have a component arising from SU(3)-invariance violating interactions.

[18]The possibility that the C-nonconserving interactions conserve isospin has been considered by Prentki and Veltman (reference 5), and by T. D. Lee, "Classification of All C-Noninvariant Electromagnetic Interactions and the Possible Existence of a Charged, but $C=1$, Particle" (to be published).

POLARIZATION IN $\pi^- + p$ ELASTIC SCATTERING AT 2.08 GeV/c†

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As part of a program to study the high energy pion-nucleon interaction, we have measured the differential cross section (DCS) and polarization (P) in $\pi^- + p$ elastic scattering at an incident pion-laboratory momentum of 2.08 GeV/c. This momentum is particularly interesting as it is near the center of a 2-mb peak observed in the π^-p total cross section measured as a function of energy.[1,2] This peak could correspond to a resonance in the isospin-$\frac{1}{2}$ system with a mass of 2190 MeV/c^2.[2,3] In addition, measurements by Damouth, Jones, and Perl of the DCS at 2.01 GeV/c exhibit, as well as the forward diffraction peak, considerable scattering at larger angles, including a prominent peak at $\cos\theta_\pi(\text{c.m.}) = 0.2$ or $-t = 1.2$ (GeV/c)^2, where t is the square of the four-momentum transfer.[4] These authors proposed that this second maximum is related to the peak in the total cross section at 2.08 GeV/c.

Other ideas have been put forward to explain the scattering at larger angles—for instance, the presence of a strongly interacting nucleon core,[5] or the formation of a compound nucleon which decays in a statistical way to many channels, including the elastic channel.[5,6] The second maximum has been interpreted by Simmons[7] as a second diffraction peak resulting from a most elementary optical model which considers only uniform absorption. Perl and Corey[8] obtained a much better fit to the data of reference 4, again using a purely absorptive model, but allowing the absorption to vary with the angular momentum l. Even this fit does not reproduce the details of the angular distribution. This indicates that a purely absorptive model is not sufficient. It is not at all certain that the second maximum is related to the peak observed in the π^-p total cross section, since similar (although not so prominent) second maxima are observed in π^+p and K^-p scattering.[4,9]

It has been pointed out that all these discussions have completely neglected spin effects,[10] and in fact our polarization measurements show that the usual assumption of a single scalar amplitude to describe elastic scattering in this energy region is not valid.

The experiment was carried out at the Argonne zero gradient synchrotron with a polarized proton target. Negative pions produced at zero deg from a 10-cm-long Cu target were directed to the apparatus shown in Fig. 1 by a standard beam transport system. At the polarized target the pion intensity was typically 1 to 2 $\times 10^5$ pions per pulse over an area 1.6 cm vertically $\times$ 2.5 cm horizontally and with $\Delta p/p = \pm 1.7\%$. Electrons were electronically removed by a gas Čerenkov counter,[11] and the beam was monitored and defined by the counters 1, 2, and $\bar{3}$.

The polarized target is similar to others already described[12,13] and uses rectangular crystals of $(0.99\ \text{La} + 0.01\ \text{Nd})_2\text{Mg}_3(\text{NO}_3)_{12}\cdot 24\ \text{H}_2\text{O}$ stacked to give a scatterer 1.9 cm vertically $\times$ 2.9 cm horizontally $\times$ 3.8 cm long. The crystals are at the center of a magnetic field of 18.67 kG.

Figure 1 also shows schematically the arrangement of counters and electronic logic for the detection of elastic scattering from the free protons of the target crystals. Scatterings in the vertical plane were measured with an acceptance in azimuthal angle of about ±10 deg.

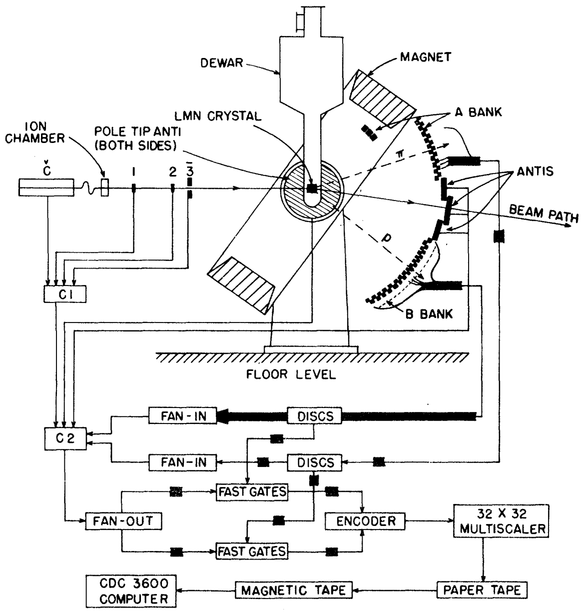

FIG. 1. Schematic view of the apparatus. $\check{C}$ is the Čerenkov counter; $C1$ and $C2$ are coincidence circuits. The heavy lines indicate a cable for each counter of the A or B bank.

Elastic π^-p scattering events were separated from other events (inelastic π^-p scattering and reactions involving complex nuclei of the target material) by means of the angular correlation between the scattered pion and the recoil proton. Each counter in the A bank defines a pion-scattering angle. For each A counter, the distribution of coincidences with counters in the B bank is measured. Then, at the position in the B bank corresponding to elastic π^-p scattering, a peak should appear. Typical results are shown in Fig. 2(a). This figure also illustrates the data reduction and background subtraction procedures. First, a Monte-Carlo program is used to calculate the expected distributions of elastic-scattering events. A typical output from the program is shown in Fig. 2(c). Events outside the expected elastic region (dashed lines) are assumed to be background and are fitted by the computer yielding the dotted line shown in Fig. 2(a). The dotted line is also assumed to represent the background under the peaks. This assumption has been investigated extensively by using protons from the Chicago cyclotron and by comparing the background fits with data obtained from nonhydrogenous targets. Figure 2(b) shows the data of Fig. 2(a) with the fitted background subtracted and is in good agreement with the predictions of the Monte-Carlo program. The program takes into account the distribution of the beam in phase space and the effects due to the magnetic field, multiple scattering, and energy loss. It also calculates the effective

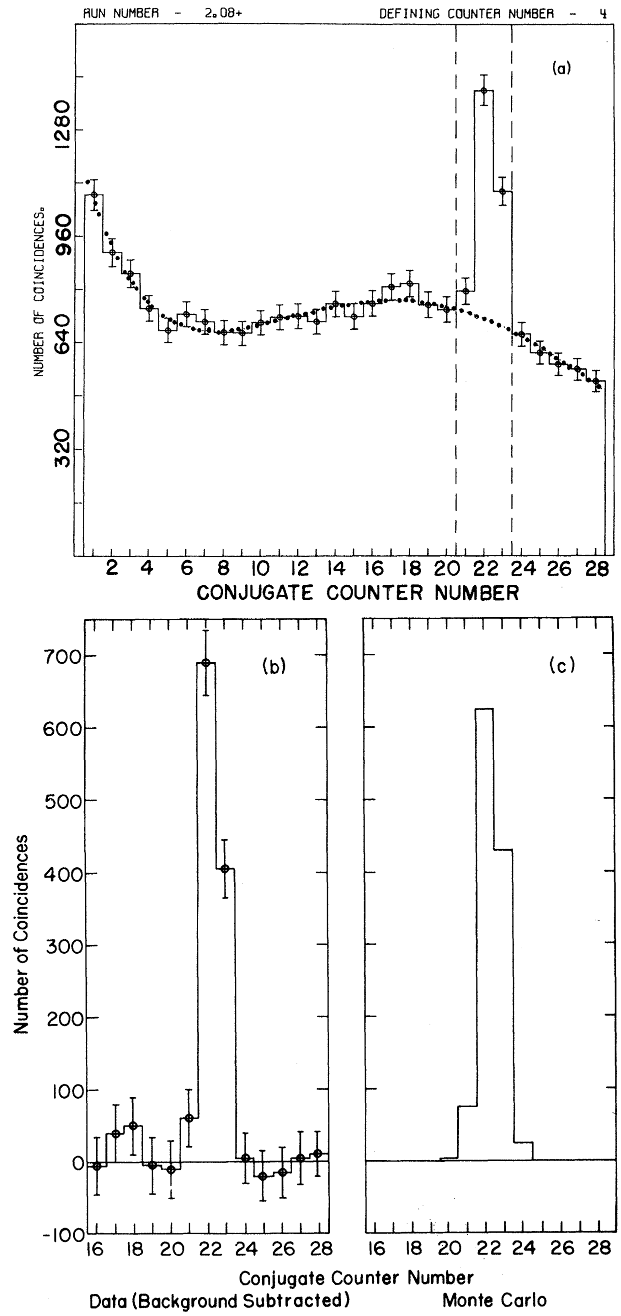

FIG. 2. Typical coincidence distribution. (a) Raw data showing elastic and computer fit to the background. (b) Elastic peak obtained after background subtraction. (c) Simulation of the same data by the Monte-Carlo program.

target thickness and the center-of-mass solid angle, effective scattering angle, and resolution of each counter. Thus we obtain the factors necessary to calculate the DCS.

The anticoincidence counters shown in Fig. 1 reduced inelastic background by a factor of 5. Additional counters not shown were used to define the acceptance in azimuthal angle.

Measurements were taken over a period of several weeks with frequent reversal of the target polarization, P_T. The target polarization (typically 50%) was monitored by a nuclear magnetic resonance (nmr) system whose output signals were digitized at frequent intervals during teach run, so that an effective target polarization weighted according to the data-taking rate could be computed. The nmr system was calibrated by measuring the asymmetry in p-p scattering at 430 MeV, where the polarization is known.[14,15] The result obtained was $P_T(\text{nmr})/P_T(\text{scattering}) = 1.0 \pm 0.16$.[16]

Our results for the DCS are shown in Fig. 3(a). The data of Damouth, Jones, and Perl[4] taken at 2.01 GeV/c are shown for comparison. The agreement is well within our estimated normalization uncertainty of ±10% and the ±8% error quoted by Damouth, Jones, and Perl. Figure 3(b) shows our results for the polarization. The polarization is negative in the diffraction peak and then goes positive and sharply negative again in the vicinity of the DCS minimum. This behavior can be qualitatively reproduced by the black-sphere absorption model of Alexander, Dar, and Karshon,[17] but the model fits badly at larger angles. These authors assumed that, in the general scattering matrix, $M = g + ih\vec{\sigma}\cdot\vec{n}$, g is mainly absorptive, and that the polarization may be approximated by $P = 2\,\mathrm{Im}g\,\mathrm{Re}h/(d\sigma/d\Omega)$. However, the contribution from the term $\mathrm{Re}g\,\mathrm{Im}h$ may be important, especially if resonant or threshold effects are present. We are currently using a variety of models in an attempt to fit the data.

We also have preliminary data at 1.70, 1.88, 2.26, and 2.50 GeV/c. Although there may be a general nonresonant mechanism contributing to the polarization, we do observe a change in the angular dependence with energy. At the maximum momentum measured so far (2.5 GeV/c), there are still large polarizations at some angles. It is clear that spin effects must be included in any meaningful analysis of elastic-scattering data in this energy region.

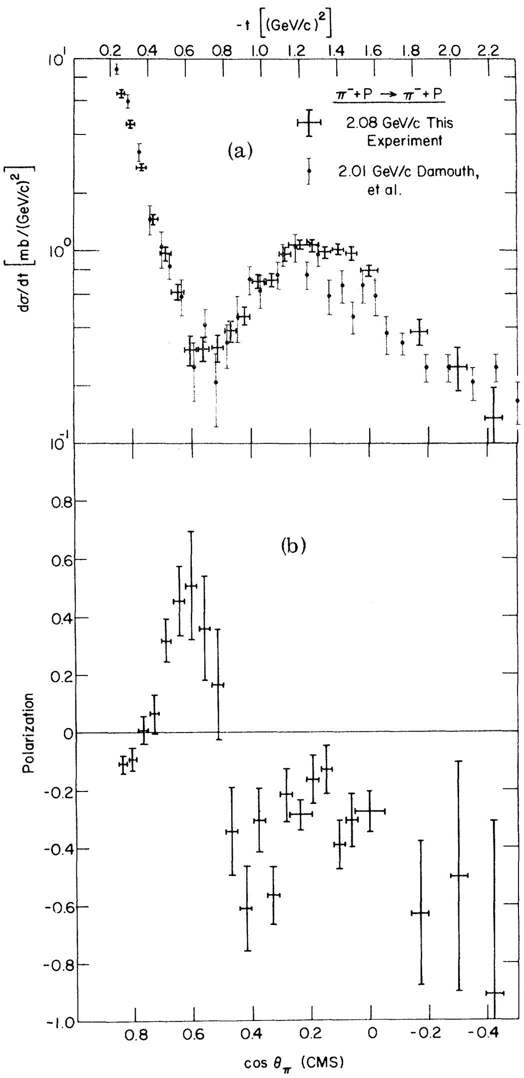

FIG. 3. Experimental results at 2.08 GeV/c. (a) DCS plotted against $\cos\theta_\pi$(c.m.). A scale of $-t$ is also shown. Values of the DCS are given in terms of $d\sigma/dt$. To obtain $d\sigma/d\Omega$ in mb/sr, divide by 3.98. The data of Damouth, Jones, and Perl at 2.01 GeV/c are plotted for the same value of $-t$, not $\cos\theta_\pi$. (b) Polarization P. Vertical bars indicate statistical errors; horizontal bars represent the angular resolution. The normalization errors on the DCS and on P are ±10 and ±16%, respectively.

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$p\bar{p}$ ANNIHILATION INTO TWO MESONS IN THE SPURION SCHEME OF BROKEN U(6,6) SYMMETRY

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The proton-antiproton annihilation at rest into two mesons is forbidden[1,2] in the limit of broken U(6,6) symmetry.[3] The same is true in the spurion scheme of broken U(6,6) symmetry,[4,2] provided we consider only momentum spurions in first order. Also most higher order terms vanish, but with the exception of one second-order term[5] which gives rather unsatisfactory results in comparison with the present experimental situation. On the other hand, within the scheme of broken U(6,6) symmetry, $p\bar{p}$ annihilation at rest into two mesons is forbidden in the meson-pole dominance model, even if momentum spurions are taken into account.[6] It is possible that this result is responsible for the fact that the two-meson annihilation is suppressed compared to three- and four-meson annihilations.

It is the purpose of this note to point out that the inclusion of the U(6) symmetry-breaking spurions[2,4] $(\gamma_5\otimes\gamma_5)\otimes\epsilon_1$ and $(\gamma_\mu\otimes\gamma_\mu)\otimes\epsilon_1$, which are still SU(3) singlets as indicated by the factor ϵ_1, gives rise to quite different and more reasonable predictions. It is the characteristic feature of the momentum spurions that they leave the mass terms invariant, and in this sense, preserve the U(6)-supermultiplet structure.[2] The annihilation amplitude into two mesons remains invariant under a group $U(6)_q$ with the generators $(1,\gamma_4\sigma_1,\gamma_4\sigma_2,\sigma_3)\otimes\gamma_a$, $a=0,\cdots,8$, where the relative momentum $\vec{q}$ of the final mesons is in the 3 direction.[2] On the other hand, the spurion $S_P=(\gamma_5\otimes\gamma_5)\otimes\epsilon_1$ splits the masses of singlet and octet pseudoscalar mesons if inserted into the mass term, but otherwise it preserves the degeneracy of supermultiplets.[2] Similarly, the spurion $S_V=(\gamma_\mu\otimes\gamma_\mu)\otimes\epsilon_1$ gives rise to a mass splitting between singlet and octet vector mesons, but in our model it is contracted only with the indices of baryon tensors.

Since $p\bar{p}$ annihilation at rest into two mesons is forbidden in the $U(6)_q$-invariant pole dominance model, we consider in the following two