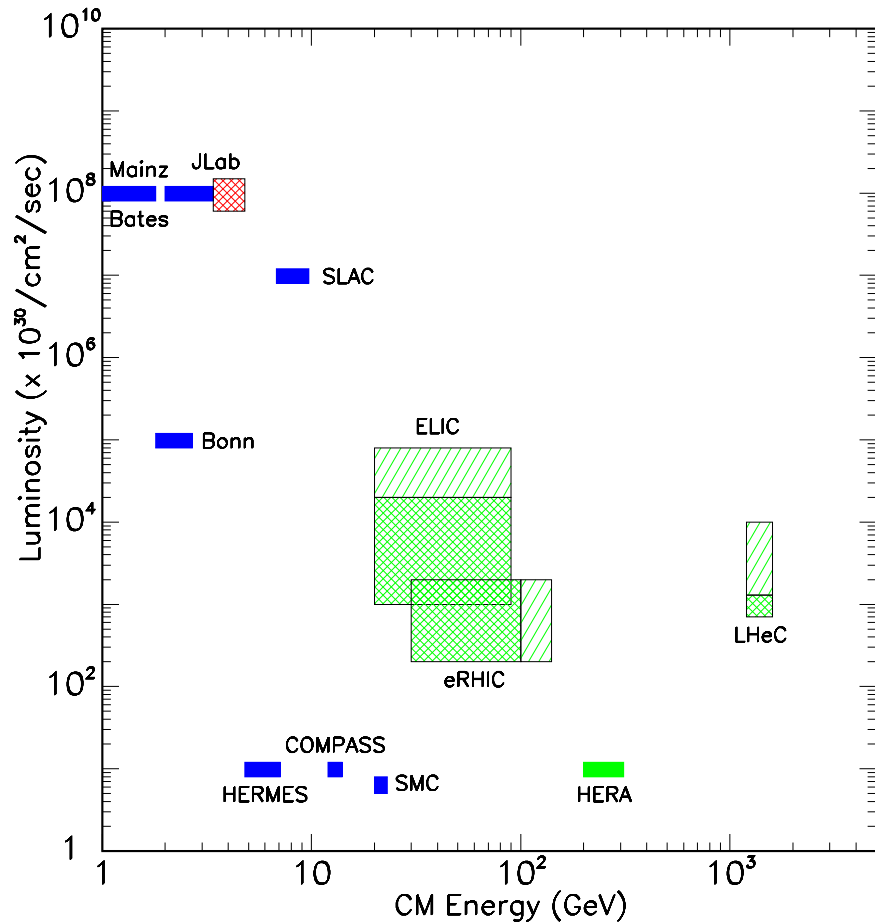


# Physics of the JLab 12 GeV Upgrade

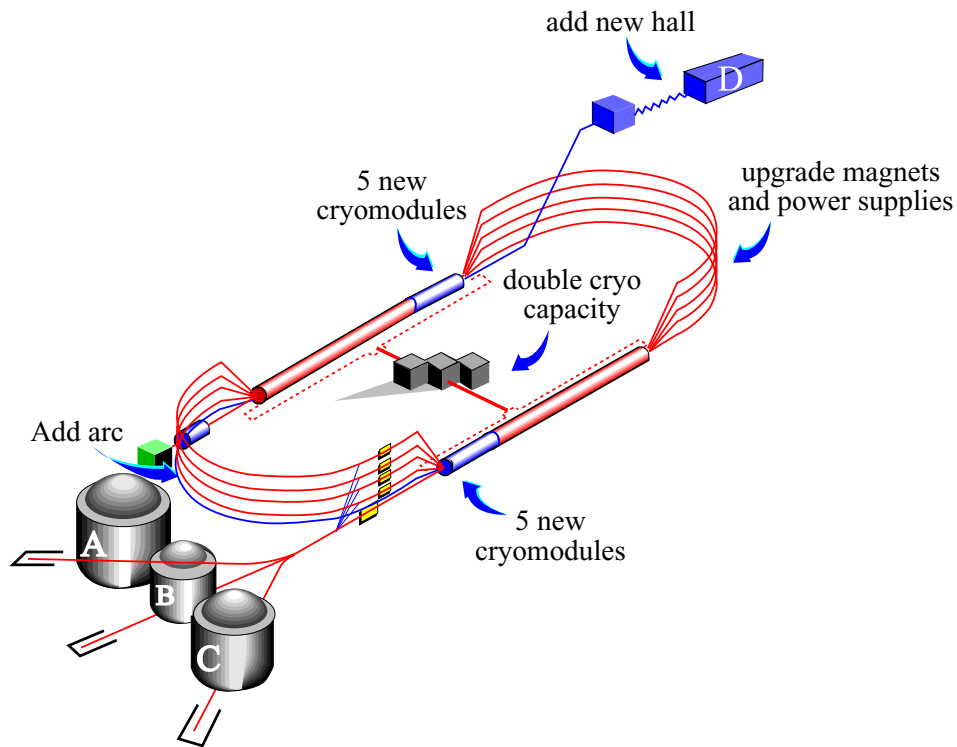
C. Weiss (JLab), EIC Workshop, INT Seattle, 19–Oct 2009



Luminosity	low-rate processes
Energy	short distances

- I) Gluonic excitations in meson spectrum
- II) Nucleon structure: Parton densities, \* spatial distributions (GPDs, form factors), orbital motion (TMDs), excited states
- III) Nuclei in QCD: Short-range correlations, \* color transparency, EMC effect
- IV) Electroweak physics: SM parameters, parity-violating form factors, DIS

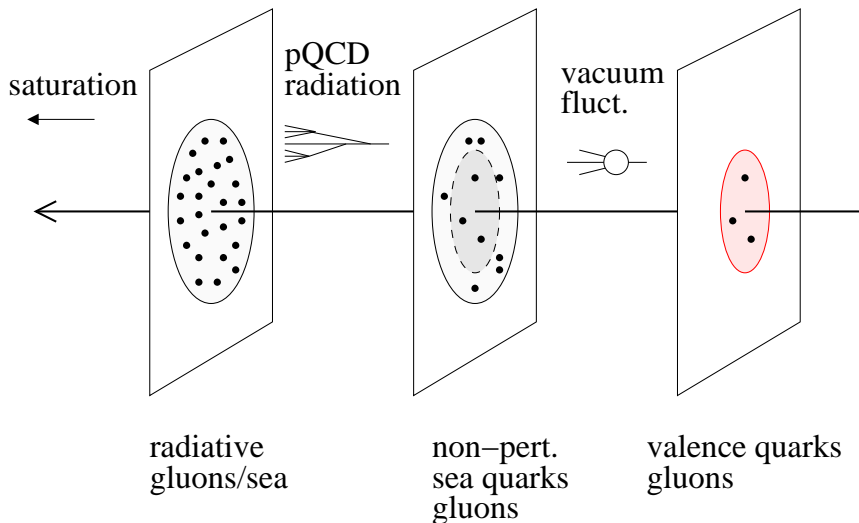
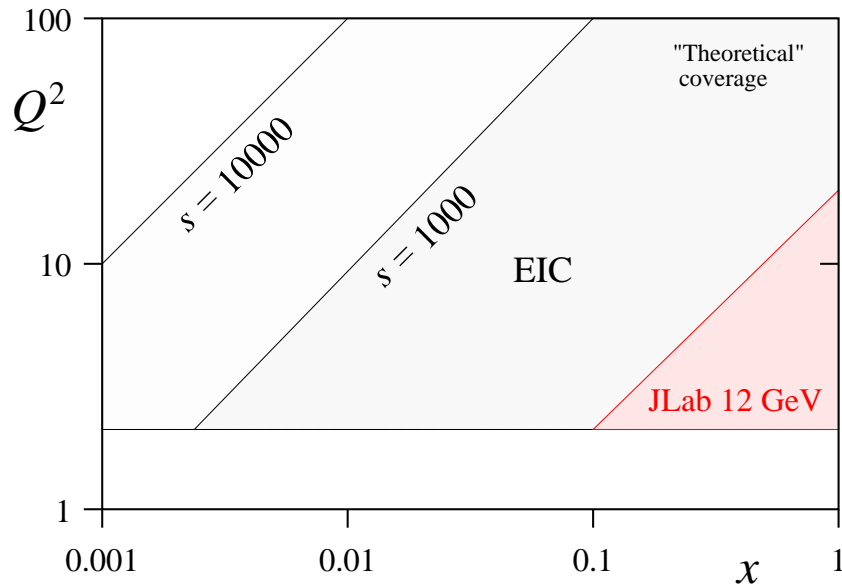
# JLab and 12 GeV Upgrade



CW beam  $\sim 100 \mu A$   
Present beam energy 6 GeV  
Operating since 1994

- “Race track” accelerator with linacs + arcs, extensible to 24 GeV
  - Uses unique superconducting RF technology + energy recovery
  - Experimental halls
    - A, C Magnetic spectrometers
    - B Large acceptance CLAS
  - 12 GeV Upgrade
    - Double beam energy 6  $\rightarrow$  12 GeV
    - Add Hall D ( $\gamma$  beam, GlueX detector)
    - Upgrade existing halls
- DOE project (CD0 2004, CD3 2008)  
Construction started, beam exp. 2013  
Total cost  $\sim 300M\$$

# Nucleon structure: Landscape



- Nucleon in QCD many-body system: Different components!

- JLab 12 GeV: Valence region

Quantum numbers: Spin, flavor

Non-perturbative dynamics

“Source” of sea quarks, gluons  
→ vacuum structure, radiation

- Measurable properties

Parton densities

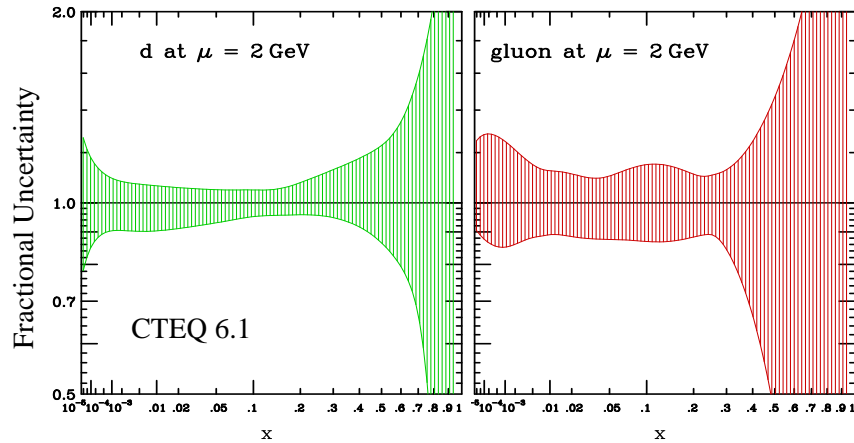
Transverse spatial distributions: GPDs, FFs

Orbital motion: TMDs, angular momentum

Correlations: “Higher twist”

- EIC: Sea quark, gluons  
Small- $x$  dynamics, saturation

# Nucleon structure: Large $x$



- Global fits: Large uncertainties in  $d$  quark, gluon at  $x > 0.4$

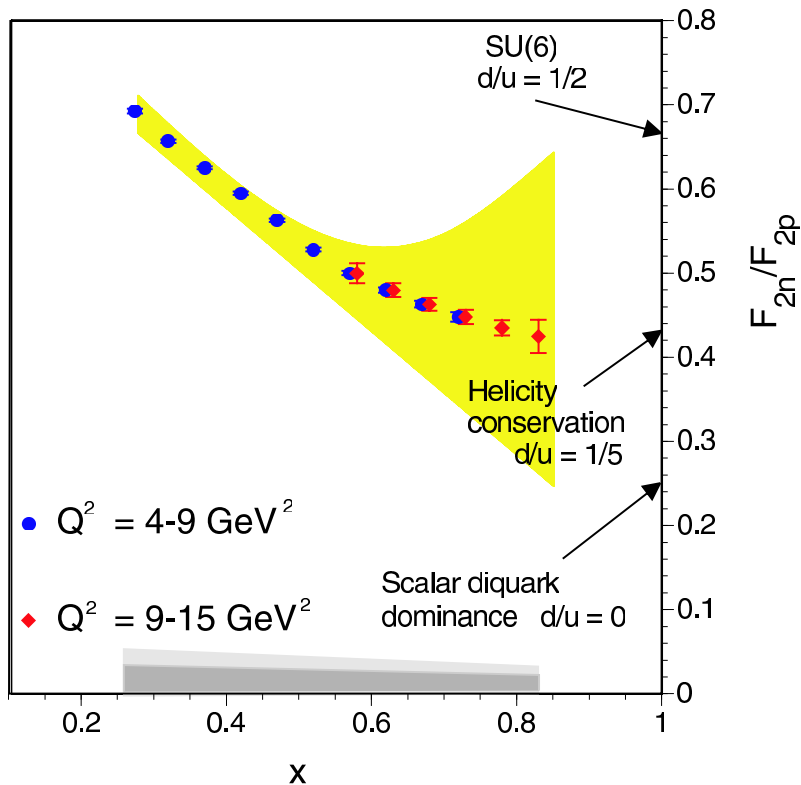
CTEQ, MSTW, GJR, Alekhin

- JLab 12 GeV: Large- $x$  inclusive structure functions . . . unique!

$d/u$  from neutron DIS with spectator tagging

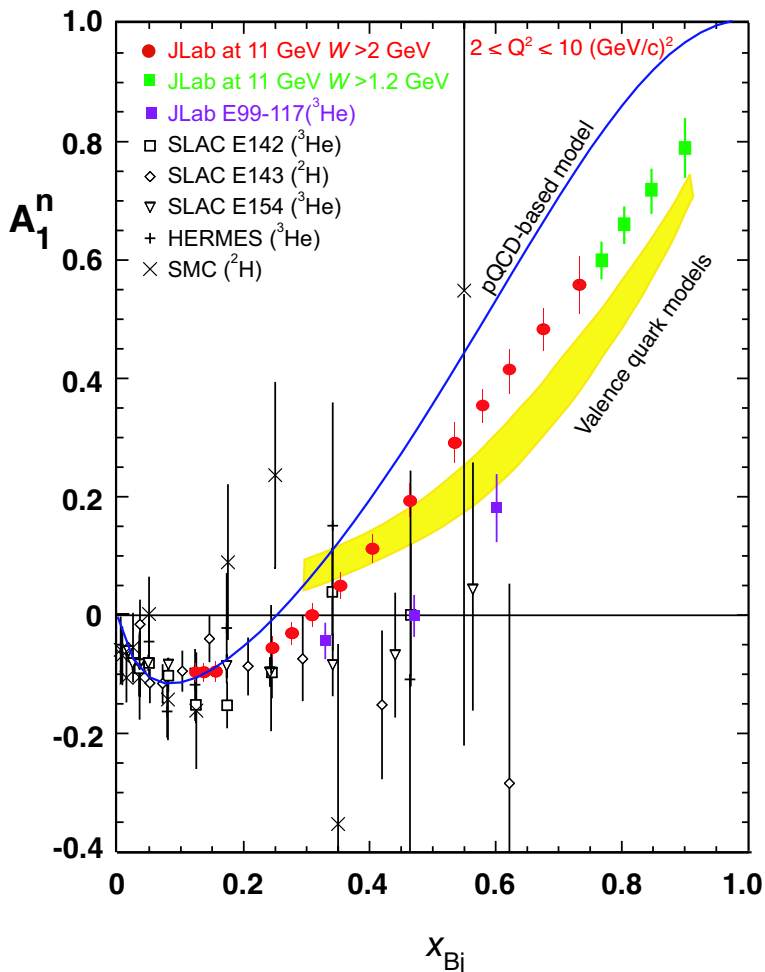
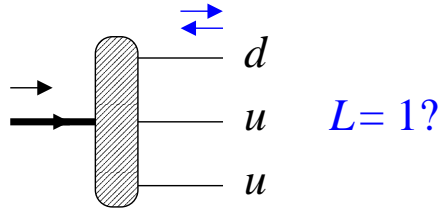
Dynamics governing basic  $3q$  configuration of nucleon

Global fits  $\rightarrow$  gluon, sea  
High-mass jets at LHC



- EIC: Charm as direct probe of gluons at  $x > 0.1$ ?

# Nucleon structure: Spin



- JLab 12 GeV:  $d$  quark polarization from neutron spin structure

$3q$  component of nucleon:  
Orbital angular momentum?

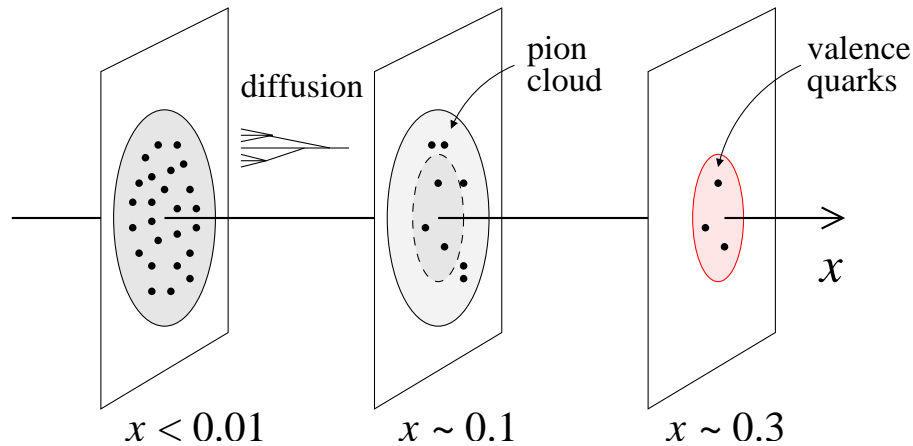
- Impact on  $\Delta G$  through global fits

JLab 12 GeV  $\xrightarrow{\text{evolution}}$  COMPASS  
+ RHIC Spin

- EIC:  $\Delta G$  from  $Q^2$  evolution  
 $\Delta q, \Delta \bar{q}$  from semi-inclusive DIS

Transversity,  $g_2$  with 12 GeV  $\rightarrow$  J.P. Chen

# Nucleon Structure: Transverse imaging



- Transverse spatial distribution of quarks/gluons

Dynamics: pion cloud, diffusion

Visualization: 3D Images

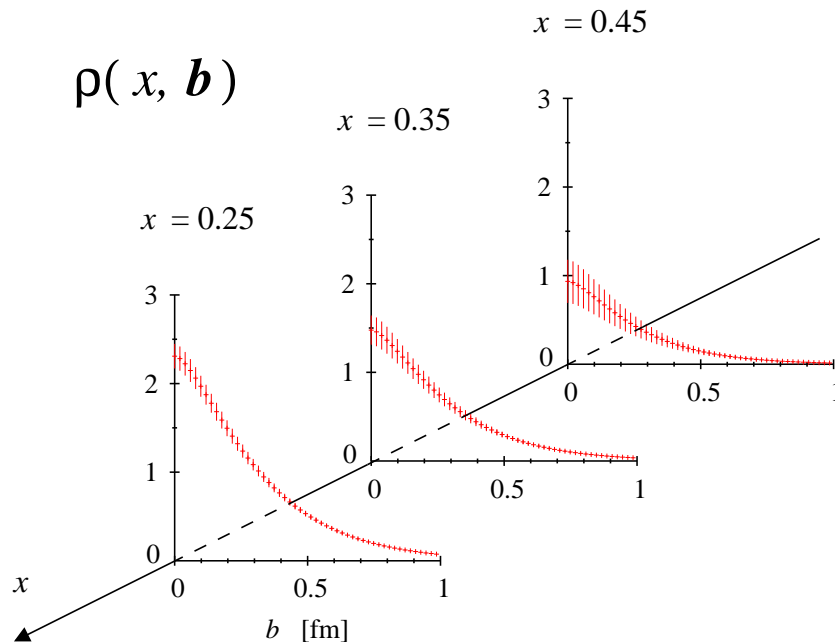
Lattice

- JLab 12 GeV: Transverse imaging in valence region

GPDs from deeply-virtual Compton scattering  $\gamma^* N \rightarrow \gamma + N$

Transverse charge densities  $\int dx \rho(x, b)$  from elastic form factors

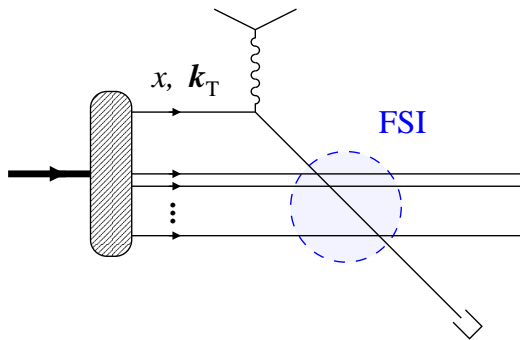
Transverse flavor/spin distributions from exclusive meson production  $\gamma^* N \rightarrow N + \pi, K, \rho, K^*, \phi(\text{gluon!})$



12 GeV simulated DVCS data + GPD model

- EIC: Gluon imaging with  $J/\psi$ , sea quarks from exclusive mesons with  $Q^2 \geq 10 \text{ GeV}^2$

# Nucleon structure: Orbital motion

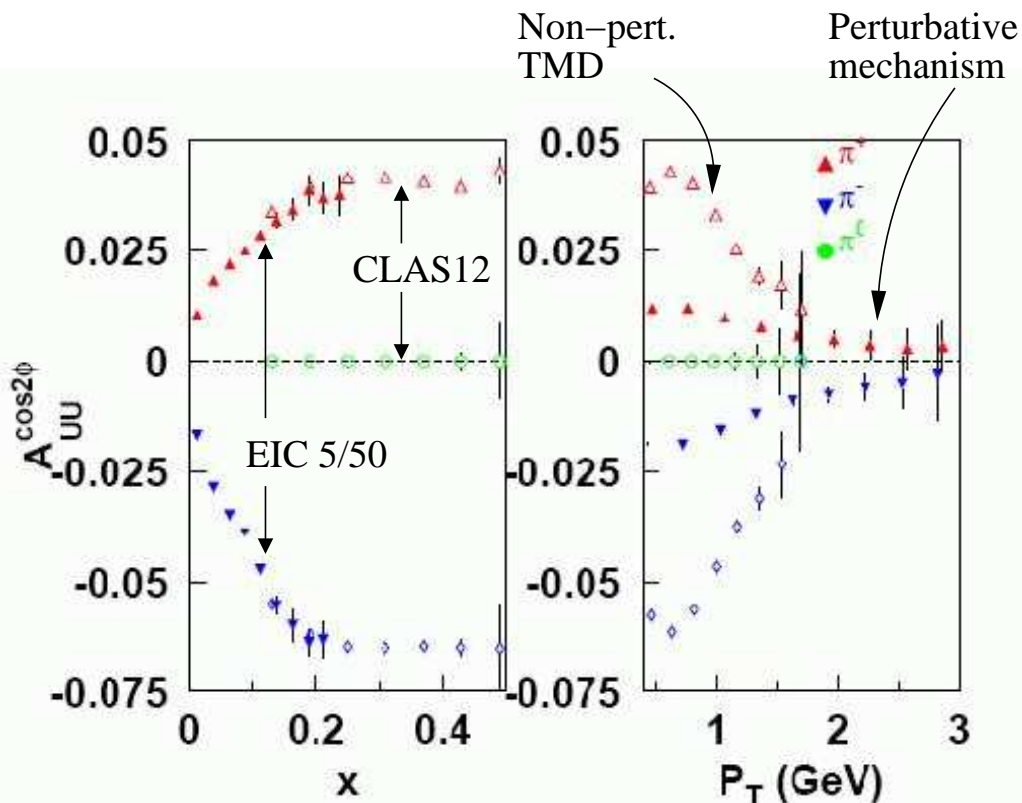


- Transverse motion,  $k_T$  dependence observable in semi-inclusive DIS

Orbital angular momentum

Spin-orbit interactions, “deformation”

QCD final-state interactions



- JLab 12 GeV: TMDs in valence region from semi-inclusive DIS

Boer-Mulders, Sivers, pretzelosity, . . .

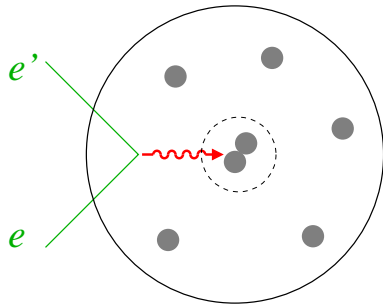
Unpolarized  $k_T$  distributions

- EIC: Low  $\rightarrow$  high  $p_T$  mechanism, twist from  $Q^2$  dependence

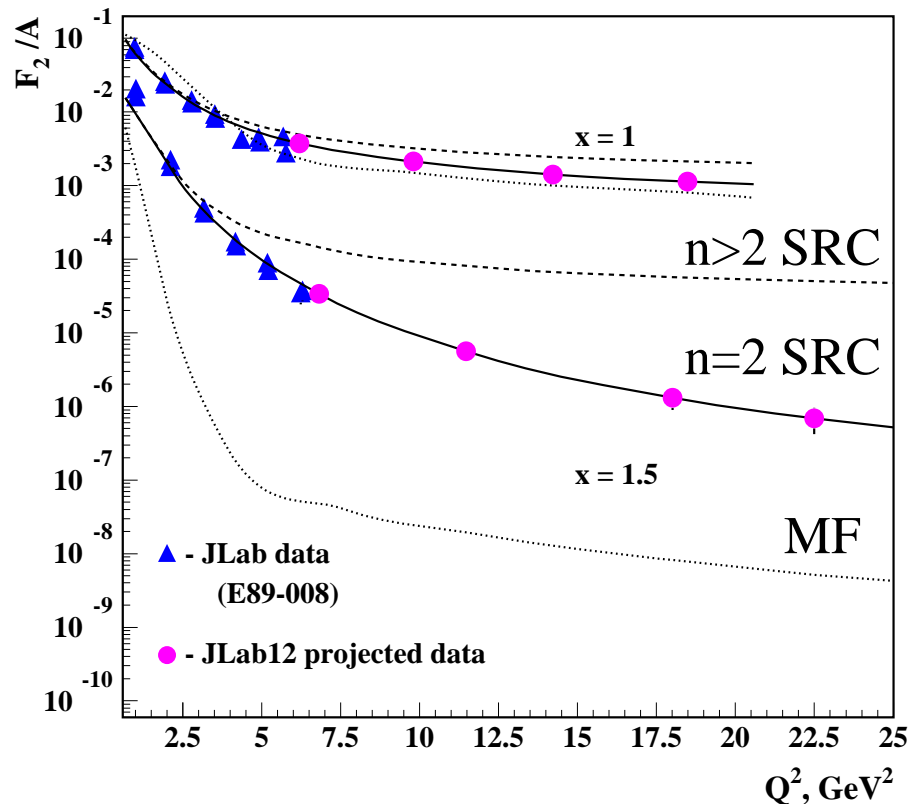
. . . requires fully differential measurements!

Boer-Mulders asymmetry: Transverse polarization of quark through spin-orbit interactions

# Nuclei in QCD: Short-range correlations



$^{56}\text{Fe}(e,e')X$



- Rare high-density configurations beyond mean field: Short-range correlations

Properties of superdense matter, neutron stars

Quark structure of short-range NN interaction

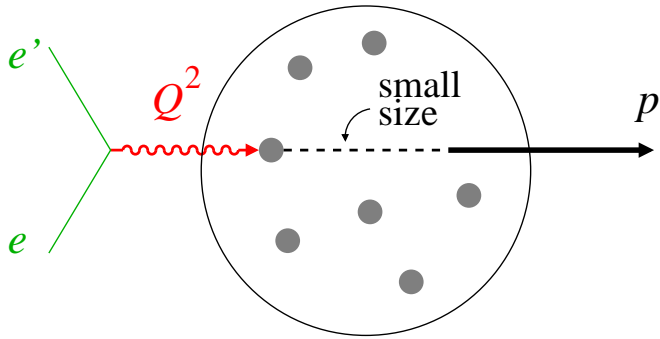
- JLab 6 GeV: First demonstration of SRCs in  $eA$  scattering through  $(e, e'p)$  Hall A, CLAS

- JLab 12 GeV: Nuclear DIS at  $x > 1$  “superfast quarks”

requires high luminosity  $L \sim 10^{37} \text{cm}^{-2}\text{s}^{-1}$



# Nuclei in QCD: Color transparency



- Small-size color singlets  $\bar{q}q, 3q$  interact weakly with hadronic matter: Color transparency

Fundamental property of QCD as gauge theory!

- JLab 12 GeV: Observe CT in high- $Q^2$  meson production  $A(e, e'\pi)X$  and proton knockout  $A(e, e'p)X$

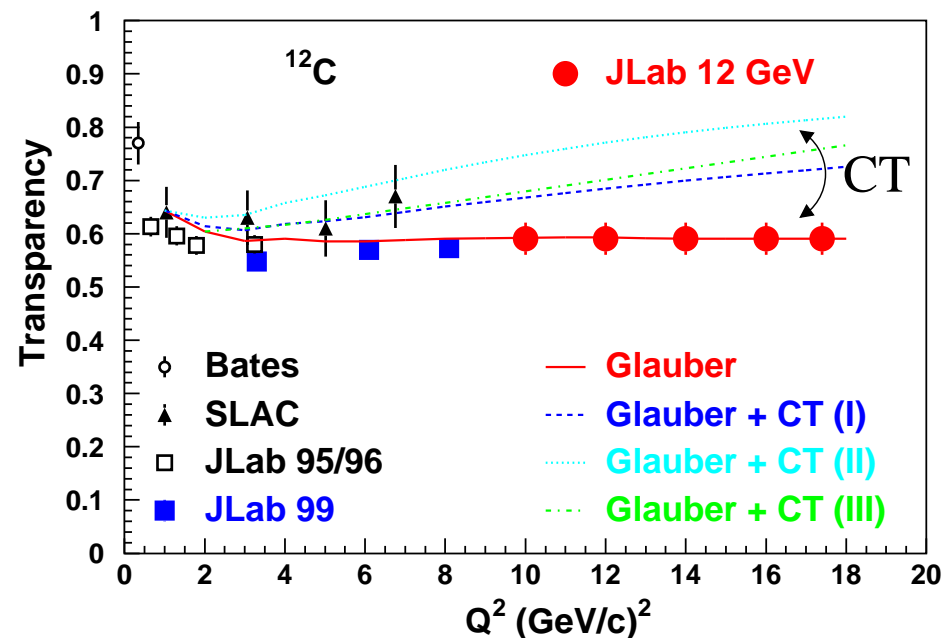
Indications of CT in 6 GeV  $\pi, \rho$

High luminosity essential!

- EIC: CT in wide kinematic regime

$\nu \rightarrow$  coherence length  
 $>$  nuclear size

$Q^2 \rightarrow$  size of configurations



# Also in JLab 12 GeV program

- Quark–hadron duality in inclusive and semi–inclusive DIS
- Quark–gluon correlations in nucleon from higher twist
- Nucleon resonance  $N^*$  excitation at high  $Q^2$
- Polarized EMC effect → extend with EIC
- Quark propagation and hadronization in medium ”

# Summary

- Combination of high luminosity and energy with JLab 12 GeV enables unique physics program in nucleon/nuclear structure in QCD

- Valence quark region essential for understanding of nucleon/nuclear structure

Spin/flavor quantum numbers, transverse size, orbital motion

Non-perturbative dynamics: Chiral symmetry breaking, confinement

Initial condition for QCD radiation

- A high-luminosity EIC will extend reach to sea quark and gluon degrees of freedom in nucleon/nuclei

→ T. Horn

Sea quark and gluon imaging

exclusive meson production

Orbital motion of quarks and gluons

semi-inclusive DIS

Interaction of small-size configurations with hadronic matter

hard processes on nuclei

Gluonic EMC effect

inclusive DIS