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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ
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# NONDIFFRACTION PHOTOPRODUCTION OF VECTOR MESONS AND THE PHOTON STRUCTURE FUNCTION

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# ՎԵԿՏՈՐԱԿԱՆ ՄԵԶՈՆՆԵՐԻ ՈՉ ԴԻՖՐԱԿՑԻՈՆ ՖՈՏՈԾՆՈՒՄԸ ԵՎ ՖՈՏՈՆԻ ԿԱՌՈՒՑՎԱԾՔԱՅԻՆ ՖՈՒՆԿՑԻԱՆ

Հադրոնների առաջացման վերամիավորման մոդելի շրջանակներում ստացված է նրանց ոչ դիֆրակցիոն ֆոտոծնման ինկլյուզիվ սպեկտրների համաձայնեցված նկարագրությունը մեծ էներգիայով ֆոտոնների բեկորացման տիրույթում։ Գնահատված են ֆոտոնի հադրոնային բաղադրիչում պարտոնների բաշխման պարամետրները և կատարված է համեմատություն $\gamma\gamma$-փոխազդեցություններում ստացված փոքր $Q^2$-ով ֆոտոնի կառուցվածքային ֆունկցիայի հետ։

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Երևան 1988

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Р.Г.БАДАЛЯН, Г.Р.ГУЛКАНЯН

# НЕДИФРАКЦИОННОЕ ФОТОРОЖДЕНИЕ ВЕКТОРНЫХ МЕЗОНОВ И СТРУКТУРНАЯ ФУНКЦИЯ ФОТОНА

В рамках рекомбинационной модели образования адронов получено самосогласованное описание имеющихся данных по инклюзивным спектрам недифракционного фоторождения векторных мезонов в области фрагментации фотона при высоких энергиях. Получены оценки для параметров распределения партонов в адронном компоненте фотона и проведено сравнение его структурной функции с измерениями структурной функции фотона в $\gamma\gamma$ - взаимодействиях при малых $Q^2$.

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R.G. BADALYAN, H.R. GULKANYAN

# NONDIFFRACTION PHOTOPRODUCTION OF VECTOR MESONS AND THE PHOTON STRUCTURE FUNCTION

In the framework of the recombination model of hadron production a self-consistent description of the available data on the inclusive spectra of the nondiffraction photoproduction of vector mesons in the fragmentation region of photons at high energies is obtained. The parameters of parton distribution in the hadron component of a photon are estimated and its structure function is compared with the measurements of the photon structure function in $\gamma\gamma$ - interactions at low $Q^2$ .

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It has long been known that high-energy photons at interactions with matter reveal hadron-like properties (see, e.g., [1] ). But the direct measurements of the structure function of the hadron component of photon (HCP) were carried out quite recently by studying the $\gamma\gamma$-interactions in non-annihilation reactions $e^+e^- \rightarrow X\, e^+e^-$ at high energies ($\sqrt{s}=29$ GeV) [2,3] .

It has been shown that one may obtain a reliable information about the structure function of the HCP at $x \leqslant 0.3$ in the region of low $Q^2$ ($0.3 < Q^2 < 1.6$ GeV$^2$). At large values of $x$ and $Q^2$ the main contribution (increasing with $x$ and $Q^2$) into the experimentally observed structure function of photon makes the so-called point-like interaction, that is why the direct measurement of the structure function of the HCP is practically limited by the region of $x < 0.4$ .

In photon-photon interaction it is practically impossible to obtain information also about the distribution functions of the strange quarks, as their contribution to the photon structure function is much less than that of nonstrange quarks. Thus, to obtain fuller information about the properties of the HCP, one must also use other (though less direct) methods for their study.

In this paper we tried to extract information of that kind from the nondiffraction photoproduction of vector mesons at high energies. With that aim we used the earlier proposed recombination-type models (see, e.g., [4] ), where a relation is established between the structure functions of incident particles and the inclusive spectra of secondary hadrons with small transverse momenta in the fragmentation region of incident particles. A high-energy photon, before its interaction with the target, comes to a hadron-like state containing a pair of "valence" quarks $(u\bar{u})$, $(d\bar{d})$ or $(s\bar{s})$ (in this paper the processes with heavier quarks are not considered) and sea parton, quark-antiquark pairs and gluons. According to the gluon-dominance hypothesis (see, e.g., [5]) the interaction of the HCP with the target, as in case of hadron interactions at high energies, takes place by means of the soft gluon exchange, and the primary particles valence and sea quarks distributions are not essentially changed. The nondiffraction production of mesons in the fragmentation region of incident particles takes place as a result of its valence quark's (antiquark's) recombination with the sea antiquark (quark) or as a result of recombination of the sea quark and antiquark of corresponding flavours. The invariant inclusive spectrum $f_V(x) = \frac{1}{\pi}\int \frac{E}{P_{max}} \times (d^2\sigma/dx\,dP_T^2)\,dP_T^2$ of the final meson V over the Feynman variable x has the form:

$$f_V(x) = \frac{\sigma_{\gamma N}}{\pi}\left(\frac{5}{9} + \frac{1}{9}\frac{\sigma_{(s\bar{s})N}}{\sigma_{(u\bar{u})N}}\right)^{-1}\left\{\frac{4}{9}f_V^{(u\bar{u})}(x) + \frac{1}{9}f_V^{(d\bar{d})}(x) + \frac{1}{9}\frac{\sigma_{(s\bar{s})N}}{\sigma_{(u\bar{u})N}}f_V^{(s\bar{s})}(x)\right\}, \quad (1)$$

where for the function $f_V^{(q\bar{q})}(x) \simeq \left(x/\sigma_{(q\bar{q})N}\right) d\sigma/dx\,(q\bar{q} \to V)$ we have

$$f_V^{(q\bar{q})}(x) = \int \Phi_V^{(q\bar{q})}(x_1,x_2)\, R_V\left(\frac{x_1}{x}, \frac{x_2}{x}\right) \delta\left(1 - \frac{x_1}{x} - \frac{x_2}{x}\right) dx_1 dx_2 . \quad (2)$$

In (1) the coefficients before $f_V^{(q\bar{q})}(x)$ are proportional to the square of the charge of the corresponding "valence" quark q . The factor $\sigma_{(s\bar{s})N} / \sigma_{(u\bar{u})N}$ takes into account the difference in the cross sections of interactions of the photon's nonstrange and strange components with the target-nucleon: $\sigma_{(s\bar{s})N} / \sigma_{(u\bar{u})N} \approx \sigma^{in}_{KN} / \sigma^{in}_{\pi N} = 0.6$ [6] . For the nondiffraction photon-nucleon cross section we have [7-9] $\sigma_{\gamma N} = 90\,\mu b$ . The functions $\Phi_V^{(q\bar{q})}(x_1,x_2)$ in (2) characterize the probability for finding in the HCP with a "valence" composition ($q\,\bar{q}$) a quark ($q_1$) and an antiquark ($\bar{q}_2$) with longitudinal momenta $x_1$ and $x_2$ ($x=x_1+x_2$), which correspond to the valence composition of the meson $V=(q_1\,\bar{q}_2)$. It is assumed, that in nondiffraction processes the final meson can contain no more than one valence quark of the HCP. One can use the Kuti-Weisskopf model [10] to parametrize the function $\Phi_V^{(q\bar{q})}(x_1,x_2)$. In accordance with such parametrization, in particular, the single-parton distribution functions of valence quarks $q_v(x)$ ($u_v(x)=\bar{u}_v(x)=d_v(x)=\bar{d}_v(x)$, $s_v(x)=\bar{s}_v(x)$ ) and sea partons $q_s(x)$ ($u_s(x)=\bar{u}_s(x)=d_s(x)=\bar{d}_s(x)$, $s_s(x)=\bar{s}_s(x)$ $G(x)$ ) in the HCP have the following form (also see [11] ):

for the nonstrange ($u\,\bar{u}$) or ($d\,\bar{d}$) component of photon

$$u_v(x) = x^{-1+\beta_N}(1-x)^{-1+\beta_N+\gamma_N} / B(\beta_N, \beta_N+\gamma_N) , \quad (3a)$$

$$u_s^N(x) = g_N x^{-1}(1-x)^{-1+2\beta_N+\gamma_N} , \quad (3b)$$

$$S_s^N(x) = \lambda U_s^N(x) \ , \tag{3c}$$

$$G^N(x) = (g_N^G/g_N)\, U_s^N(x) \tag{3d}$$

for the strange ($s\,\bar{s}$) component of photon

$$S_v(x) = x^{-1+\beta_s}(1-x)^{-1+\beta_s+\gamma_s}/B(\beta_s, \beta_s+\gamma_s) \ , \tag{4a}$$

$$U_s^s(x) = g_s x^{-1}(1-x)^{-1+2\beta_s+\gamma_s} \ , \tag{4b}$$

$$S_s^s(x) = \lambda U_s^s(x) \ , \tag{4c}$$

$$G^s(x) = (g_s^G/g_s)\, U_s^s(x) \ , \tag{4d}$$

where $\gamma_N = g_N(4+2\lambda) + g_N^G$ , $\gamma_s = g_s(4+2\lambda) + g_s^G$ ; $g_N$ and $g_N^G$ correspondingly characterize the normalization of the nonstrange quark-antiquark and gluon sea in the photon nonstrange component, $g_S$ and $g_S^G$ - in the strange component; $\lambda$ is the strange quark-antiquark sea suppression factor. It is assumed to be the same for the nonstrange and strange components of photon. To make the analysis simpler, an identical relative normalization of the gluon sea too will be assumed below: $g_N^G/g_N = g_S^G/g_S$ (in the general case $\gamma_N \neq \gamma_s$ ). The functions $\phi_V^{(q\bar{q})}(x_1, x_2)$ are completely expressed via the parameters in (3) and (4) (see, e.g., [11,12] ).

The function $R_V(z_1, z_2)$ in (2) is proportional to the probability of recombination of the quark $q_1$ and antiquark

$\bar{q}_2$ which correspondingly carry $z_1$ and $z_2$ portions of their total longitudinal momentum into the final meson V. It can be expressed via the two-valon distribution function $G_V(z_1,z_2)$ of the meson V [13] :

$$R_V(z_1,z_2) = A_V z_1 z_2 G_V(z_1,z_2), \qquad (5)$$

where $A_V$ is a factor independent of the kinematic variables and common for the lowest nonet of vector mesons. The expressions for $G_V(z_1,z_2)$ for different vector mesons are presented in the Appendix (see also [11,12] ).

The functions $f_V^{(q\bar{q})}(x)$ in (1) are completely determined by the parameters of single-parton distributions (2), (3) and by those of the recombination function (5); their expressions for different processes $\gamma p \to VX$ are presented in the Appendix.

On the basis of eq.(1) the now available experimental data [8,9] on the nondiffraction photoproduction of vector mesons $(\rho^0/\omega)$ , $\rho^{\pm}$ , $\varphi$ , $K^0(890)$, $\bar{K}^0(890)$ at high energies (20 to 70 GeV) in the beam fragmentation region $x > 0.1$ are analyzed. The contribution of tensor meson decays $K(1430) \to K(890)\pi$ was taken into account in the spectra of $K^0(890)$ and $\bar{K}^0(890)$, the data on photoproduction of which were taken from [9]. The tensor to vector meson suppression factor $A_T/A_V$ was determined from the comparison with experiment.

The fitting was done over six parameters $\gamma_N$, $g_N$, $\gamma_S$, $\lambda$ , $(A_T/A_V)$, $A_V$ . The parameters $\beta_N$ and $\beta_S$ which characterize the valence quark structure functions behaviour at $x \simeq 0$, were fixed using their connection with the intercept of the corresponding leading Regge trajectory: $\beta_N = 1-\alpha_\rho(0)=0.5$, $\beta_s = 1-\alpha_\varphi(0) = 0.9$.

As a result of fitting two solutions were obtained which satisfactorily describe the experimental data on the inclusive spectra of the vector mesons nondiffraction photoproduction (Fig.1). The fitted parameters are presented in the Table.

Table

| | $\gamma_N$ | $g_N$ | $\gamma_s$ | $\lambda$ | $A_T/A_V$ | $A_V$ | $\chi^2/NDF$ |
|---|---|---|---|---|---|---|---|
| 1 | 1.35± 0.12 | 0.19± 0.10 | 0.10± 0.10 | 0.47± 0.05 | 0.41± 0.07 | 1.7± 0.2 | 1.0 |
| 2 | 1.24± 0.14 | 0.21± 0.12 | 2.7± 0.3 | 0.20± 0.02 | 0.38± 0.07 | 1.5± 0.3 | 1.2 |

As the Table shows, both of the solutions give similar results for the tensor meson suppression factor ($A_T/A_V$) as well as for the parameters of the valence and nonstrange sea quarks distribution in the nonstrange component of photon. The distribution of valence quarks (see eq.(3) ) and the portion of momentum ( ~ 44%) carried by them do not contradict within errors the results of the pion structure function measurements in Drell-Yan processes [14] .

The two solutions strongly differ from each other by the strange sea suppression factor $\lambda$ and especially by the parameter $\gamma_s$ characterizing the structure functions of the ($s\bar{s}$) component of photon (see eq.(4) ). According to the first solution the strange quarks have a flattened distribution over $x$, $S_v(x) \sim x^{-0,1}$ , and carry away about 95% of momentum of the strange component of photon. According to the second solution the distribution is a rather steeply falling one, $S_v(x) \sim x^{-0,1}(1-x)^{2.6}$ and the strange valence quarks carry away about 40% of the momentum.

Using the parameters given in the Table one can calculate the structure function $F_2(x)$ of the hadron component of photon

$$F_2(x) = \frac{2\pi\alpha}{\gamma_\rho^2}\left[\frac{4}{9}F_u(x) + \frac{1}{9}F_d(x) + \frac{1}{9}F_s(x)\right], \qquad (6)$$

where

$$F_u(x) = \frac{8}{9}xu_v(x) + \frac{2}{9}(5+\lambda)xu_s^N(x),$$

$$F_d(x) = \frac{2}{9}xu_v(x) + \frac{2}{9}(5+\lambda)xu_3^N(x),$$

$$F_s(x) = \frac{2}{9}xS_v(x) + \frac{2}{9}(5+\lambda)xu_s^S(x).$$

Here $2\pi\alpha e_q^2/\gamma_\rho^2$ is the constant of transition of a photon into a quark-antiquark pair ($q\bar{q}$) with charge $e_q$, $\pi\alpha/\gamma_\rho^2 = (2.85 \pm 0.3)10^{-3}$ (see, e.g., [15] ).

The comparison of (6) with the direct measurements of $F_2^\gamma(x,Q^2)$ in $\gamma\gamma$- interactions at low $Q^2 (0.3 < Q^2 < 1.6$ GeV$^2$) is shown in Fig.2 . It is seen that the solution 1 satisfactorily agrees (both in the absolute and x-dependence) with the measurements of $F_2^\gamma(x,Q^2)$, while the agreement of the solution 2 is an unsatisfactory one. It seems that with appearance of new and more accurate data on the nondiffraction photoproduction of vector mesons at high energies one can extract more reliable data on the strange valence quarks distribution in the HCP.

The main conclusions in the present work can be formulated in the following manner. i) Within the framework of the hadron production recombination model a self-consistent description of the available data on the inclusive spectra of the nondiffraction photoproduction of vector mesons at high energies is obtained. ii) The parameters of hadron distribution in the HCP are estimated. The nonstrange valence quark distribution coincides, within errors, with the analogous distribution in a pion. In the nonstrange ($u\bar{u}$, $d\bar{d}$) component of photon the valence quarks carry (44±3)% of the photon momentum, the quark-antiquark sea - (40±8)%, gluons - (16±6)%. In the strange ($s\bar{s}$) component of photon the valence quarks carry about 95% of the photon momentum (solution 1). It should be noted that the "standard" Kuti-Weisskopf parametrization [10] used in this paper imposes certain restrictions on the structure functions of sea partons (3b - 3d) and (4b - 4d): their x-dependence is determined by the parameters of the valence quark structure functions (3a) and (4a), respectively. Since the photoproduction spectra are much more sensitive to the valence quark distributions than to those of sea quarks, the latters are determined with less trustworthiness from the experimental data. A more correct parametrization, suggesting a new additional parameter for the description of the sea quarks structure functions, can be used when analyzing more accurate data on the nondiffraction photoproduction of vector mesons at high energies.

iii) The photon structure function $F_2(x)$ extracted from the processes of the nondiffraction photoproduction of vector mesons agrees (solution 1) to the measured value of $F_2^{\gamma}(x,Q^2)$ in $\gamma\gamma$- interaction within the scaling range $0.3 < Q^2 < 1.6$ GeV$^2$.

## Appendix

The two-valon distribution functions of vector mesons $G_V(z_1,z_2)$ are expressed by [11,12]

$$G_{\rho,\omega}(z_1,z_2)=z_1^{\eta_N} z_2^{\eta_N}/B(\eta_N+1,\ \eta_N+1), \qquad \text{(App.1a)}$$

$$G_{\varphi}(z_1,z_2)=z_1^{\eta_s} z_2^{\eta_s}/B(\eta_s+1,\ \eta_s+1), \qquad \text{(App.1b)}$$

$$G_{K^*}(z_1,z_2)=z_1^{\eta_N} z_2^{\eta_s}/B(\eta_N+1,\eta_s+1), \qquad \text{(App.1c)}$$

where $\eta_N=-1+\gamma_N/2+\beta_N$ , $\eta_s=-1+\gamma_s/2+\beta_s$ ; it should be noted that the inclusive spectra are not practically sensitive to these parameters.

The functions $f_V^{(q\bar{q})}(x)$ in (1) have the form:

$$f_{\rho^0}^{(u\bar{u})}(x)=A_V\left(g_N C_N^{\rho} V_N(x)+g_N^2 S_N(x)\right), \qquad \text{(App.2a)}$$

$$f_{\rho^0}^{(s\bar{s})}(x)=A_V g_s^2 S_s(x) , \qquad \text{(App.2b)}$$

$$f_{\varphi}^{(u\bar{u})}(x)=A_V \lambda^2 g_N^2 S_N(x), \qquad \text{(App.2c)}$$

$$f_{\varphi}^{(s\bar{s})}(x)=A_V\left(2\lambda g_s C_s^{\varphi} V_s(x)+\lambda^2 g_s^2 S_s(x)\right), \qquad \text{(App.2d)}$$

$$f_{K^0}^{(u\bar{u})}(x)=A_V \lambda g_N^2 S_N(x), \qquad \text{(App.2e)}$$

$$f_{K^0}^{(d\bar{d})}(x)=A_V\left(\lambda g_N C_N^{K} V_N(x)+\lambda g_N^2 S_N(x)\right), \qquad \text{(App.2f)}$$

$$f_{K^0}^{(s\bar{s})}(x)=A_V\left(g_s C_s^{K} V_s(x)+\lambda g_s^2 S_s(x)\right), \qquad \text{(App.2g)}$$

where

$$V_N(x) = x^{\beta_N}(1-x)^{-1+\beta_N+\gamma_N}, \qquad \text{(App.3a)}$$

$$V_S(x) = x^{\beta_S}(1-x)^{-1+\beta_S+\gamma_S}, \qquad \text{(App.3b)}$$

$$S_N(x) = (1-x)^{-1+2\beta_N+\gamma_N}, \qquad \text{(App.3c)}$$

$$S_S(x) = (1-x)^{-1+2\beta_S+\gamma_S}, \qquad \text{(App.3d)}$$

$$C_N^{\rho} = \frac{B(\beta_N+\eta_N+1,\ \eta_N+1)}{B(\beta_N,\beta_N+\gamma_N)\,B(\eta_N+1,\ \eta_N+1)}, \qquad \text{(App.3e)}$$

$$C_S^{\varphi} = \frac{B(\beta_S+\eta_S+1,\ \eta_S+1)}{B(\beta_S,\beta_S+\gamma_S)\,B(\eta_S+1,\ \eta_S+1)}, \qquad \text{(App.3f)}$$

$$C_N^{K} = \frac{B(\beta_N+\eta_N+1,\ \eta_S+1)}{B(\beta_N,\beta_N+\gamma_N)\,B(\eta_N+1,\eta_S+1)}, \qquad \text{(App.3g)}$$

$$C_S^{K} = \frac{B(\beta_S+\eta_S+1,\ \eta_N+1)}{B(\beta_S,\beta_S+\gamma_S)\,B(\eta_S+1,\ \eta_N+1)}, \qquad \text{(App.3h)}$$

Here $B(x,y)$ is Euler's beta-function. The rest of functions $f_V^{(q\bar{q})}(x)$ are expressed via those in (App.2):

$$f_{\rho^0}^{(u\bar{u})}(x) = f_{\rho^0}^{(d\bar{d})}(x) = f_{\omega}^{(u\bar{u})}(x) = f_{\omega}^{(d\bar{d})}(x) = f_{\rho^\pm}^{(u\bar{u})}(x) = f_{\rho^\pm}^{(d\bar{d})}(x), \qquad \text{(App.4a)}$$

$$f_{\rho^0}^{(s\bar{s})}(x) = f_{\omega}^{(s\bar{s})}(x) = f_{\rho^\pm}^{(s\bar{s})}(x), \qquad \text{(App.4b)}$$

$$f_{\varphi}^{(u\bar{u})}(x) = f_{\varphi}^{(d\bar{d})}(x), \qquad \text{(App.4c)}$$

$$f_{K^0}^{(q\bar{q})}(x) = f_{\bar{K}^0}^{(q\bar{q})}(x), \quad \text{where} \quad q = u,d,s. \qquad \text{(App.4d)}$$

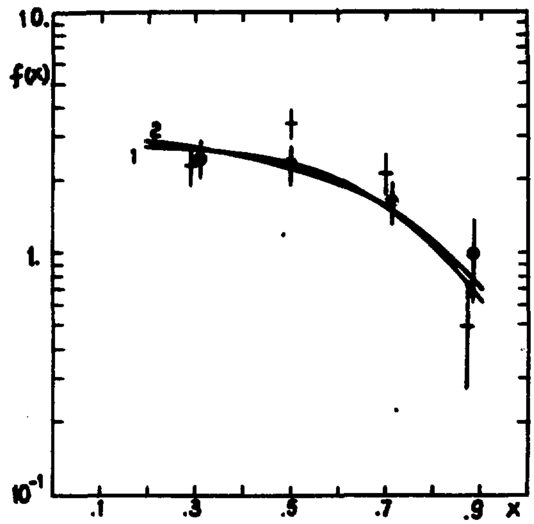


Fig.1a

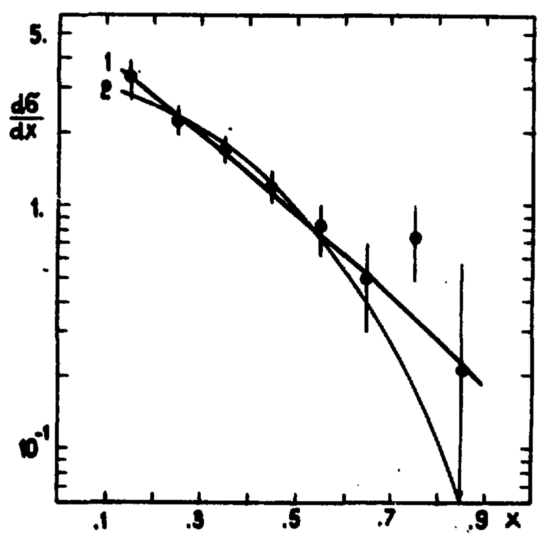


Fig.1b

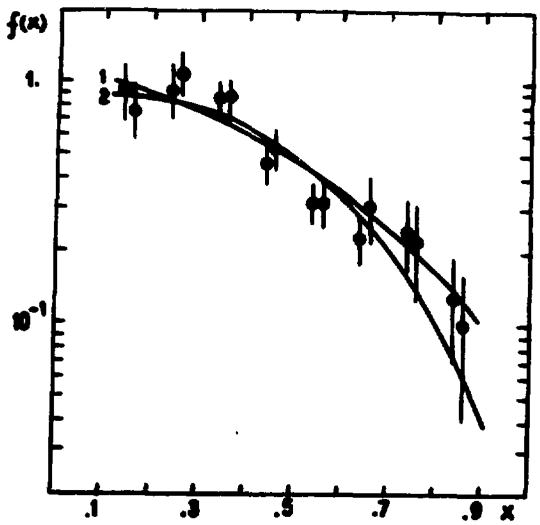


Fig.1c

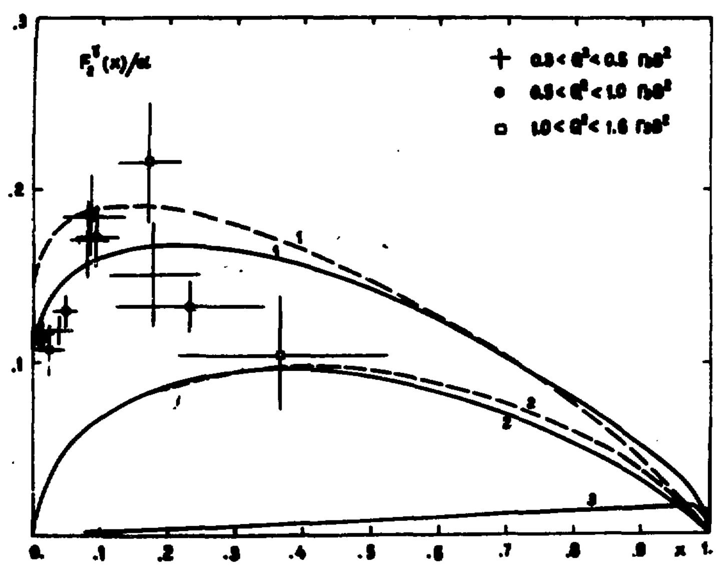


Fig.2

## Figure Captions

Fig.1 Inclusive spectra (in microbarns) of the nondiffraction production of a) ($\rho^0/\omega$) ( ● ), $\rho^{\pm}$ (+); b) $\varphi$ ( ● ) and c) $K^0(890)$ ( ● ), $\bar{K}^0(890)$ ( o ) mesons. The numbers indicate the 1st and 2nd solutions, respectively.

Fig.2 The photon hadron component structure function measured in the processes $e^+e^- \to e^+e^- X$ at $\sqrt{s}$ =29 GeV [3]. The solid curves correspond to solution 1, the dashed ones - to solution 2. The curves 1 are the structure functions obtained from the analysis of the inclusive spectra of the vector mesons nondiffraction phtoproduction; the curves 2 are structure functions connected with the nonstrange valence quarks; 3 is a structure function connected with a strange valence quark.

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