SPIN AND BEAM DYNAMICS IN THE MUON g-2 STORAGE RING – SYSTEMATIC ERRORS

YURI F. ORLOV

(Cornell University, Ithaca, New York 14853) for the (g–2) Collaboration

The Muon Storage ring at BNL is constructed to measure $a_\mu = (g-2)/2$ with accuracy 0.35 ppm. A preliminary 1997 run resulted in $a_{\mu+}$=1 165 925(15)x10^{-9}, in agreement with the previous CERN measurement. The main systematic errors connected with spin and beam dynamics, as well as their corrections, are described.

Introduction. The basic idea of the new (g-2) measurement at Brookhaven is the same as that of the last CERN measurement[1]. Muons rotate in the magnetic field of the storage ring, as shown schematically in Fig 1, $a_\mu = \frac{g-2}{2} \approx \frac{\alpha}{2\pi} > 0$, so the spin rotation frequency ω_s is bigger than the momentum rotation frequency ω_p, and as a result, spin rotates around momentum, $\theta = \omega_a t$, $\omega_a = \omega_s - \omega_p$. The electron decay signal, N(t), registered by the electron calorimeters (see also Fig.2), oscillates with frequency ω_a, which is measured in this experiment,

$$N_e = N_0 e^{-t/\tau_\mu}[1 + A(E)cos(\omega_a t + \phi(E))], \tag{1}$$

where E is the energy threshold placed on the decay electron spectrum. The main advatage of the Brookhaven (compared with the CERN) measurement is the drastically increased statistics due to the higher beam intensity at AGS and, even more important, due to the installation of the kicker into the g-2 ring, which permits us to directly inject muons - instead of pions decaying inside the ring. The 1997 preliminary run, however, was made with the pion injection; the result a_{μ^+}= (1 165 925±15)x 10^{-9}, $\triangle a_\mu/a_\mu = 13ppm$, *

*H.N. Brown[b], G. Bunce[b], R.M. Carey[a], P. Cushman[h], G.T. Danby[b], P.T. Debevec[g], H. Deng[l], W. Deninger[g], S.K. Dhawan[l], V.P. Druzhini[i], L. Duong[h], W. Earle[a] E. Efstathiadis[a], G.V. Fedotovich[i], S. Giron[h], F. Gray[g], M. Grosse-Perdekamp[l], A. Grossmann[e], U. Haeberlen[f], M. Hare[a], E.S. Hazen[a], D.W. Hertzog[g], V.W. Hughes[l], M. Iwasaki[k], K. Jungmann[e], D. Kawall[l], M. Kawamura[k], B.I. Khazin[i], J. Kindem[h], F. Krienen[a], I. Kronkvist[h], R. Larsen[b], Y.Y. Lee[b], I. Logashenko[i], R. McNabb[h], W. Meng[b], J.-L. Mi[b], J.P. Miller[a], W.M. Morse[b], C.J.G. Onderwater[g], Y. Orlov[c], C. Pai[b], C. Polly[g], J. Pretz[l], R. Prigl[b], G. zu Putlitz[e], S.I. Redin[l], O. Rind[a], B.L. Roberts[a], N. Ryskulov[i], R. Sanders[b], S. Sedykh[g], Y.K. Semertzidis[b], S. Serednyakow[i], Yu.M. Shatunov[i], E. Solodov[i], M. Sossong[g], A. Steinmetz[l], L.R. Sulak[a], C. Timmermans[h], A. Trofimov[a], D. Urner[g], D. Warburton[b], D. Winn[d], Q. Xu[b], A. Yamamoto[j], D. Zimmerman[h]([a]Department of Physics, Boston University, [b]Brookhaven Nation Laboratory, [c]Newman Laboratory, Cornell University, [d]Physics Department, Fairfield University, [e]Physikalisches Institut der Universität Heidelberg, Germany, [f]MPI für Med. Forschung, Heidelberg, Germany, [g]Department of Physics, University

is in aggreement with the CERN result. The muon injection began to work in 1998. The ultimate goal of the experiment is $\triangle a_\mu/a_\mu$ =0.35 ppm, compared with the 7.3ppm of CERN. Such accuracy requires very careful analysis, both theoretical and experimental, and the corresponding corrections of systematic errors, in particular errors related to the spin and beam dynamics. The main ones are the following.

Magnetic field accuracy and stability. In the case of planar movement,

$$\vec{\omega}_a = -\frac{e}{mc}[a\vec{B} - (a - \frac{1}{\gamma^2 - 1})\frac{\vec{v}}{c} \times \vec{E}],\ a \equiv a_\mu \tag{2}$$

If there were magnetic focusing, and hence a nonhomogeneous magnetic field, then it would be impossible to know this field with the needed accuracy $\sim$ 0.1ppm. For this reason the CERN idea[2] of a *homogeneous* magnetic field and *electric focusing* has been accepted, with $(a - \frac{1}{\gamma^2-1})$=0, i.e., with the "magic" γ, $\gamma = \gamma_m = \sqrt{\frac{1+a}{a}}$=29.3, and the "magic" momentum p_m=3.094 GeV/c. When $\gamma = \gamma_m$, the four focusing electric quadrupoles (occupying 43% of the ring) do not introduce errors into the ω_a value. In (2), B=14.5T and the (g-2) period 4.4μs (R=7.11m; the cyclotron period 149ns).

The following improvements have been introduced compared with the CERN experiment: A larger magnet aperture; special shimming devices; the circular cross-section vacuum chamber, r=4.5cm, in which the average magnetic field seen by the stored muons is less sensitive to higher field multipoles; an NMR trolley inside the vacuum chamber; measurement of the muon distribution inside the vacuum chamber by pickup electrodes and traceback of decay electrons; superconducting coils; and the superconducting inflector.

The chosen n-value, $n = \frac{R}{B\beta}\frac{\partial E_r}{\partial R}$ =0.135, V = $\pm 24k$V, places the muon betatron frequences far from the main betatron and spin resonances. Losses of particles due to beam resonances would lead to the phase and lifetime changes in(1). Spin resonances could change the ω_a value.

Radial electric field error and correction. The energy spread of the muons around the ideal "magic" energy leads to the average error caused by the electric field,

$$\left(\frac{\partial\omega_a}{\omega_a}\right)_E = -2n(1-n)\left[\left\langle\left(\frac{f - f_m}{f_m}\right)^2\right\rangle + \left\langle\frac{f - f_m}{f_m}\right\rangle\frac{f_m - f_{E=0}}{f_m}\right], \tag{3}$$

where f is the muon revolution frequency, f_m is the "magic" frequency, and $f_{E=0}$ the frequency corresponding to the radius at which the average quadrupole

of Illinois at Urbana-Champaign, [h]Department of Physics, University of Minnesota, [i]Budker Insitiute of Nuclear Physics, Novosibirsk, Russia, [j]KEK, Japan, [k]Tokyo Institute of Technology, Tokyo, Japan, [l]Department of Physics, Yale University)

electric field equals zero. (3)is approximately twice bigger than the designed statistical error 0.30=ppm. We need to measure the muon frequency distribution and introduce the corresponding correction. In this respect, an improvement over the CERN method (based on the muon bunch debunching) came from understanding that the Fourier spectrum of the *electron* decay signal at a given detector, divided by the approximately known function (1), contains all information about the *muon* frequency distribution[3]. Fig 3 shows the distribution in the 1997 run measured by the Fourier method.

Pitch correction. The systematic error due to muon vertical oscillations[4],

$$\left(\frac{\partial\omega_a}{\omega_a}\right)_{pitch} = -\frac{1}{4}\left\langle\chi_0^2\right\rangle[1-\frac{n\beta^4\omega_a^2}{(\omega_a^2-\omega_{vert}^2)}] \tag{4}$$

(where χ_0 is the angle amplitude of the vertical betatron oscillations) is of the same order as the designed statistical error. The measurement of the muon distribution inside the vacuum chamber – an improvement over the CERN experiment, as mentioned above – helps to correct this error.

In the muon injection runs, the corrected summarized systematics, related to spin and beam dynamics, are expected to be 0.12ppm.

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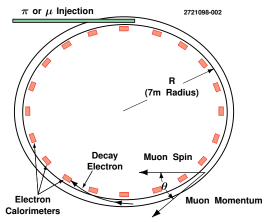

Fig. 1

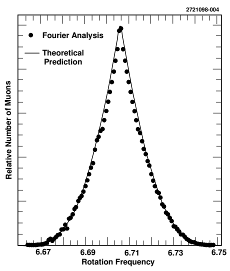

Fig. 3

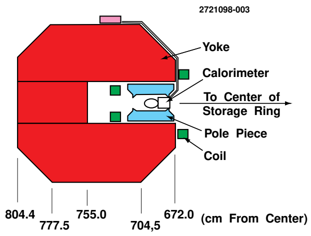

Fig. 2