
PRODUCTION OF CUMULATIVE π^+ - AND π^- -MESONS AT HIGH-ENERGY PROTON-NUCLEUS AND NUCLEUS-NUCLEUS INTERACTIONS

KH.K. OLIMOV

UDC 539
©2007

Physical and Technical Institute, Scientific Production Association "Physics – Sun",
Uzbekistan Academy of Sciences
(2b, G. Mavlyanov Str., Tashkent 700084, Uzbekistan; e-mail: olimov@uzsci.net)

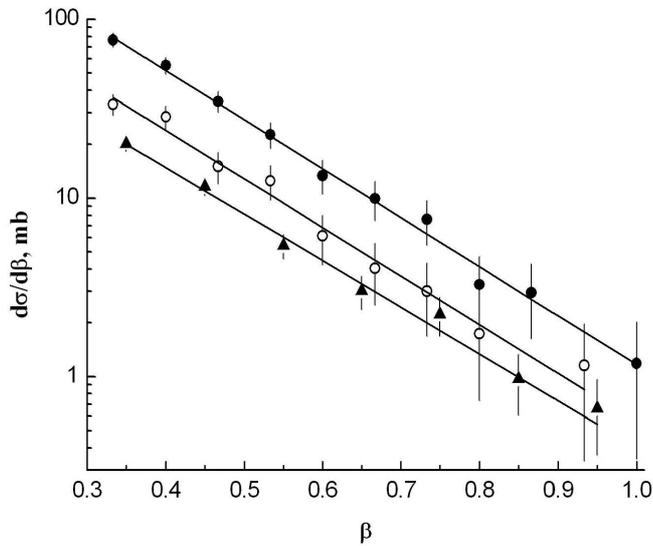
Production of cumulative π^+ - and π^- -mesons as a result of high-energy pC-, ^4HeC -, and CC-collisions has been investigated under conditions of complete geometry and for a large body of statistical data. The dependence of the inclusive production cross sections of π^+ - and π^- -mesons on the cumulative number β was shown to have a universal character, being independent of both the projectile type and the initial energy. The same production mechanism for cumulative π^+ - and π^- -mesons was observed at high energies. The independence of the mean number of cumulative π^+ - and π^- -mesons on the projectile type and the initial energy was found for the first time.

A large body of experimental materials concerning the cumulative production of particles has been collected till now, and a number of regularities of this phenomenon has been established [1]. However, the main portion of experimental data was obtained in electron experiments [1–3], at small, as a rule, solid angles of registration of cumulative particles. In this connection, it is natural that not every result obtained under those conditions could be confirmed in experiments with complete geometry. Certainly, there are a few works carried out under conditions of 4π -geometry [4–8]; unfortunately, they confirmed the conclusions of electron experiments only at a qualitative level, because they were executed for a small statistical sampling (e.g., the determination accuracy of the slope parameter by the cumulative number β was not better than 25–30%, and the goodness of a fit was not better than 50–60%) and for only a few types of interaction; moreover, different criteria of cumulative particle selection were applied. In this connection, it is of interest to carry out the study of the cumulative particle production for a larger statistical sampling of experimental materials and under the

conditions of complete geometry for various types and energies of colliding nuclei, and following the common technique.

This work deals with studying the production of cumulative π^+ - and π^- -mesons in pC-interactions at momenta of 4.2 and 9.9 GeV/c, and ^4HeC - and CC-collisions at 4.2A GeV/c.

The experimental material was collected by the participants of the international cooperation between the countries of the former Council for Mutual Economic Assistance (CMEA). Experiments were carried out on a two-meter propane bubble chamber [9–12] at the Laboratory of High Energies of JINR (Dubna, Russia) irradiated by protons and relativistic ^4He and C nuclei from a JINR synchrotron. The results of experiments were included into the data summary tape (DST) of nucleus-nucleus interactions for the two-meter propane bubble chamber in 1998 [12]. The total statistical volume of analyzed material exceeds 59,000 measured events. The methodical issues associated with stereophoto analysis, restoration of the kinematic characteristics of secondary particles, their identification, and making corrections for the loss of particles emitted at large angles with respect to the photographic plane, were described in works [9–12]. Target protons and π^+ -mesons were distinguished visually on the basis of their ionization in the momentum range $p < 0.8$ GeV/c. It should be noted that, in contrast to π^+ -mesons, π^- -ones could be identified unambiguously in experiment, because the production of K^- -mesons could be neglected if the initial momenta $p_0 < 10$ GeV/c.



Inclusive cross-sections of π^+ -meson production at pC-collisions at 9.9 GeV/c (\blacktriangle) and π^- -meson production at ^4HeC - (\circ) and CC-collisions (\bullet) at 4.2A GeV/c as functions of the cumulative number β in the range $\beta \geq 0.3$. Straight lines are the results of the approximation of experimental data by dependence (1)

The analyzed ensembles were filtered from events corresponding to elastic interactions and diffraction dissociation of a projectile nucleus in accordance with criteria given in work [12].

π^+ - and π^- -mesons with the cumulative number $\beta \geq 0.3$ and the emission angle in the laboratory system $\vartheta \geq 135^\circ$ (here, $\beta = (E - P \cos \theta)m_n$, E is the total energy, P the total momentum, and m_n the nucleon's mass equal to that of a proton) were classified as cumulative ones.

In the figure, for illustration, the dependences of the inclusive cross-sections of π^+ -mesons (for pC-collisions at $p = 9.9$ GeV/c) and π^- -mesons (for ^4HeC - and CC-

collisions at $p = 4.2A$ GeV/c) on the cumulative number β in the range $\beta \geq 0.3$ are depicted. The straight lines correspond to the results of the approximation of experimental data by the dependence

$$f(\beta) = a \exp(-b\beta), \tag{1}$$

where a is the normalization factor. The results of the approximation of experimental data concerning the distribution of π^+ - and π^- -mesons over the cumulative number β by expression (1) are presented in Table 1. It is evident that the values of the slope parameter b for cumulative π^+ - and π^- -mesons coincide for all considered types of collisions and for all values of initial energy within the statistical error limits. Therefore, in order to increase the determination accuracy of the parameter b , we additionally carried out an approximation of the total distribution of cumulative π^+ - and π^- -mesons over all collisions under consideration. The values of the quantity b obtained in such a manner (6.17 ± 0.23 and 6.25 ± 0.26 , respectively), as is seen from Table 1, turned out practically identical for cumulative π^+ - and π^- -mesons, but appeared substantially smaller than the corresponding average value of 8.1 ± 0.1 for cumulative protons, obtained by us earlier using a similar experimental material [13]. It should be noted that the values of the slope parameter for cumulative π^+ - and π^- -mesons proved to be close to the universal slope value $b_0 = 1/\langle\beta_0\rangle$, where $\langle\beta_0\rangle \approx 0.14$ is a parameter which characterizes invariant inclusive cross-sections of cumulative hadron production for medium and heavy nuclei in a wide range of initial energies [1, 14]. In Table 1, the average multiplicities, momenta, and emission angles of cumulative π^+ - and π^- -mesons for events with the production of those particles are also given. One can see that the average

Table 1. The values of the slope parameter in the parametrization by formula (1), the average number, the momentum, and the emission angle of cumulative π^+ - and π^- -mesons in events with production of those particles

Type of interaction; p_0 , GeV/c	Slope, b (χ^2)		Average number of cumulative mesons		Average momentum, GeV/c (Average emission angle, degree)	
	π^+	π^-	π^+	π^-	π^+	π^-
pC; 4.2	6.21 ± 0.81 (2.3/3 DF)	6.42 ± 1.00 (3.2/5 DF)	1.00 ± 0.01	1.02 ± 0.01	0.22 ± 0.01 (150.9 \pm 1.0)	0.20 ± 0.02 (150.4 \pm 1.3)
pC; 9.9	6.02 ± 0.41 (0.9/4 DF)	6.25 ± 0.43 (3.2/8 DF)	1.00 ± 0.01	1.01 ± 1.01	0.22 ± 0.01 (150.0 \pm 0.6)	0.22 ± 0.01 (150.1 \pm 0.7)
^4HeC ; 4.2A	6.02 ± 0.22 (3.3/4 DF)	6.27 ± 0.62 (1.3/5 DF)	1.00 ± 0.01	1.01 ± 0.01	0.22 ± 0.01 (150.5 \pm 0.8)	0.20 ± 0.02 (150.8 \pm 0.8)
CC; 4.2A	6.59 ± 0.39 (1.3/4 DF)	6.32 ± 0.39 (0.8/7 DF)	1.01 ± 0.01	1.01 ± 0.01	0.21 ± 0.01 (150.5 \pm 0.5)	0.21 ± 0.01 (150.6 \pm 0.5)
All interactions	6.17 ± 0.23 (2.9/4 DF)	6.25 ± 0.26 (3.4/6 DF)	1.00 ± 0.01	1.00 ± 1.01	0.22 ± 0.01 (150.5 \pm 0.7)	0.21 ± 0.01 (150.5 \pm 0.8)

Table 2. Event statistics for collision types, the number and the fraction of events with cumulative π^+ - and π^- -mesons, and the cross-sections of their production

Type of interaction; p_0 GeV/c	Total number of inelastic events	Number of events with cumulative mesons (cross-section σ , mb)		Share of events with cumulative mesons, %	
		π^+	π^-	π^+	π^-
pC; 4.2	6 737	110(4.3 \pm 0.4)	67(2.6 \pm 0.3)	1.6 \pm 0.2	1.0 \pm 0.1
pC; 9.9	19 996	339(4.5 \pm 0.2)	259(3.4 \pm 0.2)	1.7 \pm 0.1	1.3 \pm 0.1
^4HeC ; 4.2A	11 692	193(7.4 \pm 0.5)	185(7.1 \pm 0.5)	1.7 \pm 0.1	1.6 \pm 0.1
CC; 4.2A	21 086	433(17.0 \pm 0.8)	388(15.3 \pm 0.8)	2.1 \pm 0.1	1.8 \pm 0.1
All interactions	59 511	1075(33.2 \pm 1.0)	899(28.4 \pm 0.9)	1.8 \pm 0.1	1.5 \pm 0.1

multiplicities of cumulative π^+ - and π^- -mesons, amounting to 1.01 ± 0.01 on the average, as well as their average momenta and emission angles appeared to be practically equal and, within the statistical error limits, independent of both the type of the projectile and the initial energy value. The attained accuracy of 1% for the determination of the average multiplicity of cumulative π^+ - and π^- -mesons for events with the production of a cumulative meson is caused by the fact that only one cumulative π -meson was observed in more than 99% of events with the yield of cumulative mesons, and the probability of two cumulative mesons to be produced in a single event is negligibly small.

In Table 2, the number and the share of events with cumulative π^+ - and π^- -mesons and the cross-sections of their production are shown. It is evident that the share of events with cumulative π^+ - and π^- -mesons and their cross-sections grow with increase in the mass number of the projectile nucleus. On the average, the number of produced cumulative π^+ -mesons was higher by about 20% than that of cumulative π^- -mesons, which is in agreement with relevant data for π^- C-collisions at 40 GeV/c, where the ratio between the numbers of produced cumulative π^+ - and π^- -meson proved to be equal to 1.20 ± 0.09 [10]. The observed excess of cumulative π^+ -mesons might be caused by a positive charge of the target nucleus.

Therefore, a conclusion can be made that the same mechanism for the production of cumulative π^+ - and π^- -mesons was observed, which, similarly to their mean number, is independent of the projectile type and the initial energy.

To summarize, I would like to express my gratitude to Profs. K. Olimov and E.I. Ismatov for the helpful discussions of this work, as well as to all participants of the cooperation dealing with processing of photos obtained on the two-meter propane chamber.

The work has been supported by the NATO Reintegration Grant EAP.RIG.982790.

1. V.K. Bondarev, Fiz. Elem. Chast. At. Yadra **28**, 13 (1997).
2. V.S. Stavinsky, Fiz. Elem. Chast. At. Yadra **10**, 949 (1979).
3. G.A. Leksin, in *Nuclear Scaling. Elementary particles. Proceedings of the 3-rd ITEP School on Physics* (Atomizdat, Moscow, 1975), N 2, p. 5 (in Russian).
4. V.B. Lyubimov *et al.*, JINR preprint P1-82-363 (Dubna, 1982).
5. A.I. Anoshin *et al.*, Yad. Fiz. **36**, 409 (1982).
6. D. Armutliiski, N. Akhababyan, A.M. Baldin *et al.*, JINR preprint P1-83-327 (Dubna, 1983).
7. T. Baatar, V.B. Lyubimov, L. Serdamba *et al.*, JINR preprint P1-85-698 (Dubna, 1985).
8. A.I. Anoshin *et al.*, JINR preprint P1-81-214 (Dubna, 1981).
9. A.U. Abdurakhimov *et al.*, JINR preprint P1-6277 (Dubna, 1972).
10. G.N. Agakishiev *et al.*, JINR preprint P1-84-235 (Dubna, 1984).
11. I.A. Ivanovskaya, JINR preprint P1-91-264 (Dubna, 1991).
12. A.I. Bondarenko *et al.*, JINR preprint P1-98-292 (Dubna, 1998).
13. K. Olimov, E.Kh. Bazarov, R.N. Bekmirzaev *et al.*, Phys. At. Nucl. **70**, 709 (2007).
14. A.M. Baldin *et al.*, JINR preprint E1-82-472 (Dubna, 1982).

Received 22.12.06.

Translated from Russian by O.I. Voitenko

НАРОДЖЕННЯ КУМУЛЯТИВНИХ π^+ - ТА π^- -МЕЗОНІВ У ВЗАЄМОДІЯХ ПРОТОНІВ ТА ЯДЕР З ЯДРАМИ ПРИ ВИСОКИХ ЕНЕРГІЯХ

Х.К. Олімов

Резюме

В умовах повної геометрії на достатньо великому статистичному матеріалі досліджено народження кумулятивних π^+ - та π^- -мезонів під час pC-, ^4HeC - і CC-зіттовувань при високих енергіях. Показано, що залежність інклюзивних перерізів утворення кумулятивних π^+ - та π^- -мезонів від кумулятивного числа β має універсальний характер, що полягає у незалежності як від типу снаряда, так і від первинної енергії. Спостережено єдиний механізм утворення кумулятивних π^+ - та π^- -мезонів при високих енергіях. Вперше виявлено незалежність середнього числа кумулятивних π^+ - та π^- -мезонів від типу снаряда і первинної енергії.