

Multiplicity Fluctuations of Particles Produced in Interactions of Light Nuclei with Carbon Nuclei at a Momentum of 4.2 A GeV/c

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A nontrivial dependence of normalized fluctuations in the multiplicities of particles produced in nucleus nucleus interactions at an energy of 158 GeV/nucleon observed by the NA49 Collaboration [1] was explained in models assumed quark-gluon plasma formation. Since this mechanism can hardly be realized in hadron-nucleus and nucleus-nucleus interactions at relatively low energies, it is of interest to study the character of the fluctuations in the multiplicities of particles produced in the above interactions in order to understand the nature of the effect observed by the NA49 Collaboration.

Below we present experimental data obtained by a propane bubble chamber collaboration in LHE JINR. The chamber was exposed to protons, deuterons, α -particles, and carbon nuclei with a momentum of 4.2 A GeV/c. Methodological aspects of the picture processing and specific features of the experiment were described in [2]. Here, it should only be mentioned that π -mesons are reliably identified in the propane chamber in 4π geometry. Protons are identified at momenta up to 500 MeV/c. It is difficult to identify π^+ mesons and protons with higher momenta, but their momenta are well determined. Tracks of positively charged particles with momenta above 3 GeV/c and emission angles below 4° were treated as spectator fragments of projectile nuclei. Among protons, it was separated evaporated protons of momenta below 300 MeV/c and participant protons of momenta above 300 MeV/c without spectator protons. Multiply-charged fragments of projectile nuclei were identified by produced ionization.

In this study, the total charge of the produced particles (π^+ and π^- mesons) and participant protons, $Q = n_+ + n_- - n_{proj.fr.} - n_{evap}$, was used as a measure of collision centrality, where n_+ is the number of positively charged tracks, n_- is the number of negatively charged tracks, $n_{proj.fr.}$ is the number of spectator fragments, and n_{evap} is the number of evaporation protons.

Figure 1 shows the normalized fluctuations in the multiplicities of negatively charged particles in pC , dC , αC , and CC collisions at a momentum of 4.2 A GeV/c. Normalized fluctuations are defined as the ratio of the multiplicity distribution variance to the average multiplicity of produced particles. It is expected [3] that the normalized fluctuations will be close to one when the thermodynamic-equilibrium system of particles (quark-gluon plasma or hot hadron gas) arises. Fluctuations observed by

us, as well as those studied earlier by the NA49 Collaboration [1], show a particular dependence on the collision centrality: normalized fluctuations are close to that in nucleon-nucleon collisions in the most peripheral nucleon-nucleon collisions (at $Q = 0$). Then, the fluctuations increase drastically and decrease slowly with an increase in the centrality of collisions (with increasing Q). In central collisions, normalized fluctuations depend on the projectile nucleus and do not tend to unit in the general case.

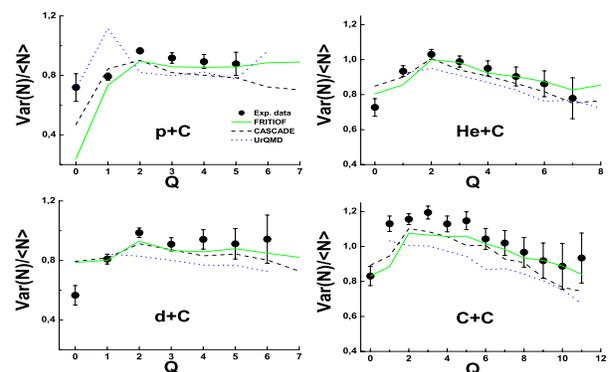


Figure 1: Scaled variances of negative charged particle multiplicity distributions in the light nuclei interactions with carbon nuclei at momentum 4.2 GeV/c/nucleon. Points are exp. data, lines are theoretical calculations. Solid lines are FRITIOF model calculations. Dashed lines are Cascade-Evaporation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

The theoretical models – FRITIOF [4], UrQMD¹⁾ [6] and the cascade evaporation model [7], qualitatively reproduce the behavior of the experimental data in contrast to the case at higher energies [1]. This allows the experimental data to be analyzed.

According to the FRITIOF model calculations, the observed fluctuations are mainly related to the fluctuations in the wounded nucleon multiplicity. Because Q fixes the number of interacted protons, the number of interacted neutrons may fluctuate. Therefore, the number of wounded nucleons also fluctuates.

The UrQMD model qualitatively reproduces the behavior of the experimental data in Fig. 1, but underestimates the normalized fluctuations in the absolute value due to that the normalized fluctuations in NN collisions in the UrQMD model are slightly smaller than those in the FRITIOF model.

¹⁾ The models FRITIOF and UrQMD were enlarged by the Statistical Multi-fragmentation model [5].

The cascade evaporation model assumes that mesons are directly produced without the nucleon resonance formation stage. Since the absorption of mesons in secondary interactions in light nuclei is small, the multiplicity of produced particles is also proportional to the multiplicity of interacting nucleons in this model and it qualitatively reproduces the data in Fig. 1.

Thus, the data in Fig. 1 are closely related to the fluctuations in the number of NN collisions in the nucleus-nucleus interaction.

Turning to the NA49 data and difficulties in their theoretical interpretation by the UrQMD, HSD, VENUS, and HIJING models [1], we note that the multiplicity of the wounded nucleons of the projectile nucleus was evaluated in the experiment using the veto calorimeter measuring the total energy of particles within a narrow angular region along the beam direction behind the target. This energy depends on the magnetic field through which the particles pass, the calorimeter calibration constants, acceptance of the calorimeter, etc. Their variation leads to variation in the energy distributions in the veto calorimeter and to variation in the selection of events on the basis of the veto calorimeter and, thus, indirectly to variation in the estimates of the wounded nucleon multiplicity. The removal of, for example, the central part of the calorimeter in order to pass the beam particles that do not undergo interaction results in a loss of peripheral interactions and a decrease in the yield of events with a large energy release. Under these conditions, it is difficult to correctly evaluate the multiplicity of the nucleons of a projectile nucleus that undergo interaction.

The energy distribution in the veto calorimeter given in [1] (see Fig. 2a, lower points) is strongly different from the one earlier published by the same collaboration [8] for the so-called minimal bias events (see Fig. 2a, upper points). The cause for the difference is not discussed in [1].

The distribution from [8] was well described by the VENUS and FRITIOF models. Description of the distribution from [1] calls for more effort. To roughly take into account the experimental conditions, we used the description of the veto calorimeter given in [9]. In the FRITIOF program, cascade interactions were simulated within the reggeon model of nuclear disintegration [10]. Three values of the parameter C_{nd} governing the cascade interaction intensity were used: $C_{nd} = 0$, cascade interactions are ignored; $C_{nd} = 0.35$ as in [11], and $C_{nd} = 0.2$. Nuclear multifragmentation was simulated within the statistical model of nuclear multifragmentation [5]. Three alternative calculations yielded similar energy distributions in the veto calorimeter (see Fig. 3a). Discrepancies between the calculated and experimental data at large and small E_V are probably due to ignored features of the veto calorimeter. The calculations also showed that nuclear fragments and evaporation nucleons al-

most always arrive at the veto calorimeter. Nucleons knocked out in the cascade interactions hit the calorimeter with a probability of about 50%, which leads to the redistribution of E_V and to fluctuations in the evaluated multiplicities of wounded nucleon. Allowance for these fluctuations makes it possible to understand the NA49 data (see Fig. 2b). Thus, the regularities observed by the NA49 Collaboration reflect both the features of the veto calorimeter and the intensity of the cascade interactions of the produced particles. More extended analysis can be found in Ref. [12].

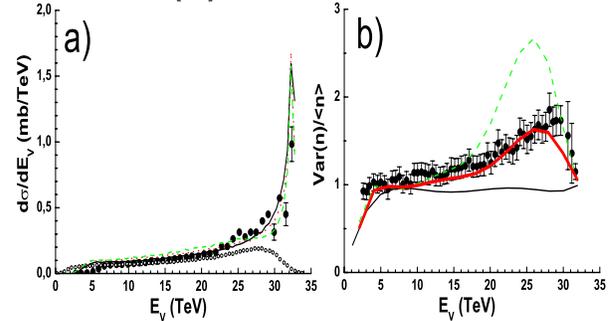


Figure 2: (a) Energy distribution in the veto calorimeter. Lower points are the renormalized experimental data from [1], and the upper points are the data from [8]. The curves are the calculations at $C_{nd} = 0$ (solid), 0.35 (dashed), and 0.2 (dotted). (b) Normalized fluctuations in multiplicities of negatively charged particles. The points are the experimental data [1]. The curve notations are the same as in (a), but the dotted curve is replaced by the thick solid curve for convenience.

References

- [1] NA49 Collaboration (C. Alt et al.), Phys. Rev. **C75** (2007) 064904; nucl-ex/0612010.
- [2] A.I.Bondarenko et al., JINR Preprint 1-98-292, Dubna, 1998.
- [3] H. Heiselberg, Phys. Rep. **351** (2001) 161; G. Baym and H. Heiselberg, Phys. Lett. **B469** (1999) 7.
- [4] B. Andersson et al., Nucl. Phys. **B281** (1987) 289; B. Nilsson-Almqvist and E. Stenlund, Comp. Phys. Commun. **43** (1987) 387.
- [5] J.P. Bondorf, A.S. Botvina, A.S. Ilinov, I.N. Mishustin, K. Sneppen, Phys. Rept. **257** (1995) 133.
- [6] S.A. Bass et al., Prog. Part. Nucl. Phys., **41** (1998) 225; M. Bleicher et al., J. Phys. **G25** (1999) 1859.
- [7] V.S. Barashenkov and V.D. Toneev, "Interaction of high energy particles and atomic nuclei with nuclei", Moscow, Atomizdat, 1972; V.S. Barashenkov, F.G. Zherygy and Zh.Zh. Musulmanbekov, Preprint JINR P2-83-117 (1983) Dubna.
- [8] NA49 Collaboration (S. Afanasiev et al.) NIM, **A430** (1999) 210.
- [9] H. Appelshäuser et al. (NA49 Collab.), Eur. Phys. J. A **2**, 383 (1998).
- [10] K. Abdel-Waged and V. V. Uzhinsky, Yad. Fiz. **60** (1997) 925 [Phys. At. Nucl. **60** (1997) 828].
- [11] M.I. Adamovich et al. (EMU-01/12 Collab.), Z. Phys. **A 359** (1997) 277.
- [12] A.S. Galoyan, E.N. Kladnitskaya, V.V. Uzhinsky, JETP Lett. **86** (2008) 630.