Mapping the Magnetically Shielded Room for the Neutron Electric Dipole Moment Experiment at TRIUMF

Presenter: **Maedeh Lavvaf**

Supervisor: **Dr. Russell Mammei**

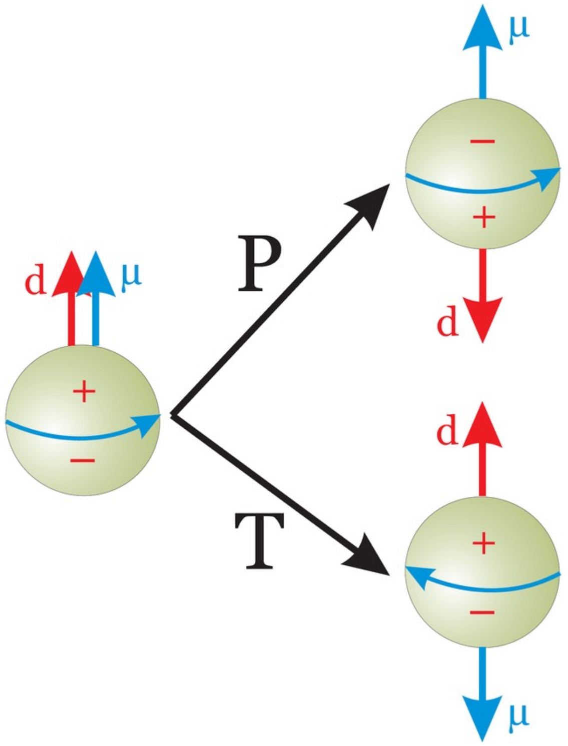
TUCAN
TRIUMF Ultra Cold Advanced Neutron source

THE UNIVERSITY OF WINNIPEG

University of Manitoba

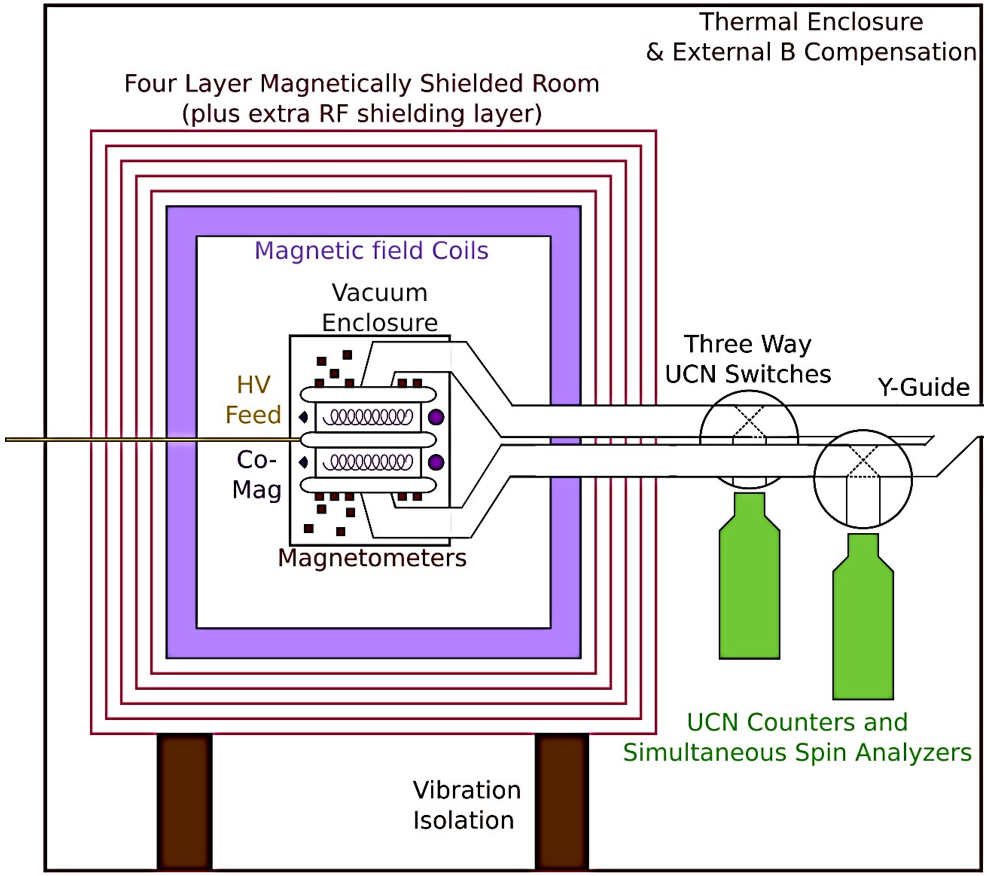
nEDM Experiment Motivation

- Helps explain matter-antimatter asymmetry
- T violation → CP violation under CPT symmetry
- Standard Model $< 10^{-30}\mathrm{ecm}$
- Current limit $1.8\times10^{-26}\mathrm{ecm}$
- TUCAN target $\sim 10^{-27}\mathrm{ecm}$ by a factor of 18



Electric dipole moment direction changes under parity, magnetic dipole moment under time-reversal

nEDM Experiment



Experimental technique:

- Put UCN in a E and B fields
- Search for a change in spin precession frequency upon E reversal

$$h\nu_{\pm} = 2\mu_n B \pm 2d_n E$$

$$E = 10\ kV/cm$$

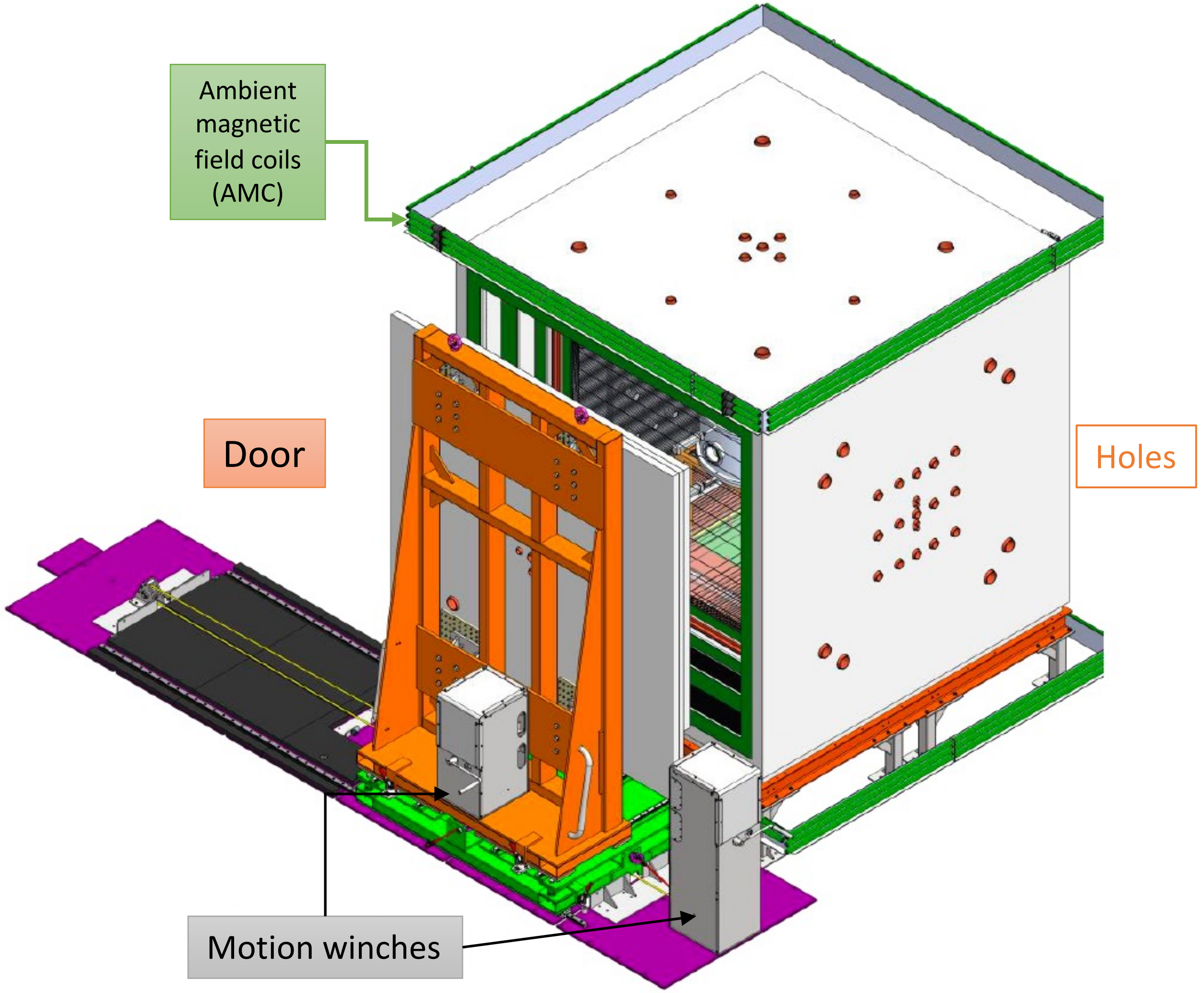
$$B = 1\mu T$$

TUCAN MSR

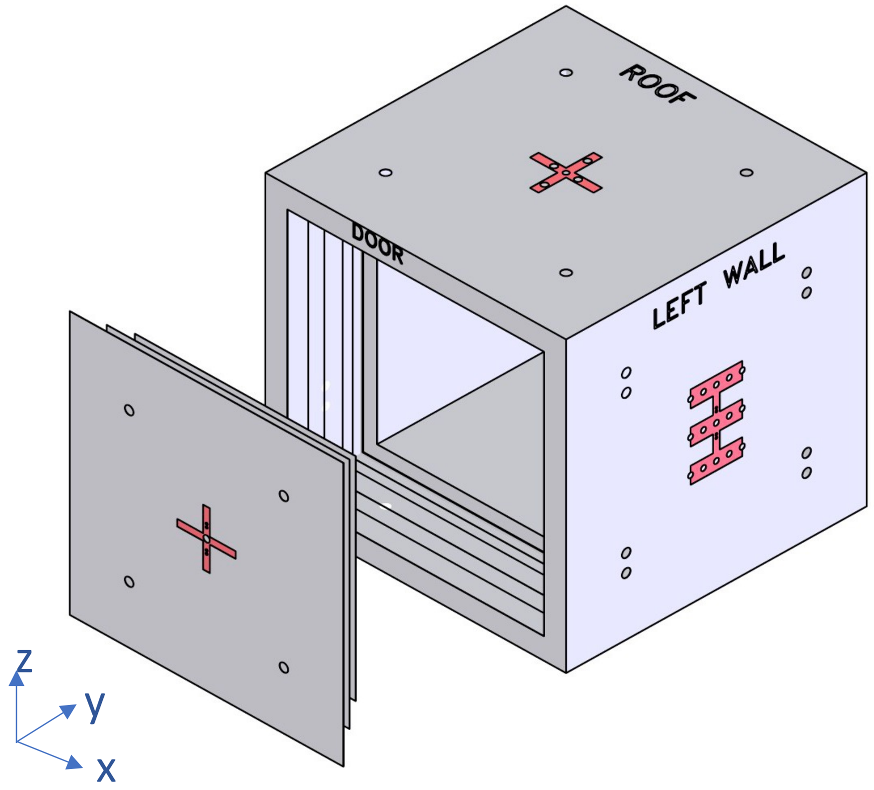
A Magnetically Shielded Room (MSR) is a multi-layer room built with high permeability material, such as mumetal, and high conductivity sheet materials, such as copper.

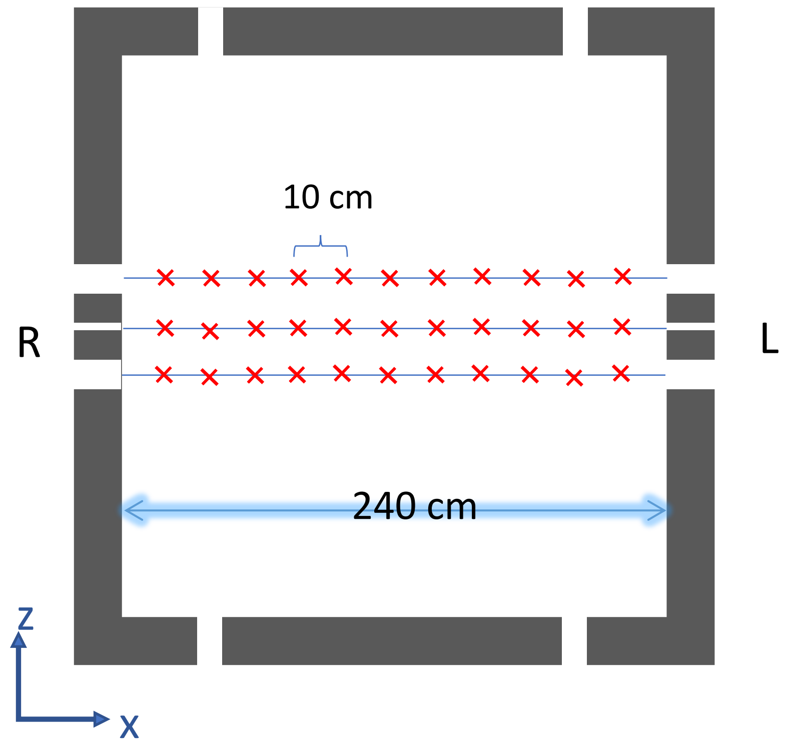
Shielding factor: 100000

Size:
- inner: 2.4 m^3
- outer: 3.5 m^3



Mapping inside the MSR





Errors:

- Perturb positions
- B field errors
- Vary the angle
- Tilting of the stick

Generating field map and pseudoinverse method

438 points for 10 cm spacing

	A	B	C
1	x (m)	y (m)	z (m)
2	-1.2	1.05	1.05
3	-1.1	1.05	1.05
4	-1	1.05	1.05
5	-0.9	1.05	1.05
6	-0.8	1.05	1.05
7	-0.7	1.05	1.05
8	-0.6	1.05	1.05
9	-0.5	1.05	1.05
10	-0.4	1.05	1.05
11	-0.3	1.05	1.05
12	-0.2	1.05	1.05
13	-0.1	1.05	1.05
14	0	1.05	1.05
15	0.1	1.05	1.05
16	0.2	1.05	1.05
17	0.3	1.05	1.05
18	0.4	1.05	1.05
19	0.5	1.05	1.05
20	0.6	1.05	1.05
21	0.7	1.05	1.05
22	0.8	1.05	1.05
23	0.9	1.05	1.05
24	1	1.05	1.05
25	1.1	1.05	1.05
26	1.2	1.05	1.05

5^{th} order glm = 2

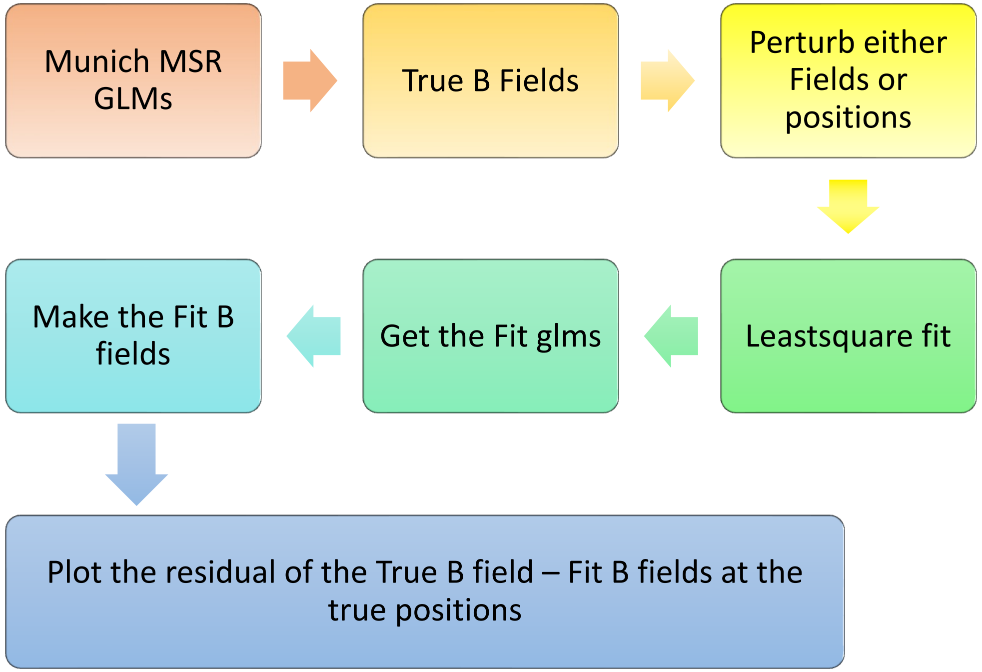
	A	B	C	D	E	F
1	X post (m)	Y pos (m)	Z pos (m)	Hxpython(A/m)	Hypython(A/m)	Hzpython(A/m)
2	-1.2	1.05	1.05	-3.0375625	-0.10646875	-10.1573125
3	-1.1	1.05	1.05	-2.572375	-1.76284375	-9.8024375
4	-1	1.05	1.05	-2.0521875	-3.47096875	-9.3030625
5	-0.9	1.05	1.05	-1.4725	-5.22484375	-8.6561875
6	-0.8	1.05	1.05	-0.8288125	-7.01846875	-7.8588125
7	-0.7	1.05	1.05	-0.116625	-8.84584375	-6.9079375
8	-0.6	1.05	1.05	0.6685625	-10.70096875	-5.8005625
9	-0.5	1.05	1.05	1.53125	-12.57784375	-4.5336875
10	-0.4	1.05	1.05	2.4759375	-14.47046875	-3.1043125
11	-0.3	1.05	1.05	3.507125	-16.37284375	-1.5094375
12	-0.2	1.05	1.05	4.6293125	-18.27896875	0.2539375
13	-0.1	1.05	1.05	5.847	-20.18284375	2.1888125
14	0	1.05	1.05	7.1646875	-22.07846875	4.2981875
15	0.1	1.05	1.05	8.586875	-23.95984375	6.5850625
16	0.2	1.05	1.05	10.1180625	-25.82096875	9.0524375
17	0.3	1.05	1.05	11.76275	-27.65584375	11.7033125
18	0.4	1.05	1.05	13.5254375	-29.45846875	14.5406875
19	0.5	1.05	1.05	15.410625	-31.22284375	17.5675625
20	0.6	1.05	1.05	17.4228125	-32.94296875	20.7869375
21	0.7	1.05	1.05	19.5665	-34.61284375	24.2018125
22	0.8	1.05	1.05	21.8461875	-36.22646875	27.8151875
23	0.9	1.05	1.05	24.266375	-37.77784375	31.6300625
24	1	1.05	1.05	26.8315625	-39.26096875	35.6494375
25	1.1	1.05	1.05	29.54625	-40.66984375	39.8763125
26	1.2	1.05	1.05	32.4149375	-41.99846875	44.3136875

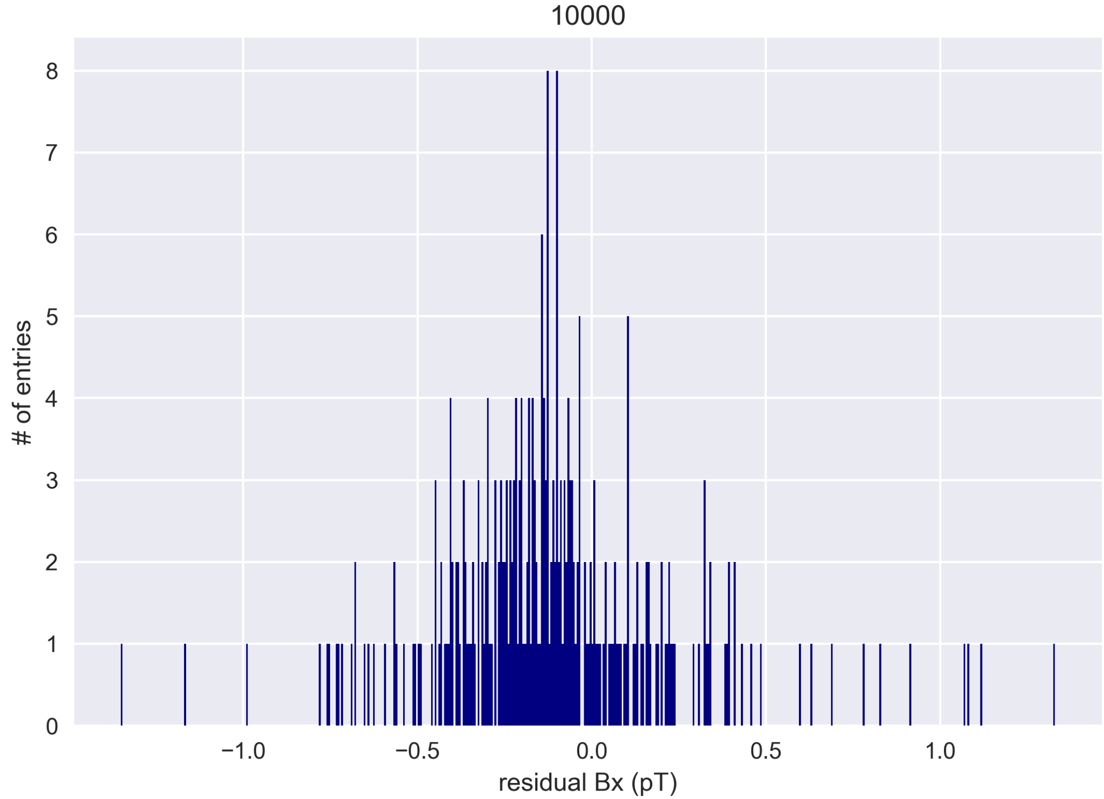
Get back glms

	A	B
1	2	
2	2	
3	2	
4	2	
5	2	
6	2	
7	2	
8	2	
9	2	
10	2	
11	2	
12	2	
13	2	
14	2	
15	2	
16	2	
17	2	
18	2	
19	2	
20	2	
21	2	
22	2	
23	2	
24	2	
25		

$G_{l,m}$ are the coefficients that describe the magnetic field in the volume by gradient.

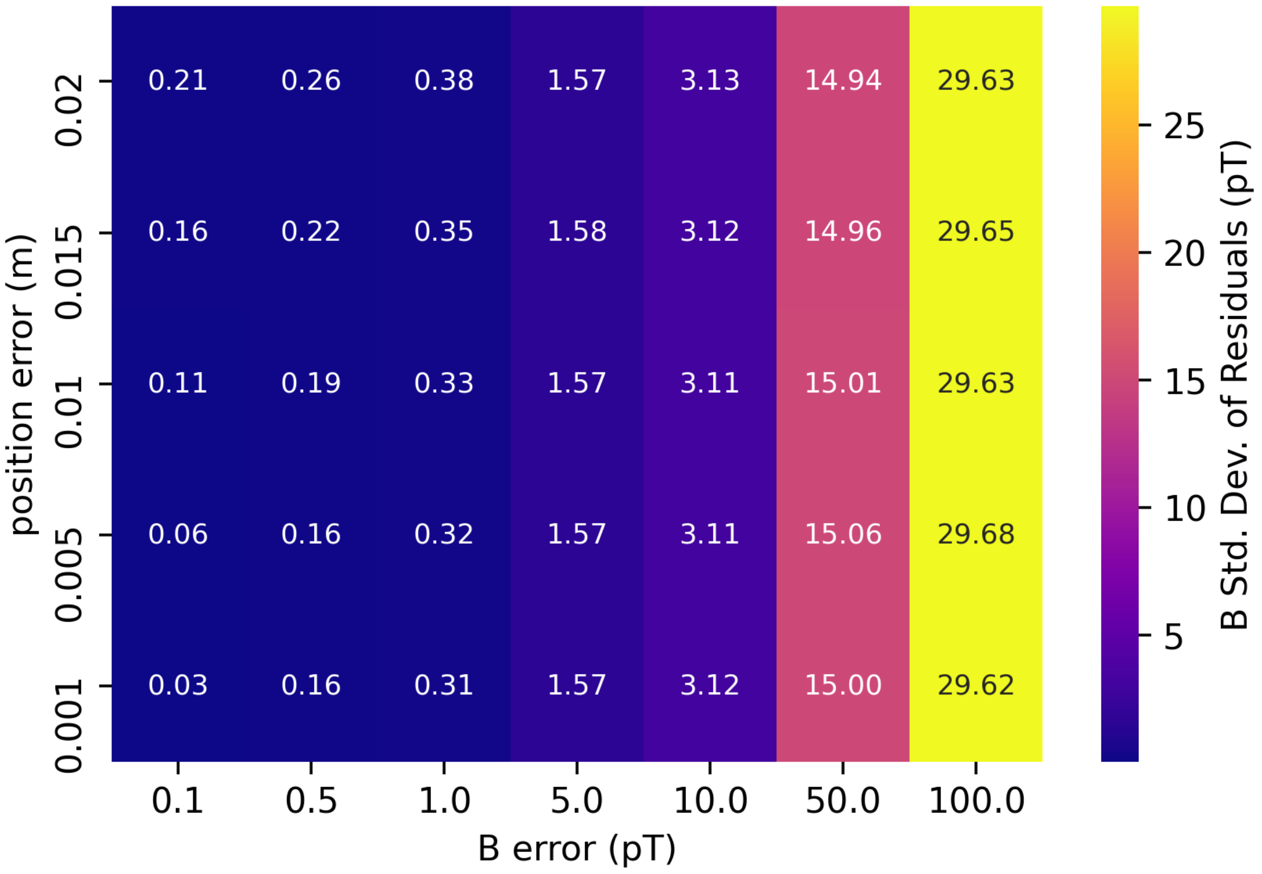
Adding errors





- Uniform errors for positions (0.1 cm)
- 1 time adding random errors
- Std.dev = 0.35381 pT

Errors effect



- Std.dev becomes 2 times larger (when B error is twice)
- B error would be dominant after 1 pT error
- We also rotate the sensor from -15 deg to 15 deg: max Std.dev in B was 1.5 pT
- We tilted the end of the “stick” by 5 cm and Std.dev in B was 1.5 pT.
- B error is the dominant error.
- The position, rotation, and tilting errors are not gonna make a huge difference.

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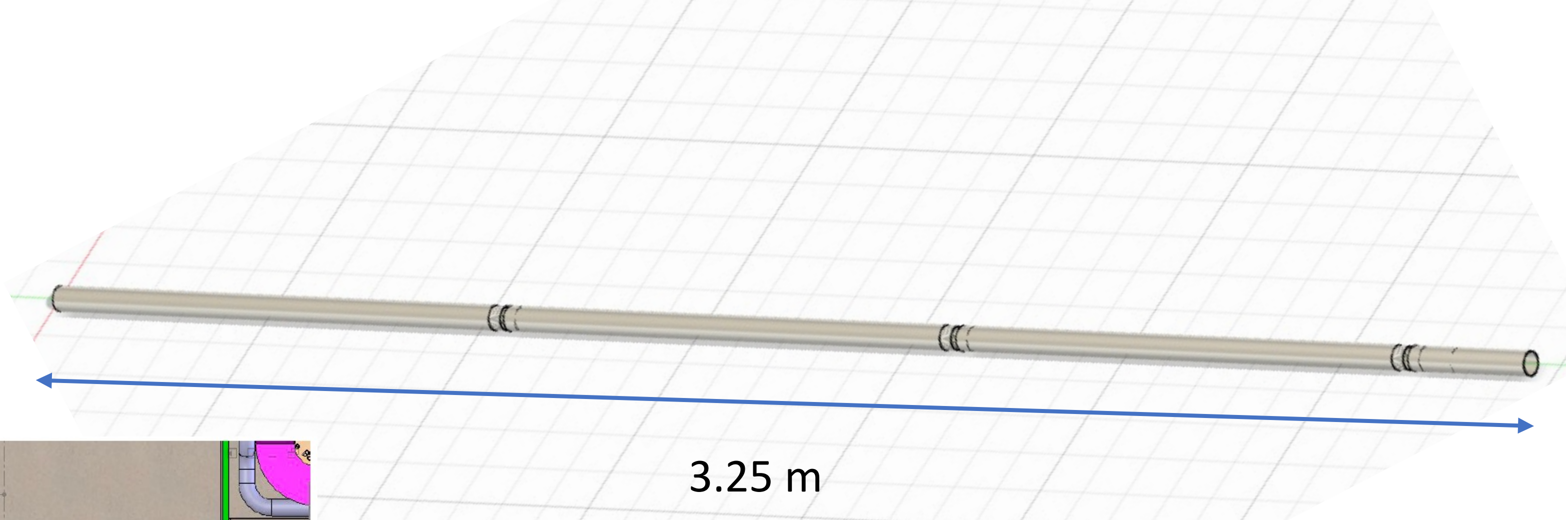
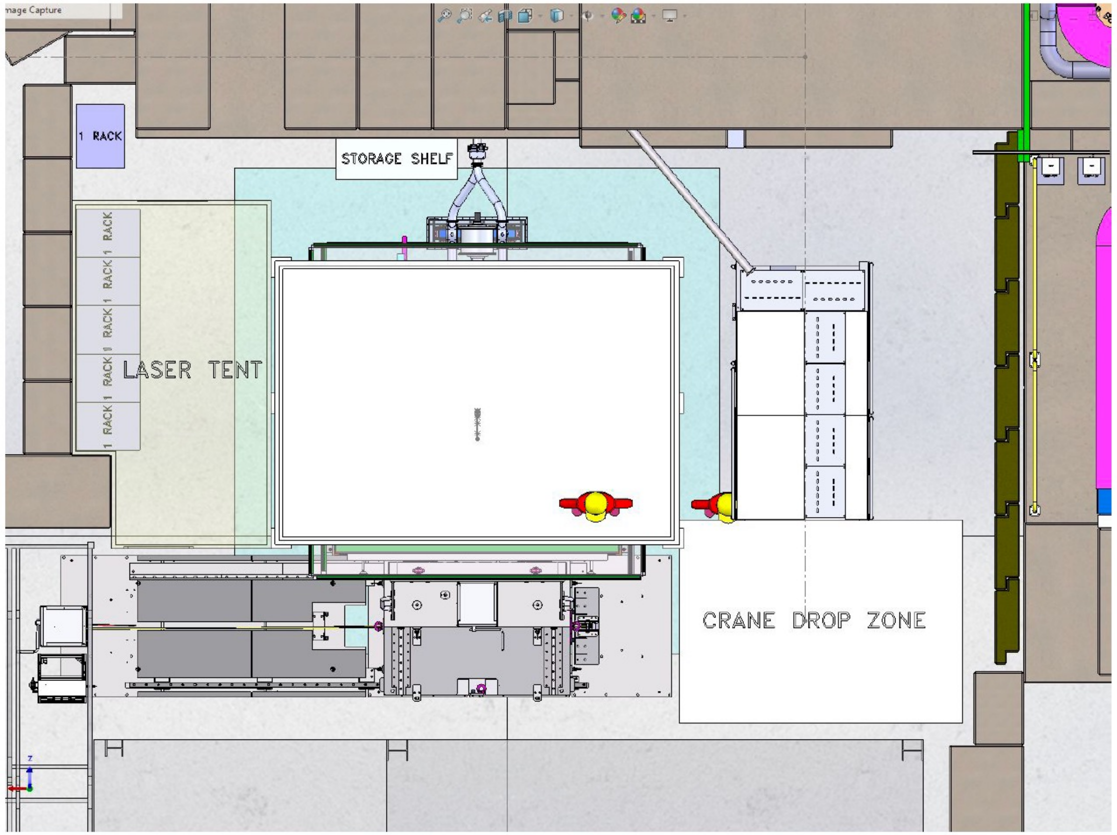
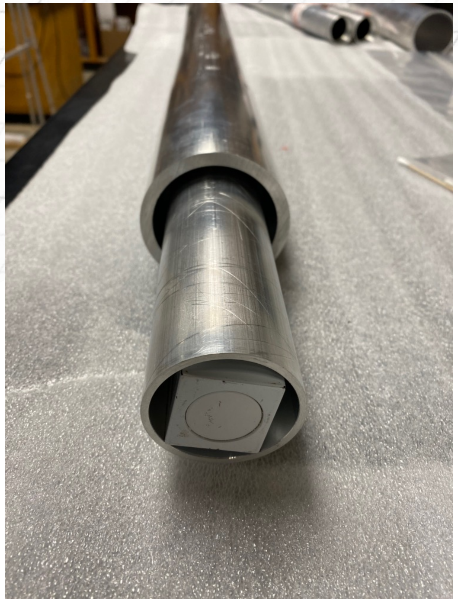
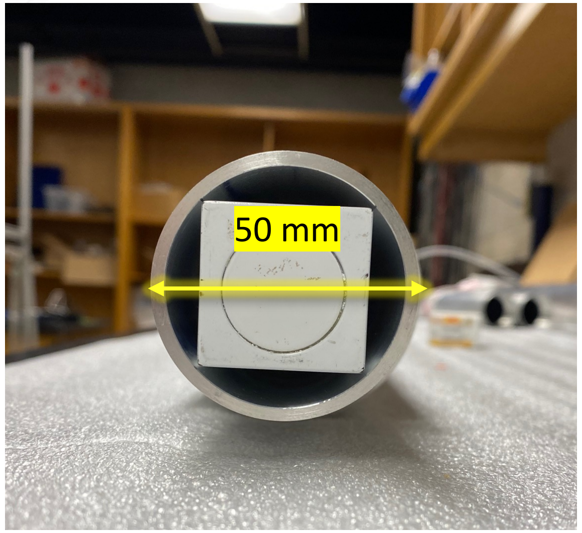
Mapping hardware









MSR Project timeline

Task name	Date
Site Prep.	July to August (2022)
Door and base built	August to November (2022)
Layers built (degaussing, assessing shielding factor and magnetic hot spots at each layer)	November (2022) to April (2023)
All 5 layers degaussing	April (2023)
Cladding, light and floor	May (2023)
Testing performance/optimization	June (2023)
MSR build complete	June (2023)
Intensive mapping	July (2023)
Coils installation	Fall 2023

Conclusion

- Trying to measure the nEDM 1.0e-27 ecm
- Having a MSR to block ambient B field to do our experiment
- My role:

  - Measuring the performance of the MSR

  - Developing the mapping system and its requirements
- MSR should be ready to map next July

Thanks for your attention!

Decomposition into spherical harmonics

In free space, $\nabla^2\Phi = 0$

$$\vec{B}(\vec{r}) = \sum_{l,m} G_{l,m} \vec{\nabla} \cdot \Phi(\vec{r}) \Rightarrow \begin{pmatrix} B_x(\vec{r}) \\ B_y(\vec{r}) \\ B_z(\vec{r}) \end{pmatrix} = \sum_{l,m} G_{l,m} \begin{pmatrix} \Pi_{x,l,m}(\vec{r}) \cdot \hat{i} \\ \Pi_{y,l,m}(\vec{r}) \cdot \hat{j} \\ \Pi_{z,l,m}(\vec{r}) \cdot \hat{k} \end{pmatrix}$$

Where $\Pi_{i,l,m}$ are the x, y, and z derivatives of the scalar basis functions. $G_{l,m}$ are then the coefficients that describe the magnetic field in the volume by gradient.

l=0

$$\begin{cases} G_{0,-1} = B_y, \\ G_{0,0} = B_z, \\ G_{0,1} = B_x. \end{cases}$$

l=1

$$\begin{cases} G_{1,-2} = \partial_y B_x = \partial_x B_y, \\ G_{1,-1} = \partial_y B_z = \partial_z B_y, \\ G_{1,0} = \partial_z B_z = -\partial_x B_x - \partial_y B_y, \\ G_{1,1} = \partial_x B_z = \partial_z B_x, \\ G_{1,2} = \frac{1}{2}(\partial_x B_x - \partial_y B_y). \end{cases}$$

Ref: C. Abel et.al, Phys. Rev. A 99, 042112 (2019)