EXCITEMENT OF PHYSICAL VACUUM

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UDC 539.12.01

The experimentally observed excess of strangeness in the proton is interpreted in a model of the Physical Vacuum (PV) excitement, suggested by the present authors. As a result, the soft photon emission spectrum as well as average energy of gluons are estimated.

1. Motivation

Motivation of this note is the need to explain some strange experimental facts in particle physics. 1.Too large value of the strangeness content $y = \langle P|\bar{s}s|P\rangle / \langle P|\bar{u}u + \bar{d}d|P\rangle$ in a nucleon. This quantity can be expressed with the experimentally measured value of the so-called σ-term:

$$\sigma = \frac{\sigma_0}{1-y}, \qquad (1)$$

with $\sigma = 80 \div 200$ MeV is the measure of chiral symmetry violation and can be expressed in terms of pion-nucleon scattering lenghts, $\sigma_0 \approx 30$ MeV and can be calculated in frames of the quark-parton model [1, Ch. 5]. It's difficult to explain too large value of $y > 0.5$.

Another experimental evidence for "too large strangeness" in a proton is provided by experiments with proton-antiproton annihilation near the threshold into mesons [2]. It turns out that in the case where initial particles are in the vacuum quantum state, the ratio of kaon production to pion production is of order of unity:

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

Both these results can be understood in frames of the model of excitement of the PV. 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 the decay of a heavy initial particle). This ecxited state is a state containing any number of gluons and light (current) quark-antiquark pairs with the quantum number of vacuum 0^{++}. We suppose the equal probabilities of the presence of quark-antiquark germs of any flavor. A PV ecxited state is similar to the state of a liquid with the temperature close to the boiling point. When the germs accept a sufficient amount of energy, the current quarks turn out to the constituent ones and, at the hadronization stage, reveal themselves as mesons or nucleons. For the case of proton-antiproton annihilation, the branching rations of kaon and pion productions are 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) become 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 $y = y_{VP} + y_I$ dominates: $y_{VP} = 0.5$ for the case of proton-antiproton annihilation, whereas the contribution of the intrinsic one, $y_I = 0.15$, is more realistic.

The mechanism of creation of mesons from the region of the ecxited vacuum state of size L reminds that of the process of creation of vapor bubbles in a hot water. When the temperature does not exceed the boiling point $T < T_c$, the bubbles which are always exist in a liquid due to fluctuations do not wax. The superficial tension dominates. The situation changes at the boiling point $T = T_c$: the new phase becomes more convenient energetically, and the number of bubbles of size R is defined as

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

where $\Delta W = \Delta E - T\Delta S + P\Delta V$ is the free energy, $\Delta W = \frac{4\pi}{3v}R^3(\mu_1(T) - \mu_2(T))R^3 + 4\pi\sigma R^2$, $\mu_{1,2}$ are the chemical potentials of liquid and gas phases, v, σ are the volume per one molecule and the superficial tension. It's 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 a possible PV intermediate state will have some enhancement, which can be associated with an intermediate state with quantum numbers $I^G(J^{PC}) = 0^+(0^{++})$, so-called σ-meson. The matrix element of the process with production of some state X with vacuum quantum numbers will have form

$$M(ab \to cX) = \frac{1}{s_1 - M_\sigma^2 + i\Gamma_\sigma M_\sigma} \times$$

$$\times M(ab \to c + \mathrm{PV}) M(\mathrm{PV} \to X) + ..., \tag{5}$$

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

We recall that, in this way, the remarkable enhancement of decay amplitudes with $\Delta T = 1/2$ in the two-pion modes of kaon decays can be understood [3].

Consider now the phenomenon of soft photon emission in collisions of hadrons. According to our model, the hot guark-gluon system appears due to the energy accepted by PV. Germs consisting from the current (light) quark-antiquark pairs of different flavors turn to pairs of constituent (heavy) quarks and gluons which can be considered as an almost equilibrium system. Almost real hadrons can be emitted from the boundary of the hot vacuum surface. This scenario is similar to the creation of our Universe. In the last case, the equilibrium between electrons, protons, and photons breaks at temperature $T = 5000$ K when the electron-proton recombination and the creation of 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 relict photons (black body spectrum)[4]:

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

where $\frac{d\rho}{d\nu}$ is the spectral spatial density of photons, $c, h\nu$ are the light velocity and the energy of photon. Maximum of the spectral distribution is located at $h\nu_0 = 2.8 k_\mathrm{B} T$. The temperature and the density of contemporary relict photons are $T_0 = 3\,\mathrm{K},\ 480\,\mathrm{cm}^{-3}$.

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

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

So the number of gluons in the hot vacuum region of size $L = 20$ fm will be of the order of several thousands. What is their fate at the hadronization stage? They can not be emitted as free particles due to their open color. Besides, they cannot create the colorless glueball state as well as they are mostly soft. The gluon excess is 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.

The dynamics of turning the soft gluons to soft photons is presumably as complicate as the phenomenon of confinement. We do not touch it here.

Averaging over the temperature of the guark-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:

$$\frac{dW}{d\nu} \sim \int\limits_0^{T_c^{-1}} d\beta f(\beta) \exp(-\beta h\nu) \sim \frac{A}{\nu} f(0). \tag{8}$$

The average energy of gluons can be estimated from the total energy deficit carried by soft photons, $\Delta E \sim 10^{-2} E$, and their number estimated above. For the case of proton-antiproton, annihilation we estimate $h\nu \sim 1 \div 2$ MeV. The spectrum behavior is the same as the QED soft photon emission one, but the quantity A can be by one order larger than the QED one [6], $A_{QED} = \frac{\alpha}{\pi} \sim 2.5 \cdot 10^{-3}$.

We are grateful to RFFI grant 03-02-17077 for supporting this work.

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ЗБУДЖЕННЯ ФІЗИЧНОГО ВАКУУМУ

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Резюме

Дано пояснення надлишку дивності у протоні, що спостерігається експериментально, за допомогою моделі збудженого фізичного вакууму, запропонованій авторами. Як результат отримано спектр випромінювання м'яких фотонів, а також середню енергію глюонів.

ВОЗБУЖДЕНИЕ ФИЗИЧЕСКОГО ВАКУУМА

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Резюме

Наблюдаемый на опыте избыток странности в протоне объясняется в модели возбужденного физического вакуума, предложенной авторами. В результате получен спектр излучения мягких фотонов, а также средняя энергия глюонов.