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

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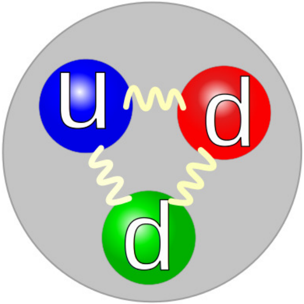
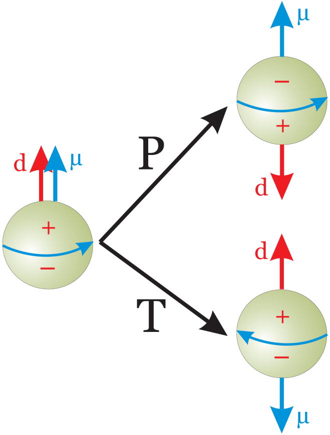
# nEDM = neutron electric dipole moment

- 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 $\omega$

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

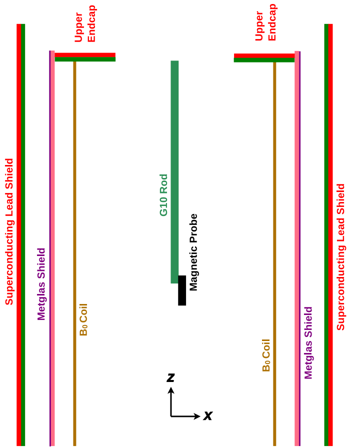
$$\Delta\omega = \pm\frac{2d_n E}{J\hbar} \pm \Delta\omega_{geo} \tag{2}$$

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

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

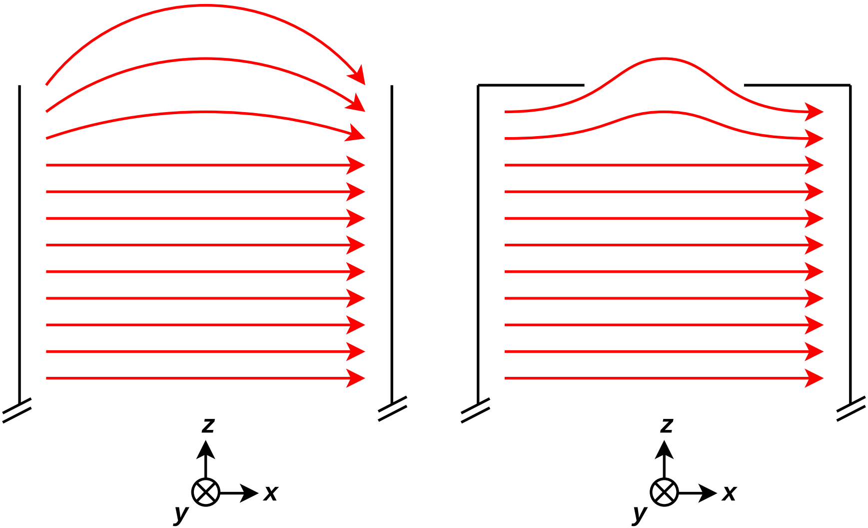
Pendlebury et. al. Geometric-phase-induced false electric dipole moment signals for particles in traps. Phys. Rev. A. 70, 032102 (2004).

# the half-scale model

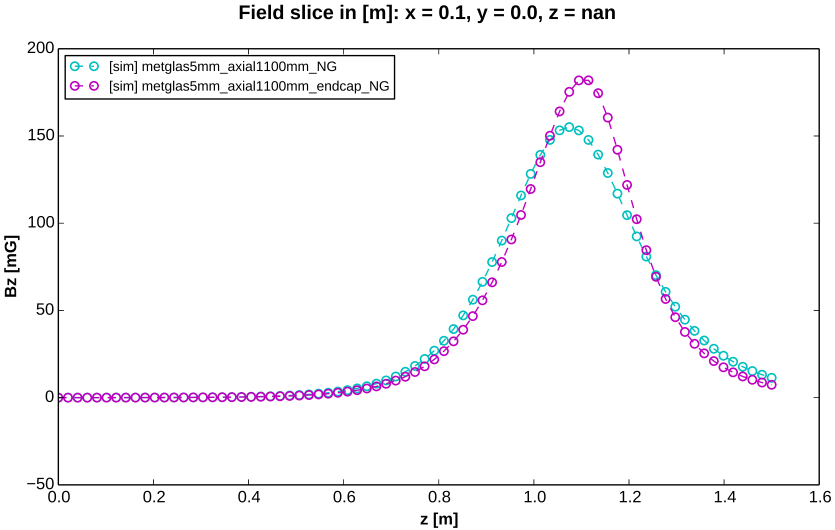



- $B_0$ coil: $\cos\theta$ coil geometry
  - **B** field in $x$ direction
- ferromagnetic Metglas shield
  - high $\mu$
- superconducting axial shield
  - $\mu = 0$
- superconducting upper endcap

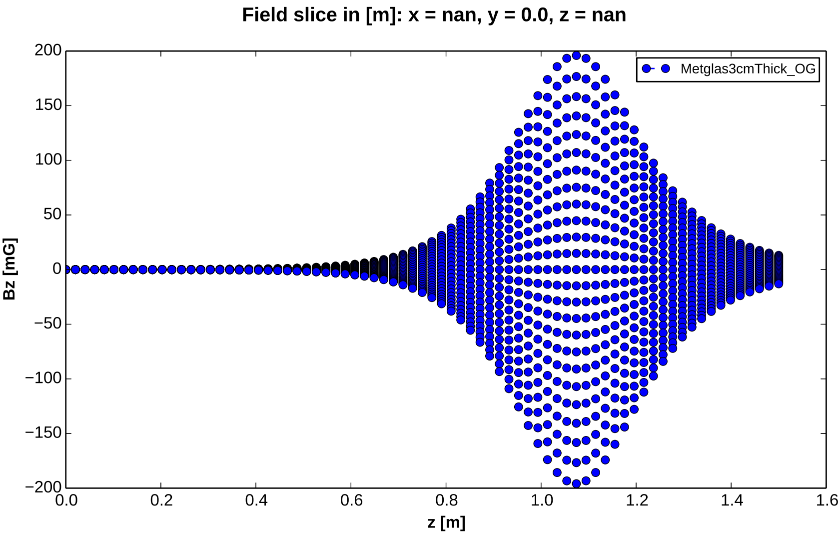
# edge effects and the superconducting endcap



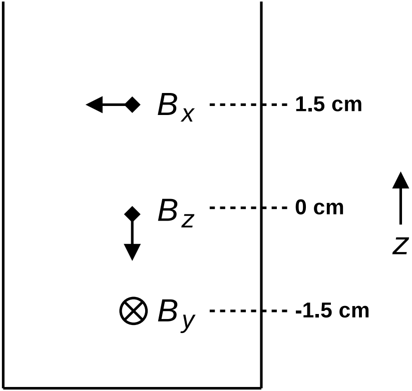
# simulations of endcap effect



# correction: probe $x$ centering

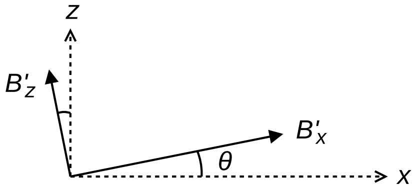


# correction: probe axis offset




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

# correction: probe tilt




$$B_x = B'_x \cos\theta - B'_z \sin\theta, \quad B_z = B'_z \cos\theta + B'_x \sin\theta \tag{3}$$

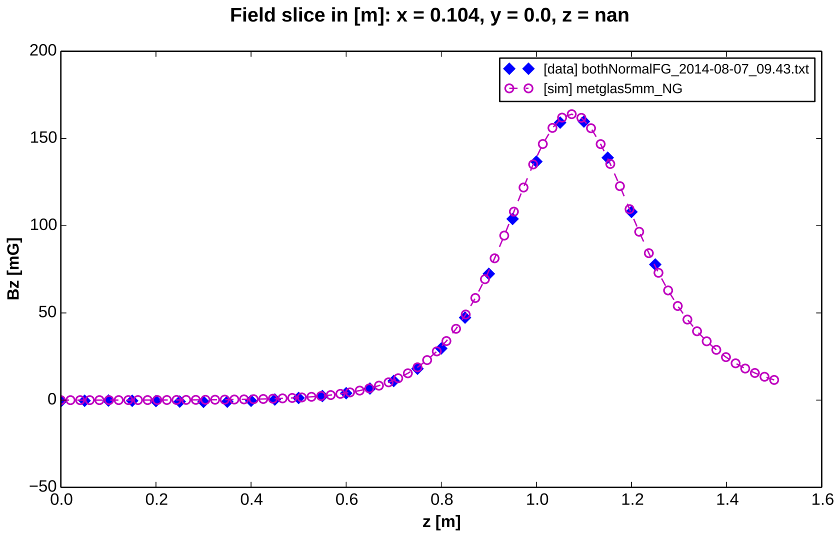
1. $\theta$ is small:

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

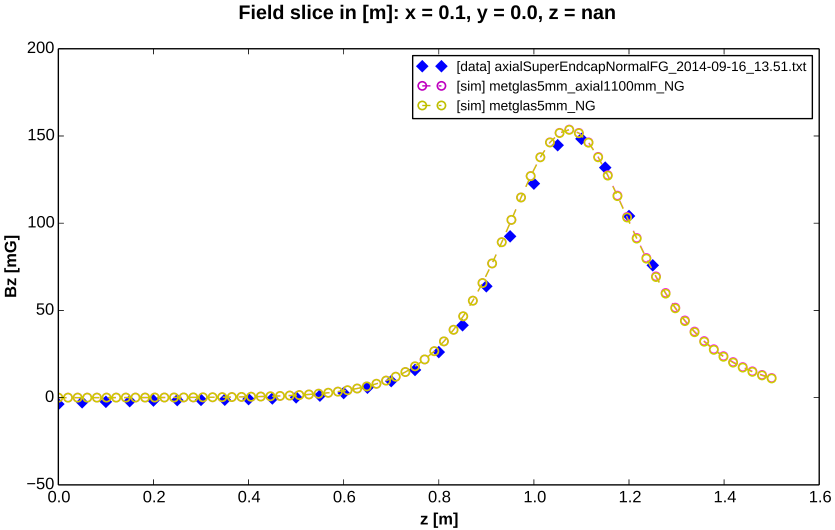
2. $B_z = 0$ at center:

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

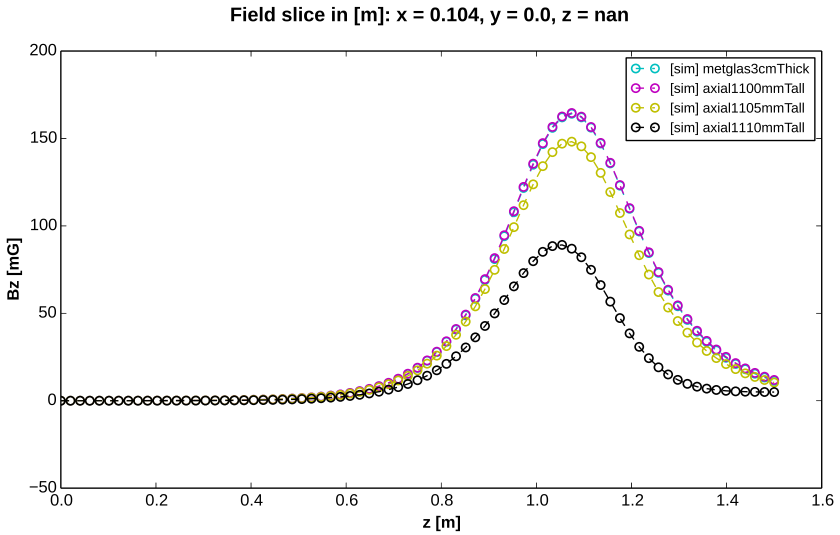
# comparison: axial shield normal, endcap normal



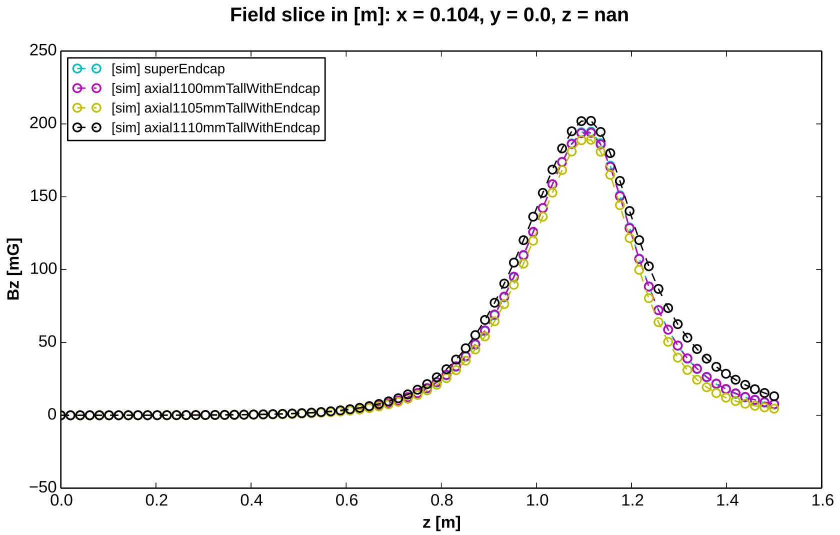
# comparison: axial shield SC, endcap normal



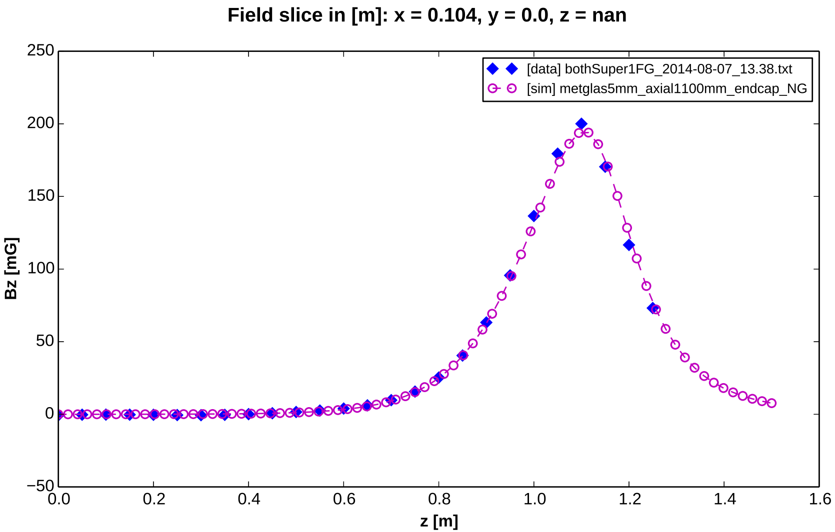
# simulation: varying axial shield height



# 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

# acknowledgments

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