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ANALYSIS OF THE DIFFERENTIAL EQUATIONS FOR THE EXCLUSIVE PROCESSES AND EXPLANATION FOR THE "MYSTERY" OF THE GAMMA-DISTRIBUTION

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1. Introduction

The processes for the generation of the different type hadron systems (components or resonances) are studied very intensively during last 15 years (see, e.g., $(^{1-11})$).

When discussing of physical characteristics for the exclusive processes

(1) $a + b \Rightarrow n_1 + n_2 + \ldots + n_{\nu}$, in which $n_1, n_2, \ldots, n_{\nu}$ hadrons of ν -types take a part, the following hypothesis by Koba, Nielsen and Olesen (KNO) (¹)' appears to be mentioned first of all: Let $\sigma(n_1, \ldots, n_{\nu})$ and σ are topological and inclusive (total) cross-sections for the prosesses (1). Then 1) their combination with the average multiplicities $\langle n_1 \rangle$ leads to the following multidimensional scaling

(2) $\prod_{i=1}^{\nu} \langle n_i \rangle \cdot \sigma(n_1, \dots, n_{\nu}) / \sigma = f(z_1, \dots, z_{\nu}),$ where $z_i = n_i / \langle n_i \rangle$; 2) from (2) it also follows a one-fold KNO-function (3a) $\langle n_o \rangle \cdot \sigma_n / \sigma \equiv \psi(z_o) = \int_0^{\infty} dz_2 \dots \int_0^{\infty} dz_{\nu} f(z_o, z_2, \dots, z_{\nu})$ for the $n_i = n_o$ charged particles in the semi-inclusive reaction (3b) $a + b \Rightarrow n_o + X$ 3) The relation (3) means a "invariance under the resonance

decay (emmision?)" We do not quite catch the third item of this hypothésis. First, according to the well know Caushy formula for ν -fold quadrature the expression (3a) is reducing to one-fold (4) $\psi(z_o) = \frac{1}{(\nu-1)!} \int_{Z_o}^{\infty} (t-z_o)^{\nu-2} f(t) dt$. if the arguments of the function (2) are additive as $t=\sum z_1$. Thus, e.g., ψ may depend on ν . This may also take place when the resonances are produced in the limited amounts and distributing (or decaying) as the Kroneker $\delta(z_1-\alpha_1)$ function, where α_1 are the decay parameters with $1=2,\ldots,\nu$. Then quadratures do not accur at all, but f may depend on ν and, consequently, the relation (3a) is broken just as that takes place for the central pseudorapidity windows $[\eta]$ (^{14.15}).

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Secondly, in some works, where it was possible to catch these effects of hadronization, unfortunately, the two-co-mponent models are considered only (^{8,9,11}). In order to show incorrectness of this restriction, we give the following example. It is not difficult to obtain the correlation relation between the mean number of the neutral particles $\langle n_0(n_c) \rangle$ and the number of the charged one n

(5)
$$\frac{\langle n_0(n_o) \rangle}{\langle n_o \rangle} = \frac{1}{\nu_{-1}} \int_{z_o}^{\infty} (t-z_o)^{\nu-1} f(t) dt \\ \int_{z_o}^{\infty} (t-z_o)^{\nu-2} f(t) dt$$

Here we substitute the function

(6) $f(t) = t^{a-\nu} \exp[-(a/\nu)t],$

which will be called the generalized gamma(Γ)-distribution. Then at $\nu < a$ the formula (5) describes the negative correlation (i.e. the right part is the decreasing function of z_{o}). When $\nu > a$ the saturation of the positive correlation is reached. Such a behaviour is in agreement with the experimental data (see, e.g., ($^{7.10,13}$)), that denotes once more the possibility of the correlated component number fluctuation.

The question now arises how well this number is defined $(^{13})$ and of whether this is a reason for the "mystery" of the well known negative binomial distribution (i.e. the origin of KNO scaling violation?).

Speaking a priori, the answer is positive: in term of KNO scaling explanation of the enigma are the generalized Γ -distribution (6) and uncertainty principle between the number ν and the correlation intensity.

Generally speaking, the methods of the investigation of (1) have reduced to solution of the problems of algebraic $\binom{4}{,}$, differential (D) $\binom{6,10}{,}$ and differential-difference (DD) $\binom{5,8}{,}$ equations. DD-eqs.(see $\binom{11,12}{,}$ and refs. therein) are being investigated most intensively in the last years. Giovannini has derived them 10 years ago with the assumption that the gluon-gluon fussion, gluon bremsstrahlung and quark-antiquarke emmision processes have the stochastic (Markovian) nature. The authors of refs. $\binom{11,12}{,}$ seem to transpose these eqs. from sub-hadronic (quark-gluon) level to hadronic one without any changes.

At present the mentioned above quark-gluon subproces-

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ses are exactly calculated in the α^3 order of QCD (¹⁶) and N=1,2 supersymmetric QCD (17,20) thanks to the modern powerfull methods (^{18,21-23}). It should be noted, that the higher order calculations of the squared matrix element for the gauge invariant set of the Feynman diagrams require full Le automatization of all computing steps and as long as that cannot be accomplished by means of the universal system REDUCE-3 (²²). Attempts to automate for the hadron exclusive processes of the a⁵ order obeying the well-known "quark counting rule" (¹⁹), have been made by Farrar and Neri (²³) in the programming language "C". We do not know the details of the calculations and below we should use some results from (¹⁸), which consist in determining a common structure for the parton squared . matrix elements in the an order. Thus, using the principle of automodelity (¹⁹), we are starting from D-eq. for the homogenous function. Its degree is exactly defined by simple dimentional analysis. Further in sect.2 on the basis of the assumption of generating several hadronic components (resonances) by means of the given number of quarks, we make averaging with the Bogolubov method (24) that leads to the chain of the D-eqs. for mean multiplicities with matrix of the multiplicity correlation . Similarity with Bogolubov equations appears more in possibility of parametrization of this matrix with the aim of cutting the chain.

In sect.3 we solve the Caushy problem by the moment method and by the combination of the characteristic equations. It should be mentioned that the arising correlation parameters obey the principle of "universality" (²⁶), according to which the parameters do not depend on the "time" variable τ and the number v. However, as it will be see below, we do not refer to a standard renormalization scheme (^{25,26}). Moreover, we do not see any disagreement with the previous results (^{6,10,26})

2. Chain of the D-eqs. with the correlated hadronic components

Recently a common structure of the differential crosssection for the n-parton processes was established in QCD

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(¹⁸). This squared matrix element for n-gluon processes is able to reproduce, for instance, the known formulae of the 4 - and 5 - gluons processes and has the following structure (7a) $|\mathbf{M}|_{ng}^2 \approx \sum (p_1 p_j)^4 \sum C_1 / [(p_1 p_2)(p_2 p_3)...(p_n p_1)],$ where C_1 are independent isotopical constants.

Gluon replacement by means of quarks, as we have verified in the α^3 order (¹⁷) leads to the negligible change of the factor in (7a) so

(7b) $\sum_{\gamma^{1}+\gamma^{2}=4}^{\sum} (p_{1}p_{1})^{4} \Rightarrow \sum_{\gamma^{1}+\gamma^{2}=4}^{\sum} (p_{1}p_{1})^{\gamma^{1}} (p_{k}p_{1})^{\gamma^{2}},$

Testing of formulae (7) in the higher order of the perturbative theory is not possible by the standard methods of the quantum field theory $(^{25})$ and computer algebra $(^{21})$ because of the absence of complete automatization of all computing steps $(^{22})$. So let us restrict ourselves by formula (7) when considering of n-quark tree diagrams with gluon exchange too. The exclusive hadron scattering at the large transferred momenta $(^{19,23})$ is taken to be realised by these diagrams.

The expression $|M|^2$ as a function of the momentum p_1, \ldots, p_n satisfies the automodelity principle, i.e. under momentum scale transformation $p_1 \Rightarrow \lambda p_1$ has to trasform as homogeneous function of corresponding dimension(¹⁹). It is easy to determine this dimension as m=-(n-4). In other words, $|M|^2$ satisfies the following D-eq.

(8)
$$\sum_{i=1}^{n} p_i \frac{\partial}{\partial p_i} |M|^2 = -m |M|^2.$$

Now turn to the hadronic level. 1. Let us suppose that the given number n of quarks is so large that we can generate the several (ν) hadron components with multiplisities n_1, \ldots, n_n so that

(9) $n = \sum_{i=1}^{\nu} N_i n_i >> 4, \quad m \cong -2n,$

where N, are the quark number in i-type hadron;

2. Integrate (8) over "entra" momenta of quarks in such way, that some of them remain for composing one (or two) in the final (initial) state;

3. Make averaging over some type of multiplicities and define from physical point of view the additional (and initial) condition for solving the chain of D-eqs. It is easy to prove that integrating of the left part of (8) over (n - 1) - momenta gives

(8a)
$$[p_1 \frac{\partial}{\partial p_1} - (n-1)] \int |\mathbf{M}|^2 \prod_{i=2}^{\nu} dp_i$$
.

If interpreting the appearing integral as a differential cross-section of the "quasiexclusive" processes

(10a) $a + b \Rightarrow c(p) + n_1 + n_2 + \dots + n_n$

where c(p) is the single separated hadron with given momentum $p=p_1$, from (8) and (9) we get the following characteristic eq.:

(10b) $-\frac{d}{d\tau} \sigma(n_1,\ldots,n_{\nu}) = - (\sum N_i n_i) \cdot \sigma (n_1,\ldots,n_{\nu}).$

The physical meaning of time variable τ can be obtained if $p^{\mu} = p_0^{\mu} e^{t}$ is a solution of eq. d $p^{\mu} = p^{\mu}$ dt, so $\tau = \ln(pp_0)/p_0^2$. When momentum p is linked with initial particles in the reaction $a + b \Rightarrow n_c + X$, then $\tau = \ln s/2m_b^2$.

And now it is not difficult to obtain a characteristic eq. for the inclusive processes $a + b \Rightarrow c(p) + X$ differential cross-section (²⁶)

(11)
$$\frac{\mathrm{d}}{\mathrm{d}\tau} \sigma = -(\sum_{i=1}^{\nu} \mathrm{N}_{i} < \mathrm{n}_{i} >)\sigma,$$

and for mean (associated) multiplicities for all $i=1,\ldots,\nu$

(12) $\frac{d}{d\tau} \langle n_{i} \rangle = -\sum_{k=1}^{\nu} N_{k} D_{ik},$

where values $D_{ik} = \langle n_i n_k \rangle - \langle n_i \rangle \langle n_k \rangle$ form the matrix of correlation (dispertion) between multiplicities of the different type hadrons also. D_{ik} are linked to the higher multiplicity moments equation of the following form:

(13b) $\frac{d}{d\tau} C(q_1, \dots, q_{\nu}) = \sum_{i=1}^{\nu} \left\{ N_i < n_i > \left[C(q_1, \dots, q_{i+1}, \dots, q_{\nu}) - C(q_1, \dots, q_1, \dots, q_{\nu}) \left[I + q_i D_{ii} / \langle n_i \rangle^2 \right] \right] \right\},$

Here normalized multiplicities moments are defined as

(13a) $C(q_1, \dots, q_{\nu}) = \int_0^{\infty} f(z_1, \dots, z_{\nu}) \prod_{\substack{i=1\\j=1}}^{\nu} z_i^{q_i} dz_i \equiv (n_1^{q_1}, \dots, n_{\nu}^{q_{\nu}}) / (n_1^{q_1}) \dots (n_{\nu}^{q_{\nu}}).$

We are going to make a procedure of splitting (cutting) starting from DD-eqs. (13a).

In order to compare we write the simple form of DD-eq. given by Giovannini et al. (5,8,11)

(14)
$$\frac{d}{dt}P_{n} = -A \cdot n \cdot P_{n} + \widetilde{A} \cdot (n-I)P_{n-1},$$

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where P_n denotes the normalized cross-section for the n-gluon sub-processes, A and A are arbitrary constants. We see that the right-hand side of eq. (14) differs from (10b) one mainly by second terms. However, the hadronization in our approach more resembles the chain of Bogolubov than Markov's one. It is interesting to note that analogous eqs., in our opinion, may result from the renormalization group analysis in the framework of QCD.

3. Solution of the Cauchy problem by methods of recurrence and combination

Let us show that nontrivial and the physically interested solutions of eqs. (10)-(13) occur only for correlated components. We start from the noncorrelated case, where $D_{ik}=0$ when $i\neq k$, i.e. matrix of correlation

(15a) $D = \begin{cases} D_{11}, \dots D_{1\nu}, \\ \dots \\ D_{\nu 1}, \dots \\ D_{\nu \nu}, \end{cases}$

is diagonal. We line the remainder elements as (15b) $D_{11} = \frac{1}{a_1} (\langle n_1 \rangle - \alpha_1)^2$

and consider the constants $a_1 \ \mu \ \alpha_1$ as "universal", i.e. independent of the parameters of the theory: τ and ν . This law is well known, for instance, for charged particles (²⁷).

As all <n,> are independent and, moreover,

C(I,...,I) = I, i.e. $\frac{d}{d\tau} C(I,...,I) = 0$, from eq.(13b) we get solution with index 2:

 $C(2,I,...,I) = \{I + \{I - (2\alpha_1/\langle n_1 \rangle) + (\alpha_1^2/\langle n_1 \rangle^2)\}.$

So as to continue the recurrence, we have else to suppose, that $\langle n_i \rangle \gg \alpha_i$ for all $i=1,\ldots,\nu$. Then it easily can be checked that for any set of indices the normalazed multiplicity moments do not depend on τ and we can obtain them recursively in the factorized form

(13c)
$$C(q_1, \ldots, q_v) = \prod_{i=1}^{v} \left\{ \Gamma(a_i + q_i) / \Gamma(a_i) \right\}$$

We inverse (13a) as the Mellin transformation and see,

consequently that the multidimensional KNO-function (2) is also restoring as a production of the one-component Γ -distributions (²⁶):

(6a) $\Psi(z_1) = \frac{a_{11}^{a_{11}}}{\Gamma(a_1)} z_1^{a_{11}^{-1}} \exp(-a_1 z_1)$

This function has been used most intensively for the last 5 years for approximation of the experimental data in the large range of the energies and for the dirrefent intervals of the pseudorapidity $|\eta|$. However, as was mentioned in Introduction, the parameter a_i figuring therein is "mysteriously" changed (^{12,13}). This points the way to go out from the one-component regime sets and to obtain a physically correct solution for the function (2).

As it has been seen, DD-eq. (13b) is recurrently solvable at the very limited conditions and it does not help us in solving this problem. Therefore we turn to the immediate analysis of the chain of the D-eqs. (10)-(12). In the general case, by linearizing matrix (15a), we can give it in the nondiagonal form with the different wheights (intensities) of the correlations

(15c)
$$D_{ik} = \frac{1}{a_{ik}} < n_i > < n_k$$

for all 1,k=1,...,v.

But the case of the saturation is conveniently considerable with the same intensities

 $a_{1k} = a$ for all 1, k = 1, ..., v.

Consequantly, the system (12) composed from ν -eqs. may be reduced to one

(16) $\frac{d \langle x \rangle}{d\tau} = -D^2(x),$ where

(16a) $\mathbf{x} = \sum_{1}^{\nu} N_{1} n_{1}, \langle \mathbf{x} \rangle = \sum_{1}^{\nu} N_{1} \langle \mathbf{n}_{1} \rangle, \ \mathbf{D}^{2} (\mathbf{x}) = \langle \mathbf{x}^{2} \rangle - \langle \mathbf{x} \rangle^{2} \Rightarrow \frac{1}{\mathbf{a}} \langle \mathbf{x} \rangle^{2}.$ For excluding dt let us divide (10b) and (11) by (16).

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Thus we get

(17a) $\frac{d}{d\langle x\rangle} \sigma(n_1, \dots, n_p) = \frac{ax}{\langle x\rangle^2} \sigma(n_1, \dots, n_p)$ (17b) $\frac{d}{d\langle x\rangle} \sigma = \frac{a}{\langle x\rangle} \sigma$ They are easy integrated (18) $\sigma(n_1, \dots, n_p) = C_1 \exp(-a - \frac{x}{\langle x\rangle}), \quad \sigma = C_2 \langle x\rangle^a,$ where C₁ and C₂ are first integrals. Let us formulate the Cauchy problems so that the combination of (18) at $\tau=0$ must satisfy the following function (19) $F(Z)=Z^{a-\nu} \exp(-aZ)$

(19) F(Z)=Z exp(-az) as an initial condition, i.e. (20) $\left\{ \langle x \rangle^{\nu} \frac{\sigma(n,\ldots,n)}{\sigma} \right\}_{\tau=0} = F(Z),$ with argument Z= x/<x>. Then we get equality $\left\{ \begin{matrix} C_1 \\ C_n \end{matrix} \right\}_{\tau=0} = x^{\mathbf{a}-\nu},$

Inserting the first integrals (18) into the last expression, it is not difficult to check up, that relation (20) is fulfilled for all values of τ and one may give it the view of (2).

Since

 $\frac{d}{d\tau} \langle n_1 \rangle = - \langle n_1 \rangle \langle x \rangle ,$

 $\langle n_1 \rangle / \langle n_1 \rangle = C_1$ are the first integrals too. And now we can determine them introducing the explicit form of (20) into the standard definition $\langle n_1 \rangle$. So we get the relations

$$\begin{split} & \mathbb{N}_1 \langle \mathbf{n}_1 \rangle = \mathbb{N}_1 \langle \mathbf{n}_1 \rangle, \quad \langle \mathbf{x} \rangle = \nu \ \mathbb{N}_1 \langle \mathbf{n}_1 \rangle, \quad \mathbf{Z} = \sum_1^{\nu} \mathbf{z}_1 / \nu, \\ & \text{which give to (20) the necessary form as KNO-scaling (2) (^{10})} \\ & (21) \quad f(\mathbf{z}_1, \dots, \mathbf{z}_{\nu}) = f(\sum \mathbf{z}_1) = \mathbb{A}(\sum \mathbf{z}_1)^{\mathbf{a} - \nu} \exp[-\frac{\mathbf{a}}{\nu} (\sum \mathbf{z}_1)] \\ & \text{where} \end{split}$$

 $A = \begin{bmatrix} \underline{a} \\ \nu \end{bmatrix} \frac{\Gamma(\nu)}{\Gamma(a)}.$

Finally, we should explain the Γ -distribution "enigma" mentioned in Introduction by means of (21). Let us consider precisely the case when $\nu > 1$ quadratures do not arise due to the Kronecker delta function $\delta(z_1 - \alpha_1)$. Then the KNO-function (3) for $n_1 = n_c$, according to (21), is parametrized in the generalized Γ -distribution form

(22) $\Psi(z_{c}) \Rightarrow (z_{c} + \alpha)^{\nu(a_{c} - 1)} \exp[-a_{e}(z_{c} + \alpha)]$.

Emphasize the means of the parameters arising here :

 $a_e = a/\nu$ is effective intensity of all types of correlations, constants ν and a characterise the birth and decay processes of resonances, accordingly. The comparison of the formulas (22) with the experimental data (¹⁵) confirms increasing of the component number ($\nu = 2,3$) in the central pseudorapidity $|\eta|$ windows and, correspondingly, decreasing of a_e so that their production will be constant, i.e. $\nu a_e = a \Rightarrow 4$. This uncertainty principle between number ν of correlated components and intensity of their correlation was also observed (^{7,10}) at the approximation of the experimental data by means of formula (5) for the neutral-charge particles correlation. If $\sigma(z_1 - \alpha_1)$ is absent, the shape of the Γ -distribution is strongly modified by the averaging over the multiplicities n_2, \ldots, n_{ν} (⁷).

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Дарбаидзе Я.З., Ростовцев В.А. Анализ дифференциальных уравнений для эксклюзивных процессов и разгадка "тайны" гамма-распределения

Выведена цепочка дифференциальных уравнений на основе рассмотрения структуры сечения тормозного излучения глюонов в древесных диаграммах кварков с целью адронизации сильно коррелированных компонент. Она решается при дополнительных условиях о степени корреляции и приводит к зависимости основных характеристик множественного процесса от числа компонент. Этим объясняется, например, известная загадка зависимости параметра гамма-распределения для КНО-функции от интервала псевдобыстрот. Установлен принцип неопределенности между числом сильно коррелированных компонент и степенью корреляции.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1989

Darbaidze Ya.Z., Rostovtsev V.A. E2-89-286 Analysis of the Differential Equations for the Exclusive Processes and Explanation for the "Mystery" of the Gamma-Distribution

The chain of the differential equations was derived on the basis of consideration of the cross-section structure of the gluon bremsstrahlung emission in multiquark tree diagrams for the purpose of hadronization of the strong correlating components. It is solved at some initial conditions for a correlation intensity of multiplici ties of hadron systems and a dependence on the component (resonance) number for the main characteristics of the multiparticle processes is obtained. This dependence is an explanation of the known for the KNO-function "mystery" of the gamma-distribution parameter dependency on the pseudorapidity intervals. Uncertainty principle between this number and the correlation intensity was established

The investigation has been performed at the Laboratory of Computing Techniques and Automation, JINR.

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