N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
PHYSICO-MATHEMATICAL SERIES
ISSN 1991-346X **https://doi.org/10.32014/2019.2518-1726.53**
Volume 4, Number 326 (2019), 143 – 150

УДК 539.12

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INVESTIGATION OF CORRELATIONS OF GENERATED NUCLEAR ACTIVE PARTICLES IN $\tilde{p}p$ - EVENTS ENRICHED BY ANNIHILATION AT MOMENTA 22.4 GeV/c AND 32 GeV/c

Abstract. Extraction of $\tilde{p}p$ - events, enriched by annihilation, allowed to carry out the analysis of multiparticle correlations for the generated particles. The correlation function $R_k(G)$ is characterizing the ratio of experimental differential distribution of quasi-rapidity intervals to differential background distribution $R_K(G) = \frac{F_K(G)}{F_K^{\phi}(G)} - 1$, where $G = \eta_{\iota+\kappa} - \eta_\iota$ - quasi-rapidities intervals, η_i and η_{i+k} - quasi-rapidity values for boundary particles in the interval with k - 1 charged particles.

The analysis of R_K dependence on G was carried out on events enriched by annihilation and non – annihilation $\tilde{p}p$ - interactions at momenta 22,4 GeV /c and 32 GeV / c, and also inelastic pp - collisions at momentum 69 GeV/c.

In interactions with “annihilation” more weak correlation of charged particles is observed, than in non-annihilation $\tilde{p}p$ - interactions. In proton – proton and non - annihilation antiproton – proton collisions similarity of correlation functions is observed.

Key words: annihilation, proton, antiproton, interaction, reaction, interval, correlation.

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I. Introduction

The multiple production of hadrons in the interactions of elementary particles, in accordance with modern views, are results from hadronization of quarks and gluons [1-4], which are the parts of the interacting particles.

Investigation of secondary charged particles correlation in the multiple production processes at high energies gives the possibility to understand the internal dynamics of the studied processes. Just for this reason it is interesting to study particle correlations and to search non-statistical fluctuation effects in the processes of multiple hadron production.

It is known that antiproton – proton interactions include inelastic collisions with nucleons in final state (i.e. the baryon number conserves), and also annihilation events where the baryon number does not conserve. Information on events of antiproton – proton annihilation can be received by an exception of the inelastic non annihilation $\tilde{p}p$ - interactions from all data set.

Usually information about $\tilde{p}p$ - annihilation at sufficiently high energy ($E_0 > 10$ GeV) has been obtained by indirect methods [5-8]. In this regard the technique was developed [9] for division of “annihilation” proton - antiproton pair and non - annihilation processes in $\tilde{p}p$ - interactions.

Distinguishing by inverted commas of $\tilde{p}p$ - annihilation word everywhere in article authors mean the set of $\tilde{p}p$ - events enriched by annihilation.

Experimental material on $\tilde{p}p$ - interactions has been obtained using 2 metre hydrogen bubble chamber (HBC) «Ludmila» [10] (22.4 GeV/c) and HBC «Mirabelle» [11] (32 GeV/c), and on pp - inelastic event - HBC «Mirabelle» [12] (69 GeV/c). The bubble chambers were exposed at Serpukhov accelerator.

2. The procedure of extraction of $\tilde{p}p$ - "annihilation" events at 32 GeV / c.

Extraction of antiproton – proton "annihilation" events was carried out in two stages.

At the first stage events with identified proton or an antiproton were excluded. The interactions, remained after procedure of exclusion of events with protons and antiprotons, can be divided into three groups:

(I) - the group of annihilation reactions, in which neutrons (antineutrons) are absent in the final state $\tilde{p}p \rightarrow k(\pi^+\pi^-)x^0$, where *k* is the integer; x^0 - neutral system;

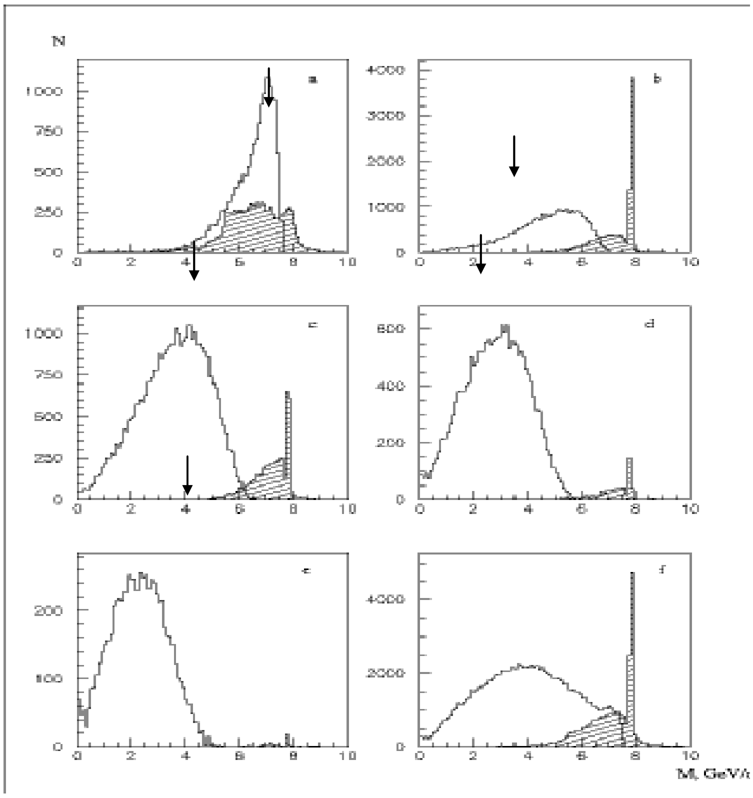
(II) - the group of non-annihilation reactions, containing neutrons (n) and antineutrons $(\tilde{n})$ in the final state $\tilde{p}p \rightarrow k(\pi^+\pi^-)n\tilde{n}x^0$;

(III) - the group with non-identified protons and antiprotons among charged particles.

At the second stage in mentioned three groups the values of missing masses were calculated on the charged particles

$$M_{miss} = [(E_0 - \sum_{i=1}^{n} E_i)^2 - (\overline{P}_0 - \sum_{i=1}^{n} \overline{P}_i)^2]^{1/2} \quad (1)$$

Corresponding distributions are shown in Fig. 1.



a) 2-prongs; b) 4-prongs; c) 6-prongs; d) 8-prongs; e) 10-prongs; f) summary distribution.

Figure 1 - Distributions on M. Unshaded histograms – distributions on M_{miss}. The shaded histograms – distributions on the effective mass $M(p\tilde{p})$, which have to be similar to missing mass of neutron – antineutron pair

During separation on $M_{miss.}$ it was considered, that presence of a neutron and an antineutron among secondary particles should sharply increase the value of missing mass. For each multiplicity selection of antiproton-proton interactions, classified as annihilation events, began with events having smaller missing masses and stopped, when the total number of selected events corresponded to evaluate antiproton-proton "annihilation" cross-section [11,13]. Chosen boundary values of $M_{miss.}$ are shown by arrow in Fig. 1.

The final distribution of all antiproton-proton interactions on different channels at 32 GeV/c is given in Table 1.

Table 1 - Distribution of number of events on channels of reaction and boundary values of $M_{miss.}$ (in GeV/c).

	Reaction	Multiplicities						
		2	4	6	8	10	≥ 12	All mult..
(1)	$\tilde{p}p \to \tilde{p}pk(\pi^+\pi^-)x^0$	8553	15080	6781	3291	927	150	34782
(2)	$\tilde{p}p \to p\pi^- k(\pi^+\pi^-)\tilde{n}x^0$	9087	11369	7303	2001	386	63	30209
(3)	$\tilde{p}p \to \tilde{p}\pi^+ k(\pi^+\pi^-)nx^0$	9335	11914	7354	1973	281	53	30910
(4)	$\tilde{p}p \to k(\pi^+\pi^-)n\tilde{n}x^0$	8891	18054	19504	8555	1809	0	56813
(5)	$\tilde{p}p \to k(\pi^+\pi^-)x^0$	6616	9140	14134	10266	5251	1969	47376
	Total	42482	65557	55076	26086	8654	2235	200090
	$M_{miss.}$ (boundary values)	6,5	4,4	3,4	3,0	3,0	3,0	-

To confirm the correctness of the described approach for separation of "annihilation" interactions with small missing masses, the effective mass distributions $M(p\tilde{p})$ (shaded histograms in Fig.1) in events with protons and antiprotons (reaction 1) were compared with missing mass distributions (unshaded histograms in Fig.1), assuming that possible contribution of neutron-antineutron pairs is imitated by distribution of effective masses for proton-antiproton pairs.

It can be seen from Fig. 1 that in six-, eight-, and ten-prong events the admixture of non-annihilation processes into reactions corresponding to "annihilation", is practically absent. This admixture equals to about 40% for 2-prong events, < 3% for 4 - prong events and ~ 12% for the total distribution.

3. Comparison of correlations in antiproton-proton "annihilation" events with corresponding data for inelastic pp - and non-annihilation $\tilde{p}p$ - interactions.

Separation of the events corresponding to antiproton-proton annihilation gives the possibility to carry out the analysis of multiparticle correlations for generated particles and to compare them with corresponding data for inelastic pp and non-annihilation $\tilde{p}p$ interactions.

The correlation function [14, 15]

$$R_K(G) = \frac{F_K(G)}{F_K^{\phi}(G)} - 1 , \tag{2}$$

where $G = \eta_{i+k} - \eta_i$ - the interval of quasirapidities; η_i and η_{i+k} - quasirapidities of boundary particles of the interval with (k - 1) charged particles inside it; $F_k(G)$ - measured differential distribution; $F_k^{\phi}(G)$ - expected differential distribution in the absence of correlations (background distribution).

The statistical error in finding of $R_k(G)$ is calculated according to formulae

$$\delta R_k(G) = (R_k(G)+1)\sqrt{(\frac{\delta F_k(G)}{F_k(G)})^2 + (\frac{\delta F_k^{\phi}(G)}{F_k^{\phi}(G)})^2} . \tag{3}$$

In Fig. 2 the results of R_k dependence on G for inclusive analysis of non-annihilation $\tilde{p}p$-interactions at momenta of primary antiprotons 22.4 GeV/c (Fig.2a), 32 GeV/c (Fig.2b) and for inelastic pp –interactions at momentum 69 GeV/c (Fig.2c) for k = (2 ÷ 5) are presented.

It is visible, that in the region of small rapidity intervals ($0 \div G_1$) and in the region of large rapidity intervals ($G > G_2$) positive correlation R_K (G) > 0 is observed, and in the region of ($G_1 > G > G_2$) the value of R_K (G) becomes negative for all considered values к=(2÷5). Here G_1 - the left point of function R_K (G) crossing with axis G; G_2 – the right point of function R_K (G) crossing with axis G.

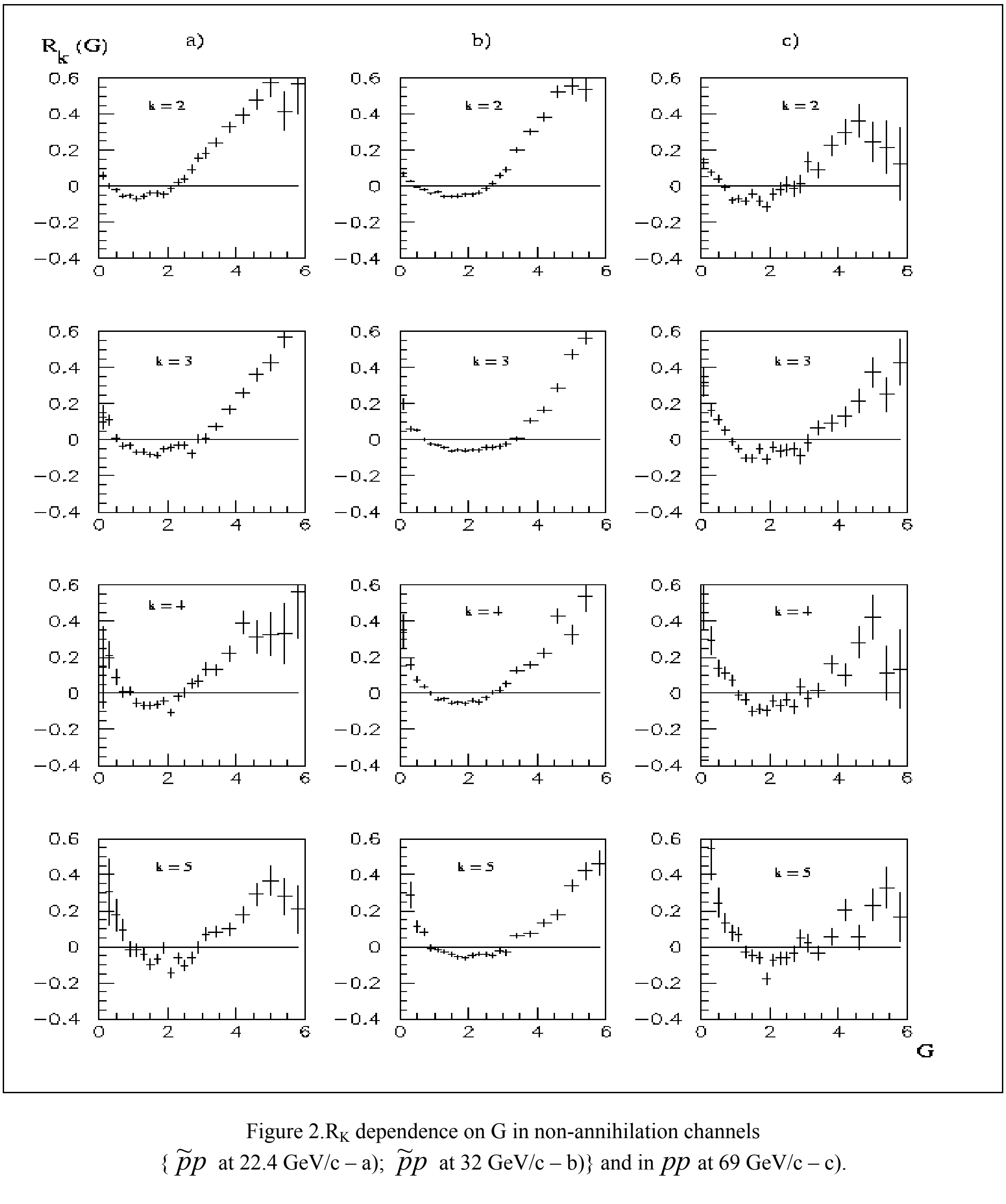


Figure 2.R_K dependence on G in non-annihilation channels
{ $\tilde{p}p$ at 22.4 GeV/c – a); $\tilde{p}p$ at 32 GeV/c – b)} and in pp at 69 GeV/c – c).

In Table 2 the values of G_1 and G_2 and also the maximal value of $R_k^{max}(G)$ inside region $0<G<G_1$ are given. The quantities G_1 and G_2 displace towards the larger values with increasing of primary particle energy (at the fixed value k). At the same time the mean quantity $\langle \Delta G \rangle = \langle G_2 - G_1 \rangle$ at k = (2 ÷ 5)

remains approximately the same in non-annihilation $\widetilde{p}p$ - interactions at 22.4 GeV/c, 32 GeV/c and in inelastic pp - collisions at 69 GeV/c and equals correspondingly to $\langle \Delta G \rangle$ = 1.8; $\langle \Delta G \rangle$ =2.0; $\langle \Delta G \rangle$ =2.2.

Table 2 - Values G_1, G_2 и R_{max} for non-annihilation interactions
(in brackets corresponding values for "annihilation" are resulted)

				$\widetilde{p}p$ 32 GeV/c			pp 69 GeV/c		
K	G_1	G_2	R_{max}	G_1	G_2	R_{max}	G_1	G_2	R_{max}
2	0.4 (0.2)	2.2 (1.2)	0.06±0.02 (0.01±0.02}	0.6 (0.2)	2.6 (1.4)	0.07±0.01 (0.02±0.02)	0.8	3.0	0.13±0.03
3	0.6 (0.6)	3.2 (1.6)	0.12±0.07 (0.00±0.02)	0.8 (0.4)	3.4 (1.8)	0.20±0.03 (0.10±0.03)	1.0	3.2	0.32±0.08
4	1.0 (0.6)	2.6 (2.0)	0.21±0.08 (0.02±0.04)	1.0 (0.4)	2.8 (2.0)	0.34±0.09 (0.35±0.10)	1.2	3.4	0.65±0.30
5	1.4 (0.8)	3.0 (2.0)	0.31±0.19 (0.00±0.01)	1.2 (0.6)	3.2 (2.4)	0.29±0.08 (0.40±0.25)	1.2	3.6	0.63±0.30

In Fig.3 the results obtained for dependence R_K on G at the analysis of reactions of antiproton-proton "annihilation" for k=(2÷5) at momenta 22.4 GeV/c (Fig 3a) and 32 GeV/c (Fig.3b) are presented.

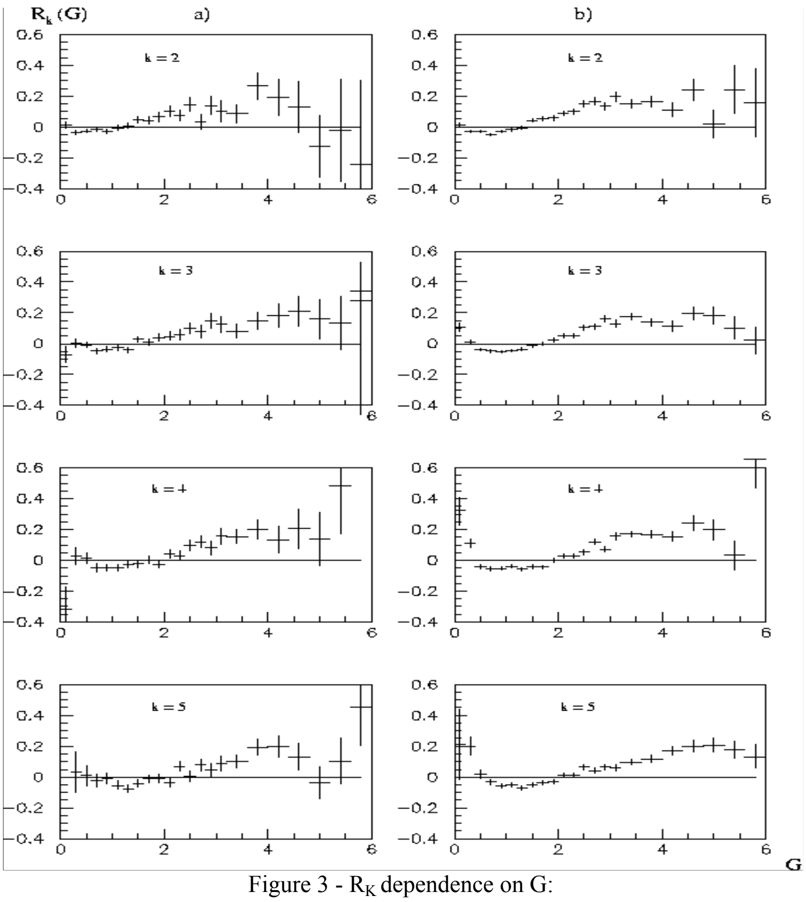


Figure 3 - R_K dependence on G:
a) $\widetilde{p}p$ -"annihilation" at 22.4 GeV/c; b) $\widetilde{p}p$ - "annihilation" at 32 GeV/c.

From comparison of Figures 2 and 3, and also the data in Table 2 can be seen that in non-annihilation $\widetilde{p}p$ - interactions the correlation is more noticeable, in comparison with "annihilation" events, the correlation of particles from non – annihilation events and qualitatively coinciding with correlation of particles in inelastic pp - interactions at 69 GeV/c.

The effect observed could probably be explained by the assumption that the mechanism of meson production goes mainly via intermediate creation of nucleon isobars, which contributes both to non-annihilation channel of $\tilde{p}p$ - collisions and to the inelastic pp - interactions.

In antiproton-proton “annihilation” events at 32 GeV/c the positive values of $R_K(G)$ in the region of small G at k=(3÷5) are observed (Fig.3b), whereas at antiproton – proton interactions at momentum 22.4 GeV/c (Fig.3a) such correlation is absent.

In Fig.4 the dependence of R_K on G is presented for each multiplicity at antiproton-proton “annihilation” at momentum 32 GeV/c with the purpose to find out the connection of observed correlations with multiplicity. In the region of small values G ($G < G_1$) correlation of particles is not observed for multiplicities 4 and 6 (the figures are not shown), but it is appreciable ($R_K(G) > 0$) for 8-prongs events at k =3 (Fig.4a) and is absent for the same 8-prongs interactions at k=4 and k=5. For events with multiplicities 10 (Fig.4b) and ≥ 12 (Fig.4c) the positive values of $R_K(G)$ are observed at k=3,4,5.

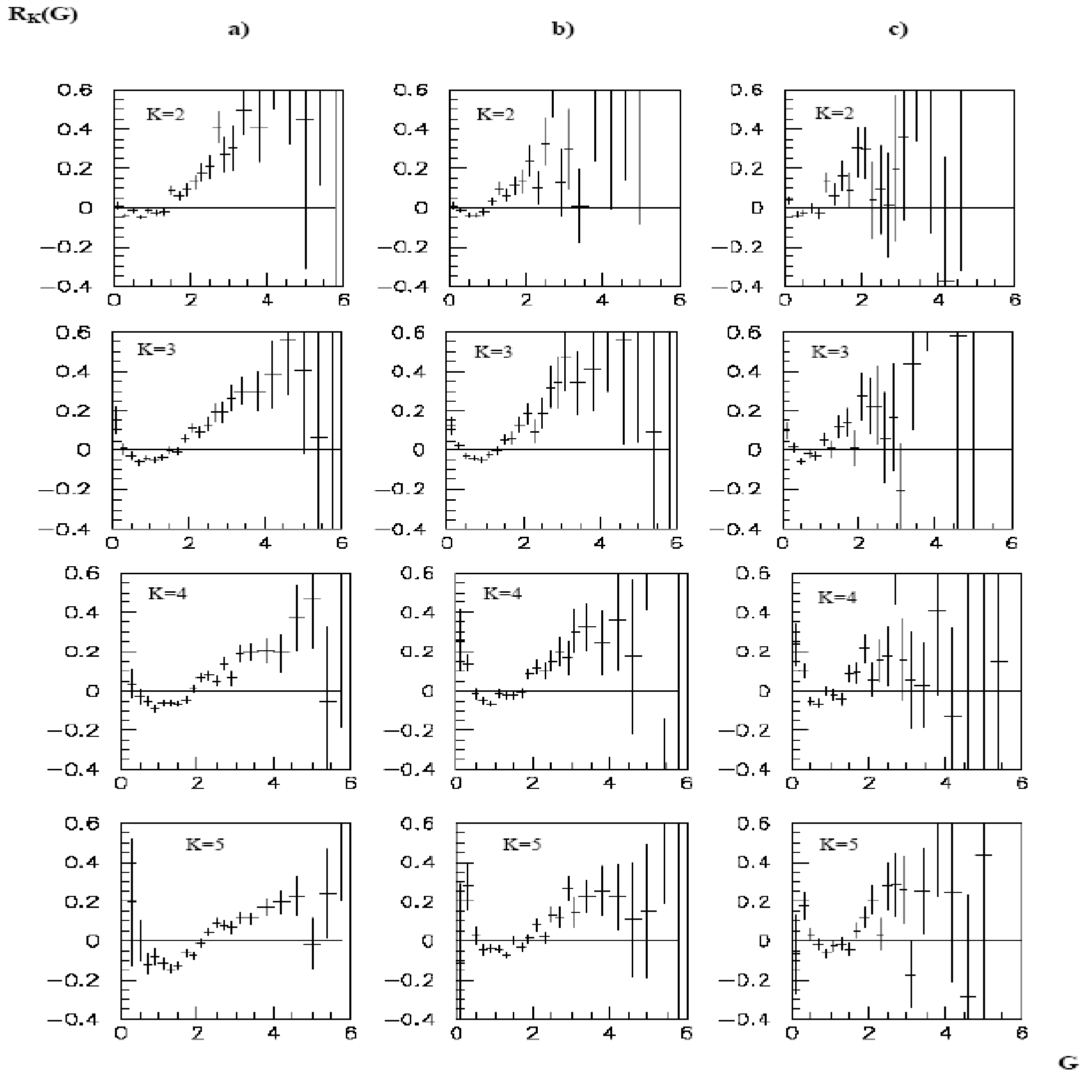


Figure 4 - R_K dependence on G for $\tilde{p}p$ -annihilation at 32 GeV/c:

a) 8-prongs; b) 10-prongs; c) ≥ 12-prongs

Thus, observed correlations of particles in inclusive channel of antiproton-proton “annihilation” are seen in interactions with multiplicities 8 and more. From here it is possible to make the conclusion that at momentum 32 GeV/c there is a new reaction channel with creation of meson resonances decaying onto 4 and more charged particles.

Summing up the results, we note the following.

In processes of anti-proton – proton “annihilation” at momentum 32 GeV /c the new reaction channel appears with formation of the meson resonances, decaying up to four and more charged particles.

In interactions of antiproton – proton “annihilation” the observed correlation of charged particles is more weak, than in non-annihilation interactions.

In proton – proton and non-annihilation antiproton – proton collisions similarity of correlation functions is observed.

The authors are sincerely grateful to participants of international collaborations «Ludmila» and «Mirabelle» for fruitful joint work in obtaining primary experimental data.

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22,4 ГэВ/с ЖӘНЕ 32 ГэВ/с ИМПУЛЬСТА АННИГИЛЯЦИЯМЕН БАЙЫТЫЛҒАН $\tilde{p}p$ - ӘСЕРЛЕСУДЕГІ ЯДРО-БЕЛСЕНДІ БӨЛШЕКТЕРДІҢ КОРРЕЛЯЦИЯСЫН ЗЕРТТЕУ

Аннотация. Аннигиляциямен байытылған $\tilde{p}p$ - әсерлесуді анықтау өндірілген бөлшектер үшін көпбөлшекті корреляция талдауын жүргізуге мүмкіндік берді. Корреляциялық $R_k(G)$ функциясы квазижылдам интервалдың тәжірибелік таралуының дифференциалдық $R_K(G) = \dfrac{F_K(G)}{F_K^{\varphi}(G)} - 1$ аялық таралуға қатынасын сипаттайды, мұндағы $G = \eta_{i+k} - \eta_i$ квазижылдамдық интервалы, ал η_i и η_{i+k} мәндері k – 1 бөлшектер интервалындағы шектік бөлшектер үшін квазижылдамдық мәні.

R_K функциясының *G* тәуелді талдауы аннигиляциямен байытылған ортада және аннигиляцияланбаған $\tilde{p}p$ -әсерлесуде 22,4 ГэВ/с және 32 ГэВ/с импульста, сондай-ақ, 69 ГэВ/с импульста серпімсіз pp -әсерлесуде жүргізілді.

Аннигиляцияланбаған pp-әсерлесудегі корреляцияға қарағанда «аннигиляциялы» әсерлесуде біршама әлсіз корреляция байқалды. Протон-протондық және аннигиляцияланбаған антипротон-протондық соқтығысуларда корреляциялық функциялардың ұқсастығы байқалды.

Түйін сөздер: аннигиляция, протон, антипротон, әсерлесу, реакция, интервал, корреляция.

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ИССЛЕДОВАНИЕ КОРРЕЛЯЦИЙ ЯДЕРНО-АКТИВНЫХ ЧАСТИЦ В $\tilde{p}p$ -ВЗАИМОДЕЙСТВИЯХ, ОБОГАЩЕННЫХ АННИГИЛЯЦИЕЙ ПРИ ИМПУЛЬСЕ 22,4 ГэВ/с и 32 ГэВ/с

Аннотация. Выделение $\tilde{p}p$ -взаимодействий, обогащенных аннигиляцией, позволило провести анализ многочастичных корреляций для генерированных частиц. Корреляционная функция $R_k(G)$ характеризует отношение экспериментального распределения квазибыстротных интервалов к дифференциальному фоновому распределению $R_K(G) = \dfrac{F_K(G)}{F_K^{\varphi}(G)} - 1$, где $G = \eta_{i+k} - \eta_i$ квазибыстротный интервал, а η_i и η_{i+k} значения квазибыстрот для граничных частиц в интервале с k – 1 частицей.

Анализ функции R_K в зависимости от *G* проводился на обогащенных аннигиляцией и не аннигиляционных $\tilde{p}p$ - взаимодействиях при импульсе 22,4 ГэВ/с и 32 ГэВ/с, а также на неупругих pp - взаимодействиях при импульсе 69 ГэВ/с.

Во взаимодействиях с “аннигиляцией” наблюдается более слабая корреляция по сравнению с корреляцией в неаннигиляционных pp-взаимодействиях. В протон-протонных и неаннигиляционных

антипротон-протонных столкновениях наблюдается сходство корреляционных функций.

Ключевые слова: аннигиляция, протон, антипротон, взаимодействие, реакция, интервал, корреляция.

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REFERENCES

[1] Troitsky S.V. Unsolved problems in particle physics // Phys. Usp., 2012, V. 55, №1-2, P. 72–95.

[2] Mangano M.L. QCD and the physics of hadronic collisions // Phys. Usp. 2010, V. 53, № 2б P. *109*–132.

[3] Dremin I M, Kaidalov A B Quantum chromodynamics and phenomenology of strong interactions // Phys. Usp. 2006, V. 49, № 3, P. 263–273.

[4] Rubakov V.A. Cosmology and the Large Hadron Collider // Phys. Usp., 2011, V. 54 № 6, P. 633–641.

[5] Raja R. Estimation of the Annihilation Component in $\bar{P}P$ Interactions // Phys.Rev., 1977, V. D16, P. 142 – 153.

[6] Boos E.G., Ermilova D.I. et al. Charge asymmetry at large p_T in inelastic *pp* - *r*eactions at 22.4 GeV/c. // Nucl. Phys. B, 1977, V. 128, № 2, P. 269 – 274.

[7] Smirrnova L.N. The Dynamics of $\tilde{p}p$ - annihilation at High Energies // Yaderrnya Fizika, 1988, V. 47, P. 419 – 430. (In Russian)

[8] Ward, C.P. *et al.* General Features Of Charged Particle Production In Anti-p P Interactions At 100-gev/c // Nucl. Phys. B, 1979, V. 153, P. 299 – 333.

[9] Boos E.G., Temiraliev T. et al. The Method of $\tilde{p}p$ - annihilation Separation at 22,4 GeV/c Momentum. // Izvestiya MON RK, NAN RK, seriya fiziko-matematicheskaya, 2000, №2, P. 35 – 44. (In Russian)

[10] Batyunya B.V., Boguslavsky I.V. et. al. Charged particle multiplicity distribution in anti pp interactions at 22.4 GeV/c // Preprint JINR E1-739, 1981, Dubna.

[11] Hanumaiah B., Sarycheva L.I. et al. Charged-particle multiplicities in pp interactions at 32 GeV/c // Nuovo Cimento A, 1982, V. 68, № 2, P. 161 – 175.

[12] Bumazhnov V.A., Ermolov P.F. et al. Negative Pion Production in Proton Proton Interactions at 69 GeV/c // Phys. Lett. B, 1974, V. 50, P. 283 - 286.

[13] Boos E.G., Temiraliev T. et al.. Cross-Section of $\tilde{p}p$ - annihilation at 32 GeV/c // Izvestiya NAN RK, seriya fiziko-matematicheskaya, 2006, № 6, P. 64 – 69. (In Russian)

[14] Boos E.G., Vinitsky A.H. et al. Study of Nuclear Density Effects on Secondary Hadrons Many-Particle Correlations // Z.Phys. 1995, V. A351, P. 209 – 216.

[15] Tasmambetov Zh.N., Rajbov N., Issenova A.A. The Construction of a Solution of a Related System of the Laguerre Type // News of the National Academy of Sciences of the Republic of Kzakhstan. Series of physic – mathematical sciences. Volume 1, Number 323 (2019) pp. 38-50. ISSN 1991-346X https://doi.org/10.32014/2019.2518-1726.5