NEW EXPERIMENT ON THE PRECISE COMPARISON OF THE ANOMALOUS MAGNETIC MOMENTS OF RELATIVISTIC ELECTRONS AND POSITRONS

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A comparison of the anomalous magnetic moments of the electron and positron has been performed using the resonance depolarization method for the VEPP-2M storage ring beams. It has been shown that the difference between the anomalous magnetic moments of the electron and positron does not exceed 1.2×10^{-7} with 95% confidence level, in agreement with the *CPT*-theorem and the principle of relativistic invariance.

At present the anomalous magnetic momentum (AMM) of the electron and positron is measured to a high precision, $\sim5\times10^{-8}$, in magnetic traps [1], wherein single particles were captured with energies in the meV range. A significant feature of our experiment is the measuring in the electron–positron storage ring VEPP-2M at a particle energy of $E=650$ MeV simultaneously for electrons and positrons kept in identical conditions, thereby optimally matching the task to compare their AMM. The first results of these measurements were presented earlier [2]. Let us shortly remind the scheme of the experiment which remains without change.

The spin precession frequency for an ultra-relativistic particle in a storage ring with transverse magnetic field H_z can be written in the form [3]

$$\Omega=\omega_s+2\mu'\langle H_z\rangle=\omega_s(1+\gamma\mu'/\mu_0)\ ,$$

where μ' is the AMM, $\mu_0=e/2m$, ω_s is the revolution frequency, set by the accelerating RF generator.

The electron and positron precession frequencies Ω^- and Ω^+ are measured by means of the technique of resonant depolarization of the polarized beams [4]. An RF device called the depolarizer generates a longitudinal magnetic field $\tilde{H}$ over a segment of the orbit of the beam, the field oscillation frequency f_d is slowly varied to cross the resonance $f_d=(1/2\pi)\times(\Omega-k\omega_s$ (k integer).

The field amplitude $\tilde{H}$ and the scanning rate $\dot{f}_d$ are selected using a calculated model of polarization degree reduction due to crossing the resonance accounting for spin frequency spread and diffusion. The spin frequency spread in the conditions of the present experiment is determined by the chromaticity of the storage ring and gives $\delta\Omega=0.8\times10^{-6}\omega_s$ [5]. Spin diffusion resulting from the quantum fluctuations in the synchrotron radiation of electrons (positrons) in the storage ring causes beam depolarization whose rate is maximum near the resonance.

Fig. 1 shows the calculated behaviour of the degree of polarization while crossing the resonance with different RF field amplitudes, related to the resonant harmonic values $W=\langle\tilde{H}\rangle/\langle H_z\rangle\omega_s$. Apparently there is an optimum value, W_{opt}, at a given rate $\dot{f}_d$ which provides total depolarization and the accuracy in determining the spin precession in its limit approaches the spin frequency spread $\delta\Omega$ by an order of magnitude, as shown with the dotted line.

The difference between depolarization frequency thus measured and the true precession frequency is of no importance regarding the aim of this experi-

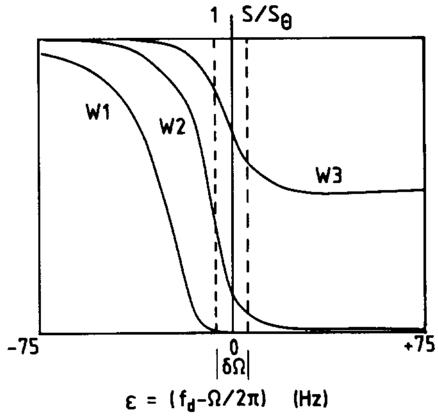

Fig. 1. The calculated behaviour of the polarization degree while crossing the resonance, $\dot{f}_d = 1.00$ Hz/s, $W1 = 1.00 \times 10^{-7}\omega_s$, $W2 = 0.35 \times 10^{-7}\omega_s$, $W3 = 0.15 \times 10^{-7}\omega_s$.

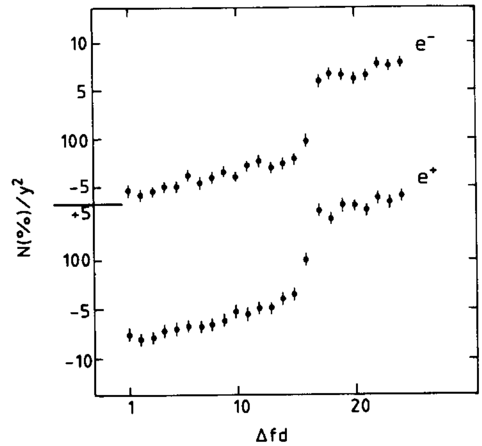

Fig. 3. The counting rates for a typical run.

ment because the former has the same value both for Ω^- and Ω^+. Therefore the error in the desired difference measurement $\Delta = \Omega^- - \Omega^+$ will be substantially less than the spread $\delta\Omega$ determined by the polarimeter accuracy in reality.

The degree of beam polarization is determined from the analysis of the elastic intra-beam scattering of the particles [6]. The system of scintillation counters (fig. 2) detects the particles lost due to this process with the counting rate of $\dot{N}$,

$$\dot{N} = 10(1 - 0.12s^2)I^2 ,$$

where I is the beam current in mA. The maximum contribution of the polarization s reaches 12%. The phase-lock to the accelerating voltage enables the detection of both electrons and counter-rotating positrons in the same system of counters concurrently.

The experiment was performed with the electron and positron stored currents $I^+ \approx I^- = 10$ mA at an energy $E = 650$ MeV, where the radiative polarization time was $\tau_p = 1$ h. After a time $t = 2\tau_p$, when the degree of polarization s attained 80%, the depolarizer was turned on in a scanning mode with a narrow band width. The total scanning time was limited by the lifetime of the beam and lasted up to ca. 1 h. The intra-beam elastic scattering count-rate normalized by the square of the beam current is shown in fig. 3 for a typical experimental run [‡1]. The time to collect statistics at each point was $\Delta t = 30$ s resulting in an accuracy of about 10% in the degree of polarization measured. The depolarization time τ_d usually satisfied the condition $\tau_d < \Delta t$ which was achieved by setting the optimum depolarizer field amplitude (two times as high as the value corresponding to one-half of the depolarization experimentally observed).

At $\tau_d < \Delta t$ depolarization may be regarded as instantaneous thus simplifying enough the processing of the experimental data, but still not introducing any systematic errors distinct from our statistical accuracy.

The processing of data obtained in several measurement runs indicted a certain frequency difference Δ in routine operation cycles of the storage ring. Spe-

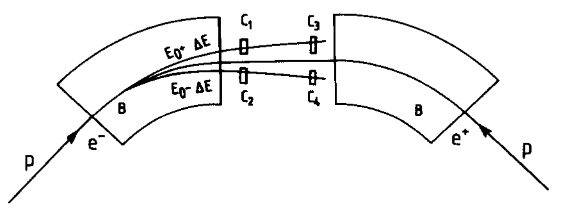

Fig. 2. The lay-out of the intra-beam scattered particle counters.

[‡1] During the run the guide field stabilization system based on NMR (with the characteristic time $\tau \sim 1$ s) and the ripple suppression system ($\tau \sim 10^{-3}$ s) provided a noise level of $\Delta H_z H_z \lesssim 10^{-6}$. In addition, the stability of the average energy of the particle was maintained within an accuracy of $\pm 1 \times 10^{-5}$ by a special slow feedback system ($\tau \sim 10$ min), which corrected the guide field level in accordance with the periodic mechanical measurements of the displacements of the dipoles and quadrupoles in the storage ring [7].

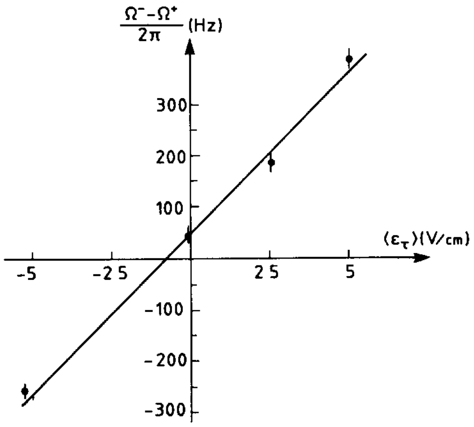

Fig. 4. The spin frequency difference as a function of the electrostatic separation.

cial measurement runs were carried out with a constant radial electric field ϵ_r applied on a segment of the orbit of the beam which should give rise to a frequency separation of $\Delta = 4\mu' c\langle \epsilon_2 \rangle = 2c(\langle \epsilon_2 \rangle / \langle H_z \rangle)\omega_s$. The results of the difference measurements of the precession frequency as a function of the separation are presented in fig. 4 giving the average value of $\Delta = \Omega^- - \Omega^+ = 2\pi$ (45 ± 5) Hz with the imposed separation $\epsilon_r = 0$.

The search for the possible origins of the like electrostatic separations resulted in turning off the power supplies of the distributed magneto-discharge pumps. Under these conditions several measurement runs were taken at the scanning rate $\dot{f}_d = 0.5$ Hz/s. Processing of the total data set by means of the maximum likelihood technique shows that the difference between the precession frequencies of the electron and positron does not exceed $2\pi \times 3$ Hz, corresponding to $\Delta\mu'/\mu' < 1.2 \times 10^{-7}$ with 95% confidence level.

The result of the comparison of the electron and positron obtained, while being inferior in accuracy, confirms the data published in ref [1], in spite of the completely different experimental conditions. A combined consideration of both results gives the best up to date verification of the *CPT*-theorem and the principle of relativistic invariance.

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