Polarized light ions

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in collaboration with Ch. Weiss
JLab LDRD project on spectator tagging

FLORIDA
INTERNATIONAL
UNIVERSITY

Outline

- Light ions at an electron-ion collider
- Nucleon structure
  - polarized deuteron spectator tagging
- Nucleon-nucleon interaction, coherence
- Imaging of light nuclei
- Experimental apparatus

Why focus on light ions at an EIC?

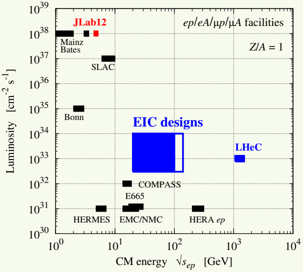
- Measurements with light ions address essential parts of the EIC physics program
  - neutron structure
  - nucleon interactions
  - coherent phenomena

- Light ions have unique features
  - polarized beams
  - breakup measurements & tagging
  - first principle theoretical calculations of initial state

- Intersection of two communities
  - high-energy scattering
  - low-energy nuclear structure

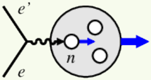
Use of light ions for high-energy scattering and QCD studies remains relatively unexplored

EIC design characteristics (for light ions)

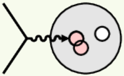


- CM energy $\sqrt{s_{eA}} = \sqrt{Z/A}\, 20 - 100\text{GeV}$ DIS at $x \sim 10^{-3} - 10^{-1}$, $Q^2 \leq 100\text{GeV}^2$
- High luminosity enables probing/measuring
  - exceptional configurations in target
  - multi-variable final states
  - polarization observables
- Polarized light ions
  - ^{3}He, other @ eRHIC
  - d, ^{3}He, other @ JLEIC (figure 8)
  - spin structure, polarized EMC, tensor pol, ...
- Forward detection of target beam remnants
  - diffractive and exclusive processes
  - coherent nuclear scattering
  - nuclear breakup and tagging
  - forward detectors integrated in designs

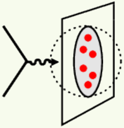
Light ions at EIC: physics objectives



- **Neutron** structure
    - flavor decomposition of quark PDFs/GPDs/TMDs
    - flavor structure of the nucleon sea
    - singlet vs non-singlet QCD evolution, leading/higher-twist effects



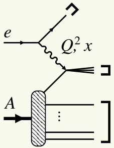
- Nucleon **interactions** in QCD
    - medium modification of quark/gluon structure
    - QCD origin of short-range nuclear force
    - nuclear gluons
    - coherence and saturation

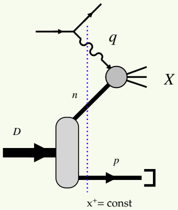


- **Imaging** nuclear bound states
    - imaging of quark-gluon degrees of freedom in nuclei through GPDs
    - clustering in nuclei

Need to control nuclear configurations that play a role in these processes

Theory: high-energy scattering with nuclei

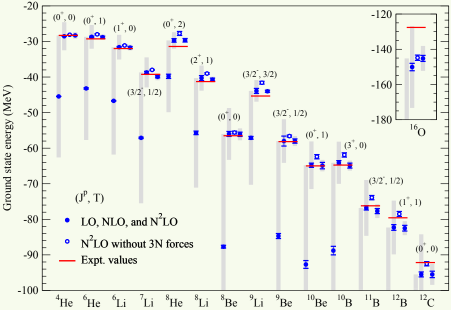




- Interplay of two scales: high-energy scattering and low-energy nuclear structure. Virtual photon probes nucleus at fixed lightcone time $x^+ = x^0 + x^3$
- Scales can be separated using methods of light-front quantization and QCD factorization
- Tools for high-energy scattering known from *ep*
- Nuclear input: light-front momentum densities, spectral functions, overlaps with specific final states in breakup/tagging reactions
  - framework known for deuteron, can be extended to ^{3}He
  - still **low-energy** nuclear physics, just formulated differently

Theory: nuclear structure calculations

- First principle NR calculations available for light ions



`LENPIC collab, PRC99 ('18)`

- Controlled expansion and hierarchy using χEFT for two- and three- body forces
- Variety of methods: finite-basis, no-core SM, GFMC, lattice EFT
- Fadeev methods for ^{3}He reactions

These tools need to be extended for applications in high-energy scattering

Neutron structure measurements

Needed for flavor separation, singlet vs non-singlet evolution etc.

- EIC will measure **inclusive** DIS on light nuclei [d,^{3}He, ^{3}H(?)]
  - Simple, no FSI effects
  - Compare n from ^{3}He $\leftrightarrow$ p from ^{3}H
  - Comparison n from ^{3}He, d

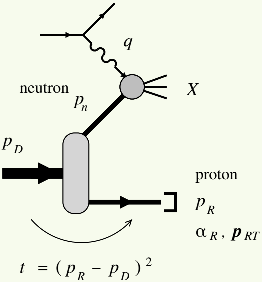
- **Uncertainties** limited by nuclear structure effects (binding, Fermi motion, non-nucleonic dof)

- ^{3}He is in particular affected because of intrinsic Δs

If we want to aim for precision, use tools that avoid these complications

Neutron structure with tagging

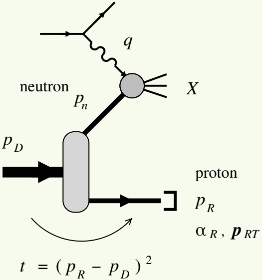
- Proton tagging offers a way of controlling the nuclear configuration



- Advantages for the deuteron
  - active nucleon identified
  - recoil momentum selects nuclear configuration (medium modifications)
  - limited possibilities for nuclear FSI, calculable
- ^{3}He $[A-1$ tagging$]$ → Talk R. Milner

- Suited for colliders: no target material ($p_p \to 0$), forward detection, polarization.
  fixed target CLAS BONuS limited to recoil momenta ∼ 70 MeV

Pole extrapolation for on-shell nucleon structure



- Allows to extract free neutron structure
  - Recoil momentum p_R controls off-shellness of neutron $t' \equiv t - m_N^2$
  - Free neutron at pole $t - m_N^2 \to 0$: "on-shell extrapolation"
  - Small deuteron binding energy results in small extrapolation length
  - Eliminates nuclear binding and FSI effects `[Sargsian,Strikman PLB '05]`

- D-wave suppressed at on-shell point → neutron $\sim 100\%$ polarized

- Precise measurements of neutron (spin) structure at an EIC

Theoretical Formalism

- General expression of SIDIS for a polarized spin 1 target
    - Tagged spectator DIS is SIDIS in the target fragmentation region

$$\vec{e} + \vec{\vec{T}} \rightarrow e' + X + h$$

- Dynamical model to express structure functions of the reaction
    - First step: impulse approximation (IA) model
    - Results for longitudinal spin asymmetries
    - FSI corrections (unpolarized `Strikman, Weiss PRC '18`)

- Light-front structure of the deuteron
    - Natural for high-energy reactions as **off-shellness of nucleons** in LF quantization remains **finite**

Polarized spin 1 particle

- Spin state described by a 3*3 density matrix in a basis of spin 1 states polarized along the collinear virtual photon-target axis

$$W_D^{\mu\nu} = Tr[\rho_{\lambda\lambda'} W^{\mu\nu}(\lambda'\lambda)]$$

- Characterized by 3 **vector** and 5 **tensor** parameters

$$S^\mu = \langle \hat{W}^\mu \rangle , \qquad T^{\mu\nu} = \frac{1}{2}\sqrt{\frac{2}{3}} \langle \hat{W}^\mu \hat{W}^\nu + \hat{W}^\nu \hat{W}^\mu + \frac{4}{3}\left(g^{\mu\nu} - \frac{\hat{P}^\mu \hat{P}^\nu}{M^2} \right) \rangle$$

- Split in longitudinal and transverse components

$$\rho_{\lambda\lambda'} = \frac{1}{3} \begin{bmatrix} 1 + \frac{3}{2} S_L + \sqrt{\frac{3}{2}} T_{LL} & \begin{array}{c} \frac{3}{2\sqrt{2}} S_T e^{-i(\phi_h - \phi_S)} \\ - \sqrt{3} T_{LT} e^{-i(\phi_h - \phi_{T_L})} \end{array} & \sqrt{\frac{3}{2}} T_{TT} e^{-i(2\phi_h - 2\phi_{T_T})} \\ \begin{array}{c} \frac{3}{2\sqrt{2}} S_T e^{i(\phi_h - \phi_S)} \\ - \sqrt{3} T_{LT} e^{i(\phi_h - \phi_{T_L})} \end{array} & 1 - \sqrt{6} T_{LL} & \begin{array}{c} \frac{3}{2\sqrt{2}} S_T e^{-i(\phi_h - \phi_S)} \\ + \sqrt{3} T_{LT} e^{-i(\phi_h - \phi_{T_L})} \end{array} \\ \sqrt{\frac{3}{2}} T_{TT} e^{i(2\phi_h - 2\phi_{T_T})} & \begin{array}{c} \frac{3}{2\sqrt{2}} S_T e^{i(\phi_h - \phi_S)} \\ + \sqrt{3} T_{LT} e^{i(\phi_h - \phi_{T_L})} \end{array} & 1 - \frac{3}{2} S_L + \sqrt{\frac{3}{2}} T_{LL} \end{bmatrix} .$$

- Can be formulated in **covariant** manner → $\rho^{\mu\nu} = \sum_{\lambda\lambda'} \epsilon^{*\mu}(\lambda')\epsilon^\nu(\lambda)\rho_{\lambda\lambda'}$

Spin 1 SIDIS: General structure of cross section

- To obtain structure functions, enumerate all possible tensor structures that obey hermiticity and transversality condition ($qW = Wq = 0$)
- Cross section has 41 structure functions,

$$\frac{d\sigma}{dxdQ^2\,d\phi_{l'}} = \frac{y^2\,\alpha^2}{Q^4(1-\epsilon)}\,(F_U + F_S + F_T)\,d\Gamma_{P_h}\,,$$

  - U + S part identical to spin 1/2 case [`Bacchetta et al. JHEP ('07)`]

$$F_U = F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos 2\phi_h F_{UU}^{\cos 2\phi_h} + h\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}$$

$$\begin{aligned}
F_S = {} & S_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{US_L}^{\sin\phi_h} + \epsilon\sin 2\phi_h F_{US_L}^{\sin 2\phi_h}\right] \\
& + S_L h\left[\sqrt{1-\epsilon^2}F_{LS_L} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LS_L}^{\cos\phi_h}\right] \\
& + S_\perp\Big[\sin(\phi_h-\phi_S)\left(F_{US_T,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{US_T,L}^{\sin(\phi_h-\phi_S)}\right) + \epsilon\sin(\phi_h+\phi_S)F_{US_T}^{\sin(\phi_h+\phi_S)} \\
& +\epsilon\sin(3\phi_h-\phi_S)F_{US_T}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{US_T}^{\sin\phi_S} + \sin(2\phi_h-\phi_S)F_{US_T}^{\sin(2\phi_h-\phi_S)}\right)\Big] \\
& + S_\perp h\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S)F_{LS_T}^{\cos(\phi_h-\phi_S)} + \\
& \sqrt{2\epsilon(1-\epsilon)}\left(\cos\phi_S F_{LS_T}^{\cos\phi_S} + \cos(2\phi_h-\phi_S)F_{LS_T}^{\cos(2\phi_h-\phi_S)}\right)\Big]\,,
\end{aligned}$$

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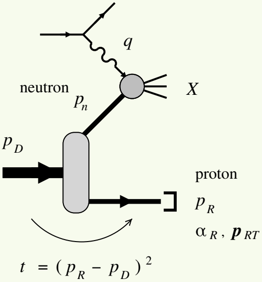
$$\frac{d\sigma}{dxdQ^2\,d\phi_{l'}} = \frac{y^2\alpha^2}{Q^4(1-\epsilon)}\,(F_U + F_S + F_T)\,d\Gamma_{P_h}\,,$$

  - 23 SF unique to the spin 1 case (tensor pol.), 4 survive in inclusive (b_{1-4}) [`Hoodbhoy, Jaffe, Manohar PLB'88`]

$$\begin{aligned}
F_T = T_{LL}\Big[&F_{UT_{LL},T} + \epsilon F_{UT_{LL},L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UT_{LL}}^{\cos\phi_h} + \epsilon\cos 2\phi_h F_{UT_{LL}}^{\cos 2\phi_h}\Big] \\
&+ T_{LL}h\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LT_{LL}}^{\sin\phi_h} \\
&+ T_{L\perp}[\cdots] + T_{L\perp}h[\cdots] \\
&+ T_{\perp\perp}\Big[\cos(2\phi_h - 2\phi_{T_\perp})\Big(F_{UT_{TT},T}^{\cos(2\phi_h-2\phi_{T_\perp})} + \epsilon F_{UT_{TT},L}^{\cos(2\phi_h-2\phi_{T_\perp})}\Big) \\
&+\epsilon\cos 2\phi_{T_\perp} F_{UT_{TT}}^{\cos 2\phi_{T_\perp}} + \epsilon\cos(4\phi_h - 2\phi_{T_\perp})F_{UT_{TT}}^{\cos(4\phi_h-2\phi_{T_\perp})} \\
&+\sqrt{2\epsilon(1+\epsilon)}\Big(\cos(\phi_h - 2\phi_{T_\perp})F_{UT_{TT}}^{\cos(\phi_h-2\phi_{T_\perp})} + \cos(3\phi_h - 2\phi_{T_\perp})F_{UT_{TT}}^{\cos(3\phi_h-2\phi_{T_\perp})}\Big)\Big] \\
&+ T_{\perp\perp}h[\cdots]
\end{aligned}$$

Tagged DIS with deuteron: model for the IA



- Hadronic tensor can be written as a product of nucleon hadronic tensor with deuteron light-front densities

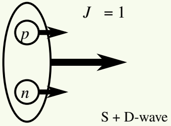
$$W_D^{\mu\nu}(\lambda', \lambda) = 4(2\pi)^3 \frac{\alpha_R}{2-\alpha_R} \sum_{i=U,z,x,y} W_{N,i}^{\mu\nu} \rho_D^i(\lambda', \lambda) ,$$

All SF can be written as

F_{ij}^k = {kin. factors} × {$F_{1,2}(\tilde{x}, Q^2)$or $g_{1,2}(\tilde{x}, Q^2)$} × {bilinear forms in deuteron radial wave function $f_0(k)$ [S-wave], $f_2(k)$ [D-wave]}

- In the IA the following structure functions are **zero** → sensitive to FSI
  - beam spin asymmetry [$F_{LU}^{\sin\phi_h}$]
  - target vector polarized single-spin asymmetry [8 SFs]
  - target tensor polarized double-spin asymmetry [7 SFs]

Deuteron light-front wave function

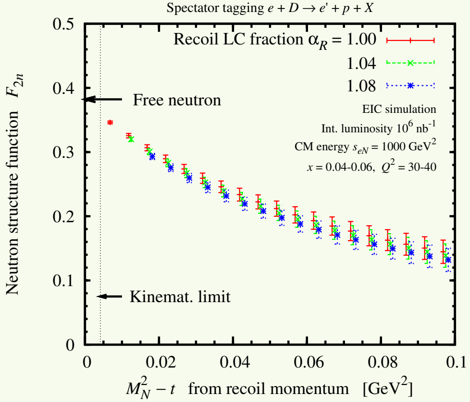


- Up to momenta of a few 100 MeV dominated by ***NN*** component
- Can be evaluated in LFQM [Coester,Keister,Polyzou et al.] or covariant Feynman diagrammatic way [Frankfurt,Sargsian,Strikman]
- One obtains a Schrödinger (non-rel) like eq. for the wave function components, rotational invariance recovered
- Light-front WF obeys baryon and momentum sum rule

$$\Psi^D_\lambda(\boldsymbol{k}_f,\lambda_1,\lambda_2)=\sqrt{E_{k_f}}\sum_{\lambda'_1\lambda'_2}\mathcal{D}^{\frac{1}{2}}_{\lambda_1\lambda'_1}[R_{fc}(k^\mu_{1f}/m_N)]\mathcal{D}^{\frac{1}{2}}_{\lambda_2\lambda'_2}[R_{fc}(k^\mu_{2f}/m_N)]\Phi^D_\lambda(\boldsymbol{k}_f,\lambda'_1,\lambda'_2)$$

- Differences with non-rel wave function:
  - appearance of the **Melosh rotations** to account for light-front quantized nucleon states
  - $\boldsymbol{k}_f$ is the relative 3-momentum of the nucleons in the light-front boosted rest frame of the free 2-nucleon state (so not a “true” kinematical variable)

Tagging: unpolarized neutron structure

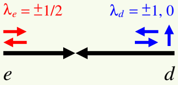


`JLab LDRD arXiv:1407.3236, arXiv:1409.5768, https://www.jlab.org/theory/tag/`

$\alpha_R = 2p_R^+/p_D^+$

- F_{2n} extracted with percent-level accuracy at $x < 0.1$
- Uncertainty mainly systematic due to intrinsic momentum spread in beam (JLab LDRD project: detailed estimates)
- In combination with proton data non-singlet $F_{2p} - F_{2n}$, sea quark flavor asymmetry $\bar{d} - \bar{u}$

Polarized structure function: longitudinal asymmetry

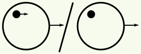


- On-shell extrapolation of double spin asymmetry
  - Nominator
    $$d\sigma_{||} \equiv \frac{1}{4}\left[\mathrm{d}\sigma(+\tfrac{1}{2},+1) - \mathrm{d}\sigma(-\tfrac{1}{2},+1) - \mathrm{d}\sigma(+\tfrac{1}{2},-1) + \mathrm{d}\sigma(-\tfrac{1}{2},-1)\right]$$
  - Two possible denominators: 3-state and 2-state
    $$d\sigma_3 \equiv \frac{1}{6}\sum_{\Lambda_e}\left[\mathrm{d}\sigma(\Lambda_e,+1) + \mathrm{d}\sigma(\Lambda_e,-1) + \mathrm{d}\sigma(\Lambda_e,0)\right]$$
    $$d\sigma_2 \equiv \frac{1}{4}\sum_{\Lambda_e}\left[\mathrm{d}\sigma(\Lambda_e,+1) + \mathrm{d}\sigma(\Lambda_e,-1)\right]$$
  - Asymmetries: **tensor polarization** enters in 2-state one
    $$A_{||,3} = \frac{d\sigma_{||}}{d\sigma_3}[\phi_h \,\mathrm{avg}] = \frac{F_{LS_L}}{F_T + \epsilon F_L}$$
    $$A_{||,2} = \frac{d\sigma_{||}}{d\sigma_2}[\phi_h \,\mathrm{avg}] = \frac{F_{LS_L}}{F_T + \epsilon F_L + \frac{1}{\sqrt{6}}(F_{T_{LL}T} + \epsilon F_{T_{LL}L})}$$
- Impulse approximation yields in the Bjorken limit $\left[\alpha_p = \frac{2p_p^+}{p_D^+}\right]$

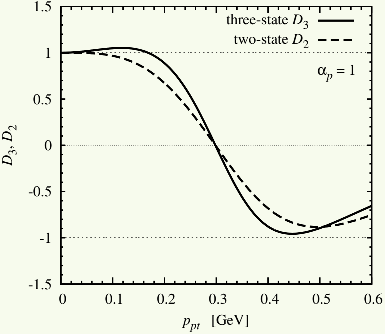
$$A_{||,i} \approx \mathcal{D}_i(\alpha_p, |p_{pT}|) A_{||n} = \mathcal{D}_i(\alpha_p, |p_{pT}|)\frac{D_{||} g_{1n}(\tilde{x}, Q^2)}{2(1+\epsilon R_n) F_{1n}(\tilde{x}, Q^2)}$$

Nuclear structure factors $\mathcal{D}_2$, $\mathcal{D}_3$

- $\mathcal{D}_2$ has **physical interpretation** as ratio of nucleon helicity density to unpolarized density in a deuteron with polarization +1.



- $\mathcal{D}_3$ has no such interpretation.



`WC, C. Weiss, PLB ('19); in preparation`

- Bounds: $-1 \leq \mathcal{D}_2 \leq 1$
- Due to lack of OAM $\mathcal{D}_2 \equiv 1$ for $p_T = 0$
- Clear contribution from D-wave at finite recoil momenta
- $\mathcal{D}_3$ violates bounds due to lack of tensor pol. contribution
- $\mathcal{D}_3 \neq 0$ for $p_T = 0$
- $\mathcal{D}_2$ closer to unity at small recoil momenta
- 2-state asymmetry is also easier experimentally!!

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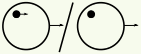
- $\mathcal{D}_2$ has **physical interpretation** as ratio of nucleon helicity density to unpolarized density in a deuteron with polarization +1. 
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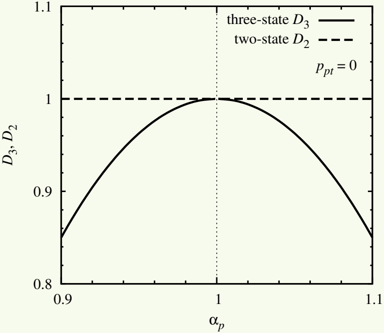

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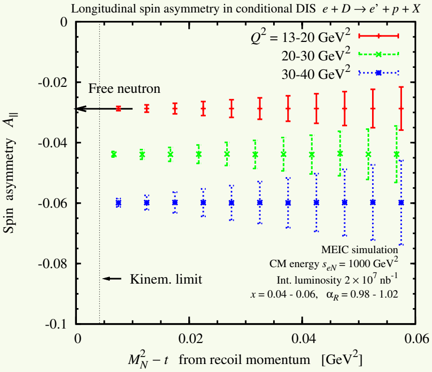
Tagging: simulations of $A_{||}$

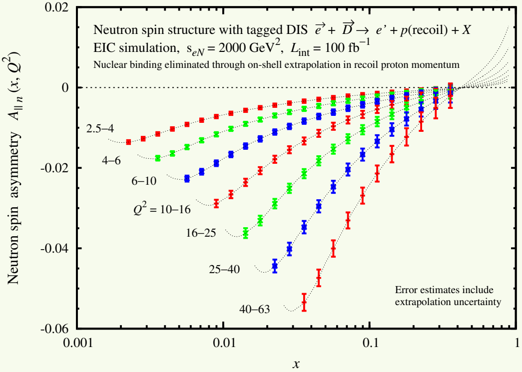


`JLab LDRD arXiv:1407.3236, arXiv:1409.5768`
`https://www.jlab.org/theory/tag/`

- D-wave suppr. at on-shell point $\rightarrow$ neutron $\sim 100\%$ polarized
- Systematic uncertainties cancel in ratio (momentum smearing, resolution effects)
- Statistics requirements
  - Physical asymmetries $\sim 0.05 - 0.1$
  - Effective polarization $P_e P_D \sim 0.5$
  - Luminosity required $\sim 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$

Tagging: simulations of $A_{||}$

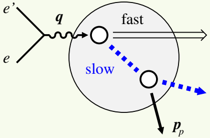
On-shell extrapolation of double spin asymm. $A_{||} = D\frac{g_{1n}}{F_{1n}} + \cdots$

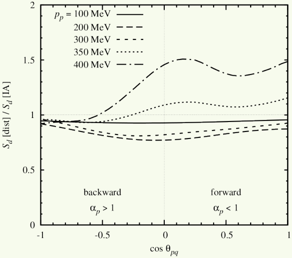


- As depolarization factor $D = \frac{y(2-y)}{2-2y+y^2}$ and $y \approx \frac{Q^2}{xs_{eN}}$, wide range of s_{eN} required!

- Precise measurement of neutron spin structure
  - separate leading- /higher-twist
  - non-singlet/singlet QCD evolution
  - pdf flavor separation $\Delta u, \Delta d$. ΔG through singlet evolution
  - non-singlet $g_{1p} - g_{1n}$ and Bjorken sum rule

Final-state interactions in tagging





`Strikman, Weiss, PRC7 035209 ('18)`

- **Issue** in tagging: DIS products can interact with spectator → rescattering, absorption
- Dominant contribution at intermediate $x \sim 0.1 - 0.5$ from "**slow**" hadrons that hadronize inside nucleus
- Measure fracture functions with EIC
- Features of the FSI of slow hadrons with spectator nucleon are similar to what is seen in quasi-elastic deuteron breakup.
- FSI vanish at the pole → pole extrapolation **still feasible**

Nucleon interactions

How do nucleon interactions emerge from QCD?

- **Short-range structure** of nuclei, NN force at very short distances
  - Quasi-elastic d breakup
  - Short-range correlation studies: (multi-)nucleon knockout w high ($>k_F$) initial momenta, 3N correlations?
  - Gluonic content

    $\gamma + D \rightarrow J/\psi + p + n$ (at high p_T) `Miller,Sievert,Venugopalan, PRC93 ('16)`

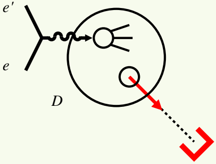
    (in)coherent J/ψ production `Mäntysaari, Schenke, 1910.03297`

- **Medium modification** of nucleon properties embedded in nucleus: EMC effect, other quantities

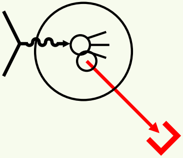
- **Non-nucleonic dof** in nuclei: Δ tagging in deuteron

JLab12 will measure some of these processes, but open questions will remain that can be addressed at EIC

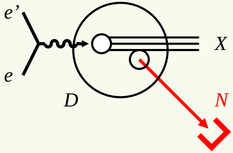
Tagging: EMC effect



average-size



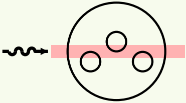
small-size



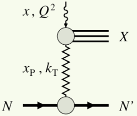
Final−state interactions

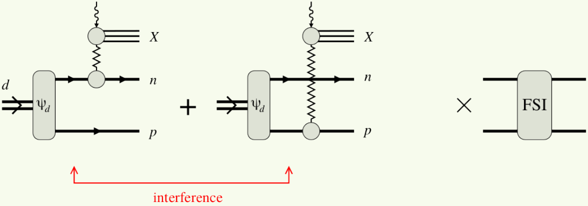
- Medium modification of nucleon structure embedded in nucleus (EMC effect)
  - dynamical origin?
  - caused by which momenta/distances in nuclear WF
  - spin-isospin dependence?
- tagged EMC effect
  - recoil momentum as extra handle on medium modification (off-shellness, size of nuclear configuration) away from the on-shell pole
  - EIC: Q^2 evolution, gluons, spin dependence!
- Interplay with final-state interactions!
  - use $\tilde{x} = 0.2$ to constrain FSI
  - constrain medium modification at higher $\tilde{x}$

Nuclear interactions: Coherence



- interaction of high-energy probe with coherent quark-gluon fields





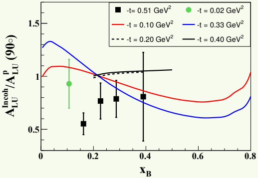
- **Shadowing** is manifestation of coherence
  - **Diffractive** DIS at $x \ll 0.1$: 10–15% of events at HERA
  - **Interference** between diffractive amplitudes
    → reduction of cross section, leading twist
  - Extensively studied in heavy nuclei
  - Is especially clean in the **deuteron**, effects can be calculated
  - **Dynamics** of shadowing can be explored in tagging: **single** and **double**
  - Tagging also results in **FSI** between the slow n and p

`[Guzey,Strikman,Weiss; in preparation]`

Nuclear imaging

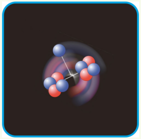
Images of nuclei in terms of quark and gluon dof

- Deeply virtual Compton scattering, meson production → **GPDs**
  - coherent: transverse imaging of nuclei
  - incoherent: medium modification of transverse nucleon densities
- **Tagged** DVCS/DVMP provides additional control over initial configuration
- Transverse **gluon** structure with exclusive coherent J/ψ production
- Polarization: ^{2}D [spin 1], ^{3}He [1/2], ^{4}He [0]
- Clustering & spin-orbit phenomena in nuclear structure of light nuclei
- Other resolved final states: SIDIS etc.



^{4}He DVCS

`M. Hattawy [CLAS], PRL123 ('19)`

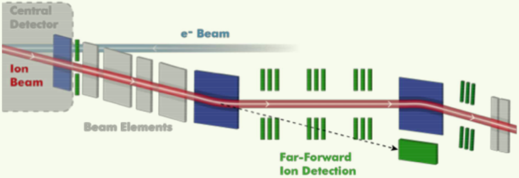


^{9}Be Clustering

Nuclear imaging: deuteron tensor polarization

- Tensor polarization in D probes **nuclear effects**
- Little explored in high-energy scattering
- Inclusive b_1 result from HERMES: no conventional nuclear calculation reproduces data
- Unique features: eg access **gluon transversity** → talk Shanahan
- Tagged cross section yields 23 additional structure functions with specific azimuthal dependences [`Cosyn,Sargsian,Weiss, in prep.`]
- T-odd SF [DSA] are zero in impulse approximation → sensitive to FSI

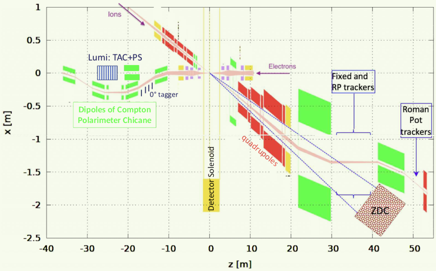
EIC: forward detection system

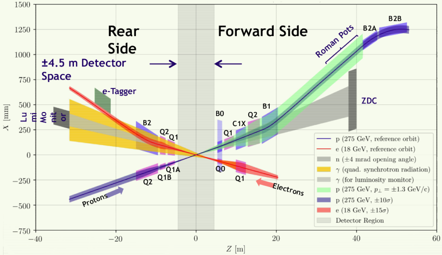


[not to scale]

- Large acceptance forward detector [concept: P. Nadel-Turonski, Ch. Hyde et al.]
  - beams collide at small crossing angle 25-50 mrad
  - forward p/n/ions travel through ion beam quadrupole magnets
  - dispersion generated by dipole magnets
  - detector systems:
    tracking in dipole magnets
    Roman pots for charged (p,ions) forward particles
    zero-degree calorimeters (ZDCs) for neutrals (neutron, photon)
- Major optimization and integration challenge
  - Forward particles with range of rigidities (momentum/charge), different from beam
  - Range in ion beam energy
  - Geometry of magnets and infrastructure
  - More complex than forward detectors at HE colliders [HERA, RHIC, LHC]

EIC: forward detection system





JLEIC IR design: V. Morozov et al 2019,
eRHIC IR design, Ch. Montag et al 2019

- IR designs
  - JLEIC and eRHIC design similar
  - Differences: crossing angle 50 [JLEIC] - 25 mrad [eRHIC]; JLEIC secondary focus at RP location
- Forward acceptance and resulotion
  - software framework developed
  - simulations on-going
- Momentum spread in ion beam
  - transverse momentum spread $\sim$ few 10 MeV
  - smearing effect: $p_T[\text{vertex}] \neq p_T[\text{measured}]$, systematic uncertainty

Conclusions

- Light ions address important parts of the EIC physics program
- Tagging and nuclear breakup measurements overcome limitations due to nuclear uncertainties in inclusive DIS → **precision machine**
- Unique observables with **polarized deuteron**: free neutron spin structure, tensor polarization
- Extraction of nucleon spin structure in a wide kinematic range
- Lots of extensions to be explored!
- EIC forward detection design ongoing

Upcoming meetings 2020

- Exploring QCD with light nuclei at EIC
  Jan 22-24, CFNS Stony Brook

  `https://indico.bnl.gov/event/6799/`

- Tomography of light nuclei at an EIC
  June 15–19, ECT* [Trento]

- Exploring QCD with Tagged Processes
  Sep 14 - Oct 23 [6 week program], Institut Pascal [Saclay, Paris]

  `https://www.universite-paris-saclay.fr/fr/exploring-qcd-with-tagged-processes`