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STABLE $S = -2$ H DIBARYON FOUND IN DUBNA

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It is shown that quasi-diffractive processes play a decisive role in the neutrals H^0 and H^+ dibaryons creation ($M_{D^+} = 1700^{+500}_{-76}$, 1250^{+500}_{-76} MeV/c^2 and $M_{D^+} = 1350^{+450}_{-85}$ MeV/c^2, respectively). A review is made of summary results from a number of papers where some convincing candidates for stable $S = -2$ H dibaryons have been revealed. The results were obtained on photographs of the JINR 2 m propane bubble chamber exposed to a 10 GeV/c proton beam. A thorough analysis of the available detection techniques and data analysis procedures has convinced that at the present reconnaissance stage the propane bubble chamber technique is adequate to the physical problem. The first results obtained suggest confidence in successful realization of investigations in the future.

The work has been performed at the Laboratory of High Energies, JINR.

Дубна — первооткрыватель стабильного $S = -2$ Н-дибариона

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Показано, что квазидифракционные процессы играют решающую роль при рождении H^0- и H^+- ($M_{D^+} = 1700^{+500}_{-76}$, 1250^{+500}_{-76} МэВ/c^2 и $M_{D^+} = 1350^{+450}_{-85}$ МэВ/c^2 соответственно) дибарионов. Представлен обзор результатов опубликованных работ, в которых были обнаружены несколько кандидатов на стабильные $S = -2$ Н-дибарионы. Результаты были получены с фотографий в 2-метровой пропановой камере, облученной протонами с энергией 10 ГэВ/с. Анализ существующих методик привел к выводу о том, что на нынешней стадии поиска дибарионов наиболее полно этой задаче отвечает методика пропановой пузырьковой камеры. Полученные первые результаты дают надежные перспективы для продолжения научных исследований.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Quark models with confinement predict the existence of exotic objects as, for instance, glueballs, hybrid states of quarks and gluons as well as multiquark hadrons. Perhaps, the most important (and exciting) among the latter are the multiquarks, stable against strong decay. The effects of vacuum are expected to become apparent most strikingly in stable multiquarks, It is important to stress that the existence of stable multiquarks is a necessary

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*In commemoration of B.A.Shahbazian

consequence of modern ideas on QCD vacuum and is a matter of principle for the comprehension of the characteristics of matter both on microscopic and cosmologic levels.

It should be noted that the detection of stable multiquarks, even of the simplest of them — the $S = -2$ stable dibaryons — is a very difficult experimental problem.

Therefore the correct choice of the detection technique and the exploration methods adequate to the physical problem are of paramount importance.

A thorough analysis of the merits and demerits of the available detection techniques and data analysis procedures has convinced us that at the present reconnaissance stage the propane bubble chamber technique is most adequate to the physical problem. Indeed, this 4π detector ensures the detection of multivertex events of the most complicated topologies unaccessible to other detectors. The moderate density ($0.41\ \mathrm{g \cdot cm^{-3}}$) and the average charge of propane ($Z = 10$) ensure measurement accuracies sufficient for reliable inclusive and exclusive multivertex kinematic analysis and identification of exotic events as well as for the successful rejection of background events able to mine the genuine ones. The relatively slow data collection is more than compensated by the high informativeness of the detected events. The scintillating fiber detectors and TPC pretending to the title of a «high speed 4π detectors» fail to compete at least today with the propane bubble chamber in the reliability of identification and measurement precision. Indeed, the density of the scintillators is $1.0 \div 1.2 \cdot \mathrm{cm^{-3}}$, i.e., 2.5 – 3.0 times higher than that of propane. This means much worse momentum and angular resolutions, especially for slow particles among which one has to seek for the bulk of the sought for heavy particles, e.g., stable dibaryons produced by K^- beams.

The correct and reliable reconstruction of a multivertex event detected in TPC reduces to the problem of image recognition that does not seem to be consistently solved. Thus both the above-mentioned techniques are today subject to growing pains, and by no means they can be considered as equivalent substitutions of bubble chamber technique.

Searching for both strange and nonstrange multiquark hadrons on photographs of the JINR 2 m propane bubble chamber (PBC) exposed to a 10 GeV/c proton beam, we have revealed a number of convincing candidates for stable $S = -2$ dibaryons [1—7]. In a part of events we have even succeeded to shed some light on the mechanism of stable dibaryon formation which seems to be bound up with long-range forces, pomeron exchanges and in the end with diffraction processes.

The dibaryons were identified via a multivertex kinematic analysis using the CERN program Grind as well as all methods of particle identification afforded by the PBC technique.

(a) First, the hypotheses on weak decays of dibaryons irrespective of the mechanism of their formation were tried.

(b) If the fits of these hypotheses were successful, «background» hypotheses possibly mining these weak decays were tried.

(c) If the latter attempts were unsuccessful, the exclusive production and weak decays of the observed dibaryons were tried.

1) The masses of these new hadrons seem to be confined to a scheme of energetic levels situated both below and above the lowest threshold for the strong decay of $S = -2$ dibaryons, i.e., $2M_{\Lambda^0}$.

The scheme is sketched below:

- A rather tightly bound (B.E. = 85 MeV/c^2) ground state H^0 of $M_{H^0} = (2146.3 \pm 1.0)$ MeV/c^2. As far the free energy is only 10 MeV/c^2 ($(M_{H^0} = M_{\Sigma^-} + M_p + 10)$ MeV/c^2), the most probable spin-parity may be $J^{\pi}_{H^0} = 0^+$. This state has been revealed via the detection of the weak decay sequence $H^0 \to p + \Sigma^-$, $\Sigma^- \to n + \pi^-$. The full (a), (b), (c) analysis has been performed [1,2].
- The first excited state H^0_1 of $M_{H^0_1} = (2195.4 \pm 9.7)$ MeV/c^2 and the most probable spin-parity $J^{\pi}_{H^0_1} = 0^+$ which rules out the electromagnetic transition $H^0_1 \to H^0 + \gamma$ and ensures the weak decay sequence $H^0_1 \to p + \Sigma^-$, $\Sigma^- \to n + \pi^-$ whose detection and the performed (a), (b), (c) analysis permitted us to reveal the H^0_1 level. Here $M_{H^0_1}$ is the weighed average of masses of events described in Refs. 3,4.
- The second excited state H^0_2 of $M_{H^0_2} = (2203.0 \pm 5.9)$ MeV/c^2 has been revealed via detection and (a), (b), (c) analysis including the electromagnetic and weak decay sequence $H^0_2 \to H^0 + \gamma$, $\gamma \to e^+ + e^-$, $H^0 \to p + \Sigma^-$, $\Sigma^- \to n + \pi^-$. The spin of the H^0_2 level should be bounded by the condition $|l - s| \le J_{H^0_2} \le |l + s|$, $s = 1$ being the spin of the γ quantum and its orbital momentum. The parity of the H^0_2 level should be $\pi_{H^0_2} = (-1)^l$ or $(-1)^{l-1}$ for 2^l-pole electric or magnetic transitions, respectively [1,2].

The electromagnetic transitions $H^0_2 \to H^0 + \begin{pmatrix} \gamma \\ e^+e^- \end{pmatrix}$ accompanied by the sequence of weak decays $H^0 \to p + \Sigma^-$, $\Sigma^- \to n + \pi^-$ are also possible. The H^0, H^0_1, H^0_2 levels were named Light $S = -2$ Stable Dibaryons.

No hypothetic positively and negatively charged counterparts of theirs have been found up to now. Instead, the levels of masses above $2M_{\Lambda^0}$ threshold named Heavy $S = -2$ Stable Dibaryons seem to form an isodoublet of neutral H and positively charged H^+ dibaryons. No negatively charged counterpart H^- has so far been detected. This fact cannot be ascribed to shortcommings of the used detection and analysis methods preventing to detect hadrons of $S = -2$ strangeness. Indeed, we have succeeded in measuring the Ξ-hyperon production cross section $\sigma\,(pp \to \Xi^- X) = (1.6 \pm 0.6)$ μb which is compatible with (7 ± 5) μb measured at CERN in *pp* collisions at 10 GeV/c.

- The Heavy Neutral Stable $S = -2$ H Dibaryon of $M_H = (2396.9 \pm 17.0)$ MeV/c^2 should probably have $J^{\pi} = 0^+$ spin-parity which rules out electromagnetic transitions $H \to H^0 + \gamma_1$ and $H^0_1 + \gamma_2$ and does not rule out weak decays $H \to p + \Sigma^-$, $\Sigma^- \to n + \pi^-$ through which the H has been detected. The full (a), (b), (c) analysis has been performed [5,6].

- The Heavy Positively Charged Stable $S=-2$ H^+ Dibaryon of $M_{H^+} = (2392.6 \pm 23.6)$ MeV/c^2 was detected and identified through the weak decay modes $H^+ \to p + \Lambda^0$ and $p + \Lambda^0 + \pi^0$, $\Lambda^0 \to p + \pi^-$. Here we succeeded only in the multivertex analyses (a) and (b) [5,6].

2) Stable dibaryons are expected to be most efficiently created in violet central collisions, especially in *A–A* ones that should be inevitably destructive for target nuclei. Contrary to this wide-spread opinion, not an event detected in PDC reveals visible blobs, evaporation protons, nuclear fragments and other objects that are indicative of considerable if not complete destruction of the target ^{12}C nucleus. Moreover some events reveal total electric charge $Q=+2$ which is characteristic of *pp* collisions. Only a group of all events has successfully stood all the three (a), (b), (c) tests. The second group has successfully stood only the tests (a) and (b).

It has been shown that in each event from the first group the stable $S=-2$ dibaryon has been created in a collision of the 10 GeV/c incident proton with an intranuclear target of baryonic number $B \geq 2$ dynamically formed during the collision. The residual nucleons always formed isotopes of $Z \leq 5$ charged nuclei with very slow recoil momenta. Their track- or rather blob-lengths amount only to fractions of the track width which is equal to 100 μm in PBC. Therefore these blobs, if visible at all, cannot be distinguished from the natural background which is due to slow δ or β electrons or even to sporadic solitary strange bubbles. All these facts are indicative of diffraction processes. For exclusive reaction channels $p + D \to H^+ + K^+ + K^+ + \pi^- + B^0$, $H^+ \to p + \Lambda^0 + \pi^0$, $\Lambda^0 \to p + \pi^-$ there exists advantageous fit for one out of two H^+. The best fit resulted for the neutron, $B=n$ hypothesis, with $\chi^2 = 0.77$ and $M_D^+ = 1350^{+450}_{-85}$. A similar analysis of the light and heavy H^0 [3,5] dibaryons led to $M_D = 1250^{+500}_{-76}$ and $M_D = 1700^{+500}_{-76}$, respectively. Thus, we were forced to state that quasi-diffractive processes («quasi» because only a part of the target nucleus is involved in the diffraction process) play a decisive role in the stable $S=-2$ dibaryon creation. This in turn means first of all decisive role played by long-range forces.

It is obvious that an exclusive multivertex analysis restoring the initial diffraction process up to the target mass is feasible when the induced intranuclear targets just over the nuclear surface and the particles produced in the diffraction process miss the residual nucleus concerving thereby their initial momentum vectors. This is the case of the first group. The events of the second group occur at smaller impact parameters when at least one of the particles resulted from the diffraction process suffers rescattering or even provocates the development of the intranuclear cascade in the residual nucleus. The restoration of the initial diffraction process in such an intermixture of different final states obviously becomes quite impossible.

At these and smaller impact parameters the probability of the intranuclear rescattaring of the weak decay products of dibaryons as well as the probability of the intranuclear conversion of slow dibaryons into two hyperons rises considerably [1—6].

- The average life-time for a weak decay of stable $S=-2$ dibaryons is no less than $3.3 \cdot 10^{-10}$ s.

- The dibaryon production effective cross section at 10 GeV/c is $\sigma(p^{12}C) < 60$ nb.

The ground state mass value M_{H^0} is close to those predicted by quark models [8—11]. In Refs. 10, 11 it was shown that the specific spin-flavour property of the instanton-induced interaction ensures strong attraction between quarks in the channel with the quantum numbers of the H^0 light dibaryon, resulting in a bound state at 2090 MeV/c^2. Recently it was shown that in the Skyrme model the $S = -2$, $I = J = 0$ dibaryon is bound by 88 MeV, i.e., has a mass 2143 MeV/c^2 [12]. There is a version of quark model which predicts the H mass compatible with $M_{H_1^0}$ and $M_{H_2^0}$ [13].

Finally, a Skryme model version [14] predicts the H mass compatible with our M_H and M_{H^+}.

In 1996, after deceased B.A.Shahbazian, the same group of authors has continued to collect statistics for strange particles V^0 and searched for stable $S = -2$ dibaryons on photographs of the JINR 2 m propane bubble chamber exposed to a 10 GeV/c proton beam. The first results obtained suggest confidence in successful realization in the future.

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