ISOSPIN ANALYSIS OF THE DIFFRACTION DISSOCIATION PROCESSES IN K^{+}p INTERACTIONS AT 5 AND 8.2 GeV/c [1]

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An analysis of the diffraction dissociation processes in K^{+}p interactions at 5 and 8.2 GeV/c K^{+} incoming momentum is presented. An isospin analysis was performed for the single dissociation processes:

$$K^{+} \rightarrow K^{*}(890)\pi \quad \text{and} \quad p \rightarrow \Delta(1236)\pi,$$

observed in the reactions:

$$K^{+}\mathrm{p} \rightarrow K^{*}(890)\pi \mathrm{N} \quad \text{and} \quad K^{+}\mathrm{p} \rightarrow K\pi\Delta(1236).$$

It confirmed the dominance of the $I = 1/2$ component in the Q bump and in the low mass $\Delta\pi$ enhancement. It is found that the interference term between the isospin 1/2 and isospin 3/2 amplitudes is small for Q region and is quite sizable for the low $\Delta\pi$ mass enhancement.

1. Introduction

We present an isospin analysis of the reactions:

$$K^{+}\mathrm{p} \rightarrow K^{*}(890)\pi\, \mathrm{N} \tag{1.1}$$

and

$$K^{+}\mathrm{p} \rightarrow K\pi\Delta(1236), \tag{1.2}$$

at 5 and 8.2 GeV/c, K^{+} incoming momentum.

At high energies *i.e.* above about 10 GeV the first two reactions are expected to be dominated by the single diffraction dissociation processes:

$$K^{+} \rightarrow K^{*}(890)\pi \tag{1.3}$$

and

$$\mathrm{p} \rightarrow \Delta(1236)\pi, \tag{1.4}$$

[1] The experimental data used in the analysis are the CERN-Brussels K^{+} Collaboration data made kindly available to the authors.

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where the system in brackets has small effective mass. Since, in the process of the diffraction dissociation of a particle the isospin should not change, one expects that the $K^*(890)\pi$ or $\Delta(1236)\pi$ system produced in these processes should be in the total isospin state $I = 1/2$.

Therefore any contribution from $I = 3/2$ must come from the non-diffractive processes. These processes at energies of 5 and 8 GeV studied here may be quite important. The possibility of selecting the isospin 1/2 contribution apart from its intrinsic interest helps to reduce the contribution of non-diffractive processes and facilitate the study of diffraction dissociation already at energies of a few GeV.

The isospin analysis can be performed for the reactions of the type (1.1) and (1.2) if the data on the different charge channels of these reactions are available.

The details of the isospin analysis can be found in Ref. [1]. Experimental results of such analysis have already been published by several groups (for a review see Ref. [2, 3].)

In Section 2 of this paper the essential experimental information concerning reactions (1.1)–(1.2) used in the analysis is presented. Section 3 is devoted to the analysis of single diffraction dissociation processes. Section 4 summarizes the results. The derivation of the essential formulae used in the analysis is sketched in the Appendix.

2. *Experimental details*

Data on four-body reactions

$$K^+p \rightarrow K^+p\pi^+\pi^- \tag{2.1}$$

$$\rightarrow K^0p\pi^+\pi^0 \tag{2.2}$$

$$\rightarrow K^0n\pi^+\pi^+ \tag{2.3}$$

at 5 and 8.2 GeV/c were used in the analysis. Numbers of events and cross-sections for every reaction are given in Table I[2].

TABLE I

Samples of events used in the analysis

Reaction	5 GeV/c		8.2 GeV/c	
	Events	[μb]	Events	[μb]
$K^+p \rightarrow K^+\pi^+\pi^-p$	6245	1950 ± 100	4781*	1350 ± 60
$\rightarrow K^0\pi^+\pi^0p$	1728	1680 ± 100	2677	1310 ± 80
$\rightarrow K^0\pi^+\pi^+n$	662	410 ± 100	608	310 ± 30

* Partial sample.

Experimental details concerning the selection of events and calculation of cross--sections were already published by the Bruxelles-CERN collaboration. For the 5 GeV/c data, see *e.g.* references [4] and [5]. At 8.2 GeV/c the following general selection criteria have been used for all studied reactions:

(*i*) only fits with χ^2 probability greater than 0.01 have been considered,

[2] The analysis of the reaction (2.1) at 8.2 GeV/c has been done on a part of the existing data.

(*ii*) in the case of $4C-1C$ ambiguity the $4C$ fit has been accepted. If N fits were accepted each was given weight $1/N$,

(*iii*) in the case of ambiguity between N fits with the same number of constraints (*e.g.* $4C-4C$ or $1C-1C$) the one with 5 times greater χ^2 probability has been retained, otherwise all N fits were considered with weight $1/N$ each.

The reaction cross-sections were taken from Ref. [6].

In order to perform the isospin analysis outlined in the Appendix one has to select channels corresponding to the production of $K^*(890)$ or $\Delta(1236)$ from the data on reactions (2.1)–(2.3). Through out the presented analysis these resonances were selected merely by the following mass cuts:

$$0.84 \text{ GeV} < M(K\pi) < 0.94 \text{ GeV} \tag{2.4}$$

for $K^*(890)$ and

$$1.14 \text{ GeV} < M(N\pi) < 1.34 \text{ GeV} \tag{2.5}$$

for $\Delta(1236)$.

In such a procedure non-resonant background events are also accepted. Their contribution although generally rather small (of the order of 10–20%), can be as large as 50% (*e.g.* for $\Delta^0(1236)$).

It is very difficult to correct the present analysis for the inclusion of background events. The only hope is that since, the least dominant resonances (like $\Delta^0(1236)$) are

TABLE II

Resonance channel cross-sections

Channel	Cross-section [μb]	
	5 GeV/c	8.2 GeV/c
$K^+p \to K^+\pi^+\pi^-p$	1950 ± 100	1350 ± 60
$\to K^{*0}(890)\pi^+p$	520 ± 40	385 ± 30
$\to K^+\pi^-\Delta^{++}(1236)$	459 ± 52	369 ± 28
$\to K^+\pi^+\Delta^0(1236)$	111 ± 42	69 ± 17
$\to K^{*0}(890)\Delta^{++}(1236)$	286 ± 30	119 ± 20
$K^+p \to K^0\pi^+\pi^0p$	1680 ± 100	1310 ± 80
$\to K^{*+}(890)\pi^0p$	385 ± 40	194 ± 23
$\to K^0\pi^0\Delta^{++}(1236)$	369 ± 40	230 ± 27
$\to K^{*+}(890)\Delta^+(1236)$	40 ± 20	34 ± 10
$\to K^{*0}(890)\Delta^{++}(1236)$	149 ± 30	45 ± 12
$K^+p \to K^0\pi^+\pi^+n$	410 ± 100	310 ± 30
$\to K^{*+}(890)\pi^+n$	134 ± 25	102 ± 18
$\to K^{*+}(890)\Delta^+(1236)$	19 ± 10	18 ± 9

produced with small cross sections compared to others, the uncertainty in their selection will not strongly affect the whole analysis.

The resonance channels cross sections were calculated using the simplest method, based on counting the number of events above a hand drawn background inside the resonance mass band and correcting it for the resonance wings[3]. Details of this method are described in reference [7]. Cross sections are listed in Table II.

3. *Isospin analysis*

The aim of the analysis is to separate different isospin contributions in the production of $K^*(890)\pi$ and $\Delta(1236)\pi$ systems in the reactions of the type (1.1) and (1.2).

Formulae relating the amplitude squared for isospin $I = 1/2$, $I = 3/2$ and the interference between the amplitudes to the cross sections of the processes observed are derived in the Appendix.

Using the formulae (A3)–(A8) we have calculated the contributions of $I = 1/2$, $I = 3/2$ and of the interference term in the production of $K^*\pi$ and $\Delta\pi$ systems. Apart from the total cross sections we have also analysed the effective mass distributions, the distributions of t' and of the Jackson decay angles for different isospin states of the $K^*\pi$ and $\Delta\pi$ systems.

The main experimental difficulty in the interpretation of the results thus obtained is the fact that at 5 and 8.2 GeV/c part of the events in resonance channels of the type (1.1) and (1.2) which were selected merely by the mass cuts (2.4) and (2.5) corresponds to the simultaneous production of $K^*(890)$ and $\Delta(1236)$. Although their presence does not invalidate the isospin analysis itself it can cast some doubt on the validity of the study of the production of $K^*(890)\pi$ and $\Delta(1236)\pi$ systems[4].

In order to correct for the influence of these events on the calculated distributions the following procedure was adopted[5]:

(*i*) for the study of $K^*(890)\pi$ and $\Delta(1236)\pi$ effective mass distributions the corrections for the reflections from reactions:

$$K^+p \rightarrow K^*(890)\,\Delta(1236),$$

[3] Cross-sections listed in Table II differ at 5 GeV/c from the ones obtained with the help of the multidimensional fitting procedure (see reference [5]). These differences seem to originate from two sources, external to both methods in question. One is the different treatment of the background under the resonance peaks. In reference [5] phase space shape was accepted, while in this paper, a more realistic hand drawn shape was used. The second one is the different description of the resonance peaks. In reference [5] p-wave relativistic Breit-Wigner functions were applied for both $K^*(890)$ and $\Delta(1236)$. In this paper simple non-relativistic Breit-Wigner functions were used. The main difference in the estimated resonance contribution when using these two types of Breit-Wigner functions comes from the high mass resonance wing where both approaches are poorly justified. For simplicity and consistency in the treatment of the data at 5 and 8.2 GeV/c we have applied the method described in reference [7] for both energies.

[4] At higher energy *e. g.* above 20 GeV/c the present analysis should be free from this difficulty as it is expected (see *e. g.* Ref. [8]) that the simultaneous production of $K^*(890)$ and $\Delta(1236)$ vanishes quickly with increasing momentum.

[5] In the calculation of the isospin cross section, the resonance channels cross-sections used do not include simultaneous $K^*(890)\Delta(1236)$ production.

were made using the data on reactions

$$K^+p \to K^{*0}(890)\,\Delta^{++}(1236)$$

as explained below,

(*ii*) for the study of t', $\cos\Theta_J$ and φ_J the following mass cuts were made

$$M(K^*(890)\pi) < 1.4 \text{ GeV} \quad \text{and} \quad M(\Delta(1236)\pi) < 1.8 \text{ GeV}.$$

These cuts leave the diffractive low mass maxima (if present) undisturbed and at the same time greatly reduce the possible reflection from the simultaneous $K^*(890)$ and $\Delta(1236)$ production (this is a kinematical effect).

Our results concerning the isospin channel cross sections are given in Table III. These cross-sections were obtained using the total channel cross-sections given in Table II.

TABLE III

Contributions of different isospin states [μb]

System	p_{lab} [GeV/c]	$I = 1/2$	$I = 3/2$	Interference term
$K^*(890)$	5	1310 ± 80	268 ± 40	202 ± 90
	8.2	817 ± 60	204 ± 40	-32 ± 60
$\Delta(1236)$	5	950 ± 260	820 ± 90	220 ± 285
	8.2	701 ± 110	511 ± 60	73 ± 120

The effective mass distributions are shown in Figs 1 and 2 for the $K^*\pi$ and the $\Delta\pi$ systems respectively. These mass distributions were corrected, as mentioned above, for the reflections from reactions $K^+p \to K^*(890)\,\Delta(1236)$. To calculate these corrections we have considered the effective mass distributions of $K^*\pi$ and $\Delta\pi$ from reaction $K^+p \to K^{*0}(890)\,\Delta^{++}(1236)$. These effective mass distributions were then normalized to the cross sections of simultaneous production of $K^*(890)$ and $\Delta(1236)$ observed in a given resonance channel (see reactions (A9)–(A14)) and subtracted from the original distributions.

The following general remarks can be made:

1) The amplitude corresponding to the isospin $I = 1/2$ is dominating, both for $K^*(890)\pi$ and $\Delta(1236)\pi$ systems.

2) The effective mass distributions display clear low mass enhancements, both for $K^*(890)\pi$ and $\Delta(1236)\pi$ systems in the isospin state $I = 1/2$. These enhancements can be identified with the known "Q" and "$\Delta\pi$" bumps (see reference [9] and [10]). The interference term between isospin $I = 1/2$ and $I = 3/2$ amplitudes is comparatively small for all $K^*\pi$ masses but reaches sizable values at low $\Delta\pi$ masses.

3) The production and decay characteristics of the $I = 1/2$ low mass enhancements *i.e.* t', $\cos\Theta_J$ and φ_J distributions (Figs 3–8) do not show any remarkable difference at

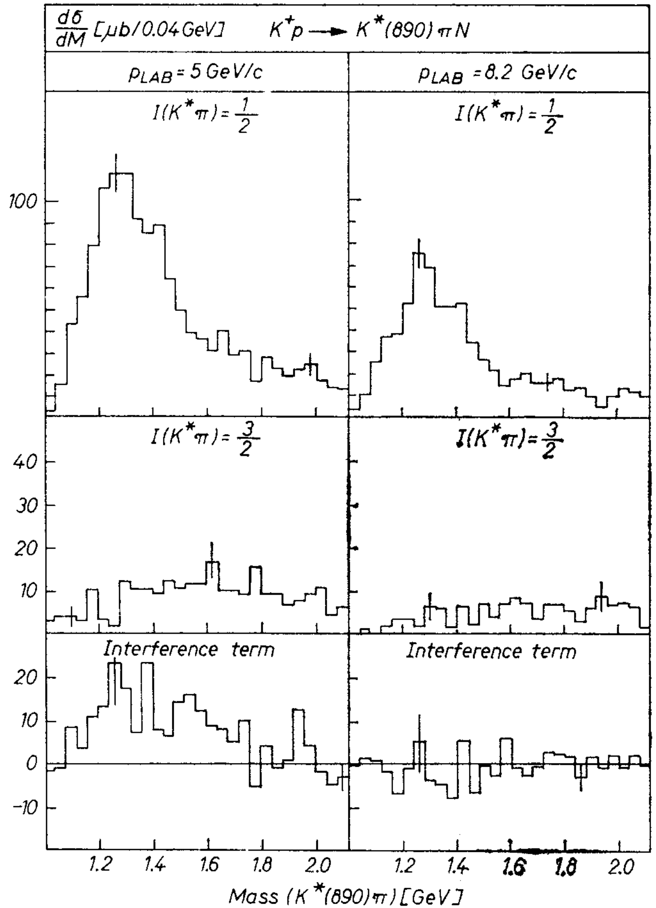

Fig. 1

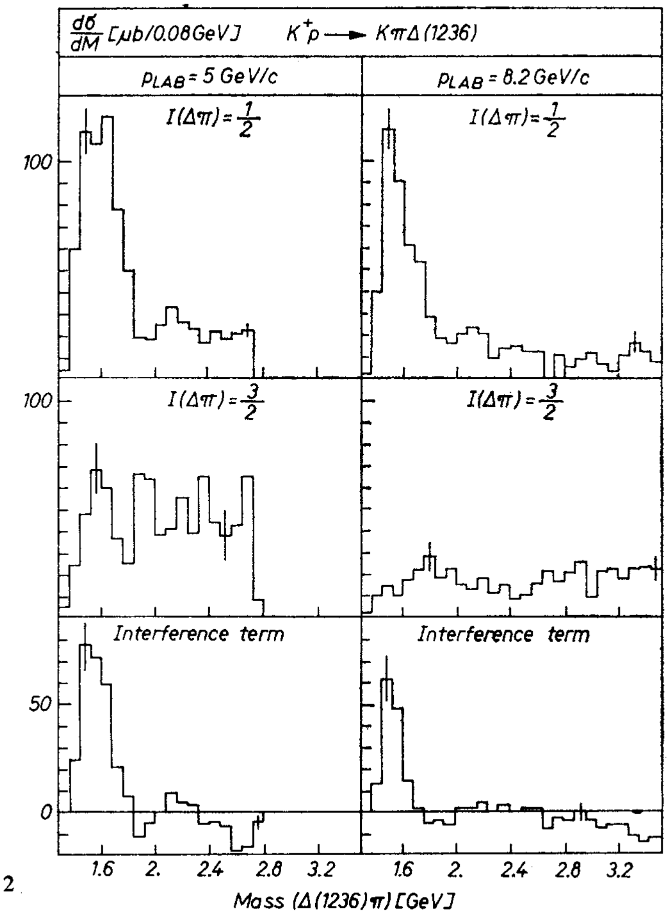

Fig. 2

Fig. 1. Distributions of the $K^*(890)\pi$ effective mass for different isospin states of the $K^*(890)\pi$ system in reaction: $K^+p \to K^*(890)\pi N$ at 5 and 8.2 GeV/c K^+ incoming momentum

Fig. 2. Distributions of the $\Delta(1236)\pi$ effective mass for different isospin states of the $\Delta(1236)\pi$ system in reaction $K^+p \to K\pi\Delta(1236)$ at 5 and 8.2 GeV/c K^+ incoming momentum

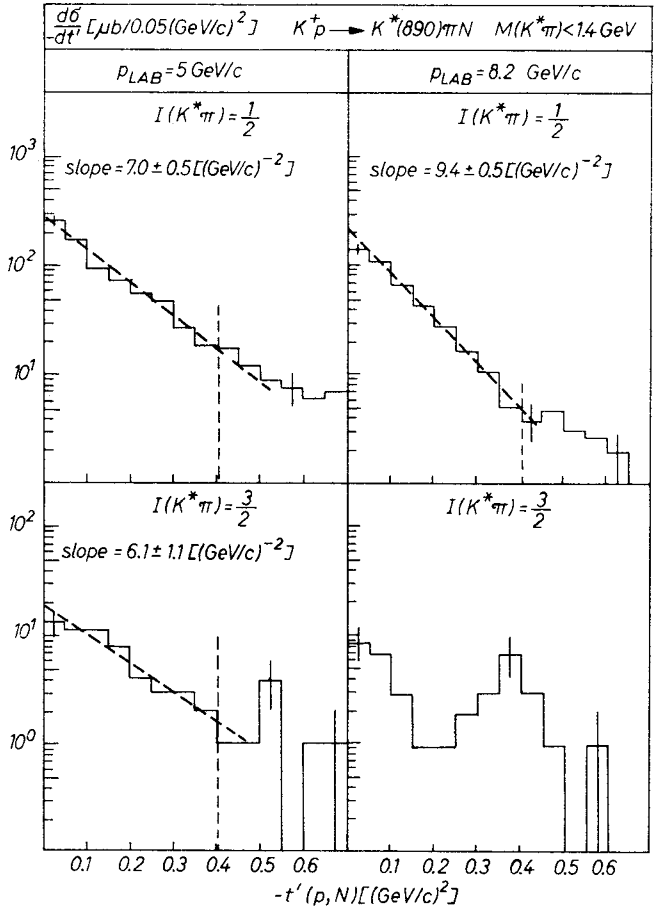

Fig. 3

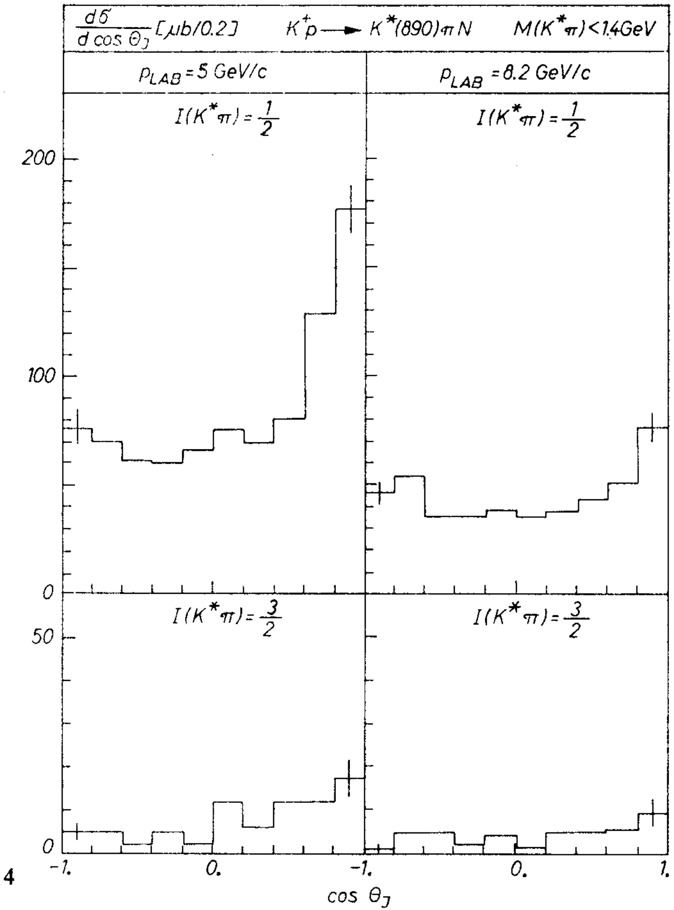

Fig. 4

Fig. 3. Distributions of the four momentum transfer t'_{K^+}, $(K^*\pi)$ for the different isospin states of the $K^*(890)\pi$ system produced in reactions: $K^+p \to K^*(890)\pi N$ at 5 and 8.2 GeV/c with mass cut $(K^*(890)\pi) < 1.4$ GeV

Fig. 4. Distributions of the cos $\Theta_{\mathrm{Jackson}}$ for the different isospin states of the $K^*(890)\pi$ system produced in reactions: $K^+p \to K^*(890)\pi N$ at 5 and 8.2 GeV/c with mass cut $(K^*(890)\pi) < 1.4$ GeV

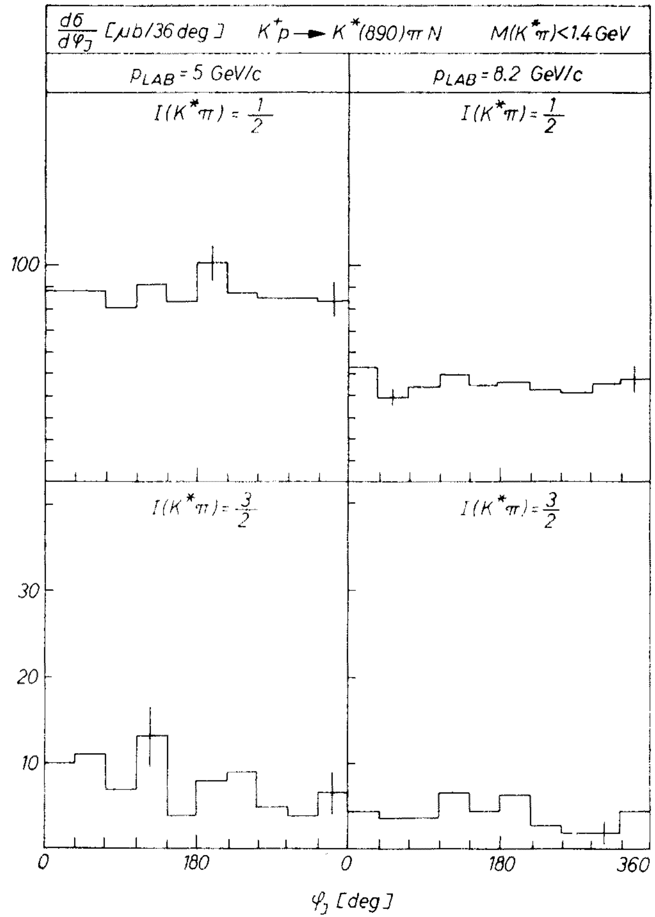

Fig. 5

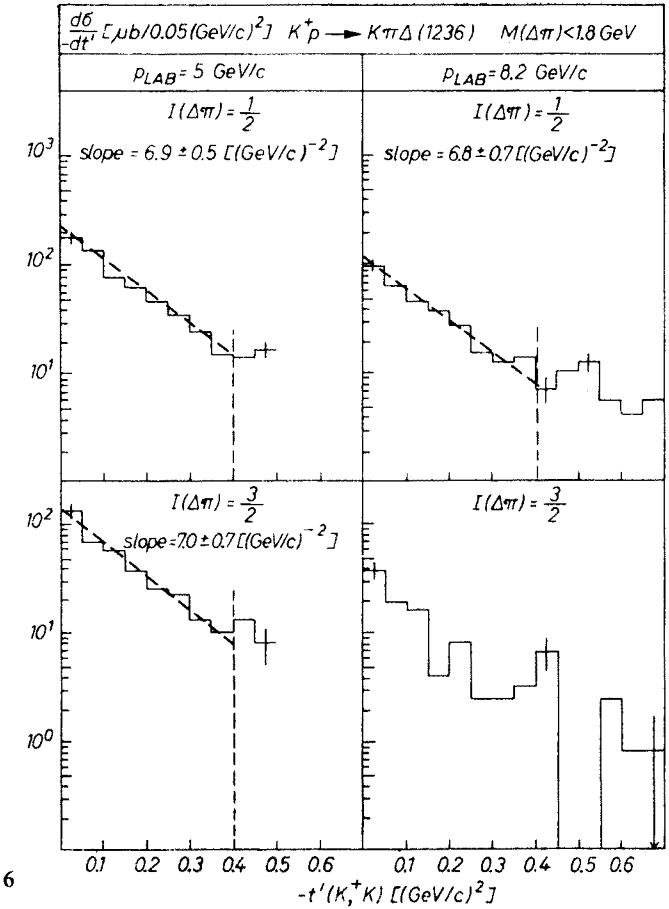

Fig. 6

Fig. 5. Distributions of the φ_{Jackson} for the different isospin states of the $K^*(890)\pi$ system produced in reactions: $K^+p \to K^*(890)\pi N$ at 5 and 8.2 GeV/c with mass cut $(K^*(890)\pi) < 1.4$ GeV

Fig. 6. Distributions of the four momentum transfer t'p, $(\Delta\pi)$ for different isospin states of $\Delta(1236)\pi$ system produced in reactions: $K^+p \to (K\pi\Delta(1236))$ at 5 and 8.2 GeV/c with the mass cut $(\Delta(1236)\pi) < 1.8$ GeV

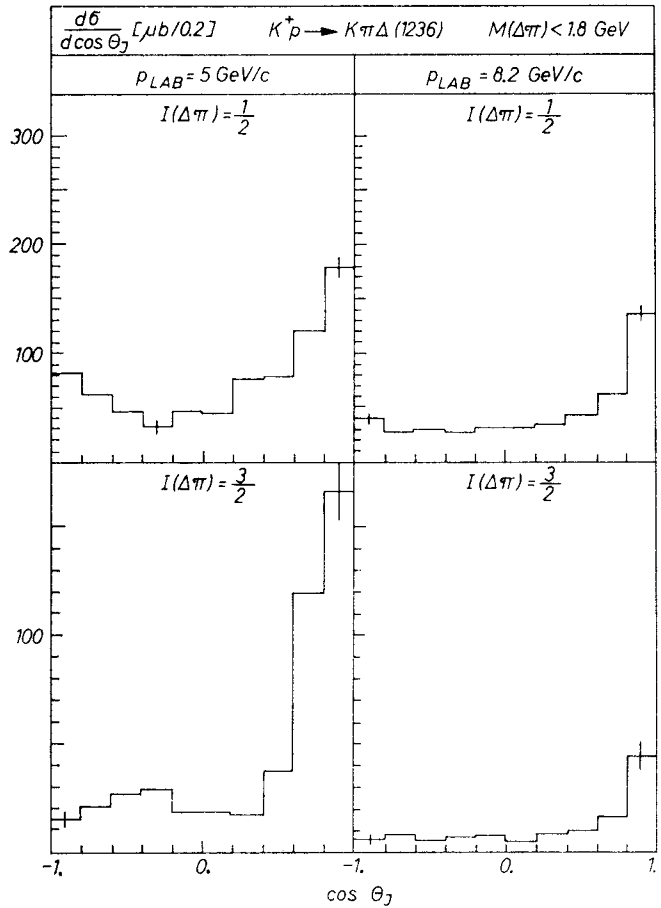

Fig. 7

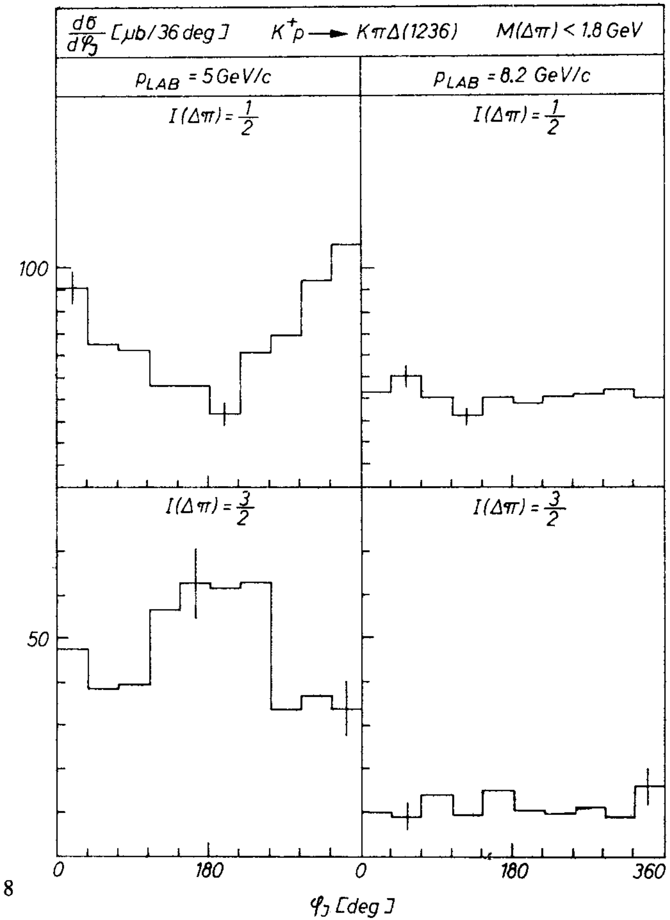

Fig. 8

Fig. 7. Distributions of the cos Θ_{Jackson} for different isospin states of $\Delta(1236)\pi$ system produced in reactions: $K^+p \to (K\pi\Delta(1236))$ at 5 and 8.2 GeV/c with the mass cut $(\Delta(1236)\pi) < 1.8$ GeV

Fig. 8. Distributions of the φ_{Jackson} for different isospin states of $\Delta(1236)\pi$ system produced in reactions: $K^+p \to (K\pi\Delta(1236))$ at 5 and 8.2 GeV/c with the mass cut $(\Delta(1236)\pi) < 1.8$ GeV

the considered energies with those observed for $I = 3/2$ amplitude. Clearly, the observed asymmetry in $\cos\Theta_J$ distributions should be associated with the reflection from reactions with simultaneous production of $K^*(890)$ and $\Delta(1236)$ [10], suggesting that high energy data would be more suitable to study the decay characteristics.

The presence and the dominance of the $I = 1/2$ low mass enhancements in the production of $K^*(890)\pi$ and $\Delta(1236)\pi$ systems can be considered as confirmation of the importance of the diffraction dissociation processes:

$$K^+ \to K^*(890)\pi \quad \text{and} \quad p \to \Delta(1236)\pi,$$

already at the energies of a few GeV.

4. Conclusions

The following K^+p reactions

$$K^+p \to K^+\pi^+\pi^-p,$$

$$\to K^0\pi^+\pi^0p,$$

and

$$\to K^0\pi^+\pi^+n,$$

at 5 and 8.2 GeV/c were analysed to look for the possible kaon and proton diffraction dissociation processes:

$$K^+ \to K^*(890)\pi, \; p \to \Delta(1236)\pi.$$

For the resonance channels:

$$K^+p \to K^*(890)\pi N \tag{4.1}$$

and

$$K^+p \to K\pi\, \Delta(1236), \tag{4.2}$$

an isospin analysis has been performed and the isospin $I = 1/2$ and $I = 3/2$ contributions in the production of $K^*(890)\pi$ and $\Delta(1236)\pi$ systems have been separated. For the low effective masses of both the ($K^*(890)\pi$) and ($\Delta(1236)\pi$) systems the $I = 1/2$ contribution dominates. The effective mass distributions of the $I = 1/2$ part of the $K^*\pi$ and $\Delta\pi$ systems are dominated by the well known Q and $\Delta\pi$ enhancements. These $I = 1/2$ enhancements are produced peripherally but no striking differences between the $I = 1/2$ and $I = 3/2$ t' distributions can be observed. A detailed study of their decay characteristics seems to require data at much higher incident momenta, for which the reflections from non-diffractive processes are greatly reduced by kinematics.

The integrated cross section corresponding to the interference between the isospin $I = 1/2$ and $I = 3/2$ amplitudes is small for the Q region but quite sizable for the low mass $\Delta\pi$ enhancement. Since in the case of K^+p interactions, the vanishing of the interference can be associated with the dominance of Pomeron exchange[6], the above observations suggest that the contribution of the dissociation like processes is more important in the case of $K^*\pi$, at considered energies.

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APPENDIX

Derivation of isospin relations

Since the K^+p initial state is a pure $I = 1$, $I_z = 1$ state, the system $K^*\pi$ in reaction (1.1) and the systems $\Delta\pi$ in reaction (1.2) can only be in the $I = 1/2$ or $I = 3/2$ state.

Treating the reactions (1.1) and (1.2) as two body reactions:

$$K^+p \to 1+2, \tag{A1}$$

where "1" and "2" denote respectively the systems $K^*(890)\pi$, $\Delta(1236)\pi$ or the single particle N or K, one can use the Eckart-Wigner theorem to write the reaction amplitude in the form:

$$A_R = \sum_{\substack{I_1, I_{1z} \\ I_2, I_{2z}}} C(I_1, I_{1z}, I_2, I_{2z}|1, 1) f_{I_1, I_2}, \tag{A2}$$

where: I_1, I_{1z}, I_2, I_{2z} denote the isospin and its projection for the final bodies; f_{I_1,I_2} is the reduced amplitude for the production of the final bodies in isospin I_1 and I_2 states.

Using the formula (A2) it is easy to write down the amplitudes for the different charge configurations of reactions (1.1) and (1.2) and try to extract the reduced amplitudes f_{I_1,I_2}. This can be done for reactions (1.1) and (1.2). The amplitudes f_{I_1} for the process of production of $K^*(890)\pi$ system can be expressed in the forms[7]

$$\int |f^K_{1/2}|^2 dV = \sigma_1 + \sigma_2 - 1/3\sigma_3 \tag{A3}$$

$$\int |f^K_{3/2}|^2 dV = 4/3\sigma_3 \tag{A4}$$

$$\int \mathrm{Re}\, f^K_{1/2} \times f^{K*}_{3/2} dV = \frac{1}{\sqrt{2}}(2\sigma_2 - \sigma_1 - 1/3\sigma_3) \tag{A5}$$

and for the system $\Delta\pi$ in the forms:

$$\int / f^p_{1/2}|^2 dV = \tfrac{4}{3}\sigma_4 + 2\sigma_6 - \tfrac{8}{9}\sigma_5 \tag{A6}$$

[6] This conclusion follows from the fact that since the Pomeron exchange process is expected to be represented by the purely imaginary amplitude therefore it cannot interfere with the purely real amplitude expected to represent the sum of other exchanges for the exotic s channel K^+p interactions.

[7] Subscript of f_{I_2} refers to the total isospin of the $K^*\pi$ or $\Delta\pi$ system. The remaining particle in reaction (1.1) or (1.2) has always $I_2 = 1/2$. Integration is carried over any volume of phase space.

$$\int |f^{p}_{3/2}|^2 dV = \tfrac{20}{9}\, \sigma_5 \tag{A7}$$

$$\int \mathrm{Re}\, f^{p}_{1/2} \times f^{p*}_{3/2} dV = \frac{\sqrt{5}}{3}\left(3\sigma_6 - \sigma_4 - \frac{2}{3}\sigma_5\right) \tag{A8}$$

where the integration region common for all the integrals may be chosen arbitrarily and σ_i's denote the cross sections for the following processes:

$$\sigma_1 : K^+p \to K^{*0}(890)\pi^+p \tag{A9}$$

$$\sigma_2 : K^+p \to K^{*+}(890)\pi^0p \tag{A10}$$

$$\sigma_3 : K^+p \to K^{*+}(890)\pi^+n \tag{A11}$$

$$\sigma_4 : K^+p \to K^+\pi^-\Delta^{++}(1236) \tag{A12}$$

$$\sigma_5 : K^+p \to K^0\pi^0\Delta^{++}(1236) \tag{A13}$$

$$\sigma_6 : K^+p \to K^+\pi^+\Delta^0(1236) \tag{A14}$$

REFERENCES

[1] Z. Koba, R. Møllerud, L. Veje, *Nucl. Phys.*, **B26**, 134 (1971).

[2] F. Verbeure, *Experimental Results on Exclusive Reactions*, rapporteur's talk at the 3rd International Colloquium on Multiparticle Reactions, Zakopane, Poland. Also CERN/D. Ph. II/Phys. 72-42.

[3] N. A. Törnqvist, *Comments on Isospin Analysis of Diffraction Dissociation*, Preprint of the Research Institute of Helsinki No. 18-71, August 1971.

[4] R. George *et al.*, Brussels-CERN Collaboration, *Nuovo Cimento*, **49**, 9 (1967).

[5] W. De Baere *et al.*, Brussels-CERN Collaboration, Nuovo Cimento, **61A**, 397 (1969).

[6] W. De Baere *et al.*, *Experimental Results on K^+p Interactions at* 5 *and* 8.2 *GeV/c Incoming K^+ Momentum*, Brussels-CERN Collaboration, CERN/D. Ph. II/Phys. 72-36.

[7] A. Eskreys, J. Figiel, P. Malecki, A. Zalewska, K. Zalewski, *Method of estimating the cross sections for resonance production*, Report of Institute of Nuclear Physics, No. 840/TH/1973.

[8] D. R. O. Morrison, *Phys. Lett.*, **22**, 528 (1966).

[9] A. Firestone, Proceedings of International Conference on Meson Spectroscopy p. 229 (1970), Columbia University Press, New York.

[10] G. Ciapetti *et al.*, CERN-Birmingham-Brussels-Mons-Saclay-Paris Collaboration, *Study of the reaction $K^+p \to K^{*0}(890)\Delta^{++}$ from 4.6-16.0 GeV/c*, CERN, preprint CERN/D. Ph. II/Phys. 73-19.