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Универсальность векторных взаимодействий
и кумулятивное образование векторных мезонов

Отмечена важность экспериментального изучения кумулятивного образования векторных мезонов в инклюзивных реакциях адрон-ядерного взаимодействия при высоких энергиях для проверки динамического проявления сохраняющихся квантовых чисел согласно теории Янга-Миллса и выяснения возможной роли многобарионных кластеров в реакциях кумулятивного образования частиц. В рамках двухкомпонентной модели, учитывающей "некогерентный" механизм диссоциации составляющих кварков и "когерентный" механизм реджеонного обмена, дана численная оценка усиления выхода ω-мезонов относительно выхода η-мезонов в кумулятивной области, обусловленного возможной пропорциональностью амплитуды фрагментации барионного кластера с испусканием ω-мезона его гиперзаряду и барионному числу.

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Universality of Vector Interactions and the
Cumulative Production of Vector Mesons

We point to the importance of the experimental study of the vector meson cumulative production and to a possibility of observing in these processes manifestation of the dynamic properties of the conserved quantum numbers (isospin, hypercharge and baryon number) suggested by the Yang-Mills theory.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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The cumulative production of particles in nuclear collisions is a powerful tool for studying the structure and dynamics of nuclear matter at small distances and is extensively investigated at present /1-4/. The cumulative effect is most reliably distinguished from the other effects which can simulate it (internuclear rescattering, Fermi motion etc.) in the region of limiting fragmentation of nuclei. The limiting fragmentation of nuclei starts /1/ at energies corresponding to the difference of the rapidities of a target y_a and a fragmenting nucleus y_b which satisfies the condition $|y_a - y_b| > 2$. This is in agreement with the idea about the correlation length in the rapidity space which is common for hadron physics and is well confirmed by experimental data.

A large amount of experimental data on the cumulative effect in the region of limiting fragmentation of nuclei has recently been accumulated. According to the condition $|y_a - y_b| > 2$ the limiting fragmentation of nuclei begins at energies 4 GeV/nucleon in nucleus-nucleus collisions and at energies lower than 1 GeV in collisions of light particles with nuclei. In these reactions, not only hadrons, but also leptons and even gamma quanta and neutrinos were taken to serve as the particles on which the fragmentation of nuclei proceeds.

The aim of the present paper is to pay attention to the fact that it is important to study the cumulative production of resonances and, in the first place, of vector mesons (ρ, ω, etc.) taking into consideration a possibility of observing in these processes manifestation of the dynamic properties of the conserved quantum numbers. According to the gauge principle of introduction of interactions /5/ the local generalization of the internal hadron symmetries leads to massless vector fields the coupling constants of which must satisfy the universality condition, i.e. must be proportional to the appropriate quantum numbers. Following Sakurai /6/ it is common use to identify the fields of ρ, ω and ϕ mesons with those gauge fields the coupling constants of which should be proportional to the appropriate isospin components and to linear combinations (due to SU(3) symmetry violation and singlet-octet mixing of states) of the quantum numbers B and Y. The mass of vector mesons gives evidence for the violation of the local gauge invariance of the theory. Nevertheless the experimental check of the universality of the coupling constants of ρ and ω meson yields hopeful results /7,8,9/. Within 20-30% the "Dirac" ρ meson-nucleon coupling constant is in agreement with the photon - ρ meson transition coupling constant and the $\rho\pi\pi$ coupling constant. The assumption on the universality of the ω meson Regge trajectory residues is also in satisfactory agreement with experiment /9/.

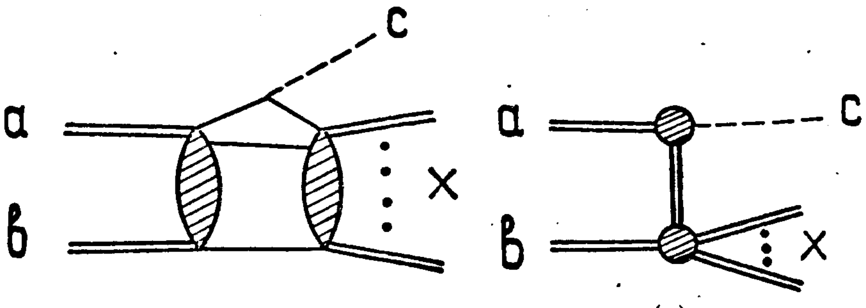
The application of the ideas of universality to the vector meson cumulative production processes is of double interest: firstly, from the point of view of an additional check of the important dynamic symmetry, secondly, as a tool for clarifying a possible role of multibaryon clasters (i.e. virtual states of the type of the quark "bag" with baryon number $B \geq 2$) in the cumulative particle production reactions /1-4/. The expected effect consists in that in the region of nucleus-target fragmentation there must be an essential increase of the relative yield of vector mesons with increasing the order of cumulativity (i.e. the minimal number of the nucleons of a nucleus necessary for the reaction to proceed). The coupling constants of hyperneutral vector mesons with a baryon claster, which are a fragmentation product of this claster, must be proportional to its baryon number, hypercharge or isospin. The numerical values of these constants are expected to increase with increasing number of nucleons in the claster (the order of cumulativity). The effect is expected to be stronger for ω mesons than for ρ mesons due to the relatively large ωNN coupling constant and because of the fact that the nucleon isospins are added as vectors while the baryon numbers and hypercharges as scalars.

To decrease uncertainties in the analysis of the data we suggest to consider the ratio of the invariant inclusive production cross sections for cumulative η and ω mesons, $R_{\eta/\omega}$, in hadron-nucleus collisions in the target-nucleus fragmentation region. To estimate numerically the ω enhancement effect under discussion we assume the following two-component model of meson production. The inclusive cross section for the reaction $a+b \to c+X$ is supposed to consist of two terms

$$E_c \frac{d\sigma}{dp_c}(ab \to cX) = N(1-x_F)^n + C(1-x_F)^{1-2\alpha_{eff}} \qquad (1)$$

corresponding to two different mechanisms: "non-coherent" dissociation of the constituent quark from a fragmenting claster /10/ (fig. 1a) and the "coherent" part corresponding to the fragmentation of the claster as a whole taking into account the Regge exchange in the crossing channel which possesses suitable numbers and a maximum effective index $\alpha_{eff}(0)$ (fig. 1b).

In eq. (1) N and C are functions of the kinematic variables of the reaction under consideration which are weakly dependent on the scale variable x_F, the exponent n is assumed to be equal to a value which is given by the quark counting for the distribution function of valence quarks. The



(a) (b)

Fig. 1. Mechanism of the "noncoherent" (a) and "coherent" (b) c meson production in the reaction $a+b \to c\,X$.

exponent of the second term is chosen according to the Feynman hypothesis[12] about smooth "sewing" of the inclusive cross section with the appropriate limiting two-particle process the cross section of which is parametrized by the standard Regge method: $\frac{d\sigma}{dt} \sim s^{2\,(\alpha_{eff}-1)}$

In what follows we restrict ourselves to the consideration of the simplest reaction involving deuterons. The cross section for the reaction $p\,(8.6\ \mathrm{GeV/c}) + d \to \pi^+(180^\circ) + X$ was recently measured in the cumulative region[12] and the data obtained make it possible to check the applicability of eq. (1) for the description of the cross section. By fixing $n=9$ and $\alpha_{eff} = -0.75$ it is possible, on the basis of eq. (1), to describe satisfactorily the experiment (see fig. 2) if it is assumed $N_\pi = 105$ mb/ster.GeV^2 and $C_\pi / N_\pi = 3.2 \times 10^{-4}$. The numerical values of n and α_{eff} correspond to quark counting for six-quark system and the effective Regge exponent of dibaryon exchange $\alpha_{eff}(B=2) = 2\alpha_\Delta - 1$, where $\alpha_\Delta = 0.1 \div 0.15$ is the Regge exponent of the Δ resonance trajectory lying higher than the other baryon trajectories.

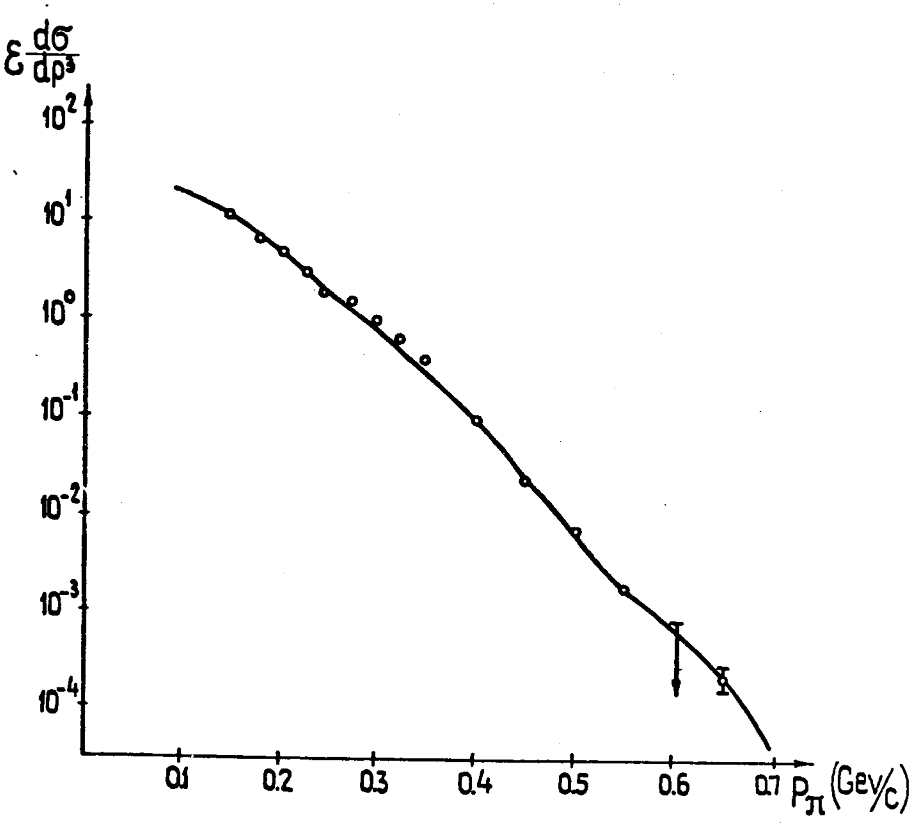


Fig. 2. The cross section for the inclusive reaction $p(8.6\ \mathrm{GeV/c}) + d \to \pi^+(180^\circ) + X$. The continuous line corresponds to the cross section parametrization according to eq. (1) (see the text).

To describe the reactions

$$h + d \to \left\{ \begin{array}{l} \eta\,(180^\circ) + X \\ \omega\,(180^\circ) + X \end{array} \right. \qquad (2)$$

we use the expression (1) with $\frac{C_\omega}{N_\omega} = r \cdot C_\eta / N_\eta \approx r\ \frac{C_\pi}{N_\pi}$

and $\frac{N_\eta}{N_\omega} \approx 0.4$ which corresponds to the data of ref. /13/ dealing with quasi-inclusive η and ω meson production studies.

To demonstrate the ω universality and ω enhancement effects we consider two cases: $r = 1$ and $r = 4$. The curves $R_{\eta/\omega}(x_F)$ as functions of the Feynman variable x_F are given in fig. 3. The straight line corresponds to $r = 1$, i.e. the absence of the ω effect. It may be expected that in the range of the values of the cumulative number $K \lesssim 2$ the ratio of the production cross sections for η and ω mesons on heavy nuclei corresponds qualitatively to the behaviour of this ratio for the deuteron since in this region the two-nucleon, i.e. six-quark clasters are of predominance. Fig. 4 gives a plot for $R_{\eta/\omega}(p_{lab.})$ as a function of the meson momentum in the lab. system. The transition from x_F to $p_{lab.}$ corresponds to the kinematics of the interaction of an 4 GeV/c initial pion with a two-nucleon system at rest. Due to the difference

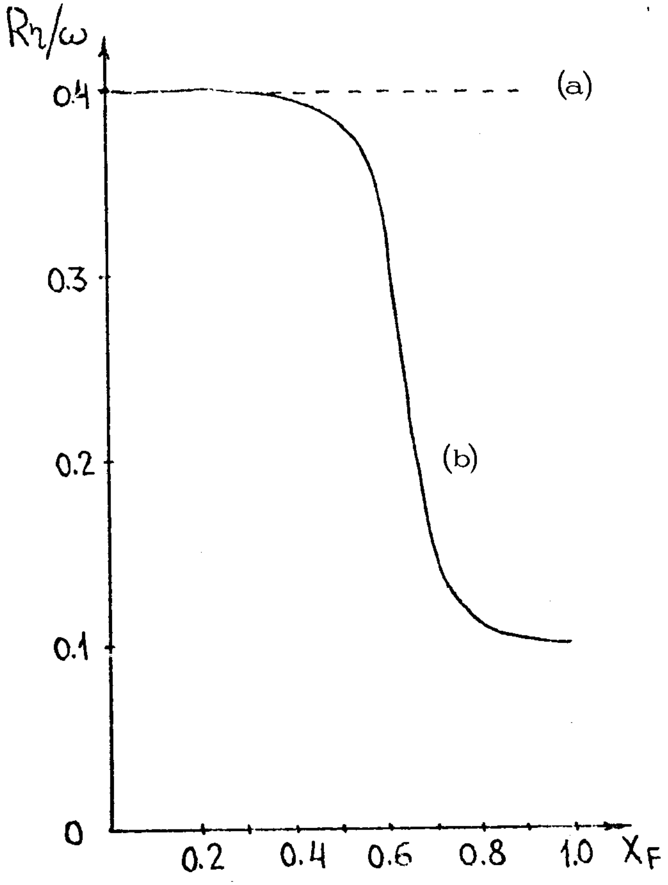


Fig. 3. Plot for $R_{\eta/\omega}$ as a function of x_F.

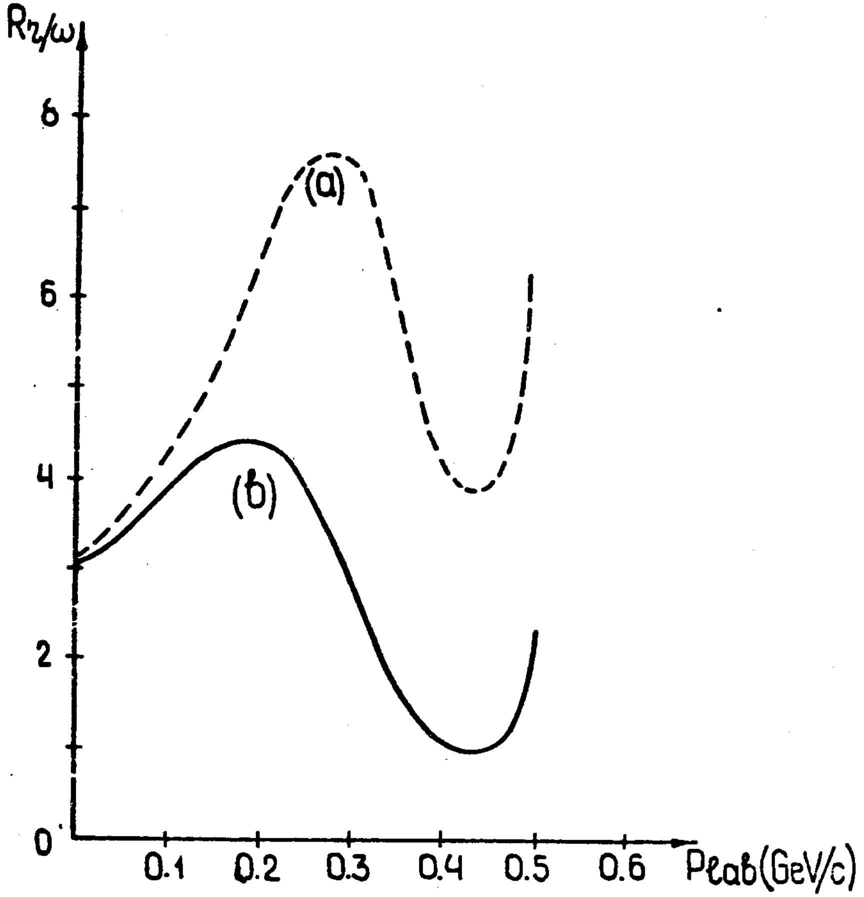


Fig. 4. Plot for $R_{\eta/\omega}$ as a function of $p_{lab.}$.

of the η and ω meson masses $x_F(\eta) < x_F(\omega)$ for the same meson momentum in the lab. system. This just explains the fact that the production cross section for η mesons is larger than that for ω mesons when $p_{lab}(\eta)=p_{lab}(\omega)$. To the value $r=4$ there corresponds the curve (b) on fig. 4. The manifestation of the dynamic properties of the baryon charge is seen to be clealy cut in the cumulative region of ω meson production. A sharp increase of $R_{\eta/\omega}(p_{lab})$ at $p_{lab.} > 0.45$ GeV/c is explained by the approach to the kinematic boundary. This boundary is reached at lower momenta in the ω meson production reaction, and here obviously $R_{\eta/\omega} \to \infty$ In nuclei with $A > 2$ the behaviour of $R_{\eta/\omega}$ will be quite different. Due to the fact that three- and so on nucleon clasters become involved in the reaction for which a relative increase of the ω meson yield may be still larger (the enhancement factor $r = B^2 \geq 9$) we should rather expect a further decrease of $R_{\eta/\omega}$ with increasing p_{lab} .

In conclusion we summarize the above ideas and and make some additional remarks:

1. The experimental study of the cumulative vector meson production makes it possible to check a number of important hypotheses dealing with the multibaryon dynamics and the hadron interaction physics as a whole.

2. From the quantitative point of view the effect of increase of the relative cumulative ω meson yield may turn out to be important.

3. The study of the ω meson production as a function of the atomic number of a fragmenting nucleus is of great interest. If the predictions of a number of models (see, e.g. ref./1/) concerning the increase of the value m in the functional dependence A^m with increasing the cumulative order are valid,then due to the enhancement factor $r=B^2$ the rate of increase of this value for ω mesons may be larger than in the cumulative pseudoscalar meson production reactions.

4. An additional possibility of obtaining valuable information on the reaction dynamics is provided by the measurement of the elements of the spin density matrix of vector resonances.

5. It is also important to consider the reactions closely related to the processes under discussion: production of cumulative "direct" photons and leptons, measurement of the ρ meson yield and observation of the $\omega-\rho$ interference in appropriate identical decay channels, etc.

6. The considerations based on the hypotheses about the universality of tensor interactions and the tensor meson coupling constants allow one to expect an increase of the relative yield of tensor mesons in the transition to the cumulative region. In this connection it is interesting to measure the ratio of the η' and f meson yields in the region of fragmentation of nuclei. With increasing the order of cumulativity this ratio can qualitatively behave like that for the η and ω meson yields.

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