Preparing a Measurement of the Charge of the free Neutron within qBounce

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Abstract

With a new Gravity Resonance Spectroscopy technique we plan to probe the electric neutrality of the neutron. This is possible by using Ramsey's Method of separated oscillating fields. The approach has the potential to improve the 25 years old existing limit [1] [11]. Our project is related to the question of the quantisation of the electric charge, which is a well established experimental observation. But charge quantisation in the Standard Model of Particle Physics requires an additional free parameter, which must be determined experimentally. A charge measurement is a promising way to refine the theoretical framework and thus has consequences for various topics i.e. neutron-antineutron oscillations or the search for a Grand Unified Theory.

Motivation

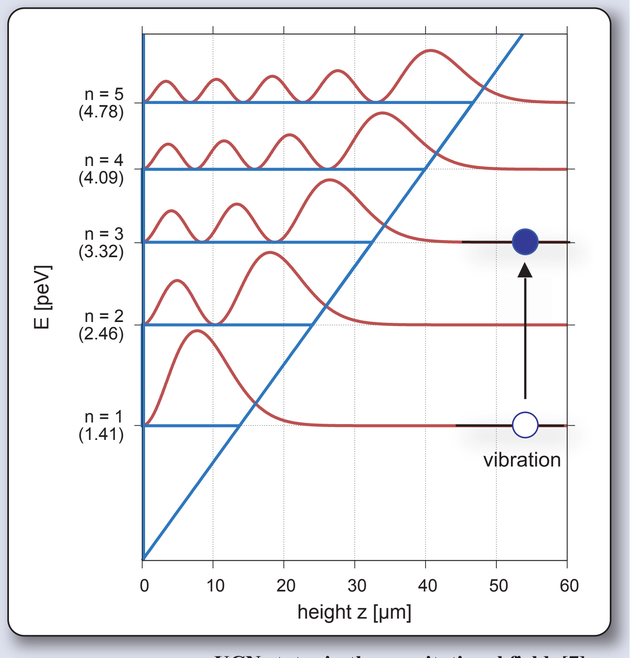
* Despite conservation laws and observations, the neutrality of the neutron is an open question.
* Many competing extensions to the Standard Model.
* A new limit would narrow down the landscape of possible extensions.
* GRS together with Ramsey's method provides a new approach to probe the neutrons charge.

Gravity Resonance Spectroscopy

An ultra-cold neutron forms bound states in earths gravitational field over a flat mirror [6] as shown in the figure on the right side.

These states were observed for the first time in 2002 [3].
In 2011, a system was implemented to drive transitions between these states in an one-region setup [5].

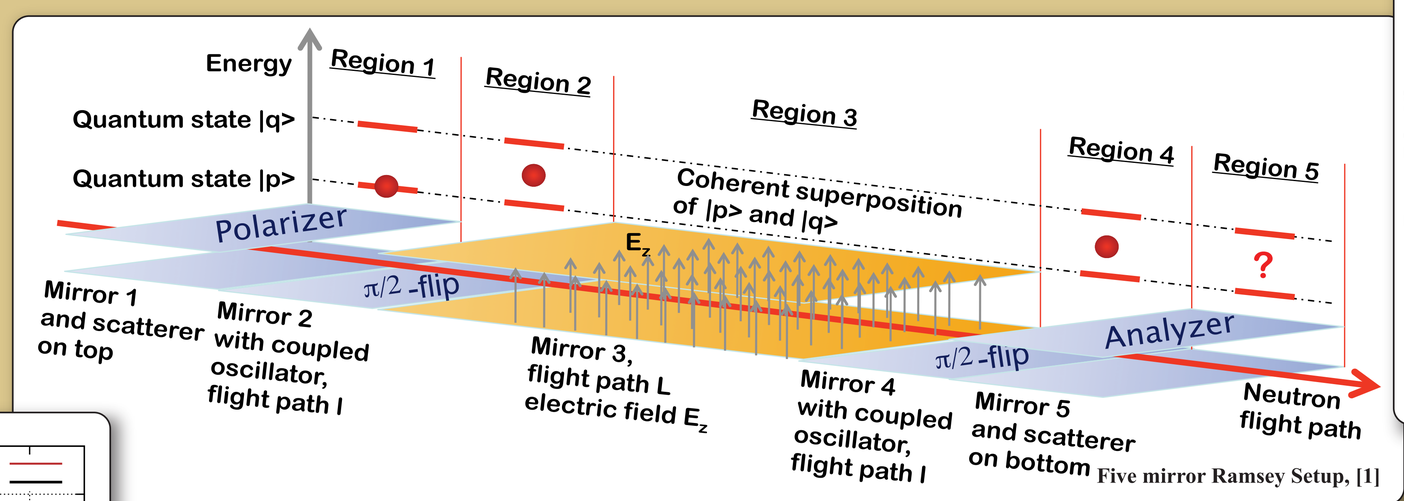
Building up on these results, we successfully drove several transitions between different states with a three-region setup in 2012.



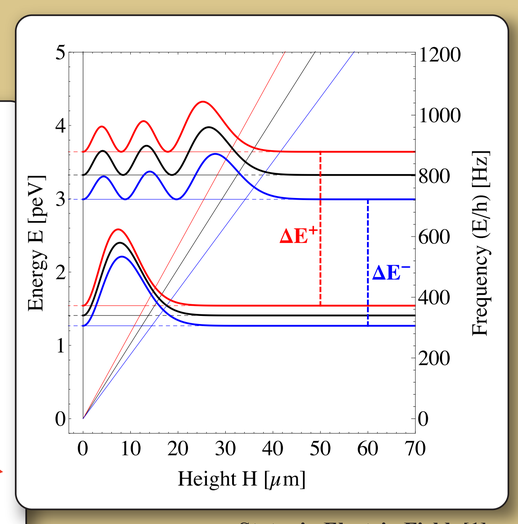
UCN states in the gravitational field, [7]

GRS and the charge of the Neutron

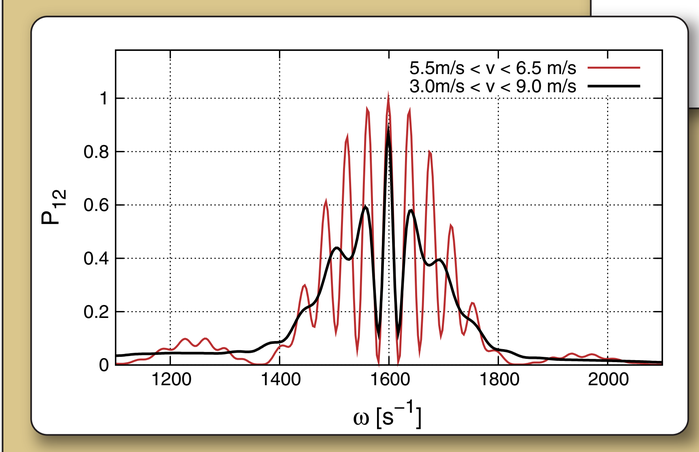
By implementing Ramsey`s Method of separated oscillating fields, one can further enhance the GRS technique. The system would consist of five-regions. Region one and five take care of preparing and selecting a set of gravitationally bound states. Region two applies a π/2-pulse and thereby transfers the prepared set in a superposition of two states.



Five mirror Ramsey Setup, [1]



States in Electric-Field, [1]



Transition probability for different velocity distributions, [2]

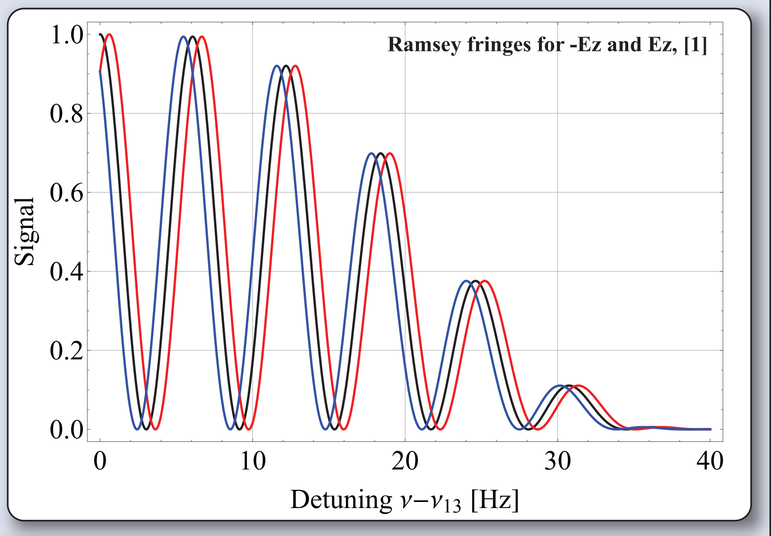
After this, region three allows the phase to evolve and region four then transfers it back in the initial state by another π/2-pulse. If in region three a homogeneous E-field is applied, then in the case of a non-vanishing charge the neutrons would accumulate an additional phase. With this phase the second π/2-pulse transfers the neutrons in a slightly different occupancy, which results in a change in transmission behind region five. This is measurable with our online low-background detectors [4].

$$\left\{-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial z^2} + (mg \pm q|\vec{E}_z|)z\right\}\Psi_n = E_n\Psi_n$$

$$\Delta\nu = \nu_{pq}^{(0)}\left(\left(1+\frac{qE_z}{mg}\right)^{\frac{2}{3}} - \left(1-\frac{qE_z}{mg}\right)^{\frac{2}{3}}\right)$$

Sensitivity

A charge measurement would consist of three measurement points ($E_z = \pm E_0, E_z = 0$).
By choosing a slightly detuned position compared to ν_{pq}, namley the point of the steepest slope, one can increase significantly on the sensitivity for deviations from the case $E_z = 0$.



$$q = \frac{1}{\kappa}\frac{1}{\sqrt{N}}\frac{1}{\frac{\partial r}{\partial \nu}\Big|\nu_{pq}}\frac{3}{4}\frac{mg}{E_z}$$

$$\kappa = \frac{I_0 - I_{pq}}{I_0 + I_{pq}}$$

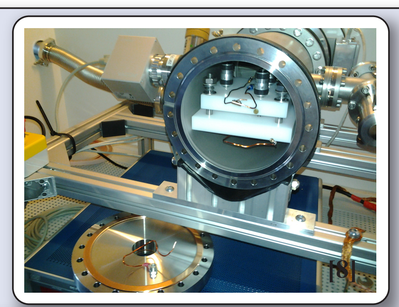
$$E_z = 50\,\mathrm{kV/mm} \qquad |1\rangle \rightarrow |7\rangle$$

$$R = 100\,\mathrm{mHz}$$

$$\delta q \approx 3.3 \cdot 10^{-20}\,\frac{\mathrm{q_e}}{\sqrt{\mathrm{Day}}}$$

Status

Mirror Alignment:
We developed a technique to align several mirrors over a distance of over 40cm to an accuracy of less than 1μm. This enabled us to build and test a three-regions setup.



Electric-Field:
In previous tests we were able to reach electric fields around 40kV/mm.

Setup	E-Field [kv/mm]
First trial - Alu. Mirror [10]	39
Second trial - Alu. Mirror [9]	46
Third trial - Neutron Mirror	42

Outlook

We want to further improve the maximal electric field that we can apply to our mirrors and reduce sparks that could damage the surface. A crucial step will be to use our alignment techniques to build up a setup to store and experiment on quantum mechanical states.

For inquiring minds...

[1] Katharina Durstberger-Rennhofer et al, Phys. Rev. D 84, 036004 (2011)
[2] Abele et al., Phys. Rev. D 81, 0650 19 (2010)
[3] Nesvizhevsky et al., Nature 415, 297 (2002)
[4] Jenke et al., Nucl. Instr. Meth. A 06 024 (2013)
[5] Jenke et al., Nature Physics 7, 468-472 (2011)
[6] Luschikov and Frank, ZhETF 9, 607-609 (1978)
[7] Jenke, Diploma Thesis (2008)
[8] Iro, Bachlor Thesis (2013)
[9] Spanring, Bachlor Thesis (2013)
[10] Schrangl, Bachlor Thesis (2012)
[11] Baumann et al., Phys. Rev. D 37, 11 (1988)

Acknowledgements

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