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EXCITATION OF PHYSICAL VACUUM

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Introducing such a notion as a "excitation of physical vacuum" we do an attempt to explain some strange experimental facts such as large value of σ-term measured in pion-nucleon low energy scattering, $\Delta T = 1/2$ rule in kaon two pion decay modes, the ratio of strange to nonstrange yield in low energy proton-antiproton annihilation, excess of soft photons in hadron's collisions. As a test of our approach we suggest to measure the multiparticle production processes and decays of heavy virtual objects. Some estimates for $\rho \to 4\pi, J/\Psi' \to 2\pi 2\mu$ decay widths modification and exclusive Dis are given.

1 Motivation

Motivation of this note is the need to explain some strange experimental facts in particle physics.

One of them is too large value of strangeness content $y =< P|\bar{s}s|P > / < P|\bar{u}u + \bar{d}d|P >$ in the nucleon $|P >$ state. This quantity can be expressed with the experimentally measured value of so called σ- term:

$$\sigma = \frac{\sigma_0}{1-y}, \tag{1}$$

with $\sigma = 80 - 200MeV$-the measure of chiral symmetry violation and can be expressed in terms of pion-nucleon scattering lengths, $\sigma_0 \approx 30MeV$-can be calculated in frames of quark-parton model ([1], Chapter 5). It is difficult to explain too large value of $y > 0,5$.

Another one is the experimental evidence about "too large strangeness" in proton which follows from the experiments with annihilation of proton and antiproton near threshold into mesons [2]. It turns out that in the case when initial particles are in state ${}^3P_0$ the ratio of kaon production to pion production is of order of unity:

$$\frac{Br(\bar{p}p \to KK)}{Br(\bar{p}p \to \pi\pi)} \approx 1 \tag{2}$$

contrary to the state ${}^3S_1$ where this ratio is small.

We mention here the problem of understanding of an excess of soft photons created at high energy hadrons collisions [3]. There are some uncertainties in model description of high multiplicity processes [4]. As well we mention here the long-standing problem of explanation of $\Delta T = \frac{1}{2}$ rule in weak kaon decays.

2 Physical vacuum excitation

In this note we do an attempt to understand these phenomena in frames of model of the Physical Vacuum (PV) excitement [5]. We regard PV as a Dirac cellar which can be excited when accepting some amount of energy released during the collision of initial particles (or decay of heavy initial particle). This excited state is a state containing any number of gluons and light (current) quark-antiquark pairs with quantum number of vacuum 0^{++}. We suppose the equal probabilities of presence of quark-antiquark germs of any flavor. PV excited state is similar to the state of a liquid with the temperature close to the boiling point. When the germs accept sufficient amount of energy the current quarks turn out to the constituent ones and at the hadronization stage reveals itself as a mesons or nucleons. For the case proton-antiproton annihilation the branching ration of kaon and pion production is expected to be approximately equal.

For collisions with total energy large enough to produce the charm germs or the ones of beauty the rates of production of corresponding hadrons (when taking into account the difference of phase volumes) becomes of the same order. From this point of view the experimental result (2) can be accepted. As for (1) we expect the PV contribution to $y = y_{PV} + y_I$ dominate $y_{PV} = 0,5$ for the case of proton-antiproton annihilation whereas the contribution of the intrinsic one $y_I = 0,15$ is more realistic one. In paper [6] the value of $\sigma \approx 80 MeV$ was obtained in frames of Nambu-Iona-Lazinio model with σ-pole intermediate state.

The mechanism of the meson creation from the region of the excited vacuum state of the size L remind the process of vapor bubbles creation in a hot water [7]. When the temperature do not exceed the boiling point $T < T_c$ the bubbles which are always exist in a liquid due to fluctuations do not increase. The superficial tension dominate. The situation changes in the boiling point $T = T_c$: the new phase becomes more convenient energetically and the number of the bubble of size R creation become dominate:

$$n(R) \sim exp(-\Delta W(R)/T) \sim exp(-a(T - T_c)R^3), \tag{3}$$

with $\Delta W = \Delta E - T\Delta S + P\Delta V$-free energy, $\Delta W = \frac{4\pi}{3v} R^3(\mu_1(T) - \mu_2(T)) + 4\pi\sigma R^2$, $\mu_{1,2}$ are the chemical potentials of liquid and gas phases, v, σ-the volume per one molecule and the superficial tension. It is important to note that the probability of creation of a large bubble (hadron in a gluon liquid) have a resonance form:

$$W \sim \int r^2 exp(-a(T - T_c)r^3)dr \sim \frac{1}{|T - T_c|} = \frac{1}{|M - E|}. \tag{4}$$

This expression remind the Breit-Wigner form and, presumably, can be confirmed taking into account the dynamics of this process. We can conclude that any process with possible PV intermediate state will have some enhancement, which can be associated with intermediate state with quantum numbers $I^G(J^{PC}) = 0^+(0^{++})$, so called σ-meson. The matrix element of process with production some state X with vacuum quantum numbers will have a form

$$M(ab \to cX) = \frac{1}{s_1 - M_\sigma^2 + i\Gamma_\sigma M_\sigma} M(ab \to c + PV)M(PV \to X) + ..., \tag{5}$$

with dots denoting the contributions which do not contains the σ-pole contribution; s_1-is the invariant mass square of the set of particles X.

We remind that in this way the remarkable enhancement of decay amplitudes with $\Delta T = 1/2$ in two pion modes of kaon decays can be understood [8].

Consider now the phenomenon of soft photon emission at hadrons collisions. According to our model the hot quark-gluon system appears as a result of energy accepted by PV. Germs consisting from the current (light) quark-antiquark pairs of different flavors turns to pairs of constituent (heavy) quarks and gluons which can be considered as almost equilibrium system. Almost real hadrons can be emitted from the boundary of hot vacuum surface as a real hadrons. This scenario is similar to Big Bump one resulting our Universe creation. In the last case the equilibrium between electrons, protons and photons breaks at temperature $T = 3000^0 K$ when the electron-proton recombination and the creation of a neutral atoms take place. At this stage photons cease to interact with the matter and start to expand as a relic ones. At the contemporary moment we observe the spectrum of relic photons (black body spectrum)[9]:

$$\frac{d\rho}{d\nu} = \frac{8\pi}{c^3}\frac{\nu^2}{e^{\frac{h\nu}{T}} - 1} \tag{6}$$

with $d\rho/d\nu$ - the spectral spatial density of photons, $c, h\nu$ - are the light velocity and the energy of photon. Maximum of spectral distribution is located at $h\nu_0 = 2.8 k_B T$. The temperature and the density of contemporary relic photons are $T_0 = 3^0 K$ and $480 cm^{-3}$, correspondingly.

Massless gluons interacting with quarks similarly to photons have a zero chemical potential and therefore obey the black body emission spectrum. Gluon density at the deconfinement temperature $T_c \approx 200 MeV$ can be estimated as

$$\rho_{gl} = 2.4(\frac{T_c}{T_0})^3 * 10^{-37}(fm)^{-3} \approx 0.3(fm)^{-3}. \tag{7}$$

So the number of gluons in the hot vacuum region of size $L = 20 fm$ will be of order of a few hundreds. What is the fate of them at the hadronization stage? They can not be emitted as a free particles due to their open color. Besides they can not create the colorless glueball state as well as they are mostly soft. The gluon excess are accepted by the quarks which are now heavy. These hadrons are almost on the mass shell. The energy excess is emitted by means of soft photons.

Dynamics of turning the soft gluons to soft photons is presumably as complicate as the confinement phenomenon one. We will not touch it here.

Averaging on the temperature of quark-gluon system from the beginning stage $T >> T_c$ up to $T = T_c$ at the final hadronization stage one can estimate the soft photon emission spectrum:

$$\frac{dW}{d\nu} \sim \int_0^{T_c^{-1}} d\beta f(\beta) exp(-\beta h\nu) \sim \frac{A}{\nu} f(0). \tag{8}$$

The average energy of gluons can be estimated from the total energy deficits carrying by soft photons $\Delta E \sim 10^{-2} E$ and the number of them estimated above. For the case of proton antiproton annihilation we estimate $h\nu \sim 1-2MeV$. The spectrum behavior is the same as QED soft photon emission one, but the quantity A can be an order large the QED one [10] $A_{QED} = \frac{\alpha}{\pi} \sim 2.5 * 10^{-3}$.

3 High multiplicity process

Let now consider the manifestation of PV mechanism in high multiplicity processes. For definiteness let first consider the decay of particle with rather high mass. Such as $\rho \to 4\pi; J/\Psi \to 2\pi\mu\bar{\mu}$. Matrix element will have an additional term which corresponds to 2 pions created by PV and the off mass shell meson decaying by 2 particles channel.

The quantum number of the set of pions created from PV have vacuum quantum numbers $J^{PC} = 0^{++}$ and, besides, zero total 3-momentum in the rest frame of decaying particle. The last feature is specific one for PV excitation mechanism.

It is easy to see that the corresponding contribution to the total width do not contain an interference term of traditional matrix element of n particles decay and $n-2$ decay matrix element with 2 pions created by PV mechanism. Really -the kinematics of creation are quite different.

So in general the width will have a form of some finite sum of contributions with 2 pions,4 pions and so on created through PV excitation channel.

To obtain some definite predictions we must work in frames of model (we want it to be called "a corrupt model"(CM)). We suggest the effective Lagrangian which takes into account PV excitation can be build starting from the usual one L_0 as [11]

$$L_{eff} = L_0[1 + c_2\frac{\vec{\pi}^2}{f_\pi^2} + c_4(\frac{\vec{\pi}^2}{f_\pi^2})^2 + ...], \tag{9}$$

with f_π-pion decay constant. So the matrix element of decay process of heavy object A to set of particles a, accompanied by emission of set of $2n$ pions $A(P_A) \to a+2n\pi$, some of them created through the PV excitation mechanism will have a form (see Fig. 1):

$$\begin{aligned} &< A, PV|L_{eff}|a, 2n\pi >= M_0(A \to a + 2n\pi) \\ &+\sum\nolimits_{k=1}^{n} M_k(A \to a_k + 2k\pi)M_0(a_k \to a + 2(n-k)\pi) \\ &+\sum\nolimits_{k=1}^{n} M_0(A \to a + \sigma_k + 2(n-k)\pi)M_k(a_k \to 2k\pi). \end{aligned} \tag{10}$$

where $|a_k>, |\sigma_k>$ -are the intermediate states with quantum numbers of A and vacuum respectively.

To take into account energy distribution between sets of final-state particles, we will write the phase volume in form:

$$\begin{aligned} d\Phi_{a,2n\pi} &= \delta^4(P_A - \sum p_a - \sum\nolimits_{i=1}^{2n} q_i)\Pi\frac{d^3p_a}{2\epsilon_a}\prod\nolimits_{i=1}^{2n}\frac{d^3q_i}{2\omega_i} \\ &= d^4q\delta^4(P_A - q - \sum p_a - \sum\nolimits_{i=1}^{2(n-k)} q_i)\prod\nolimits_{j-1}^{2(n-k)}\frac{d^3q_i}{2\omega_i}\prod\frac{d^3p_a}{2\varepsilon_a} * \delta^4(q - \sum\nolimits_{j=1}^{2k} q_i)\prod\nolimits_{j=1}^{2k}\frac{d^3q_j}{2\omega_j}. \end{aligned} \tag{11}$$

Keeping in mind the kinematical fact of absence of interference terms of different contributions to the matrix element the width can be put in form (we imply the rest frame of decaying particle):

$$\Gamma(A \to a + 2n\pi)(M_A) = \Gamma_0(A \to a + 2n\pi)(M_A) \tag{12}$$

$$+\sum_{k=1}^{n} \lambda_k \int_{a(k)}^{b(k)} q_0^3 P_k(q_0) dq_0 [\frac{\Gamma_0(A \to a + \sigma_k + 2(n-k)\pi)(M_A)}{(q_0^2 - M_{\sigma_k}^2)^2 + M_{\sigma_k}^2 \Gamma_{\sigma_k}^2}$$

$$+\frac{(1 - \frac{q_0}{M_A})\Gamma_0(A \to a + 2(n-k)\pi)(M_A - q_0)}{((M_A - q_0)^2 - M_{a_k}^2)^2 + M_{a_k}^2 \Gamma_{a_k}^2}].$$

with $\Gamma_0(M)$-is the width calculated in frames of standard field theory. Here we denote $a(k) = 2km_\pi, b(k) = M_A - m_a - 2(n-k)m_\pi$, and the phase volume of $2k$ particles in the nonrelativistic case [12]:

$$\int \delta(q_0 - \sum \omega_i)\delta^3(\sum_{i=1}^{2k} \vec{q}_i)\Pi \frac{d^3 q_i}{2\omega_i} = c_k((q_0 - 2km_\pi)/f_\pi)^{3k-\frac{5}{2}} = c_k P_k(q_0). \tag{13}$$

We use the realistic assumption $M(A \to a_k + 2(n-k)\pi) = M(\sigma_k \to 2k\pi) = M_k$. To realize the requirement of zero total 3-momentum of set $2k$ pions created through PV excitation mechanism, we use the (model-dependent) assumption:

$$|M_{2k}|^2 = q_0^3 \lambda_k c_k^{-1} \delta^3(\vec{q}). \tag{14}$$

The quantities M_k, Γ_k, λ_k can be considered as a free parameters.

For illustrations let consider 4-particles channels decays of ρ and Ψ':

$$\Gamma(\rho \to 4\pi) = \Gamma_0 + \Delta\Gamma_\rho, \tag{15}$$

with Γ_0 can be found in [13](and the references therein) and (see Fig. 2)

$$\Delta\Gamma_\rho = \lambda_1 \int_{2m_\pi}^{M_\rho - 2m_\pi} q_0^3 dq_0 \beta(q_0)[\frac{(1 - \frac{q_0}{M_\rho})\Gamma_{\rho \to 2\pi}(M_\rho - q_0)}{((M_\rho - q_0)^2 - M_\rho^2)^2 + M_\rho^2 \Gamma_\rho^2} + \frac{\Gamma_{\rho \to 2\pi + \sigma}(M_\rho)}{(q_0^2 - M_\sigma^2)^2 + M_\sigma^2 \Gamma_\sigma^2}] \tag{16}$$

$$\beta(q_0) = \sqrt{1 - \frac{4m_\pi^2}{q_0^2}}, \Gamma_{\rho \to 2\pi}(M) = \frac{M g_{\rho\pi\pi}^2}{48\pi}(1 - \frac{4m_\pi^2}{M^2})^{3/2}.$$

For $\Psi' \to 2\pi\mu\bar{\mu}$ decay we have $\Gamma = \Gamma_0 + \Delta\Gamma_\Psi$ with (see Fig. 3)

$$\Delta\Gamma_\Psi = \lambda_1 \int_{2m_\pi}^{M_{\Psi'} - 2m_\mu} q_0^3 dq_0 \beta(q_0)[\frac{(1 - \frac{q_0}{M_{\Psi'}})\Gamma_{J/\Psi \to \mu_+\mu_-}(M_{\Psi'} - q_0)}{((M_{\Psi'} - q_0)^2 - M_{J/\Psi}^2)^2 + M_{J/\Psi}^2 \Gamma_{J/\Psi}^2} + \frac{\Gamma_{\Psi' \to \sigma + \mu_+\mu_-}(M_{\Psi'})}{(q_0^2 - M_\sigma^2)^2 + M_\sigma^2 \Gamma_\sigma^2}] \tag{17}$$

We remind when describing the e^+e^- annihilation experiments, besides the possibility of vacuum excitation considered above for energies exceeding the ρ meson mass, the additional contributions connected with higher meson resonance excitation must be taken into account [14].

Model suggested will give the same result as in the traditional field theory for such a processes as $e^+e^- \to \pi^+\pi^-\pi^0; K^+K^-\pi^0; a\bar{a}\gamma$.

Really in our model in the center of mass frame of the initial electron and positron the sum of 3-momentum of two particles created by vacuum excitation is zero as well as the 3-momentum of the third particle.In this kinematics the PV-matrix element equals zero.

The events with possible groups of the final particles with quantum numbers of vacuum and with the zero 3-momentum in the rest frame of decaying particle can be searched at colliders with creation of large number particles such as proton-proton or nucleus-nucleus collisions, DIS-experiments.

For the last one the exclusive set up becomes to be more convenient. We consider DIS process with creation of jets with effective mass M_j;Q^2; q_0 square of momentum transferred from electron to the proton;energy transferred and two additional pions which are originated from vacuum exitation mechanism and have total 3-momentum zero (at proton rest reference frame) and energy q_0'. the corresponding cross section will have a form:

$$d\sigma^{jet+2\pi}(Q^2, q_0, M_j) = \lambda \int\limits_{2m_\pi}^{q_0-M_j} \frac{(q_0')^3 dq_0'}{(Q_1^2)^2} \times d\sigma^{jet}(Q_1^2, q_0 - q_0', M_j), Q_1^2 = Q^2 + 2q_0 q_0' - (q_0')^2 \quad (18)$$

4 Discussion

The idea of PV excitation through energy transfer to Dirac cellar remind the idea of using tadpoles in sixteenth to explain $SU(3)$-symmetry violation [15], so it is not new one.

The effective Lagrangian used above to describe multipion production was first suggested by S. Wienberg [11] in frames of current algebra and further was derived in models with nonlinear realization of symmetry [16].

PV excitation state $|\sigma_k>$ with quantum numbers of vacuum $J^{PC} = 0^{++}$ can exist as a particle with definite mass and width and, besides, as a some object which can not be interpreted as a definite particle. Situation remind the pomeron-state with quantum numbers $J^{PC} = 1^{++}$ used to describe high energy hadron hadron scattering,which can not be associated with the definite particle.

The dominant role of gluons in creation of jets at hadrons collisions was underlined in papers of Carruthers and E. V. Shuryak [17].

In paper of one of us (MKV) a reason why the ration of $K \to 2\pi$ decays matrix elements $M(K_s \to \pi^+\pi^-)/M(K^+ \to \pi^+\pi^0) \sim 50$ was given: really in the neutral kaon 2 pions decay the intermediate state with vacuum quantum numbers with mass value close to kaon mass was shown to give the dominant contribution [8]. The similar enhancement have a place in three pion decays of kaons if the corresponding scalar state with mass value close to 2pion mass exist. But in the latest case the bound state of two pions not connected with σ-meson state can be more relevant.

Another way to verify the physical vacuum excitation mechanism is to study the deep inelastic electron proton scattering with creation of hard jets and pair of pions which have zero 3 momentum in the rest frame of proton.

Formulae sited above have a rather qualitative meaning.

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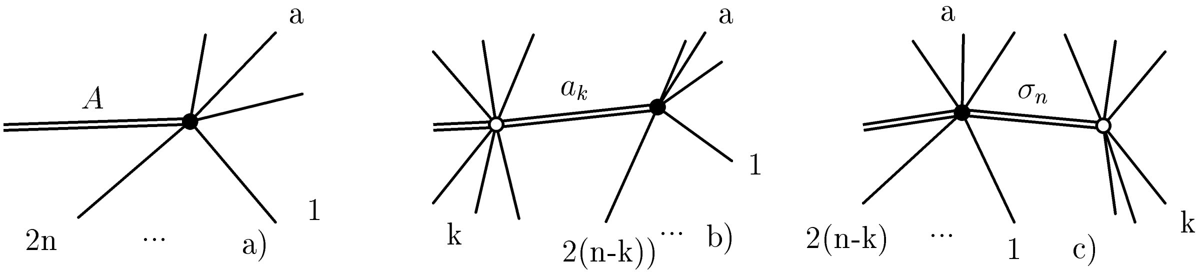

Figure 1. Contribution to decay $A \to a + 2n\pi$ matrix element: a) without PV excitation, b) $2k$ pions created through PV excitation with quantum numbers of A intermediate state. c) $2k$-pions created by PV excitation with vacuum quantum numbers intermediate state.

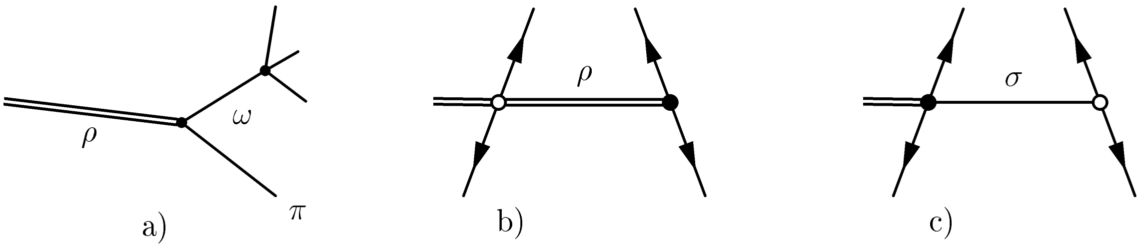

Figure 2. Feynman diagrams for $\rho \to 4\pi$ decay: a) without PV excitation, b,c) two-pion production through PV excitation.

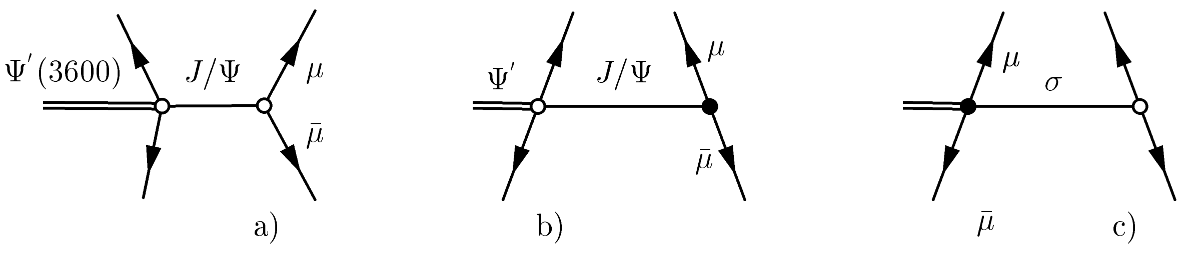

Figure 3. Feynman diagrams for $\Psi'(3600) \to 2\pi\mu^+\mu^-$ decay: a) without PV excitation, b,c) two-pion created from PV excitation.