Search for shock waves in nucleus–nucleus collisions

E. S. Basova, A. I. Bondarenko, K. G. Gulamov, U. G. Gulyamov, Sh. Z. Nasyrov, L. N. Svechnikova, and G. M. Chernov

Institute of Nuclear Physics, Uzbek Academy of Sciences
(Submitted July 12, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **24**, No. 4, 257–260 (20 August 1976)

The hypothesis that nuclear shock waves are produced by inelastic collisions of light relativistic nuclei with nuclei was experimentally verified (with negative result).

PACS numbers: 13.80.Fj, 13.80.Kp, 25.60.Cy, 25.70.+a

Following the work by Glassgold *et al.* [1], who indicated the possibility of occurence of nuclear shock waves (NSW) when a high-energy hadron goes through a nucleus, a number of concrete NSW mechanisms have been proposed, [2–8], notwithstanding certain doubts concerning the applicability of the equations of relativistic hydrodynamics to nuclear systems. [9,10] The experimental data on NSW are skimpy and contradictory [11–13]; we note only inclusive angular distributions of slow (nuclear) particles have been studied.

We have carried out an experimental test of the NSW hypothesis with the aid of correlation analysis methods.

The employed experimental material consisted of inelastic collisions of the nuclei ^{4}He and ^{14}N with emulsion nuclei selected for the measurements without any discrimination whatever from those obtained in double scanning "along the track" of emulsion stacks irradiated in JINR and Berkeley accelerators. The kinetic energy of the α particles and of the nitrogen nuclei was 13.5 and 29.4 GeV, and the numbers of the investigated αA and NA events were 1084 and

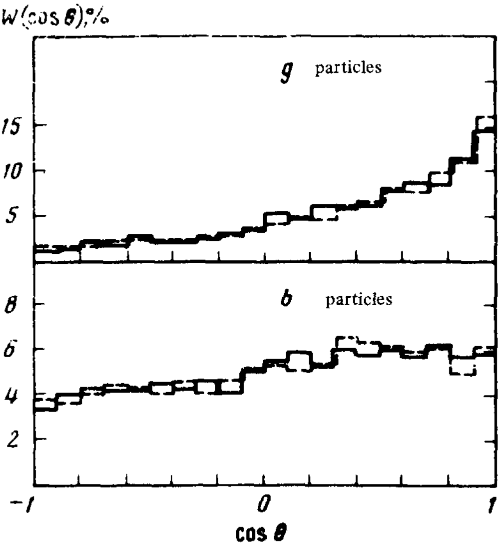

FIG. 1. Inclusive angular distributions of g and b particles from αA (dashed histograms) and NA (solid histograms) collisions.

504, respectively. [1)] All the secondary particles were grouped, on the basis of measurements of the range and ionization, into "black" (b particles; $T_p < 25$ MeV for protons), "gray" (g particles; $25 < T_p < 400$ MeV), and shower (s particles, which are not considered in this communication). The bombarding-nuclei relativistic fragments with $Z \geq 2$ were reliably identified and were not included in the numbers of the b and g particles.

Figure 1 shows the inclusive angular distribution of the b and the g particles from the αA and NA collisions; it is evident that no noticeable "singularities" of any kind are observed. It seems to us that it is difficult to extract from an analysis of these distributions any reliable information on the presence (or absence) of NSW; a more sensitive test for this purpose is obviously a search for possible correlations between the particles.

A common prediction of all the NSW models [2-8] is predominant emission of particles of nuclear matter in a direction perpendicular to the surface of the Mach cone, which leads inevitably to the appearance of "short-range" (with respect to the angle variables) correlations between them. In the real case, the Mach cone is smeared out as a result of the Fermi motion of the nucleons inside the nuclei, but quantitative calculations [7] show that the degree of "smearing" is small ($\sim 20°$), so that the short-range character of the correlations should be preserved.

We use the formalism of two-particle correlation functions

$$C_2(x_1, x_2) = \frac{1}{\sigma_{in}} \frac{d^2\sigma}{dx_1 dx_2} - \frac{1}{\sigma_{in}^2} \frac{d\sigma}{dx_1} \frac{d\sigma}{dx_2}, \quad (1)$$

$$R_2(x_1, x_2) = \sigma_{in} \frac{d^2\sigma}{dx_1 dx_2} \Big/ \frac{d\sigma}{dx_1} \frac{d\sigma}{dx_2} - 1 \quad (2)$$

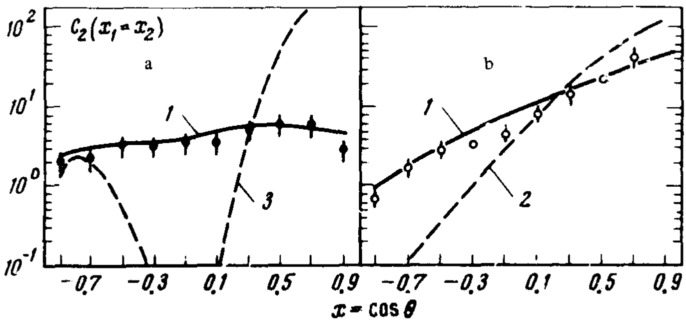

FIG. 2. Correlation function $C_2(x_1 \cdot x_2 = x_1)$ for b particles (a) and g particles (b) from NA collisions. Curves 1—independent emission of particles, 2—calculation for NSW [6], 3—in accord with $d\sigma/d\theta$ from [11].

($x=\cos\theta$). Since the presence of a multiplicity spectrum (n_g and n_b) and the possible dependence of $d\sigma/dx$ on n lead to strong pseudocorrelations, we have calculated C_2 and R_2 for artificial events randomly chosen by the Monte Carlo method under the following assumptions: a) the g and b particles are emitted independently pairwise; b) the distributions with respect to n_b and n_g coincide with the empirical ones; c) $d\sigma/dx$ coincide with the corresponding "semi-inclusive" (i.e., at fixed n_b and n_g) empirical distributions. Finally, to estimate the sensitivity of the method to observation of NSW, we have simulated also events in which the angular spectra for the g particles agreed with the calculations [6], and for the b particles they agreed with the empirical inclusive x-distribution from [11].

The experimental and calculated values of C_2 for NA collisions (the diagonals of the correlation matrix at values $x_1 \approx x_2$) are shown (by way of example) in Fig. 2. A similar picture is observed also at all other values of x_1 and x_2, and for αA collisions. The following can be concluded:

1) The data do not contradict the hypothesis of independent emission of b and g particles (i.e., for example, the cascade mechanism) in nucleus-nucleus collisions at energies of several GeV/nucleon.

2) The absence of correlations contradicts the hypothesis that a noticeable role is played by NSW in nucleus-nucleus collisions.

For the sake of clarity Fig. 3 (again by way of example) shows the distributions of $d\sigma/d|\theta_1-\theta_2|$ for b and g particles from NA collisions together with the calculated ones in accordance with the models described above, and also with the simplest "background" distribution that follows from the assumption $d\sigma/dx=\text{const}$. The data for the b particles do not contradict this last assumption, and for g particles an excess above the "background" is observed in the region $\Delta\theta \lesssim 35°$, obviously because of the non-uniformity of $d\sigma/dx$ (Fig. 1). Even if this excess is attributed to NSW, the upper bound of the cross section of this process for NA collisions is only $0.05\,\sigma_{in}(^{14}NA)$, which is much less than the value predicted by a number of models (e.g., [7]).

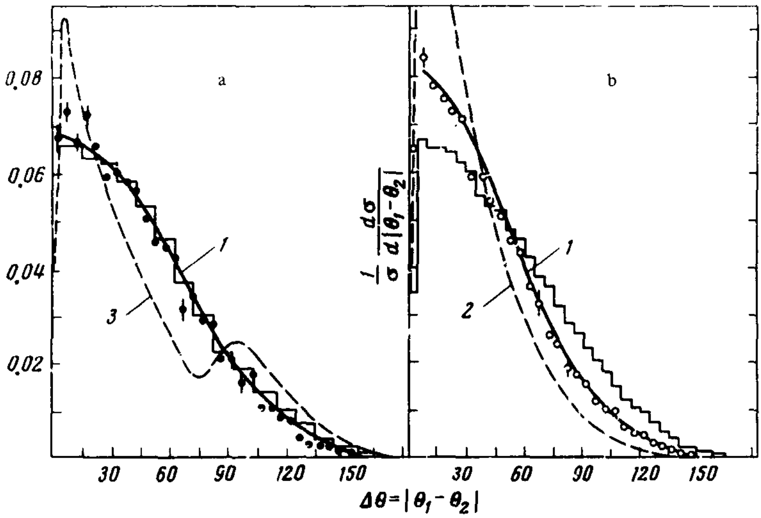

FIG. 3. Distributions in $\Delta\theta$ for b particles (a) and g particles (b) from NA collisions. The curves are the same as in Fig. 2. Histogram—calculation for isotropic angular distribution.

The authors are deeply grateful to H. H. Heckman and also to the JINR Group and K. D. Tolstov for supplying the emulsion stacks irradiated in Berkeley and Dubna, respectively, and the colleagues in the collaboration [14] for joint acquisition of some of the statistics of the A cases.

1)Our statistics greatly exceed the statistics of [11], in which observation of NSW was reported.

---

[1]A. E. Glassgold *et al.*, Ann. Physics (NY) **6**, 1 (1959).
[2]W. Sheid *et al.* Phys. Rev. Lett. **32**, 741 (1974).
[3]C. Y. Wong and T. A. Welton, Phys. Lett. **49B**, 243 (1974).
[4]M. I. Sobel *et al.*, Nucl. Phys. **A251**, 502 (1975).
[5]Y. Kitazoe and M. Sano, Osaka Reports OULNS 75-6, 75-7, 1975.
[6]A. A. Amsden *et al.*, Phys. Rev. Lett. **35**, 905 (1975).
[7]B. A. Rumyantsev, Pis'ma Zh. Eksp. Teor. Fiz. **22**, 114 (1975) [JETP Lett. **22**, 51 (1975)]; B. A. Rumyantsev, V. B. Telitsyn, and V. I. Yurchenko, ibid. **23**, 309 (1976) [**23**, 279 (1976)].
[8]B N. Kalinkin and V. L. Shmonin, JINR Preprint R2-7871, Dubna, 1974.
[9]G. F. Bertsch, Phys. Rev. Lett. **34**, 697 (1975).
[10]G. F. Chapline, Livermore Preprint UCRL-76065, 1974.
[11]H. G. Baumgardt *et al.*, Z. Physik **273**, 359 (1975).
[12]L. P. Remsberg and D. G. Perry, Phys. Rev. Lett **35**, 361 (1975).
[13]A. M. Poskanzer *et al.*, ibid. **35**, 1701 (1975).
[14]Warsaw-Dubna-Krakow-Leningrad-Moscow-Tashkent Collaboration, JINR Commun. (Soobshchenie) R1-8313, 1974.