Are neutrons really neutral?

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Abstract

We developed an optical device for ultracold neutrons and investigated the influence of a tilt of its neutron guiding components. The analysis of our results [1] has shown the potential to test the electric neutrality of the free neutron on the $10^{-22} q_e$ scale with such a method.

Atom and neutron neutrality as well as electric charge quantization (ECQ) are well-established experimental observations. However, their true understanding still remains a long standing question of basic interest ever since the discovery of an elementary electric charge by Milikan and others. In the present framework of the Standard Model (SM) of fundamental particle physics, ECQ implies that the charges of all known particles can be derived from integer multiples of one fundamental electric charge, namely that of the d-quark with $Q_d = -1/3\, q_e$. The appearance of ECQ is associated with basic principles of the underlying structure of the SM such as gauge invariance of the Lagrangian. However, ECQ might not be a natural consequence of this model as there remains still one unknown parameter which could, in principle, lead to charge dequantization. As a consequence, so called neutral particles like the neutron could carry a small 'rest charge'.

Today's experimental accuracy on the neutron's neutrality has reached a sensitivity of $10^{-21}\, q_e$. Such direct measurements have in common that any beam deflection Δx of a charged particle depends on the square of its traveling time in an electric field E:

$$\Delta x \propto \frac{q\,E}{m}\, t^2, \tag{1}$$

where q is the charge and m the mass of the particle. Due to the low velocity of ultracold neutrons (UCN), < 7 m/s compared to cold or thermal neutrons, the square traveling time t^2 and hence the discovery potential of the method can be improved significantly in a UCN beam experiment.

Our experimental setup can be described as a high-resolution optical camera for UCN (see Fig. 1) and [1]: A neutron beam (a) is fragmented via an entrance grating (b). After a flight path along neutron guides (e) and between a situated perpendicular electric field (not shown here), the neutrons encounter a cylindrical mirror (f) which reflects the UCN back and focuses the image of the entrance grating back onto an exit grating (g). The exit grating is moved across the incident beam profile. This results in a modulation of the detected count rate as shown in our last annual report. According to (1),

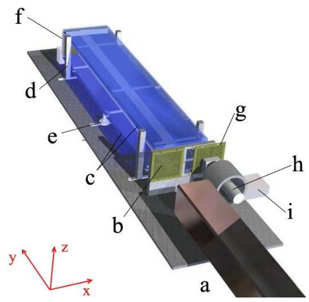

Figure 1: Draft of the experiment, at scale.

a presence of a neutron electric charge would lead to a shift in the observed count rate being maximum at the steep slope of the observed modulation curve.

With an upgrade of this experiment in 2009, we investigated the apparently most important systematic effect of a tilt of the neutron guides in z-direction. Such a tilt (which could arise e.g. from electrostatic forces between the electrodes) limits the discovery potential of the method as it would mimic an electric charge. Aiming at a sensitivity of $\delta q_n = 10^{-22} q_e$, the acceptable limit for such a tilt was found to be on the μm-scale.

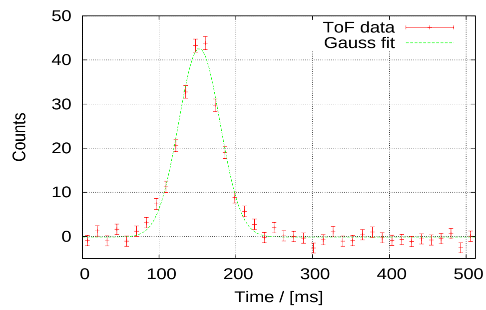

Figure 2: ToF spectrum of UCN between the two gratings.

We further developed a direct measurement of the mean transit time (from which $t^2 = 0.022\,\text{s}^2$ can be derived) in the relevant region along the situated electrodes by means of a dedicated chopper system, see Fig. 2. Further information can be found in [1].

[1] C. Plonka-Spehr et al., DOI: 10.1016/j.nima.2010.02.110

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