Magnetic Holding Field Requirements for UCN Precession in the TUCAN EDM Experiment

TUCAN
TRIUMF Ultra Cold Advanced Neutron source

M. McCrea
TUCAN Collaboration

University of Winnipeg

CAP 2022
2021/06/09

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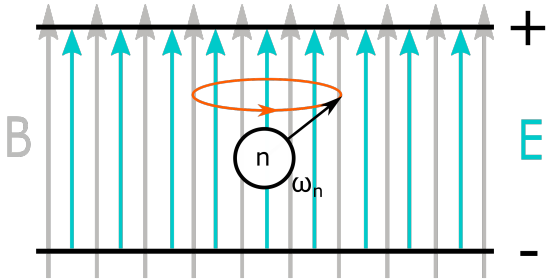
Why Measure a Neutron EDM?

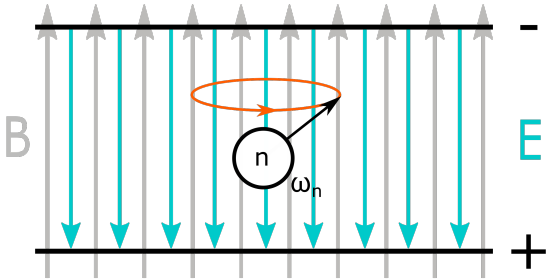
- The goal of the TUCAN Collaboration is to construct an Ultra Cold Neutron (UCN) source, and use it to measure the neutron Electric Dipole Moment (nEDM) to a accuracy of $1 \times 10^{-27} e\,cm$.
- Neutron Electric Dipole Moment (nEDM) experiments are part of a searches for new sources of CP violation in the Standard Model.
- One motivation for this is the baryon asymmetry in the universe is orders of magnitude larger than predicted by the standard model:

  Measured Baryon Asymmetry $\eta = n_B/n_\gamma = \sim 6 \times 10^{-10}$

  Standard Model Prediction $\eta = 1 \times 10^{-18}$.

nEDM Measurement Method





$$\mathbf{H} = -\mu \mathbf{B}\frac{\mathbf{S}}{s} - d\mathbf{E}\frac{\mathbf{S}}{s} \quad (1)$$

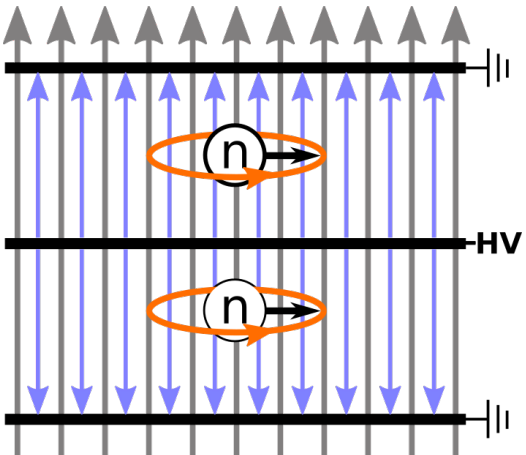
$$\hbar\omega_n^{\uparrow\uparrow} = \mu B + dE \quad (2)$$

$$T\mathbf{H} = -\mu \mathbf{B}\frac{\mathbf{S}}{s} + d\mathbf{E}\frac{\mathbf{S}}{s} \quad (3)$$

$$\hbar\omega_n^{\uparrow\downarrow} = \mu B - dE \quad (4)$$

$$\hbar\omega_n^{\uparrow\uparrow} - \hbar\omega_n^{\uparrow\downarrow} = 2dE \quad (5)$$

Motivation For Magnetic Field Uniformity Requirements

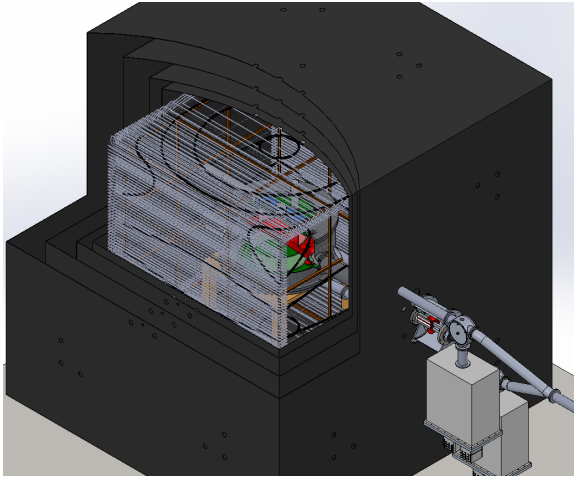


A highly uniform magnetic field in the measurement cells is required for two reasons:

- To maintain the neutron polarization in the measurement cell as variations in the field will change the neutron precession frequency throughout the cell dephasing the neutrons over time.
- To prevent systematic effects due to specific field shapes such as:

$$d_{Hg}^{false} = -\frac{\hbar\gamma_n\gamma_{Hg}199}{2c^2}\langle xB_x + yB_y\rangle. \quad (6)$$

Magnetic Field Production

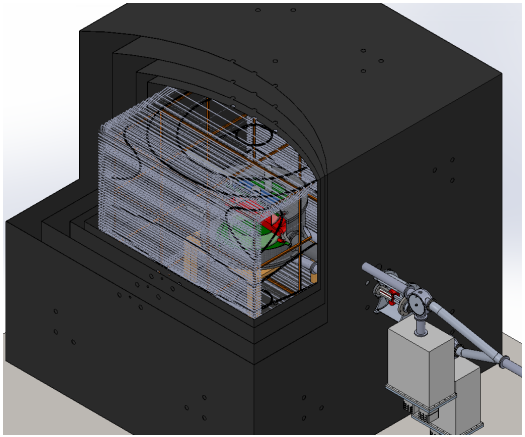


A magnetically shielded room, MSR, (black) will be used to shield the measurement cells from external magnetic fields.

3 Different electromagnet sets will be used to produce the static neutron precession field:

- B_0 Holding Field Coil (grey)
- $n \times n$ Coil Array (orange)
  - M3-7 J. Martin, Magnetic resonance requirements and shim coil design for the TUCAN EDM experiment
- $G_{\ell,0}$ Systematic Coils (black)

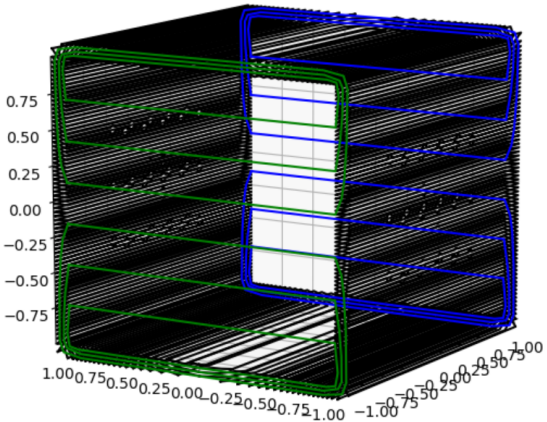
Magnetic Requirements



For the details of the precession field:

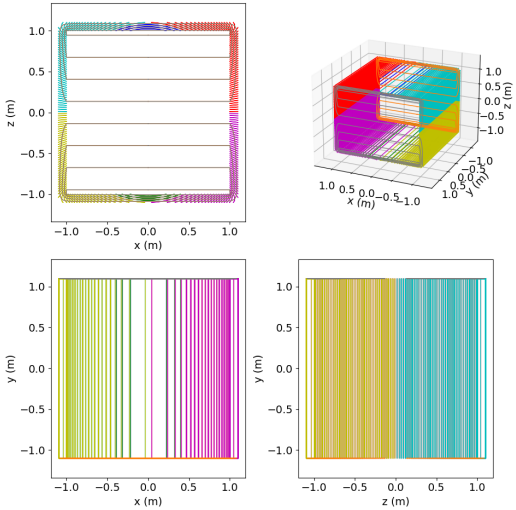
- $B_z = 1\,\mu\mathrm{T}$.
- With the uniformity requirements:
  - $\Delta B_z = |max(B_z) - min(B_z)| < 140\ \mathrm{pT} = 0.000140\,\mu\mathrm{T}$
  - $\sigma(B_z) < 40\ \mathrm{pT} = 0.000040\,\mu\mathrm{T}$
- Precise mechanical alignment of the electromagnet windings are required to meet these requirements.

B0 Coil Design

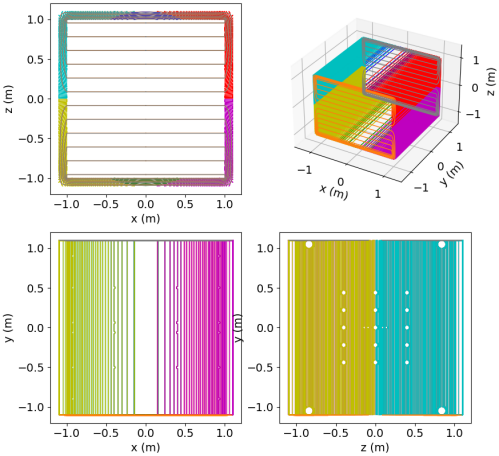


- Square Cosine Theta Coil
- Self shielded design decouples the coil from the surrounding metals increasing stability over time.
- Simulations of the field using Biot-Savart Law show that to meet the field uniformity requirements wires must be placed with an accuracy of $1\ \mathrm{mm}$.

B0 Coil Modifications

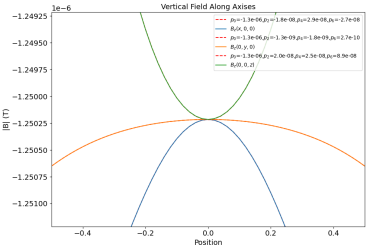


Original

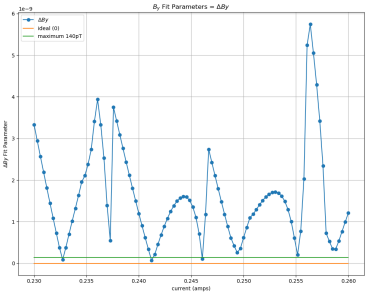


Rerouted Coil

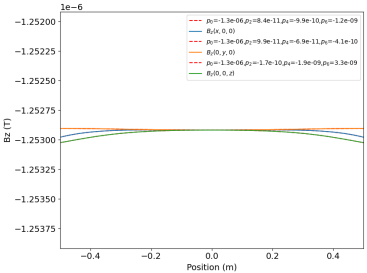
B0 Coil Re-optimization



1. Original

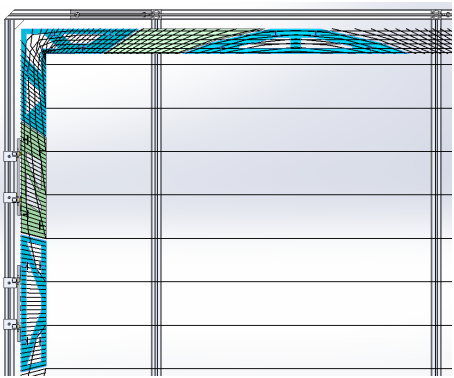


2. Scan of Equipotential Spacing

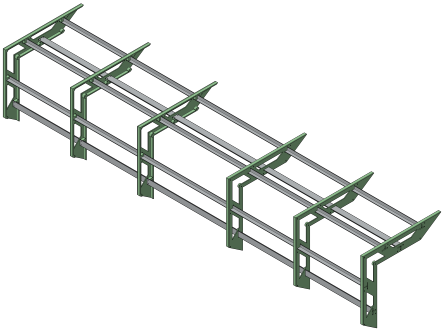


3.Optimized

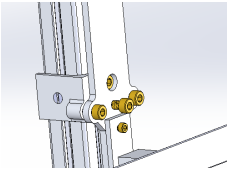
Coil Assembly Method



Coil Divisions

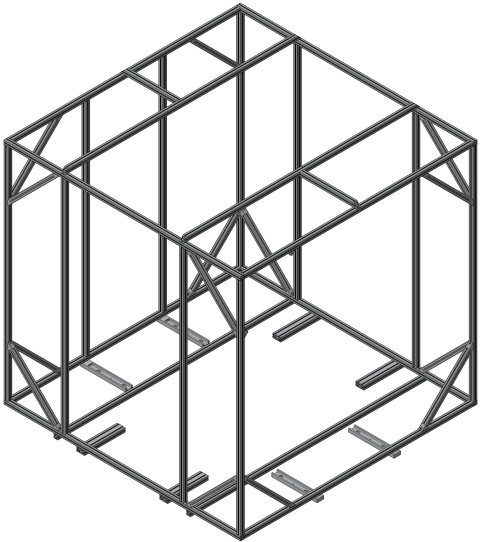


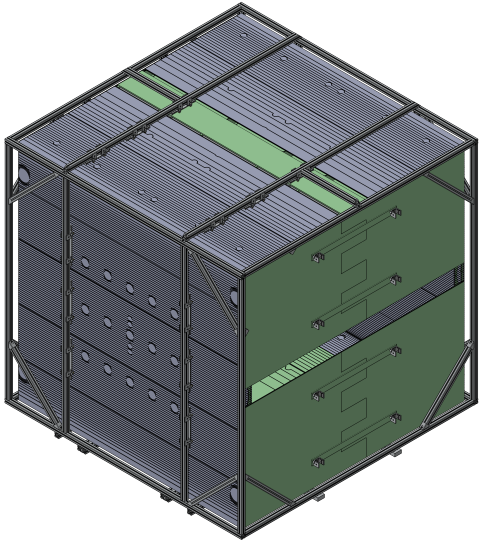
Corner Frame Assembly



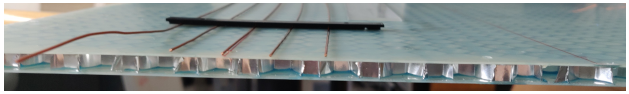
Frame Adjuster

Coil Body Assembly

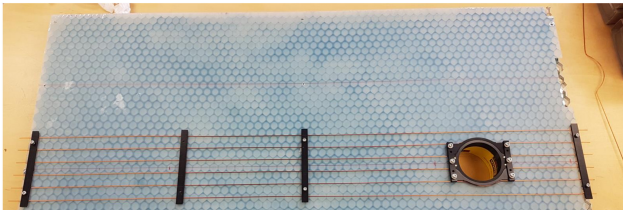




Coil Assembly



Edge



Face

- For long term stability and the floor load limits of the MSR it is required to maximize stiffness at low overall mass.
- To accomplish this G10 sheets spaced with a hex-cell spacer are epoxied together to create a stiff light weight surface.
- This is done on a granite table, and the prototype is flat to within 0.4 mm

Summary

- The neutron holding field requirements set stringent requirements on the coil construction.
- The current coil design should be able to feasibly address those requirements.
- Prototyping is currently underway of the coil components.

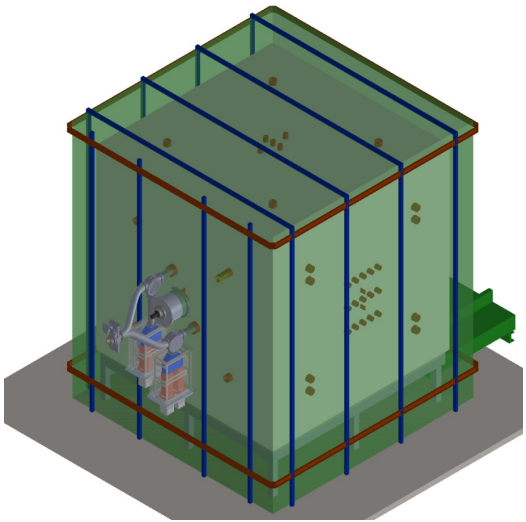
Thank you for Listening.

Other TUCAN nEDM Talks:

- M3-7 Mapping the Magnetically Shielded Room for the Neutron Electric Dipole Moment Experiment at TRIUMF, Maedeh Lavvaf
- M3-7 Magnetic resonance requirements and shim coil design for the TUCAN, Jeff Martin
- T3-3 The cyclotron based high-yield ultracold neutron source and neutron electric dipole moment experiment, Rudiger Picker EDM experimen

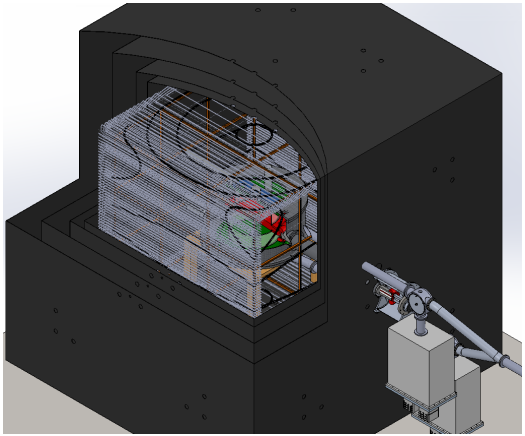
Spare Slides

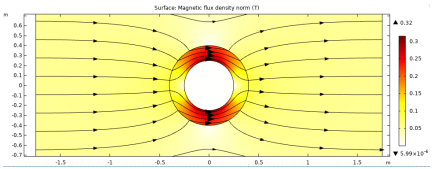
Exterior Coils



- A set of external coils around the MSR (red) will be used to cancel a significant fraction of the external field around the room.
- This active magnetic shielding will further improve the magnetic shielding factor from external fields.

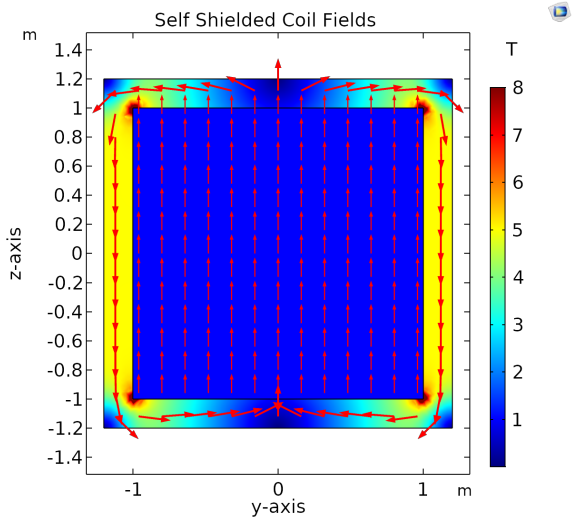
Magnetic Shielding Room





A magnetic shielding room composed of multiple layers of high magnetic permeability material that will redirect ambient magnetic fields away from the center of the room will be used to reduce the ambient magnetic fields by a factor of 100000.

B0 Coil



- This coil will provide the 1 μT precession field for the neutrons.
- The coils is self shielding, the outer layer of the coil will re-direct the magnetic flux inside itself minimizing the flux coupling to the magnetic shielding.
- The wire positions are carefully chosen such that the field in the measurement cells is very uniform.