Transverse Target Activities

Chris Keith

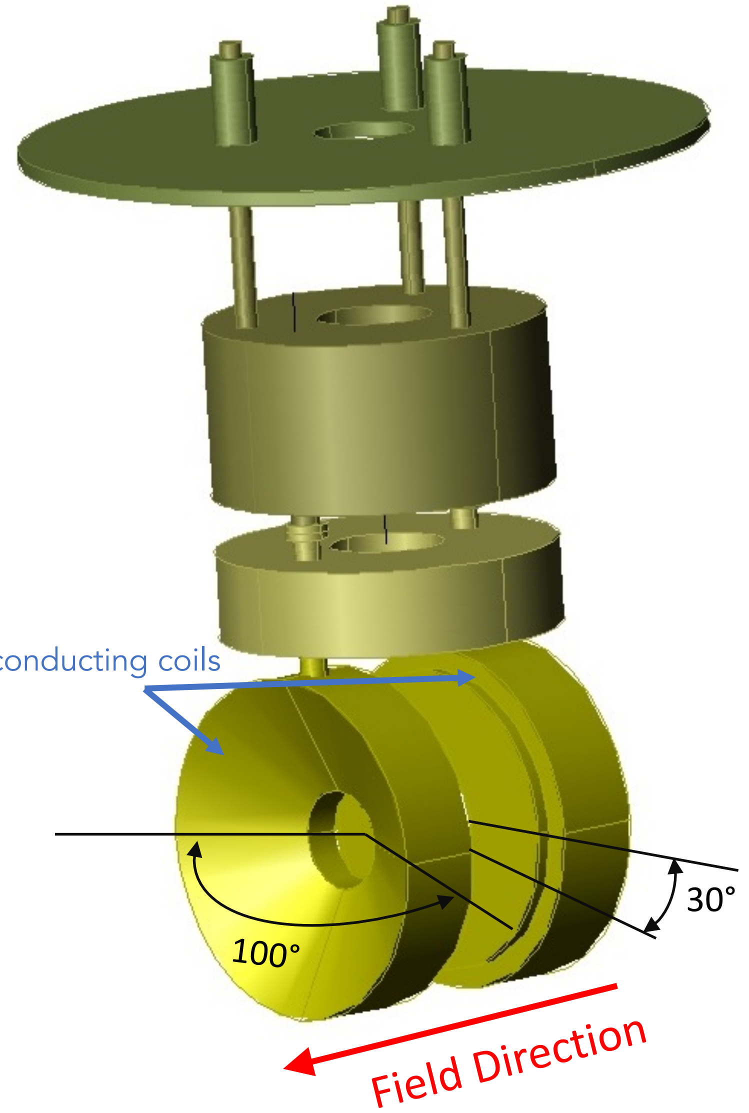
Jefferson Lab Target Group

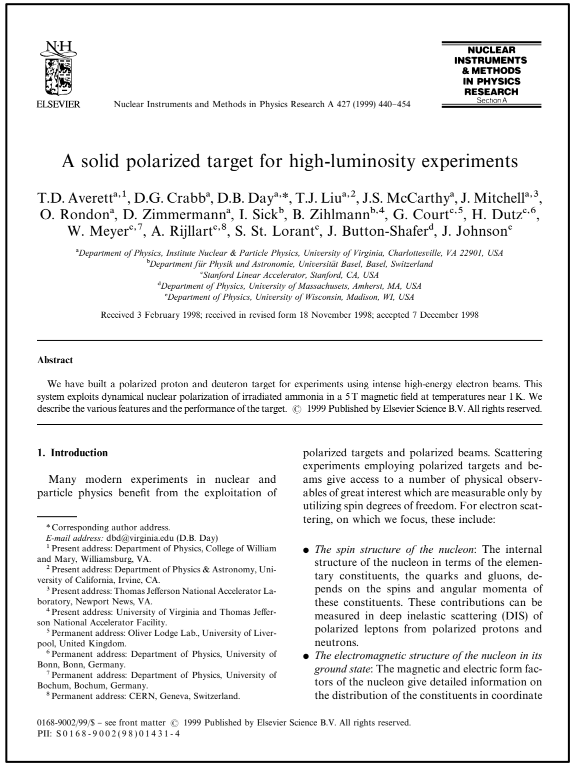
First, some history

The original polarized target at JLab (the “UVa Target”) was solid ammonia, polarized at 1K and 5T

The Helmholtz geometry of the superconducting split-coil magnet gave acceptances:
±50° for longitudinal polarization
±15° for transverse polarization

The magnet was damaged following multiple quenches and is no longer operational





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A solid polarized target for high-luminosity experiments

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Abstract

We have built a polarized proton and deuteron target for experiments using intense high-energy electron beams. This system exploits dynamical nuclear polarization of irradiated ammonia in a 5 T magnetic field at temperatures near 1 K. We describe the various features and the performance of the target. © 1999 Published by Elsevier Science B.V. All rights reserved.

1. Introduction

Many modern experiments in nuclear and particle physics benefit from the exploitation of polarized targets and polarized beams. Scattering experiments employing polarized targets and beams give access to a number of physical observables of great interest which are measurable only by utilizing spin degrees of freedom. For electron scattering, on which we focus, these include:

- *The spin structure of the nucleon*: The internal structure of the nucleon in terms of the elementary constituents, the quarks and gluons, depends on the spins and angular momenta of these constituents. These contributions can be measured in deep inelastic scattering (DIS) of polarized leptons from polarized protons and neutrons.
- *The electromagnetic structure of the nucleon in its ground state*: The magnetic and electric form factors of the nucleon give detailed information on the distribution of the constituents in coordinate

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First, some history

For the g2p and GEp experiments in Hall A, the magnet was hastily replaced with a similar magnet from a polarized target in Hall B

Fig. 2. Hall B polarized target magnet suspended from the Hall C polarized target cryostat, after covering with super-insulation.

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Dynamically polarized target for the g_2^p and G_E^p experiments at Jefferson Lab

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ABSTRACT

We describe a dynamically polarized target that has been utilized for two electron scattering experiments in Hall A at Jefferson Lab. The primary components of the target are a new, high cooling power ^4He evaporation refrigerator, and a re-purposed, superconducting split-coil magnet. It has been used to polarize protons in irradiated NH_3 at a temperature of 1 K and at fields of 2.5 and 5.0 T. The performance of the target material in the electron beam under these conditions will be discussed. Maximum polarizations of 28% and 95% were obtained at those fields, respectively. To satisfy the requirements of both experiments, the magnet had to be routinely rotated between angles of 0°, 6°, and 90° with respect to the incident electron beam. This was accomplished using a new rotating vacuum seal which permits rotations to be performed in only a few minutes.

1. Introduction

Dynamically polarized solid targets play an integral role in the physics program at Jefferson Lab. To date, they have been utilized on several occasions in experimental Halls B and C to examine the spin structure and the electromagnetic structure of both the proton and the neutron, as well as the excited states of the proton. The targets operated in those halls have been described in separate articles [1–3], while the target described here marks the first use of a solid polarized target in experimental Hall A. It mainly consists of components used previously in Halls B and C, heavily modified to satisfy the requirements of the Hall A experiments. In addition, new components have been fabricated for improved performance, reliability, and safety.

2. Experimental overview

Two separate experiments requiring a dynamically polarized proton target were approved for operation in Hall A at Jefferson Lab. The first of these experiments, referred to as "g_2^p," aimed to measure the proton's transverse spin structure function g_2^p at momentum-transfer squared values as low as $Q^2 \lesssim 0.02$ GeV/c² [4]. The second experiment, herein referred to as "G_E^p," measured the proton elastic form factor ratio $\mu G_E/G_M$ in the range $Q^2 = 0.01$–0.7 GeV/c² [5]. Both experiments examined the scattering of spin polarized electrons from spin polarized protons at very forward angles. To extend the measurements to the lowest Q^2 values, a normally conducting septum magnet was located between the polarized target and the two Hall A spectrometers to bend the most forward-going scattered electrons into the spectrometers. Both experiments proposed to use the polarized target system that had been utilized in Hall C on three previous occasions as well as at SLAC and is described by Averett et al. [1]. This system features a high cooling power ^4He evaporation refrigerator, a target insert accommodating multiple target samples, and a 5 T superconducting split-coil magnet[3] specifically designed for scattering experiments with a wide range of field directions.

Because of their similar electron-beam energy requirements and because they shared much of the same equipment, the two experiments ran concurrently. However, they required different values for directions of the proton polarization (and therefore the target's magnetic field). For the g_2^p experiment, this direction was 90° with respect to the incident electron beam, while for G_E^p it was 6°. Additional measurements were made at 0° to measure g_1^p for

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The Hall B magnet is slightly smaller, but gives the same acceptances:
±50° for longitudinal polarization
±15° for transverse polarization

First, some history

At the same time, the Target Group designed and built new inserts for the frozen ammonia samples, a new 1K evaporation refrigerator, and new vertical and rotational motion mechanisms for the target.

The target performance was quite good during these experiments.

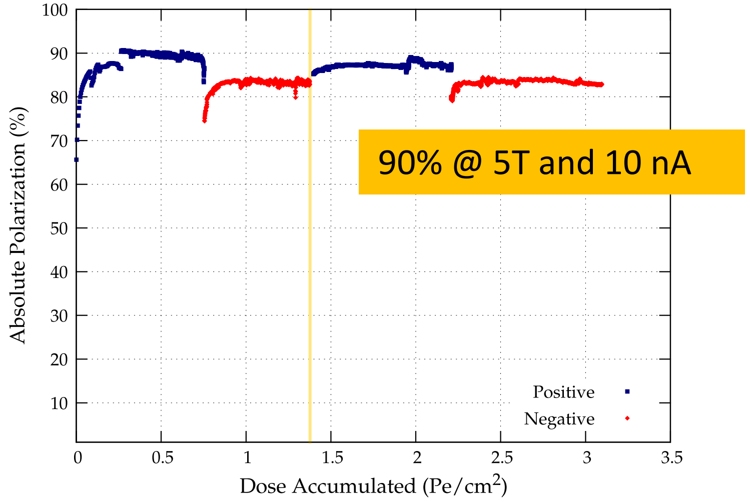
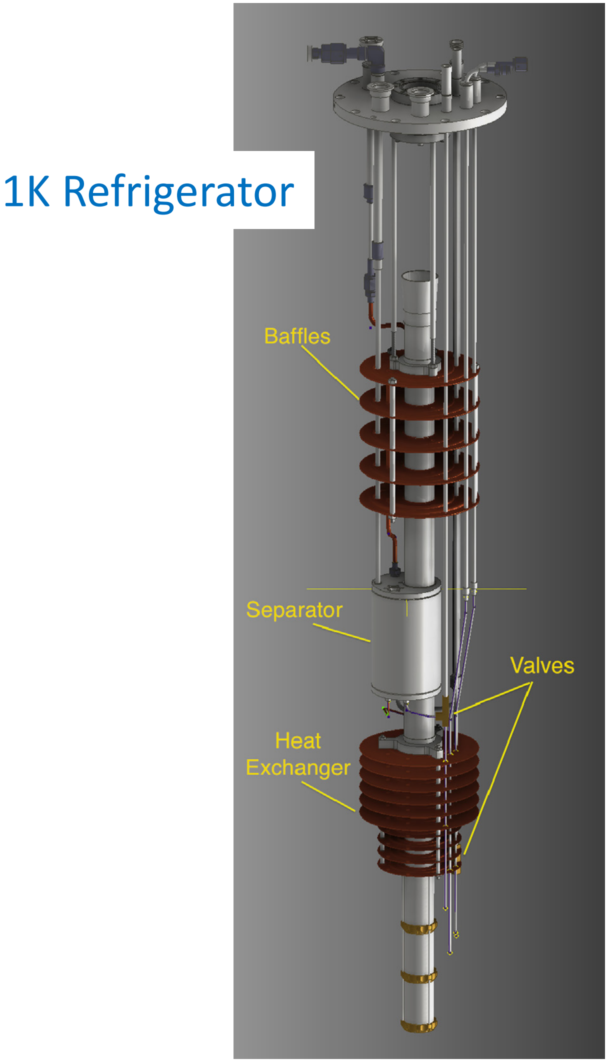


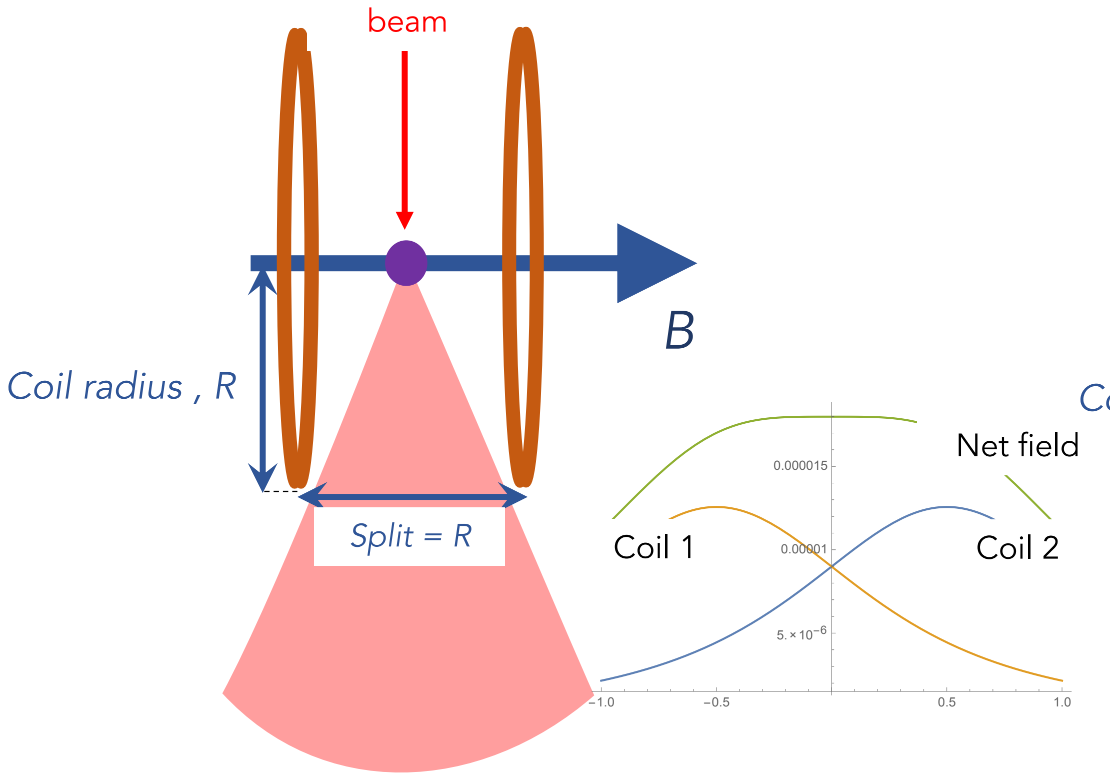
Fig. 8. Polarization vs. dose for the material which accounted for over half the total dose accumulated during G_E^p, taken with a 5 T magnet field and a 10 nA beam current. The vertical line represents removal and storage at 77 K.

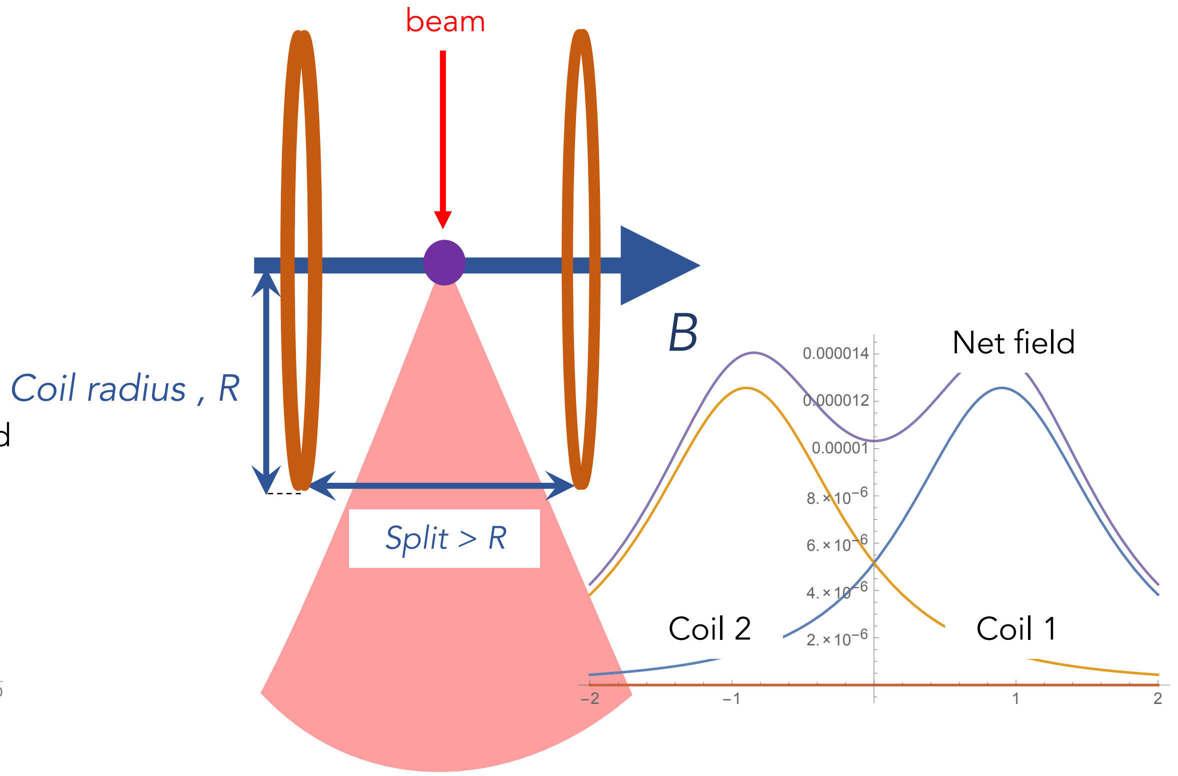


A magnet for transverse experiments

In 2019, at the request of the CPS collaboration, I began investigating a polarized target magnet that gave better acceptance in the transverse orientation (field ⊥ to beam).

This requires increasing the gap between the two coil packages.
However, doing so ruins the high uniformity required for dynamic polarization (~100 ppm).
The magnet has to be shimmed to improve the uniformity.





A magnet for transverse experiments

In 2020, bids went out for a new superconducting magnet with better geometry for transverse experiments.

The contract was awarded to Scientific Magnetics

Jefferson Lab
Thomas Jefferson National Accelerator Facility
Exploring the Nature of Matter

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Group Leader, Cryogenic and Polarized Targets
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Split coil magnet for transversely polarized target at JLab

Summary of Preliminary Specifications

Central field: ≥ 5.0 T in the horizontal plane

Uniformity: ≤ 100 ppm over a cylindrical volume ∅25 × 30 mm^2
(cylinder axis is horizontal & perpendicular to field)

Field stability: ≤ 100 ppm per hour

Access dimensions: Vertical: ≥ 10 cm dia.
Para. to field: n.a.
Perp. to field[1]: ≥ 50° aperture angle (60° preferred)

Coolant: 4.2 K LHe with or without recondenser, or cryogen free

[1] The magnet structure shall not occlude particles scattered from the center of the field into a right circular cone with 50° aperture angle, oriented in the horizontal plane and at a right angle to the magnetic field.

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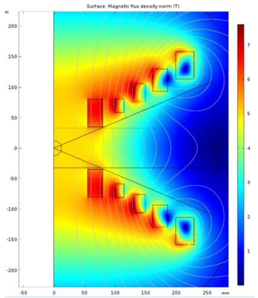
SCIENTIFIC MAGNETICS

RFP No. JSA-20-R395667
Technical & Commercial Proposal: Jefferson Laboratory

5T split pair magnet for Dynamic Nuclear Polarization



Scientific Magnetics is a trading name of Space Cryomagnetics Ltd. Registered in England and Wales. Company No. 3950388.
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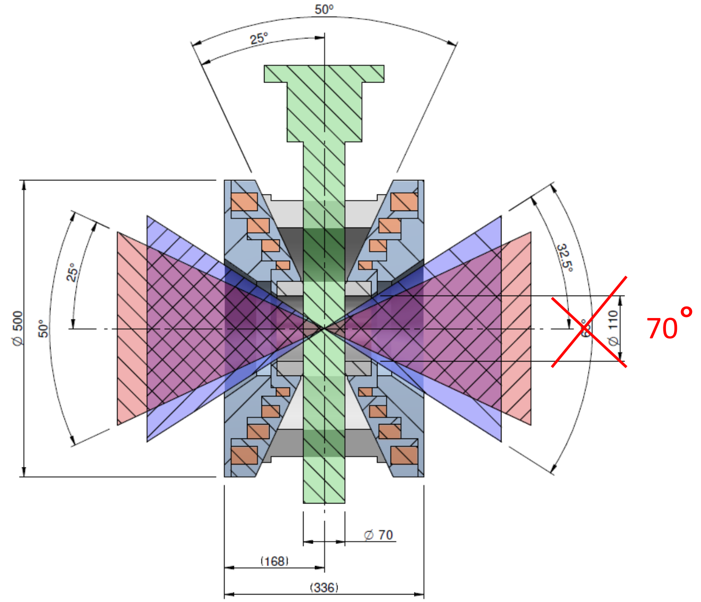
Commercial in Confidence

The new magnet will provide acceptances:
±35° for longitudinal polarization (30% smaller)
±25° for transverse polarization (67% larger)



Cross-section through the magnet showing the beam and cold finger access diameters (in mm) and

A magnet for transverse experiments

The coils will be shimmed using iron (SAE 1020)

- Cost saving
- Higher coil margin (SSP)
- Uniformity guaranteed only at 5.0 T

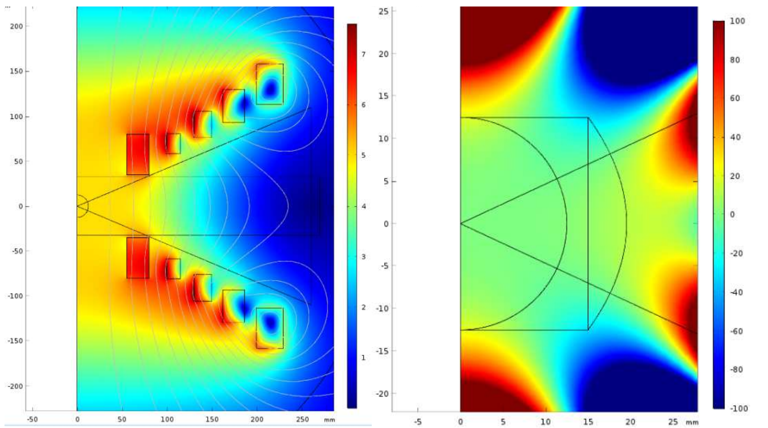


Figure 1: 2D axis-symmetric model of the field profile. Left image shows the peak fields on the coils reaching 7.6T. Right image is homogeneity plotted on a scale from -100ppm to 100ppm.

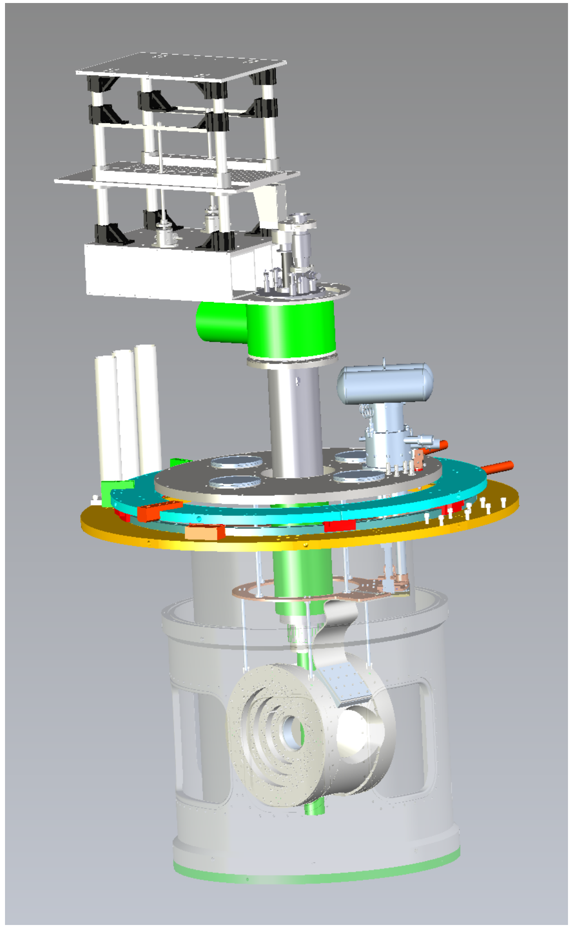
The superconductor for this magnet is calculated to operate at a short sample percentage of ≤60% with a temperature margin of >0.6 K (assuming the coils operate at 4.2K). Often in cryogen free

The coils will be cooled ≤ 4K by a pulse-tube cryocooler

- Higher acceptance
- High reliability
- Autonomy from ESR and LHe in general
- Slower cooling (3 days from R.T., 8 h from quench)

A magnet for transverse experiments

The magnet package is designed to satisfy two philosophies



1. A drop-in replacement for the existing g2p/GEP target system
   - Existing 1 K refrigerator
   - Existing ammonia sample inserts
   - Existing vacuum chamber
   - Existing rotational and vertical motion mechanisms
   - Existing support structure

A magnet for transverse experiments

The magnet package is designed to satisfy two philosophies

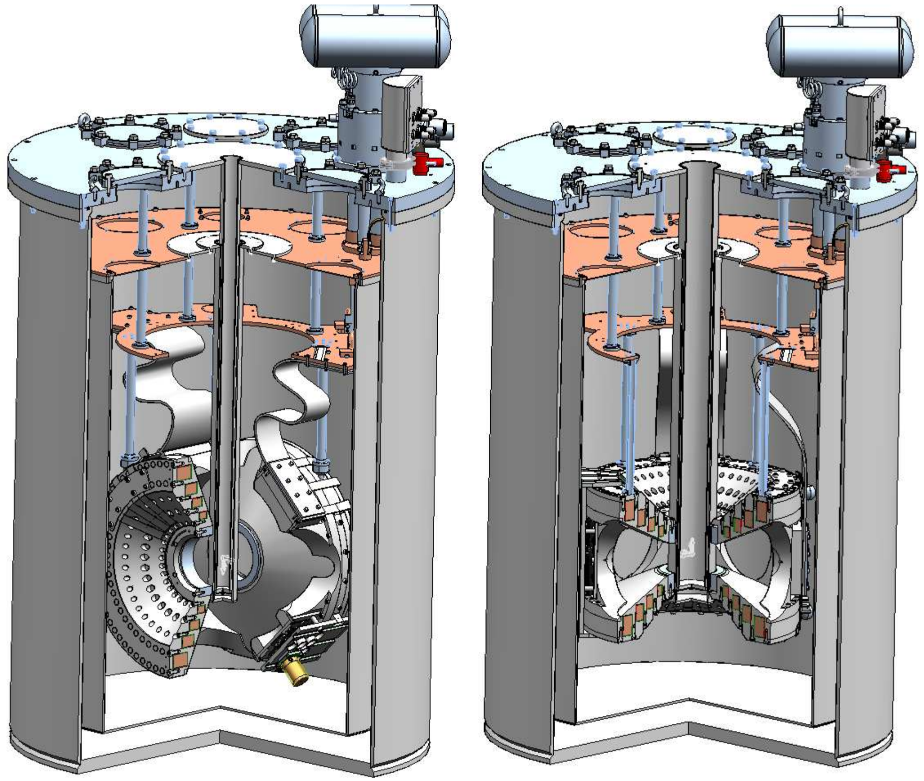


Figure 7: Cut-away of the 2 orientations for the magnet.

2. Highly configurable for other uses and future upgrades
   - 2nd pulse tube for faster cooling
   - Replaceable supports for greater strength
   - Horizontal or vertical field orientation
   - Cryogen-free 1 K refrigerator

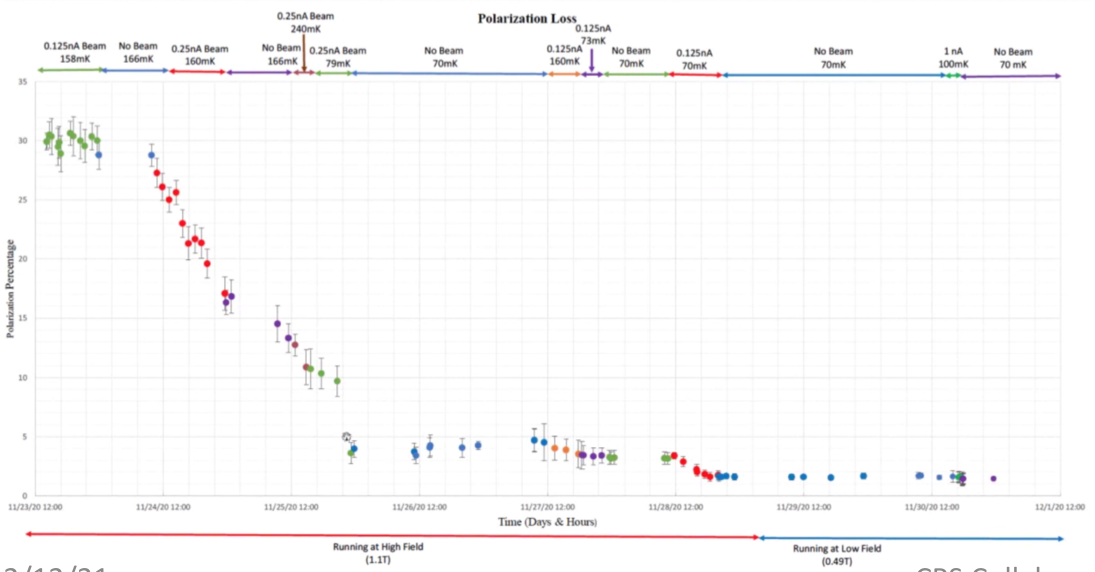
Anticipated delivery date is Aug. 2021

A magnet for transverse experiments

One potential use of the magnet (besides CPS) is in Hall B, for Run Group H

C12-11-111: *Transverse spin effects in SIDIS at 11 GeV with a transversely polarized target using CLAS12*
C12-12-009: *Measurement of transversity with dihadron production in SIDIS with transversely polarized target*
C12-12-010: *Deeply Virtual Compton Scattering at 11 GeV with transversely polarized target using CLAS12*

- All rated ‘A’
- All “High Impact”
- All conditionally approved upon demonstration of HDice target with electrons (1-2 nA)



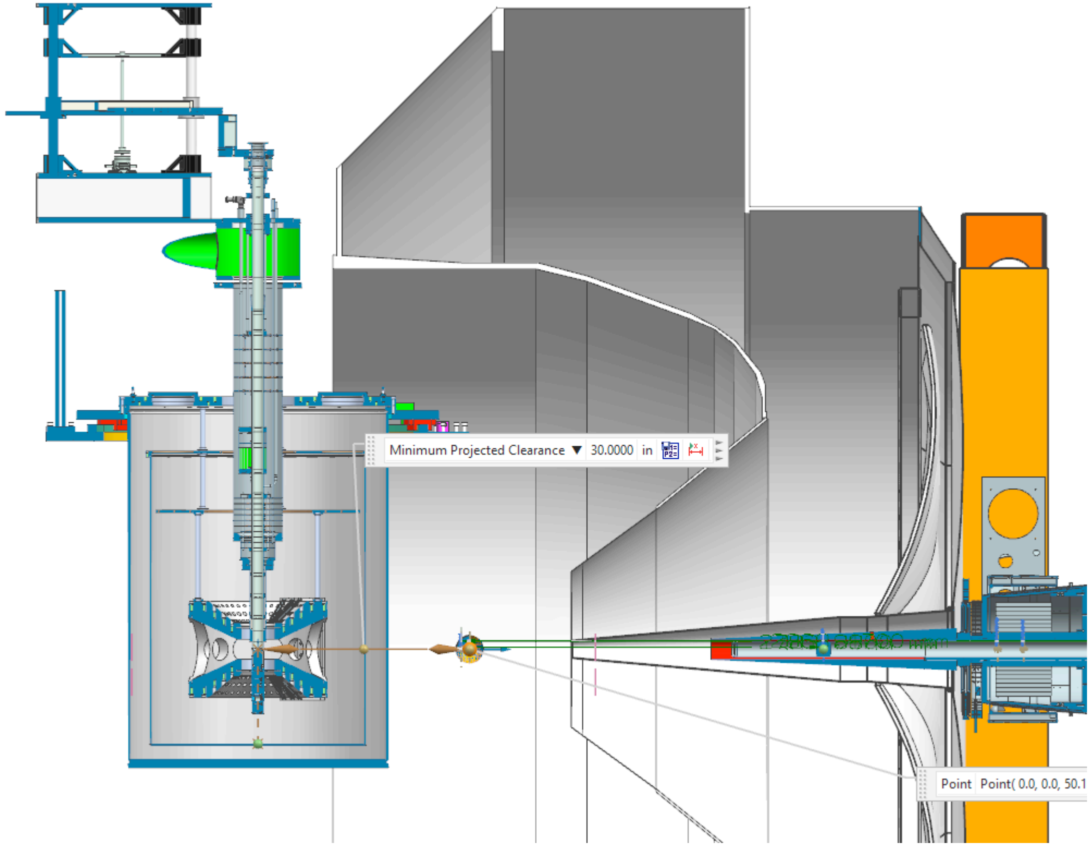
Unfortunately, recent HDice tests at the UITF indicate that it isn’t yet compatible with electron beams (short lifetime).

Plan B target

One potential use of the magnet (besides CPS) is in Hall B, for Run Group H

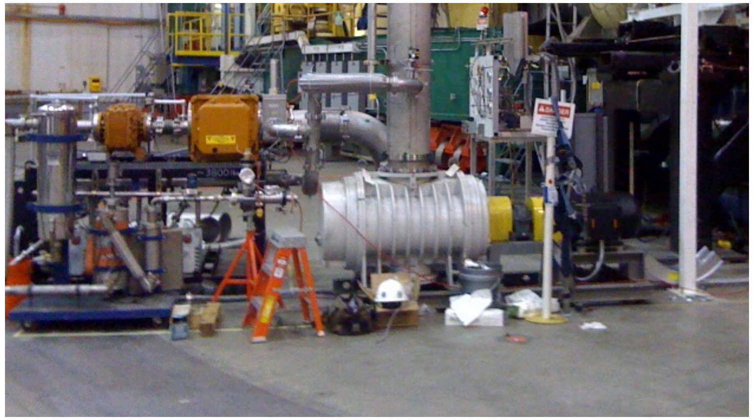
Various "Plan B" scenarios using dynamically polarized ammonia were considered.

The most promising is a 5T/1K target located in place of the CLAS12 central detector.

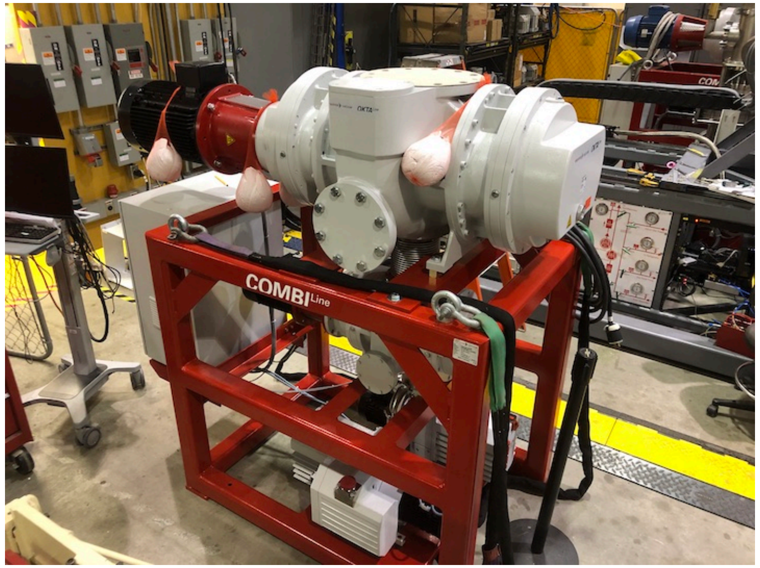


Other bits and pieces

The high-speed roots pumping system for the UVa target is 40+ years old.



These will be replaced by a new (2020) system.
(Two sets on hand)

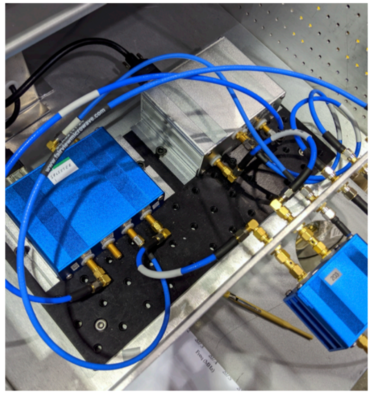


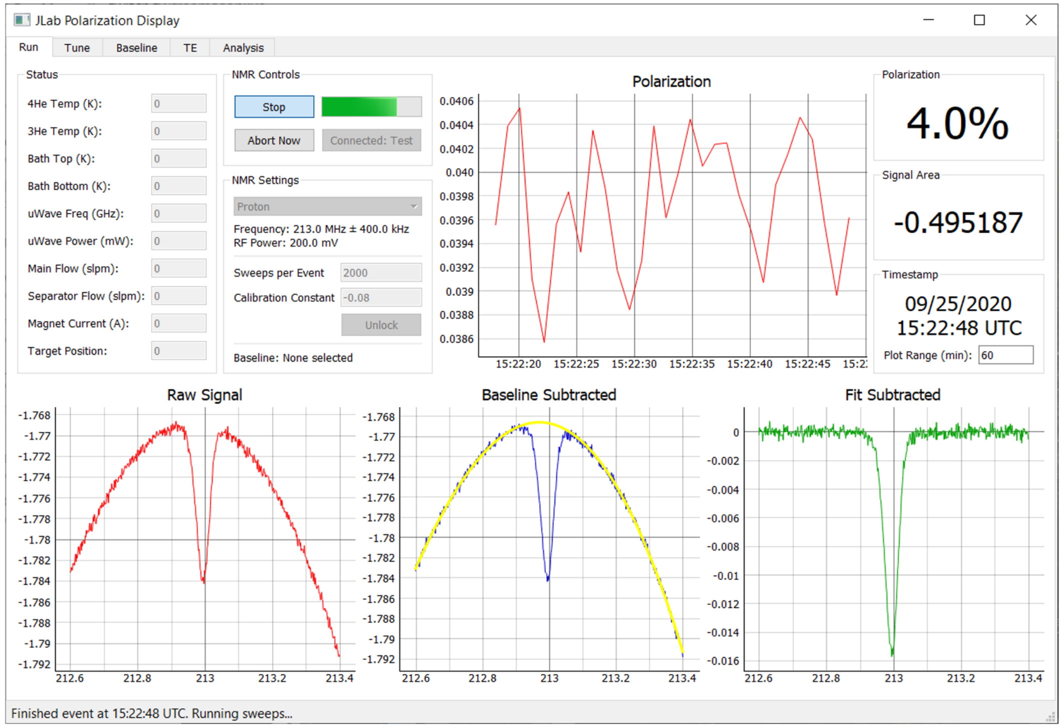
Other bits and pieces

Collaboration between JLab Target Group and Fast Electronics Group is developing a new NMR Q-meter system.

Replacement for the 40+ year old Liverpool Q-meter

- Modular: easy to modify and upgrade
- Modern components
- FPGA controller
- Python-based software
- Remote control





Summary

A target system optimized for transverse polarization is being developed

System is a mixture of existing and new equipment

- New, wide-split superconducting magnet
- New pumps
- New NMR
- Existing vacuum chamber
- Existing 1 K ‘fridge
- Existing microwaves

System will be modular and flexible for use in numerous halls and experiments

- CPS
- Run Group C
- SoLID
- Tensor b1 and Azz experiments