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Physics

Azimuthal Correlations between Protons in the Backward and Forward Hemispheres in Nucleus-Nucleus Collisions at a Momentum of 4.2 GeV/c per Nucleon

Lida Chkhaidze*, **Tamar Djobava***, **Lali Kharkhelauri***

High Energy Physics Institute, I. Javakhishvili Tbilisi State University

(Presented by Academy Member Anzor Khelashvili)

ABSTRACT. Multiparticle azimuthal correlations between protons have been investigated in (d, He)C, CC, (d,He)Ta and CTa collisions at a momentum of 4.2 GeV/c and "back-to-back" correlations have been observed. Essentially, correlation function $C(\Delta\varphi)$ for protons from these collisions increases with $\Delta\varphi$ and reaches maximum at $\Delta\varphi = 180^0$ (the angle between the vector sums of the forward and backward emitted protons). The asymmetry coefficient $|\xi|$ decreases and the strength of correlation ς increases with increase of the projectile and target mass numbers. The dependence of the mean of the square transverse momentum in the reaction plane $<P_X^2>$ on $\Delta\varphi$ shows similar behaviour for all observed interactions.

The data stem from the propane bubble chamber (PBC-500) system utilized at JINR. The quark gluon string and the ultrarelativistic quantum molecular dynamics models satisfactorily describe the experimental results. *© 2012 Bull. Georg. Natl. Acad. Sci.*

Key words: *multiparticle azimuthal correlations, collision, nucleus, proton.*

One of the main goals of relativistic heavy-ion collisions experiments is to study nuclear matter under extreme conditions of high densities and temperatures [1,2]. The most impressive results of high energy heavy ion research so far are the collective phenomena discovered in these reactions. Study of multiparticle correlations [3-6] offers unique information on the space-time evolution of the colliding system. Over the last years we have studied experimental data using the collective variables depending on the transverse momentum of all secondary particles in the azimuthal plane, to reveal nontrivial effects in nucleus-nucleus collisions [7-11].

In this paper we present the results of the analysis of multiparticle correlations in (d, He)C, CC, (d,He)Ta and CTa collisions (4.2 GeV/c). Azimuthal correlations between protons and the dependence of these correlations on the projectile (A_P) and target (A_T) nucleus mass numbers have been investigated.

Table 1. The number of experimental and generated events (N_{event}) and participant protons ($N_{prot.}$), the asymmetry coefficient (x) and the strength of the correlation (V) in (d,He)C, CC, (d,He)Ta and CTa collisions.

A_P, A_T	N_{event}	ξ	ς
(d,He)C exp.	14318	-0.417±0.015	0.411 ± 0.015
UrQMDM	59218	-0.418± 0.009	0.410±0.009
CC exp.	15962	-0.369±0.013	0.461 ± 0.014
QGSM	36 457	-0.357±0.010	0.474±0.011
(d,He)Ta exp.	2956	-0.309 ±0.028	0.528±0.033
UrQMDM	17629	-0.321±0.022	0.514±0.025
CTa exp.	2469	-0.234±0.033	0.571±0.043
QGSM	42295	-0.242±0.010	0.610±0.013

Experimental data. The data of dC, HeC, CC, dTa, HeTa and CTa interactions have been obtained using 2 m Propane Bubble Chamber (PBC-500) of JINR (3.4 GeV/nucleon). The chamber was placed in a magnetic field of 1.5 T. Three Ta plates 140x70x1 mm in size mounted into the fiducial volume of the chamber at a distance of 93 mm from each other, served as a nuclear target. Protons with momentum p<150 MeV/c have not been detected within this chamber (as far as their track lengths l<2 mm) and protons with p<200 MeV/c are absorbed in Ta target plate (the detector biases).

The method of separation of dC, HeC and CC collisions in propane, the processing of the data, identification of particles and discussion of corrections is described in detail in [12]. Corrections by azimuthal angle distributions for protons were added. Because protons only with momentum p<750 MeV/c were identified, added identification of π^+ -mesons removal of their admixture from the positive charged particles was necessary. The identification was carried out by statistical methods, it had been assumed that π^- and π^+ mesons have similar distributions [10]. In order to increase the statistics, (d, He)C and (d, He)Ta collisions were combined for further analysis. In separating the so-called "participant proton" from fragmentation products, the following criteria were adopted: $p > 3$ GeV/c and $\vartheta < 4°$ (for C target), $p > 3.5$ GeV/c and angle $\vartheta < 3°$ (for Ta target) for projectile fragmentation and $p < 0.3$ GeV/c (for C target), $p < 0.25$ GeV/c (for Ta target) for target fragmentation. A sub-sample of "semicentral" collisions with the number of particles $N \geq 3$ was selected for analysis from the whole ensemble of (d, He)C, CC, (d,He)Ta and CTa inelastic collisions (see Table 1).

Azimuthal correlations between protons The procedure for study of the correlations between groups of particles was developed in Refs. [5,6]. The azimuthal correlation function was defined by the relative opening angle between the transverse momentum vector sums of particles emitted forward and backward hemispheres in the target fragmentation region ($y_t \approx 0.2$). The data were obtained at 4.9, 60 and 200 GeV (BEVALAC, CERN/SPS).

We applied this method for our data, but the analysis was carried-out in the central rapidity region instead of the target rapidity range of Refs. [5, 6]. The analysis was performed event by event, in each event we denote the vectors $\vec{Q}_B = \sum_{y_i < \langle y \rangle} \vec{P}_{\perp_i}$ and $\vec{Q}_F = \sum_{y_i \geq \langle y \rangle} \vec{P}_{\perp_i}$, <y> was determined by two approaches: average rapidity in each event or in each colliding pair of nuclei. It was mentioned that the results coincide within statistical errors. Then the correlation function C(Δφ) is constructed as follows C(Δφ) = dN/dΔφ, where Δφ is the angle between these vectors:

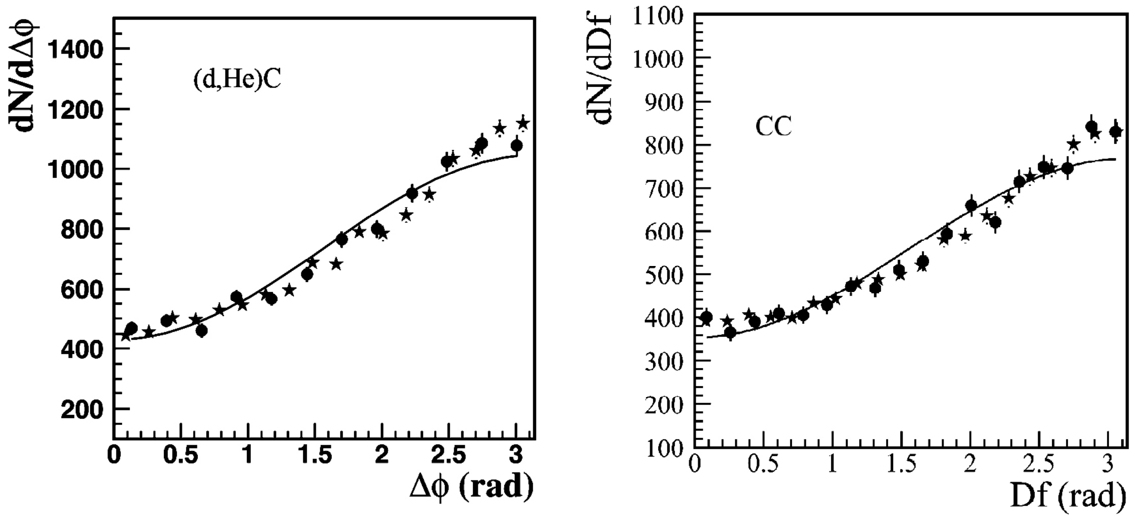

Fig. 1. Dependence of the correlation function C(Δφ) on the Δφ for protons from (d,He)C and CC collisions: • – experimental and ★ – generated (see text) data, respectively. The curves are the results of the approximation of the data (see text).

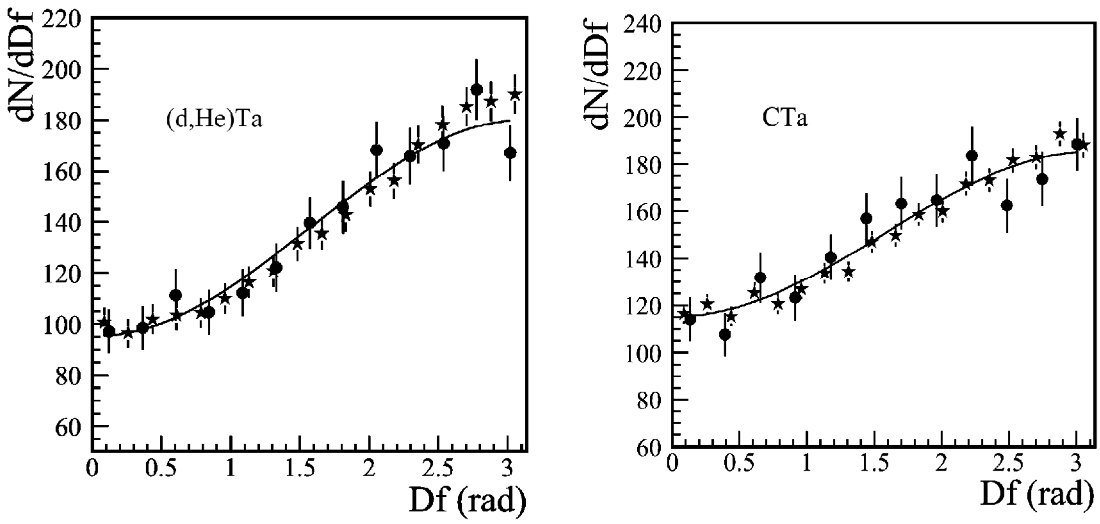

Fig. 2. Dependence of the correlation function C(Δφ) on the Δφ for protons from (d,He)Ta and CTa collisions: • – experimental and ★ – generated (see text) data, respectively. The curves are the results of the approximation of the data (see text).

$$\Delta\varphi = \arccos\frac{(\vec{Q}_B \cdot \vec{Q}_F)}{(|\vec{Q}_B| \cdot |\vec{Q}_F|)}. \qquad (1)$$

Essentially, C(Δφ) measures whether the particles in the backward and forward hemispheres are preferentially emitted "back-to back" (Δφ = 180^0) or "side-by-side" (Δφ =0^0).

Figs.1, 2 show the experimental correlation function C(Δφ) for protons from (d,He)C, CC, (d,He)Ta and CTa collisions. One can observe from the Figures a clear back-to-back correlation for protons (correlation increases with Δφ, reaches maximum at Δφ = 180^0). To quantify these experimental results, the data were fitted by C(Δφ) = 1+ξcos(Δφ). Results of the fitting are listed in Table 1. The strength of the correlation is defined as:

$$\varsigma = C(0°)/C(180°) = (1+\xi)/(1-\xi) \qquad (2)$$

As can be seen from Table 1, the asymmetry coefficient ξ<0 and thus the strength of correlation ς<1 for protons in these interactions.

We studied the dependence of the asymmetry coefficient (ξ) on mass numbers of projectile (A_P) and target (A_T) for protons. The absolute values of ξ

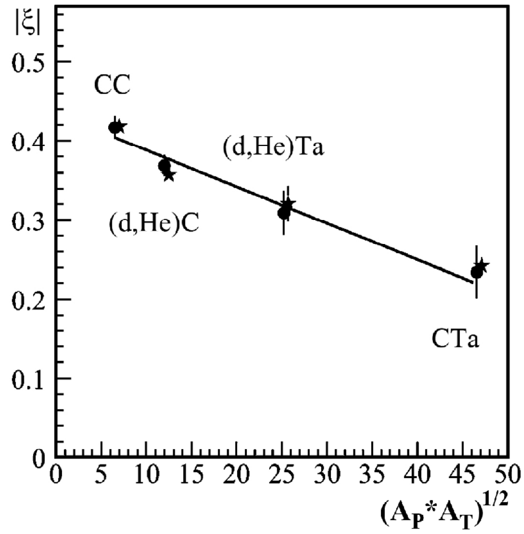

Fig. 3. Dependence of the asymmetry coefficient (□) on $(A_P \times A_T)^{1/2}$ for protons in (d,He)C, CC, (d,He)Ta and CTa collisions: • – the experimental and ★ – generated (see text) data.

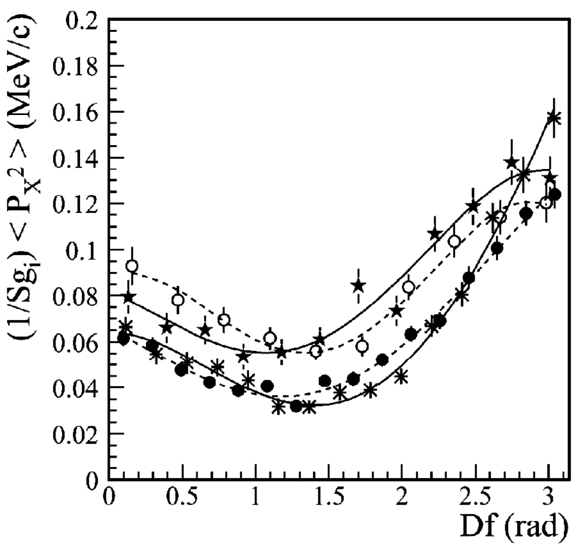

Fig. 4. Dependence of $< P_X^2 >$ on $\Delta\varphi$ (as described in the text) for protons in: * – (d,He)C, • – CC, o – (d,He)Ta, ★ – CTa collisions. Solid and dashed curves are the results of the approximation of the data by 4th order polynomal.

for protons decrease linearly with the increase of (A_P, A_T), from -0.417±0.014 for (d,He)C up to -0.234±0.028 for CTa (see Table 1, Fig. 3) .

Back-to-back correlation was observed between protons or pions with the Plastic-Ball detector protons in p + Au collisions at energy of 4.9, 60 and 200 GeV/nucleon [5, 6, 13]. Because the azimuthal correlation function was defined in the target fragmentation region, the correlation parameters in the wide range of energy increases inappreciably.

In CC (2500 event) inelastic interactions at a momentum of 4.2 GeV/c per nucleon in the 2-meter propane buble chamber at the JINR [4] were the back-to-back azimuthal correlations observed between protons or pions, emitted in the forward and backward hemispheres in the c.m.s. of the collisions ($-0.5 < y < 0.5$). The absolute value of the asymmetry coefficient is $\xi = 0.26 \pm 0.01$ [4]. Since these results were obtained on the minor statistics of our data CC (15962 events), we determined $\xi = 0.24 \pm 0.01$ under the same conditions.

Several theoretical models have been proposed for nucleus-nucleus collisions at high energy. We used the Quark Gluon String Model (QGSM) [14, 15] and Ultra-relativistic Quantum Molecular Dynamics Model (UrQMDM) [16-18] for comparison with experimental data. The QGSM is based on the Regge and string phenomenology of particle production in inelastic binary hadron collisions. The UrQMD model is now widely applied for simulations of particle production and flow effects in various nucleus-nucleus interactions [19, 20], although its original design was directed towards high energies.

We generated CC (2.65 fm) and CTa (6.53 fm) interactions by QGSM and dC (2.79 fm), HeC (2.79 fm), dTa (5.31 fm) and HeTa (5.46 fm) interactions by UrQMDM, as well as 50000 events for dC, HeC, CC, CTa and 1000 events for dTa, HeTa collisions.

The experimental selection criteria were applied to the generated events and the protons with deep angles greater than 60~grad were excluded, because in the experiment the registration efficiency of such vertical tracks is low. From the generated events, events with two protons were selected for C-target p>150 MeV/c and for Ta-target p > 200 MeV/c (Table 1).

There is a fairly good agreement between the experimental and the theoretical distributions (Figs. 1÷3).

As obtained in our previous articles [7, 8, 21, 22], the dependence of the mean transverse momentum in the reaction plane $< P_X >$ on the rapidity y showed the typical S-shape behaviour in collisions observed for protons and pions. In order to extend these investigations, we obtained the relation between $<P_X^2>$ and the angle $\Delta\varphi$ (opening angle between $\mathbf{Q}_B$ and $\mathbf{Q}_F$ vectors). These distributions are normalised on the sum weights of all events (Fig. 4). One can see from this figure that the distributions show similar behaviour for protons for all pairs of nuclei.

In summary, a study of azimuthal correlations between protons in (d,He)C, CC, (d,He)Ta and CTa collisions has been carried out.

1. For protons ²back-to-back² correlations were observed in these interactions. The asymmetry coefficient $|\xi|$ decreases and the strength of correlation ς ($\varsigma < 1$) increases with increase of the (A_P, A_T).

2. The dependence of the mean of the square transverse momentum in the reaction plane $< P_X^2>$ on $\Delta\varphi$ (the angle between the vector sums of the forward and backward emitted protons) shows similar behaviour for all observed interactions.

3. The QGSM and UrQMDM satisfactorily describe azimuthal correlations of protons for all pairs of nuclei.

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ფიზიკა

წინა და უკანა ნახევარსფეროებში გამოსხივებულ პროტონებს შორის აზიმუტური კორელაციების შესწავლა 4.2 გევ/c ნუკლონზე იმპულსის დროს

ლ. ჩხაიძე*, თ. ჯობავა*, ლ. ხარხელაური*

** ი. ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტის მაღალი ენერგიების ფიზიკის ინსტიტუტი*

(წარმოდგენილია აკადემიის წევრის ა. ხელაშვილის მიერ)

გამოკვლეულია პროტონებს შორის მრავალნაწილაკოვანი აზიმუტური კორელაციები (d, He)-C, C-C, (d,He)-Ta, C-Ta დაჯახებებში 4.2 გევ/c ნუკლონზე იმპულსის დროს და დამზერილია ე.წ. "back-to-back" კორელაციები. არსებითად, განხილულ დაჯახებებში პროტონებისათვის C($\Delta\varphi$)-კორელაციის ფუნქცია იზრდება $\Delta\varphi$-კუთხის ზრდასთან ერთად და აღწევს მაქსიმუმს $\Delta\varphi = 180^0$. $|\xi|$ ასიმეტრიის კოეფიციენტი მცირდება, ხოლო ς კორელაციის პარამეტრი იზრდება დამცემი და სამიზნის მასური რიცხვების ზრდასთან ერთად. რეაქციის სიბრტყეში განივი იმპულსის გეგმილის კვადრატის საშუალოს $\Delta\varphi$-კუთხეზე დამოკიდებულება მსგავსია ყველა განხილული ბირთვული წყვილისთვის.

ექსპერიმენტული მასალა მიღებულია JINR-ის დანადგარზე პროპანის ბუშტოვანი კამერის (PBC-500) მეშვეობით. კვარკ-გლუონური სიმური მოდელი (QGSM) და ულტრა რელატივისტური კვანტურ-მოლეკულურ დინამიკური მოდელი (UrQMDM) დამაკმაყოფილებლად აღწერს ექსპერიმენტულ შედეგებს.

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