White Paper on Measuring the Muon g-2 Frequency in a Muon Storage Ring.

Y.K. Semertzidis, W.M. Morse

Brookhaven National Laboratory

November 30, 2000

Abstract

We are proposing to use the synchrotron radiation emitted by the muon decay electrons at the bending sections of the storage ring in order to deduce the muon g-2 frequency and hence the stored muon beam energy.

1 Introduction

In a muon storage ring there is a need to find the energy of the stored beam to high accuracy. The prevailing idea at this time is to find this energy by detecting the muon g-2 frequency and compare it to its cyclotron frequency. [1] The g-2 frequency is given by:

$$\omega_a = a_\mu \frac{e}{m_\mu} B, \tag{1}$$

the cyclotron frequency by

$$\omega_c = \frac{e}{\gamma m_\mu} B, \tag{2}$$

From Eqs. (1) and (2) we get

$$\omega_a = a_\mu \gamma \omega_c, \tag{3}$$

which means that the muon spin precesses by $a_\mu \gamma 2\pi$ radians faster than the momentum per revolution. Since the muon beam bunch length is designed to be of the order of 1ns, both ω_a and ω_c can be measured with high accuracy and hence γ.

2 Muon g-2 Frequency Detection Methods

The traditional way of observing the muon g-2 frequency is to detect the decay electron number as a function of time and energy of the electrons. [2, 3] The number of positrons above a certain energy threshold (E_t) versus time (t) obeys the following equation:

$$N(t) = N_0 e^{-\frac{t}{\tau_\mu}} [1 + A(E_t) \cos(\omega t + \phi(E_t))], \tag{4}$$

with N_0 a normalization factor, τ_μ the muon lifetime, $A(E_t)$ the asymmetry which depends on the energy threshold, ω is the g-2 angular frequency and $\phi(E_t)$ is the g-2 phase which also depends on the energy threshold. There are alternative ways to find the g-2 frequency by plotting the decay electron energy versus time (Q-method) [4] or by weighing each electron by the asymmetry based on its energy. [5]

The decay electrons have, on average, less energy than the muons and are bend by the magnetic field towards smaller radii where they can be captured by a detector. It turns out that the total energy reaching the electron detector is of great concern. [6] At 50GeV the muon decay rate is 1.6×10^{10}decays/m/s, depositing some 84kW power in the 1750m ring or 48Watts/meter on average. [7]

We are proposing to use the synchrotron radiation (SR) emitted by the decay electrons at the arc sections to measure the g-2 frequency of the muons. This will alleviate the loading of the detectors since only a small fraction of the total electron energy will be captured.

In a muon storage ring of both the bow tie and racetrack type there are two straight sections and two arcs. The energy loss (in MeV) per revolution due to synchrotron radiation is given by:

$$\frac{\mathrm{E_{loss}}}{\mathrm{revolution}}[\mathrm{MeV}] = \frac{4\pi}{3}\frac{\alpha\hbar c}{R}\beta^3\gamma^4, \quad (5)$$

which for a 50GeV muon stored beam ($\gamma = 475$, $R = 43$m) is 7eV per revolution. The energy loss of the decay electrons, however, is 13GeV per revolution (or 6.5GeV per arc) for the 50GeV energy, 1.5GeV for 25GeV electrons (R for 25GeV electrons is half of that for 50GeV), and 500MeV for 17GeV. Since the forward going electrons have, on average, higher energy than the backward going electrons it should be fairly easy (a study is needed here) to tell the muon spin direction by looking at the synchrotron radiation in view of its fourth power dependence on the electron γ.

The SR spectrum has a $1/E$ dependence and the emittance cone is $1/\gamma$ tangential to the electron orbit. In order to restrict the amount of energy reaching the detector per revolution one may choose to have a small opening tangential to the electron orbit at one arc.

References

[1] R. Raja and A. Tollestrup, Phys. Rev. D58(1998)013005.

[2] J. Bailey *et al.*, Nucl. Phys. **B150**, 1 (1979); F.J.M. Farley and E. Picasso in Quantum Electrodynamics, ed. T. Kinoshita, (World Scientific, Singapore, 1990).

[3] H.N. Brown *et al.*, Phys.Rev.D62:091101, (2000).

[4] W. Morse, “A New Method of Analysis”, g-2 note #93, October 1991.

[5] J. Pretz, “Reducing the Statistical Error on the g-2 Frequency by Using a Weighting Procedure”, g-2 note #326, November 1998.

[6] Iuliu Stumer, BNL, Omega Group Meeting presentation on “Muon Collider Studies”, 20 November, 2000.

[7] “A feasibility Study of a Neutrino Source Based on a Muon Storage Ring”, N. Holtkamp *et al.*, Fermilab-Pub-00/108E, June 2000.