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A LIGHT SCALAR-HLQBS INTERPLAY AND A HLQBS WEAK DECAY TEST

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Взаимодействие легкого скаляра с тяжело-легким кварковым связанным состоянием и тест на слабый распад

Обсуждается взаимодействие между легким скалярным бозоном (бозоном Хиггса) и тяжело-легким кварковым связанным состоянием (ТЛКСС) с изменением ароматов в тяжелом секторе. Вычислены переходные формфакторы в слабых лептонных распадах псевдоскалярных ТЛКСС.

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A Light Scalar-HLQBS Interplay and a HLQBS Weak Decay Test

The interplay between a light scalar boson (Higgs) and a heavy-light quark bound system (HLQBS) in the flavour-changing of the heavy quarks is presented. The estimations of the transition formfactors in the weak leptonic decays of the pseudoscalar HLQBS are proposed.

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

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1. The experimental activity in the quarkonia (containing one heavy quark Q and one light antiquark $\bar{q}$) physics is stimulated by intense theoretical investigations around the HLQBS interactions and their transitions. We define the ground state of HLQBS as $\bar{q}\hat{O}_r Q^f(v)$ for the pseudoscalar $\hat{O}_r = i\gamma_5$ or vector $\hat{O}_r = i\hat{\varepsilon}$ mesons, where the f-flavour heavy quark field $Q^f(v)$ with the constituent quark mass $\hat{m}_Q$ and four-velocity v is related to the conventional field operator $\hat{Q}^f$ by $\hat{Q}^f = \exp(-i\hat{m}_Q vx)Q^f(v)$. The light quark q stands for a standard coloumn vector in the flavour SU(3). It is well known as much progress has been made in this area (e.g. Isgur-Wise-Grinstein heavy-quark symmetry in quantum chromodynamics (QCD) [1],...) by many authors.

The heavy-light quark bound system (HLQBS) can be well understood, because the remarkble feature is that these quarkonia are small. The QCD-oriented effective quark potential model is a good real model from which it can be extract the vertex functions (VF) of the HLQBS, the transition form-factors (TFF), the decay width,... The effective dynamical characteristics of the HLQBS are the typical internal momenta, which are defined mostly by the light quark, and the heavy quark (with the four-momentum f_Q^μ) virtuality $\nu_Q = (f_Q^2/\hat{m}_Q^2 - 1)$ which is much smaller than unity and in the limit $m_Q \to \infty$ the virtuality $\nu_Q \to 0$ (the heavy quark is almost on-shell).

2. The modern particle physics is keeping the key problem with the origin of mass. In the Standard Model (SM) the generation of vector boson and fermion masses is related to the existence of Higgs boson. The decays of the HLQBS in the flavour changing of the heavy quarks are the good current test program to search for both the light charged and neutral scalar bosons (Higgs, h) with the masses which are of an order of the QCD-hadronic scale (around $1 \div 2$ Gev mass interval). There is no the model independent both upper and lower bound on the mass of such a scalar particle. In the paper [2] the authors have established a lower bound for the Higgs-particle mass, $m_h = 18$ Mev from the neutron-nucleus scattering data at the given Higgs-boson-nucleon coupling constant. In fact, the mass of any elementary scalar boson (Higgs) is sensitive to radiative corrections, which are quadratically divergent in the SM. One of the main problem consists from the differences among the coupling constants both of the charged leptons and quarks with the light scalar particle. This is also very difficult to understand within the framework of the SM. From the phenomenological point of view the theoreticians have not yet had any correct knowledges about the Higgs states.

The possible existence of the light scalar bosons (Higgs) in the model with several scalar doublets and with a sufficiently superheavy t-quark ($m_t > m_{Z,W}$), which are consistent with the present experimental bound given by $m_t > 100$ Gev, provides the unique possibility for h-production in the decays both of the HLQBS and of the exotic heavy-light hybrid mesons, which contain the massive vector (gluonic) field (here m_t and $m_{Z,W}$ are the masses of t-quark and the gauge bosons Z,W, respectively).

3. The local interaction lagrangian for the couplings of the pseudoscalar meson to a light scalar boson h with mass m_h in the low momentum limit $\vec{p}_h \to 0$ ($m_h < \hat{m}_Q$) linear with the scalar field term can be written in the standard form (keeping both the heavy and light flavour numbers, N_H and N_L, respectively, since $m_h > \hat{m}_q$, where $\hat{m}_q$ is the light constituent quark)

$$L_{int} = -(1+\frac{h}{\eta})\sum_l m_l \bar{l}l + \frac{N}{12\pi}(\alpha_S G^a_{\mu\nu}G^{\mu\nu a})\frac{h}{\eta} - -(1+\frac{h}{\eta})^2(m^2_Z Z^\mu Z_\mu + 2m^2_W W^{+\mu}W^-_\mu), \quad N = N_H + N_L, \quad \eta \simeq 247 \text{ Gev} . \tag{1}$$

The first term in (1) represents the direct contact interaction of the h-boson with all fermions l with masses m_l , but the second term provides the effective gluon-scalar boson interaction, induced by the constituent light- and heavy- quark loops, $G^a_{\mu\nu}$ is the gluon field strength. The mass reduction $mass \to mass(1 + h/\eta)$ of all massive particles involving (1) has been account. In the case when one doublet is responsible for the up-type quark, while the other gives rise to the down-quark masses the couplings of the physical charged scalars to the up- and down-type quarks via the SU(2) coupling constant g are

$$\sum_i\sum_j \frac{g}{\sqrt{2}}\left[\frac{m_{u_i}}{m_W}\frac{1}{\tan\beta}\bar{u}_i K_{ij} P_L d_j + \frac{m_{d_i}}{m_W}\tan\beta \bar{u}_i\, K_{ij} P_R d_j\right] H^\pm + h.c.,$$

where $\tan\beta$ is the ratio of the two vacuum expectation values, $P_{R,L} = 0.5(1\pm\gamma_5)$ are the elements of the Cabibbo-Kobayashi- Maskawa (CKM) matrix.

The expression for the effective coupling constant g_{eff} of the interaction of h-boson field, {h}, with the pseudoscalar quarkonia looks like

$$g_{eff}\bar{X}_{Q_1\bar{q}}\{h\}X_{Q_2\bar{q}} = -\langle Q_1\bar{q} \mid \frac{2N}{27}\Theta^\mu_\mu + +(1-\frac{2N}{27})\sum_f \hat{m}_f \bar{f}f \mid Q_2\bar{q}\rangle\{h\}, \quad f: u, d, s, \tag{2}$$

where $X_{Q_1\bar{q}}$ and $X_{Q_2\bar{q}}$ are the HLQBS amplitudes,$\hat{m}_f$ and f are the mass and the field of any light flavours,

$$\Theta^\mu_\mu = -\frac{b\alpha_s}{8\pi}G^a_{\mu\nu}G^{\mu\nu a} + \sum_f \hat{m}_f \bar{f}f, \quad f: u, d, s,$$

$b = 11-(2/3)N_L$ is the first coefficient of the β-function, $\beta(\alpha_s) = -b(\alpha_s/2\pi)+ O(\alpha_s^2)$. To choose the truth direction in the proposal of the production of the real light scalar boson (Higgs) it is very instructive to use a σ-model (as the first step of this test) which characterized by the following lagrangian density

$$L^{eff}_\sigma = \frac{1}{2}(\partial_\nu h)^2 + \frac{1}{2}\mu^2 h^2 - \frac{1}{4}\lambda h^4 + \bar{f}(i\hat{\partial} - gh)f,$$

where g is the coupling constant of the fermion (f) - scalar (h) interaction. Based on the one-loop approximation [3] the asymptotic behaviour of the effective potential for large {h} looks like

$$V^{as}_{eff} = -\frac{1}{2}\mu^2 h^2 + \frac{1}{4}\lambda h^4 + \frac{9}{64\pi^2}\ln(\frac{3}{2})\lambda^2 h^4 + +\frac{9\lambda^2 - 4g^4}{64\pi^2}h^4 \ln(\frac{\lambda h^2}{\mu^2}), \quad (g^2/\lambda) \sim \sqrt{2}. \tag{3}$$

The negative contribution of the fermions at $g^2 > (3/2)\lambda$ leads to the fact the effective potential (3) does not limited in the negative region of the own values. Therefore, so-constructed effective asymptotic model leads to the fact the classical state point of the h-field, $\{h_{cl}\} = \mu\sqrt{\lambda}$ is unstable (wrong vacuum) at large values of the scalar boson-fermions coupling constant $g^2 \gg \lambda$ (or it means that $m_h \ll \sum m_f$ for all fermions f) and it provides the spontaneus generation of the large scalar field (Higgs). So, at $\lambda \ll g^2$ there is a domain of $\{h\} \to \{h_{as}\}$,$\{h_{as}\} > \{h\}$, where $V^{as}_{eff}(h_{as}) < V_{eff}(\mu/\sqrt{\lambda})$ and the one-loop approximation gives a real physical results at $g^4\ln(h^2_{as}\lambda/\mu^2) \sim \lambda$, but $\lambda \ll 1$ (true vacuum).

In addition to this the possibility of the production of the light scalar bosons (Higgs) in the decays $B^-(b\bar{u}) \to h^- + D^o(c\bar{u})$ and $B_c(b\bar{c}) \to h^- + \eta(c\bar{c})$ is connected with the nontrivial vacuum stability problem. The effective constant g_{eff} of the interaction between quarkonia and a scalar boson (Higgs) in (2) is defined as ($f \to (\sqrt{2}/3)f$)

$$g_{eff}\bar{X}_{Q_1\bar{q}}\{h\}X_{Q_2\bar{q}} = -\frac{2}{9}\langle Q_1\bar{q} \mid \Theta^\mu_\mu \mid Q_2\bar{q}\rangle\{h\},$$

where $g_{eff} = -(2/9)\tilde{m}$ and $\tilde{m}X_{Q_1\bar{q}}X_{Q_2\bar{q}} = \langle Q_1\bar{q} \mid \Theta^{\mu}_{\mu} \mid Q_2\bar{q}\rangle$. The heavy quarks have been integrated out of the theory. This result can be generalized on the more wide class of the theories, e.g. Glashow-Weinberg-Salam theory, that leads to the class of the limit on the masses of the scalar bosons (Higgs) and fermions in this effective asymptotic theory.

4. Since the HLQBS contains the relativistic light antiquark the hadron is assumed to obey a bound state equation (with the relativistic kinematics), whose solution as the VF $\Gamma(f_1, \tilde{f}_2, \tau\lambda \mid P)$ provides the complete information of the internal structure of the constituents with four-momenta f_1 and $\tilde{f}_2$ inside the HLQBS with four-momentum $P^{\mu}, f_1^{\mu} + \tilde{f}_2^{\mu} = P^{\mu} \pm \tau\lambda^{\mu}, \lambda^{\mu} = P^{\mu}/\sqrt{P^2}$, [4]. The relativistic covariant bound state eq. for $\Gamma(\ldots)$ is [5]: $(P + \tau\lambda)^2\Gamma(p; P \mid \tau\lambda) \simeq 8\int d\Omega_{p'}\tilde{w}(p, p'; P \mid \tau\lambda)\cdot$

$$\frac{\Gamma(p'; P \mid \tau\lambda)}{2(\lambda p')[\lambda(2p' - P) - iO]}(p'P)\left[\frac{(p'P)}{M^2}(P + \tau\lambda)^2 - \tilde{\mu}^2\left(1 + \frac{\tau}{\sqrt{P^2}}\right)\right], \quad (4)$$

where $\tilde{\mu}$ is the relativistic reduced flavour mass, $p^{\mu} = 0.5[(f_1 - \tilde{f}_2)^{\mu} + P^{\mu}(1 \pm \tau/\sqrt{P^2})(0.5 - \varepsilon)]$ is the 4- vector of relative momentum, $\varepsilon = 0.5[1 + (\hat{m}_Q^2 - \hat{m}_q^2)/P^2]$.

The interaction kernel $w(R)$ in (4) can be interpreted in $\mathcal{R}^D$ as an effective potential between Q and $\bar{q}$ with the particular colour structure of all type of the interactions including the potentials that confine two particles inside the hadron and having a rising structure with the distance R:

$$w(R) = \sum_{i<j}\sum_{a=0}^{n_f}\left\{\frac{\lambda_i^a}{2}\frac{\lambda_j^a}{2}\right\}\beta^{-1}[w_p(R < R_c) + w_{np}(R > R_c)] + U,$$

where λ_i^c are the generators of $SU(n_f)$ flavour group with $Tr\{\lambda^a\lambda^b\} = 2\delta^{ab}$, $\beta = (11n_c - 2n_f)/6$, constant $U > 0$, $w_p(R < R_c) = C(R)/R$, but $C(R)$ can be interpreted as a charge, the QCD characteristic scale on which the nonperturbative fluctuation dominates $R_c = \Lambda^{-1}\exp(-2\pi/b) = 0.12fm$ at $\Lambda = 200$ Mev, $b = (11 - 2n_f/n_c)/3$ and at $n_c = n_f$ (n_f and n_c are the numbers of flavour and colours, respectively).

In the nonperturbative region one can find the following general scalar form representation for $w_{np}(R > R_c)$ in the first order of the coupling constant (of the gauge field) g^2 in $\mathcal{R}^D$:

$$w_{np}(R > R_c) = g^2R^{\alpha}[a + bR^{\beta}\ln(\mu R)], \quad (5)$$

where α, β and a, b are arbitrary numbers and functions, respectvely, μ is the mass dimensional parameter. Note that the rising function $w_{np}(R > R_c)$

with $R \to \infty$ converts into the singular object $\tilde{w}_{np}(p^2)$ at $p^2 = 0$, because the main contribution gives the term

$$(4\mu^2/p^2)^{\frac{\alpha+\beta+D}{2}} \quad \text{at } \alpha, \beta > 0.$$

Therefore, the function (5) can be considered as a formal Fourier distribution of the generalised function $\tilde{w}_{np}(p^2)$, defined in the all p-space cutting the small region around the point $\vec{p}^{\,2} = 0$, where we have an integrable singularity as

$$(\mid \vec{p} \mid^2)^{1-\frac{\alpha+\beta+D}{2}}, \qquad 0 < \alpha + \beta < 2.$$

The propagator

$$\Delta(k) \simeq 0.5 \text{ weak} \lim_{\kappa^2 \to 0}\left[\frac{\partial^2}{\partial\kappa^2}\frac{1}{-k^2 + \kappa^2 - io} + 2i\pi^2\ln(\kappa^2/\mu^2)\delta(k)\right]$$

of the model free "gluon" scalar field G, which obeys the two-ordered quadratic differential eq. $\Box^2 G = 0$ [5], provides the leading linear-type behaviour of the potential in the lowest order of the coupling constant λ^2 in the mass units

$$w(R) \simeq (\lambda^2/8\pi)R[\gamma_E + \ln(\mu R)],$$

where $\gamma_E \simeq 0.577\ldots$ is Euler-Maskerony constant.

We shall use the following momentum distribution of the heavy- light quarks inside the hadron

$$\Gamma(p) = (E_Q + Eq - \sqrt{P^2})C_p\exp(-\tilde{\mu}^2\sinh^2\xi_p/(2\nu^2)), \quad (6)$$
$$C_p = \sqrt{P^2}/(\pi^{\frac{3}{4}}\nu^{\frac{3}{2}}), \; E_j = \sqrt{\hat{m}_j^2 + \vec{p}^{\,2}}, \; j : Q, q,$$

obtained from the solution of eq. (4) in $\mathcal{R}^3$-space with the interaction kernel (5) in the leading order at $\alpha = 2$, $\beta = 0$, predicted by the calculation of the transition amplitudes [6]. Here ξ_p is the quark rapidity and ν is the universal spring constant, accumulated the flavour independent QCD-oriented structure of the two-quark Bethe-Salpeter picture. But it is more instructive to characterise this model by the reduced constant $\bar{\nu} = [\alpha_s(M)]^{-1}\nu$, which is common to all the heavy-light flavour sector and α_s is the HLQBS mass M-dependent QCD spring constant.

5. The weak leptonic decays $(Q\bar{q}) \to l\nu_l$ have provided a valuable information on the properties of the HLQBS, in particular CKM matrix elements $\mid V_{cb} \mid$ and $\mid V_{ub} \mid$ in the B-meson decays [7]. Using the general principles of the constructing the pseudoscalar bound state amplitude on the base of the zero-relative energy reduction formalism in quantum field theory [4], it is easy to find the weak decay TFF F_p (from

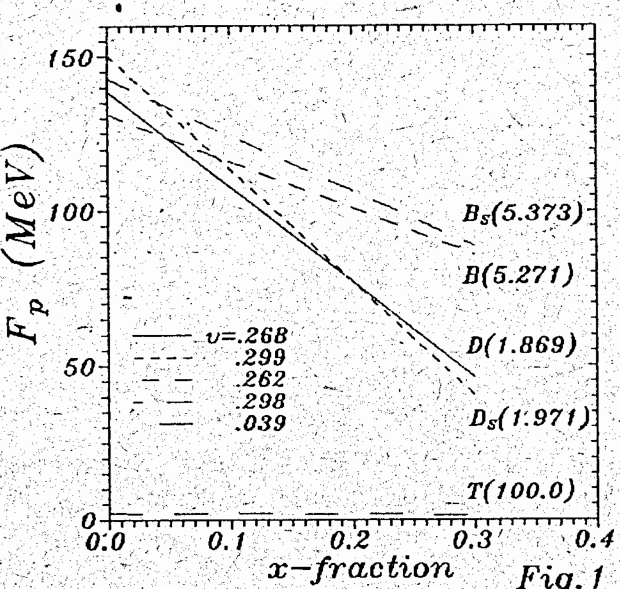

Fig. 1

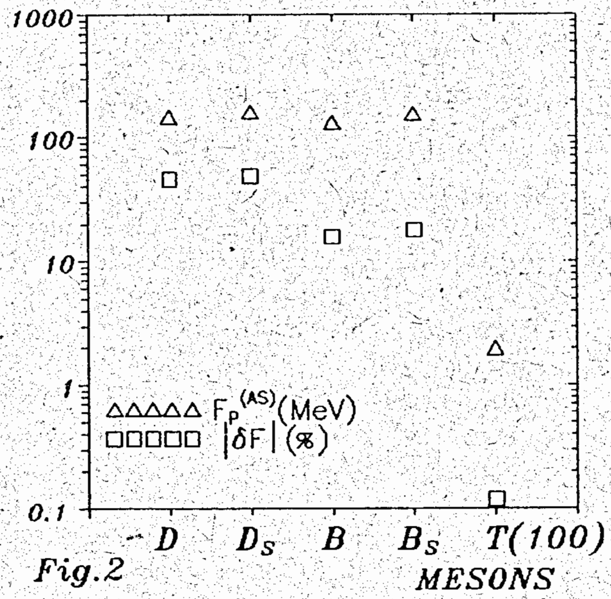

Fig. 2

$\langle 0 \mid J_\nu^5 \mid P\rangle = \sqrt{2}F_P P_\mu$, $J_\mu^5 = \bar{q}\gamma_\mu\gamma_5 Q)$

$$F_P = \frac{1}{\sqrt{2\pi}}\int \frac{d^3p}{E_Q E_q}\,\frac{\Gamma(p)}{M^2 - 4E_q^2 + io}[\Delta\, M(1-x) - 2\hat{m}_Q E_q], \quad (7)$$

where $\Delta = \hat{m}_Q - \hat{m}_q$ and by x we denote the fraction of the antiquark 4-momentum $\tilde{f}_2^\mu$ in the initial 4-momentum P^μ : $\tilde{f}_2^\mu = xP^\mu$. It is clear that in the $\hat{m}_Q \sim M \to \infty$ limit x is going to zero. The asymptotic limit of (7) at $\hat{m}_Q \to \infty$ based on the VF (6) provides the $M^{-1/2}$ asymptotic scaling law (ASL) and becomes

$$F_P^{AS} \to \frac{2\pi^{\frac{1}{4}}\nu^{\frac{3}{2}}}{\sqrt{M}}(1+\delta F)\ ,\ |\,\delta F\,| = 4\sqrt{2}\frac{\nu}{\sqrt{\pi}M}\ . \quad (8)$$

The numerical calculations both of (7) and (8) using VF (6) for D-, D_s-, B-, B_s- mesons and the exotic heavy top-quark state T(100) are given in Figs.1 and 2. The values of ν are extracted from [8].

6. • The considered above model with the σ-like fermion-light scalar boson (Higgs) interaction lagrangian (1) leads to the physical state, where the vacuum will be as unstable if the masses of the scalar (Higgs) particles would be rather small compared to the fermion (quark) sector.

• The resulting calculations for B-, B_s- and T- mesons indicate the $M^{-\frac{1}{2}}$ -ASL (for $M > 5$ Gev) at small values of x. The TFF F_D^{AS} and $F_{D_s}^{AS}$ have large corrections $|\ \delta F\ |$ (shown in Fig.2),which suggest these TFF break the ASL. Within the quark content inside the D_s-meson the TFF F_{D_s} is strongly dipped by the term in the last brackets in the r.h.s. of (7) since it must contain the mass difference $\hat{m}_c - \hat{m}_s$.

• Note that the short contributions are known in the HLQBS for a given top quark mass with a precision, e.g. for $B-$meson, of $O(< 20\%)$. Therefore, if the top quark will be found, then the study of HLQBS leads to the physical test on the non-standard physics, that gives us a more complete and precise understanding on the level $O(10\%)$. of the long-distance contributions in the transitions between heavy and light quarks.

References

[1] N.Isgur and M.B.Wise, Phys.Lett. B232 (1989) 113; idem, Phys.Lett. B237 (1990) 527; B.Grinstein, SSCL-Preprint-34 (1992).

[2] H.Leeb, J.Schmiedmayer, Phys.Rev.Lett. 68 (1992) 1472.

[3] I.V.Krive, A.D.Linde, Nucl.Phys. B117 (1976) 265.

[4] V.G.Kadyshevsky, Nucl.Phys. B6 (1968) 125.

[5] G.A.Kozlov, Nuovo Cimento A105 (1992) 139.

[6] G.A.Kozlov, Intern.Journ.Mod.Phys. A7 (1992) 1935.

[7] A.Ali, in B-Decays, ed. S.Stone (World Scien., Singapore, (1992).

[8] S.Bhatnagar, D.S.Kulshreshtha and A.N.Mitra, Phys.Lett. B263 (1991) 485.

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