in inclusive DIS

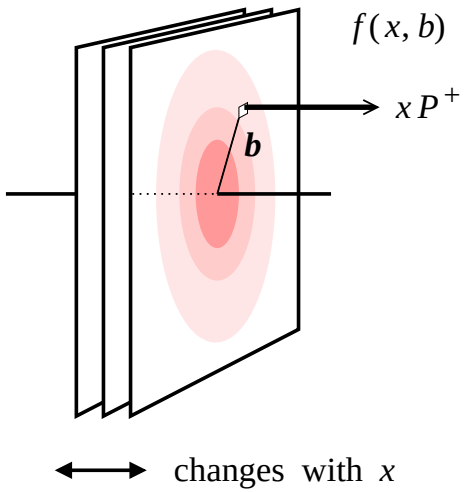
  Wide kinematic coverage enables
  study of Q^2 evolution

- Synergies EIC $\leftrightarrow$ JLab12

  Global QCD fits incl. large–x data
  JAM Collaboration: Melnitchouk et al.

  Orbital angular momentum
  $\rightarrow$ Discussion

Nucleon: Spatial distributions

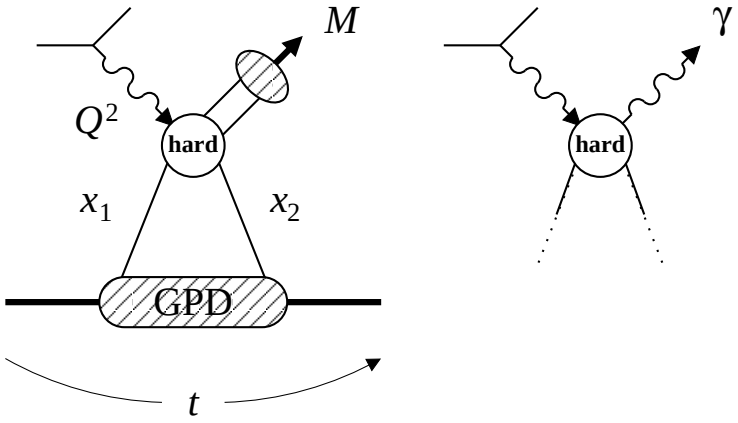


- How are quarks/gluons distributed in transverse space?

  Fundamental size and "shape" of nucleon in QCD
  Leading–twist, calculable in LQCD

  Distributions change with x:
  Chiral dynamics, QCD radiation

  Hard exclusive processes $\gamma^* N \to M + N$:
  GPDs $\equiv$ partonic form factors of nucleon



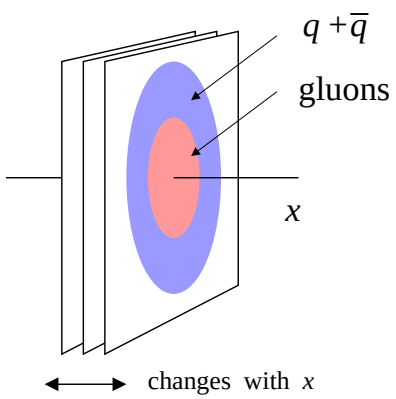
- JLab12: Valence quark imaging with exclusive processes

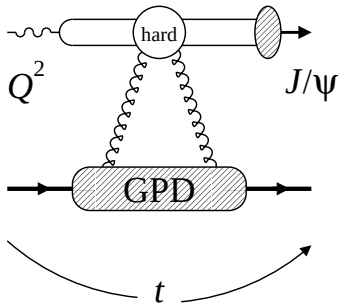
  DVCS $\gamma^* N \to \gamma + N$: Extensive program,
  GPDs from polarization observables

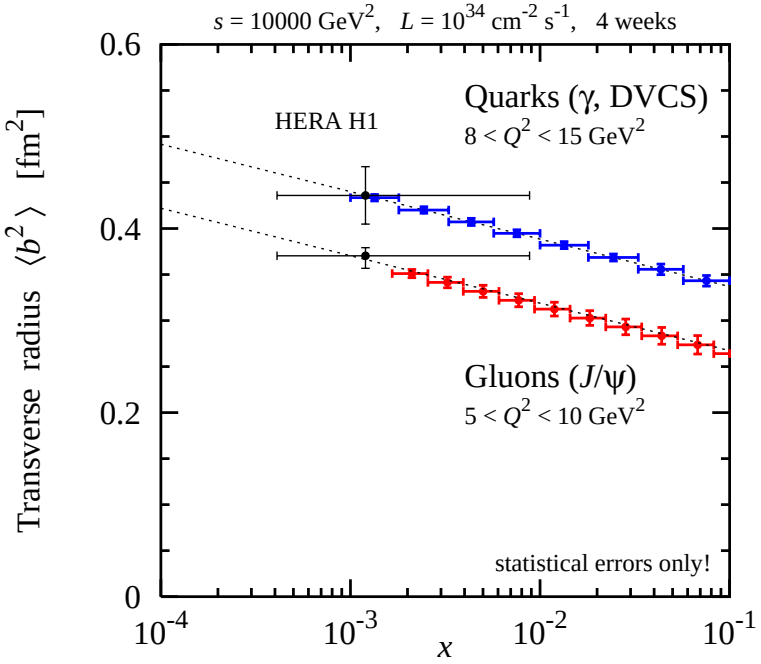
  Mesons: Quark transversity with π^0/η,
  large–x gluons with ϕ

  Precise observables, but limited phase space
  Reaction mechanism? Leading $\leftrightarrow$ higher twist?

Nucleon: Spatial distributions







- EIC: Quark/gluon imaging at $x < 0.1$

  J/ψ: Gluon imaging. Clean probe. Input for saturation models, multiparton interactions in pp@LHC

  DVCS: Quarks/gluons, polarization Dispersion analysis, model-independent
  Combination of JLab12 and EIC data → Talk Fazio

  Light mesons: Non-singlet quarks
  π^+, π^0 polarized quarks
  ρ^+, K^{*+} flavor non-singlet
  Selective, unique, never measured!

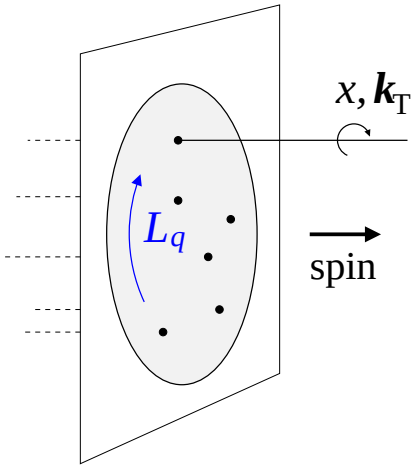
- Synergies JLab12 ↔ EIC

  Wide coverage helps to unravel exclusive reaction mechanism

  x, Q^2 evolution of transverse distributions

  Global analysis of DVCS data

Nucleon: Orbital motion



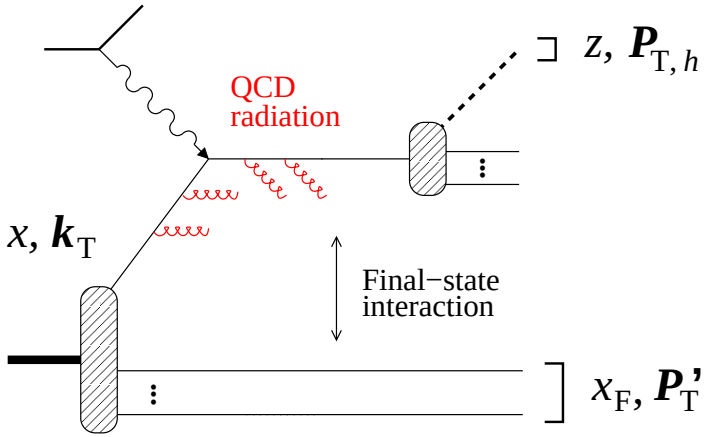
- Transverse motion of quarks/gluons?

  Non-pert. dynamics, spin-orbit forces, orbital angular momentum?

  Observable hadron $P_{T,h}$ compounded from intrinsic k_T of quark, QCD radiation, fragmentation process: How separate?
  Theoretical progress: TMD factorization, evolution

- JLab12: Semi-incl DIS in valence region

  Precise observables, but limited phase space



- EIC: Wide kinematic range for SIDIS

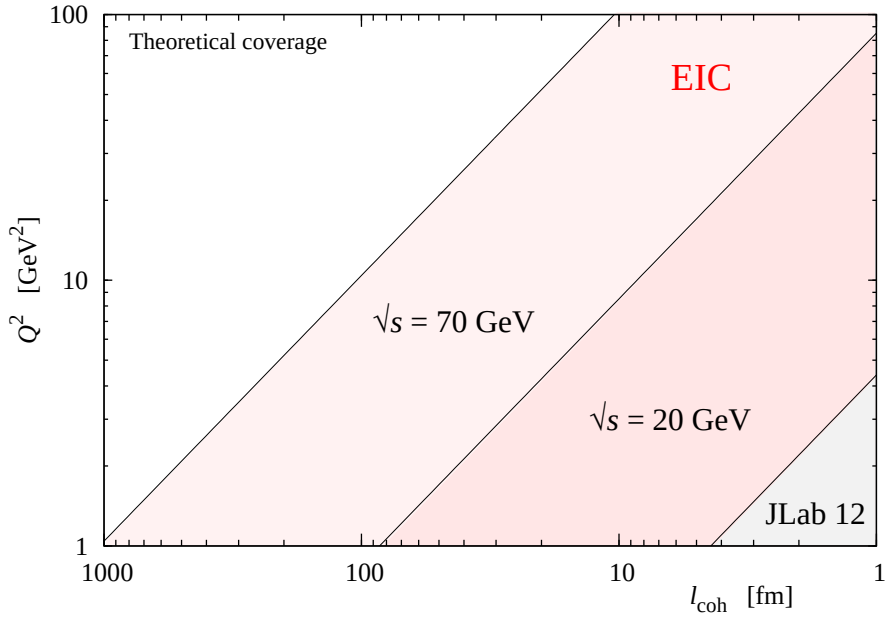
  QCD–based mechanism, low $\rightarrow$ high $P_{T,h}$

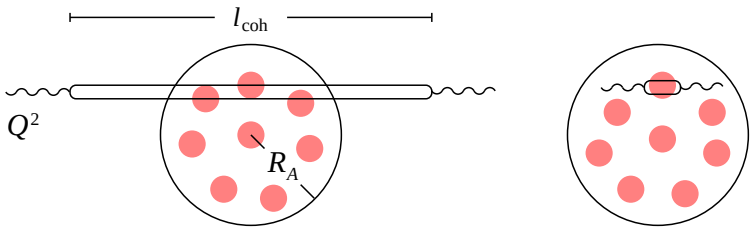
  Q^2 evolution, QCD radiation

  Target fragmentation and correlations: New information on nucleon structure!

- Synergies JLab12 $\leftrightarrow$ EIC

Nuclei: Color fields





- Small–size probe of color fields

  Color fields change with energy and probe size!

- JLab 12: Coherence length short

  Quark structure of bound nucleon

  Short–range NN correlations, $x > 1$

- EIC: Wide range of probe size and coherence length

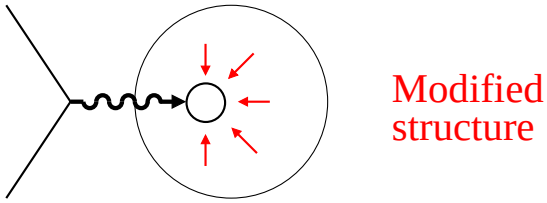
  Nuclear sea quarks and gluons

  Collective color fields in nuclei: Shadowing, diffraction

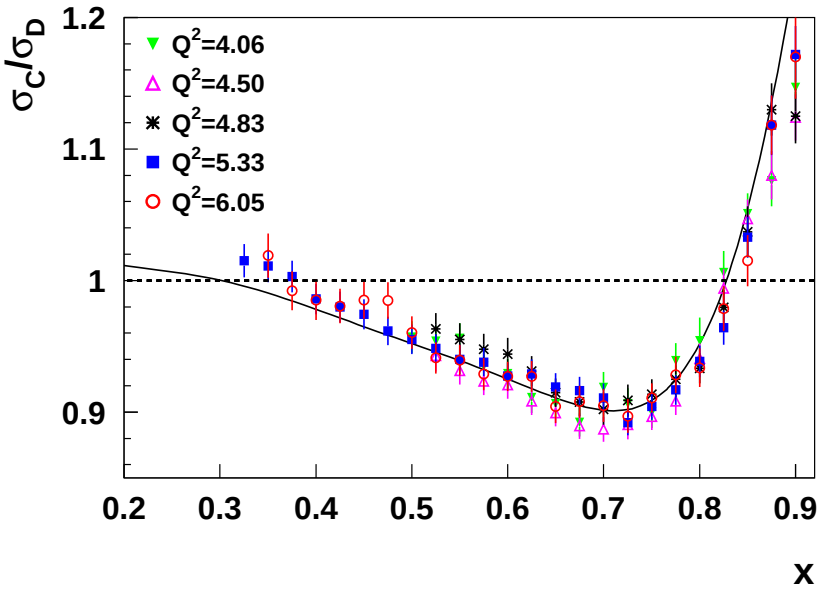
  High gluon densities, saturation

  Explore short-range nuclear structure and coherent QCD phenomena!

Nuclei: Bound nucleon structure



⟵ Fermi motion ⟶



JLab 6 GeV: Seely et al. 2009.
Extended measurements with 12 GeV

- How are the nucleon's quark/antiquark distributions modified in the nucleus?

  Modification caused by "mean field" or short–range NN correlations?

  QCD origin of NN interaction?

- JLab 6/12 GeV: Inclusive $eA \to e' + X$

  σ_A/σ_D ratio shows modification

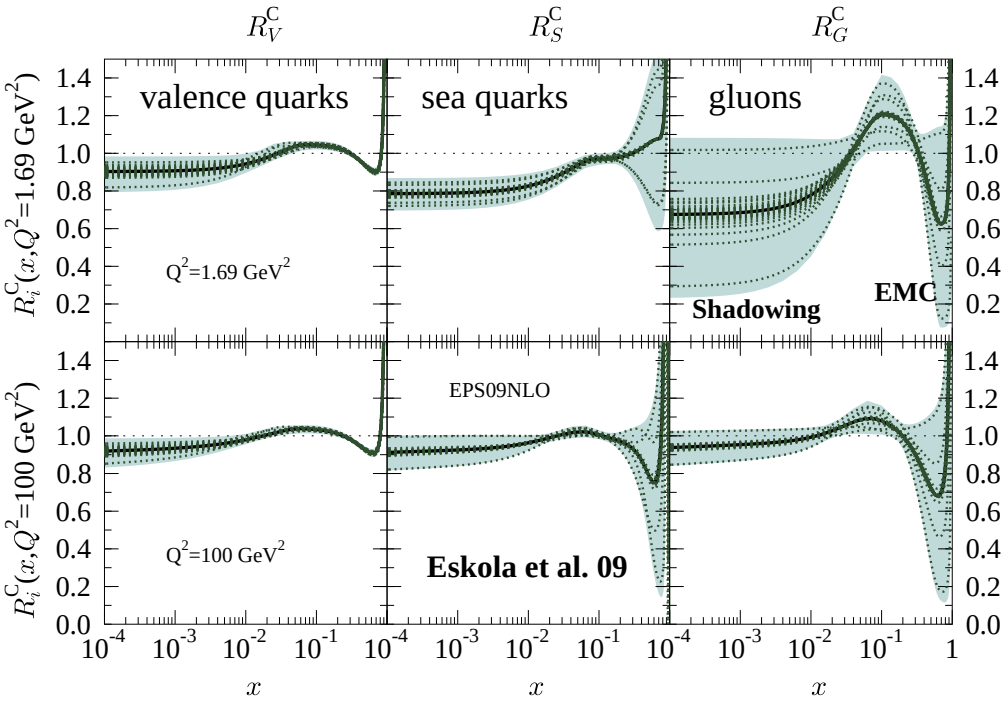
  Spectator tagging $eA \to e' + N + X$: Short-range correlations?

  Spin/isospin dependence: Polarized nuclei, different A

- Other measurements

  SRCs with $x > 1$, quasi-elastic $e(e'N)X$

Nuclei: Sea quarks, gluons, coherence

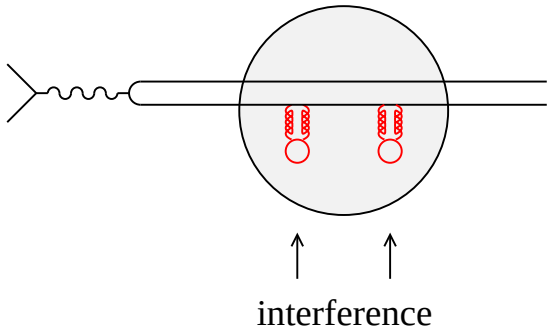


- EIC: Nuclear quark and gluon densities

  Sea, gluons poorly known!

  Wide coverage in x, Q^2

  Synergies 12 GeV – EIC: Normalization of nuclear cross sections, global QCD fits

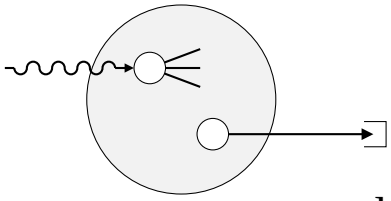


- Shadowing at $x \ll 0.1$

  Coherent scattering from $N > 2$ nucleons
  Fundamental QCD prediction, related to diffraction

  Important for understanding approach to saturation at small x

Nuclei: Final states



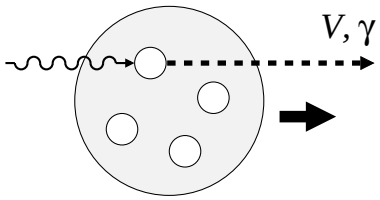
tagged

- Spectator tagging $D(e, e'p)X$

  Neutron structure, bound nucleon

  JLab12: Unpolarized D, CLAS BONUS detector

  EIC: Polarized D, forward p/n detection
  Great potential! JLab 2014 LDRD project → Talk Kijun Park

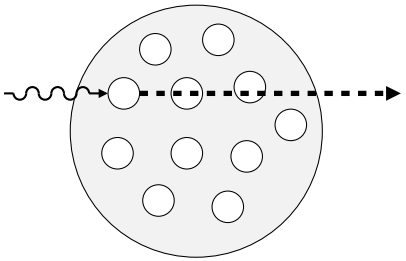


coherent

- Coherent nuclear processes $A(e, e'M)A$

  JLab12: GPDs of light nuclei, matter distibution

  EIC: Impact parameter dependent shadowing
  Guzey et al.; Kowalski, Caldwell 09. Heavy nuclei very challeging



transparency

- Color transparency in meson production

  Fundamental prediction of QCD!

  JLab12: Hadron formation inside nucleus,
  onset of color transparency

  EIC: Wide range of formation length
  and probe size, detailed CT studies
  Complement saturation experiments: "Disappearance" at high Q^2

Summary

- JLab 12 and EIC complementary

  JLab12: Valence quark region in eN; single–nucleon structure in eA

  EIC: Sea quarks, gluons, Q^2 dependence in eN; coherent fields in eA

- Synergies in global physics questions

  GPDs/TMDs: Wide range of EIC will establish/refine QCD–based description; physics analysis with both JLab12 ($x > 0.1$) and EIC data

  Orbital angular momentum: Form factors/large–x PDFs from JLab12, inclusive ΔG from EIC

  Nuclear structure functions: x, Q^2 dependence from EIC; normalization from JLab12 and other expts

  . . . more examples!

- JLab Users increasingly involved in EIC R&D

  Natural next step after JLab12