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SCALE VARIABLE FOR DESCRIPTION OF CUMULATIVE PARTICLE PRODUCTION IN NUCLEUS-NUCLEUS COLLISIONS

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A phenomenological approach is proposed to describe a cumulative particle production in nucleus-nucleus collisions. It is founded on a unification of a relativistic invariant scale variable (cumulative number) and takes into account fluctons (a high momentum components) in both colliding nuclei. Inclusive spectra of cumulative particles are shown to be fitted by a single exponential function. A slope parameter of exponent tends to a constant value as initial energy of a collision increases. This approach makes possible a prediction of absolute values of cross section in a twice cumulative region where a contribution of both fluctons is essential.

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

Масштабная переменная для описания кумулятивного рождения частиц в ядро-ядерных столкновениях

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Предложен феноменологический подход к описанию кумулятивного рождения в ядро-ядерных столкновениях. Этот подход базируется на расширении понятия масштабной переменной (кумулятивного числа) с учетом наличия флуктонов (высокоимпульсной компоненты) в обоих сталкивающихся ядрах. Показано, что при таком подходе инклюзивные спектры описываются экспонентой с наклоном, который с ростом энергии сталкивающихся ядер стремится к постоянной величине. Предсказана величина инклюзивного сечения для столкновений, когда существенны флуктоны в обоих ядрах (двойной кумулятив).

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A relativistic invariant scale variable $X_{I(II)}$ introduced by A.M.Baldin and V.S.Stavinsky [1,2] is widely used for an analysis of experimental data on a fragmentation of nuclei (see, for example, [3,4,5,6,7]). It is considered as a minimal fraction of 4-momentum of a fragmenting nucleus needed to obey the 4-momentum conservation law for a production of a particle with a given momentum and mass in a proton-nucleus collision. Inclusive invariant cross sections vs X can be presented in the following parametrization:

$$E\frac{d\sigma}{dp} = C_I(\theta)\exp(-X_I/\overline{X}_I), \qquad (1)$$

where $C_I(\theta)$ is an angle and particle type depending constant; E, beam energy per nucleon; X_I, cumulative number; $\overline{X}$, a slope parameter (for example, see fig.1). The slope parameter has the same value for different type secondary particles and weakly depends on a collision energy starting from 3—4 GeV/nucleon. Values of X greater than 1 correspond to a cumulative production. As in the case of a cumulative number, a generalized scale variable can be derived from the expression for the 4-momentum conservation law

$$x_I P_I + x_{II} P_{II} = P_1 + P_R, \qquad (2)$$

where P_I and P_{II} are 4-momenta per nucleon of colliding nuclei; x_I and x_{II} are dimensionless fractions of the 4-momenta; P_1, a 4-momentum of an inclusively studied particle; P_R, a total 4-momentum of recoiled particles; a region of allowed values of both X is defined by the following expression

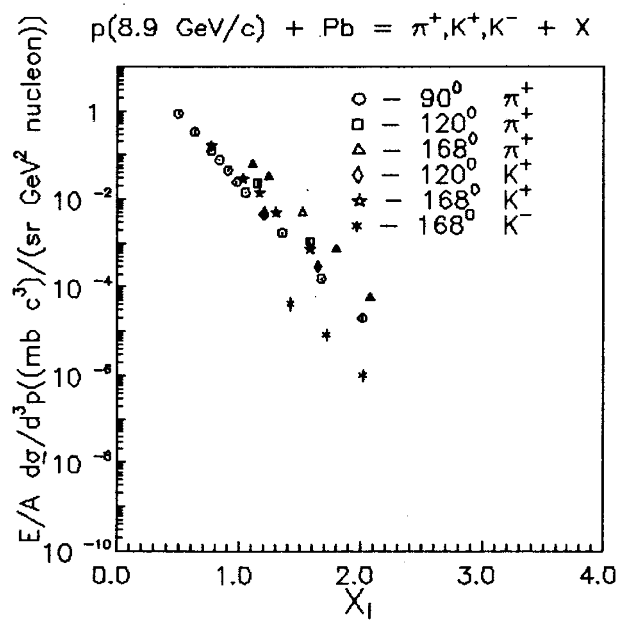

Fig. 1. Invariant differential cross section as a function of scale variable [3]

$$P_R^2 \geq (x_I m_n + x_{II} m_n + m_2)^2. \tag{3}$$

It leads to the limitation

$$x_I \geq x_I(x_{II}) = \frac{x_{II}A + D}{x_{II}C - B}. \tag{4}$$

The following designations are introduced

$$A = (P_{II}\, P_1) + m_n m_2, \tag{5}$$

$$B + (P_I P_1) + m_n m_2, \tag{6}$$

$$C = (P_{II} P_I) + m_n m_2, \tag{7}$$

$$D = (m_2^2 + m_1^2)\,/\,2, \tag{8}$$

where m_n is a nucleon mass; m_1, a produced particle mass; m_2, an additional particle mass needed to satisfy the quantum numbers conservation laws in a studied reaction. For proton production m_2 is equal to a proton mass taken with a negative sign, for pion — $m_2 = 0$, for K^- — a kaon mass, etc. A dependence of one cumulative number vs another is shown in fig 2. It should be

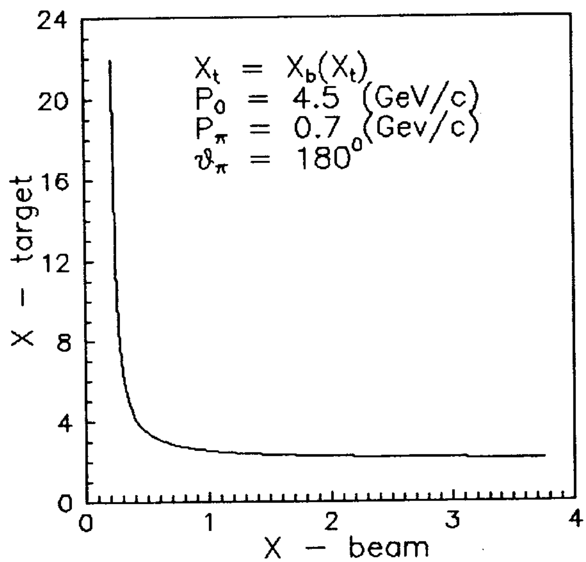

Fig.2. A dependence of one cumulative number vs another

stressed these variables are very convenient for an analysis of subthreshold reactions.

Let us suppose that a probability to find a configuration in a nucleus with a fraction of a 4-momentum x is dropping exponentially with slope parameter $\overline{X}_S$

$$W(x)\,dx \sim \exp(-x / \overline{X}_S). \tag{9}$$

In this case one can draw an expression for an invariant cross section

$$E\frac{d\sigma}{dp} \sim \int_{x_I^{\min}}^{A_I} dx_I \int_{x_{II}(x_I)}^{A_{II}} dx_{II} \exp(- x_I / \overline{X}_S) \exp(-x_{II} / \overline{X}_S) =$$
$$= \int_{x_I^{\min}}^{A_I} dx_I \exp(- (x_I + x_{II}(x_I)) / \overline{X}_S)). \tag{10}$$

Due to the rapid drop of the integrated function, a value of the integral is proportional to a value of the integrated function in a point of a maximum. Taking into account this circumstance we obtain from expression (10)

$$E\frac{d\sigma}{dp} = C_S(\theta) \exp(-X_S / \overline{X}_S). \tag{11}$$

Demanding a minimum of the exponent argument in (10) we derive a generalized scale variable X_S

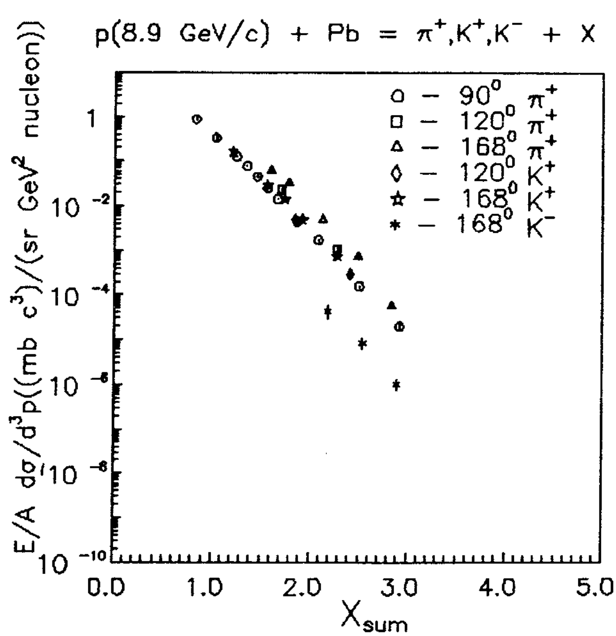

Fig.3. Invariant differential cross section as a function of generalized scale variable [3]

$$\frac{d}{x_I}(x_I^* + x_{II}(x_I^*)) = 0, \tag{12}$$

$$X_I^S = x_I^* = \frac{A + \sqrt{(AB + CD)}}{C}, \tag{13}$$

$$X_{II}^S = x_{II}^* = \frac{B + \sqrt{(AB + CD)}}{C}, \tag{14}$$

$$X_S = x_I^S + X_{II}^S. \tag{15}$$

Figure 3 shows the same experimental data as in fig.1 vs X_S. Comparing these figures one can conclude that the X_S exponent fits a data not worse than a cumulative number exponent, but the C coefficient is more weakly dependent on a production angle in the case of a generalized scale variable.

The data on a cumulative pion production at angle near 160° measured with a variation of a collision energy are presented in fig.4. It can be seen the slope parameter ceases changing at an energy about 30 GeV (fig.5). Besides, we are used to analyze data on a pion production in a kinematical region forbidden for a free nucleon collision at a collision energy of 2 GeV [8, 9]. An accuracy of description of the data in an interval with a 6 order of magnitude drop of a cross section is about 40 — 50%.

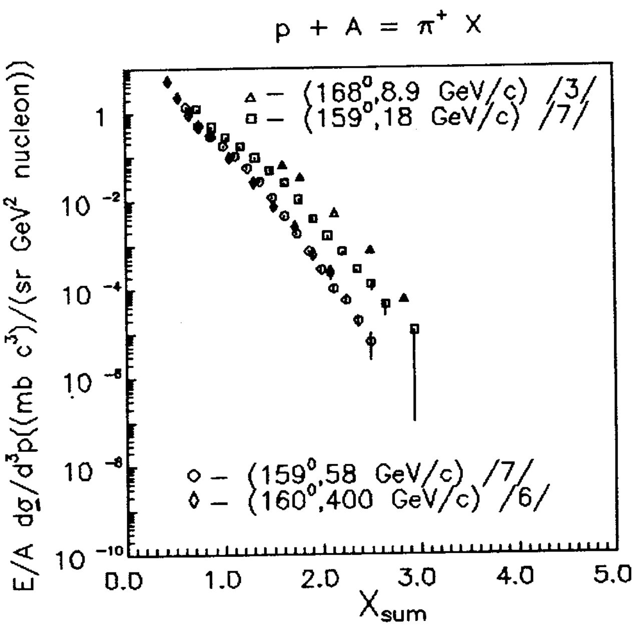

Fig.4. Pion cross section vs generalized scale variable and collision energy

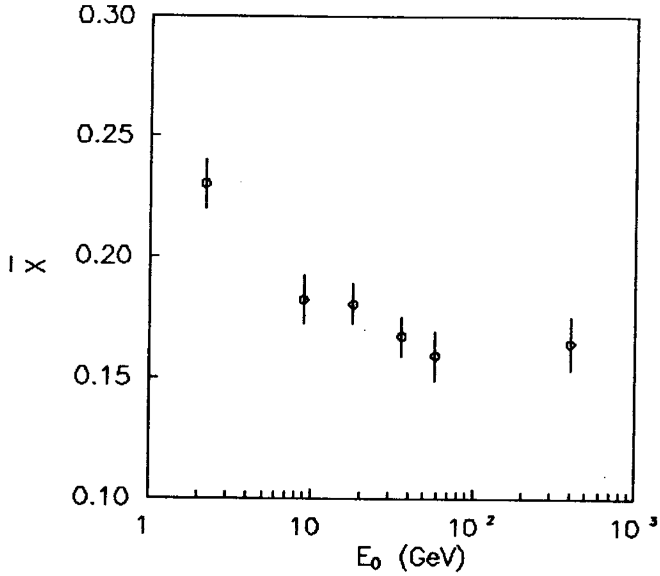

Fig.5. Slope parameter ($\overline{X}_S$) as a function of collision energy

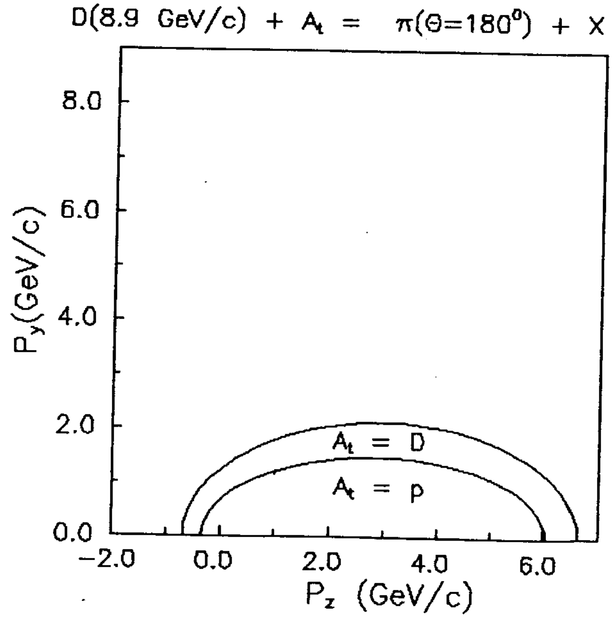

Fig.6. Kinematical region of pion production in DP and DD collisions

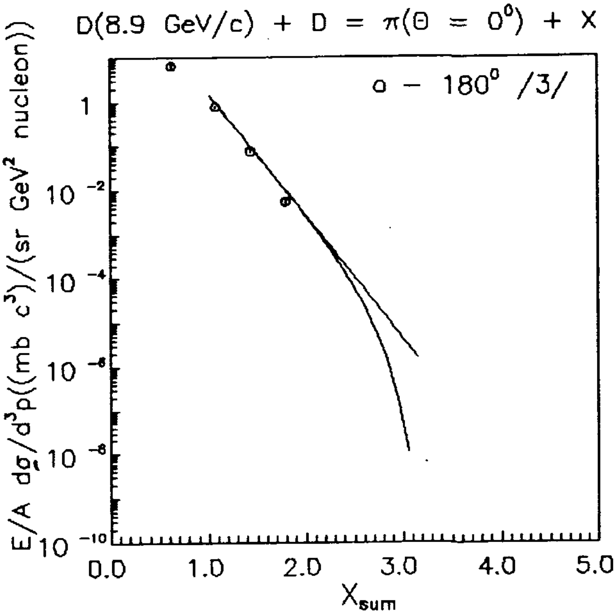

Fig.7. Pion cross section for DD collision

The parameterization (9) makes possible to predict a value of a cross section where a cumulative number dependence is inapplicable. To illustrate let us consider a deuteron fragmentation into a pion on a proton and on a deuteron (or more heavy nucleus). Corresponding kinematical ellipses of reactions are presented in fig.6. Flucton-flucton collisions may contribute in a region between two ellipses ($X_I > 1, X_{II} > 1$, or a twice cumulative region).

A prediction of a cross section behavior for this kind of a reaction is shown in fig.7 (solid line). The experimental points in the figure were taken from paper [3], where a deuteron fragmetation into pions at an angle of 180° was studied. The dashed line is a result of a cumulative number parameterization, i.e., one of X was put equal to 1.

Thus, our approach takes into account an influence of fluctons in both colliding nuclei while keeping all merits of a cumulative particle description with a relativistic invariant scale variable. It seems to be an important conclusion to plan experiments with a preselection of extreme initial states of colliding nuclei. One of practical applications of this idea is a quark-gluon plasma search in colliding nuclear beams.

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