High-energy nuclear physics with spectator tagging

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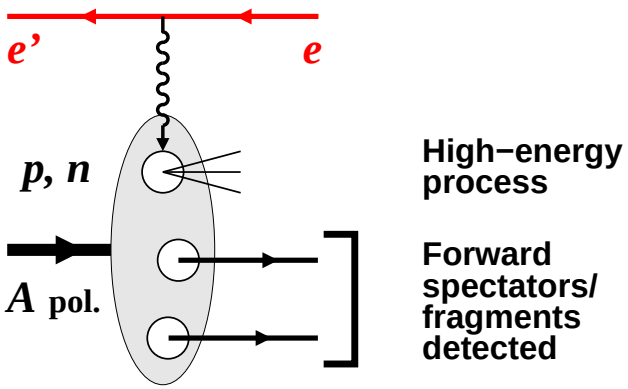


- High-energy eA scattering

  Energy, luminosity, polarization

  Physics objectives with light nuclei

- Spectator nucleon tagging

  Free neutron structure & spin

  Bound nucleon structure, EMC effect

  Short-range correlations, non-nucleonic DOF

  Coherent phenomena at $x \ll 0.1$

- Future facilities

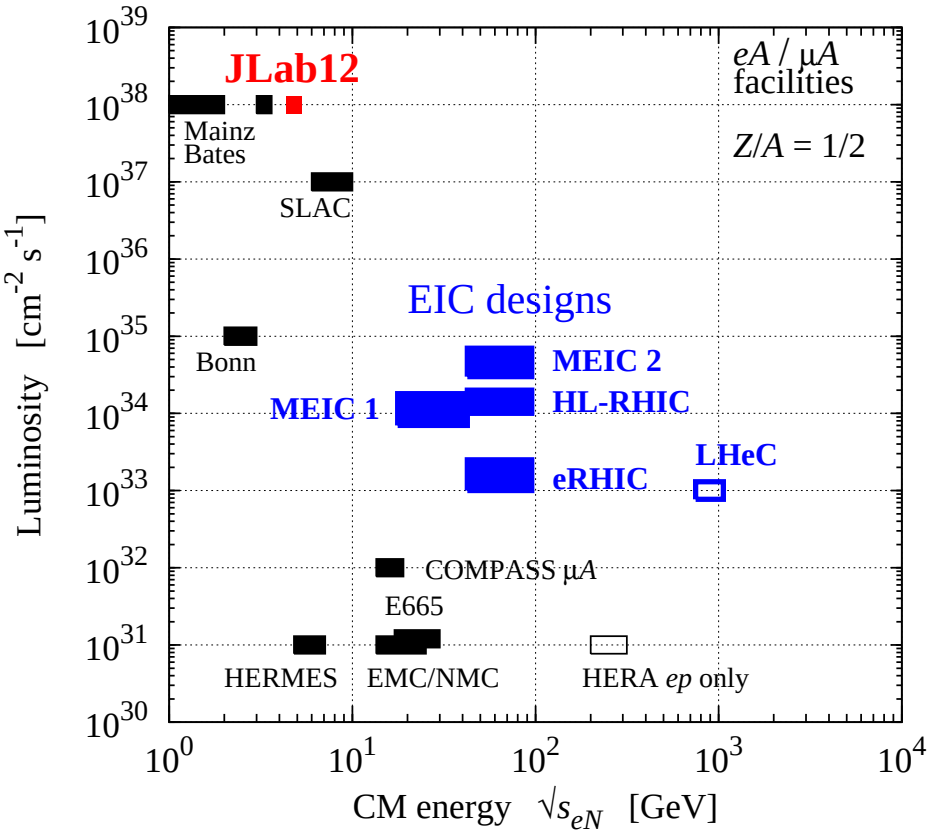
  JLab 12 GeV: Hall A/C, CLAS12 BONuS

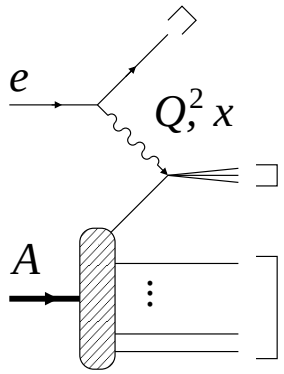
  EIC: Forward detection, polarized D

OLD DOMINION UNIVERSITY
IDEA FUSION

Jefferson Lab

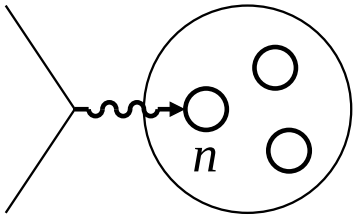
Light nuclei: Energy, luminosity, polarization

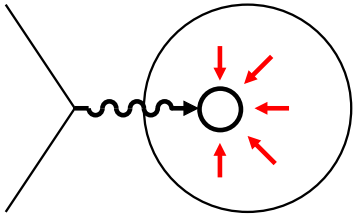


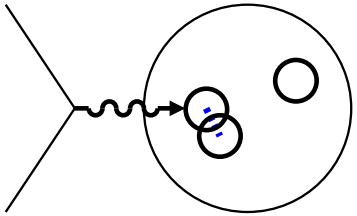


- Scattering energy
  - Resolution scale $1/Q$
  - LC fraction x: Type of constituents, target configurations
- Luminosity
  - Exceptional configurations in target
  - Multi-variable final states
  - Polarization observables
- JLab 12 GeV: Fixed–target eA
  - Highest luminosity!
  - Polarized D, $^3\mathrm{He}$
- EIC: First eA collider
  - Luminosity $\sim$1000$\times$ HERA ep
  - eRHIC: unpol D, pol $^3\mathrm{He}$
    MEIC: polarized D and $^3\mathrm{He}$

Light nuclei: Physics objectives







[Nucleus rest frame view]

- Neutron structure

  Flavor decomposition of PDFs, asymmetry $\bar{u} - \bar{d}$, quark spin Δu, Δd, gluon polarization Δg

  How to account for binding, polarization, FSI?

- Nuclear modification of partonic structure

  $x > 0.2$ EMC effect
  $x \ll 0.1$ Coherent scattering, shadowing

  How to control nuclear environment?
  Instantaneous configuration?

- Short-range correlations

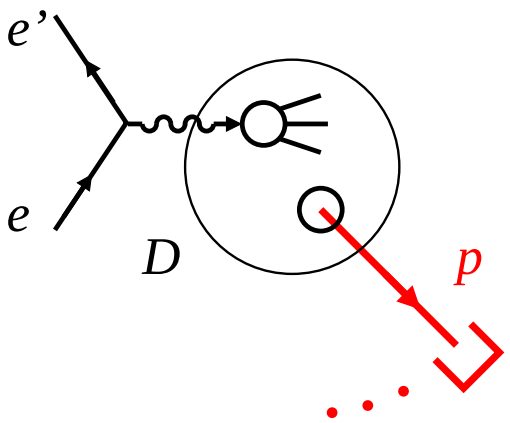
  NN interactions, non-nucleonic DOF

  How to identify correlations?
  Isospin structure? Universality?

$\rightarrow$ Inclusive scattering + theory

$\rightarrow$ Experimental information on final state! $\leftarrow$

Light nuclei: Nucleon tagging



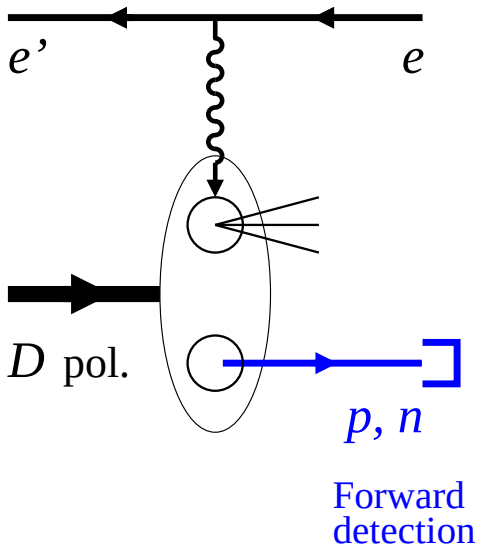
- Nucleon tagging

  Deuteron $A = 2$: Simplest system, wave function known, limited FSI

  Identify active nucleon, control quantum state w. recoil momentum

- Fixed-target experiments

  Recoil momentum $p_R \sim$ 10–100 MeV
  Proton slow, isotropic



- Colliding–beam experiments

  $p_{R\|} \approx p_D/2 \sim$ few 10 GeV longitudinal
  $p_{RT} \sim$ 10–100 MeV transverse

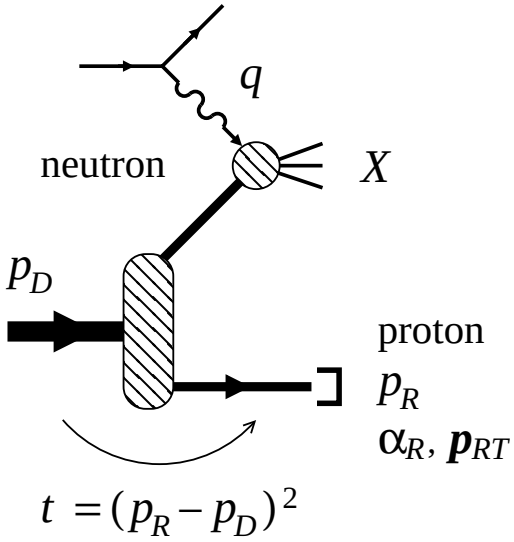
  Forward detection technologies

  Polarization D beams, longitud/transv

  Neutron tagging possible

  Uniquely suited, great potential!

Neutron structure: Unpolarized



- Inclusive DIS: Nuclear corrections

  $x > 0.5$ Binding effects?

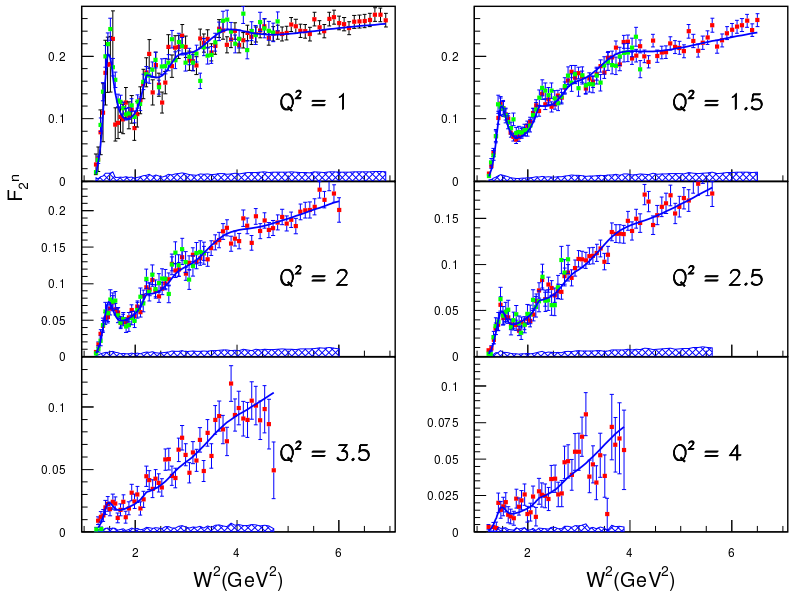
  $x < 0.1$ pn difference only few %

- Proton tagging $e + D \to e' + p + X$

  Cross section has pole at $t = M_N^2$

  Free neutron from on-shell extrapolation in recoil momentum

  Model-independent, eliminates FSI
  Sargsian, Strikman 05. Cf. Chew–Low extrapolation in πN



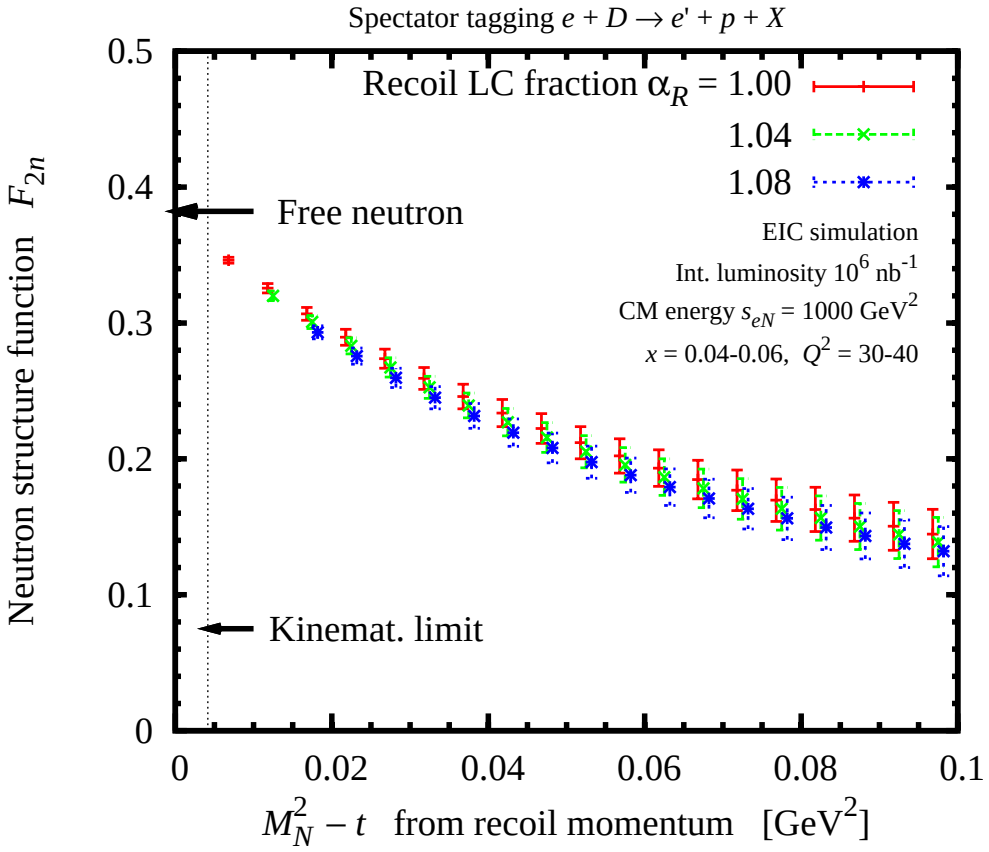
- Fixed-target: CLAS BONuS → **Tkachenko**

  Uses recoil momenta p_R = 70–150 MeV, backward angles

  Impact on PDF analysis, duality → **Melnitchouk**

  12 GeV extensions → **Dupre, Zhang, Charles**

Neutron structure: Unpolarized



- MEIC: Precise neutron structure measurements with proton tagging and on-shell extrapolation

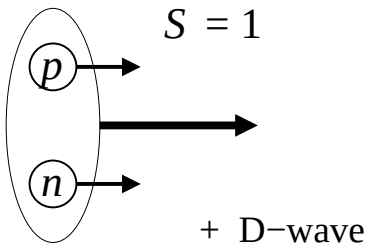
  → **Park**

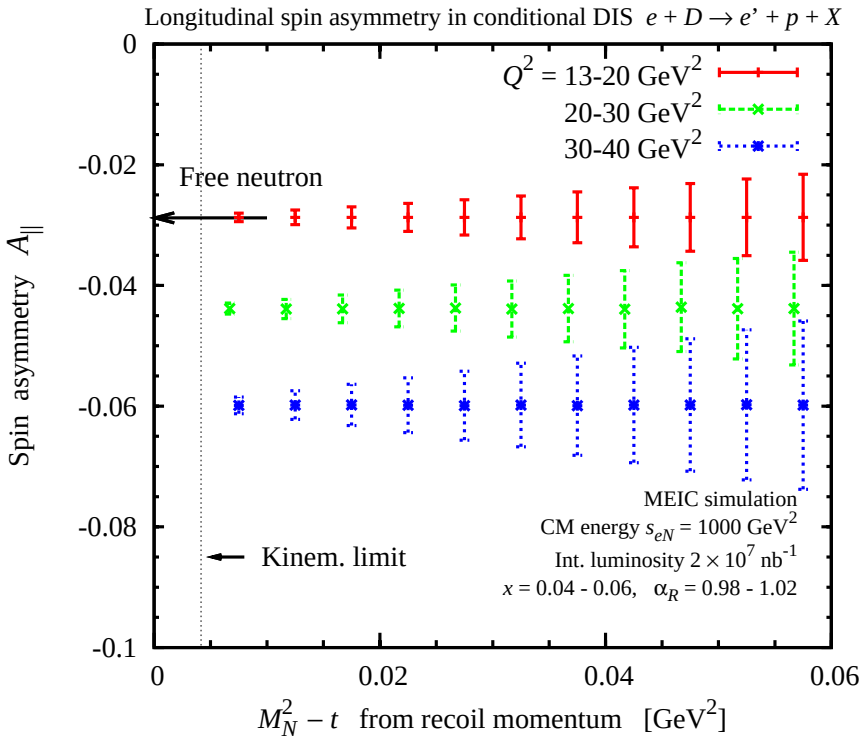
  Full coverage down to $p_{RT} \sim 0$

  Sufficient momentum resolution: Detector resolution, beam momentum spread

  Large x accessible with high luminosity

Neutron structure: Polarized





- Neutron data needed

  Flavor separation $\Delta u, \Delta d$

  Singlet vs. nonsinglet Q^2–evolution: Gluons, higher twist

- Inclusive DIS: $^3\mathrm{He}$ target

  JLab 6/12 GeV program → **Cates**

  EIC: Wide coverage

- MEIC: Neutron spin structure w. polarized D and proton tagging

  On-shell extrapolation of asymmetry

  D–wave suppressed at on-shell point

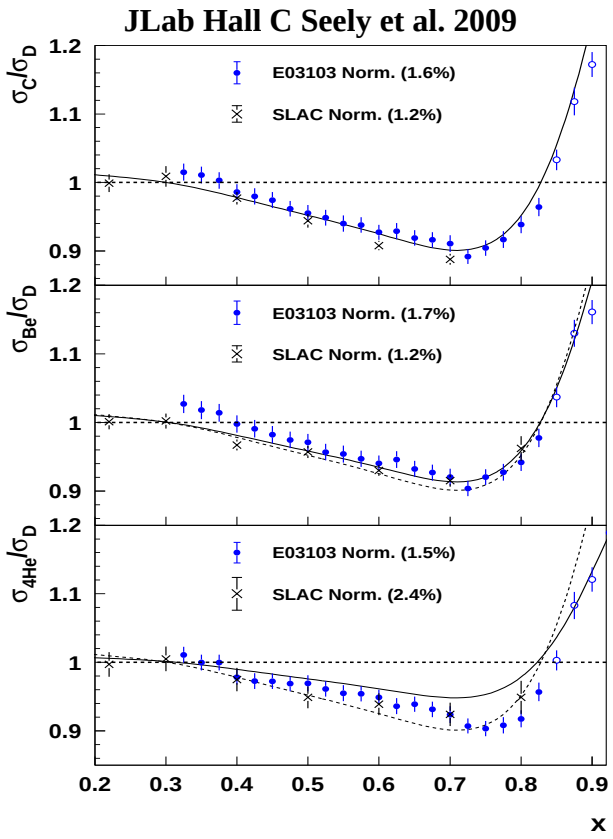
  Impact on polarized PDF analysis

  Bjorken sum rule: → **Deur**
  α_S from Q^2 dependence

Neutron structure: Nuclear theory input

- Deuteron light–front structure for tagging → **Miller**
  Covariant description of deuteron → **Van Orden**
- Polarization effects in tagging → **Sargsian**
- Final–state interaction models for tagging at large and small x → **Cosyn**
- Shadowing effects in tagging at small x → **Guzey**
- $^3\mathrm{He}$ spectral function for inclusive polarized DIS → **Scopetta**
- Nuclear structure from EFT-controled interactions → **Pastore**

Nuclear modification: EMC effect



- Modification of quark/gluon structure

  → **Higinbotham**

  Dynamical origin?

  What momenta and distances in nuclear wave function cause modification?

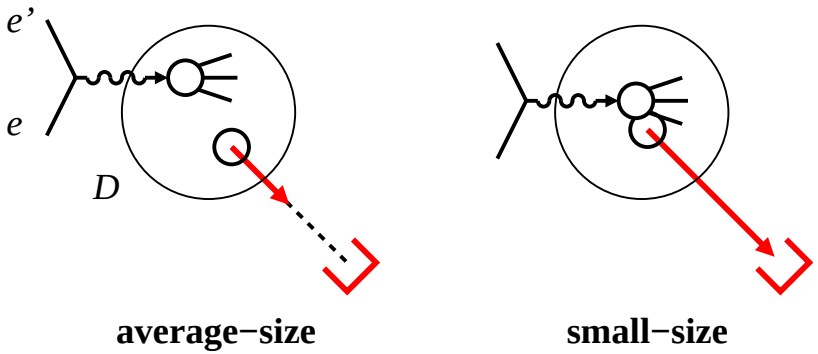
  Spin–isospin dependence?

- JLab12/EIC: EMC effect in tagged DIS

  → **Schmookler**

  Modification as function of recoil mom

  Control size of configurations!

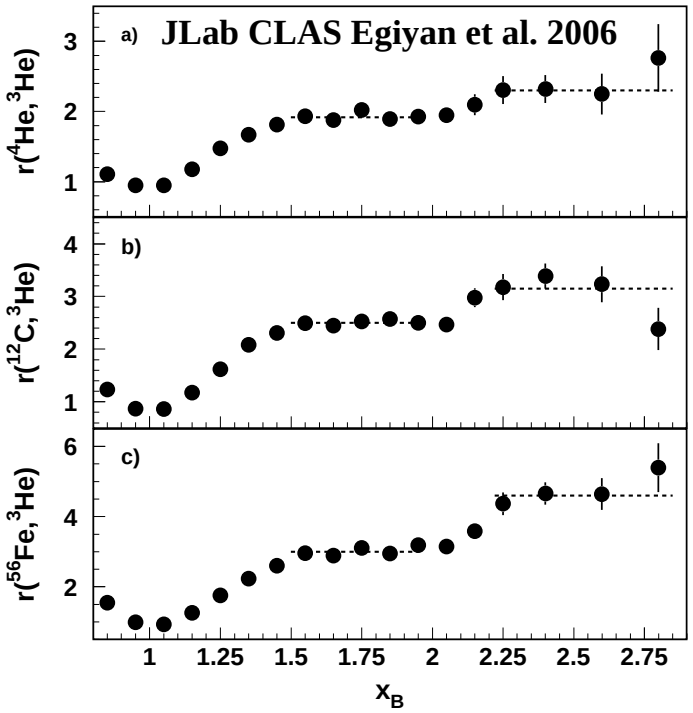


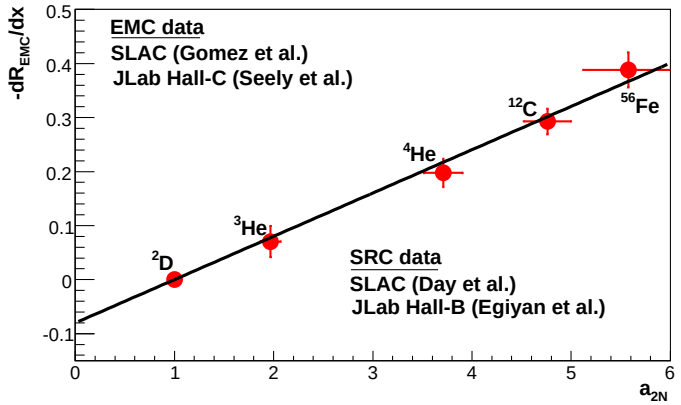
- EIC: New possibilities

  Q^2 evolution and gluons

  Spin dependence with polarized D

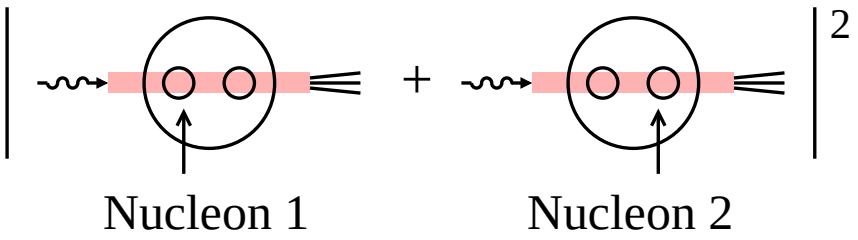
Nuclear modification: Short-range correlations





- Short–range NN correlations → **Strikman**
  - High–momentum component of nuclear WF
  - Universality, spin–isospin dependence
  - Short–range NN interaction $\leftrightarrow$ QCD
  - Non-nucleonic DOF?
- JLab 6/12 GeV program → **Weinstein**
  - Inclusive: $x > 1$ → **Fomin**
  - Tagged: $(e, e'p)$, $(e, e'NN)$
- SRCs in tagged DIS
  - Quark/gluon structure of SRC
  - EMC effect driven by SRCs? → **Higinbotham**

Coherent effects, tensor polarization



- Coherent effects at $x \ll 0.1$

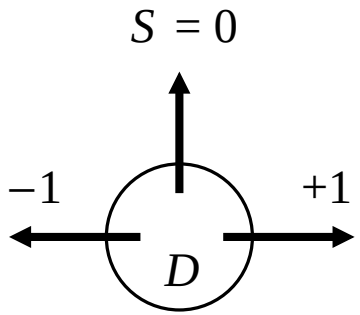
  → **Guzey**

  Coherence length $> NN$ distance: Quantum–mechanical interference

  Inclusive DIS: Shadowing

  Tagged DIS: Strong effect on recoil momentum dependence

  EIC: Explore coherence in $A = 2$, quantify approach to saturation



- Tensor polarization → **Long**

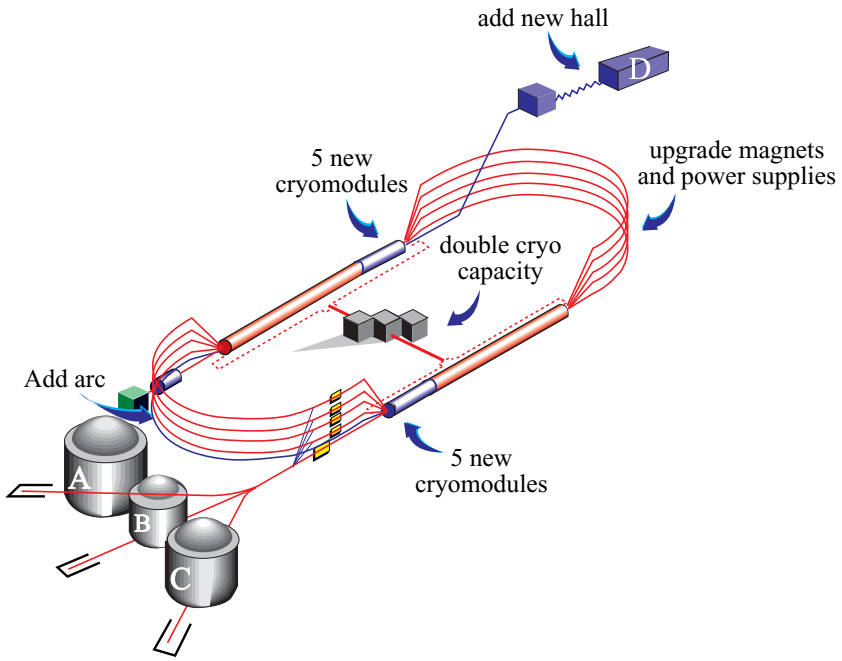
  Tensor SF zero on free nucleon, requires interactions or coherence

  JLab12 experiments planned

  EIC: Tensor polarized D beams, kinematic access to $x < 0.1$

  → **Morozov**

Facilities: JLab 12 GeV

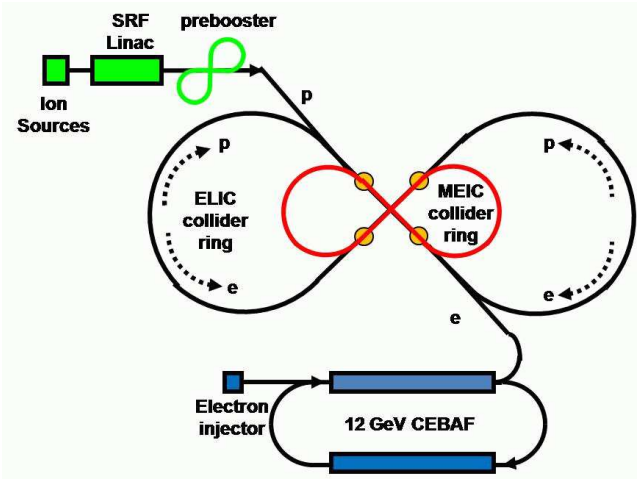


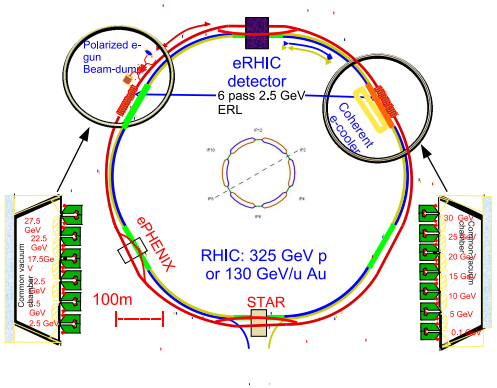
CW beam $\sim 100\,\mu A$
Accelerator operating since 1994

- CEBAF "race track" accelerator with linacs + arcs, now at 12 GeV
  - Uses unique superconducting RF technology
  - Extensible to max. 24 GeV
- Experimental halls and detectors
  - A, C Magnetic spectrometers
    SHMS upgrade on-going
  - B New large-acceptance detector
    CLAS12 under construction
  - D γ beam, GlueX detector
    being commissioned

  Additional devices planned: Moller, SOLID
- Broad physics program: Spectroscopy, hadron structure, nuclear physics, electroweak
- Tagging experiments
  - CLAS12 + BONUS detector
  - Halls A/C

Facilities: Electron–Ion Collider





Convergence in design goals

Differences in technological challenges

- JLab ring–ring design MEIC

  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 $\sim 10^{34}$ cm^{-2}s^{-1} over wide energy range
  Figure–8 for polarization transport, up to four IP's

- BNL linac–ring design eRHIC

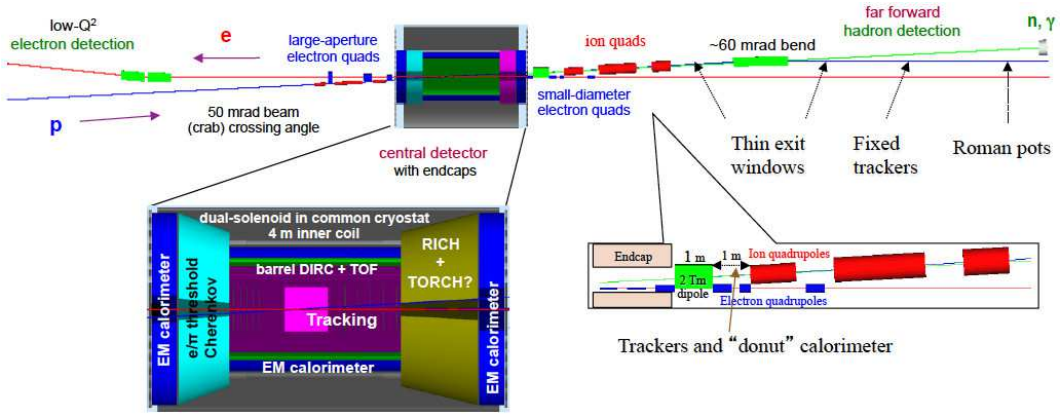
  RHIC proton/ion beam up to 325 GeV
  5–20 (30) GeV electrons from linac in tunnel staged
  Luminosity $\sim 10^{34}(10^{33})$ over wide range
  Re-use RHIC detectors? ePHENIX

- Related proposals

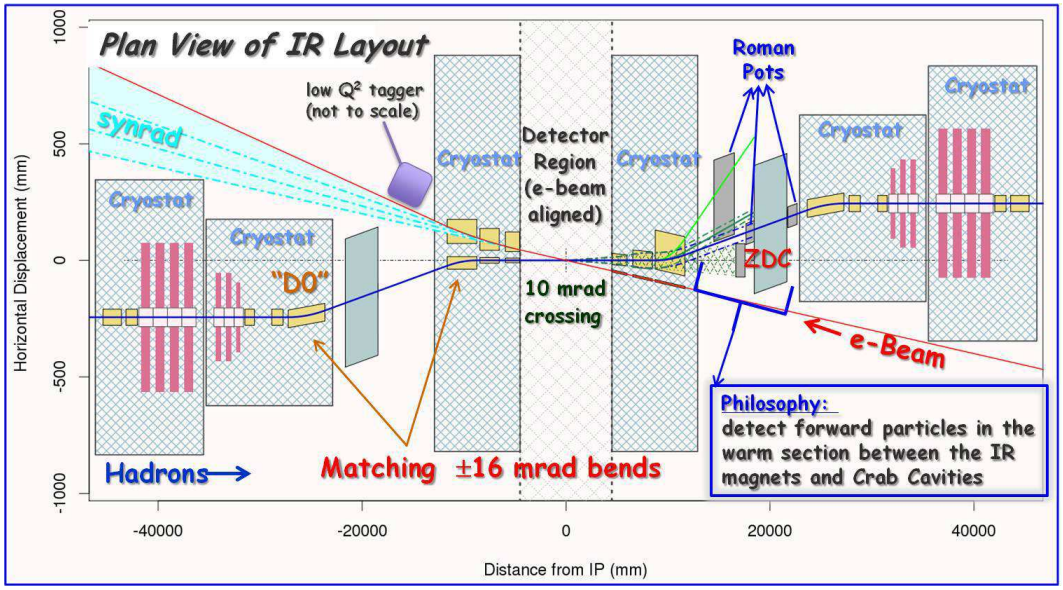
  CERN LHeC: 20–150 GeV on 7 TeV ep
  Ring–ring and linac–ring discussed, $L \sim 10^{33}$
  Mainly particle physics after LHC, but also high–energy QCD

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

Facilities: Forward detection



MEIC IR and forward detector



eRHIC IR and forward detector

- Forward detection of protons, neutrons, nuclear fragments

  Integrated with IR/optics design: Particles travel through final focusing magnets

  Extensive work at eRHIC, MEIC
  → **Parker, Morozov**

  Experience w. heavy ions at LHC
  → **Tapia Takaki**

- Tagging requirements

  Coverage for forward protons with $0 < p_{RT} \lesssim 300\ \mathrm{MeV}$ and $\Delta p_{R\|}/(p_{\mathrm{beam}}/2) \lesssim 0.2$

  Resolution $\Delta p_{RT} \ll 100\,\mathrm{MeV}$ and $\Delta p_{R\|}/p_{R\|} \ll 10^{-2}$

  Forward neutron detection with sufficient angular/position resolution

Summary

- Spectator tagging enables next–generation studies of short-range nuclear structure and QCD
- Tagging program with JLab 12 GeV developing
- Ideally suited for collider, great opportunities with EIC
- Intersection of different fields

  QCD and partonic structure
  Low-energy nuclear structure
  Detector concepts
  Accelerator design

- Looking forward to new impulses from this workshop!