

## Concept of a Muon Profile Monitor with Scintillating Fibers

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### I. INTRODUCTION

A muon storage ring of 3.094 GeV/c momentum is being constructed at BNL under the collaboration among US, German, Russian and Japanese high energy physics laboratories and universities. It will be used for the measurement of muon anomalous magnetic moment.[1] Fig. 1 shows the structure of the storage ring. It consists of 360° continuous guiding magnetic dipole field and four vertically focusing electrostatic quadrupoles and as a whole it forms a weak-focusing system. There is no RF system in it.

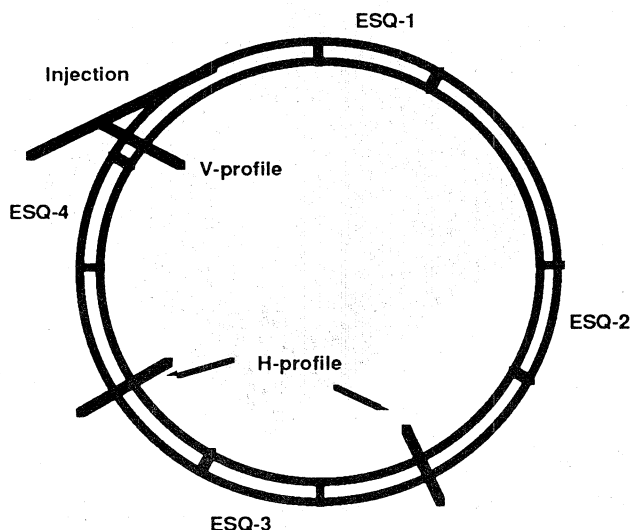


Fig.1 Muon storage ring

In the past, muon  $g-2$  experiment has been performed at CERN three times and the final one reached the precision of 7 ppm.[2] New experiment aims at the precision of 0.35 ppm. In the  $g-2$  experiment we detect the decay electron inside the ring. The yield has a modulation frequency  $\omega_a$  as the difference between the spin precession frequency  $\omega_s$  and the cyclotron frequency  $\omega_c$  of circulating polarized muon beam due to the parity violation.

$$\omega_a = \omega_s - \omega_c = (eB/mc)a$$

where  $a$  is the anomalous magnetic moment defined as  $a = (g - 2)/2$  and  $g$  is the gyromagnetic ratio of a muon defined by the ratio of the magnetic moment  $\mu$  and the spin  $s$  as  $\mu/s = (eh/4\pi mc)g$ .

Owing to the momentum and spacial spread of stored muon beam,  $\omega_a$  of the beam particle will have spread if the

magnetic field  $B$  is not uniform. Hence, very stable and uniform magnetic field will be formed by the use of a superconducting dipole magnet and high quality pole faces. Design value of field uniformity is about 1 ppm after careful shimming work. However, if there are some inhomogeneity left, we must estimate the effective field seen by the beam not to deteriorate the accuracy of the experiment. For that purpose a muon profile monitor is very useful and it can even relax the requirement for the magnetic field uniformity.

One particular features of this storage ring is its very low beam intensity, of the order of  $2 \times 10^4$  at most. Hence, the signal level of the stored beam from a popular pickup electrode will be of the same order as thermal noise. (Farley has proposed to measure the moment of beam distribution with many electrodes around the beam. In order to improve S/N ratio of each pickup electrode signal he also proposed to synchronously sample the electrode signal and accumulate. His method requires many revolution times and does not give instantaneous information about the beam distribution.) Some other high gain detection scheme is necessary to make real-time beam observation. In this respect, application of techniques of high energy physics experiment will be useful since they often deal with the detection of a single particle, the lowest beam intensity. Scintillation counter is a good example. It consists of a scintillator and a high gain photomultiplier (PMT). Beam distribution, or beam profile, can be measured with a set of a scintillating fiber array and photomultipliers. The light yield from each fiber will be proportional to the number of particle passing through it.

### II. SCINTILLATING FIBER PROFILE MONITOR

Fig.2 shows the concept of the fiber profile monitor. A muon excites scintillation light in a fiber and the light is guided in the fiber up to a PMT cathode.

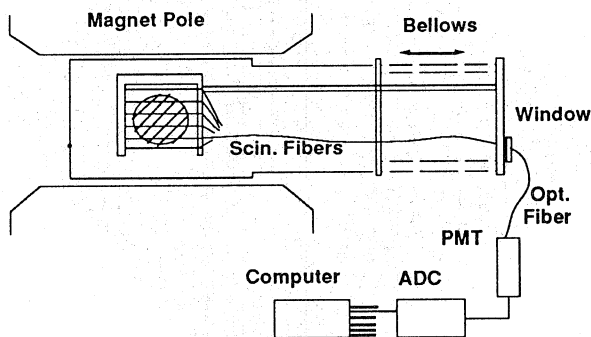


Fig. 2 Schematic of a scintillating fiberprofile monitor

Output of the PMT's are put into ADCs and stored in a memory. Relative intensity of each fiber indicates the beam distribution over the aperture of 90 mm diameter with a vertical fiber array and a horizontal array. Even for a very short life of the stored beam (64  $\mu$ s) it will be possible to measure the profile several times during a single storage and follow the time evolution of the muon profile. Since the detection efficiency of each channel is not uniform (due to the variation of photomultiplier gain and optical transmission efficiency), calibration of sensitivity is necessary. For this purpose, fiber array frame will be rotated by right angles so that each fiber sees the common part of the beam.

The fiber array is expected as a diagnostic tool at the commissioning of the ring. If the electrostatic quadrupole is turned off, the horizontal profile monitor at the 180° position from the inflector will indicate the beam momentum error. Further, another horizontal monitor at the 270° position of the injection point is used to adjust the kicker strength in the case of muon injection.

In this fiber monitor scheme, the interaction between the fiber material and muon beam is of concern in two aspects. One is the muon emittance growth due to multiple scattering and the other is radiation damage of the fiber.

### III. SIMULATION STUDY

Most serious problem in a fiber monitor is the destructive effect of the fiber material on the stored beam due to multiple scattering. Initial thought was that muon makes only a few thousand revolutions during its life time and the scattering by very sparsely arranged material would not make fatal effect. The scattering of the fiber array in the presence of weak focusing is estimated by the simulation. In the simulation, we used a random number generator and created particles which have gaussian distribution in almost all of the variables as horizontal and vertical beam position, horizontal and vertical beam divergence and in momentum. The effect of the fiber array is represented by the change of angle of motion at the location of the fiber by the quantity when a particle hit a fiber. Energy loss (or momentum change) was not taken into account but will be necessary to include in the future simulation. The average of the angle change is given by the following semi-empirical formula,

$$\theta = (13.6/\beta cp)(x/X) [1 + 0.038 \ln(x/X)]$$

where  $p$  and  $\beta c$  are the momentum (in MeV/c) and the velocity of muon and  $x/X$  is the thickness of the scattering material in radiation lengths and  $x$  is the thickness of the scattering material. Scintillating fiber is mainly made of polystyrene, for which  $X$  is about 0.45 m. For the fiber diameter 0.3 mm,  $\theta = 0.085$  mrad. Scattering angle at each passage through a fiber is also given by random numbers. We assume circular aperture limit of 45 mm radius. Fig. 3 shows the decrease of muon number during the storage. Large decrease of muon in the first few revolutions is due to the scraping by the aperture. In the absence of fibers, later beam

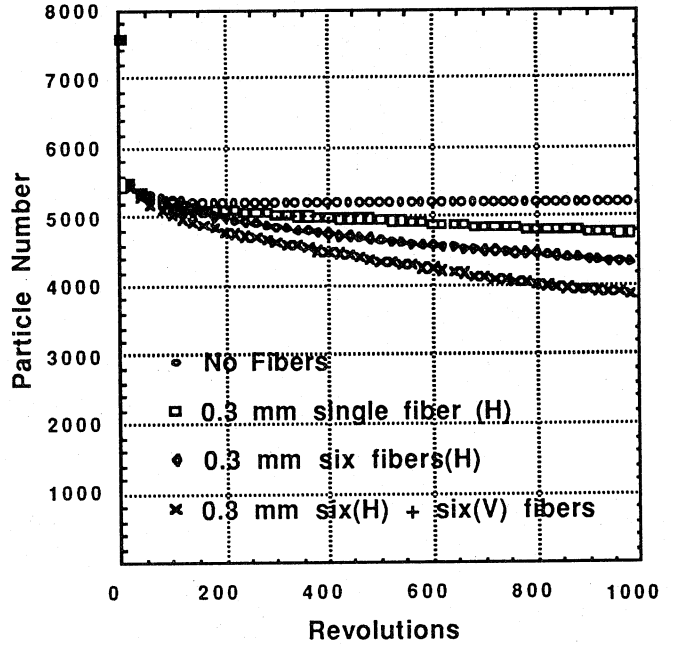


Fig. 3 Decrease of muon due to multiple scattering by fibers. Natural muon decay is not included.

loss is small but the destructive effect is noticeable even with the thinnest fiber (0.3 mm diameter) available. Hence, the profile measurement can be made in a test run only and the fiber must be drawn back during physics experiment because the scattered particles make serious background for the decay electron measurement.

Fig. 4 shows the horizontal profile after 1000 revolutions without a fiber and in the presence of horizontal and vertical fiber monitors of 0.3 mm fibers over 10 cm range.

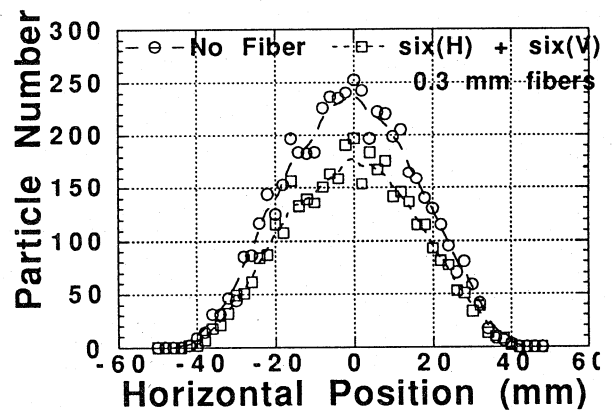


Fig. 4 Simulation for the horizontal distribution of muons after 1000 revolutions at the location of profile monitor

Reliable result would be obtained in the early period of storage while the scattering effect is not so much accumulated. However, we see that a relative profile pattern is not very much different from that for the original profile even after 1000 revolutions. This seems to exhibit the effectiveness of fiber profile monitor.

#### IV. PRELIMINARY BEAM TEST OF A PHOTOMULTIPLIER

Two kinds of scintillating fiber profile monitor configuration has been considered. One is to use a single multianode PMT and the other is to use independent single PMTs. We made preliminary tests for both scheme in the secondary beam line of KEK 12GeV PS where the we have pion/muon beam flux of about 2000 particles in 1.5 sec spill time. In the first test geometry, 1 mm diameter fiber arrays are connected to a multianode photomultiplier, Hamamatsu H4139. Anode output voltage for a single passage of 2 GeV/c particle is about 40mV. The signal level is sufficient but cross talk was observed among the multianode channels. This is not an adequate feature for profile measurement. In the second scheme, 1 mm fibers are connected to individual PMTs, Hamamatsu R657.

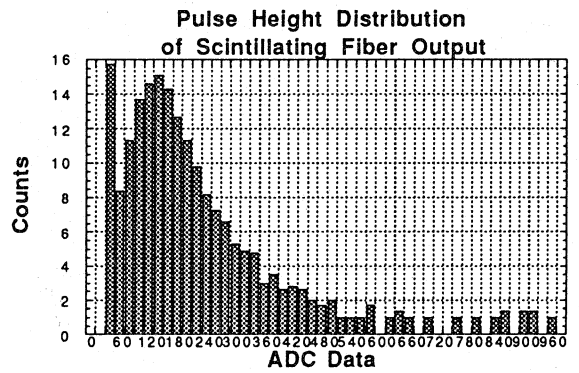


Fig. 6 Pulse height distribution of PMT signal

#### V. REFERENCES

- [1] "Muon g-2 Design Report AGS821" BNL, July 1992
- [2] J.Baily et al., Nucl.Phys. B150, 1 (1979)

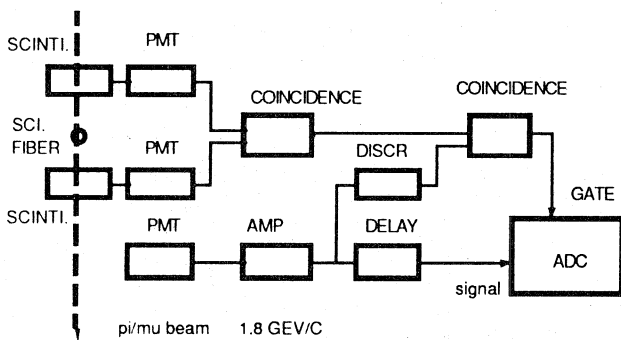


Fig.5 Schematic of the scintillating fiber beam test

Configuration of the signal detection is shown in Fig. 5. Pulse height distribution of the output is shown in Fig. 6. From the mean value and the width of the distribution we can approximately estimate the number of photoelectron yield at the photocathode if normal distribution is assumed. It ranges around three. Since the instantaneous beam intensity in the muon ring is much higher, scintillating fiber profile monitor looks feasible.