

A novel Penning trap design for the measurement of the (anti)proton g -factor*

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The precise determination of the g -factor of the proton and the antiproton together with their comparison is a stringent test of the CPT invariance theorem in the baryonic sector [1]. In our experiment, which is part of the FLAIR collaboration, the g -factor of a single, isolated (anti)proton will be determined by utilizing the continuous Stern-Gerlach effect [2] in a double Penning trap setup [3]. The system consists of a precision trap (PT) and an analysis trap (AT). In the PT, we have a homogeneous magnetic field. Introducing an inhomogeneous magnetic field $B = B_0 + B_2 z$ via a ferromagnetic ring electrode in the AT couples the axial oscillation frequency and the direction of the magnetic moment of the (anti)proton. Due to this coupling, an induction of a spin-flip in the precision trap will affect a change of the particles axial frequency in the AT, given by

$$\Delta\omega_z = \frac{B_2}{m_p \omega_z} \mu_p . \quad (1)$$

This frequency shift can be measured by a phase-sensitive detection method, applied in the AT [4]. From the measurement of the characteristic eigenfrequencies of the (anti)proton in the Penning trap via the FT-ICR method (Fourier transform - ion cyclotron resonance), the free cyclotron frequency ω_c of the particle can be extracted. The g -factor can be evaluated by the relation

$$g = 2 \frac{\omega_L}{\omega_c} , \quad (2)$$

where ω_L is the Larmor-frequency. The oscillating particle induces image currents in the electrodes of the trap, which can be detected by high-Q resonance circuits. Therefore, superconductive inductances will be used, so that the whole experiment has to be operated at cryogenic temperatures. Other essential effects of the low temperature surroundings are an increase of the signal-to-noise ratio and a rise of the storage time [5]. Another important effect is the reduction of the line width of the g -factor resonance. This is caused by a smaller thermal drift in the axial frequency space, due to the small temperature in the Boltzmann-factor [6].

In well-known past experiments, Dehmelt and Van Dyck measured the electron g factor. Since the magnetic moment of the proton is smaller than the Bohr-magneton by a factor of 658, common cylindrical geometries are improper

to detect the spin-flip. Therefore we developed a novel trap design with a toroidal ring electrode. A sketch of the trap is shown in Fig. 1a. The substantial advantage of the toroidal trap design is an increase of the B_2 term by a factor of ≈ 3 compared to the cylindrical geometry. The axial fre-

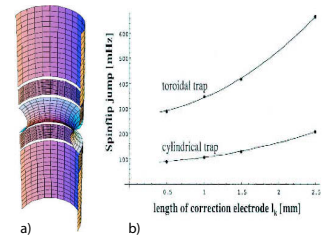


Figure 1: a) Inner surfaces of the cylindrical Penning trap with a toroidal ring. b) Comparison of the axial frequency shift in a toroidal and a cylindrical trap as a function of the length l_k of the correction electrode

quency shift, that is caused by a spin-flip, does not only depend on the shape of the ring electrode, it is also influenced by the length of the correction electrodes (Fig. 1b), the inner radius of the trap, the full trap length and the axial dimensions of the ring electrode. In a detailed study, the frequency shift caused by a spin-flip has been optimized with respect to other experimental parameters, like the sensitivity of the axial frequency with respect to voltage fluctuations, the electronic detection sensitivity, the harmonicity range of the trapping potential and the time constants for resistive cooling. The complete trap setup is in construction now. Furthermore, in 2005 the pulse tube cooler has been characterized and the design of the cryostat has been finished. Next the details for the electronic detection will be developed. After the measurement of the proton g -factor, the experiment will be continued at the FLAIR facility with a single trapped antiproton

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