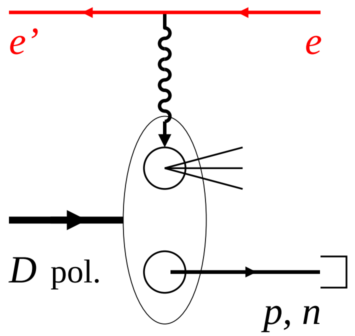
# Neutron structure with spectator tagging at MEIC

C. Weiss (JLab), Users Group Workshop 2014, JLab, 03–Jun–14

Jefferson Lab




Kinematic reach in $x, Q^2$

Ion polarization $L, T$, tensor

Forward detection of $p, n, D$

**Precision measurements using $eD$ with forward tagging**

- Light ion physics with EIC

  Physics objectives

  Polarized deuterium

  Spectator nucleon tagging

- Forward $p/n$ tagging with deuterium

  Free neutron through on-shell extrapolation

  Bound nucleon structure

  Polarization

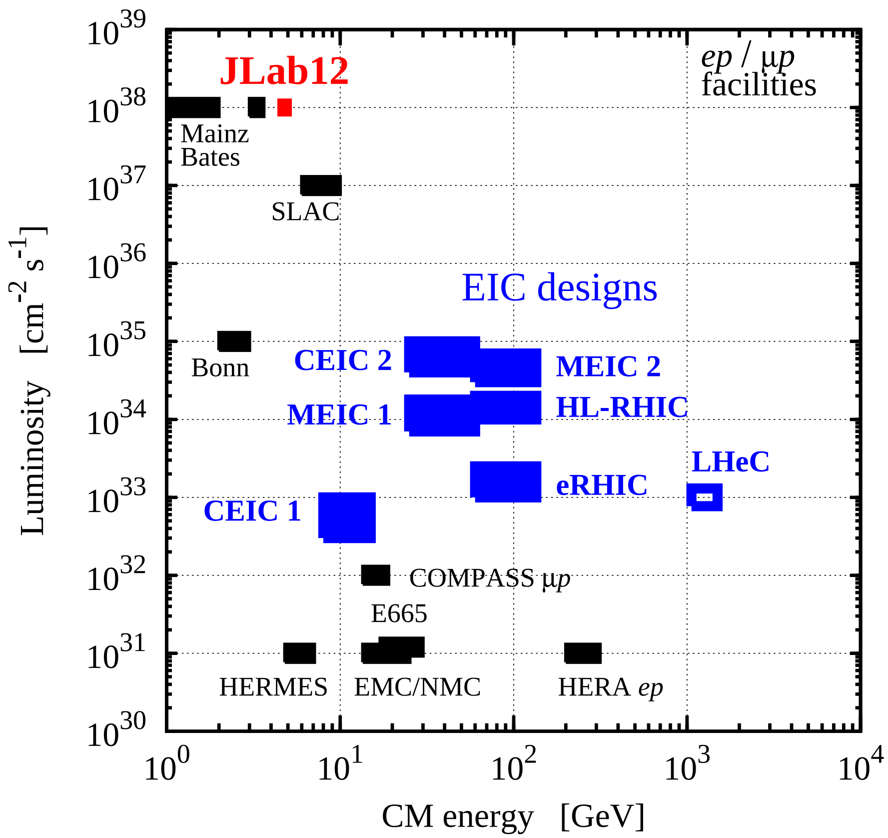
  Shadowing and coherence at $x \ll 0.1$

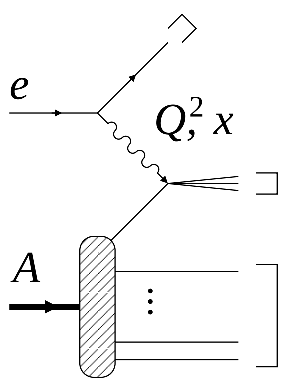
- R&D status and prospects

  Forward detection with JLab MEIC

  JLab 2014 LDRD project

# Light ions: Energy, luminosity, polarization




- CM energy 10-40 GeV/nucleon
  MEIC 1. Higher energy upgrade

  $Q^2 \sim$ few 10 GeV$^2$ for DIS

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

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

  Exceptional configurations in target

  Multi-variable final states

  Polarization effects

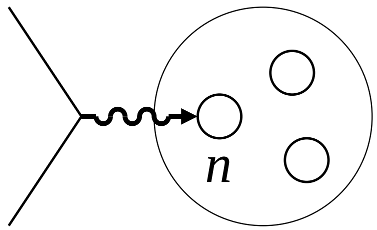
- Polarized light ions

  eRHIC: unpol $D$, pol $^3$He

  MEIC: polarized $D$ and $^3$He
  Figure-8 design

- $ep$ physics program
  → 2012 White Paper, reviews. Talk A. Deshpande

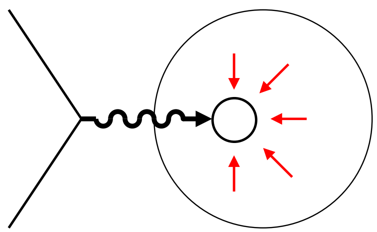
# Light ions: Physics objectives




- Neutron structure

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

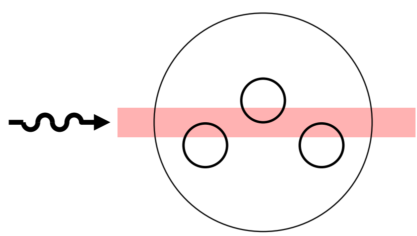
  How to account for binding, polarization, final–state interactions?



- Bound nucleon in QCD

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

  How to control nuclear environment?



[Nucleus rest frame view]

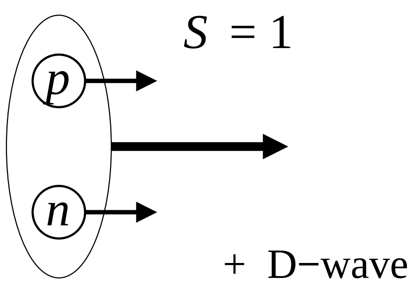
- Coherence and saturation

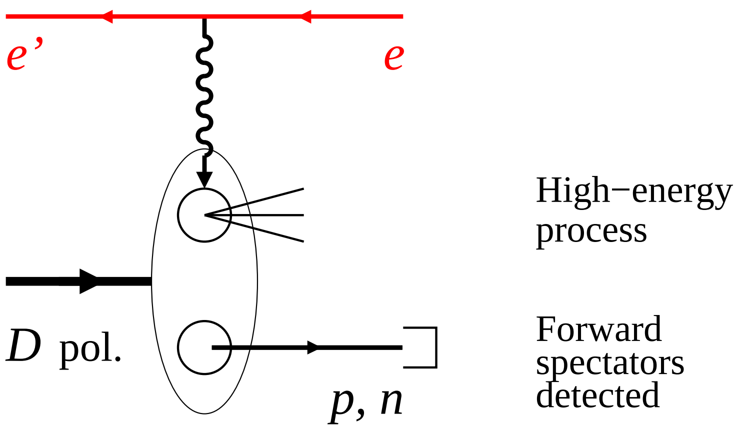
  Interaction of high–energy probe with coherent quark/gluon fields

  How to quantify onset of coherence? Signatures of saturation?

- Challenges to be addressed by theory and new experimental techniques! $\longleftarrow$

# Light ions: Deuterium and spectator tagging




- Polarized deuterium

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

  Neutron spin–polarized

  Limited possibilities for nuclear final–state interaction

  Coherent effects at $N = 2$
  Complementary to saturation in large nuclei

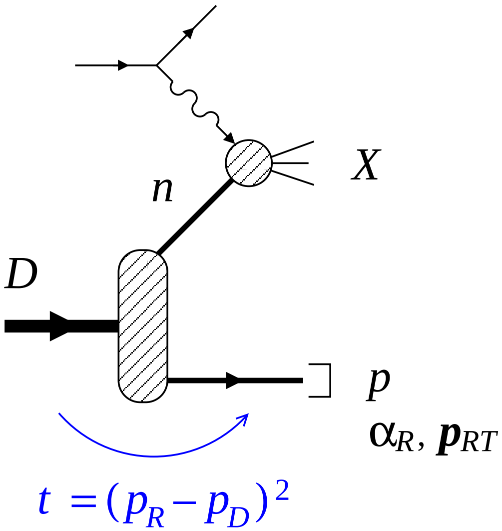
- Spectator nucleon tagging

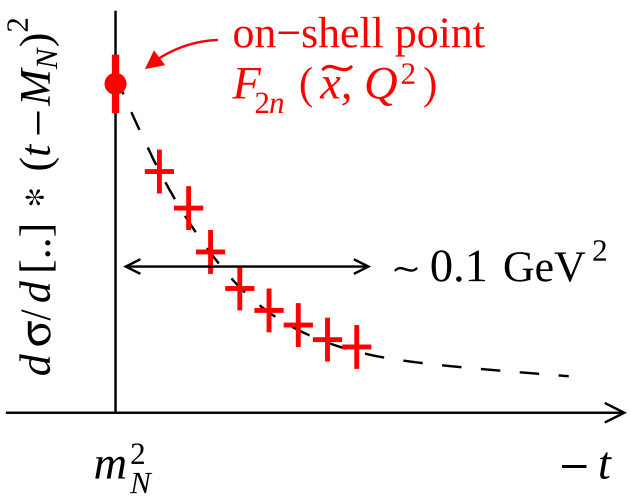
  Detection of forward proton or neutron

  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

# Spectator tagging: Extracting neutron structure




$t = \text{function}(\alpha_R, \boldsymbol{p}_{RT})$

- Light-cone momentum of recoil proton

$$\frac{\alpha_R}{2} = \frac{E_R + p_R^z}{E_D + p_D^z} \quad \text{and} \quad \boldsymbol{p}_{RT}$$

- Cross section in impulse approximation
  Frankfurt, Strikman 81

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

$$\times\ S_D(\alpha_R, \boldsymbol{p}_{RT})\ \ F_{2n}\left(\frac{x}{2-\alpha_R}, Q^2\right)\ +\ \ldots$$

Deuteron LF spectral fn — Neutron structure fn

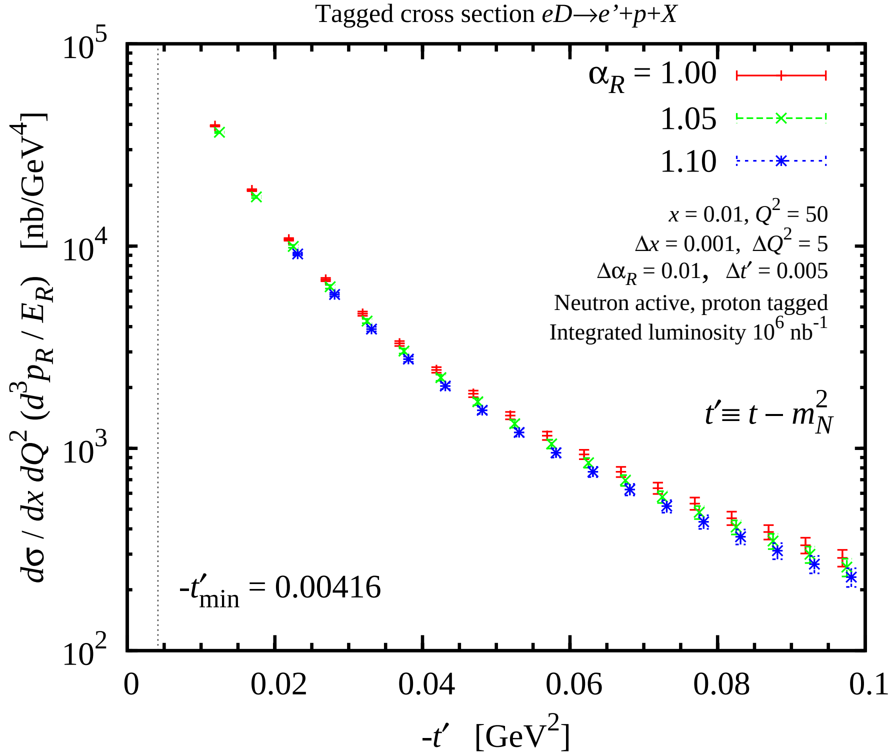
- On-shell extrapolation $t \rightarrow M_N^2$
  Cf. Chew–Low extrapolation in $\pi N$, $NN$ scattering

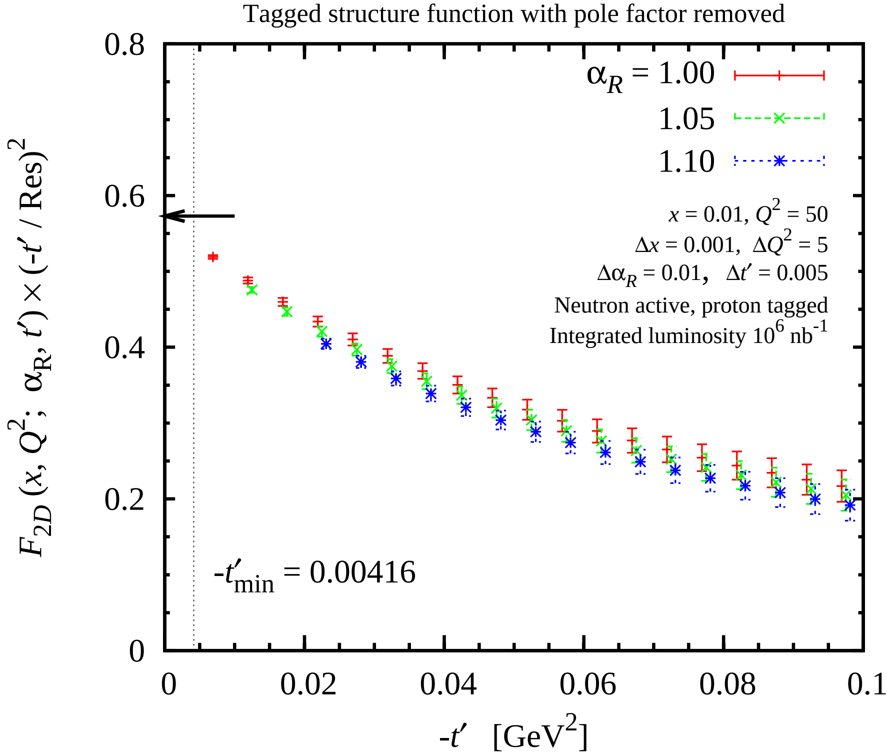
  Free neutron structure at pole

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

  Model–independent method!

# Spectator tagging: EIC projections JLab LDRD project




- Stat errors based on integrated lumi $10^6\,\mathrm{nb}^{-1}$ 2 weeks at $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  Overall error systematics-dominated, full MC simulation in progress

- On-shell extrapolation appears feasible

  Extrapolation smooth after taking out nucleon pole factor

  Test universality: $t'$ dependence at different $\alpha_R$

  Excellent rates for spin/flavor asymmetries

# Spectator tagging: Applications

- Unpolarized neutron structure $F_2^n, F_L^n$

  Isovector $p - n$ at $x < 10^{-1}$ constrains sea quark flavor asymmetry $\bar{d} - \bar{u}$

- Bound proton through neutron spectator tagging

  Compare tagged SF at $t = m_N^2$ with free proton measurement to validate method

  Quantify nuclear binding effect on quark/gluon distributions through $t$–dependence: Connection with short-range $NN$ correlations?

- Neutron spin structure functions $g_1^n, g_2^n$ **in progress**

  Isoscalar $p + n$ for $\Delta G$, especially at large $x$

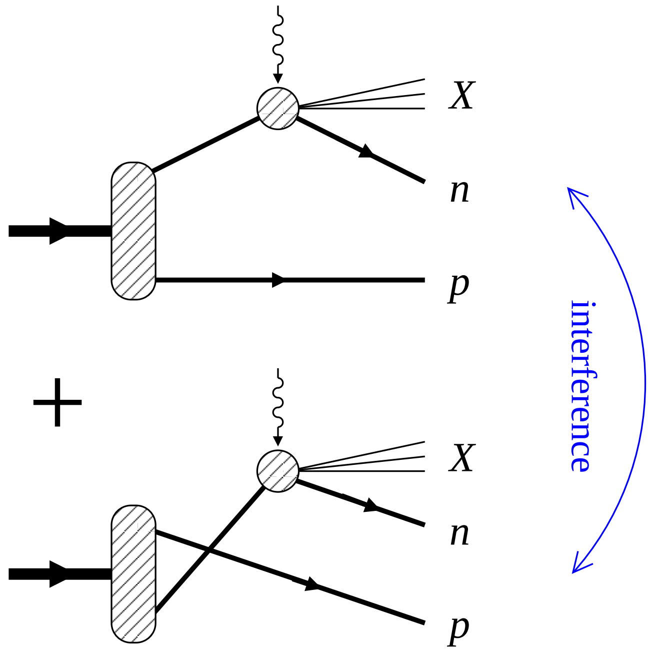
  Isovector $p - n$ for $\Delta u - \Delta d$

  Bjorken sum rule: Fundamental quantity, tests high-order pQCD calculations

  Cleanest possible extraction of neutron spin structure!

- Other DIS final states: Semi-inclusive, exclusive, DVCS

# Spectator tagging: Coherent effects




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

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

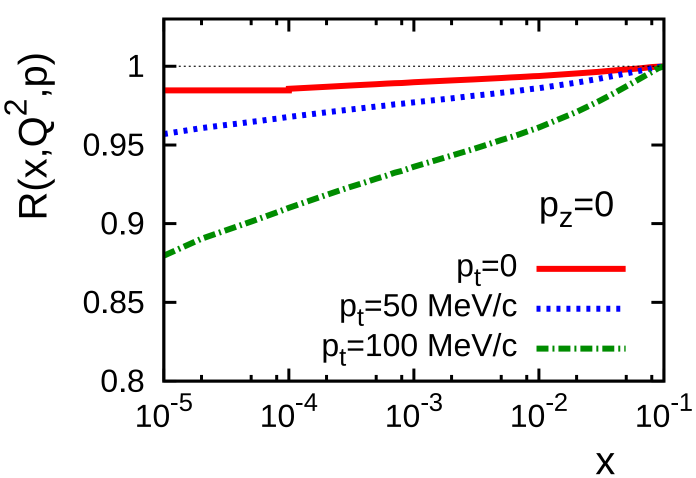
  Interference between scattering on $p$ and $n$
  Calculable: Gribov 70's. Frankfurt, Guzey, Strikman 02+

- Shadowing in tagged DIS

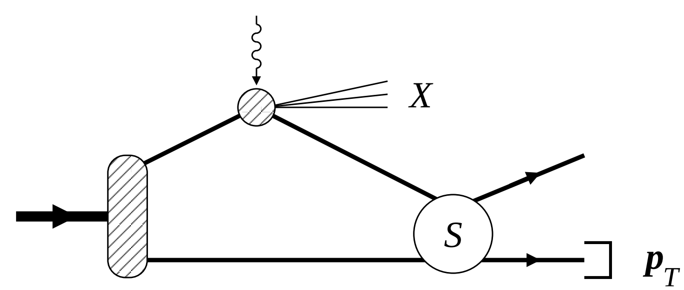
  Clean coherent effect with $N = 2$

  Essential for systematics in $p - n$
  Also polarized. Needs to be controlled!

  Strong low-energy FSI between $p$ and $n$ distorts $p_T$ spectrum, spin/isospin dep.
  Guzey, Strikman, CW; in progress



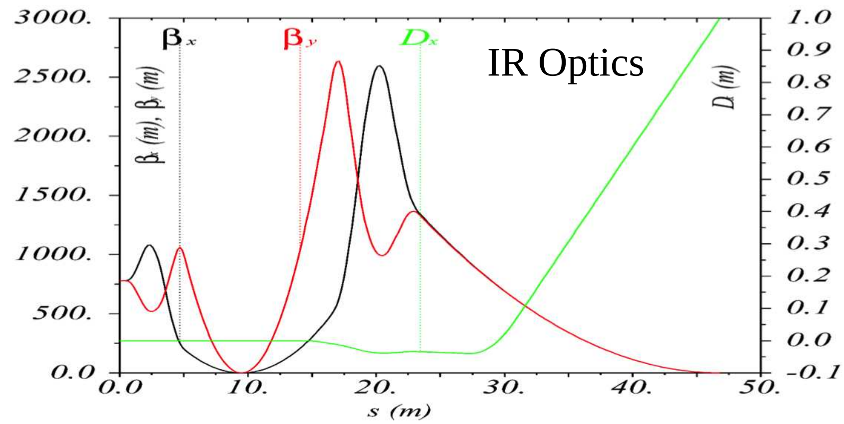

Frankfurt, Guzey, Strikman 11. Guzey LDRD 2014

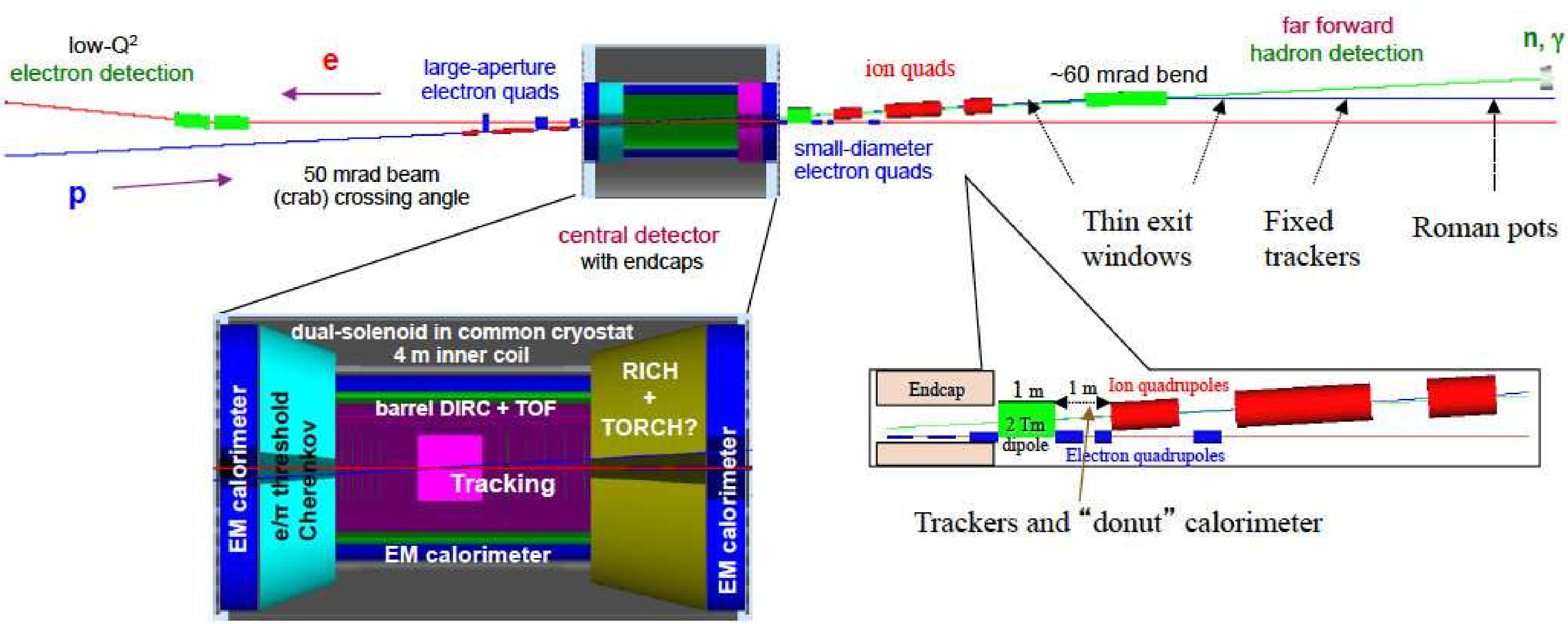


# MEIC: Full–acceptance detector [Slide P. Nadel-Turonski]

Design goals

- Detection/identification of complete final state
- Acceptance and resolution for forward protons, fragments, neutrons
- Low–$Q^2$ electron tagger for photoproduction




More information at `http://eic.jlab.org/`

# MEIC: Far-forward detection [Slide P. Nadel-Turonski]

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

  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 10$\sigma$ 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

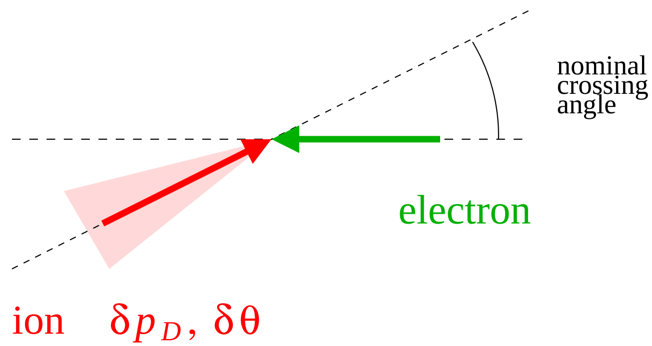
  Should be limited only by initial state (beam)

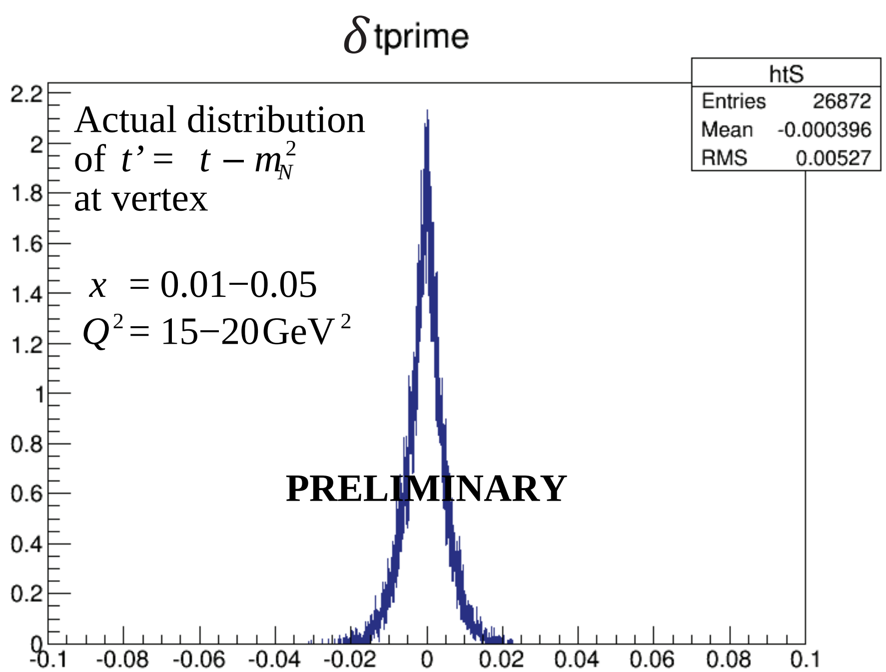
  Longitudinal $dp/p$: $4 \times 10^{-4}$ $\longleftarrow$
  Angular in $\theta$, for all $\phi$: 0.2 mrad
  $p_{RT} \sim 15\,\mathrm{MeV}/c$ resolution for tagged 50 GeV/A deuterium beam $\longleftarrow$

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

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

# MEIC: Momentum spread in beam




**Ch. Hyde, K. Park et al.: JLab LDRD project**

- Intrinsic momentum spread in ion beam "smears" recoil momentum

  $p_R\,(\text{measured}) \neq p_R\,(\text{vertex})$

  Dominant uncertainty for MEIC
  Larger than detector resolution. Different for eRHIC!

  At nominal MEIC emittance
  $\delta p_D / p_D = 3 \times 10^{-4}$
  $\delta\theta = 2 \times 10^{-4}$

- Effect on $t' = t - M_N^2$

  Dominant effect from ion $\delta\theta$

  Smearing width $\lesssim$ bin size

- On-shell extrapolation appears feasible!

# LDRD: Polarized light ions with EIC@JLab

**JLab FY14 LDRD Project**

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 spectator tagging
Develop event generators for MC simulations of inclusive, diffractive and exclusive final states
Simulate processes with schematic modeling of EIC beam/detector/IR characteristics
Analyze pseudodata and quantify physics output of spectator tagging

**Resources**

50% FTE experimental physics postdoc, shared with ODU: Kijun Park
Theory collaborators as long-term visitors in Summer 2014: Sargsian, Guzey, Cosyn
10% FTE of JLab Staff: Weiss, Higinbotham

**Collaboration**

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

**More information on Wiki**

`https://eic.jlab.org/forward_tagging/`

# LDRD: Status and next steps

**Physics models**

Unpolarized $eD \to e' + N + X$ with nuclear binding, final-state interactions
theory+codes ready, testing/documentation in progress

Unpolarized $eD \to e' + pn + X$ with diffraction/shadowing
theory+code ready, low-energy final-state interaction in progress

Polarized $eD \to e' + N + X$ theory+code developing,
Polarized $e^3\mathrm{He} \to N + X$ scheduled (summer 14)

**MC generators**

FSGEN-based generator (nucleus rest frame) adapted from fixed-target code

New generator developed for collider kinematics (detector frame),
including intrinsic momentum spread of beam particles

Codes available on github, testing/documentation in progress

Polarized beams, diffractive final state $eD \to e' + pn + X$ scheduled (summer 14)

**Process simulations**

On-shell extrapolation in $eD \to e' + N + X$
Effect of intrinsic momentum spread
Hookup to GEMC detector MC to study tracking, acceptance

Physics extraction from pseudodata, extension to polarized $eD$ (summer 14)

# Summary

- Next-generation nuclear DIS measurements enabled by

  Polarized deuterium beam
  Forward $p, n$ detection
  EIC kinematic reach

  } Unique combination!

- R&D to establish forward tagging at MEIC as standard method

  Theory: Polarization, final–state interactions, . . .

  Simulations: Acceptance, tracking, systematic errors, . . .

- Users welcome!

  Natural continuation of JLab 6/12 GeV nuclear program:
  BONUS, SRCs, EMC effect, DVCS, exclusive processes

  Tools made available: Physics models, event generators

  Increasing interest