TH. 747

A METHOD OF CALCULATING CHARGE BRANCHING RATIOS SUGGESTED BY THE STATISTICAL MODEL

K. Zalewski and J. Danysz

CERN - Geneva

A B S T R A C T

The problem of calculating charge branching ratios for multiple production processes is discussed. A method of calculation suggested by the statistical model is described and applied to π^+p interactions at 4 GeV/c, $p\bar{p}$ annihilations at 3 GeV/c and K^+p interactions at 3.0, 3.5 and 5.0 GeV/c. The results are compared with experiment.

67/165/5 - TH. 747
7 April 1967

1. INTRODUCTION

The method described in this paper is applicable to the determination of charge branching ratios. By charge branching ratios we understand branching ratios between final states which differ only by charge configurations. E.g., we shall be able to calculate branching ratios between the following processes, where in each, six pions are produced:

$$p + \bar{p} \longrightarrow 3\pi^+ + 3\pi^- \tag{1}$$

$$p + \bar{p} \longrightarrow 2\pi^+ + 2\pi^- + 2\pi^0 \tag{2}$$

$$p + \bar{p} \longrightarrow \pi^+ + \pi^- + 4\pi^0 \tag{3}$$

$$p + \bar{p} \longrightarrow 6\pi^0 \tag{4}$$

but we have no predictions about the relation between, say, the cross-section for process (1) and the cross-section for the production of four pions and a nucleon-antinucleon pair.

In the following we often refer to probabilities. For instance $P(3\pi^+, 3\pi^-)$ is the probability of channel (1). These probabilities are always normalized to one for the set of channels differing only by charge configurations. For instance the sum of probabilities for channels (1)-(4) equals one.

Experimentally in the process $p\bar{p} \to 6\pi$ the cross-section for channel (1) is the only one which is measured directly. The other cross-sections are only estimated from indirect arguments; therefore a theoretical estimate should be helpful. In other cases it is possible to measure cross-sections for several channels differing only by charge configurations. Such cases can be used to test our method. The same method is applicable when resonances are produced. For instance in Section 5 we give charge branching ratios for the process $K^+p \to K^* N^* \pi$.

If, however, a final state can be reached both directly and through the production and subsequent decay of resonances, we must know how much of the process goes through resonance production. The charge branching ratios for the final state depend on the branching ratios for resonance production. Consequently, the method can be inverted and measured charge branching ratios can be used to estimate the resonance production.

To summarize: the method gives a correlation between the branching ratios for resonance production and the charge branching ratios for final particles.

2. MODEL INDEPENDENT RESULTS

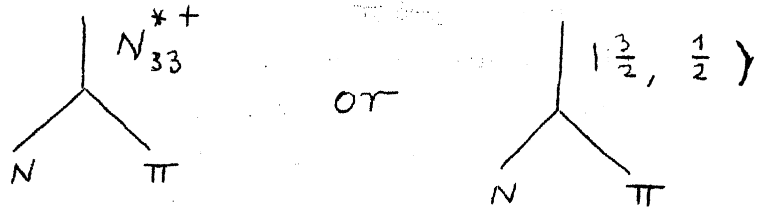
Assuming isospin conservation we can calculate some charge branching ratios without further assumptions. E.g., for the process

$$N^*_{33} \begin{cases} \longrightarrow p\,\pi^0 \\ \longrightarrow n\,\pi^+ \end{cases} \qquad (5)$$

we find, squaring the corresponding Clebsch-Gordan coefficients, the probabilities:

$$P(p,\pi^0) = \frac{2}{3} \qquad P(n\,\pi^+) = \frac{1}{3} \qquad (6)$$

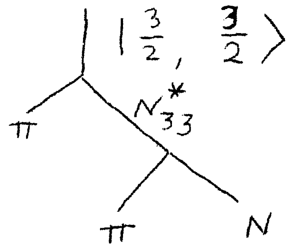
In the following we shall find it convenient to use a diagrammatic representation for processes. E.g., for process (5) we shall write



(7)

If the N* is produced together with another particle from some other initial state, and if the isospins for the other particle and for the initial state are known, we can still calculate the charge branching ratios by simply using Clebsch-Gordan coefficients.

E.g., for

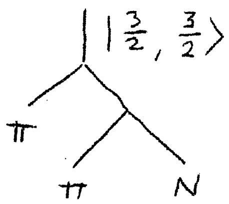


(8)

$$P(n, \pi^+, \pi^+) = \frac{2}{15} \qquad P(p, \pi^+, \pi^0) = \frac{13}{15} \tag{9}$$

In this calculation the probabilities for the final state $p\pi^+\pi^0$ reached through $\pi^0 N^{*++}$ and through $\pi^+ N^{*+}$ are added incoherently, i.e.,ignoring the interference of the N^{*+} and N^{*++} bands on the Dalitz plot. Such an approximation might be bad for a calculation of the distribution on the Dalitz plot, but it should not affect much the integrated cross-sections, because the regions with constructive and destructive interference compensate each other. This was discussed theoretically by Schmid [1]. A practical example may be found in the paper by Bland et al. [2].

If the intermediate isospin had not been known, i.e., for



(10)

it would have been impossible to calculate the charge branching ratios without further assumptions. Indeed when the intermediate isospin in (10) is $\frac{3}{2}$ we obtain the result (9), while for the intermediate isospin $\frac{1}{2}$ a similar calculation yields

$$P(n, \pi^+, \pi^+) = \frac{2}{3} \qquad P(p, \pi^+, \pi^0) = \frac{1}{3} \tag{11}$$

It is even not true that the correct charge branching ratio has to be some average of (9) and (11).

In order to see that, let us denote by A_T the production amplitude for $n\pi^+\pi^+$ with the intermediate isospin T. We have

$$P(n, \pi^+, \pi^+) \sim |A_{3/2} + A_{1/2}|^2 = \tag{12}$$
$$= |A_{3/2}|^2 + |A_{1/2}|^2 + 2\,\mathrm{Re}\, A^*_{3/2} A_{1/2}$$

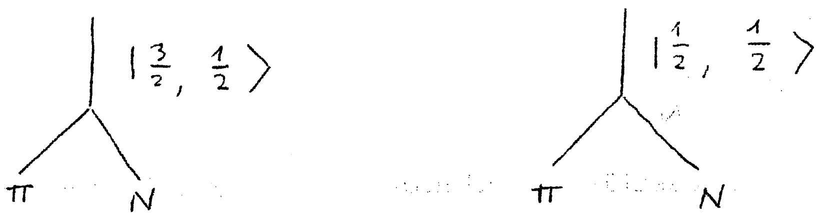
Here the sign $\sim$ means that the probability is obtained from the expression at the right-hand side by integrating over all the possible final momenta configurations and normalizing. As seen from (12) the interference term can cancel the other two terms and give zero probability in spite of the fact that neither $|A_{\frac{3}{2}}|^2$ nor $|A_{\frac{1}{2}}|^2$ is zero. Such cases are known. Let us consider for instance the process

$$\pi^- + p \longrightarrow \pi + N \tag{13}$$

The $\pi^- p$ system has no definite isospin, but using Clebsch-Gordan coefficients it may be decomposed into isospin eigenstates

$$|\pi^- p\rangle = \sqrt{\tfrac{1}{3}}\,|T=\tfrac{3}{2}\rangle + \sqrt{\tfrac{2}{3}}\,|T=\tfrac{1}{2}\rangle \tag{14}$$

thus again the amplitude is the sum of contributions from two diagrams:



(15)

The probability $P(n, \pi^0)$ is for the two situations 2/3 and 1/3 respectively, while experimentally it is known that at sufficiently high energies

$$P(n, \pi^0) \approx 0 \tag{16}$$

In the following sections we ignore interference terms. In order to make it plausible we give the following (non rigorous) argument that the situation met with in the example above is likely to occur only at low multiplicities, and that at higher multiplicities we may expect the interference terms to be relatively small. In order to obtain P we integrate over all the possible configurations of final momenta. The number of such configurations is very large and increases rapidly with the number of particles in the final state. Thus P is a sum of very many contributions. For the non-interference terms all the contributions are positive. For the interference terms the contributions can have "a priori" any sign, and it is likely that they will cancel in the sum.

In concluding this section, let us discuss a case where it can be proved that the interference terms cancel exactly. We consider the processes

(17)

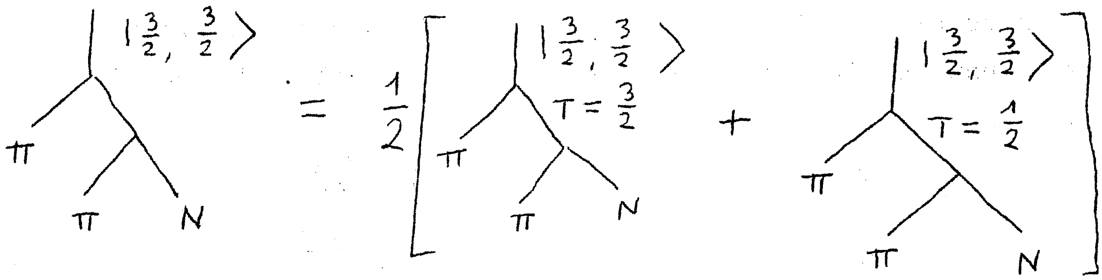
where T denotes the isospin of the intermediate state. Since the pions are bosons the amplitude in (a) must be antisymmetric and the amplitude in (b) symmetric with respect to the exchange of pions in momentum space. Consequently the interference term gives zero, when integrated over all possible configurations of final momenta.

3. STATISTICAL METHOD OF CALCULATING CHARGE BRANCHING RATIOS

Except for some simple cases, as illustrated by examples in the preceding section, it is necessary to introduce some model type assumptions in order to obtain charge branching ratios. The simplest assumption, which we further call statistical is described below.

Before going into details, we would like to stress, however, that the statistical method of calculating charge branching ratios is not equivalent with the statistical model of multiple production. It is just the simplest conjecture for charge branching ratios in any theory where there is no correlation between the charges and momenta of the particles. In the language of the statistical model the phase space integrals cancel when charge branching ratios are calculated and it is irrelevant how various parts of the phase space are weighted.

For a given initial isospin the probability is calculated as the arithmetical average of the probabilities calculated with all the possible assumptions about the intermediate isospins. E.g., for process (10)

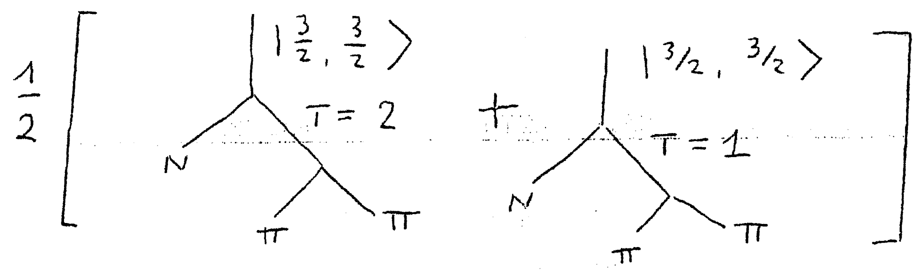


(18)

Substituting the numbers given in the preceding section we get

$$P(p, \pi^+, \pi^0) = \frac{3}{5} \qquad P(n, \pi^+, \pi^+) = \frac{2}{5} \tag{19}$$

The result does not depend on the order in which the particles are coupled (e.g., Zalewski [3]). Therefore instead of (18) we might have used



(18a)

If the initial state is not an isospin eigenstate, we decompose it into isospin eigenstates, calculate the charge branching ratios for each initial isospin which occurs in the decomposition, and calculate the average, weighting each probability with the square of the coefficient of the corresponding amplitude in the decomposition. E.g., for $\pi^- p$

scattering [compare (14)] it would be necessary to calculate the charge branching ratios for initial isospins $\frac{1}{2}$ and $\frac{3}{2}$. The probabilities are

$$P = \frac{1}{3} P^{T=3/2} + \frac{2}{3} P^{T=1/2} \qquad (20)$$

This method of calculation was described by Cerulus [4], who tabulated the probabilities for some cases of interest. The calculation of probabilities for various intermediate and initial isospins is very simple in principle, but for higher multiplicities it is very cumbersome. Therefore it is much more convenient to use a closed formula which yields directly the average probabilities for a given initial isospin [Cerulus [5]]. The formula can be written in the form [Zalewski [3]]

$$P^{T}_{(\ldots, n_{jk}, \ldots)} = \frac{\prod n_k!}{\prod n_{jk}!} \left(T + \frac{1}{2}\right) 2^{-M} \int_{-1}^{1} (1+x)^M \prod_{i=0}^{n} P^{0,2m_i}_{t_i - m_i}(x)\, dx \qquad (21)$$

with

$$M = \sum_{i=0}^{n} m_i \qquad (22)$$

Here n, n_k, and n_{jk} denote the total number of particles in the final state, the number of particles belonging to the k-th isomultiplet and the number of particles in the j-th charge state of the k-th isomultiplet. Thus

$$n_k = \sum n_{jk} \qquad (23)$$

$$n = \sum n_k \qquad (24)$$

Both T and t_0 denote the initial isospin, t_i is the isospin of the i-th particle. m_0 and m_i denote the moduli of the third components of the total isospin and of the isospin of the i-th particle. $P^{o,2m}_{t_i-m_i}(x)$ are Jacobi polynomials. Their general definition is

$$P^{o,2m}_{t-m}(x) = 2^{-t+m} \sum_{\nu=0}^{t-m} \binom{t-m}{\nu} \binom{t+m}{t-m-\nu} (1+x)^{\nu} (x-1)^{t-m-\nu} \qquad (25)$$

but it simplifies considerably for cases which are practically important Since

$$P^{o,2m}_{0}(x) = 1 \qquad (26)$$

The polynomial is 1 for nucleons, K, $\pi^{\pm}$ and ω mesons, and in general whenever t=m. The only other case we needed was for t=m+1:

$$P^{o,2m}_{1}(x) = t\,x - m \qquad (27)$$

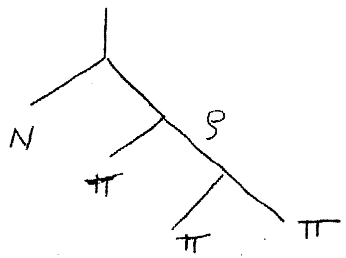
which yields x for π^{o} and 1.5x-0.5 for the $m=\frac{1}{2}$ components of a $\frac{3}{2}$ resonance.

Recently calculations of charge branching ratios for $\pi^{+}p$ (4 GeV/c and 8 GeV/c) and $\pi^{-}p$ (10 GeV/c) scattering were performed by Bartke [6] and Bartke and Czyzewski [7]. The authors used the measured cross-sections for fitted channels and formula (21) to predict the partial cross-sections for no fit channels. The result was checked by comparing the predicted total cross-section for pion production with experiment. The agreement found was very satisfactory as shown in Table I.

In this calculation the production of resonances was completely ignored. Since it is known that, actually, the production rate for resonances in some of the channels considered is very high, we repeated the calculation introducing the resonances. We found that the result for the total cross-section in $\pi^{+}p$ scattering at 4 GeV/c (we had not enough data on resonance production in the other two experiments to make a comparison) remained satisfactory. Moreover the method could be extended to $p\bar{p}$ annihilations and K^+p scattering, where the approximation with no resonances gives bad results.

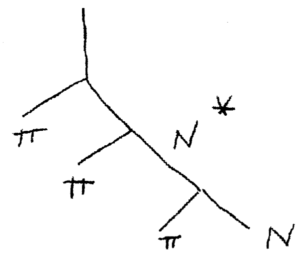
4. CALCULATION OF CHARGE BRANCHING RATIOS USING INFORMATION ABOUT THE RESONANCE PRODUCTION

The statistical method described in the previous section can be used for calculating charge branching ratios for final states including resonances. E.g., we can calculate charge branching ratios for $p\rho\pi\pi$, or for $N^*\rho\pi$. Using such results and ordinary Clebsch-Gordan coefficients we can obtain charge branching ratios for the $N\pi\pi\pi$ system assuming that the final state is reached through an intermediate state with a ρ



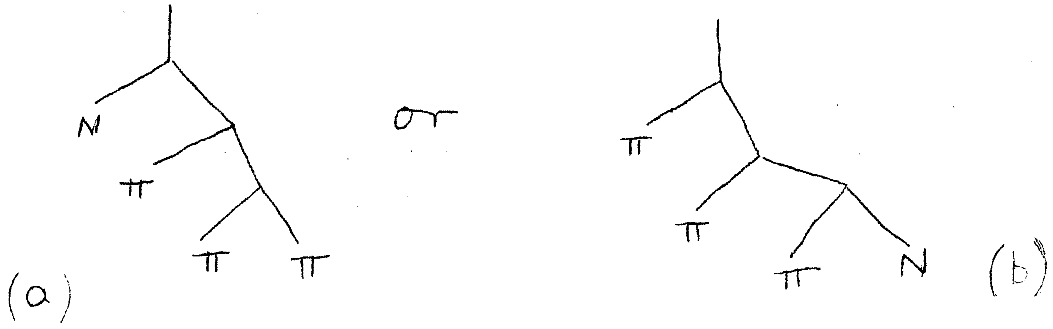
(28)

or through an intermediate state with an N^*



(29)

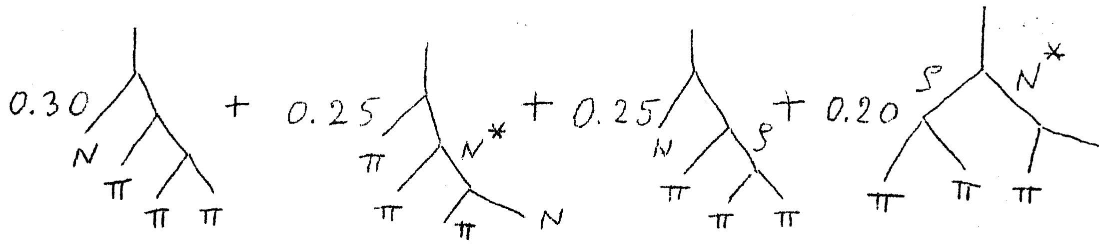
Results are in general different from each other and different from the result of a calculation without resonances



(30)

It is seen from the general formula (21) that there is no difference between (a) and (b).

We calculate the charge branching ratios for the final state by taking the weighted average of the probabilities obtained with all assumptions about resonance production. The probabilities are weighted with the experimental cross-sections for resonance production. E.g., if for $p\pi^+\pi^+\pi^-$ channel the fractions of events with no resonance, with N^* but no other resonances, with ρ but no other resonances, and both N^* and ρ with no other resonances are 30%, 25%, 25% and 20%, which implies that no other resonance is produced, our calculation is summarized by the diagram



(31)

We applied the method to π^+p scattering at 4 GeV/c, to $p\bar{p}$ annihilations at rest and at 3 GeV/c, to $p\bar{n}$ annihilations at rest, and to the resonance production in K^+p scattering at 3, 3.5, and 5 GeV/c. Part of the results is presented and discussed in the next section.

5. EXAMPLES

A. π^+p interactions at 4 GeV/c

The π^+p scattering at 4 GeV/c was studied by the British-German collaboration [8), 9)]. The experimental results for the fitted channels are given in the first column of Table II. In the next six columns theoretical cross-sections obtained with various assumptions are given. At each multiplicity the theoretical cross-sections are normalized so that the total fitted cross-section at this multiplicity is reproduced correctly. In the cases when the predicted cross-section for fitted channels is zero (ω production in the $N5\pi$ and $N7\pi$ channels) the cross-sections are normalized arbitrarily to 1 mb.

Our first remark is that at lower multiplicities the charge branching ratios depend strongly on the hypothesis about resonance production. For higher multiplicities the dependence is weaker (except for the hypothesis of ω production, when some channels are forbidden). Therefore at lower multiplicities we have a strong correlation between the cross-section for resonance production and the charge branching ratios. At higher multiplicities we approach more nearly absolute predictions.

The results may be checked by comparing with experiment the measured charge branching ratios: one in each of the groups of channels $N2\pi$, $N4\pi$, and $N6\pi$. Moreover by computing and comparing with experiment the total cross-section for pion production and the cross-sections for no fit two-prong and four-prong events, each with or without a proton. This comparison is shown in the last five lines of Table II.

It is seen from the table that the hypothesis, pion only, is the best out of the six which are presented. In particular, as mentioned in Section 3, the total cross-section for pion production comes out very well. We shall see now what is the effect of the inclusion of resonance production.

The data about resonance production are summarized in Table III. The errors are of 20 - 30%. Resonances, other than those listed in the headings of the columns, are ignored and the cross-sections for the no resonance subchannels are adjusted so as to give the correct total cross-section for each channel. This is equivalent to the assumption that the effect of all those other less important subchannels averages out and gives the statistical result. For some subchannels only the production of N^{*++} was given in the experimental papers. In such cases the production of other components of the N^* isomultiplet was estimated using the statistical assumption. For the $N7\pi$ channels, where the resonance production was not determined we assumed by analogy with the $N6\pi$ channels that 50% goes with N^* production and the remaining 50% with $N^*\omega$ production.

The weighted averages of the cross-sections are given in the last column of Table II. Because of large errors in the cross-sections for resonance production these numbers are rather uncertain, but the overall agreement with experiment seems encouraging.

The experimental errors are too large to warrant a detailed analysis, however we would like to make a few comments. In the $N\pi\pi$ channels the N^* and ρ production affects very strongly the charge branching ratio. A large production of resonances would be incompatible with the observed partial cross-sections. Experimentally the production of resonances is small, but somewhat larger than expected. Assuming that both theory and experiment are right this might mean that there is some production of the $N^*_{\frac{1}{2}}$ resonances, which partly compensates the effect of the $N^*_{\frac{3}{2}}$ and of the ρ . In the $N4\pi$ channels there is an improvement with respect to the calculation with no resonances. In the $N6\pi$ channels the statistics are too poor to draw any conclusion.

The total cross-section comes out a little too small, however, changing within errors the branching ratios for resonance production it is possible to get also the exact result. Besides the production of ω -s in the $N5\pi$ channels was completely omitted, since there is no experimental data about it. Including it improves both the total cross-section and the cross-sections for four-prong no fits.

B. Nucleon-antinucleon annihilations at 3 GeV/c

As our second example we shall discuss the annihilations of $p\bar{p}$ pairs into pions. $p\bar{p}$ annihilations at 3 GeV/c were studied by Czyżewski et al. [10] and by Ferbel et al. [11]. We included in our compilation also the data of Danysz et al. [12] obtained at 3.28 GeV/c.

In Table IV we present the experimental cross-sections and the theoretical cross-sections calculated under various hypotheses, for $p\bar{p}$ annihilations with 2 - 8 pions in the final state.

In Table V the relevant experimental data about resonance production are collected. These data are rather incomplete; moreover some of them have large errors. Therefore the average values given in Table IV should be understood as rough estimates only. In order to complete the list of cross-sections we have to make some ad hoc assumptions. For multiplicities lower than eight pions we put equal to zero all the cross-sections for resonances or pairs of resonances which had not been observed. For the multiplicity 8, where none of the resonances had been observed, we chose the weight 0.2 for each of the five hypotheses considered.

It is seen from Table IV that in all the cases where experimental charge branching ratios are known the introduction of resonances gives an improvement of the predicted charge branching ratios. This is especially important for the annihilations into eight pions, where the hypothesis pions only gives particularly bad results.

In concluding this Section we would like to stress the importance of double resonance production. In the $\bar{p}n$ annihilation experiment, Bettini et al. [13] report a substantial production of pairs $\rho\rho$ in some fitted channels. Calculations show that this implies a much richer production of such pairs in some no fit channels and provides a very effective mechanism for filling the gap between the experimental total annihilation rate, and the total annihilation rate calculated using an incomplete set of hypotheses about resonance production.

C. K^+p scattering

In Table VI we present the experimental data [14] and the statistical results for the processes

$$K^+ + p \rightarrow K^* + N^* + \pi \qquad (32)$$

$$K^+ + p \rightarrow K^* + N + \pi + \pi \qquad (33)$$

$$K^{+} + p \rightarrow K + N^{*} + \pi + \pi \qquad (34)$$

$$K^{+} + p \rightarrow K + N + \pi + \pi + \pi \qquad (35)$$

at 3.0, 3.5 and 5.0 GeV/c incident kaon momentum. The theoretical cross-sections are normalized for each given channel and for each given energy to the total cross-section measured. The only exception is channel (32) at 3 GeV/c where, in order to get agreement with the experimental data, we normalized to 0.8 of the measured cross-section. This change is well within the limits of the experimental error.

The over-all agreement with experiment is good. In the whole table there are only two cases when the discrepancy between theory and experiment exceeds significantly the doubled experimental error. In both a neutron is produced at the highest energy (5 GeV/c).

ACKNOWLEDGEMENTS

The authors are greatful to Professor J. Prentki and Professor L. Van Hove for hospitality in the Theoretical Study Division at CERN. One of the authors (K.Z) wishes to thank Professor L. Van Hove and Dr. V. Henry for helpful conversations.

TABLE I

Comparison of the total cross-sections for pion production calculated by Bartke and Czyżewski [7] with experiment.

	π^+p		π^-p
	4 GeV/c	8 GeV/c	10 GeV/c
Experimental	20.1 mb	17.9 mb	18.5 mb
Theoretical	20.3 mb	18.3 mb	18.5 mb

TABLE II

π^+p interactions at 4 GeV/c. Cross-sections in mb.

Channel	Experiment	πN	πN^*	$\pi\omega N$	$\pi\omega N^*$	$\pi\rho N$	$\pi\rho N^*$	Average
n++	1.44	1.50	0.50					1.20
p+0	2.31	2.25	3.25			3.75		2.55
p++-	3.09	3.09	3.09			3.09	3.09	3.09
n++0		2.47	1.13			4.12	0.69	1.89
p+00		2.16	2.11			3.09	1.37	2.20
n+++-	0.93	1.25	0.84			0.67	0.25	0.86
p++0-	3.43	3.11	3.51	4.36	4.36	3.69	4.11	3.51
n++00		1.37	0.93			1.34	0.75	0.98
p+000		0.81	0.89			0.59	0.50	0.74
p+++--	0.25±0.04	0.25	0.25			0.25	0.25	0.25
n+++0-		0.43	0.29	0.40	0.13	0.62	0.33	0.29
p++00-		0.57	0.54	0.60	0.87	0.94	0.86	0.54
n++000		0.17	0.12			0.22	0.14	0.12
p+0000		0.07	0.10			0.07	0.05	0.10
n++++--	0.04±0.01	0.06	0.05			0.04	0.03	0.02
p+++0--	0.25±0.04	0.23	0.24	0.29	0.29	0.25	0.26	0.27
n+++00-		0.20	0.16	0.23	0.11	0.24	0.18	0.13
p++000-		0.18	0.20	0.22	0.20	0.21	0.23	0.18
n++0000		0.04	0.03			0.04	0.03	0.03
p+00000		0.02	0.02			0.01	0.01	0.01
p++++---	(0.01)	0.010	0.010			0.010	0.010	0.010
n++++0--		0.027	0.020	0.19	0.14	0.034	0.024	0.044
p+++00--		0.048	0.048	0.48	0.57	0.074	0.072	0.119
n+++000-		0.029	0.022	0.21	0.15	0.043	0.031	0.041
p++0000-		0.020	0.020	0.12	0.14	0.028	0.027	0.037
n++00000		0.004	0.003			0.004	0.004	0.003
p+000000		0.001	0.001			0.001	0.001	0.001
σ_{inel}	20.1	20.33	18.38			23.40	17.88	19.19
p+Z^0	3.32	3.06	3.10			3.76	1.95	3.05
n++Y^0	2.88	4.05	2.21			5.71	1.67	3.02
p++-Z^0	1.33	0.77	0.78			1.18	1.53	0.78
n+++-Y^0	0.87	0.66	0.47			0.89	0.88	0.49

+, -, 0, Y^0 and Z^0 denote π^+, π^-, π^0, one or more neutral particles, and more than one neutral particle. σ_{inel} does not include strange particle production.

TABLE III

π^+p interactions at 4 GeV/c. Experimental cross-sections for resonance production.

channel	cross-section in mb						Reference
	$N\pi$	$N^*\pi$	$N\pi\omega$	$N^*\pi\omega$	$N\pi\rho$	$N^*\pi\rho$	Brit-Ger. Collaboration
$p\pi^+\pi^0$	1.56	0.4	-	-	0.35	-	1965
$p\pi^+\pi^+\pi^-$	0.5	0.35	-	-	0.65	0.6	1965
$p\pi^+\pi^+\pi^-\pi^0$	1.0	1.7	0.5	0.35	0.1	0.2	1965
$p\pi^+\pi^+\pi^+\pi^-\pi^-$	-	0.25	-	-	-	-	1966
$p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$	-	0.10	-	0.15	-	-	1966

TABLE IV

$p\bar{p}$ interactions at 3 GeV/c. Cross-sections in mb.

Channel	Experiment	π	$\rho\pi$	$\omega\pi$	$\rho\rho\pi$	$\omega\rho\pi$	Average
+-	0.008±0.003	0.008					0.008
oo		0.002					0.002
+-o	0.3 ±0.1	0.3	0.3				0.30
ooo		0.035					0.03
++--	0.75 ±0.1	0.75	0.75		0.75		0.75
+-oo		1.06	1.8	1.0	6.		1.30
oooo		0.06					0.04
++--o	4.1 ±0.6	4.1	4.1	4.1	4.1	4.1	4.10
+-ooo		2.15	1.9	1.0	1.8		1.63
ooooo		0.09					0.05
+++---	1.05 ±0.15	1.05	1.05		1.05		1.05
++--oo	5.1 ±1.5	3.62	5.8	5.1	9.0	5.1	6.20
+-oooo		1.00	1.22	0.65	1.05		1.17
oooooo		0.02					0.00
+++---o	2.8 ±0.15	2.8	2.8	2.8	2.8	2.8	2.80
++--ooo	6.0 ±1.5	3.43	3.83	3.97	4.38	6.6	4.12
+-ooooo		0.58	0.44	0.24	0.26		0.38
ooooooo		0.015					0.00
++++----	0.11 ±0.015	0.11	0.11		0.11		0.11
+++---oo	2.6 ±0.5	0.66	1.06	2.6	1.30	2.6	2.68
++--oooo	2 ±1	0.42	0.65	1.36	0.68	1.2	1.43
+-oooooo		0.04	0.06	0.00	0.03		0.04
oooooooo		0.00					0.00

The notation used in this Table is the same as in Table II.

TABLE V

$p\bar{p}$ annihilations at 3 GeV/c. Experimental cross-sections for resonance production.

Channel	cross-section in mb					References
	$\rho^0\pi$	$\rho^\pm\pi$	$\omega\pi$	$\rho\rho\pi$	$\rho\omega\pi$	
$\pi^+\pi^+\pi^-\pi^-$	0.25					10)
$\pi^+\pi^+\pi^-\pi^-\pi^0$	0.8		0.3			10), 11)
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	1.			0.14		11), 12)
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^0$	0.9	0.2	0.9		0.3	11), 12)

TABLE VI

K^+p interactions. Cross-sections in mb.

	3.0 GeV/c		3.5 GeV/c		5.0 GeV/c	
	Exper	Th	Exper	Th	Exper	Th
$K^{*+}N^{*++}\pi^-$	117± 32	156	200±33	162	185±41	184
$K^{*o}N^{*++}\pi^o$	157± 38	111	80±27	122	180±32	138
$K^{*o}N^{*o}\pi^+$	21± 35	74	48±42	81	81±27	92
$K^{*+}N^{*o}\pi^+$	222±111	74	18±81	81	60±72	92
$K^{*+}p\,\pi^+\pi^-$	32± 54	24	52±39	63	197±52	159
$K^{*o}p\,\pi^+\pi^o$	8± 42	18	81±35	47	143±33	120
$K^{*o}n\,\pi^+\pi^+$	13± 16	12	9±18	32	17±15	79
$N^{*++}K^+\pi^o\pi^-$	78± 53	58	152±36	77	133±56	85
$N^{*++}K^o\pi^+\pi^-$	89± 42	72	97±53	96	123±28	106
$N^{*+}K^+\pi^+\pi^-$	9± 26	43	51±26	57	35±35	63
$N^{*o}K^+\pi^+\pi^o$	61±150	43	0±54	57	0±66	63
$N^{*o}K^o\pi^+\pi^+$	0± 69	22	0±54	29	39±48	32
$N^{*-}K^+\pi^+\pi^+$	32± 25	36	63±19	48	72±15	53
$p\,K^+\pi^+\pi^-\pi^o$	208± 87	186	229±57	206	486±80	375
$p\,K^o\pi^+\pi^+\pi^-$	114± 66	116	167±68	128	247±60	235
$n\,K^+\pi^+\pi^+\pi^-$	94± 40	116	165±34	128	109±33	235

REFERENCES

1) C. Schmid, Phys.Rev. to be published.

2) R.W. Bland, M.G. Bowler, J.L. Brown, G. Goldhaber, S. Goldhaber, J.A. Kadyk and G.H. Trilling, Phys.Rev.Letters 17, 939 (1966).

3) K. Zalewski, Acta Phys.Polon. 28, 207 (1965).

4) F. Cerulus, Nuovo Cimento Suppl. 15, 402 (1960).

5) F. Cerulus, Nuovo Cimento 19, 528 (1961).

6) J. Bartke, Nuclear Phys. 82, 673 (1966).

7) J. Bartke and O. Czyzewski, Berkeley Conference (1966).

8) Aachen-Berlin-Birmingham-Bonn-Hamburg-London (IC)-München Collaboration, Phys.Rev. 138, B897 (1965).

9) Aachen-Berlin-Bonn-Hamburg-München Collaboration, Nuovo Cimento 44, 530 (1966).

10) O. Czyzewski, B. Escoubes, Y. Goldschmidt-Clermont, M. Guinea-Moorhead, T. Hofmokl, D.R.O. Morrison and S. De Unamuno, Sienna International Conference on Elementary Particles, 1, 271 (1963).

11) T. Ferbel, J. Sandweiss, H.D. Taft, M. Gailloud, T.W. Morris, R.M. Lea and T.E. Kalergopulos, Proc. of 1962 Int. Conf. on High Energy Physics at CERN, p. 76 (1962), and
T. Ferbel, thesis presented at Yale University (1963) and
T. Ferbel, A. Firestone, J. Sandweiss, H.D. Taft, M. Gailloud, T.W. Morris, W.J. Willis, A.H. Bachman, P. Baumel and R.M. Lea, Phys.Rev. 143, 1096 (1966).

12) J.A. Danysz, thesis presented in Cracov (1966) and
J.A. Danysz, B.R. French and V. Simak, preprint CERN/D.Ph.II/
Physics 67-1 (submitted to N.C.).

13) A. Bettini et al. quoted by Goldhaber at the Berkeley Conference, (1966).

14) V. Henri, private communication.