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Search for hybrid baryons in the CLAS12 experiment at JLab

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We suggest a theoretical framework for the description of hybrid baryons ($qqq\,g$) bound states in relativistic model dealing with constituent quarks and gluons as building block of such exotic states. Our consideration will be based on the use of interpolating currents in terms of constituent quarks and gluon. From our point of view physics of hybrid state is promising for searching higher-Fock states in conventional hadrons – quark-gluon components.

I. HYBRID BARYONS

The hybrid baryons as bound states of three quarks in the adjoint color representation dimension 8 and a gluon can be searched by the CLAS12 Experiment (Hall B) at JLab. It calls for a comprehensive study of such exotic states. We propose a relativistic model dealing with constituent quarks and gluons as building blocks of exotic states.

One can expect that in the ground state of the hybrid its quark component is in the S-wave and symmetric color-spin (CS) state classified by the $[3]_{CS}$ Young scheme. This configuration corresponds to the maximal color-magnetic attraction of quarks in hybrid. In correspondence with the Pauli exclusion principle such a hybrid baryon is fully antisymmetic in the flavor (F) space, where its Young scheme is $[1^3]_F$. Therefore, this state must have quite definite flavor content (uds). Such flavor stucture of the hybrid state stimulates intensive production of strange particles in the reactions of photo- and electroexcitation of low-lying hybrid baryons. For example, one expects enhancement of the K meson production due to the process $\gamma^* + p \to N + 2K$ (see left diagram in Fig.1), in which the role of the uds component of the hybrid baryon is very important. Production of hybrid baryon $\Lambda^{*g}_{1/2^+}$ is a nonperturbative process, in which a gluon produced by interacting by highly energetic photon with quark is conversing into a constituent gluon g in the $g + uds$ configuration. Formation of the low-lying configuration $g + uds$ is followed by emission of K meson. It is possible a capture of emitted K mesons and production of a second hybrid resonance with quantum numbers of baryon with negative parity $N^{*g}_{1/2^-}$ (see right diagram in Fig.1), which must with big probability decay via nonstrange channell ($N + \pi$, $N + \eta$, etc.). Note that a study of processes with hybrid baryons gives a possibility to test a $3q + g$ Fock component in conventional bayrons (like nucleons, hyperons, etc.). For example in diagrams shown in Fig. 1 we propose that electroexcitation of hybrid baryons occurs due to a presence of $3q + g$ component in proton.

Our consideration will be based on the use of interpolating currents in terms of constituent quarks and gluon. In paricular, the interpolating current describing a coupling of three quarks in the adjoint color representation of dimension 8 with color constituent gluon with $J^P = 1^+$ reads

$$J_{ijk} = \varepsilon^{abc}\, G^{ad}_{\mu\nu}\, \gamma^\mu q^d_i\, q^b_j\, C\gamma^\nu q^c_k\,, \tag{1}$$

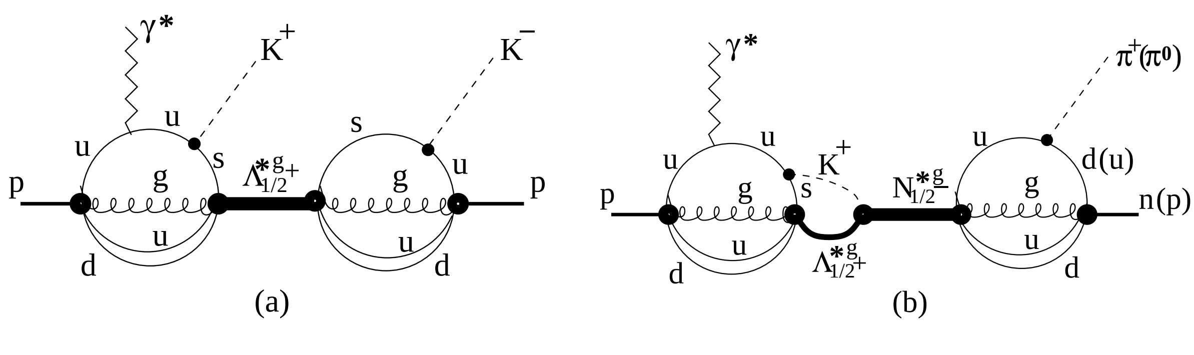

FIG. 1: Diagrams describing electroexcitation of hybrid baryons. Solid circles denote the couplings of baryons with their constituents.

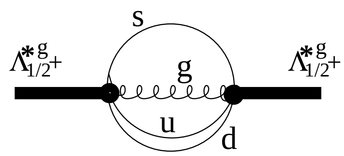

FIG. 2: The hybrid baryon mass operator.

where $C = \gamma^0\gamma^2$ is the charge conjugation matrix; i, j, k are the flavor indices; a, b, c, d are the color indices. Here q_i^a and $G_{\mu\nu}^{ad}$ are the fields representing quark and stress tensor of gluon, respectively.

The corresponding phenomenological Lagrangians describing the coupling of hybrid baryon B with its interpolating current is given by

$$\mathcal{L}_B(x) = g_B\, \bar{B}_{ijk}(x) J_{ijk}(x) + \text{H.c.} \tag{2}$$

where $J_{ijk}(x)$ is nonlocal extension of the interpolating current introduced in Eq. (1)

$$J_{ijk}(x) = \int d^4x_1 \ldots x_4\, F\Big(\sum_{i<j}(x_i - x_j)^2\Big)\, \varepsilon^{abc}\, G_{\mu\nu}^{ad}(x_4)\, \gamma^\mu q_i^d(x_1)\, q_j^b(x_2)\, C\gamma^\nu q_k^c(x_3)\,, \tag{3}$$

and $F\Big(\sum\limits_{i<j}(x_i - x_j)^2\Big)$ is the correlation function describing the distribution of three quarks and a gluon in a hybrid baryon. Such Lagrangian is an extension of relativistic quark model for mesons, baryons and tetraquarks proposed and developed in Refs. [1, 2]. The coupling constant g_B is calculated from the compositeness condition [3]

$$Z_B = 1 - \Sigma_B'(m_B) = 0\,, \tag{4}$$

where m_B mass of the hybrid baron and Σ_B' is the derivative of its mass operator, which is described by the diagram in Fig.2. Note, the compositeness condition is the powerful method in quantum field theory for study of composite bound states (hadrons, glueball, hybrid, hadronic atoms and molecules, multiquark states), which was extensively used in Refs. [1, 2, 4].

[1] M. A. Ivanov, M. P. Locher and V. E. Lyubovitskij, Few Body Syst. **21**, 131 (1996); M. A. Ivanov, V. E. Lyubovitskij, J. G. Körner and P. Kroll, Phys. Rev. D **56**, 348 (1997); I. V. Anikin, M. A. Ivanov, N. B. Kulimanova and V. E. Lyubovitskij, Z. Phys. C **65**, 681 (1995); M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij and A. G. Rusetsky, Phys. Rev. D **60**, 094002 (1999); T. Branz, A. Faessler, T. Gutsche, M. A. Ivanov, J. G. Korner and V. E. Lyubovitskij, Phys. Rev. D **81**, 034010 (2010); T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij and P. Santorelli, Phys. Rev. D **87**, 074031 (2013).

[2] S. Dubnicka, A. Z. Dubnickova, M. A. Ivanov and J. G. Korner, Phys. Rev. D **81**, 114007 (2010); S. Dubnicka, A. Z. Dubnickova, M. A. Ivanov, J. G. Korner and G. G. Saidullaeva, AIP Conf. Proc. **1343**, 385 (2011); S. Dubnicka, A. Z. Dubnickova, M. A. Ivanov, J. G. Koerner, P. Santorelli and G. G. Saidullaeva, Phys. Rev. D **84**, 014006 (2011)

[3] S. Weinberg, Phys. Rev. **130**, 776 (1963); A. Salam, Nuovo Cim. **25**, 224 (1962); K. Hayashi, M. Hirayama, T. Muta, N. Seto and T. Shirafuji, Fortsch. Phys. **15**, 625 (1967);

[4] G. V. Efimov and M. A. Ivanov, *The Quark Confinement Model of Hadrons*, (IOP Publishing, Bristol & Philadelphia, 1993).