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MC simulations for RT nEDM systematics

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Introduction

One important aspect of the study of systematic effects in room-temperature (RT) nEDM [1] is the inhomogeneous spatial distribution of the stored UCN, coming from gravity, causing Larmor frequency shift and depolarization. Lowest energy neutrons average the inhomogeneous magnetic field closer to the chamber bottom, in contrast to fast Hg-comagnetometer atoms sampling the field uniformly. Also the fraction of diffuse (non-specular) reflections influences how trajectories average the field over the volume of the precession chamber.

Goal

Aim was to calculate the resonance frequency shifts and variations in the transversal depolarization time (T_2) coming from changes in the fraction of diffuse reflections. We also compared to theoretical predictions for simple magnetic field configurations as bench-marks for the realistic field calculations.

Simulations were done using MCUCN [2] developed in the PSI UCN physics group.

Spin handling in MCUCN

- $E_{kin} \gg \mu B \Rightarrow$ Bloch equations along the analytical trajectory: $\frac{d\mathbf{S}}{dt} = \mathbf{S} \times (\gamma \mathbf{B})$
- Time, position and velocity dependent (e.g. via $\mathbf{E}\times\mathbf{v}/c^2$) magnetic fields applied in analytical form, e.g. implementing parameterized fields.
- Field parameterization is obtained by fitting measured maps using Cartesian harmonic basis functions.
- A required precision ε can be set as an input parameter: maximal error per step allowed for each spin vector component.
- Runge-Kutta-Fehlberg method implemented: in the same step 4th and 5th order calculation of the differences ΔS_x, ΔS_y, or $\Delta S_z > \varepsilon \Rightarrow$ step size reduced.

MC of Ramsey cycles

- initial energy spectrum (MC)
- cylindrical chamber volume
- coating parameters: optical potentials, loss and diffuse reflection parameters,
- linear sinusoidal flipping RF signal
- inhomogeneous magnetic field in the precession chamber around 1 μT as parameterized from Cs magnetometer data.

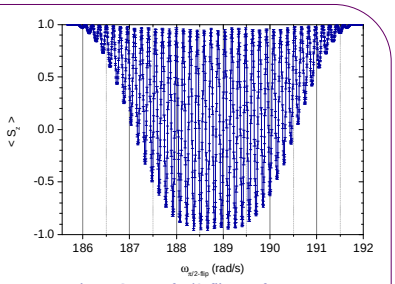

Fig.1: Scan of π/2-flipper frequency in the Ramsey cycle for a real field.

Spin precession code benchmarked with theory (an example)

Frequency shift from quadrupole

$$B_{xy} = q \begin{pmatrix} y \\ x \end{pmatrix}$$

MCUCN scan of Ramsey resonance with 1 ω-sample ≡ 1 trajectory

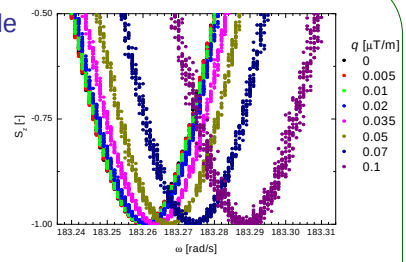

Fig.2: Shift in the resonance fringe as a function of the q-parameter.

Ramsey-Bloch-Siegert shift was calculated [3] as

$$\Delta\omega_{res} = \frac{\gamma^2}{2\omega_0}\left\langle B_x^2 + B_y^2 \right\rangle = \frac{\gamma^2 q^2 R^2}{4\omega_0}$$

and compared to the resonance frequencies in Fig. 2.

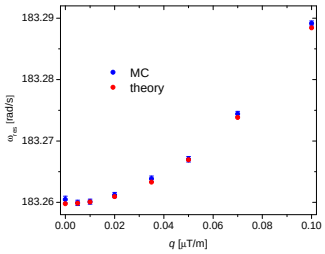

Fig.3: Ramsey resonance frequency dependence on q – match within ~1σ.

Change in diffuse fraction influences T_2 and resonance frequency

We considered Lambert model for diffuse reflections (p_{diff} in %)

Field parametrization from Cs magnetometer measurements:

$$B_z = B_0 + g_x x + g_y y + \boxed{g_z z} + g_{xx}(x^2 - z^2) + g_{yy}(y^2 - z^2) + g_{xy} x y + g_{xz} x z + g_{yz} y z$$

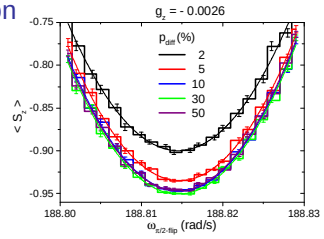

Fig.4: Central fringe of the Ramsey pattern as a function of p_{diff}.

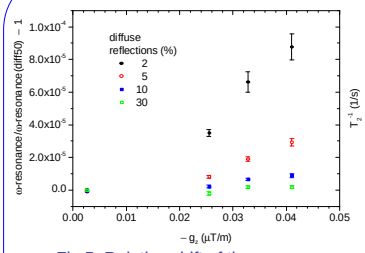

Fig.5: Relative shift of the resonance frequency as a function of g_z and p_{diff}.

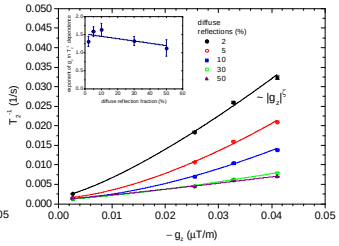

Fig.6: $T_2^{-1}(g_z)$ dependence and fit exponent ζ (insert) as a function of p_{diff}.

Conclusions

- Caused by magnetic field inhomogeneities, the Ramsey resonance frequency and the transversal depolarization time T_2 will be influenced by the fraction of non-specular reflections in the precession chamber – compare to [4].
- By increasing the roughness of the insulator ring constituting the side of the precession chamber can increase the T_2 time by factor 1.3-2 – this has to be tested experimentally since the current p_{diff} is not known.

Acknowledgement

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References

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[4] P.G. Harris et al., arXiv:1306.1252v1 [physics.atom-ph] 5 Jun 2013
[5] PL-Grid Cyfronet webpage http://www.cyfronet.krakow.pl/en