NN' zoom meeting • April 14, 2026

Progress:

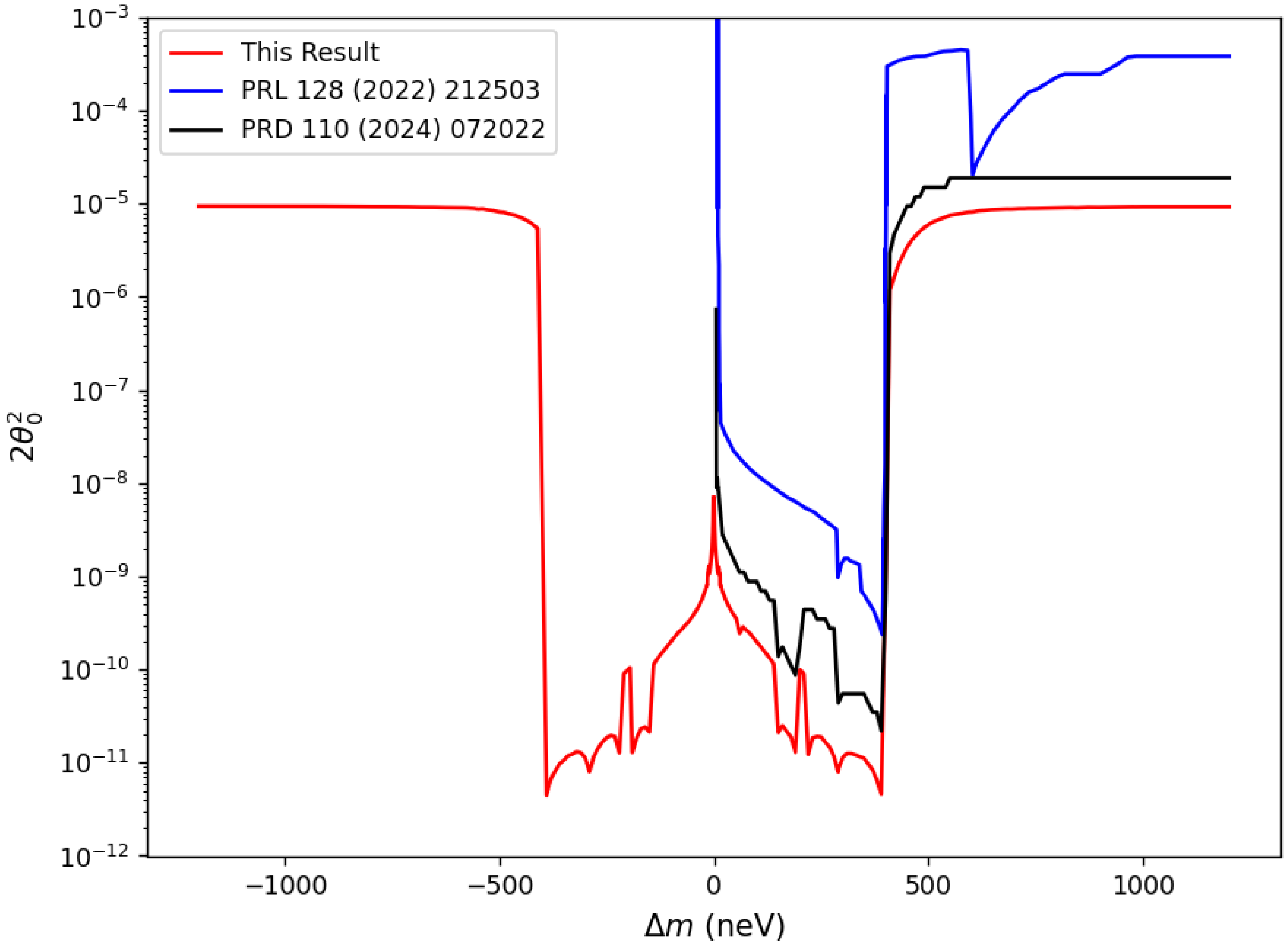
- Linus finished his 24 butterfly simulations for PRD paper – last meeting
- Now Nathan making drawings for the paper including our results and latest UCN PSI limits
- German's slides from the last meeting will be uploaded to INDICO site for this meeting

Agenda:

1. Nathan -Update on drawings for PRD paper 15'
2. AOB

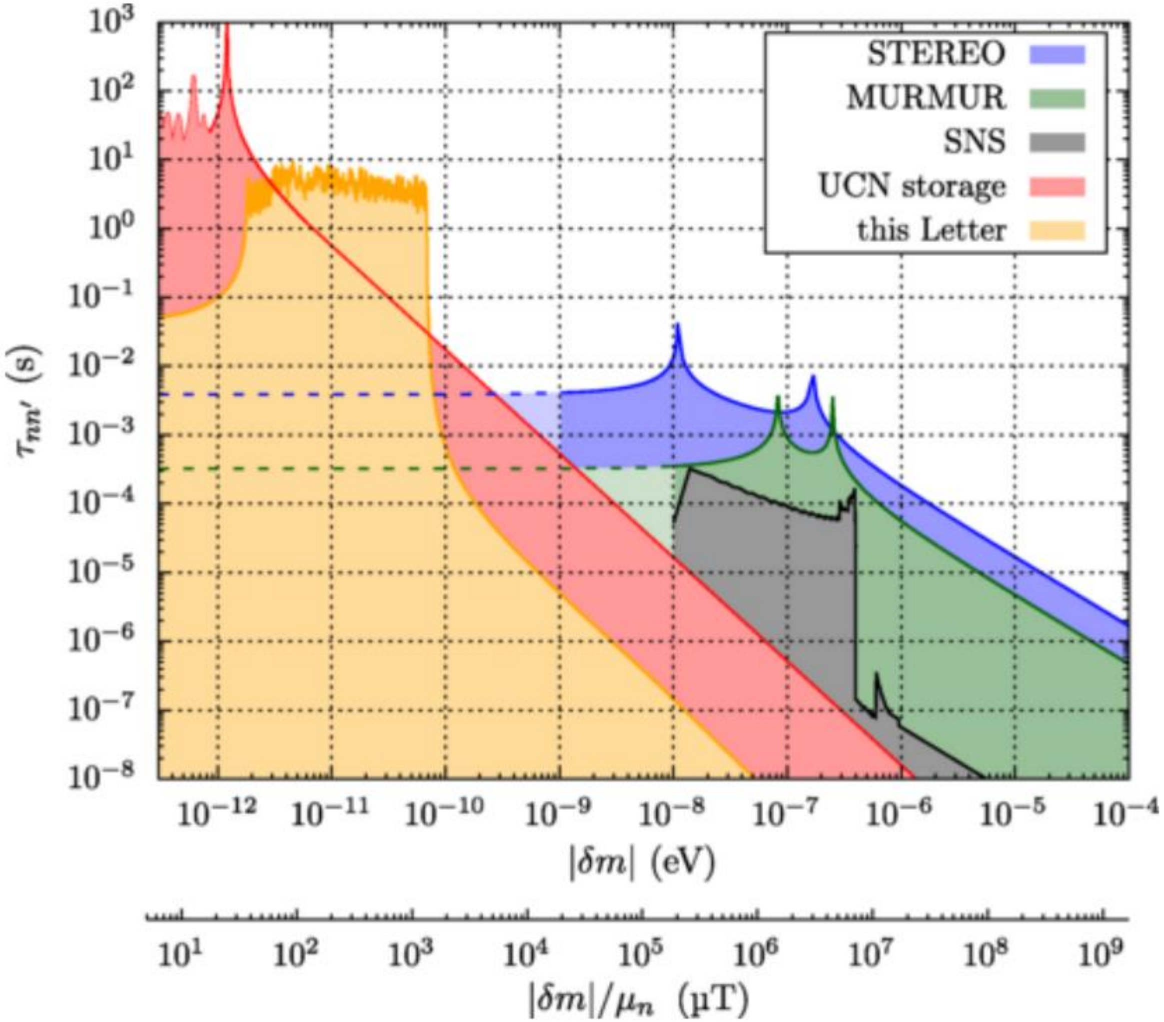
Nathan Whittington, April 14, 2026

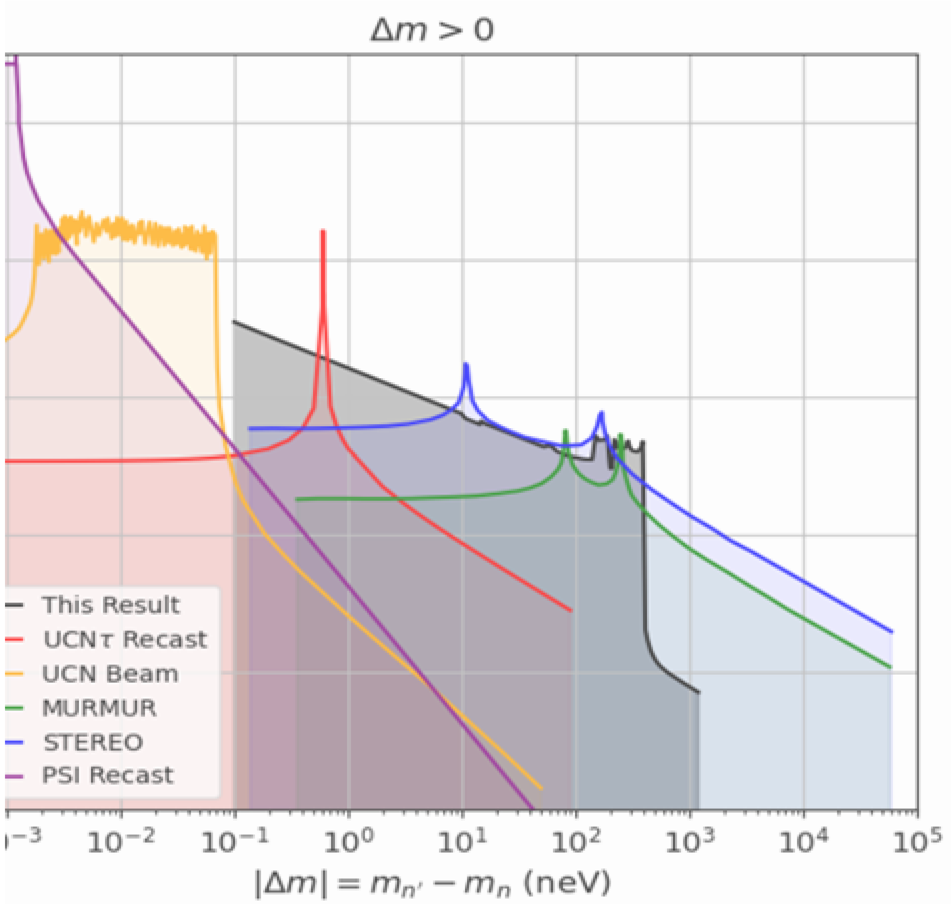
Relative Limit plot



Search for Neutron-to-Hidden-Neutron Oscillations in an Ultracold Neutron Beam

DOI: https://doi.org/10.1103/PhysRevLett.131.191801





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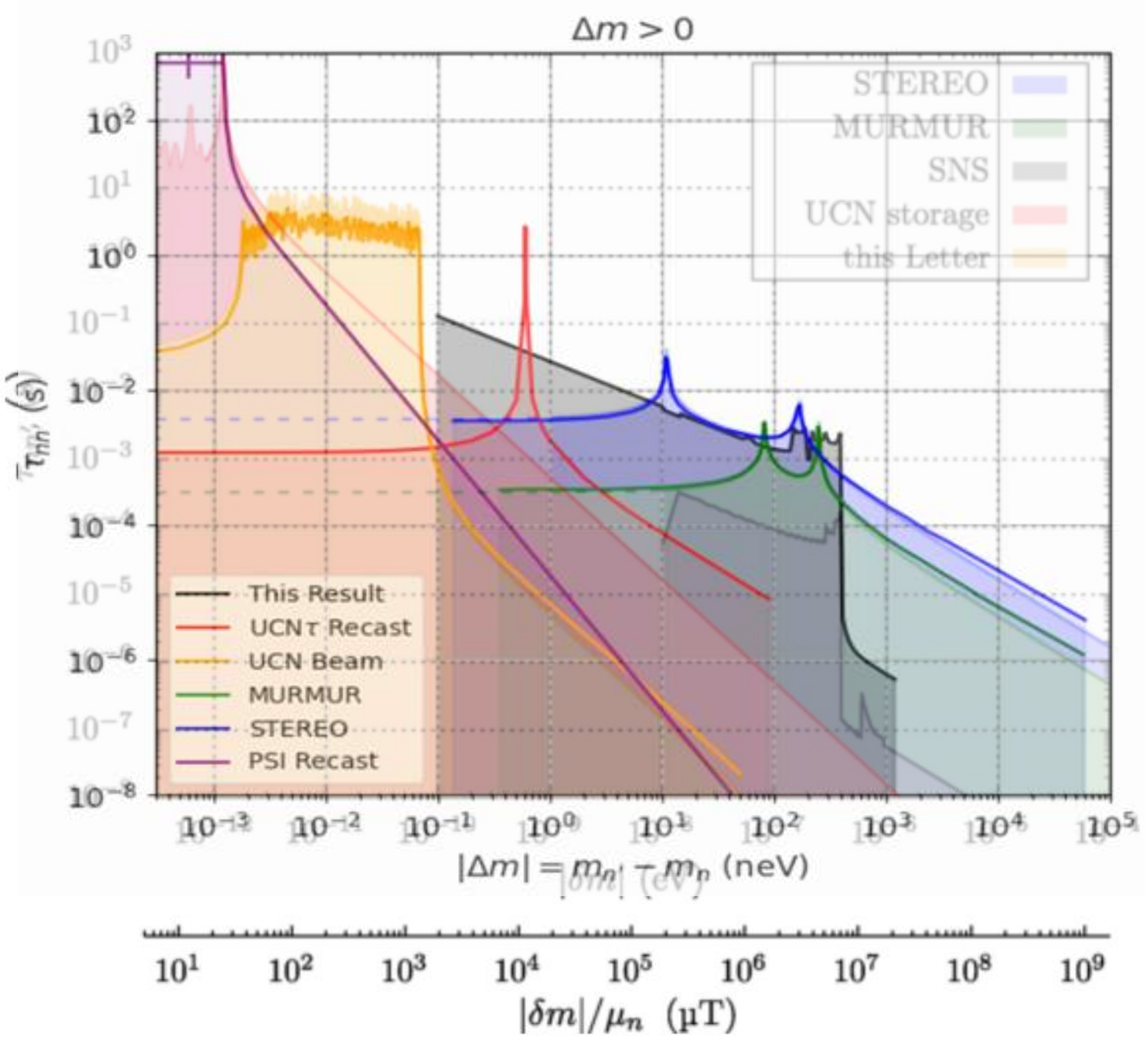


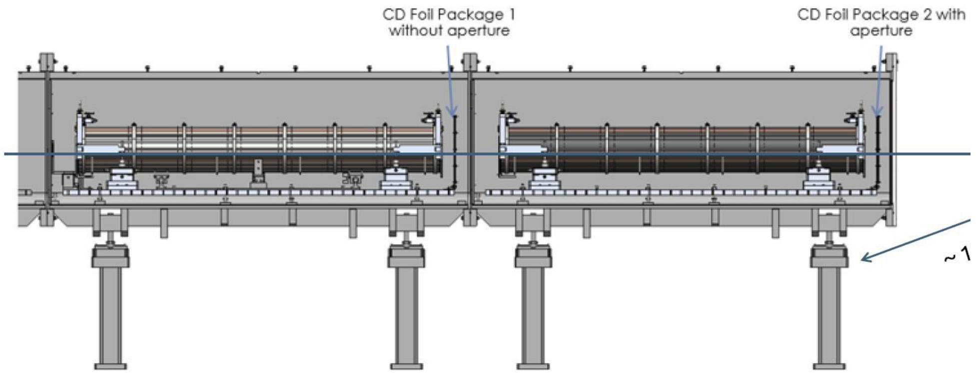
Study of Background Magnetic Field Distribution for Neutron Transition Magnetic Moment Searches

Student: German Luzin
Supervisor: Valentina Santoro
Co-Supervisor: Linus Persson
External supervisor: Yuri Kamyshkov

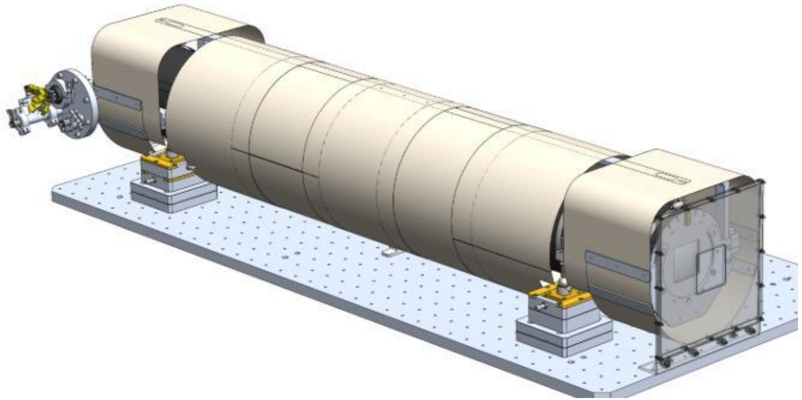
Project Scope

- Study of background magnetic field distribution in neutron experiments HFIR/ESS
- Work with existing magnetic field measurements from the GP-SANS beamline at ORNL
- Reconstruct the magnetic field inside the beamline using
  - scalar potential
  - spherical harmonic expansion
  - least-squares fitting
- Implement the reconstructed field in COMSOL simulations
- Study field homogeneity inside of the magnetic shielding

Motivation for the study of the magnetic field

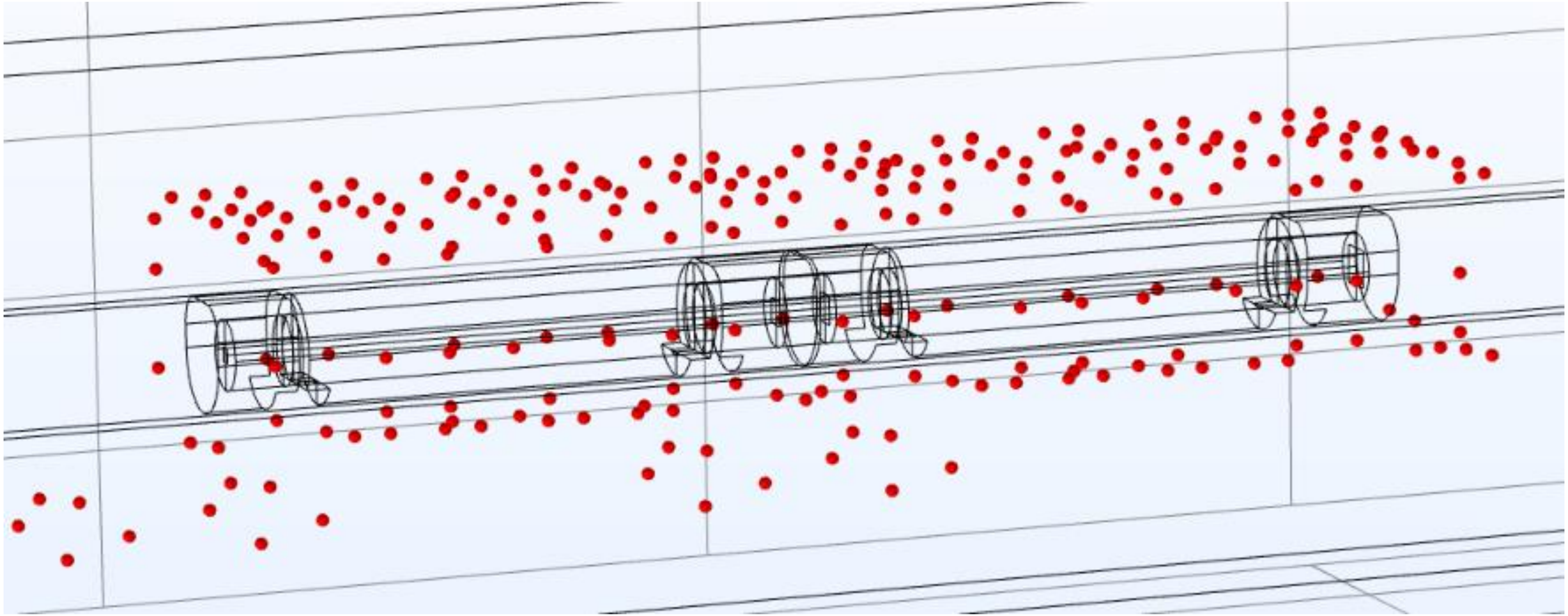


Boxes 7 and 8 of the GP-SANS beamline



Magnetic shielding blueprint

Measurement points



Measurements of the magnetic field at GP-SANS

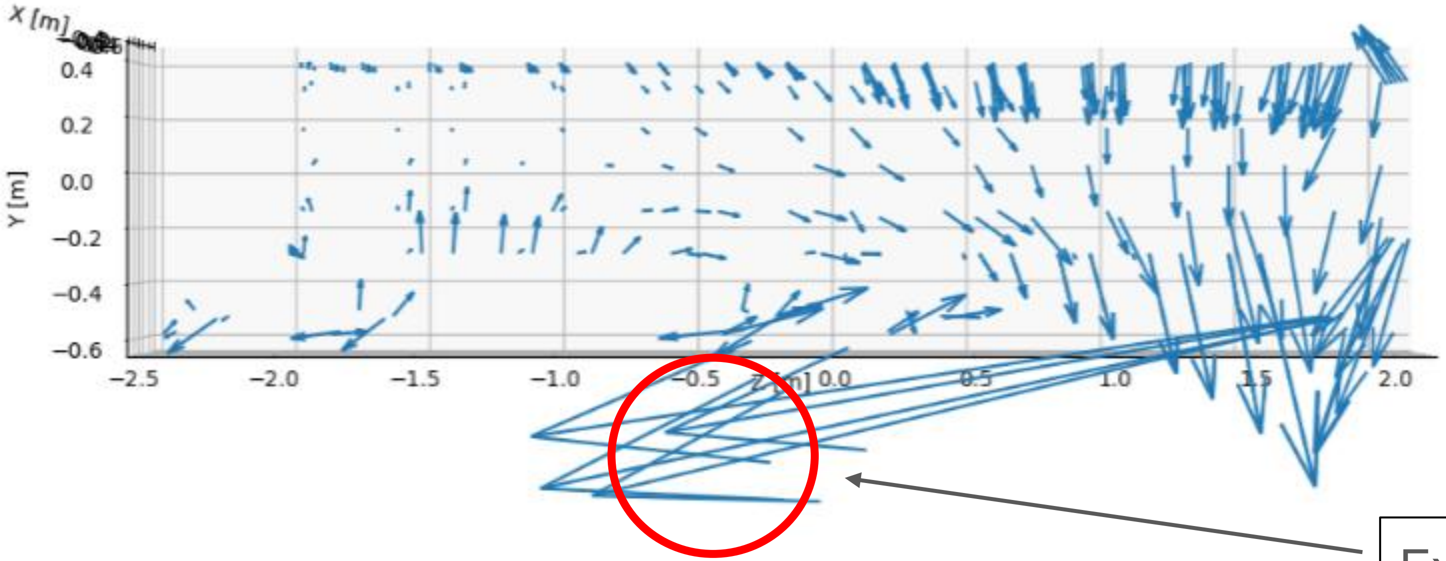


Figure 5: Magnetic field measurements, B in nT.

Excluded from the fit

Magnetic scalar potential and fitting

In a source free region: $\nabla \times \mathbf{B} = 0$ $\nabla \cdot \mathbf{B} = 0$

Thus we can write: $\mathbf{B}(\mathbf{r}) = -\nabla\Phi(\mathbf{r}),$ $\nabla^2\Phi = 0.$

A general solution of Laplace's equation in spherical coordinates is a sum of spherical harmonics:

$$\Phi(r,\theta,\phi) = \sum_{l=0}^{L} \sum_{m=-l}^{l} \left(a_{lm}\, r^l + b_{lm}\, r^{-(l+1)}\right) Y_l^m(\theta,\phi)$$

For a field regular at the origin (no divergence):

$$\Phi(r,\theta,\phi) = \sum_{l=0}^{L} \sum_{m=-l}^{l} c_{lm}\, r^l Y_l^m(\theta,\phi).$$

Magnetic scalar potential and fitting

Define basis scalar potentials: $\Phi_{lm}(r,\theta,\phi) = r^l Y_l^m(\theta,\phi)$

Such that: $\Phi(\mathbf{r}) = \sum_{l,m} c_{lm}\, \Phi_{lm}(\mathbf{r}),$

The gradient becomes: $\mathbf{B}(\mathbf{r}) = -\nabla\Phi(\mathbf{r}) = \sum_{l,m} c_{lm}\, \mathbf{G}_{lm}(\mathbf{r})$

With $\mathbf{G}_{lm}(\mathbf{r}) = -\nabla\Phi_{lm}(\mathbf{r}) = -\nabla\big[r^l Y_l^m(\theta,\phi)\big]$

Magnetic scalar potential and fitting

Assume we have field values at N points (from measurement around box):

$$\mathbf{B}_i = \mathbf{B}(\mathbf{r}_i), \qquad i = 1, \ldots, N.$$

The model prediction at $\mathbf{r}_i$ is: $\mathbf{B}_{\text{model}}(\mathbf{r}_i) = \sum_{l,m} c_{lm}\, \mathbf{G}_{lm}(\mathbf{r}_i).$

Define the least-squares cost function:

$$J(\{c_{lm}\}) = \sum_{i=1}^{N} \|\mathbf{B}_i - \mathbf{B}_{\text{model}}(\mathbf{r}_i)\|^2 = \sum_{i=1}^{N} \left\| \mathbf{B}_i - \sum_{l,m} c_{lm}\, \mathbf{G}_{lm}(\mathbf{r}_i) \right\|^2$$

We want to find c_{lm} such that:

$$\{c_{lm}\} = \arg\min J.$$

RMS norm of the magnetic field and fit residuals

$$\mathbf{r}_i = \mathbf{B}_i - \mathbf{B}_{\text{model}}(\mathbf{r}_i)$$

residuals

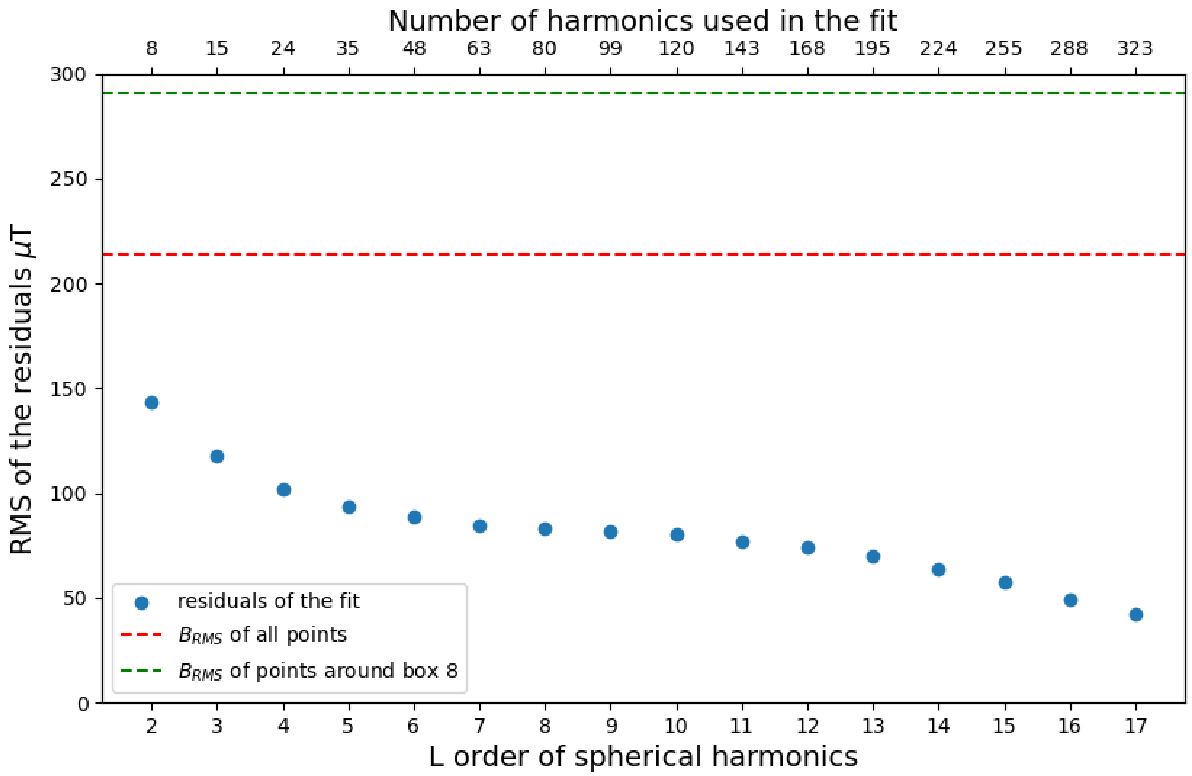
$$r_{\text{RMS}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} ||\mathbf{r}_i||^2}$$

rms norm of the residuals

$$B_{\text{RMS}} = \sqrt{\frac{1}{N}\sum ||\mathbf{B}_i||^2}$$

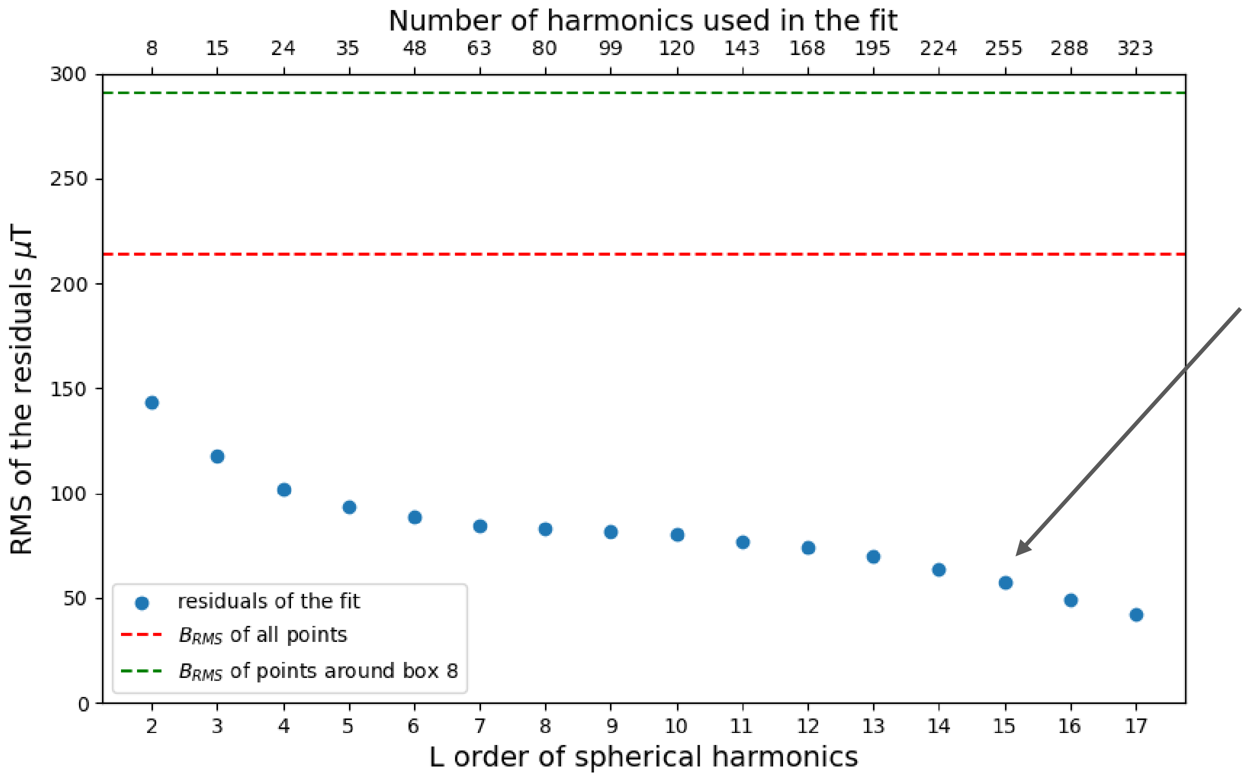
rms norm of the magnetic field vectors

Fitting results



Number of points
N = 264

Fitting results



Number of points
N = 264

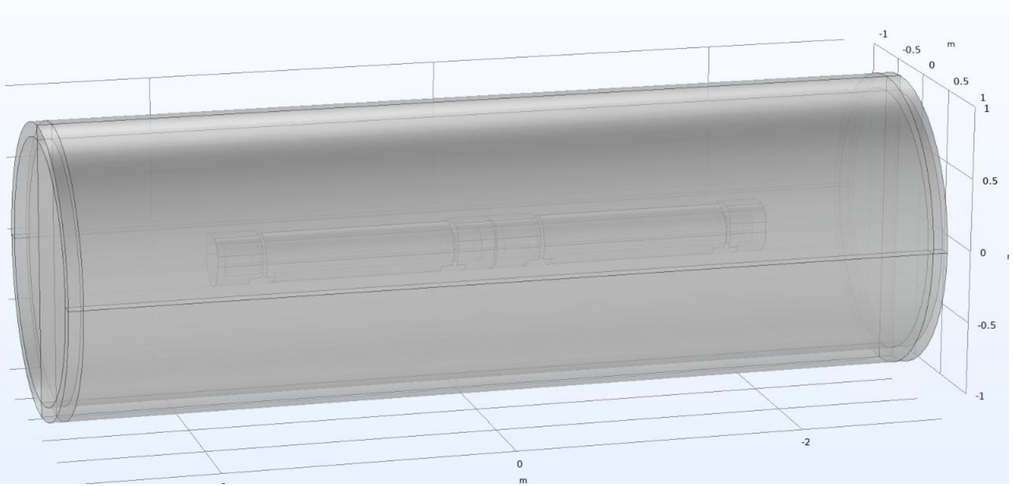
At L = 15
Relative error is
0.22 - 0.29

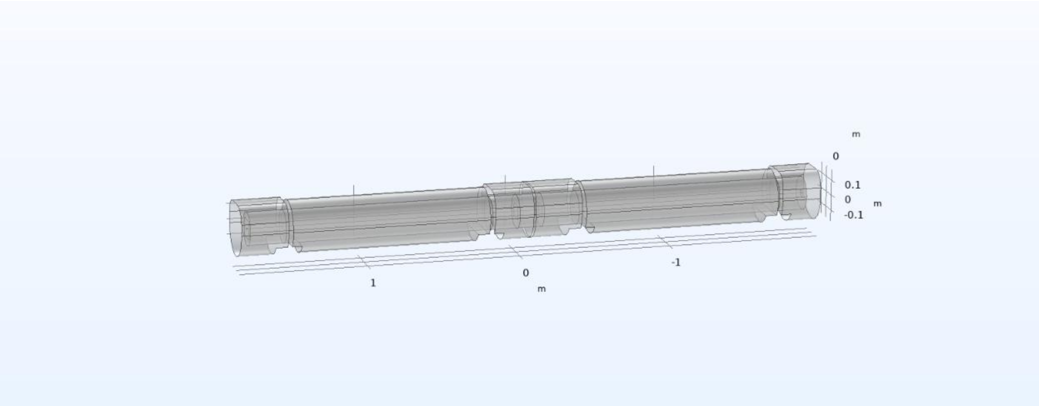
Simulation setup

- Comsol multiphysics 6.3
- mfnc - magnetic fields no currents
- Simulated volume - close to measurement boundary
- Volume boundary - scalar potential

Simulation setup

Overall volume and mumetal shield inside



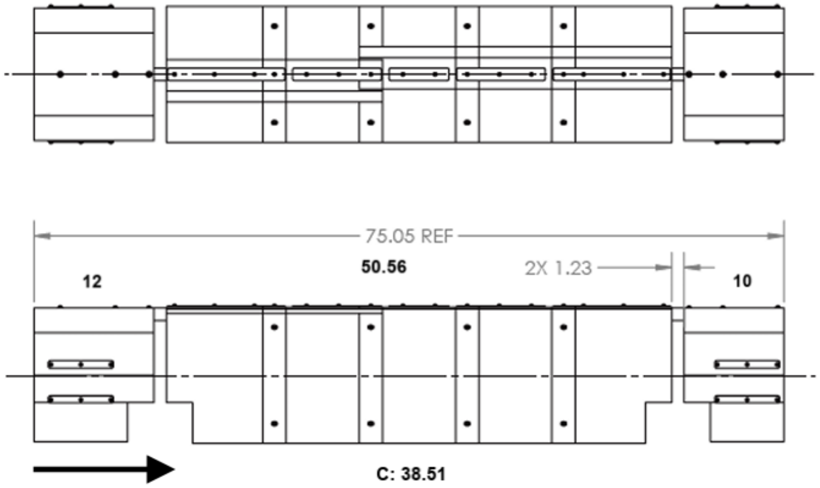


Simulation setup

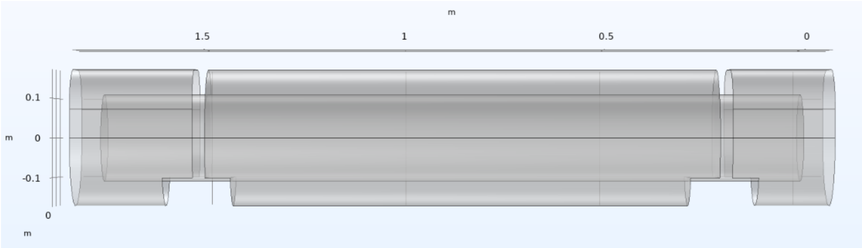
Outer and inner mu metal shields are defined via magnetic shielding bc in comsol.

Inner shield

Outer shield and caps



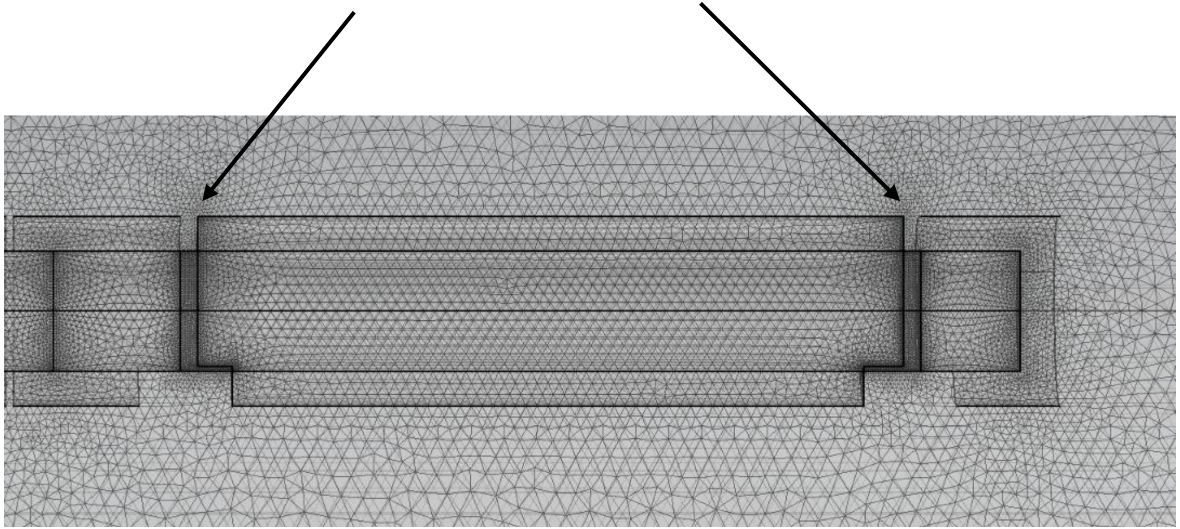
blueprint



Comsol model

Simulation - meshing

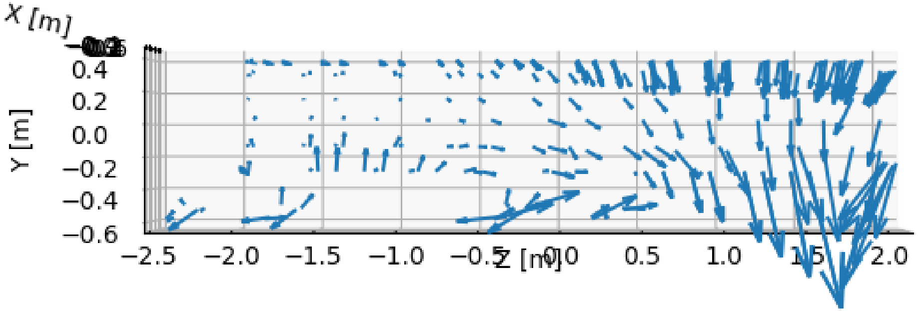
Improved mesh in
sensitive areas



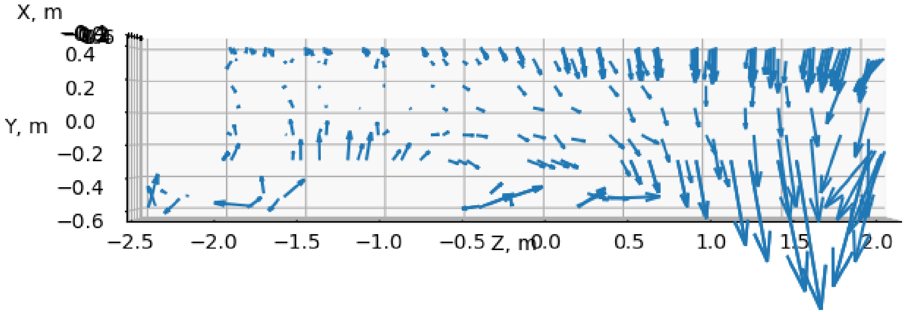
Simulation results

After running a simulation with some boundary conditions I extracted magnetic field vectors from the simulation at thepoints that were used previously in analysis

Simulation results - visual validation



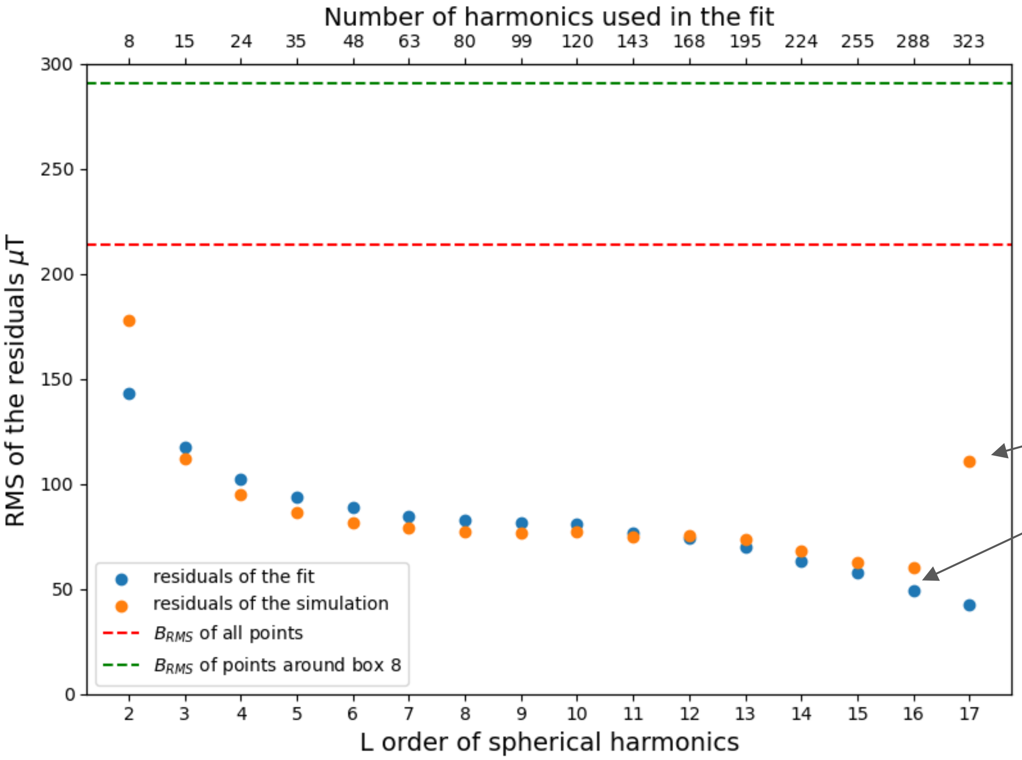
measured



Best approximation

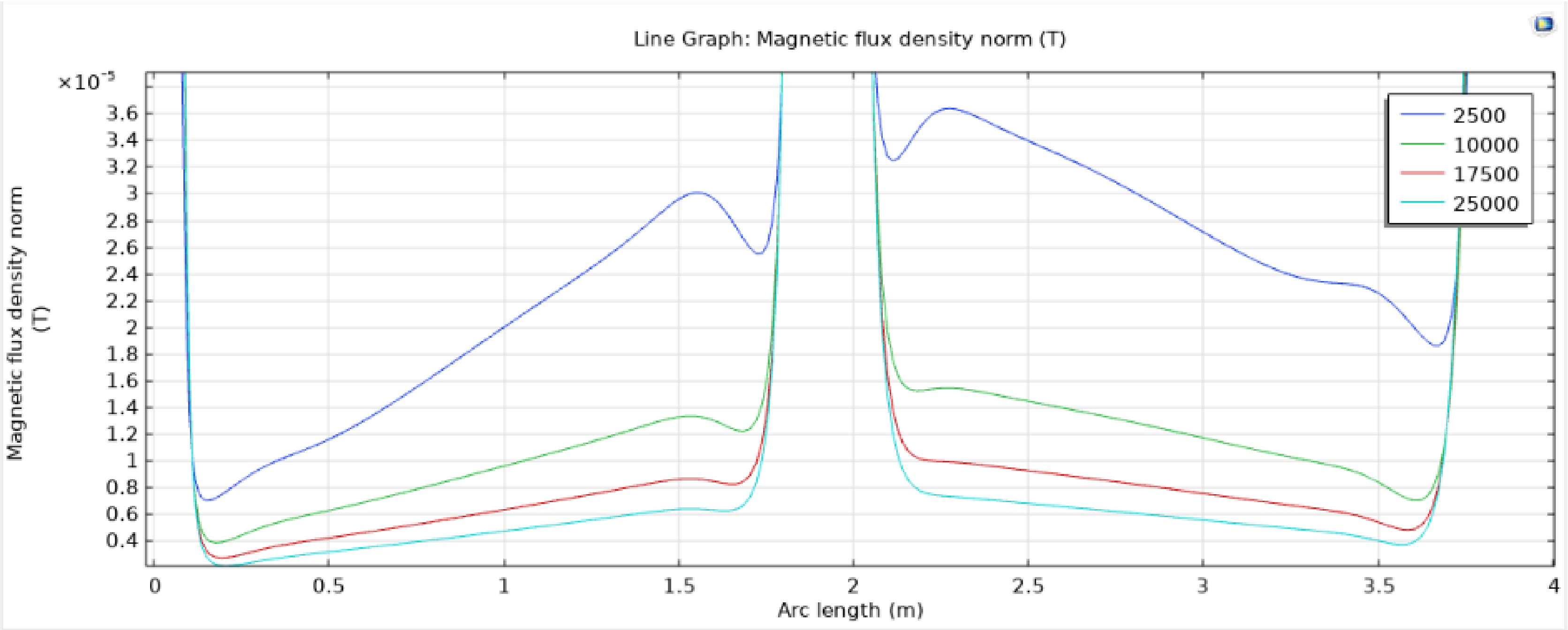
Vector plot of the magnetic field vectors

Simulation results



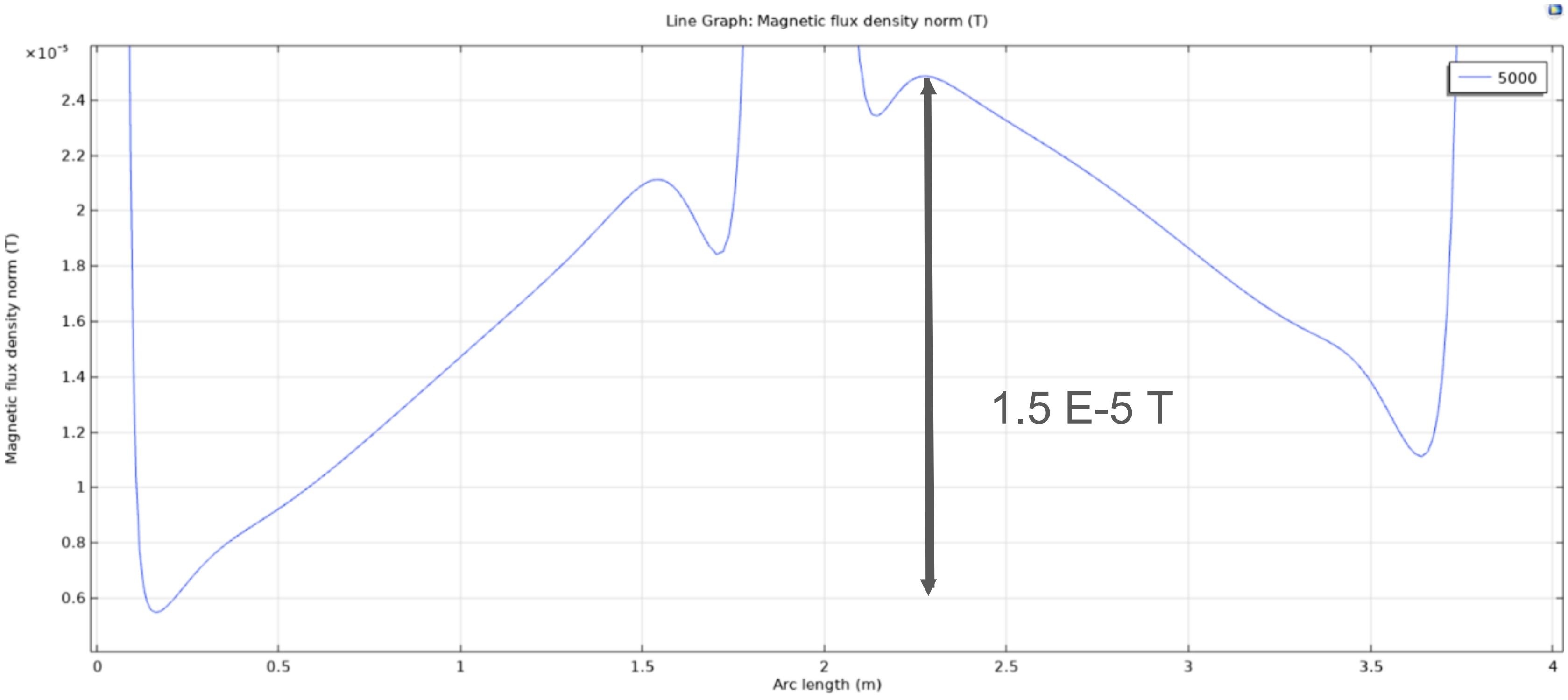
Requires finer mesh to resolve accurately (out of resources)

Delta B = 70-280 mG



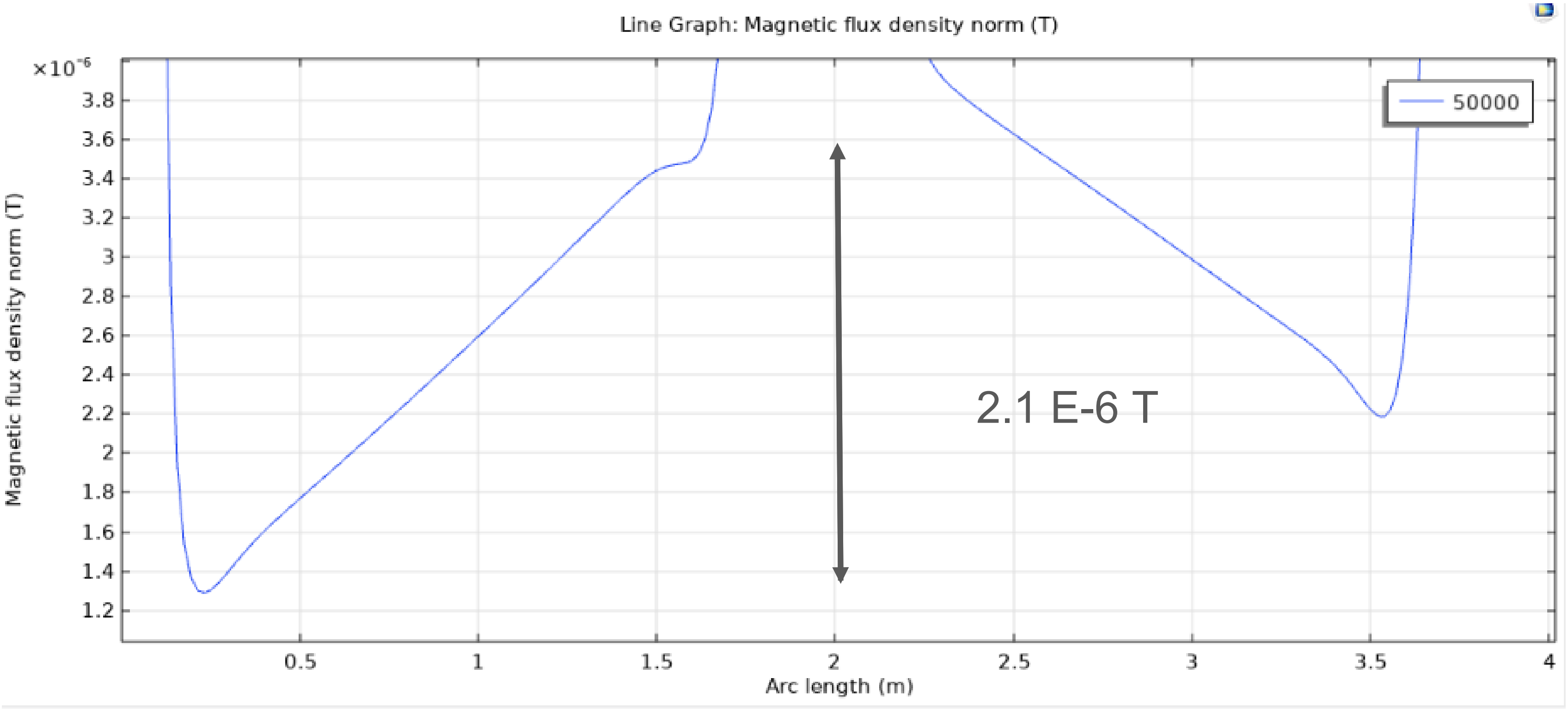
At 2500

Mu = 5000

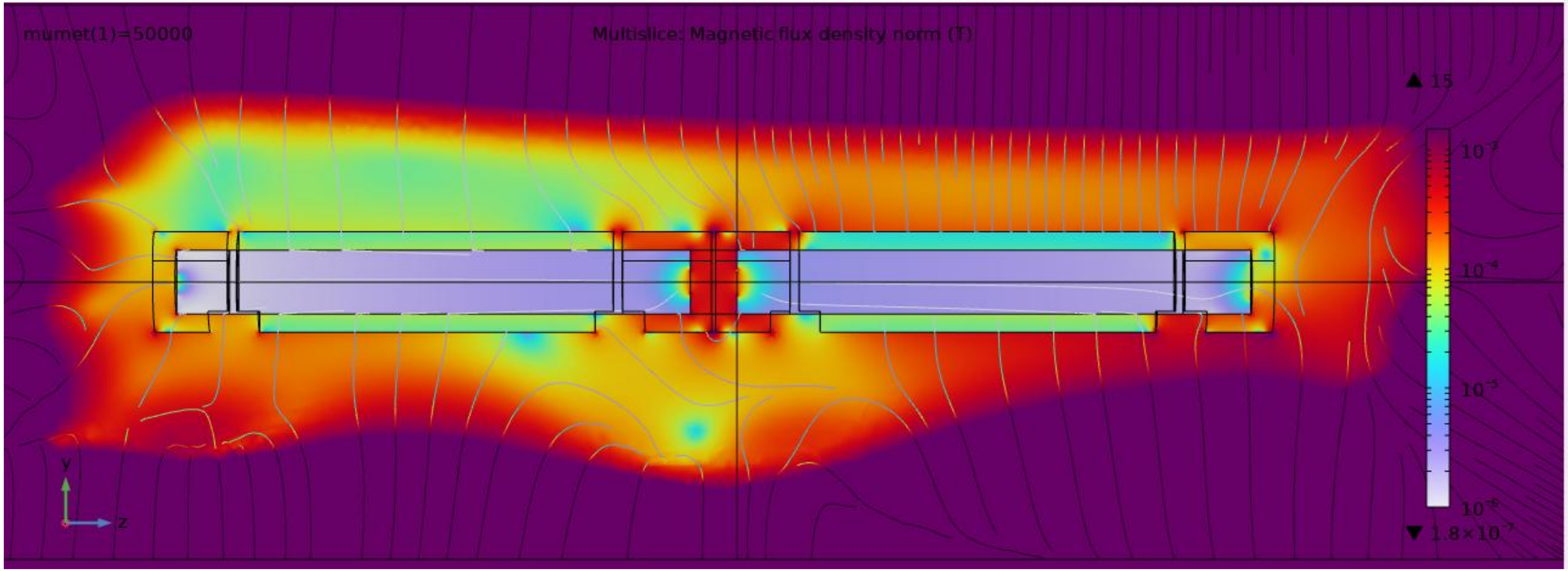


Line Graph: Magnetic flux density norm (T)
×10⁻⁵
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
Magnetic flux density norm (T)
0
0.5
1
1.5
2
2.5
3
3.5
4
Arc length (m)
5000
1.5 E-5 T

Mu = 50000


Line Graph: Magnetic flux density norm (T)
×10⁻⁶
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
Magnetic flux density norm (T)
0.5
1
1.5
2
2.5
3
3.5
4
Arc length (m)
50000
2.1 E-6 T

Mu = 50000


mumet(1)=50000
Multislice: Magnetic flux density norm (T)
▲ 15
10^-3
10^-4
10^-5
10^-6
▼ 1.8×10^-7
y
z