Magnetic Mapping for the ^6He Experiment

REU Final Presentation

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Outline

Motivation

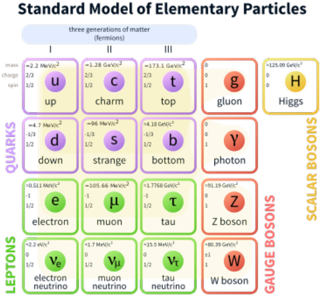
- Search for Beyond the Standard Model (BSM) physics through precision experiment
- predicted by other theories: supersymmetry, Grand Unified Theories

Background - Weak Interaction

- Weak interaction - fundamental force
- responsible for β decay

$$^{6}\text{He} \rightarrow {}^{6}\text{Li} + e^{-} + \bar{\nu}_e$$

- mediated by W^{-} boson
- new physics: interactions

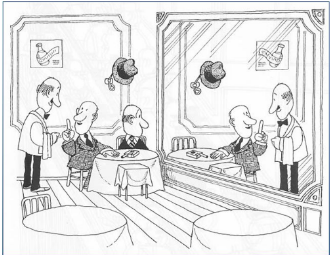


Background - Parity Violation

- *Parity* is the inversion of spatial coordinates

$$(ct, x, y, z) \rightarrow (ct, -x, -y, -z)$$
$$\hat{P}\vec{r} = -\vec{r}$$
$$\hat{P}\vec{L} = (-\vec{r}) \times (-\vec{p}) = \vec{r} \times \vec{p}$$

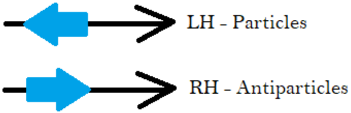
- Parity shows symmetry under the inversion of spatial coordinates
- with parity: expected both right- and left-handed particles
- Chien Sheng-Wu 1957 - left-handed particles only



Helicity and Chirality

Helicity:

$$H = \frac{\vec{p}\cdot\vec{s}}{|\vec{p}||\vec{s}|} = \pm 1$$



Helicity *not* Lorentz invariant
$\rightarrow$ solution: define *Chirality*

$$e^L = \sqrt{\frac{1+\frac{p}{E}}{2}}\, e^{H=-1} + \sqrt{\frac{1-\frac{p}{E}}{2}}\, e^{H=+1}$$

$$e^R = \sqrt{\frac{1-\frac{p}{E}}{2}}\, e^{H=-1} + \sqrt{\frac{1+\frac{p}{E}}{2}}\, e^{H=+1}$$

$$e^R e^L = \sqrt{1-(\tfrac{p}{E})^2} = \frac{m}{E}$$

Interaction Hamiltonian

Interaction Hamiltonian for ^{6}He beta decay:

$$H_{int} = \bar{\psi}_f \gamma^\mu \gamma_5 \psi_i (2 C_A e^{-L} \gamma_\mu \gamma_5 \nu_e^L) + \boxed{\bar{\psi}_f \sigma^{\mu\nu} \psi_i [(C_T - C_T') e^{-L} \sigma_{\mu\nu} \nu_e^R + (C_T + C_T') e^{-R} \sigma_{\mu\nu} \nu_e^L]}$$

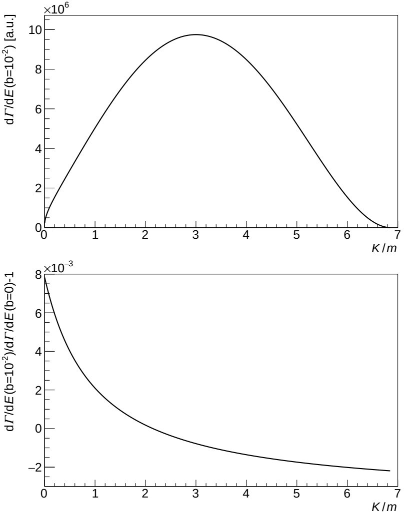
Search for tensor currents ($\sigma_{\mu\nu}$)

Chirality-flipping - Fierz Interference

- terms that include RH & LH are chirality flipping
- show small distortions to spectrum

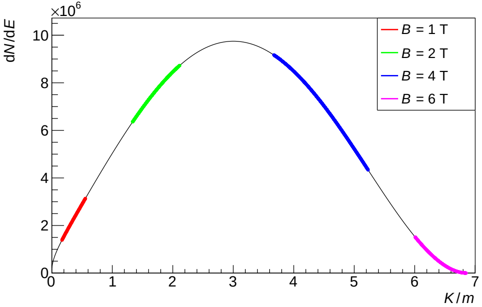
$$dW = dW_0(1 + a\frac{\bar{p}_e \cdot \bar{p}_\nu}{E_e E_\nu} + b\frac{\Gamma m_e}{E_e})$$

$$b \approx \frac{(C_T + C'_T)}{C_A}$$



Measuring the β spectrum - CRES technique

- need precision measurements of the entire spectrum
- 6 GHz bandwidth, tune magnet
- Cyclotron Radiation Emission Spectroscopy (Project 8)



$$\omega_c = \frac{qBc^2}{E_e}$$

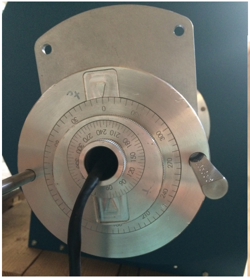
My Contribution

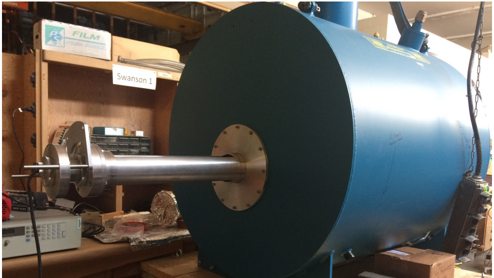
Magnetic Modeling

1. adapt NMR probe
2. multipole expansion
3. position mapping

The Gadget

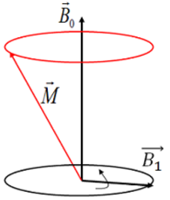
Place the probe in the magnet at a particular location ($\hat{r}$, $\hat{\theta}$, $\hat{z}$)

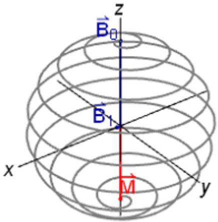




Nuclear Magnetic Resonance (NMR) Principles

- start with a sample in a magnetic field, B_0
- perturb with a small oscillating field, B_1
- at resonance, induces an energy transition by flipping magnetization
- produces a strong signal at this frequency - characteristic of magnetic field seen by nucleus
- use this magnitude measurement & fit to multipole expansion





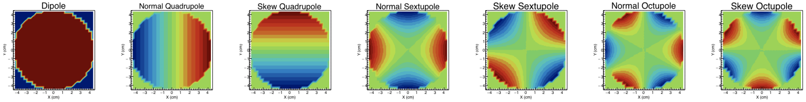
Multipole Expansion

Laplace's Equation:

$$\nabla^2 \phi_m = 0$$

Solutions: Taylor Expansion with spherical harmonics:

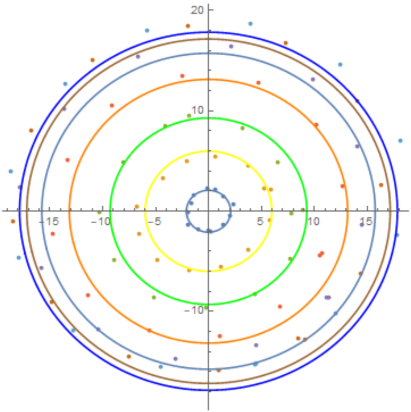
$$\phi_m = \sum_{l=0}^{\infty} \sum_{m=-l}^{l} \left(a_l^m r^l + b_l^m r^{-(l+1)}\right) Y_l^m$$



Theodolite Mapping

- accurate position measurements for probe
- position accuracy impacts accuracy of Linear Least Squares fit in code

Position mapping: z=-20 cm



- Mean (x,y) values for set r
- colors show r-value
- Additional measurements: z=0 and z=+20 cm (not yet finished)

Future Investigation

- Finish position mapping of magnet
- Automate gadget & Teslameter data collection process
- Improvements on multipole model

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References

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