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Physics

Experimental Study of Azimuthal Correlations of Pions in π^{-}(p, n, C) Collisions at Momentum of 40 GeV/c

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Azimuthal correlations between the same type particles (π^{-} or π^{+}) were studied at the moment of 40 GeV/c for π^{-}(p, n) and π^{-}C collisions. The data were obtained from Propane Bubble Chamber (PBC-500) systems utilized at JINR (Joint Institute for Nuclear Research). Experiment was performed at the Serpukhov synchrophasotron. Study of azimuthal correlations offers unique information about space-time evolution of the interactions. Azimuthal correlations was investigated by using correlation function $C(\Delta\varphi)=dN/d(\Delta\varphi)$, where $\Delta\varphi$ represents the angle between the sums of transverse momenta vectors for particles emitted in the forward and backward hemispheres. The π^{-}(p, n) systems are the lightest, in which these effects have ever been detected for pions. For pions (π^{-} and π^{+}) exhibit a "back-to back" ("negative") azimuthal correlations in all colliding systems π^{-}(p, n, C) consistent with that for protons in nucleus-nucleus systems. The correlation coefficient $|\xi|$ insignificantly changes with the change of the pion's type (the change of the sign of pions) and it is almost the same within errors for π^{-} and π^{+} mesons in all interactions. It should be mentioned that there is no change of the correlation's type ("back-to-back" and "side-by-side" correlations) with increasing the mass number of target A_T nuclei in π^{-}(p, n, C) collisions. The obtained results provide important information on the mechanism of meson-nucleon and meson-nucleus interactions at 40 GeV/c, as well as on characteristics of the produced nuclear matter. The pions a back-to-back correlations obtained in all colliding systems π^{-}(p, n, C) are the same as for a light nucleus-nucleus collisions. *© 2022 Bull. Georg. Natl. Acad. Sci.*

azimuthal correlations, collision, mesons, pions

The primary goal of current relativistic heavy ion research is the creation and study of nuclear matter at high energy densities [1, 2]. Such a phase of the confined quarks and gluons has been predicted to survive for ~3-10 fm/c in Au-Au collisions at the Relativistic Heavy Ion Collider (RHIC) [3] and several experimental probes have been proposed for its possible detection and study [4]. The most prominent feature of multi-particle correlations in AA collisions is due to collective flow (elliptic flow) [5, 6], an azimuthal anisotropy in momentum space induced by strong expansion of the initial almond-shaped overlap area of two nuclei [5]. Collective flow constitutes in important observable [7] because it is thought to be driven by pressure built up early in the collision, and therefore can reflect conditions exciting in the first few fm/c. Collective flow leads to anisotropy in the azimuthal distribution of emitted particles. Studies of elliptic flow have been carried out over a wide range of energies and systems at both RHIC and the LHC [2, 8-12]. Studies of multi-particle correlations have provided crucial insight into the underlying mechanism of particle production in relativistic heavy-ion collisions and offers unique information about space-time evolution of the collective system [13, 14]. One of the interesting methods proposed in [15, 16] is the conventional division of phase space into forward and backward moving particles according to the rapidity and emission angle and into slow and fast particles according to energy.

During last years we analyzed our experimental data following the method [15, 16]. The collective variables and their dependencies on the transverse momentum of all secondary charged particles in the azimuthal plane were studied to reveal a nontrivial effects in nucleus-nucleus [17-21] and nucleon-nucleon [22] collisions. We investigated multiparticle azimuthal correlations of protons and pions in central and inelastic collisions at a momenta of 4.2, 4.5, 10 and 40 GeV/c/nucleon within three experiments of JINR: a) SKM-200-GIBS collaboration - a 2m streamer chamber was placed in a magnetic field and was irradiated with the different nucleus beams at a momentum of 4.5 GeV/c/nucleon; b) PBC-500 collaboration - a 2 m Propane Bubble Chamber of JINR was placed in a magnetic field and was irradiated with the different nucleus beams at a momentum of 4.2 GeV/c/nucleon; c) PBC-500 collaboration - a 2 m Propane Bubble Chamber of JINR irradiated at Serpukhov proton synchrotron by the nucleon and pions beams at a momentum of 10 and 40 GeV/c. In order to investigate the mechanism of nucleus-nucleus interactions we studied the correlations of these particles with respect to the reaction plane (directed and elliptic flows) [17-19, 22], as well as with respect to the opening angle between particles emitted in the forward and backward hemispheres [20, 21].

In the presnt paper are presented the azimuthal correlations between pions (π^- or π^+) at the momentum of 40 GeV/c in π^-(p, n, C) collisions. Moreover, characteristics of pions emitted from those collisions, were determined and provided for comparison at the different colliding systems and the dependence of these correlations on the target meson-nucleun and meson-nucleus collisions were investigated. The data were obtained from the Propane Bubble Chamber of JINR at Serpukhov's synchrophazotron.

Experimental Data

The data were obtained from Propane Bubble Chamber systems (PBC-500). The 2 meter long Propane Bubble Chamber (PBC-500) was placed in the magnetic field of 1.5 T. The procedures for separating out the π^-(p, n, C) collisions in propane (C_3H_8) and the processing of the data including particle identification and corrections were described in detail in [23, 24]. The identification probability of π^-C collision events are one, π^-p - 0.338, of π^-n - 0.973. The corrections of missing particles are 1.023 for -mesons and 1.046 - π^+-mesons. Finnally, the weights of the particles (π^- and π^+) in the distributions are multiplied by two values: the probabilities of the type of interaction (π^-p, π^-n and π^-C) and the corrections of missing particles in these collisions.

Experimental data sample contain 25422 events, from which 12765 corresponds to π^-p, 3986 - π^-n, 8671 - π^-C collisions, respectivelly. The average multiplicity of all charged particles ($<n_\pm>$) in π^-(p, n, C) collisions is 6.96±0.03 and $<n_{\pi-}>=3.52\pm0.02$,

$<n_{\pi+}>$ =3.33±0.02 while, the average momentum of π^--mesons $<p_{\pi-}>$=5.31±0.32 GeV/c, $<p_{\pi+}>$= 3.07 ±0.18 GeV/c in π^-(p, n, C) collisions.

For the study of multiparticle azimuthal correlations the events were selected by requiring the minimal numbers of pions (π^- or π^+), $N_\pi^+\geq4$, $N_\pi^-\geq4$ in π^-(p, C) collisions and $N_\pi^+\geq3$, $N_\pi^-\geq3$ in π^-n collisions, respectively. For the analysis the pions with momentum of p>0.05 GeV/c and p < 40 GeV/c were selected.

Azimuthal correlations between pions. The method for studying the correlation between the groups of particles was developed in Refs [15, 16]. The azimuthal correlation function was defined by the relative opening angle between the transverse momentum vector sums of particles emitted forward and backward with respect to the rest frame of the target nucleus (larger or smaller a rapidity of y_0=0.2). The method was used for the analysis of the data obtained at different experiments of BEVALAC, CERN/SPS at energies of 4.9, 60 and 200 GeV/nucleon.

We applied this method for the analysis of our data, but the analysis was carried out in the central rapidity region of c. m. system instead of the target rapidity range of [15, 16]. It is important to mention that the analysis for pions produced in meson-nucleon and meson-nucleus collisions, which is completely different from the dynamics of nucleus-nucleus interactions is performed for the first time in this paper.

The analysis was performed event by event. In each event we denoted the vectors:

$$\vec{Q}_B = \sum_{y_i < y_c} \vec{P}_{\perp_i} \tag{1}$$

and

$$\vec{Q}_F = \sum_{y_i \geq y_c} \vec{P}_{\perp_i} \,, \tag{2}$$

where y_c is an average rapidity of pions for each colliding pears π^-(p, n, C). The correlation function C(Δφ) was determined as:

$$C(\Delta\varphi)=dN/d\Delta\varphi, \tag{3}$$

where Δφ is the angle between the vectors $\vec{Q}_B$ and $\vec{Q}_F$:

$$\Delta\varphi = \arccos\frac{(\vec{Q}_B \cdot \vec{Q}_F)}{(|\vec{Q}_B| \cdot |\vec{Q}_F|)}\,. \tag{4}$$

Essentially, C(Δφ) measures whether the particles are preferentially emitted “back-to back” or “side-by-side” correlations. “Back-to back” means the “negative” correlations, where C(Δφ) increases with Δφ and reaches a maximum at Δφ=180°; “Side-by-side” means the “positive” correlations, where C(Δφ) decreases with Δφ and has a maximum at Δφ = 0° [15, 16].

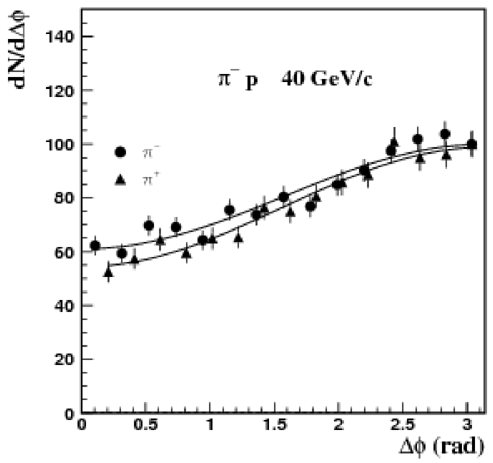
In view of the strong coupling between the nucleons and pions, it is interesting to know the correlations between pions. Thus, we have studied correlations between pions in π^-(p, n, C) collisions. Fig.1÷3 show the experimental correlation function C(Δφ) for these particles in π^-(p, n, C) collisions. One can observe from the Figures a clear correlation for pions. To quantify these experimental results, the data were fitted by the function:

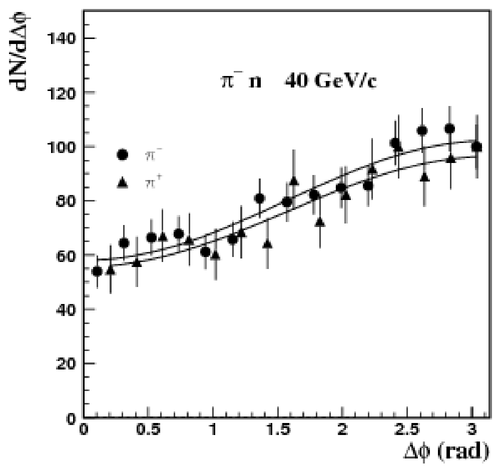
$$C(\Delta\varphi) = 1 + \xi\cos(\Delta\varphi). \tag{5}$$

Results of the fitting are listed in Table 1. The strength of the correlation is defined as:

$$\varsigma = C(0^0) / C(180^0) = (1 + \xi)/(1 - \xi). \tag{6}$$

As it can be seen the correlation coefficient ξ<0 and thus the strength of correlation ς< 1 for pions in all interactions. This means that the pions preferentially are emitted back-to-back in π^-(p, n, C) collisions. One can observe from Fig.1 that a clear back-to-back (ξ< 0, ς< 1) correlations for pions for meson-mucleon and meson-nucleus systems (Table) are obtained. This type of correlations is similar to the correlations of pions in light nucleus-nucleus collisions and as far as for protons in all colliding systems studied in Refs. [15, 16, 20, 21]. We have studied also a dependence of the correlation coefficient (ξ) on mass numbers of target A_T for pions. The absolute values of ξ for pions almost does not change with increase of the mass numbers of target A_T and with the change of the pion's types (π^- or π^+) (Table).





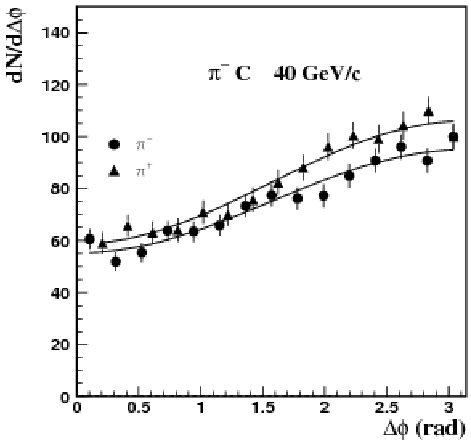


Fig. 1. The dependence of the correlation function C(Δφ) on the Δφ from π^-(p, n, C) collision (40 GeV/c) for π^- (●) and for π^+ (▲) pions, correspondingly. Results of the approximation of the data see text.

Back-to-back correlations were observed between protons with the Plastic-Ball detector in p+Au collisions at energy of 4.9, 200 GeV/c/nucleon and in (O, S)Au reactions at 200 GeV/c/nucleon [15, 16, 25, 26]. Because the azimuthal correlation function was defined in the target fragmentation region the correlation parameters in the wide range of energy increases inappreciable.

We applied this method also in our previous articles [20, 21] where the analysis was carried out as in the whole rapidity region, as well as in the target fragmentation region.

Table. The numbers of experimental events (N_{event}) and of pions ($N_{\pi-}$, $N_{\pi+}$), the correlation coefficient (ξ), the identification probability (w) of colliding systems π^-(p, n, C) (40 GeV/c)

	N_{exp}	$N_{\pi-}$	$N_{\pi+}$	$\xi_{\pi-}$	$\xi_{\pi+}$	w
π^-p	12765 5828 5203	34698 22462	32066 19735	-0.242± 0.018	-0.290± 0.021	4313 / 12765
π^-n	3986 1834 892	11336 7208	7128 3249	-0.275 ± 0032	-0.267 ± 0.050	3879 / 3986
π^-C	8671 5303 5350	30350 23579	32751 26328	-0.264 ±0.020	-0.287 ±0.021	1

As is well known, the back-to back emission of protons can be understood as results of (local) transverse momentum conservation [16]. Back-to-back pion correlation (ξ< 0 and ς<1) for light systems and the side-by-side pion azimuthal correlations (ξ> 0 and ς> 1) for heavy, asymmetric pairs, i.e. change of the pion's azimuthal correlation type [14, 15, 16] in nucleus-nucleus collisions are in agreement with our previously presented in Refs [20, 21] and the results obtained in this paper. Another investigations of large angle two-particle correlations carried out at the 3.6 AGeV C-beam in Dubna [12] showed a back-to-back pion correlation for a light target (Al) and a side-by-side correlation for a heavy target (Pb). For protons a back-to-back correlation was observed for all targets. Again, these results appear to be consistent with our results observed for pion azimuthal correlations of the light nucleus-nucleus collisions and for protons in all nucleus-nucleus collisions investigated by us. Back-to-back pion's correlations were observed in this work, although the mechanism of interactions π^-(p, n, C) (40 GeV/c) are completely different.

The reason for the observed difference between protons and pions is that the pions are absorbed in the excited target matter ($\pi + N \to \Delta$ and $\Delta + N \to N + N$) [15, 16]. While the back-to-back emission of protons can be understood as a result of the transverse momentum conservation, the side-by-side correlation of pions can be naturally explained on the base that pions, which are created in collision, suffer at b≠0 fm (b is the impact parameter) either rescattering or even complete absorption in the target spectator matter. Both processes will result in a relative depletion of pions in the geometrical direction of the target spectator matter and hence will cause an azimuthal side-by-side correlation as observed in the experimental data.

Conclusion

The study of azimuthal correlations between the same type particles (π^- or π^+) in π^-(p, n, C) (40 GeV/c\) collisions have been carried out:

1. The π^-(p, n) systems are the lightest studied one, in which azimuthal correlations between pions (π^- or π^+) in the “backward” and “forward” hemispheres have ever been detected.
2. Azimuthal correlations between the same type particles (π^- or π^+) in meson-nucleun and meson-nucleus collisions, exhibit "back-to back" (negative) correlations and these results are consistent with the results for the light nucleus-nucleus collisions and also, for protons in all of the colliding systems.
3. The correlation coefficient |ξ| insignificantly changes with change of pion's sign (π^- and π^+) and almost does not change, within errors, with increase of the mass numbers of target (A_T) in π^-(p, n, C) (40 GeV/c\) collisions.

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ფიზიკა

პიონების აზიმუტალური კორელაციების ექსპერიმენტული შესწავლა π^-(p, n, C) დაჯახებებში 40 GeV/c იმპულსის დროს

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(წარმოდგენილია აკადემიის წევრის ა. ხელაშვილის მიერ)

შესწავლილ იქნა აზიმუტალური კორელაციები ერთი და იმავე ტიპის ნაწილაკებს (π^- ან π^+) შორის π^-(p, n) და π^-C დაჯახებებში 40 გევ/c იმპულსის დროს. ექსპერიმენტული მასალა მიღებულ იქნა ბირთვული კვლევების გაერთიანებული ინსტიტუტის (JINR) მაღალი ენერგიების ლაბორატორიაში ფილმური დეტექტორის პროპანის ორმეტრიანი ბუშტოვანი კამერის (PBC-500) მეშვეობით. ექსპერიმენტი განხორციელდა სერპუხოვოს სინქროპაზოტრონზე. მრავალნაწილაკოვანი აზიმუტალური კორელაციების შესწავლა იძლევა ინფორმაციას ურთიერთქმედების პროცესის განვითარებაზე დროსა და სივრცეში. მრავალნაწილაკოვანი აზიმუტალური კორელაციები შეისწავლება $C(\Delta\phi)=dN/d(\Delta\phi)$ კორელაციის ფუნქციის დამოკიდებულებით ურთიერთქმედების არის სისწრაფის ფიქსირებული მნიშვნელობით დაყოფილ „წინა“ და „უკანა“ ნახევარსფეროებში გამოდინებული ნაწილაკების განივი იმპულსების ჯამურ ვექტორებს შორის $\Delta\phi$-კუთხისგან. π^-(p, n) ყველაზე მსუბუქი სისტემებია, რომლებშიც დღემდე დაკვირვებული პიონებისათვის აზიმუტალური კორელაციები. პიონებისთვის (π^- და π^+) მიღებული "back-to-back" (უარყოფითი) აზიმუტალური კორელაციები აღნიშნულ დაჯახებებში π^-(p, n, C) პროტონების ანალოგიური კორელაციების მსგავსია ბირთვ-ბირთვულ დაჯახებებში. პიონებისთვის კორელაციის კოეფიციენტი $|\xi|$ უმნიშვნელოდ იცვლება პიონების ტიპის შეცვლისას (პიონის ნიშნის ცვლილება) და ცდომილების ფარგლებში თითქმის უცვლელია π^- და π^+-მეზონებისათვის განხილულ დაჯახებებში. ასევე უნდა აღინიშნოს, რომ არ ხდება აზიმუტალური კორელაციის ტიპის ცვლილება ("back-to-back"-უარყოფითიდან “side-by-side”-დადებითზე) სამიზნის მასური რიცხვის (A_T) გაზრდისას. მიღებული შედეგები იძლევა მნიშვნელოვან ინფორმაციას მეზონ–ნუკლონური და მეზონ–ბირთვული ურთიერთქმედებების მექანიზმზე 40 გევ/c იმპულსის დროს, რაც განსაზღვრავს წარმოქმნილი ბირთვული მატერიის მახასიათებლებს პიონებისათვის π^-(p, n, C) დაჯახებებში. დამზერილი ("back-to-back") უარყოფითი კორელაციები მსუბუქ ბირთვულ წყვილებში დაბადებული პიონების კორელაციის მსგავსია.

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