B0 Magnetic Field Coil Design and Fabrication for the LANL nEDM Experiment

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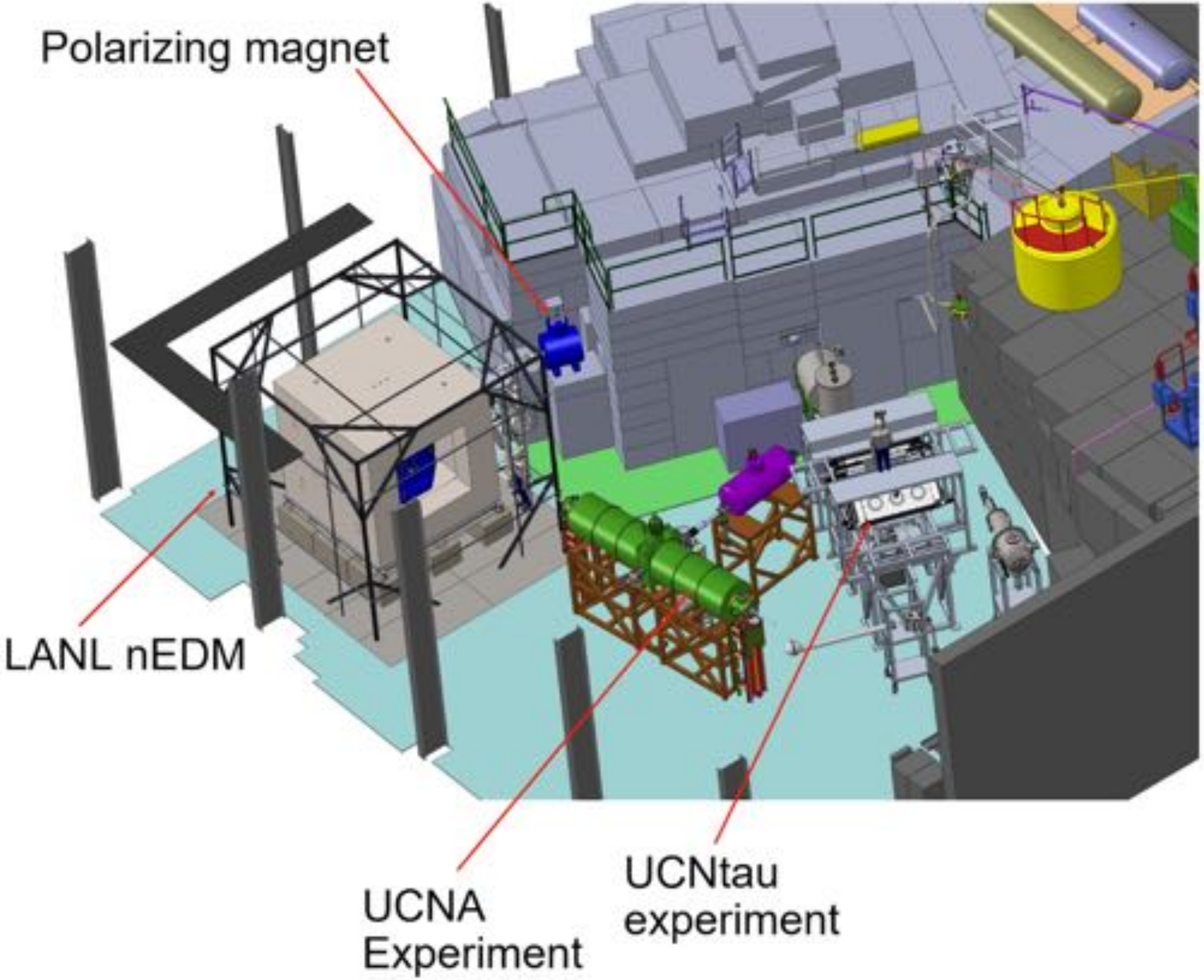
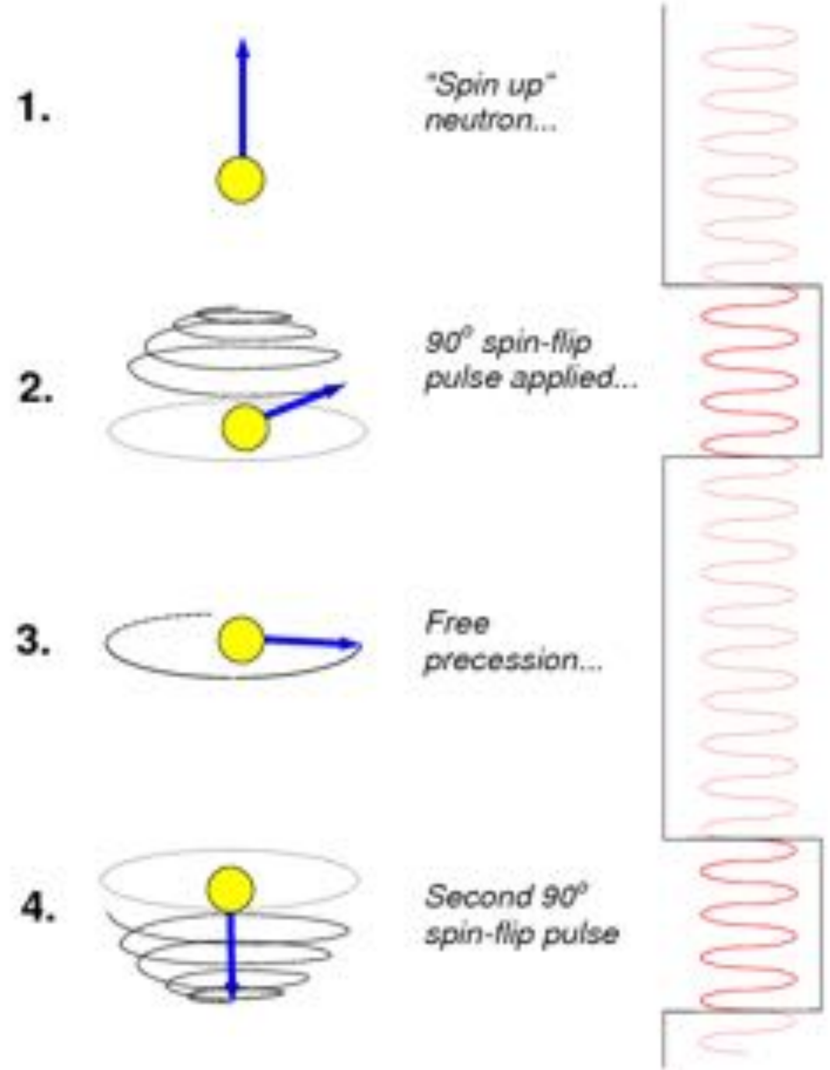
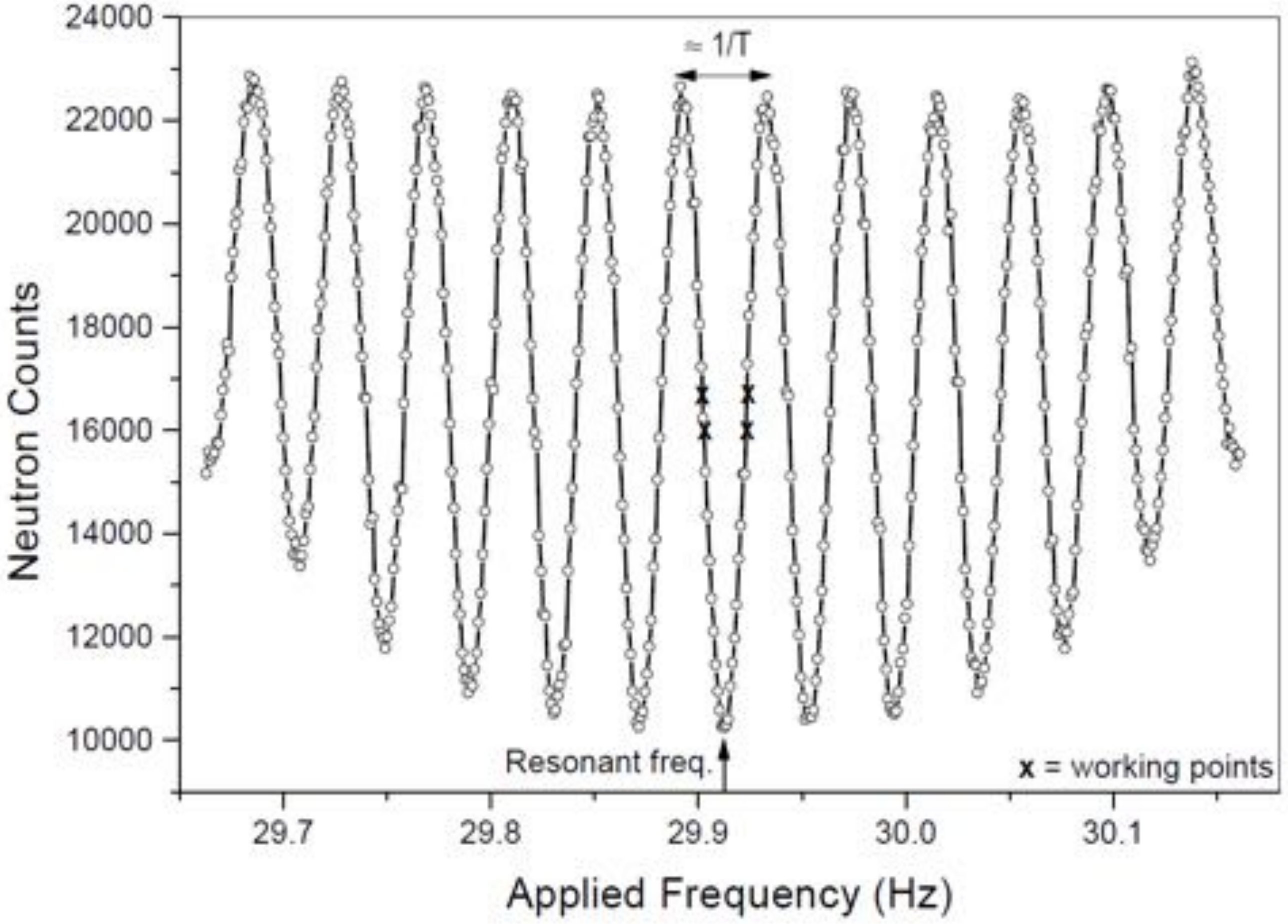


Ramsey Method

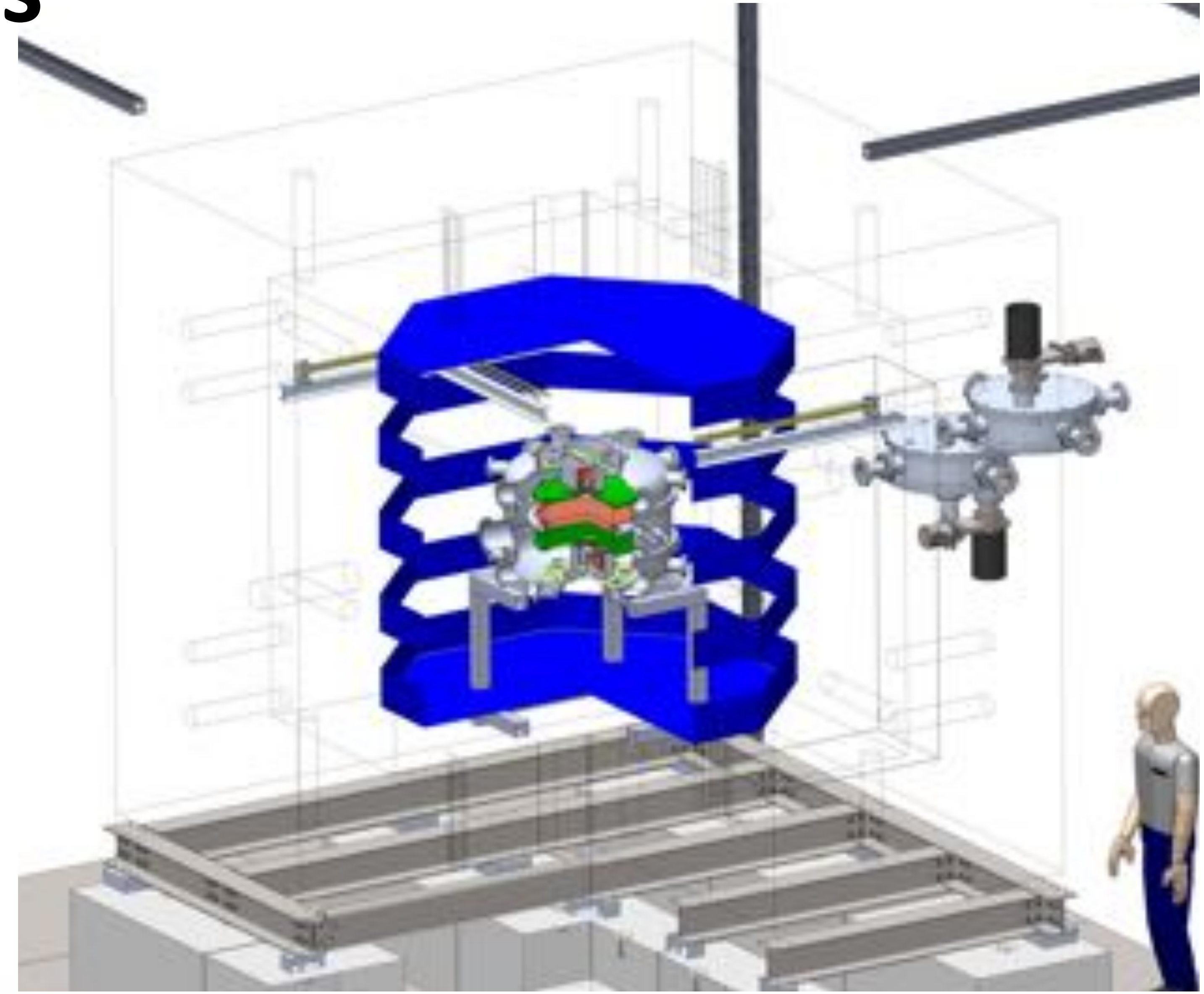


Ramsey Fringes



Magnetic Field Specs

- Provide highly uniform magnetic field
  - $\left\langle \frac{dB_z}{dz} \right\rangle < .3\ nT/m$
- Transport the polarized neutrons into the cell volume
  - $\alpha > .8$ where $\alpha = A * P_n$

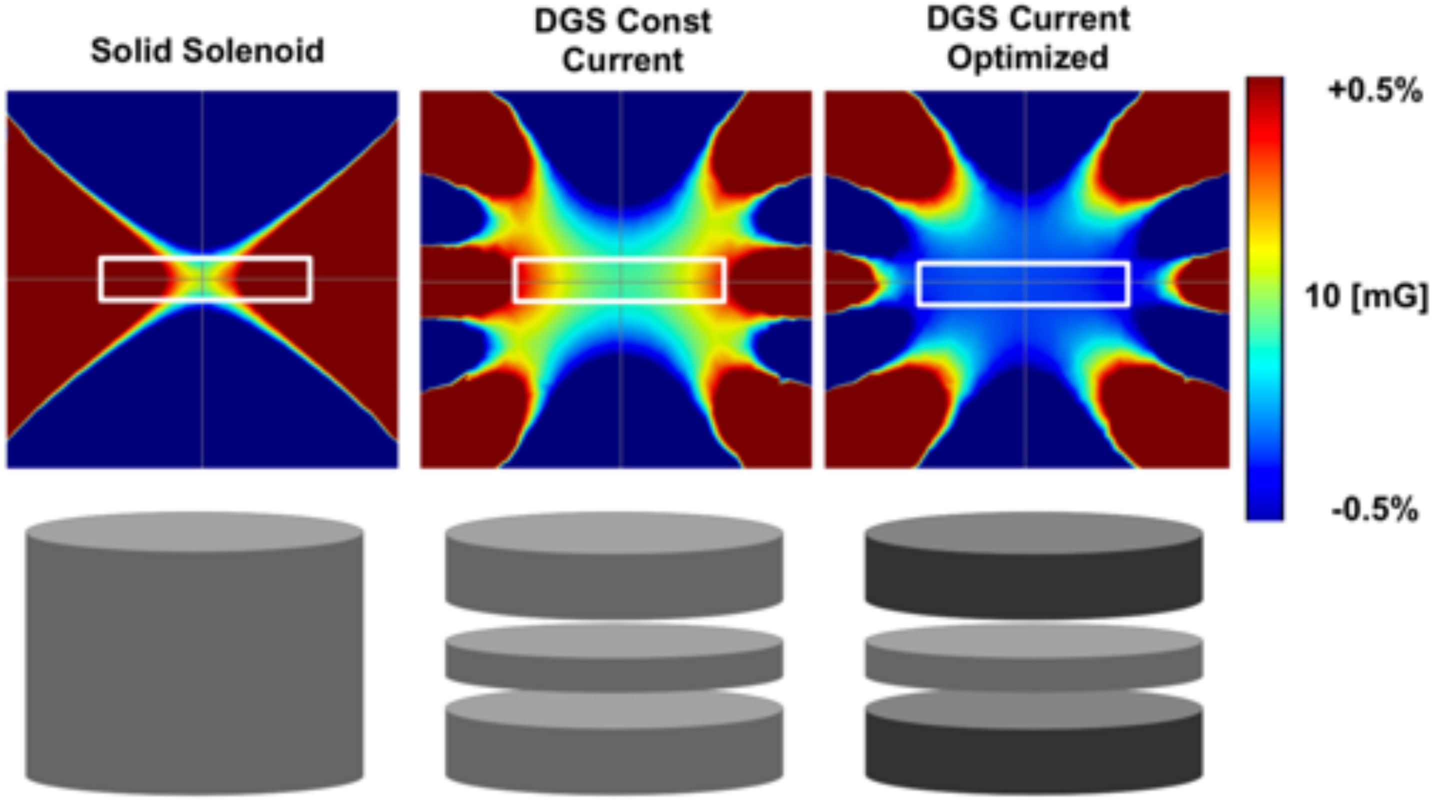


B_0—Gapped Solenoid

- Compared to a solenoid with equal dimensions, the field in the central volume produced by a gapped solenoid is more uniform

- The uniformity of the field produced by the gapped solenoid can be tuned by adjusting the relative currents of the coil sections.

- The gaps provide regions for optical paths, neutrons guides, etc. to enter into the interior of the coil

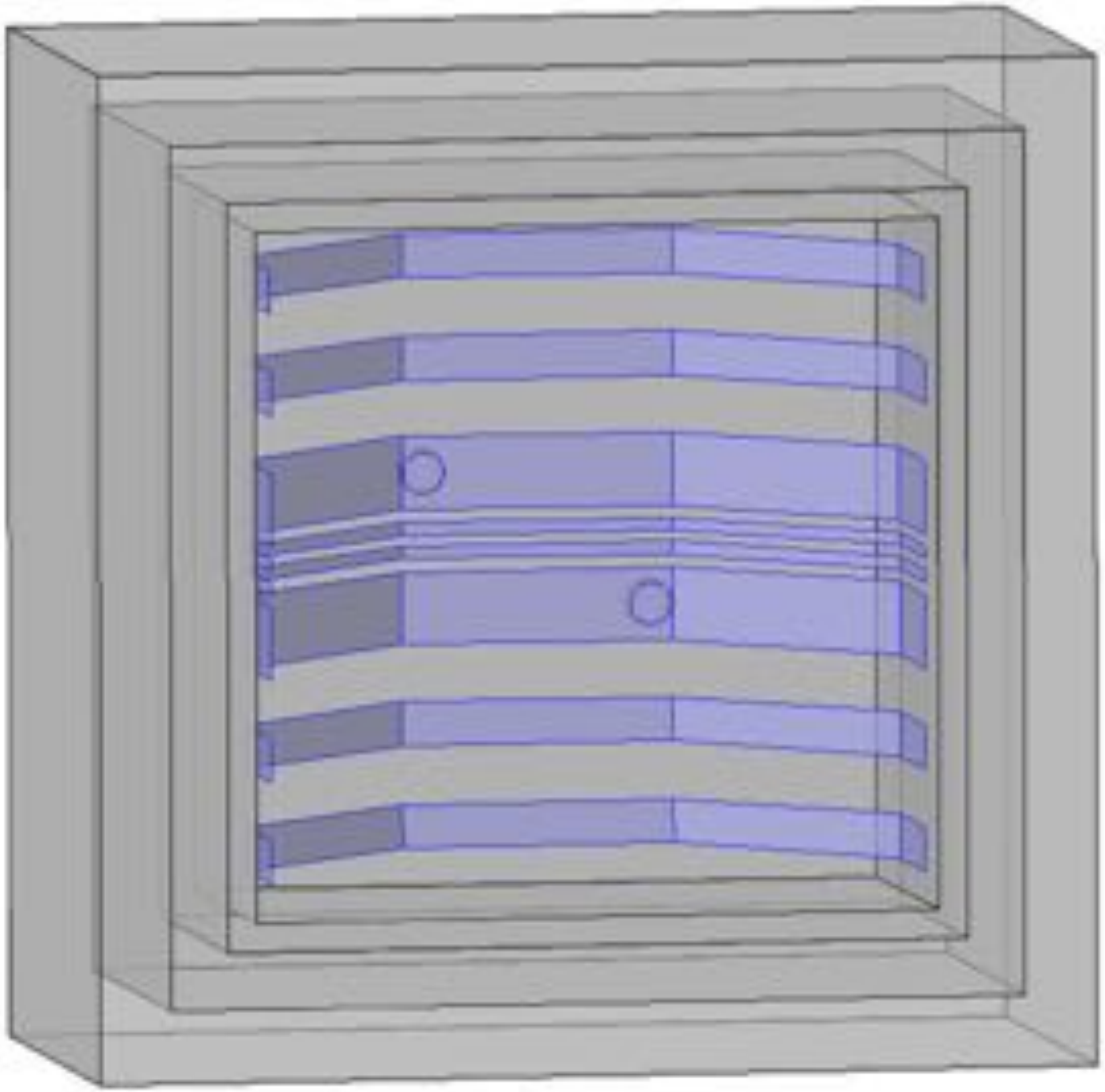


Dadisman, James Ryan, "MAGNETIC FIELD DESIGN TO REDUCE SYSTEMATIC EFFECTS IN NEUTRON ELECTRIC DIPOLE MOMENT MEASUREMENTS" (2018). *Theses and Dissertations--Physics and Astronomy*. 53. https://uknowledge.uky.edu/physastron_etds/53

B_0 Coil Geometry

- Split Solenoid Design
  - 7 gaps
  - Octagonal cross section
  - 2 independent currents
  - Using shielding as the flux return

- The model parameters were optimized in COMSOL to minimize magnetic field gradients
  - $\left\langle \frac{dB_z}{dz} \right\rangle < .2\ nT/m$



B_0 Features

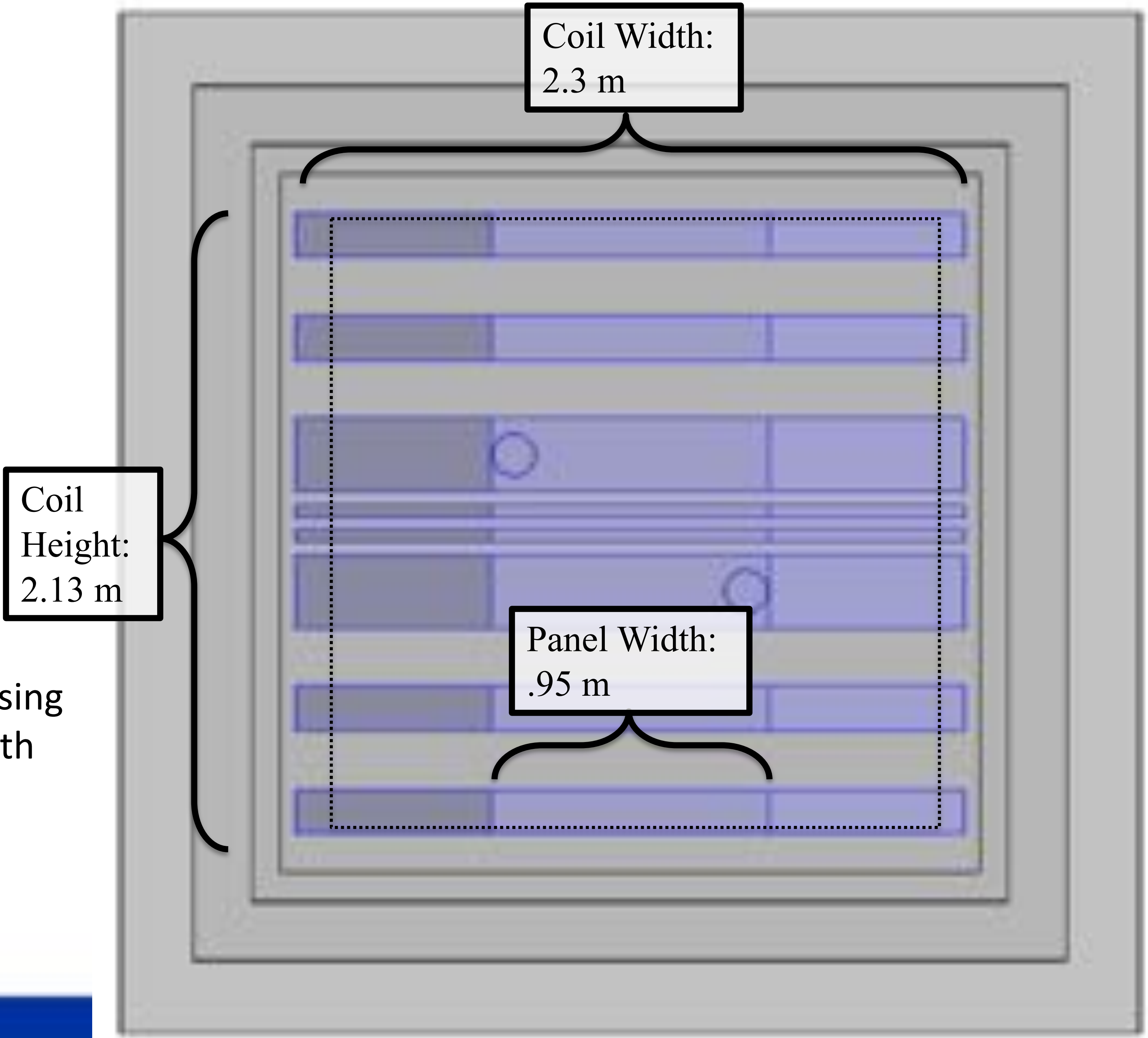
- Large coils are desirable for maximizing uniformity, but present engineering challenges

Assembled coil is larger than the door

Difficult to access the interior of the coil

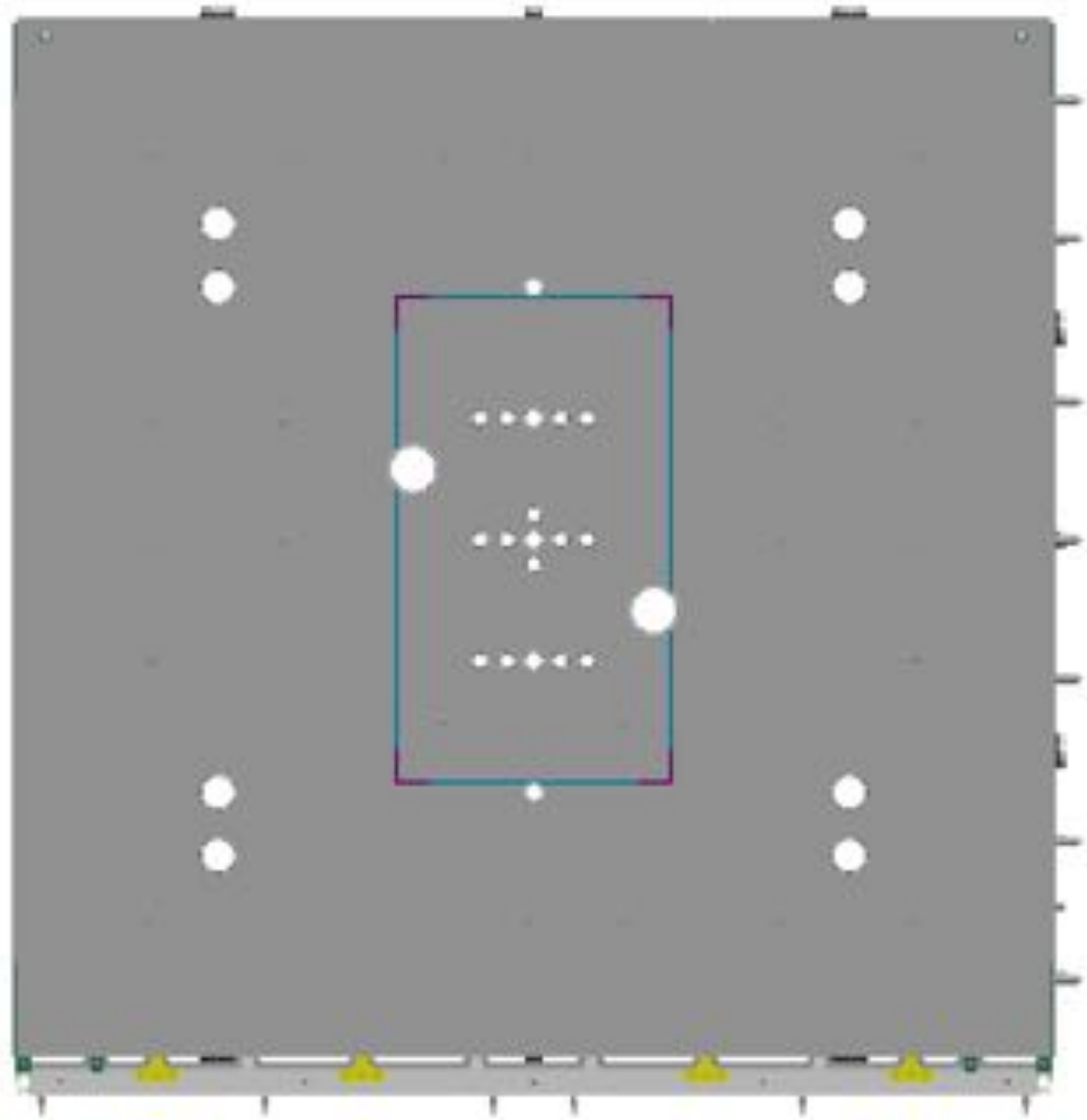
Large cylinders are difficult to construct and store

B_0 coil will be constructed using PCB panels with custom, quick connectors



Gap Locations

- Laser path for magnetometry pumping/probing
- Neutron Guide
- Electronic Feedthroughs
- Mapping Plane



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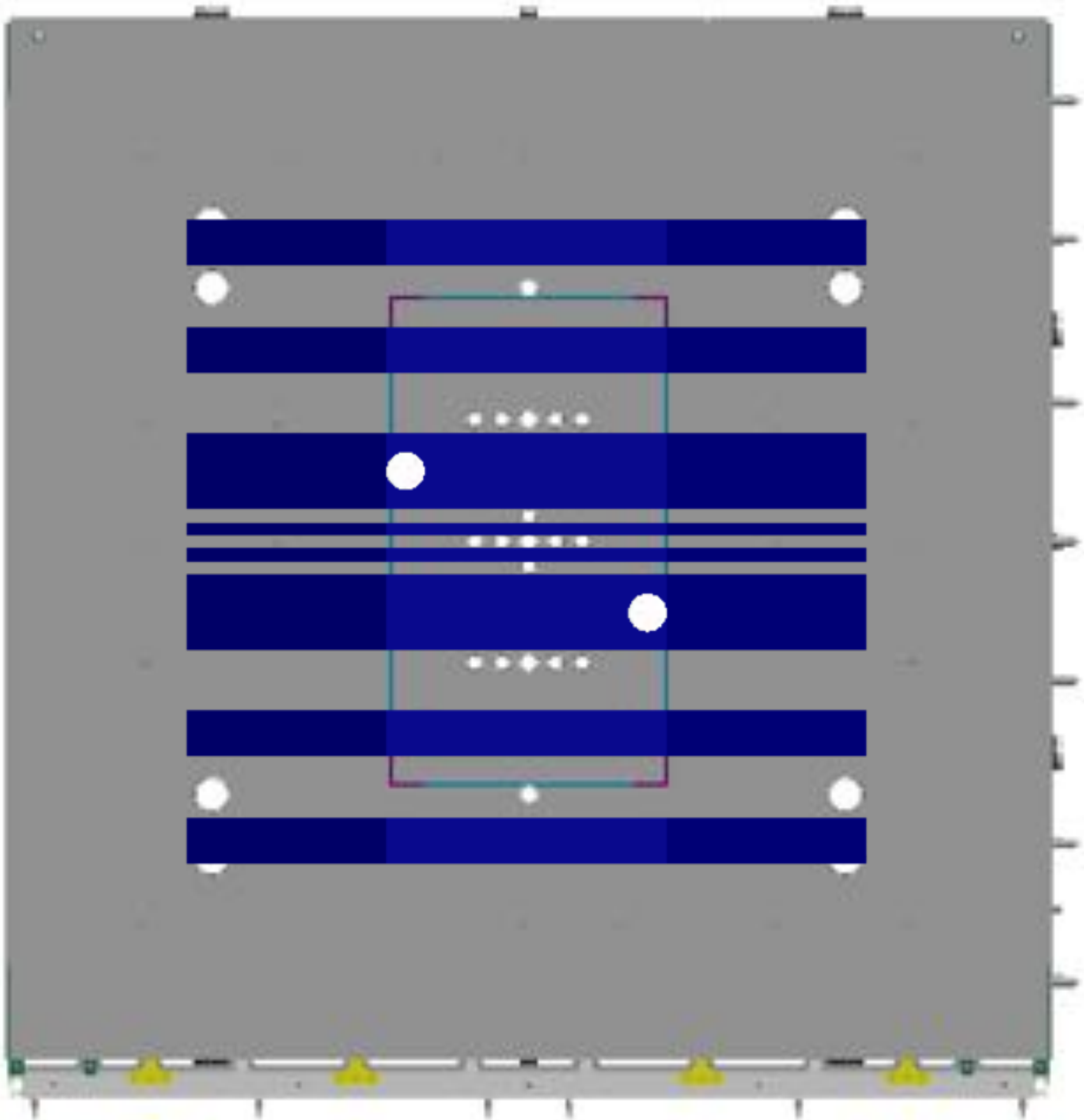
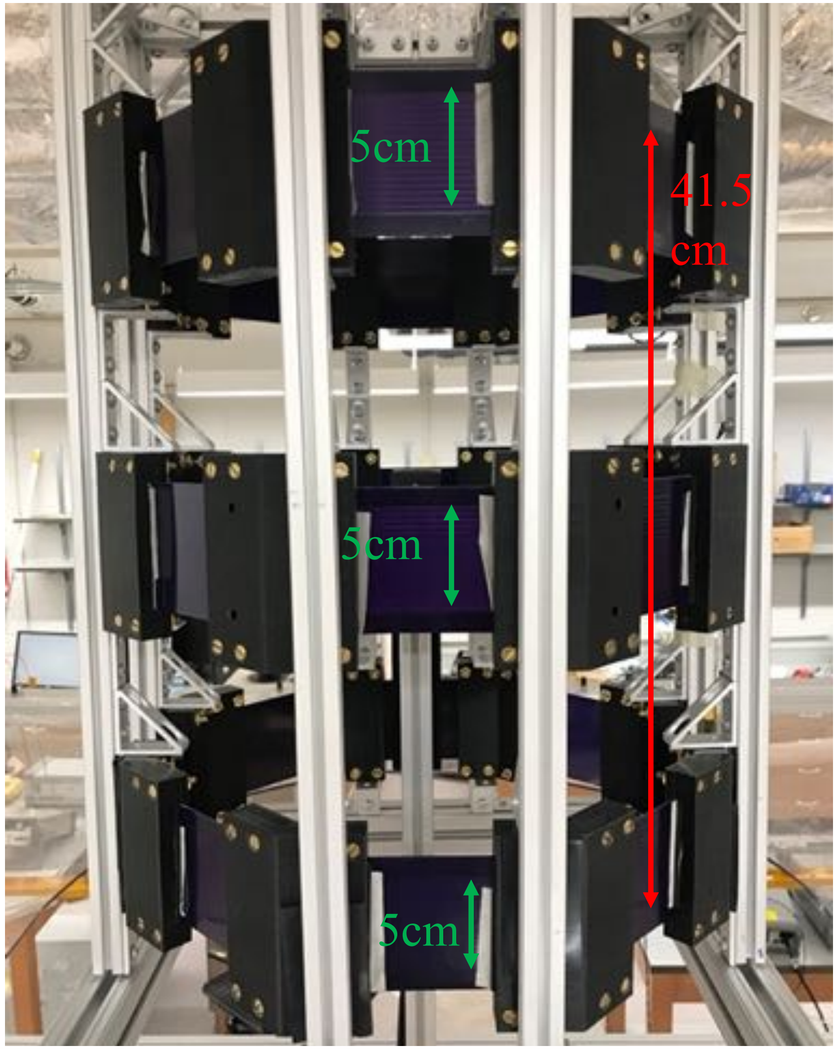
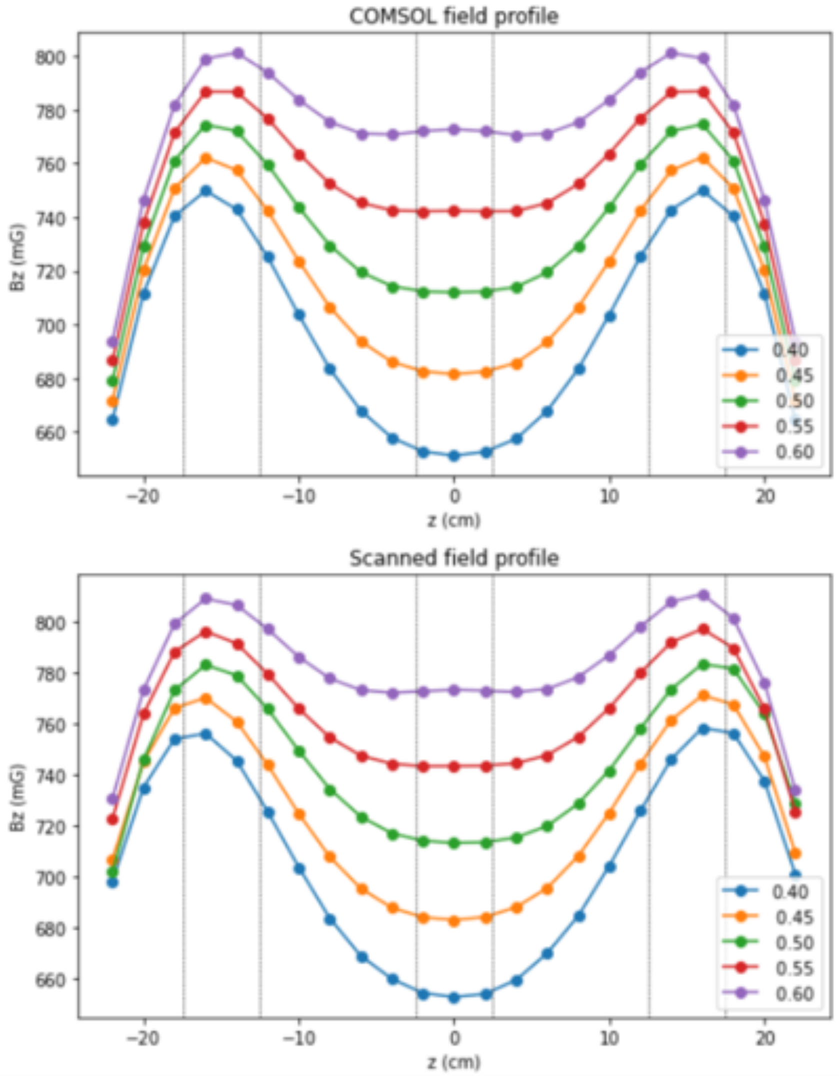


B_0 Prototyping—1/7 Scale (P. Amara Palamure)

- Test corner connectors
- Compare field from PCB to COMSOL
- First iteration of frame

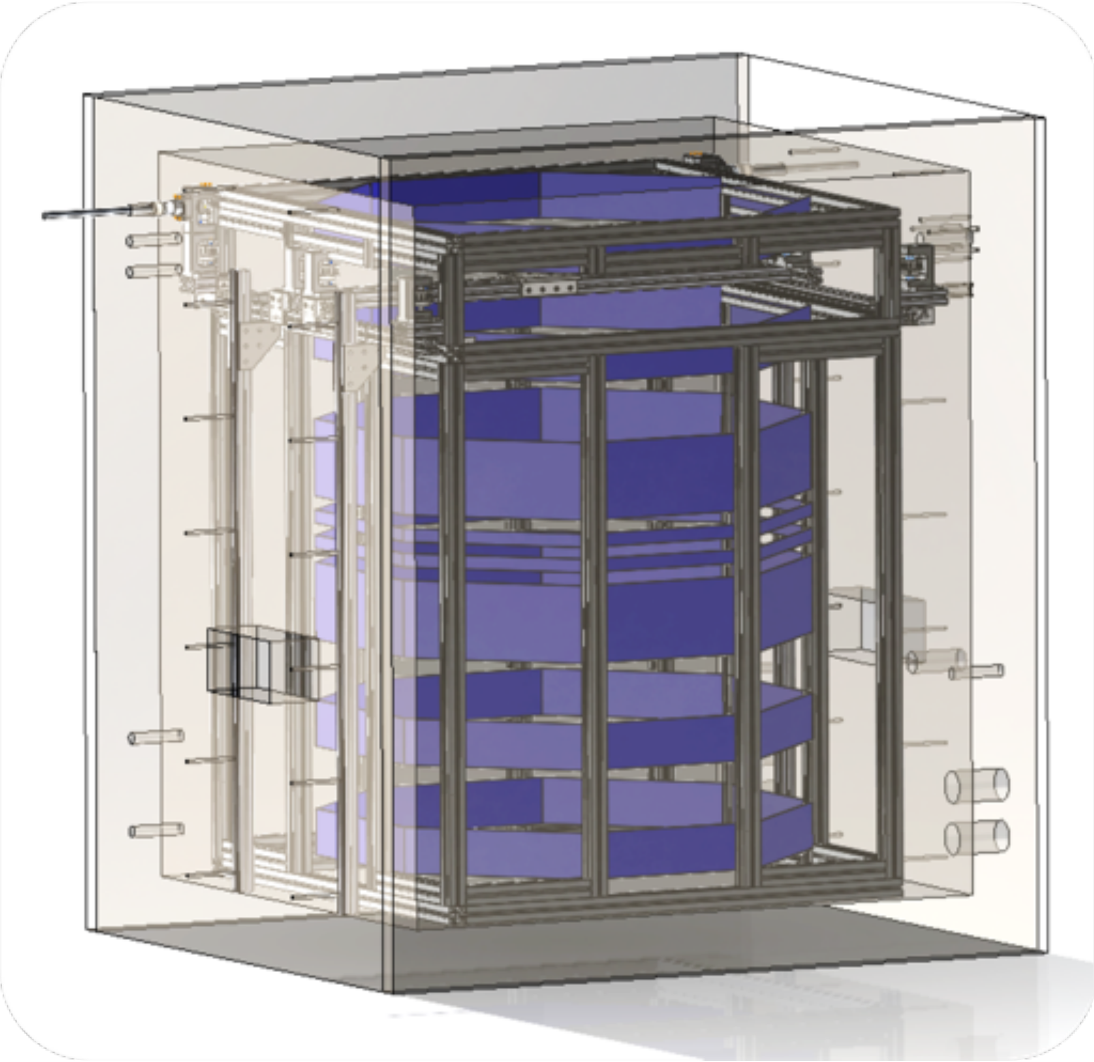




J. Brewington

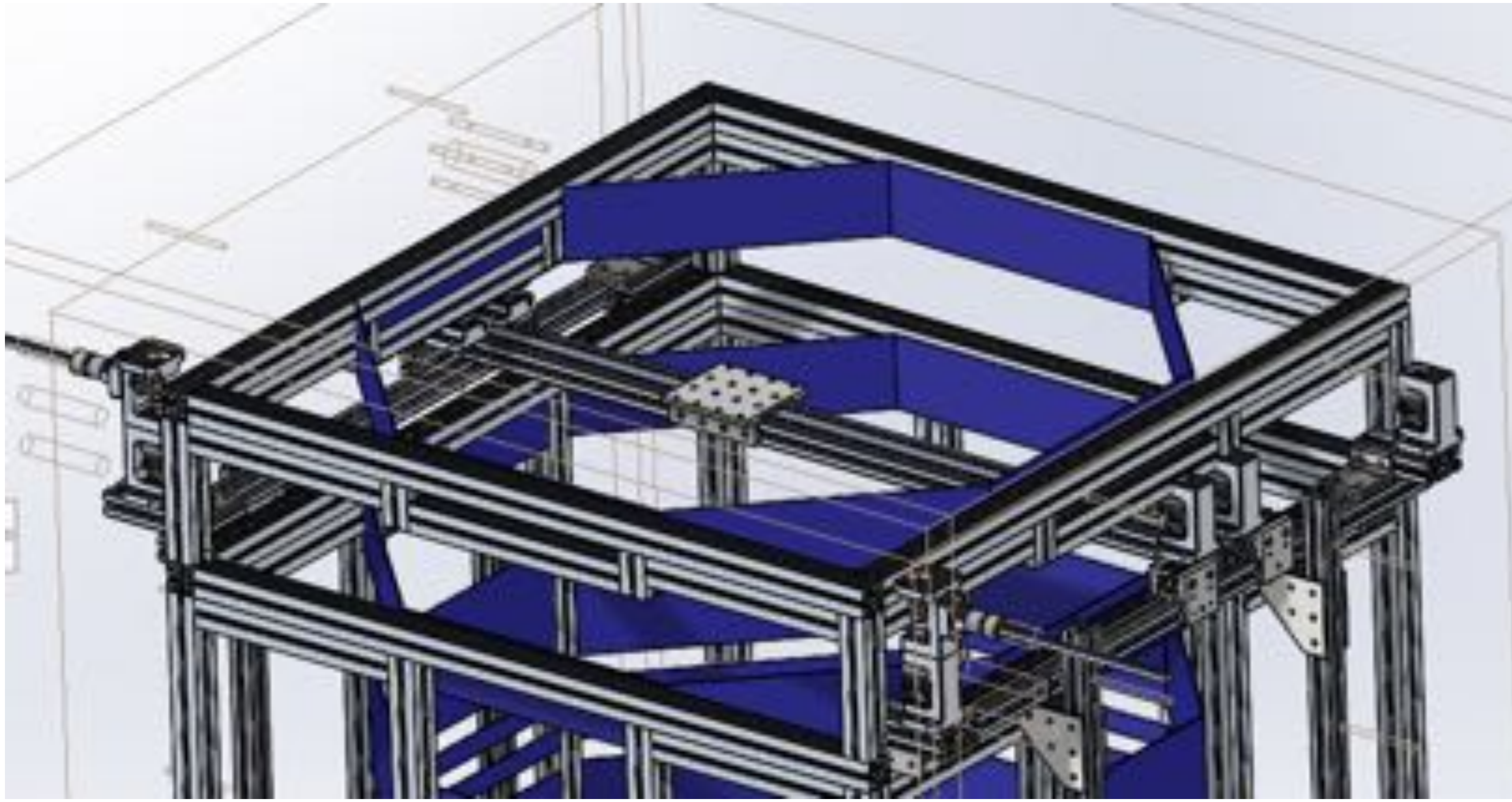
½ Scale B_0 Prototype

- Finishing design phase
- Will be housed in existing MSR at LANL
- Based on modeling, we expect the coil to produce $\left\langle \frac{dB_z}{dz} \right\rangle < 1\ \mathrm{nT/m}$



Mapping

- H-frame mapper
- Similar to expected implementation for full scale
- Shim coils—see next take by Austin Reid



Spin Transport

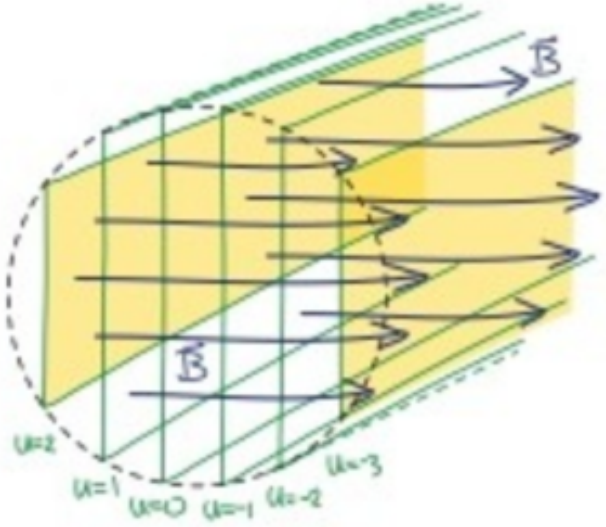
From the PPM to the switchers:

- Rectangular Helmholtz coils provide a large magnetic field in the neutron guide regions
- Roughly uniform magnitude throughout
- Transverse to the guide direction to reduce leakage though MSR penetrations

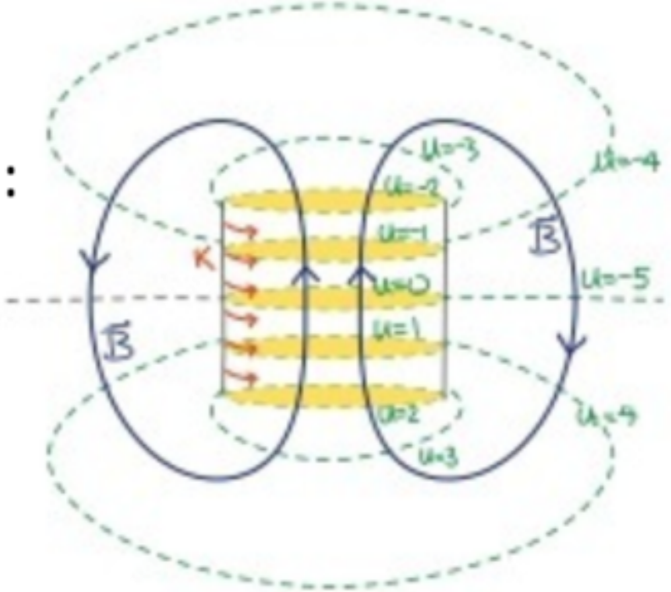
Spin Transport Design

- Transport coils were designed using a technique developed by Chris Crawford (*U Kentucky*)
  - Construct a FEA model for your coil geometry
  - Impose flux condition for your ideal field on the coil surfaces
  - Solve the Laplace equation for the given boundary conditions
  - The magnetic potential on the surface of the coil represents your current winding pattern

Cos-theta coil:



Solenoid:

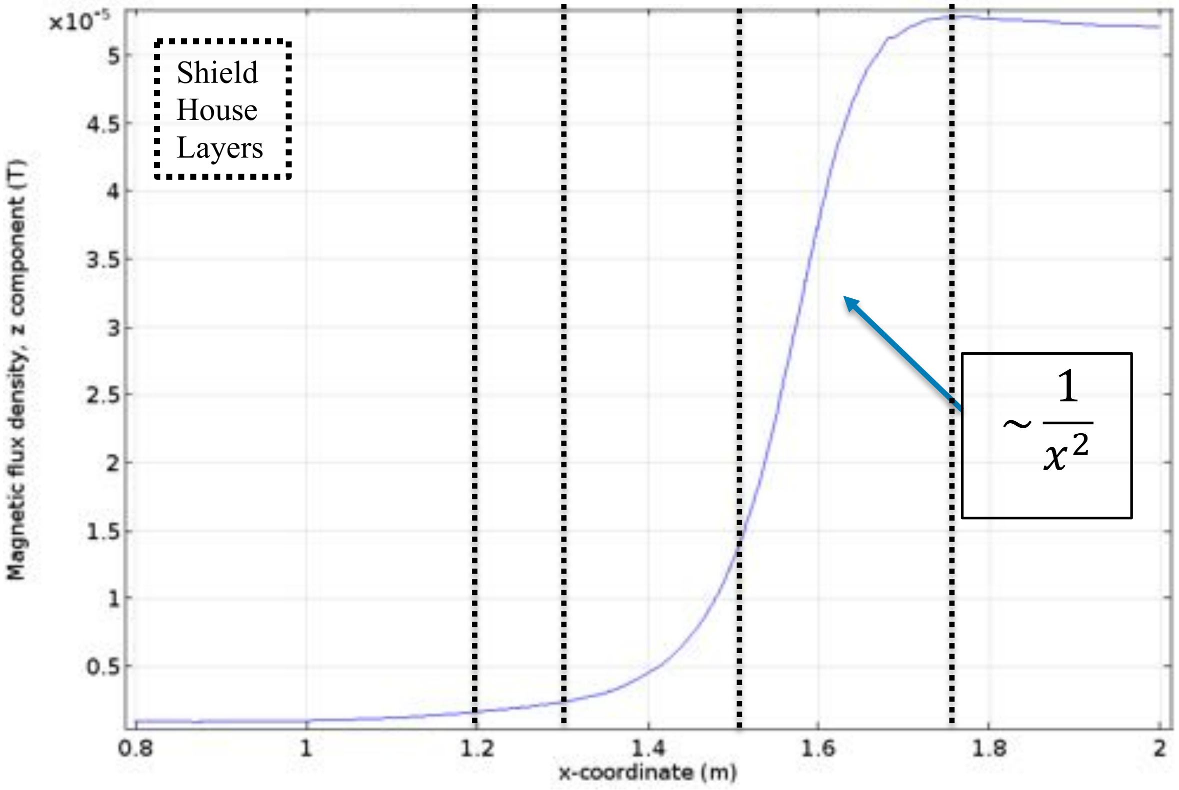


Images from Chris Crawford

Spin Transport Coils

- Coils provide field to keep spins aligned in z direction
- Requirements:
  - Overcome ambient magnetic field on the outside of the shield
  - Match the B_0 field on the interior of the shielding
  - Maintain adiabatic condition with respect to the field gradients
  - Don't distort the B_0 field

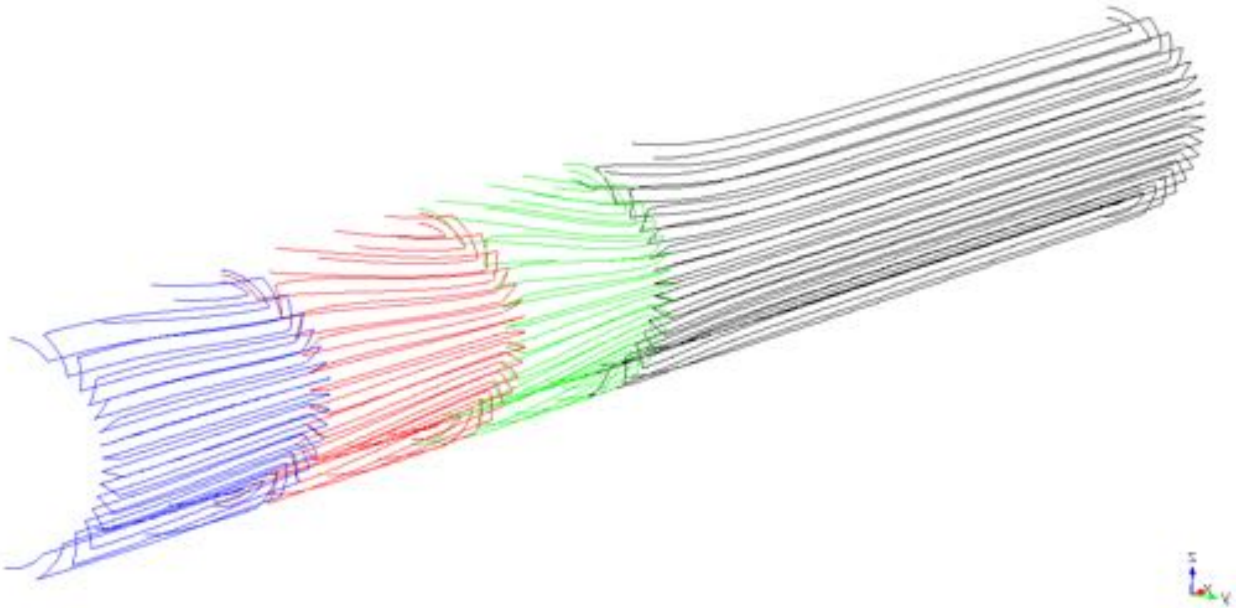
$|B_0|$ along the axis of the Spin Transport Coils

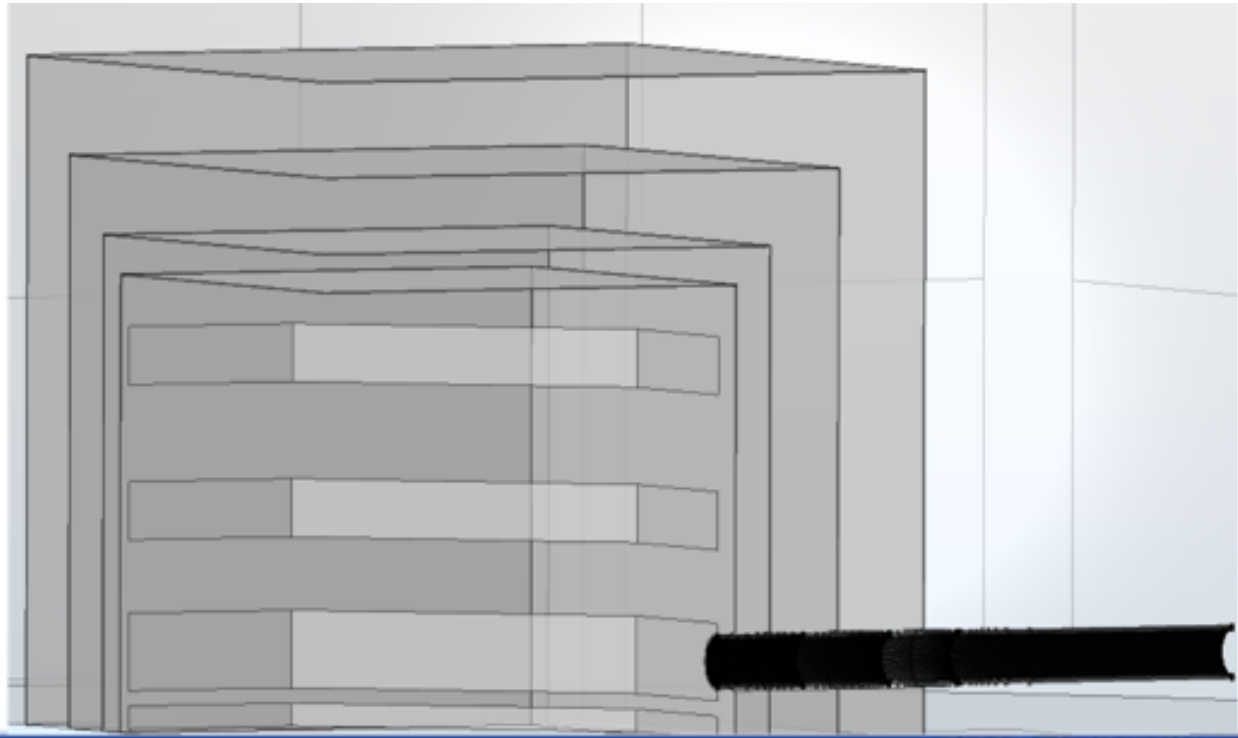


$$\kappa = \frac{\left|\left((\boldsymbol{v} \cdot \boldsymbol{\nabla})\boldsymbol{B}\right) \times \boldsymbol{B}\right| \ / \ B^2}{\gamma_n B}$$

Spin Transport Coils

- Double layer, modified Cos θ coil
- Solved for contours on a cylindrical shell
- 4 coils shown on the top right
  - Only one half of coils shown
  - Clam-shell design around neutron guide
  - Each coil (color) has independent current applied





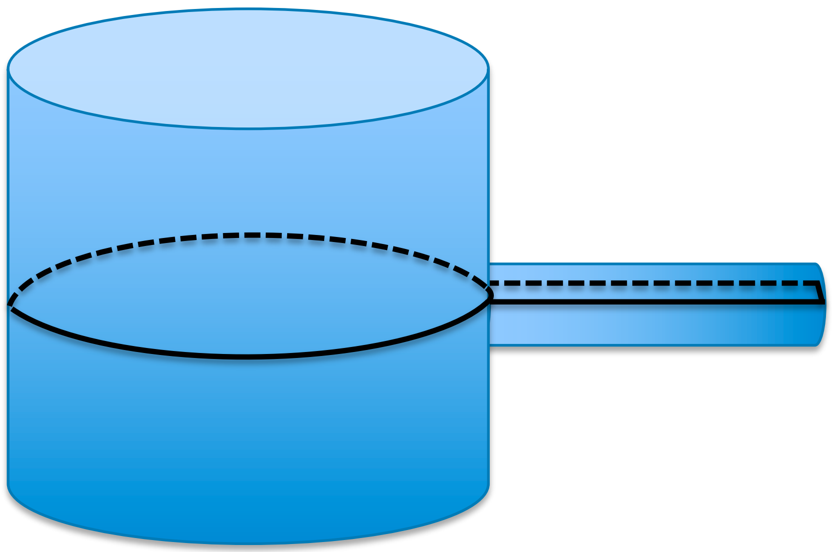
Spin-Transport Interface

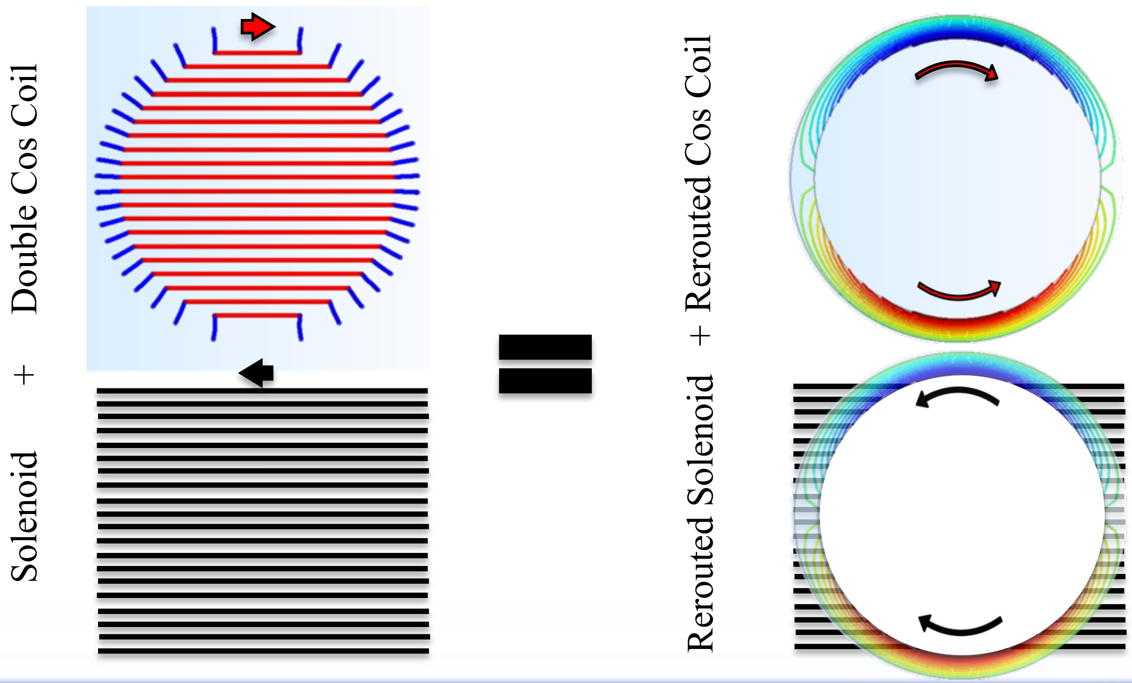
- Magnetic scalar potential design technique requires a closed surface on which windings will be places

- The gaps in the B_0 coil violate this condition

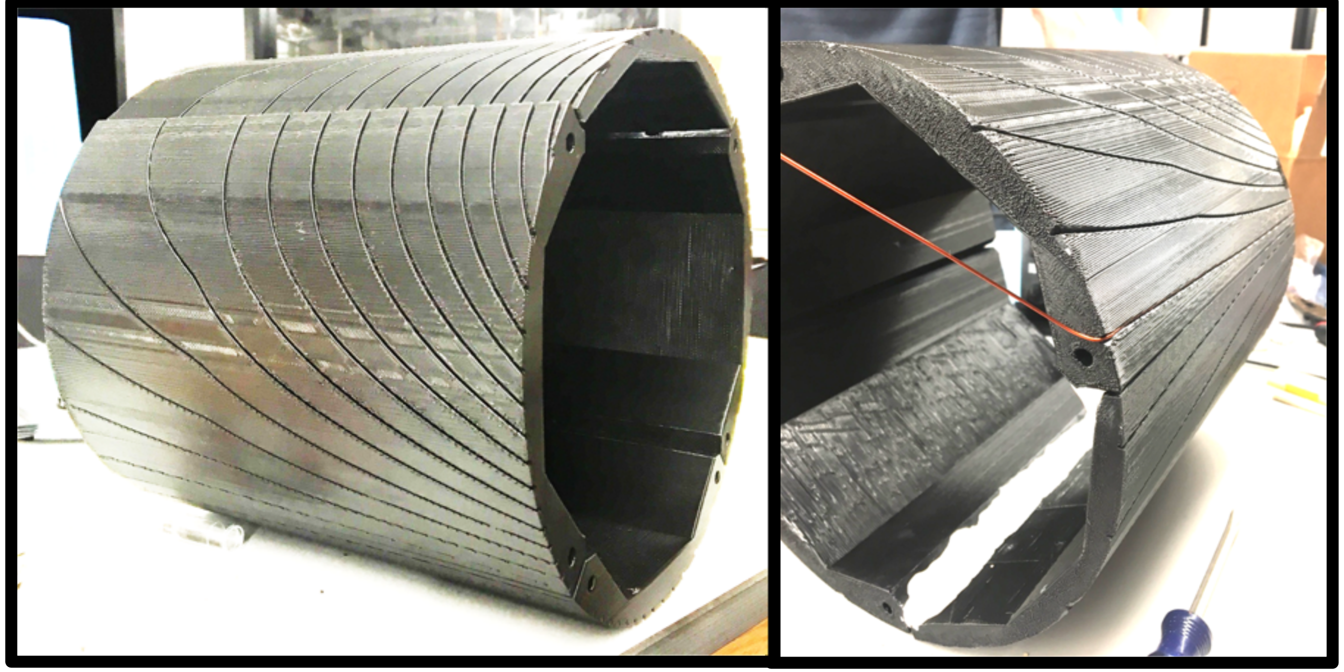
- We can still make the transport coils “pseudo-continuous” with the B_0 coil to reduce transport field leakage

Coil Providing Vertical Magnetic Field

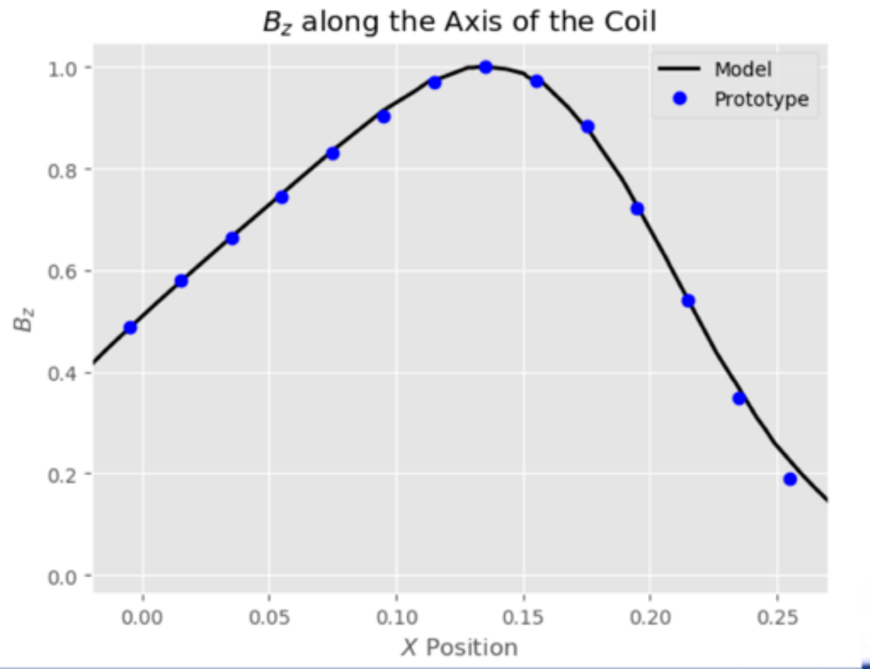




Prototyping



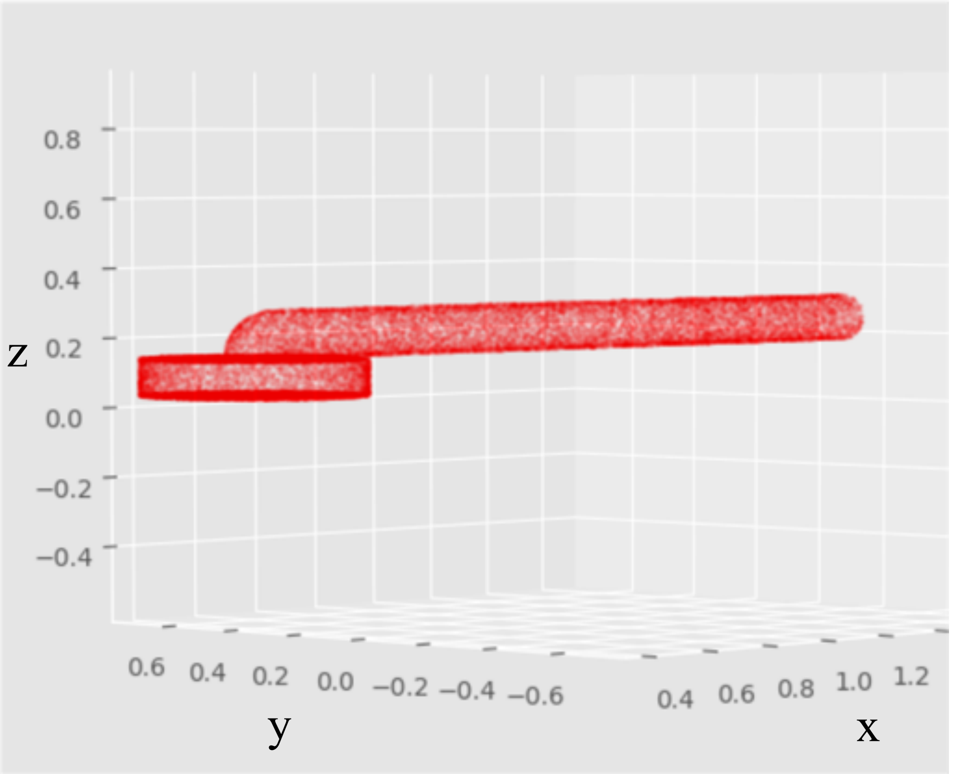
- 3D printed cylindrical shell
- Grooves for wires
- Matches expected field from COMSOL



Simulation Work

- Using PENTrack to analyze efficiency of transport coils
- In-house simulation being developed and benchmarked against PENTrack
- Working on coil design for finalized experimental setup
  - Results coming soon

3D Plot of collision points for simulated neutron for visualizing geometry



Summary

- COMSOL used to design the B_0 and spin transport coils
- B_0 design completed
  - Prototyping is underway
- Spin transport design in final stages
- Using PENTrack to simulate spin dynamics in modeled magnetic field

- Work in progress…
  - B_1 coil design
  - Shim coils (A. Reid)
  - Simulation development
  - Many new ideas to consider from this workshop!

Thank you!

Los Alamos Neutron EDM Collaboration

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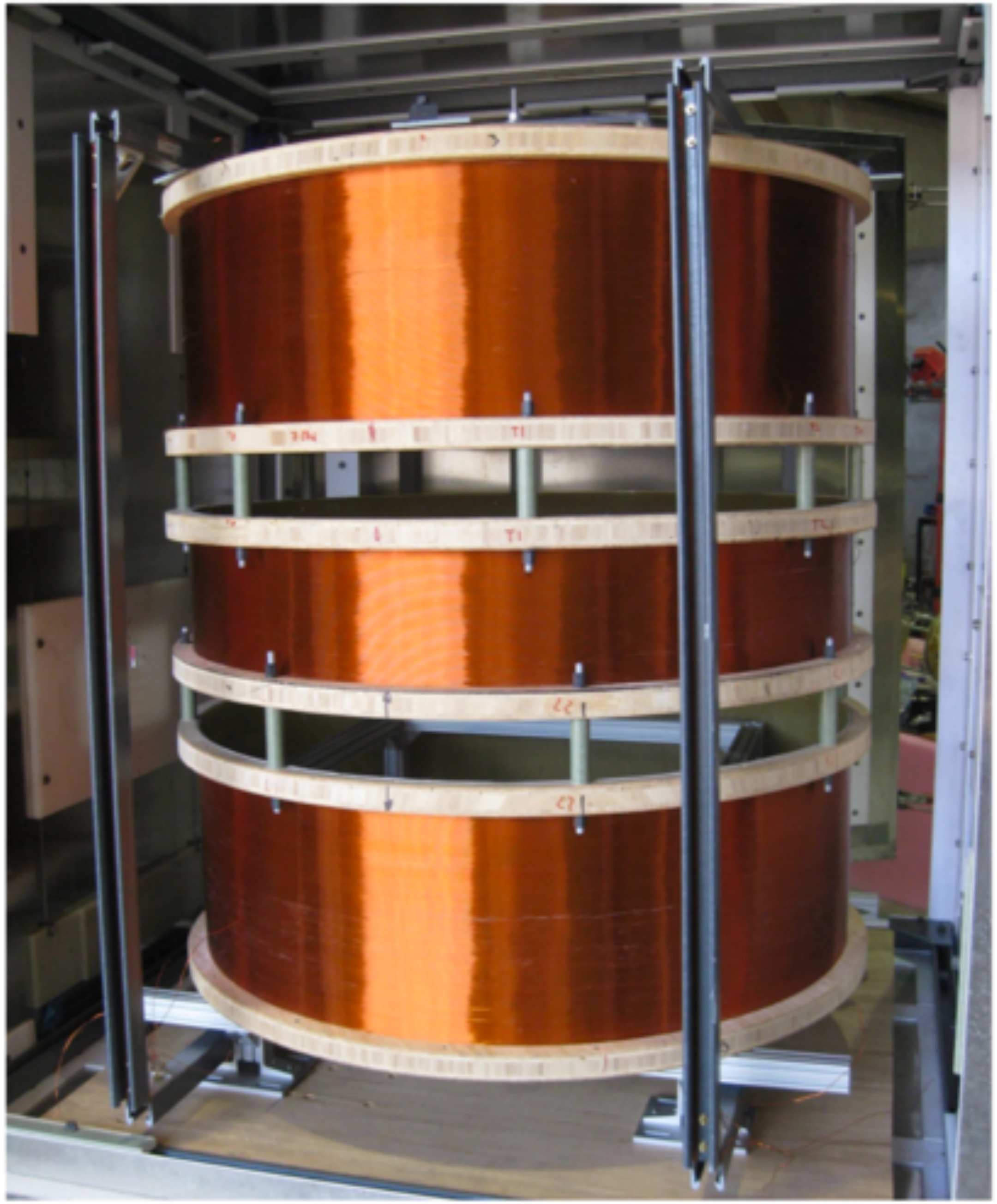
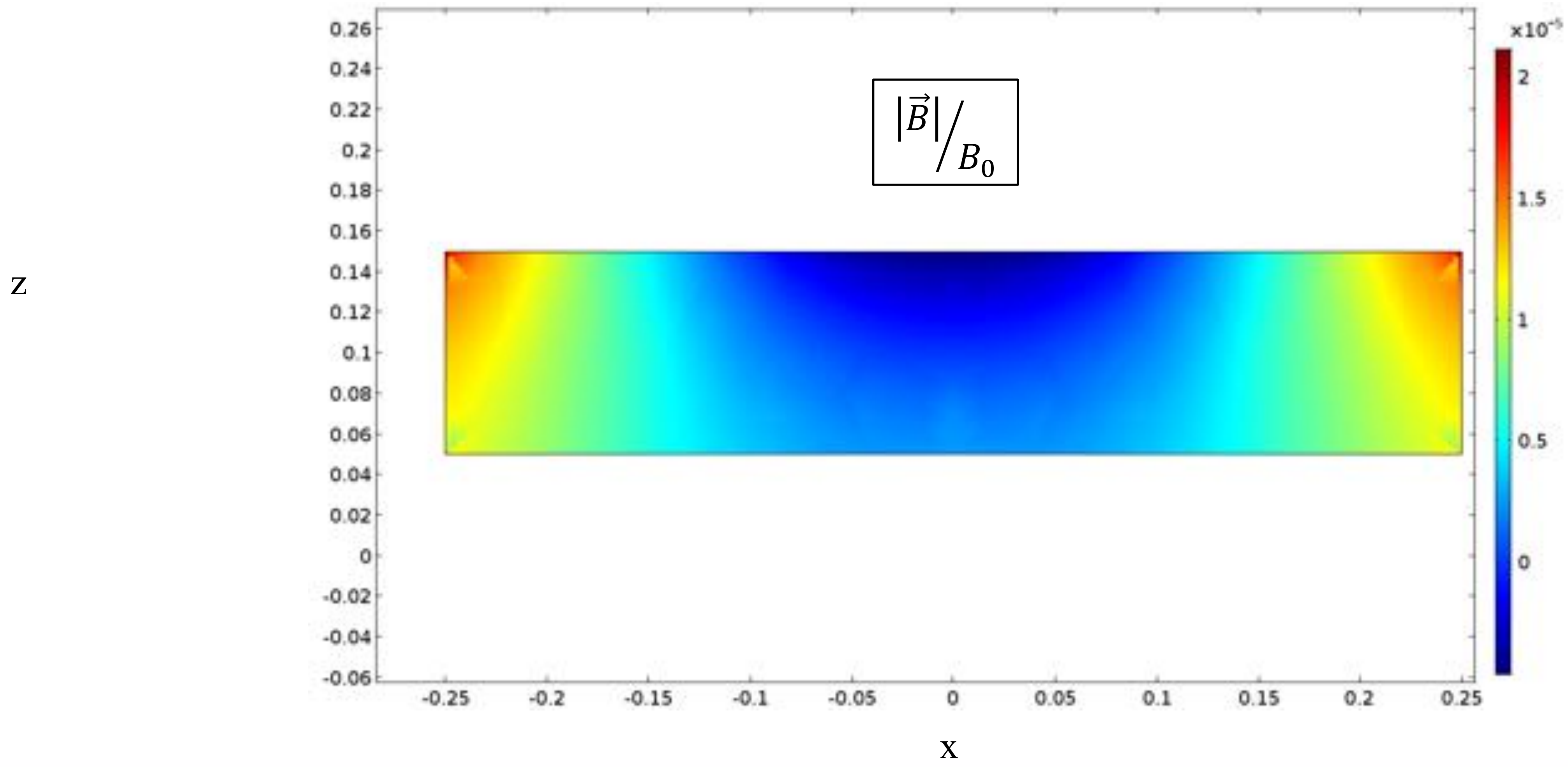
Backup Slides

Prototype

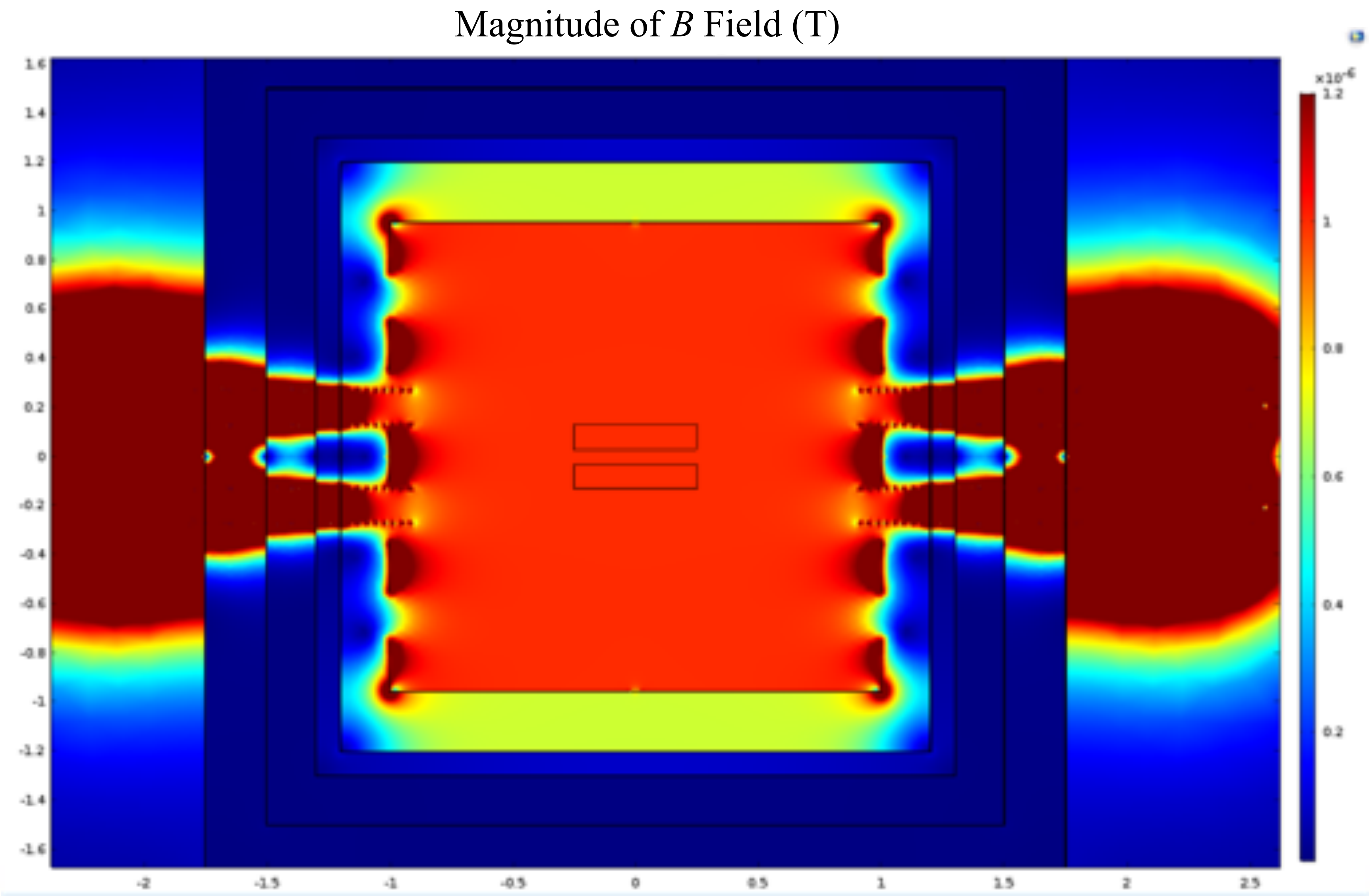
- Ryan Dadisman (*ORNL*) designed a double gapped solenoid (DGS) for the single-cell experimental setup at LANL
- Ryan and Alina Aleksandrova constructed the prototype DGS (shown in place within the original shield house)
- Maps of the prototype coil in the shield house were taken and compared to the modeled coil and shielding with good agreement



B_0 Field Profile in Cell Volume



Field Profile with transport coils



Updated Design—Field Profile