region has also been searched for possible evidence of the resonance observed by Schulz[6] using electron scattering. At best only a very small peak was observed, hardly distinguishable above the statistical variations in the counting rate. Additional work is planned using other gases.

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INVESTIGATION OF ABSORPTION EFFECTS IN THE REACTION $\pi^- + p \to \pi^- + \pi^0 + p$ AT 4 GeV/c *†

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The importance of absorptive effects on production amplitudes for peripheral scattering at high energies has been considered recently by several authors.[1-4] We wish to report the results of an analysis of absorptive effects in a study of 390 events of the type

$$\pi^- + p \to \pi^- + \pi^0 + p \tag{1}$$

at 4 GeV/c obtained by the German-British Collaboration at CERN.[5]

We selected 133 events of the type

$$\pi^- + p \to \rho^- + p, \tag{2}$$

with π^-, π^0 effective mass between 0.6 and 0.9 GeV. It has been shown[5] that the ρ^- is produced peripherally in this reaction, with a cross section of 0.45 ± 0.08 mb. Since this is a very small fraction of the total cross section, it is reasonable to expect absorption effects in the initial and final states of Reaction (2), with competing open channels tending to reduce the low partial-wave amplitudes below the values given by the simple peripheral model. If no appreciable cancellation between competitive inelastic channels occurs,[6] it should be possible to investigate the absorption effects experimentally.

Ross and Shaw,[1] using a distorted-wave Born approximation, have predicted that the initial- and final-state interactions in events of type (2) should lead to demonstrable shifts in position and width of the ρ peak with increasing four-momentum transfer. We see no evidence for such shifts in these data; however, the limited statistics might well permit such effects to go undetected.

Durand and Chiu[2] have used a modified distorted-wave Born approximation including the rather significant spin dependence of the reaction to calculate the effect of absorption terms on the differential cross section for Reaction (2). Their prediction is compared with experiment in Fig. 1, in which the dependence of cross section on momentum transfer is shown by the distribution of the proton c.m.-system angle. For the curve labeled $\langle\pi\rangle$ the coupling constants were taken as $g_{\pi NN}^2/4\pi = 14.5$ and $g_{\pi\pi\rho}^2/4\pi = 2.2$,[7] and

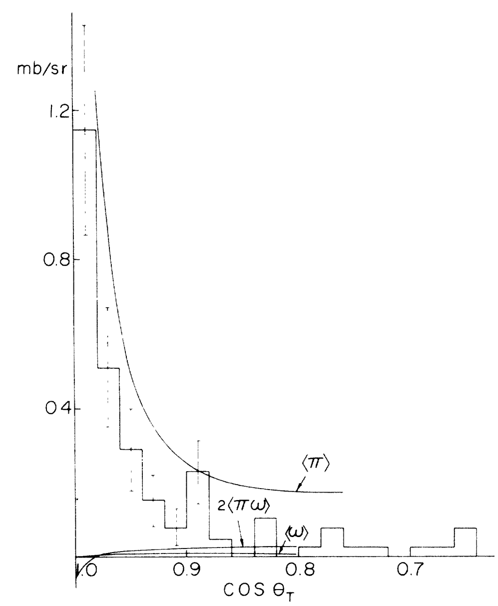

FIG. 1. Differential cross section for the reaction $\pi^- + p \to \rho^- + p$ near the forward direction. The theoretical curves calculated from the model of Durand and Chiu for one-pion exchange $\langle\pi\rangle$, for one-omega exchange $\langle\omega\rangle$, and the interference term $2\langle\pi\omega\rangle$ are shown for comparison.

the range parameter $\nu = 0.25$ GeV was obtained from an exponential fit to the elastic scattering data at this energy.

The agreement of the curve $\langle\pi\rangle$ with experiment is reasonably good. It seems also clear that ω exchange (the curve labeled $\langle\omega\rangle$), and the interference term $2\langle\pi\omega\rangle$, which can be nonzero when absorption effects are considered, are of no importance. Although there are essentially no free parameters in the theoretical fit, uncertainties in the values of the coupling constants used, lack of information as to the ρ,p elastic scattering amplitudes and the consequent use of π,p elastic scattering amplitudes in their stead, and uncertainties in the background subtraction in the analysis from which the cross section for Reaction (2) was obtained could shift the absolute values slightly, either upward or downward. Consequently, it is difficult to draw any certain conclusions as to whether the data require the inclusion of a form factor in the calculation to improve the fit, although there is a systematic trend for the data points to lie below the predicted values. It has previously been shown[5] that a good fit to the same data can be obtained using the Selleri modification[8] to simple one-meson exchange, which takes into account the form factors at the vertices. It is perhaps fair to say that the data for ρ-p production at 4 GeV/c can be fitted as well by considering initial- and final-state absorption only, neglecting form factors, as by considering the form factor for the absorption of a virtual pion by the ρ, while neglecting absorption effects in the initial and final states. The correct interpretation might well lie between these extremes.

Gottfried and Jackson[3] have considered absorptive effects due to competing inelastic channels in a distorted-wave Born approximation in which the spins of the particles participating in the reaction are taken into account. We have measured the angles θ and φ for which these authors give the distributions

$$w(\cos\theta) = \text{const} \times [(1-\rho_{0,0}) + (3\rho_{0,0}-1)\cos^2\theta] \quad (3)$$

and

$$w(\varphi) = \text{const} \times [(1-2\rho_{1,-1}) + 4\rho_{1,-1}\sin^2\varphi]. \quad (4)$$

Here the $\rho_{m,m'}$ are the elements of the spin-space density matrix, θ is the polar angle between the incoming π^- and the decay π^- measured in the ρ^- rest system, and φ is the corresponding azimuth angle with $\varphi = 0$ in the production plane (φ is equivalent to the Treiman-Yang angle).

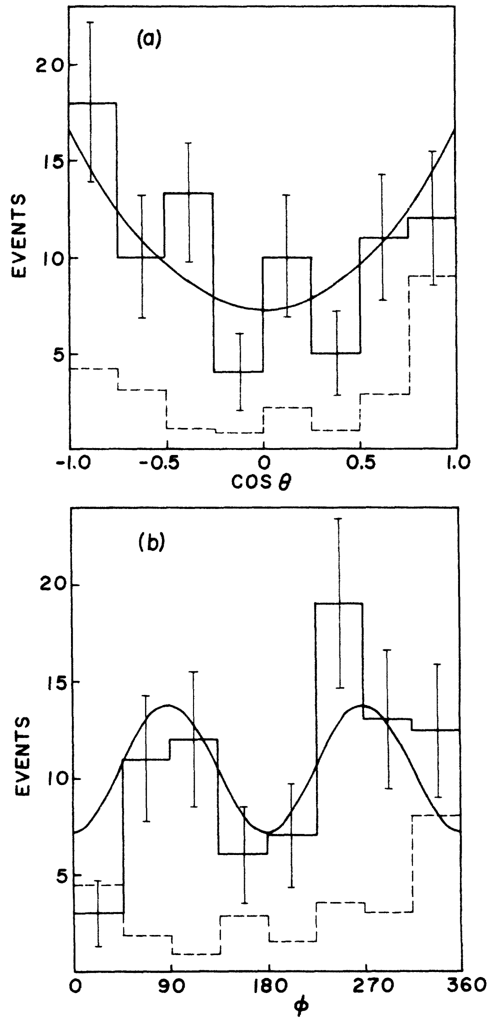

FIG. 2. Distributions of (a) the cosine of the polar angle θ and (b) of the azimuthal angle φ in the ρ^- rest system for ρ production events with $-t \leq 15\mu^2$. Events within the ρ peak are shown by the solid line, while the dashed line shows the corresponding distribution for events outside the ρ peak in the same range of t. The curves show the maximum-likelihood fits to Eqs. (3) and (4).

The measured distributions of $\cos\theta$ and of φ for all events of type (2) with $-t \leq 15\ \mu^2$ are shown in Fig. 2. The maximum likelihood fits for Eqs. (3) and (4), obtained with $\rho_{0,0} = 0.53^{+0.12}_{-0.11}$ and $\rho_{1,-1} = 0.16^{+0.09}_{-0.10}$, are shown as smooth curves in the figure. These spin-density matrix elements may be compared with the values $\rho_{0,0} = 0.70 \pm 0.08$ and $\rho_{1,-1} = 0.17 \pm 0.14$ reported for the reaction

$$\pi^+ + p \rightarrow \rho^+ + p \quad (5)$$

at the same energy.[9]

The matrix elements $\rho_{0,0}$ and $\rho_{1,-1}$ are expected to vary with production angle with a dependence that is sensitive to the absorption parameters obtained in the elastic scattering fit. Assuming pure pseudoscalar meson (π) exchange, for a weighted average over the production angle interval $1.0 \geq \cos\Theta \geq 0.9$ the treatment of Gottfried and Jackson leads to values for $\rho_{0,0}$ in the range 0.7-0.8, and $\rho_{1,-1}$ in the range 0.04-0.02, depending on the degree of absorption assumed.

The values obtained for $\rho_{0,0}$ and $\rho_{1,-1}$ are in rough agreement with Gottfried and Jackson's prediction. For pure vector-meson (ω) exchange, one expects $\rho_{0,0}$ to approach zero and $\rho_{1,-1}$ to be large. It seems unlikely that there is any appreciable ω exchange, as noted above in connection with the angular distributions shown in Fig. 1.[10] Contributions from events in the background under the ρ peak, which could be as high as 30%, may influence the $\cos\theta$ and φ distributions to some extent. Uncertainties in the t dependence of this background, and the statistics of the numbers of events involved, make a background subtraction impracticable. Some estimate of this effect may be obtained by comparing the $\cos\theta$ and φ distributions of all events under the ρ peak (solid line) with distributions for events with $0.3 \leq M_{\pi\pi} < 0.6$ and $0.9 < M_{\pi\pi} \leq 1.15$ in the same range of four-momentum transfer (dashed line, Fig. 2). These distributions are not quite isotropic.

The data show significant deviations from the values of $\rho_{0,0} = 1.0$ and $\rho_{1,-1} = 0$ that would be expected for one-pion exchange if initial- and final-state absorption were unimportant. There is no evidence for vector-meson exchange contribution to the ρ^- production reaction. Differences between measured values for the spin-density matrix elements and the predictions of Gottfried and Jackson may be statistical, or due to unsubtracted background. If they are real, it would suggest that treatment of meson exchange in peripheral collisions is not yet complete. It is perhaps worth noting that the anisotropy in the distribution of $\cos\theta$ for events of the type

$$\pi^- + p \to \rho^0 + n, \tag{6}$$

which is particularly prominent at 4 GeV/c in events for which $-t \leq 15\ \mu^2$, is not predicted by these pion-exchange models.

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[10]This is also shown by the value for $\mathrm{Re}\rho_{1,0} = (-\frac{5}{4}\sqrt{2}) \times \langle \sin 2\theta \cos\varphi \rangle$ which we find to be -0.06 ± 0.05. For one-pion exchange neglecting absorption effects, this parameter should be zero. Including initial- and final-state absorption, Gottfried and Jackson find $\rho_{1,0}$ to be in the range -0.12 to -0.17, depending on the degree of absorption assumed.