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ANTIPROTON-PROTON ANNIHILATION AT 32 GeV/c AND NUCLEON STRUCTURE

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The inclusive meson spectra in $\bar{p}p$-annihilation at 32 GeV/c from the experiment with the liquid hydrogen bubble chamber "Mirabelle" are analyzed in the quark-gluon string model. It is established that in $\bar{p}p$-annihilation the structure functions of quarks in the nucleon are asymmetric and analogous to the structure functions of quarks in reactions with the conservation of baryons.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Антипротон-протонная аннигиляция при импульсе 32 ГэВ/с и структура нуклона

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Инклюзивные спектры мезонов в процессе $\bar{p}p$-аннигиляции при импульсе 32 ГэВ/с, полученные в эксперименте на жидководородной пузырьковой камере "Мирабель", анализируются в модели кварк-глюонных струн. Установлено, что структурные функции кварков в нуклоне в процессе $\bar{p}p$-аннигиляции несимметричны и аналогичны структурным функциям кварков в реакциях с сохранением барионов. Для описания свойств $\bar{p}p$-аннигиляции необходимо учитывать дополнительные струны между морскими кварками нуклонов.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

1. Introduction

The $\bar{p}p$-annihilation process is of special interest for the study of the quark structure of the nucleon. The nucleon structure is completely destructed in $\bar{p}p$-annihilation. In this case the diquark in the nucleon is known not to exist as a physical entity. What is unknown is whether the structure functions of quarks in the nucleon are changed or not. This question is discussed in the present report.

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2. Experiment

The experiment was conducted with the hydrogen bubble chamber "Mirabelle". The $\bar{p}p$-interactions at 32 GeV/c were studied on the basis of the statistics consisting of 250 thousand completely measured events. The pp-interactions are studied at the same momentum (at present 45 thousand measured events; the data processing is in progress)[1,2]. The results of these experiments made it possible to estimate the topological $\bar{p}p$-annihilation cross sections at 32 GeV/c[1] (fig.1). 650 events of the exclusive 4C and 1C-fit $\bar{p}p$-annihilation channels have been identified

$$\bar{p}p \to n\pi^{\pm}$$

$$4 \le n \le 12 .$$

$$\bar{p}p \to n\pi^{\pm} + \pi^{o}$$

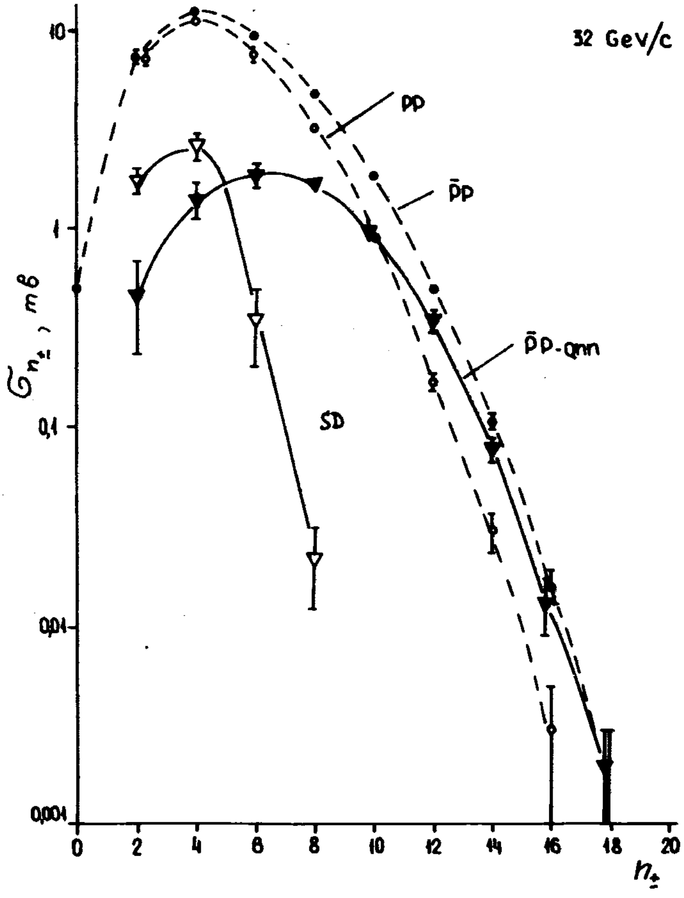


Fig.1. Multiplicity distributions in $\bar{p}p$-, pp-interactions and $\bar{p}p$-annihilation at 32 GeV/c.

These channels were used to reconstruct the inclusive meson spectra in the $\bar{p}p$-annihilation process /3,4/. The reconstruction method is described in /3/. The method consists in summation of the π-meson distributions from the exclusive channels and the weight factors which correspond to the multiplicity distribution of particles in $\bar{p}p$-annihilation.

The charged-to-neutral meson ratio was determined in the model /5/. The analysis of the charge distribution in the exclusive $\bar{p}p$-channels and of the total electric charge in the hemisphere in the reconstructed inclusive distribution showed that two or three valence quarks of each nucleon survive in $\bar{p}p$-annihilation /4,6/. Thus, these data showed that the quark structure of the nucleon is clearly exhibited in $\bar{p}p$-annihilation. The problem arises now to reproduce the observed features of $\bar{p}p$-annihilation in the Monte-Carlo quark model where hadrons are produced due to break of the colour strings which arise between the quarks of initial nucleons.

3. $\bar{p}p$-Annihilation Simulation

Figure 2 shows the diagrams which represent possible $\bar{p}p$-annihilation mechanisms. These diagrams differ in the number of strings between valence quarks of nucleons, i.e. in the number of valence quarks which survived in $\bar{p}p$-annihilation, and in the number of additional strings between sea quarks of nucleons.

In each of these diagrams the fraction of the initial momentum carried away by the nucleon quark, and the transverse momentum of the quark were determined first of all. To satisfy the law of energy-momentum conservation, it was assumed that the mass of quarks is not fixed. The momenta and the squared masses of quarks unambi-

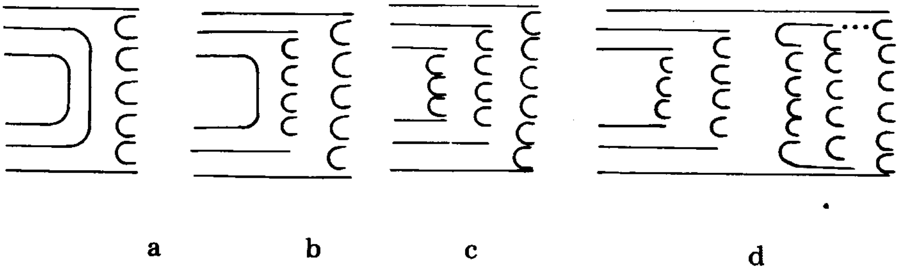


Fig.2. $\bar{p}p$-annihilation diagrams.

guously determined the momentum and the energy parameters of strings. The break of a string into hadrons and resonances occurred in its rest frame. After the break had been completed, the parameters of the particles were converted into the centre-of-mass system of colliding nucleons. The break of a string and the decay of resonances are described in ref. /7/. The main parameters used in the simulation are reported in ref. /8/.

To determine the energy and the longitudinal momentum of the hadron, we used the fragmentation functions of quarks at the ends of strings with the corresponding Regge behaviour at $z \to 1$ /9/. Here

$$z = (E_h + P_{\parallel_h})/(E_q + P_{\parallel_q}); \quad E_h, E_q, P_{\parallel_h}, P_{\parallel_q}$$

are the energy and the longitudinal momentum of hadron h and quark q, respectively. The asymptotics of the fragmentation functions at $z \to 1$ depends on the flavour of the quark, the transverse momentum and the type of the hadron into which the quark fragments.

The iterative string break procedure described correctly the behaviour of the fragmentation function $D(z) \sim 1/z$ at $z \to 0$. When the string mass $M_s \le M_0$, where $M_0 = M_R + 0.3$ GeV, M_R is the resonance mass, the string breaks isotropically with the rejection by the space volume.

The structure functions for the $\bar{p}p$-annihilation process were specified in two ways. First, it was assumed that all the quarks in the nucleon are equivalent and the quark distribution is:

$$u(x) \sim \frac{1}{\sqrt{x}} \frac{1}{\sqrt{1-x}}; \quad u(x_1, x_2) \sim \frac{1}{\sqrt{x_1}} \frac{1}{\sqrt{x_2}} \frac{1}{\sqrt{1-x_1-x_2}} \tag{1}$$

the diagrams with two and three strings, respectively. When one string was formed, it contained the whole of the reaction energy.

Secondly, when two strings are formed, the structure functions are written as:

$$u(x) \sim x^{\alpha-0.5} (1-x)^{\beta-0.5}, \tag{2}$$

where $\alpha = 1.5$, $\beta = 1.5$ for the u-quark, and $\alpha, \beta = 2.5$ for the d-quark. When three strings are formed, the fractions of the quark momenta are determined sequentially: the decay into a quark and a diquark and, next, the disintegration of the diquark by the same expressions (2).

When five or more strings are formed, which make up 30% of the $\bar{p}p$-events at 32 GeV/c, the x distribution from ref. /10/ was used, except for the disintegration of the diquark asymmetric, according to (2). The sea quarks were assumed to have the $1/\sqrt{x}$ distribution at $x \to 0$. At the asymmetric structure functions of valence quarks (2) in the two-string formation the u- and d-quarks of the proton carry away 60% and 40% of the initial momentum, respectively.

The parametrization of the transverse momenta of quarks which was used in simulation and ensured the agreement with the experimental $p_{\perp}^{2}$-distribution in $\bar{p}p$-annihilation, is given in ref. /8/.

4. The Main Results

The charged multiplicity distributions for $\bar{p}p$-annihilation at 32 GeV/c, which were obtained in the model for different $\bar{p}p$-annihilation diagrams, are compared in fig.3 with the experimental distribution. One can see from this figure that not a single diagram taken separately can describe the experimental distribution. The events with large $n_{\pm} \geq 12$ can be obtained only in the diagrams which contain additional strings between sea quarks. To describe the complete distribution, different types of diagrams are to be considered.

The relative contributions of different $\bar{p}p$-annihilation diagrams were determined so that to provide the best description of the experimental multiplicity distributions at 12, 32 and 100 GeV/c. It was

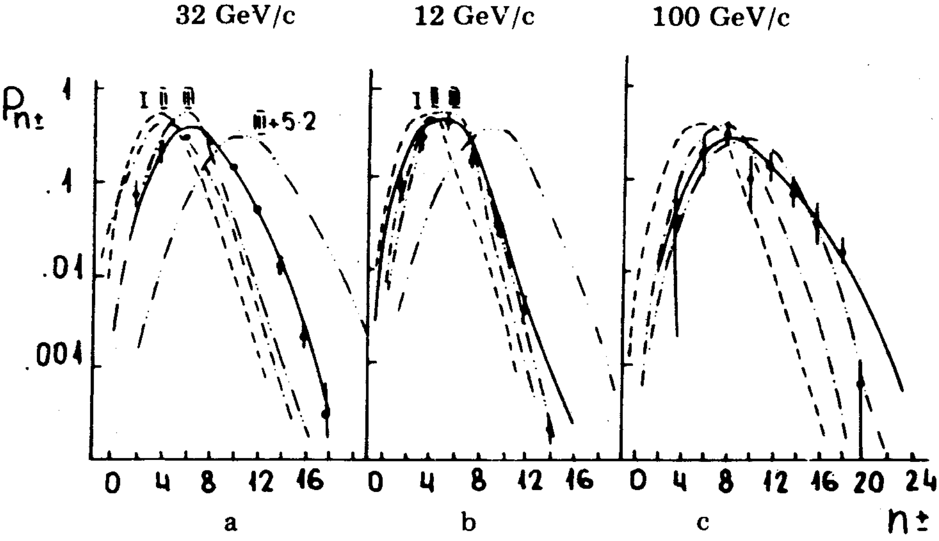


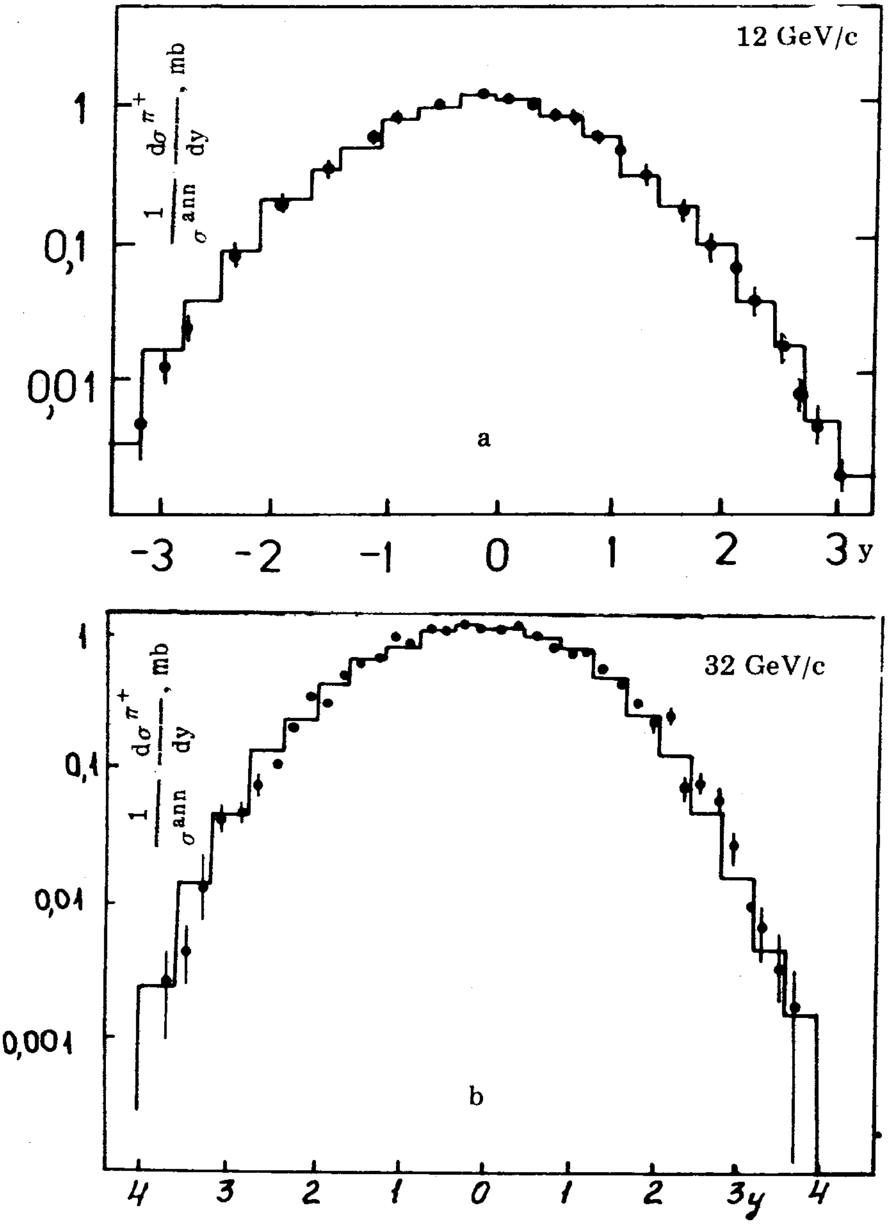
Fig.3. Multiplicity distributions in $\bar{p}p$-annihilation at 32 (a), 12 (b) and 100 GeV/c (c). The dots — experiment; the full curve — model; the broken curves — diagrams with 1, 2, 3 and 10 strings.

taken into account that the energy dependences of the contributions from the diagrams shown in fig.2a (σ_1) and 2b (σ_2) are of the form[11-13] :

$$\sigma_1\,(s) = C_1 s^{-1.5},$$

$$\sigma_2\,(s) = C_2 s^{-1.0},$$

$$C_1 = 290 \pm 5 \text{ mb GeV}^3,\ C_2 = 95 \pm 5 \text{ mb GeV}^2.$$



The contribution of the diagrams shown in figs. 2c, d (σ_3), was determined from the relation:

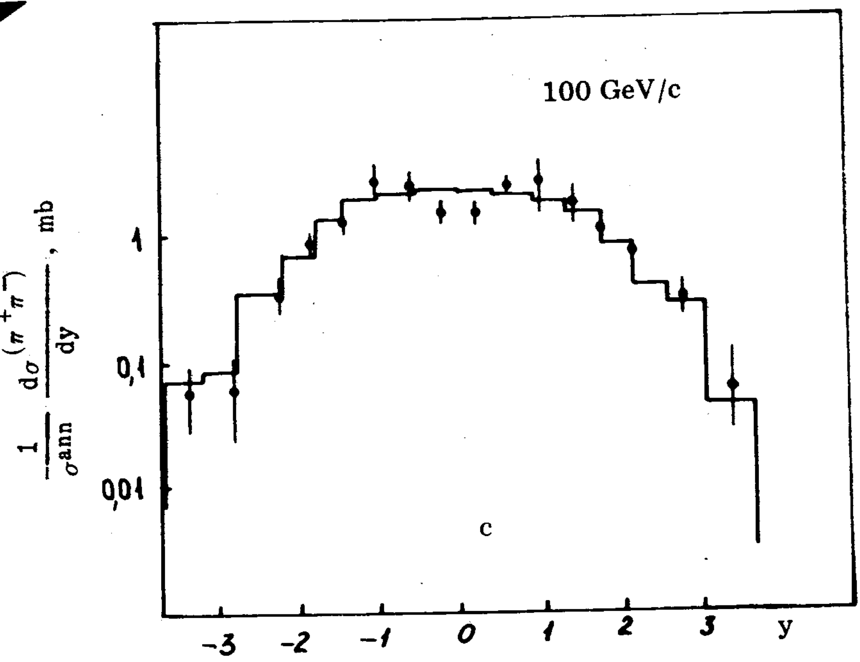
$$\sigma_3 = \sigma^{ann} - \sigma_1 - \sigma_2$$

σ^{ann} is the experimentally measured $\bar{p}p$-annihilation cross section. Since the contribution of the three-string diagram is dominant, as is seen from fig.3, the contribution of the strings between sea quarks was taken into account only for this diagrams. The expressions from refs./12, 13/ for the relative contributions of diagrams with a different number of strings between sea quarks, led to overestimated cross sections for large $n_\pm$. Agreement with experiment is achieved when the weights of these diagrams are chosen in the form analogous to /10/ :

$$w_n = \frac{\sigma_n}{\sum\limits_n \sigma_n} = (1 + A n^2)\, e^{-Bn} / \sum_n \sigma_n ,$$

where n = 1, 2, 3, ..., 8; A = 3.5; B = 2.35 — 0.25 ln($\sqrt{s}$) (fig. 3b, c). The value of n = 1 corresponds to the formation of three strings on valence

Fig.4. Rapidity distributions of π-mesons in $\bar{p}p$-annihilation at 12 (a), 32 (b) and 100 GeV/c (c). The dots — experiment. The histograms — model.



quarks; and the value of n = 2, to the formation of additional two strings on sea quarks, etc.

Thus, in the string quark model the $\bar{p}p$-annihilation process at energies of 12-100 GeV/c is described by the sum of different diagrams. It is imperative that the strings between sea quarks on nucleons be allowed for. The model description of the data is shown in fig.3a-c (full curves). The description of the multiplicity distribution also ensures satisfactory agreement between the experimental rapidity distribution and the model (fig.4a-c).

The rapidity density distribution at y = 0 is the most characteristic distribution of the spectra for diagrams with a different number of strings. It is seen that in the model this parameter is described satisfactorily. The shape of the structure function of π^+-mesons F(x) in $\bar{p}p$-annihilation at 32 GeV/c for diagrams with one, two and more strings is shown in fig.5a. The experimental distribution is added here for comparison. It follows from fig.5a that the most energetic π-mesons in $\bar{p}p$-annihilation arise from the diagrams with a small number of strings. The experimental observation of these particles indicates the necessity of taking into account the diagrams with a small number of strings. The distributions shown in figs. 3, 4 are weakly sensitive to the specific form of the structure function of quarks (1) or (2). The choice of the structure functions of quarks is essential for describing the asym-

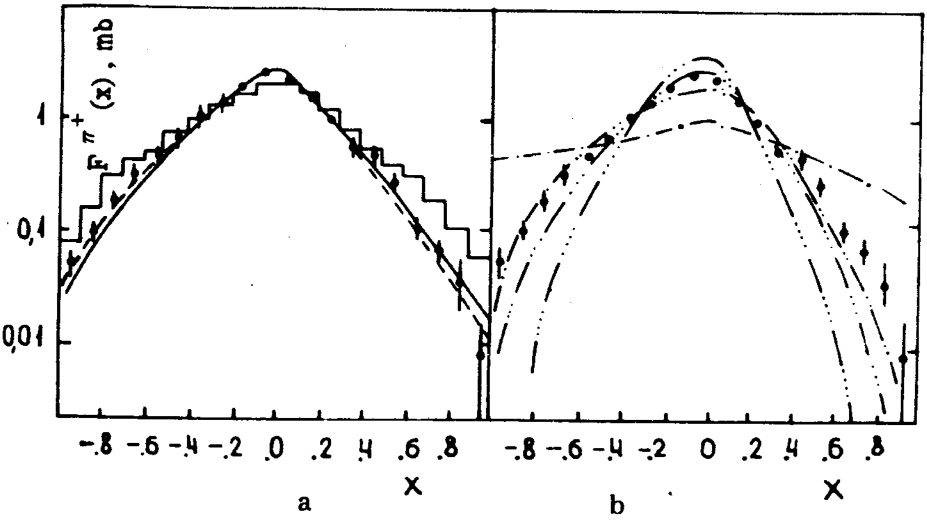
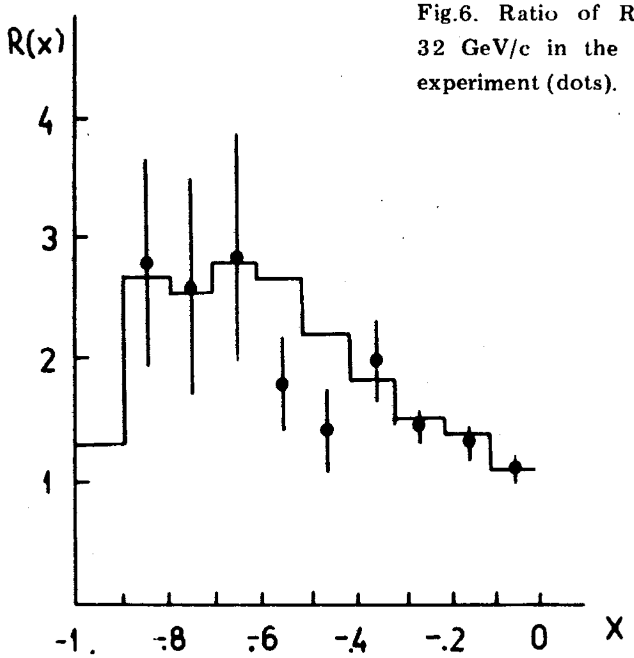


Fig.5. F(x) distribution for π^+-mesons in $\bar{p}p$-annihilation at 32 GeV/c; a) in the model with the production of baryons (—), without the production of baryons (-----), at symmetric structure functions (1) in the diagram with two strings (histogram); — experiment; b) with asymmetric structure functions for the diagrams with 1, 2, 3 and 5 strings.

Fig.6. Ratio of R(x) for $\bar{p}p$-annihilation at 32 GeV/c in the model (histogram) and in experiment (dots).



metry of the structure functions of π^+-mesons F(x). This is seen from fig. 5 which presents the calculated spectra F(x) for symmetric (1) and asymmetric (2) structure functions of quarks in the nucleon which were obtained for the diagrams with two strings between valence quarks (fig.2b). The symmetric structure functions give a much weaker degree of asymmetry of the π^+-meson spectrum. The ratio R(x) = $= F^{\pi^+}(x)/F^{\pi^-}(x)$ at $x < 0$ in experiment and in the model with the structure functions of quarks (2) with allowance for the contributions of all above-noted diagrams is shown in Fig.6. The calculated and experimental R(x) distributions are the same within the errors. However, the errors are large for most of the dots. The most reliable goodness-of-fit test for the asymmetry of spectra is the quantity $\langle Q\rangle = \langle n_+\rangle - \langle n_-\rangle|_{x<0}$ (the mean total electric charge of particles in the c.m. backward hemisphere). This quantity is the integral asymmetry parameter. Calculations showed that $\langle Q\rangle$ is actually insensitive to the specific form of the fragmentation function of quarks (Lund, Field-Feynman, Kaidalov-fragmentation functions /9/) and it is determined by the type of the diagram, i.e. the number of fragmenting valence quarks, and by the structure function of quarks in the nucleon.

At the symmetric structure functions (1) the quantity for all three fragmentation functions is not higher than 0.1 even if the strings are produced on all three valence quarks. At the asymmetric structure functions (2) for $\bar{p}p$-annihilation with the formation of one, two, three, five and more strings $<Q>=$ 0.14, 0.29, 0.38 and 0.32, respectively. When the contributions of all the diagrams are included, the calculations yield $<Q>=0.32\pm0.02$ at 12, 32 and 100 GeV/c. This value is somewhat lower as compared with the experimental result at 32 GeV/c /4/ — $Q = 0.42 \pm 0.01$. However, agreement is, on the whole, satisfactory. Note that the calculated value will increase up to 0.35 ± 0.02 if we exclude from the model the events with the production of baryon pairs.

Thus, the strong asymmetry of the meson spectra in $\bar{p}p$-annihilation, observed in experiment, means that the structure functions of quarks in the nucleon and in the destruction of the diquark are asymmetric and analogous to the structure functions of quarks in reactions with the conservation of baryons. Two, three and more number of strings contribute in $\bar{p}p$-annihilation mechanism.

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