Proposal: Magnetic field profile of a third-scale model for the nEDM experiment

A. Biswas

Kellogg Radiation Laboratory, California Institute of Technology

I. MOTIVATION

Charge-parity (CP) violation plays a critical role in explaining matter-antimatter asymmetry in the universe and guiding theories beyond the Standard Model. The experimental search for instances of CP violation is ongoing.[1,2] A nonzero electric dipole moment (EDM) in the neutron would constitute such a violation and can be measured through the shift in Larmor precession frequency of ultra-cold neutrons (UCN) in electric and magnetic fields.[3] An upper limit of $2.9 \times 10^{-26} \ e \cdot cm$ was established in 2006.[2]

Experiments using these methods are prone to a geometric phase (GP) effect, caused by gradients of the magnetic field, that can lead to a false signal: a nonzero measurement even if the true EDM is zero.[2,3] Eliminating the GP effect requires precise engineering to create a space-uniform magnetic field. Field uniformity also elongates the neutron spin polarization lifetime.[6]

Here, we describe a third-scale model of a shielded magnet designed to create a field suitable for a more precise nEDM measurement. New structural features of the third-scale are based on studies of a previous half-scale model and simulations of superconducting shielding geometries.

Precise measurements of the magnetic field profile in this new model are needed to determine the potential effectiveness of its components in the full-scale nEDM experiment, which will take place at Oak Ridge National Laboratory (ORNL). Field gradients near the shielding and near the center of the magnet are particularly good indicators of how well the superconducting shielding can enforce field uniformity and mitigate the GP effect.

II. PREVIOUS WORK

Over the summer of 2014, I studied the effectiveness of a specific component of the previous nEDM magnet model: a superconducting lead endcap designed to mitigate edge effects in the magnetic field. Measured field maps with the closely matched simulations and indicated that the endcap shifts field peaks away from magnet center, decreasing field gradients in the desired regions. My studies concluded that the presence of a single endcap in the previous model effectiely mitigated edge effects.

This result justifies the new design in the third-scale model: a shorter cylinder where the ends are much closer to the measurement cells. Two endcaps are included in the third-scale to control edge effects. The resulting design is much more compact.

III. CONSTRUCTING THE 1/3-SCALE MODEL

The construction process for third-scale model involves simulations of slight variations in the design, finalizing the design, building new components (both the magnetic coil and shielding), and assembly in the synchrotron lab in Lauritsen. I started work on the simulations in December and will be involved in the construction process during the school year.

Structurally, the third-scale model is composed of various cylindrical components nested inside one another in a Russian doll type structure. The B_0 coil, a cylindrical structure with wires coiled along its surface, produces a magnetic field pointing primarily in a direction orthogonal to the cylinder's central axis. The wires are arranged in a particular $\cos \theta$ coil geometry to produce this field.[6] An initial version of the B_0 coil for the third-scale model will be adapted from the one used in the previous model. Studies on the effect of the coil's distortion parameter, a measure of the wire geometry, on field uniformity will guide the design of an updated version.

Surrounding the B_0 coil are several open-ended cylindrical shields. A ferromagnetic Metglas shield promotes field uniformity by reinforcing field lines perpendicular to its surface. Outside the Metglas, there is an axial lead shield which goes superconducting when the magnet is placed in a cryostat and cooled below 7 K. This shield protects the field inside the magnet from environmental fluctuations by redirecting external field lines along its surface.

Two lead endcaps close the top and bottom ends of the axial lead shield. The top endcap contains a small central hole to allow a magnetic probe to enter the cavity inside the B_0 coil, while the bottom endcap is circular. As noted, previous studies suggest that these endcaps will mitigate edge effects and enforce field uniformity near magnet center; the measurements I plan to take this summer will determine their effectiveness. The model is encased in an aluminum shell for uniform cooling inside the cryostat.

IV. METHODS & CHALLENGES

The apparatus used for magnetic field measurements on the third-scale model, such as the magnetic probe, mounts, etc. will be determined as the third-scale design is finalized over February - April.

Over the summer, magnetic field measurements will be taken with a probe that will enter the B_0 cavity through the central opening in the top lead endcap. The size

of this opening is small to make the endcap more effective, but this presents a challenge in moving the probe. Though the mounting mechanism for the probe is yet to be finalized, we will most likely use an elbow-style mount that allows the probe to move more freely inside the B_0 cavity despite the small opening.

This new mount, and the overall new structure of the third-scale model, will introduce various new systematic errors to identify and correct before comparing our measured field maps with simulations. This will require significant adaptation of the data analysis code written for the previous model: conversion from the mount's geometry to Cartesian coordinates, interfacing with the new probe, and more. The variable angle of the mount will also introduce new uncertainties which will need to be accurately determined by experiment.

V. TIMELINE

The following is a list of checkpoints with approximate expected times to completion. Some of these tasks are disjoint. For example: assembly of the third-scale model will begin during the year; the expected time shown in the period of work that will fall during SURF. Fata acquisition will happen in multiple stages depending on our cryostat cooldown schedule, and work on other tasks will be done between these stages.

Task	Time
Assemble third-scale model	2 weeks
Develop LabView interfaces for new components	1 week
Adapt 2014 data analysis code for new interfaces	2 weeks
Data acquisition, room temp. and superconducting	2 weeks
Systematic error analysis and correction	3 weeks

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[4] "Search for the nEDM at Caltech." Kellogg Radiation Laboratory ⟨krl.caltech.edu⟩ (2014).

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[6] Perez Galvan, A., B. Plaster, J. Boissevain, R. Carr, B. W. Filippone, M. P. Mendenhall, R. Schmid, R. Alarcon, and S. Balascuta. "High uniformity magnetic coil for search of neutron electric dipole moment." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 660, no. 1 (2011): 147-153.

[7] Mendenhall, M. P. `RotationShield` source. ⟨https://github.com/mpmendenhall/rotationshield⟩ (2014).