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Abstract

Positive muons from the Berkeley 184-inch synchrocyclotron were stopped in various materials and the asymmetry of positrons from their decay was determined by using a magnetic spectrometer method. The measurements of the polarization are in agreement with that predicted by the two-component neutrino theory.

The product of the muon beam polarization and of ξ, the parameter of the two-component neutrino theory, was measured as $0.89 \pm .09$.

PRELIMINARY RESULTS ON THE MOMENTUM DEPENDENCE OF THE ASYMMETRY IN β DECAY*

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The two-component theory for muon decay[1,2] gives a predicted normalized spectrum for beta decay of completely polarized muons at rest:

$$dN(x,\theta) = \left[2x^2\ 3-2x + \xi \cos\ \theta\ (1-2x)\right] dx\, d\Omega(4\pi)^{-1}, \tag{1}$$

where x is essentially (for all energies considered in this measurement) the total β energy in units of the maximum total β energy, Ω is the solid angle of β momentum, and θ is the angle between the β momentum and the muon spin direction. The sign of ξ is positive for positive muons, and we have

$$|\xi| = \frac{g_V g_A^* + g_V^* g_A}{|g_V|^2 + |g_A|^2} = \frac{0.87 \pm 0.12}{R}, \tag{2}$$

where g_A and g_V are the polar vector and axial vector coupling constants, and R is a measure of the degree of depolarization in the stopping material and of the polarization of the beam.[3,4] Measurements of the energy variation by the use of an integral range measurement and a precessing magnetic field have been reported by Weinrich[4] and by Pontecorvo et al.[5] Telegdi[6] and Cassels[7] have used total-absorption scintillation spectrometers. Low-energy bubble chamber data have also been obtained.[8]

To measure the asymmetric part of the spectrum, we have used the following technique. A polarized μ^+ beam produced by decay of pions made by the internal beam of the 184-in. cyclotron comes to rest in an absorber-counter sandwich. A magnetic field is produced by a Helmholtz coil giving either a depolarizing field of 0 ± 0.7 or 55 ± 10 gauss over the volume of the muon targets. The μ^+ are analyzed with a 180° $n = \frac{1}{2}$ magnetic spectrometer with a coincidence counting matrix to define several energy channels per field setting. The beam particles are put into anticoincidence with the events so that only particles produced in the targets and counters are detected. Figure 1 shows a side view of the equipment.

The spectrometer is set at an angle to the muon beam of $\sim 7^{\circ}$ for most of the data. A few points were run with an angle of 141°.[6]

The yield with the field on, Y(H), is essentially the unpolarized μ-decay spectrum, and the yield at zero field, Y(0), is the polarized spectrum. The asymmetry is given by

$$\Delta(x) = \frac{Y(H) - Y(0)}{Y(H)} = -\frac{1-2x}{3-2x} \cdot R\,\xi \cos\,\theta .$$

The data in Table I are the results for combinations of lithium, carbon, and bromoform targets. There are resolution effects that depend on the target thicknesses as well as the momentum band of the spectrometer. The counters defined a momentum band of $\Delta p/p = 7.6\,\%$, full width at half maximum. The most serious effects are caused by radiation straggling for points $x < 0.5$.

Background counts were taken by removing the muon-stopping targets. This method of background correction assumed that the background did not vary rapidly with energy, i.e., that it was the same for the three parts of each target. The background included also beam particles that were not rejected by the anticoincidence circuits and positrons originating from muons stopping in the targets. The latter contribute an asymmetric part to the background. However, owing to depolarization of the muons in the counter, the effect is small. In order to check the method, the pion-beam polarization was measured in the same manner as that of the muons. As expected, this measurement showed no significant asymmetry (i.e., $\Delta(x) = -0.059 \pm 0.113$ at $x = 0.453$ and $\Delta(x) = -0.029 \pm 0.100$ at $x = 0.866$).

If high-energy muons strike the spectrometer vacuum chamber wall, some inelastically scattered electrons are counted. These were found as distortions in the unpolarized spectrum at the low-energy point, and the first 80° sector of the vacuum chamber was lined with a baffle counter. The output of this counter was placed in anticoincidence with the events.

Figure 2 shows the data corrected for background, ionization loss, and radiation straggling in the targets and counters as well as for virtual photon processes and inner bremsstrahlung.[9] The other resolution effects do not contribute uncertainties outside the accuracies of the applied corrections. The solid line drawn in Fig. 2 represents the polarization expected on the basis of the two-component neutrino theory for a value of $R\xi = 0.89$. Inspection of Fig. 2 shows all measurements to be consistent with this curve except for two points. The low-energy one of these points, drawn with broken error flags, represents an asymmetry measurement when the anticoincidence counter lining the spectrometer vacuum chamber was not on its voltage plateau and hence not sufficiently sensitive for an efficient rejection of particles inelastically scattered on the vacuum chamber walls.

With these qualifications, we conclude from the data that (a) $R\xi = 0.89 \pm 0.09$ for our pion beam, this value being the error-weighted mean based on all data for $x > 0.5$ (the error is its external standard deviation; its internal standard deviation is $\pm$ 0.03); (b) the asymmetry changes rapidly in going from $x = 0.5$ to $x = 1.0$; and (c) the asymmetry for $x = 0.5$ is small, and our data are not sufficiently accurate to establish a sign reversal. Further investigations of the polarization at low energies with spectrometer and counter methods are planned.

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$$dN(x,\theta) \propto \left\{3(1-x) + 2\rho\left(\frac{4}{3}x - 1\right) \pm \xi \cos\theta \left[(1-x) + 2\delta\left(\frac{4}{3}x - 1\right)\right]\right\} x^2 dx d\Omega$$

in the usual notation; see, e.g., Ref. 9.

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10. Calculations of resolution effects are being made and will be reported in future discussions of this work.

Table I

Asymmetry data for various spectrometer settings[a]

Spectrometer momentum setting (x')	Target material	Average β energy (x)	Spread in x	Measured asymmetry $\left(\frac{\Delta}{\cos\theta}\right)$ (%)	Calculated radiation straggling correction (%)	Correction for virtual photon emission and inner bremsstrahlung (%)	Net asymmetry $\left(\frac{\Delta}{\cos\theta}\right)$ (%)
0.282	Li	0.326	± .028	28.2 ± 10.1	2.6	1.7	23.9 ± 10.1[b]
		0.381	± .028	-17.1 ± 19.0	4.8	1.5	-23.4 ± 19.0
		0.436	± .028	25.1 ± 13.4	7.7	1.2	16.2 ± 13.4
		0.326	± .028	-11.1 ± 12.5	2.6	1.7	-15.4 ± 12.5
		0.381	± .028	18.0 ± 10.7	4.8	1.5	11.7 ± 10.7
		0.436	± .028	14.8 ± 12.1	7.7	1.2	5.9 ± 12.1
0.282		0.348	± .049	9.3 ± 9.4	3.4	1.5	4.4 ± 9.4
		0.446	± .049	8.3 ± 8.3	13.7	1.2	- 6.6 ± 8.3
		0.545	± 0.49	19.3 ± 7.2	8.9	1.0	9.4 ± 7.2
0.659		0.718	± .049	36.6 ± 5.6	2.3	0.9	33.4 ± 5.6
		0.825	± .049	43.5 ± 4.2	2.7	0.6	40.2 ± 4.2
		0.924	± .049	55.0 ± 5.6	3.1	0.3	51.6 ± 5.6
0.722		0.788	± .049	45.0 ± 3.2	1.8	0.7	42.5 ± 3.2
		0.887	± .049	39.8 ± 3.9	2.6	0.4	36.8 ± 3.9
		0.985	± .049	80.5 ± 12.4	1.4	0.1	79.0 ± 12.4
0.722	$CHBr_3$	0.788	± .051	36.1 ± 8.6	5.0	0.7	30.4 ± 8.6
		0.887	± .051	66.7 ± 20.2	9.3	0.4	57.0 ± 20.2
0.361	C	0.453	± .075	2.5 ± 12.3	6.0	1.2	- 4.7 ± 12.3
0.505		0.597	± .075	- 8.2 ± 22.9	3.2	1.0	-12.4 ± 22.9
0.722		0.813	± .075	34.9 ± 8.9	3.3	0.7	30.9 ± 8.9
0.866		0.956	± .075	70.7 ± 11.5	2.1	0.6	68.0 ± 11.5
0.289		0.379	± .075	-15.4 ± 18.7	6.1	1.5	-23.0 ± 18.7
0.866		0.956	± .075	85.4 ± 17.7	2.1	0.3	83.0 ± 17.7

[a] The energies are in E/W, where W = 52.8 Mev.

[b] This point is drawn with broken error flags in Fig. 2 (see text).

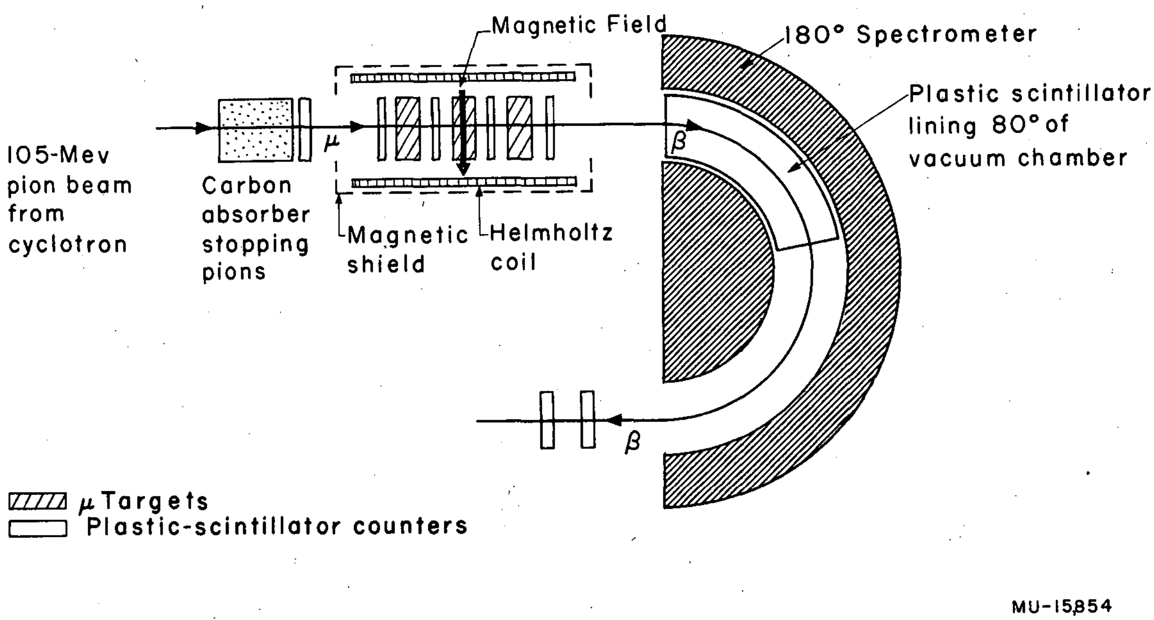

Fig. 1. Side view of the experimental apparatus. Pions stop in the absorber telescope, and muons stop in the target-counter sandwich. The β^+ particles leave the target and enter the spectrometer vacuum chamber at $\sim 7^0$ with respect to the beam direction for most measurements.

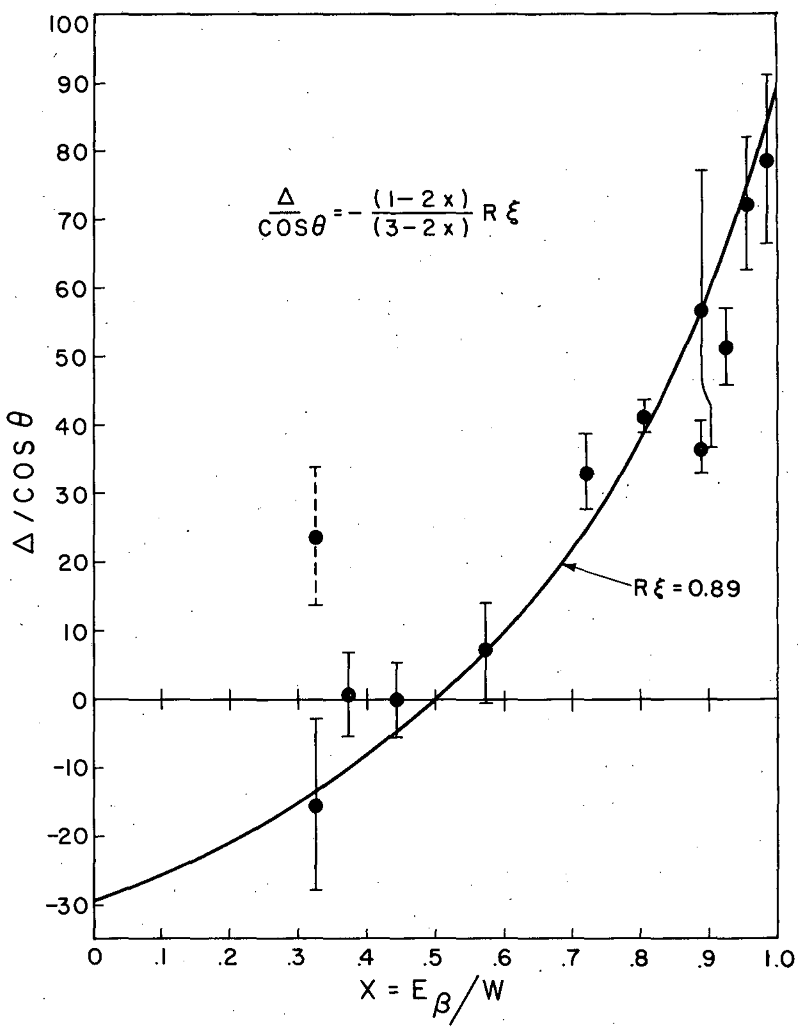

Fig. 2. Results for the asymmetry measurement for various targets. In order that these data might appear on a similar scale, each point was corrected for radiation straggling before being plotted. Shown is the simplest two-component theory for $R\xi = 0.89$.