Tensor Polarized Deuteron at an Electron-Ion Collider

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Abstract. The deuteron is a simple, spin-1 nuclear system. This makes it an effective test-bed for investigating nuclear physics. In addition, it is also relatively easy to polarize. Tensor polarization provides new opportunities to study properties of the nucleus. This is a significant part of the motivation for a polarized deuteron beam for an electron-ion collider envisioned for the future. This paper will discuss the motivation and a useful physics starting point for such a facility.

1. Motivation
The deuteron is a spin-1 system that can be considered as a simple lab for nuclear physics. Its spatial distribution depends on its spin-state [1]. Tensor polarization presents a unique opportunity to study the spin structure of a nuclear system due to it providing access to the spin \( m = 0, \pm 1 \) of the deuteron rather than the 1/2-spin of the neutron or proton only. In essence it is a combination of quark and nuclear physics.

Inclusive scattering incident on a tensor polarized deuteron results in 4 additional spin-structure functions denoted \( b_1, b_2, b_3, b_4 \) [2, 3]. Of these functions, \( b_1, b_2 \) have been extracted by the HERMES collaboration [4]. The smaller \( x \) kinematics of an EIC would also make it possible to access anti-shadowing and coherent (2-body) scattering.

2. A Starting Point: \( b_1 \)
In essence, the deuteron provides a combination of quark and nuclear physics. Extraction of \( b_1 \) is done via deep inelastic scattering (DIS), yet it depends on the deuterons spin-state. This allows for investigation of nuclear effects at the partonic level.

Calculations predict \( b_1 \) to vanish in the absence of nuclear effects [2]. Even accounting for the d-state admixture, it is expected to be very small. Various calculations predict \( b_1 \) to be on order of \( 10^{-4} - 10^{-3} \), depending on it taking in to account relativistic convolution with binding [5] or the Bethe-Salpeter formalism [6].

The sole data set with which \( b_1 \) was extracted is from HERMES [4]. The observable is tensor asymmetry \( A_{zz} \), which is the normalized cross-section difference. From this \( b_1 \) is calculated via the relation \( b_1 = 3/2(F_1 A_{zz}) \). Here \( F_1 \) is the unpolarized structure function. There is a complementary measurement proposed for Jefferson Lab [13].

Predictions for \( b_1 \) as \( x \to 0 \) show it rapidly increasing, indicating double scattering [7, 8]. In addition, predictions for \( b_2 \) and \( A_{zz} \) indicate possibilities for disentangling predictions at small \( x \) [9, 10].
Studies of Tensor Polarized Deuteron Beam

The staged, medium energy electron-ion collider (MEIC) concept at Jefferson Lab envisions a polarized deuteron beam for various reasons [11]. Due to its small magnetic moment, polarization would be very difficult to maintain for a deuteron beam at sufficiently high energies. The MEIC design calls for an innovative figure-8 ion complex, which would allow the polarization to survive with a spin rotation around a certain axis using magnetic inserts. With this the deuteron polarization would then remain stable and point along the rotation axis at the inserts location. Simulations studies are underway for this.

Deuteron spin manipulation has been studied at IUCF and COSY [12]. What these studies showed was that spin-1 is a linear combination of vector and tensor polarizations $P_V$ and $P_T$, respectively. The IUCF study used a 270 MeV, vertically polarized deuteron beam in a storage ring. The COSY study was fairly similar. The beam was fast RF-cycled through 4 polarization states to reduce systematic uncertainties: $(P_V, P_T) = (1, 1), (-1, 1), (0, 1), (0, -2)$. These states can be flipped by bunches or extracted at an experiment point.

Summary

A tensor-polarized deuteron provides a spin-1 system that is a combination of quark and nuclear physics. This results in new physics opportunities, which includes new spin-structure functions. Of these, $b_1$ may be a good starting for an electron-ion collider. A considerable reason for this is that HERMES measures it with a complementary measurement proposed at Jefferson Lab. A polarized deuteron beam is included as part of the MEIC design. Simulation studies are underway for this. Previous studies have been carried out at the IUCF storage ring and similarly at COSY.
References
[1] Carlson J and Schiavalla R 1988 Rev. Mod. Phys. 70 743; Forrest J L et al 1996 Phys. Rev. C 54 646
[2] Hoodbhoy P, Jaffe R L, and Manohar A 1989 Nucl. Phys. B 312 571
[3] Frankfurt L L and Strikman M I 1983 Nucl. Phys. A 405 557
[4] Airapetian A et al 2005 Phys. Rev. Lett. 95 242001 Riedl C 2005 Ph.D. thesis, DESY-THESIS-2005-027
[5] Khan H and Hoodbhoy P 1991 Phys. Rev. C 44 1219
[6] Umnikov A Y 1997 Phys. Lett. B 391 177
[7] Edelmann J, Piller G, and Weise W 1998 Phys. Rev. C 57 3392
[8] Frankfurt L, Guzey V, and Strikman M 2006 Mod. Phys. Lett. A 21 23
[9] Bora K and Jaffe R L 1998 Phys. Rev. D 57 6906
[10] Nikolaeva N N, Schäfer W 1997 Phys. Lett. B 398 245
[11] Abeyratne S et al 2012 arXiv:1209.0757
[12] Morozov V S 2007 Ph. D. thesis, Univ. of Michigan
[13] Chen J P et al 2013 E12-13-011, Jefferson Lab PAC 40