MEIC polarized deuteron R&D

C. Weiss, JLab Theory

FY14/15 LDRD Project “Physics potential of polarized light ions with EIC@JLab”

Overview

Physics potential of polarized light ions with EIC@JLab
FY14/15 LDRD project, joint theoretical & experimental effort, ~160K/year

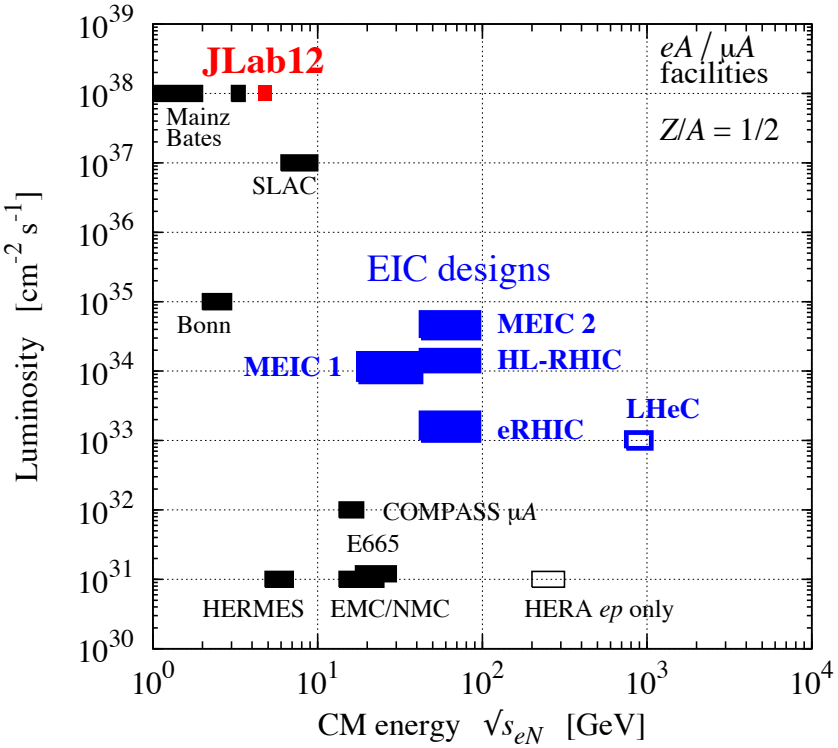
JLab Physics: D. Higinbotham (10% FTE), P. Nadel-Turonski
JLab Theory: C. Weiss* (20% FTE), W. Melnitchouk
Theory visitors: W. Cosyn (Ghent), V. Guzey (Petersburg NPI), M. Sargsian (FIU)
Experimental postdoc: K. Park (50% FTE, ODU)

Objective: Enable next-generation measurements using **polarized deuteron** and **spectator nucleon tagging** with MEIC: Neutron spin structure, nuclear modification of quarks/gluons, coherent fields at small *x*

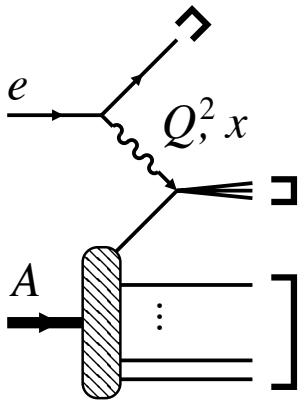
Tasks: Develop theoretical models for high-energy tagged *eD* scattering, perform process simulations with MEIC beam & detector design, quantify physics impact

Tools & results publicly available at: **https://www.jlab.org/theory/tag/**
Extensive collaboration with users

Context: EIC eA capabilities

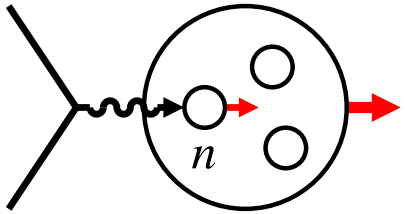
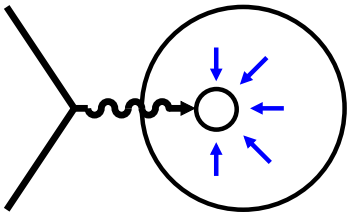
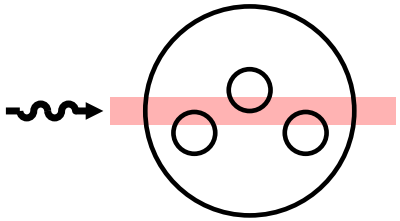


- EIC greatly expands capabilities for high-energy *eA* scattering



CM energy	20–100 GeV/nucleon	sea quarks, gluons, Q^2 dependence
Luminosity	~10^{34} cm^{-2} s^{-1}	multivariable final states, exceptional configs
Polarization	MEIC polarized D + 3He, eRHIC polarized 3He	spin observables

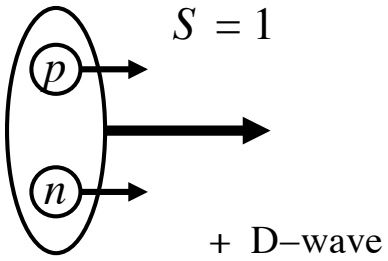
Context: EIC light ion physics

Neutron structure	Flavor decomposition of PDFs/GPDs/TMDs	
Nuclear modification of quarks/gluons	QCD origin of nuclear force, non-nucleonic degrees of freedom	
Coherent scattering, shadowing at small x	Collective gluon fields	

EIC White Paper: A. Accardi et al, arXiv:1212.1701

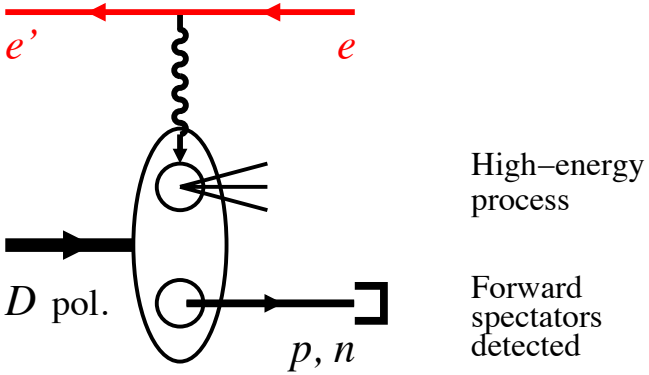
- Dominant uncertainty: Nuclear configurations during high-energy process. Proton or neutron active? Nucleon binding? Polarization?
- New experimental & theoretical techniques needed… available with MEIC!

Methods: Polarized D, spectator tagging



Polarized deuteron

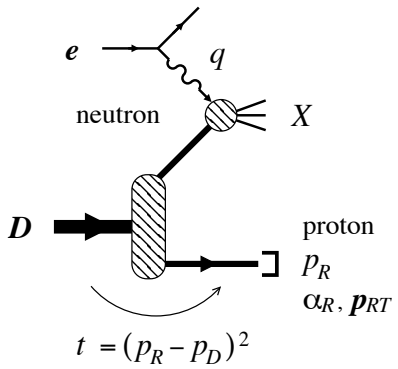
- Wave function simple, known
- Neutron polarized
- Non-nucleonic Delta's suppressed

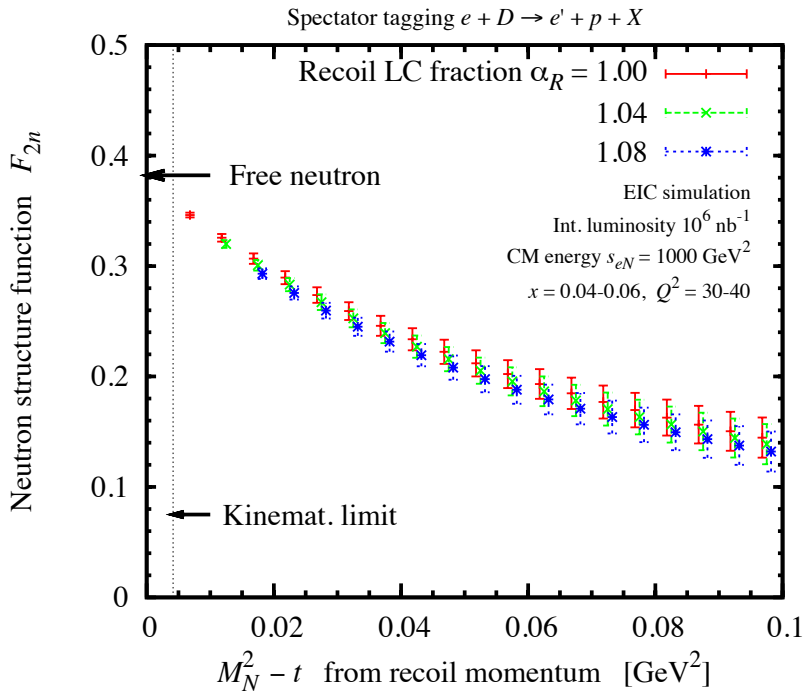


Spectator nucleon tagging

- Identifies active nucleon, controls quantum state
- Uniquely suited for collider: Forward detectors for charged & neutral fragments, no target material, possible with polarized deuteron
  [Fixed-target unpol: CLAS BoNuS 6/12 GeV]
- This project: Develop potential!

Results: Free neutron structure





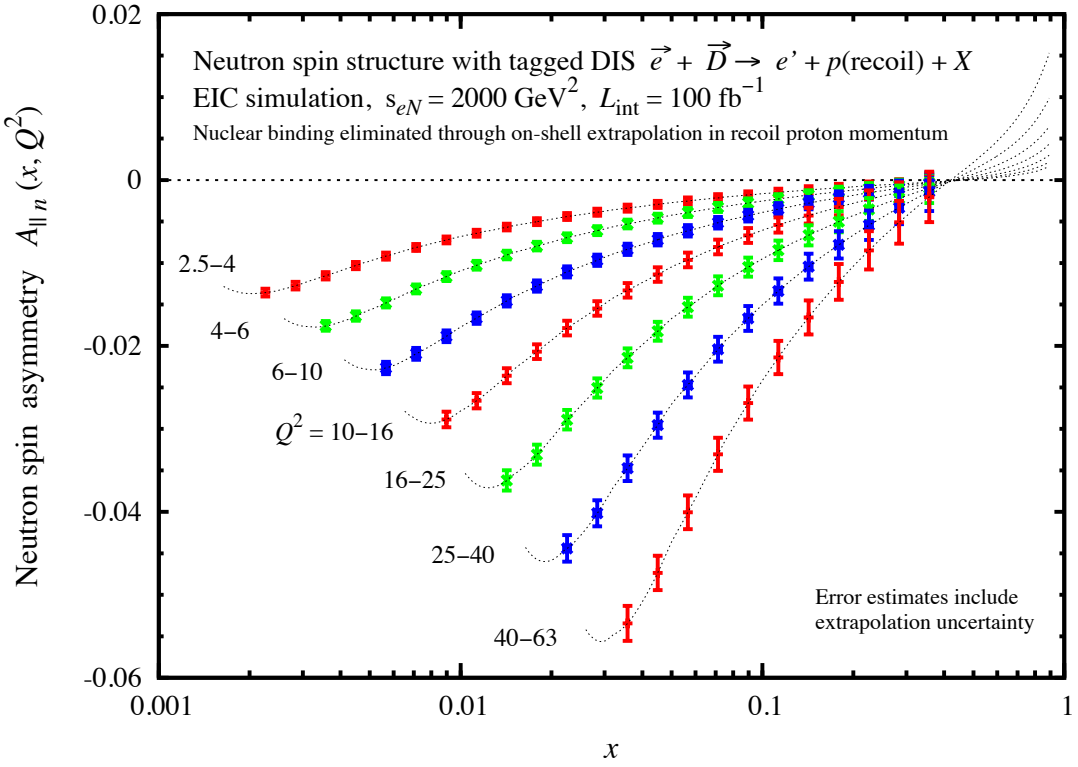
Tagged DIS *e + D —> e' + p + X*

- Recoil proton momentum controls neutron's off-shellness
- Free neutron from on-shell extrapolation t —> M_N^2
- Model-independent method, eliminates nuclear binding and final-state interactions
  Sargsian, Strikman PLB 639, 223 (2006)

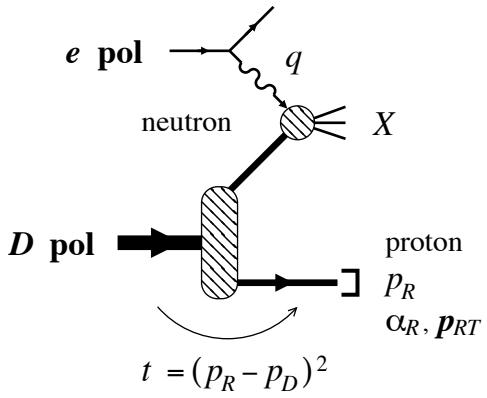
R&D results https://www.jlab.org/theory/tag/

- Theoretical models: Cross sections, codes, **arXiv:1407.3236, article in progress**
- Simulations, stat & sys uncertainties quantified
- Few-percent-level measurements feasible with MEIC

Results: Neutron spin structure



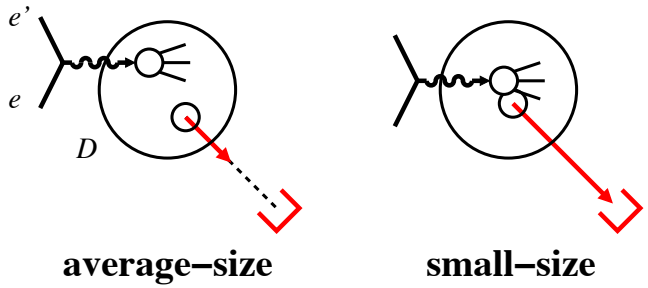
Polarized tagged DIS
e + D —> e' + p + X



- Precision measurements of neutron spin structure with tagging + on-shell extrapolation **arXiv:1409.5768, article in progress**
- Detailed simulations, stat & sys uncertainties quantified
- Physics impact: Polarized PDFs, QCD evolution (in progress)

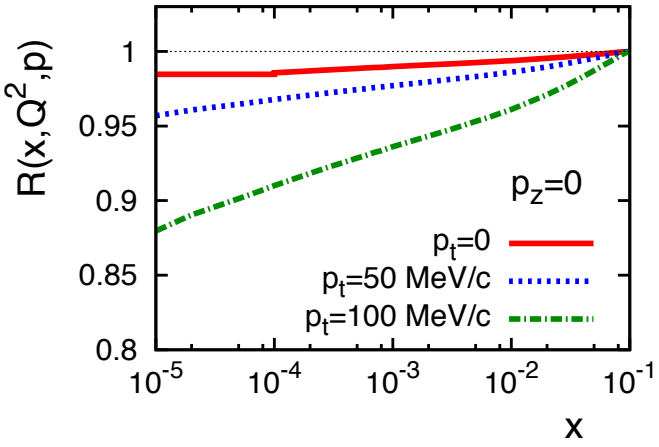
Results: Nuclear modifications, small x

EMC effect in tagged DIS



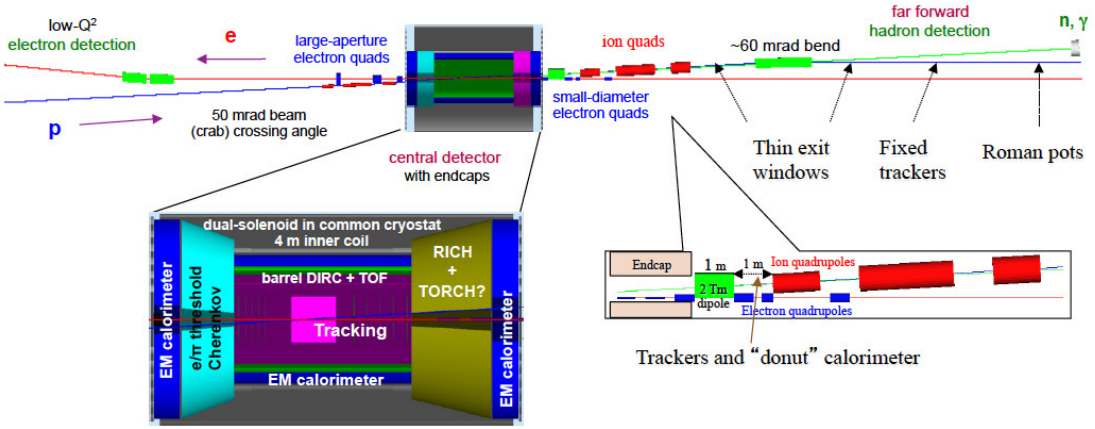
- Recoil momentum controls size of NN configuration in D
- Study nuclear modification as function of size — new method!
- Feasible with MEIC (in progress)

Shadowing in tagged DIS at small x



- Theory of shadowing in tagged DIS developed: Guzey et al. 2014/15 https://www.jlab.org/theory/tag/
- Explore coherent nuclear gluon fields with tagging at MEIC — new method!
- Shadowing controls approach to saturation at small *x*

Apparatus: MEIC forward detector



- MEIC forward detector designed for spectator tagging
- R&D project interfaces with MEIC detector development

Acceptance for ions and fragments	Essentially full coverage	Rigidity different from beam. Large magnet apertures, small gradients
Acceptance for elastic recoil	Longitud. momentum up to 99.5%, angles down to 2 mrad	Rigidity same as beam. Large dispersion generated after IP
Momentum and angular resolution	Longitudinal $dp_L/p_L \sim 10^{-4}$ Angular ~ 0.2 mrad p_T ~ 15 MeV for 50 GeV beam	Magnetic field as analyzer

https://eic.jlab.org/wiki/

Summary: Progress to date

- Developed **theoretical cross section models** for high-energy eD scattering at EIC with spectator tagging: unpolarized, polarized, diffractive final state. FORTRAN/C++ codes with documentation, publicly available at **https://www.jlab.org/theory/tag/**
- Developed **Monte-Carlo simulation tools** (event generators, analysis tools) for high-energy eD scattering at EIC with spectator tagging. Maintained on github area, can be adapted by users.
- Performed **process simulations** with EIC beam and detector configuration and demonstrated feasibility of precise neutron structure measurements: *Statistical errors:* Counting rate estimates. *Systematic errors:* Momentum resolution, polarization, analysis procedures
- Published preliminary results in proceedings: **arXiv:1407.3236, arXiv:1409.5768,** technical report. Journal articles in preparation
- Presented project results at **2014 DNP Town Meetings** on Nuclear Structure and Nuclear Astrophysics (Texas A&M, Aug 21-23) and QCD (Temple, Sep 13-15, 2014)
- Organized **topical workshop** "*High-energy nuclear physics with spectator tagging*", ODU Norfolk, VA, USA, March 9-11, 2015. More than 40 participants, great interest **http://www.jlab.org/indico/event/Tagging2015** .
- Disseminated results in **>17 presentations** at international nuclear physics conferences and workshops, EIC meetings, JLab User's Meeting and 2014/15 APS Meetings,

Summary: Planned or in progress

- Develop theoretical model of **final-state interactions** in deep-inelastic scattering (DIS) with spectator tagging at EIC.Final-state interactions affect recoil momentum dependence. Visiting scientists have unique expertise: Cosyn, Guzey, Sargsian

- Explore the **EMC effect and NN interactions** in DIS with spectator tagging.Preliminary results presented: C. Weiss, APS Spring Meeting, Baltimore, MD, April 12, 2015

- Extend tagging at EIC to **3He break-up channels:** Complements deuteron, probes different spin/isospin structures, tests universality. 3He much more complex system than deuteron.

- Complete **documentation** of simulation tools and physics results. Tech. report JLAB-THY-14-1997 available at **https://www.jlab.org/theory/tag/weiss/tag.pdf** Journal publications in preparation (theory, simulations)

- Expand **outreach to potential EIC collaborators** and enable follow-up R&D.University groups at Old Dominion (Hyde, Kuhn, Weinstein), MIT (Or Hen), Stony Brook (Deshpande), Mississippi (Dutta), Tel Aviv (Piasetzky), Perugia Theory (Scopetta et al.)

Summary

- Polarized deuteron and spectator tagging with MEIC enable next-generation measurements with full control of the nuclear configuration and quantified systematic precision. *These methods will be essential to guarantee physics results commensurate with the expected experimental precision and to realize the full potential of EIC in nucleon structure and light ion physics.*
- JLab Theory Center acting in leadership role in EIC R&D: Conceptual and programmatic development, modeling and simulation, LDRD project management.
- JLab Users have responded very positively to light-ion LDRD project at JLab and will use the tools and results to develop new physics applications and perform follow-up R&D, e.g. detector development.
- Further sustained funding of theoretical research in high-energy eA physics (intersection of high-energy scattering and nuclear structure) will be needed to realize the full potential of EIC's light ion program: Support for young researchers, retention of critical expertise, collaboration with university groups.