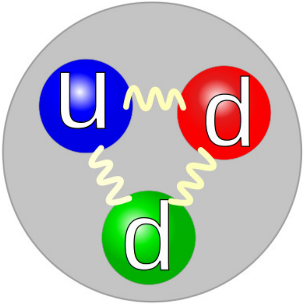
Effects of a superconducting lead endcap on the magnetic field profile for the nEDM search

Aritra Biswas
Kellogg Radiation Laboratory
Mentors: Brad Filippone, Simon Slutsky

November 19, 2014

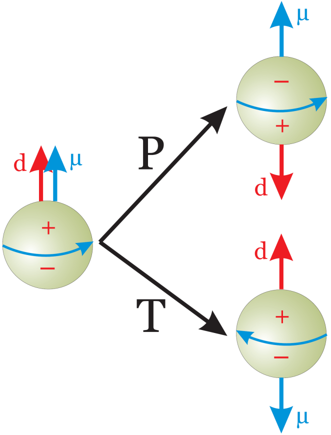
nEDM = neutron electric dipole moment

- distributed + and - charges inside neutron
- electric dipole moment (EDM) measures separation between centers of + and - charge



Horvath A. Quark structure neutron. Wikimedia.

why does the nEDM matter?



- $C : q \mapsto -q$
- $P : (t, x, y, z) \mapsto (t, -x, -y, -z)$
- $T : (t, x, y, z) \mapsto (-t, x, y, z)$

- CPT symmetry
  $+$ P violation
  $+$ T violation
  $\Rightarrow$ CP violation

- reformulations of Standard Model
- matter-antimatter asymmetry

Knecht A. 22 May 2008. Parity and time reversal violation. Wikimedia. Public domain.

how do we measure the nEDM?

- put ultra-cold neutrons (UCN) in **E** and **B** fields
- neutron's spin will precess at frequency ω

$$\omega_{\uparrow\uparrow} = -\frac{\mu_n B + d_n E}{J\hbar}, \quad \omega_{\uparrow\downarrow} = -\frac{\mu_n B - d_n E}{J\hbar} \tag{1}$$

$$\Delta\omega = \pm\frac{2d_n E}{J\hbar} \pm \Delta\omega_{geo} \tag{2}$$

- $\frac{\partial \mathbf{B}}{\partial(x,y,z)} \neq 0 \Rightarrow \frac{\partial \mathbf{B}}{\partial t} \neq 0 \Rightarrow$ **E** field $\Rightarrow \Delta\omega_{geo}$

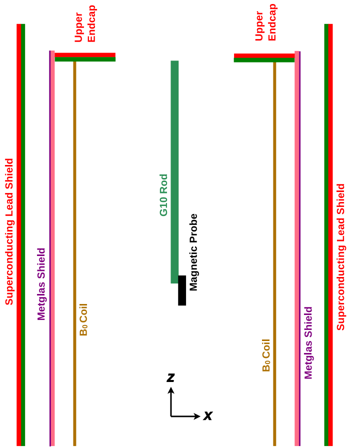
- geometric phase $\Rightarrow$ false measurement!
- engineering challenge: creating an uniform magnetic field

Pendlebury et. al. Geometric-phase-induced false electric dipole moment signals for particles in traps. Phys. Rev. A. 70, 032102 (2004).

the half-scale model

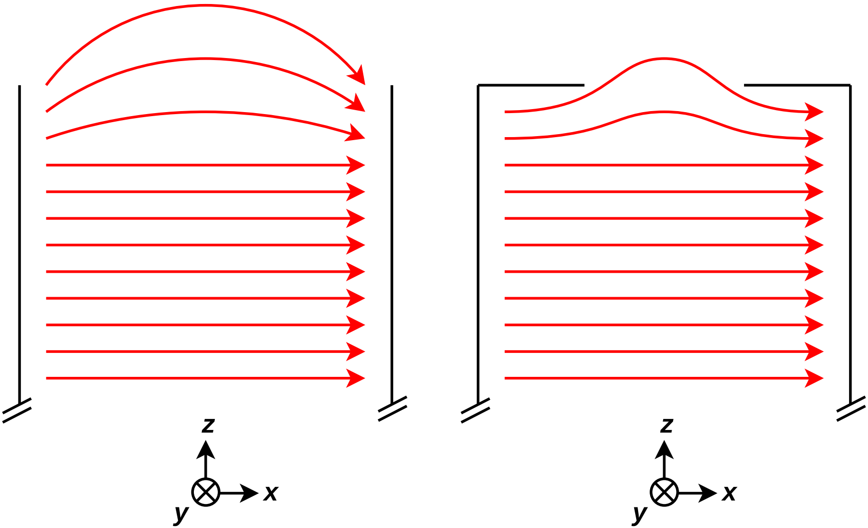
- about 2 meters tall
- inside a cryostat
  (cools to 4 K)
- only creates **B** field;
  no measurement cells
- final experiment at Oak
  Ridge National Laboratory

inside the half-scale model

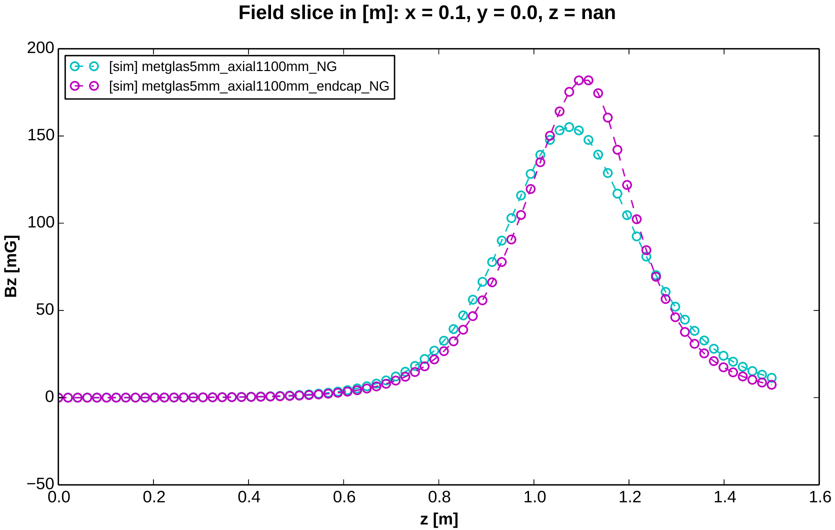


- B_0 coil: $\cos\theta$ coil geometry
  - **B** field in x direction
- ferromagnetic Metglas shield
  - high μ
- superconducting axial shield
  - $\mu = 0$
- superconducting upper endcap

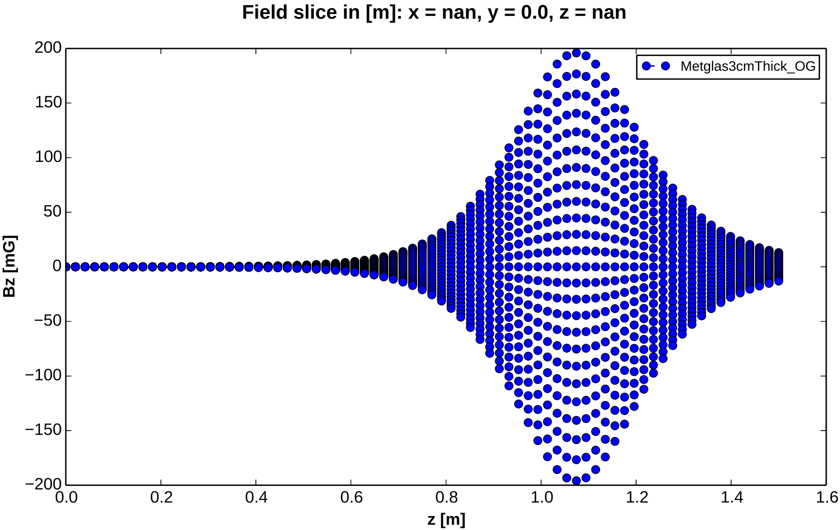
edge effects and the superconducting endcap



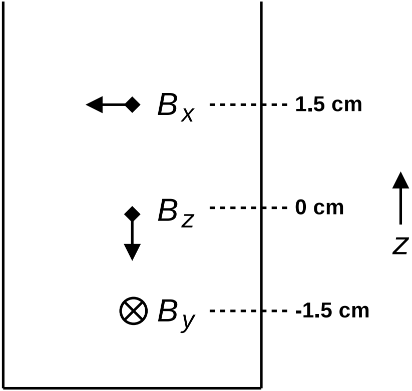
simulations of endcap effect



correction: probe *x* centering

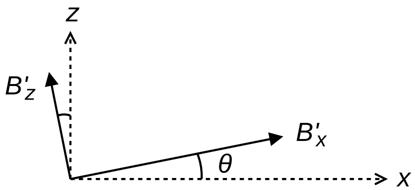


correction: probe axis offset



- 3 separate 1-axis probes
- incomplete vector map
- need to store z-axis offset vector along with z array

correction: probe tilt



$$B_x = B'_x \cos\theta - B'_z \sin\theta, \quad B_z = B'_z \cos\theta + B'_x \sin\theta \qquad (3)$$

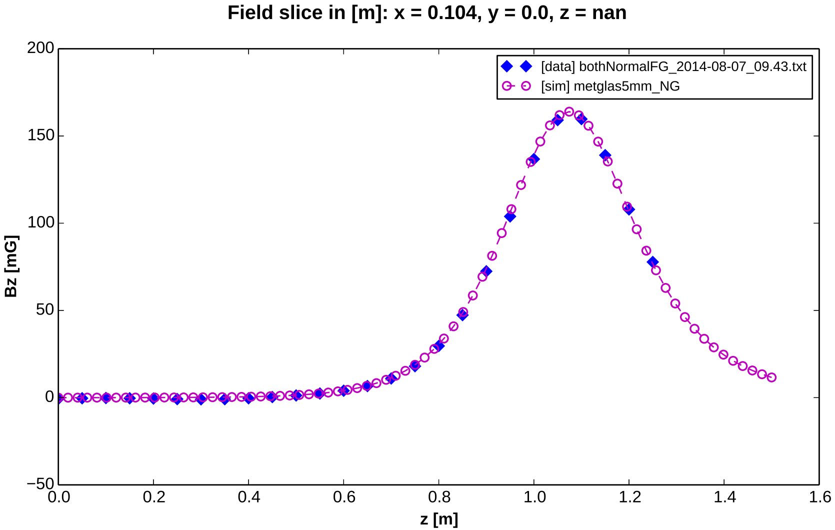
1. θ is small:

$$B_x = B'_x - B'_z\theta, \quad B_z = B'_z + B'_x\theta$$

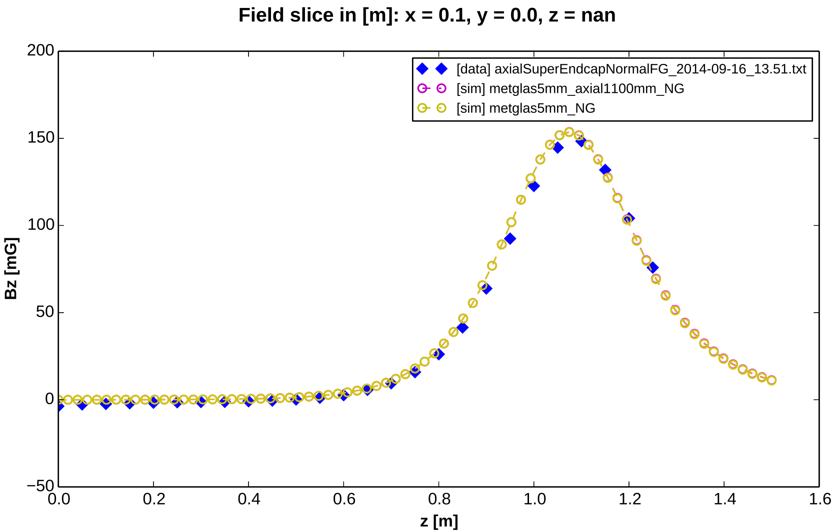
2. $B_z = 0$ at center:

$$\theta = -\frac{B'_z}{B'_x}$$

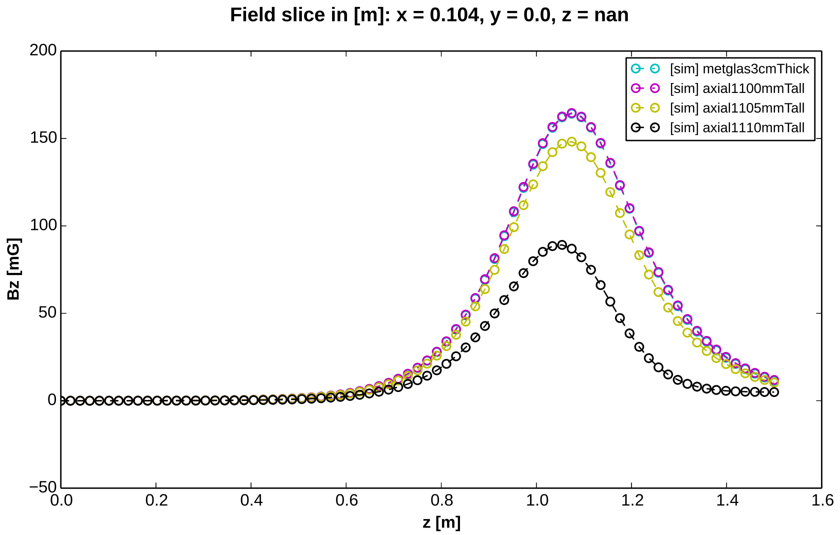
comparison: axial shield normal, endcap normal



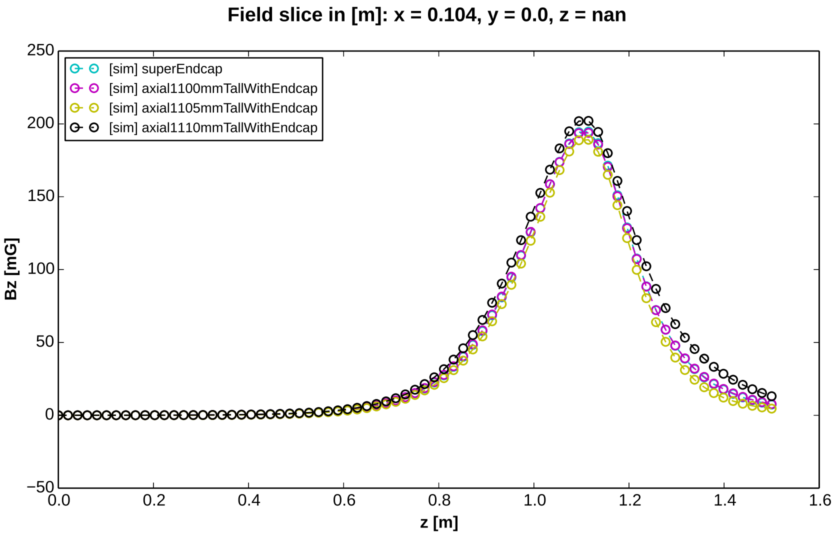
comparison: axial shield SC, endcap normal



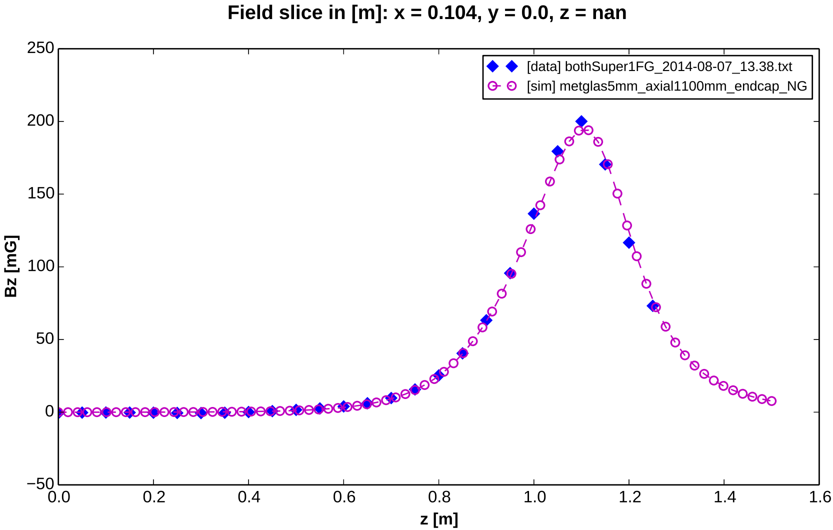
simulation: varying axial shield height



simulation: varying axial shield height, with endcap



comparison: axial shield SC, endcap SC



analysis

- simulations are effective in predicting endcap behaviors
- motivates further simulated studies with different endcap geometries
- our endcap seems to shift the B_z peak away from magnet center
- axial shield effect is stronger when more of it is “uncovered” by the Metglas
- SC endcap hides axial shield influence, even over small variation in height

ongoing and future work

- endcap will likely be effective in final experiment
- new model with top and bottom endcaps
- analysis of field gradients in measurement cell volumes

acknowledgments

- Mentor: Brad Filippone
- Co-mentor: Simon Slutsky
- Chris Swank, Chub Osthelder, Bob Carr
- Arthur R. Adams SFP Fellowship
- Caltech SURF Program