# Observation of anomalous nucleus-nucleus interaction and its interpretation

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The interaction of a chromium atom with $E_{\text{kin}} \sim 20$ GeV/$n$ in nuclear emulsion is analyzed. The unusual characteristics of the event ($N_s = 272, \theta_{s\,1/2} = 14°$, $N_h = N_g = 8$) are accounted for by assuming that a relativistic compound system, which includes the total energy of a large fraction of nucleons of both nuclei, is produced in the central collisions.

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An event has been identified in the interactions of cosmic-ray nuclei of the iron group with a large multiplicity of relativistic $s$ particles. The change of the incident nucleus $z_0 = 24 \pm 2$. The interaction formula $z_0 \to N_b + N_g + N_s$, where $N_b$ is the number of black tracks ($E_{\text{kin}}$ =0–31 MeV/$n$) and $N_g$ is the number of gray tracks ($E_{\text{kin}}$ = 31–450 MeV/$n$), has the form: $24 \to 0 + 8 + 272$. The half-angle of the $s$ particle $\theta_{s1/2} = 14°$. The quasi-velocity distribution of $s$ particles $\eta = \ln \tan\theta/2$ is shown in Fig. 1. The fragments of the incident nucleus with the charge $z \geqslant 2$ are missing. The unusual aspect of the event is that the observed quasi-velocity distribution in the fragmentation region of the incident nucleus, the small value of $N_h$ and the large multiplicity of $N_s$ cannot be reconciled in the context of the currently accepted ideas. The recently proposed nuclear-pionization model in the simple form described in Refs. Refs. 1 and 2 is also unable to explain this effect. An estimate of the energy of an incident nucleus from the location of proton fragments at minimum angles in the $\eta$ distribution gives a value $E_{\text{kin}} \leqslant 15$–$20$ GeV/$n$. According to conventional classification for a small number of $h$ tracks ($N_h = N_b + N_g$), this event can be attributed to either the collision with an oxygen nucleus or to the peripheral collision with a heavy emulsion nucleus (Ag, Br). The first option must be rejected, since the multiplicity of the produced particles, according to the estimates of the experiment[3] and the model representations,[1] does not exceed 30–50 in this case even in the central collisions, a figure which is almost an order of magnitude smaller than that observed in the analyzed event. The second option also contradicts the experiment. Because of the similarity of radii of the Ag, Br, and Cr nuclei ($R_{\text{Ag Br}}/R_{\text{Cr}} \leqslant 1.2$), a peripheral collision with respect to the target nucleus must also be a peripheral collision with respect to the incident nucleus. However, a total disintegration of the chromium nucleus, occurs. The proton fragments from the nonoverlapped part of the incident nucleus, whose production in large numbers in the peripheral collision is predicted, are missing in the $\eta$ distribution at small angles; this favors a small impact parameter. An interpretation of this event without the inclusion of exotic physical phenomena (for example, the existence of a superheavy neutron nucleus or antinucleus) requires an

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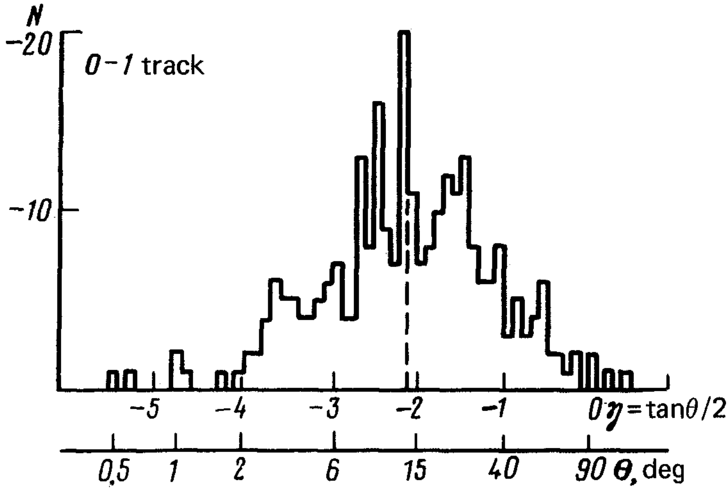


FIG. 1. Distribution of relativistic, single-charge particles with respect to the quasi velocity $\eta = \ln \tan \theta_{1/2}$ and angle $\theta$ in the direction of motion of the incident nucleus.

explanation of the process that leads to an enhanced meson yield and a small number of nonrelativistic particles from the target nucleus.

To explain the event in terms of the model,[2] we must take into account that in addition to the dominating pionization process (formation of a cluster and leading systems which carry away a large fraction of the energy of colliding hadrons) with an appreciable cross section $\sigma_c$, a channel for production of complete compound systems, (which include the total energy of colliding hadrons), is present in the hadronic collisions. The existence of such channel can be deduced from an analysis of cumulative processes[4] and from the production of particles with large transverse momenta.[5] In terms of the model,[2] this means that a fraction of nucleons is captured by the central pionization cluster during the interaction of nuclei. The number of these nucleons in the simplest optical approximation is determined by the expression

$$N = N_1 + N_2 = \int T_1(x, y)\{1 - \exp[-\sigma_c T_2(x, y)]\}dxdy + \int T_2(x, y)\{1 - \exp[-\sigma_c T_3(x, y)]\}dxdy, \quad (1)$$

where $T_i(x,y) = \int \rho_i(x,y,z)dz$; $x$, $y$, and $z$ are the space coordinates (the $z$ axis coincides with the collision axis), and $\rho_i$ is the Fermi distribution of the nucleon density in the nuclei 1 and 2. By taking into account Eq. (1), where $\sigma_c = 0.25\ \sigma_{\text{in}}$,[4] this model[2] makes it possible to obtain the dependences of $N_s$ and $\theta_{s\,1/2}$ on $E_{\text{kin}}$ (Fig. 2) for the collisions of Cr and Br nuclei with zero impact parameter. According to these dependences, the values of $N_s$ and $\theta_{s\,1/2}$ correspond to $E_{\text{kin}} \sim 20$ GeV/$n$. The number of nucleons in Br nucleus that become relativistic at this energy (those captured by the central cluster and those not captured by it but with an energy >450 MeV) is $N_{\text{rel}} = 43$. If we assume that the neutrons and protons are distributed identically in the Br nucleus, then the number of nonrelativistic fragments produced as a result

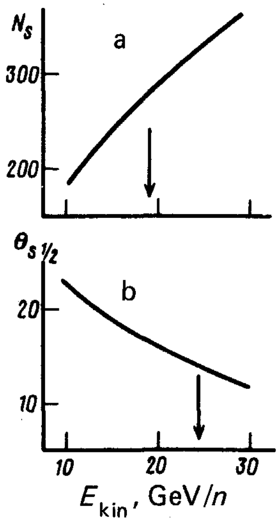


FIG. 2. Calculated dependences of the kinetic energy of an incident nucleus of the multiplicity of relativistic particles (a) and of the half-angle of emission (b) for the Cr + Br system for the impact parameter $B = 0$ with allowance for the capture a fraction of nucleons by the central pionization cluster. The cross section for production of a compound system is $\sigma_c = 0.25\ \sigma_{in}$. The arrows indicate the energy of the incident nucleus, which corresponds to the measured values $N_s = 272$ - ($E_{kin} \approx 19$ GeV/$n$) and $\theta_{s\,1/2} = 14°$ - ($E_{kin} \approx 24.5$ GeV/$n$).

of splitting of the Br nucleus in this event $N_h \rightarrow (z_{Br}/A_{Br})(A_{Br} - N_{rel}) \approx 17$. There are indications, however, that the periphery of heavy nuclei is enriched by neturons.[6] Since the main source of nonrelativistic particles in the central collision of Cr and Br nuclei is the periphery of the Br nucleus, the real value of $N_h$ may turn out to be even closer to the measured value. A decrease of $N_h$ may also be caused by an increase of the effective value of $\sigma_c$ in a nucleus-nucleus interaction, as compared with the cumulative hadron-nucleus interaction due to the absence of a constraint on the size of the compound system in its recurrent interactions with nucleons.

Thus, by taking into account the possible production of compound systems, we can explain not only the main characteristics of such "anomalous" events but also ascertain their close connection with the factors that regulate the production of cumulative particles and particles with large $p_\perp$. Our analysis also indicates that some criteria for identification of "central" collisions of heavy nuclei must be revised.


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