

STATUS OF THE LEGS POLARIZED HD TARGET

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A solid, polarized *HD* target has been developed for the measurement of double-polarization observables in the Δ resonance region. Since the use of the first target in-beam in November 2001, dramatic improvements have been made to the in-beam and transfer cryostats and the NMR circuit has been redesigned and is well understood.

With the development of the Strongly Polarized Hydrogen deuteride ICE target (SPHICE), the LEGS (the Laser Electron Gamma Source) experimental program has begun a program of double-polarization measurements starting with the Gerasimov-Drell-Hearn and forward spin polarizability sum rules for the nucleon. SPHICE is a high purity target that can be highly polarized. Coupled with the large acceptance Spin ASYmmetry detector array, SASY, the measurement of the one- and two-pion photoproduction from the nucleon, especially the neutron, can be done with good precision in a relatively short run period.

SPHICE represents a new technology utilizing molecular *HD* in the solid state¹. Targets are polarized at low temperature (10-15 mK) and high field (15 T) in a large dilution refrigerator. The spin-lattice coupling which permits polarization of these targets is effected by a small ($\approx 10^{-4}$) concentration of ortho- H_2 (molecular rotational angular momentum, $J =$

1). Since these molecules decay at low temperature to the magnetically inert $J = 0$ para- H_2 with a time constant of ≈ 6 days, the spin-lattice relaxation time, T_1 , increases with time spent at the polarizing condition. The nucleons are polarized by equilibrating the target at low-temperature and high-field.

Holding the target in the polarizing conditions for 50-100 days increases T_1 sufficiently to permit target extraction using a specially designed transfer cryostat²(TC). The frozen spin targets can then be stored or transported in a storage dewar (1.5 K/10 T) or inserted directly into the in-beam cryostat (IBC). The T_1 for \vec{H} in storage is several months depending on the purity of the HD.

The factor ultimately determining the time required to hold the target in the polarization conditions is the concentration of para- D_2 . This spin 1, $J = 1$ molecule also couples to the H and D spins and has a decay time (to the inert ortho- D_2 state) approximately 3 times longer than that of ortho- H_2 . This places stringent requirements on the purity of the HD.

Targets are produced in a top-loading dilution refrigerator containing a superconducting solenoid long enough to produce up to three $5 \text{ cm} \times 2.5 \text{ cm}$ \emptyset targets simultaneously. Since the production of the first target, the base temperature of this system has been lowered from 17mK (with the magnetic field on) to 8-10mk by improving the isolation from the vacuum pumping system vibrations which produce eddy current heating. This increases the initial polarization of the target from $\approx 70\%$ to $\approx 90\%$.

Once the spins are frozen in, the field is reduced, the system is warmed to 2 K, and the TC is inserted. This device, containing both LN_2 and LHe jackets, has a central portion that can translate and rotate making it possible to screw the TC cold finger into the target mount and withdraw the target from the refrigerator. While in the TC, polarization is maintained with a small magnet providing a few hundred Gauss field. The target may then be either inserted into the IBC or into storage for later use. The existing TC built by Orsay has been a source of many problems and will be replaced by a new one, built at Jülich. This new device will be delivered in the summer of 2004. A comparison of the Orsay and Jülich TC's is shown in table 1.

With almost 10 times the holding field and greatly improved alignment and positioning reproducibility, the Jülich TC will permit more deliberate transfers done with greater control, thereby ensuring consistently successful transfers. The extended reach will enable us to take full advantage of the capabilities of the dilution refrigerator.

Table 1. A comparison of the main characteristics of the Orsay and Jülich transfer cryostats.

Characteristic	Orsay-TC Performance	Jülich-TC Performance
Magnetic Holding field	0.017 T (High- T_c LN ₂ -cooled solenoid)	0.130 T (NdFeB Halback dipole)
Number of targets that can be retrieved from dilution refrigerator	2	3
Stability and alignment	Loose and poor reproducibility	Tight and reproducible

The IBC was upgraded in the spring of 2004. The original Orsay-IBC is a pumped ^4He system maintaining the target at 1.3 K. The polarization holding field, 0.65 T, is provided by a small superconducting solenoid inside the IBC. The newly installed IBC built by Quantum Technologies in Vancouver, BC operates at 0.3K and 1.0 T using a $^3\text{He}/^4\text{He}$ dilution refrigerator. A comparison of the Orsay and Quantum IBC's is given in table 2

Table 2. A comparison of the main characteristics of the Orsay and Quantum Technologies in-beam cryostats.

Characteristic	Orsay-IBC Performance	Quantum-IBC Performance
Target Temperature	1.3 T	0.3 T
Magnetic Holding field	0.65 T	1.0 T
Horizontal Stability (running position)	Required frequent adjustments	Very stable
Tipped Stability (during target loading)	Inherently unstable	Very stable
Operations at 6-7 K	Impossible	Stable, but some development is needed
Cool-down Time	2 days	2.5 days
LHe usage	300 Liters/day	120 Liters/day

The improvements in temperature and holding field with the Quantum IBC will dramatically increase the in-beam spin relaxation time. This capability permits the production of targets that can be used in-beam for months with high average polarization.

The target cell is machined from a single piece of Kel-F so that the only hydrogen seen by the NMR system is from the *HD*. The only other extraneous material in the photon beam is the Al cooling wires. Because *HD* at 10-15 mK is a poor thermal conductor and the $\text{o-H}_2 \rightarrow \text{p-H}_2$ conversion generates heat throughout the target, these wires are required to ensure a

uniform low temperature while polarizing. The current target design uses 2050 50 μm wires representing 20% of the HD by weight. They are soldered to a threaded copper ring that provides the thermal and mechanical connection to the refrigeration system.

Gas of the purity necessary for target production is not available commercially, so commercially available gas (98% HD , 1.5% H_2 , and 0.5% D_2) is distilled to reduce the H_2 and D_2 concentrations to less than 10^{-4} . Using this purified gas, the first target polarization began in August 2001. The HD was equilibrated in the dilution refrigerator at 18 mK and 15 T. In September, once the polarization relaxation time had increased sufficiently, the field was lowered to do NMR and the polarizations were found to be $P_H = 70\%$ and $P_D = 17\%$.

Because this was the first target, many tests were made transferring the target to and from storage and the IBC. In addition, problems with the Orsay IBC also required additional transfers. In November, 2001, when this first target was finally put in the beam, the polarizations were $P_H = 30\%$ and $P_D = 6\%$. The relaxation times measured in-beam were $T_1^H = 13$ and $T_1^D = 36$ days. During the 111 days that the target was held in the polarizing conditions the para- D_2 concentration decreased by a factor of 477. The T_1 for \vec{H} in the Orsay in-beam cryostat (1.25 K/0.65 T) is approximately 2 weeks and for \vec{D} it is 6 weeks. The high quality data obtained in 3 days of running with this target have been presented elsewhere^{3,4}.

The target polarization uncertainty was unacceptably large for this first target. As a result, we have developed a crossed-coil system for measuring both the real and imaginary components of the susceptibility directly. Using one set of coils as a transmitter and another set, at 90° to the first, as a receiver, the real and imaginary parts of the response are measured simultaneously and the polarization is extracted from a fit to both components using a sophisticated circuit model with the target polarization as the only free parameter. This technique allows polarizations be determined better than $\pm 5\%$ now. With the new IBC, which admits 6 K operation, we can add additional checks of the thermal equilibrium polarization at the end of an experiment and lower the uncertainties to about $\pm 2\%$. Typical NMR scans obtained with the crossed-coil method are shown in Figure 1.

Although much of our effort since the production of the first target has gone into the design and development of improved cryostats and NMR techniques, it has proven possible to prepare another target using the existing equipment. In May, 2004, a greatly aged target (lifetime ≥ 3 months for hydrogen at in-beam conditions) with polarizations of $P_H = 54\%$ and

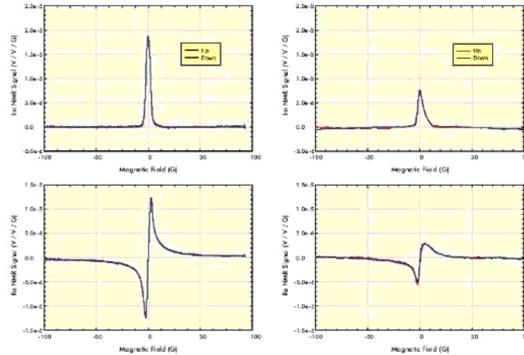


Figure 1. The real and imaginary parts of the NMR scan data for both hydrogen and deuterium. The top row shows the imaginary portion and the bottom row contains the real part. The left side shows hydrogen scans and the right side shows deuterium. Note that there are two lines on each plot, showing data for scanning up and down in magnetic field.

$P_D = 21\%$ was produced. The designs of the Jülich TC and the Quantum IBC incorporate many changes and improvements that will insure that future targets have higher polarization and can be successfully manipulated reliably.

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