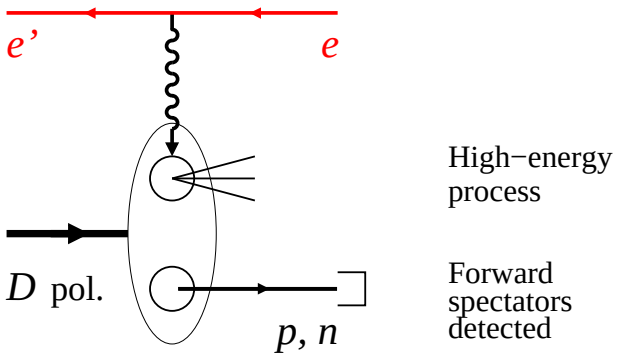
# Quark–gluon structure of light nuclei with spectator tagging at EIC

C. Weiss (JLab), APS April Meeting 2015, Baltimore, 12–Apr–15

Jefferson Lab



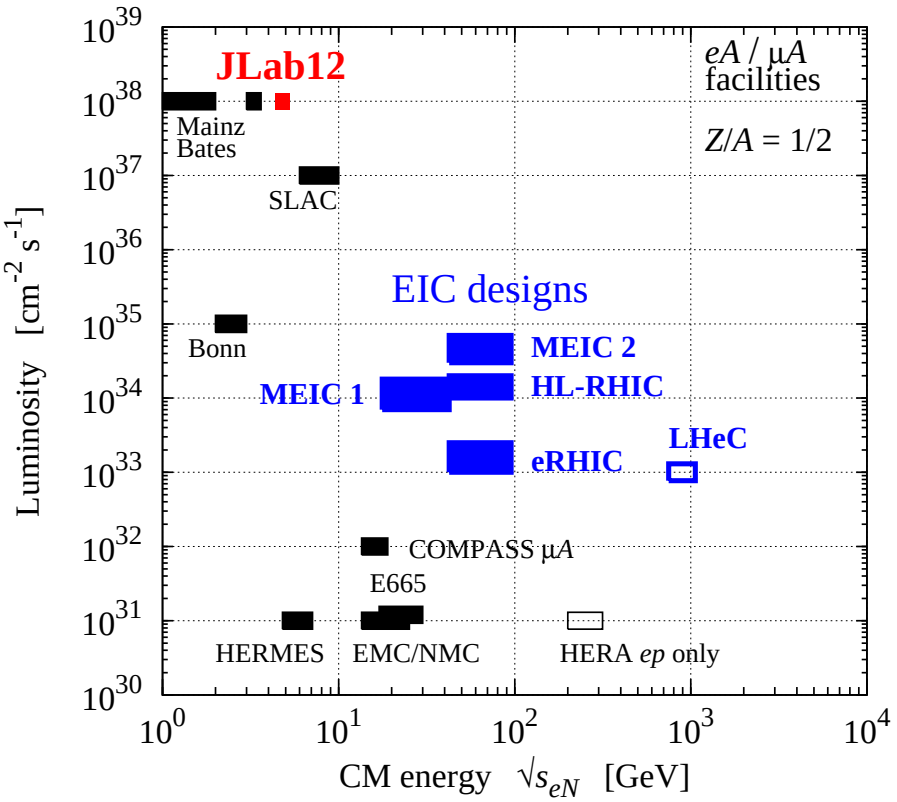

Kinematic reach in $x, Q^2$
Ion polarization $L, T$, tensor

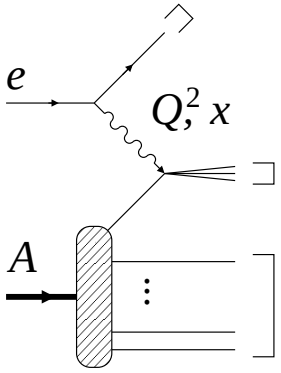
$\times$

Precision and control through spectator nucleon tagging

- Light ion physics at EIC
  - Physics objectives
  - Polarized deuteron
  - Spectator nucleon tagging
- Precision measurements with tagging
  - Free neutron structure functions
  - Polarized neutron structure
  - Bound nucleon structure and EMC effect
  - Coherence and shadowing at $x \ll 0.1$
- Experimental apparatus and R&D
  JLab 2014/15 LDRD Project: Simulation tools, resources

# Light ions: Energy, luminosity, polarization




- CM energy $\sqrt{s_{eN}} \sim$ 20–100 GeV

  $Q^2 \sim$ few 10 $\mathrm{GeV}^2$ for DIS

  $x \sim 10^{-1}$–$10^{-3}$ for sea quarks, gluons

- Luminosity $\sim 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

  Exceptional configurations in target

  Multi-variable final states

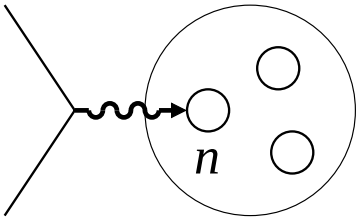
  Polarization effects

- Polarized light ions

  eRHIC: unpol $D$, pol $^3\mathrm{He}$

  MEIC: polarized $D$ and $^3\mathrm{He}$ with Figure-8 ring layout

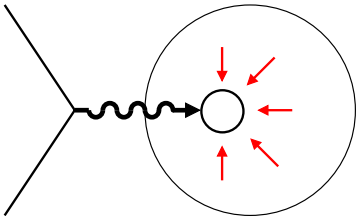
# Light ions: Physics objectives




- Neutron structure

  Flavor decomposition of quark spin,
  sea quarks $\Delta\bar{u}$, $\Delta\bar{d}$, gluon polarization $\Delta g$

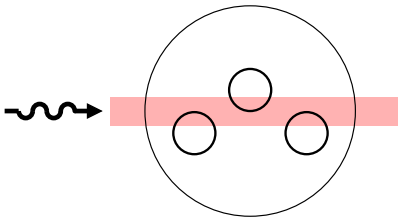
  How to account for binding, polarization,
  final–state interactions?



- Bound nucleon in QCD

  Modification of basic quark/gluon structure by
  nuclear medium, QCD origin of nuclear forces

  How to control nuclear environment?



- Coherence and saturation

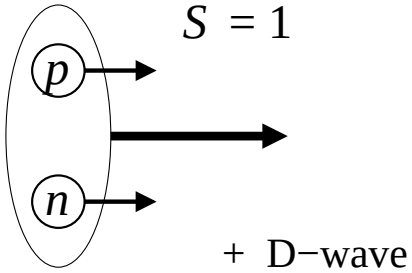
  Interaction of high–energy probe with
  coherent quark/gluon fields

  How to verify onset of coherence?

[Nucleus rest frame view]

- Challenges to be addressed by theory
  and new experimental techniques! ←

# Light ions: Deuteron, spectator tagging

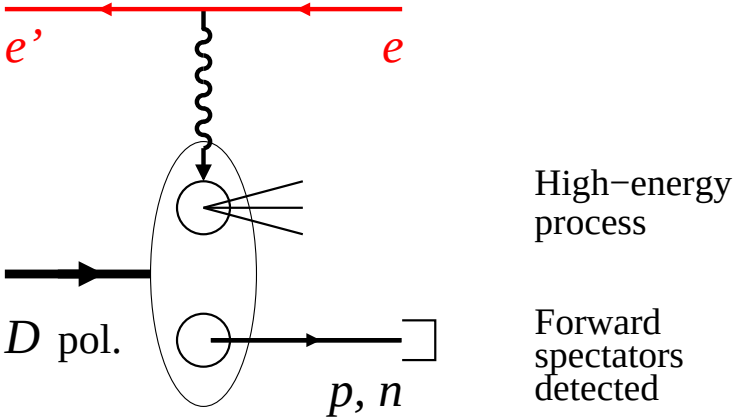



- Polarized deuterium

  Wave function simple, known well
  incl. light-cone wave function for high–energy processes

  Neutron spin–polarized

  Limited possibilities for nuclear final–state interaction



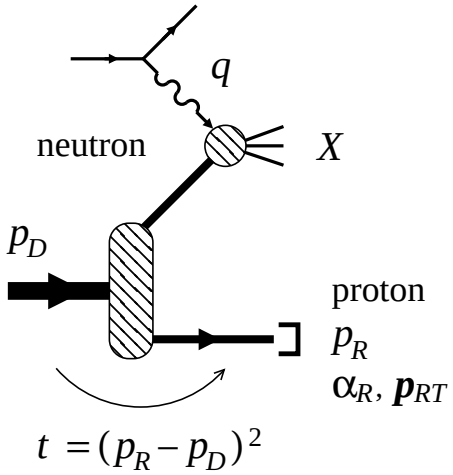

- Spectator nucleon tagging

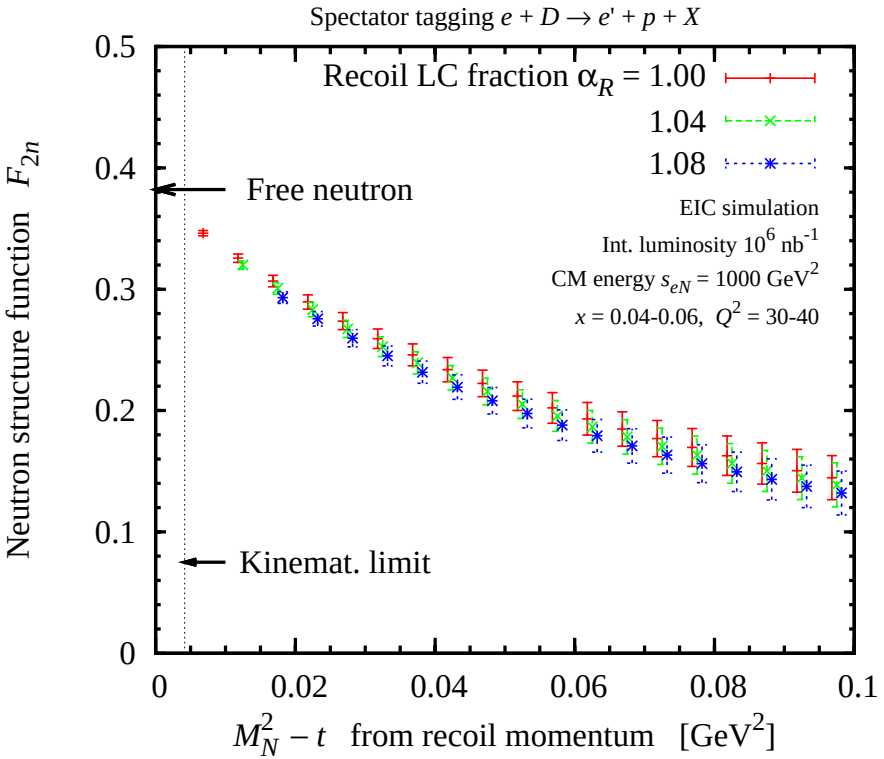
  Detection of forward proton or neutron

  Identifies active nucleon, controls quantum state

  Unique for collider: No target material, forward detection of charged/neutral p's, polarized ion beams
  Tagging with fixed target: CLAS BONUS, limited to recoil momenta $p_R > 100$ MeV

# Tagging: Free neutron structure




- Extract free neutron structure

  Recoil momentum defines/controls neutron's off-shellness $t - M_N^2$

  Free neutron at pole $t - M_N^2$: On-shell extrapolation

  Model-independent method!

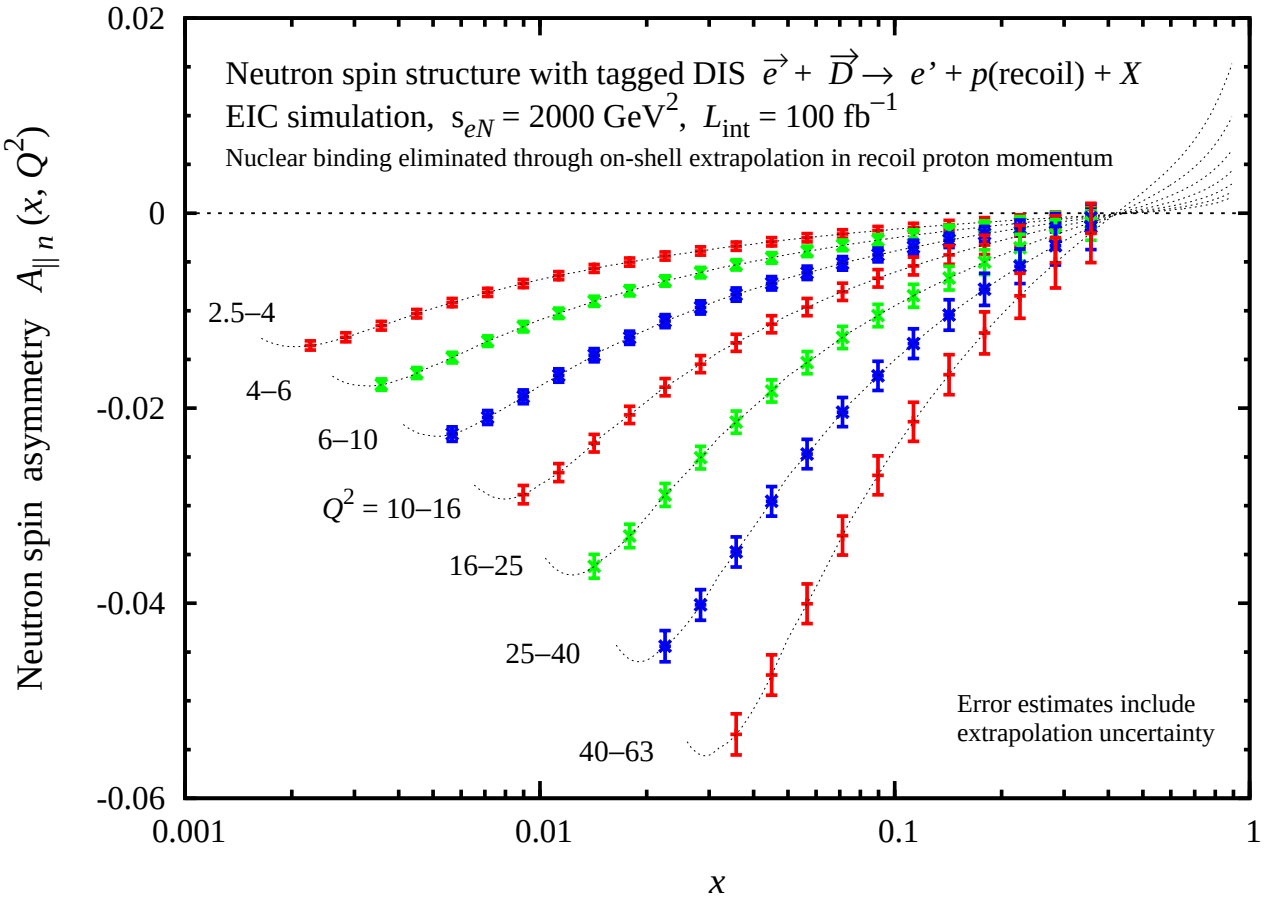
  Eliminates nuclear binding effects and final–state interaction

- Precise measurements

  $F_{2n}$ extracted with percent-level accuracy at $x < 0.1$
  JLab LDRD project: Detailed uncertainty estimates

  Non-singlet $F_{2p} - F_{2n}$ at $x \lesssim 0.1$, sea quark flavor asymmetry $\bar{d} - \bar{u}$

# Tagging: Polarized neutron structure




$$A_{\|n} = \frac{\sigma(+-) - \sigma(++)}{\sigma(+-) + \sigma(++)}$$

$$= D \frac{g_1}{F_1} + \ldots$$

$$D = \frac{y(2-y)}{2 - 2y + y^2}$$

depolarization factor

$$y = \frac{Q^2}{x s_{eN}}$$

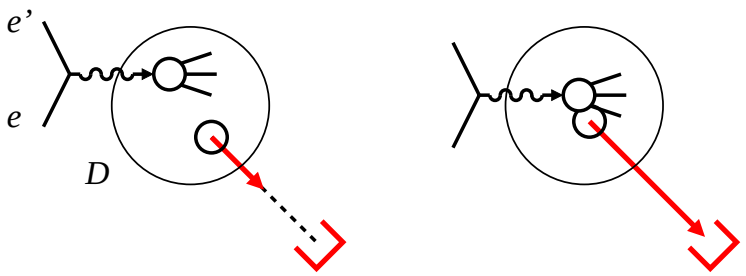
- Precise measurement of neutron spin structure

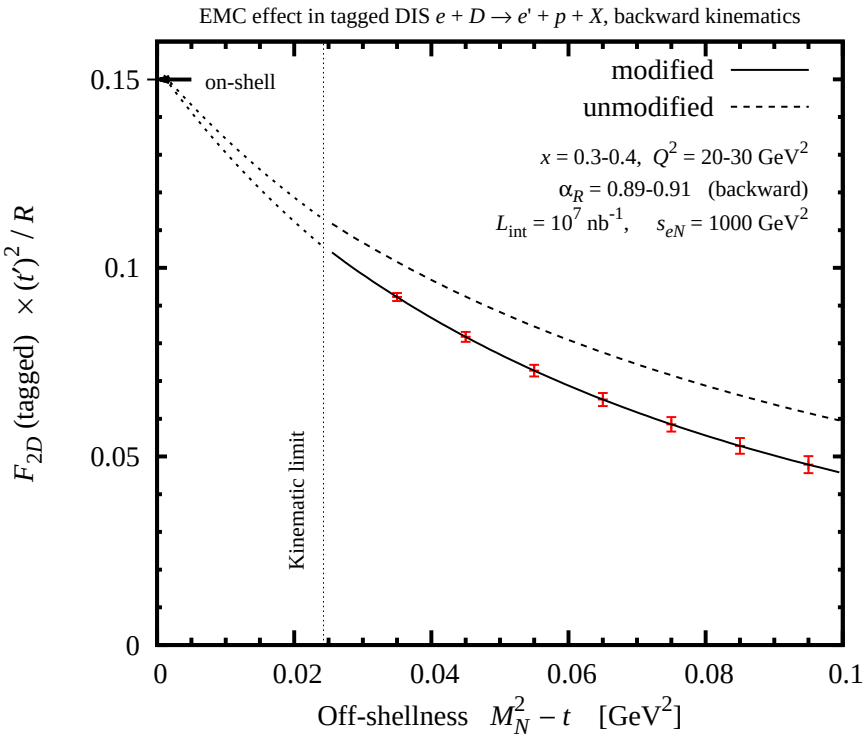
  Wide kinematic range: Leading ↔ higher twist, QCD evolution

  Parton density fits: Flavor separation $\Delta u \leftrightarrow \Delta d$, gluon spin $\Delta G$

  Nonsinglet $g_{1p} - g_{1n}$ and Bjorken sum rule

# Tagging: EMC effect




- Nucleon's quark/gluon structure modified in nucleus $A \neq \sum N$

  Seen in inclusive DIS: EMC effect

  Dynamical origin?

  What momenta and distances in nuclear wave function cause modification?

  Spin–isospin dependence?

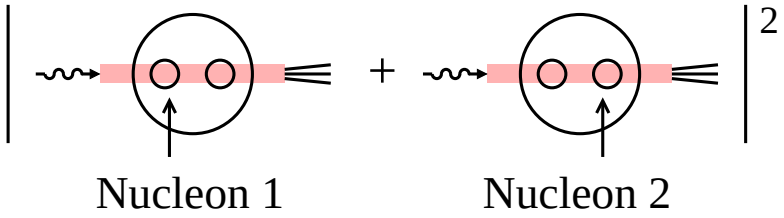
- EMC effect in tagged DIS

  Study modification as function of recoil momentum $\leftrightarrow$ off-shellness

  Control size of nuclear configuration!

  EIC: $Q^2$ evolution, gluons, spin dependence with polarized $D$

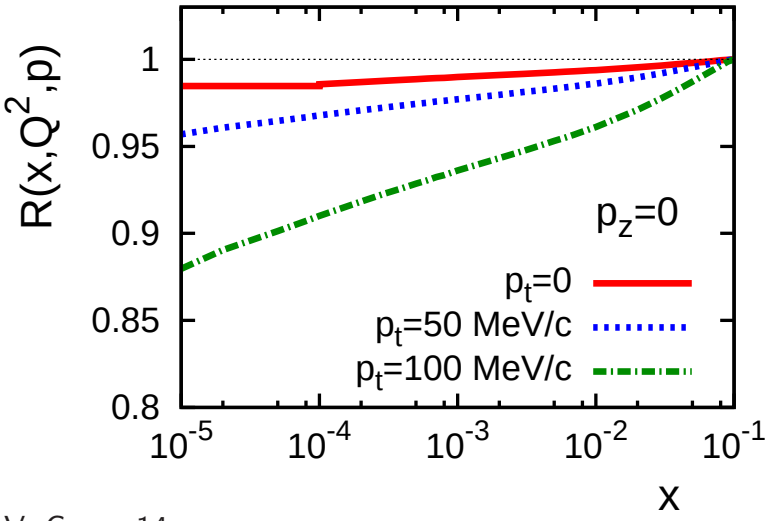
# Tagging: Coherence and shadowing




- Coherent scattering at $x \ll 0.1$

  Coherence length $\gtrsim NN$ distance: Quantum–mechanical interference of scattering from different nucleons

  Inclusive DIS: Shadowing




- Coherence in tagged DIS

  Explore interference as function of recoil momentum

  Strong effect, controled studies

  Important for quantifying approach to saturation at small $x$

V. Guzey 14

# Experimental apparatus and R&D

- Tagging requires dedicated forward detector with sufficient coverage and momentum resolution, integrated with EIC accelerator design (interaction region, beam optics, beam quality)
  JLab MEIC forward detector optimized for tagging

- R&D project develops simulation tools (physics models, event generators, analysis tools) and performs detailed process simulations
  Tools, documentation and results publicly available at `https://www.jlab.org/theory/tag/`
  Open for collaboration!

# Summary

- EIC will dramatically expand the capabilities for exploring the short-range structure of light nuclei with electromagnetic probes

- Spectator tagging in $eD$ scattering enables next-generation measurements with maximal control and unprecedented accuracy

  Neutron structure functions, including spin
  Nuclear modifications of quark/gluon structure
  Coherence and shadowing