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YEREVAN PHYSICS INSTITUTE

R.G. BADALYAN, S.A. KORCHAGIN

CONTRIBUTIONS OF RECOMBINATION AND FUSION MECHANISMS TO INCLUSIVE SPECTRA OF MESONS, GLUEBALLS AND DRELL-YAN LEPTON PAIRS IN pp-INTERACTIONS

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Ռ.Գ.ԲԱԴԱԼՅԱՆ, Ս.Ա.ԿՈՐՁԱԳԻՆ

ՌԵԿՈՄԲԻՆԱՑԻԱՅԻ ԵՎ ՄԻԱՁՈՒԼՄԱՆ ՄԵԽԱՆԻԶՄՆԵՐԻ ԴԵՐԸ ՄԵԶՈՆՆԵՐԻ, ԳԼՅՈՒԲՈԼՆԵՐԻ ԵՎ ԴՐԵԼ-ՅԱՆԻ ԼԵՓԹՈՆԱՅԻՆ ԶՈՒՅԳԵՐԻ ԻՆԿԼՅՈՒԶԻՎ ՍՊԵԿՏՐԵՐՈՒՄ՝ pp-ՓՈԽԱԶԴԵՑՈՒԹՅՈՒՆՆԵՐՈՒՄ

Ռեկոմբինացիայի և միձուլման մեխանիզմների կինեմատիկական վերլուծության հիման վրա ցույց է տրված, որ տարբեր կինեմատիկական տիրույթներում մասնիկների /մեզոնների, գլյուբոլների, ինչպես նաև Դրել-Յանի լեփթոնային զույգերի/ ծնման այդ մեխանիզմների ներդրումը հադրոնային փոխազդեցություններում զգալիորեն տարբեր է: Մասնավորապես, ստացված է, որ pp-փոխազդեցություններում $M \lesssim 1,5$ ԳէՎ զանգվածով մասնիկները հատվածավորման տիրույթներում /$|x| \gtrsim 0,2$/ ծնվում են, հիմնականում, ռեկոմբինացիոն մեխանիզմով, այն ժամանակ, երբ $M \gtrsim 2$ ԳէՎ զանգվածների ծնման դեպքում և կենտրոնական տիրույթում /$|x| \lesssim 0,1$/ մասնիկների ծնման հիմնական մեխանիզմն է տարբեր փոխազդող հադրոններից քվարկների /գլյուոնների/ միաձուլումը:

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Introduction

At present, in describing the inclusive production of hadrons with low transverse momenta in hadron-hadron interactions within the quark-parton representations, there are widely used the recombination-type models [1-5] and fusion models [6-8] . In models of the first group it is assumed that the final hadron with a mass M , longitudinal momentum $P_{\parallel} = x\sqrt{s}/2$ (where $\sqrt{s}$ is total energy in the c.m.s.) and transverse momentum $P_{\perp}$ is produced as a result of recombination of structural components (quarks, gluons or complex quark-gluon systems - valons) of one of the interacting hadrons in its fragmentation region ($x > 0$ for a beam particle, and $x < 0$ for a target particle in the c.m.s. of interaction). As to the fusion models, here it is assumed that the final hadron is produced owing to fusion of structural components of both interacting hadrons.

In the present work, following the analysis of the phase space of interacting structural components of initial hadrons, we have shown that in different kinematic regions over variables M , x and $P_{\perp}$ (where M is a mass of a produced particle) contributions from the recombination and fusion mechanisms to inclusive spectra of final particles (mesons, glueballs and Drell-Yan lepton pairs) are essentially different. The determination of contributions of the recombination and fusion mechanisms to inclusive spectra of mesons with low $p_\perp$, glueballs and lepton pairs is highly urgent. Such an investigation will allow one to understand what is the contribution of different mechanisms to inclusive spectra of light and heavy mesons and thereby to substantiate results obtained in Refs [9-12] pertaining to structure functions of a kaon [9,10], hadronic component of photon [11] as well as quark-gluon systems into which nonstrange quarks and diquarks transform in the process of evolution [12]. Results of the analysis can be used to estimate contributions of the recombination and fusion mechanisms to the processes of production of glueballs and Drell-Yan lepton pairs in hadronic interactions.

1. Phase Space in Recombination and Fusion Models

At recombination or fusion of a quark (antiquark or gluon) of longitudinal and transverse momenta $P_{1\parallel} = x_1\sqrt{s}/2$, $P_{1\perp} = t_1\sqrt{s}/2$, with an antiquark (quark or gluon) of longitudinal and transverse momenta $P_{2\parallel} = x_2\sqrt{s}/2$, $P_{2\perp} = t_2\sqrt{s}/2$, into a hadron (lepton pair or glueball) of a mass M ($\tau = M^2/S$), longitudinal and transverse momenta $P_\parallel = x\sqrt{s}/2$, $P_\perp = t\sqrt{s}/2$, we have ($\sqrt{s}$ is the energy in the c.m.s.):

$$x = x_1 \pm x_2 \tag{1a}$$

$$t^2 = t_1^2 + t_2^2 + 2t_1t_2\cos\varphi \tag{1b}$$

$$2\tau = \sqrt{(x_1^2+t_1^2)(x_2^2+t_2^2)} \mp x_1x_2 - t_1t_2\cos\varphi \tag{1c}$$

where a scalar product of vectors $\vec{t}_1$ and $\vec{t}_2$ is $\vec{t}_1\vec{t}_2 = t_1t_2\cos\varphi$; φ is the angle between vectors $\vec{t}_1$ and $\vec{t}_2$ that lie in the plane normal to the interaction axis. The upper sign in expressions (1a) and (1c) refers to the recombination kinematics (below in the text R-kinematics), the down sign refers to the fusion model kinematics (F-kinematics). In expression (1c) masses of constituent components (quarks and gluons) are taken zero.

The solvability condition for equations (1a) and (1c) with respect to x_1 and x_2 as well as the requirement $|\cos\varphi| \leqslant 1$ determine an admissible phase space in the plane ($t_1\, t_2$):

$$|t_1 - t_2| \leqslant t \leqslant t_1 + t_2 \tag{2a}$$

$$t_1 + t_2 \leqslant \sqrt{t^2 + 4\tau} \tag{2b}$$

Here, in the incident hadron fragmentation region ($x \geqslant 0$ and hence $x_1 \geqslant 0$) we have two solutions R_1 and R_2 corresponding to R-kinematics and one solution F corresponding to F-kinematics:

$$x_1^{R_1} = \left[x(t_1^2 + \vec{t}_1\vec{t}_2 + 2\tau) + \sqrt{D}\right]/(t^2 + 4\tau) \tag{3a}$$

$$x_2^{R_1} = \left[x(t_2^2 + \vec{t}_1\vec{t}_2 + 2\tau) - \sqrt{D}\right]/(t^2 + 4\tau) \tag{3b}$$

$$X_1^{R_2} = \left[x(t_1^2 + \vec{t}_1\vec{t}_2 + 2\tau) - \sqrt{D}\right]/(t^2 + 4\tau) \qquad (4a)$$

$$X_2^{R_2} = \left[x(t_2^2 + \vec{t}_1\vec{t}_2 + 2\tau) + \sqrt{D}\right]/(t^2 + 4\tau) \qquad (4b)$$

$$X_1^{F} = \left[x(t_1^2 + \vec{t}_1\vec{t}_2 + 2\tau) + \sqrt{D}\right]/(t^2 + 4\tau) = X_1^{R_1} \qquad (5a)$$

$$X_2^{F} = \left[-x(t_2^2 + \vec{t}_1\vec{t}_2 + 2\tau) + \sqrt{D}\right]/(t^2 + 4\tau) = -X_2^{R_1} \qquad (5b)$$

where $D = (\sqrt{t^2+4\tau} + t_1 + t_2)(\sqrt{t^2+4\tau} - t_1 - t_2) \times$

$$\times(\sqrt{t^2+4\tau} + |t_1 - t_2|)(\sqrt{t^2+4\tau} - |t_1 - t_2|)(x^2 + t^2 + 4\tau)/4.$$

In the region $t_2 \geqslant \sqrt{x^2+t^2+4\tau} - \sqrt{x^2+t_1^2}$ we have $X_2^{R_1} \geqslant 0$ ($X_2^F \leqslant 0$), hence a particle of mass M is produced by R_1 -kinematics, whereas at $t_2 \leqslant \sqrt{x^2+t^2+4\tau} - \sqrt{x^2+t_1^2}$ we have $X_2^F \geqslant 0$ ($X_2^{R_1} \leqslant 0$), so a particle of mass M is produced by fusion of a quark and antiquark (or two gluons) from different hadrons. Kinematic region for solution R_2 is determined by condition $X_1^{R_2} \geqslant 0$ or $t_2^2 \geqslant t^2 + t_1^2 + 4\tau - 2t_1\sqrt{x^2+t^2+4\tau}$. Admissible kinematic regions for R_1 , R_2 and F -kinematics are shown in Fig.1.

The conditions $X_1^{R_1} \leqslant 1$, $X_2^{R_2} \leqslant 1$ and $X_1^F \leqslant 1$ hold at

$$\tau + t^2/4 \leqslant (1 - x) \qquad (6)$$

In hadron-hadron interactions the mass of a produced particle (meson, glueball or invariant mass of a lepton pair) M with longitudinal and transverse momenta x and t is coupled with the quantity $W^2 = (\sum_h P_h)^2$ (where sum is taken over all four-momenta of the final state particles except for the one of interest) by the relation:

$$\tau = 1 + W^2/S - \sqrt{x^2 + t^2 + 4W^2/S}\,. \qquad (7)$$

It follows from this relation that M^2 takes a maximum value $S(1 - \sqrt{x^2+t^2})$ at $W^2 \simeq 0$, whereas at $W^2/S \simeq (1 - \sqrt{x^2+t^2})$ we have $M^2 \simeq 0$. Thus $M^2 \leqslant S(1 - \sqrt{x^2+t^2})$. This condition is stronger than condition (6), and hence at $M^2 \leqslant S(1 - \sqrt{x^2+t^2})$ we have $X_1^{R_1} \leqslant 1$, $X_2^{R_2} \leqslant 1$ and $X_1^F \leqslant 1$. Phase space of a final particle of mass M , longitudinal and transverse momenta x and $\vec{t}$, respectively, is determined by conditions (see Fig.2):

$$x^2 + t^2 \leqslant (1 - \tau)^2 \qquad (8a)$$

$$0 \leqslant \tau \leqslant 1 \qquad (8b)$$

2. Spectra of Mesons, Glueballs and Drell-Yan Lepton Pairs in pp-Interactions

Differential cross section of a produced meson (glueball or lepton pair) of mass M in pp-interactions is determined by the expression:

$$d^6\sigma = \sigma_0(M^2) F(x_1, x_2) T(P_{1\perp}) T(P_{2\perp}) d^3\vec{P}_1 d^3\vec{P}_2 \qquad (9)$$

where $F(x_1, x_2)$ is distribution of a quark and antiquark (or two gluons) in the incident proton in case of R-kinematics, and $F(x_1,x_2)=q_1(x_1)\bar{q}_2(x_2)$, where $q_1(x_1)(\bar{q}_2(x_2))$ is distribution of quark (antiquark) in the first (second) proton (or $F(x_1,x_2)=G(x_1)G(x_2)$ where $G(x)$ is distribution of gluons in the proton). $T(P_\perp)$ is distribution of a quark (antiquark or gluon) in the proton over transverse momentum $P_\perp$. Below, for this distribution we'll use the unity-normalized ($\int T(P_\perp)d^2\vec{P}_\perp=1$) expression:

$$T(P_\perp)=\frac{1}{2\,\overline{P_\perp^2}}\exp\left(-\frac{P_\perp^2}{\overline{P_\perp^2}}\right) \tag{10}$$

or

$$T(t)=\frac{2}{s\,\overline{t^2}}\exp\left(-\frac{t^2}{\overline{t^2}}\right) \tag{11}$$

where $\overline{t^2}=4\overline{P_\perp^2}/s$, $\sqrt{\overline{P_\perp^2}}\simeq 0.3$ GeV is average transverse momentum of quarks (gluons) in hadrons. The phase space of a quark and antiquark (or two gluons) $d^3\vec{P}_1 d^3\vec{P}_2=2\pi t_1 t_2\times dx_1 dx_2 dt_1 dt_2 d\varphi$ where $\vec{P}_1$ and $\vec{P}_2$ are three-dimensional momenta of a quark and antiquark (or two gluons) which recombine or fuse into a final particle.

In expression (9) $\sigma_0(M^2)$ is the elementary process cross section which in the case of meson or glueball production is determined by a usual Breit-Wigner formula (provided that the width $\Gamma\ll M_R$ where M_R is a mass of meson resonance or glueball) [13] :

$$\sigma_0(M^2)\simeq 8\pi(2J+1)\frac{\Gamma_0\Gamma}{(M^2-M_R^2)^2+\Gamma^2M_R^2}\approx \tag{12}$$

$$\approx 8\pi^2(2J+1)\frac{\Gamma_0}{M_R}\delta(M^2-M_R^2),$$

where J is a meson or glueball spin, Γ_0 is decay width over channel $M\to q_1\bar{q}_2$ (or, in the glueball case, $G\to gg$). For the process of Drell-Yan lepton pair production we have

$$\sigma_0(M^2)=4\pi\alpha^2/9M^2 \tag{13}$$

where α is fine-structure constant.

The N-multiple differential cross section over variables $Z_j=Z_j(x_1,x_2,t_1,t_2,\varphi)$ where $j=1,2,\dots,N$ is determined by the expression [14] :

$$\frac{d^N\sigma}{dZ_1\dots dZ_N}=2\pi\int\sigma_0(M^2)F(x_1,x_2)T(t_1)T(t_2)\times \tag{14}$$
$$\times\prod_{j=1}^{N}\delta(Z_j-Z_j(x_1,x_2,t_1,t_2,\varphi))t_1t_2dx_1dx_2dt_1dt_2d\varphi$$

Following this expression, for inclusive spectra of a meson (glueball or lepton pair) we find:

$$\frac{d^3\sigma}{dM^2dx\,dt^2}=2\pi\sigma_0(M^2)\int F(x_1,x_2)T(t_1)T(t_2)\delta(M^2-M^2(x_1,x_2,t_1,t_2,\varphi))\times$$
$$\times\delta(x-x(x_1,x_2))\delta(t^2-t^2(t_1,t_2,\varphi))t_1t_2dx_1dx_2dt_1dt_2d\varphi= \tag{15a}$$
$$=2\pi\sigma_0(M^2)\int F(x_1,x_2)T(t_1)T(t_2)J(M^2,x,t^2,t_1,t_2)t_1t_2dt_1dt_2.$$

$$\frac{d^2\sigma}{dM^2dx}=2\pi\sigma_0(M^2)\times \tag{15b}$$
$$\times\int F(x_1,x_2)T(t_1)T(t_2)J(M^2,x,t^2,t_1,t_2)t_1t_2dt_1dt_2dt^2$$

$$\frac{d\sigma}{dM^2} = 2\pi\sigma_0(M^2)\times$$

$$\times\int F(x_1,x_2)T(t_1)T(t_2)J(M^2,x,t^2,t_1,t_2)\,t_1 t_2\,dt_1\,dt_2\,dt^2\,dx \qquad (15c)$$

where $J(M^2,x,t^2,t_1,t_2)$ is a jacobian of transition from variables x_1,x_2,φ to M^2,x,t^2. The regions of integration over variables t_1 and t_2 for various kinematics, as well as over variables t^2 and x are shown in Figs 1 and 2.

On the basis of expressions (3)-(5), for R_1, R_2 and F_- kinematics we have:

$$J_{R_1}(M^2,x,t^2,t_1,t_2) = \left(2C/S(t^2+4\tau)^2\right)\times \qquad (16a)$$

$$\times\left|x(t_1^2-t_2^2)+2\sqrt{D}-(A+B/A)(t^2+4\tau)\right|$$

$$J_{R_2}(M^2,x,t^2,t_1,t_2) = \left(2C/S(t^2+4\tau)^2\right)\times \qquad (16b)$$

$$\times\left|x(t_1^2-t_2^2)-2\sqrt{D}+(A+B/A)(t^2+4\tau)\right|$$

$$J_F(M^2,x,t^2,t_1,t_2) = \left(2C/S(t^2+4\tau)^3\right)\times \qquad (16c)$$

$$\times\Big|x(t_1^4-t_2^4+8t_1^2t_2^2)+2xB(3t_1^2+t_2^2)+$$

$$+4Ax^2(t_2^2+B)-2\sqrt{D}(t_1^2-t_2^2)-$$

$$-(A+B/A)(t^2+4\tau)^2\Big|$$

wherein the following notations are introduced:

$$A = \sqrt{D}/(x^2+t^2+4\tau) \qquad (17a)$$

$$B = 2\tau+\vec{t}_1\vec{t}_2 = t^2+4\tau-t_1^2-t_2^2 \qquad (17b)$$

$$C = \left|\frac{\partial\varphi}{\partial t^2}\right| = \frac{1/2t_1t_2}{\sqrt{1-(t^2-t_1^2-t_2^2)^2/4t_1^2t_2^2}} \qquad (17c)$$

For distribution of partons in a proton over variables x_1 and x_2 we used the parametrization from Refs [15,16] within which we have:

$$xu(x) = 17.4x^{0.5}(1-x)^{3.5}\exp(-2.3(1-x)) \qquad (18a)$$

$$xd(x) = 8.7x^{0.5}(1-x)^{4.5}\exp(-2.1(1-x)) \qquad (18b)$$

$$xS_a(x) = 7.5g_a(1-x)^{5.}\exp(-2.(1-x)) \qquad (18c)$$

$$xG(x) = 7.5g_G(1-x)^7\exp(-2.(1-x)) \qquad (18d)$$

and for two-parton distributions, on the basis of a modified Kuti-Weisskopf parametrization [15,16] we have:

$$x_1x_2F_{u\bar{u}}(x_1,x_2) = 17.4g_a x_1^{0.5}(1-x_2)(1-x)^{3.5}\exp(-2.3(1-x)) \qquad (19a)$$

$$x_1x_2F_{d\bar{d}}(x_1,x_2) = 8.7g_a x_1^{0.5}(1-x_1)(1-x_2)(1-x)^{3.5}\exp(-2.1(1-x)) \qquad (19b)$$

$$x_1 x_2 F_{a\bar{b}}(x_1,x_2) = 7.5 g_a g_{\bar{b}} (1-x_1)(1-x_2)(1-x)^4 \exp(-2.(1-x)) \quad (19c)$$

$$x_1 x_2 F_{gg}(x_1,x_2) = 7.5 g_G^2 (1-x_1)^3 (1-x_2)^3 (1-x)^4 \exp(-2.(1-x)) \quad (19d)$$

In expressions (18) $x = x_1$ or $x = x_2$, and in (19) $x = x_1 + x_2$; $S_a(x)$ are distributions of sea quarks (antiquarks) of genus $a = u, \bar{u}, d, \bar{d}, s, \bar{s}$ - $g_u = g_{\bar{u}} = g_d = g_{\bar{d}} = 0.12$, $g_s = g_{\bar{s}} = 0.015$, $g_G = 3$.

Results of Monte Carlo simulations based on expressions (15) are presented in Figs 3-6. The results show that in the kinematic región $M \leqslant 1.5$ GeV and $x \geqslant 0.2$ particles are produced largely via the recombination mechanism of quarks (gluons), whereas in the central region of interaction, $|x| \leqslant 0.1$, and at production of large masses, $M \geqslant 2$ GeV, the fusion of quarks (gluons) from two interacting hadrons is the major mechanism of particle production. Note, that the conclusion about the dominant contribution to the central region $|x| \leqslant 0.1$ from the fusion mechanism decides the problem of continuous transition of inclusive spectra through the central region of interaction (continuous transition from the fragmentation region of the incident hadron to the fragmentation region of the target) which apparently does not take place for the recombination mechanism of hadron production in the case of interaction of different initial hadrons (πp - and Kp -interactions, see Ref. [17]).

The conclusion about the dominant contribution of the recombination mechanism to the spectra of hadrons of mass $M \leqslant 1.5$ GeV in the fragmentation regions of interacting particles $|x| \geqslant 0.2$ is the basis for earlier obtained results on structure functions of a kaon [9] , hadronic component of a photon [11] , fragmentation functions of nonstrange quarks and diquarks [12] , as well as for results concerning production probabilities for various S- and P-wave meson multiplets [10].

All these results have been obtained on the assumption that hadrons (glueballs) of a mass less than or of the order of 1.5 GeV in fragmentation regions of various quark-gluon systems (proton, π -, K-mesons and hadronic component of a photon after soft interaction with matter as well as systems formed owing to quark and diquark evolution) are produced via the recombination of quarks (gluons) of the fragmentized quark-gluon system.

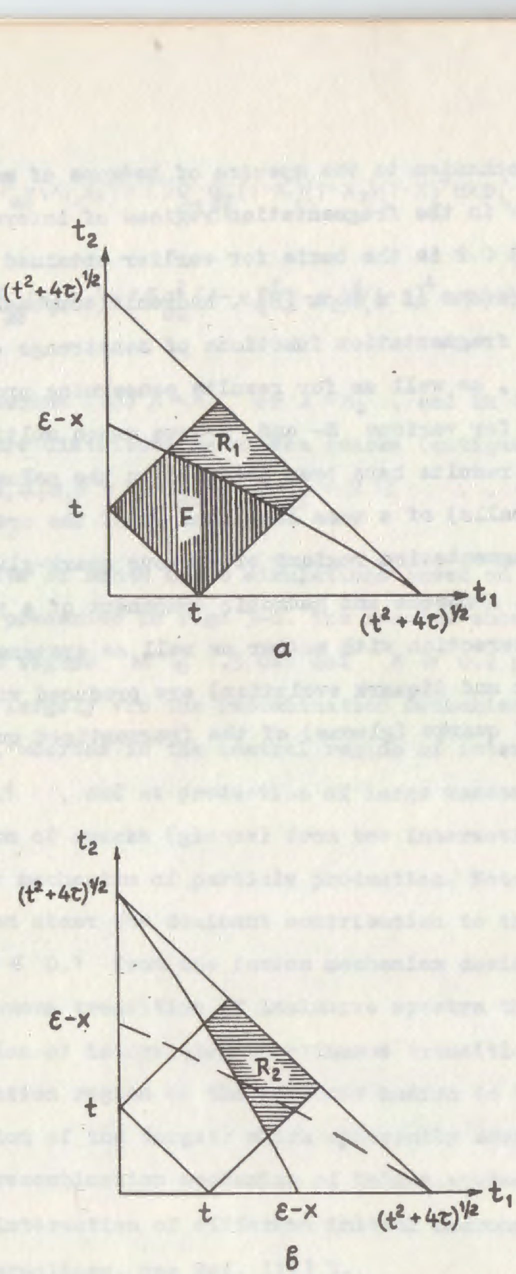

Fig.1

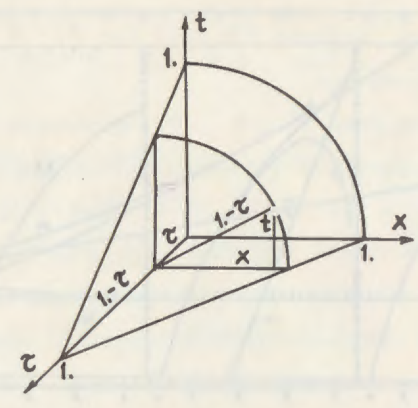

Fig.2

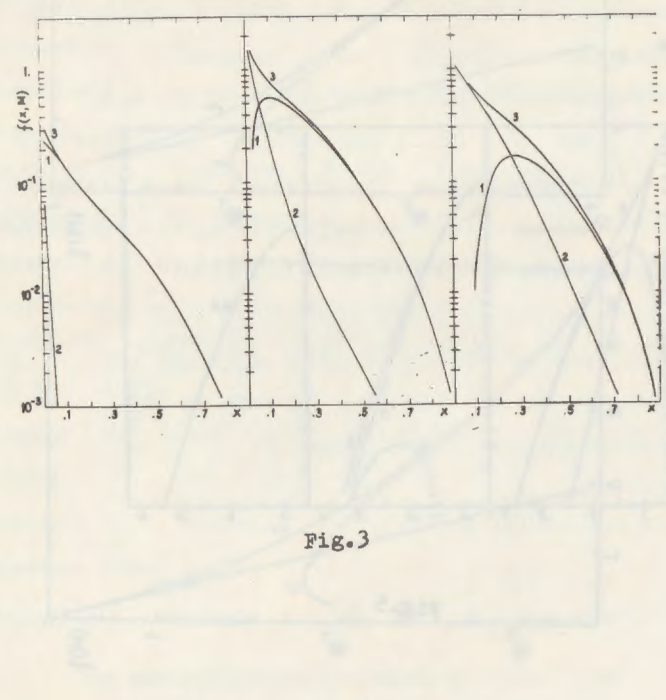

Fig.3

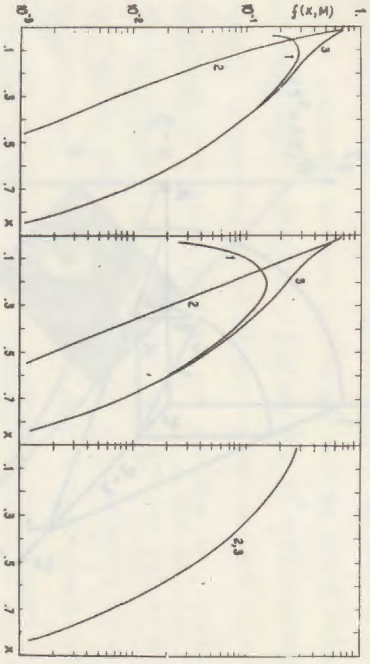

Fig.4

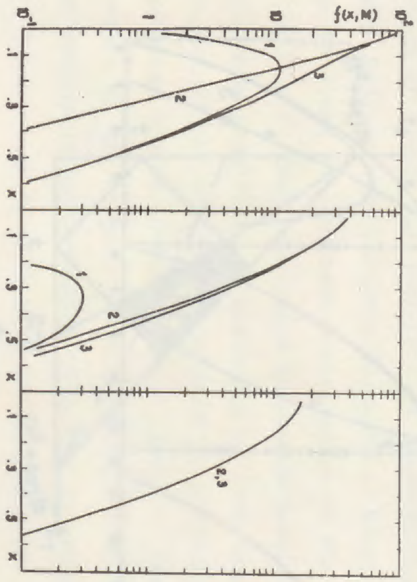

Fig.5

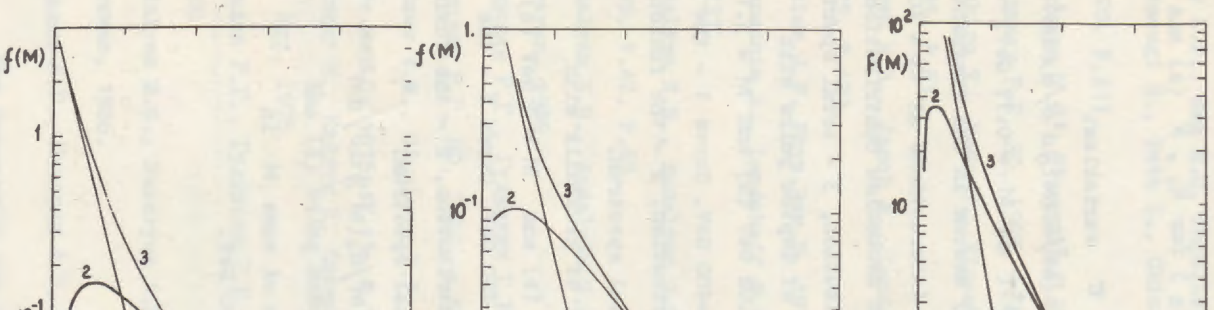

Fig.6

Figure Captions

Fig.1. Phase space in plane (t_1 t_2) for R_1 , F (a) and R_2(b) kinematics.

Fig.2. Phase space over X , t , τ variables.

Fig.3. Inclusive spectrum $f(X,M)=(M^2/\sigma_0(M^2))d^2\sigma/dx\,dM^2$ π^+(a– M = 0.14 GeV), ρ^+ (b– M = 0.77 GeV) and A_2^+ (c– M = 1.32 GeV) mesons in the fragmentation region of the proton in pp-interactions at E_p = 400 GeV. Curve 1 – the recombination mechanism contribution, 2 – the fusion model contribution, 3 – total spectrum.

Fig.4. Inclusive spectrum $f(X,M)$ of lepton pairs with M = 0.77 GeV (a), M = 1.02 GeV (b) and M = 3.1 GeV(c) in pp-interactions at E_p =400 GeV. Curve 1 – the recombination mechanism contribution, 2 – the fusion model contribution, 3 – total spectrum.

Fig.5. Inclusive spectrum $f(X,M)$ of glueballs with M = 1 GeV (a), M = 2 GeV (b) and M = 3 GeV (c) in pp-interactions at E_p = 400 GeV. Curve 1 – the recombination mechanism contribution, 2 – the fusion model contribution, 3 – total spectrum.

Fig.6. The cross section $f(M)=(M^2/\sigma_0(M^2))\,d\sigma/dM^2$ of produced mesons (a), lepton pairs (b) and glueballs (c) as a function of mass M in pp-interactions at E_p · 400 GeV.

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