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G.M. Tumaikin, Yu.M. Shatunov.

HIGH ACCURACY COMPARISON OF THE ELECTRON AND POSITRON MAGNETIC MOMENTS.

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ABSTRACT

A comparison of the electron and positron anomalous magnetic moments has been performed using the resonance depolarization method for the VEPP-2M storage ring beams. It has been shown, that the difference between anomalous magnetic moments of electron and positron doesn't exceed $1.0 \cdot 10^{-5}$ with 95 % confidence level in agreement with CPT-theorem prediction on equality of the particle and antiparticle magnetic moments. The achieved accuracy is two orders better than that available up to now.

At present the electron anomalous magnetic moment (AMM) has been measured in magnetic traps /1/ with a high accuracy $\sim 3.10^{-6}$, and the measurement result within the limits of an error is an agreement with a quantumelectrodynamics calculation/ 2/ the accuracy of which is of the same order. The accuracy of the positron AMM measured by the same procedure /3/ is much worse and equals $\sim 10^{-3}$. A further improvement in the positron AMM measurement accuracy is a serious problem.

The above experiments /1,3/ have been performed using different apparata. The particular feature of our experiment is that it has been held in the electron-positron storage ring at the same conditions both for electron and positron, providing the best way to compare the magnetic moments of these particles.

The expression for the spin precession frequency Ω of an ultrarelativistic electron or positron /4/ in a storage ring without electrical and longitudinal magnetic field can be rewritten as follows :

$$\Omega = \omega_s + 2\mu'\overline{\mathcal{H}} = \omega_s\left(1+\gamma\frac{\mu'}{\mu_0}\right)$$

where μ' - AMM electron or positron, $\mu_0 = e/2m$, $\overline{\mathcal{H}}$ -average value of the guiding magnetic field, ω_s -revolution frequency, set by an external HF-generator.

Thus, by measuring the frequencies Ω_- and Ω_+ (for electron and positron) one can observe the difference in the AMM or set the upper limit for this value.

The frequencies Ω_- and Ω_+ are measured by a method of the beam resonance depolarization by a high frequency external field /5,6/. In our experiment the longitudinal magnetic field with the frequency f_d is used induced by a depolarizer in one of the sections of the orbit.

Provided that the resonance condition is met

$$f_d = \frac{\Omega - \omega_s}{2\pi} = \frac{2\mu'\overline{\mathcal{H}}}{2\pi} = \frac{\mu'}{\mu_0}\,\frac{\omega_s\gamma}{\pi}$$

beam depolarization occurs and it is detected by a variation in the counting rate of elastic scattering of the particle within bunches /7/.

For measurement of the both beam polarization a special system of counters was set (Fig.1) in one of the straight sections of the VEPP-2M storage ring. Particles scattered within a bunch in the adjacent section are deflected by the field of a bending magnet and pass through two pairs of scintillation counters in coincidence. The pairs of particles with an energy transfer ±(4÷8)% are detected. The counting rate of such events is of the order 1Hz at the beam current 1 ma, the maximum polarization contribution to the counting rate is equal to 15 %. A coincidence with a phase of accelerating voltage enables to detect electrons and positrons moving in the opposite directions by one system of counters.

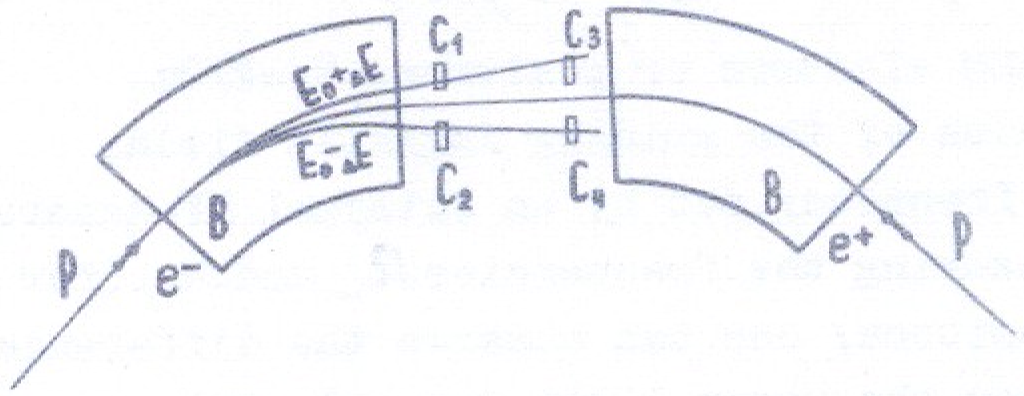

Fig.1 Layout of counters for measurement of both beam polarization;
C_1- C_4 are the scintillation counters in coincidence
B are the bending magnets of the VEPP-2M storage ring
P is the equilibrium orbit

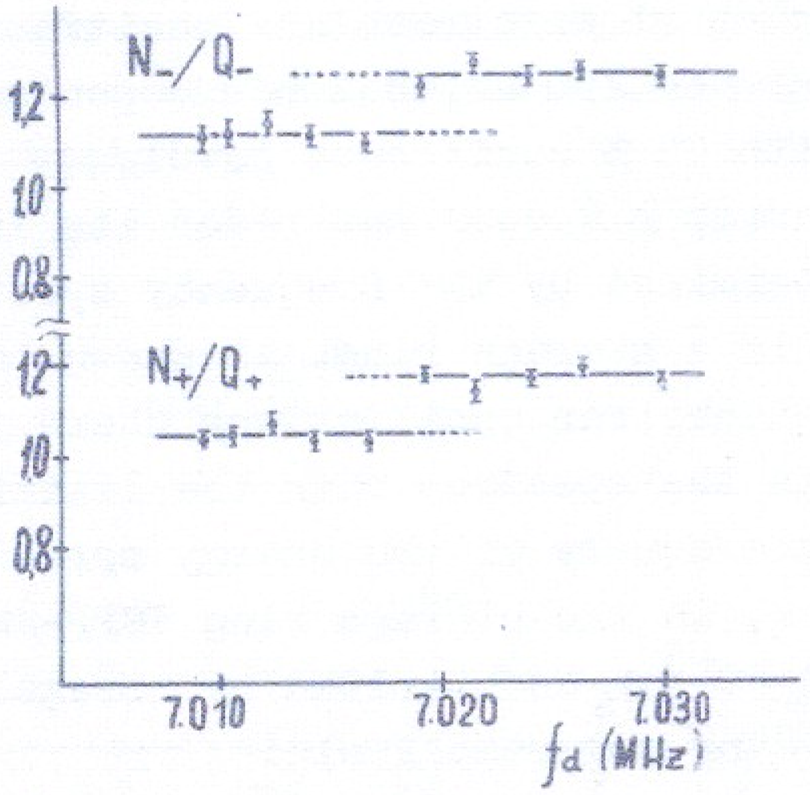

Fig.2 The counting rates of the elastic scattering events within a bunch of electrons and positrons versus depolarizer frequency.

The experiment was carried out with$\sim$15 ma electron and positron stored currents at the energy 625 mev, where the time of radiative polarization τ_p was about 1 hour. In t=2τ_p a depolarizer was switched on and the counting rates of the elastic scattering events within a bunch for each beam were measured. The depolarizer operated in a scanning mode: the depolarization frequency f_d was varied at a constant rate $\sim$ 10 Hz/sec. The scanning time, the scanning rate and the depolarization time ($\sim$10 sec) were chosen so that the best accuracy would be obtained in the determination of the frequencies Ω_- and Ω_+ .

The total scanning time was usually about 1 hour. During this time a control was performed for the orbit position to an accuracy ± 0.1 MM, for the stability of the storage ring magnetic field to an accuracy$\sim 10^{-5}$, for the beam size and for a number of other parameters.

Fig.2 presents the results of a typical measurement run, from which it is seen that both beams are depolarized within the frequency range of$\sim$1kHz.

The data handling of several runs by using maximum likelyood method has shown that the difference in the beam depolarization frequencies of electrons and positrons $\Delta\Omega = \Omega_{-} - \Omega_{+}$ does not exceed 250 Hz, that corresponds to $\Delta\mu'/\mu' < 1.0 \cdot 10^{-5}$ with 95 % confidence level.

The obtained accuracy $\Delta\Omega$ does not reach its limiting value, which is determined by the frequency spectrum of the spin motion in a storage ring. As shown in /5/ after averaging over synchrotron oscillations there is a readily detected line in the spectrum with the limiting width proportional to the square of the energy spread ($\sim 10^{-7}\omega_s$). Now, howerer, in the storage ring VEPP-2M the line width is about $10^{-5}\omega_s$ and limited by irregular fluctuations of the guiding magnetic field.

One can try to imagine the existence of a mechanism of simultaneous destroying of polarization inspite of the difference in precession frequencies. There fore the control runs have been performed with radial electric field $\mathcal{E}_r$ in one of the orbit sections. The expression for spin precession frequency in this case will be the following

$$\Omega_{\mp} = \omega_s + 2\mu'(\mathcal{H} \mp c\,\overline{\mathcal{E}}_r)$$

As shown in Fig.3 the measured value of the shift is in agreement with predicted one and change their sign in the electrical field of opposite direction.

The result obtained in our work is the most rigorous experimental test of identity of magnetic moments of particle and antiparticle. The existing now upper limit on $\Delta\mu'/\mu'$ for electron and positron equals $2.1 \cdot 10^{-3}$/3/ with 95 % confidence level. The same value for positive and negative muons obtained with muon storage ring in CERN is $1.6 \cdot 10^{-3}$/8/ approximately corresponding to our result for the absolute value of difference in AMM of particle and antiparticle.

The result of our experiment can also be interpreted as a limitation on the difference between electrical dipole moments of electron p_- and positron p_+ (assuming the identity of AMM of the these particles) with 95 % confidence level:

$$\sqrt{p_-^2 - p_+^2} < 2.0 \cdot 10^{-16}\ e\cdot\text{cm}$$

The limit on the value of electrical dipole moment of electron existing now is $3 \cdot 10^{-24}\ e\cdot\text{cm}$/9/.

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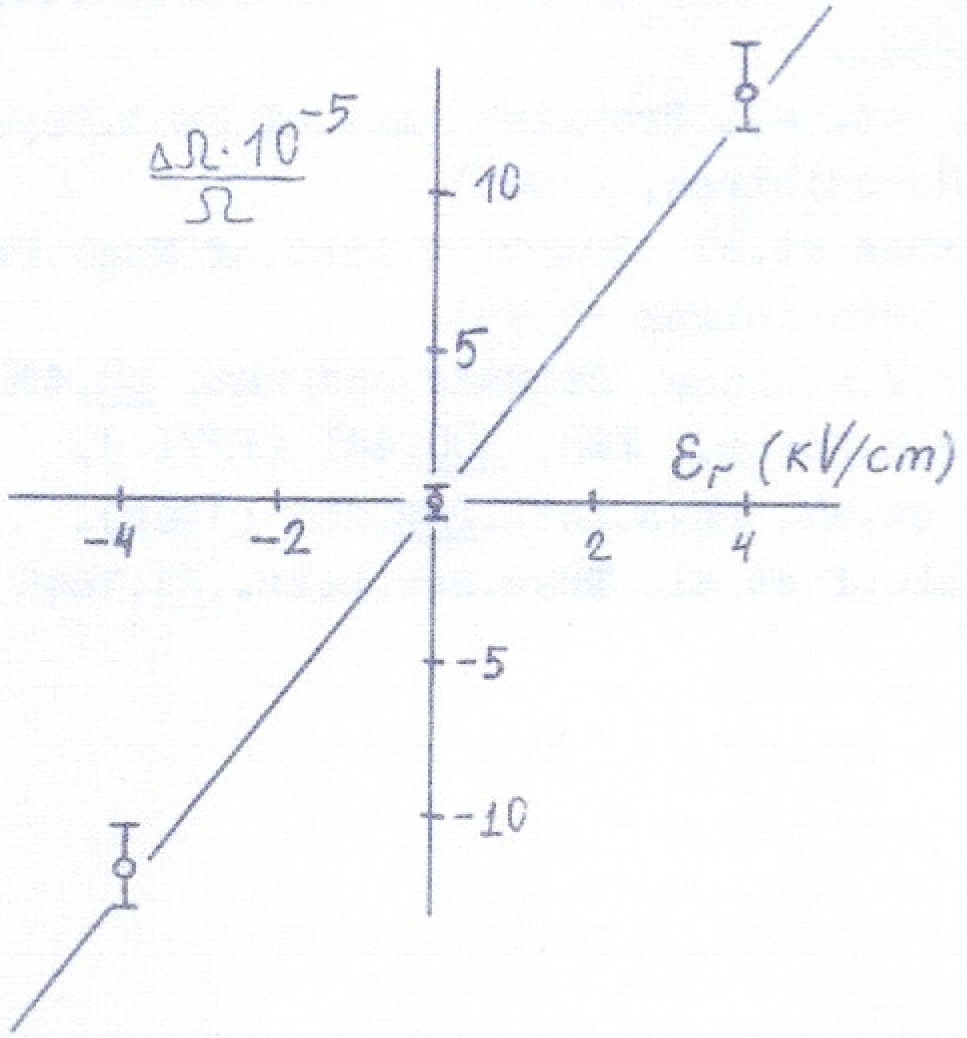

Fig. 3 The electron and positron depolarization frequency shift versus radial field value.

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