Self Shielded Holding Field Coil for the nEDM Experiment at TRIUMF

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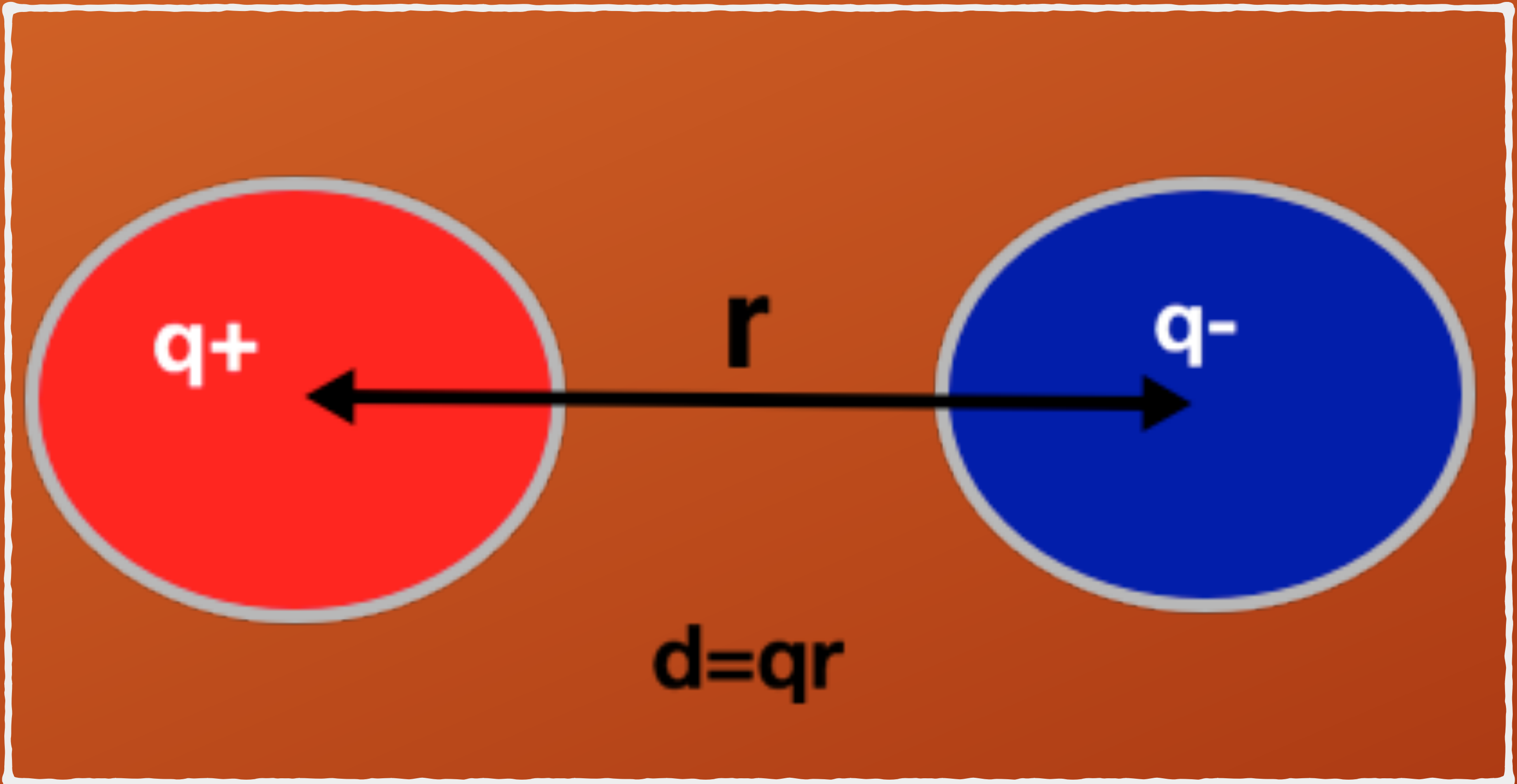
Why nEDM?

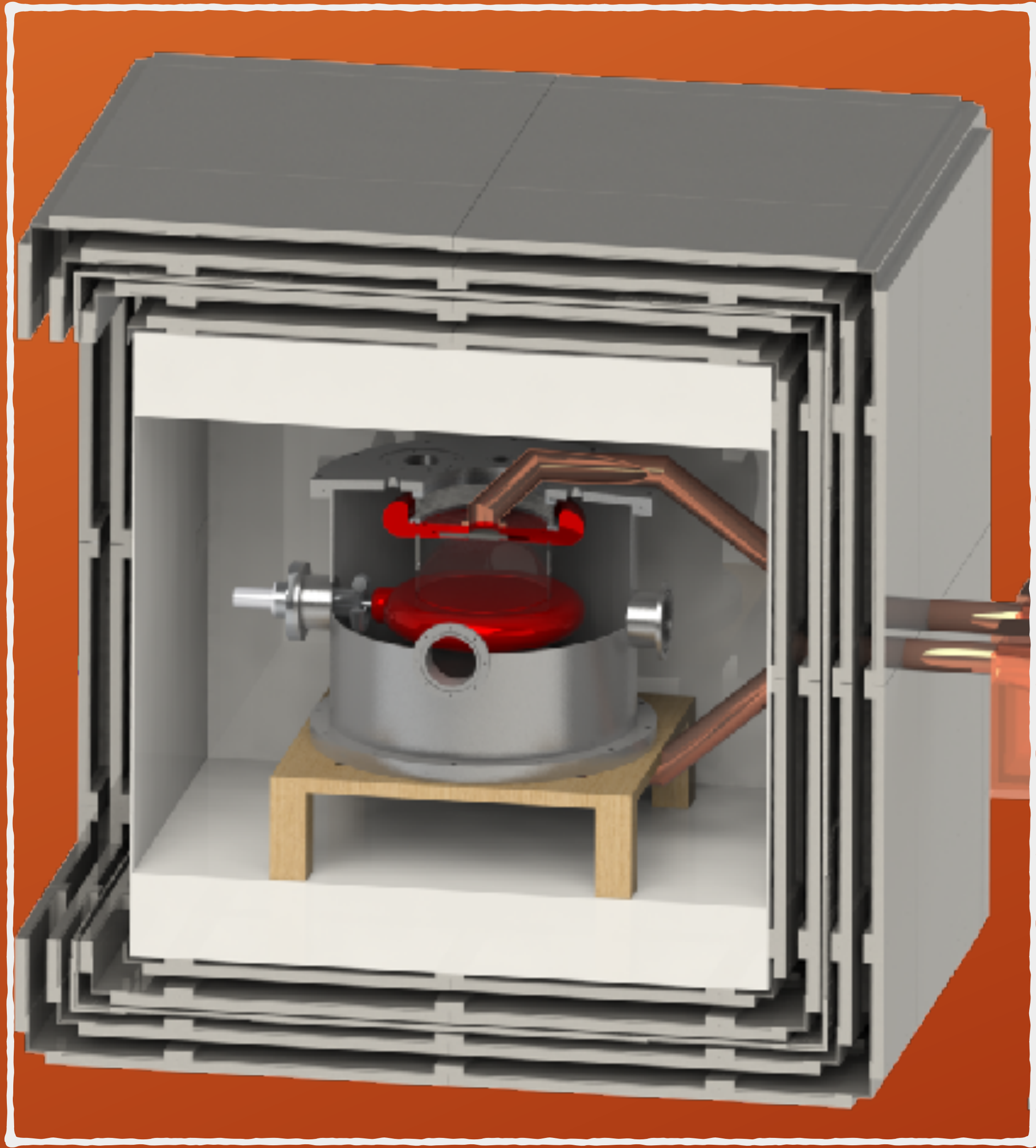
- The electric dipole moment is the distance between positive and negative charges within a system.
- The size of the neutron Electric Dipole Moment predicted by the standard model via the CP violating phase of the CKM matrix is $\sim 10^{-31}$
- Larger value could help explain the baryon asymmetry



The nEDM experiment at TRIUMF

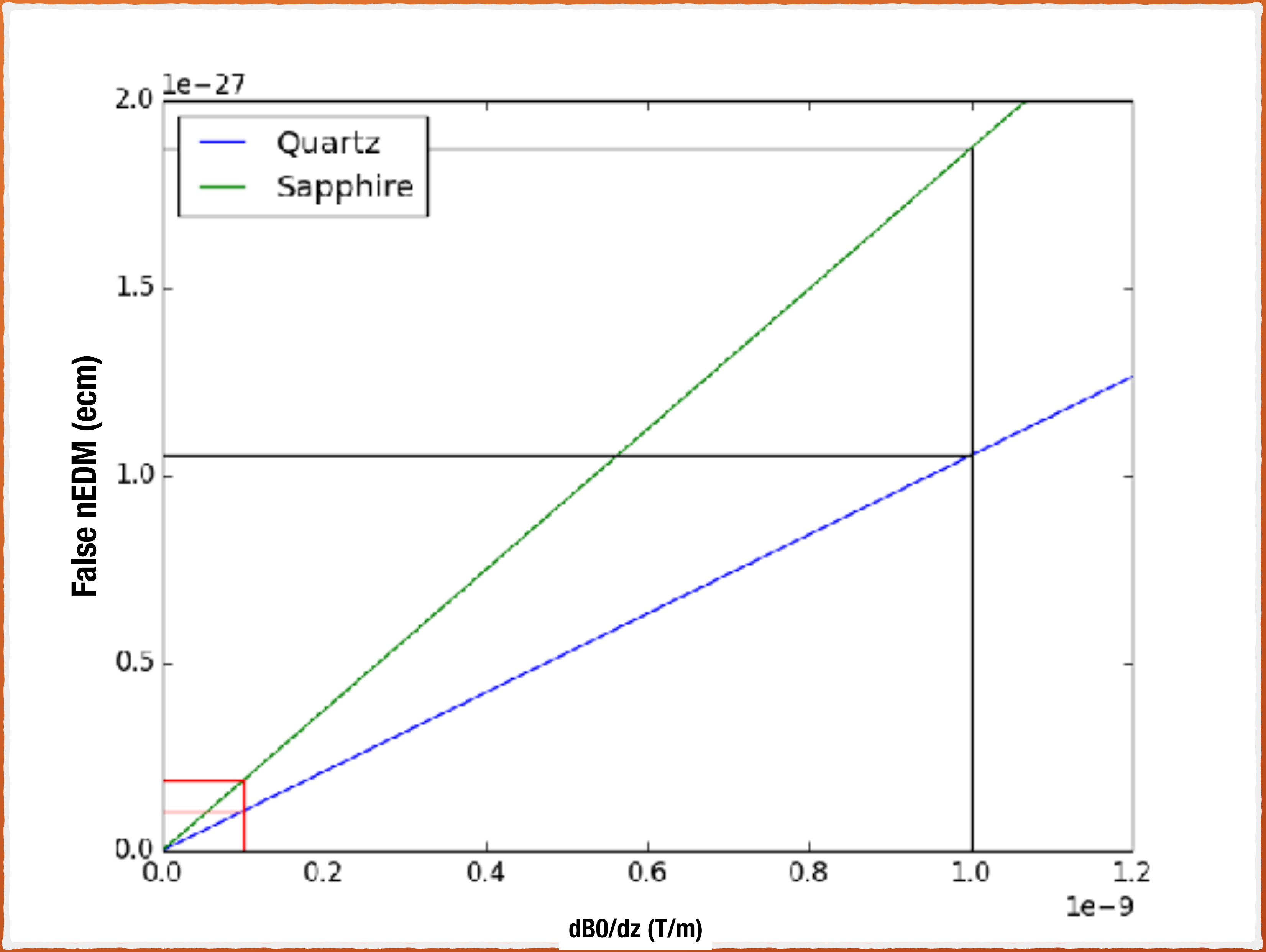
- Uses new high intensity ultra cold neutron (UCN) production technique.
- Next generation experiments are aiming for $d_n < 10^{-27(28)} e \cdot cm$.
- Homogeneity of the B_0 field is major systematic error. Leading to a false nEDM

$$d_{n false} = -\frac{\hbar}{4}\frac{\langle v_n^2 \rangle}{c^2}\frac{1}{B_{0z}^2}\frac{\partial B_{0z}}{\partial z}$$



Pendlebury, J. M, et all,(2004)

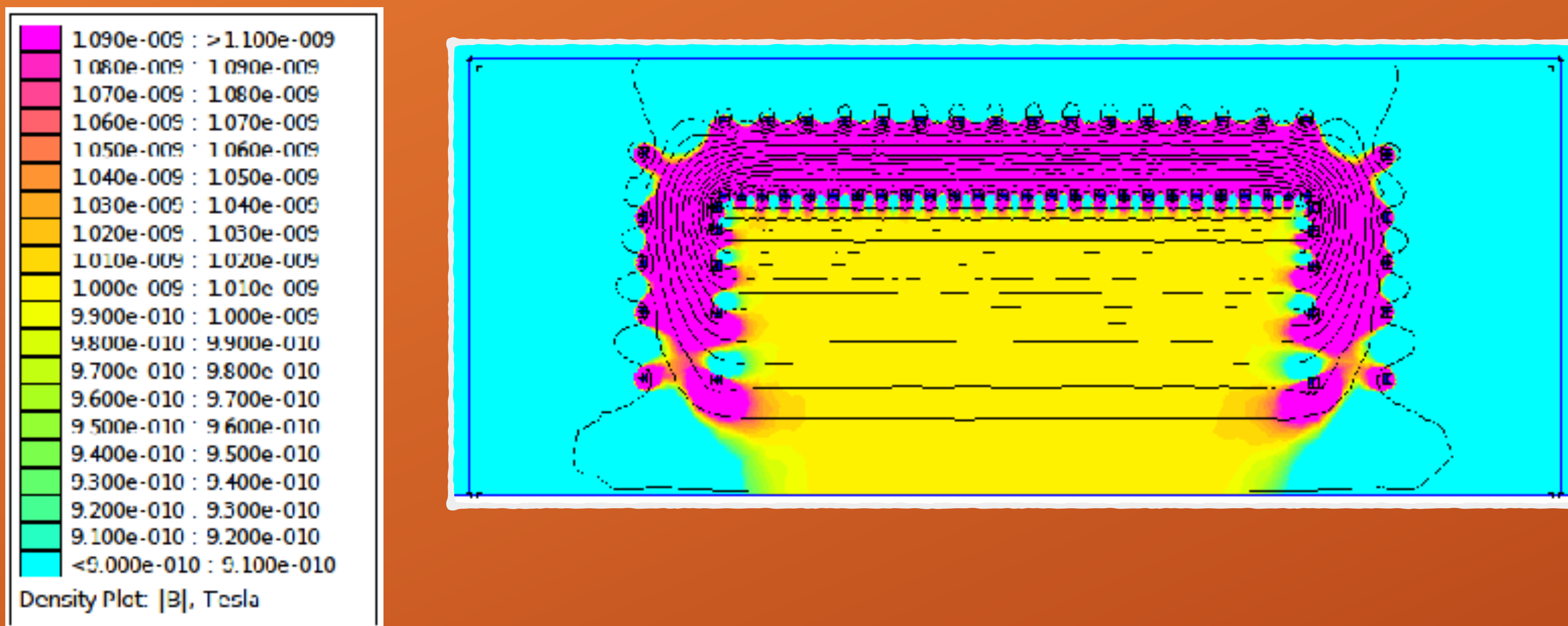
Magnetic Requirements



Fermi Potential, Quartz ~90neV, Sapphire~160eV

- Comparison of two nEDM cell materials and how important they are with regards to field homogeneity requirements
- We want 0.1nT/m because this produces a much smaller false nEDM.

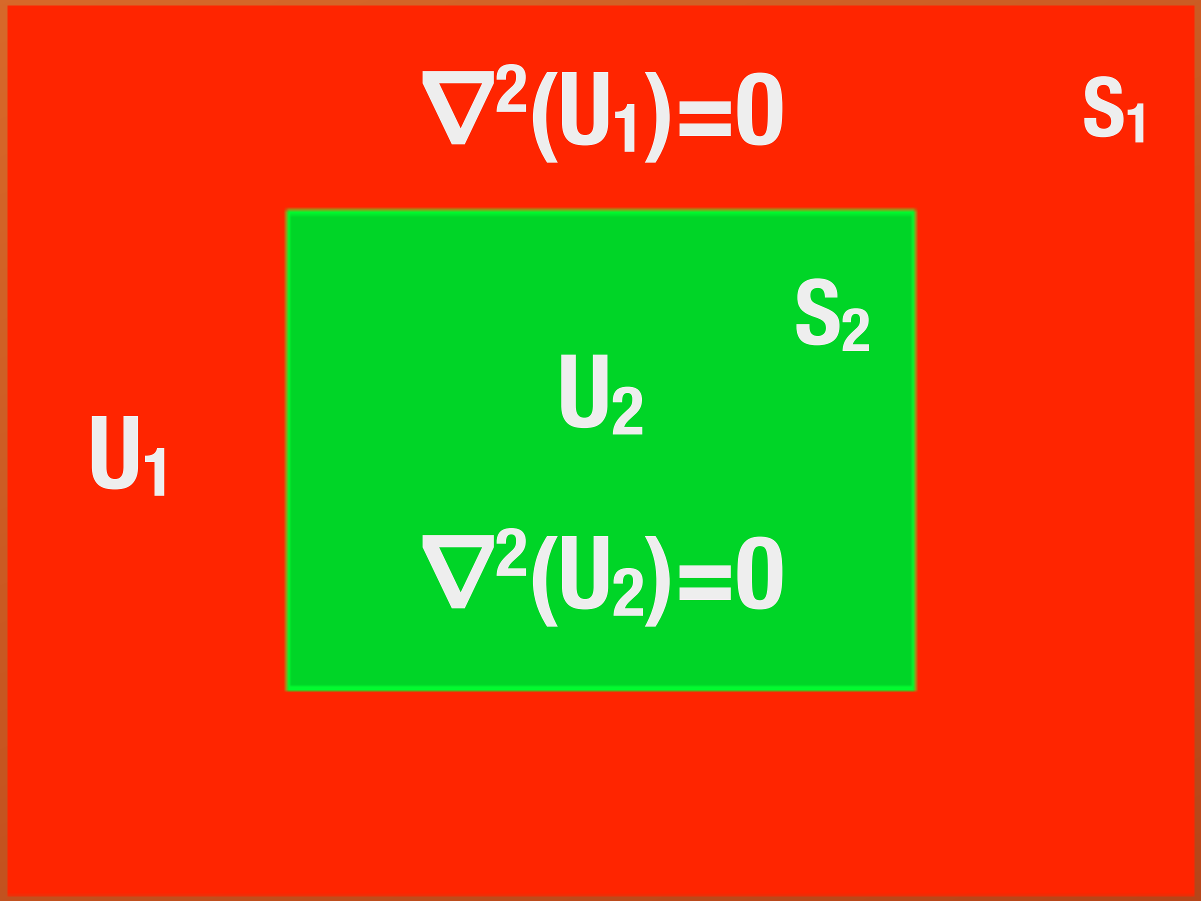
Self Shielded Coil



- ☐ Self contained
- ☐ Inner coils creates magnetic field, outer contains field by application of opposing field.
- ☐ Unknown manufacturing tolerance.

Coil Design Theory

We use Maxwells equations with no free currents or magnetic materials. This means the magnetic field strength (H) can be defined as $H=-\nabla U$ where U is the magnetic scalar potential, and in the regions of free space $\nabla^2 U=0$



We then apply appropriate boundary conditions, that require $U_1=U_2$ at surface 2 and no flux leaving surface 1

Getting Current Wire Placement

ΔU=U$_1$-U$_2$,

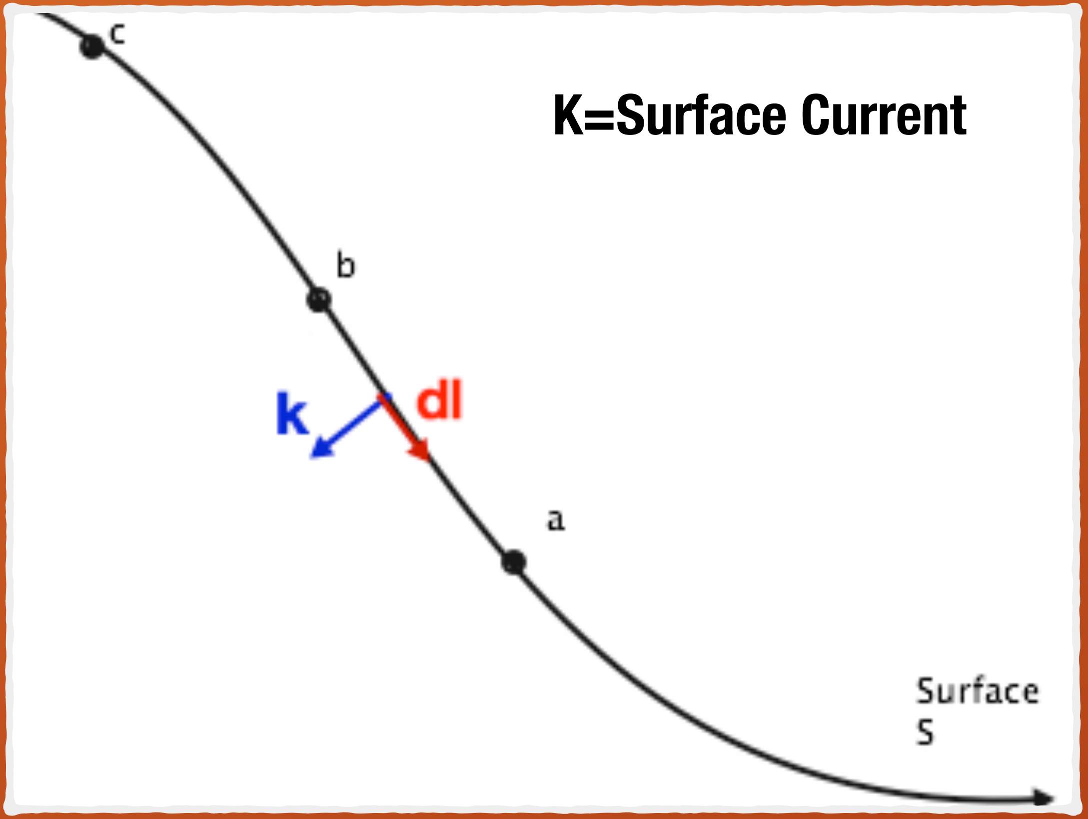
$$\int_a^b [-\overrightarrow{\nabla}(\Delta U)] \cdot d\overrightarrow{l} = -(\Delta U_b - \Delta U_a)$$

This takes you from one contour of constant ∇U containing point a to another containing point b. Then using boundary condition.

$$\hat{n} \times [-\overrightarrow{\nabla}(\Delta U)] = \frac{4\pi}{c}\overrightarrow{K}$$

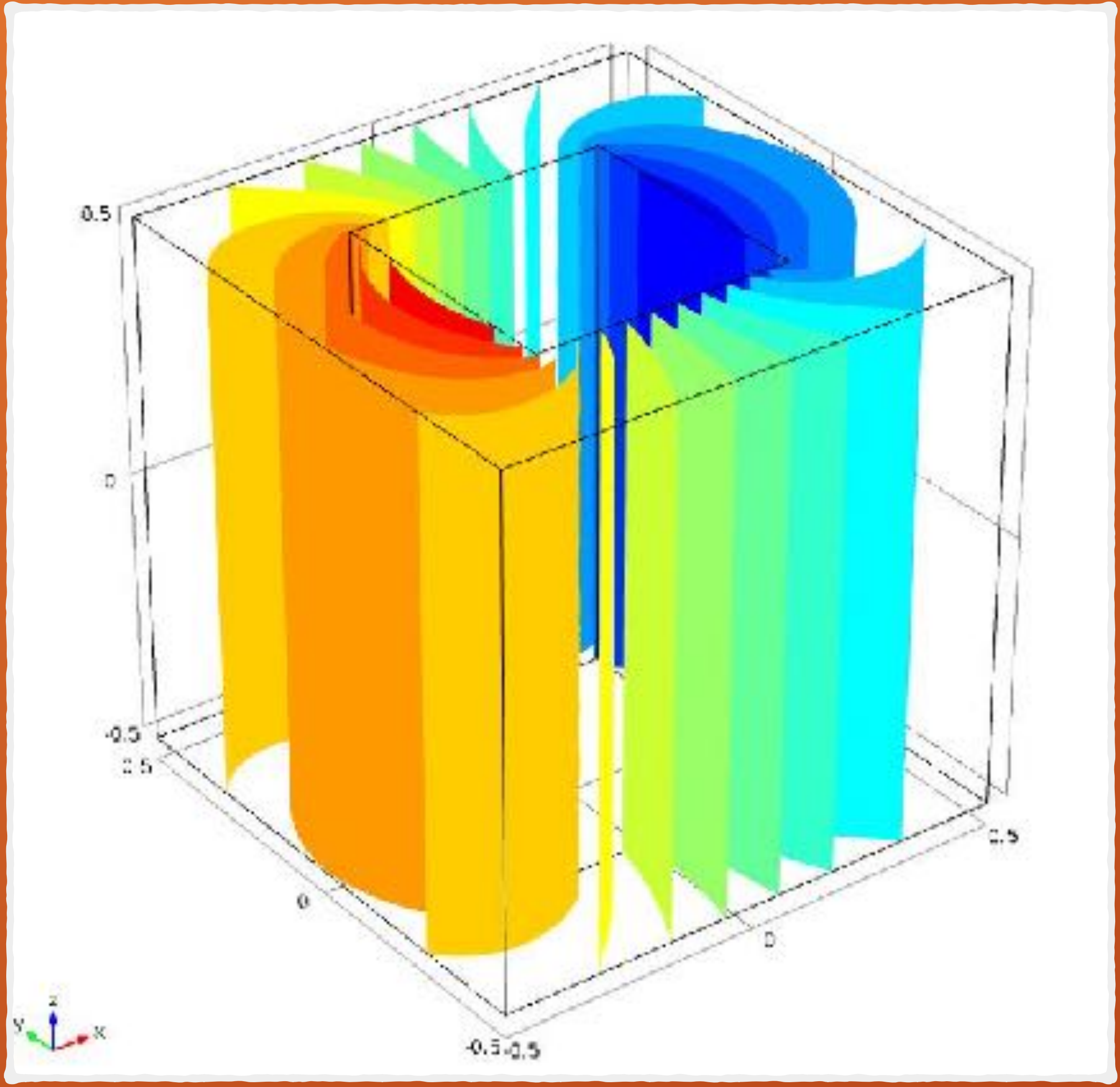
We get that the difference in ∇U's is equivalent to the surface current between a and b

$$\int_a^b (\overrightarrow{K} \times d\overrightarrow{l}) \cdot \hat{n} = -I$$



If the contours are equally spaced then the surface current is the same between each of the contours and can be approximated by equally spaced wires in contours of constant ΔU

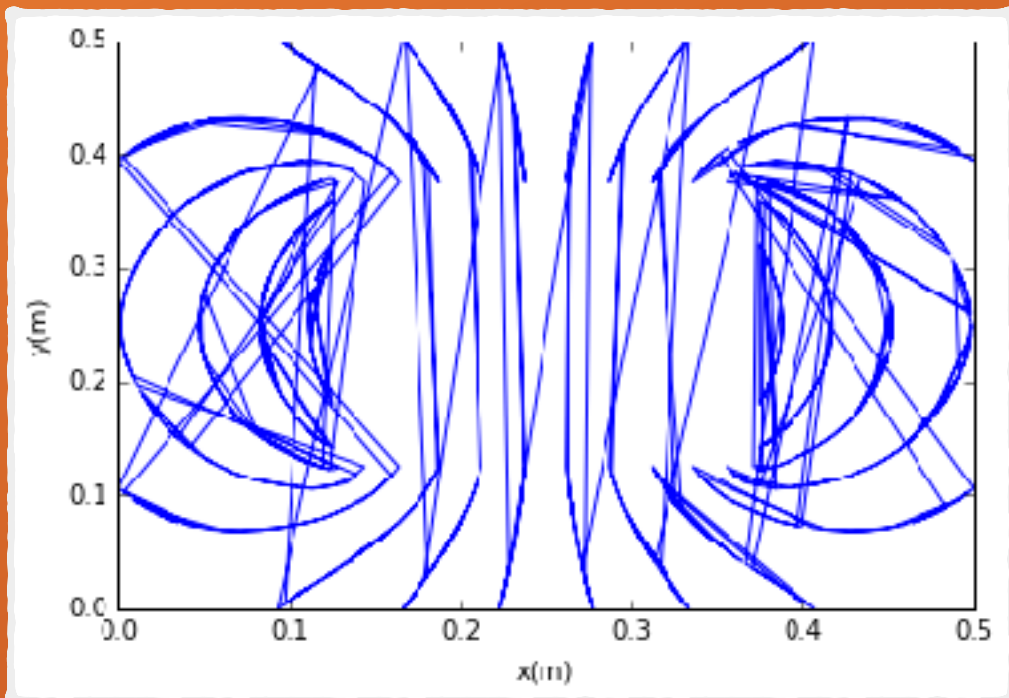
COMSOL

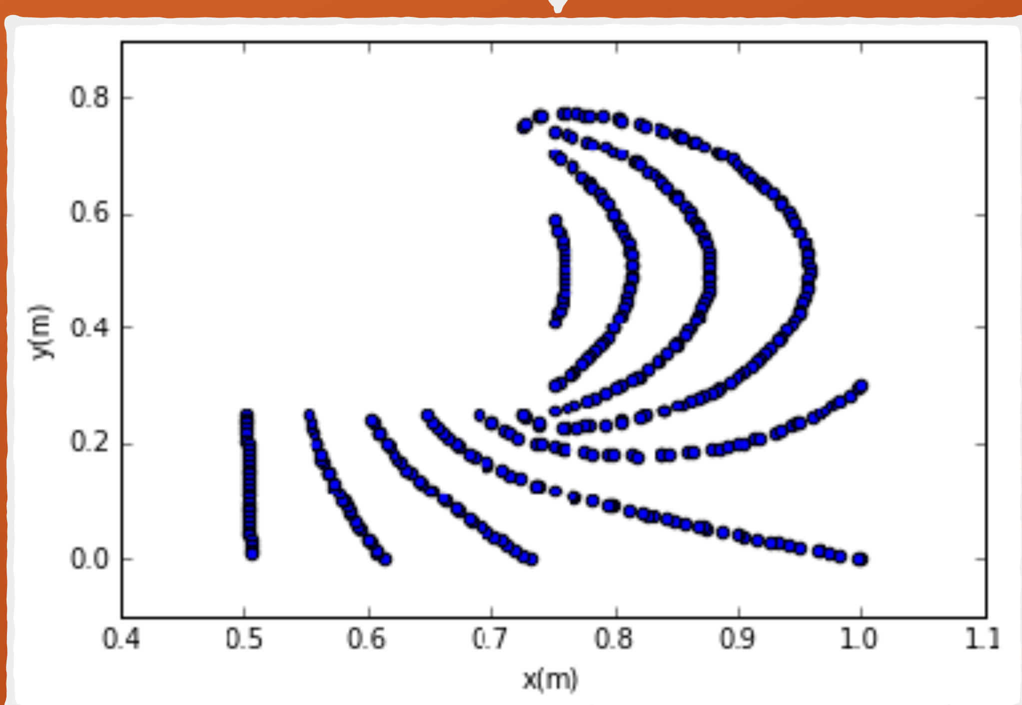


- Finite Element Analysis (FEA)
- Employs boundary conditions to define current placement for the desire magnetic field.
- Giving contours of constant ΔΔU (change in ΔU)

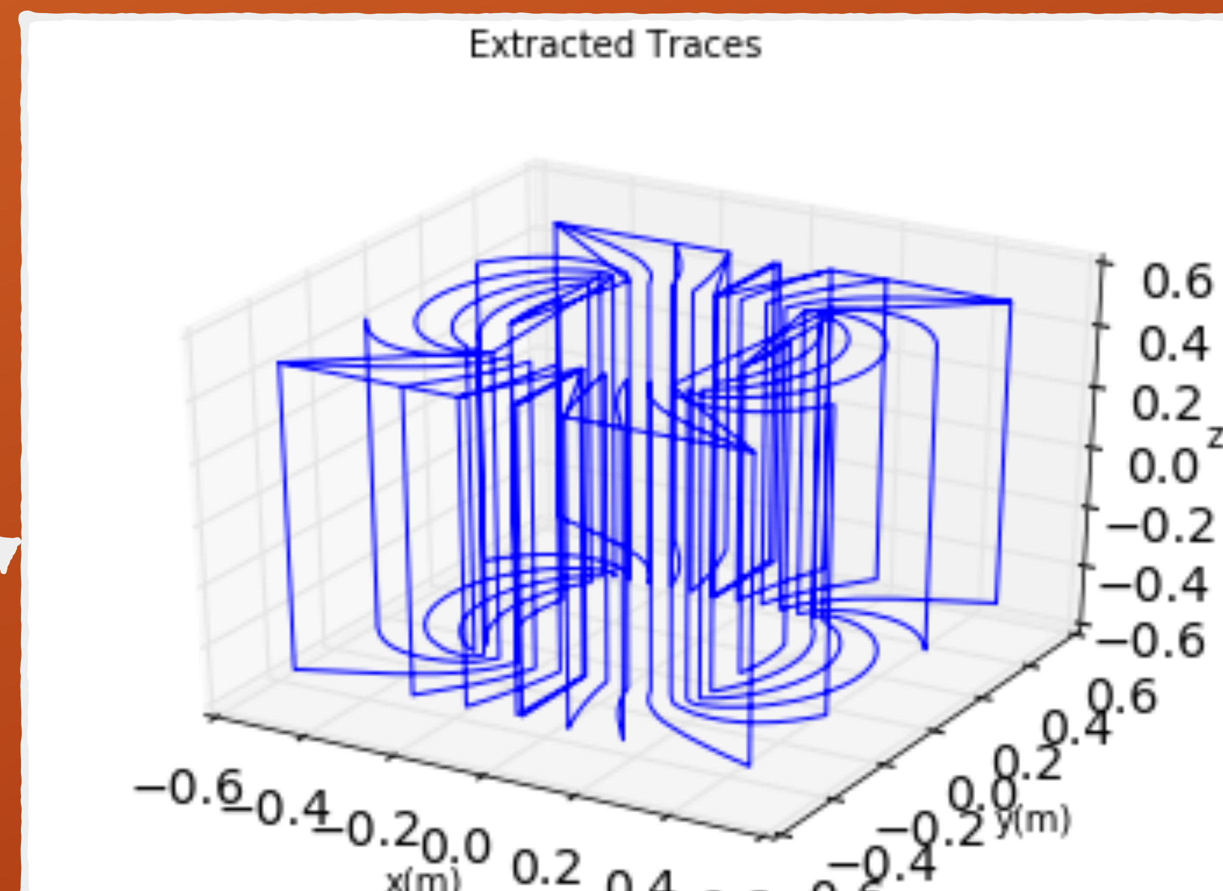
We take these contours and interpret them as wires.

Sorting Points

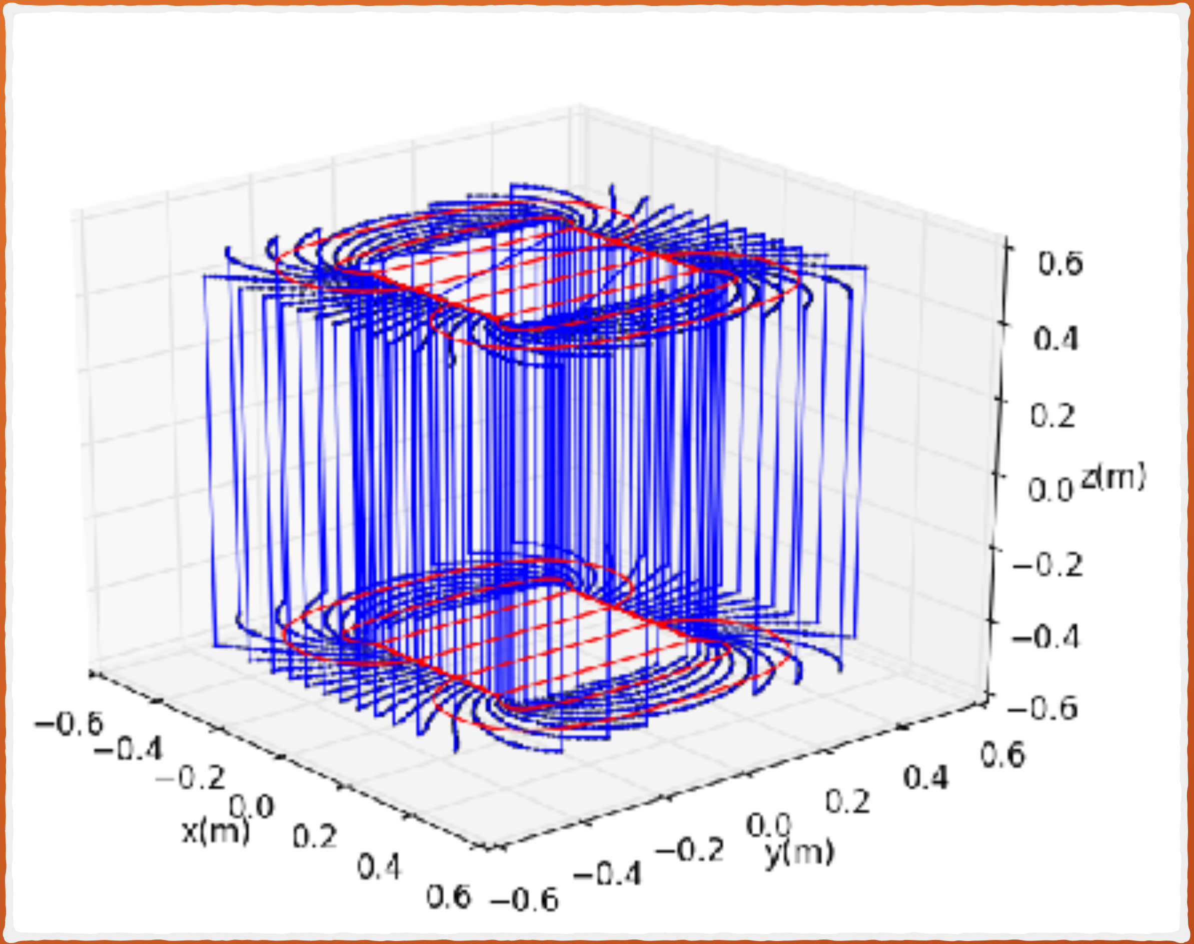


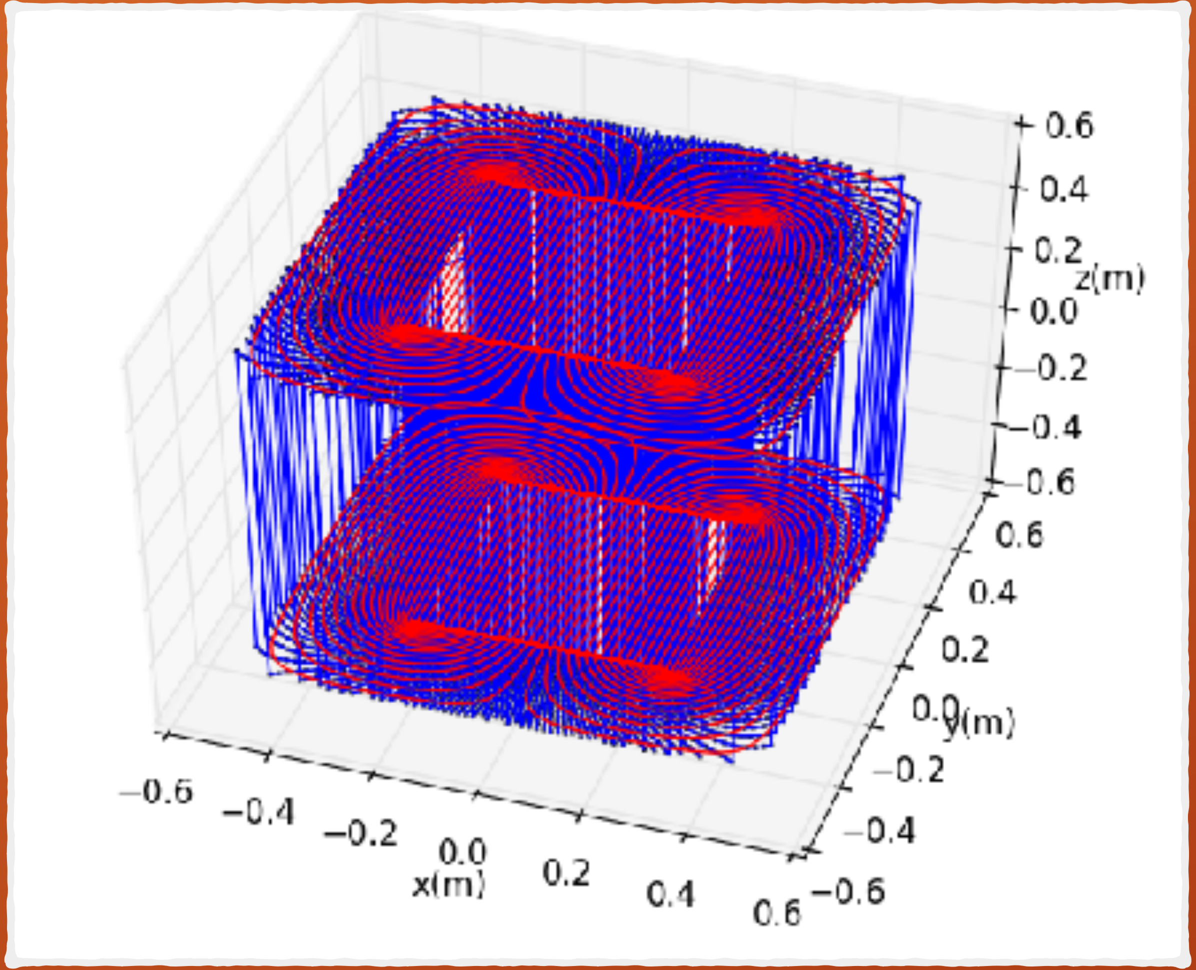


- COMSOL outputs the points separating the levels of constant ΔΔU, but not necessarily the right order.
- Uses Python script to take COMSOL's output and put it a format suitable for a Biot Savart calculation



Model Variations

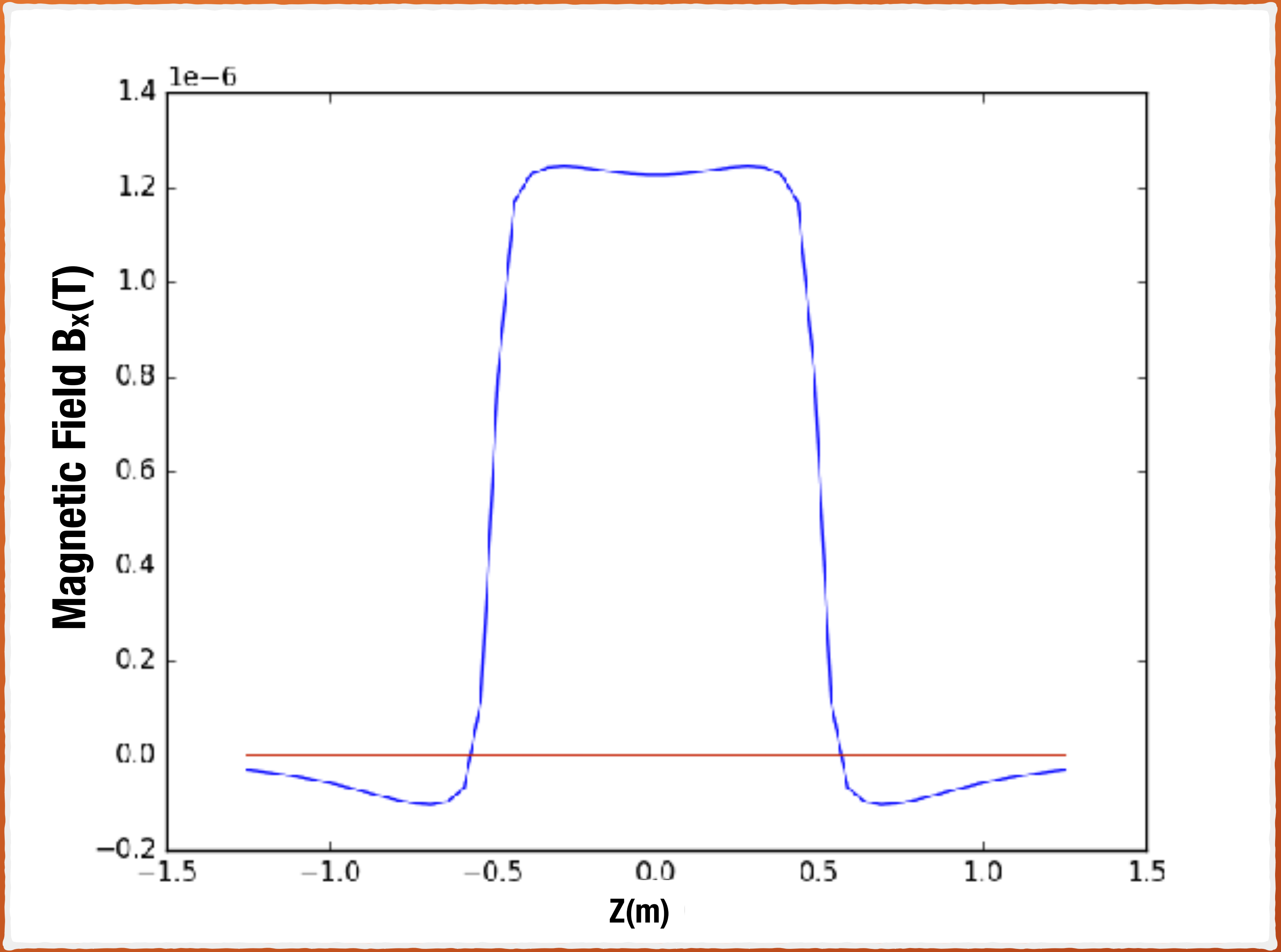




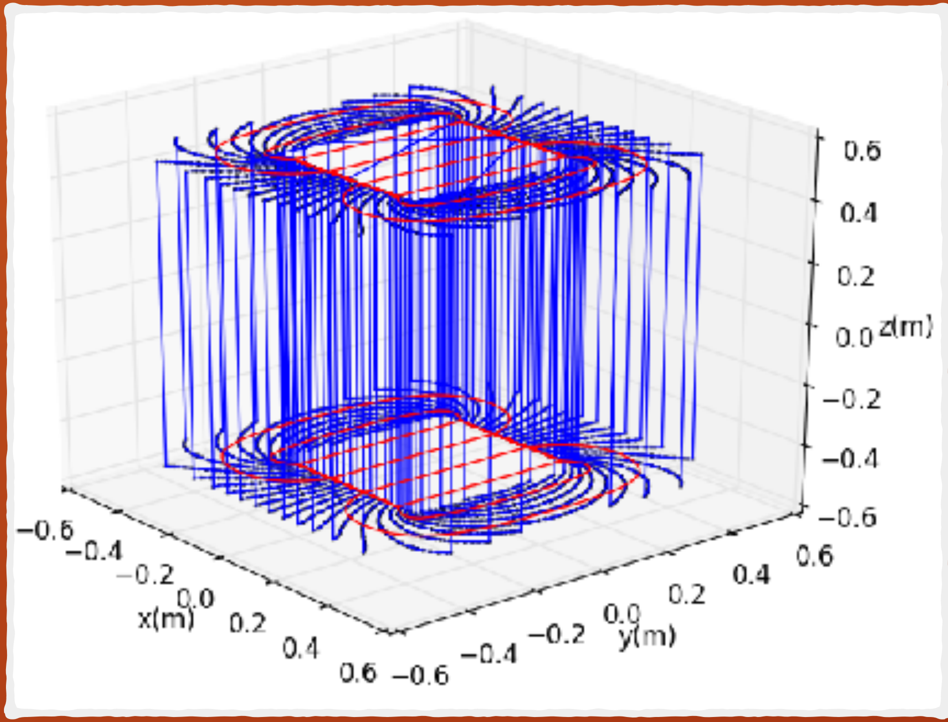
Main coil=64 turn
End cap=4 turn

Right: Main coil=256 turn
End cap=32 turn

Magnetic Field



- We use Biot Savart calculation to find the magnetic field created by the coil



Magnetic field along the z-axis, Blue $=B_x$ and Red$=B_z$ and Green $=B_y$

Future Work

- Fabrication tolerance investigation
  - Current wire zig zags on surface.
  - Comparisons on moving each coil lop.
- Full optimization of coil
- Gradient compensation coils

Thanks

- Dr Chris Crawford
- CINP
- NSERC
- University of Winnipeg