made with an additional 5.183 g of material gave an asymmetry difference of $(-5.255 \pm 1.73) \times 10^{-3}$. Assuming the mass asymmetry varies linearly with the additional mass, the correction for the 293 mg of apparatus is $(-0.297 \pm 0.10) \times 10^{-3}$, leading to a corrected lepton charge asymmetry of $A_L = (+3.33 \pm 0.48) \times 10^{-3}$.

Calculations made with different values of the branching ratio for the $K$ decay to muons and to electrons and for different form factors for the muon decays displayed no effect on $A_L$ beyond the statistical significance of the calculations of about $\pm 0.10 \times 10^{-3}$. Rather subjective tests were also made concerning the effect of small distortions of the data on the results; these were also negative to the same degree of accuracy.

The result for the lepton asymmetry is in agreement with the value of $(3.42 \pm 0.06) \times 10^{-3}$ for the asymmetry derived[1] on the basis that a $CP$-invariance violation in the $K_L^0$ decays can be defined completely with the one parameter which describes the rate of transitions from $K_2^0$ to $K_1^0$ states, a conclusion which follows from the superweak model of $CP$-invariance violation. Here we accept the new value of $9.0 \times 10^{-11}$ for the $K_S^0$ mean life and use $|\eta| = 2.35 \times 10^{-3}$. Taking the $\mu/e$ branching ratio in $K_L^0$ decays as 0.65, the contribution of the muon decay mode to the measured asymmetry is 43%. If the electron asymmetry is taken as the superweak value, which is consistent with the measurements of this asymmetry, the muon asymmetry measured in the experiment is $(3.21 \pm 1.15) \times 10^{-3}$ which does not agree with certain other measurements.[2]

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[1]Previous work is reviewed by C. Rubbia, in *Proceedings of the Sixteenth International Conference on High Energy Physics, The University of Chicago and National Accelerator Laboratory, 1972,* edited by J. D. Jackson and A. Roberts (National Accelerator Laboratory, Batavia, Ill., 1973).

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# $K_{e3}^0$ Charge Asymmetry*

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We have measured the charge asymmetry in $K_{e3}^0$ decay and searched for variations in the asymmetry across the Dalitz plot. Ascribing any variation to a $T$-noninvariant form factor, we find $\mathrm{Im}\lambda = 0.001 \pm 0.025$. The integrated asymmetry is $(N^+ - N^-)/(N^+ + N^-) = (3.18 \pm 0.38) \times 10^{-3}$.

With $CPT$ invariance the asymmetry in the distribution of charges in three-body electronic decay of the $K_L^0$ is

$$\delta = \frac{N_e^+ - N_e^-}{N_e^+ + N_e^-} = 2\,\mathrm{Re}\,\epsilon \frac{1 - |x|^2}{|1 - x|^2} + \delta_{FS}(T_\pi, T_e),$$

where $N_e^+$ and $N_e^-$ are the numbers of electrons of indicated charge, $\epsilon$ is the customary $CP$-nonconservation parameter associated with the mass-decay matrix,[1] $x$ is the ratio of $\Delta S = -\Delta Q$ to $\Delta S = \Delta Q$ amplitudes, and $\delta_{FS}(T_\pi, T_e)$ is a term originating from interference between time-reversal-noninvariant amplitudes and final-state (electromagnetic) interactions between $\pi$ and $e$ at c.m. energies $T_\pi$ and $T_e$. As demonstrated by Okun'[2] and Ryan,[3] $\delta_{FS}$ can be expected to be no more than $\sim 10^{-3}\alpha \simeq 10^{-5}$ if the experimental measurement of $\delta$ integrates uniformly over the Dalitz plot. Notwithstanding the small size of this integrated effect, final-state interactions do produce a modulation of the asymmetry across the Dalitz plot of $O(\alpha(T\text{-noninvariant amplitudes}))$.[4,5] Since the experimental error in the determination of $\delta$ is approaching $10^{-2}\alpha$, neglect of $\delta_{FS}$ in the analysis of $K_{l3}$ asymmetry data is perhaps no longer justified. Furthermore, as emphasized by Bell and Zia,[4] the $T$-noninvariant form-factor parameter, $\mathrm{Im}\lambda$, which is not otherwise uniquely identifiable, reveals itself in a variation of the asymmetry across the Dalitz plot.

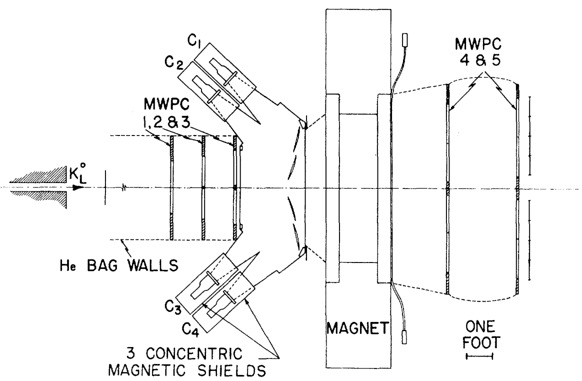


FIG. 1. Plan view of the spectrometer arrangement in the neutral beam. "MWPC": multiwire proportional counters.

The measurement was performed at the Brookhaven National Laboratory alternating-gradient synchrotron in a neutral beam produced at 20° by 29-GeV/$c$ protons incident on a BeO target. The configuration of the apparatus was similar to that used in previous experiments.[6] A plan view of the experimental gear is shown in Fig. 1. The main change in the apparatus for the present experiment was the replacement of wire spark chambers with multiwire proportional chambers to decrease dead time and reduce the frequency of accidental tracks.[7] Other especially relevant features follow: The signal-wire spacing in the multiwire proportional chambers was $\frac{1}{8}$ in. Relatively coarse spatial resolution was adequate. Correspondingly, to conserve electronics, the signal wires were tied together in groups of six to nine for readout. Horizontal information alone was recorded. The spectrometer magnet was set at $p_\perp = 116$ MeV/$c$. The Cherenkov counters for electron identification used $CO_2$ at atmospheric pressure as the radiator. These counters were placed between the decay volume and the magnet so that, with the reflective optics, the phototubes were naturally positioned away from the magnet. Furthermore, the axes of the phototubes were placed in the median horizontal plane of the magnet to minimize axial magnetic field components, which are difficult to shield against.

The most precise previous measurements of the $K_{e3}$ charge asymmetry[8-10] included systematic corrections almost as large as the measured value. These corrections were due largely to the difference in absorption of $\pi^+$ and $\pi^-$ mesons in the mass of the detector. To reduce these differential absorption effects, careful attention was given to averaging the isospin content of the mass in the detector to zero. In addition, the mass was reduced to the greatest extent possible. From the average decay point it was 0.637 g/cm$^2$. To correct experimentally for absorption effects, the mass of the detector was increased to 2.49 and 4.78 g/cm$^2$, by replacing He with air and adding thicknesses of carbon, Plexiglas, and Aclar.[11] The spatial distribution of the additional mass and its isotopic constitution followed the minimum-mass configuration as closely as possible. The largest departure from spatial scaling came in the Cherenkov counter where the 0.150 g/cm$^2$ of $CO_2$ was scaled upward by placing carbon before and after the 75-cm-long counter.

In the course of the experiment, $\sim 10^8$ events of all mass configurations were recorded in 500 magnetic field reversals. After momentum, fiducial volume, and trajectory cuts, and elimination of events involving anticoincidence-counter signatures, approximately $4\times 10^7$ events acquired in the minimum-mass configuration remained. These events were divided into two classes: (1) where the two charged particles diverged from each other in the magnetic field of the spectrometer, and (2) where they converged. The gross asymmetry from combining both classes was $\delta = (3.45 \pm 0.23)\times 10^{-3}$. However, the measured asymmetry for these two classes of events differed by $\Delta\delta = (1.64 \pm 0.53)\times 10^{-3}$. A detailed examination of the data revealed that the difference in the result for the two classes was due to a small change in the relative sensitivity of the Cherenkov counters on magnetic field reversal.[12] Such a change required the presence of an axial magnetic field component at the position of the Cherenkov counter phototubes, probably caused by small departures from complete magnetic symmetry about the median horizontal plane. With significant loss of statistical accuracy this problem was eliminated by dividing the data into small elements of "Cherenkov phase space," i.e., elements of electron-trajectory position and angle, in the region where the electron crossed the Cherenkov counter.[13] In each of these elements, asymmetries of diverging and converging events were computed separately, and the two asymmetries averaged with equal weight. The final result is the weighted mean of the results from all the elements. The consistency of the data is good, $\chi^2 = 62$ for 79 degrees of freedom. The intrinsic apparatus asymmetry, as measured by the number of electrons on the right and left, is

$$(N_R - N_L)/(N_R + N_L) = (4.32 \pm 0.32)\times 10^{-3}.$$

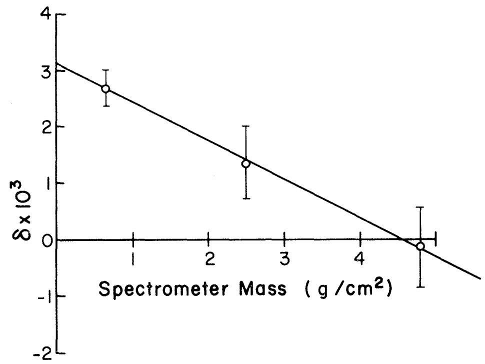


FIG. 2. The asymmetry $\delta = (N^+ - N^-)/(N^+ + N^-)$ as a function of the detector mass.

The events obtained in the minimum-mass configuration were transformed to the c.m. system using for the momentum of the $K$ the visible momentum along the beam axis. The resulting Dalitz plot was divided into eleven elements, a number consistent with the measurement resolution and the accuracy intrinsic to the transformation to the c.m., as confirmed by Monte Carlo calculations. The asymmetries in these eleven elements are all highly consistent with the mean, $\chi^2 = 4.2$ for 10 degrees of freedom. Therefore, in the absence of any evidence for final-state interaction effects, we are justified in combining the data from all regions of the Dalitz plot without regard to the variation in detector sensitivity across the plot.

Figure 2 shows the measured asymmetry as a function of mass. The assumption of a linear mass effect is clearly justified and the data are accordingly extrapolated to zero mass. The result is $\delta = (3.06 \pm 0.38) \times 10^{-3}$ with a slope of $(0.70 \pm 0.18) \times 10^{-3}$ g$^{-1}$. This measured slope is consistent with the calculated slope of $0.55 \times 10^{-3}$ g$^{-1}$ obtained from knowledge of $\pi^+$- and $\pi^-$-nucleon and positron-annihilation cross sections. Corrections to the asymmetry for background and anti-counter inefficiencies total $(0.12 \pm 0.05) \times 10^{-3}$. The result is

$$\delta = (3.18 \pm 0.38) \times 10^{-3}.$$

Recent experiments suggest that the older values of $|\eta_{+-}|$ were low by ~14%.[14,15] Assuming $x = 0$ and the $CP$ noninvariance to be in the mass matrix ($\epsilon' = 0$), the predicted $\delta$'s from the old and new values of $|\eta_{+-}|$ are, respectively, $\delta = 2.86 \times 10^{-3}$ and $\delta = 3.32 \times 10^{-3}$.

Returning to the question of an asymmetry variation across the Dalitz plot, we have fitted the data with the model of Bell and Zia[4] in which the $T$ noninvariance is incorporated in an imaginary component of the form-factor parameter $\lambda$. We find $\mathrm{Im}\lambda = 0.001 \pm 0.025$. It is interesting that the relatively coarse Dalitz-plot information available in this experiment leads to a limit on $\mathrm{Im}\lambda$ which is much smaller than could have been detected as a quadratic effect in the experiments specifically devoted to $\lambda$.[16]

Alternatively, Brodine[5] has shown that an imaginary $x$ coupled with differences in the form factors for the $\Delta S = \Delta Q$ and $\Delta S = -\Delta Q$ hadronic currents leads to variations across the Dalitz plot similar to those produced by $\mathrm{Im}\lambda$. However, if we assume that the form-factor difference approximates $\lambda$ itself (0.025), and use the present upper limit on $|\mathrm{Im}x|$ (0.04), we find that the possible contribution to the asymmetry from $\Delta S = -\Delta Q$ $T$-noninvariant effects is equivalent to only 4% of our error in measuring $\mathrm{Im}\lambda$. Therefore, any asymmetry variation across the Dalitz plot observed with the sensitivity of this experiment would be more naturally ascribed to nonzero $\mathrm{Im}\lambda$.

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[6]R. K. Carnegie *et al.*, Phys. Rev. D 6, 2335 (1972).

[7]Substantial experimental detail and a preliminary analysis of the data is contained in R. C. Webb, Ph.D. thesis, Princeton University Technical Report No. COO-3072-13, 1972 (unpublished).

[8]S. Bennett *et al.*, Phys. Rev. Lett. 19, 993 (1967).

[9]J. Marx *et al.*, Phys. Lett. 32B, 219 (1970).

[10]V. A. Ashford *et al.*, Phys. Lett. 38B, 47 (1972).

[11]Fluorocarbon film (Allied Chemical Co. trademark) used in the multiwire proportional counter windows.

[12]Because of the normalization procedure a previous experiment utilizing charge asymmetries (Ref. 6) would not have been sensitive to this systematic effect.

[13]This procedure was made possible by the fact that electron trajectories within the Cherenkov counter were, to a first approximation, independent of the sign of the electron charge. The relative numbers of in- and out-bending events varied widely over the aperture of the Cherenkov counters. It was for this reason that the averaging was done over relatively small elements of "Cherenkov phase space."

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# Measurement of $p+p \to p+X$ between 50 and 400 GeV*

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We present measurements of the invariant cross section for the inclusive reaction $p+p \to p+X$ in the region $0.14<|t|<0.38$ GeV$^2$, $100<s<750$ GeV$^2$, and $0.80<x<0.93$.

In a recent Letter[1] we presented the first results of our study of the reaction

$$p+p \to p+X \quad (1+2\to 3+X) \tag{1}$$

using the internal $H_2$ jet target at the National Accelerator Laboratory (NAL). The results of Ref. 1 confirmed the phenomenon of diffractive excitation of the target (beam) particle into high masses, first observed at the CERN intersecting storage rings (ISR).[2] Furthermore, by studying the energy dependence of Reaction (1) for $40 \le P_1 \le 260$ GeV we established the presence of a large energy-independent component which we identified with a nonvanishing triple Pomeron coupling[3] for values of the momentum transfer $t=-0.33$ and $-0.45$ GeV$^2$. The results presented here extend our previous measurements to lower $t$ values ($-0.14$ GeV$^2$) and higher energies ($P_1=400$ GeV). The experimental setup is similar to the earlier experiment which is described in Ref. 1. The main modification consisted in replacing the Al absorbers which determined two momentum intervals for the recoil nucleon by a total-absorption scintillation counter. The energy and velocity of the recoil particles are measured by pulse height in the 20-cm-long absorption counter and time of flight over 186 cm. The resulting scatter plot of pulse height versus time of flight has two distinct bands corresponding to recoil protons and pions. The pulse-height information is used only to remove pions. The remaining events in each 0.7-nsec-wide time-of-flight bin are summed over pulse height and represent the number of protons over the corresponding four-momentum transfer interval. This procedure avoids the loss of proton events through interactions in the absorption counter which lead to inferior pulse heights. We applied a small $t$-dependent correction to the raw data in order to take into account the loss of events through multiple Coulomb scattering in the material in front of the total absorption counter. This effect was calculated by a Monte Carlo program and checked empirically by varying the amount of material between the target and absorption counter. The correction amounted to an 8% increase at our lowest $|t|$ value and was negligible for $|t|>0.28$ GeV$^2$.

Our results are expressed in terms of the invariant cross section $s d^2\sigma/dt\,dM^2$ which is a function of the three Lorentz-invariant quantities[1]

$$s \simeq 2mE_1, \tag{2a}$$

$$t=-2m(E_3-m), \tag{2b}$$

$$x=1-M_X^2/s \simeq (E_3-P_3\cos\theta_3)/m, \tag{2c}$$

where $s$, $t$, and $M_X^2$ are the squares of the center-of-mass energy, the four-momentum transfer, and the missing mass, respectively. The angle between incident and recoil proton is $\theta_3$