Experience on precise energy calibration from Novosibirsk

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Introduction

- The radiative self-polarization of electrons was predicted by Sokolov and Ternov in 1963.
- Polarization studies started in BINP since 1968 by Yu.M. Shatunov and A.N.Skrinsky at first electron-positron collider VEPP-2. Still, first evidence of the resonance depolarization obtained at VEPP-2 was not published.
- A team of theoreticians headed by V.N. Baier contributed a lot for understanding of the self-polarization phenomena.
- Later on Ya. S. Derbenev, A.N.Skrinsky and A.M.Kondratenko developed the generalized approach for treatment of the polarization behavior in the arbitrary ring lattices.
- Since 1975 a lot of energy calibrations were made at VEPP-2M, VEPP-4, VEPP-4M and now at VEPP-2000. The resonant depolarization technique was used to measure the masses of many particles and narrow resonances, such as ϕ, J/ψ, Υ. Also R(s) was measured using the resonant depolarization for precise energy control.

BINP has performed 3 experiments on comparison of the electron and positron magnetic moments

1. S.I. Serednyakov, V.A. Sidorov, A.N. Skrinsky, G.M. Tumaikin, Ju.M. Shatunov: “High accuracy comparison of the electron and positron magnetic moments”. Physics Letters B, Volume 66, Issue 1 - 3 January 1977, Pages 102-104. **AMM difference 1x10^{-5}.**

2. I.B.Vasserman, P.V.Vorobyov, E.S.Gluskin, P.M.Ivanov, G.Ya.Kezerashvili, I.A.Koop, A.P.Lysenko, A.A.Mikhailichenko, I.N.Nesterenko, E.A.Perevedentsev, A.A.Polunin, S.I.Serednyakov, A.N.Skrinsky, Yu.M.Shatunov. “New experiment on the precise comparison of the anomalous magnetic moments of relativistic electrons and positrons”, Physics Letters B, Volume 187, Issues 1–2, 19 March 1987, Pages 172-174. **AMM difference 1.2x10^{-7}.**

3. I.B.Vasserman, P.V.Vorobyov, E.S.Gluskin, P.M.Ivanov, I.A.Koop, G.Ya.Kezerashvili, A.P.Lysenko, I.N.Nesterenko, E.A.Perevedentsev, A.A.Mikhailichenko, A.A.Polunin, S.I.Serednyakov, A.N.Skrinsky, Yu.M.Shatunov: “Comparison of the electron and positron anomalous magnetic moments: Experiment 1987”, Physics Letters B, Volume 198, Issue 2, 19 November 1987, Pages 302-306. **AMM difference 1x10^{-8}.**

Touschek polarimetry

- Touschek effect provides most simple polarimetry at low energies.

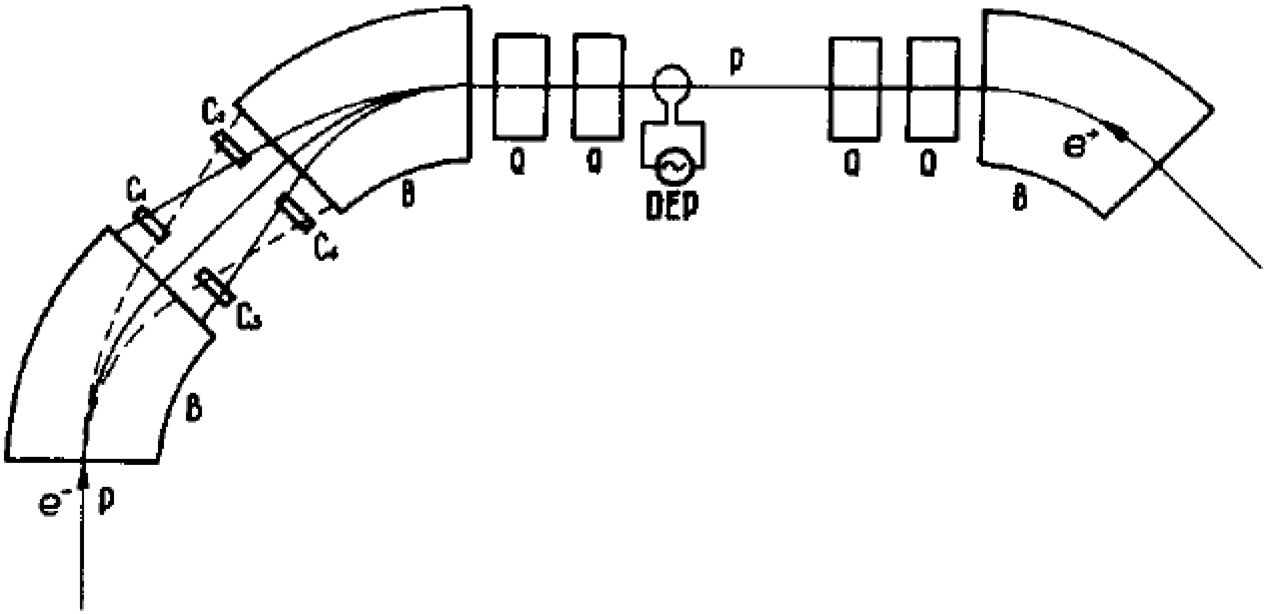

Fig. 1. The apparatus for measurement of both beam polarization in the storage ring VEPP-2M: P – the part of the equilibrium orbit; B – bending magnets of the VEPP-2M storage ring; Q – quadrupole lenses; DEP – the depolarizer; C_1 – C_4 – scintillation counters in coincidence.

Touschek polarimetry, cont.

- But the polarization asymmetry is not too large and is proportional only to P^2, not to P (as in the Compton device). So, for VEPP-2M, for instance, one has:

$$dN/dt = 40(\text{Hz})\cdot(1 - 0.15\cdot P^2)\cdot I(\text{mA})^2$$

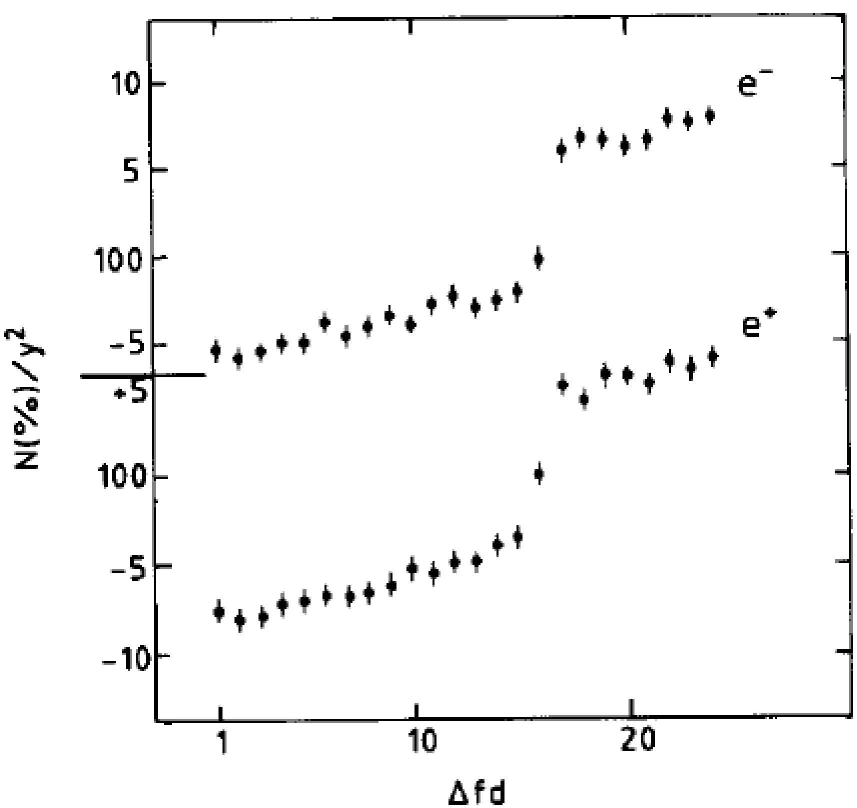

Fig. 3. The counting rates for a typical run.

Experiment 1986.

I.B.Vasserman, P.V.Vorobyov, E.S.Gluskin, P.M.Ivanov, G.Ya.Kezerashvili, I.A.Koop, A.P.Lysenko, A.A.Mikhailichenko, I.N.Nesterenko, E.A.Perevedentsev, A.A.Polunin, S.I.Serednyakov, A.N.Skrinsky, Yu.M.Shatunov. “New experiment on the precise comparison of the anomalous magnetic moments of relativistic electrons and positrons”, Physics Letters B, Volume 187, Issues 1–2, 19 March 1987, Pages 172-174. Institute of Nuclear Physics, 630090 Novosibirsk, USSR, Received 12 November 1986.

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 rang beams. It has been shown that the difference between the anomalous magnetic moments of the electron and positron does not exceed $\mathbf{1.2 \times 10^{-7}}$ with 95% confidence level, in agreement with the CPT-theorem and the principle of relativistic invariance.

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 result of the comparison of the electron and positron obtained, while being inferior in accuracy, confirms the data published in ref [P. B. Schwmdberg, R.S. Van Dyck Jr. and H. G. Dehmelt, Phys. Rev Lett. 47 (1981) 1679], 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.

Crossing the resonance by depolarizer's frequency

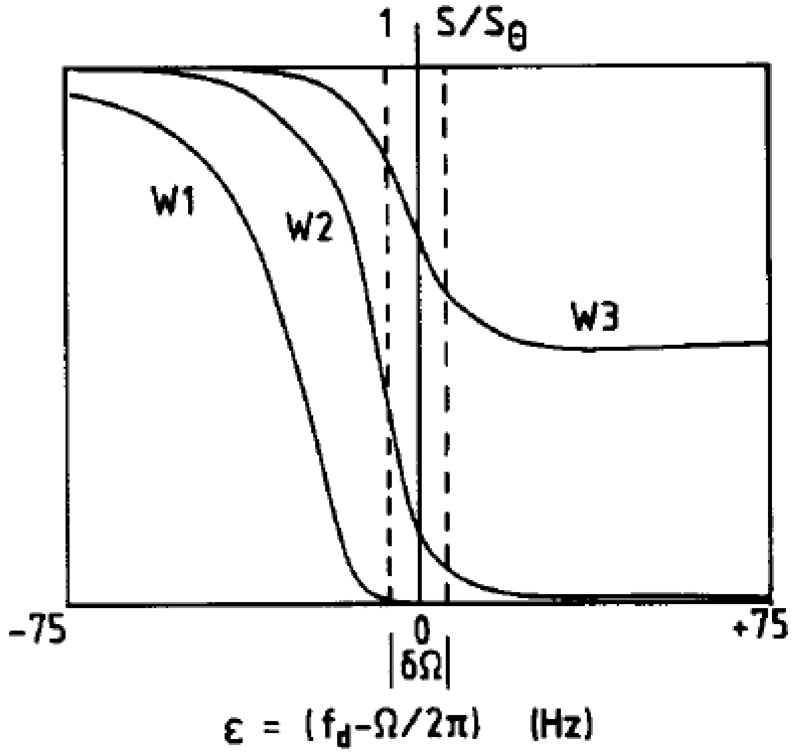

Fig. 1. The calculated behaviour of the polarization degree while crossing the resonance, $\dot{f}_d = 1.00$ Hz/s, $W1 = 1.00\times10^{-7}\omega_s$, $W2 = 0.35\times10^{-7}\omega_s$, $W3 = 0.15\times10^{-7}\omega_s$.

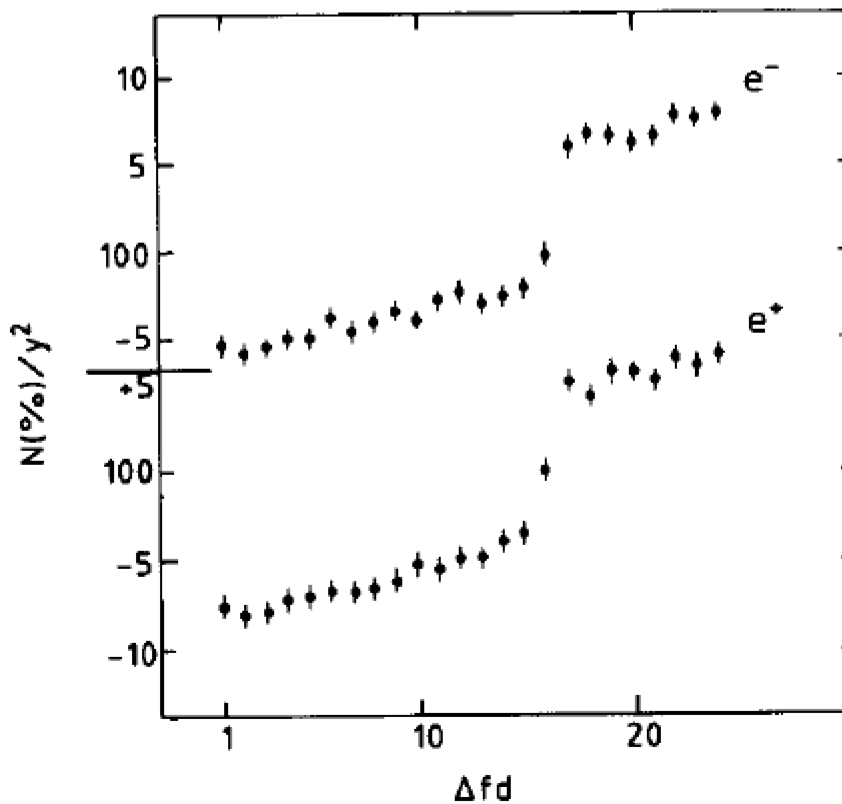

Fig. 3. The counting rates for a typical run.

Validation of the sensitivity to magnetic moments difference

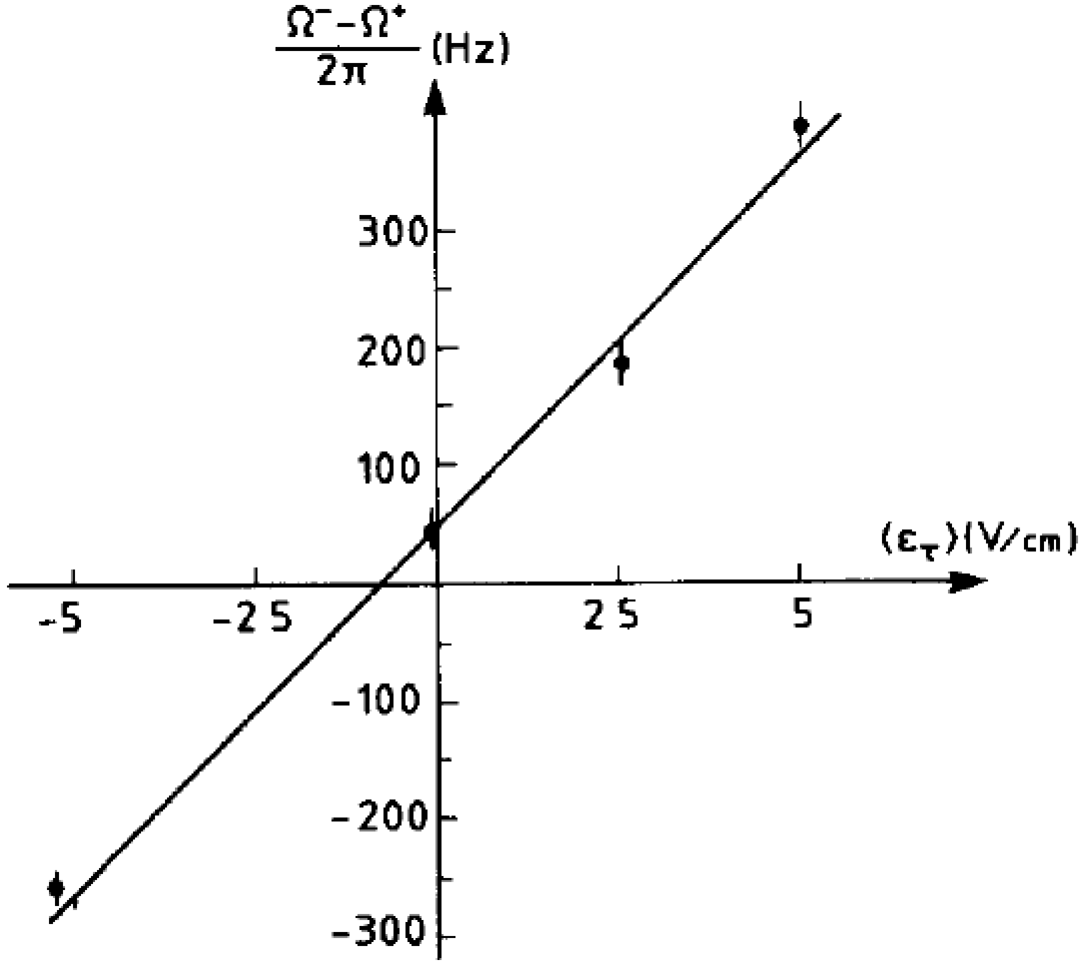

Fig. 4. The spin frequency difference as a function of the electrostatic separation.

Sensitivities and field stabilization in VEPP-2M

During the run the guide field stabilization system based on NMR (with the characteristic time τ ~1 s) and the ripple suppression system ($\tau \sim 10^{-3}$ s) provided a noise level of $\Delta H/H \sim 1\cdot10^{-6}$. In addition, the stability of the average energy of the particle was maintained within an accuracy of $\Delta E/E \sim \pm1\cdot10^{-6}$ by a special slow feedback system (τ ~ 10 min), which corrected the guide field level in accordance with the periodical mechanical measurements of the displacements of the dipoles and quadrupoles in the storage ring [B.A. Baklakov et al., Proc VII All-Union Conf. on Charged particles accelerators, Vol 1, p. 338.]

The result of the comparison of the electron and positron obtained, while being inferior in accuracy, confirms the data published in ref [P. B. Schwmdberg, R.S. Van Dyck Jr. and H. G. Dehmelt, Phys. Rev Lett. 47 (1981) 1679], 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.

Experiment 1987

I.B.Vasserman, P.V.Vorobyov, E.S.Gluskin, P.M.Ivanov, I.A.Koop, G.Ya.Kezerashvili, A.P.Lysenko, I.N.Nesterenko, E.A.Perevedentsev, A.A.Mikhailichenko, A.A.Polunin, S.I.Serednyakov, A.N.Skrinsky, Yu.M.Shatunov:"Comparison of the electron and positron anomalous magnetic moments: Experiment 1987", Physics Letters B, Volume 198, Issue 2, 19 November 1987, Pages 302-306. Received 25 August 1987.

The anomalous magnetic moments of relativistic electrons and positrons have been compared by measuring **the spin precession phase difference** Δφ at a given time interval Δt. The difference in the anomalous magnetic moments between the electron and the positron has been shown to lie within **$1\text{x}10^{-8}$** at 95% confidence level, which improves the accuracy of the previous measurements by an order of magnitude.

$$\Delta\varphi = \int_0^{\Delta t} (\Omega^{+} - \Omega^{-})\,dt$$

With $\Delta t = 1$ s the number of free spin precession turns was about 10^7.

The measurements begin at the time t= $3\tau_d$ after the injection, when the polarization degree builds up to S_0=0.85. At the point A the RF flipper device is switched on twice for short periods of time Δt to rotate the spins to the horizontal plane then back upright. 10 min past, from point B onwards the depolarization is performed by another RF device named depolarizer. Relating the leaps at the points A and B one can determine both the absolute value of S_1/S_0 and the sign of S_1. See next slide:

Experiment 1987: cont.1

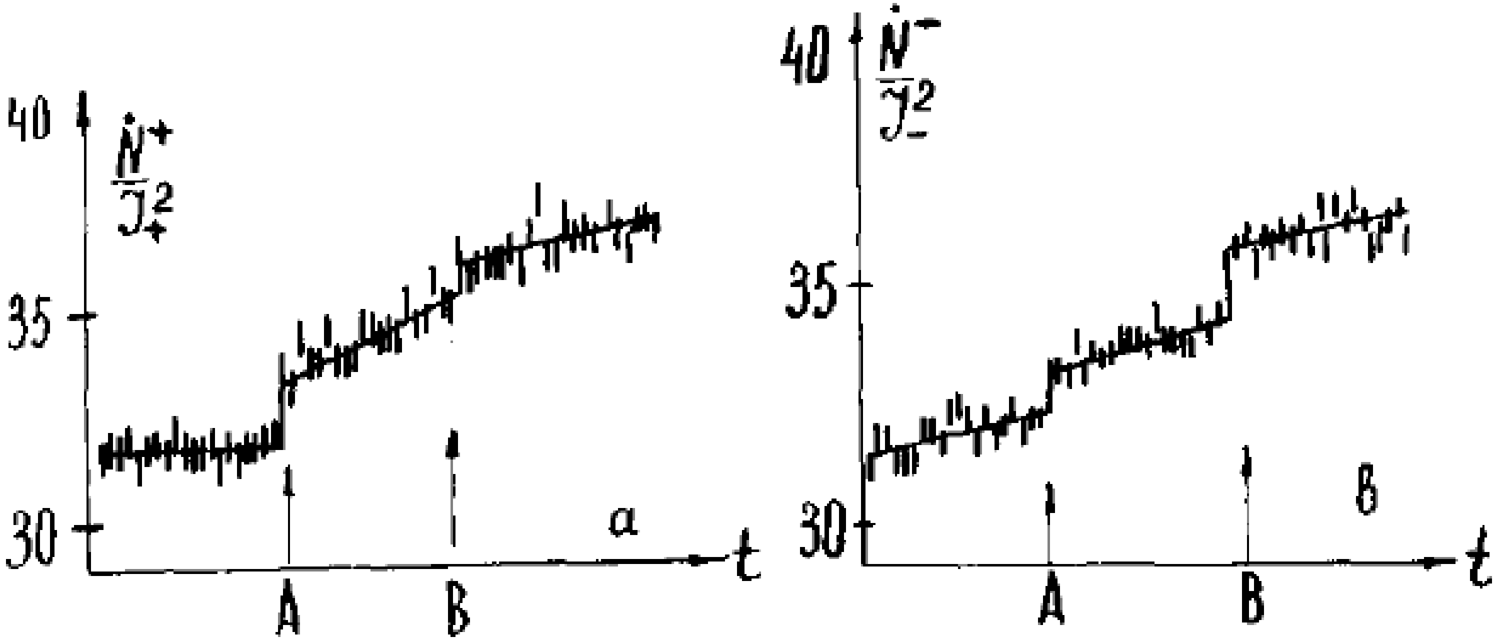

Fig. 1. Time dependence of the elastic scattering event rate, normalized on the beam current squared, for the typical run when the restored polarization of the positron (a) and the electron (b) beam differed in sign ($S_1^+/S_0=-0.8$, $S_1^-/S_0=0.8$).

One can see that the slope of the positron curve changes drastically after point A because of negative sign of the restored polarization after two successive half-flips, while the electron beam curve does not show such a behavior because the restored beam polarization is positive.

Experiment 1987: cont.2

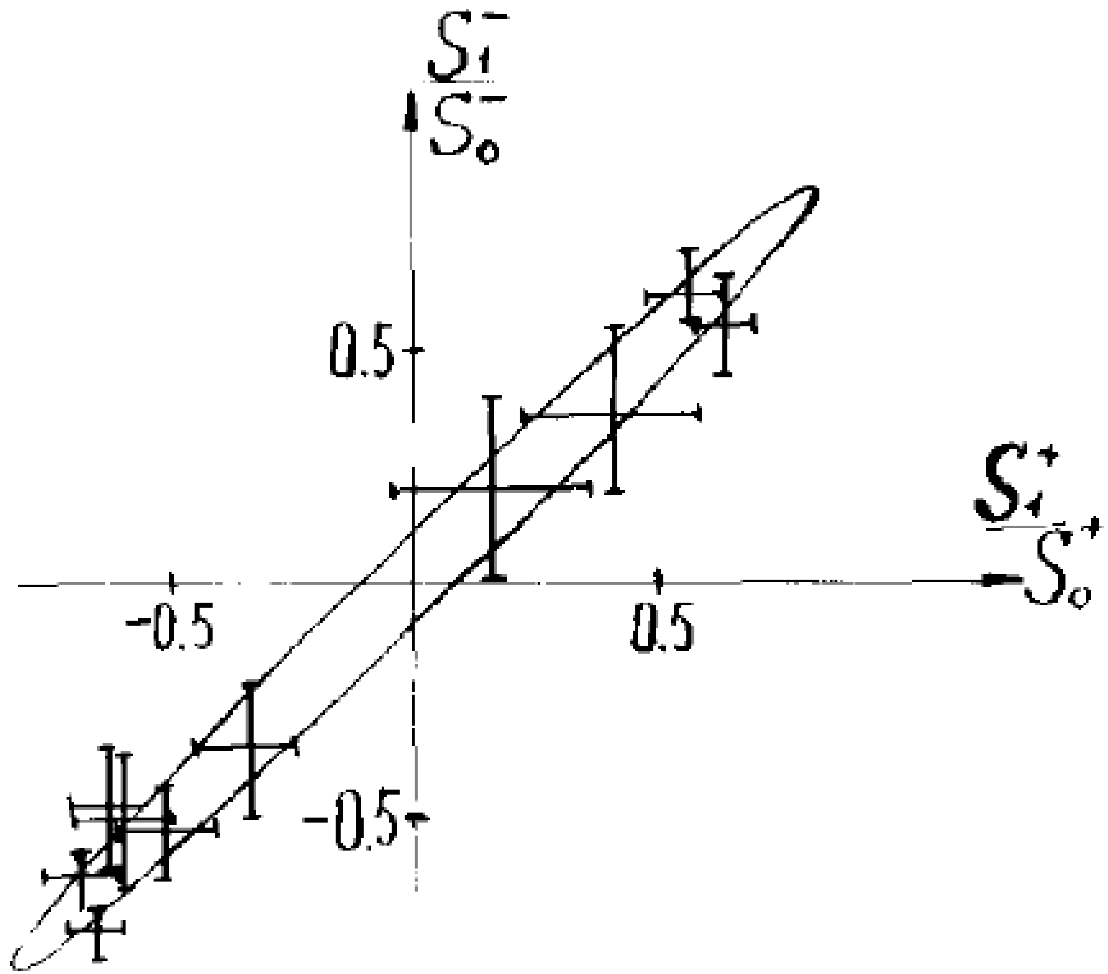

Fig. 2. The restored polarization degrees for electrons and positrons, measured without spin precession frequencies separation by the horizontal electrostatic field.

Experiment 1987: cont.3

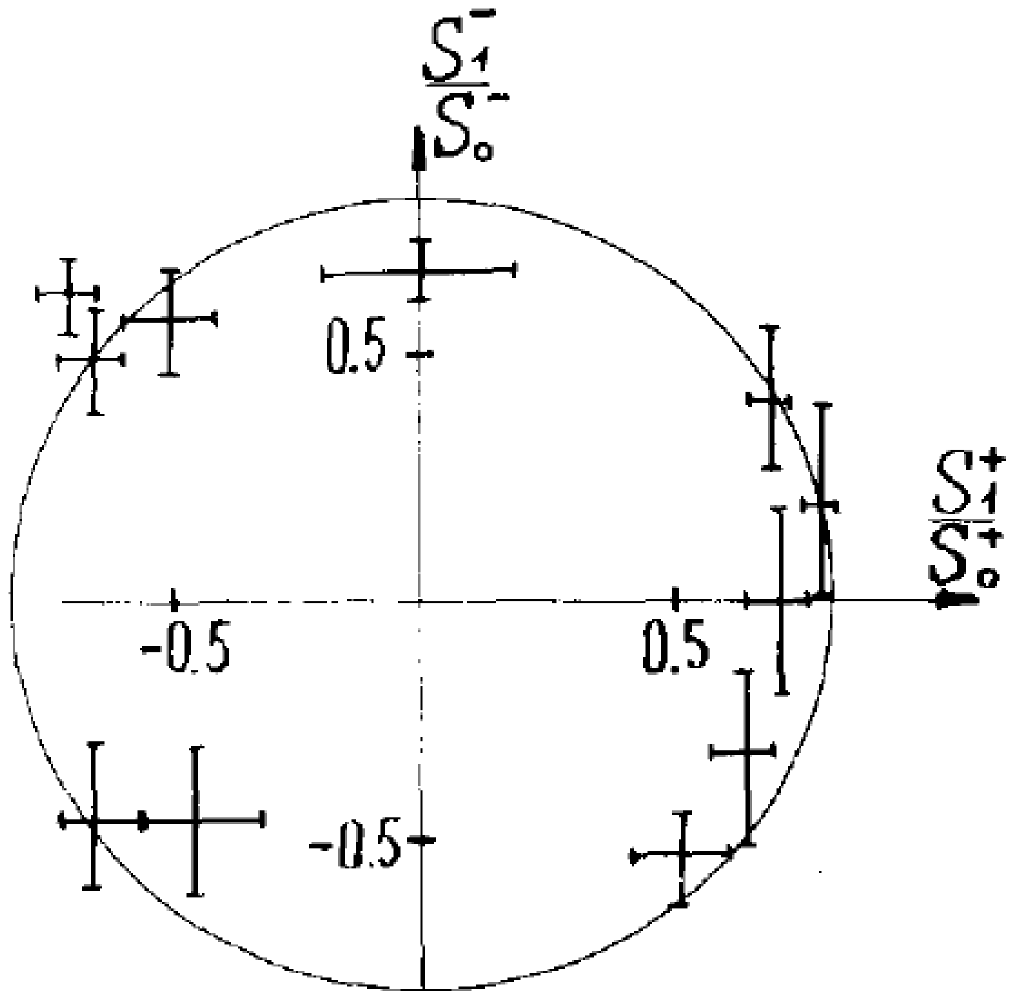

Fig. 3. The restored polarization degrees for electrons and positrons, measured with spin precession frequencies separated by the horizontal electrostatic field at $\Delta = \Omega^+ - \Omega^- = 2.5$ Hz.

Experiment 1987: cont.4

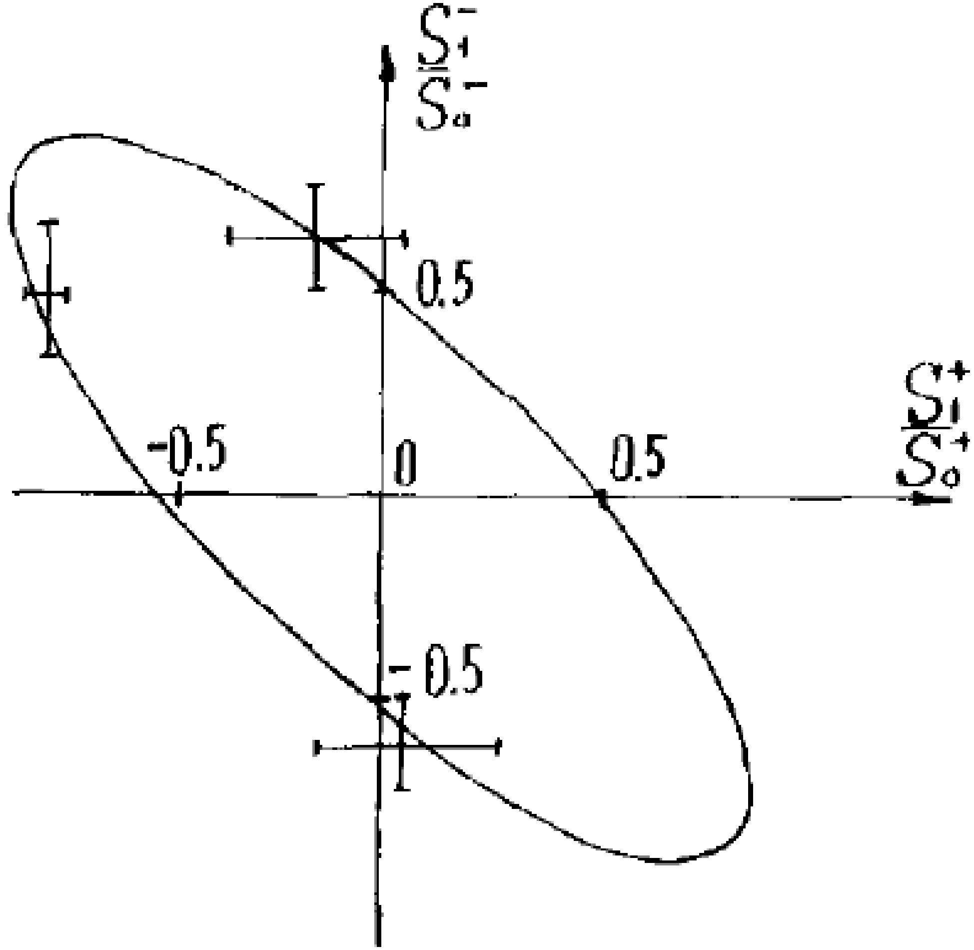

Fig. 4. The spin frequency separation is 2.5 times greater than in fig. 3.

Spin tune spread

- Spin tune spread limits the width of the spin resonance and a time of free coherent spin precession, like in our Experiment 1987.
- That time we have realized that lengthening of an orbit of any oscillating particle forces the negative shift of its energy to become synchronous with an RF [I.A.Koop and Ju.M.Shatunov, “The spin precession tune spread in the storage ring”, EPAC1988, pp.738-739.]
- Sextupoles provide some additional bending field integral at x<0, which, instead, lead to the increase of a particle energy. Thus, the positive energy shift from sextupoles can compensate the negative contribution from the orbit lengthening.

- For strong focusing machines main contribution to relative energy shift comes from the horizontal betatron oscillations. Then, neglecting weak other terms, one gets:

$$\bar{\delta} = \alpha^{-1} \frac{\varepsilon_x}{2R} \cdot \gamma \frac{\partial Q_x}{\partial \gamma}$$

- For FCC-ee this is very small number: in the order of $\bar{\delta}$=10^{-8} , if $\gamma \frac{\partial Q_x}{\partial \gamma}$=1
- Therefore, the decoherence in FCC-ee is governed not by this effect, but by high value of the synchrotron modulation index.

Conclusion

- In previous epoch the resonant depolarization was the main tool at BINP to control the beam energy with the unique precision.
- And the Touschek polarimeter was the main device for measuring the polarization degree (but only by means of fast depolarization).
- Now we move to use the Compton backscattering spectrometers for both our colliders: VEPP-2000 and VEPP-4M (N.Muchnoi will talk this about).
- Still, to check that Compton spectrometry works well we do sometimes the resonant depolarizations as well.

- At extremely high energies, like planned for FCC-ee, the resonant depolarization is only one ingredient of beam energy calibration procedure.
- It should be complemented by precise, with the relative accuracy about 10^{-3}, saw-tooth measurements technique, to get the wanted 10^{-6} of the local beam energy determination accuracy at IP.
- The last cannot be accomplished by measuring only RF voltages and phases. On our opinion, the saw-tooth distribution along a ring needs to be measured as well.
- To do so, we suggest to foresee possibility to inject of both sign beams into each of two FCC-ee rings to be able to measure x-coordinate difference of counter-circulating beams.