# Magnetic resonance requirements and shim coils for TUCAN

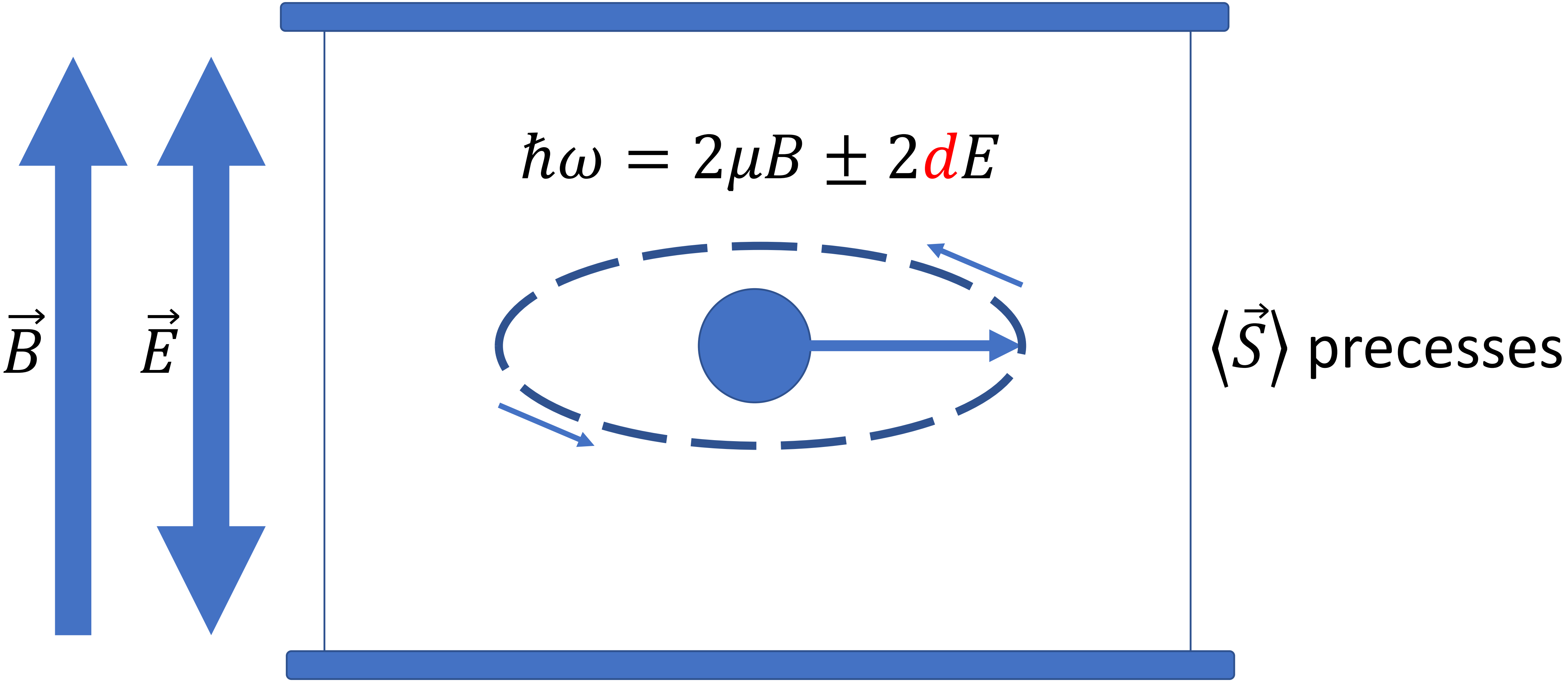
## TRIUMF Ultra-Cold Advanced Neutron project

Jeff Martin, The University of Winnipeg

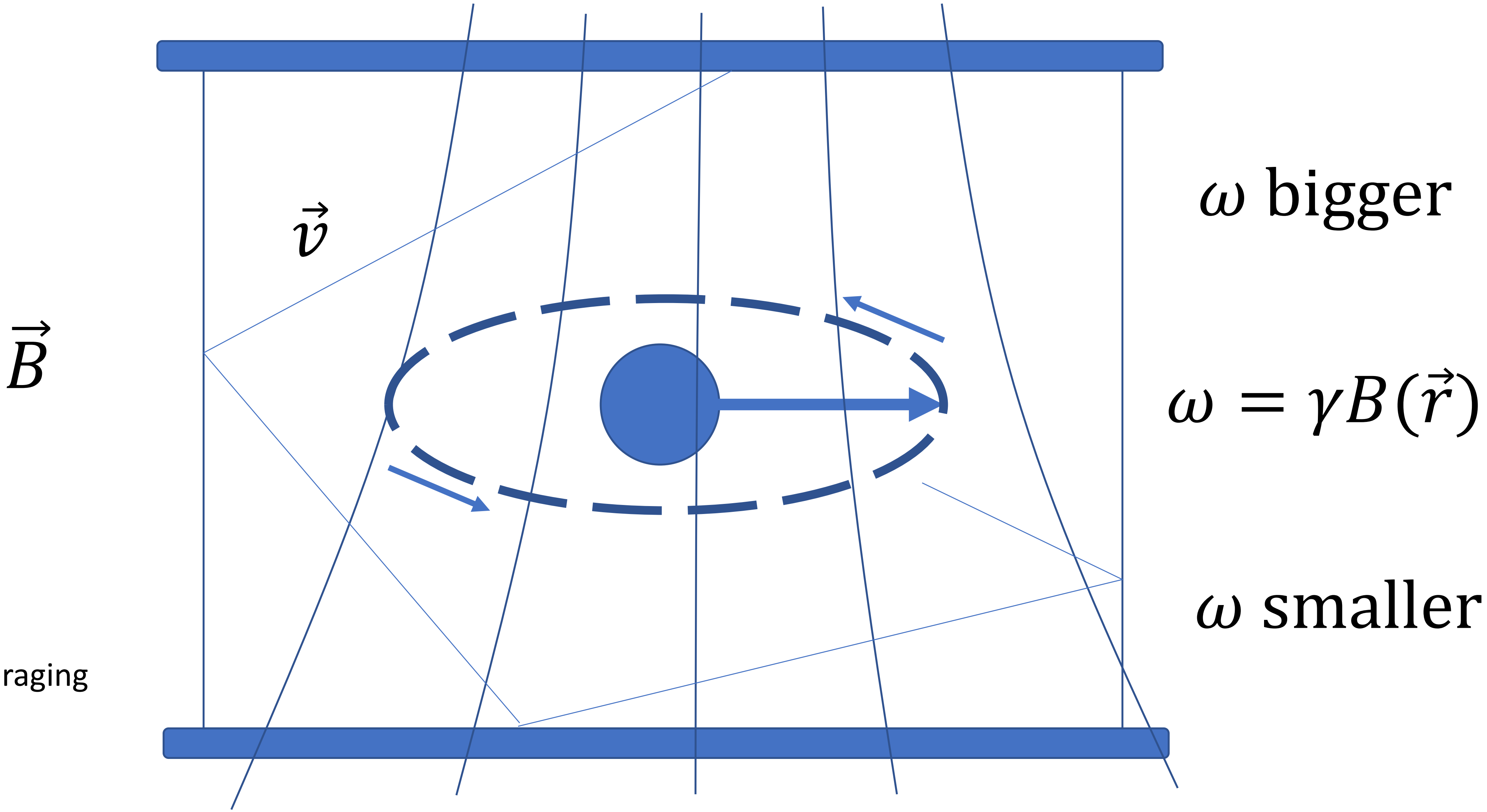
TUCAN
Collaboration

CAP Congress 2022

# How to measure the neutron EDM

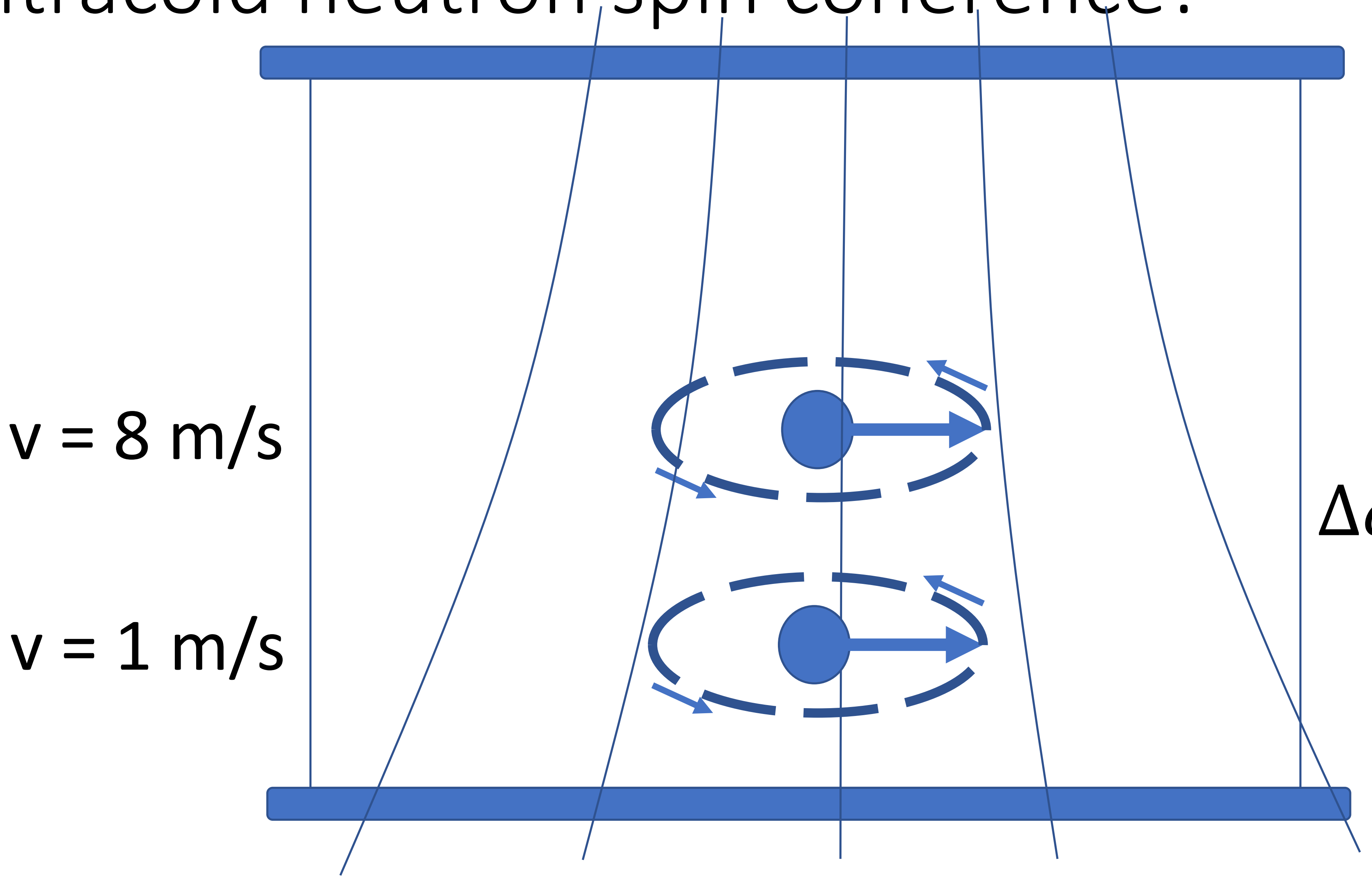


# What if the magnetic field isn't homogeneous?




Mitigated by
motional averaging

# Kinetic energy distribution and gravity affect ultracold neutron spin coherence!



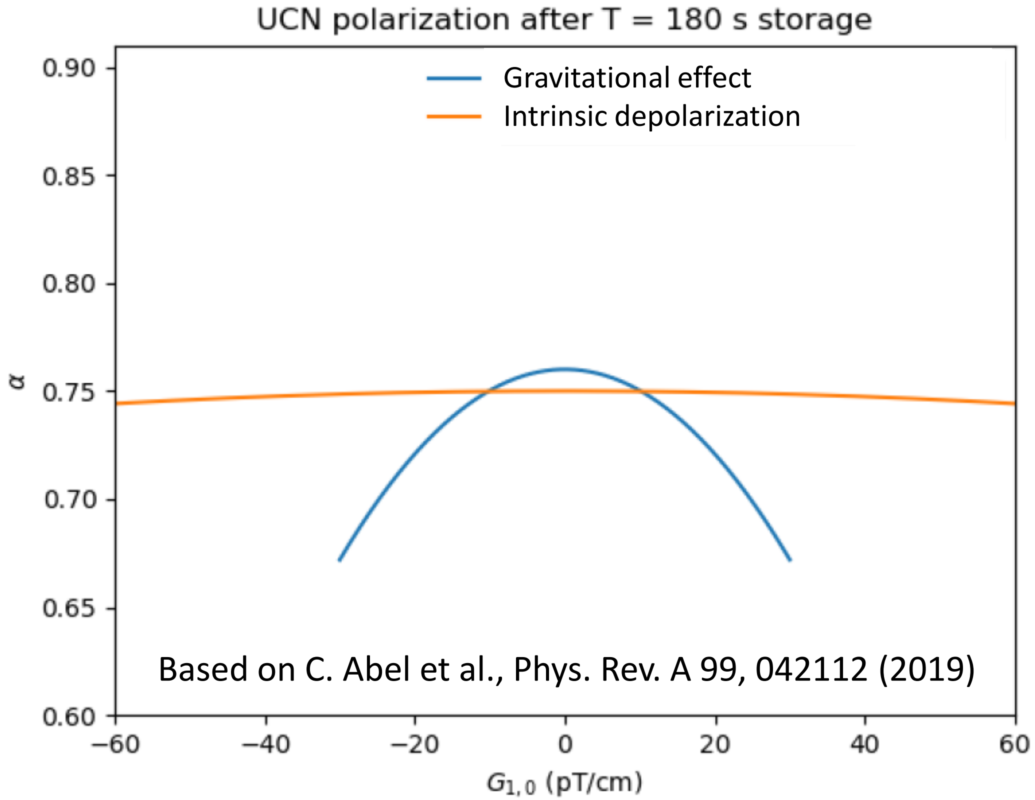

$$\Delta\omega = \gamma \frac{dB}{dz} \Delta h$$

dephasing, signal loss

# Loss of UCN polarization (α) over time

- Gravitational effect $\alpha_{\text{grav}} = \alpha_0 - \frac{1}{2}\gamma_n^2 G_{1,0}^2 \text{Var}[\bar{z}] T^2$

- Also: intrinsic depolarization (propagation in inhomogenous field)

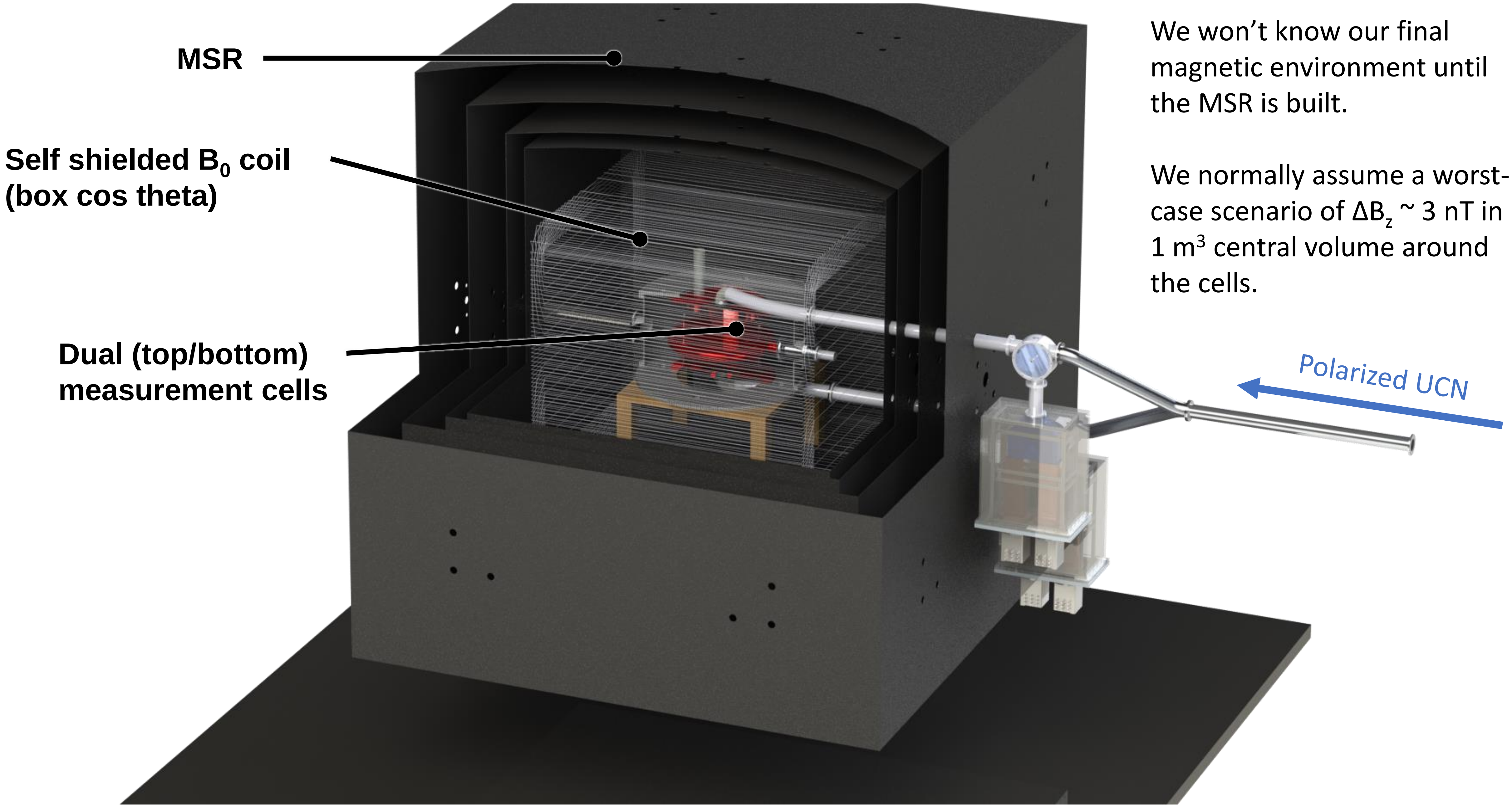



## TUCAN requirement:

$\Delta B_z < 140 \text{ pT}$ or $\sigma(B_z) < 40 \text{ pT}$

when measured over the region of the EDM cell(s), within the 1 μT main field

# TUCAN EDM experiment layout

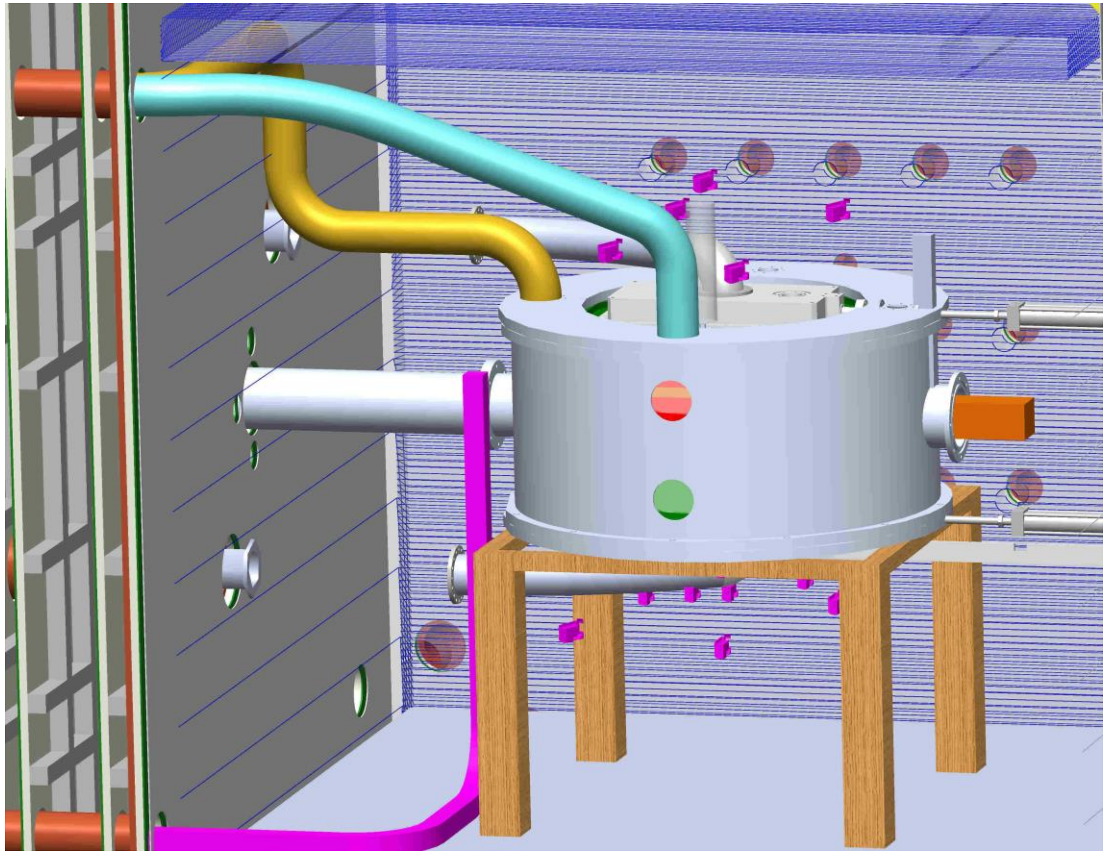



We won't know our final magnetic environment until the MSR is built.

We normally assume a worst-case scenario of $\Delta B_z \sim 3$ nT in a 1 $m^3$ central volume around the cells.

# Measuring the field

- Cs magnetometers at fixed positions around the measurement cells (W. Klassen at UBC)
- Mapping the field using external mapping system (M. Lavvaf)
- Mapping the field using internal mapping system (B. Franke, *et al*. at TRIUMF)



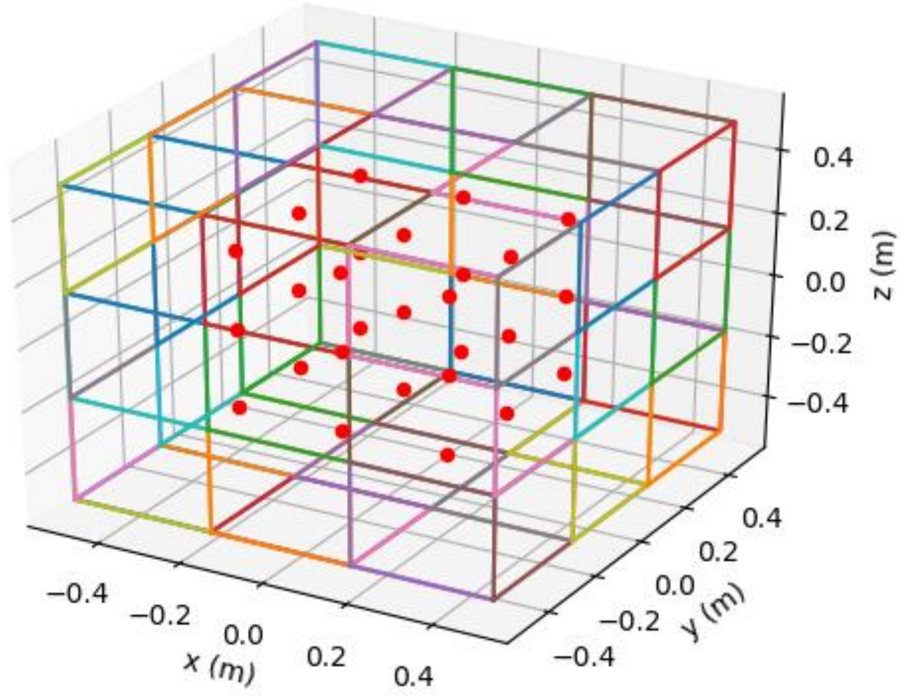
# Tailoring the field based on measurement

- Place set of square coils on cubic surface around cells.
- At each of the sensor positions $B_i = \sum_{j=1}^{c} M_{ij} I_j$ or $B = MI$ where $M$ is a matrix
- We can determine the currents to set on each coil to generate a target field using

$$I_{\text{set}} = M^{-1} B_{\text{target}}$$

- Problem: $M$ is not a square matrix; use SVD: $M = USV^T \rightarrow M^{-1} = VS^{-1}U^T$ where $S$ is diagonal and same dimension as $M$.

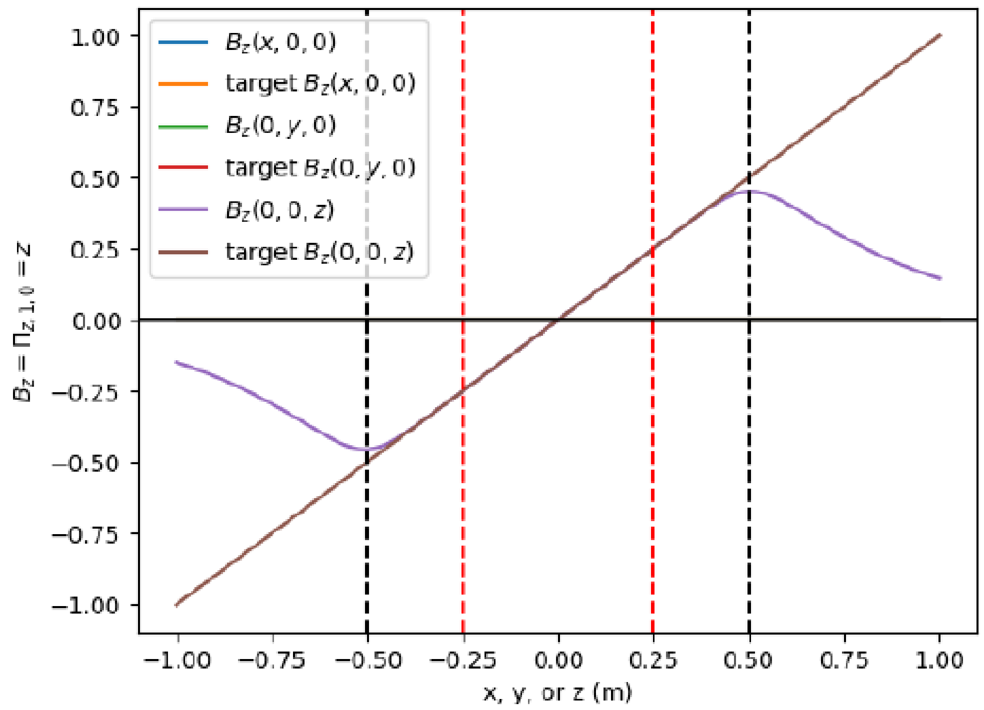
- Matrix problems: ill conditioning, bad modes, truncation
- Experimental problems: sensor positioning, sensor orientation, location of coils, magnetic mapping of coils, …



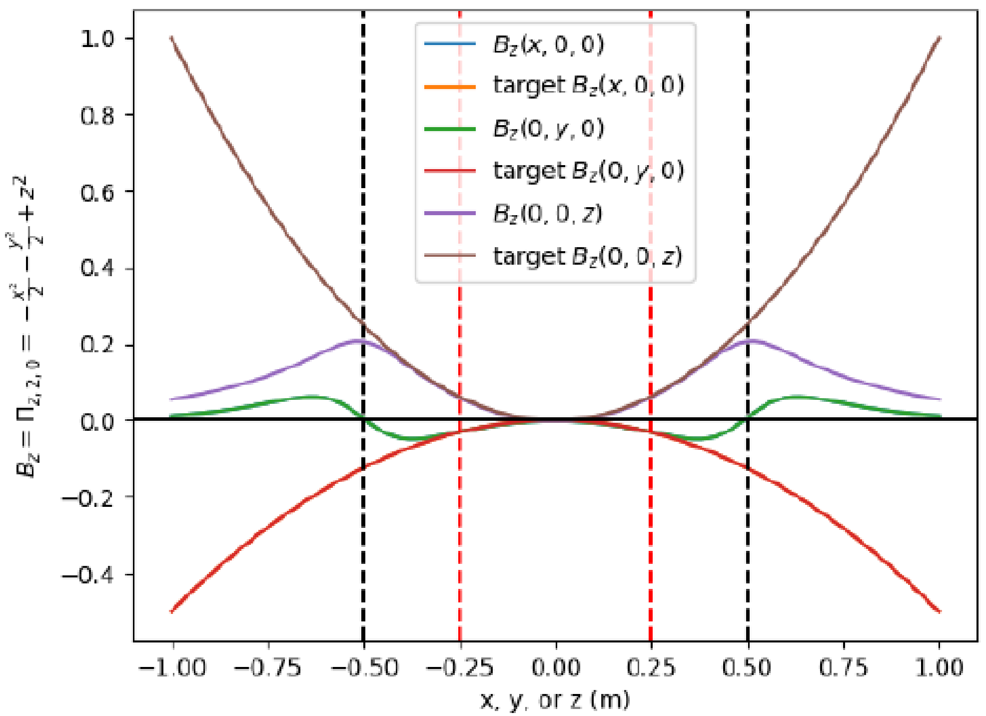

Example: 9 square coils on each of 6 faces of a cube
= 54 coils

27 sensor positions x 3 axes
= 81 sensor axes

# Sample results

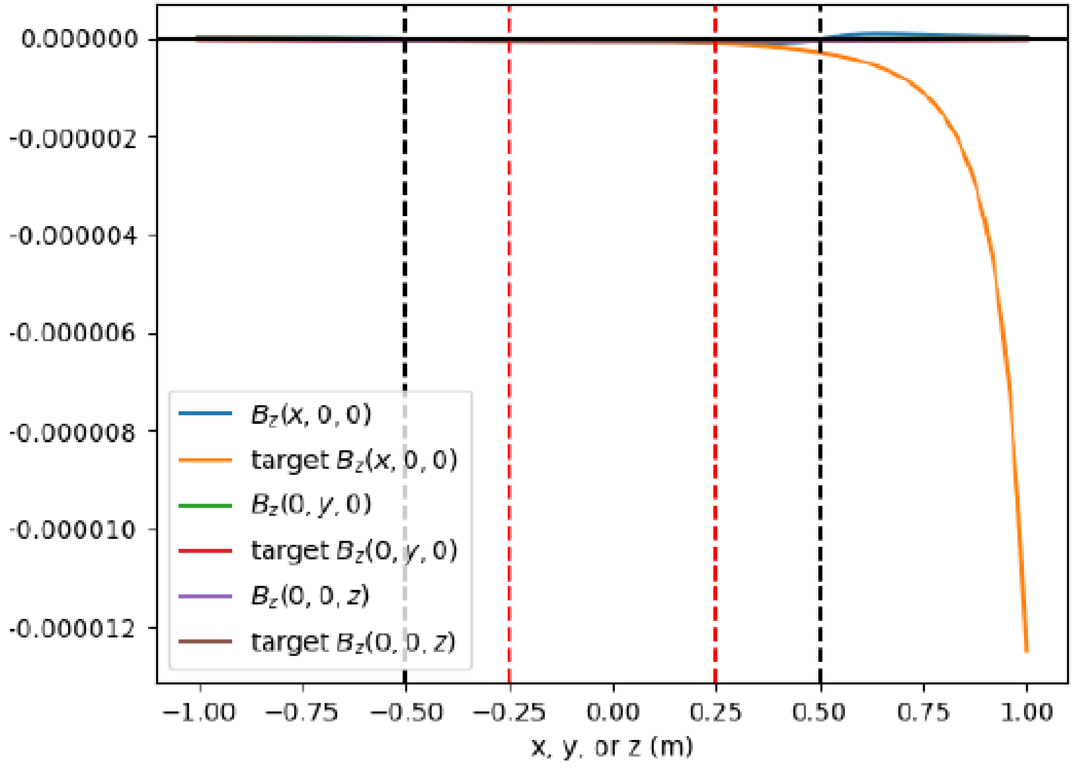



Perfectly linear gradient

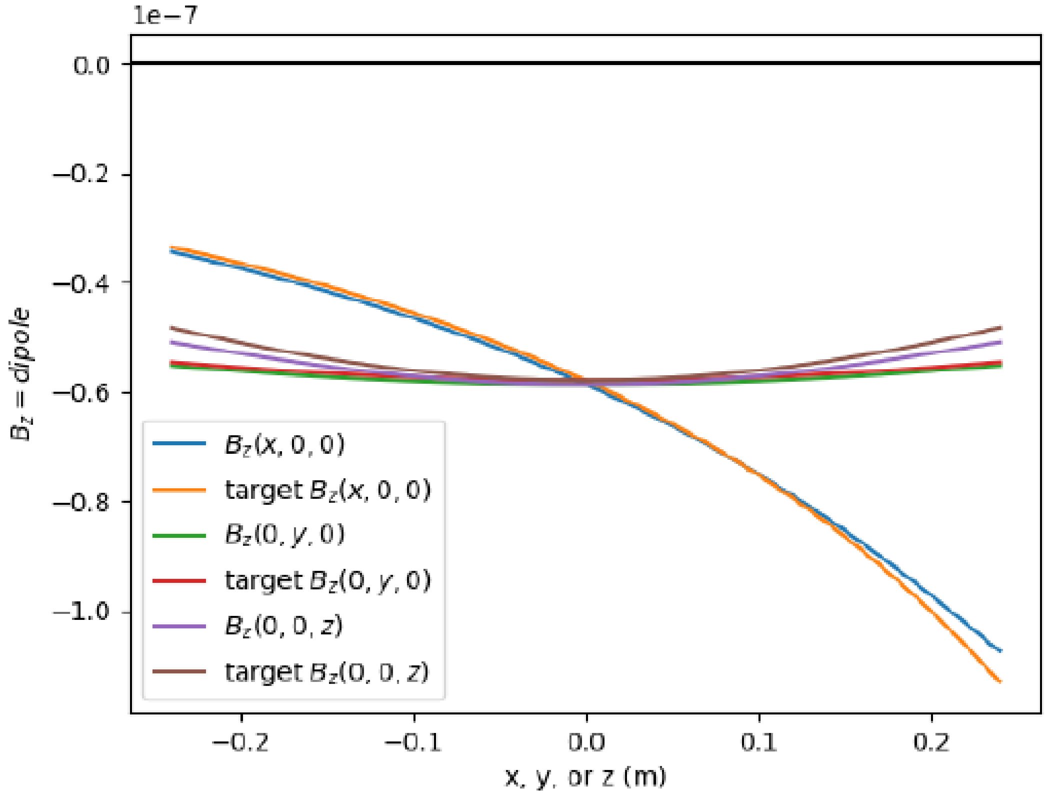



Quadratic

# Dipole on inner surface of MSR



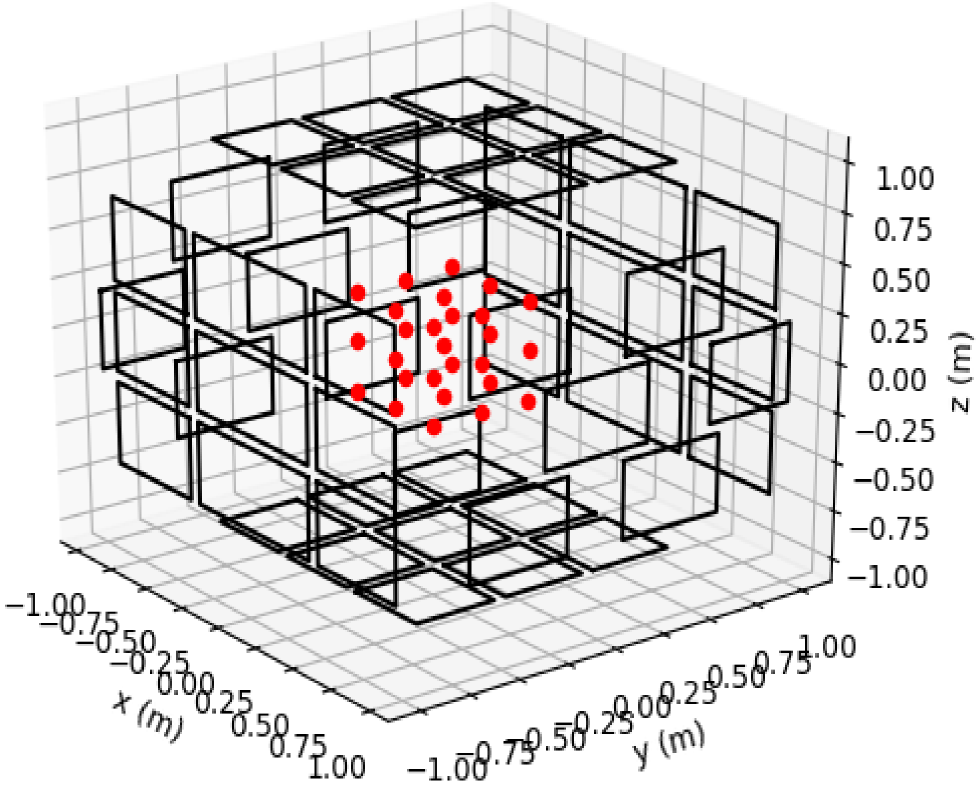

Dipole at z = 1.1 m




Zoomed in to central 0.5 m
region on each axis

# Results and conclusion

- When quantitatively measuring over the UCN cells, the coil system meets the requirements for TUCAN ($\Delta B_z < 140$ pT, $\sigma(B_z) < 40$ pT).
- Now moving into engineering of coil system:
  - Interface/mounting to $B_0$ coil (M. McCrea, N. Massacret at TRIUMF)
  - Development of multichannel stable current source (S. Ahmed, A. Jaison)
- Incredibly flexible design with simple geometry capable of generating arbitrary fields.




More realistic concept for TUCAN:

- Inner surface of $B_0$ coil used for mounting
- Coils adjusted to avoid conflicts with all feedthroughs to the experiment (UCN guides, high-voltage).

Works even better than original concept! (K. Augusto)

# Thank you!

Research Manitoba

Chaires de recherche du Canada
Canada Research Chairs
Canada

NSERC
CRSNG

BC Knowledge Development Fund

Japan Society for the Promotion of Science
Founded 1932

INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION
FONDATION CANADIENNE POUR L'INNOVATION