Next-generation nuclear DIS: spectator tagging with light ions at an EIC

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JLab LDRD project '14–'15 on spectator tagging

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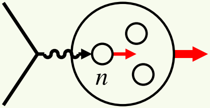
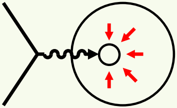
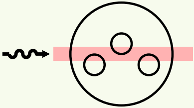
Light ions: physics objectives



- **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

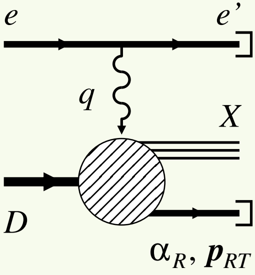


- **Bound** nucleons in QCD
  - medium modification of quark/gluon structure
  - QCD origin of short-range nuclear force



- **Coherence** and saturation
  - interaction of high-energy probe with coherent quark-gluon fields

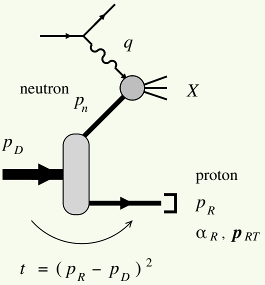
Tagged spectator DIS process with deuteron



- DIS off a nuclear target with a slow (relative to nucleus c.m.) nucleon detected in the final state
- Control nuclear configuration
- Advantages for the deuteron
  - simple *NN* system, non-nucleonic ($\Delta\Delta$) dof suppressed
  - active nucleon identified
  - recoil momentum selects nuclear configuration (medium modifications)
  - limited possibilities for nuclear FSI, calculable

- Wealth of possibilities to study (nuclear) QCD dynamics
- Will be possible in a wide kinematic range @ EIC (**polarized** for JLEIC)
- suited for colliders: no target material, forward detection, transverse pol.
  fixed target CLAS BONuS limited to recoil momenta $\sim$ 70 MeV

Pole extrapolation for on-shell nucleon structure



- Allows to extract free neutron structure in a **model independent** way
  - Recoil momentum p_R controls off-shellness of neutron $t - m_N^2$
  - 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 structure at an EIC

Outline

- Theoretical Formalism
- Neutron structure with pole extrapolation for EIC
- Experimental apparatus
- Deuteron b_1 in inclusive DIS

What is needed?

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

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

- Dynamical model to express structure functions of the reaction
  - First step: impulse approximation (IA) model

- 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

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

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,

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

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

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

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

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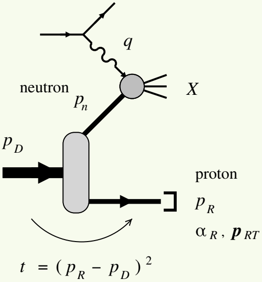
- Cross section has 41 structure functions,

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

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

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

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

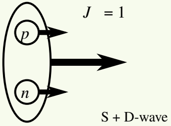
$$W_D^{\mu\nu}(\lambda', \lambda) = 4(2\pi)^3 \frac{\alpha_R}{2-\alpha_R} \sum_{i=U,z,x,y} W_{N,i}^{\mu\nu} \rho_D^i(\lambda', \lambda)\,,$$

All SF can be written as

$F_{ij}^k = \{\text{kin. factors}\} \times \{F_{1,2}(\tilde{x}, Q^2) \text{or}\, g_{1,2}(\tilde{x}, Q^2)\} \times \{$bilinear forms in deuteron radial wave function $U(k), W(k)\}$

- 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



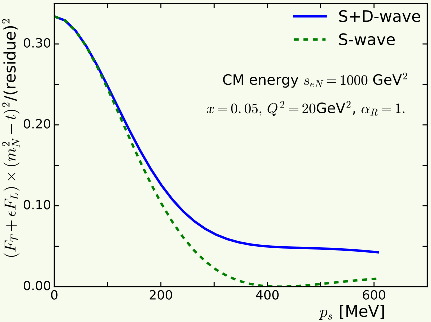
- Up to momenta of a few 100 MeV dominated by ***NN*** component
- Can be evaluated in LFQM [Coester,Keister,Polyzou et al.] or covariant Feynman diagrammatic way [Frankfurt,Sargsian,Strikman]

- 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

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

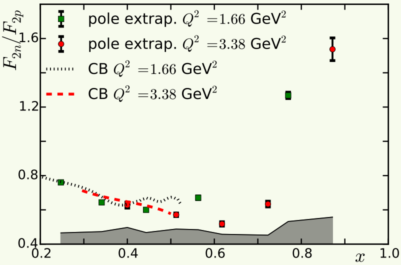
- Differences with non-rel wave function:
  - appearance of the **Melosh rotations** to account for light-front quantized nucleon states
  - $\boldsymbol{k}_f$ is the relative 3-momentum of the nucleons in the light-front boosted rest frame of the free 2-nucleon state (so not a “true” kinematical variable)

Unpolarized structure function



- Extrapolation for $(m_N^2 - t) \to 0$ corresponds to on-shell neutron $F_{2N}(x, Q^2)$
- Clear effect of deuteron D-wave, largest in the region dominated by the tensor part of the NN-interaction
- D-wave drops out at the on-shell point

Use Bonus data: F_{2n}/F_{2p}

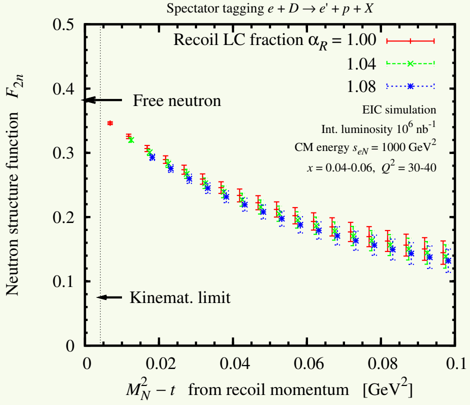


WC, M. Sargsian, PRC93 '16

- Robust results wrt deuteron wave function, fsi parameters, normalization of the data used in the extraction.
- Good agreement with Christy, Bosted parametrization at lower x values
- **Striking rise** of the ratio at high x, but **sub-DIS Q^2**
- Relevant for the dynamical generation of high-momentum quarks [imbalanced Fermi systems]

Tagging: free neutron structure

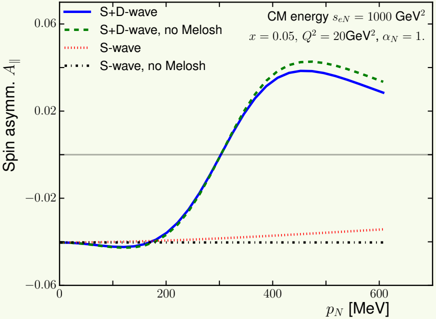
Precise measurements of F_{2n}



JLab LDRD arXiv:1407.3236, arXiv:1409.5768

- F_{2n} extracted with percent-level accuracy at $x < 0.1$
- Uncertainty mainly systematic (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



- Spin asymmetry

$$A_{||} = \frac{\sigma(++) - \sigma(-+) - \sigma(+-) + -\sigma(--)}{\sigma(++) + \sigma(-+) + -\sigma(+-) + -\sigma(--)}[\phi_h \text{avg}]$$

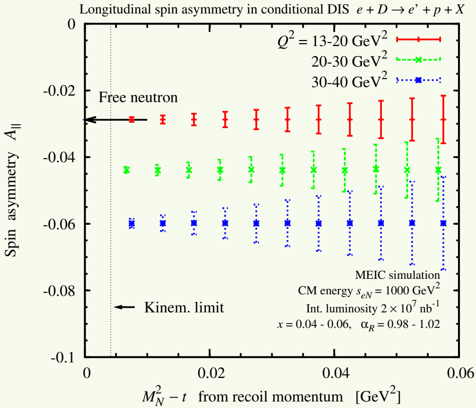
$$= \frac{F_{LS_L}}{F_T + \epsilon F_L} \propto \frac{g_{1n}}{F_{1n}}$$

- Again clear contribution from D-wave at finite recoil momenta
- Relativistic nuclear effects through Melosh rotations, grow with recoil momenta
- Both effects drop out near the on-shell extrapolation point

Tagging: polarized neutron structure

On-shell extrapolation of double spin asymm.

$$A_{||} = \frac{\sigma(++)-\sigma(-+)-\sigma(+-)+-\sigma(--)}{\sigma(++)+\sigma(-+)+-\sigma(+-)+-\sigma(--)}[\phi_h \text{avg}] = \frac{F_{LS_L}}{F_T+\epsilon F_L} = D\frac{g_{1n}}{F_{1n}} + \cdots$$

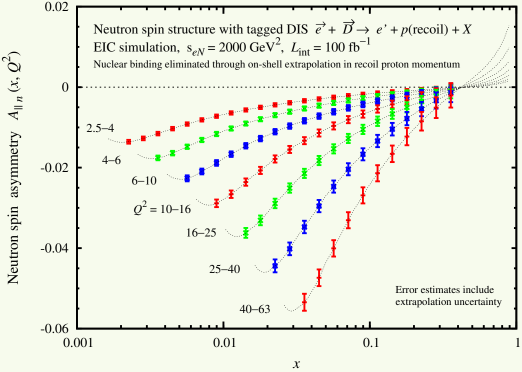


JLab LDRD arXiv:1407.3236, arXiv:1409.5768

- 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: polarized neutron structure II

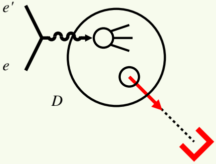
On-shell extrapolation of double spin asymm. $A_{||} = D\frac{g_{1n}}{F_{1n}} + \cdots$



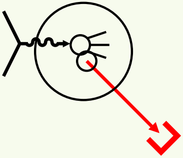
- As depolarization factor $D = \frac{y(2-y)}{2-2y+y^2}$ and $y \approx \frac{Q^2}{xs_{eN}}$, wide range of s_{eN} required!

- 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

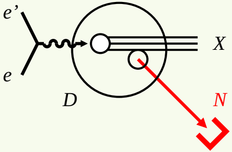
Tagging: EMC effect



average-size



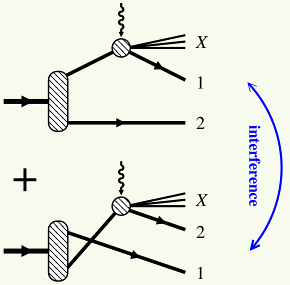
small-size

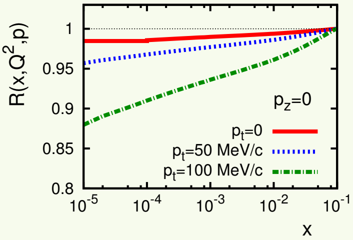


Final−state interactions

- 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 $\tilde{x}$

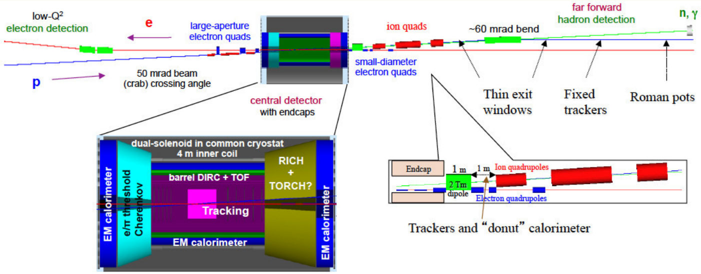
Tagging: Coherence and shadowing at small x





- Shadowing in inclusive DIS $x \ll 10^{-1}$
  - Diffractive DIS on single nucleon (leading twist, HERA)
  - Interference of DIS on nucleon 1 and 2
  - Calculable in terms of nucleon diffractive structure functions [Gribov 70s, Frankfurt,Guzey,Strikman '02+]
- Shadowing in tagged DIS
  - Explore shadowing through recoil momentum dependence [Guzey,Strikman,Weiss; in progress]
  - Reveal nuclear momentum components building op coherent fields at small x
  - Study coherence in $A = 2$, complimentary to $A \gg 1$
- Coherent scattering $e + D \to e + M + D$
  Exclusive meson production, DVCS, nuclear GPDs

JLEIC full-acceptance detector



P. Nadel-Turonski et al.

- Forward detector integrated in interaction region & beam optics
- Good acceptance for elastic recoil

  Rigidity same as beam. Large dispersion generated *after* IP

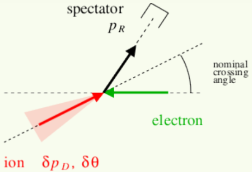
  Longitudinal momentum up to 99.5% of beam, angles down to 2 mrad (10 σ)
- Good acceptance for spectators and ion fragments

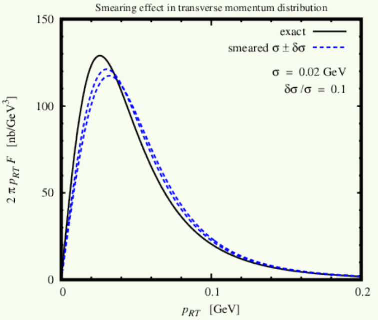
  Rigidity different from beam. Large magnet apertures, small gradients
- Good momentum and angular resolution

  Longitudinal $dp/p \sim 4 \times 10^{-4}$, angular $\delta\theta \sim 0.2$ mrad

  $p_{TR} \sim 15\,\text{MeV}/c$ resolution for tagged 50 GeV/A deuterium beam

JLEIC: Momentum spread in beam





[Ch. Hyde, K. Park et al.]

- Intrinsic beam spread in ion beam "smears" recoil momentum
  - transverse momentum spread of $\sigma \approx 20$ MeV ($\delta\sigma/\sigma \sim 10\%$)
  - p_R(measured) $\neq$ p_R(vertex)
  - Systematic correlated uncertainty, x, Q^2 independent
- Dominant syst. uncertainty at JLEIC, detector resolution much higher than beam momentum spread (diff for eRHIC)
- On-shell extrapolation feasible!!

Tagging: developments and extensions

- Final-state interactions in tagged $e + D$
  - distorts recoil momentum dependence away from the on-shell pole $t \neq m_N^2$
  - broad momentum distribution, interactions of spectator with slow debris [Strikman,Weiss;in progress. Ciofi, Kopeliovich 02]
  - maximized/minimized by choice of kinematics. Constrain FSI models.
  - azimuthal and spin observables non-zero through FSI
- Tagging with complex nuclei $A > 2$
  - isospin dependence, universality of bound nucleon structure
  - $A - 1$ ground state recoil
- Resolved final states: SIDIS on neutron, hard exclusive channels

R&D project at JLAB

- Develop simulation tools (physics models, event generators, analysis tools) for DIS on light ions with spectator tagging at MEIC and study physics impact.
- ran FY14-15
  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)
- **Tools, documentation, results publicly available. Open for collaboration!**
- More info:
  `https://www.jlab.org/theory/tag/`
  `arXiv:1407.3236`, `arXiv:1409.5768v1`, `arXiv:1601.066665`, `arXiv:1609.01970`

Inclusive DIS Xsection on pol. spin 1 with unpol. beam

$$\frac{d\sigma}{dx\,dQ^2} = \frac{\pi y^2 \alpha^2}{Q^4(1-\epsilon)}\Big[F_{UU,T} + \epsilon F_{UU,L} + T_{LL}\left(F_{UT_{LL},T} + \epsilon F_{UT_{LL},L}\right) + T_{L\perp}\cos\phi_{T_L}\sqrt{2\epsilon(1+\epsilon)}\,F_{UT_{LT}}^{\cos\phi_{T_L}} + T_{\perp\perp}\cos(2\phi_{T_\perp})\,\epsilon\,F_{UT_{TT}}^{\cos(2\phi_{T_\perp})}\Big],$$

- 4 tensor polarized structures can be related to the b_{1-4} introduced by Hoodbhoy, Jaffe, Manohar [Nucl. Phys. B 312]
  $F_{UT_{LL},T} = -\frac{1}{x}\sqrt{\frac{2}{3}}\left[2(1+\gamma^2)xb_1 - \gamma^2\left(\frac{1}{6}b_2 - \frac{1}{2}b_3\right)\right]$
- Alternative set of b_{1-3}, Δ by Edelmann Piller Weise [Z. Phys. A 357]. Two sets are **equal only in the scaling limit**!
- In the parton model: distribution of unpol. quarks in pol. hadron
  $b_1 = \frac{1}{2}\sum_q e_q^2(q^0 - q^1)$
- Obeys Callan-Gross like relation in the scaling limit $2xb_1(x) = b_2(x)$
- Obeys Kumano-Close sum rule $\int dx b_1(x) = 0$ [PRD42, 2377]

b_1 for the deuteron

- *np*-component: b_1 is only non-zero due to the D-wave admixture in the deuteron, small.
- Interplay of nuclear and quark degrees of freedom.
- Measured @ Hermes [PRL95, 242001], not small + sign change. No agreement with conventional deuteron models.
- Upcoming measurements at JLab12 for $x < 1$ (DIS) and $x > 1$ (QE) [arXiv:1311.4835]
- Also possible @ Fermilab in DY [Kumano, Song, PRD94, 054022], EIC with polarized deuteron beam and ILC with a fixed target experiment

Conventional calculations for deuteron b_1

- Important to provide an accurate calculation of deuteron b_1 in a conventional nuclear model to constrain possible exotic mechanisms
- Consider *np* component, convolution approach [unpol. nucleon structure $\otimes$ pol. deuteron momentum distribution]
- Only one (?) published Khan, Hoodbhoy [PRC44, 1219]

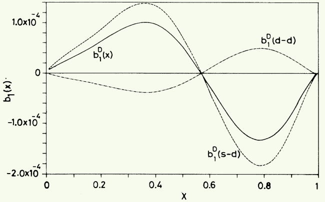
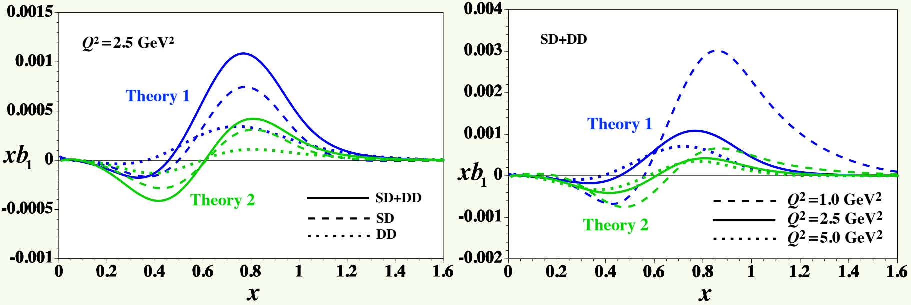


FIG. 2. $b_1^D(x)$ (solid curve), the *s-d* contribution to $b_1^D(x)$ (dashed curve), and the *d-d* contribution to $b_1^D(x)$ (dot-dashed curve).

- Updated check in two similar models: one standard convolution model with instant form deuteron wave function, one in the virtual nucleon approximation with light-front deuteron wf [W.C., Y. Dong, S. Kumano, M. Sargsian, PRD95(074036) '17]

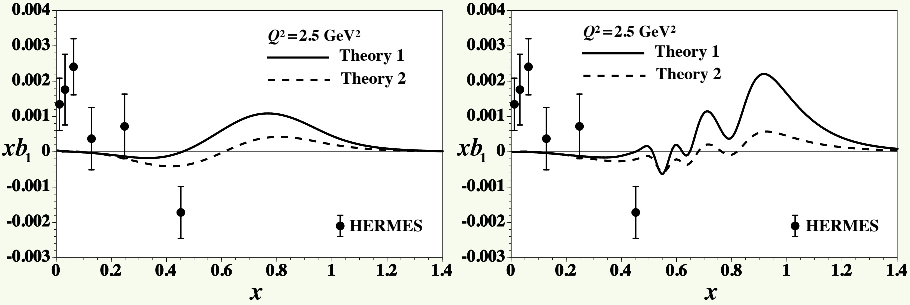
Comparison between two models



MSTW08 nucleon pdfs, CDBonn deuteron wf, SLAC $R = F_L/F_T$

- Differences with Khan, Hoodbhoy calculation
  - different sign *SD* term
  - non-zero distribution at $x > 1$
- Significant nuclear higher-twist effects at low Q^2
- *DD*-term is not small (given $\sim 5\%$ *D*-wave admixture)

Comparison with Hermes data



MSTW08 SLAC (Bodek, Ricci)

- Clear mismatch between data and calculations in size
- Future JLab12 data should shed more light
- Possible contribution from exotic mechanism → Miller [PRC89,045203] hidden color + pions
- Higher twist effects?

How was b_1 extracted?

- Experimental measured asymmetry [θ_q is angle between momentum transfer and polarization axis]

$$A_{zz} = \frac{2\sigma^+ - 2\sigma^0}{2\sigma^+ + \sigma^0} = \frac{\sqrt{2}}{4\sqrt{3}(F_{UU,T} + \epsilon F_{UU,L})} \Big\{ [1 + 3\cos 2\theta_q] \left(F_{UT_{LL},T} + \epsilon F_{UT_{LL},L} \right) +$$
$$3 \sin 2\theta_q \sqrt{2\epsilon(1+\epsilon)} F_{UT_{LT}}^{\cos\phi_T} + 3[1 - \cos 2\theta_q] \epsilon F_{UT_{TT}}^{\cos 2\phi_{T_\perp}} \Big\},$$

- **Only** when $\theta_q = 0$ and scaling relations applied, higher twist $b_{3,4}$ neglected, we have

$$A_{zz} \to \sqrt{\frac{2}{3}} \frac{F_{UT_{LL},T}}{F_{UU,T}} \to -\frac{2}{3} \frac{b_1}{F_1}$$

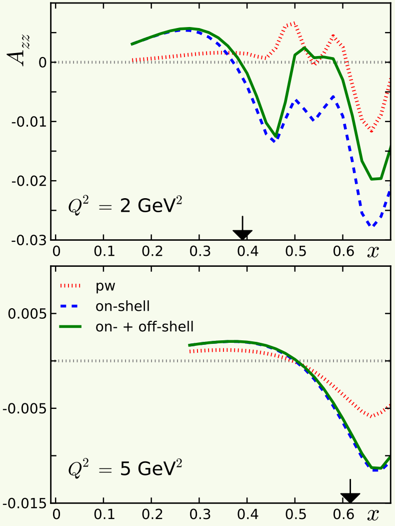
- Q^2-range of Hermes experiment quite low values: 0.5–5 GeV^2

Calculation of $b_{1,4}$ in VNA model

x	Q^2 (GeV^2)	$b_1(10^{-4})$	$b_2(10^{-5})$	$b_3(10^{-3})$	$b_4(10^{-3})$	$b_2/(2xb_1)$	$\gamma = 2Mx/Q$
0.012	0.51	2.81	0.264	-1.34	5.06	0.783	0.0315
0.032	1.06	6.92	1.97	-1.87	7.51	0.890	0.0583
0.063	1.65	3.50	0.265	-2.02	7.96	0.120	0.0920
0.128	2.33	-1.80	-7.38	-2.13	7.49	3.20	0.157
0.248	3.11	-8.39	-28.1	-2.09	4.58	1.35	0.264
0.452	4.69	-6.18	-21.7	-1.11	-0.58	0.777	0.392

- VNA calculation only including *pn* IA contribution
- Higher twist b_3, b_4 not small compared to b_1, b_2
- Callan-Gross relation not satisfied
- "Improved" extraction feasible?
- Direct comparison of VNA calculations of A_{zz} at largest x value is still two orders of magnitude too small!

Final-state interactions in A_{zz}



WC, M. Sargsian, arXiv:1407.1653

WC,W. Melnitchouk, MS, PRC89 ('14)

- Only resonance contributions considered in the FSI, eikonal rescattering of produced X with spectator nucleon
- JLab 12 GeV kinematics considered
- Only spin independent FSI included
- Non-negligable contribution from FSI even at low x, but **not enough** to match Hermes data
- Convolution (D-wave dominance → high spectator momenta) can pick up resonance contributions through the convolution
- Size of FSI effects decreases at higher Q^2 (phase-space effect)

Conclusions

- General form of SIDIS with a spin 1 target, 23 tensor polarized structure functions unique to spin 1
- Results for the impulse approximation using deuteron light-front structure
- Important contributions from deuteron D-wave, Melosh rotations at larger spectator momenta. Become small if one does pole extrapolation of observables.
- Recoil momentum dependence permits separation of nuclear and nucleon structure
- Spectator tagging in eD scattering with EIC enables next-generation measurements with maximal control and unprecedented accuracy
  - Neutron structure functions, including spin
  - Nuclear modifications of quark/gluon structure
  - Coherence and shadowing
- Calculation of b_1 in standard convolution models
  - differences with older calcaultion
  - contributions from nuclear higher twist effects, account for in experimental exraction from the measured asymmetry