RAPID COMMUNICATIONS

PHYSICAL REVIEW C VOLUME 40, NUMBER 4 OCTOBER 1989

# Two-particle rapidity correlations in $d$C, $\alpha$C, and CC interactions at 4.2 GeV/$c$ per nucleon

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(Received 18 April 1989)

Two-particle rapidity correlations are studied in $d$C, $\alpha$C, and CC interactions at 4.2 GeV/$c$ per nucleon using 2 m propane bubble chamber. The influence of collision centrality on the short-range correlation strength is also analyzed. Comparison with the Dubna intranuclear cascade model indicates that the independent nucleon-nucleon collisions may account for the observed correlations.

There has been an increasing interest in the study of high-energy nucleus-nucleus collisions in recent years with the main research goal to extract a new phenomena peculiar to highly excited, dense, nuclear matter. Experimental discovery of such a kind of phenomena demands detailed study of the multiparticle processes, and in particular, the analysis of various correlation characteristics in nucleus-nucleus collisions.

The particle correlations have been extensively studied in high-energy hadronic interactions.[1–3] One of the prominent results of all these experiments is the presence of two-particle short-range correlations. In nucleus-nucleus collisions, the correlations have been studied, so far, in momentum space between identical particles[4–8] and in the azimuthal plane,[9,10] However, there is practically no data on the two-particle correlations in the longitudinal phase space.[11,12]

In this Rapid Communication two-particle rapidity correlations are studied in inelastic $d$C, $\alpha$C, and CC interactions at $p=4.2$ GeV/$c$ per nucleon. Experimental data were obtained in the Joint Institute for Nuclear Research (JINR) 2 m propane bubble chamber exposed on the Dubna synchrophasotron. By using criteria suggested in Ref. 13, 70%–80% of all inelastic interactions were selected. A statistical weight was assigned to the unselected carbon/hydrogen events, and was determined from the relations between inelastic cross sections for nucleus-nucleus and proton-nucleus interactions. The protons were also selected by the statistical method applied on all positive particles with momentum $p>500$ MeV/$c$.

In nucleus-nucleus collisions, all nucleons may be classified into participants which interact strongly during the collision and spectators which are not actively involved in the interaction. In our experiment, the projectile spectators were protons and heavier fragments with momentum of $p/Z>3$ GeV/$c$ and emission angle $\Theta_l<4°$. The target spectators were protons with momentum $p<300$ MeV/$c$. Remaining protons were classified as participant protons and were used in the following analysis.

The experimental results are compared with the calculations performed on the basis of the Dubna intranuclear cascade model [(DCM) in the following]. In that model the inelastic nucleus-nucleus interactions are treated as a superposition of successive quasifree two-particle collisions described by the relativistic Boltzmann equation. The main assumptions and features of the model are presented in Ref. 14. It has been shown previously that the model reproduces correctly the multiplicities and inclusive spectra of the secondary particles.[13,15–17] The experimental samples consist of 5740 $d$C, 3260 $\alpha$C, and 5160 CC inelastic interactions. A comparison is made with 17600 $d$C, 11560 $\alpha$C, and 12900 CC interactions generated according to DCM.

The two-particle correlations are studied as a function of the rapidity $y=0.5\ln[(E+p_L)/(E-p_L)]$, using the normalized correlation function defined by

$$R_2(y_1,y_2)=[\rho_2(y_1,y_2)/\rho_1(y_1)\rho_1(y_2)]-1\,,$$

where $\rho_1(y)=\sigma_{\text{in}}^{-1}d\sigma/dy$ and $\rho_2(y_1,y_2)=\sigma_{\text{in}}^{-1}d^2\sigma/dy_1dy_2$ are the single- and two-particle densities, respectively. $\sigma_{\text{in}}$ is the inelastic cross section. Values of $R_2(y_1,y_2)$ different from zero indicate the existence of correlations between particles. Dynamical effects are not the only cause for the positive values of the correlation function. It is well known that different production mechanisms, the dependence of the one-particle distributions $\rho_1(y)$ on multiplicity, as well as the trivial correlations due to the kinematical constraints in individual events, all lead to strong pseudocorrelations, i.e., to $R_2(y_1,y_2)\neq 0$, even in the absence of dynamical correlations. This problem can be avoided by comparison with the DCM. In this way, all "nondynamical" effects are taken into account and any enhancement of the experimental values of $R_2(y_1,y_2)$, over DCM results, may be considered as a manifestation of dynamical correlations.

Figure 1 shows the correlation function $R_2(y_1,y_2=y_1)$ vs $y_1$ (short-range correlations) for the proton-proton pair

 

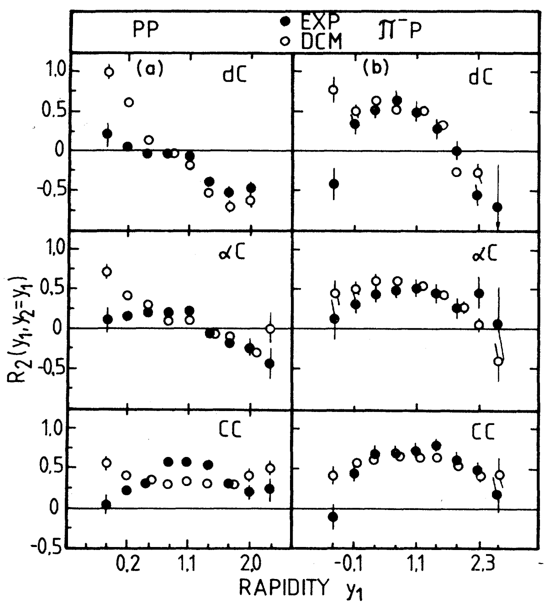


FIG. 1. $R_2(y_1,y_2=y_1)$ vs $y_1$, for $d$C, $\alpha$C, and CC interactions (filled circles). Open circles represent DCM predictions (a) for $pp$ pairs, (b) for $\pi^-p$ pairs.

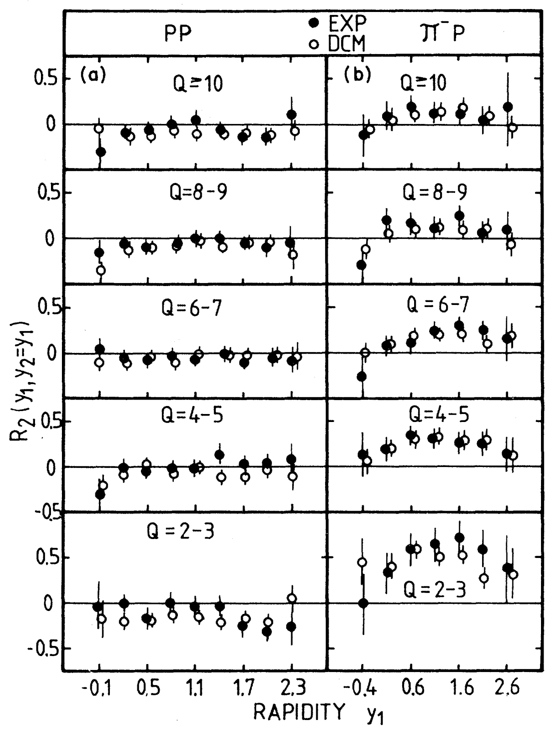


FIG. 2. $R_2(y_1,y_2=y_1)$ vs $y_1$, for CC interactions with various numbers of interacting protons (filled circles). Open circles represent DCM predictions (a) for $pp$ pairs, (b) for $\pi^-p$ pairs.

production ($pp$ pairs) and proton-$\pi^-$ meson pair production ($p\pi^-$ pairs) in $d$C, $\alpha$C, and CC interactions. Figure 1 contains both experimental (filled circles) and DCM (open circles) values. For $pp$-pairs [Fig. 1(a)] short-range correlations strongly depend on the projectile nucleus. In $d$C and $\alpha$C interactions, negative correlations are observed on the projectile side (high $y$) due to energy momentum conservation. Going to lower rapidities, $R_2^{pp}$ increases and reaches positive values. DCM correctly reproduces the experimental values, with exception of the target fragmentation region where the model increases the correlations due to overestimation of the cascading processes. In CC collisions the short-range correlations have a maximum value in the central rapidity region and approach zero in the fragmentation regions. In this case disagreement with the model is appreciable.

There are strong positive short-range correlations among $\pi^-$ mesons and protons [Fig. 1(b)] which are in the backward $y$ region independent on the atomic mass of the incident nucleus. For $y > y_{\text{c.m.}} = 1.1$, $R_2^{p\pi}$ increases with the mass of the projectile. DCM calculations are in good agreement with experiment in this case.

In order to study the observed correlations in more detail we investigated the behavior of the $R_2$ function in CC interactions for various numbers of participant protons. This number is defined via $Q = n_+ - n_- - n_{\text{fragm}}$, where $n_{\text{fragm}}$ is the number of spectators from the projectile and target and $n_+(n_-)$ is the number of positive (negative) charged particles.[16] The $Q$ value, as a measure of the quantity of nuclear matter involved in the interaction, is correlated with the degree of the collision centrality: high $Q$ value corresponds to the event with small impact parameter, i.e., to central or multinucleon interaction.[17] Additionally, the average multiplicity of charged particles increases with $Q$.

Figure 2 shows $R_2(y_1,y_2=y_1)$ vs $y_1$, for $pp$ pairs and $\pi^-p$ pairs in CC interactions with fixed number of interacting protons. In comparison with inclusive two-particle correlations, at fixed $Q$, the strength of correlations significantly decreases. Figure 2(a) shows that for peripheral (small $Q$) and central ($Q \geq 10$) collisions the $R_2^{pp}(y_1,y_2=y_1)$ values are, within experimental errors, close to zero. In peripheral interactions ($Q = 2-3$) participate in average 2.4 protons from the projectile and target, and there is small probability that both of them are produced with the close rapidities. In the events with $Q \geq 10$ participate in average 9.9 protons, and short-range correlations should arise as a manifestation of collective processes. Their absence indicates that in central collisions a superposition of independent nucleon-nucleon collisions dominates, but it does not exclude that the strong background of uncorrelated protons could suppress dynamical correlations.

In the case of $\pi^-p$ pairs, [Fig. 2(b)], the situation is quite different. Positive correlations are observed even when the number of interacting protons is fixed, but the strength of correlations decreases with increasing $Q$. At energies of a few GeV per nucleon almost all pions are produced through $\Delta$ isobars, so that their formation and decay is responsible for a short-range effect. Weakening of $\pi^-p$ correlations with increasing $Q$, points to the incoherence of processes during the collisions. The agreement between DCM and the experimental data is striking. In this model three-particle reaction channels are realized mainly through isobar production and, in that way, only kinematics of isobar formation is taken into account.

In conclusion, the two-particle rapidity correlations among the protons and $\pi^-$ mesons from $d$C, $\alpha$C, and CC interactions at 4.2 GeV/$c$ per nucleon are studied. In order to discern real dynamical correlations, a comparison with the Dubna intranuclear cascade model is performed. It is found that the experimentally observed short-range correlations are not in contradiction with the model of independent nucleon-nucleon collisions (like DCM). We found no indications for complete coherence in these reactions.

The authors are grateful to the team operating the JINR 2 m propane bubble chamber, the technical staff, and our colleagues at the collaborating institutions for assistance in film taking and data processing. We would also like to thank V. G. Grishin and Yu. M. Shabelski for valuable discussions and I. Mendaš for carefully reading and preparing the manuscript.

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