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ANGULAR CORRELATION FOR LOW-ENERGY POSITRONS EMITTED IN $\pi^+ - \mu^+ - e^+$ DECAY

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The energies of 1099 positrons from $\pi^+ - \mu^+ - e^+$ decays in photographic emulsions and the angles ϑ between the muon and positron tracks have been measured. It is shown that in the energy regions ϵ = (0 to 0.3), (0.3 to 0.6) and (> 0.9), the value of $\overline{\cos\vartheta}$, which is proportional to the asymmetry parameter, is $+0.18 \pm 0.10$, 0.00 ± 0.04 and -0.09 ± 0.04, respectively. (ϵ is the positron energy as a fraction of its maximum energy.) 201 low-energy positrons ($\epsilon < 0.3$) were selected and measured out of a total of 8000 $\pi^+ - \mu^+ - e^+$ decays. For these positrons $\overline{\cos\vartheta} = +0.07 \pm 0.05$. A χ^2 test shows that the probability of positive asymmetry in the 0 to 0.3 energy range is close to 95%.

AFTER the discovery of parity nonconservation in weak interactions, the energy dependence of the angular correlation of positrons in $\pi^+ - \mu^+ - e^+$ decay was studied by several groups. In references 1 and 2 it was shown that the asymmetry parameter increases with positron energy. This is in qualitative agreement with the two-component neutrino theory.

The measurements of the Columbia group[3] and of Mukhin, Ozerov, and Pontecorvo,[4] which were performed by electronic methods, showed that above 20 or 25 Mev the energy dependence of asymmetry agrees with the two-component theory to within a statistical error of 5 to 10%. In this theory the average cosine of the angle ϑ between the spin direction of the muon and the direction of positron emission in $\mu^+ - e^+$ decay is related to the positron energy ϵ as follows:

$$\overline{\cos\vartheta} = \frac{\alpha\lambda}{3}\frac{2\varepsilon - 1}{3 - 2\varepsilon}. \qquad (1)$$

Here ϵ is the positron energy as a fraction of its maximum energy; λ is a parameter of the theory, defined as the ratio between the vector and axial-vector interaction constants; α is a coefficient that indicates the fraction of muons which preserve their polarization before decay. It follows from (1) that the asymmetry is large for ϵ close to 1, that it vanishes at the middle of the spectrum ($\overline{\cos\vartheta} = 0$ for $\epsilon = \frac{1}{2}$), and that its sign is reversed at low energies ($\epsilon < \frac{1}{2}$). Since it is known from experiment that at high energies $\overline{\cos\vartheta} < 0$ ($\lambda < 0$), we may expect for $\epsilon < \frac{1}{2}$ a positive value of $\overline{\cos\vartheta}$.

Asymmetry at low energies was the principal subject of the present investigation. NIKFI-P emulsions 400 μ thick were exposed to a π^+-meson beam in the synchrocyclotron of the Joint Institute for Nuclear Research. Positron tracks from $\pi^+ - \mu^+ - e^+$ decays in the emulsions were selected according to the criteria given in reference 2. As a result of these criteria we can assume that we were investigating correlation in a plane rather than in space. This increases $\overline{\cos\vartheta}$ appreciably since for correlation in a plane we have

$$\overline{\cos\vartheta} = \frac{\alpha\lambda}{2}\frac{2\varepsilon - 1}{3 - 2\varepsilon}. \qquad (2)$$

But due to the finite thickness of the emulsions the geometry of the measurements is somewhat different from plane geometry. Appropriate corrections are easily introduced. The values of $\overline{\cos\vartheta}$ must be 7 to 10% smaller than those obtained by means of (2).

Positron energies were determined from third differences by the usual multiple scattering method with a signal-to-noise ratio which was considerably larger than 2.5 on the average. The mean error of our energy measurements was close to 15%. The angle ϑ was measured to within 1 or 2 degrees.

In the first of two series of measurements we obtained the energies and angles ϑ for 1099 positron tracks which satisfied the selection criteria. These included the data for 580 tracks given in reference 2. The results are given in Table I, which shows the energy intervals of the positrons and the total numbers of tracks observed in these intervals. The fourth line of the table gives the experimental value of $\overline{\cos\vartheta}$ obtained by examin-

TABLE I

Angle ϑ		Interval of energy ε			
		0—0.3	0.3—0.6	0.6—0.9	0.9
0—180°	Number of particles n $\overline{\cos\vartheta} \pm 0.7/\sqrt{n}$	46 +0.18±0.10	333 0.00±0.04	440 —0.05±0.03	280 —0.09±0.04
0—60°; 120—180°	Number of particles n $\overline{\cos\vartheta} \pm 0.85/\sqrt{n}$	34 +0.30±0.15	231 0.00±0.06	300 —0.06±0.05	198 —0.16±0.06

ing all angles from 0 to 180°. The last line gives the values of $\overline{\cos\vartheta}$ for angles from 0 to 60° and from 120 to 180°. In the last case $\overline{\cos\vartheta}$ must be 1.4 times greater than the value obtained by using all angles. From these data we see that in agreement with theory the asymmetry parameter or $\overline{\cos\vartheta}$, which is proportional to it, is close to zero near $\epsilon = \frac{1}{2}$ ($0.3 < \epsilon < 0.6$). In the region 0 to 0.3, the sign of the asymmetry is reversed: $\overline{\cos\vartheta} = +0.18 \pm 0.10$ for all 46 particles and $\overline{\cos\vartheta} = +0.30 \pm 0.15$ for 34 of these 46 particles for which ϑ is between the limits 0 to 60° and 120 to 180°. The data thus indicates that at low energies $\overline{\cos\vartheta}$ is positive although the statistical reliability of this result is small.

The second set of measurements was obtained for the purpose of improving the statistical accuracy of the results at low energies. In a systematic scan of $\pi^+ - \mu^+ - e^+$ decays about 8000 tracks were selected according to the selection criteria; low-energy positron tracks were selected from among these. A preliminary scan of the 8000 tracks was performed to select those which in three lengths of 180μ (the field of view of an ocular micrometer with 40×15 magnification) give an average deviation that exceeds 5μ from a straight line. This preliminary scan yielded about 500 tracks on which multiple scattering was then measured by ordinary methods. Of these tracks, 155 had energies below $\epsilon = 0.3$; we thus increased the number of positrons in the initial spectral region from 46 to 201. The energies of the other particles selected in this way did not exceed $\epsilon = 0.8$.

Table II summarizes the asymmetry data from both sets of measurements at low energies. For $\epsilon = 0.3 - 0.6$ asymmetry is absent as previously, whereas for the energy interval $0 - 0.3$, where the number of particles is almost four times greater than in the first series of measurements, positive asymmetry is observed as previously.

In comparing the experimental and theoretical values of $\overline{\cos\vartheta}$ we must calculate $\overline{\cos\vartheta}$ in the energy interval of interest. The two-component theory easily yields a value of +0.11 for $\overline{\cos\vartheta}$ in the 0 to 0.3 energy interval. It must be taken into account that in emulsions the observed asymmetry is greatly reduced by depolarization; the asymmetry parameter in emulsion averaged over the entire spectrum is close to 0.1 (reference 5) instead of 0.33 for $\alpha = 1$. The corresponding value of $\overline{\cos\vartheta}$ will then be +0.03. Finally, it must be taken into account that the dispersion of scattering and bremsstrahlung measurements of electrons in emulsion transfers high-energy electrons to the low-energy region and thus reduces the positive value of $\overline{\cos\vartheta}$ in this region. The correction for dispersion obtained by suitable "smearing" of the theoretical spectra leads to a reduction of $\overline{\cos\vartheta}$ by 25 or 30% in the 0 to 0.3 energy interval. We must, moreover, consider the reduction of $\overline{\cos\vartheta}$ which results from radiative corrections to the spectrum.[6] In first approximation the two corrections are added and reduce the theoretical value of $\overline{\cos\vartheta}$ by about 40%. The final theoretical value of $\overline{\cos\vartheta}$ is ~ +0.02 for 0 to 180° and, correspondingly, ~ +0.03 for 0 to 60° and 120 to 180°. The measurements (Table II) are $\overline{\cos\vartheta} = +0.07 \pm 0.05$ $+0.13 \pm 0.07$, respectively.

TABLE II

Angle ϑ		Interval of energy ε	
		0—0.3	0.3—0.6
0—180°	Number of particles $\overline{\cos\vartheta}$	201 +0.07±0.05	499 +0.01±0.03
0—60°; 120—180°	Number of particles $\overline{\cos\vartheta}$	141 +0.13±0.07	337 +0.01±0.05

A χ^2 test of the result shows that the probability of positive asymmetry in the 0 to 0.3 energy region is close to 95%. The result obtained is considerably larger than the theoretical asymmetry.

The statistical accuracy of the measurements will have to be considerably improved, however, to provide a quantitative test of the theory at low energies.

Measurements similar to ours have recently been performed by Pershin and others using a propane bubble chamber. The results obtained by these workers are close to ours.[7]

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