Polarized Transverse Target

For Hall A & C

Chris Keith, JLab Target Group

Jefferson Lab
Target Group

Outline

The High Luminosity Polarized Target

- Description
- Some History
- Current status

A transverse magnet with wide acceptance

- Basic Ideas
- Some examples

Summary & Recommendations

Target Description

The target was designed and built by Oxford Instruments for electron scattering experiments at SLAC and JLab with luminosities up to 10^{35} (g cm^{-2} s^{-1})

The core components are a 5 Telsa superconducting magnet and a 1 K ^{4}He evaporation refrigerator

The target has a history of very high performance, but less-than-perfect reliability.

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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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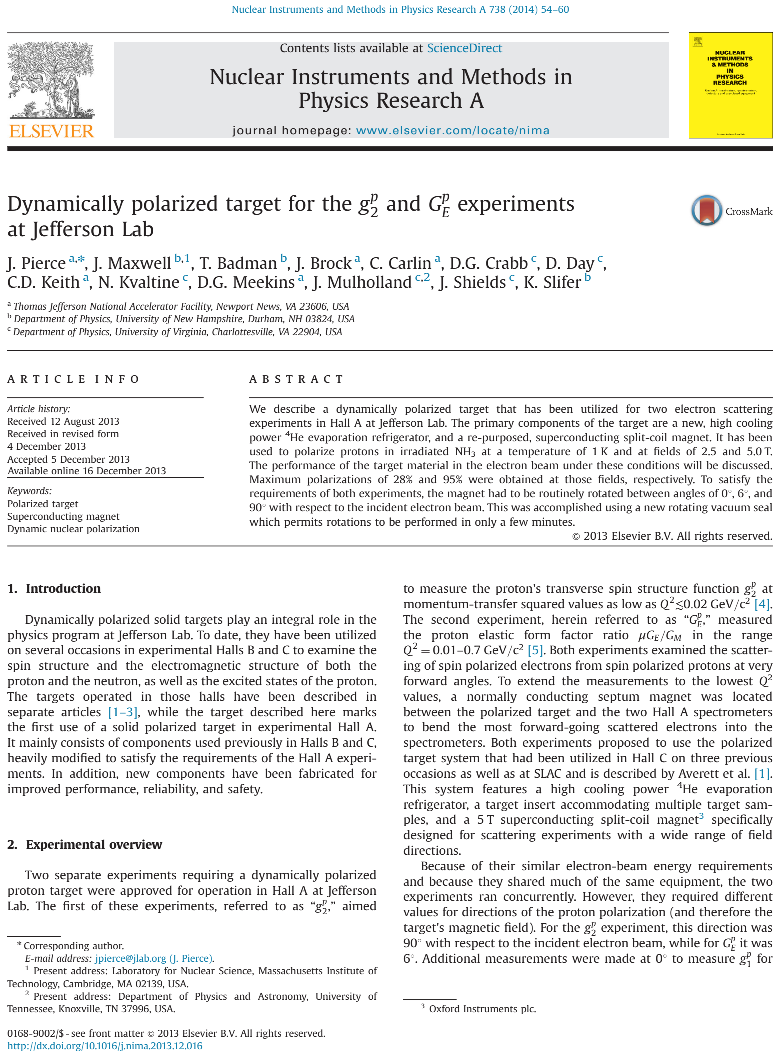
Target Description

Its last use was in Hall A (2012) for the $g^p{}_2$ and $G^p{}_E$ experiments

The target received a *substantial* overhaul in preparation for these experiments

- new target inserts
- new vertical motion for targets samples
- new rotation mechanism for magnet
- new 1 K refrigerator
- "new" 5 Tesla magnet



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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.

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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 $Q^2 \lesssim 0.02\ \mathrm{GeV}/c^2$ [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 $Q^2 = 0.01$–$0.7\ \mathrm{GeV}/c^2$ [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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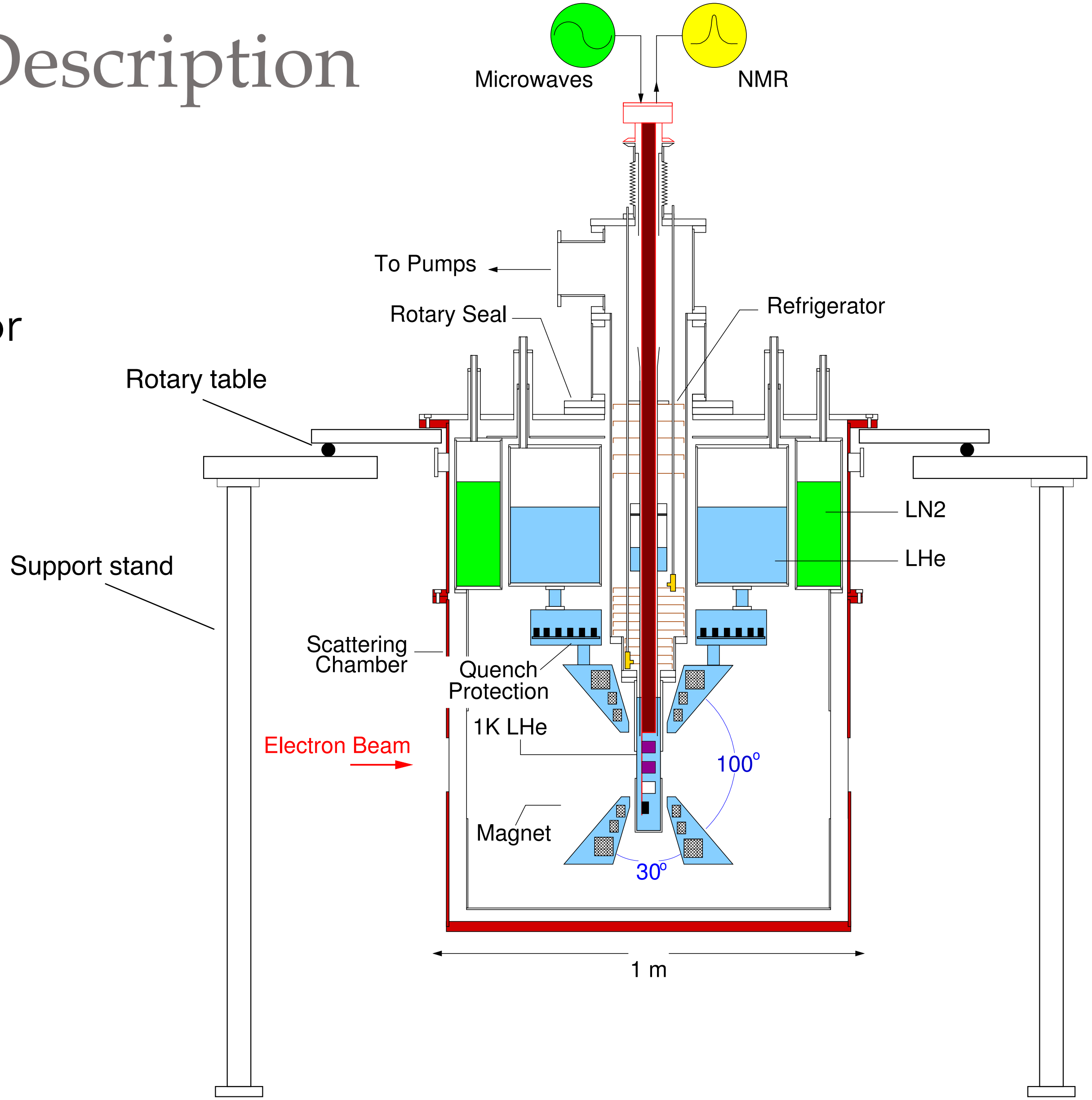
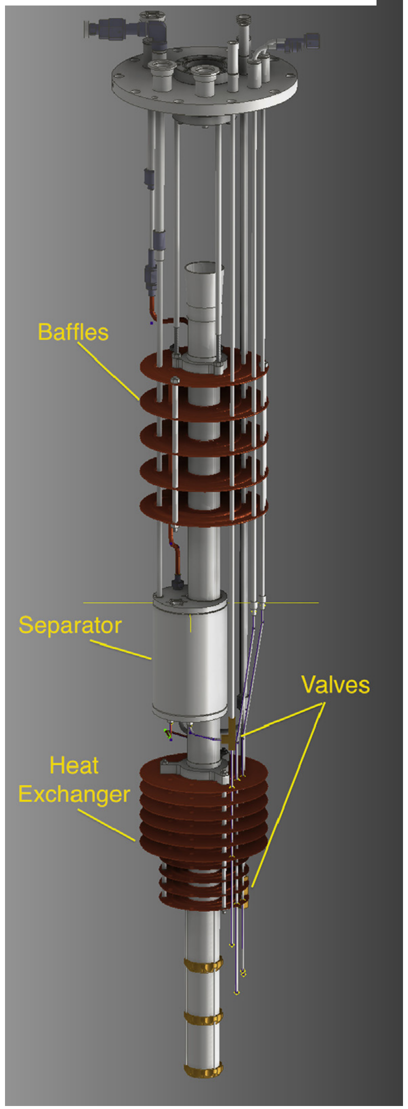
Target Description

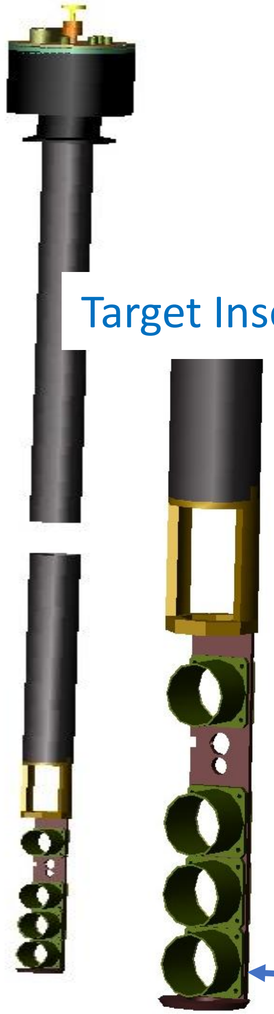
This cartoon shows the target prior to the installation in Hall A, with *the original 5 T magnet.*

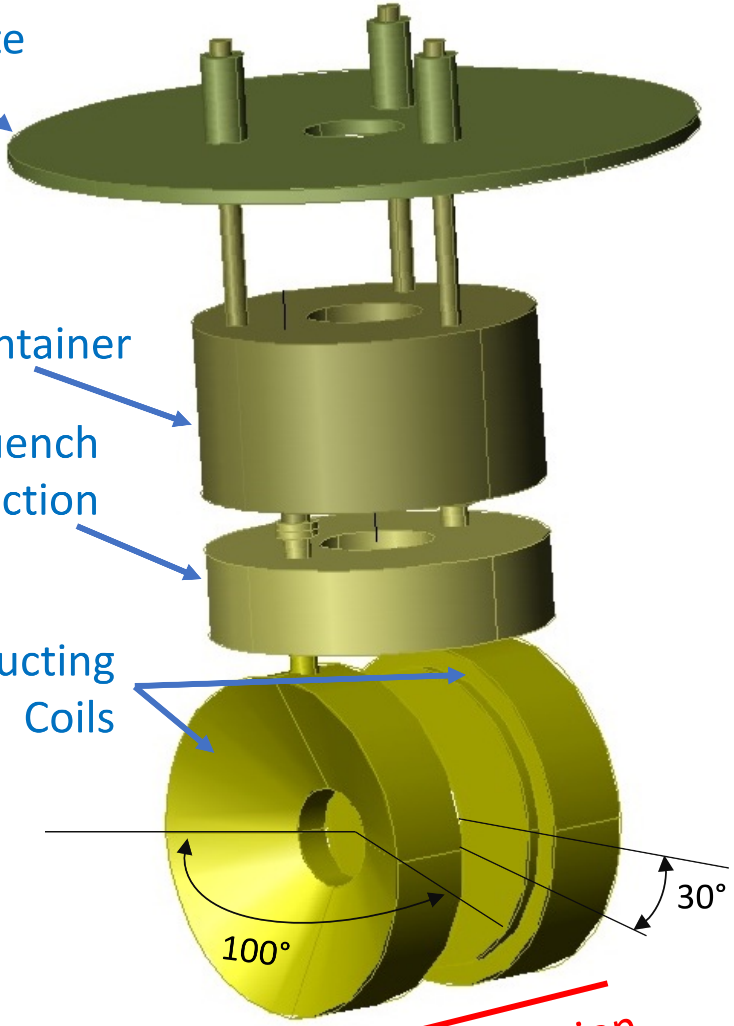


Target Description

1K Refrigerator







Some history

The original 5 Tesla magnet exploded in 1998 as a result of catastrophic loss of vacuum during *Gen98*.

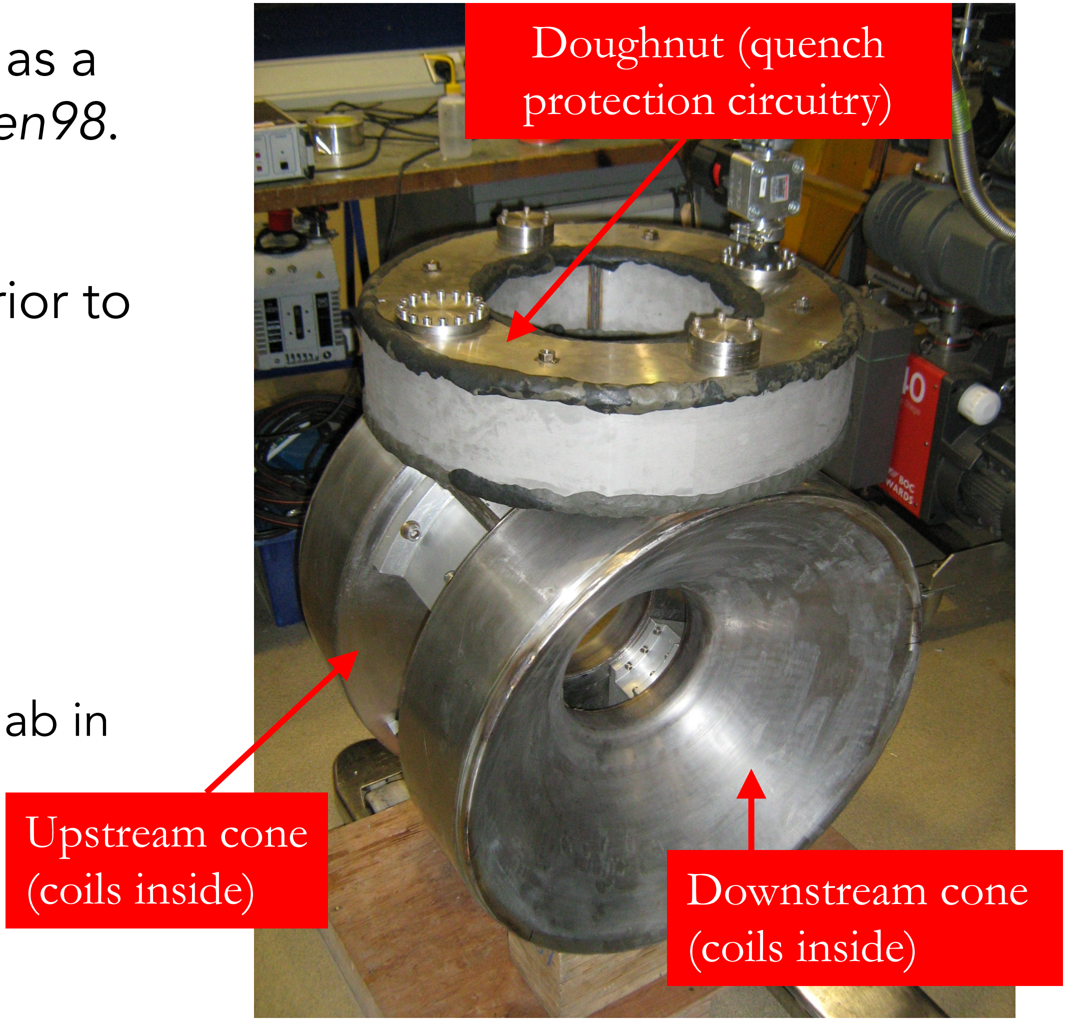
- Repaired at JLab

Magnet quenched and was damaged again prior to and during *SANE*.

- More repairs at JLab.
- Magnet operated erratically during *SANE*, quenching more than a dozen times.

Returned to Oxford for refurbishment in 2009.

- Quenched again (4 T) during final tests at Jlab in preparation for g^p_2 and G^p_E.



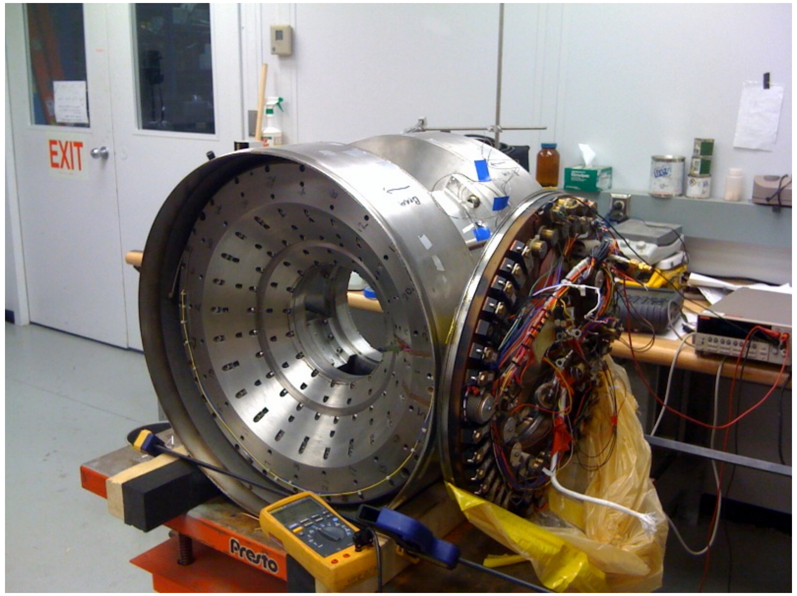
Some history

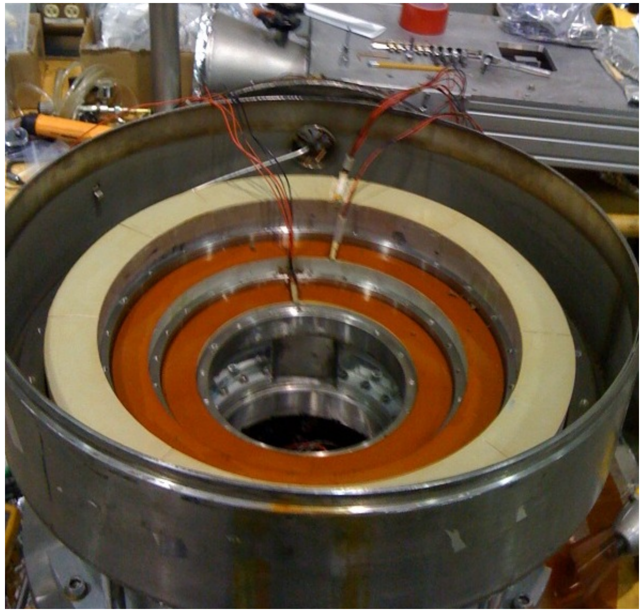
Initial hopes were that wiring was damaged inside the quench protection doughnut.

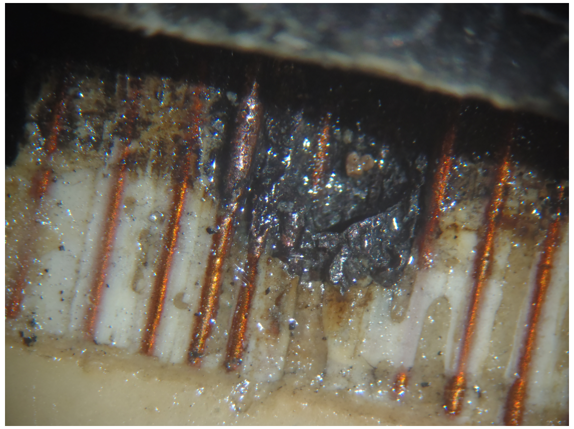
This was the case following the 1998 quench.

It was also true this time, but further damage was found inside the coils themselves.

I did not think we could repair it in time to save g^p_2 and G^p_E - so we went to Plan B.







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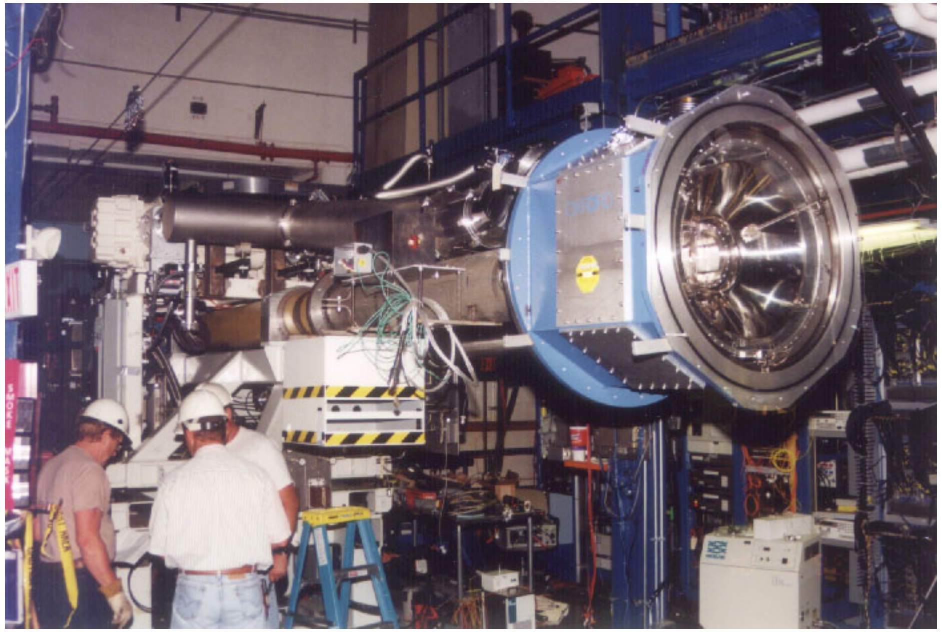
Target Group

Some history

Plan B

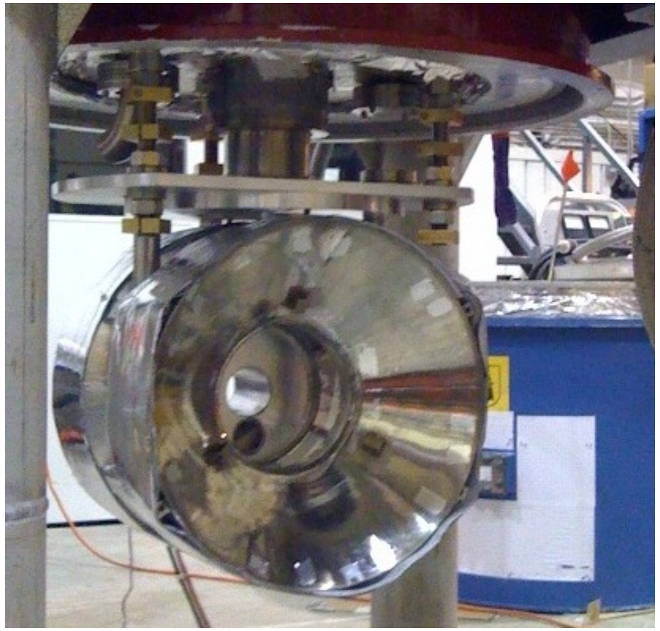
Replace the broken magnet with a (somewhat) similar magnet from the Hall B polarized target.

The physics program using this target was completed, so management approved the decision.



Hall B Polarized Target

Magnet in the target lab.
Ready for removal.



Magnet in its new home.

Perfomance

Very good performance during g2p & Gep (J. Pierce *et al*, NIM A 738 (2014) 54)

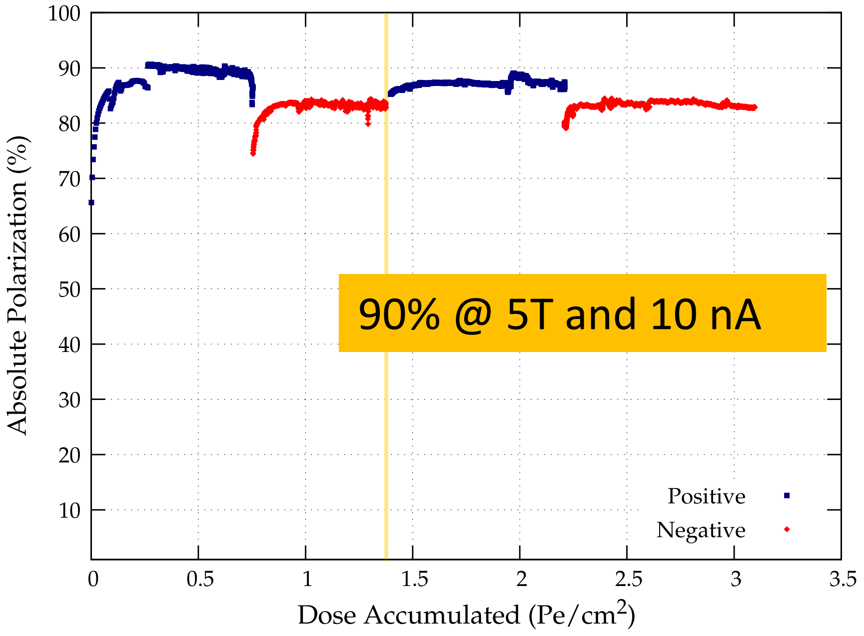


Fig. 8. Polarization vs. dose for the material which accounted for over half the total dose accumulated during G_E^p, taken with a 5 T magnet field and a 10 nA beam current. The vertical line represents removal and storage at 77 K.

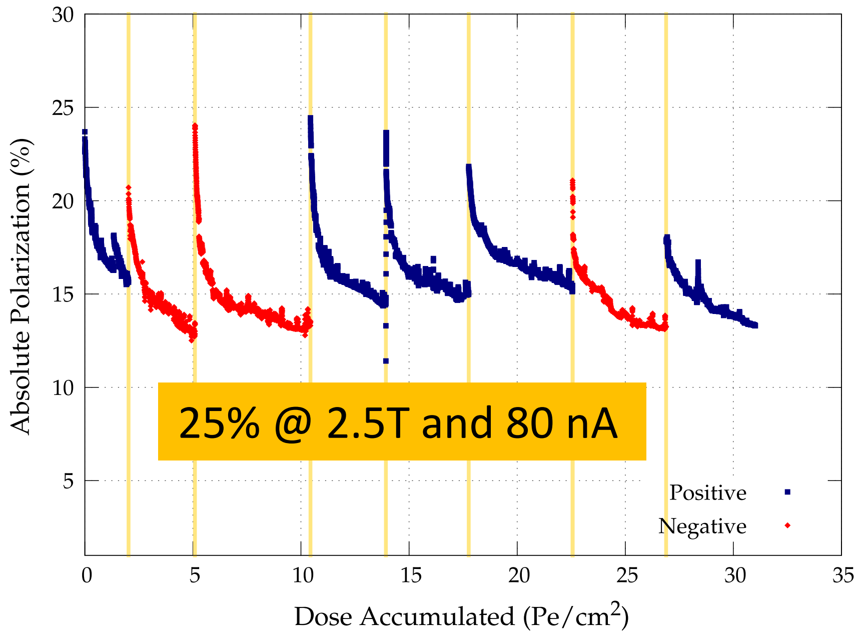


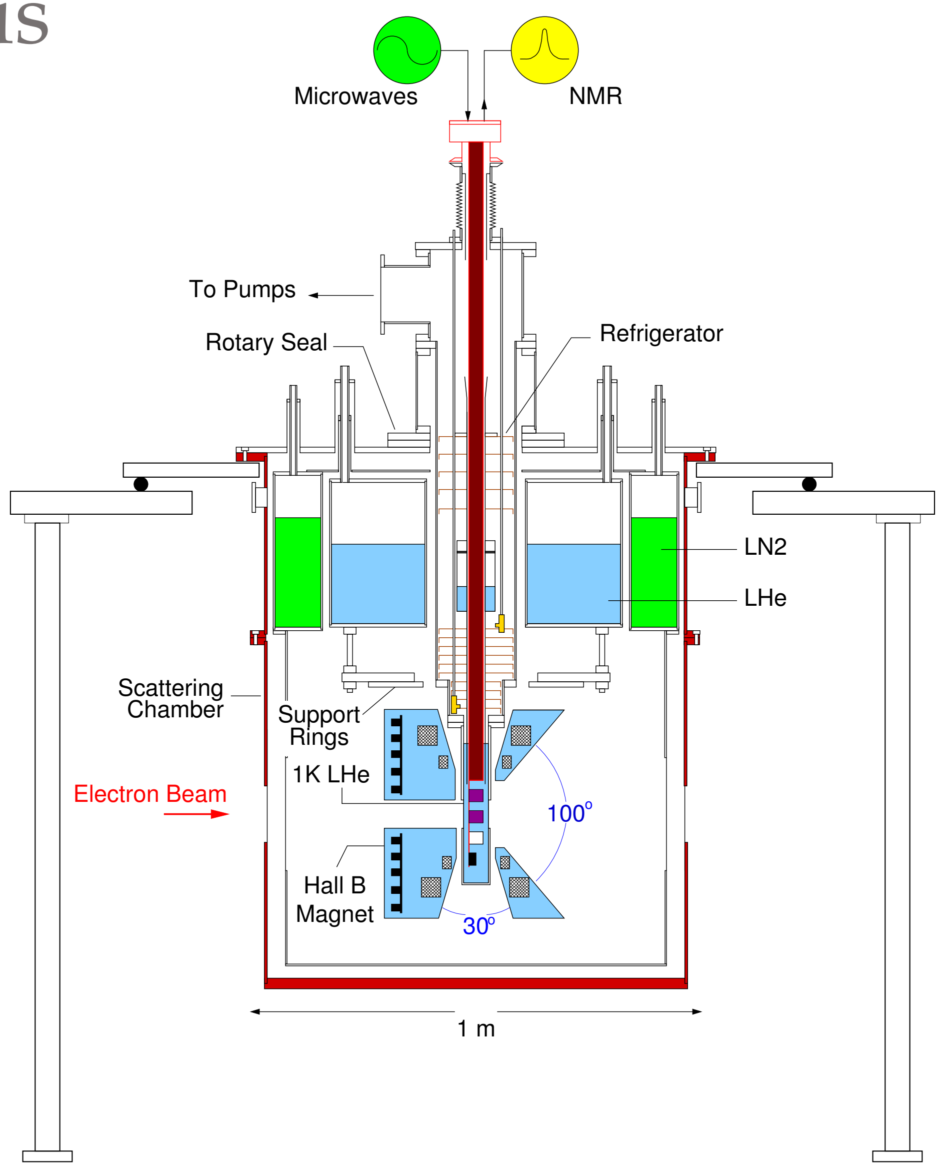
Fig. 9. Polarization vs. dose for the material which accounted for a third of the total dose accumulated during the g_2^p 2.5 T magnet field running, under a 80 nA beam current. Vertical lines represent anneals.

Current status

This is the system with the Hall B replacement magnet.

<u>Two magnets are not identical.</u>

- Hall B magnet is slightly smaller (might affect deuteron polarization)
- Conical opening on downstream side only
- Quench protection is located on the upstream side of the magnet, rather than on top
- Upstream bore is a lot smaller



Jefferson Lab Target Group

Future Magnet Designs

Our goal is to replace the current Hall B coils with two separate magnets

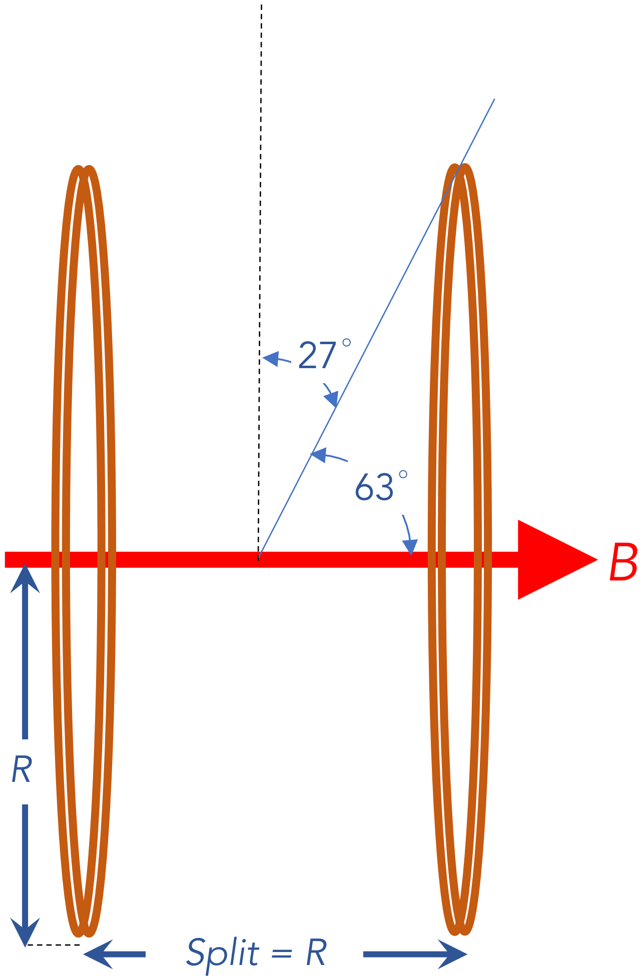
1. A general purpose magnet (original Hall C?) intended mostly at longitudinal polarization $\alpha = \pm 50°$ and $\beta = \pm 15°$
2. A dedicated magnet for transverse polarization with an opening angle $\beta \geq \pm 25°\text{-}30°$

The field for both magnets should be ≥ 5 Tesla, with a uniformity $\Delta B/B \sim 100$ ppm over a region ⌀2 cm x 3 cm (the current target size)

Design both for use with the existing target infrastructure

→ *Make them interchangeable!*

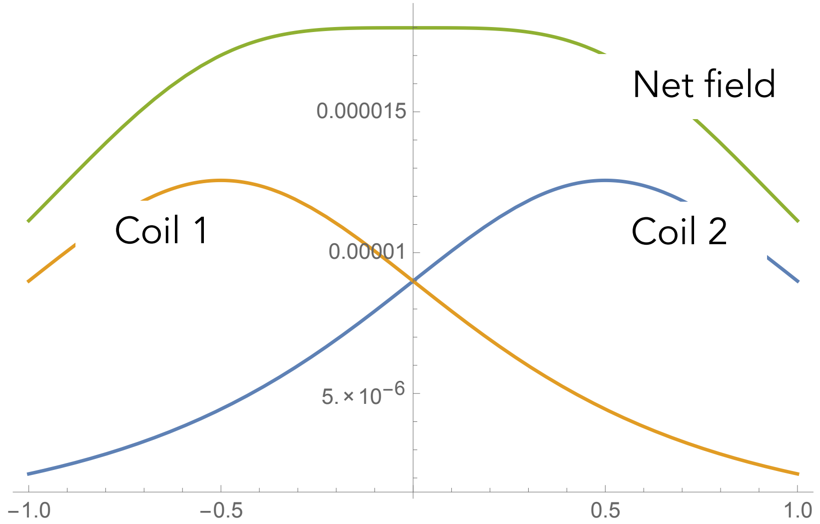
Future Magnet Designs



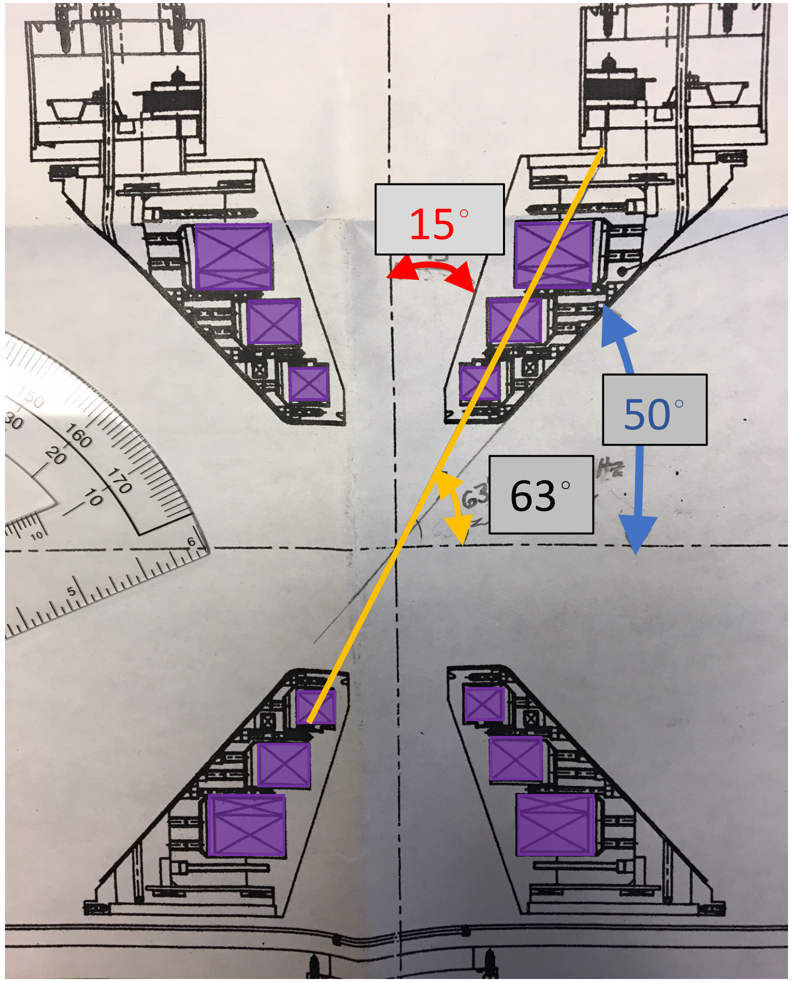
The Helmholtz configuration of split-coil magnets (*Split = coil radius*) provides a very flat, on-axis field profile.

This provides longitudinal and transverse opening angles of approximately ±63° and ± 27°, respectively.

Note that each coil only has to produce about 70% of the desired field (5T) at the center.



Future Magnet Designs



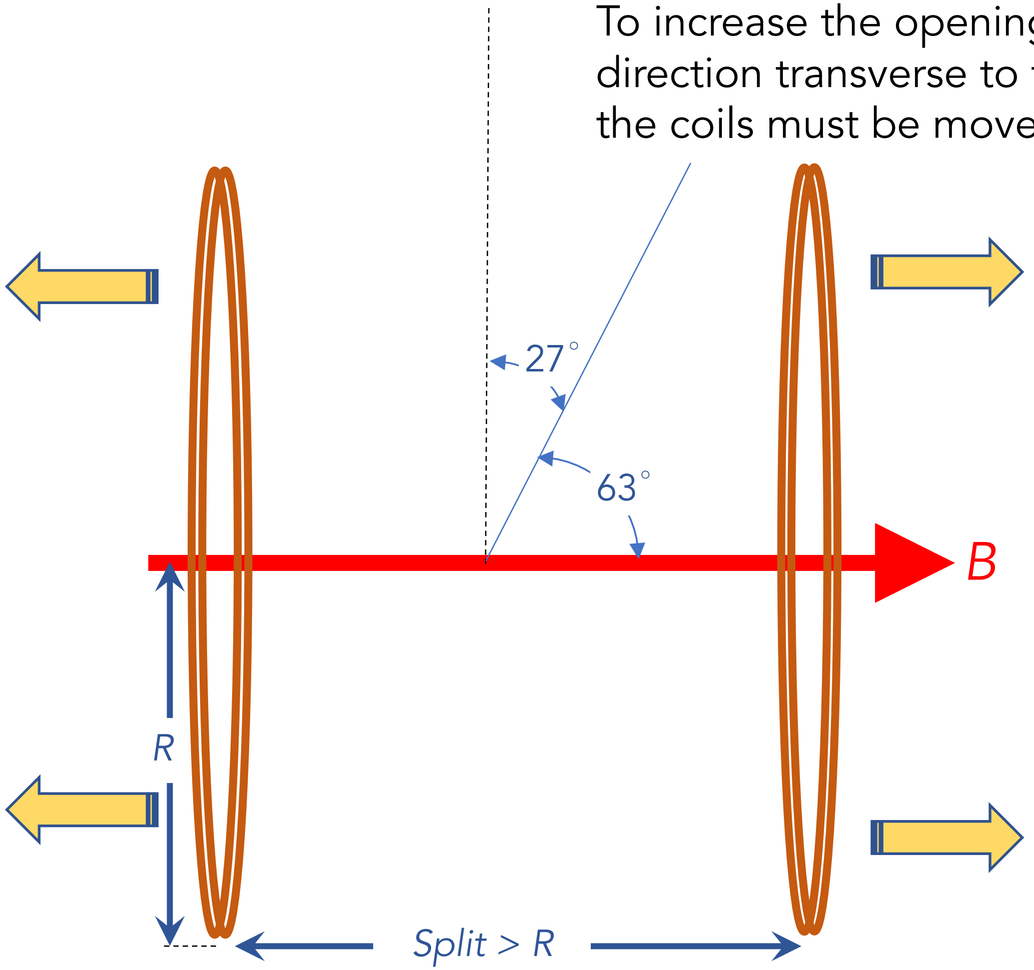
The original UVa/SLAC/Hall C magnet consisted of four pairs of coils arranged along the 63° "Helmholtz Line".

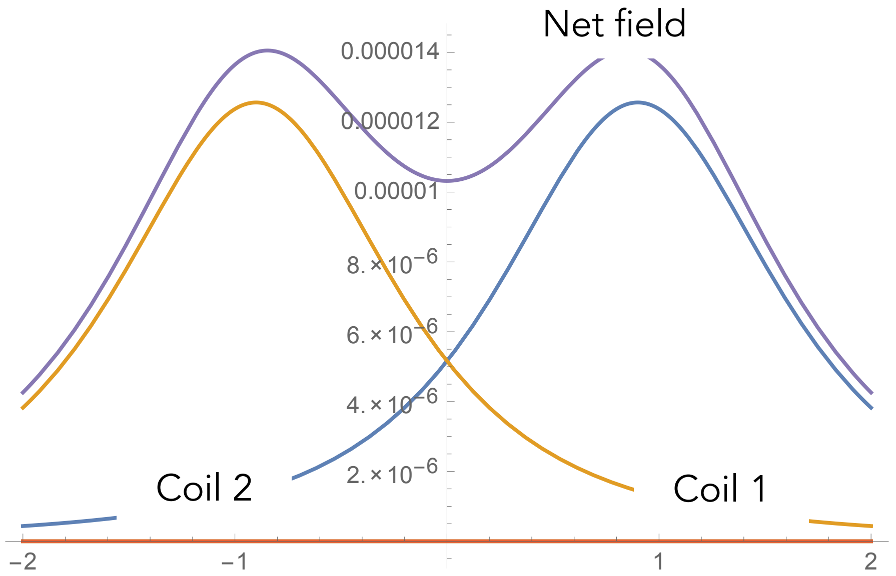
However, the nonzero size of the windings and the support structure reduces the opening angles to ±50° and ±15°.

That is, both opening angles are reduced by about ±12°

Future Magnet Designs

To increase the opening in the direction transverse to the field, the coils must be moved apart.

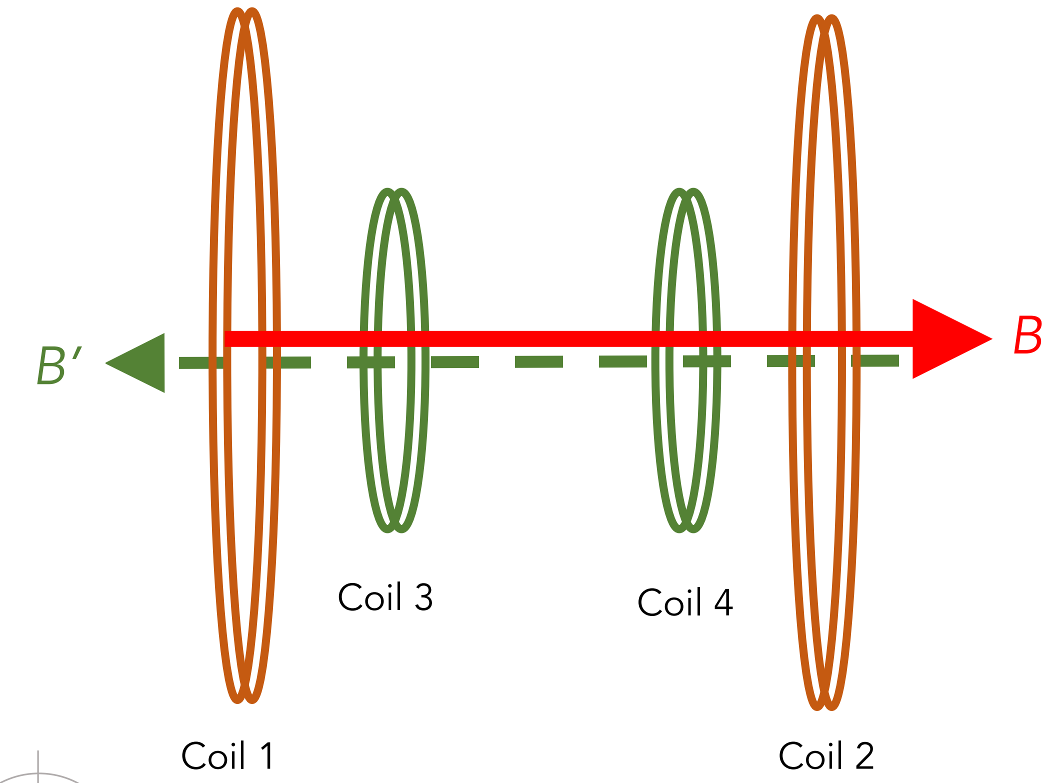


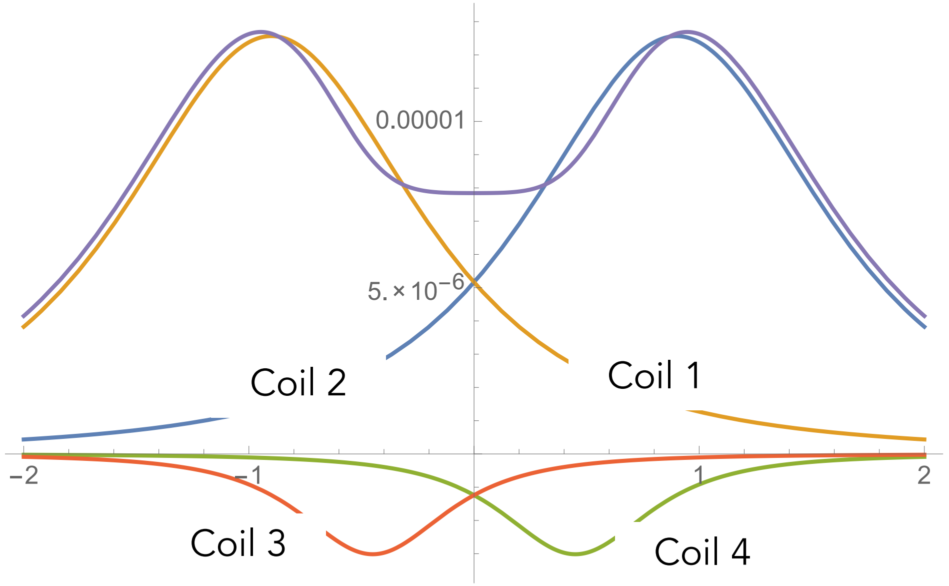


This produces a depression in the central field region that needs to eliminated for successful DNP ($\Delta B/B \lesssim 100$ ppm).

Future Magnet Designs

The uniformity can be improved using correction coils with negative current.
This is configuration (1f) in the paper by H. Deportes, "Superconducting Magnets for Polarized Targets", 2nd International Conference on Polarized Targets (1971).



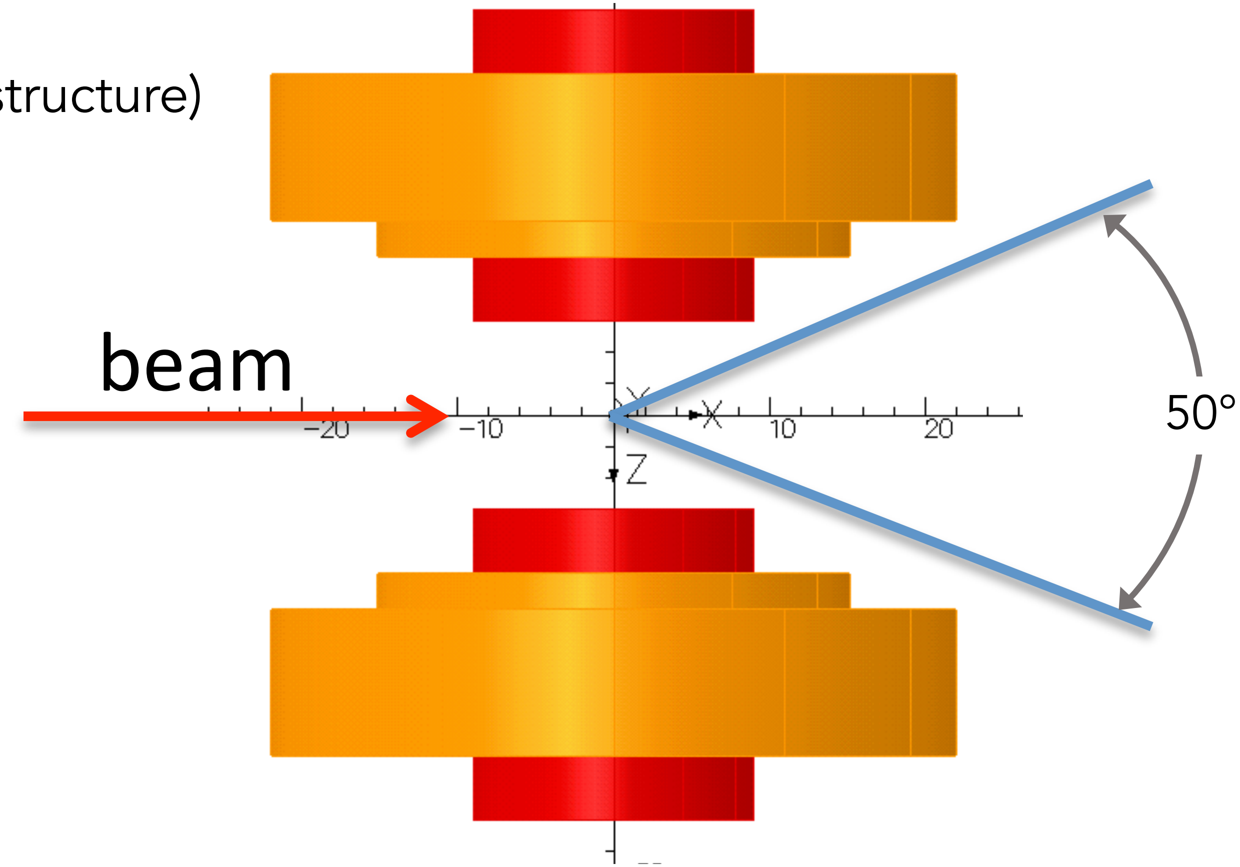


Note that the field is now significantly larger outside the central region.

Future Magnet Designs

Bogdan Wojtsekhowski

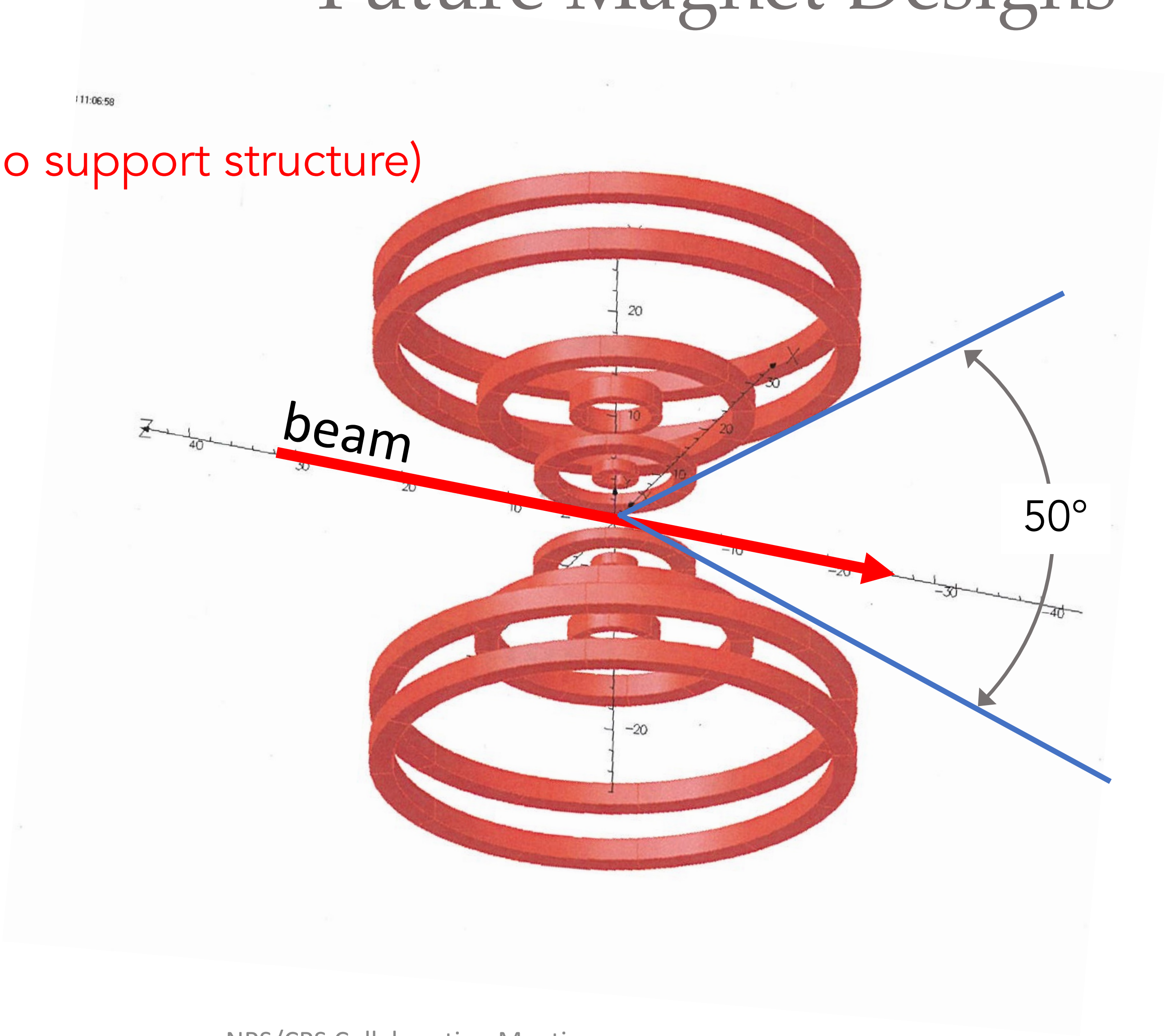
- ±29° open aperture (no support structure)
- 4.1 Tesla central field
- 15 ppm over target volume
- 12 cm split (no support structure)



Future Magnet Designs

Paul Brindza

- ±25° open aperture (no support structure)
- 4.9 Tesla central field
- 100 - 1800 ppm
- 8 cm split (coils only)

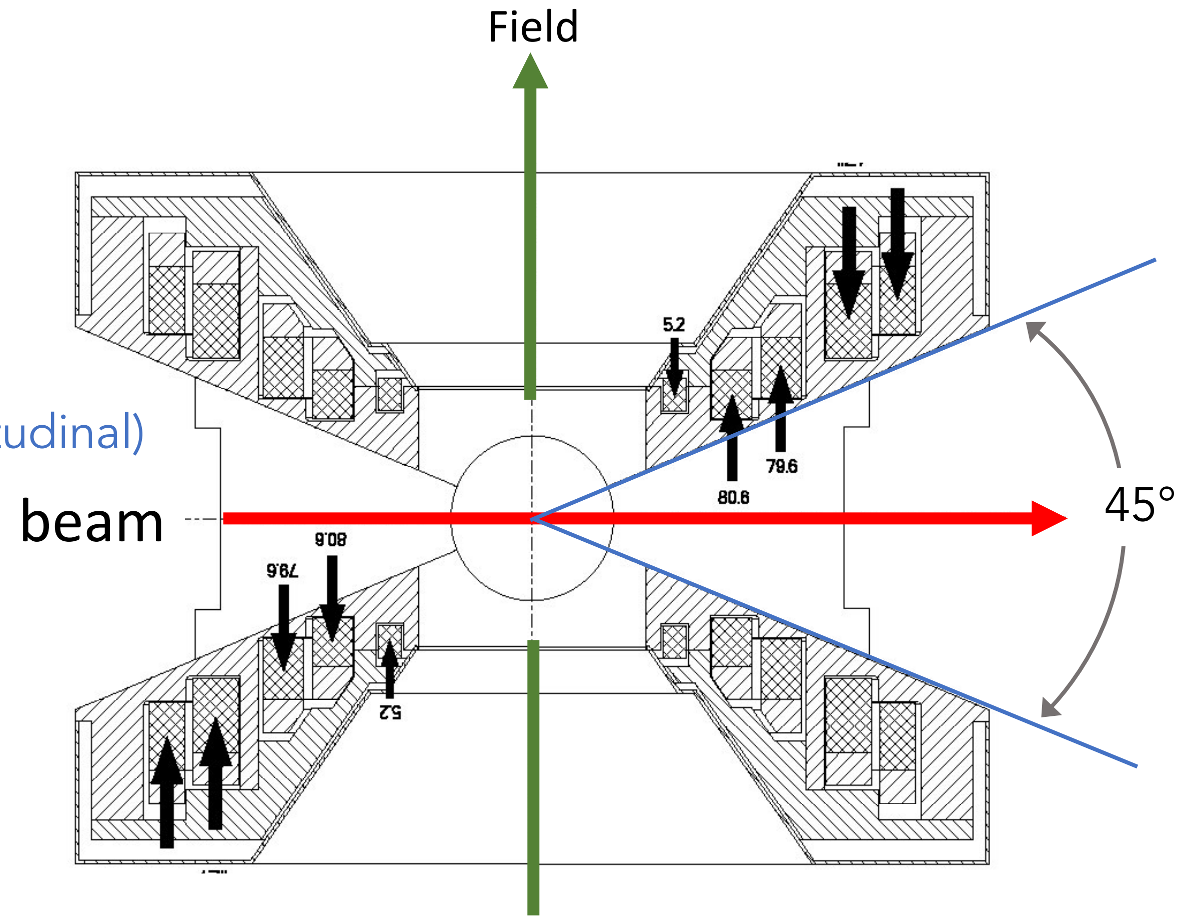


Future Magnet Designs

<u>Oxford Instruments</u>

- ±22.5° open aperture
- 4.2 Tesla central field
- 300 ppm
- 10 cm vertical bore

- ±35° open aperture (longitudinal)



One more thing

The 12,000 m^3/hr pumping system is 40+ years old.

We need new pumps badly.

Summary & Recommendations

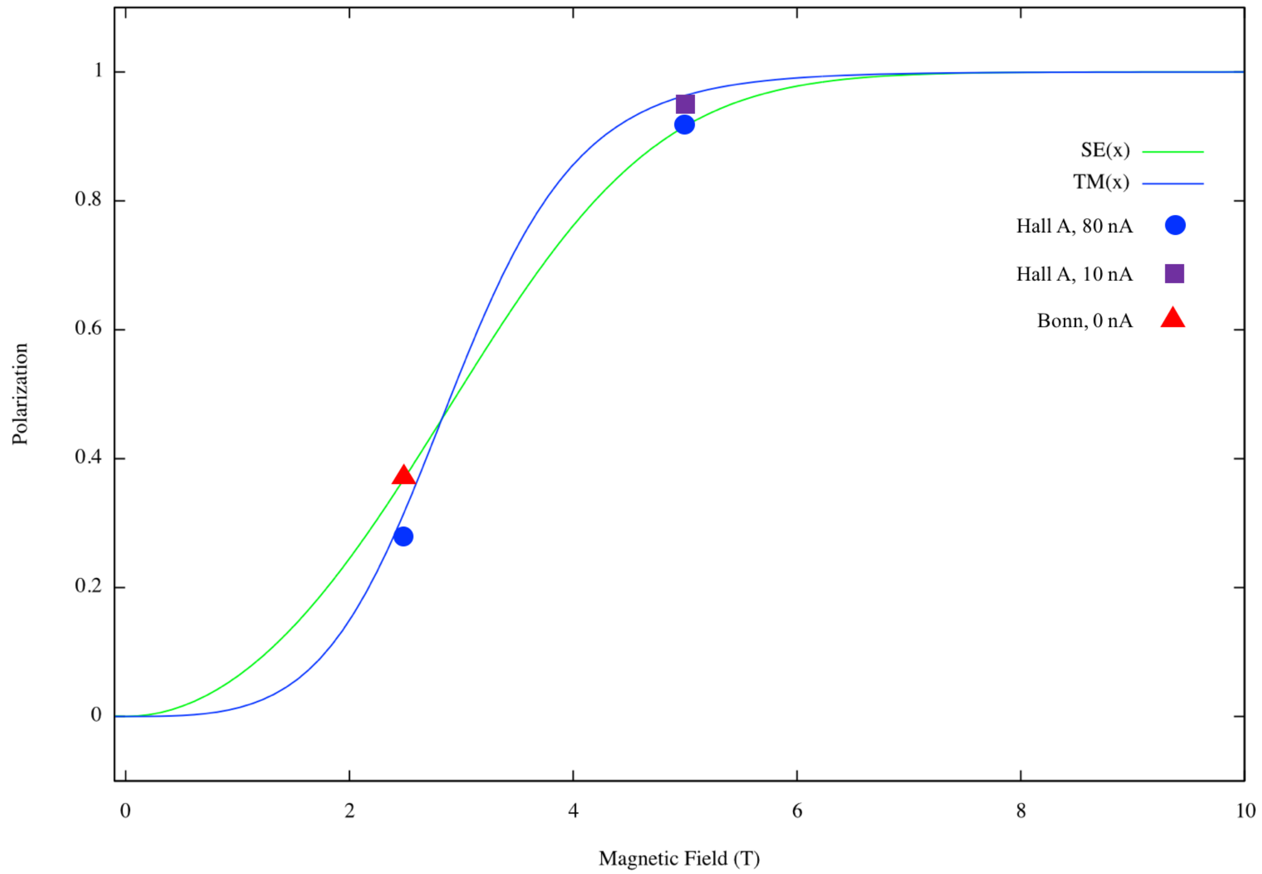
- The high luminosity polarized target for Hall A & C received a major overhaul in c. 2011
- Operated extremely well during G^p_E and g^p_2
- Two systems should be updated for future 12 GeV experiments
  1. Roots pumping system
  2. Superconducting magnet(s)

- Recommend two (interchangeable) magnets for 12 GeV operations
  1. A general purpose magnet for longitudinal polarization (±55°)
  2. A dedicated magnet for transverse polarization (±25°)

- Two transverse designs appear close to meeting the requirements
  - Still require significant design refinement and engineering analysis

Back-up slides

NH3 polarization versus field



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