Remarks on Muon $g-2$ Experiments and Possible CP Violation in $\pi \to \mu \to e$ Decay

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While it is generally asumed that $\pi \to \mu \to e$ decay conserves CP, it is possible for a small CP-violating asymmetry to arise from physics beyond the Standard Model. One possibility to search for such an effect is to compare the polarization of μ^+ from the decay of π^+ with that of μ^- from the decay of π^- [1]. Such a measurement is feasible using existing apparatus for the measurement of the anomalous magnetic moment $(g-2)$ of the muon and is sensitive to possible CP violation both in pion and in muon decay.

The muon anomalous magnetic moment has been measured to high precision in a series of experiments at CERN [2] and will soon be measured again at the Brookhaven AGS [3]. In these experiments, which use a storage ring to trap muons from π decay, electrons from μ decay are observed as the muon spin precesses in a magnetic field. The counting rate of electrons oscillates in time, with amplitude A proportional to the degree of polarization of the muons, according to [2]

$$N_e(E > E_t, t) = N_0 e^{-t/\tau}[1 - A(E_t)\cos 2\pi f_a t + \phi]\,. \quad (1)$$

Here $N_e(E > E_t, t)$ is the number of electrons observed (as a function of the time t) with energy E exceeding a threshold E_t, τ the muon lifetime, $A(E_t)$ the product of the muon and electron polarizations, f_a the precession frequency due to the muon anomalous magnetic moment $g-2$, and ϕ an arbitrary phase reflecting experimental details. A precise comparison of the oscillation amplitudes A_{π^+} and A_{π^-} for muons from π^+ and π^- decay can thus be extracted from the data.

In Fig. 15 of their paper "Final Report on the CERN Muon Storage Ring," Bailey *et al.* [4] give measurements of A_{π^+} and A_{π^-} for four threshold energies. While no error estimates are presented, they may be derived from the spread in the given values. The $A(E_t)$ values extracted from that figure are listed in Table 1. The resulting CP asymmetry is

$$A_{CP} \equiv \frac{A_{\pi^+} - A_{\pi^-}}{A_{\pi^+} + A_{\pi^-}}\,, \quad (2)$$

also shown in Table 1 for each threshold value. Since the four samples are not independent, the four results should not be averaged. As the threshold is decreased the polarization decreases, reducing sensitivity to A_{CP}. But we see that for thresholds 1 through 3 the reduction in polarization is approximately compensated by the increase in statistics. For each of those samples, the limit at 90% confidence is well approximated by

$$-0.01 < A_{CP} < 0.02\,, \quad (3)$$

which we take as the first available limit on CP violation in the $\pi \to \mu \to e$ decay chain.

Since the statistics vary widely for the four samples, with fewer than 10% of events satisfying threshold 1 but 80% satisfying threshold 4, yet the spread of values for each of the four samples is comparable, we may infer that the measurement is dominated by systematic rather than statistical uncertainty. The goal of the AGS experiment is to improve on the CERN results by a factor 20. With attention to the systematics of the measurement of A, the limit on the CP asymmetry may improve considerably.

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Note Added. After submission of this article, the author became aware of a previous paper by Field, Picasso, and Combley [5] presenting a similar analysis. While Field, Picasso, and Combley do not proceed as far in deriving a quantitative result, they present a more detailed discussion of the underlying theory.

TABLE I. Oscillation amplitude A (see text) as measured by Bailey *et al.* for four values of the electron energy threshold E_t (extracted from Fig. 15 of Ref. [4]) for π^+ and π^- decay, and CP asymmetry A_{CP} inferred therefrom.

	Th 1	Th 2	Th 3	Th 4
A_{π^+}	0.385 ± 0.003	0.309 ± 0.003	0.244 ± 0.003	0.160 ± 0.004
A_{π^-}	0.383 ± 0.005	0.303 ± 0.004	0.238 ± 0.001	0.163 ± 0.005
A_{CP}	0.002 ± 0.008	0.009 ± 0.009	0.011 ± 0.007	-0.007 ± 0.020

[1] J. F. Donoghue, X. G. He, and S. Pakvasa, in Phys. Rev. D **34**, 833 (1986), show that such a polarization asymmetry is *CP*-violating in the case of hyperon decay; a similar argument applies here.
[2] F. J. M. Farley and E. Picasso, in **Quantum electrodynamics**, T. Kinoshita (ed.), World Scientific, Singapore, 1990, p. 479, and references therein.
[3] B. L. Roberts *et al.*, "Status of the New Muon $(g-2)$ Experiment," to appear in Proc. 28th International Conference on High-Energy Physics (ICHEP 96), Warsaw, Poland, 25–31 July 1996.
[4] J. Bailey *et al.*, Nucl. Phys. **B150**, 1 (1979).
[5] J. H. Field, E. Picasso, and F. Combley, Sov. Phys. Usp. **22**(4), 199 (1979).