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 $\rightarrow$ sea quarks, gluons
  Spin/flavor densities
  Spatial distributions
  Orbital motion

- **Color fields in nuclei**
  Local properties $\rightarrow$ coherent fields
  Quarks/gluons in bound nucleon
  Coherence, shadowing, saturation

- **Other topics**
  Hadrons from color charge:
  Fragmentation, medium effects
  Electroweak probes
**Energy–luminosity frontier**

[Summary plot 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. $x \rightarrow 1$

  EIC: Sea quarks, gluons, scale dependence

- Physical characteristics

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

  Transverse spatial distributions GPDs

  Orbital motion TMDs

  Multiparticle correlations GPDs

  Learn about dynamics!

  Densities with operator definition $\langle N | \text{QCD–Op} | N \rangle$

  Calculable with non-perturbative methods, LQCD
**Nucleon: Valence quark polarization**

- How are valence quarks in nucleon polarized at $x \rightarrow 1$?
  - Basic $3q$ component of nucleon wave fn
  - Non-perturbative QCD interactions?
  - Orbital angular momentum $L = 1$?
  - Poorly constrained by present data

- Present data
  - JLab12 proj.
  - Combination of energy and luminosity!
  - Many more applications: Spatial imaging, orbital motion

- JLab12: Map $u, d$ quark polarization precisely up to $x \sim 0.8$
  - Inclusive DIS with $p$ and $n$ targets

- What about gluons at large $x$?
  - 30% of momentum carried by gluons at $Q^2 \sim 0.5 \text{ GeV}^2$
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-inclusive DIS
  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 $p\bar{p}$ EMC/SMC, SLAC, HERMES, COMPASS, JLab 6/12 GeV. RHIC Spin

- EIC: Definitive measurement of gluon polarization in inclusive DIS
  - Wide kinematic coverage enables study of $Q^2$ evolution

- Synergies EIC ↔ JLab12
  - Global QCD fits incl. large-$x$ data
  - JAM Collaboration: Melnitchouk et al.
  - Orbital angular momentum

M. Stratmann, INT Workshop 2010
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 $\gamma^* N \rightarrow M + N$:
  GPDs $\equiv$ partonic form factors of nucleon

- JLab12: Valence quark imaging with exclusive processes

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

  Mesons: Quark transversity with $\pi^0/\eta$, large-$x$ gluons with $\phi$

  Precise observables, but limited phase space

Reaction mechanism? Leading $\leftrightarrow$ higher twist?
Nucleon: Spatial distributions

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

  $J/\psi$: 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

  Light mesons: Non-singlet quarks $\pi^+, \pi^0$ polarized quarks
  $\rho^+, K^{*+}$ 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

- 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 $eA \rightarrow e' + X$
  
  $\sigma_A/\sigma_D$ ratio shows modification
  
  Spectator tagging $eA \rightarrow e' + N + X$:
  Short-range correlations?
  
  Spin/isospin dependence:
  Polarized nuclei, different $A$

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

Extended measurements with 12 GeV
**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

- 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 nuclear processes $A(e, e'M)A$
  JLab12: GPDs of light nuclei, matter distribution
  EIC: Impact parameter dependent shadowing
  Guzey et al.; Kowalski, Caldwell 09. Heavy nuclei very challenging

- 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 $\Delta G$ 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