DIRECT MEASUREMENT OF MUON POLARIZATION IN $e^+e^- \rightarrow \mu^-\mu^+$

P. Limon, M.L. Stevenson, W. A. Wenzel

ABSTRACT

Two detectors are considered that are thick enough to stop 15 GeV $\mu^{\pm}$, with polarimeters to measure the polarization. Nearly 4π coverage would require a uranium ball of 10^4 tons and a polarimeter of 3000-4000 tons. A more nearly feasible approach uses a small angle 1500 ton detector with uranium plus magnetized iron to focus the muons on to a 400 ton polarimeter.

A. INTRODUCTION

In general, the direct measurement of muon polarization at PEP involves serious problems with regard first to the high size and cost of the device to stop and measure the decay of the 15 GeV muons, and second to the low counting rates associated with the polarization measurement. Compared with that for the simplest asymmetry measurements the time-integrated luminosity for measurement of polarization with comparable percentage error is nearly two orders of magnitude greater. One factor of ten is lost because of the limited analyzing power (squared) of the standard polarimeter. Another large factor is lost in detection efficiency because of absorption of decay electrons in the polarimeter, loss of muons through range straggling, etc.

The information on the weak interactions given by muon helicity measurements is also obtainable by asymmetry measurements provided that the longitudinal polarization of the e^- (or e^+) beam can be controlled. There are potential limitations in this procedure too, however. Firstly, large beam polarization may not be available at PEP. Secondly, the polarization of the beam may not be under the experimenters' control for a large part of the time. Finally, asymmetry may occur through two photon as well as weak interference with the dominant one photon exchange, whereas the existence of longitudinal muon polarization, in the absence of polarization in the incident beam (s), is an unambiguous indication of parity violation. For these reasons we have attempted, in spite of the difficulties noted above, to define possible experimental arrangements to measure muon polarization directly. We have considered the problems only for 15 GeV.

B. 4π DETECTOR

Figure 1 shows a brute force approach with a 4π detector. The uranium ball of 5M radius is surrounded by an aluminum polarimeter of 3M radial thickness. The specifications are given in the Table. We assume that the uranium will be made "available". Though the handling problems would be severe, they are not impossible. The floor loading for example is not excessive. Note that the use of iron instead of uranium would require an inner ball of more than twice the radius and nearly four times the weight. The polarimeter volume would be more than three times as large.

A $\mu^+\mu^=$ event would be identified by a concidence between two opposite scintillation counters in a simple inner hodoscope and by the arrival of at least one muon at the polarimeter. About half the positive muons would stop in the polarimeter. The front-back asymmetry would be measured with wire proportional chambers operated with low resolution, i.e. with wire signals ganged together to simplify the electronics. The negative muons would be absorbed relatively promptly without providing polarization information. An average measurement of positive muon polarization at the 1% level would require a run of about 10^{40} cm^{-2} time-integrated luminosity.

This experimental approach seems prohibitive primarily because of the cost of the polarimeter, for which the radial thickness is determined by energy straggling in the degrader. As evaluated by M. Strovink and A. Ogawa, this is dominated by the single large energy losses in μ-e scattering. It is therefore relatively independent of the material of the degrader. Considerable savings would be possible if zinc instead of aluminum could be used for the polarmeter itself (see Table). We haven't studied in detail its suitability as a polarimeter material.

C. SELECTIVE DETECTOR

In the absence of beam polarization the differential cross-section may be written (Mikaelian's notation,

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{8s}\left\{(1+2aR)(1+\cos^2\theta) + 4cR\cos\theta + 2h_-\left[bR(1+\cos\theta)^2 + dR(1+\cos^2\theta)\right]\right\}$$

where h_ is the helicity of the negative muon, produced at angle θ with respect to the e^- beam.

The weak interaction coefficient 2aR is second order in the weak vector coupling constant. Its determination requires measurement of the absolute rate relative to that for the one photon term. The asymmetry term 4cR is second order in the weak axial vector coupling constant. The bR and dR terms, giving the polarization effects, depend on V,A interference.

The dR term exists only if e-μ universality is violated. Hence parity violation is best detected through the bR term, for which the muon polarizations tend to follow the motion of charge in the initial beams. We have;

$$P_- = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx 2bR \, \frac{(1+\cos\theta)^2}{1+\cos^2\theta} + 2dR$$

A polarization measurement of the bR term can be carried out with a detector of relatively small solid angle. In terms of running time for measuring an effect at a given number of standard deviation, a figure of merit for a detector is,

$$M \equiv \left[\int_{detector} P^2 \, d\sigma\right] \Big/ \left[\int_{4\pi} P^2 \, d\sigma\right]$$

For an axially symmetric detector with,

Θ_{min} = 10-deg, Θ_{max} = 50-deg, we find $M_{bR} \approx 0.508$, $M_{dR} = 0.214$

In other words a detector with about one sixth the solid angle of the 4π detector would need only twice the running time to measure bR to a given precision. Assuming that an effect exists, the bR and dR terms can be separated with a run with the beam directions reversed.

By using magnetized iron as well as uranium in the degrader, we can reduce the size of the polarimeter by nearly an order of magnitude relative to that required for the 4π detector, and at the same time simplify its design by aligning all gaps normal to the beam axis. Such a detector is shown in Figure 2. The specifications are given in the Table. Though not especially optimized it appears that this detector would fit into a standard intersection region and would not be prohibitive in cost.

Obviously very high luminosity is desirable for these experiments. As shown in the Figures and Table for both detectors, beam line elements can be brought to within a few meters of the intersection.

TABLE

	4π Detector		Selective Detector	
DEGRADER				
Volume of Uranium	520 m^3		77 m^3	
Weight of Uranium	9800 T (metric)		1460 T	
Volume of Magnet	----		160 m^3	
Weight of Magnet	----		1270	
Cost of Fe @ $200/T	----		$ 0.25 M	
Average Residual Energy	0.75 GeV		0.75 GeV	
Rms (proj.) coulomb scat. angle	0.17		$\leq$ 0.17	
Rms (proj.) scat. displacement	0.21 m		$\leq$ 0.21 m	
POLARIMETER				
Material	Al.	Zn.	Al.	Zn.
Plate thickness	5 cm	2 cm	5 cm	2 cm
Gap thickness	1 cm	1 cm	1 cm	1 cm
Number of gaps	50	50	50	50
Volume of polarimeter	1600 m^3	630 m^3	170 m^3	85 m^3
Weight of polarimeter	3600 T	3000 T	380 T	400 T
Cost of raw material	$8M @ $1/lb	$2M @ $0.3/lb	$0.84 M	$0.27 M
Number of 2m-long sense wires	$1.3 \cdot 10^6$	$1.0 \cdot 10^6$	$1.4 \cdot 10^5$	$1.4 \cdot 10^5$
Number of electronics channels	$\sim 10^5$	$\sim 10^5$	$\sim 10^4$	$\sim 10^4$
Number of 30 T	120	100	13	13
EXPERIMENTAL AREAS				
Extent above beam line (assembled)	8 m	6.5 m	4.8 m	4.8 m
Extent below beam line (assembled)	8 m	6.5 m	4.8 m	4.8 m
Extent along beam line (assembled)	± 8 m	± 6.5 m	+ 9.5 m, -4.5 m	+ 8 m, - 4.5 m
Average floor loading	67 T/m^3	96 T/m^3	38 T/m^3	45 T/m^3
Access of beam line elements:				
at 1 m diameter	± 4 m		± 4 m	
at 0.5 m diameter	± 3 m		± 3 m	

FIGURE 1 - 4π DETECTOR

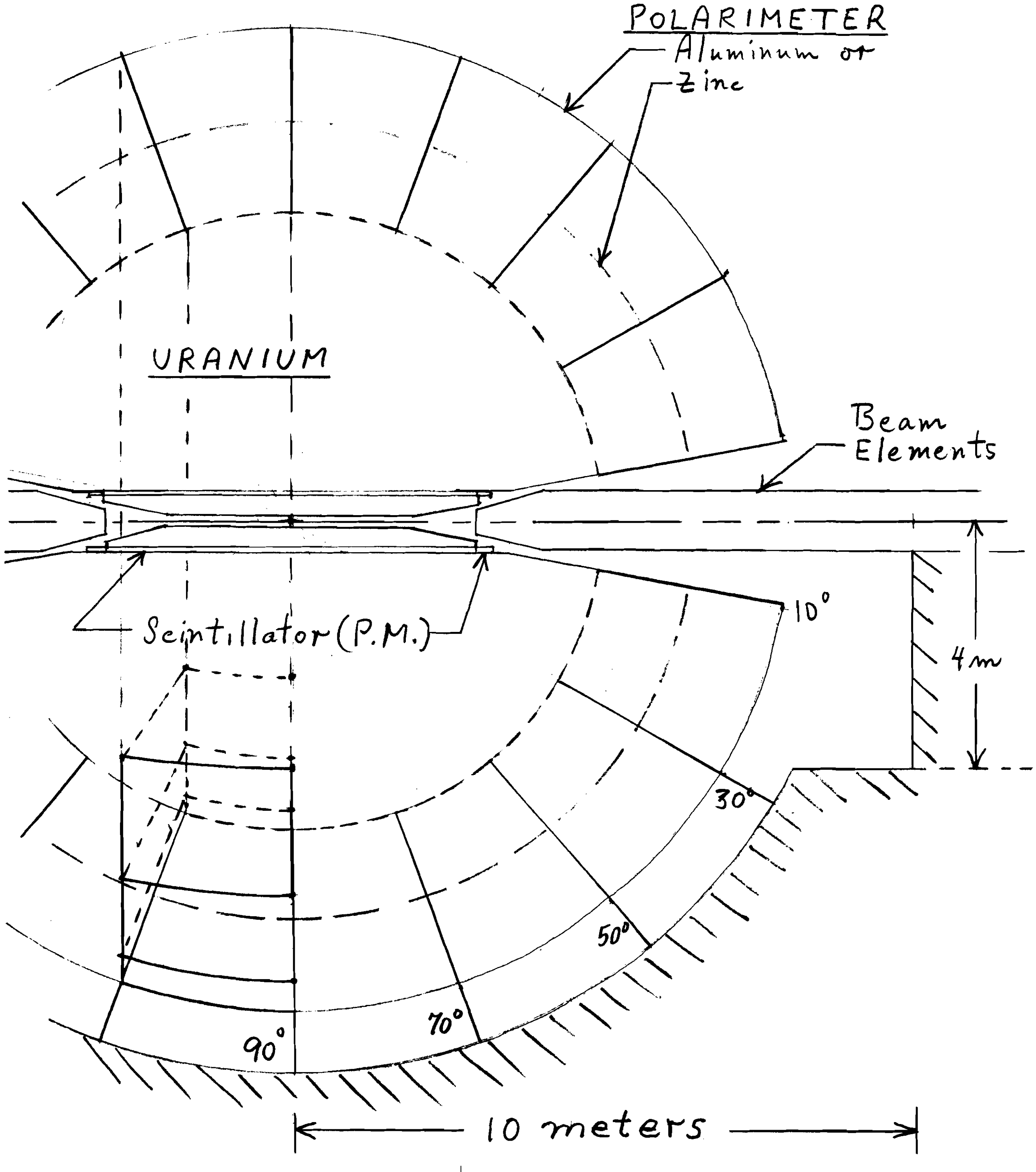

FIGURE 2 - SELECTIVE DETECTOR