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STUDY OF MESON RESONANCE PRODUCTION IN π^-N AND $\pi^{-12}C$ INTERACTIONS AT 40 GEV/C

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1. INTRODUCTION

In the recent years it has been established that copious resonance production is an important feature of multiple processes at high energies. As is shown in papers [1-3], about 50-80% of the observed secondary particles produced in these processes arise via the decay of known resonances. Since that a dominant trend in an experimental study of the dynamics of multiple processes is nowadays to investigate characteristics of resonance production.

Some characteristics of resonance production were discussed previously in reviews [4,5]. In this paper we present only new experimental results on light meson resonance (ρ°, ω° and f°) production in π N(N = p,n) and $\pi^- \, {}^{12}C$ interactions at 40 GeV/c. These results were obtained by the 2-m propane-bubble-chamber group at the LHE, JINR.

2. EXPERIMANTAL METHOD FOR STUDYING RESONANCE STATES

Unlike the situation at low energies, at high energies ($E_{LAB} \geq 10$ GeV) the resonance extraction procedure is a considerable difficulty due to the fact that hadron-nucleon or hadron-nucleus collision produces many particles ($\langle n \rangle \gtrsim 10-12$). Indeed, even if one assumes that only ρ° mesons are produced, then their number is $N(\rho) = n/2$, while the number of background combinations amounts to $N(\pi^+\pi^-) \sim n^2$. That's why there are serious methodic problems with studying characteristics of resonance production.

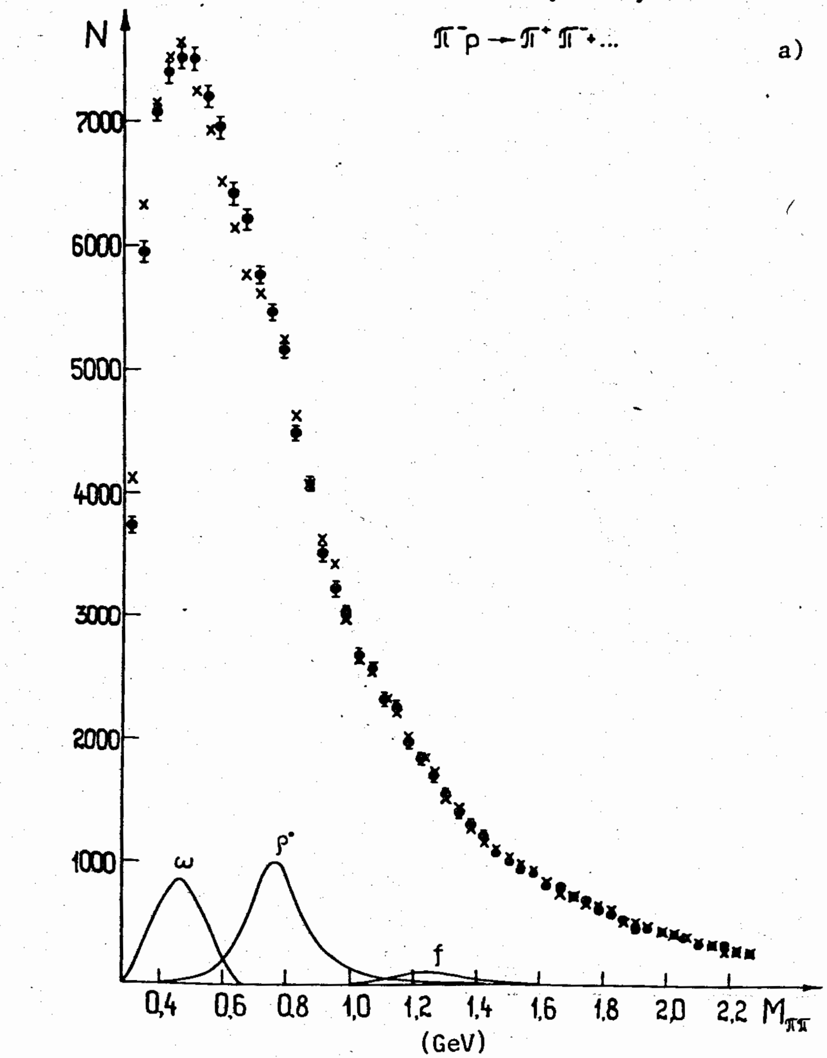
Details of the experiment at 40 GeV/c (scanning procedure, selection criteria, track identification, etc.) are published elsewhere [6-9].

The analysis was based on ~15000 inelastic π^-p interactions with the number of charged secondaries $n_{ch} \gtrsim 2$, ~5000 π^-n interactions with $n_{ch} \geq 3$ and ~11000 π^-C interactions with $n_{ch} \geq 4$. The slow protons with $0.15 \leq P_{lab.} \leq 0.7$ GeV/c were identified by ionization. The rest of the charged secondaries were considered as pions. In this case ~15% of positive pions were misidentified as fast protons. The $K^\pm$ and $\Sigma^\pm$ contamination was about 4-5% of the number of charged particles [9].

To obtain characteristics of ρ, ω, f resonance production in the reaction

$$\pi^- A \to \pi^+ \pi^- X, \tag{1}$$

where $A = p, n, {}^{12}C$, the $\pi^+ \pi^-$ invariant mass distribution $M(\pi^+\pi^-)$ was analyzed. In so doing the correct choice of background is very important. It is quite evident also that while considering the invariant dipion mass distribution $M(\pi^+\pi^-)$, we should take into account the contribution of the resonances with three-body decay modes containing



$(\pi^+\pi^-)$ -pairs in the final states. At our energy it is reasonable to take into account ω- and η-resonances with $(\pi^+\pi^-\pi^o)$ decay modes. But the cross section of η-meson in the reaction (1) at 40 GeV/c is estimated to be small. Moreover, the branching ratio of the $(\pi^+\pi^-\pi^o)$ channel for η is equal to 25%. So for the experimental analysis we consider the reflection of $\omega \to \pi^+\pi^-\pi^o$ decay into the dipion invariant mass distribution $M(\pi^+\pi^-)$.

In fig. 1 we show the invariant mass distribution $M(\pi^+\pi^-)$ obtained in the reactions (1). This distribution was fitted by the following function:

$$\frac{dN}{dM} = \Phi(M)[1 + \alpha B W_\rho(M) + \beta B W_f(M) + \gamma F(M)], \tag{2}$$

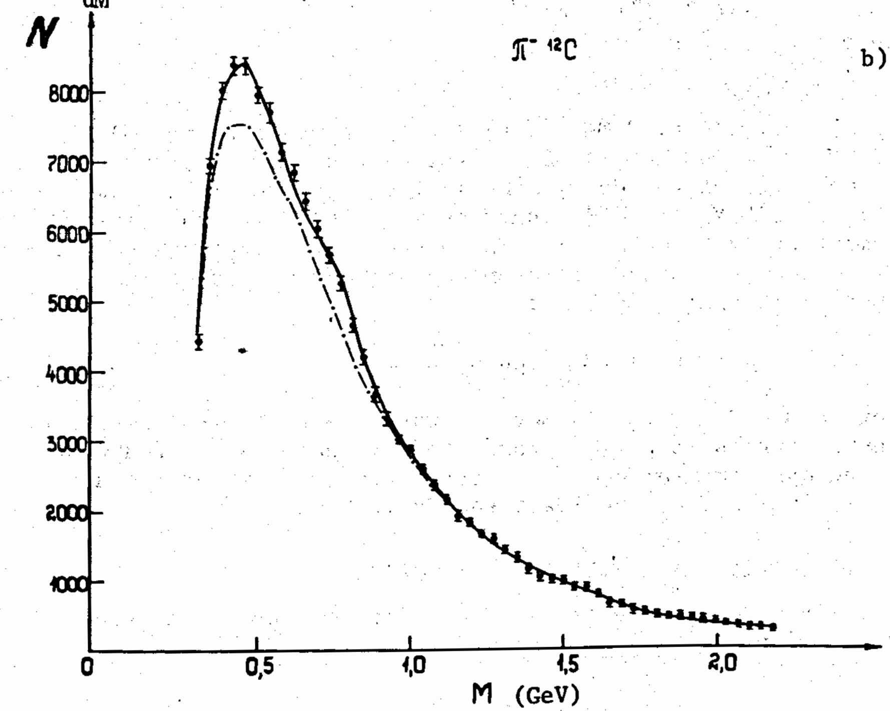


Fig. 1. The inclusive invariant mass distribution $M(\pi^+\pi^-)$ for π^-p(a) and for $\pi^- \, {}^{12}C$(b) interactions. (a) ● - Experimental data. × - Results of the fit by formula (2). The contributions of ρ, ω and f-resonances are given in the lower part of the picture. (b) ● - Experimental data. —— - Results of the fit by formula (2). -·-·- - Background distribution.

where $\Phi(M)$ is the background distribution; $BW(M)$ the relativistic Breit-Wigner function; $F(M)$, invariant mass distribution of $\pi^+\pi^-$ pairs coming from the $\omega \to \pi^+\pi^-\pi^o$ decay; α, β and γ the particle contributions of ρ^o, f and ω resonances.

We use the invariant mass distribution $M(\pi^\pm\pi^\pm)$ as a background in the following form:

$$\Phi(M) = a\frac{dN}{dM(\pi^+\pi^+)} + b\frac{dN}{dM(\pi^-\pi^-)}, \quad (3)$$

where a and b are normalizing factors. Breit-Wigner functions were taken as follows:

$$BW(M) = \frac{M^2}{q}\frac{M_0\Gamma}{(M^2-M_0^2) + M_0^2\Gamma^2}, \quad (4)$$

where

$$\Gamma = \Gamma_0\,(q/q_0)^{2\ell+1}\,(M/M_0), \quad (5)$$

$M_0 = 770$ MeV, $\Gamma_0 = 150$ MeV, $\ell = 1$ (in the case of ρ^o meson); $M_0 = 1270$ MeV, $\Gamma_0 = 180$ MeV, $\ell = 2$ (in the case of f meson) and q is the momentum of the decay pion in the resonance rest frame, q_0 is q at $M = M_0$. The F(M) function was taken with the matrix element of $\omega \to 3\pi$ decay. The influence of the experimental errors $\sigma(m)$ on the shape of resonance signals was taken into account in the following way:

$$BW(M) = \frac{1}{\sqrt{2\pi}}\int BW(M)\frac{1}{\sigma(m)}\exp\left[-\frac{(M-m)^2}{2\sigma^2(m)}\right]dm, \quad (6)$$

where $\sigma(m) = .07m - 0.019$ GeV. It turned out that the distribution of errors is well approximated by the Gaussian function.

The experimental $M(\pi^+\pi^-)$ distribution was fitted to function (2) by means of the least-square method.

3. CROSS SECTIONS OF RESONANCE PRODUCTION

Inclusive cross sections of ρ^o, ω and f resonance production are given in Table 1.

Table 1

Reaction	Cross section (mb)		
	ρ^o	ω^o	f^o
π^-p	8.1±0.7	7.3±0.8	1.3±0.5
π^-n	6.5±1.0	6.1±1.2	0.9±0.5
$\pi^{-12}C$	70.5±7.5	75.0±9.0	7.5±7.5

Table II

n_{ch}	$\langle n_\rho \rangle$			$\langle n_\omega \rangle$		
	π^-p	π^-n	$\pi^{-12}C$	π^-p	π^-n	$\pi^{-12}C$
4	0.19 ± 0.03		0.12 ± 0.03	0.16 ± 0.03		0.07 ± 0.03
5		0.23±0.09	0.18 ± 0.06		0.11±0.07	0.17 ± 0.07
6	0.35 ± 0.05		0.23 ± 0.05	0.40 ± 0.06		0.29 ± 0.05
7		0.54±0.16	0.35 ± 0.09		0.43±0.18	0.35 ± 0.11
8	0.72 ± 0.11		0.52 ± 0.10	0.51 ± 0.12		0.51 ± 0.11
9		1.16±0.27	0.43 ± 0.15		1.43±0.38	0.56 ± 0.17
≥10	1.00 ± 0.18		0.96 ± 0.17	0.94 ± 0.24		0.79 ± 0.21
≥11		1.40±0.50	0.88 ± 0.19		1.56±0.66	1.07 ± 0.24
≥4 (π^-n-interact. ≥5)	0.45 ± 0.04	0.54±0.08	0.47 ± 0.05	0.40 ± 0.04	0.50±0.10	0.50 ± 0.06

As is seen from Table 1, the ρ, ω and f meson cross sections are approximately the same in both π^-p and π^-n interactions and their values agree with the quark model predictions.

The cross section of ω meson, obtained by the direct way, i.e., from the $M(\pi^+\pi^-\pi^\circ)$ distribution, was estimated to be 6±2 mb. This value agrees with the result in Table I.

4. AVERAGE MULTIPLICITIES OF ρ° AND ω RESONANCES

Average multiplicities of ρ° and ω resonances per one inelastic π^-N interaction in the reactions (1) are shown in Table 1. As is seen from Table II, the average number of resonances grows with increasing n_{ch} in all of the types of intercations. The mean multiplicity of these resonances is about 0.5, i.e., there is, on average, one resonance (ρ° or ω) produced per each inelastic interaction. The production of ρ° and ω resonances weakly depends on the type of nucleon target (p or n).

The π^--meson fraction from the decay of resonances in the reactions (1) is given in Table III.

Table III

π^--meson fraction from the decay of resonances	Type of interaction		
	π^-p	π^-n	$\pi^-\,{}^{12}C$
$\langle\rho\rangle/\langle\pi^-\rangle$	0.14±0.01	0.14±0.02	0.15±0.02
$\langle\omega\rangle/\langle\pi^-\rangle$	0.13±0.01	0.13±0.02	0.16±0.02
$\langle f\rangle/\langle\pi^-\rangle$	0.02±0.01	-	0.02±0.02

As is seen from Table III, the ratio of the number of π^--mesons from the decay of ρ°, ω and f resonances to the total number of negative pions does not depend on the target type within the errors. Our data show also that about 30% of negative pions come from these resonances.

5. INCLUSIVE ρ° DIFFERENTIAL CROSS-SECTIONS

In this section some of the revealed features of ρ° differential cross sections are discussed. We have studied ρ° production versus $P_\perp^2$, longitudinal c.m.s. rapidity and Feynman x. For this purpose the invariant mass distribution of $\pi^+\pi^-$ pairs getting into certain intervals of the above-mentioned variables, was analyzed. The result of the analysis is shown in Fig. 2. Straight lines are the result of the following approximation:

$$\frac{d\sigma}{dP_\perp^2} = A\exp(-BP_\perp^2) \tag{7}$$

here A is the normalizing coefficient and B the slope parameter. Values of slope parameter B for different types of interactions are presented in Table IV.

As is seen from Table IV, the ρ° differential cross sections do not depend on the target type. The obtained values (Table IV) also agree, within the errors, with the data at other energies [11,12].

The analysis of the ρ° differential cross section versus c.m.s. rapidity (Y*) for pion-nucleon and pion-nucleus interactions reveals a difference in their behaviour for different fragmentation regions. Our data show the ρ° meson enhancement in the target fragmentation region for $\pi^-\,{}^{12}C$ interactions compared to the π^-N-interactions. This may be due to the fact that in $\pi^-\,{}^{12}C$-interactions more than one nucleon, on the average, is involved. The decrease of the number of ρ° mesons in the pion fragmentation region in $\pi^-\,{}^{12}C$ interactions can be explained by the quark absorption inside the

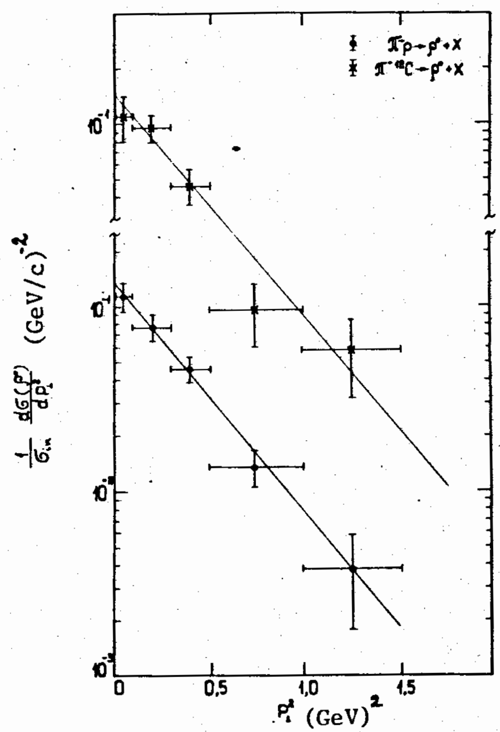


Fig. 2. The $P_\perp^2$ distributions of ρ° mesons produced in π^-p and $\pi^-\,{}^{12}C$ interactions.

Table IV

Interaction	Slope parameter B $(GeV/c)^{-2}$
$\pi^- p$	2.7 ± 0.3
$\pi^- n$	3.0 ± 0.4
$\pi^{-12}C$	2.7 ± 0.4

nucleus in the framework of the additive quark model/8/. The ratio of the cross section for ρ°-production in the central region to that in the pion fragmentation region $\sigma^c(\rho)/\sigma^t_{\pi^-}(\rho) \approx 2$ for $\pi^- N$ interactions is also in good agreement with the predictions of this model.

6. CONCLUSIONS

I would like to stress here that the experimental data on meson resonance production in pion-nucleon and pion-nucleus interactions at 4.0 GeV/c, obtained by the 2-m propane bubble chamber group at the LHE, JINR, give new information on the dynamics of multiple processes at high energies and enable us to check the validity of some additive quark model predictions.

In particular, I conclude:

a) Our data confirm the previously established fact of copious meson resonance production in pion-nucleon and pion-nucleus collisions at 40 GeV/c. This means that pions produced in these processes are mainly indirect products of the reaction and weakly reflect the dynamics of interaction. Thus, the experimental study of different type of resonance production in multiple processes is necessary to understand the nature of strong interactions.

b) Analysis of the inclusive ρ° differential cross sections versus $P_\perp^2$ shows that they are independent of the type. These distributions are satisfactorily approximated by the exponential function $(\exp(-BP_\perp^2))$ with the same values of the slope parameter B within the errors.

c) Comparison of the basic experimental data on the characteristics of meson (ρ, ω, f) resonance production with the additive quark model predictions demonstrates correctness of these consequences and the validity of the model for multiple processes.

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