Tests of rotation symmetry with spin precession of ultacold neutrons

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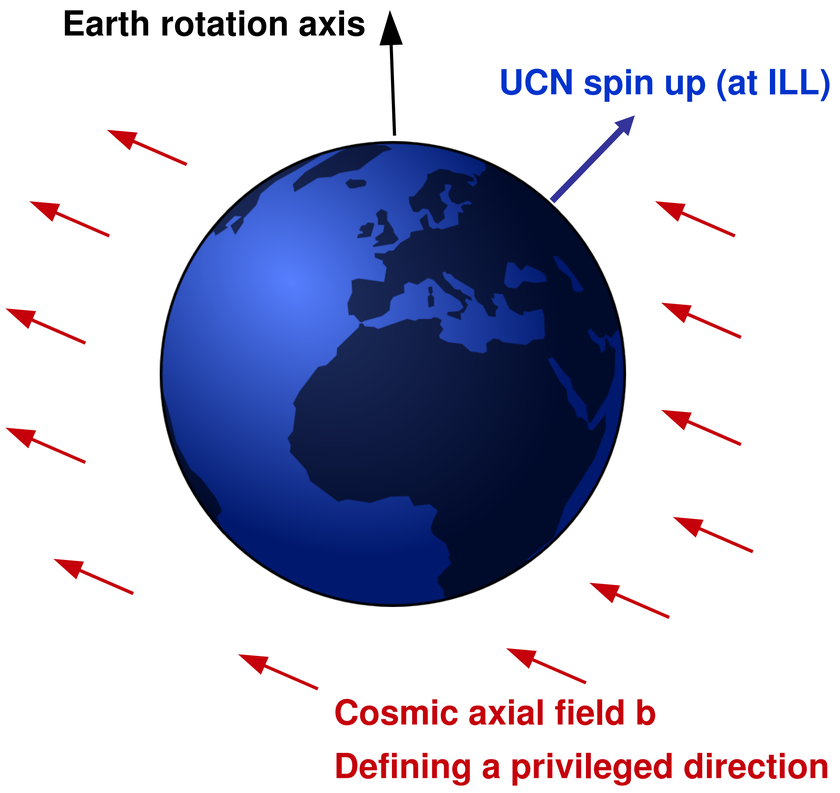


1 Motivations

From rotation symmetry, a neutron spin is static in a zero magnetic field. Looking for deviations of this law allows sensitive tests of rotation invariance, based on the search for a Lorentz-violating interaction potential V.

$$V = \sigma \cdot \mathbf{b}$$

Neutron spin

cosmic axial field. Static in a cosmological frame, daily rotating in the lab frame.

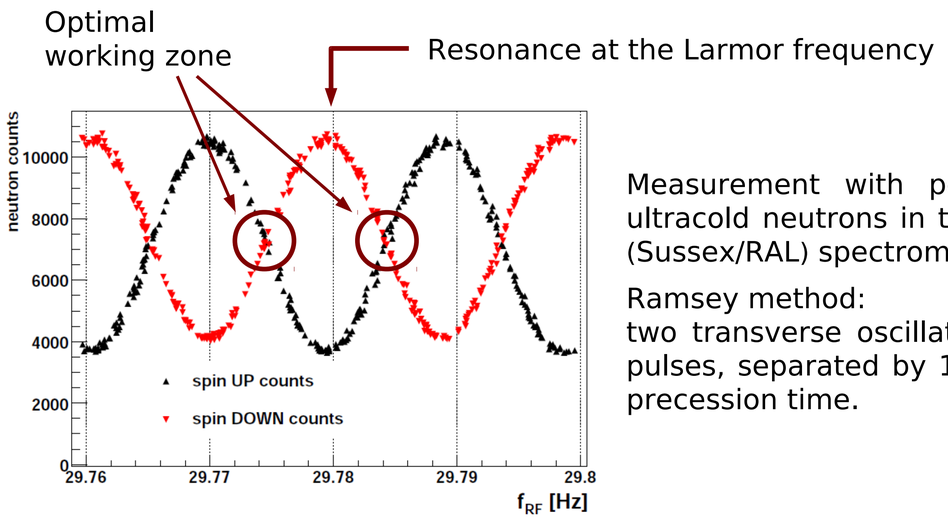
In presence of a normal vertical magnetic field **B**, the exotic potential V modifies the neutron Larmor frequency.

$$f_n = \frac{1}{2\pi}\left|\gamma_n \mathbf{B} + \frac{2}{\hbar}\tilde{\mathbf{b}}\right|$$

Sought effect:
daily modulation of the neutron Larmor frequency

$$f_n(t) = \frac{\gamma_n}{2\pi}B + \frac{1}{\pi\hbar}b_\perp \cos(\lambda)\sin\left(\frac{2\pi t}{24\mathrm{h}} + \phi\right)$$

2 Ramsey method in the OILL apparatus



Measurement with polarized ultracold neutrons in the OILL (Sussex/RAL) spectrometer.

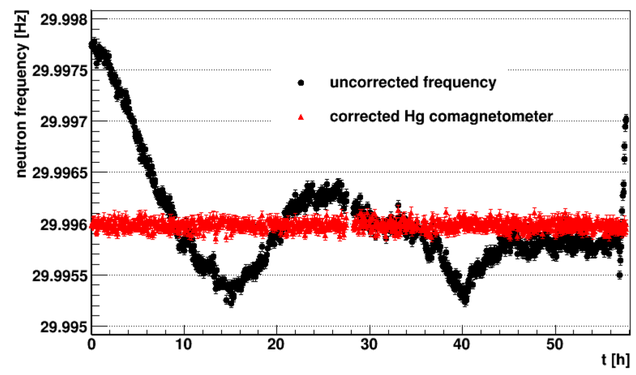
Ramsey method:
two transverse oscillating π/2 pulses, separated by 100 s of precession time.

Statistical accuracy per cycle at PF2 ILL:

$$\Delta f_n = \frac{1}{2\pi\alpha\, T\, \sqrt{N}} \approx 30\ \mu\mathrm{Hz}$$

Neutron polarization — Precession time — UCN counts

3 Clock comparison with mercury precession



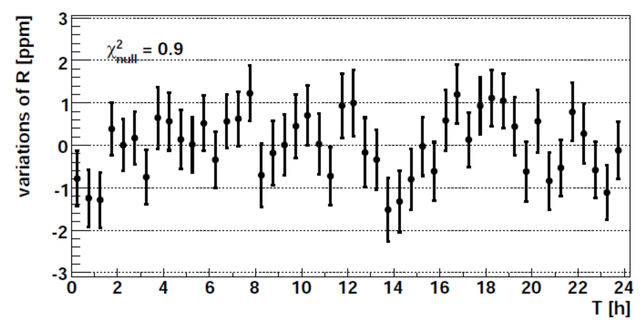
Even protected by the magnetic shield (shielding factor of 10 000), natural drifts of the B-field could hide a cosmic signal. The OILL spectrometer is equipped with a ^{199}Hg comagnetometer to monitor the B-field fluctuations, by probing optically the precession of Hg spins. Precision: 40 fT per cycle.

We performed a **clock comparison experiment,** looking at the stability of the ratio of the neutron to mercury precession frequencies.

$$R(t) = \frac{f_n}{f_{\mathrm{Hg}}} = \frac{\gamma_n}{\gamma_{\mathrm{Hg}}} + \frac{b_\perp \cos(\lambda)}{\pi\hbar f_{\mathrm{Hg}}}\sin\left(2\pi t/24\mathrm{h} + \phi\right)$$

4 Limits on the cosmic axial field

Binned data recorded with OILL@ILL
5 days in April 2008 + 6 days in december 2008



No daily modulation is observed

$$b_\perp < 1\times 10^{-20}\,\mathrm{eV} \quad 95\%\ \mathrm{C.L.}$$

System	Particle	$b_\perp$ [eV]
Hg & Cs	bound neutron	9×10^{-22}
	electron	2×10^{-20}
Xe & He	bound neutron	2×10^{-22}
H	proton	4×10^{-18}
e	electron	7×10^{-22}
μ	positive muon	2×10^{-15}
	negative muon	3×10^{-15}
n & Hg	free neutron	1×10^{-20}

Comparison with existing limits on the coupling to different particles.

5 Probing a cosmic EDM tensor

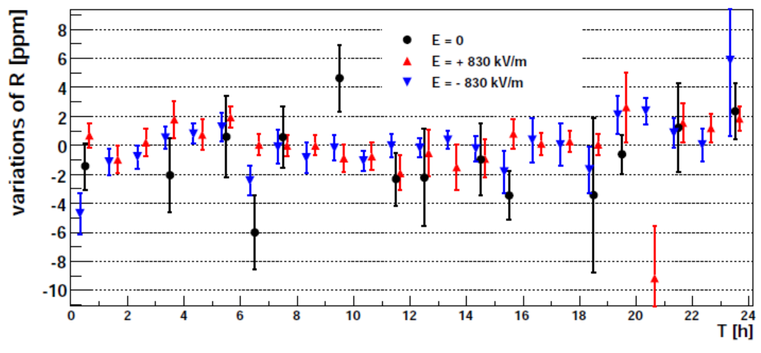
In presence of an electric field E, more sophisticated Lorentz-violating effects can be looked at [Bolokhov *et al* PRD **78** (2008)]
The sought phenomenon is a Pockels effect on neutron spin in vaccuum.
A non-zero Lorentz-violating background tensor d_{ij} would induce a neutron electric dipole moment with oscillation periods of 12h and 24h.

$$V = b_i\sigma_i - d_{ij}\sigma_i E_j$$

Cosmic axial field — **cosmic EDM tensor**.

$$d_{12} = \cos^2\lambda\sqrt{\frac{1}{4}(d_{XX} - d_{YY})^2 + d_{XY}^2}$$
$$d_{24} = 2\cos\lambda\sin\lambda\sqrt{d_{XZ}^2 + d_{YZ}^2},$$

Result with OILL@ILL in december 2008



No modulation is observed

$$d_{12} < 10\times10^{-25}\ e\,\mathrm{cm}$$
$$d_{24} < 14\times10^{-25}\ e\,\mathrm{cm}$$

References

I. Altarev *et al*, Phys. Rev. Lett **103** 081602 (2009)
I. Altarev *et al*, ArXiv:1006.4967
I. Altarev *et al*, ArXiv:1009.6060
S. Roccia, PhD thesis