

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՏԻՏՈՒՏ
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STRUCTURE FUNCTION OF CARBON NUCLEUS
IN CUMULATIVE π -MESON PHOTOPRODUCTION PROCESSES.

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ԿԷ. ԵՂԻՑԱՆ, Մ.Ս. ՕՂԱՆՔԱՆՆԱՆ

ԱՍԽԱՍՆԻ ՄԻՋՈՒԿԻ ԿԱՌՈՒՑՎԱԾՔԱՑՈՒՆ ՅՈՒՆԿՅՈՒՆ
ԿՈՒՄՈՒԼՅԱՑԻՎ π -ՄԵՐՈՆՆԵՐԻ ՅՈՑՈՍՆՍԱՆ ԸՆԹԱՅՐՈՒՄ

Տերված են ^{12}C բիրտի վրա $E_{\gamma}^{\text{max}}=4,5$ ՉէՎ սահմանային էներգիայի
ֆոտոններով π -մեզոնների ծննդի տվյալների /10,11/ վերլուծության
արդյունքները $f_{\pi}(\alpha, P_{\perp}^2)$ ինվարիանտ կորվածքի ֆակտորիզացման վերաբերյալ
սեղերայինների սառցման տեսանկյունից:

Ցույց է տրված, որ $f_{\pi}(\alpha, P_{\perp}^2) \sim f_{1\pi}(\alpha) \cdot f_{2\pi}(P_{\perp}^2)$ ներկայացման դեպքում,
որտեղ $f_{1\pi}(\alpha) \sim \exp(-\alpha/\alpha_0)$ և $f_{2\pi}(P_{\perp}^2) \sim \exp(-P_{\perp}^2/P_{0\perp}^2)$, $\alpha_0(P_{\perp}^2)$ և
 $\langle P_{0\perp}^2(\alpha) \rangle$ թերաբյուրի պարամետրերը կարող են փոխվել ոչ ավելի, քան 40%-ի
սահմաններում: Համեմատված են նաև կամուրջային պրոտոնների և π -մեզոնների
ֆոտո և եռարտածման որոշ տվյալներ /6,13,14,15/: Դրանք բերում են այն
եզրահանգման, որ այդ երկու տիպի ֆակտորիզացիաների դեպքում կամուրջային
մասնիկների ծննդի մեխանիզմների ներքառմանը տարբեր են, որը
տեսակետից նաև բացատրաբար է պահանջում:

Երևանի ֆիզիկայի ինստիտուտ
Երևան 1992



Центральный научно-исследовательский институт информатики
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One of the effective sources of information on nuclear quark-parton structure function is the study of the limited fragmentation of nuclei into the fast particles. As the most typical of such processes, apparently the cumulative particle production should be regarded.

Let us consider the reaction



where C is a cumulative particle that is the fragment of nuclear matter. To obtain the structure function of fragmenting system (nucleus or its part) the invariant cross section f_c of process (1), according [1], can be presented in the general form as

$$f_c \equiv \frac{K_c d^3\sigma}{dP_c^3} = \sigma CG(\alpha, p_\perp), \quad (2)$$

where $G(\alpha, p_\perp)$ is a structure function of the fragmentator, α is the ratio of quark longitudinal momentum to the average momentum of nucleon in nuclei, in the infinite momentum frame, p_\perp is a quark transverse momentum, σ - is the cross section of the process, where quark - spectator (or product of its hadronization) avoids secondary interaction [1]. Assume, that quark hadronization is "soft" and momentum distribution of registered hadron coincides with spectator quarks' one. In this case the quantity C , which characterizes the quark fragmentation, can be considered as a constant, and the parameter α is equal to $\alpha = (E - p \cos\theta)/m$ and $p_\perp = p \sin\theta$, where E , p and θ - are the energy, momentum and angle of registered hadron in the laboratory frame, m - is the mass of nucleon.

The most of the experimental data on the cumulative particle production by hadrons were analyzed to obtain the parameters of the α -distribution of $G(\alpha, p_\perp)$ function. In [2] a compilation of existing data is presented, which shows that $G(\alpha, p_\perp)$ function depends on α exponentially:

$$G_N(\alpha, p_\perp) \Big|_{p = \text{const}} \sim e^{-\alpha/\alpha_0} \quad (3)$$

with average value of parameter $\alpha_0 = 0.14$. This is in good agreement with α_0 , obtained from the μ -meson deep inelastic

scattering on ^{12}C at $K_{\mu} = 200 \text{ GeV}$ and $Q_{\mu}^2 > 5 (\text{GeV}/c)^2$ [3].

The dependence of nuclear structure functions on transverse momentum in hadroproduction of cumulative particles were studied in [4,5,6]. It was shown, that invariant cross section of cumulative π -meson production $f_{\pi}(x, P_{\perp})$, and therefore structure function $G_{\pi}(x, P_{\perp})$, is factorized into the two functions depending of x and P_{\perp} . In [6] such a factorization was not obtained for the cumulative protons.

Nuclear structure function in the cumulative particle photoproduction was investigated in [7,8,9] for the secondary protons only. It has been shown that: i) structure functions, as a function of α at constant P_{\perp} , can be fitted by the exponents (3) with $\alpha_0 = 0.135 \pm 0.015$, that is in good agreement with α_0 in the hadroproduction, and ii) the invariant cross section can be factorized, $f_p(\alpha, P_{\perp}) = f_{1p}(\alpha) f_{2p}(P_{\perp})$, with the accuracy approximately 40%. In addition, it had been shown [8], that there is an enhancement of high momentum part in α -distribution for heavy nuclei, that was well described in multiquark bag model [9].

The data on cumulative π -meson photoproduction [10,11] have not been used to obtain nuclear structure functions. Meanwhile, such an analysis is desirable, since in contrast to that of the cumulative protons, in this case the contribution of the final state interaction is sufficiently smaller (there are no preexisting π -mesons in nucleus).

In this work the experimental results on π -meson photoproduction at ^{12}C nucleus [10, 11] are analyzed to obtain information on the nuclear structure function.

2. EXPERIMENTAL RESULTS

Reaction (1) for inclusive π -meson production on ^{12}C was investigated at $E_{\gamma}^{\text{max}} = 4.5 \text{ GeV}$ bremsstrahlung photon beam of Yerevan synchrotron with the "Deuteron" set-up [12]. The secondary π -meson spectra were measured in the kinetic energy range $T_{\pi} = 0.2 \div 1.2 \text{ GeV}$ at the registration angles $\theta_{\pi} = 20^{\circ} \div 120^{\circ}$. In Fig. 1

the obtained two-dimensional (T_{π}, θ_{π}) distribution is shown. To obtain the corresponding (α, P_{\perp}) distribution (where $\alpha = \alpha(T_{\pi}, \theta_{\pi})$ and $P_{\perp} = P_{\perp}(T_{\pi}, \theta_{\pi})$), the full surface in (T_{π}, θ_{π}) phase space is used (Fig.1), that agrees with the experimental data in the most perfect way (the method of minimal squares was used). Existence of such a surface allowed to find out the points in the (α, P_{\perp}) space which had no analogues in the measured points. We assume that there are no peculiarities in the interpolated regions of that surface, i.e. the surface is smooth. The presentation of data not in the form of separate T_{π} dependences at the constant values θ_{π} and v.v. has one more advantage: the error bars in determination of cross section at the (α, P_{\perp}) points are less than the statistical errors at the measured points, because for every (α, P_{\perp}) point the number of the used points, which are measured in experiment, is higher.

In Fig. 2 the P_{\perp} dependences of photopion invariant yields at the fixed α values are shown. For a factorized invariant yield $f(\alpha, P_{\perp})$ the parallel P_{\perp} -dependences are expected. The degree of non-parallelity of curves in Fig.2 is well illustrated in Fig.3, where the P_{\perp} -dependences of the ratio $f_{\pi}(\alpha, P_{\perp})/f_{\pi}(\alpha, 0)$ are shown. The $f_{\pi}(\alpha, 0)$ functions were obtained by extrapolation of the curves in Fig. 2 into the point $P_{\perp} = 0$.

For the quantitative estimations of the parallelity of P_{\perp}^2 dependences, i.e. of factorization of $f_{\pi}(\alpha, P_{\perp})$, usually they are described by the exponential functions

$$f_{\pi}(\alpha, P_{\perp})|_{\alpha=\alpha_1} \sim \exp(-P_{\perp}^2/P_{0_1}^2) \quad (4)$$

In practice, the P_{\perp} dependences of $f_{\pi}(\alpha, P_{\perp})$ in the whole range of P_{\perp} variation can be described not by one, but by several exponents, each of which is valid in the different parts of P_{\perp} variation range. Due to this, the experimental data in Fig. 2 were fitted according (4) in two ways: using one exponent for the whole range of P_{\perp} variation and by two exponents in two equal subranges of P_{\perp} . In Fig.4 the dependences of the parameters $\langle P_{\perp}^2 \rangle \equiv P_{0_1}^2$ as a function of α for all the three cases are shown (the dependence marked by 2 corresponds to the fit by the one exponent). As one can see, the $\langle P_{\perp}^2 \rangle$ increases (though rather slightly) with α in all three cases. The same rise is observed for

the cumulative photoprotons that is illustrated in Fig.5, where the dependences of $\langle p_{\perp}^2 \rangle$ on $\alpha-B$ for protons (\square, \blacksquare) and π -mesons (Δ, \blacktriangle) are presented. The use of $\alpha-B$, where B is a baryonic number of cumulative particle instead of α , is explained in [4] by the existence of preexisting baryon (proton) in nuclei. The data in Fig.5 show that $\langle p_{\perp}^2 \rangle$ i) are similar for protons and π -mesons, and ii) varies only almost 35% (in interval of $\langle p_{\perp}^2 \rangle \cong 0.25 \div 0.35$ GeV/c) at changing of α from 1 to 2,5.

The dependence of photopion's invariant cross sections on α at fixed P_{\perp} may be fitted also by the exponent $e^{-\alpha/\alpha_0}$. These dependences are shown in Fig.6. If parameter α_0 is varied with P_{\perp} , one can state about violation of factorization of the function $f_{\pi}(\alpha, P_{\perp})$. The P_{\perp} -dependence of parameter α_0 , obtained at the range of $\alpha-B=0.8+2.5$ is presented in Fig.7. A relatively small (about 35+40%) rise is evident for both α_0^{π} and α_0^p in the $P_{\perp}=0+1.2$ GeV/c interval. The presented results essentially differ from those obtained in hadroproduction [6]. This is clearly illustrated in Fig.5, where, alongside with the photoproduction data, the $\langle p_{\perp}^2 \rangle$ dependences for cumulative π -mesons and protons produced by primary protons with momentum 10 GeV/c, are displayed. These data were extracted from [6]. In the hadroproduction case $\langle p_{\perp}^2 \rangle$ changes by several times (compare with 30%-40% in the case of photoproduction). It should be pointed out, that this difference will increase, if instead of α the Stavinsky variable X_C (as in [6]) will be used, because $X_C > \alpha$.

3. THE DATA DISCUSSION

The problem of nuclear structure function dependence on P_{\perp} in cumulative particle production was theoretically studied in [13,14].

In [13] the problem of cumulative particle production on the internuclear multiquark configurations was discussed. Contributions of spectator mechanism, direct knockout and final state rescattering of primaries of cumulative particles were discussed. For the invariant yield of cumulative particle the

expression

$$f(\alpha, P_{\perp}) = \frac{N \alpha^2 a^4}{(\alpha a_n + a)^4} e^{-a\alpha} (\beta \exp(-aP_{\perp}^2/\alpha m_0^2) + \alpha \exp(-bP_{\perp})) \quad (5)$$

was obtained, where parameter β determines the contribution of spectator mechanism, while $a/\alpha m_0^2$ is the slope parameter of P_{\perp}^2 -distribution for the spectator mechanism, b is the same for direct and secondary processes; m_0 is the mass of nucleon in case of cumulative protons, and some characteristic mass in case of pions (which does not coincide certainly with the pion mass).

At $P_{\perp}=0$ expression (5) becomes to the almost exponential α dependence:

$$f(\alpha, P_{\perp}=0) \sim \exp(-a \alpha) \quad (6)$$

Using (6) the value of a can be obtained. For the π -meson and proton photoproduction (see Fig.7) $\alpha_0^{\pi} = 0.125 \pm 0.005$ and $\alpha_0^p = 0.11 \pm 0.005$, consequently $a_{\pi} = 1/\alpha_0^{\pi} = 8 \pm 0.3$ and $a_p = 1/\alpha_0^p = 9.1 \pm 0.4$. For the hadroproduction the value $a=7$ was found in [13].

The mechanism of cumulative particle production, based on the colour interactions of incident particles with the multiquark internuclear configurations, was discussed in [14]. The existence of cumulative particle transverse momentum is completely determined by the quark transverse momentum in multiquark clusters. The linear dependence of $\langle p_{\perp}^2 \rangle$ on α is expected with a twice higher slope for cumulative π -mesons, than for protons. In [14] the comparison of theoretical result with experimental one [6] shows quite satisfactory agreement.

The α -dependence of $\langle p_{\perp}^2 \rangle$, obtained from our experimental data of photoproduction of cumulative protons and π -mesons (Fig.5), show that these dependences also are almost linear, but much more weak than predicted in [13,14] and measured in [6]. Moreover, dependences on α - B for protons and π -mesons practically are the same.

In the framework of theoretical approaches discussed in [13] and [14] these differences can be explained by the different influences of different mechanisms in the two types of interactions. It can be proposed that these differences between

photo- and hadroproduction are connected with limitation in phase space due to the small average energy of bremsstrahlung photon beam. However, the full experimental data, obtained up to now, indicate that main regulation of cumulative particle production is invariant with respect to the type and energy of primary particles. In particular, the slopes T_0 of kinetic energy spectra do not depend on primary energies at $E_0 \geq 0.6$ GeV [15+19].

Apparently, the experimental dependence $\langle p_{\perp}^2 \rangle$ on α in the photoproduction of cumulative particle requires the improvement of theoretical approaches.

In conclusion the authors would like to express their gratitude to the colleagues at Photonuclear Laboratory of Yerevan Physics Institute for the assistance in measurements and data handling as well as for the useful discussions.

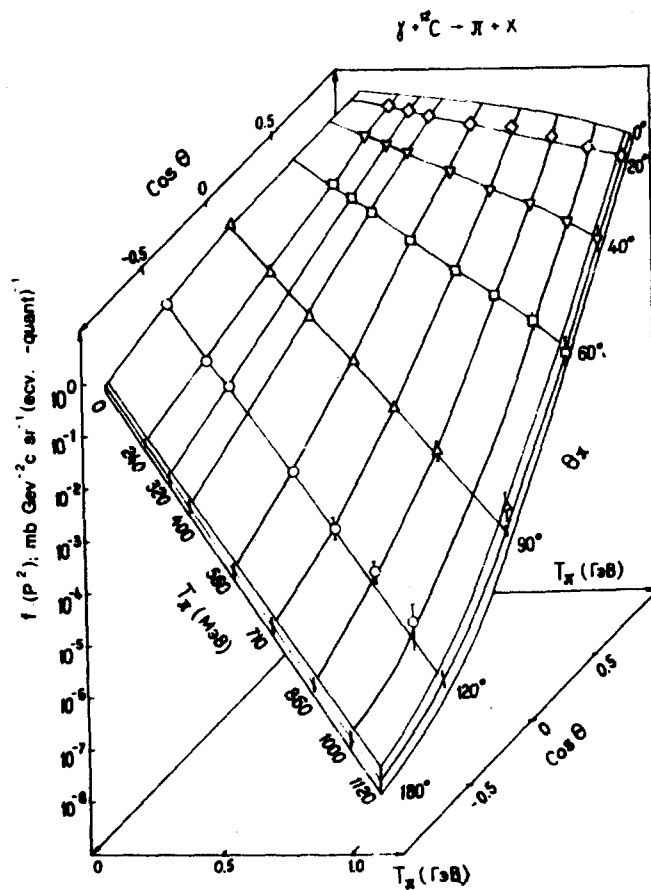
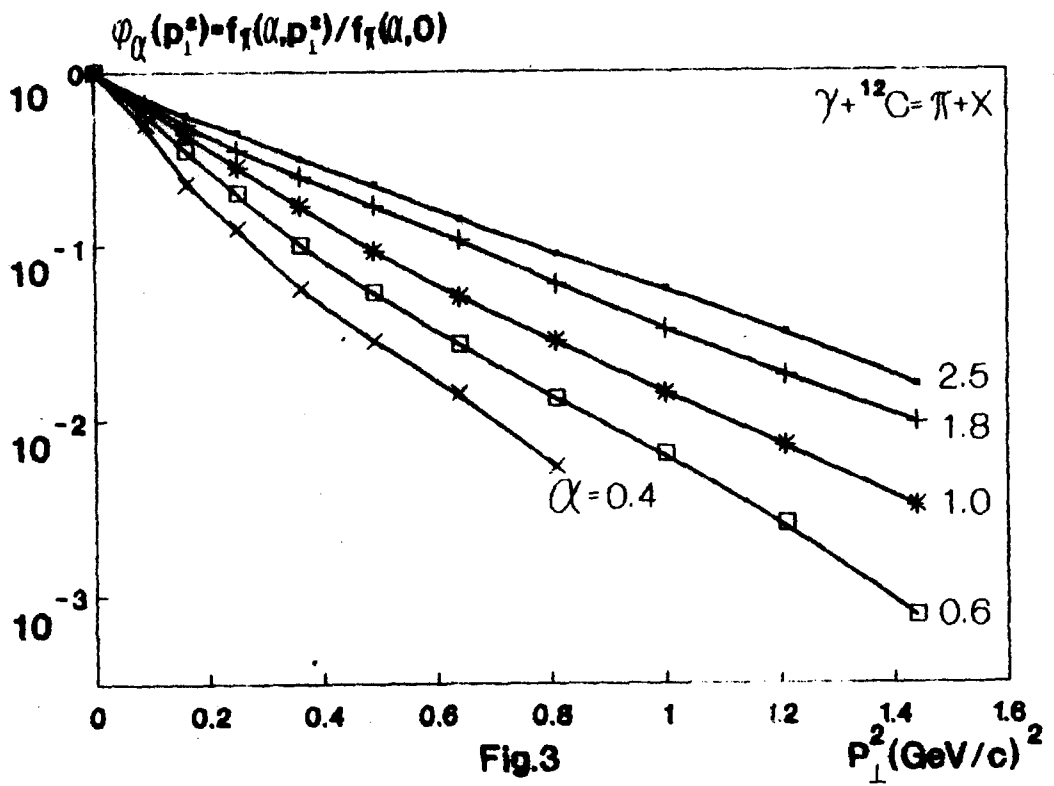
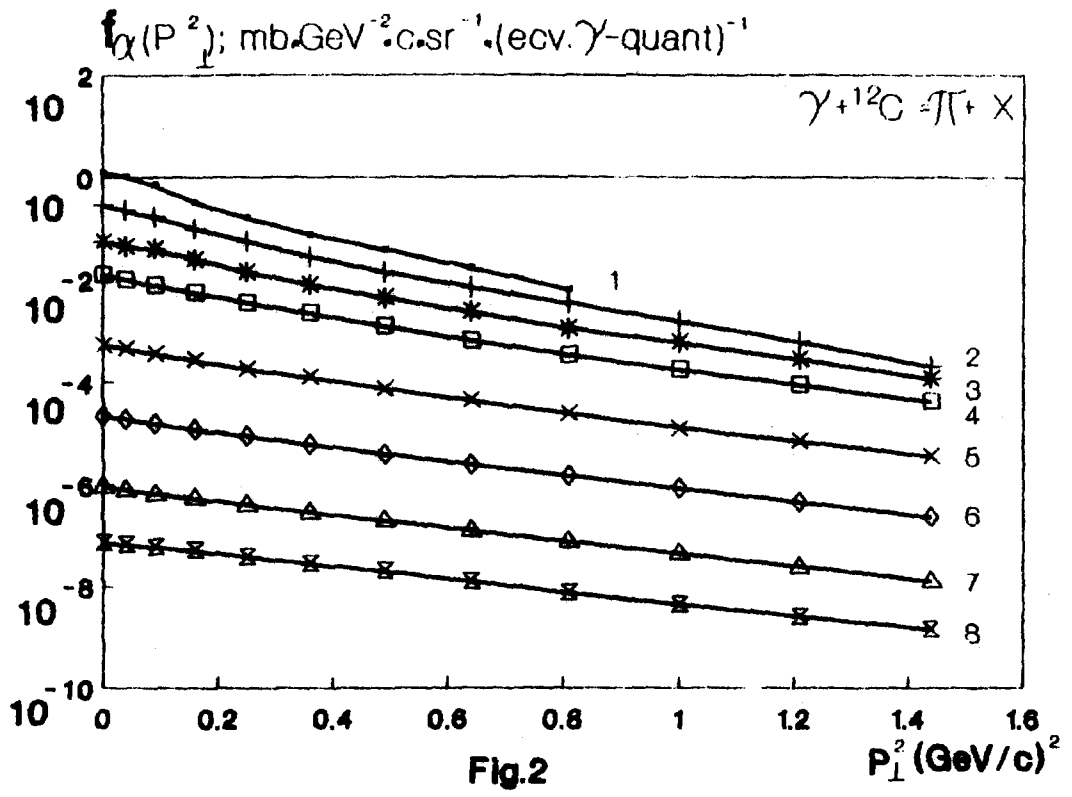
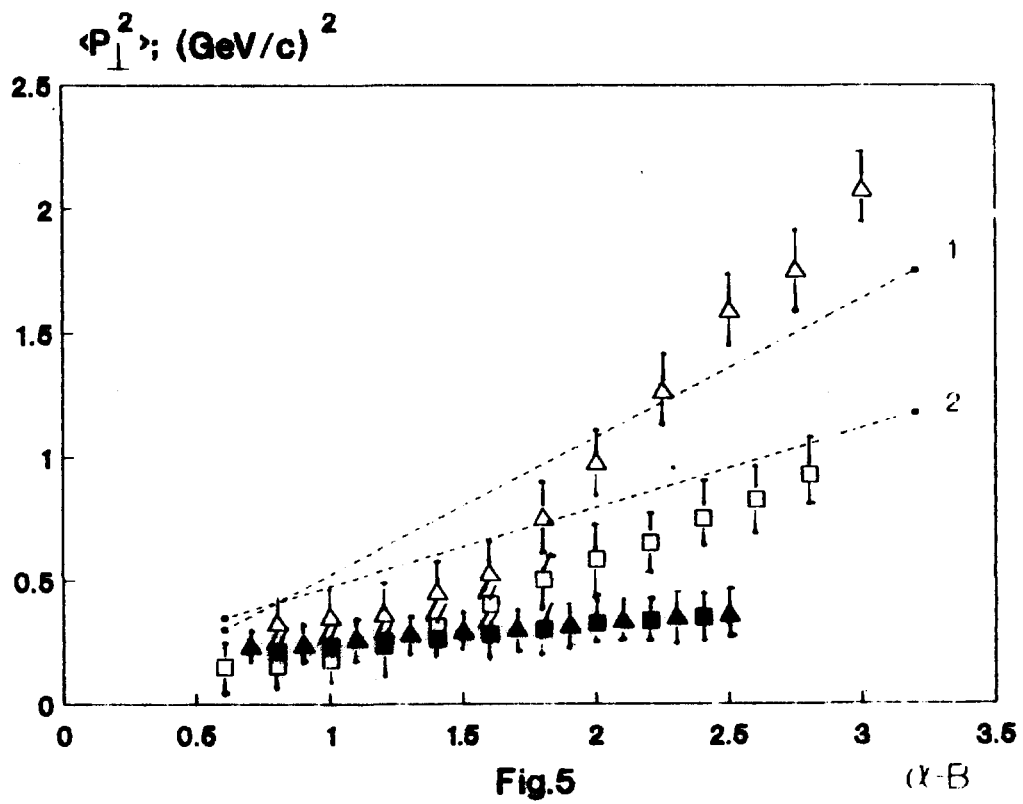
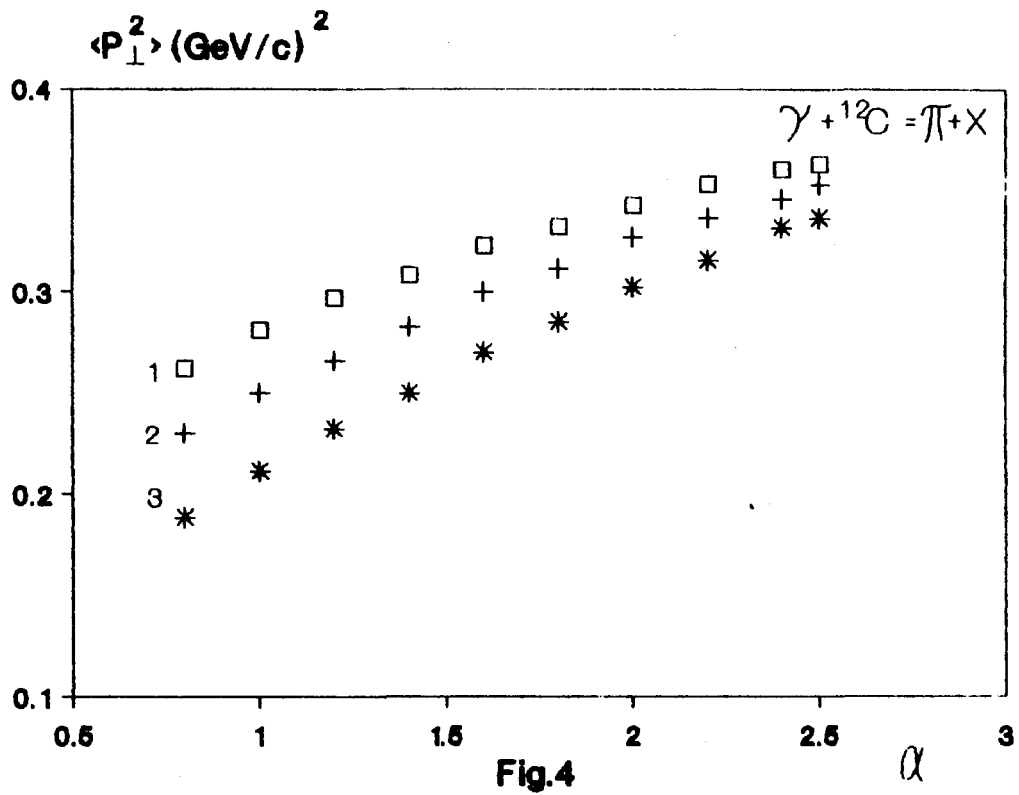


Fig. 1





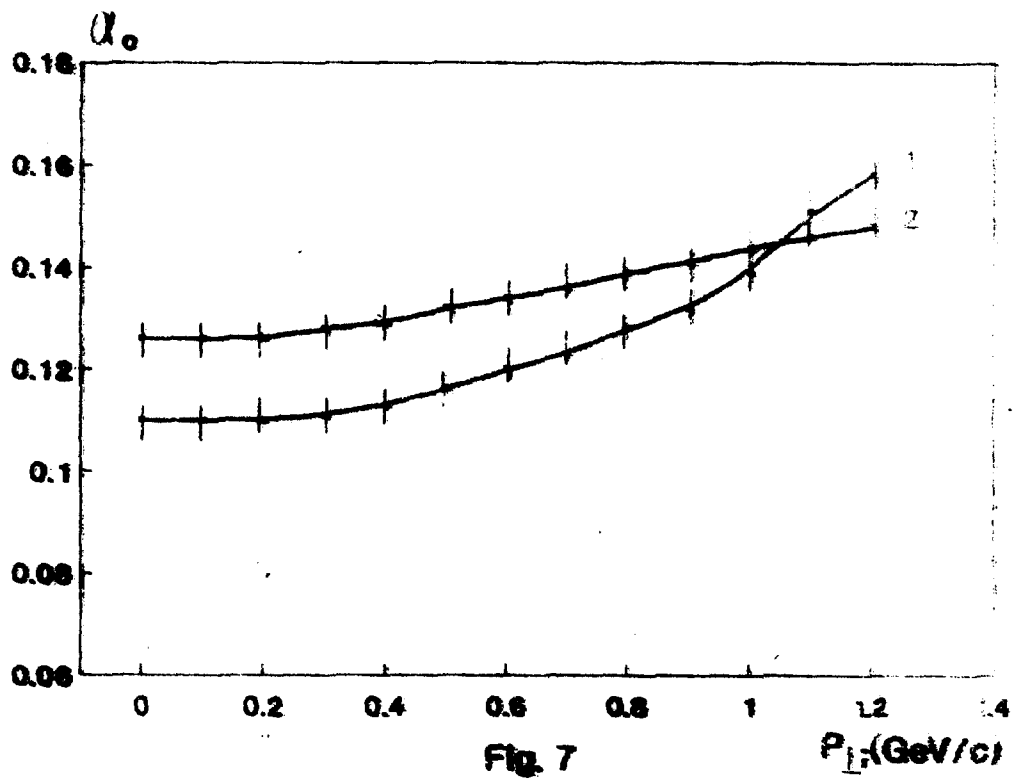
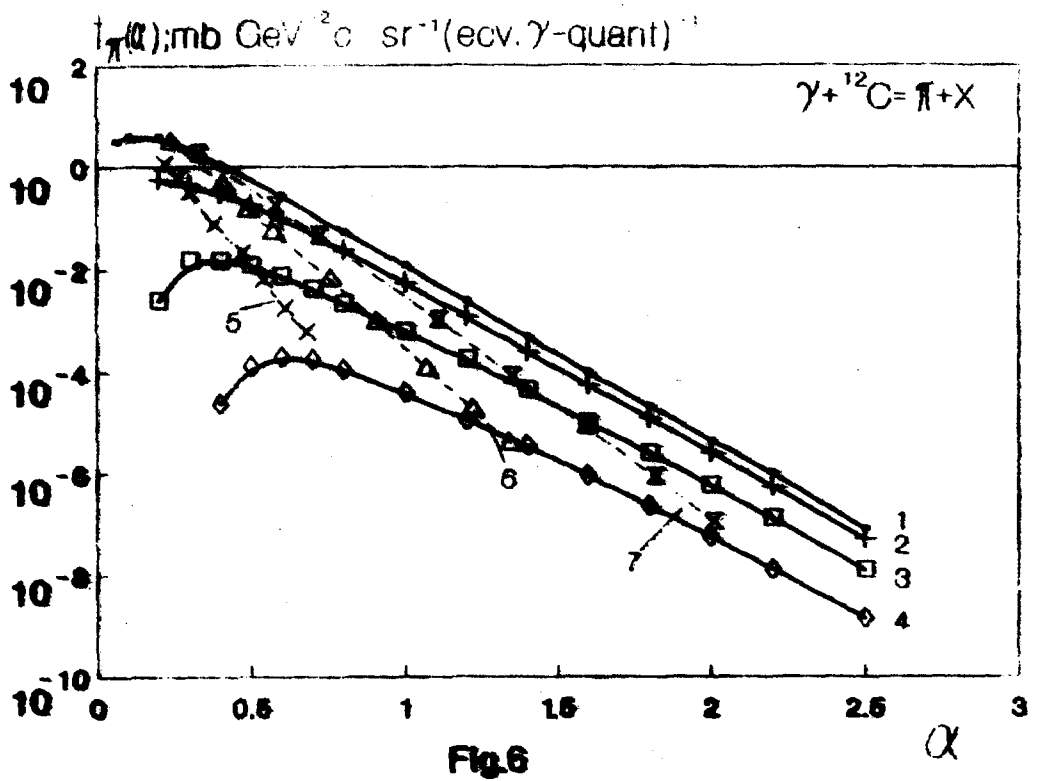


FIGURE CAPTIONS

FIG.1. Two-dimensional distributions of invariant yield $f_{\pi}(T_{\pi}, \theta_{\pi})$ of photopions. The surface was constructed through the experimental points using the method of minimal squares by the power polynome on the variables T_{π} and θ_{π} . The error bars of experimental points are statistical.

FIG.2. P_{\perp}^2 dependences of photopion invariant yields at the fixed values of α . 1- $\alpha=0.4$; 2- 0.6; 3- 0.8; 4- 1.0; 5- 1.4; 6- 1.8; 7- 2.2; 8- 2.5. The calculation error bars are shown.

FIG.3. P_{\perp}^2 dependence of ratio $\varphi_{\alpha}(P_{\perp}^2) = f_{\pi}(\alpha, P_{\perp}) / f_{\pi}(\alpha, 0)$ for the fixed α . The values $f_{\pi}(\alpha, 0)$ were obtained by extrapolation of the curves in Fig. 2 into the points $P_{\perp} = 0$.

FIG.4. Dependence of parameter $\langle P_{\perp}^2 \rangle$ on α (see (4)). The lower (3) and upper (1) dependences correspond the regions $P_{\perp}=0+0.6$ and $P_{\perp}=0.6+1.2$, respectively, the middle one corresponds to the whole region of $P_{\perp}=0+1.2$.

FIG. 5. Dependence of parameter $\langle P_{\perp}^2 \rangle$ (for protons - (\square, \blacksquare) and for π -mesons - (Δ, \blacktriangle)) on $\alpha-B$, where B is a baryonic number. For π -mesons $B_{\pi}=0$, while for protons $B_p=1$. The light symbols correspond to the primary protons [6], the dark ones are the results of this work. Shaded lines (1- for pions and 2- protons) corresponds to the framework of [14].

FIG.6. α dependence of invariant yield $f_{\pi}(\alpha, P_{\perp})$ for the fixed values of P_{\perp} and/or θ : (1 - $P_{\perp}=0.$, 2 - $P_{\perp}=0.4$, 3 - $P_{\perp}=0.8$, 4 - $P_{\perp}=1.2$, 5 - $\theta_{\pi}=60^{\circ}$, 6 - $\theta_{\pi}=90^{\circ}$, 7 - $\theta_{\pi}=120^{\circ}$). The lines are drawn through the points using the method of minimal squares.

FIG. 7. P_{\perp} dependence of parameter α_0 for protons (1) and π -mesons (2).

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СТРУКТУРНАЯ ФУНКЦИЯ ЯДРА УГЛЕРОДА В ПРОЦЕССЕ ФОТОРОЖДЕНИЯ
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