Exotic hadrons

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Abstract. We review the modern status of exotic hadrons. It is point out that complex structure of nonperturbative QCD vacuum gives a strong influence to the properties of exotic hadrons. The importance of the investigations of exotic hadron properties in quark-gluon plasma is emphasized.

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The constituent quark models are widely used for the description of hadron properties. In the framework of such approach the most observed meson states are quark-antiquark bound states and baryons are three-quark system. However, there are no an evident reasons to forbid the existence of so-called exotic states. For example, in various versions of the constituent quark model the multiquark states with number of quark and antiquark more then three should exist as well. Moreover, the quark-gluon hybrid states and glueballs which include valence gluons are under discussion now. There are two types of exotic states. Hidden exotic states can have the same quantum numbers as the ordinary hadrons. Open exotic states have quantum numbers which impossible to obtain within quark-antiquark and three-quark model for hadrons. Some of them may be with open and hidden exotics. The history of the hadron exotics was started many years ago in a famous Jaffe's papers [1]. Unfortunately, due to large masses of exotic states one might expect that they should decay very fast to usual hadrons. However, some possible exceptions from that rule was found. One of them is famous H-dihyperon with quark content *udsuds*. Indeed, it was shown within imporved bag model, that strong flavor- and spin-dependent instanton induced interaction between quarks might lead to deeply bound H-dibaryon state [2]. We should stress that instanton induced interaction is related to the complex topological structure of QCD vacuum [3, 4]. The importance of such interaction in spectroscopy of usual and exotic hadrons was shown in many papers (see, for example, reviews [5, 6]).

Recently, the development of the exotic spectroscopy was related mainly to attempts to discribe properties of θ^+ pentaquark which was expected to have small width (about 15 MeV) and small mass (about 1540 MeV) which has been predicted within soliton model for the baryons [7]. Within the constituent quark model such state is the bound state of two *ud* diquarks and one strange antiquark [8] or the bound state of *ud* diquark and $ud\bar{s}$ in the instanton-antiinstanton field [9, 10]. Unfortunately, experimental situation around this state is highly controversial. Some of the experimental groups, e.g. [11, 12], report on the observation of this state, but other high statistics experiments (see, for example [13]) do not see such resonance. Furthermore, it was shown recently, that more pronounced LEPs data [14] might be explained by final particle rescattering effect [15].

We should also emphasize that within the quark model it is rather difficult to explain the modern experimental restrictions for the width of such resonance, $\Gamma < 1MeV$ [11]. Furthermore, the precise calculations of the θ^+ mass within the QCD sum rules [16] give larger value of its mass comparing to the soliton model prediction and show a very weak signal for the bound state. Within the soliton model θ^+ is the member of flavor antidecuplet. Therefore, if such model is correct, the other members of antidecuplet should exist as well. At the present time the candidate for nonstrange pentaquark $N^*(1685)$ is under discussion [17] and first experimental indication for the existence of such resonance was published very recently [18].

At present, increasing attention is coming to the problem of four-quark states, called tetraquarks. The interest to these states is related to the necessity to explain the scalar meson spectrum, which does not follow the predictions of naive quark-antiquark model. Central problem here is the sigma($f_0(600)$)- meson which probably has very complicated internal structure. For the long time even existence of such state was in doubts because the pion-pion scattering phase does not change on 90° at resonance. The problem has been solved in recent papers by Achasov with collaborators [19]. They show that within the sigma model the sigma-pole contribution is hidden in the large background amplitude of the pion-pion scattering. At the present time the sigma-meson is considered as a well established resonance with the mass around 440 MeV and the width about 540 MeV [20]. From the theoretical point of view the sigma-meson may include large admixture of four-quark state [21] or/and glueball [22], [23]. Furthermore, the properties of the sigma-meson in quark-gluon plasma (QGP) and in vacuum might be different. This observation open a new way to investigate the properties of QGP through changing of properties of the sigma-meson produced in heavy ion collisions [24], [25].

Very interesting bound states predicted within different QCD based approaches are hybrids, quark-gluon bound states. The famous candidate for such hybrid is $\pi(1600)$ state with exotic quantum numbers, $J^{PC} = 1^{-+}$. The evidence for $\pi(1600)$ was obtained for the first time by VES Collaboration at Protvino [26] and recently the search of this state was continued by E852 Collaboration at Brookhaven, by CLAS at CEBAF and by COMPASS at CERN. The result of the analysis of data coming from these experiments is rather controversial [27], [28], [29]. Therefore, the intensive search of hybrids is continued at several current experiments.

Glueball states are one of the firm predictions of QCD and their properties are studied in different approaches based on QCD, for example, within the lattice QCD and QCD sum rules (see review [30]). The main activity in this field is related to the investigation of low mass glueball states with zero spin and quantum numbers $J^{PC} = 0^{\pm+}$ and to tensor glueball, $J^{PC} = 2^{++}$. Recent calculations show significant mixing of zero spin glueballs with ordinary quarkonium states and therefore the ambiguity problem of theoretical interpretation of the experimental data for such states growths. From our point of view, cleaner glueball channel is the tensor channel, where the mixing with quark-antiquark states is expected to be very small.

It has been suggested that the glueballs can exist above deconfinement temperature and may play an important role in the dynamic of strongly interacting Quark-Gluon Plasma (QGP) [33, 31]. In particular, in [31] it is suggested that a very light pseudoscalar glueball can exist in QGP and might be responsible for the residual strong interaction between gluons. The lattice results showing a change of sign of the gluon condensate [32] and a small value of the topological susceptibility [35] above T_c can be explained in the glueball picture as well. Furthermore, one expects that the suppression of the mixing between glueballs and quarkonium states in the QGP leads to a smaller width for former as compared to the vacuum [33]. This property opens the possibility for clear separation of the glueball and the quark states in heavy ion collisions. Such separation is rather difficult in other hadron reactions due to existence of strong glueball-quarkonium mixing in the vacuum.

In the conclusion we would like to mention the large numbers of exotic candidates, so-called XYZ mesons, with charm quark content, which were found recently in BES-II, BELLE and BaBar experiments. Most of such states have unexpected values of the masses and widths [36]. Investigation of the hadron exotics is included also in the future experiments: PANDA (FAIR), GlueX (CEBAF) and BES-III.

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