HDice, Highly-Polarized Low-Background Frozen-Spin HD Targets for CLAS experiments at Jefferson Lab

2012 J. Phys.: Conf. Ser. 400 052042

(http://iopscience.iop.org/1742-6596/400/5/052042)

Journal of Physics: Conference Series **400** (2012) 052042 doi:10.1088/1742-6596/400/5/052042

HDice, Highly-Polarized Low-Background Frozen-Spin HD Targets for CLAS experiments at Jefferson Lab

X Wei[1], C Bass[1], A D'Angelo[2], A Deur[1], G Dezern[1], D Ho[3], T Kageya[1], M Khandaker[1,4], D Kashy[1], V Laine[1,5], M Lowry[1], T O'Connell[6], A M Sandorfi[1], R W Teachey[1], C S Whisnant[7] and M Zarecky[1]

[1]Jefferson Lab, Newport News, VA 23606, USA
[2]Universita di Roma "Tor Vergata" and INFN-Sezione di Roma2, Rome, Italy
[3]Carnegie-Mellon University, Pittsburgh, PA 15213, USA
[4]Norfolk State University, Norfolk, VA 23504, USA
[5]Blaise Pascal University, Clermont-Ferrand, France
[6]University of Connecticut, Storrs, CT 06269, USA
[7]James-Madison University, Harrisonburg PA 22807, USA

xwei@jlab.org

Abstract. Large, portable frozen-spin HD (Deuterium-Hydride) targets have been developed for studying nucleon spin properties with low backgrounds. Protons and Deuterons in HD are polarized at low temperatures (~10mK) inside a vertical dilution refrigerator (Oxford Kelvinox-1000) containing a high magnetic field (up to 17T). The targets reach a frozen-spin state within a few months, after which they can be cold transferred to an In-Beam Cryostat (IBC). The IBC, a thin-walled dilution refrigerator operating either horizontally or vertically, is use with quasi-4π detector systems in open geometries with minimal energy loss for exiting reaction products in nucleon structure experiments. The first application of this advanced target system has been used for Spin Sum Rule experiments at the LEGS facility in Brookhaven National Laboratory. An improved target production and handling system has been developed at Jefferson Lab for experiments with the CEBAF Large Acceptance Spectrometer, CLAS.

1. HDice target

Polarized Deuterium Hydride, HD, in the frozen-spin mode has been used for nuclear and particle physics experiments, initially for measuring Spin Sum Rules[1] at the LEGS facility in Brookhaven National Laboratory, and has recently been prepared for use in Hall B of Jefferson Lab[2]. The original concept of polarizing HD was proposed by Honig in 1967[3]. In HD, intrinsic relaxation times are extremely long, but trace impurities of H_2 and D_2 at the 10^{-4} to 10^{-3} level readily polarize at high magnetic field and low temperature. These rapidly transfer their polarization to HD via spin exchange and then decay to magnetically inert states, creating an effective “Polarization-Switch”. The switch is engaged by “aging” in the polarizing condition to let the population of impurities in magnetically sensitive states decay to their inert ground states. In this process a frozen-spin mode is achieved. Figure 1 shows the lowest levels of the solid hydrogens involved in the polarization process.

There are numerous advantages of using frozen-spin HD for nuclear and particle physics measurements. It has the lowest dilution factor among all other solid targets, having only one neutron and two protons (bound and free), all of which are polarizable. The Proton and Deuteron spins can be transferred between them as desired with RF transitions. Since the target is in a frozen-spin mode, it can be transferred at 2K and several hundred gauss. With no symmetry constraints on the molecular wave-function and little or no coupling to the lattice, solid HD can maintain polarization almost indefinitely in much relaxed conditions of up to ½ K and a few kilo-gauss. With decay times of years, targets can be made far in advance and stored in preparation for complex experiments.

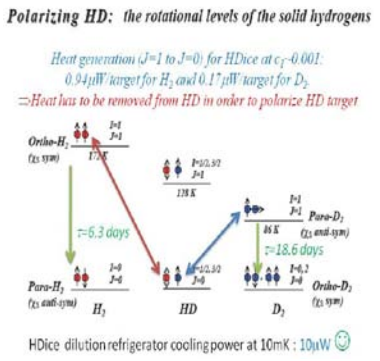

Figure 1. Polarization-Switch.

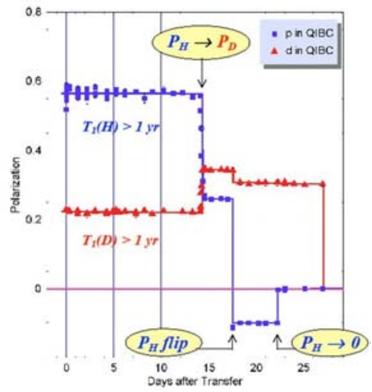

Figure 2. Polarization transfer.

Once the HD is in the frozen spin state, one can flip the polarizations of H and D, or transfer the polarization between H and D with RF transitions. Figure 2 shows an example of such polarization manipulations during an experiment at BNL[1]. Large scale samples, up to 2 ½ cm diameter × 5 cm long (1 mole), have been used as targets in experiments. Some recent results are shown in figures 3 and 4.

Following initial studies at Syracuse, a system of cryostats and sample manipulation tools were developed at Brookhaven National Lab during the last decade[4,5]. Recently these have been transferred to Jefferson Lab where an expanded facility has been developed to supply HD targets with photon and (potentially) electron beams in Hall B[6].

2. Applications

The first HD application for nuclear physics was a series of measurements conducted at LEGS during 2004-2006. Figure 3 shows the missing-mass plots for two reaction channels and Figure 4 displays the running integral of the GDH Sum Rule[1]. These precision measurements have resolved an apparent puzzle and brought this sum rule evaluation down to its standard expectation[1].

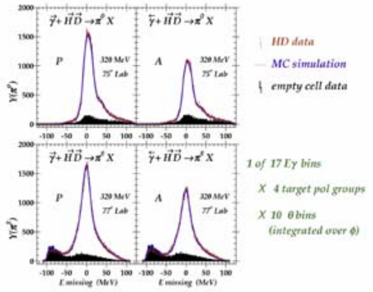

Figure 3. Missing mass for π channels with an HD target[1].

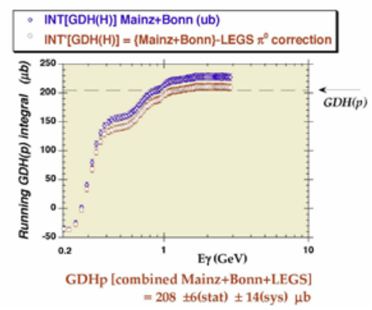

Figure 4. The results of GDH Sum Rule measurements[1].

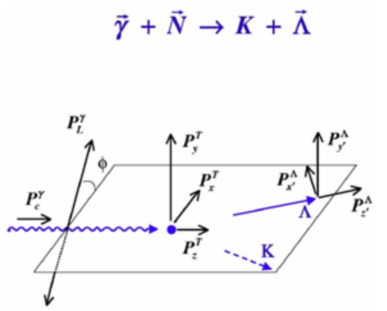

Figure 5. A schematic of polarization variables in a "*Complete Experiment*".

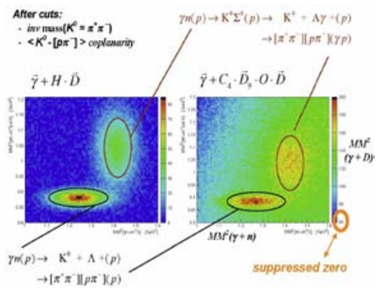

Figure 6. Missing mass plots from Monte Carlo simulation for HD and C_4H_9OH [2].

In a search for new excited states of the nucleon, the *g14* experiment is under preparation to use frozen-spin solid HD (*HDice*) and Jefferson Lab's CEBAF Large Acceptance Spectrometer (CLAS) to measure all 16 possible polarization observables, including all target, beam and recoil polarization asymmetries in the $\gamma + N \rightarrow K + \Lambda$ reaction[2]. Figure 5 illustrates the reaction plane and all contributing spins. Figure 6 reveals clear advantages of HD compared to a deuterated-butanol target. The missing mass plots show Monte Carlo Simulation for $\boldsymbol{\gamma}$ on HD, the left penal and for $\boldsymbol{\gamma}$ on a butanol target in the right penal. Note the background level on the right panel is suppressed. Due to much lower backgrounds levels, any desired level of statistics is achieved with much less running time using HD.

3. HD polarization at manipulation at Jefferson Lab

The HDice target system involves five specialized dewars for different functionalities. HD gas with appropriate impurity levels is condensed into a target cell inside a *Production Dewar* (PD), a pumped ^{4}He cryostat with a 2 Tesla magnet from Janis. There, thermal equilibrium NMR signals from HD are measured to calibrate the polarization monitoring system. The target is then moved with a Transfer Cryostat (TC), a 3 m cold screw-driver equipped with both liquid helium and nitrogen spaces and a transverse 0.11 Tesla Halbach Dipole. The HD is loaded into an Oxford Instruments dilution refrigerator (ODR), Kelvinox-1000 with a 15/17 Tesla magnet to polarize and age. After reaching its frozen-spin mode, it is then cold-transferred back to the PD for measuring the polarization of both protons and deuterons. The target is then transferred into a Storage Dewar (SD), a pumped ^{4}He cryostat with a 8/10 Tesla magnet from Janis, and finally into an in-beam cryostat (CLAS-IBC), a new dilution refrigerator, which can be run in both vertical (target loading) and horizontal (reaction data) positions, built at Jefferson Lab, Figure 7, with both longitudinal and transverse magnet fields. The stages in loading a polarized HD target into the CLAS detector at Jefferson Lab are illustrated in Figure 8. The new cryostat and its piping system have been designed to ASME Boiler Pressure codes.

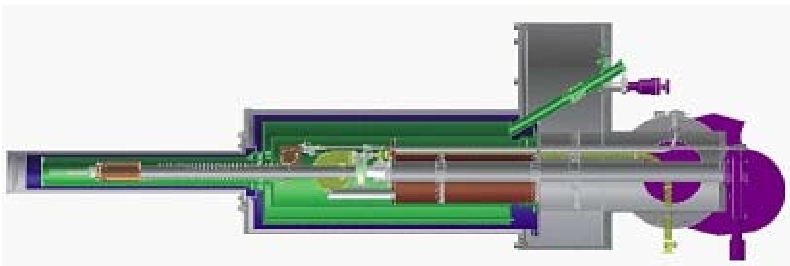

Figure 7. CLAS-IBC, a horizontal dilution refrigerator with three superconducting magnets; runs in vertical position for HD load in.

The CLAS-IBC has been constructed and commissioned. Cooling with helium only from room temperature takes 3 days. A minimum temperature of 35 mK has been achieved and the cooling power at 165 mK was 3 mW. All 3 superconducting magnets, which produce both longitudinal and transverse field as well as an ancillary field, and a room temperature backup coil have met design specifications.

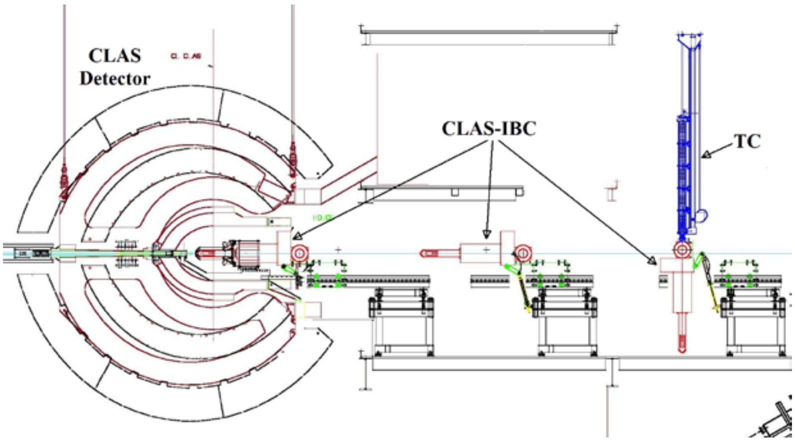

Figure 8. Target manipulations inside the experimental hall. Steps right to left: TC loads HD target into CLAS-IBC in vertical position; IBC is rotated to horizontal position; IBC is rolled into the CLAS detector for experiments.

4. Conclusions

Solid HD has many proven advantages as a target for spin measurements with electromagnetic probes. The chief characteristics of this advanced polarized target are its *frozen-spin mode*, with low holding fields (sub-Tesla) at relatively warm temperatures (up to 0.5 K), and low background with essentially no dilution, which results in smaller statistical errors and shorter running time. Furthermore, the production facility can be separated from experimental site, which has many logistic advantages.

A new *HDice* target facility has been developed at Jefferson Lab where experiments with CLAS are now in preparation. An initial commissioning run was completed in April-May 2011. Final preparations are under way for the *g14* $\gamma + HD$ experiment, which will begin in November of 2011 and run through April 2012. In May of 2012 HD target performance with electrons will be tested.

5. Acknowledgements

This work was supported by the US Department of Energy, Office of Nuclear Physics Division, under contract no. DE-AC05-06OR23177 under which Jefferson Science Associates operates Jefferson Lab.

References

[1] LEGS-Spin Collaboration, S. Hoblit et al., *Phys. Rev. Lett.* **102**, 172002 (2009).
[2] The g14-HDice experiment, http://www.jlab.org/exp_prog/proposals/06/PR-06-101.pdf
[3] A. Honig, Phys. Rev. Lett. 19, 1009 (1967); A. Honig et al., *Nucl. Inst. Meth.* A356, 39 (1995).
[4] X. Wei et al., *Physica B*, 284-288, 2051 (2000).
[5] X. Wei et al., *AIP Conf. Proc.* **570**, 846 (2001); C. Bade et al., *ibid.*, **675**, 862 (2003).
[6] A.M. Sandorfi et al., *Workshop on Exclusive Reactions at High Momentum Transfer*, Newport News, VA, May, 2007, World Scientific, New Jersey (2008) p. 425.