Multiplicity Fluctuations in Interactions of Light Nuclei with Carbon Nuclei at Momentum of 4.2 GeV/c per Nucleon and Their Theoretical Interpretation

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Аннотация

Представлены экспериментальные данные о флуктуациях множественностей отрицательно заряженных частиц во взаимодействиях легких ядер (p, d, ^4He, ^{12}C) с ядрами углерода при импульсе 4.2 ГэВ/с/нуклон, полученные в условиях 4π геометрии. Данные показывают поведение, аналогичное наблюдавшемуся ранее Сотрудничеством NA-49.

Для анализа данных использованы каскадно-испарительная модель, модель FRITIOF и модель UrQMD 1.3. Впервые достигнуто теоретическое описание зависимости флуктуаций от центральности соударений ядер без привлечения экзотических предположений. Согласно модели FRITIOF, зависимость флуктуации множественностей от центральности соударений обусловлена как флуктуациями числа “раненных” нуклонов, так и флуктуациями, обусловленными механизмом процесса множественного рождения.

A nontrivial dependence of a scaled variance of multiplicity distribution of produced particles in nucleus-nucleus interactions at energy of 158 GeV/nucleon observed by the NA-49 Collaboration [1] (see also [2, 3]) has received explanation in the string-fusion model [4] and in the statistical model [5]. According to the string-fusion model, large multiplicity fluctuations are caused by large fluctuations of quark-gluon string multiplicity in peripheral interactions when they start to overlap and fuse. It is assumed in the statistical model that a thermodynamical equilibrium system is created in the interactions, and a relation between the volume of the system and the volume of 2-particle interactions determines the multiplicity fluctuations. It is difficult to imagine that some of these scenarios are realized at sufficiently low energy in hadron-nucleus and nucleus-nucleus interactions. Thus, it is interesting to study the produced particles multiplicity fluctuations in nucleus-nucleus interactions in order to understand the nature of the effect observed by the NA-49 Collaboration.

Below we present experimental data obtained by a propane bubble chamber collaboration in LHE JINR. The chamber was irradiated by protons, deutrons, α-particles and carbon nuclei with momentum of 4.2 GeV/c per nucleon. Methods of picture processing and peculiarity of the experimental conditions are presented in the paper [6]. π^--mesons were identified quite well in the propane chamber in 4π-geometry. Protons were identified up to 500 MeV/c. At larger momenta the separation of protons and π^+-mesons is complicated, but their momenta are defined well. The tracks of positive charged particles with momentum larger than 3 GeV/c and emission angle less than 4^o were considered as spectator protons of projectile nuclei. The evaporated protons with momentum less than 300 MeV/c and proton-participants with momentum larger than 300 MeV/c without spectators were selected among protons. Multi-charged fragments of projectile nuclei were determined by ionization. A summary charge (Q) of the produced particles (π^+-,

π^--mesons and proton-participants) has been used as a collision centrality in this paper, $Q = n_+ - n_- - n_{evap} - n_{strp}$.

In Fig. 1 we present the scaled variances of negative charged particle multiplicity distributions in pC-, dC-, αC and CC-interactions at momentum 4.2 GeV/c per nucleon. The scaled variance of a distribution is determined as a ratio of the distribution variance to a mean multiplicity of particles. It is expected [7] that the scaled variance will be close to unity for a thermodynamical equilibrium system of particles (quark-gluon plasma or hot hadronic gas). Both the multiplicity fluctuations observed by us and those studied by the NA-49 collaboration [1] show defined dependence on the collision centrality.

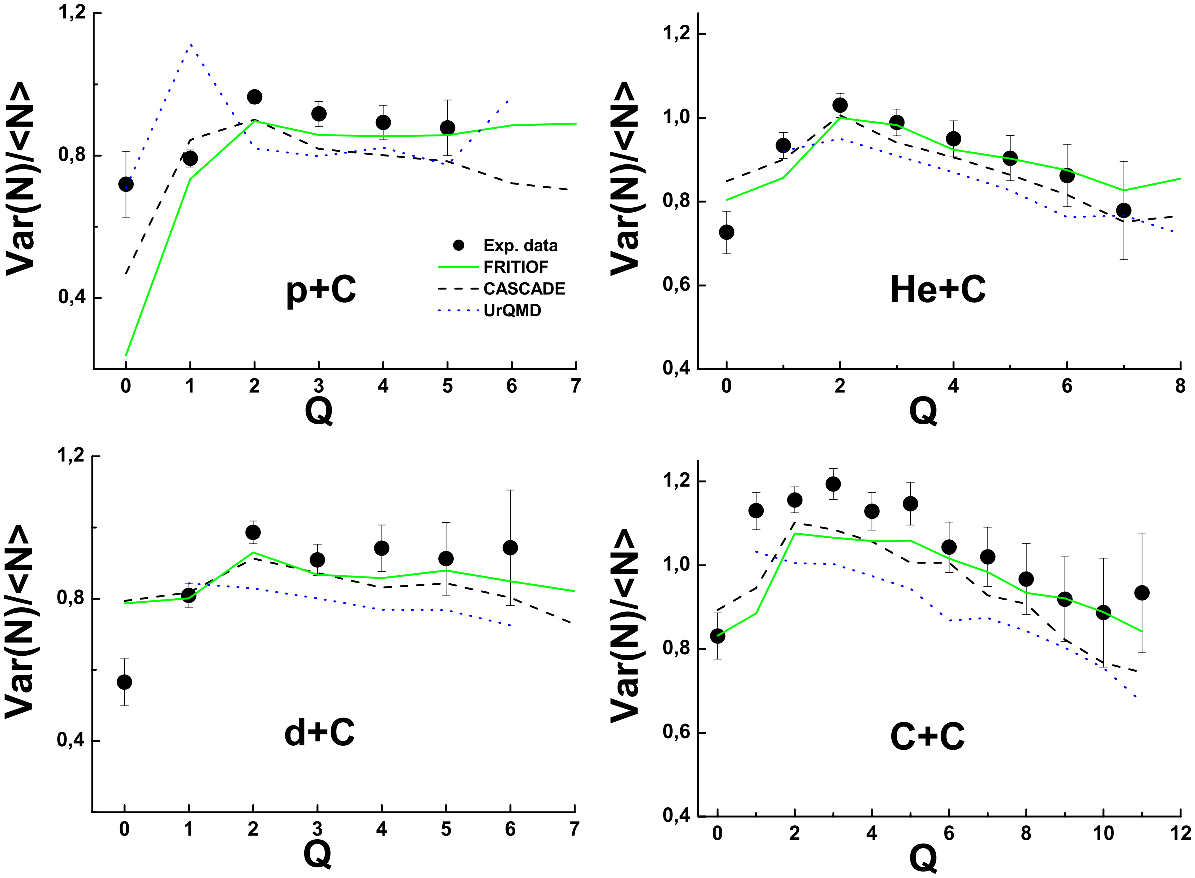

Fig. 1: Scaled variances of negative charged particle multiplicity distributions in the light nuclei interactions with carbon nuclei at momentum 4.2 GeV/c/nucleon. Points are experimental data, lines are theoretical calculations. Solid lines are FRITIOF model calculations. Dushed lines are Cascade-Evaporation model calculations. Dotted lines are UrQMD model calculations

Scaled variances in peripheral interactions ($Q = 0$) are close to ones in nucleon-nucleon collisions. After that there is a big rise of the fluctuations, and their slowly decrease with increase of collision centrality (increase of Q). The scaled variances depend on projectile nuclei in central interactions, and less than unity in common case.

The theoretical models applied by us – FRITIOF [8], UrQMD[1)] [10] and the Cascade-Evaporation model [11] reproduce qualitatively the behaviour of our experimental data in contrast to the situation at higher energies [1]. This allows us to analyze the experimental data.

[1)] The models FRITIOF and UrQMD were enlarged by the Statistical Multi-fragmentation model [9].

According to Ref. [7] the scaled variance of multiplicity distribution at presence of many independent sources of particle generation is determined as:

$$\omega = \frac{< n^2 > - < n >^2}{< n >} + < n > \frac{< N_s^2 > - < N_s >^2}{< N_s >}, \tag{1}$$

where $< n >$ is the average multiplicity of particles produced by a source, and $< N_s >$ is the average multiplicity of the sources. So, the scaled variance has not to depend on the collision centrality at small fluctuations of the source multiplicity and grows with increase of interaction energy.

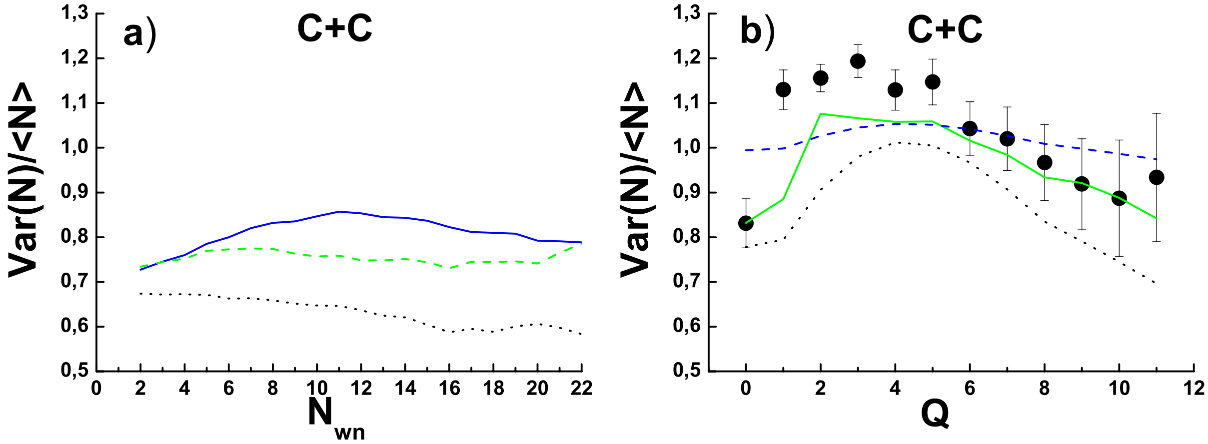

Fig. 2: Scaled variances of multiplicity distributions. Points are the experimental data of Fig. 1. The dotted line (Fig. 2a) presents the multiplicity fluctuations of produced particles caused by inelastic NN-collisions only. The dashed line (Fig. 2a) is the calculation of the fluctuations at the elastic and inelastic scatterings. The solid line (Fig. 2a) presents the fluctuations at the consideration of ejected nucleons as "wounded"ones. The dotted line (Fig. 2b) is the scaled variance of the multiplicity distribution of the "wounded"and ejected nucleons as a function of the collision centrality. The dashed line (Fig. 2b) – see description in the text. The solid line (Fig. 2b) is the result of complete calculation

The FRITIOF model assumes that nucleons of interacting nuclei turn to excited states with continuous mass spectra due to binary collisions. The excited, “wounded” nucleons fragment into observed particles. We have checked that the FRITIOF model predicts slowly decrease of the scaled variance in CC-interactions at fixed multiplicity of “wounded” nucleons and at a consideration of inelastic nucleon-nucleon collisions only (see Fig. 2a dotted line). Taking into account elastic scattering of nucleons leads to increase of the scaled variance (a little bit) (see Fig. 2a dashed line). The elastic scattering introduces additional fluctuations into multi-particle production processes. If we consider nucleons ejected at the cascade stage of interactions as “wounded” ones[2], then the fluctuations grow up, and their dependence on multiplicity of “wounded” nucleons appears (see Fig. 2a solid line). So, various aspects of multi-particle production do not allow one to understand completely the observed dependence of fluctuations on the collision centrality.

According to Eq.(1), the scaled variance is also connected with the “wounded” nucleon multiplicity fluctuations. Dotted line in Fig. 2b shows their strong dependence on Q. Let us mark that the quantity Q is nearly equal to the multiplicity of the “wounded” protons. At fixed Q, the multiplicity of the “wounded” neutrons can fluctuate. Thus, the total multiplicity of the “wounded” nucleons also fluctuates at fixed Q. Inserting the

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[2] This depends on experimental conditions.

calculated "wounded" nucleon multiplicity fluctuations in Eq. 1 and using $(< n^2 > - < n >^2)/ < n >= 0.8$ and $< n >= 0.25$ (see Fig. 2a), we have a result roughly close to the experimental data (see Fig. 2b dashed line). So, we can say that the amplitude of the scaled variance of the negative particle multiplicity distribution is mainly determined by the fluctuations in NN-collisions. The Q dependence of the scaled variance is closely connected with experimental conditions of centrality selection.

According to the UrQMD model, the creation of various baryonic resonances is a dominant process at our energy. The multiplicity of produced particles will be proportional to the multiplicity of the "wounded" nucleons, if one neglects secondary interactions of the resonances, that is acceptably for $AC-$interactions. Thus, we can assume that the first term of Eq. 1 for $AC-$interactions is approximately equal to one in NN-collisions, and the scaled variance of multiplicity distribution is determined by the fluctuations of the "wounded"nucleon multiplicity. Since the fluctuations of the "wounded" nucleon multiplicity are similar for FRITIOF and UrQMD models, the UrQMD model reproduces qualitatively the dependence of the scaled variance on Q. However, our calculations show that the UrQMD model underestimates the scaled variance for NN-interactions. It is the main reason why the model underestimates the experimental data in Fig. 1.

The Cascade-Evaporation model assumes a direct production of mesons without baryonic resonance creation. As the probability of the meson absorption is small for light nuclei, we can consider the meson production as an independent emission of mesons. In this case, the Q-dependence of the scaled variance is determined by Q-dependence of the "wounded" nucleon multiplicity fluctuations. These fluctuations are treated similarly by all considered models. Thus, the cascade model reproduces quite well the experimental data of Fig. 1.

Summing up, we can say that the data of Fig. 1 are strongly connected with the fluctuations of the multiplicity of the NN-collisions. The calculations of the multiplicity by the FRITIOF model are quite sensitive to the elastic NN-interaction cross-section. The UrQMD model results can be put in agreement with the experimental data at 10% increasing of the elastic NN-interaction cross-section. It can be explained by influence of nuclear medium on the NN-collision properties. It is one of the ways to improve the models. Another way is to take into account the diffraction dissociation processes. A consideration of these processes can lead to increase of the multiplicity fluctuations.

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