PERIPHERAL PRODUCTION OF ρ^0 MESONS BY PIONS OF 12 AND 18 BeV/c*

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In an experiment performed at CERN on the production of pion pairs by negative pions of high energy, the data on neutral rho production cross sections integrated over a range of final nucleon excited states agree well with the one-pion-exchange calculation without correction for initial- or final-state absorption or a form-factor term. The validity of this simple model is interpreted in the context of absorptive effects by considering that these absorptive processes only feed the inelastic (excited nucleon) channels which are already included in the calculation.

Negative pion beams of 12 and 18 BeV/c were directed onto a small polyethylene target through a system of magnets and spark chambers, and pairs of emerging pions were analyzed with a subsequent array of chambers, magnet, and counters. This experiment has been described,[1] and some preliminary results have been presented.[2] Events which triggered the system and were recorded have been analyzed in terms of the incident pion momentum, p; the invariant mass m, invariant four-momentum transfer t, the decay angles θ^* and φ of the di-pion; and of the invariant mass M' resulting at the nucleon vertex. For the data included in this analysis, M' was integrated from M (the nucleon mass) to 2500 MeV. Because of the aperture of the second magnet and the geometry of the trigger counters, a given rho production event had typically a 5% or less probability of detection, depending on φ, θ^*, t, etc. The detection probability of each event was computed and the resulting distributions and cross sections were accordingly weighted.

The cross section for neutral rho production resulting in the recoil of a single neutron is given by[3]

$$\frac{d\sigma}{dt}=\frac{\pi}{4}\chi\left(\frac{g_{\pi NN}{}^2}{4\pi}\right)\left(\frac{g_{\rho\pi\pi}{}^2}{4\pi}\right)\frac{t[t-(m-\mu)^2][t-(m+\mu)^2]}{p^2m^2M^2(t-\mu^2)^2}, \tag{1}$$

where $\chi=(2/\pi)\tan^{-1}(\Delta m/\Gamma)$ accounts for the range of di-pion mass, Δm included. The pion-nucleon coupling constant $(g_{\pi NN}{}^2/4\pi)$ is taken as 15, and the rho-pion coupling constant $(g_{\rho\pi\pi}{}^2/4\pi)$ is taken as 1.6 (corresponding to a width, Γ, of 80 MeV). If the nucleon is left excited on absorption of the exchanged pion, the expression for the rho-production cross section becomes[3]

$$\frac{d^2\sigma}{dtdM'^2}=\frac{-\chi}{16\pi}\left(\frac{g_{\rho\pi\pi}{}^2}{4\pi}\right)\frac{\sigma_{\pi N}(M')[(M^2+M'^2-t)^2-4M^2M'^2]^{1/2}[t-(m-\mu)^2][t-(m+\mu)^2]}{p^2m^2M^2(t-\mu^2)^2}, \tag{2}$$

where $\sigma_{\pi N}(M')$ is the total pion-nucleon cross section at an energy (M'). In this experiment, account was taken of the polyethylene target by using $\sigma_{\pi N}(M')=\frac{1}{3}\sigma_{\pi^+p}+\frac{2}{3}\sigma_{\pi^-p}$ and correcting the effective number of target nucleons in carbon to $A^{2/3}$. The calculated cross sections for expressions (1) and (2) are given in Table I.

Experiments at lower energies have required an additional term in Eq. (1) of the form[4]

$$F(t)=[(\Lambda^2-\mu^2)/(\Lambda^2-t)]^2, \tag{3}$$

where $\Lambda^2\simeq 6\mu^2$ has given reasonable agreement with the experiments. The effect of this term is also given in Table I for this value of Λ.

The experimental cross sections, based on over 6000 di-pion events, including about 600 rho events within the given ranges of m, t, and M', are given in Table II, and the 18-BeV data are presented in Fig. 1. These are preliminary results both in number of events and in the precision of the detection probability calculation, and the normalization is uncertain by as much as 50%. However, no effect is known which would cause the shape of the cross section vs four-momentum transfer to be seriously in error.

The values in Table I substantiate the observation that a single nucleon in the final state is quite improbable relative to states where $M' > M+\mu$, and the magnitudes of the experimental values are very much larger than the cross

Table I. Calculated cross sections for ρ^0 production by pions. $700 < m < 800$ MeV; $M+\mu < M' < 2500$ MeV.

p (BeV/c)	Interval of $-t$ [(BeV/c)^2]	Eq. (1) integrated over the given interval of t (microbarns): Eq. (1)	Eq. (1)×$F(t)$ from Eq. (3)	Eq. (2) integrated over the given interval of t and over M' to 2500 MeV (microbarns): Eq. (2)	Eq. (2)×$F(t)$ from Eq. (3)
18	0-0.05	4.7	2.1	37.3	17.4
	0.05-0.10	4.2	1.16	80.2	21.3
	0.10-0.20	6.8	0.98	113.6	17.3
	0.20-0.30	5.9	0.52	58.6	4.4
	0-0.30	21.6	4.8	289.7	60.4
12	0-0.05	10.6	4.7	36.4	15.0
	0.05-0.10	9.5	2.6	86.8	23.2
	0.10-0.20	15.4	2.2	194.6	28.9
	0-0.20	35.5	9.5	317.8	67.1

Table II. Experimentally measured cross sections for ρ^0 production by pions. $700 < m < 800$ MeV, $M+\mu < M' < 2500$ MeV.

p (BeV/c)	Interval of $-t$ [(BeV/c)^2]	Integrated cross section (microbarns)	Estimated error[a]	Differential cross section [mb (BeV/c)$^{-2}$]	Estimated error[b]
18	0-0.05	43.7	30%	0.874	14%
	0.05-0.10	77.4	30%	1.548	10%
	0.10-0.20	112.5	40%	1.125	10%
	0.20-0.30	49.9	50%	0.499	21%
	0-0.30	283.5	40%		
12	0-0.05	55.4	40%	1.107	12%
	0.05-0.10	142.7	40%	2.854	10%
	0.10-0.20	270.3	50%	2.703	9%
	0-0.20	468.4	50%		

[a]Systematic error included.
[b]Statistical error only.

sections for Eq. (1). This is borne out in the observed differential cross section vs M' (integrated over $0 < |t| < 0.3$), plotted in Fig. 2 for the 18-BeV data, where the single nucleon is not seen.

There have been recent discussions concerning whether Eq. (3) represents a pion-nucleon interaction form factor which would reduce cross sections for interactions at large values of $|t|$,[5] or whether this is due rather to initial- and final-state interactions of the pion or rho with the nucleon, which would be more probable at larger values of $|t|$ and which would have an effect on the differential cross sections similar to Eq. (3).[6] A priori, there seems to be no reason why a form factor should depend on other than t, e.g. why this experiment at 12 and 18 BeV should show a result different from experiments at 2 and 4 BeV. Furthermore, if a form-factor correction is appropriate for Eq. (1), then it should be equally appropriate for Eq. (2). The models of Ross and Show and of Gottfried and Jackson should depend principally on t since $\sigma_{\pi N}$ is only very weakly dependant on p above 2 BeV. It is plausible that $\sigma_{\rho N}$ is also only weakly dependant on p. From Tables I and II it is seen that the data are entirely consistent with Eq. (2) with no additional terms necessary (excepting normalization adjustment at 12 BeV), while a term such as given by Eq. (3) would produce a factor of 12 reduction in cross section in the largest $|t|$ bin relative to the smallest for the 18-BeV case, and a corresponding factor of 6.5

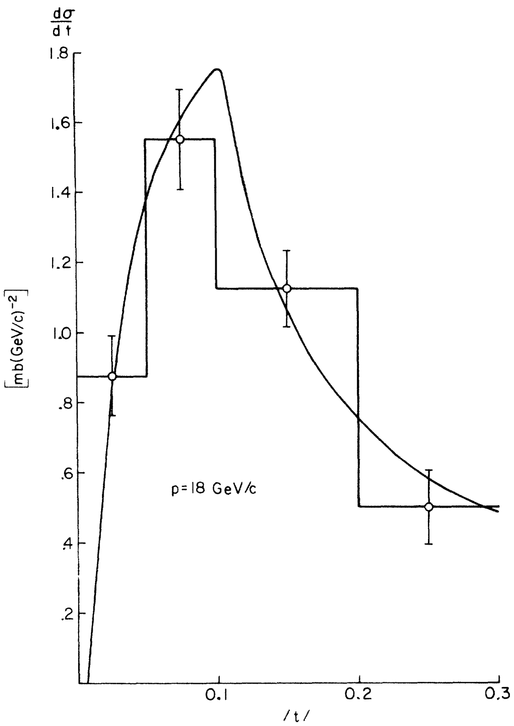

FIG. 1. Differential cross section for ρ^0 production by 18-BeV/c pions vs four-momentum transfer, t. The solid line is Eq. (2) integrated over M' from $M+\mu$ to 2500 MeV. The histogram shows the experimental data, where the errors are statistical uncertainties. An additional normalization uncertainty of ±50 % is not shown.

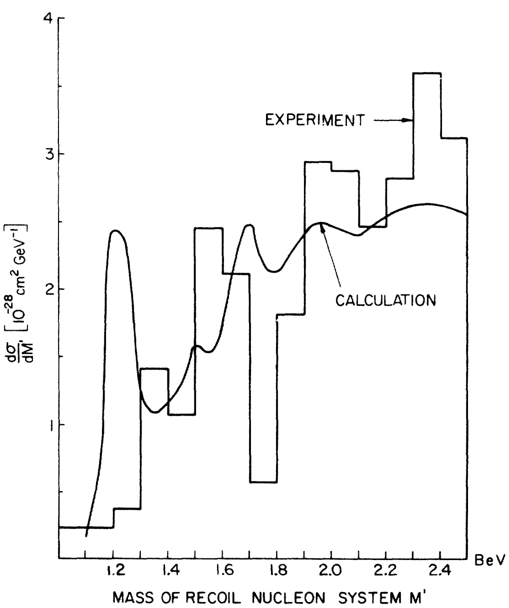

FIG. 2. Differential cross section for ρ^0 production by 18-BeV/c pions vs missing mass, M', at the nucleon vertex. The solid line is Eq. (2) integrated over t from 0 to -0.3 (BeV/c)^2. The histogram shows the data.

for the 12-BeV case.

It is proposed that this can be understood in the context of the model containing initial- and final-state interactions. The primary consequence of a final-state interaction between the rho and the nucleon may be excitation (or de-excitation) of the nucleon to a nearby level (e.g. isobar) with little effect on the passing rho. If the one-pion exchange process is permitted to feed a large range of final nucleon states (range of M') and these states are incoherent with the states resulting from the final rho interaction, then there may in fact be little net effect on the cross section integrated over M'. Correspondingly, an initial-state interaction of the pion with the nucleon could lead to nucleon excitation, and the one-pion exchange could then occur either with the excited nucleon system (isobar) or with just the bare nucleon. In either case a one-pion exchange expression such as Eq. (2) would probably be suitable. The model, then, allows the nucleon to be excited or shifted in energy (M') either before, in the process of, or after the one-pion exchange; and the consequence of this is little different than the case where only the one excitation would occur. From phase-space arguments a shift upwards in energy may be more probable than a shift downward (from an already excited nucleon state). This may account for the paucity of the ($\frac{3}{2}$, $\frac{3}{2}$) isobar in the M' distribution (Fig. 2).

This model suggests an asymmetry between the boson and nucleon vertices as far as the consequences of the initial- and final-state interactions are concerned. If the initial state carried the pion into some higher state or the final state transformed the rho into a different state there would be expected some reduction in rho production at large $|t|$. Perhaps this is not a factor only because the level density of di-pion states (containing only the f^0, ρ, and perhaps σ) is less than that of the nucleon system.

It should be noted that the use of high energies here permits relatively high excitations of the nucleon while maintaining conditions appropriate for peripheral processes. Thus at $t=-0.1$ (BeV/c)^2, $M'=2500$ is kinematically accessible with $p=18$ BeV/c, while at $p=4$ BeV/c, $M'=1400$ is the maximum accessible at this t value.

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B. Elsner, D. Harting, and W. Middelkoop, in addition to the author. The analysis was directed by B. Zacharov, and valuable contributions were made by E. Bleuler. At the University of Michigan, E. Coleman, B. Loo, and S. Powell have assisted in the analysis. R. Deck, S. Berman, S. Drell, A. Goldhaber, and M. Ross have all contributed concepts and clarifications on this subject in their valuable discussions with the author. Finally, the hospitality and collaboration of CERN in the execution of this experiment and subsequent data analysis is greatly appreciated.

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IMPLICATIONS OF SU(6) SYMMETRY FOR TOTAL CROSS SECTIONS*

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There has been much speculation recently about the possibility of applying to elementary-particle physics the Wigner[1] supermultiplet theory in nuclear physics. One considers the group SU(6),[2] which contains as a subgroup SU(2) $\times$ SU(3). The first factor refers to rotations in spin space, the second to the internal symmetry group. The difficult problems of reconciling these ideas with the principle of relativity are still open. As a consequence, the application of SU(6) notions has so far been confined to static questions, such as the identification of multiplets, mass formulas, electromagnetic properties, etc. Rules for operating with SU(6) become laid down in the course of these applications. In the above context the predictions of the theory have met with remarkable experimental success.

One would also like to apply (develop?) the theory to more general questions involving scattering reactions among particles. Here, in general, one must come to grips with the meaning of SU(6) in a relativistic context. However, even in advance of any full clarification of the theory in this direction, we suggest here that a limited class of new problems can be explored in something like the spirit of what has already been developed.

Namely, let us consider the forward elastic scattering of pseudoscalar mesons on baryons. In the laboratory frame, the initial and final baryons are at rest and the forward scattering amplitude can be written

$$f(0°) \sim \int d^4x\, e^{iq\cdot x}\langle 0,B|[j(x),j(0)]\theta(x_0)|0,B\rangle, \quad (1)$$

where $|0,B\rangle$ is the state of a baryon at rest. The operator $j(x)$ is the source function of the pseudoscalar meson field $\varphi(x)$. Precisely because the initial and final states describe baryons at rest in the same frame, it presumably has a meaning to regard the baryon states as belonging to a definite SU(6) multiplet—the 56-dimensional representation according to currently accepted assignments. But the question arises whether it makes sense to assign definite SU(6) transformation properties to the meson field $\varphi(x)$. The state $|0,M\rangle$ of a meson at rest is obtained from the vacuum state $|0\rangle$ according to the operation

$$|0,M\rangle \sim \int d^3x\, e^{ik\cdot x}\overleftrightarrow{\frac{\partial}{\partial x_0}}\varphi(x)|0\rangle \quad (x_0 \to \pm\infty), \quad (2)$$

where $\vec{k}=0$ and k_0 = meson mass. Since the me-