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SLAC-YALE POLARIZED PROTON TARGET*

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ABSTRACT

A 50 kG, 1°K longitudinally polarized proton target has been built for use in an intense electron beam. Data on the target performance in two experiments completed at SLAC are presented. Design considerations for a possible future device are discussed.

I. INTRODUCTION

The target described here was specifically built to study deep inelastic scattering of polarized electrons on polarized protons. The experiment, per se, and the polarized beam are discussed elsewhere in these proceedings. The collaboration of builders includes Dave Coward, Steve St. Lorant, and myself from SLAC and Asher Etkin, John Wesley, Vernon Hughes, Peter Cooper, Satish Dhawan, Richard Ehrlich, Bob Fong-Tom, Doug Palmer, Paul Souder, and Percy Yen from Yale.

The use of a 50 kG field and the special features required for operation in an intense beam make this target rather unique and I shall concentrate on these points.[1] First I shall describe the components, then the performance during two recent experiments at SLAC, and then present some thoughts about hypothetical future targets of this type.

II. COMPONENTS

A schematic of the target showing all the essential features is given in Figure 1.

A. Magnet

The 50 kG superconducting magnet is made of 4 coils of niobium titanium, placed to give an 8th order corrected solenoidal field. The warm bore is ~15 cm diameter by ~40 cm long and the field is uniform to ± 80 ppm over

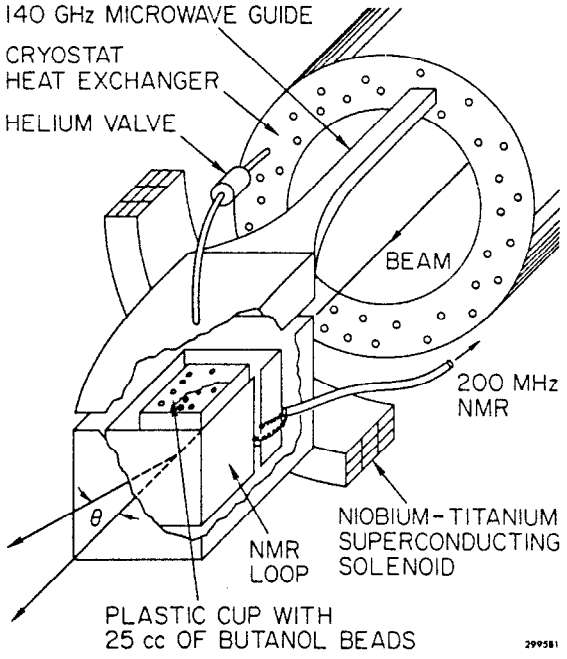

Fig. 1. Schematic of the SLAC-Yale polarized target with principal components.

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the $2.5 \times 2.5 \times 4.8$ cm^3 target volume. A cross section through coil and dewar is in Figure 2. The power supply[2] delivers ~700 amps to the magnet (nonpersistent mode) through ~50 m of a low resistive bus bar made of conventional structural aluminum angle and regulates to ±15 ppm via a transductor. The magnet is brought up to and down from its operating point by running the supply in voltage control, with a charging voltage of ~.5 volt equivalent to ~ 1 amp/sec.

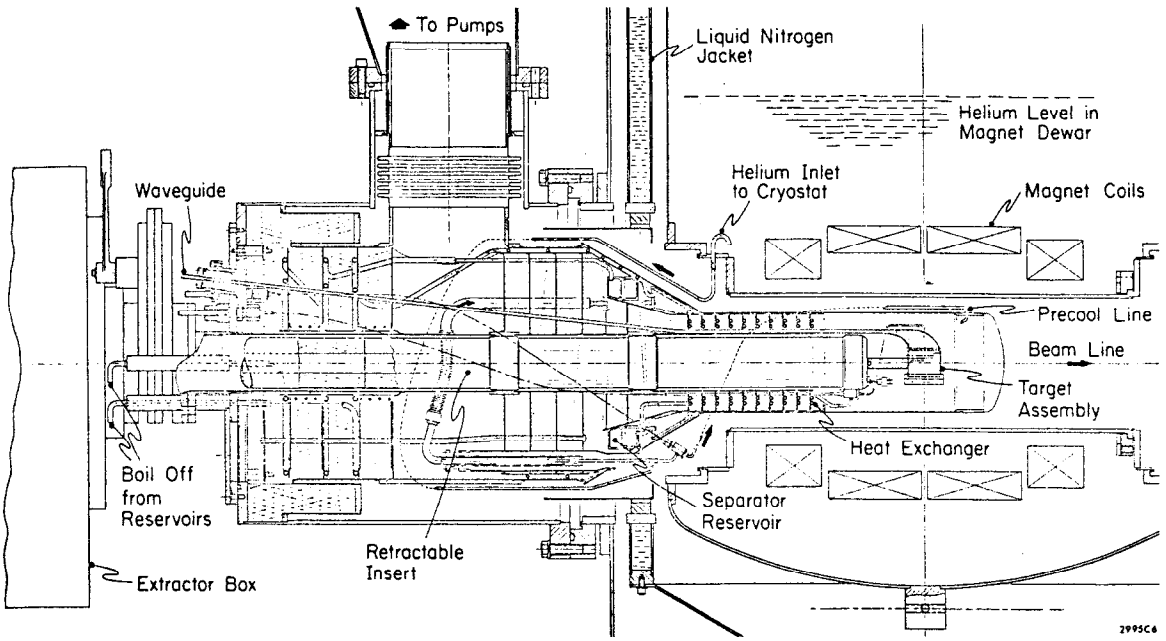

Fig. 2. Detail of the magnet dewar and cryostat in cross section. The scale is given by the ~1 meter diameter of the dewar. Significant features are labeled. An overview of the complete structure, emphasizing the extractor box is shown in Figure 5.

Large voltages (> 1 volt) across the magnet coil, excessive current in a series shunt, or power supply faults open a dc contactor and isolate the supply. The energy stored in the magnet is then dissipated over several minutes in a 50 mΩ resistor made of a stainless steel strap which is mounted in series with high current diodes across the current leads. Low helium level indication results in slow rundown of the magnet via the supply instead of this more abrupt "dump". The magnet has survived several such crises.

B. Microwaves

A backward wave oscillator (BWO) supplies the 140 GHz microwave power[3] through ~1 m of coin silver oversize guide (WR28), a 90° bend with vacuum window, another meter of oversized guide of gold-plated stainless steel (to reduce heat leaks to the cryostat), to a tapered horn made by electroforming copper on a hand-shaped aluminum form. The supplies are elaborately interlocked against the multitude of faults to which the delicate and expensive tube is subject. An iron box shields the BWO from the substantial stray field of the solenoid.

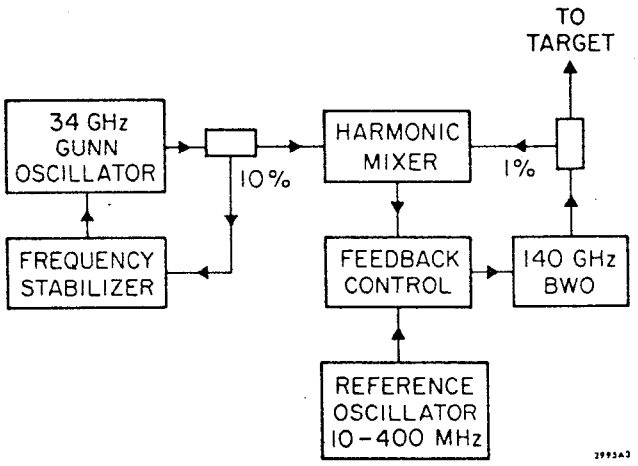

Fig. 3. Circuit schematic of 140 GHz lock system.

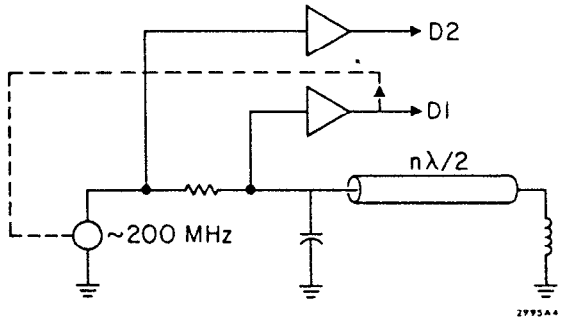

Fig. 4. NMR circuit schematic.

A 'soft' feedback system locks the frequency of the BWO to a stabilized GUNN oscillator reference as shown in Figure 3.[4] Although the BWO is reasonably stable and has good spectral purity without stabilization, the lock provides frequency measurement, straightforward return to operating point, and protects against occasional shifts in frequency. For these reasons, the lock was essential in this very busy experiment.

The "cavity" formed by horn and bottom cup of the target is not microwave tight, but we believe that in view of the large absorption of power in the sample the leakage is not serious. Earlier tests with a closed cavity are consistent with this viewpoint.

C. NMR

The parallel tank system is illustrated in Figure 4. Constant voltage at D1 is achieved via fast feedback to the gain of the sweep oscillator and a slow gated feedback on D2 reduces drifts. The

signal, D2, is proportional to admittance. The 400 kHz sweep is run at ~100 Hz with a 10% duty cycle and successive points in the line (typically 60 kHz FWHM) are accumulated in a 100 channel boxcar integrator, which is read out every 30 seconds by the experiment's data logging computer.

D. Cryostat

The helium-4 cryostat is shown in Figure 1. Liquid is taken from above the magnet through the insulating high vacuum region to the heat exchanger or through a simple precool valve directly to the cold end of the cryostat. Boiloff from the two reservoirs is used to cool insulating baffles, and the liquid is leaked to the target cup by a modified commercial fine metering valve. Two rotary blowers and a Stokes forepump provide ~1500 ℓ/sec pumping through a 50 cm diameter line to give ~700 mW cooling at 1.03 ^{o}K.

Cryostat instrumentation includes platinum resistance and carbon resistance thermometers, a carbon glass thermometer[5] with the 150μ pressure monitored by conventional thermocouple and a capacitance manometer.[6]

The entire target is shown in Figure 5, including the mechanism used to extract the target. The ~1 meter long, 7 cm diameter tube which holds the target cup and NMR loop is quickly cranked into the evacuated extractor box, and the intervening gate valve closed. After bleeding the box to helium gas, targets may be exchanged, the box pumped out and tube inserted with minimal contamination, heating, or loss of time. A standard 500ℓ helium supply dewar (not shown) is used to transfer liquid into the magnet dewar, which holds ~200ℓ. A valveless vacuum-insulated line is left in place and ~60ℓ of helium is transferred periodically by applying a pressure differential. All helium gas from target and pumps is recovered via a low pressure line to the SLAC recovery system.

E. Material

Target material is prepared according to traditional recipes[7] of 1, butanol with 5% water, saturated with porphyrexide (~1.4%). The required ~1.5 mm diameter beads were then mass-produced, 250 cc at a time,[8] and loaded into 2.5 × 2.5 × 4.8 cm^3 (25 cc) mylar cups of ≲.4 mm wall thickness.[9]

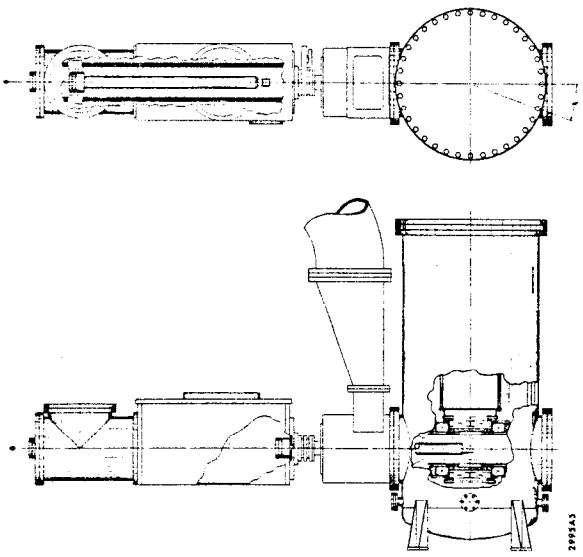

Fig. 5. Overall view of the target. The dewar is about 2 meters high. The insert is shown extracted in the plan view.

III. OPERATION

The target was polarized at 48.6 kG and 1.03^{o}K using fixed microwave frequency and changing the B field and NMR frequency to change sign. The peaks of maximum polarization were separated by ~175 gauss. Thermal relaxation times were typically ~30 minutes for an unirradiated sample.

Microwave power delivered to the sample was measured by observing the small pressure transients produced by turning the BWO power on and off, and calibrating to the effects of introducing heat by a wire wound resistor at the cup. We obtained 300 mW and 450 mW in the cavity for two different BWO tubes. The transient size also depended on whether or not the B field was set at a polarizing condition, giving us a direct measure of the power actually absorbed in the polarizing process. We obtain ~2 mW/cc, which agrees with the expected value calculated from $h\nu/T1$. The carbon resistor in the cup is very sensitive to microwave power level and to sample absorption and qualitatively confirms this result.

At this power level we had initial exponential polarizing times of 3 to 4 minutes for an unirradiated target. This degraded with successive irradiations of a target and also became nonexponential, resulting in times of 20 to 30 minutes to completely polarize a target.

Apparent polarization had to be corrected for non-butanol-associated hydrogen in the TE signal and for NMR nonlinearities. The first effect, about 10%, which arises mainly from the mylar cup, was measured by taking a TE on an empty cup. Using large samples of mylar, we also determined the T1 of this background as ~60 minutes, so there was no problem of dramatically different time constants in extracting the effect.

The nonlinearities were essentially determined by letting a fully polarized sample decay with the BWO off. The deviation from an exponential is large as expected, given the large fractional enhanced signals of .4 to .5, and is shown in Figure 6. With those corrections we obtained initial polarizations of +70% and -60% for an unirradiated target.

The beam of $\lesssim 10^{11}$ electrons/sec was scanned across an area about 20% larger than the 2.5×2.5 cm^2 face of the target cup on a pulse-to-pulse basis, with a full scan taking ~$2\frac{1}{2}$ seconds. With this uniform illumination, the polarization degraded exponentially with integrated beam dose of 4×10^{14} e$^-$/cm^2 for negative polarization and 1.5×10^{14} e$^-$/cm^2 for positive polarization.

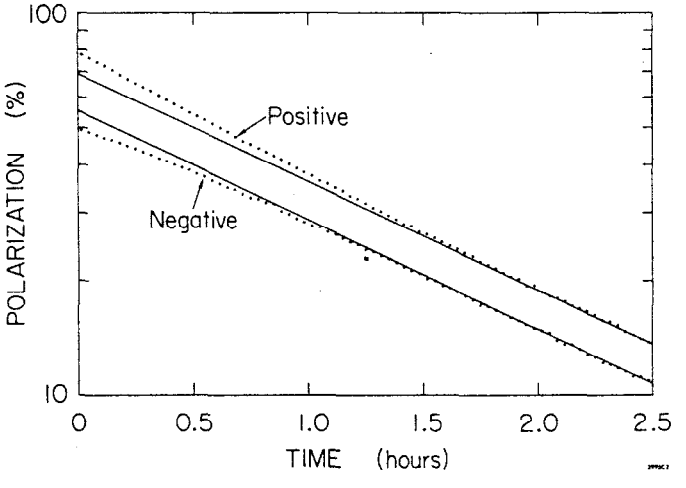

Fig. 6. Thermal relaxation curves for the two polarizations, showing the NMR nonlinearity at large polarization.

When the polarization had dropped to ~2/3 its initial value (2 - 3 hours of beam) we shut off to anneal. By withdrawing the target cup into the extractor box, thermal radiation would warm the material to the anneal temperature of ~130°K in about 6 minutes, after which the target was reinserted and 1°K operation reestablished by 5 minutes of precooling. The target was repolarized while the beam was retuned, giving a total downtime of ~45 minutes. After 7 or 8 such cycles of beam (~6×10^{14} e/cm^2), the target was replaced,

which, apart from the requirement of a TE, took 15 minutes.

In all, the average polarization over a run was a little more than 50% with a duty cycle for the target of about 70%.

This polarization of free protons is of course reduced by the presence of nonpolarizable protons and neutrons in the butanol molecule itself and in the liquid helium and windows of the target structure. These last two items were ~8% and ~12% of the target, so that the polarization was reduced by $.8 \times 10/74 \sim .11$. For reactions insensitive to neutrons (like elastic scattering or double arm experiments) of course this reduction is only half as bad.

The total liquid helium consumption rate came to 220 liters/day including transfer losses, etc., with better than 98% recovery.

IV. HINDSIGHT

Defining analyzing power as average polarization times the square root of continuous beam times target length $(.11 \times .55)(.70 \times .8 \times 10^{11}$ e/sec $\times 3.8$ cm$)^{1/2}$, this target may be the heavyweight champion, and we are quite pleased with it. However, were we to do it again, some important changes would be made. I will list them in the context of building a hypothetical superheavyweight.

A. Separate the cryostat from the magnet dewar. The coupling made independent testing of the cryostat impossible and, more importantly, the passage of liquid helium through tubes, joints, and valves in the high vacuum region created many problems with leaks.

B. Make the wave guide easily removable. This target is power-starved and several tests show that twice the microwave power would have given us dramatic improvements in polarizing time and depolarizing dose. With the BWO at maximum output, we still had to husband our power and we were restrained from further tests with wave guide and cavity designs that might improve matters because the guide was permanently built into the cryostat.

C. The NMR electronics should be as simple and standardized as possible - one should go to a constant current system with commercial sweeps and amplifiers.

D. Reduce background from windows still more.

E. Simplify the cryostat using only 1 reservoir and placing the precool valve within the cryostat.

F. Mount the cryostat vertically to allow the rotations of magnetic field that turn out to be of substantial importance to the experiment.

G. Experiment with other materials which may have higher radiation resistance. In particular, one ought to try iso-butanol and sec-butanol which, in terms of beam required to produce color centers, are 5 to 10 times less sensitive than n-butanol. (Tert-butanol is 100 times less sensitive, but does not have the usual vitrification properties and might have other problems.[10])

REFERENCES

1. A brief description of the early results from the project may be found in W. Ash, Proc. BNL Workshop on Physics with Polarized Targets, 3-8 June 1974, BNL 20415 (1975), p. 309.
2. The supply (Model ISR2182) with transductor was manufactured to specification by TRANSREX, Gulton Industries, Torrance, California.
3. The tube, type CO20B, is from Thompson-CSF. Components for the lock system and other instrumentation are from Varian, TRG, Baytron, and Control Data.
4. Descriptions of the power supply, soft lock, and guide measurements are contained in various Yale reports by S. Dhawan, A. Etkin, R. Fong-Tom, and P. Yen.
5. This new device, Lake Shore Cryotronics CGR-1-250, has negligible magnetic field sensitivity and survived the high radiation environment of our experiment. It is a preferred alternative to germanium resistance precision thermometry.
6. MKS Instruments, Burlington, Massachusetts.
7. M. Borghini et al., Nucl. Instrum. Methods 84, 168 (1970).
8. W. W. Ash, Nucl. Instrum. Methods 134, 9 (1976).
9. These cups had to contain liquid helium as well as beads and withstand the radiation. We thermoformed these of a newly developed Mylar-TF 1500 film kindly supplied us by A. J. Seckner, Jr., Du Pont, Wilmington, Delaware.
10. R. S. Alger et al., "Irradiation Effects in Simple Organic Solids," J. Chem. Phys. 30, 695 (1959).