СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E1-97-342

O.B.Abdinov[1], A.I.Anoshin[2], A.M.Bagirov[1],
J.Bogdanowicz[3], A.A.Kuznetsov, M.K.Suleimanov[1]

STUDY OF SINGLE-PARTICLE CORRELATIONS IN EVENTS WITH THE TOTAL DISINTEGRATION OF NUCLEI

[1]Physics Institute, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[2]SRI NP, Moscow State University, Russia
[3]SINS, Warsaw, Poland

1997

Абдинов О.Б. и др. Е1-97-342

Изучение одночастичных корреляций в событиях с полным развалом ядер

Приведены новые экспериментальные данные о поведении одночастичных двумерных корреляционных функций R в зависимости от числа испущенных из ядер нуклонов Q и от массы ядра снаряда A_p. Рассмотрены взаимодействия π^--мезонов (при импульсах 40 ГэВ/с), протонов, ядер d, ^{4}He и ^{12}C с ядром углерода (при импульсах 4,2 А ГэВ/с). Значения R были получены отдельно для π^--мезонов и для протонов. При этом нормировка R производилась таким образом, что $-1 \le R \le 1$. Значение $R = 0$ соответствует случаю отсутствия корреляций. Обнаружено, что только в случае слабых корреляций ($|R| < 0{,}30$) имеет место зависимость значений R от Q и от A_p. Установлено, что в основном (около 90 % случаев) эти корреляции связаны с переменной p_t и имеют нелинейный характер — в зависимости от значений величины Q выделяются области с разным поведением зависимости R от Q, т.е. имеется смена режимов в поведении функции R от Q. Определены граничные значения $Q = Q^*$ соответствующих переходов из одной области зависимости R от Q в другую. Замечено, что с увеличением A_p корреляции слабеют и в ^{12}СС-взаимодействиях они становятся минимальными. Одновременно обнаружено, что с ослаблением корреляций в области $Q \ge Q^*$ (область полного развала ядер) меняется и характер зависимости R от Q.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1997

Abdinov O.B. et al. E1-97-342

Study of Single-Particle Correlations in Events with the Total Disintegration of Nuclei

New experimental data on the behaviour of the single-particle two-dimensional correlation functions R versus Q (Q is the number of nucleons emitted from nuclei) and A_p (A_p is the mass of projectile nuclei) are presented.

The interactions of π^--mesons (at a momentum of 40 GeV/c), protons, d, ^{4}He and ^{12}C nuclei with carbon nuclei (at a momentum of 4.2 A Gev/c) are considered. The values of R are obtained separately for π^--mesons and protons. In so doing, the values of R are normalized so that $-1 \le R \le 1$. The value of $R = 0$ corresponds to the case of the absence of correlations. It has been found that the Q- and A_p-dependence of R takes place only for weak correlations ($R < 0.3$). In the main (90 %), these correlations are connected with the variable p_t and have a nonlinear character, that is the regions with different characters of the Q-dependence of R are separated: there is a change of regimes in the Q-dependences of R. The boundary values of $Q = Q^*$, corresponding to the transitions from one dependence region to another, are determined. The correlations weaken with increasing A_p, and they become minimum in ^{12}CC interactions. Simultaneously with weakening the correlations in the region of large $Q \ge Q^*$, the character of the Q-dependence of R changes.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 1997

1 Introduction

The probability distributions of observing π^-C, pC, dC, ^{4}HeC and ^{12}CC events with the given values of the variable Q (Q is $Q = N_+ - N_{\pi^-}$ and N_+ and N_{π^-} are the numbers of positive particles and π^--mesons, respectively) are studied in papers [1]. In this experiment, the variable Q is proportional to the number of protons emitted from nuclei during the interaction . [1] The dependences of the mean characteristics and the inclusive spectra of secondary π - mesons and protons on Q are studied in papers [2-3]. [2] The results , obtained in these papers , confirm our assumption that a boundary value of Q^* for Q exists (its excess leads to the total disintegration of nuclei (TDN)) . We have assumed that the processes of TDN are qualitatively new ones, different in their characteristics from "usual" processes (the group with $Q \geq 1$). We could determine the values of Q^* at which there are qualitative changes in the behaviour of the characteristics of the studied events . With the aim of confirming these assumptions , we applied a single-particle two-dimensional correlation analysis for π^--mesons and protons emitted in these events. The study of the correlation effects in particle production is the source of information on the dynamics of interaction supplementing the information obtained from the single-particle inclusive distributions, from the analysis of the mean characteristics and so on. [4]. The Q-dependence of the single-particle correlation functions is investigated in this paper.

2 Correlation function

The single-particle two-dimensional correlation function $R(x, z)$ is used in the analysis . It is connected with that the correlations strengthen when passing to high orders of R [5-7]. The values of $R(x, z)$ for the variables x, z were calculated by the following formula :

$$R(x, z) = (Exz - ExEz)/(\sigma(x)\sigma(z)).$$

Here Exz is the mixed mathematical expectation of quantities x and z ; Ex and Ez are the mathematical expectations of x and z,

[1] In detail using the variable Q , see paper [1] .
[2] For this, the groups of events with

$$Q \geq 1; 2; 3; ...$$

were defined. Then, for each group the mean characteristics and the invariant inclusive spectra were obtained.

respectively ; $\sigma(x)$ and $\sigma(z)$ are r.m.s. deviations of x and z , respectively.

To evaluate Exz, Ex, Ez, $\sigma(x)$ and $\sigma(z)$, the following formulae were used :

$$Exz = (1/N)\sum_{i=1}^{40}\sum_{j=1}^{40} N_{ij}x_i z_j$$

$$Ex = (1/N)\sum_{i=1}^{40} N_i x_i$$

$$Ez = (1/N)\sum_{j=1}^{40} N_j z_j$$

$$\sigma(x) = (Ex^2 - (Ex)^2)^{1/2}, \sigma(z) = (Ez^2 - (Ez)^2)^{1/2}$$

$$Ex^2 = (1/N)\sum_{i=1}^{40} N_i x_i^2,\ Ez^2 = (1/N)\sum_{j=1}^{40} N_j z_j^2 .$$

In these formulae , N_{ij} is the number of particles hitting an (i,j) -th cell .

$$N = \sum_{i=1}^{40}\sum_{j=1}^{40} N_{ij},\ N_i = \sum_{j=1}^{40} N_{ij}, N_j = \sum_{i=1}^{40} N_{ij} .$$

During the construction of the two-dimensional distributions for the chosen variables , the intervals , corresponding to them were divided into 40 subintervals.

3 Methods of the experiment

The experimental data have been obtained from the 2-m propane bubble chamber of LHE, JINR . In this experiment, we used 8791 $\pi^- C$ interactions at $P_{\pi^-} = 40 GeV/c$ (for methodical details see [8]) and also 5284 pC , 6735 dC , 4852 HeC and 7327 CC interactions at a momentum of 4.2 A GeV/c(for methodical details see [9]) . The available statistical material was separated into the groups of events with the following values of Q:

$$Q \geq 1; 2; 3; ..Q^*; ... \ (1).$$

The values of R were determined for π^- - mesons and protons from these groups of events . In this case , we considered only π^- - mesons and protons with the errors in measuring the momenta not exceeding 30 %.

We considered the following correlation functions $R(p,\theta)$, $R(p,p_t)$, $R(p,y)$, $R(p,\beta)$, $R(\theta,p_t)$, $R(\theta,y)$, $R(\theta,\beta^0)$, $R(p_t,y)$,$R(p_t,\beta^0)$, $R(y,\beta^0)$, where :

- p are momenta in the laboratory coordinate system (lcs)
- θ - emitted angles in the lcs
- p_t - transverse momenta,
- y - rapidities in the lcs.

β^0 - orders of cumulativity (here β^0 = (E-p_L) / m_N , E is the total energy (in the lcs), p_L is the longitudinal momentum (in the lcs) and m_N is the nucleon mass).

The correlations between p_t and p_L for π^- - mesons , produced in dC interactions at 1.7 and 4.2 GeV/c per nucleon , were studied in paper [10]. The dependence of the π^-- mesons distribution density on these variables was observed. The forms of these distributions turned out to depend on beam energy. The measurements of the y and p_t distribution of protons in S+W, O+W and p+W reactions at 200 GeV/A were carried out [11]. The density of the y distribution was found to grow linearly with increasing transverse energy for all the 3 reactions. However, the slope in p+W is sharper than in O +W and S+W. The rapidity density in p+W is much larger than it was predicted on the basis of summing nucleus-nucleus collisions without taking into account nuclear effects pointing to the importance of rescattering effects. The results obtianed in papers [10-11] show a good perspective of using the R function for revealing qualitatively new phenomena in interactions of relativistic nuclei.

In our experiment , in all cases the parameters β^0, θ, y were chosen in the intervals :

$0 \leq \beta^0 \leq 3, 0 \leq \theta \leq 180^0$ and $-2 \leq y \leq 3.5$.

The parameters p and p_t in $pC, dC, {}^4HeC, {}^{12}CC$ interactions were chosen from the intervals :

$0 \leq p \leq 10GeV$ и $0 \leq p_t \leq 4GeV$

both for protons and for π^- - mesons. In $\pi^- C$ interactions , the values of p and p_t for protons were chosen from the following intervals:

$0 \leq p \leq 1GeV$ and $0 \leq p_t \leq 1GeV$,

and for π^- - mesons :
$0 \leq p \leq 40 Gev$ and $0 \leq p_t \leq 4 GeV$.

4 The results of the experiment and discussion

The values of R at different Q for different pairs were obtained using the method described above. In all , the Q-dependences for 100 R functions were obtained (10 types of R functions separately for π^- - mesons and protons in 5 types of interactions, see above). According to the character of the Q - dependence of R , the data can be divided into two groups : group I - the data on the Q independence of R and group II - the data showing the Q dependence of R . The data from the first group were approximated with an $a * Q + b$ expression , where a (for this group of data , the values of a turned out to be close to zero) and b are the fitting parameters. [3] The values of b are presented in tables 1 and 2. The cases from the second group are denoted by dashes. The absolute values of R depending on Q for this group of data are shown in figures 1-5 (the curves are hand-drawn). [4] From the data in tables 1-2 , one can see the following :

- the Q-dependence of R is not observed in 71 % cases (of 100, group I of data), and the function R respectively depends on Q (group II of data) in 29 % cases ,
- in 90 % cases of group II the Q-dependence of R is mainly due to the variable p_t,
- in group I, the values of R for nucleus-nucleus interactions (R_{AA}) are lager than those for pion -nucleus interactions ($R_{\pi^- A}$), ($R_{\pi^+ A}$).
- the data from group I also point to the independence of the behaviour of projectile mass (A_p) in nucleus-nucleus interactions.

[3] We do not present the measured errors of b but take them into account in our conclusions.

[4] We do not present the data on a) $\pi^- C$ interactions and want to note that there is a weak Q-dependence of $R(\theta, p_t)$, $R(p_t, y)$ and the change of regimes in the dependences at $Q = 3 - 4$ for protons in these interactions. The values of Q for the point of changing the regime agree well with the obtained values at these points in papers [1-3] for $\pi^- C$ interactions ; b) the values of $R(p, \beta^0)$ depending on Q in pC interactions (for π^-- mesons and protons) and dC interactions (for protons). For these cases , the values of $R(p, \beta^0)$ decrease with increasing Q. In so doing , this dependence has a linear character for π^- - mesons and almost a logarithmic character for protons ; c) the values of $R(p_t, \beta^0)$ as in this case the behaviour of R versus Q for pC , dC and ^4HeC interactions is similar to those shown in figs. 3-5. For ^{12}CC - interactions , the behaviour of $R(p_t, \beta^0)$ as a function of Q is a line with "break" in its character.

From figs. 1-5, one can draw the following conclusions :

- in 75 % cases , the Q-dependence of R has a nonlinear character, i.e. the regions with different Q-dependences of R are separated , or the change of regimes takes place in these dependences. The totality of these data allows one to determine the boundary values of $Q = Q^*$ corresponding to the transition from one region to another. The values of Q^* for different events (separately for π^-- mesons and protons) are presented in table 3 (the functions R from the Q-dependences of which the values of Q^* were obtained , are shown in columns III and Y). These values of Q^* mainly coincide with those obtained in previous papers [1-3] and used for event selection with TDN. Thus , we have that the correlation analysis also confirms that events with TDN qualitatively differ from "usual" events and it is necessary to use condition (1) for their separation. Here , it should be noted that a visual determination of the values of Q^* do not allow one to speak of correct values. For the present a qualitative result is only important for us evidencing the extreme of such boundaries , because this confirms our main affirmation that the TDN processes are those in which so a large (boundary) fraction of nuclear nucleons is emitted whose excess leads to showing qualitatively new properties (see paper [1]). In particular, from the analysis results presented in the above figures , it has been found that
- 82 % of cases from group II have $R < 0.3$, i.e. weak correlations related to the variable p_t and depending on Q , mainly take place ,
- in all the considered cases , a strong change of the form of the Q-dependence of $| R |$ and the values of $| R |$ on A_p is observed. For example , the correlations decrease with increasing A_p , and they become minimum in ^{12}CC interactions (this result agrees well with the conclusions of paper [11]). The character of the Q - dependence of $| R |$ also changes simultaneously with weakening the correlations in the region of large Q (TDN region) This dependence is a line with "break" for pC , dC interactions , it is of the step-by-step form for ^4HeC interactions and the "zigzag" form for CC interactions. It is possible that the "zigzag" form is the result of the influence of density fluctuations of nuclear matter in the TDN region on these dependences.

In earlier paper [12] , (in the studies of the multiplicity distributions and their second moments for negative charged particles produced in "central" collisions ("CC") and in interactions of minimum trigger in $^{32}S+S$ collisions at 200 A GeV over different rapidity intervals), it has been found that the models of FRITIOF and VENUS mainly describe the dependence of second moments on rapidity intervals for the events with minimium trigger and not for "CC". The conclusion has been drawn that the behaviour of second moments for "CC" indicated to increasing the multiplicity fluctuation . These observations support the conclusions from the analysis of entropy. The entropy for central $^{32}S + S$ is larger than that expected in the models. The results of the present paper also confirm this conclusion. We also think that the "zigzag" form in events with the total disintegration of nuclei can be connected with the density fluctuations of nuclear matter at large Q.

Under these experimental conditions , we observed a strong Q-dependence of the mean values of the kinetic energy of π^- mesons in ^{12}CC interactions in the region $Q \geq Q^*$ - of the total disintegration of nuclei. The present results show that this is possibly due to the fluctuations of nuclear density in events with the total disintegration of nuclei. It has already been concluded [13] the transparency of nuclear matter in "CC" decreases significantly. In the authors' opinion , it testifies of a high baryon density reached in the investigated interactions. We assume that at our energies they are mixed states corresponding to different degrees of freedom , as well as quark - gluon degrees of freedom;

- for protons, the behaviours of $R(\theta, p_t)$ (fig. 4) and $R(p_t, y)$ (fig. 5) versus Q are similar and differ from the behaviour of the Q - dependence of $R(p, p_t)$ (fig. 3).

The authors consider it their pleasant debt to thank the staff of the 2-m propane bubble chamber for giving the experimental material, N. Amelin and A. Golokhvastov for useful discussions , Rogochevskiy O.V. for his help and also Academician A.M. Baldin for his permanent attention to work.

Table 1. For π^- - mesons

Type of events.	π^-C	pC	dC	^4HeC	^{12}CC
$R(p,\theta)$	- 0.35	- 0.49	- 0.52	- 0.49	- 0.48
$R(p,p_t)$	0.33	0.62	0.52	0.49	0.50
$R(p,y)$	0.58	0.67	0.71	0.70	0.69
$R(p,\beta^0)$	-0.20	-	-	-0.22	-0.19
$R(\theta,p_t)$	-0.07	-	-	-	-
$R(\theta,y)$	-0.88	-0.93	-0.92	-0.91	-0.90
$R(\theta,\beta^0)$	0.72	0.83	0.78	0.79	0.78
$R(p_t,y)$	0.15	-	-	-	-
$R(p_t,\beta^0)$	0.26	0.31	0.42	0.43	0.45
$R(y,\beta^0)$	-0.61	-0.79	-0.73	-0.73	-0.71

Table 2. For protons

Type of events	π^-C	pC	dC	^4HeC	^{12}CC
$R(p,\theta)$	-0.30	-0.67	-0.68	-0.63	-0.63
$R(p,p_t)$	0.70	-	-	-	-
$R(p,y)$	0.51	0.97	0.96	0.93	0.93
$R(p,\beta^0)$	-0.20	-	-0.85	-0.80	-0.78
$R(\theta,p_t)$	-	-	-	-	-
$R(\theta,y)$	-0.88	-0.80	-0.81	-0.80	-0.82
$R(\theta,\beta^0)$	0.91	0.90	0.90	0.92	0.93
$R(p_t,y)$	-	-	-	-	-
$R(p_t,\beta^0)$	0.10	-	-	-	-
$R(y,\beta^0)$	-0.94	-0.94	-0.95	-0.94	-0.94

Table 3. Boundary values of $Q = Q^{*}$ [5]

Type of events	protons		π^-- mesons	
	Q^*	from Q-dependence of	Q^*	from Q-dependence of
$\pi^- C$	3-4*	$R(\theta, p_t)$	-	-
	3-4*	$R(p_t, y)$	-	-
pC	3-4	$R(\theta, p_t)$	-	-
	3-4	$R(p_t, y)$	-	-
	3-4	$R(p, p_t)$	-	-
	3-4	$R(p_t, \beta^0)$	-	-
dC	-	-	3-5	$R(\theta, p_t)$
	5-6*	$R(p_t, y)$	3-4	$R(p_t, y)$
	5-6*	$R(p, p_t)$	-	-
^4HeC	4-6*	$R(\theta, p_t)$	3-4	$R(\theta, p_t)$
	3-6*	$R(p_t, y)$	3-4	$R(p_t, y)$
	4-6*	$R(p, p_t)$	-	-
	4-6*	$R(p_t, \beta^0)$	-	-
^{12}CC	5-6* 10-11*	$R(\theta, p_t)$	6* 9-10*	$R(\theta, p_t)$
	5-6* 9-10*	$R(p_t, y)$	4-7* 9-10*	$R(p_t, y)$
	5-6* 8-9*	$R(p, p_t)$	-	-
	5-6* 9-10*	$R(p, p_t)$	-	-

5* The cases of coincidence of the values of Q^* from the data in fig. 1-5 with the values obtaned in [1-3] are noted.

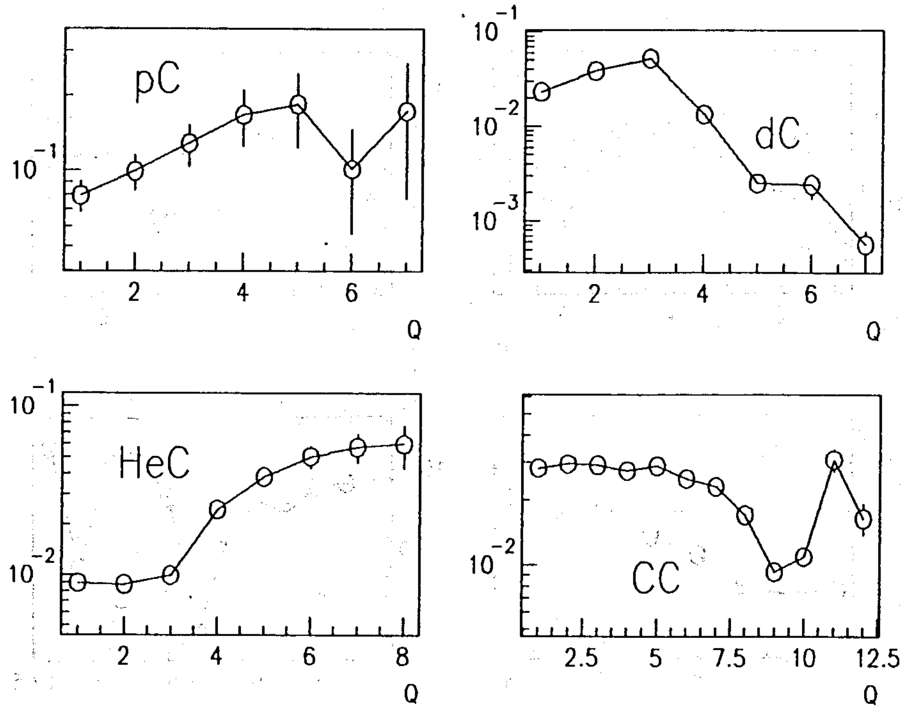

Fig. 1. Q–dependence of | R(ϑ,pt) | for π– – mesons.

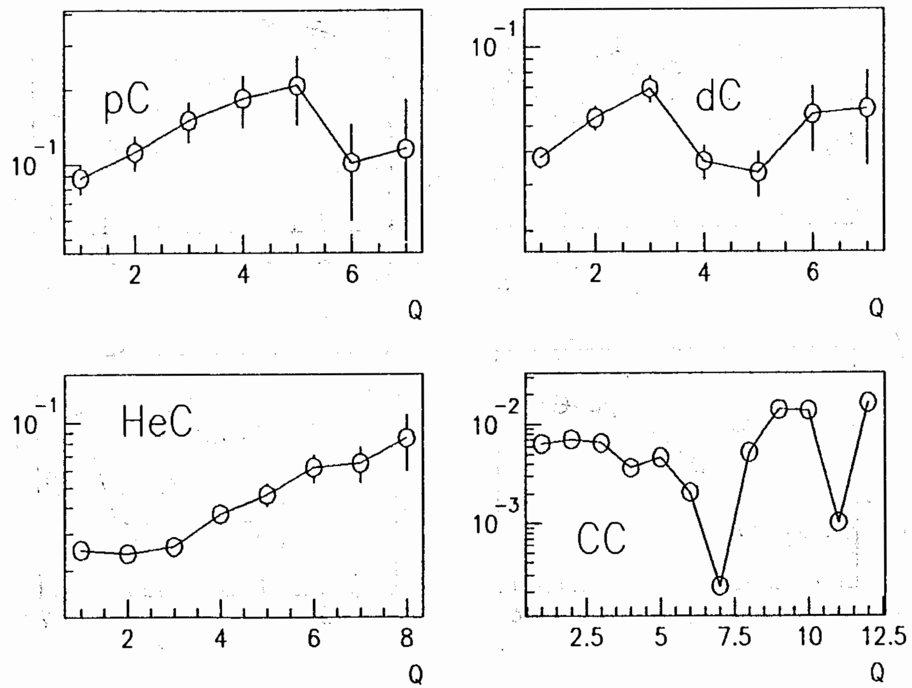

Fig. 2. Q–dependence of | R(pt,y) | for π– – mesons.

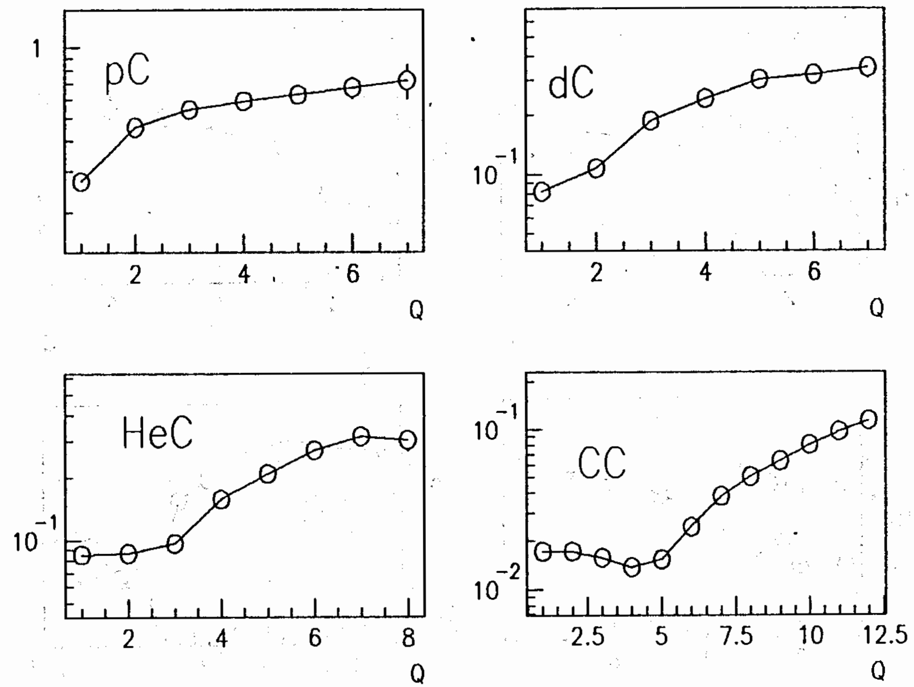

Fig. 3. Q–dependence of | R(p,pt) | for protons.

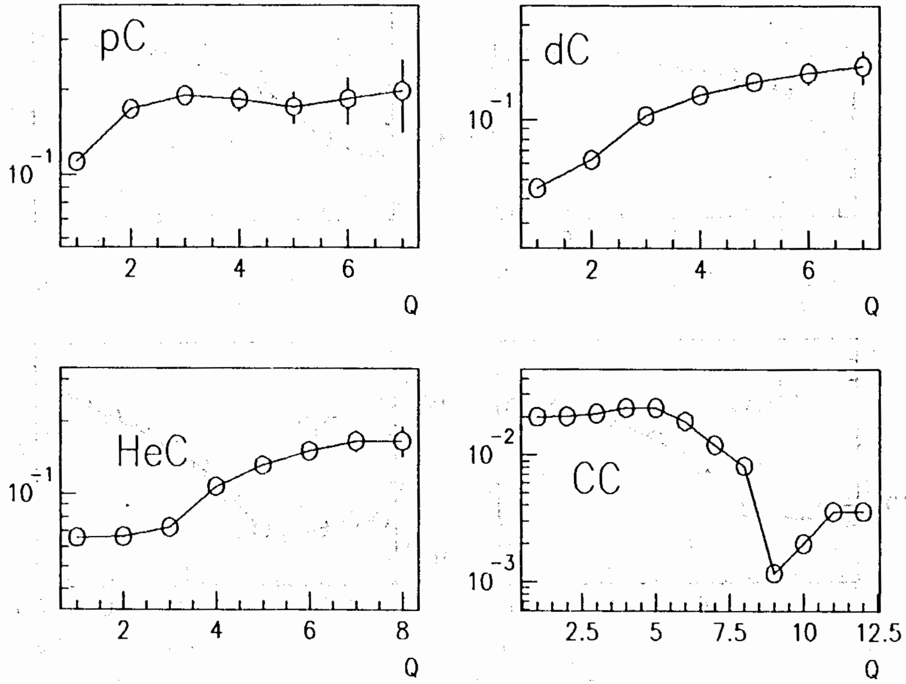

Fig. 4. Q–dependence of | R(ϑ,pt) | for protons.

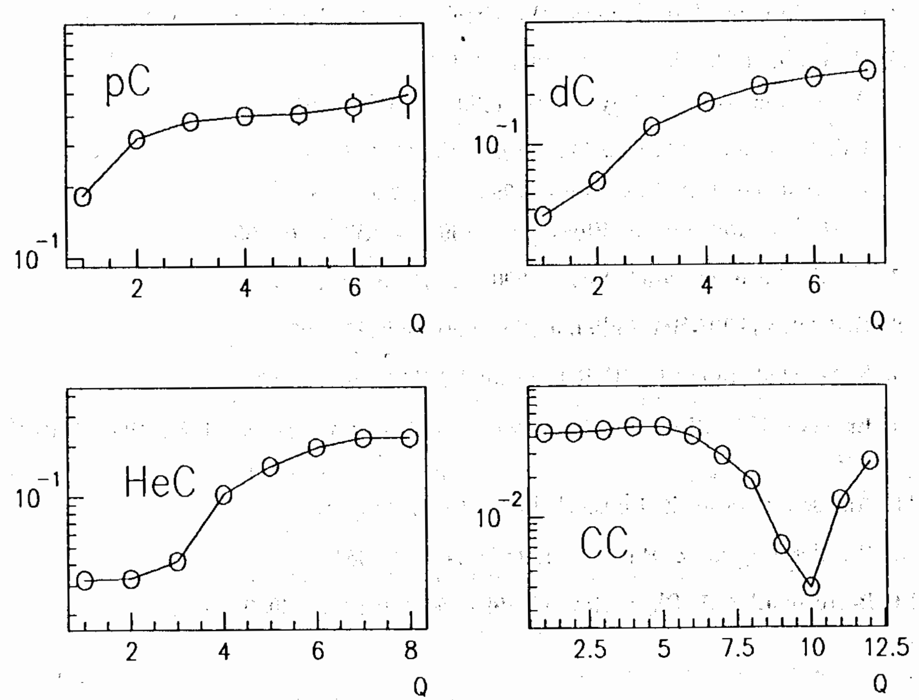

Fig. 5. Q–dependence of | R(pt,y) | for protons.

References

1. Abdinov O.B. et. al. Journal "JINR Rapid Communications " N 1[75],1996.
2. Abdinov O.B. et. al. Journal "JINR Rapid Communications " N 1[81],1997.
3. Abdinov O.B. et. al. JINR Communications , E1-97-178, Dubna , 1997.
4. E.A. De Wolf , I.M. Dremin , W. Kittel. Journal "UFN" ,vol.163, N 1 , p. 3-62.
5. P. Abreu et al. Phys. Lett. 1990. V. B247. P. 137.
   A. De Angelis Mod. Phys. Lett. 1990. V. A5. P. 2395.
6. I.V. Ajienko et al. Phys. Lett. 1989. V. B222. P. 306.
   I.V. Ajienko et al. Phys. Lett. 1990. V. B235. P. 373.
   N.M. Agababyan et al. Phys. Lett. 1991. V. B261. P. 165.
7. C. Albajar et al. Nucl. Phys. 1990 . V. B345. P. 1.
8. BBCDHSSTTU-BW.Collabor.Phys.Lett.,39B,371,1972.
9. N.Akhababian et al.- JINR Preprint 1-12114,Dubna,1979.
10. Ermakov K.N. ,Rogochevskiy O.V. ,Stabnikov M.V. Preprint RAS, 1994 N 2012, 1-11.
11. Akesson T. et al. Z. Phys. C. 1992 53 N 2, 183-191.
12. Bachler J. et al. Z. Phys. C. 1992 56 N 3 347-354.
13. Berrette J. et al. Phys. Rev. C. 1994. 50 N 6 3047 - 3059.

Received by Publishing Department
on November 13, 1997.