DESIGN OF A FROZEN SPIN TARGET FOR CLAS

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A frozen spin target for the CEBAF Large Acceptance Spectrometer (CLAS) is under construction for a series of experiments that scatter tagged, polarized photons from both longitudinally and transversely polarized protons. Compared to the polarized target previously used inside CLAS, the proposed frozen spin target will better utilize the spectrometer's nearly 4π acceptance. The target material will be dynamically polarized at 5 T and 0.3 K and then cooled to about 0.05 K by a horizontal $^3He/^4He$ dilution refrigerator. The polarization will be preserved by internal superconducting coils providing 0.3–0.5 T.

1. Introduction

The CEBAF Large Acceptance Spectrometer (CLAS) in Hall B at Jefferson Lab is a highly segmented detector system with an acceptance of almost 4π [1]. Considerable data have been collected using CLAS with both electron and tagged photon beams incident upon a variety of targets. Among these, a polarized target has been previously reported [2] in which frozen samples of $^{15}NH_3$ and $^{15}ND_3$ were cooled to 1 K and dynamically polarized by continuous microwave irradiation inside a 5 T superconducting Helmholtz magnet. Due to the geometry and construction of the magnet, only particles scattered in a forward cone of $\pm 55°$ were detected.

However, a number of tagged photon experiments requiring a polarized proton target have been recently accepted or proposed for which the above target is not acceptable [3, 4, 5, 6]. For instance, these projects require targets that can be polarized in either the longitudinal or transverse directions while providing an open aperture of $7 - 140$ degrees in the polar angle and $0 - 2\pi$ in azimuth.

To meet these and additional demands, a new polarized target is currently under construction at Jefferson Lab that will utilize the so-called "Frozen Spin" technique. Here, the target material is cooled to approximately 0.5 K and dynamically polarized outside the spectrometer using a highly homogeneous magnetic field (usually 2.5 or 5.0 T). Once polarized, the target is then cooled to a temperature low enough to preserve (or "freeze") the nuclear polarization in a more moderate "holding" field of about 0.5 T. The target can then be moved inside the spectrometer, and data acquisition with the tagged photon beam can commence. During this time the polarization decays with a time constant of several days, after which the target must be removed from the spectrometer for repolarization.

Integral to the frozen spin technique are the extraordinarily long nuclear spin-lattice relaxation times observed for dielectric materials at low temperatures. For example, the relaxation rate of protons in butanol at 60 mK and 0.5 T is about 600 hours [7]. This temperature is easily achieved inside the mixing chamber of a ^{3}He/^{4}He dilution refrigerator, and the field can be generated by a relatively thin superconducting coil surrounding the target material.

The remainder of this article describes the design and status of various components for the CLAS Frozen Spin Target.

2. Frozen Spin Target

2.1. *Polarizing Magnet*

Historically, dynamic nuclear polarization (DNP) for nuclear and particle physics experiments has been carried out at 2.5 or 5.0 T. At these field strengths, DNP can be successfully applied to a variety of materials at temperatures near or below 1 K. The homogeneity of this field should be 10^{-4} (or better) in order to resolve the ESR line width of paramagnetic radicals inside the target material, necessary for the DNP process.

For the CLAS Frozen Spin Target, we have purchased and received a 5.1 T solenoid with a horizontal warm bore of 127 mm diameter.[a] Based on our own field map, the field is uniform to $\Delta B/B < 3 \times 10^{-5}$ over the volume of the polarized target, 15×50 mm (diameter $\times$ length).

[a]Cryomagnetics, Inc., Oak Ridge, TN, USA

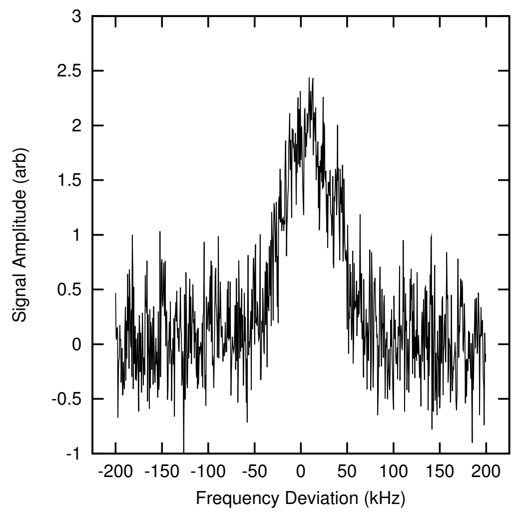

Figure 1. NMR signal of protons in CH_2 in thermal equilibrium at 1.5 K and 0.3 T . A thin superconducting solenoid, described in the text, was used to generate the field.

2.2. *Holding Magnets*

The homogeneity requirements for the magnetic field used to maintain polarization during data acquisition are less stringent than that for the polarizing magnet. Previous groups have shown that it is possible to use either the fringe field of the polarizing magnet or the field of the spectrometer itself. However, Dutz *et al.* [8] have demonstrated that the holding field can also be generated by a small, superconducting solenoid mounted inside the polarizing refrigerator. If the coil windings are kept very thin, the energy loss of charged particles as they scatter through the windings will remain at an acceptable level. As an added benefit, the homogeneity of this coil can be good enough to resolve the proton's NMR line, and the target polarization can be monitored during data acquisition.

We have constructed a number of thin solenoids similar to that described by Dutz *et al.* [8]. The NMR line shape of a CH_2 sample cooled to approximately 1 K inside one of our prototypes is shown in Figure 1. This coil, consisting of 2 layers of 0.11 mm monofilament NbTi wire, produced a maximum field of 0.32 T, with homogeneity $\Delta B/B < 3 \times 10^{-3}$.

Realization of an internal magnet for transverse polarization will be more problematic. Thus far we have used the OPERA/TOSCA software packages to model "saddle" coil dipoles with a "cosine" current distribution between the layers of the dipole [9]. One such coil has been produced, and will be tested in the near future.

2.3. *Dilution Refrigerator*

A horizontal ^{3}He/^{4}He dilution refrigerator will be used for cooling the target material. The horizontal design is dictated by the geometry of CLAS, and a schematic drawing of our design is shown in Figure 2.

The cooling power requirements for the dilution refrigerator are twofold. First, it must absorb ~30 mW of microwave power while the target is being polarized at 0.5 K. Second, it should provide sufficient cooling power (a few μW) while in the Frozen Spin mode to compensate for the heat produced by the photon beam, thermal radiation, conduction of mechanical supports, and vibration. A brief description of the refrigerator design is given below.

Circulation of ^{3}He through the dilution refrigerator is accomplished by a 3300 m^3/h set of vacuum pumps used for the existing Hall B polarized target [2]. The ^{3}He gas entering the refrigerator is first cooled by a ^{4}He precooling circuit consisting of vessels containing liquid ^{4}He at approximately 4.2 K (separator) and 1.5 K (evaporator). Vapor pumped from the separator is used to cool a heat shield surrounding the dilution unit. This vapor also cools the incoming ^{3}He/^{4}He gas to 5 K in a tube-in-tube counterflow heat exchanger, followed by a coiled heat exchanger inside the separator. The ^{3}He is then cooled to about 2.5 K via heat exchange with gas pumped from the evaporator and condensed inside a coil submerged in the evaporator's 1.5 K liquid. A small needle valve located downstream of this coil is used to maintain a constant condensation pressure.

The dilution unit of the refrigerator consists of a distillation pot (still), a tube-in-shell heat exchanger, and a final tube-in-tube heat exchanger. The latter is constructed from thin-walled cupronickel tubes inside a stainless steel tube. The cupronickel tubes have a 1 mm thick layer of 1 micron silver powder sintered to both the inner and outer walls to substantially increase the surface area for heat exchange between the concentrated and dilute ^{3}He flow streams. Sinters prepared from this powder provide a surface area of approximately 0.5 m^2/g, and we expect a total surface area of about 50 m^2.

The mixing chamber (mixer) is constructed of a PCTFE cup glued to the end of a thin-walled, stainless steel vacuum load lock which is heat sunk to the separator, evaporator, still, and tube-in-shell heat exchanger. The target material is attached to a 2 m long insertion tube and loaded into the mixer via the load lock. A knife edge seal between the insert and load lock seals the target inside the mixer.

The holding coils are wound on a thin aluminum carrier surrounding the mixing chamber and heat sunk to the still. Both the microwave waveguide for polarizing the target and the NMR coils for measuring the polarization are located in the annular gap between the mixer and holding coil.

The dilution refrigerator is currently under construction.

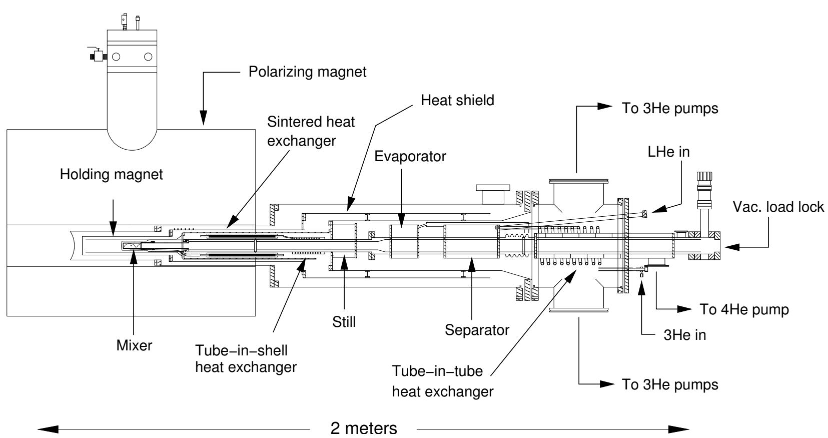

Figure 2. Schematic drawing of the CLAS Frozen Spin Target located inside the 5 T polarizing magnet.

Acknowledgments

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