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SEARCH FOR CORRELATIONS BETWEEN PROTONS EMITTED IN HIGH ENERGY HADRON-NUCLEUS COLLISIONS

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1. INTRODUCTION

One of the most important problems in investigations of the hadron-nucleus interactions at high energies is to reveal mechanisms of the particle (hadron) production and nucleon emission. The search for the mechanism of the nucleon (or proton only) emission in $\pi^- + Xe$ interactions at 3.5 GeV/c momentum, described here, is a particular case of the topics of the day.

The mechanisms are characterized by some centers or «clusters» of the phase variable groupings, for example of: longitudinal momenta p_{II}, variables $\eta = -\ln\left(tg\frac{\theta}{2}\right)$, rapidity $y = \frac{1}{2}\ln(E + p_{II})/(E - p_{II})$ used for a description of the particles ejected in the interactions (θ — the particle ejection angle, E — the total energy of the particle).

Application of the conventional statistical analysis for one- or two-dimensional projections of the $(3n - 4)$-dimensional variables phase space does not provide a possibility of evaluating the contribution from various mechanisms; often, it is impossible to indicate the existence of a mechanism — because of the variables overlap, fig.1. The peer into total sample variables phase space and the analysis of the particle grouping in some regions of it, have been carried out by T.Ludlam and R.Slansky [1], in the case of hadron-hadron interactions.

Let us discuss, within the frames of this method, the problem of the distinction between two models of particle ejection from an atomic nucleus caused by high energy hadronic projectile. In the first case, let the final state be the result of, e.g., the intranuclear cascade mechanism [2] and $p(y)$ be the distribution corresponding to it. In the second case, we assume $p(y)$ to be the weighed sum of distribution $p_1(y)$ and $p_2(y)$ — from the intranuclear cascade and the coherent pipe [3] mechanism, correspondingly. When in an experiment the ejection of particles goes according to the first or the second manner, the distributions $p(y)$ are similar. Larger fluctuations of the variables are expected relatively to the mean distribution in the case when two mechanisms are acting, however. Inclusive cross-section, connected with $p(y)$, does not give the possibility of distinguishing the two general models, and the fluctuation analysis becomes to be of particular significance.

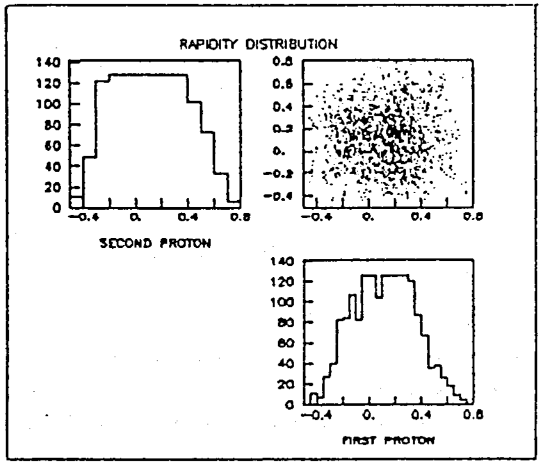

Fig.1. Rapidity distribution for pairs of protons in $(3n-4)$-dimension phase space

The purpose of this work is a selection of various mechanisms of the nucleon (proton, in particular) emission from the xenon nucleus in the $\pi^- +$ Xe nuclear collisions, on the basis of the fluctuation analysis. Calculations have been performed for each individual $\pi^- +$ Xe collision event using for its description, as the variables, the rapidity of k emitted protons.

The samples of all the collisions under analysis were divided into classes of events with identical proton multiplicity k.

2. EXPERIMENTAL DATA

The statistical analysis is based on the total number $N = 4725$ of $\pi^- +$ Xe interactions, table 1, with $k = 1, 2, \ldots, 10$ emitted protons of kinetic energies $E_{kin} \geq 20$ MeV in the final state.

The events are collected in our earlier experiment [4] in which the 180 litre xenon bubble chamber [5] of the parallelepipedal form ($103\times44\times40$ cm^3) has been exposed to pion beam at 3.5 GeV/c momentum from the accelerator of the Institute of Theoretical and Experimental Physics in Moscow; the experimental procedure is described in the paper cited [4].

In fig.1, the rapidity distribution is shown for pairs of protons in the $(3n-4)$-dimensional space of the phase variables.

Table 1. Characteristics of the $\pi^- +$ Xe nuclear collision events at 3.5 GeV/c momentum, analysed in this work. The symbols and denotations used are explained in section 3

Number of protons, k	Number of events, N_k	$\langle\omega_k^2\rangle$	$\Delta\langle\omega_k^2\rangle$	$\frac{1}{6k}$
1	1162	0.1690	0.0022	0.1667
2	946	0.0916	0.0022	0.0833
3	718	0.0672	0.0020	0.0556
4	602	0.0487	0.0018	0.0417
5	475	0.0383	0.0016	0.0333
6	352	0.0319	0.0014	0.0278
7	220	0.0260	0.0015	0.0238
8	143	0.0200	0.0013	0.0208
9	77	0.0183	0.0016	0.0185
10	30	0.0220	0.0038	0.0167
$E_{kin} \geq 20$ MeV	$\sum N_k = 4725$			

3. THE METHOD

For each i-th event with k emitted protons the rapidity is calculated: $y^* = \frac{1}{2}\ln(E+p_{II})/(E-p_{II})$ and the density distribution $p(y^*)$ is constructed. For a comparison of the distributions for various numbers of protons, the variable y^* is transformed to the form: $y = (y^* - \mu)/\alpha$, where μ and α are the mean values and the dispersion of the $p(y^*)$ distribution, correspondingly.

Subsequently, experimental increasing function:

$$S_{i,k}(y) = \frac{r}{k} \tag{1}$$

is constructed for each of the events, where r is the number of protons with the rapidity not larger than y. For all the events with k protons the density distribution $p(y)$ is constructed and corresponding to it increasing function $F(y)$. The function:

$$m_{i,k}(y) = [S_{i,k}(y) - F(y)]^2 p(y) \tag{2}$$

and the statistics

$$\omega_{i,k}^2 = \int_{y_{min}}^{y_{max}} m_{i,k}(y)\,dy = \frac{1}{12k^2} + \frac{1}{k}\sum_{r=1}^{k}\left[F(y) - \frac{2r-1}{2k}\right]^2 \tag{3}$$

are the fluctuation measure of the function $S_{i,k}(y)$ for an individual event around the mean distribution described by the function $F(y)$. The functions $S_{i,k}(y)$ and $F(y)$ are determined directly from the experimental data, using the relation:

$$F(y) = \frac{1}{N_k}\sum_{i=1}^{N_k} S_{i,k}(y) = \langle S_k(y)\rangle. \qquad (4)$$

The averaged for N_k events function

$$M_k(y) = \langle [S_{i,k}(y) - F(y)]^2\rangle\, p(y) \qquad (5)$$

is the measure of the fluctuation for each individual event with k protons. The mean value $\omega^2_{i,k}$ is connected with $M_k(y)$ by the relation:

$$\langle\omega^2_k\rangle = \int M_k(y)\, dy. \qquad (6)$$

For the independent emission of k protons the statistics $\langle\omega^2_k\rangle$ value is equal to [6,7] $1/6k$. The values of $M(y)$ and ω^2 are not the measure of the clasterization effects, but the comparison of these values with the results of a modeling of the independent emission could reveal such effects in the interactions under the analysis.

In order to compare the effects taking place in events with k protons in the final state, the standardized fluctuation function of the shape:

$$\mathrm{STM}(y) = \frac{M_{\mathrm{EXP}}(y) - M_{\mathrm{MOD}}(y)}{M_{\mathrm{MOD}}(y)} \qquad (7)$$

has been introduced. The consequences concerning the fluctuations can be obtained on the basis of the STM(y) function and the comparison of corresponding distributions; and statistics, from the modeling and the experiment.

4. RESULTS AND DISCUSSION

The results of the analysis described above are presented in table 1 and on figures 2—7.

On the basis of corresponding diagrams, reflecting the fluctuations in the kinematical space of the variable rapidity of the protons emitted from the target-nucleus in nuclear $\pi^- +$ Xe collisions at 3.5 GeV/c momentum, there can be formulated the following results; the mostly important should be emphasized:

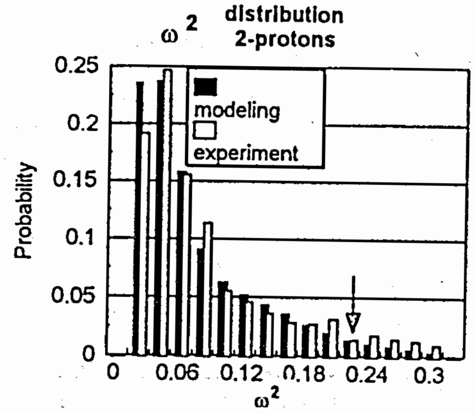

Fig.2. The probability distribution of ω^2 values for the sample of events with $k = 2$ protons

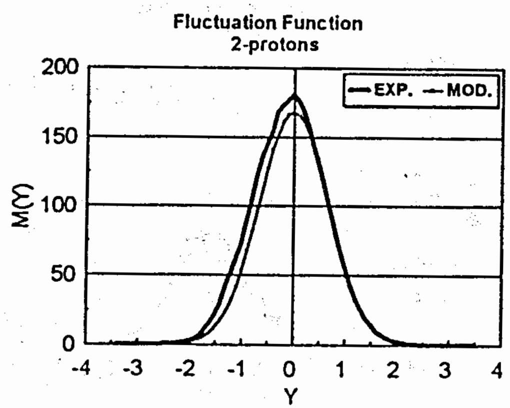

Fig.3. The fluctuation function $M(y)$ for the sample of events with $k = 2$ protons

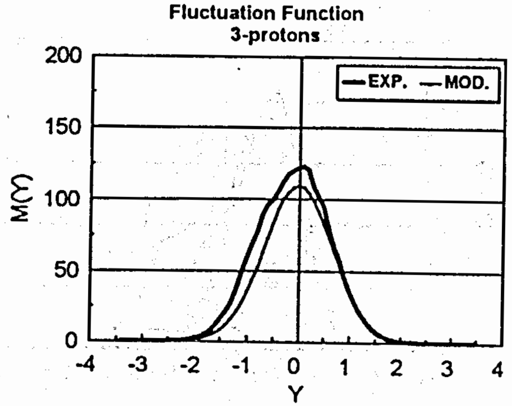

Fig.4. The fluctuation function $M(y)$ for the sample of events with $k = 3$ protons

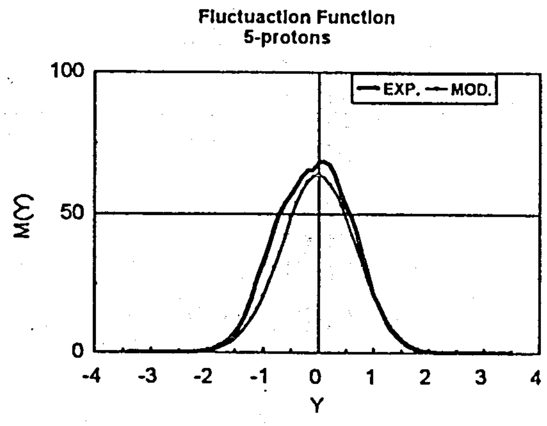

Fig.5. The fluctuation function $M(y)$ for the sample of events with $k = 5$ protons

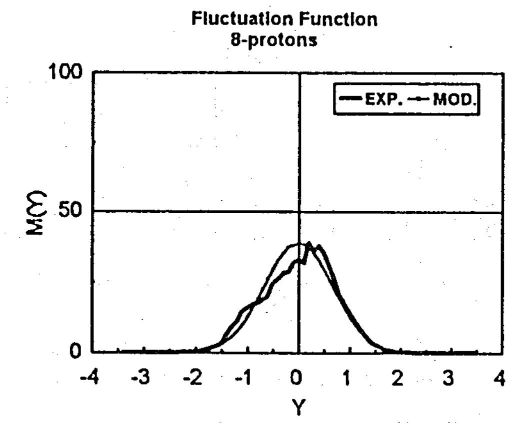

Fig.6. The fluctuation function $M(y)$ for the sample of events with $k = 8$ protons

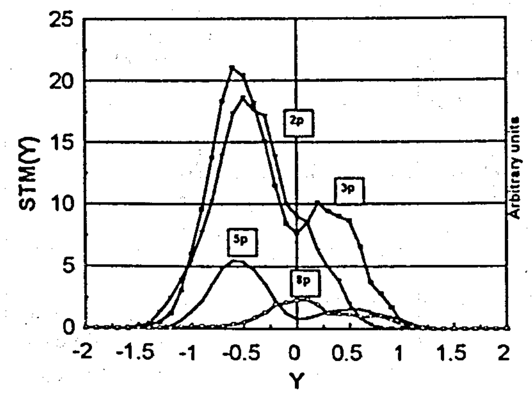

Fig.7. The standardized fluctuation function $M(y)$ for the samples of events with $k = 2,3,5$ and 8 protons

1.The values of the testing statistics for the independent emission of the protons are a few percent smaller than the corresponding values for the experimental data.

2. With the increasing of the number of the emitted protons the number of the grouping centers of kinematical variables in the phase space increases, fig.7. The grouping effects manifest themselves, especially for the protons emitted into the backward hemisphere ($y < 0$).

3. The contribution of the fluctuations decreases with the increase of the number of the emitted protons.

In conclusion, from the results of the analysis it should be stated that the clusterization is an experimental fact — outside the limits of statistical errors, for the proton multiplicities $k < 8$, table 1; this result can be extrapolated and for the emitted neutrons, for all the emitted nucleons.

In Laboratory of High Energies, JINR, the investigations of the proton clusterization started with the work of A.M.Baldin et al. [8].

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