*q*BOUNCE: probing neutron's neutrality with Ramsey-GRS

Joachim Bosina[1,2], G. Cronenberg[1], K. Durstberger-Rennhofer[1], H. Filter[1], A. Gassner[1], P. Geltenbort[2], A.N. Ivanov[1], T. Jenke[2]
C. Killian[1,2], E. Kreuzgruber[1], J. Micko[1,2], J. Piso[1], M. Pitschmann[1], T. Rechberger[1], R.I.P. Sedmik[1], M. Thalhammer[1,2], H. Abele[1]

[1] *Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Vienna, Austria*
[2] *Institut Laue-Langevin, 71 avenue des Martyrs, CS 20156, 38042 Grenoble Cedex 9, France*

NEUTRONS FOR SOCIETY

ATOMINSTITUT

Abstract

The *q*BOUNCE-experiment focuses on the control and understanding of a gravitationally interacting elementary quantum system using gravity resonance spectroscopy (GRS) with ultracold neutrons (UCN). This technique offers a new way of looking at gravitation at short distances based on quantum interference [1,2]. In the past years, the *q*BOUNCE collaboration has designed and built a new Ramsey-type GRS experiment at the Institute Laue-Langevin (Grenoble), which increases the achievable sensitivity by more than an order of magnitude with respect to previous implementations [3].

In 2018 we were able to demonstrate gravitational state transitions [7]. The new Ramsey-type implementation is not only sensitive to a range of hypothetical variations of Newton's potential at the micro-scale [5,6], but it can also be used to test the electric charge neutrality of the neutron [4].

Theory

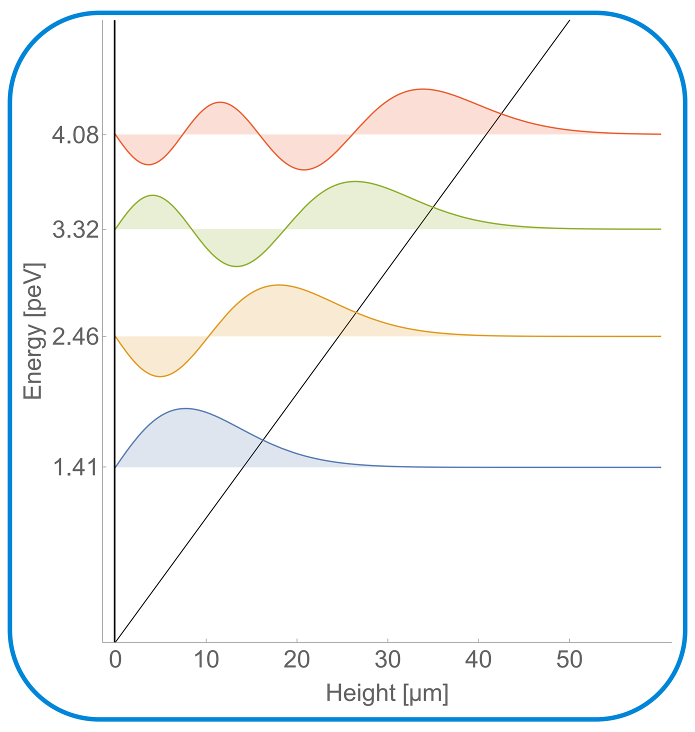
Ultracold neutrons form eigenstates (colored curves) in the gravity potential of the earth:

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

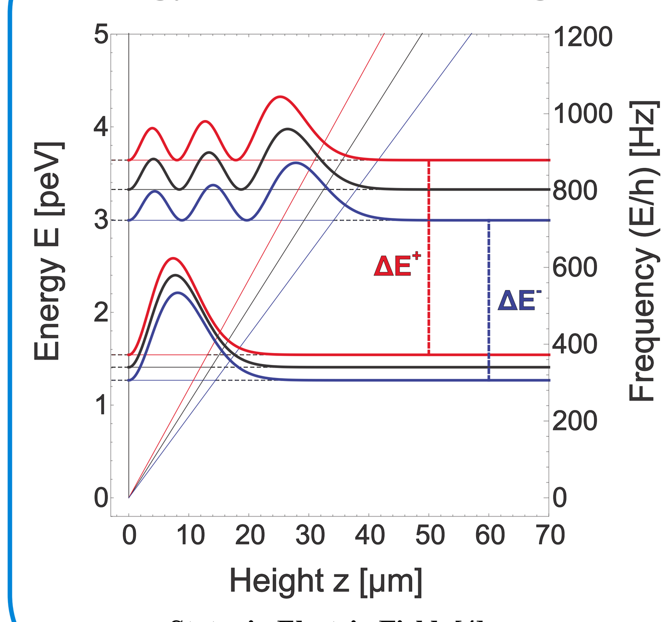
$$\Psi_n(z=0) = 0$$

$$\Psi_n(z) = c_n \mathrm{Ai}\left(\frac{z}{z_0} - \frac{E_n}{E_0}\right)$$

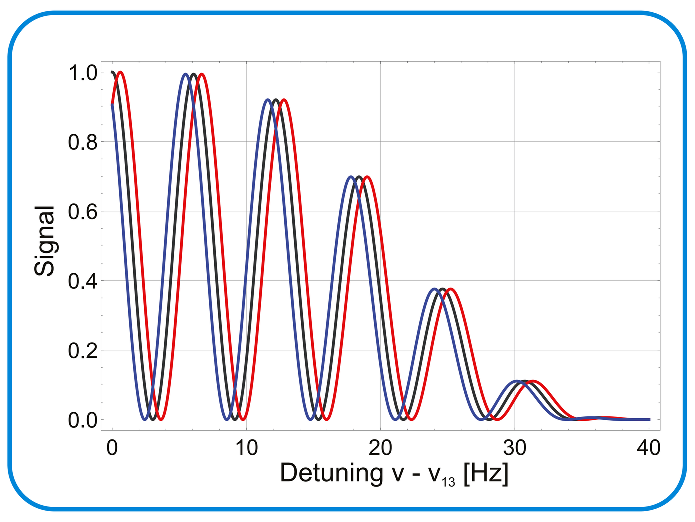
Airy functions *Ai* : Solutions of Schrödinger's equation for a neutron at height *z* in a linear potential with a hypothetical electric charge *q*



Energy shifts due to charge

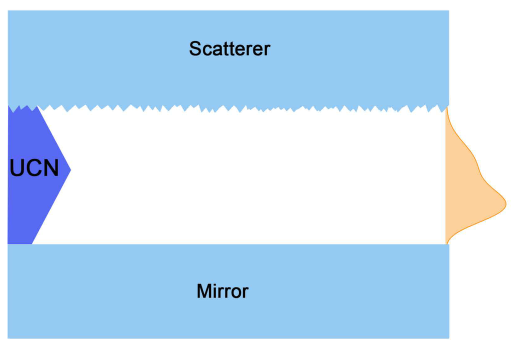


States in Electric-Field, [4]



Ongoing: Ramsey's method tests the neutrality of the neutron

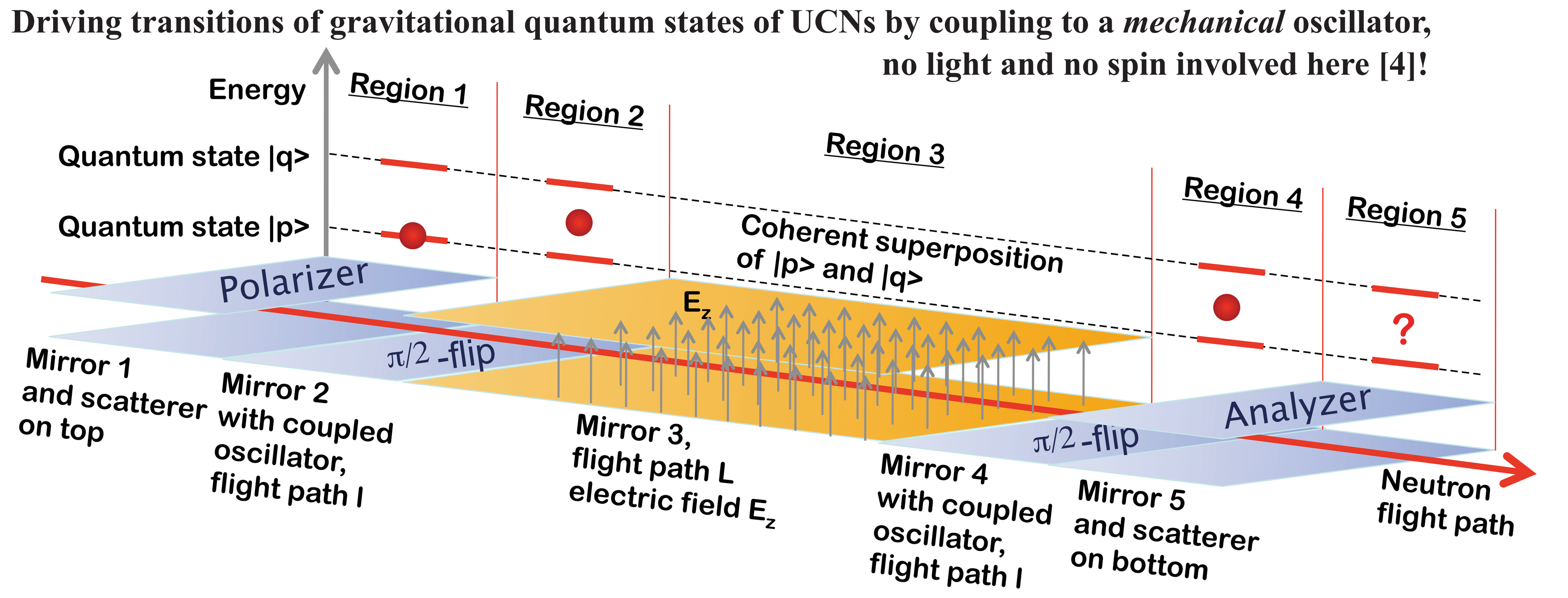
Region 1 / 5
State selector / analyzer - the lower flat mirror totally reflects UCNs and the upper rough glass plate (scatterer) scatters them out of setup. Therefore, higher states are suppressed.

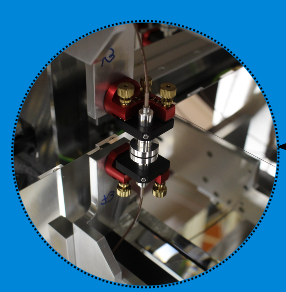


Region 2 / 4
Transitions between gravitational quantum states as neutrons couple to the **mechanically driven harmonic oscillations of the mirror.**

Region 3
Phase evolution of the coherent superposition of two eigenstates
(Applied electric fields changes the evolution time!)

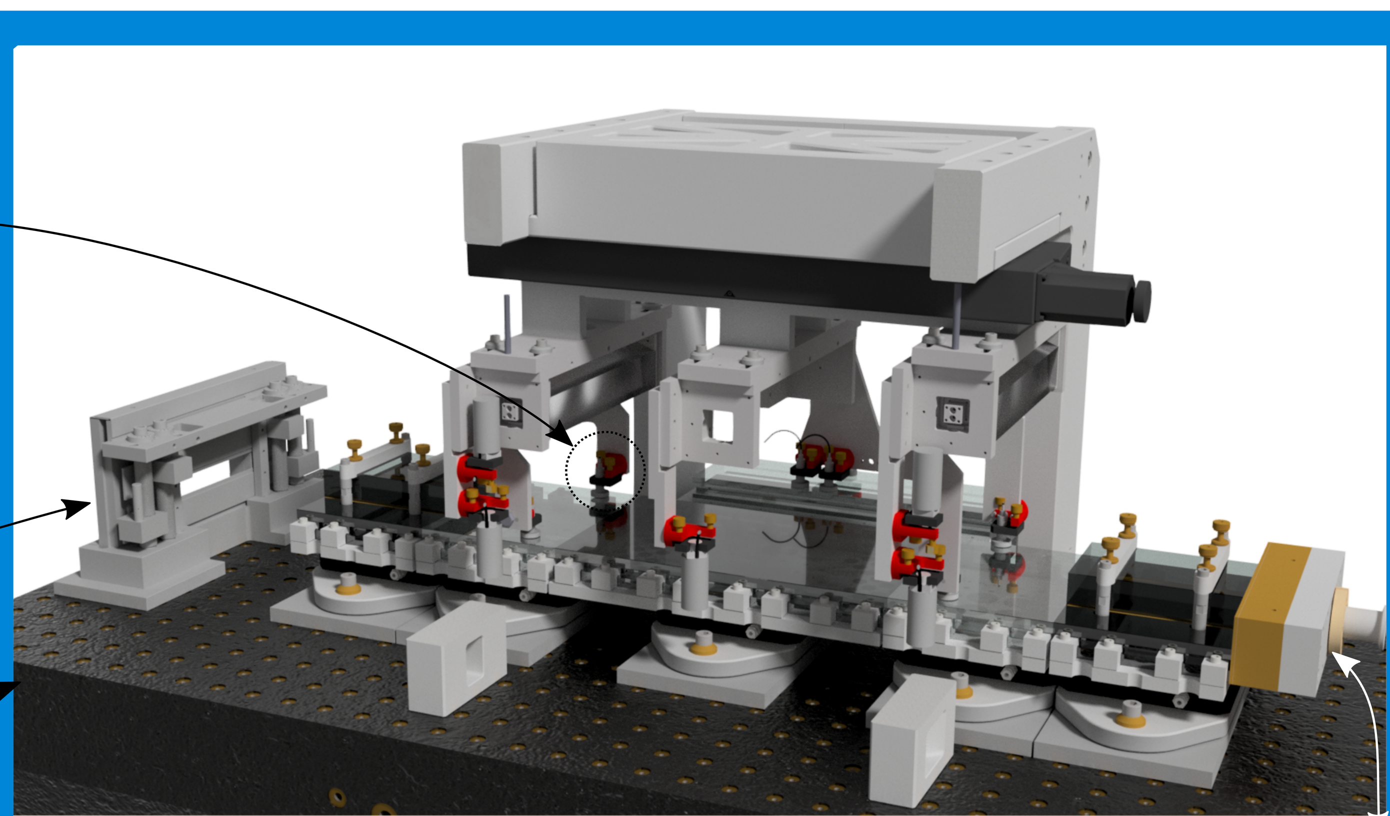
Driving transitions of gravitational quantum states of UCNs by coupling to a *mechanical* oscillator, no light and no spin involved here [4]!



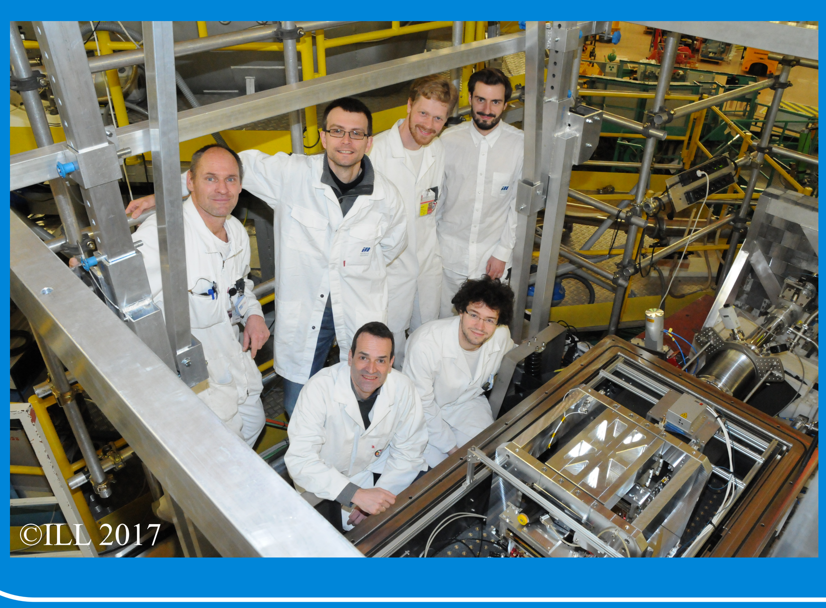


capacitive sensors:
- mirror alignment

aperture:
- velocity selection
- v_n = 5 - 13 m/s

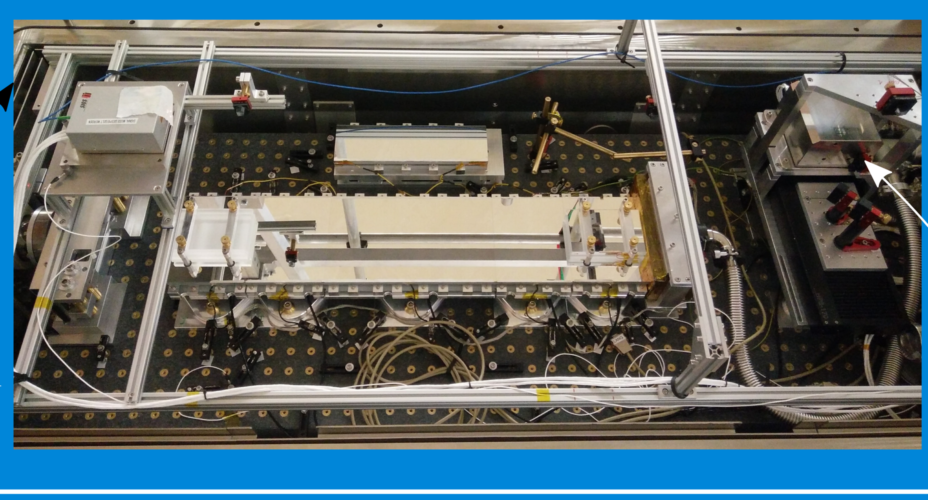


*q*BOUNCE - Collaboration



granite surface plate:
- flatness < 2 µm
- horizontal active leveling

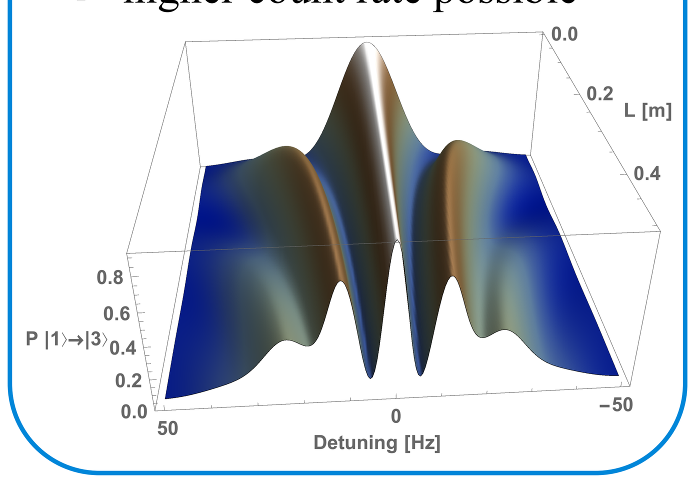
vacuum chamber:
- 2 layers of µ-metal
- fully automatic evacuation
- ~ 5 x 10^{-5} mbar

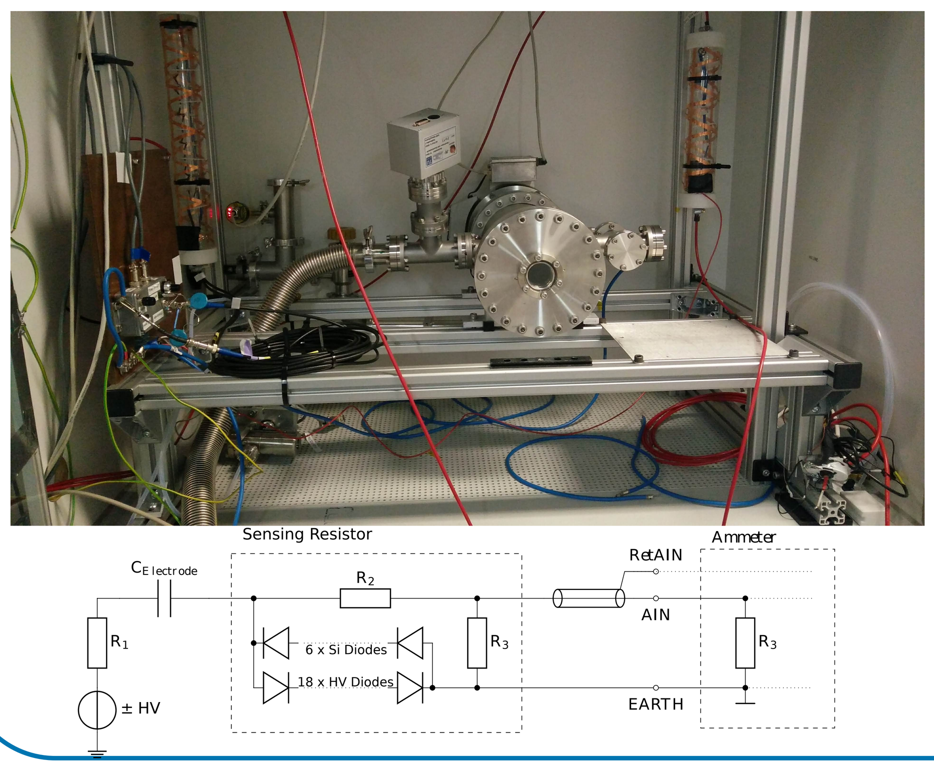


neutron counter tube:
- low background
- r_B = (0.707 ± 0.094) ×10^{-3}s^{-1}

Laser interferometer:
- mirror monitoring
- frequency, amplitude, phase

From Rabi to Ramsey:
Expected transition probability for |1⟩↔|3⟩ with varying length L of Region III, detuning from the transition frequency.
Additionally, Ramsey fringes show self-focusing effect for broader velocity spectrum due to separated interaction regions
➔ higher count rate possible



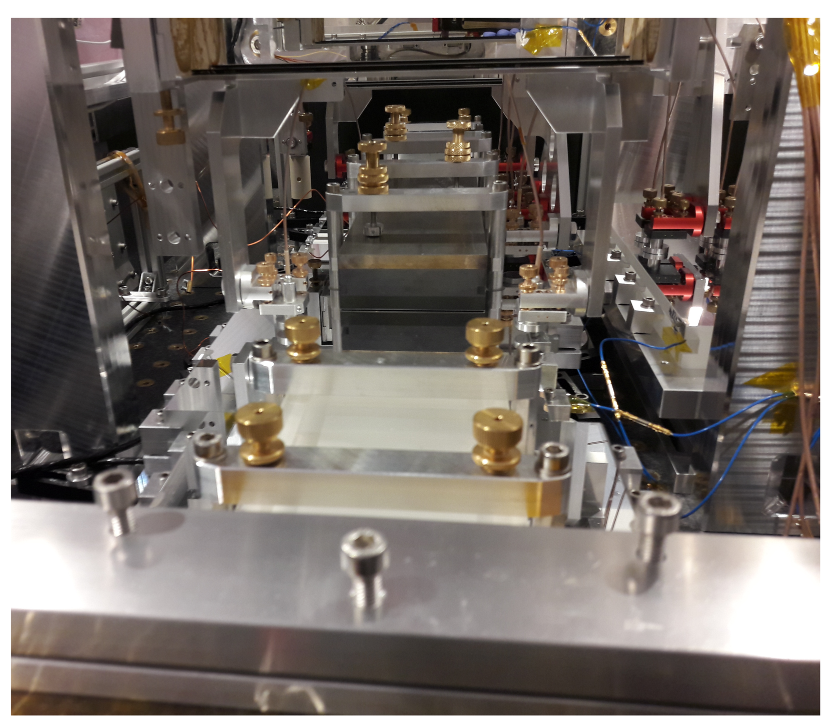


Electrode test setup

After the measurements in Grenoble the electrode was intensively tested in Vienna at a designated setup (as seen left) in order to find the maximal field strength by observing a destructive breakthrough.
At a distance of 99.6(13) µm and up to 2 kV (~20 kV/mm) we observed a complete linear behavior. At total applied voltages up to 5 kV no destructive breakthrough occurred and non linearities of the setup played a crucial role. Further investigations are ongoing.

Neutron's electric charge

The electrode (as seen in photo to the right) applies a very strong electric field in Region III to probe the neutron's electric charge [4].
Two measurement series at field strength of 4.83(5) & 8.45(9) kV/mm and a distance of 207(1) µm scanned the transition |2⟩↔|4⟩.
These fields shift the neutron energy states depending on the charge if it is none-zero.
(as seen in the plots above).



Acknowledgments

FWF Der Wissenschaftsfonds.
I529-N20, I531-N20, I862-N20 and P26781-N20

ANR-2011-ISO4-007-02

$\int dk \Pi$ Doktoratskolleg Particles and Interactions

DFG Priority Programme (SPP) 1491

For inquiring minds...

[1] Jenke et al., Nature Physics **7**, 468-472 (2011)
[2] Jenke et al., Phys. Rev. Lett. **112**, 151105 (2014)
[3] Abele et al., Phys. Rev. **D 81**, 065019 (2010)
[4] Durstberger-Rennhofer et al., Phys. Rev. **D 84**, 036004 (2011)
[5] Cronenberg et al., PoS(EPS-HEP2015) **408**
[6] Cronenberg et al., Nature Physics (2018)
[7] Rechberger, PhD-Thesis, TU Wien (2018)