ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E1 - 9817

N.S.Amaglobeli, Yu.A.Budagov, V.B.Flyagin,
Yu.F.Lomakin, V.S.Rumyantsev, R.G.Salukvadze,
Sh.S.Shoshiashvili, L.Šándor, V.B.Vinogradov,
A.G.Volodko

ANALYSIS OF THE PARTIAL AND TOPOLOGICAL CROSS SECTIONS OF π^- p INTERACTIONS AT 5 GEV/C

1976

E1 - 9817

N.S.Amaglobeli,[1] Yu.A.Budagov, V.B.Flyagin,
Yu.F.Lomakin, V.S.Rumyantsev,[2] R.G.Salukvadze,[1]
Sh.S.Shoshiashvili,[1] L.Šándor, V.B.Vinogradov,
A.G.Volodko

ANALYSIS OF THE PARTIAL AND TOPOLOGICAL CROSS SECTIONS OF π^- p INTERACTIONS AT 5 GEV/C

Submitted to "ЯФ" and the XVIII International Conference on High Energy Physics, Tbilisi, 1976.

[1] Tbilisi State University.

[2] Institute of Physics, Minsk, USSR.

I. Introduction

At present the multiplicity distributions of secondary particles produced in hadron-hadron interactions are the subject of intensive theoretical and experimental investigations. The importance of this problem is due to the fact that the analysis of the shape and the parameters of the above distributions allows one to draw certain conclusions on the mechanism of secondary particle production. However, data on the multiplicity distributions of charged particles are the basic source of such experimental information. Data on the multiplicity distributions of neutral particles, and in this connection of all secondaries, are extremely insufficient *, though neutral particles are about one third of the total number of secondaries.

In experiments performed with a 1-meter propane bubble chamber at the Laboratory of Nuclear Problems, JINR,[2] extensive information was obtained on the partial cross sections of reaction channels with the given number of neutral pions in the final state in $\pi^- p$ -interactions at 5 *GeV/c* [3]. The analysis of these data together with the results of measurements of the partial cross sections of $\pi^- p$ -interactions obtained by means of hydrogen bubble chambers both at 5 *GeV/c* [4] and at energies close to 5 *GeV/c* [5] momenta allow one to have a complete set of partial cross sections as well as the multiplicity distributions of secondary particles practically of any type.

---

* Ref. [1] presents the multiplicity distributions of neutral pions and the total number of secondaries produced in $\pi^- p$ -interactions at 40 *GeV/c*.

Here the available experimental data on partial and topological cross sections of the reaction

$$\pi^- p \to N + n_+ \pi^+ + n_- \pi^- + n_0 \pi^0 \qquad (1)$$

at 5 *GeV/c* are analysed, where N is the nucleon, n_+, n_-, n_0 are the numbers of π^+, π^- and π^0 mesons, respectively.

The multiplicity distributions of π^+, π^- and π^0-mesons, charged particles and all secondary particles have been obtained and analysed. The agreement of some theoretical models and empirical formulae with the distributions under investigation has been checked. The correlations between secondary particles have been considered.

II. The Analysis of Experimental Data on the Partial Cross Sections of $\pi^- p$ -Interactions at 5 GeV/c

The total cross section of reaction (1) can be expressed as follows:

$$\sigma_{(1)} = \sigma_{tot} - \sigma_{el} - \sigma_{str}, \qquad (2)$$

where σ_{tot} is the total cross section, σ_{el} is the elastic scattering cross section, σ_{STR} is the cross section of strange particle production. The values of σ_{tot}, σ_{el}, and σ_{str} at 5 *GeV/c* have been determined by interpolating data at close energies quoted in ref. /5/. Similarly, the topological cross sections σ_8 of eight-prong events and $\sigma(p\pi^-\pi^0)$, $\sigma(p\pi^- Z^0)$ *, $\sigma(\pi^+\pi^- Z^0)$, cross sections have been obtained. The results of interpolation are presented in *Table 1*.

* In brackets the final state particles are indicated. The Z^0 symbol corresponds to the state with more than one neutral particle.

Table 1

	σ_{tot}	σ_{el}	σ_{str}	σ_8	$\sigma_{(1)}$	$\sigma(p\pi^-\pi^0)$	$\sigma(p\pi^- Z^0)$	$\sigma(\pi^+\pi^- Z^0)$
mb	29.24 ±0.40	5.44 ±0.50	2.40 ±0.20	0.05 ±0.02	21.4 ±0.6	1.40 ±0.12	2.26 ±0.25	4.65 ±0.24

The topological cross section σ_8 is smaller than 0.3% of the total cross section σ_{tot}. Preliminary evaluations have shown that the production cross section of more than eight particles in the final state is negligibly small. Therefore, one may consider only the cross sections of inelastic interactions with 0, 2, 4 and 6 charged particles in the final state and the total number of secondaries not larger than eight.

The data on the partial cross sections of the reactions

$$\begin{aligned} \pi^- p \to\ & p\pi^- + (2,3,4,5)\ \pi^0 \\ & p 2\pi^+ 3\pi^- 2\pi^0 \\ & n 3\pi^+ 3\pi^- \pi^0 \end{aligned} \qquad (3)$$

are absent. These cross sections have been evaluated on the basis of the statistical isospin-independent model /6/ permitting the calculation of the relative probabilities $\eta_{i,n}$ of i-th charge configuration of the final state containing n particles. The satisfactory agreement of this model with the experimental data on the partial cross sections of $\pi^- p$ -interactions in the energy range of 1-16 *GeV* has been shown in ref. /7/.

On the basis of experimental data on the cross sections of reactions involving n particles in the final state and on the coefficients $\eta_{i,n}$ the cross sections $\sigma(p\pi^- Z^0)$ and σ(6 prons, Z^0) were subdivided amongst reaction channels (3).

Thus, the combined analysis of experimental data on the partial cross sections of $\pi^- p$ -interactions both at 5 *GeV/c* and at close values of momenta as well as the application of the statistical isospin-independent model allowed obtaining the complete set of partial and topological cross sections $\sigma'_{n_{ch}}$ and the n_0 π^0 -meson production cross sections σ'_{n_0}. The results are presented in *Table 2*. The same *Table* presents also the cross sections $\sigma_{n_{ch}}$ and σ_{n_0} for total inelastic $\pi^- p$ - interactions (Including strange particle production).

Figure 1 shows the dependence of the topological cross sections $\sigma_{n_{ch}}$ upon c.m.s. energy E*. The cross sections of the same topology are connected by solid lines. It is seen that the obtained topological cross sections (presented in *Table 2*) agree well with the results of other experiments. *Figure 2* shows the experimental values of the charge exchange coefficients K_n ($p \to n$)*) with respect to the total number of secondaries n in the final

Table 2

n_0 \ n_{ch}	PARTIAL CROSS SECTIONS $\sigma(n_{ch}, n_0)$ (mb): 0	2		4		6		σ'_{n_0} (mb)	σ_{n_0} (mb)
	n	$n\pi^+\pi^-$	$p\pi^-$	$n2\pi^+2\pi^-$	$p\pi^+2\pi^-$	$n3\pi^-3\pi^+$	$p2\pi^+3\pi^-$	$n_0\pi^0+X'$	$n_0\pi^0+X$
$0\pi^0$		1.97±0.13		1.10±0.03	1.84±0.04	0.084±0.015	0.23±0.01	5.22±0.15	6.44±0.18
$1\pi^0$	0.12±0.04	2.49±0.50	1.40±0.12	1.33±0.23	1.91±0.06	0.096±0.015	0.30±0.012	7.63±0.65	8.65±0.65
$2\pi^0$	0.84±0.13	1.23±0.20	1.45±0.15	0.68±0.10	1.17±0.14		0.125±0.012	5.50±0.30	5.57±0.30
$3\pi^0$	0.16±0.09	0.54±0.10	0.70±0.08	0.16±0.03	0.70±0.07			2.26±0.20	2.26±0.20
$4\pi^0$	0.13±0.03	0.35±0.06	0.08±0.03		0.09±0.02			0.71±0.07	0.71±0.07
$5\pi^0$	0.12±0.02	0.04±0.02	0.03±0.01					0.19±0.03	0.19±0.03
$\sigma'_{n_{ch}}$	1.37±0.05	10.28±0.50		8.90±0.40		0.83±0.05		21.4±0.5	
$\sigma_{n_{ch}}$	1.66±0.10	11.58±0.50		9.66±0.30		0.87±0.05			23.8±0.5

---

*) $K_n = \frac{\sigma_n(N)}{\sigma_n}$ where σ_n is the sum of the cross sections of reactions (1) for fixed value of n ; $\sigma_n(N)$ is a part of σ_n for reactions (1) with neutron production.

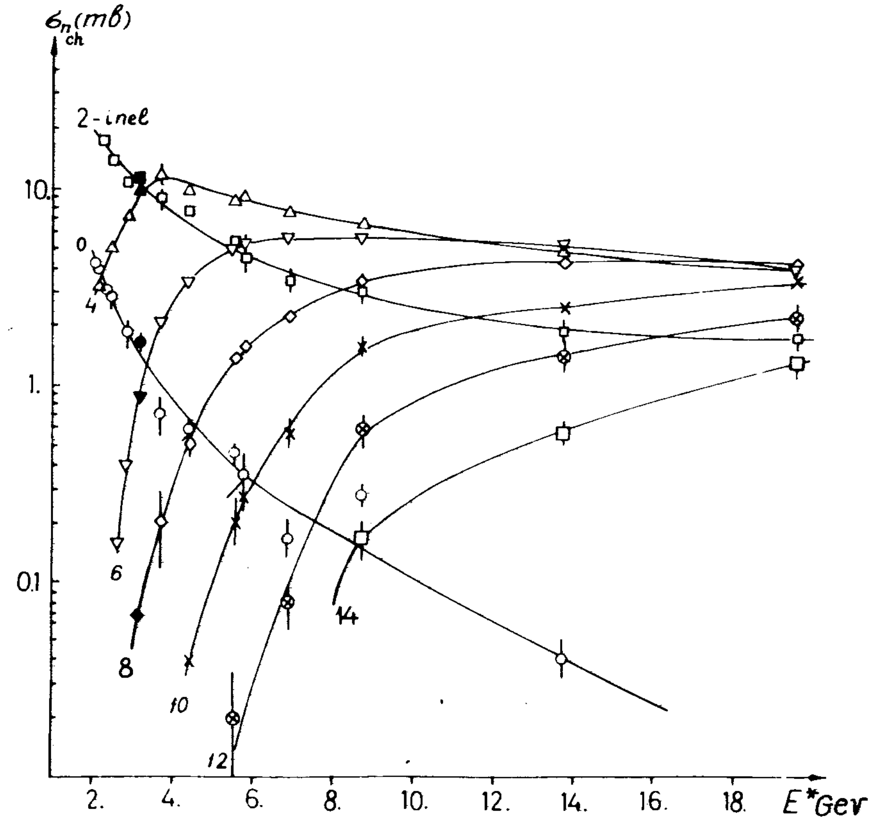

Fig. 1. The dependence of the topological cross sections of $\pi^- p$ interactions upon c.m.s. energy. Black symbols are the values of $\sigma_{n_{ch}}$ at 5 GeV/c.

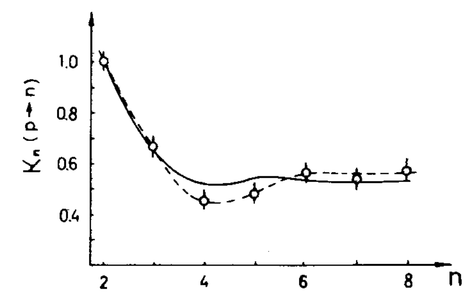

Fig. 2. Dependence of the charge exchange coefficient K_n *upon the total number,* n *, of secondary particles.*

state for reaction (1). The solid curve corresponds to the statistical isospin-independent model (the dash-and-dot curve is drawn by hand). It is seen that the model agrees satisfactorily with the experiment.

III. Mean Characteristics of Multiplicity Distributions of Secondaries

Table 3 presents the values of the inclusive cross sections of π^+, π^- and π^0 -meson production and a number of the characteristics of multiplicity distributions for these particles: the average multiplicity, $\langle n_i \rangle$, the dispersion, D_i, two-particle correlation integrals, f_2^{ii}, the quantities $\langle n_i(n_i-1)\rangle$ and $D_i/\langle n_i \rangle$.

This *Table* presents also the same characteristics of multiplicity distributions for both charged and all secondary particles.

Table 3

		σ_{incl} (mb)	$\langle n_i \rangle$	$\langle n_i(n_i-1)\rangle$	$D_i=(\langle n_i^2\rangle-\langle n_i\rangle^2)^{1/2}$	$\langle n_i\rangle/D_i$	$f_2^{ii}=D_i^2-\langle n_i\rangle$
without strange particles	π^-	30.6±1.4	1.43±0.05	1.06±0.04	0.67±0.04	2.13±0.18	-0.98±0.09
	π^+	20.6±1.0	0.96±0.03	0.41±0.02	0.67±0.03	1.43±0.09	-0.51±0.07
	π^0	29.2±0.7	1.36±0.05	1.72±0.08	1.11±0.05	1.22±0.06	-0.12±0.10
	n'_{ch}		2.86±0.09	7.1±0.2	1.34±0.09	2.1±0.2	-1.06±0.33
	n		4.76±0.18	20.04±0.75	1.33±0.32	3.60±1.0	-3.01±0.96
with strange particl.	π^0	30.5±0.7	1.28±0.05	1.57±0.07	1.10±0.05	1.16±0.05	-0.07±0.10
	n_{ch}		2.82±0.07	6.95±0.19	1.35±0.07	2.09±0.15	-1.00±0.25

The average multiplicities and, hence, the inclusive cross sections of π^- and π^0 -meson production coincide within errors. These values for π^+ -mesons are about 1.4 times smaller.

The $\langle n_0\rangle/(\langle n_+\rangle+\langle n_-\rangle)$ ratio in our case is 0.560± ±0.025. Thus, the violation of the asymptotic relation, $\langle n_0\rangle=0.5(\langle n_+\rangle+\langle n_-\rangle)$ resulting from the isotopic invariance for the structure functions of particles relating to the same isomultiplet [11] at 5 *GeV* is 14%.

The two last columns of *Table 3* present the characteristics of multiplicity distributions of neutral pions and charged particles n_{ch} for total inelastic $\pi^- p$ -interactions including strange particle production. It is seen that within errors these characteristics are not sensitive to strange particle production.

The values of the f_2^{ii} correlation integrals indicate that neutral pions are produced independently of each other (the integral f_2^{oo} within errors is equal to zero), while the production of charged pions is correlated (the values of f_2^{--} and f_2^{++} differ from zero).

IV. Multiplicity Distributions of Secondary Particles

The multiplicity distributions of π^+, π^- and π^0 -mesons, charged particles and the total number of secondaries, n, for reaction (1) are shown in *Figs. 3a, 3b, 4a, 4b, and 5*, respectively. Of all these distributions only the multiplicity distribution of neutral pions is well described (in the consequence of the zero value of f_2^{oo}) by the Poisson formula (the dashed line in *Fig. 4a*). The parameter of the Poisson distribution $a = 1.38 \pm 0.02$ coincides with $\langle n_0\rangle = 1.36 \pm 0.05$.

The multiplicity distributions of π^+, π^- and π^0 -mesons and charged particles, n'_{ch}, (solid line in *Figs.3a, 3b, 4a, 4b*, respectively) have been calculated according to the statistical model of multiple particle production [8]. There is only qualitative agreement of this model with experimental data.

As has been shown in refs. [9,10] at 10-200 *GeV* the n_{ch} distribution agrees satisfactorily with the empirical formula of Czyzewski and Rybicki [9]

$$\sigma_{n_{ch}} = \sigma_{in} \frac{2d}{D} e^{-d^2} d^{2(dx+d^2)} / \Gamma(dx + d^2 + 1), \qquad (4)$$

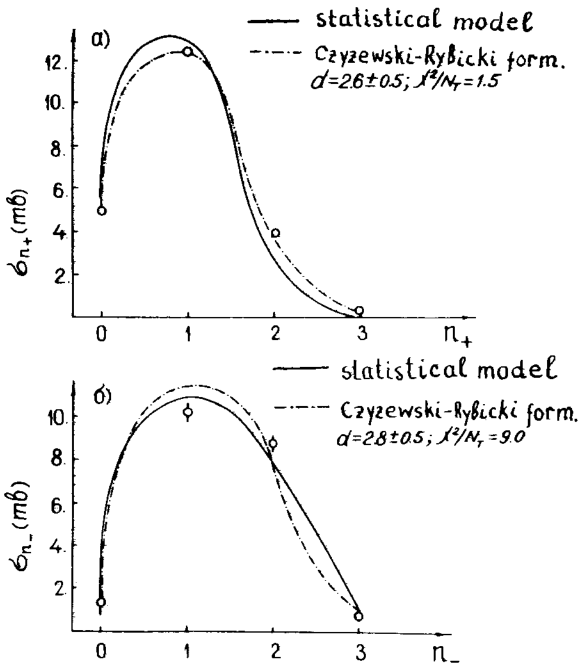

Fig. 3. Dependence of the σ_{n_+} and σ_{n_-} cross sections upon the number of produced π^+ and π^- mesons.

where $x = (n_{ch} - \langle n_{ch} \rangle)/D$, D is dispersion of distribution. d is a free parameter. Over the whole energy interval $d = 1.8$ and is practically independent of the type of initial particles. By using the Czyzewski-Rybicki formula (the dash-and-dotted line in *Figs.3,4,5*) for approximating the multiplicity distributions of secondary particle produced in reaction (1) the following results have been obtained:

- The distribution of the number of all secondary particles agrees well with the formula (4) with the fixed value $d = 1.8$ ($P(\chi)^2 = 0{,}10$);
- Satisfactory agreement is obtained for n_+ and n_0 distributions with $d = 2.6$ ($P(\chi^2) = 0.05$) and $d = 1.25$ ($P(\chi^2) = 0.20$), respectively;
- n_- and n'_{ch} distributions are not described well by formula (4) ($P(\chi^2) \leq 0.01$).

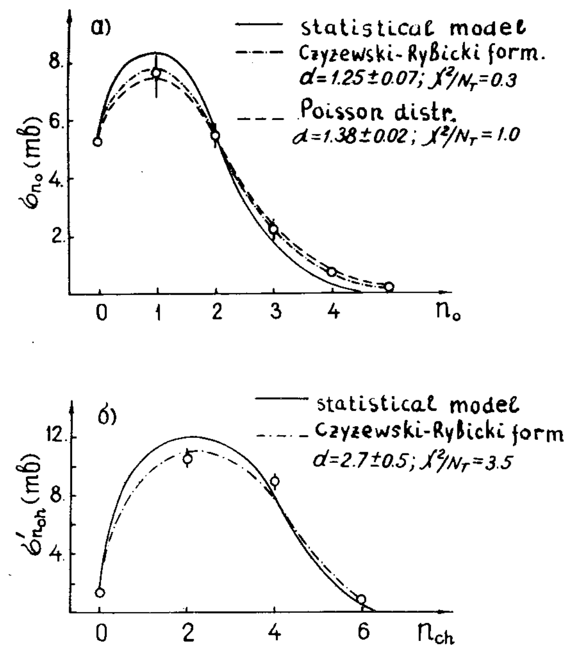

Fig. 4. Dependence of σ_{n_0} and $\sigma'_{n_{ch}}$ cross sections upon the number of neutral pions and charged particles.

V. Correlations in the Yields of Secondary Particles

The investigation of the multiplicity correlations of secondary particles is one of the sources of information on the dynamics of multiple particle production. *Figure* 6 shows our experimental data for reaction (1) on the dependence of the average multiplicity of c type particle upon the number of associated particles of the d type. These dependences were approximated by the linear function (the solid curves in *Fig. 6)*

$$\langle n_c \rangle_{n_d} = a_{cd} + b_{cd} n_d , \quad c \neq d ,$$

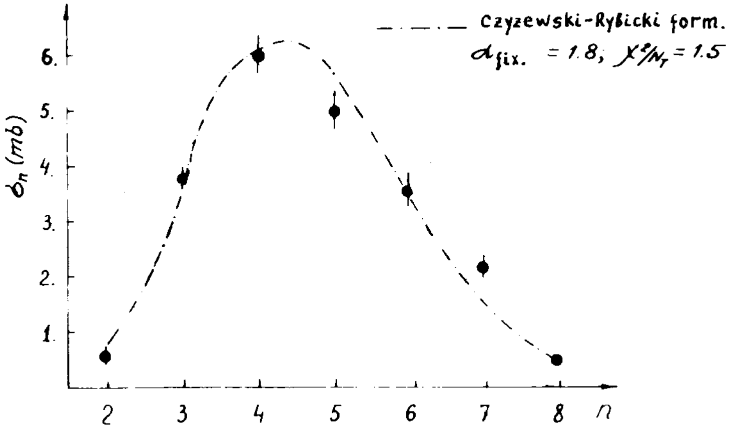

Fig. 5. Dependence of the σ_n cross sections upon the total number, n , of secondary particles.

where a_{cd} and b_{cd} are free parameters. The results of approximations are presented in *Table 4*. The two-particle correlation integrals

$$f_2^{cd} = \langle n_c n_d - \delta_{cd} n_c \rangle - \langle n_c \rangle \langle n_d \rangle$$

for π -mesons of variuos charges are presented in

Table 4.

	$a_{c,d}$	$b_{c,d}$
$\langle n_- \rangle_{n+}$	0.67±0.02	0.77±0.03
$\langle n_+ \rangle_{n-}$	-0.11 ±0.05	0.72 ±0.03
$\langle n_+ \rangle_{n_0}$	1.65 ±0.04	-0.17 ±0.03
$\langle n_- \rangle_{n_0}$	1.27 ±0.04	-0.21 ±0.02
$\langle n_0 \rangle_{n+}$	1.79 ±0.08	-0.44±0.08
$\langle n_0 \rangle_{n-}$	1.85 ±0.09	-0.37 ±0.04

Table 5. The above data on the dependence of $\langle n_c \rangle_{n_d}$ and the values of f_2^{cd} allow one to draw the following conclusions:

Table 5.

d \ c	π^0	π^+	π^-
π^0	-0.12±0.10	-0.26±0.08	-0.24±0.07
π^+	–	-0.51 ±0.07	0.34±0.05
π^-	–	–	-0.98±0.09

a) There is a strong positive correlation in the yields of π^+ and π^--mesons due to charge conservation;

b) Negative correlation between neutral and charged pions reflects the predominant role of the kinematic correlations at the given energy;

c) Mutually independent production is observed only for neutral pions at the given energy.

To conclude let us summarize the results of this paper.

1. The complete set of partial cross sections of $\pi^- p$ -interactions at 5 *GeV/c* have been obtained. It allowed one to calculate the inclusive cross section of π^+, π^- and π^0 -meson production. The parameters of multiplicity distributions for secondary particles of various types have been calculated.

2. The dependence of the charge exchange coefficients upon the total number of secondary particles agrees satisfactorily with the predictions of statistical isospin-independent model.

3. The multiplicity distributions for π^+, π^- and π^0 -mesons, charged and all secondary particles have been obtained.

4. At 5 *GeV/c* there is only qualitative agreement of the Czyzewski-Rybicki formula with the multiplicity distribution of charged particles.

5. It has been established that the multiplicity distribution of neutral pions agrees well with the Poisson distribution.

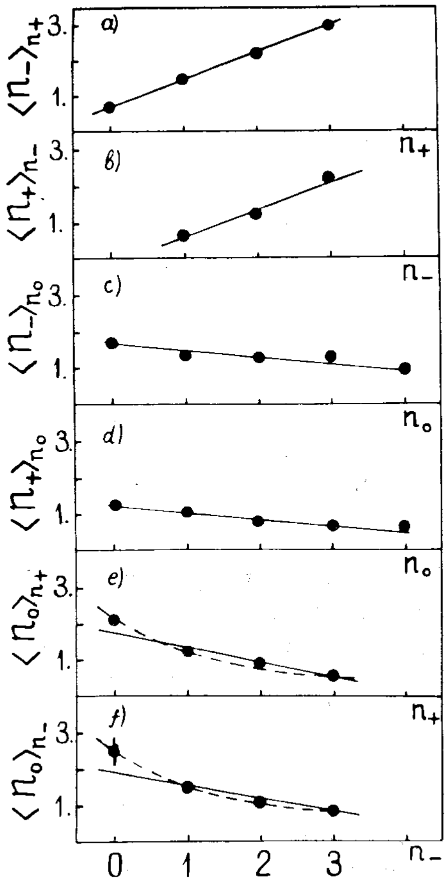

Fig. 6. Dependence of the average number of pions of c type upon the number of pions of d type. (Dashed curves have been drawn by hand).

References

1. *N.A.Angelov et al. JINR, P1-8187, Dubna, 1974.*
2. *A.V.Bogomolov, Yu.A.Budagov et al. Prib.Tekhn.Exp., 1, 61 (1964).*
3. *Yu.A.Budagov et al. Jad.Fiz., 15, 1165 (1972).*

Yu.A.Budagov et al. Jad. Fiz., 12, 1222 /1970/.
N.S.Amaglobeli et al. Jad. Fiz., 23, 978 /1976/.
Yu.A.Budagov et al. JINR Communication, 1-6568, Dubna, 1972.
4. *V.V.Glagolev et al. JINR Preprint, P1-6847, Dubna, 1972.*
H.Böttcher et al. Rev. Roum. Phys., 19, 81 (1974).
L.Abesalashvili et al. JINR Communication, P1-7027, Dubna, 1973.
5. *E.Bracci et al. "Compilation of Cross Section $1-\pi^-$ and π^+ Induced Reactions", CERN/HERA 72-1, Geneva, 1972.*
6. *F.Cerulus. Nuovo Cim.Suppl., 15, 402 (1960).*
7. *V.B.Vinogradov et al. JINR Preprint, P1-5471, Dubna, 1970.*
8. *S.Belenky et al. UFN 62, ser. 2, 1 (1957).*
9. *O.Czyzewski, K.Rybicki. Nucl.Phys., B47, 633(1972).*
10. *E. De Wolf et al. Nucl.Phys., B87, 325 (1975).*
11. *V.G.Grishin. JINR Preprint, P2-7032, Dubna, 1973.*

Received by Publishing Department on May 25, 1976.