

Tensor-polarized SIDIS Measurements with SBS in Hall C

David Ruth

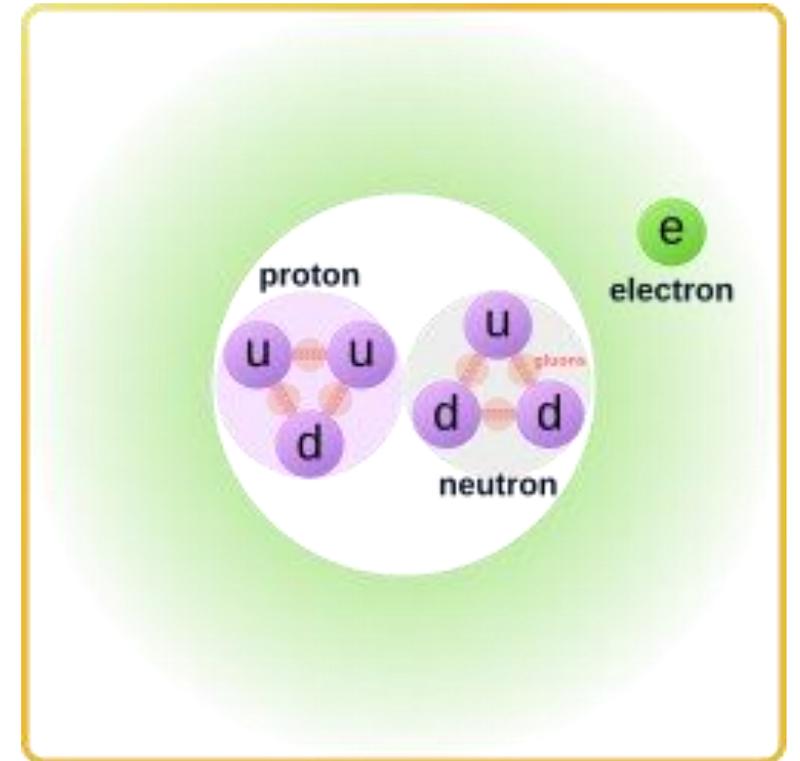
On Behalf of the Tensor SIDIS Collaboration

SBS 2026 Collaboration Meeting



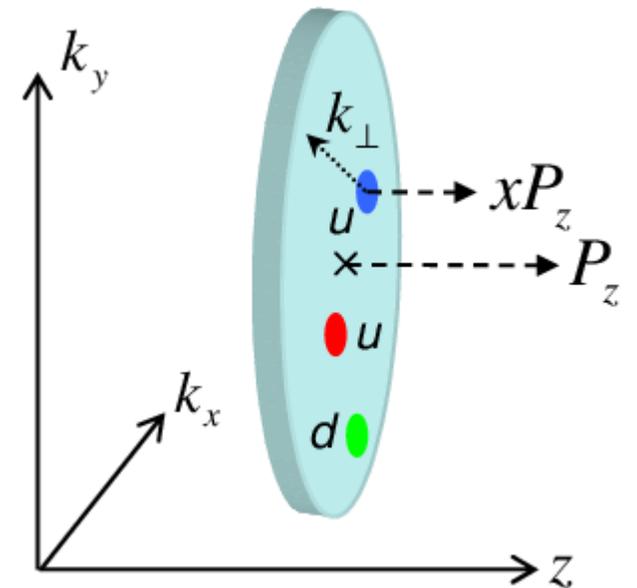
Studying Nucleon & Deuteron Structure

- Understanding nucleon & nuclear structure is **the core of JLab's mission**
- **Simplest Nucleus: Deuteron**
- Tensor Structure: *“Is a deuteron just a simple bound state of **p** and **n** or is there more complexity?”*
- Nucleon Structure Observables:
- GPDs, PDFs, **TMDs**, Form Factors...

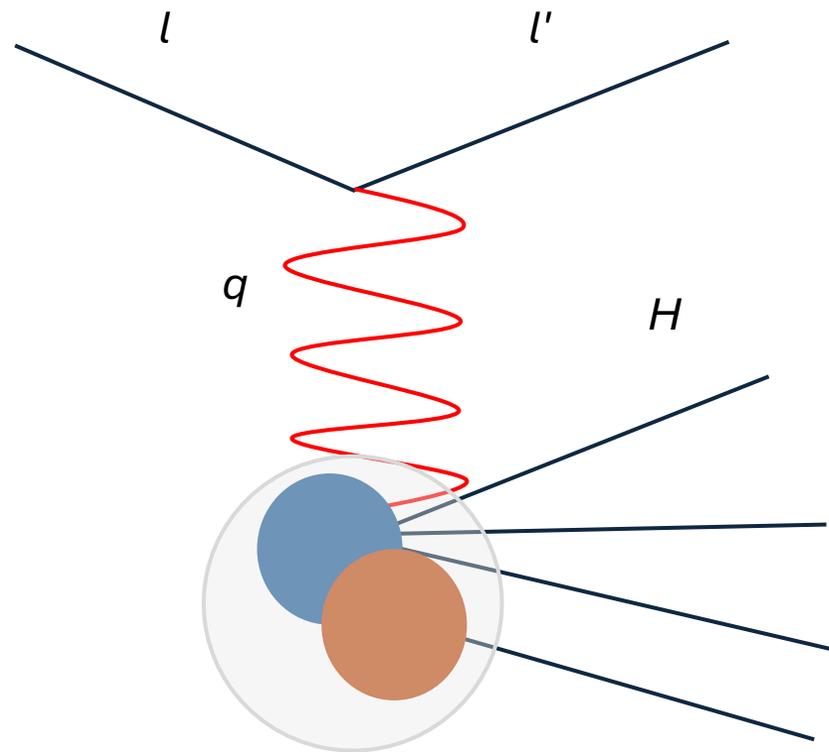


TMDs are essential for investigating nuclear structure

- **Transverse-Momentum-Dependent** distribution functions: parton structure in x and \mathbf{k}_T (transverse momentum)
- Unique Capabilities for:
 - Hadron Tomography
 - Color Degrees of Freedom
 - Understanding Transverse Momentum Structure
- Extensive past and current studies on spin $\frac{1}{2}$ nucleon TMDs



Spin-1 Deuteron TMDs Never Before Measured!



- Suite of Tensor TMDs never before measured:

	$[\gamma^+]$		$[\gamma^+ \gamma_5]$		$[i\sigma^{i+} \gamma_5]$	
	TR-even	TR-odd	TR-even	TR-odd	TR-even	TR-odd
U	f_1					(h_1^\perp)
L			g_{1L}		h_{1L}^\perp	
T		(f_{1T}^\perp)	g_{1T}		h_{1T} h_{1T}^\perp	
LL	f_{1LL}					(h_{1LL}^\perp)
LT	f_{1LT}			(g_{1LT})		$(h'_{1LT}$ $h_{1LT}^\perp)$
TT	f_{1TT}			(g_{1TT})		$(h'_{1TT}$ $h_{1TT}^\perp)$

- Needs Semi-Inclusive Deep-Inelastic Scattering (SIDIS)

SIDIS Kinematic Variables & Cross Section

- Φ_h : Angle between lepton plane and hadron plane
- Φ_s : Angle between lepton plane and nucleon spin

$$\cos \phi_h = \frac{\hat{\mathbf{q}} \times \mathbf{l}}{|\hat{\mathbf{q}} \times \mathbf{l}|} \cdot \frac{\hat{\mathbf{q}} \times \mathbf{P}_h}{|\hat{\mathbf{q}} \times \mathbf{P}_h|}$$

$$\sin \phi_h = \frac{(\mathbf{l} \times \mathbf{P}_h) \cdot \hat{\mathbf{q}}}{|\hat{\mathbf{q}} \times \mathbf{l}| |\hat{\mathbf{q}} \times \mathbf{P}_h|}$$

$$x = \frac{Q^2}{2P \cdot q} \quad z = \frac{P_h \cdot P}{P \cdot q}$$

$$\frac{d\sigma}{dx dy d\psi dz d\phi_h dP_{h\perp}^2} = \frac{y^2 \alpha^2}{2(1-\epsilon)xyQ^2} \left(1 + \frac{\gamma^2}{2x}\right) \left[F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} \cos \phi_h F_{UU}^{\cos \phi_h} \right. \\ \left. + \epsilon \cos(2\phi_h) F_{UU}^{\cos(2\phi_h)} + \lambda_e \sqrt{2\epsilon(1-\epsilon)} \sin \phi_h F_{LU}^{\sin \phi_h} \right]$$

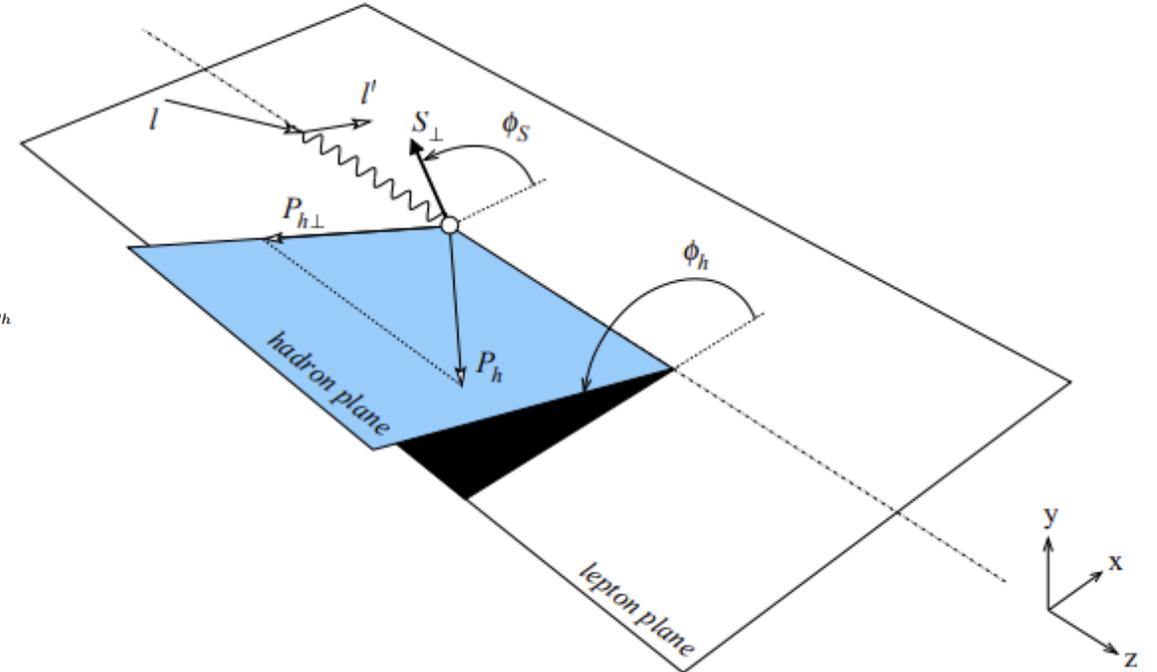
Vector polarization:

$$+ S_{\parallel} \left\{ \sqrt{2\epsilon(1+\epsilon)} \sin \phi_h F_{UL}^{\sin \phi_h} + \epsilon \sin(2\phi_h) F_{UL}^{\sin 2\phi_h} \right\}$$

$$+ S_{\parallel} \lambda_e \left\{ \sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)} \cos \phi_h F_{LL}^{\cos \phi_h} \right\}$$

Tensor Polarization:

$$+ T_{\parallel\parallel} \left\{ F_{U(LL),T} + \epsilon F_{U(LL),L} + \sqrt{2\epsilon(1+\epsilon)} \cos \phi_h F_{U(LL)}^{\cos \phi_h} \right. \\ \left. + \epsilon \cos(2\phi_h) F_{U(LL)}^{\cos 2\phi_h} + \lambda_e \sqrt{2\epsilon(1-\epsilon)} \sin \phi_h F_{L(LL)}^{\sin \phi_h} \right\}$$

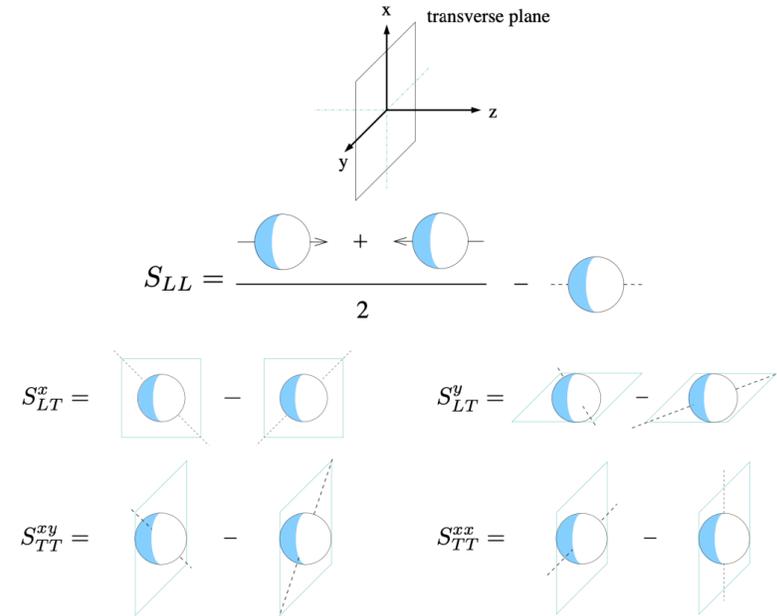


A. Bacchetta

(9)

Spin-1 Deuteron TMDs need tensor polarization

- $T_{\parallel\parallel\parallel} = \frac{N_1 + N_{-1} - 2N_0}{N_{tot}}$
- Compares (1,-1) states to (0) spin state
- Extremely sparse global tensor-polarized measurements, especially for SIDIS



A. Bacchetta,
Phys.Rev. D62
(2000) 114004

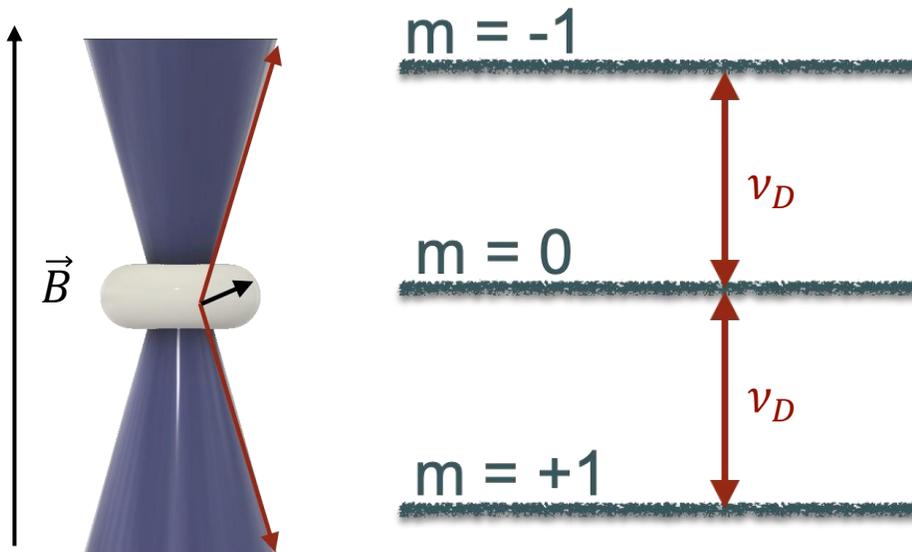
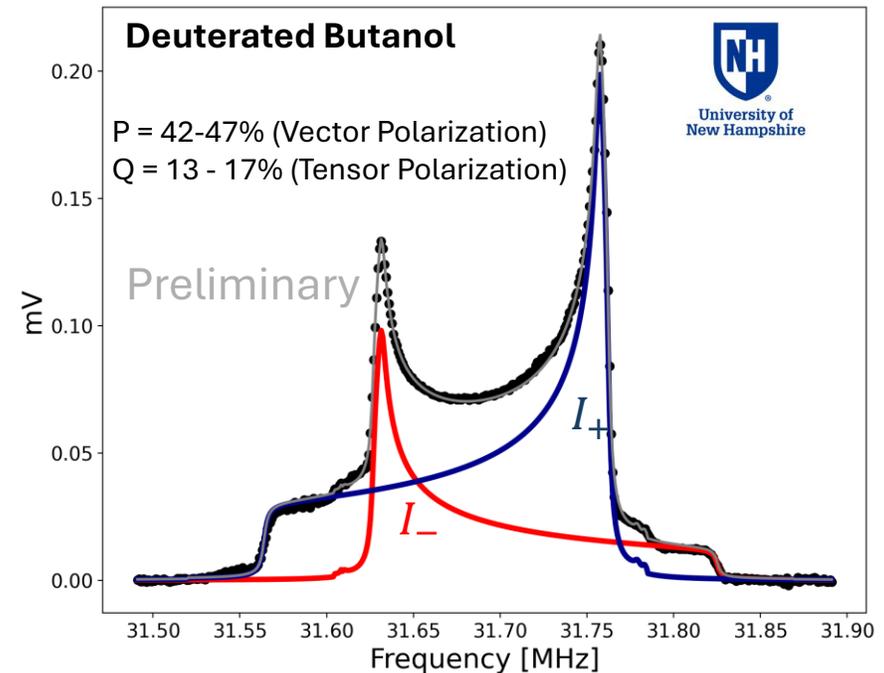
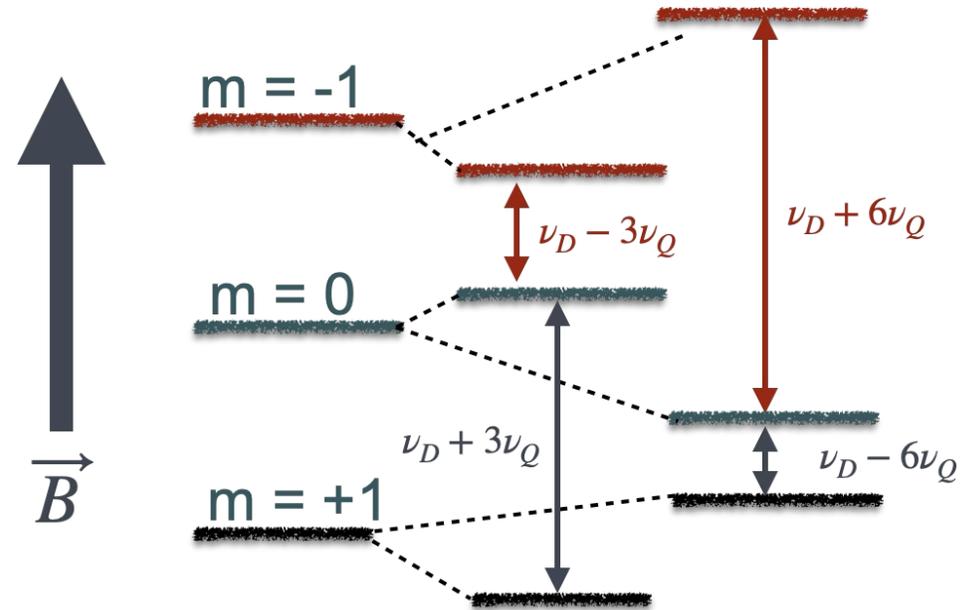


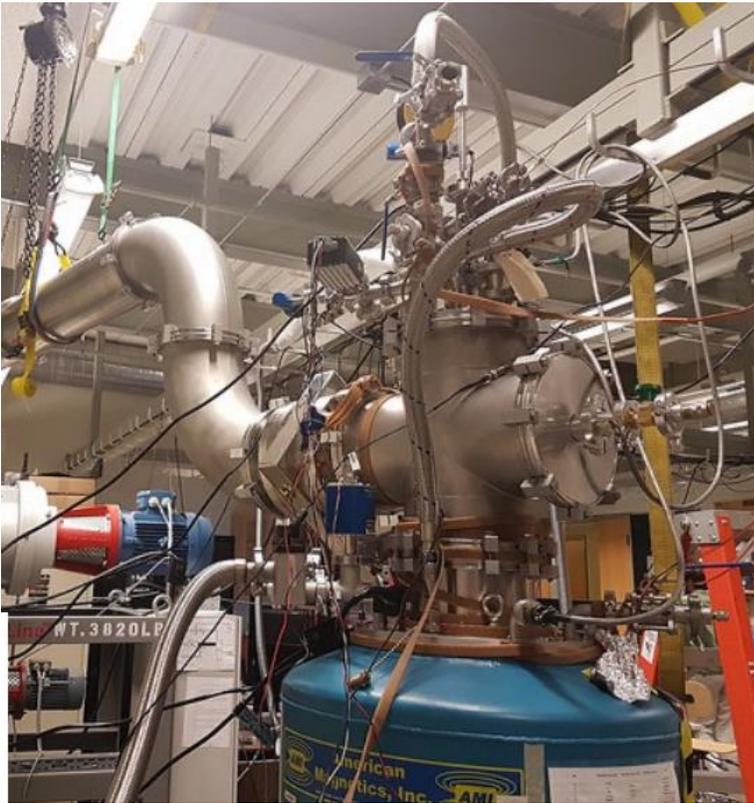
Diagram courtesy N. Santiesteban

Tensor Polarization

- Dynamic Nuclear Polarization
- Magnetic Field + Microwaves:
Around 10% Pol.
- Specialty tensor target with RF
enhancement techniques – up
to 30% Tensor Pol.
- Tensor target will be deployed
in Hall C for b_1/A_{zz}
experiments



Tensor Target Status & Outlook



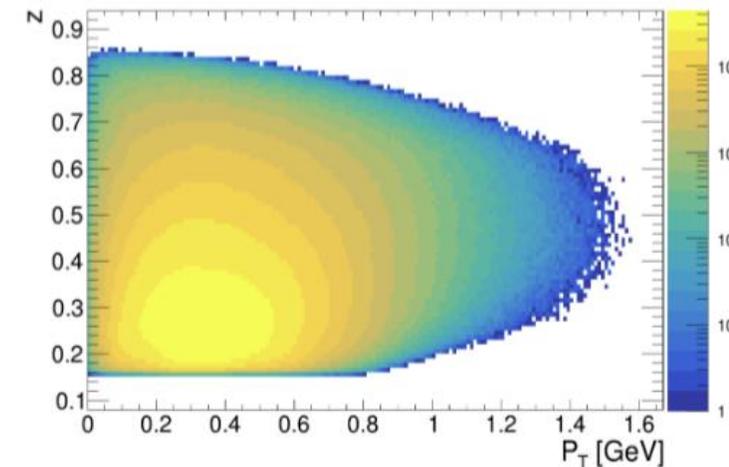
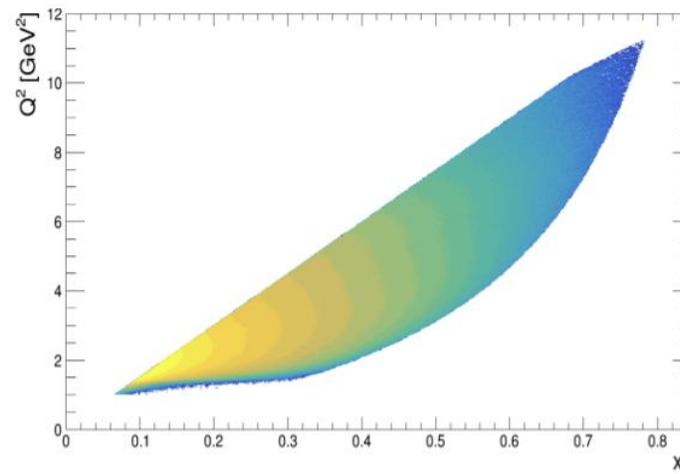
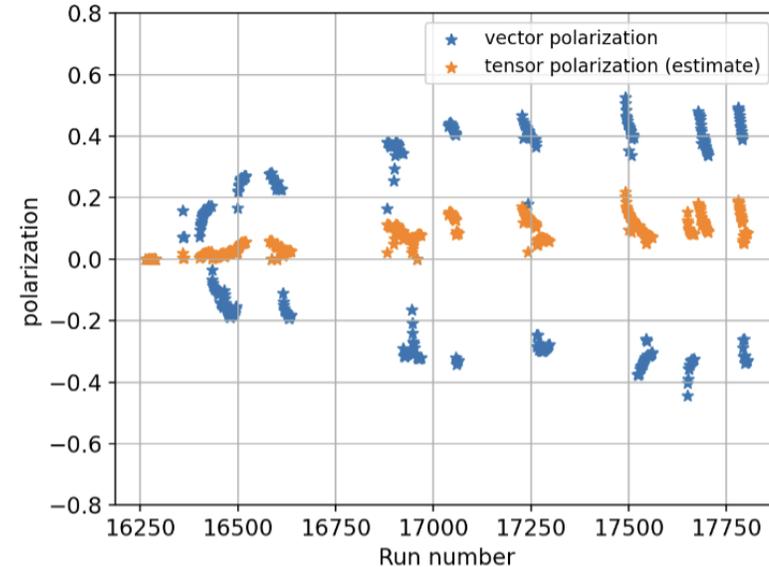
UNH Polarized Target (K. Slifer,
E. Long, N. Santiesteban)

- Development work at:   
- 30% Tensor Pol. achieved at UVA in D-Butanol (D. Keller)
- 15-20% max Tensor Pol. in ND3 at UNH/UVA, with work ongoing to achieve consistent performance
- Discussions ongoing about the possibility of **user-led efforts** to build the tensor target at JLab, UVA, or another institution



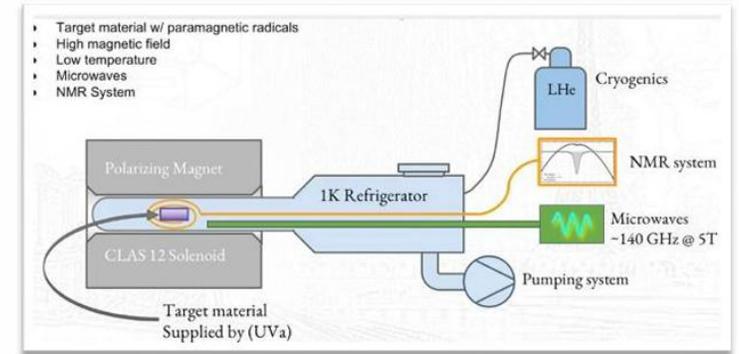
Tensor TMDs: can we use any existing data?

- **CLAS-Approved-Analysis (CAA)** to use RG-C data from Hall B
- Equilibrium tensor polarization ($\sim 10\%$) sufficient for a first extraction
- Analysis is in progress...
- But we will get **much better statistics** from a dedicated measurement

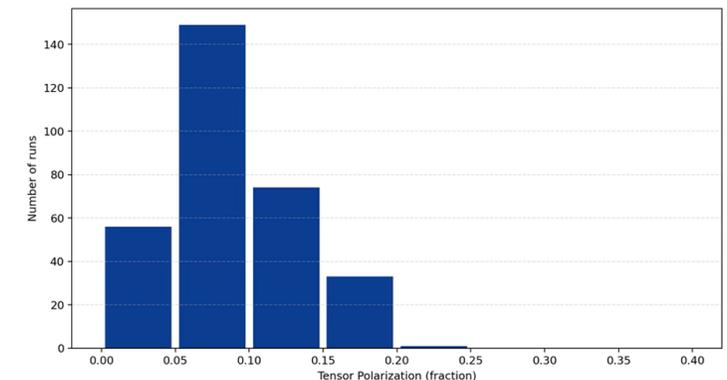
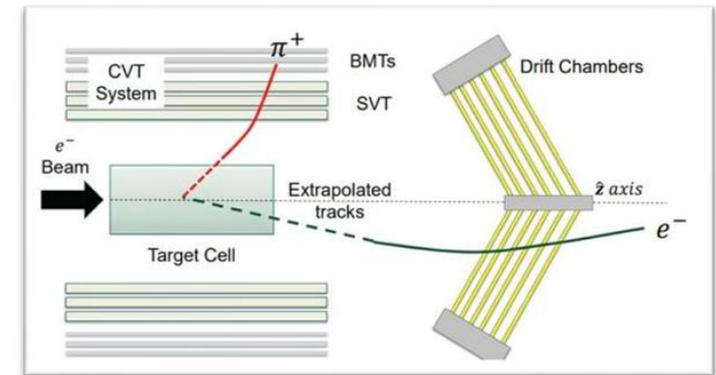


RG-C CAA Progress

- 3 Students (M. Farooq, C. Lama, A. Arora) working on polarization + DIS analysis
- 1 Student (H. Chinchay) working on dilutions + SIDIS analysis
- Working group is growing – NMSU students may be joining the analysis soon!
- Thanks to the RG-C and overall CLAS collaboration for the usage of their data and much help to the students
- Working towards preliminary results!



Courtesy of Gregory Matousek



2024 LOI + Proposal in the works...

- HMS Acceptance not large enough to get the needed hadron statistics
- **Use SBS (Hadron)** and SHMS (Lepton) to do a SIDIS measurement in Hall C
- Collect data over a range of vector polarization magnitudes and directions to isolate tensor part of XS
- LOI12-24-002 Submitted to PAC52
- **Encouraged to submit a full proposal!**

Spin-1 TMDs and Structure Functions of the Deuteron

A Letter of Intent to Jefferson Lab PAC 52

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A. Bacchetta
University of Pavia, IT

I. P. Fernando, D. Keller
University of Virginia, VA

J. P. Chen, J. Poudel
Thomas Jefferson National Accelerator Facility, VA

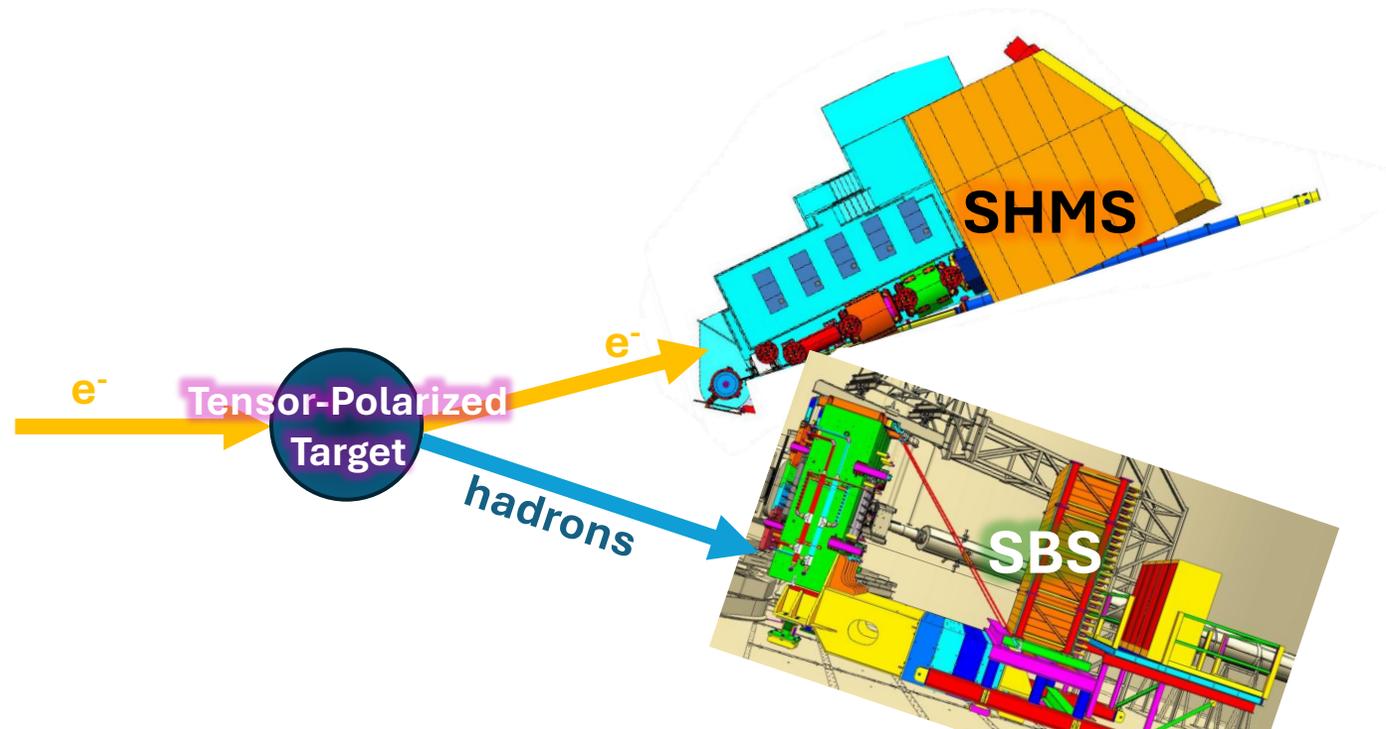
Abstract

In pursuit of enhanced understanding of the structure of matter, one of our most vital tools is that of the distribution function, which allows us to map the partonic structure of the nucleon with respect to various kinematic variables. One set of functions that is currently of interest to the nuclear physics community is that of the Transverse Momentum Dependent distribution functions, or TMDs. These functions describe partonic structure as a function of the transverse parton momentum k_T and the longitudinal momentum fraction x , and provide crucial information about quark-gluon correlations. Though single particle spin- $\frac{1}{2}$ TMDs have been studied in proton and neutron targets, we are missing information about the quark-gluon correlations associated with the tensor structure of light nuclei. With a spin-1 tensor-polarized nucleus, the simplest case of which is the deuteron, it is possible to study the ten new leading-twist TMDs which have never been investigated previously, and which can be used to illuminate the complex partonic correlations in multiple-nucleon light nuclei. This Letter of Intent focuses on the extraction of the spin-1 tensor-polarized component of the Semi-inclusive Deep Inelastic Scattering cross-section.

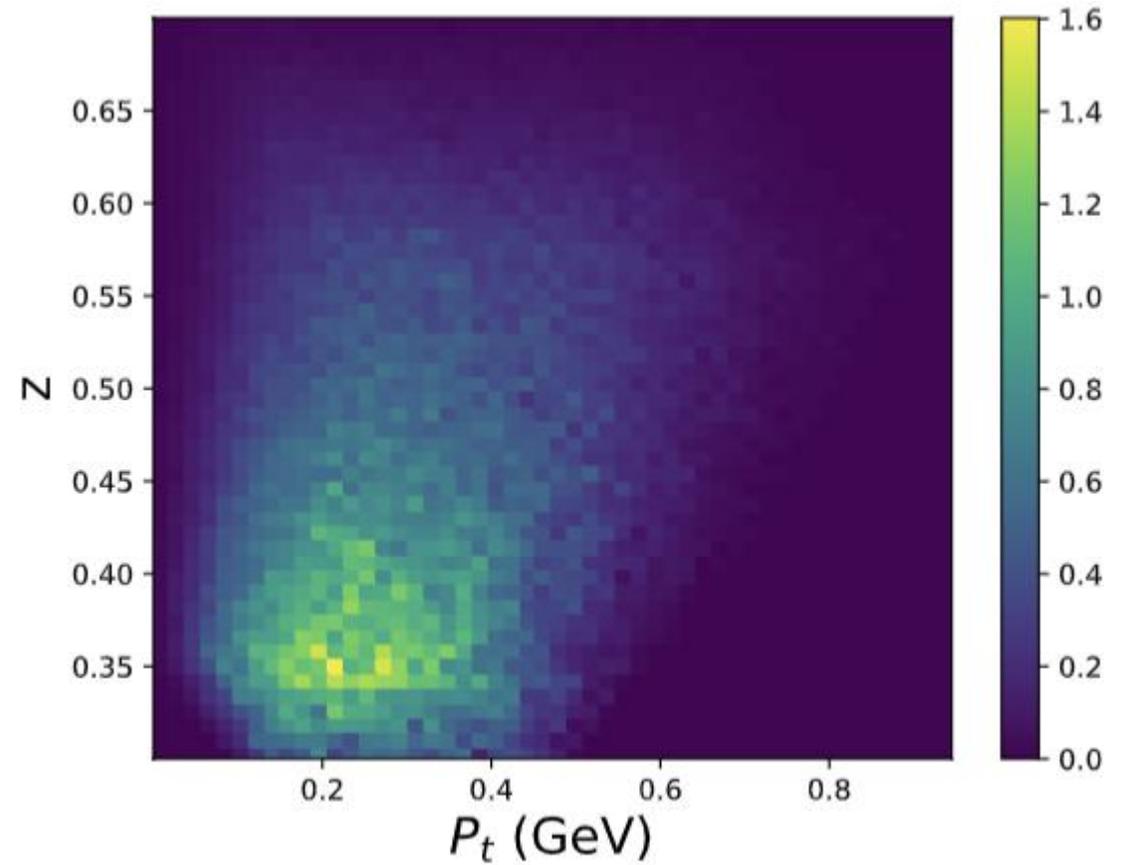
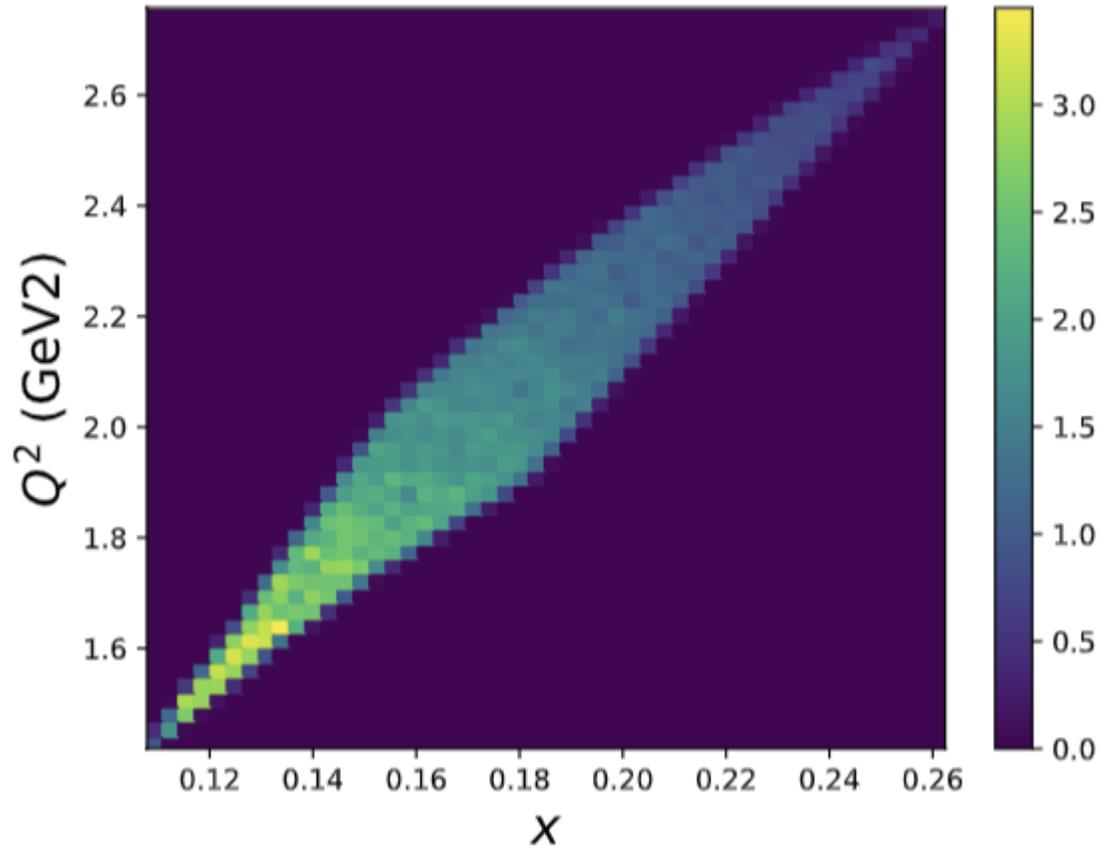
Planned Coincidence Measurement

- Measure SIDIS Cross Section for tensor polarized and unpolarized data
- Extract Structure Functions
- World first look at Spin-1 Deuteron TMDs
- In progress for planned submission to *PAC-54!*

	θ (deg.)	ϕ (deg.)	P (GeV)
Electron	10.3 - 12.4	-2.87 - 2.87	4.0 - 5.4
Hadron	5.0 - 15.0	167 - 193	2.0 - 4.0



Expected Coverage (1 Setting)



Cross Section & Analysis Conceit

- If we have data with equal and opposite vector polarization:

$$\sigma_{meas}^+ = \frac{1}{2} \left(\sigma_u^D + S_{\parallel}^+ \sigma_S + T_{\parallel\parallel} \sigma_T + \sum_i \sigma^i \right)$$

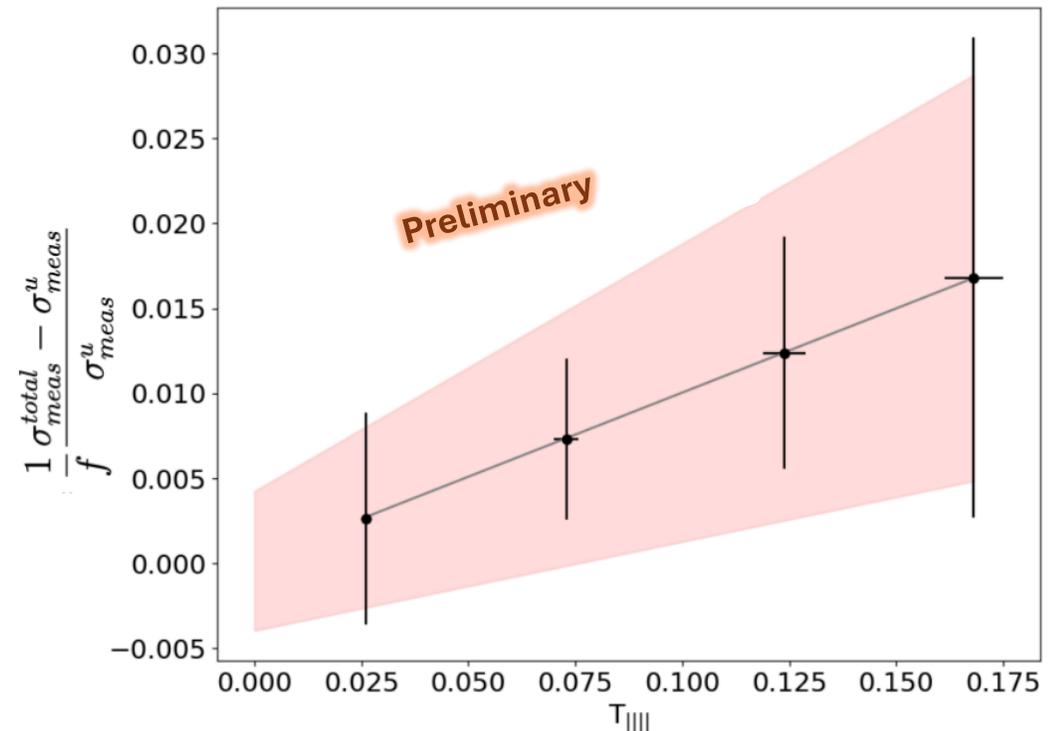
$$\sigma_{meas}^- = \frac{1}{2} \left(\sigma_u^D + S_{\parallel}^- \sigma_S + T_{\parallel\parallel} \sigma_T + \sum_i \sigma^i \right)$$

$$\sigma_{meas}^{total} = \sigma_{meas}^+ + \sigma_{meas}^- = \sigma_u^D + T_{\parallel\parallel} \sigma_T + \sum_i \sigma^i$$

- Algebra to obtain an asymmetry-like quantity:

$$T_{\parallel\parallel} \frac{\sigma_T}{\sigma_u^D} = \frac{1}{f} \frac{\sigma_{meas}^{total} - \sigma_{meas}^u}{\sigma_{meas}^u}$$

- Slope is the tensor part of the XS!



courtesy N. Santiesteban

Structure Functions

- TMDs are linked to set of tensor structure functions

$$F_{U(LL),T} = C [f_{1LL} D_1] \quad \text{Naïve: 10\% of unpolarized } F_{UU,T}$$

$$F_{U(LL),L} = 0$$

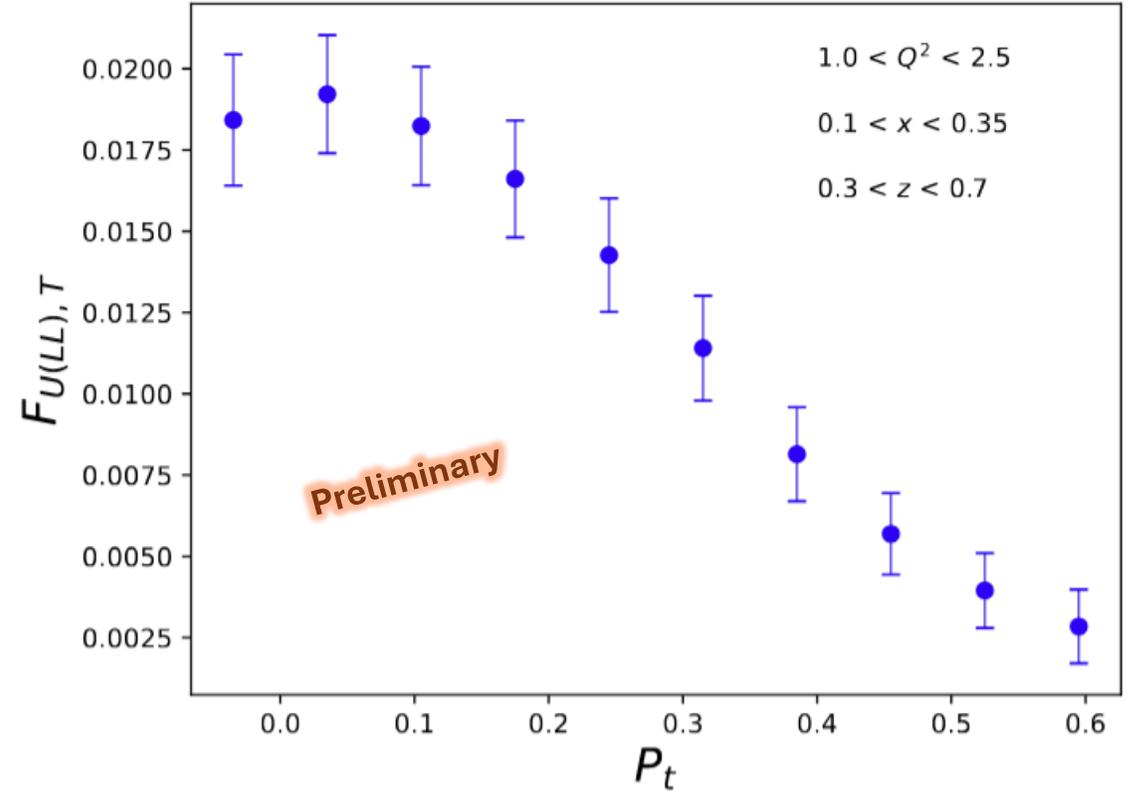
$$F_{U(LL)}^{\cos \phi_h} = \frac{2M}{Q} C \left[-\frac{\hat{\mathbf{h}} \cdot \mathbf{k}_T}{M_h} \left(x h_{LL} H_1^\perp + \frac{M_h}{M} f_{1LL} \frac{\tilde{D}^\perp}{z} \right) - \frac{\hat{\mathbf{h}} \cdot \mathbf{p}_T}{M} \left(x f_{LL}^\perp D_1 + \frac{M_h}{M} h_{1LL}^\perp \frac{\tilde{H}}{z} \right) \right]$$

$$F_{U(LL)}^{\cos 2\phi_h} = C \left[-\frac{2(\hat{\mathbf{h}} \cdot \mathbf{k}_T)(\hat{\mathbf{h}} \cdot \mathbf{p}_T) - \mathbf{k}_T \cdot \mathbf{p}_T}{MM_h} \times h_{1LL}^\perp H_1^\perp \right]$$

$$F_{L(LL)}^{\sin \phi_h} = \frac{2M}{Q} C \left[-\frac{\hat{\mathbf{h}} \cdot \mathbf{k}_T}{M_h} \left(x e_{LL} H_1^\perp + \frac{M_h}{M} f_{1LL} \frac{\tilde{G}^\perp}{z} \right) + \frac{\hat{\mathbf{h}} \cdot \mathbf{p}_T}{M} \left(x g_{LL}^\perp D_1 + \frac{M_h}{M} h_{1LL}^\perp \frac{\tilde{E}}{z} \right) \right]$$

TMDs

Fragmentation Functions



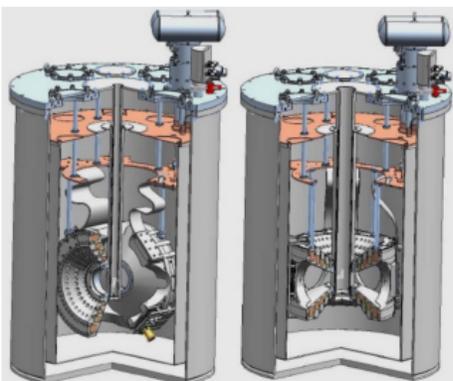
Projected rate for 5 days @ 80 nA



The prospective (tentative) plan with transversely tensor polarized ND₃ target

by Ishara Fernando, Forhad Hossain & Dustin Keller
(for the UVA Spin-Physics Group)

- Proposals for JLab PAC (2026)



Pic credits C. Keith (JLab)

$$F_{U(TT),T}^{\cos(2\phi_h - 2\phi_{LT})} = C \left[-\frac{2(\hat{h} \cdot \mathbf{p}_T)^2 - p_T^2}{M^2} f_{1TT} D_1 \right]$$

$$F_{L(TT)}^{\sin(2\phi_h - 2\phi_{TT})} = C \left[-\frac{2(\hat{h} \cdot \mathbf{p}_T)^2 - p_T^2}{M^2} g_{1TT} D_1 \right]$$

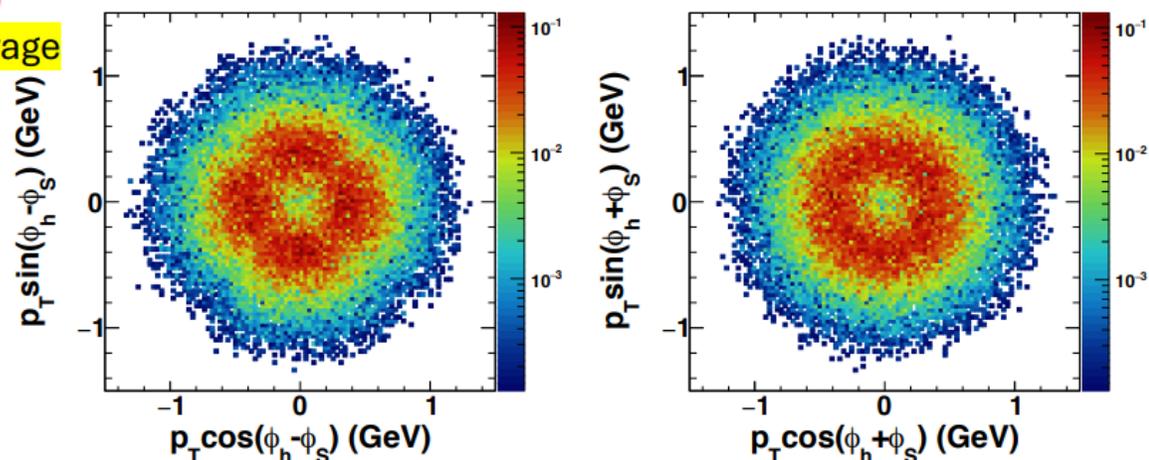
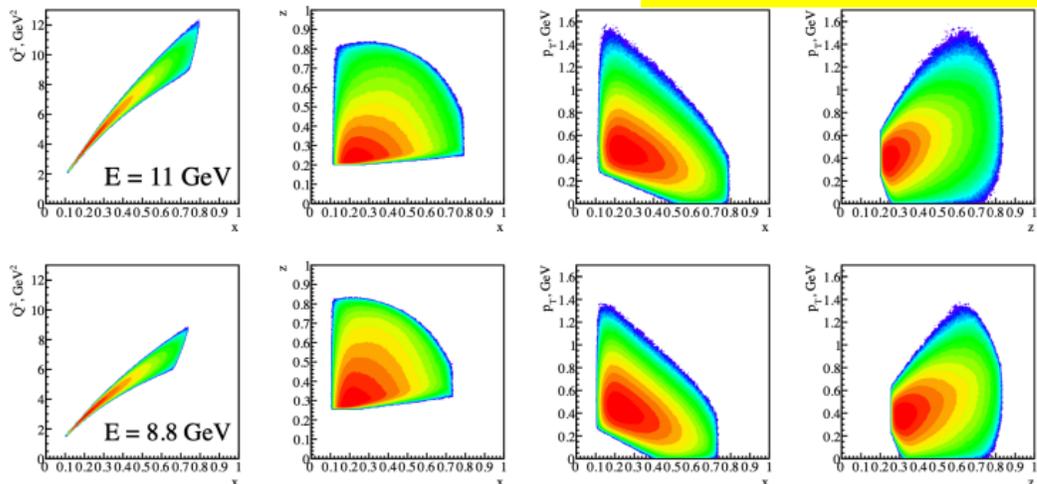
$$F_{U(TT)}^{\cos(2\phi_{TT})} = C \left[\frac{\mathbf{k}_T \cdot \mathbf{p}_T}{MM_h} h_{1TT} H_1^\perp \right]$$

First Generation Tensor Experiments

Using standard DNP temps and intensity: 1K and 100nA

To run sequentially after the data taking for $F_{U,(LL)}$ @ Hall C

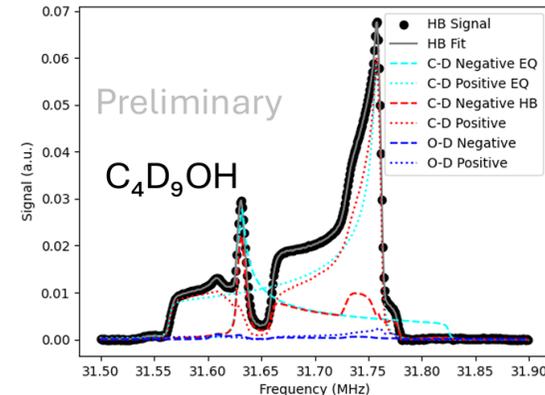
SBS SIDIS Kinematic Coverage



Pic credits G. Cates (UVA)

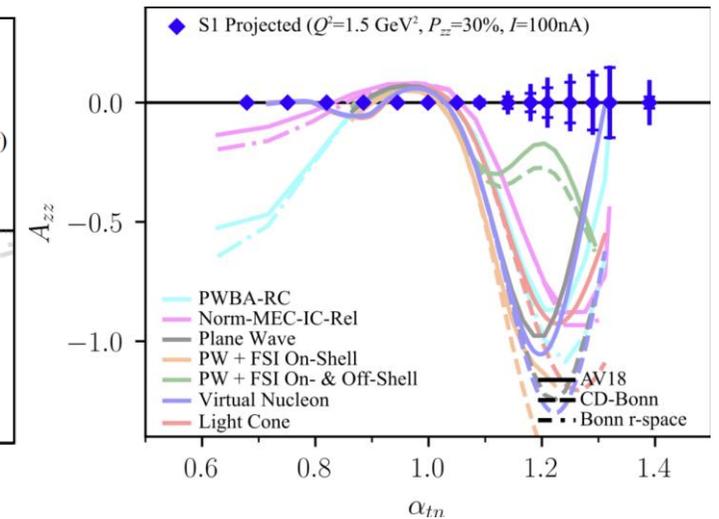
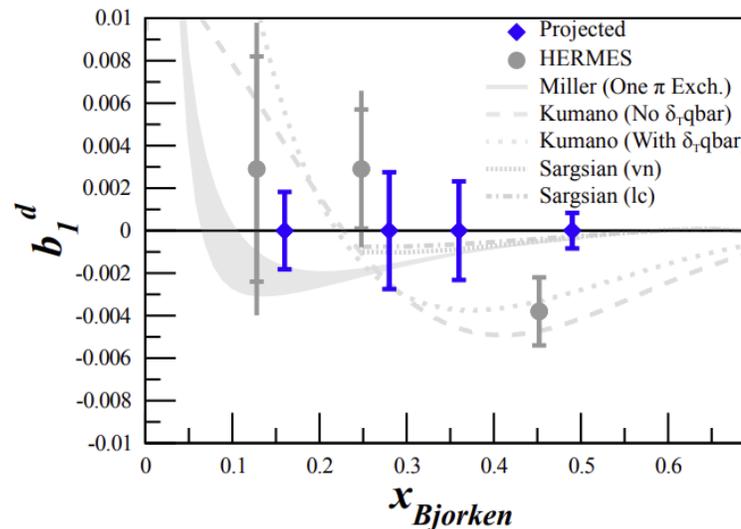
Other Tensor Experiments & Timeline Outlook

- This new SIDIS program joins 2 approved DIS experiments using tensor polarization
- b_1 and A_{zz} collaborations preparing for an ERR in Hall C
- Recent timeline: b_1 and A_{zz} in 2030
- **Tensor SIDIS:** possibly right after (2031) if the experiment is approved



**December 2025
UNH Hole-Burning Data**

Courtesy of M. Farooq, C. Lama, E. Long, M. McClellan



Thanks to all our collaborators!

Experimental



Nathaly Santiesteban
(UNH)



Karl Slifer
(UNH)



Elena Long
(UNH)



Jian-Ping Chen (JLab)



Dustin Keller (Uva)



David Ruth (NMSU)



Jiwan Poudel (JLab)

Theory Support



Alessandro Bacchetta
(Pavia U.)



Ian Cloet
(Argonne Lab)

Students



Chetra Lama
UNH



Muhammad Farooq
(UNH)



Anchit Arora
(UNH)



Hector Chinchay-Espino
(UNH)

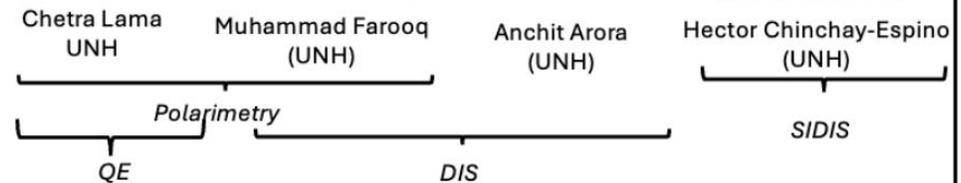
Postdocs



Jan Vanek (UNH)

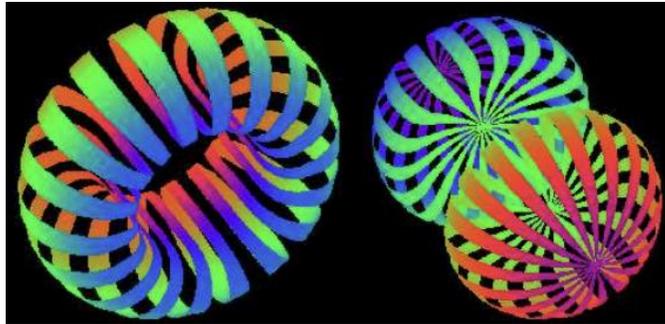


Ishara Fernando (Uva)



Meetings

- **SIDIS Meetings:** Mondays at 10:30 AM EST
- **General Tensor Polarized Meetings:** Every-other Friday at 1:30 PM EST



- Large and **growing** group...
- All are welcome! Let us know if you are interested in Tensor spin physics and please join us!

Next Steps + Full Proposal

- Full Hall C SIDIS Proposals currently targeted for this Summer 2026
- CLAS-Approved Analysis underway
- DIS Experiments preparing for an ERR

- We hope to work with the SBS collaboration to set up this SIDIS program!

- **With the help of SBS and Tensor Polarization, we can accomplish exciting things!**