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ON PION-PRODUCTION INTENSITIES IN HADRON-NUCLEUS COLLISIONS

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Об интенсивности рождения π-мезонов в адрон-ядерных столкновениях

Даются распределения $P(n_\pi)$ подлинных множественностей $n_{\pi^{+-0}}$, $n_{\pi^{+-}}$ и n_{π^0} π-мезонов, рожденных в $\pi^- + \mathrm{Xe}$ ядерных столкновениях при 3,5 ГэВ/с. Распределения хорошо описываются негативным биномиальным распределением (НБР).

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On Pion-Production Intensities in Hadron-Nucleus Collisions

Genuine multiplicity n_π distributions $P(n_\pi)$ of pions produced in $\pi^- + \mathrm{Xe}$ nuclear collision at 3.5 GeV/c momentum are presented for $n_{\pi^{+-0}}$, $n_{\pi^{+-}}$ and n_{π^0}. The multiplicities are excellently described by the negative binomial distributions (NBD).

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

Communication of the Joint Institute for Nuclear Research. Dubna, 1996

1. INTRODUCTION

In this paper, genuine multiplicity and multiplicity distributions measures of the pions produced in π^- + Xe nuclear collision reactions at 3.5 GeV/c momentum are presented and analysed. Distributions of the multiplicities characterize the intensity of the meson production in the samples of events in which incident hadron used to collide with a target nucleus. The sample of events consists of π^{+-0} mesons registered with almost 100% efficiency, through 4π emission angle; the kinetic energy values of the registered neutral pions are $E_{\pi^0} \geq 0$ MeV [1]. Such accurate data are of interest not only in high energy physics but for applications in discussions on accelerator-breeding concepts as well.

The collision events were registered in the 180 litre xenon bubble chamber ($104 \times 40 \times 43$ см^3) without magnetic field [2].

The experimental procedure is omitted here, as it is described widely enough in our former works [1].

This work contains our new results on the produced particle intensities study, and is a continuation of our former works [1,3,4].

2. GENUINE MULTIPLICITY MEASURES OF THE PRODUCED PIONS

The probability distribution functions are defined usually for all non-negative integers (n = 0, 1, 2, 3, ...). The genuine multiplicity measures denoted hereafter by n (n = 0, 1, 2, 3, ...) should be used in statistical analysing of the experimentally obtained particle multiplicities data, in order to meet the requirement of probability distribution function — such as Poissonian or the NBD (Negative Binomial Distribution) formulas. The genuine multiplicity measures can be always converted into the charge multiplicities n_{ch} for a given type of collisions, usually applied in data from the track detectors.

In this section, the genuine pion multiplicity distributions $P(n_{\pi^{+-0}} - 1) \equiv P(n_\pi - 1)$, $P(n_{\pi^{+-}} - 1)$, and $P(n_{\pi^0})$ are presented, as determined experimentally in the 180 litre xenon bubble chamber exposed to negatively charged pions at 3.5 GeV/c, in the laboratory system; in the CMS of $(\pi^- p)$ the energy $E_{CMS} = \sqrt{S} = 2.72$ GeV.

It is well known, as well, that the number of charged particles n_{ch}, or the number of prongs, is not a good multiplicity measure, since it includes initial charges of the colliding particles and due to charge conservation in each collision reaction, negative and positive partners are totally correlated. The number of charged particles is always even $(n_{ch} = 0, 2, 4, 6, \ldots)$ or always odd $(n_{ch} = 1, 3, 5, 7, \ldots)$, depending on the initial charges of the colliding particles. However, it is here a unique possibility to use the measured multiplicities of neutral hadrons, of the neutral pions, which are registered and identified in the 180 litre xenon bubble chamber with an efficiency near 100% at their kinetic energies $E_{\pi^0} \geq 0$ MeV, and their characteristics — as energies, momenta, angles of emission are measured with an average accuracy not smaller than for the charged particles in other detectors [1.2].

The genuine multiplicities of the π^{+-0}, π^{+-} and π^0 mesons, obtained experimentally in $\pi^- + \mathrm{Xe}$ collisions at 3.5 GeV/c momentum are presented in figures 1—3 [3] $(n_\pi - 1)$, $(n_{\pi^{-+}} - 1)$, n_{π^0}, and correspond to the numbers of the created pions.

So, the distributions $P(n_\pi - 1)$, $P(n_{\pi^{+-}} - 1)$ and $P(n_{\pi^0})$ in the figures 1—3 are for the genuine numbers of the pions produced in the $\pi^- + \mathrm{Xe}$ collisions under consideration.

3. THE DESCRIPTIONS OF THE PION MULTIPLICITY DISTRIBUTIONS

In starting the descriptions of the genuine pion multiplicity distribution, it should be remembered that in one of our former works the following results have been obtained [4]: The free-parameterless model [5] reproduces the multiplicity n_{ch} (or intensity n_{ch}) distribitions of the produced charged particles quantitatively well enough, without any free parameters in terms of corresponding data on hadron-nucleon collisions and known data on target nucleus size and matter density distribution in it. Within the frames of this model, the distributions of the particle production intensities in hadron-nucleus collisions are represented by simple formulas derived [4,5] on the basis of picture of the collision process; this picture was prompted experimentally [4,5].

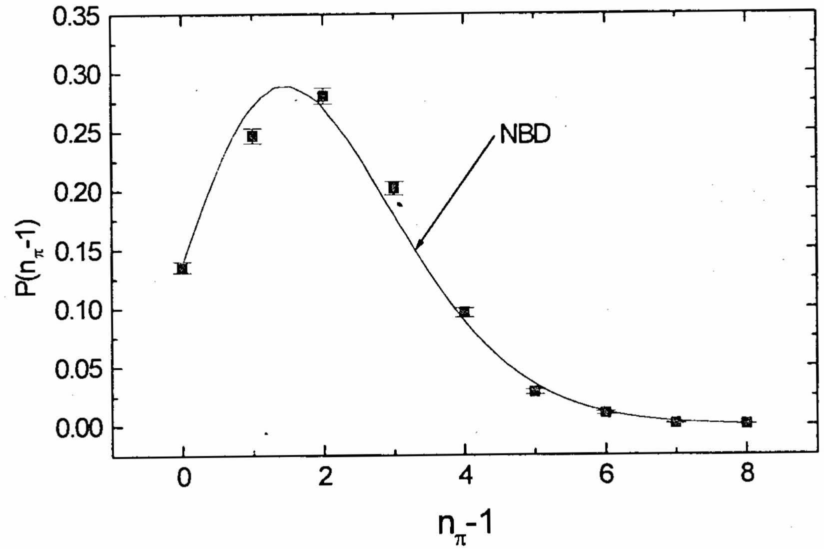

Fig.1. Multiplicity $(n_{\pi^{+-0}} - 1)$ distributions $P(n_{\pi^{+-0}} - 1)$ of produced pions in $\pi^- + \mathrm{Xe}$ nuclear collision reaction at 3.5 GeV/c in lab. system ($E_{CM} = \sqrt{S} = 2.72$ GeV in (p, π^-) CM system). Black points — experimental data [3]; solid line — Negative Binomial Distribution (see Tab.1)

Three samples of the nuclear collision events at 3.5 GeV/c were analysed separately: I. All the $\pi^- + \mathrm{Xe}$ collision events with $n_{\pi^{+-0}} = n_\pi$ mesons emitted in any of them, $n_\pi = 0, 1, 2, \ldots$, fig.1. II. All the $\pi^- + \mathrm{Xe}$ collision events with any number of electrically charged π^{+-} mesons $n_{\pi^{+-}}$, without any of the π^0 mesons, emitted in the registered collision $n_{\pi^{+-}} = n_{\pi^{(+-)}}$, fig.2. III. All the $\pi^- + \mathrm{Xe}$ collision events in which any number n_{π^0} of π^0 mesons is emitted, fig.3. On figures 1 and 2, where the distributions $n_{\pi^{+-0}} = n_\pi$ and $n_{\pi^{+-}}$ of the π's charged components were registered, the genuine multiplicities $n_\pi - 1$ and $n_{\pi^{+-}} - 1$ were taken into account, instead of the observed n_π- and $n_{\pi^{+-}}$-because of the charged pion projectile. The multiplicities n_{π^0} are taken directly from measurements, without any correction.

We do not perform here the expression of the genuine multiplicity distribution within the frames of the free-parameterless model. We are not ready

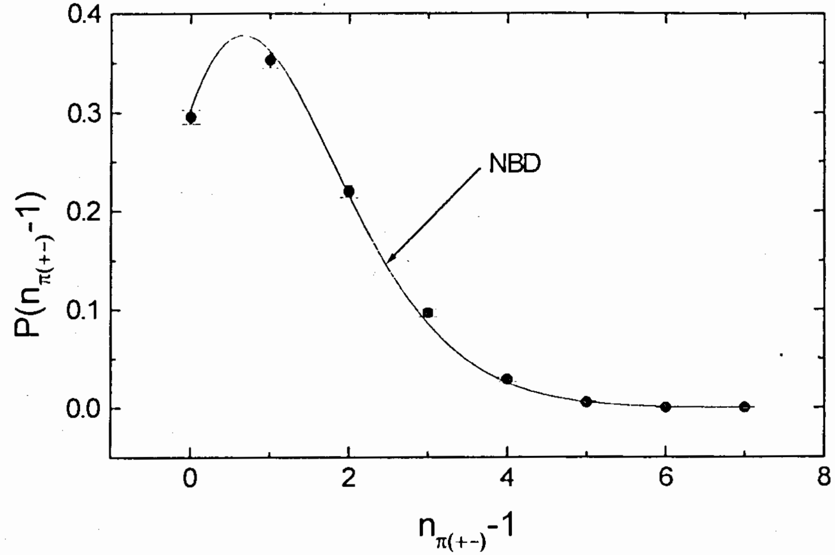

Fig.2. Multiplicity $(n_{\pi^{+-}} - 1)$ distributions $P(n_{\pi^{+-}} - 1)$ of produced pions in $\pi^- + Xe$ nuclear collision reaction at 3.5 GeV/c in lab. system ($E_{CM} = \sqrt{S} = 2.72$ GeV in (p, π^-) CM system) . Black points — experimental data [3]; solid line — Negative Binomial Distribution (see Tab.2)

to realize it because of absence of adequate data from the elementary collision reactions at corresponding energies.

Let us now apply the negative binomial distribution [6] to describe genuine data on multiplicities distributions in $\pi^- + Xe$ nucleus collisionsat 3.5 GeV.c in the laboratory system, which is equivalent to $E_{CMS} = \sqrt{S} = 2.72$ GeV, in $(\pi^- p)$ C.M. system.

The Negative Binomial Didtribution (NBD) belongs to the family of the Poissonian tranforms of some probability density functions used in statistical physics [7,8]. The most popular of them is described in the work of R.Szwed et al. [6].

Let us use the multiplicity distribution of π^0 mesons produced in $\pi^- + Xe$ collisions at 3.5 GeV/c in the laboratory system (or 2.72 in (πp) C.M. system); the genuine multiplicity $n = 0, 1, 2, 3, \ldots$. The description of this distribution by the NBD is attempted.

The NBD distribution

$$P(n) = \binom{n+k-1}{n} \frac{(\bar{n}/k)^n}{\left(1 + \frac{\bar{n}}{k}\right)^{n+k}} \qquad (1)$$

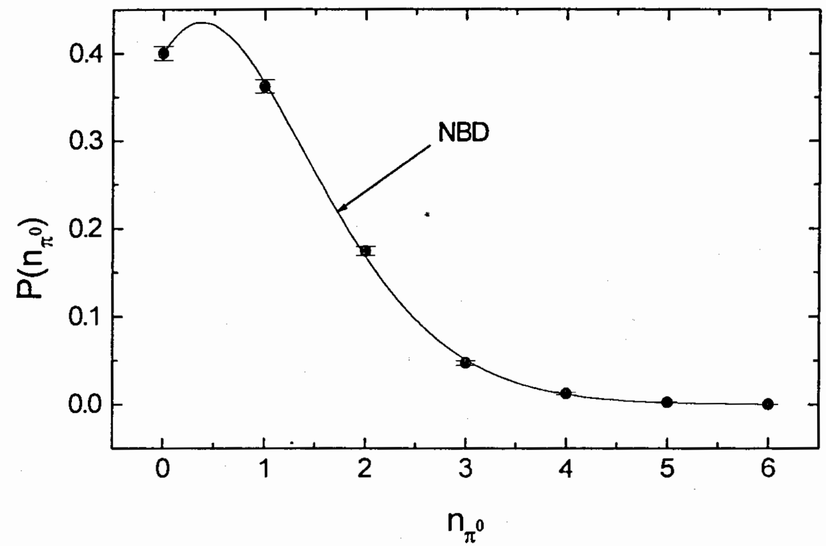

Fig.3. Multiplicity n_{π^0} distributions $P(n_{\pi^0})$ of produced pions in $\pi^- + Xe$ nuclear collision reaction at 3.5 GeV/c in lab. system ($E_{CM} = \sqrt{S} = 2.72$ GeV in (p, π^-) CM system). Black points — experimental data [3]; solid line — Negative Binomial Distribution (see Tab.3).

has two free parameters $\bar{n}$ and k varying with energy; $\bar{n}$ is interpreted as the average multiplicity. The dispersion is:

$$D^2_{NBD} = \bar{n} + \bar{n}^2. \qquad (2)$$

In order to distinguish between the theoretical values of the average multiplicity $\bar{n}$ and dispersion D_{NBD}, and the experimental ones, the latter are denoted by $\langle n \rangle$ and D.

Let us use one of the methods of choosing the best set of parameter $\bar{n}$ and k to describe a given multiplicity distribution. In assuming that $\bar{n}$ and D_{NBD} are equal to experimentally measured $\langle n \rangle$ and D, one gets:

$$\bar{n} = \langle n \rangle, \quad k = \frac{\langle n \rangle^2}{D^2 - \langle n \rangle}. \qquad (3)$$

For certain energy, at which k grows to infinity, $1/k = 0$; it corresponds to the Poissonian distribution.

All the three genuine distributions were analyzed, results of the analysis are presented in tables 1—3. From the data obtained, it can be stated that: the NBD as well as the Poissonian distributions describe well enough the experimental data — figs.1—3 and tables 1—3.

Table 1. Characteristics of the $n_\pi - 1 = n_{\pi^{+-0}}$ multiplicity distributions $P(n_\pi - 1)$

Experimental		Quantity	Poissonian	NBD
$n_\pi - 1$	$P(n_\pi - 1)$	χ^2	10.0	10.0
0	840			
1	1532	ndf	8	7
2	1741			
3	1253			
4	596	$\bar{n}$	1.99 ± 0.02	1.99 ± 0.02
5	176			
6	64	k		$7.5 \cdot 10^{11}$
7	8			
8	3	$1/k$		→0
9	—			
$<n_\pi - 1> = 1.99 \pm 0.02$				

Table 2. Characteristics of the $n_{\pi^{+-}} - 1$ distribution $P(n_{\pi^{+-}} - 1)$

Experimental		Quantity	Poissonian	NBD
$n_{\pi^{+-}} - 1$	$P(n_{\pi^{+-}} - 1)$	χ^2	0.13	8.2
0	1717			
1	2048	ndf	7	6
2	1277			
3	561	$\bar{n}$	1.19 ± 0.01	1.19 ± 0.01
4	168			
5	32	k		$2.3 \cdot 10^{11}$
6	1			
7	1	$1/k$		→0
$<n_{\pi^{+-}} - 1> = 1.05 \pm 0.03$				

Table 3. Characteristics of the n_{π^0} distribution $P(n_{\pi^0})$

Experimental		Quantity	Poissonian	NBD
n_{π^0}	$P(n_{\pi^0})$	χ^2	1.1	1.07
0	2523	ndf	6	5
1	2285			
2	1098	$\bar{n}$	1.199 ± 0.01	1.19 ± 0.01
3	299			
4	80	k		$2 \cdot 10^9$
5	15			
6	1	$1/k$		→0
$<n_{\pi^0}> = 0.92 \pm 0.02$				

4. CONCLUSIONS AND REMARKS

The genuine multiplicity $n_{\pi^{+-0}}$, $n_{\pi^{+-}}$ and n_{π^0} distributions $P(n_{\pi^{+-0}})$, $P(n_{\pi^{+-}})$ and $P(n_{\pi^0})$ of the pions produced in the nuclear $\pi^- + Xe$ collision are excellently described by the Negative Binomial Distribution (as well as by the Poissonian one).

On the other hand, it is known [4,5] that particles (pions in particular) are plentifully produced by some intermediate objects which used to decay into observed particles after left the parent nucleus.

It is known [9] that NBD has been promoted to the status of a new empirical law expressing multiplicity distributions of particles in high energy collisions. In contrary, in one of works of R.Szwed et al. [6], it is stated that the negative binomial distribution is found to have serious shortcomings which cast doubts on its usefulness in describing and interpreting experimental data. In such a situation, additional critical analysis of this problem is needed. In such an analysis the physical meaning of the NBD or of the Poissonian one (when $1/k \to 0$) should be deeply analysed.

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