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[4] It should be noted that in the absence of an asymmetry, nonzero β does not necessarily imply a C-invariance violation, since the p- and f-wave interference term would also give rise to a $\cos^2\theta$ dependence in the angular distribution.

Measurement of the Charge Asymmetry in the Decay $\eta \to \pi^+\pi^-\pi^0$ †

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We have measured the charge asymmetry in the decay $\eta \to \pi^+\pi^-\pi^0$. η's were produced in the reaction $\pi^-p \to \eta n$ at 730 and 810 MeV/c incident pion momentum. We obtain an asymmetry of -0.0005 ± 0.0022 for 220 659 events. We see no evidence for C-invariance violation in this decay.

We have carried out an experiment at the Princeton-Pennsylvania accelerator to determine if there exists any difference between the π^+ and π^- energy spectra in the decay $\eta \to \pi^+\pi^-\pi^0$.[1] The preceding Letter[2] describes the experimental technique and the methods of analysis employed in the experiment. In this Letter, we discuss our data for the three-pion decay, together with our understanding of the systematic biases which could influence the result.

A number of significant improvements were incorporated into this experiment to reduce biases which could have been present in a previous measurement of the asymmetry.[3] The principal improvements were as follows:

(1) The greatly increased size of the sonic spark chambers, resulting in greater geometrical efficiency, made it feasible to trigger the chambers with a one-pion trigger. This substantially reduced possible trigger biases in the sample and increased the efficiency for detection of low energy pions.

(2) Each of the two spark-chamber arrays employed six gaps. This made the system much less sensitive to gap efficiency ($\geq 97\%$ for each gap), and facilitated the rejection of scattered events.

(3) The high-voltage and clearing fields were oppositely directed in adjacent gaps. This gave rise to an oppositely directed $\vec{E} \times \vec{B}$ for even and odd gaps, and made it possible to measure the drift and correct for it. This is discussed further below.

(4) An additional neutron counter 5 in. in diameter and 11 in. long of solid plastic scintillator was located at the center of the neutron counter array, along the beam line and 30 ft from the hydrogen target. This counter detected axially symmetric events from the reaction $\pi^-p \to \pi^+\pi^-n$. The total transverse momentum of the π^+ and π^- should center at zero for these events. Study of the events obtained from this counter provided a quantitative determination of the measurement bias level of the experiment.

(5) The hydrogen-target assembly was designed in such a way that no supports lay in the path of any particle capable of causing a trigger. This reduced the contribution to the biases of charge-asymmetric scattering in intervening material.

From 17 000 000 spark-chamber triggers, we obtained approximately 5 500 000 reconstructable events. Of these, 85% were from the background reaction $\pi^-p \to \pi^+\pi^-n$. The background reaction was removed by calculating the missing mass M_y^2 of the undetected neutrals, where y is defined by $\pi^-p \to \pi^+\pi^-y$. Discarding events with $M_y^2 < 1.15 M_n^2$, where M_n is the neutron mass, removes most of the background reaction and no 3π events. Further cuts were made on the χ^2 from the track reconstruction, and on the event vertex position, requiring that it lay within the hydrogen target volume. There remained 413 000 events, which included the reactions $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^+\pi^-\gamma$.

The separation of these two reactions was made by considering the x particle in the reaction $\pi^-p \to \pi^+\pi^-nx$. By eliminating events for which the energy of x was less than 115 MeV, we eliminated a large fraction of $\eta \to \pi^+\pi^-\gamma$ events and no $\eta \to \pi^+\pi^-\pi^0$ events. Finally, we eliminated those events for which $M_x^2 < 0.5 M_\pi^2$. After these cuts,

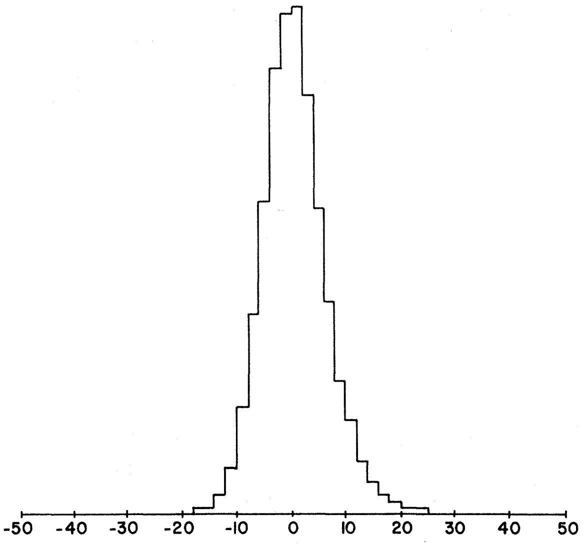

FIG. 1. Neutron time-of-flight spectrum for pulse heights above 100. One channel corresponds to 0.2048 nsec.

239 319 events remained.

The time-of-flight distribution of these events is shown in Fig. 1. The small amount of nonresonant 3π background still present in this sample was removed by performing a linear background subtraction. We then calculated the asymmetry, defined as

$$A = (N_+ - N_-)/(N_+ + N_-),$$

where N_+ is the number of events for which π^+ has greater energy than π^-, and N_- is the number of events for which the π^- has the greater energy in the η rest system. For the 220 659 events remaining after the background subtraction, we find $A = -0.0005 \pm 0.0022$. The asymmetry plotted as a function of the Dalitz coordinates x and y is shown in Figs. 2(a) and 2(b).

We have also calculated the sextant asymmetry, defined as

$$A_s = \frac{N(\mathrm{I}) + N(\mathrm{III}) + N(\mathrm{V}) - N(\mathrm{II}) - N(\mathrm{IV}) - N(\mathrm{VI})}{N(\mathrm{I}) + N(\mathrm{II}) + N(\mathrm{III}) + N(\mathrm{IV}) + N(\mathrm{V}) + N(\mathrm{VI})},$$

where the Roman numerals refer to sextants of the Dalitz plot [see Fig. 2(c)]. A_s is sensitive to an $I = 0$ C-invariance-violating final state.[4] We obtain $A_s = 0.0010 \pm 0.0022$.

The quadrant asymmetry A_q, defined in terms of Dalitz-plot quadrants in a manner analogous to A_s, is sensitive to an $I = 2$ final state. We find $A_q = -0.0007 \pm 0.0022$. Finally we have fitted the right-left asymmetry, evaluated in rectangular bins over the Dalitz plot, assuming an expansion of the matrix element of the form

$$|M(x,y)|^2 = 1 + ax + by + cxy + \cdots,$$

where $x = \sqrt{3}(T_{\pi^+} - T_{\pi^-})/Q$, $y = 3T_{\pi^0}/Q - 1$, and $Q = T_{\pi^+} + T_{\pi^-} + T_{\pi^0}$. The fit is sensitive to the coefficients a and c. Using a value for b of 0.54, obtained by a separate analysis,[5] we find that $a = 0.002 \pm 0.003$ and $c = -0.002 \pm 0.004$. $\chi^2 = 48$ for 63 degrees of freedom. This result is not sensitive to the value of b.

The errors quoted with the right-left asymmetry and the sextant and quadrant asymmetries are purely statistical. In order to get an estimate of possible biases arising from the procedures of the analysis, we have varied the cuts involved in the event selection and examined the effect on the asymmetry. Varying the M_y^2 cut and the E_x cut has no effect. A 10% increase in the cuts on χ^2 from the track fitting results in an asymmetry of 0.0003 ± 0.0022. A 10% decrease in the vertex cut gives an asymmetry of 0.0008 ± 0.0027. Varying the M_x^2 cut to $0.4M_{\pi^0}^2$ and $0.6M_{\pi^0}^2$ produces asymmetries of -0.0007 ± 0.0022 and -0.0013 ± 0.0022, respectively. Asymmetries obtained with opposite polarities of the magnetic field were -0.002 and 0.001.

The remaining source of bias is the $\vec{E} \times \vec{B}$ drift

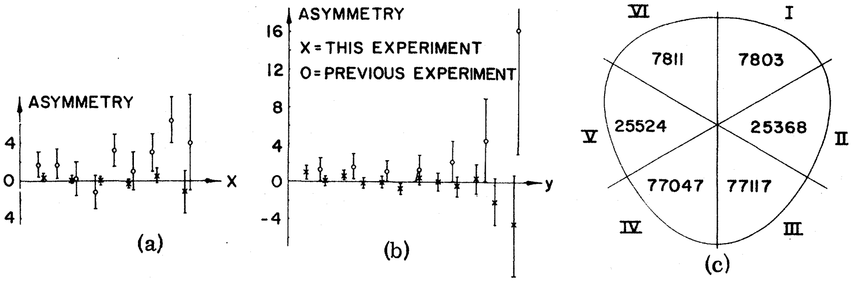

FIG. 2. (a) Charge asymmetry in the decay $\eta \to \pi^+\pi^-\pi^0$, plotted as a function of the Dalitz coordinate x. The previous experiment is that of Ref. 3. (b) Asymmetry versus Dalitz coordinate y. (c) Distribution of the events over the sextants of the Dalitz plot.

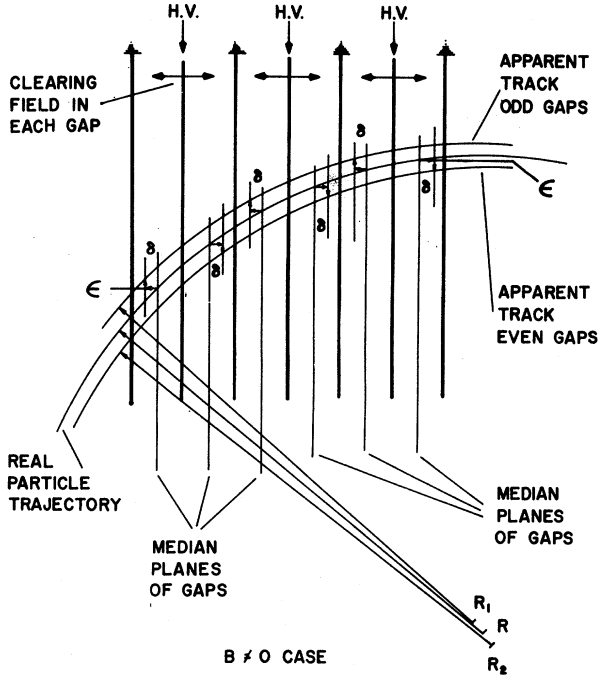

FIG. 3. Effect of the $\vec{E}\times\vec{B}$ drift. $\vec{B}$ is directed into the plane of the paper in this illustration.

in the spark chambers. During the time between the passage of the pions through the chambers and the formation of the spark at the position of the trajectory, the ionization drifts under the influence of the gap clearing field and high-voltage pulse, and the magnetic field of the analyzing magnet. Since the electric fields are oppositely directed in adjacent gaps, a separation of the track in the even and odd gaps results. This is shown schematically in Fig. 3. From this separation, the horizontal and vertical components of the drift, δ and ϵ, can be calculated assuming they are the same in magnitude in all gaps. Average $\bar{\delta}$ and $\bar{\epsilon}$ were obtained in this way for all runs and were on the order of 1 mm in magnitude.

Small variations in δ and ϵ arise from the very small differences in gap width and from the variation of the magnetic field along the trajectory. To account for these effects, we introduced a correction to ϵ of the form

$$\epsilon_i = \bar{\epsilon}_i(1 - \alpha \Delta B_z/\bar{B}_z)(1 - C_i)$$

for each gap, and a similar expression for δ. $\bar{B}_z$ is the average value of the magnetic field strength (9 kG), and ΔB_z is the difference between the field strength at the spark location and the average field. We restrict the discussion to ϵ since δ does not affect the asymmetry.

The parameters α and C_i were determined by fits to twelve-spark cosmic-ray events. We find α to be 0.6 ± 0.1, and the C_i, different for each gap, are typically 0.040 ± 0.005. Calculating the asymmetry for different values of these parameters, we obtain the following results:

α	C_i	A
0.4	Unchanged	-0.0017
0.8	Unchanged	0.0014
0.6	0	-0.0014

The systematic errors resulting from uncertainties in our knowledge of δ and ϵ are less than 0.2%.

This conclusion is confirmed by data from the neutron counter located on the beam line. We have calculated the total transverse momentum of the pions from the reaction $\pi^-p \to \pi^+\pi^-n$ for 3432 events whose neutrons entered this counter. Using the fitted values for α and C_i, we obtain -0.02 ± 0.29 MeV/c. If α is varied from 0.2 to 0.8, the transverse momentum varies from -0.20 to 0.41 MeV/c. We take this as independent evidence that α lies within the limits we have stated, and consequently, that systematic errors from all the sources we have considered are no greater than 0.2%.

The support of the Princeton-Pennsylvania accelerator staff during our run, which coincided with the phasing out of the accelerator, was unflagging. We especially thank Professor Milton White, Professor Walter Wales, and Professor Halsey Allen. We also thank Kenneth Gray of Brookhaven National Laboratory for his invaluable assistance in setting up the apparatus; the members of the technical staff at Nevis Laboratories, especially C. Y. Au, H. Cunitz, M. Rollberg, and F. W. Sippach for their contributions to the design of the experiment; and A. Wijangco and I. Gaines for their assistance during the data taking.

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