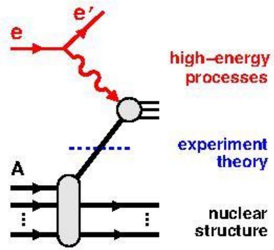
The Measurement of Tensor Observables and Deuteron Structure Function

Summer School “Light-ion physics in the EIC era:
From nuclear structure to high-energy processes”



Chhetra Lama

25/06/2025

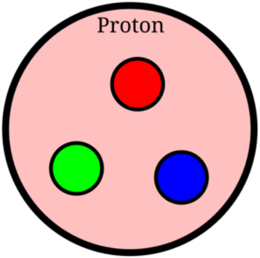
University of New Hampshire

FLORIDA INTERNATIONAL UNIVERSITY

Protons & Deuterons

Proton

Spin- $\frac{1}{2}$ System



Three valence quarks + gluons and sea quarks

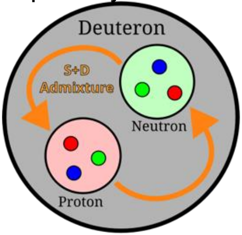
No nudeon-nucleon interactions

$m = \pm \frac{1}{2}$

S. Kumano, IOP Proc. Tens. Pol. Targ. (2014)

Deuteron

Spin-1 System



Proton-Neutron bound state

Simplest nuclear system: nucleon interaction effects

$m = \pm 1, 0$

Courtesy:Allison Zec

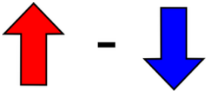
What Deuterons Do That Protons Don't

Proton

Spin- $\frac{1}{2}$ System

$m = +\frac{1}{2}$ $m = -\frac{1}{2}$

"Typical" Vector Polarization



$$P_z = p_+ - p_-$$

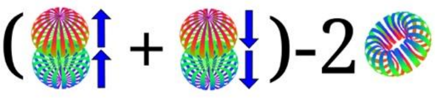
J Forest, et al, PRC 54646 (1996)

Deuteron

Spin-1 System

$m = +1$ $m = 0$ $m = -1$

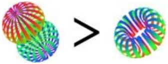
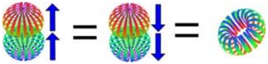
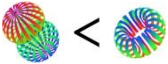
Vector and Tensor Polarization

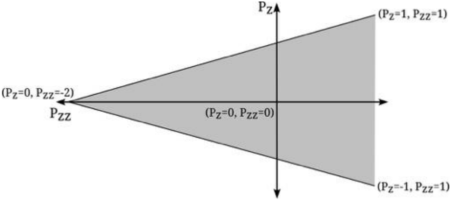


$$P_{zz} = (p_+ + p_-) - 2p_0$$

Courtesy:Allison Zec

Tensor Polarization Properties

If…	Then…
	$0 < P_{zz} \leq 1$
	$P_{zz} = 0$
	$-2 \leq P_{zz} < 0$



- P_z ranges from -1 to +1
- P_{zz} ranges from -2 to +1
- In deuterons both P_z and P_{zz} can be nonzero simultaneously

Courtesy:Allison Zec

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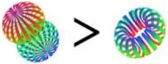
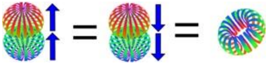
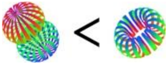
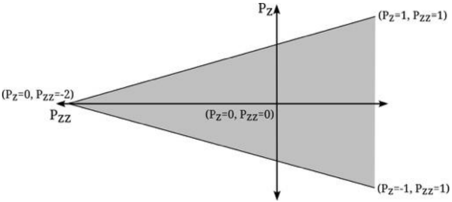
	$0 < P_{zz} \leq 1$
	$P_{zz} = 0$
	$-2 \leq P_{zz} < 0$



A high-luminosity tensor-polarized target has promise as a novel probe of nuclear physics

Courtesy:Allison Zec

Tensor Observables

$$\frac{d^2\sigma}{dk d\Omega} = \sigma_0 \left[1 + h_e (P_z A_{\parallel} + P_{zz} A_T^{ed}) + P_z A_V^d + \frac{1}{2} P_{zz} \, A_{zz} \right]$$

Here σ_0 is unpolarized cross section, h_e is electron beam helicity, $A_{||}, A_T^{ed}$, A_V^d and A_{zz} are symmetries dependent on the polarization angle

W. Leidemann, E.L. Tomusiak, H. Arenhovel, Phys. Rev. C 43 1022 (1991)

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Tensor Asymmetry and Structure Function

For $0.8 \leq \; \boldsymbol{x} \leq \; 1.8$

σ_p =polarized cross section

σ_0 =unpolarized cross section

$$A_{zz} = \frac{2}{f P_{zz}} \left(\frac{\boldsymbol{\sigma}_p}{\boldsymbol{\sigma}_0} - 1 \right)$$

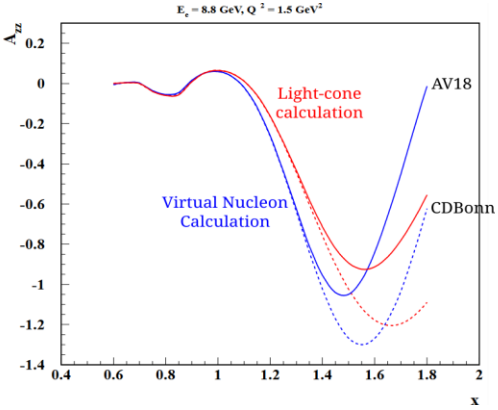
for $x \leq \; 0.5$

$$b_1 = -\frac{3}{2} F_1 A_{zz}$$

- Currently no quasielastic data available
- Difficult to measure with just vector polarized deuterons

M. Sargsian, M. Strikman arXiv:1409.6056

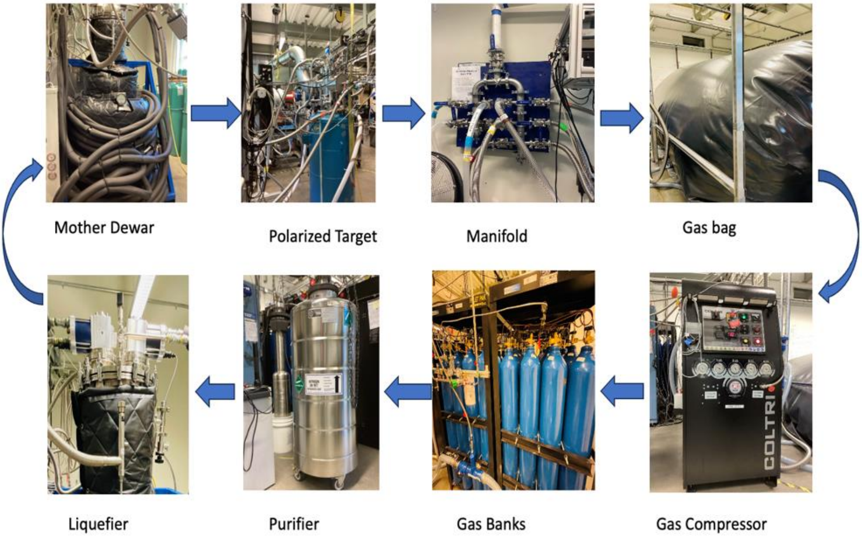
E. Long *et al*, JLab C12-15-005



Above: Two theory models: AV18 (solid) and CDBonn (dashed) for two different calculation frameworks predicting the quasielastic value of A_{zz}.

Courtesy:Allison Zec

Tensor Enhancement @UNH DNP Lab



Experimental setup for the cooldown at the UNH Polarized Target lab

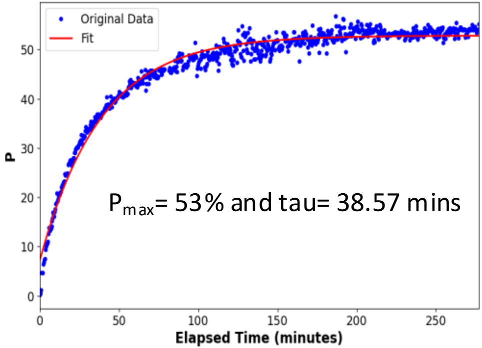
Tensor Enhancement by Holeburning

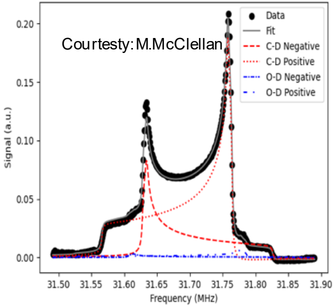
Polarization

$$\mathbf{P} = -(\mathbf{P}_{\mathbf{max}} - \mathbf{P}_0)\, e^{-\frac{t-t_0}{\tau}} + \mathbf{P}_{\mathbf{max}}$$

$$P_z = p_+ - p_-$$

$$P_{zz} = (p_+ + p_-) - 2p_0$$

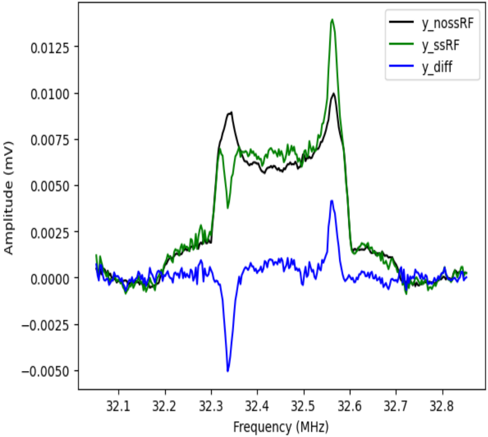




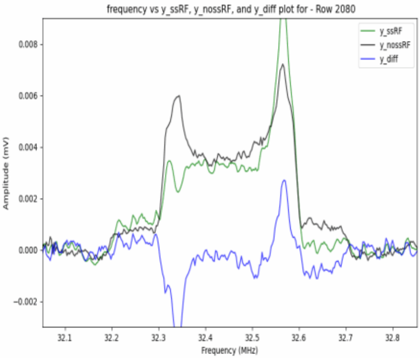
Data from UNH Lab

Holeburning Continued

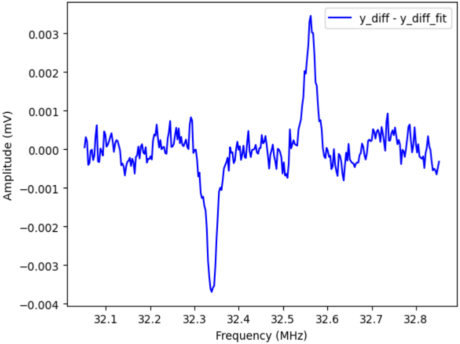
After multiple applications of holeburning we are able to achieve 16% tensor polarization on d-butanol. We are currently working on improvements to our equipment design so that our system will perform even better. Our goal is to achieve 30% tensor polarization using this technique.



Holeburning Relaxation Time



Livetime animation of Holeburning

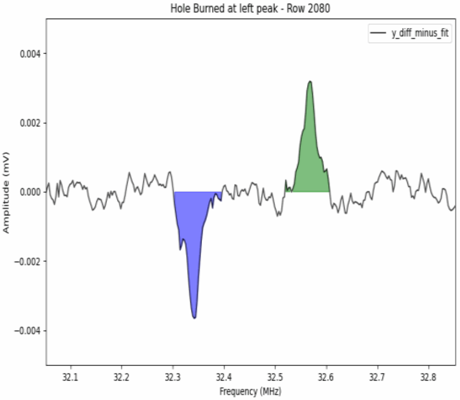


Difference in ssRF-nossRF

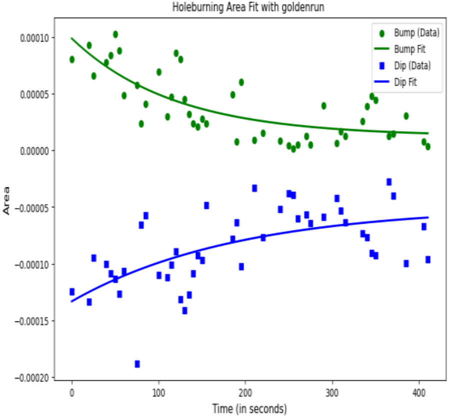
Holeburning Relaxation Time Continued

$$\text{Area} = \sum_i y_i \cdot \Delta x_i$$

$$A(t) = A_{\max} \cdot e^{-\frac{t-t_0}{\tau}}$$

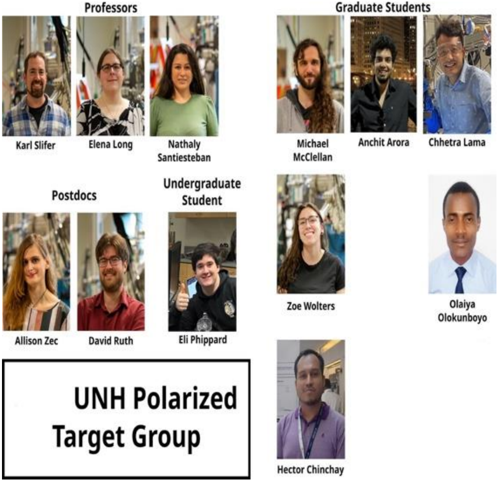


Corresponding area



Area curve fitting

Summary



NPG group at UNH

- Tensor polarized targets present new opportunities for high-luminosity experiments such as b_1 and A_{zz}
- DNP tried-and-true method for target polarization
- UNH NPG has demonstrated tensor polarization capability

Question?

Thank you!
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