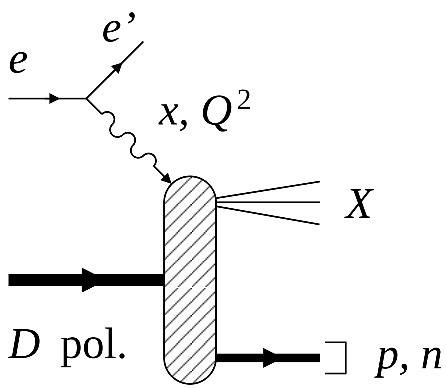
Polarized deuterium physics with EIC

C. Weiss (JLab), Tensor Polarized Solid Target Workshop, JLab, 11–Mar–14



Kinematic reach in x, Q^2 for sea quarks, gluons, coherence

Ion polarization L, T, tensor

Forward detection of p, n, D

Precision measurements using eD with forward tagging

- Electron-Ion Collider overview

  Design specifications

  eA physics objectives

  Why deuterium

- Polarized deuterium with EIC

  Inclusive $eD \rightarrow e' + X$

  Spectator tagging $eD \rightarrow e' + p/n + X$: Neutron structure, bound nucleon

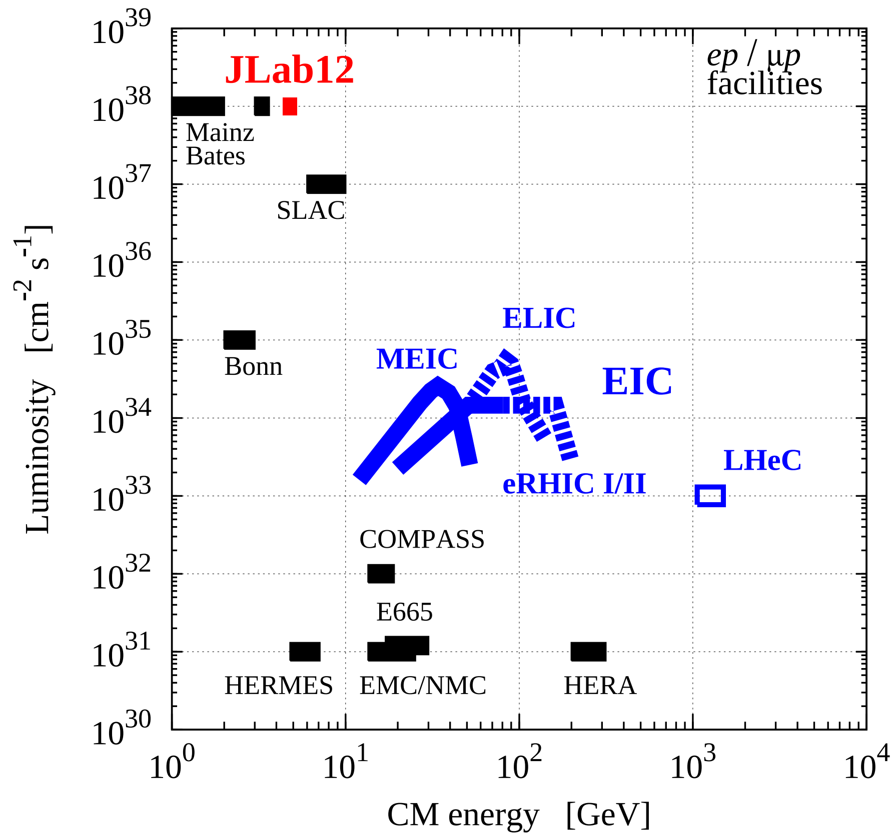
  Multiple scattering: Shadowing, tensor polarization

- Accelerator and detector designs

  Forward detection with JLab MEIC

- JLab 2014 LDRD project

EIC: Specifications



Convergence in design goals
Differences in technological challenges

- Energy–luminosity frontier

  First eA collider!

  First polarized ep/eA collider!

- Design specifications

  CM energy 20-70 GeV/nucleon,
  higher energies in 2nd stage

  Luminosity $\sim 10^{34}$ cm^{-2} s^{-1}
  over wide range of energies

  Proton and ion polarization
  Polarized deuterium with JLab design only!

  Detection of forward p, n,
  nuclear fragments

- ep physics program

  Sea quark spin/flavor, gluon Δg
  spatial distributions, orbital motion
  "3D nucleon structure" 2012 White Paper, reviews

EIC: eA physics goals

Neutron structure: Flavor decomposition of quark spin, Δg $\leftarrow$

Bound nucleon: Modification of quark/gluon structure by nuclear medium $\leftarrow$

Collective quark/gluon fields: Shadowing, diffraction, high densities $\leftarrow$

Nucleus as filter: Color transparency, parton propagation, hadronization

Importance of deuterium

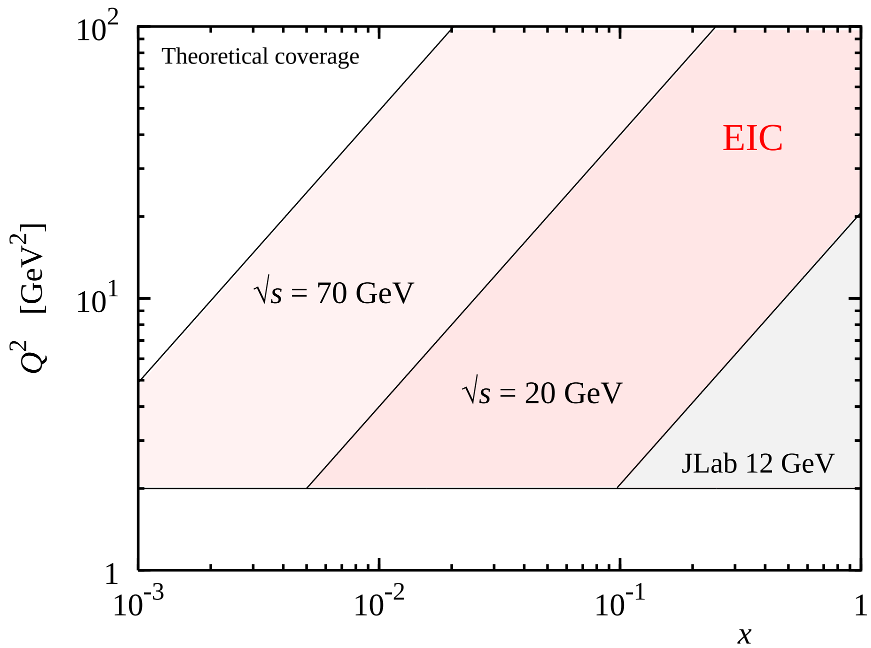
Simple structure: Wave function (incl. light-front), polarization

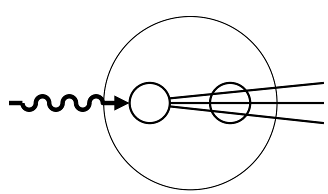
Manageable multiple scattering: Final-state interactions, coherence

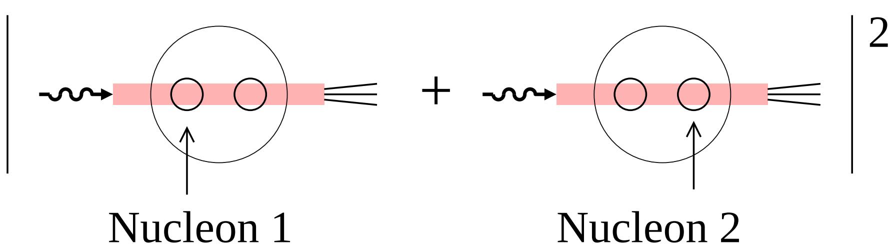
Effective control through spectator tagging

Tensor polarization as $N = 2$ observable

Deuterium: Inclusive scattering







- Inclusive $eD \to e' + X$

  $eD + ep$: Spin/flavor of sea quarks at $x \sim 10^{-1}$–10^{-3}

  eD alone: ΔG from isoscalar Q^2 evolution

  Excellent statistics, accuracy limited by systematics, e.g. polarimetry

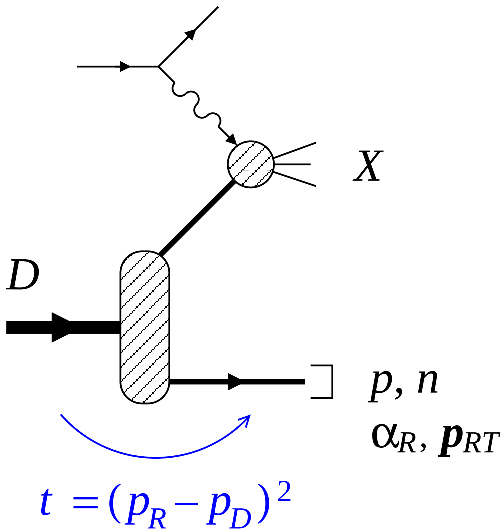
- Theoretical uncertainty in nucleon structure extraction

  Final–state interactions: Debris hits downstream nucleon

  Shadowing: Coherent scattering from both nucleons, $x < 10^{-1}$

- Much better control with spectator tagging

Deuterium: Spectator tagging



- Tagged DIS $eD \to p/n + X$

  Control quantum state of active nucleon

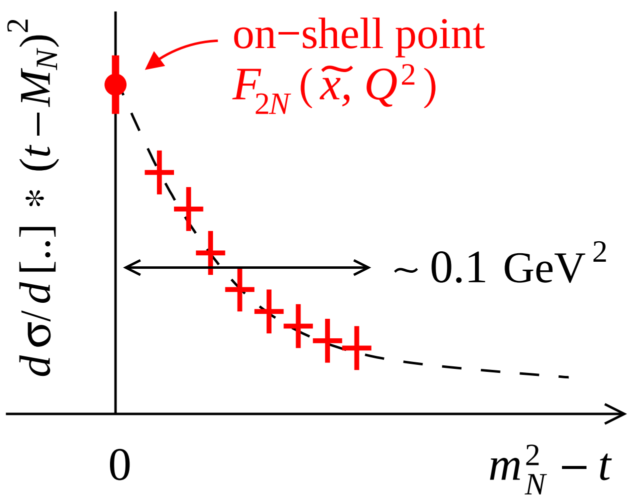
  Measure recoil LC momentum $\alpha_R, \boldsymbol{p}_{RT}$

- Impulse approximation
  FS81; Melnitchouk, Sargsian, Strikman 97

$$\frac{d\sigma}{dx\; dQ^2\; (d\alpha_R/\alpha_R)\; d^2p_{TR}} \;=\; \text{factor}$$

$$\times\; |\psi_D^{\text{LC}}(\alpha_R, \boldsymbol{p}_{TR})|^2\; F_{2N}[x/(2-\alpha_R), Q^2]$$

Deuteron LCWF Nucleon SF



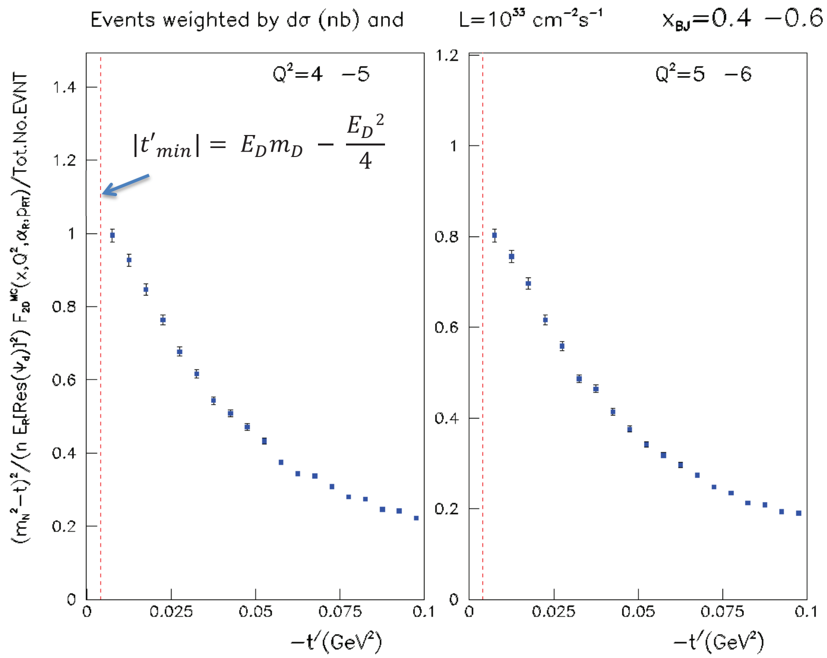
- On-shell extrapolation $t \to M_N^2$
  Cf. Chew–Low extrapolation in πN, NN scattering

  Free nucleon structure at pole

  Pole value not affected by FSI
  Sargsian, Strikman 05: "No-loop theorem"

  Model–independent method!

Deuterium: Spectator tagging with MEIC



K. Park, based on cross section model by M. Sargsian

- Extract free nucleon structure

  Forward detection down to $p_{TR} \sim 0$ uses most of momentum distribution

  Excellent momentum resolution $\Delta\alpha_R = O(10^{-4}), \ \Delta p_{TR} \sim 15\,\mathrm{MeV}$

  Accuracy limited by intrinsic momentum spread in ion beam

  On-shell extrapolation appears feasible, MC simulations in progress
  JLab LDRD Project "Polarized light ions with EIC@JLab"

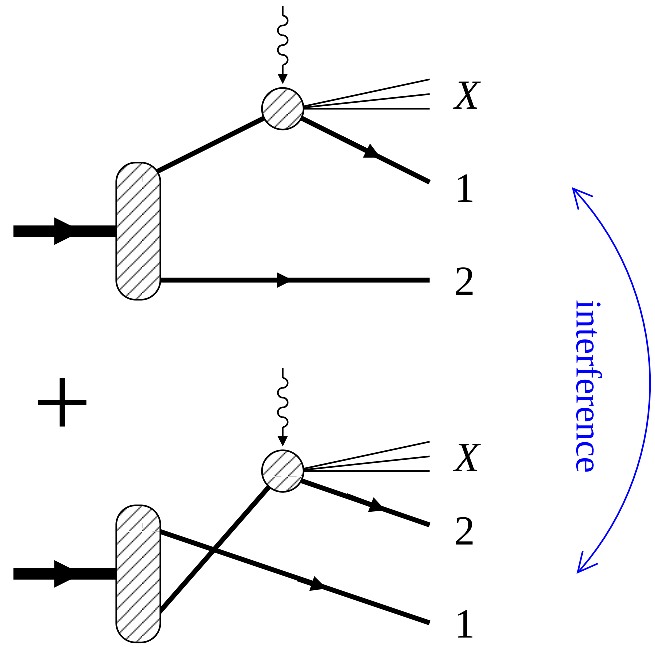
- Many applications

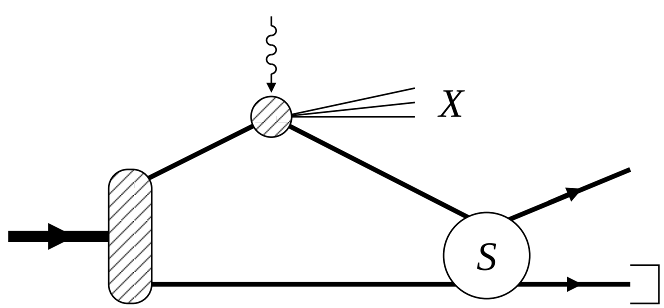
  Neutron structure F_2^n at $x < 10^{-1}$, especially nonsinglet $(p - n) \sim (u - d)$

  Bound proton through neutron tagging, comparison with free proton structure

  Spin structure function g_1^n for polarized PDF fits

Deuterium: Coherent effects





- Shadowing in inclusive DIS $x \ll 10^{-1}$

  Diffractive scattering on single nucleon
  Leading-twist effect! Seen at HERA

  Interference between scattering on nucleons 1 and 2

  Nuclear effect calculable in terms of nucleon's diffractive structure functions
  Gribov 70's. Frankfurt, Guzey, Strikman 02+

  Determines approach to "saturation"

- Shadowing in tagged DIS

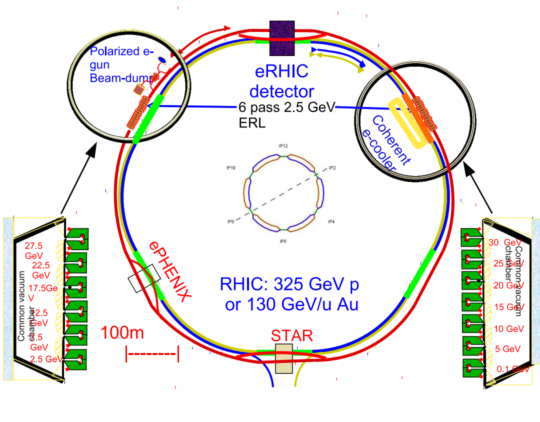
  New experimental tests through recoil momentum dependence
  Guzey, Strikman, CW; in progress

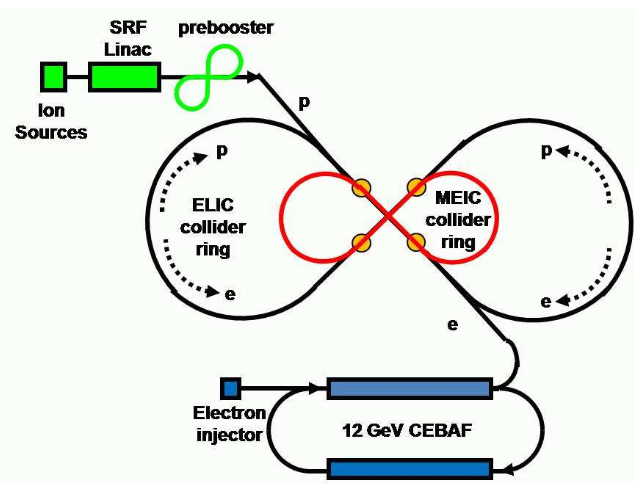
  Clean coherent effect with $N = 2$

  Extend to polarized DIS!
  Tensor polarization also $N = 2 \rightarrow$ Talk Kalantarians

- Coherent scattering $eD \rightarrow e + M + D$
  Exclusive meson production, DVCS, nuclear GPDs

Facilities: EIC accelerator designs





Convergence in design parameters, "staging."
Different technological challenges!

- BNL linac–ring design eRHIC

  RHIC proton/ion beam up to 325 GeV

  5–20 (30) GeV electron linac in tunnel staged

  Luminosity $\sim 10^{33-34}$ cm^{-2}s^{-1} over wide range

  Re-use RHIC detectors? PHENIX, STAR

- JLab ring–ring design MEIC/ELIC

  11 GeV CEBAF as injector continued fixed-target op

  Medium–energy: 1 km ring, 3–11 on 60/96 GeV

  High–energy: 2.5 km ring, 3–11 on 250 GeV

  Luminosity $\sim 10^{34}$ over wide range

  Figure–8 for polarization transport Up to four IPs

  Polarized deuterium beam ⟵

- Related proposals

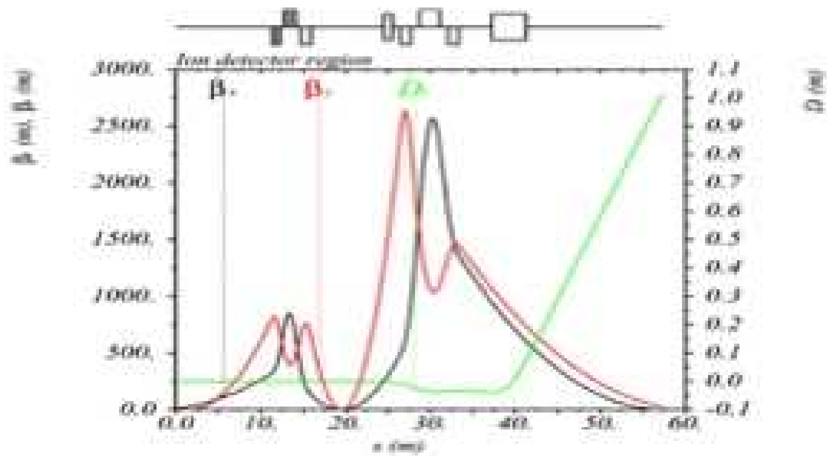
  CERN LHeC: 20–150 GeV on 7 TeV ep unpol
  Ring–ring and linac–ring discussed, $L \sim 10^{33}$

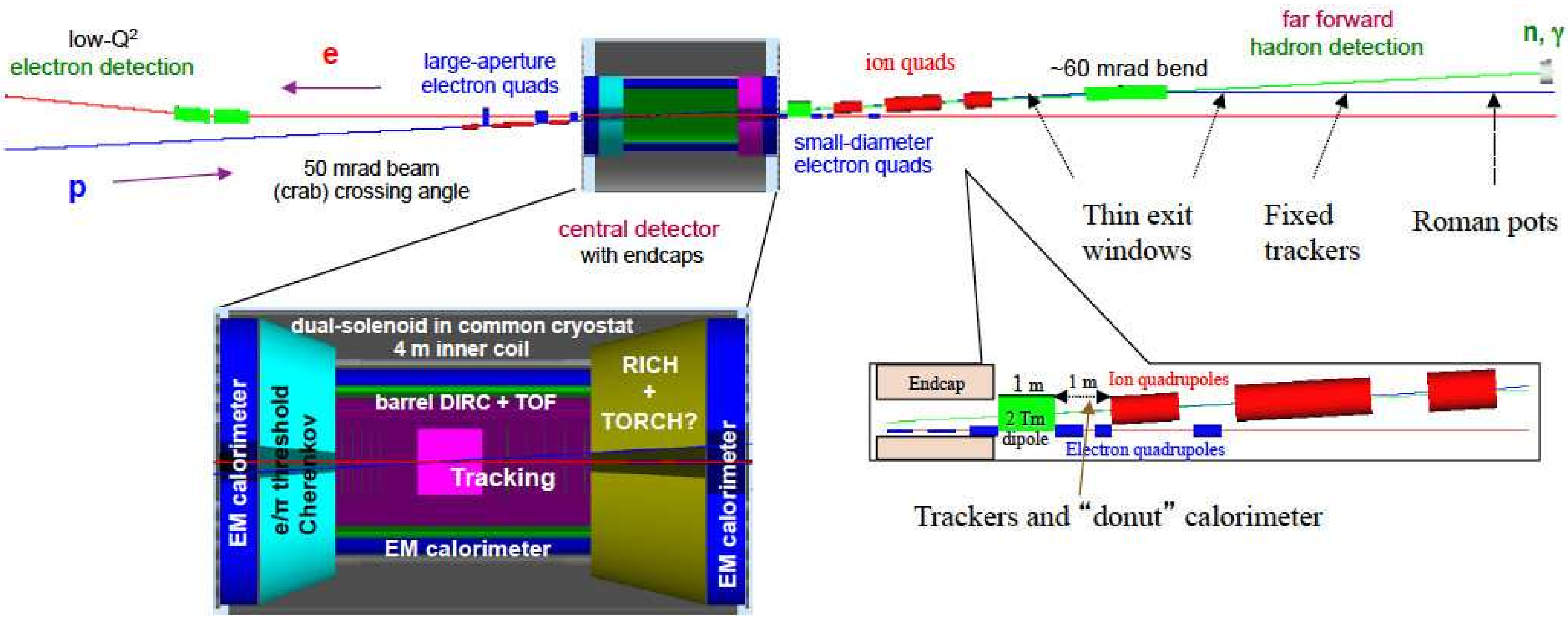
  EIC@China project in Lanzhou
  Design targets similar to JLab MEIC

Facilities: MEIC full–acceptance detector [Slide P. Nadel-Turonski]

Design goals

- Detection/identification of complete final state
- Recoil p_T resolution $\ll$ Fermi momentum
- Low–Q^2 electron tagger for photoproduction





Facilities: MEIC far-forward detection [Slide P. Nadel-Turonski]

- Good acceptance for all ion fragments – rigidity different from beam

  Large magnet apertures (small gradients at a fixed maximum peak field)

  Roman pots not needed for spectators and high-p_T fragments

- Good acceptance for low–p_T recoils – rigidity similar to beam

  Small beam size at detection point (downstream focus, efficient cooling)

  Large dispersion (generated after the IP, $D = D' = 0$ at the IP)

  With 10σ beam size cut, the low–p_T recoil proton acceptance is
  Energy up to 99.5% of the beam for all angles
  Angular down to 2 mrad for all energies

- Good momentum and angular resolution

  Should be limited only by initial state (beam)

  Longitudinal dp/p: 4×10^{-4}
  Angular in θ, for all ϕ: 0.2 mrad
  $p_{TR} \sim 15\,\mathrm{MeV}/c$ resolution for tagged 50 GeV/A deuterium beam

  Long, instrumented drift space (no apertures, magnets, etc.)

- Sufficient beam line separation ($\sim$ 1 m)

LDRD project: Polarized light ions

D. Higinbotham, W. Melnitchouk, P. Nadel–Turonski, K. Park, C. Weiss (JLab),
Ch. Hyde (ODU), M. Sargsian (FIU), V. Guzey (PNPI),
with collaborators W. Cosyn (Ghent), S. Kuhn (ODU), M. Strikman (PSU), Zh. Zhao (JLab)

Objectives
Develop physics models for DIS processes on polarized light ions (D, 3He) with tagged nucleons
Implement in MC generator with schematic modeling of EIC beam/detector characteristics
Simulate processes and demonstrate feasibility of physics extraction

- Project started Dec 2013

- 50% FTE experimental physics postdoc (shared with ODU): Kijun Park
  Senior theory collaborators as long-term visitors in Summer 2014

- Cross section model for unpolarized D available (Sargsian)
  Shadowing model being developed (Guzey)
  MC generator development in progress (Park, Higinbotham, Hyde, Nadel-Turonski)
  Simulations of extraction of unpolarized F_2^p, F_2^n with forward tagging
  Next steps: Final-state interactions, polarized g_1^p, g_1^n, DVCS

- Open for collaboration!
  Physics models and generators to be made available
  Extension to other processes of interest possible

Summary

- Deuteron as target of choice for precision nuclear physics

  Free neutron structure from on-shell extrapolation

  Polarization, incl. tensor

  Coherent effects at $N = 2$

- JLab MEIC offers unique opportunities for eD measurements

  Kinematic reach for sea quarks, gluons, coherence

  Polarization, incl. tensor

  Forward tagging of p, n, D

  Qualitative advances!

- Natural extension of JLab 6/12 GeV nuclear physics program

  Unique expertise! Much to contribute. . .