Effectiveness of a superconducting lead endcap in minimizing magnetic field gradients for the nEDM search

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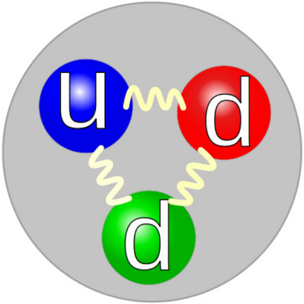
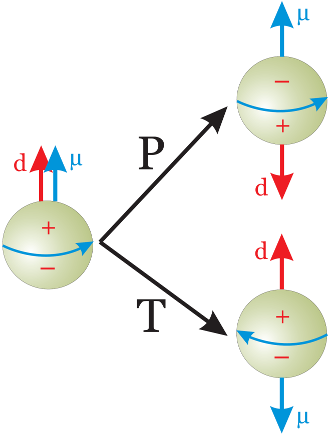
nEDM = neutron electric dipole moment

- up quark: $\frac{2}{3}e$
- each down quark: -$\frac{1}{3}e$
- electric dipole moment: vector measuring separation between + and - charges and their orientation



Horvath A. Quark structure neutron. Wikimedia.

why does the nEDM matter?



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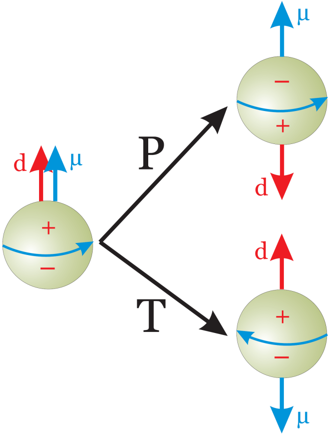

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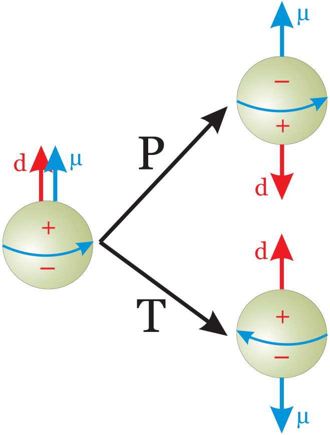

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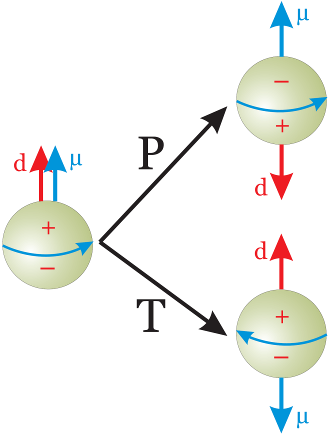

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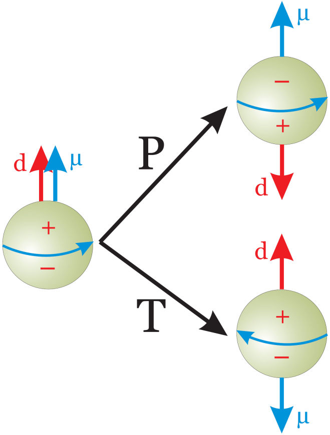

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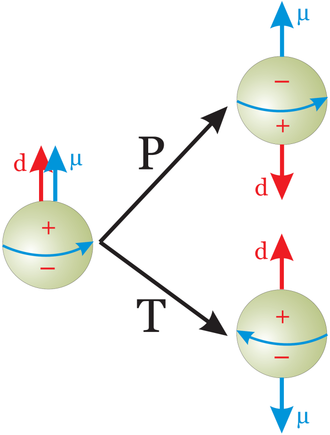

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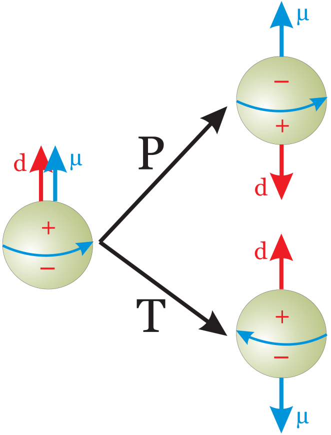

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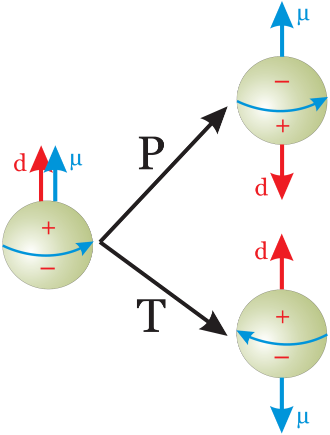

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- reformulations of Standard Model
- matter-antimatter asymmetry

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how do we measure the nEDM?

- put ultra-cold neutrons (UCN) in **E** and **B** fields

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

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- geometric phase $\Rightarrow$ false measurement!

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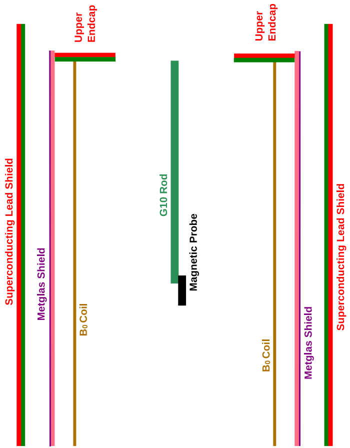
creating an uniform magnetic field



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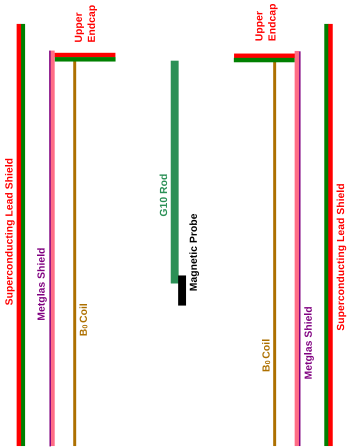

- B_0 coil: $\cos\theta$ coil geometry, emulates sheet current

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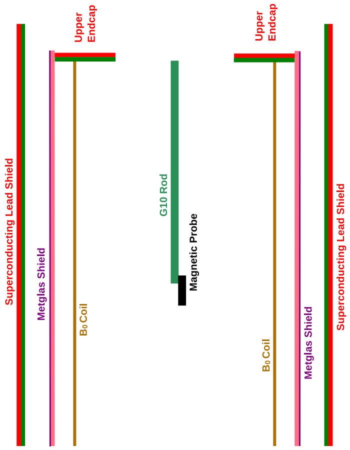

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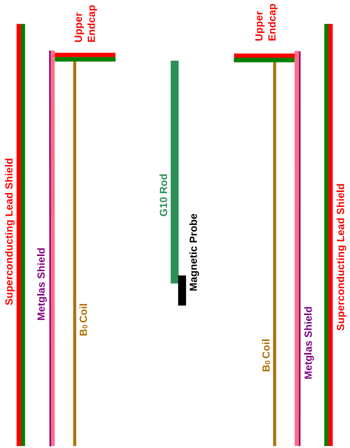

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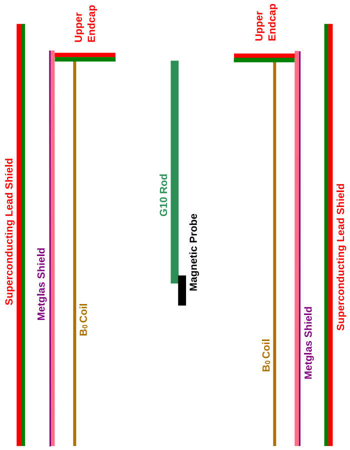
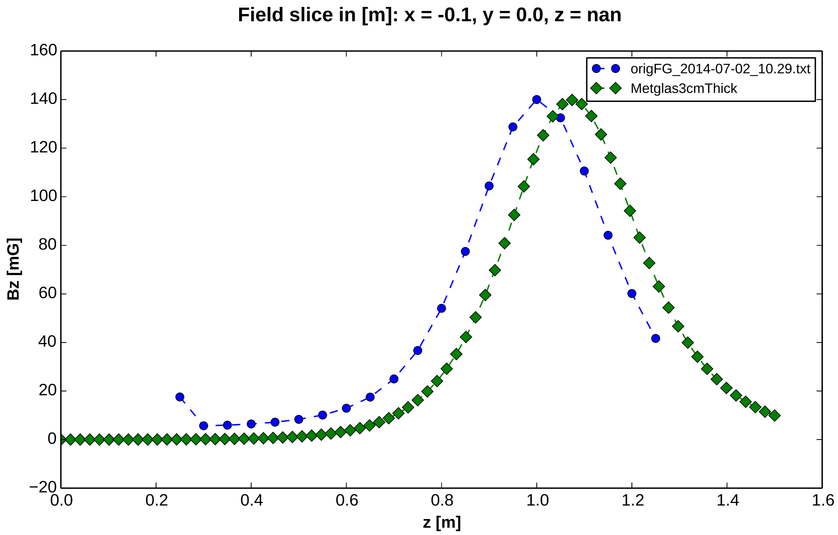


- B_0 coil: $\cos\theta$ coil geometry, emulates sheet current
- ferromagnetic Metglas shield
- superconducting axial shield
- superconducting upper endcap

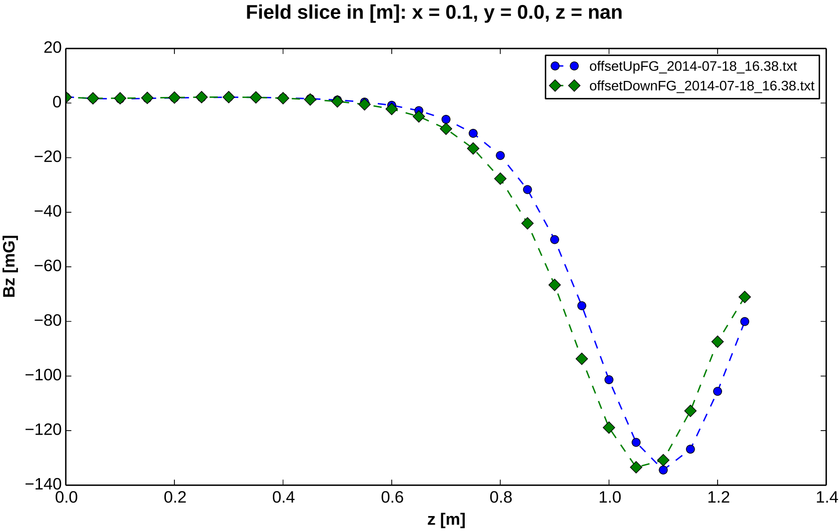
analyzing the magnetic field profile

- simulate experiment and calculate field
- compare simulation and measurement in warm case
- correct measurements
- use simulation to predict effects of endcap
- see whether measurements agree

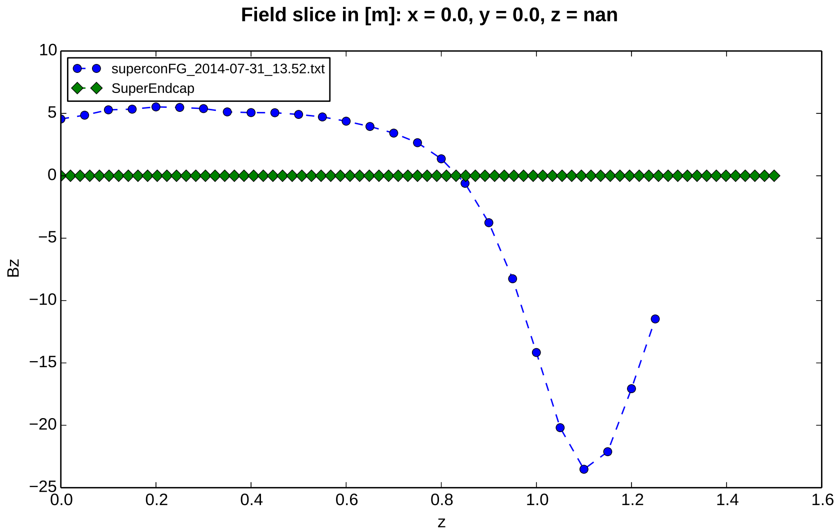
original comparison, warm



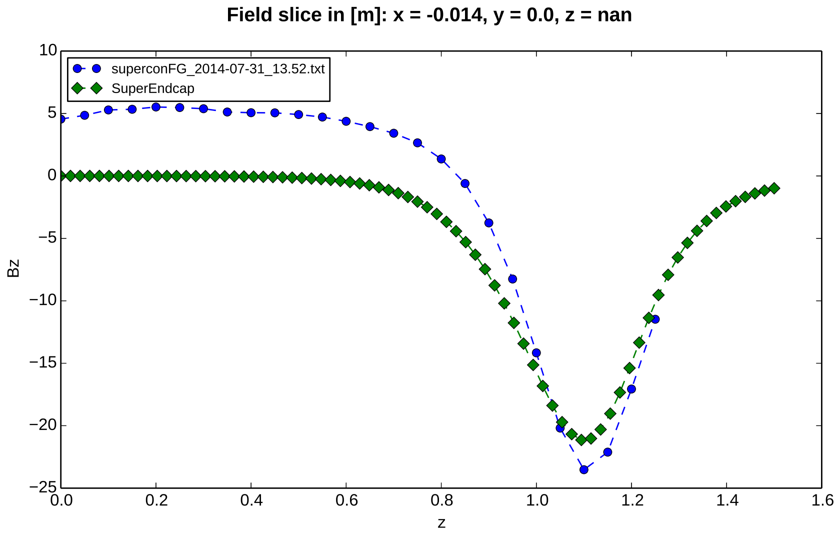
correction 1: probe measurement time



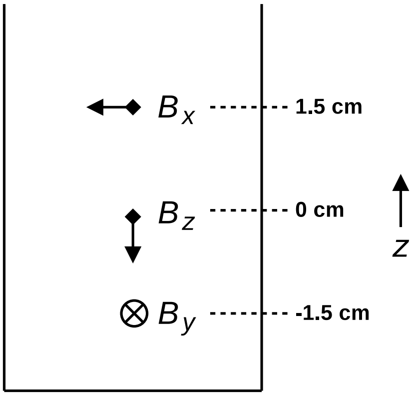
correction 2: x centering, superconducting



correction 2: x centering, superconducting, 1.4 cm offset



correction 3: probe offset



- 3 separate 1-axis probes

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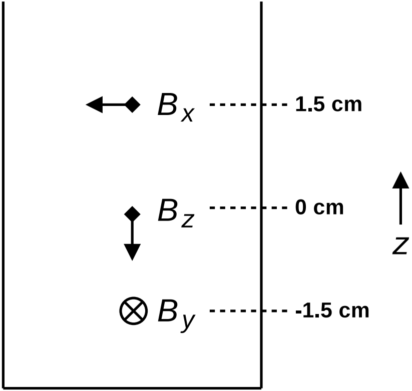

- 3 separate 1-axis probes
- incomplete vector map

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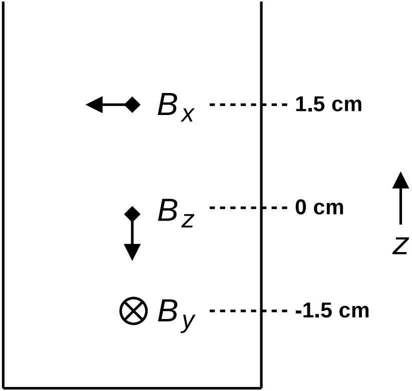

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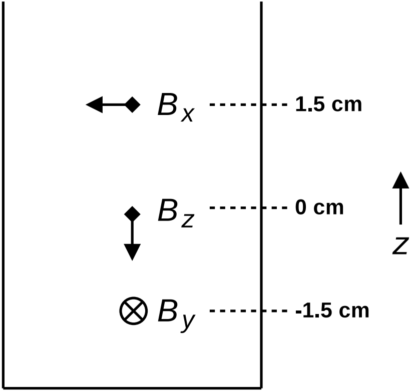
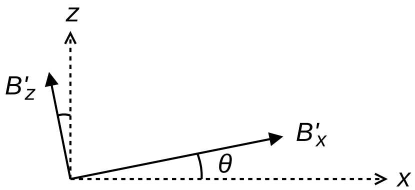


- 3 separate 1-axis probes
- incomplete vector map
- need to store z-axis offset vector along with z array
- `OffsetAxis` class to return proper spatial axis array based on desired vector component

correction 4: probe tilt



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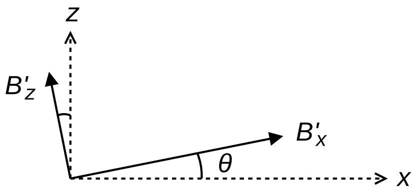

$$B_x = B'_x \cos\theta - B'_z \sin\theta, \quad B_z = B'_z \cos\theta + B'_x \sin\theta \qquad (3)$$

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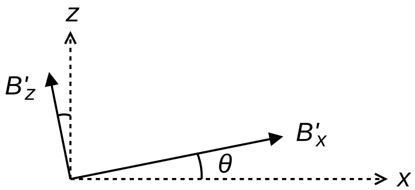

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1. θ is small:

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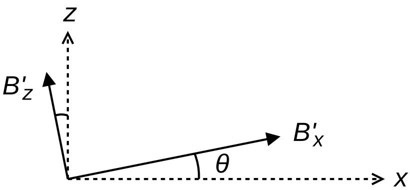

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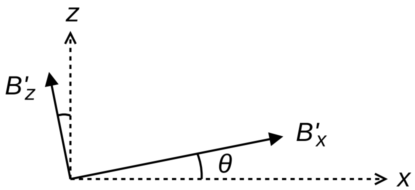

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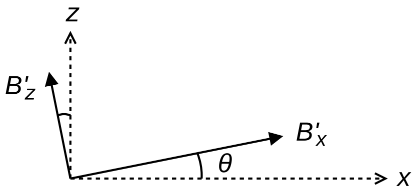

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$$\theta = -\frac{B'_z}{B'_x}$$