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Ассоциативная множественность в реакции $\pi^- p \to \pi^0 + X$ при 5 ГэВ/с

Представлены экспериментальные данные о зависимости ассоциативной множественности заряженных частиц от квадрата недостающей массы в реакции $\pi^- p \to \pi^0 + X$ при 5 ГэВ/с. Распределения π^0 -мезонов восстановлены из соответствующих распределений γ -квантов из реакции $\pi^- p \to \gamma + X$. В статистику включено 7940 γ -квантов. Показано, что в поведении ассоциативной множественности при энергии 5 ГэВ наблюдаются закономерности, обнаруженные ранее при более высоких энергиях.

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Associated Multiplicity in the Reaction $\pi^- p \to \pi^0 + X$ at 5 GeV/c

The results of investigation of the associated charged particle multiplicity as a function of the missing mass squared in the reaction $\pi^- p \to \pi^0 + X$ at 5 GeV/c are presented. The π^0 -meson distributions are reconstructed from the corresponding γ-quanta distributions in the reaction $\pi^- p \to \gamma + X$. The statistics includes 7940 γ -quanta. The regularities found earlier at higher energies are observed in the behaviour of associated multiplicity at 5 GeV.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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A number of experimental and theoretical papers [1-5] have been devoted to the analysis of associated multiplicity that is charged particle multiplicity of the system X produced in the inclusive reaction

$$a + b \to c + X. \qquad (1)$$

The dependence of parameters of associated multiplicity distribution (average multiplicity $\langle n \rangle$, dispersion $D^2 = \langle n^2 \rangle - \langle n \rangle^2$, normalized moments $C_k = \langle n^k \rangle / \langle n \rangle^k$ and so on) on incident particle energy and kinematical characteristics ξ of the particle c are the object of investigation. By definition the probability of associated production of n charged particles is *

$$P_n(\xi) = (d\sigma_n / d\xi) / \sum_n (d\sigma_n / d\xi),$$

where $d\sigma_n / d\xi$ is a ξ distribution for events with n charged particles in the X system. Here ξ denotes usual variables like $x = 2p_L^* / \sqrt{s}$, p_T, M_X^2 and so on, where p_L^* and p_T are longitudinal and transverse momenta of the particle c in c.m.s., M_X^2 is the effective mass squared of the system X.

Experimental data on associated multiplicity in the inclusive reactions with the production of $\pi^\pm$, K^0- and $\bar{K}^0$ -mesons, slow protons and Λ -hyperons are obtained in the $\pi^\pm p$ -interactions at 5-205 GeV/c [6-11],

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* Here and below for simplicity we omit the dependence on s (the c.m.s. total energy squared).

in $K^{\pm}p$ -interactions at 5-32 *GeV/c* [12-14] and in pp-interactions at 19-405 *GeV/c* [15-17]. Data on the multiplicity of charged particles associated with π°-meson exist at ISR energy only [18].

In the present paper the results of the investigation of the M_x^2 dependence of associated charged particle multiplicity in the reaction

$$\pi^- p \to \pi^{\circ} + X \qquad (2)$$

at 5 *GeV/c* are presented. A comparison with the characteristics of total charged particle multiplicity distribution in the reaction

$$\pi^- p \to X \qquad (3)$$

at $s = M_X^2$ is made. The distribution parameters for reaction (3) at momenta ≤ 5 *GeV/c* were calculated from the topological cross sections presented in compilation [19]. The inclusive distributions of reaction (2) were reconstructed from the corresponding distributions of the reaction

$$\pi^- p \to \gamma + X \qquad (4)$$

on the basis of the method described in ref. [20]. The reconstruction procedure is considered in the *Appendix*.

For the analysis we used 0-, 2-, 4- and 6-prong events with gamma-quanta detected with a JINR one-meter propane bubble chamber [21]. The statistics includes 7940 gamma-quanta. The processing of events with gamma-quanta and results of the former investigations have been published elsewhere (see, for example, ref. [22]).

The experimental investigation of the average associative multiplicity in the $K^{\pm}p$ -interactions at 5-32 *GeV/c* [12,13] has shown a change in the rate of increase of $\langle n(M_X^2)\rangle$ with M_X^2 about the value $M_X^2 \approx s/2$. In the region $M_X^2 \leq s/2$ the values of $\langle n(M_X^2)\rangle$ are close to the values of $\langle n(s)\rangle$ at $s = M_X^2$. In the region $M_X^2 \geq s/2$ the growth of $\langle n(M_X^2)\rangle$ with M_X^2 is more rapid than at smaller M_X^2 and noticeably exceeds the increase rate of

$\langle n(s)\rangle$ with s. As has been noted [13], such a break in the M_X^2 dependence of $\langle n(M_X^2)\rangle$ becomes less visible with decreasing incident energy. From the relation

$$M_X^2 = s + m_c^2 - 2\sqrt{s}\sqrt{s x^2/4 + p_T^2 + m_c^2}\ ,$$

where m_c is mass of the inclusive particle c, and from the limitation of $\langle p_T\rangle$ it follows that the transition from the small values of M_X^2 to large ones corresponds to the transition of particle c from the fragmentation region $(|x| \approx 1)$ to the central region $(|x| \approx 0)$. Thus a break in the behaviour of $\langle n(M_X^2)\rangle$ can point out the difference in the production mechanisms of associated particles in these regions [12].

Figure 1 shows the experimental values of $\langle n(M_X^2)\rangle$ and $\langle n(s)\rangle$ for reactions (2) and (3) and also average associated multiplicity for the reaction

$$\pi^- p \to \pi^- + X \qquad (5)$$

at 5 *GeV/c* [6]. It is seen that $\langle n(M_X^2)\rangle$ is an increasing function of M_X^2 which coincides within errors with $\langle n(s)\rangle$ and with the average multiplicity associated with the π^--meson. In the whole range of M_X^2 no statistically significant change in the increase rate of $\langle n(M_X^2)\rangle$ with M_X^2 is observed. Our data are well described by the function

$$\langle n(M_X^2)\rangle = a + b \ln M_X^2\ ,$$

predicted by the models of multiperipheral type [1]. As a result of approximation $a = 0.43 \pm 0.10$, $b = 1.07 \pm 0.06$ was obtained at the value χ^2_{min} /number of points $= 1.6/8$.

As is pointed out in ref. [13] the change of production mechanism is displayed more visibly in the behaviour of the function

$$G(M_X^2) = \frac{1}{\sigma_{in}} \frac{d\sigma}{dM_X^2} (\langle n(M_X^2)\rangle - \langle n(s)\rangle)$$

than in the dependence of $\langle n(M_X^2)\rangle$ on M_X^2. A distinguishing feature of this function is the existence of the minimum whose position is the same as that of the break in the M_X^2 dependence of $\langle n(M_X^2)\rangle$.

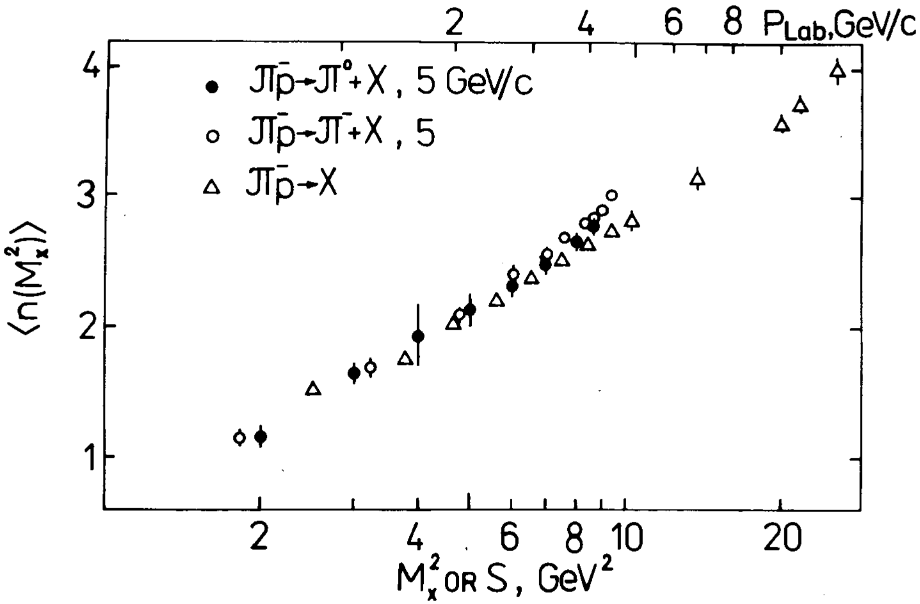

Fig. 1. The average associative multiplicity $\langle n(M_X^2)\rangle$ *versus* M_X^2. • *- for the reaction* $\pi^- p \to \pi^0 + X$ *at 5 GeV/c,* o *- for the reaction* $\pi^- p \to \pi^- + X$ *at 5 GeV/c,* Δ *- the* s *dependence of* $\langle n(s)\rangle$ *for the reaction* $\pi^- p \to X$.

Figure 2 shows the function $G(M_X^2)$ obtained in our experiment. As an example, $G(M_X^2)$ for the reaction $K^+ p \to K^0 + X$ at 8.2 *GeV/c* [13] is given. A clear minimum at $M_X^2 \simeq 7$ *GeV*^{2} is seen in our data. The shift of this minimum towards larger M_X^2 (in comparison with the expected $M_X^2 \simeq 5$ *GeV*^{2}) seems to be due to a small width of the central region at our energy.

The multiplicity correlations between charged particles in the system X, produced in the association with inclusive particle c, are determined by means of the correlation moment

$$f_2^{cc} = \langle n(n-1)\rangle - \langle n\rangle^2 .$$

The experimental investigation of the M_X^2 dependence of the $f_2^{cc}(M_X^2)$ in the reaction $pp \to p_{slow} + X$ at 102-405 *GeV/c* [15] has shown that behaviour of $f_2^{cc}(M_X^2)$ is similar to that of $f_2^{cc}(s)$ in the reaction $pp \to X$ at $s = M_X^2$.

Figure 3 shows M_X^2 dependence of the $f_2^{cc}(M_X^2)$ for reactions (2) and (5) and also s dependence of the $f_2^{cc}(s)$ for reaction (3). The correlation moments for reaction (5) were calculated from the approximating functions for the dispersion $D^2(M_X^2)$ and $\langle n(M_X^2)\rangle$ from refs [6,7]. Our data in the region $M_X^2 \geq 7$ *GeV*^{2} within errors coincide with correlation moments in reaction (5)

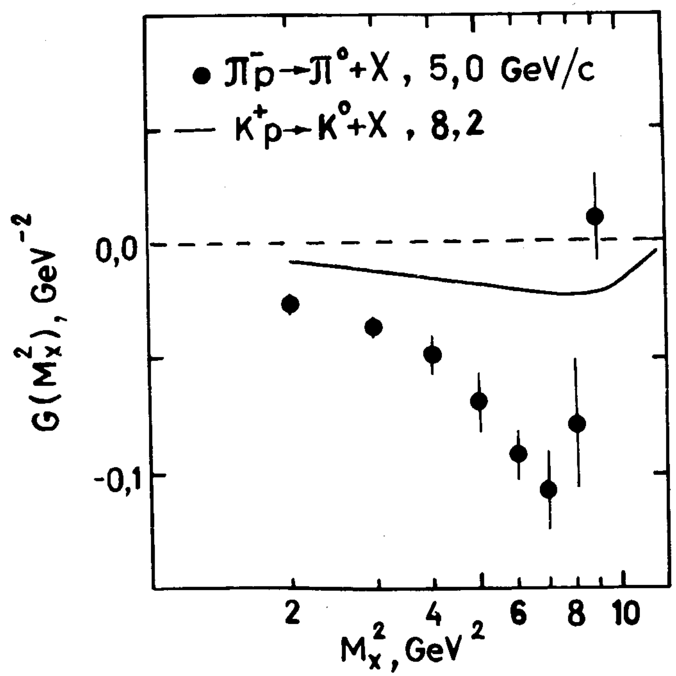

Fig. 2. The function $G(M_X^2)$ *versus* M_X^2 *for the reaction* $\pi^- p \to \pi^0 + X$ *at 5 GeV/c. The solid curve represents* $G(M_X^2)$ *for the reaction* $K^+ p \to K^0 + X$ *at 8.2 GeV/c.*

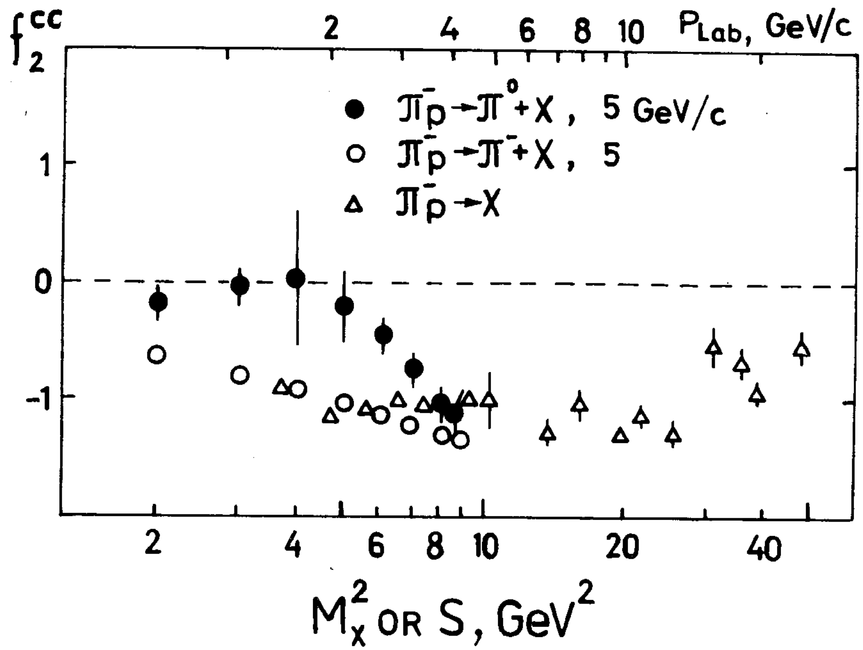

Fig. 3. The correlation moment f_2^{cc} *versus* M_X^2 *or* s: • *-for the reaction* $\pi^- p \to \pi^0 + X$ *at 5 GeV/c,* o *-for the reaction* $\pi^- p \to \pi^- + X$ *at 5 GeV/c,* Δ *-for the reaction* $\pi^- p \to X$.

and with $f_2^{cc}(s)$. The negative values of f_2^{cc} indicate the presence of correlations connected with the conservation laws. The increase of $f_2^{cc}(M_X^2)$ in the region of smaller M_X^2 reflects mainly an influence of the threshold effects. The correlation moments in reactions (3) and (5) weakly depend on M_X^2 and are close to value -1.

In a general case the values of multiplicity distribution parameters at minimal values of M_X^2 or s are determined by the reaction channels having the smallest production threshold. It follows that for reaction $\pi^- p \to X$ and in our case $f_2^{cc} \to 0$ at small s or M_X^2. For the reaction $\pi^- p \to \pi^- + X$ this limit is -1. As is seen from *fig. 3*, the approach of f_2^{cc} to zero is slower than in the $f_2^{cc}(M_X^2)$ case. It is worth

to note that the spectra $d\sigma_n/dM_X^2$ used in the construction of $f_2^{cc}(M_X^2)$ are obtained as a result of the approximation and are smooth functions. On the other hand, in the region of small s the behaviour of $\sigma_n(s)$ is more complicated as a result of the production of resonances in intermediate states. This could cause a difference between $f_2^{cc}(M_X^2)$ and $f_2^{cc}(s)$ in the region of small M_X^2 and s.

The generalization of the KNO-scaling for associated multiplicity gives the following relation

$$\langle n(s, M_X^2)\rangle P_n(s, M_X^2) = \phi(s, M_X^2, z) \xrightarrow[M_X^2 \to \infty]{s \to \infty} \Psi(z), \qquad (6)$$

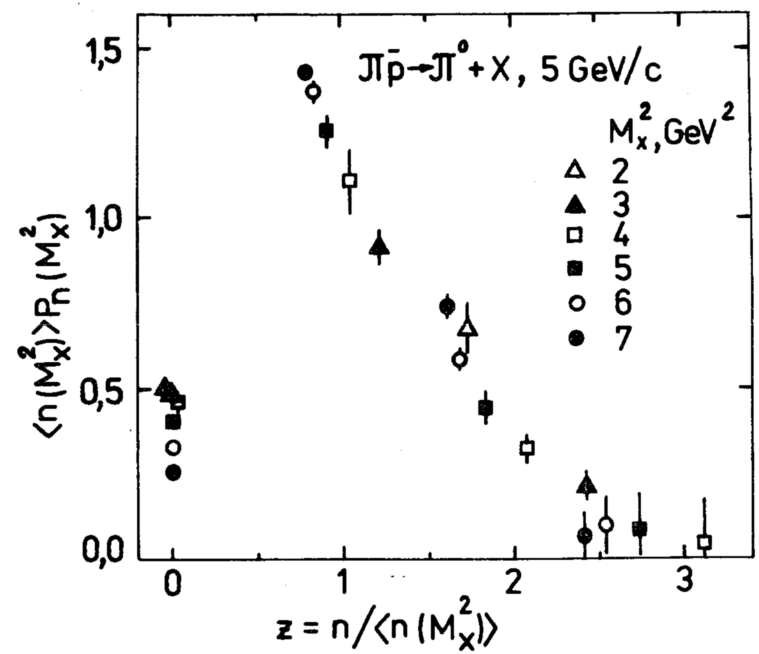

Fig. 4. Plot of $\langle n(M_X^2)\rangle P_n(M_X^2)$ *versus* $z = n/\langle n(M_X^2)\rangle$ *in the reaction* $\pi^- p \to \pi^0 + X$ *at 5 GeV/c for the set of values* M_X^2: Δ *- 2,* ▲ *- 3,* □ *- 4,* ■ *- 5,* o *- 6,* • *- 7 GeV*^{2}.

where $z = n/\langle n(s, M_X^2)\rangle$. Data in pp-interactions at 102-405 *GeV/c* [23] and in $\pi^- p$-interactions at 5 and 40 *GeV/c* [7] show approximated validity of the KNO-scaling for associated multiplicity.

Figure 4 presents $\phi(M_X^2, z)$ distributions for a set of values M_X^2 obtained in our experiment. It is seen that experimental points in the z region under consideration are grouped near to some common curve. This behaviour agrees with weak M_X^2 dependence of the distributions $\phi(M_X^2, z)$.

It is well known that asymptotical relation (6) is equivalent to the independence of normalized moments

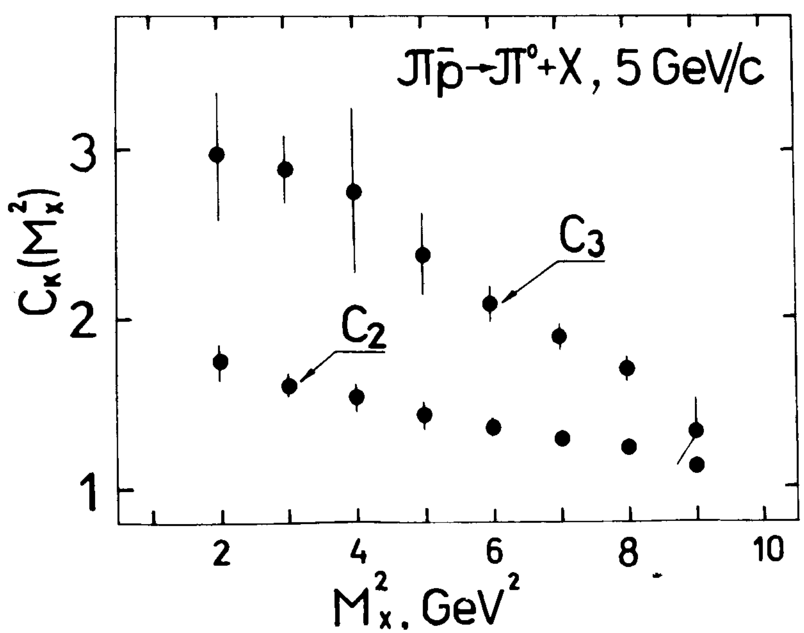

Fig. 5. The normalized associative moments C_2 *and* C_3 *versus* M_X^2 *for the reaction* $\pi^- p \to \pi^\circ + X$ *at 5 GeV/c.*

$$C_k(s, M_X^2) = \langle n(s, M_X^2)^k\rangle / \langle n(s, M_X^2)\rangle^k$$

upon s and M_X^2. The approach to the asymptotics is displayed more visible in the behaviour of moments C_k than in the behaviour of distributions $\phi(s, M_X^2, z)$. *Figure 5* presents the M_X^2 dependence of moments C_2 and C_3 for reaction (2). In the whole region of M_X^2 both moments are a monotonously decreasing functions of M_X^2. This indicates that asymptotical behaviour of distributions $\phi(M_X^2, z)$ at our energy has not been reached.

In conclusion let us summarize the basic results of this paper.

1. The M_X^2 dependence of the parameters of associative multiplicity has been analysed in the reaction $\pi^- p \to \pi^\circ + X$ at 5 *GeV/c*. The behaviour of the parameters of associative multiplicity shows the regularities observed earlier at higher energies.

2. Data about dependence of associated charged particle multiplicity on kinematical characteristics of inclusive π°-meson at energies below 1500 *GeV* have been obtained for the first time.

APPENDIX

According to our estimates 99% of γ-quanta produced in the reaction

$$\pi^- p \to \gamma + X \qquad (1)$$

at 5 *GeV/c* are decay products of π°-mesons from reaction

$$\pi^- p \to \pi^\circ + X \,. \qquad (2)$$

This makes it possible to use an integral equation [20] which relates energy spectrum of gamma-quanta with that of π°-mesons. By means of the relation

$$M_X^2 = s + m_c^2 - 2\sqrt{s}\, E_c^* \;,$$

where m_c and E^*_c are mass and energy of the inclusive particle in c.m.s.,one can obtain from this integral equation another one for the missing mass squared distributions. As a result, we obtain

$$\frac{d\sigma}{dM^2_{X\gamma}} = \frac{1}{\sqrt{s}} \int \frac{d\sigma}{dM^2_{X\pi}} \frac{dM^2_{X\pi}}{\sqrt{\omega_0^2 - m_0^2}}, \qquad (3)$$

where $\omega_0 = (s + m_0^2 - M^2_{X\pi})/(2\sqrt{s})$, m_0 is mass of π° -meson. The lower integration limit is determined as a minimal value of $M^2_{X\pi}$ in reaction (2). The higher one depends on M^2_X and has the form

$$\phi(M^2_{X\gamma}) = M^2_{X\gamma}\,(1 - \frac{m_0^2}{s - M^2_{X\gamma}}).$$

It is possible to express the distribution $d\sigma/dM^2_{X\pi}$ in an analytical form

$$\frac{d\sigma}{dM^2_{X\pi}} = f(M^2_X, a_i),$$

where a_i are free parameters. The values of parameters are determined by fitting the right-hand side of eq. (3) to experimental distributions of γ -quanta.

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