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THE OBSERVATION OF A POSSIBLE STABLE DIBARYON

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A search for Stable Dibaryon (SD) of I = 0, Y = 0, JP = 0^+ via its weak decay mode $SD \to \Sigma^- + P$ was undertaken in proton-propane interactions at 11.0 GeV/c, using 2m propane bubble chamber. A V°-particle, pointing to a two-prong interaction and satisfying the kinematics of the above two-body decay mode with a high confidence level, was found. The possibility of imitation of the observed event by background processes was investigated for a series of chains of strong reactions and for weak decays. We succeeded to show the significance of the SD-production hypothesis on a deuteron-mass fluctuon via $pd \to K^+ p K^\circ SD$ reaction. The mass of the event treated as $SD \to \Sigma^- + P$ appeared to be (2170.0 ± 1.3) MeV/c^2, its life-time being $0.676 \cdot 10^{-10}$ sec. Both are in agreement with the predictions of the MIT Bag Model for the so-called H-dihyperon. The upper limit for the production cross section of the SD in proton-propane interactions at 11 GeV/c is estimated to be 83 nb. Perhaps this event can be considered as a first evidence for a six-quark bound state - H-dihyperon.

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

Наблюдение возможного стабильного дибариона

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Предпринят поиск стабильного дибариона с квантовыми числами I = 0, Y = 0, JP = 0^+ по двухчастичной моде слабого распада $SD \to \Sigma^- + P$ во взаимодействиях протон-пропан при 11 ГэВ/с. Обнаружена V°-частица, испущенная из двухлучевого взаимодействия, с высокой значимостью, удовлетворяющая указанной моде распада. Исследованы возможности имитации этого события фоновыми процессами цепочек реакций, вызванных сильными взаимодействиями, а также слабыми распадами. Показана значимость гипотезы рождения SD на ядерном флуктоне дейтронной массы в реакции $pd \to K^+ p K^\circ SD$.

Масса частицы для гипотезы SD оказалась равной /2170,0±1,3/ МэВ/c^2. Время жизни оценивается для этого события в $0{,}676 \cdot 10^{-10}$ с. Оба эти параметра согласуются с предсказаниями модели мешков Массачусетского технологического института для так называемого Н-дигиперона. Верхний предел образования SD во взаимодействиях протон-пропан при 11 ГэВ/с оценивается в 83 нб. Возможно, это событие следует рассматривать как первое указание на связанное шестикварковое состояние Н-дигиперон.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Making up our mind to elucidate the role of baryon number, strangeness and hypercharge in strong interactions, we have investigated the invariant mass spectra of forty nine hadronic systems, varying the mentioned quantum numbers in the limits: $0 \le B \le 6$, $-2 \le S \le 1$, $0 \le Y \le 6$. It turned out that resonance peaks had revealed the invariant mass spectra of $Y \le 1$ systems only. In the exotic sector candidates in threes for $Q^6 - \Lambda p$ and $Q^4\bar{Q}^1 - \Lambda\pi\pi$ as well as in ones for $Q^6 - \Lambda p\pi$, $\Lambda\Lambda$, and $Q^9 - \Lambda\Lambda p$ were found /1/.

So far as invariant masses refer to free systems, a hypercharge selection rule was suggested: "The hypercharge of free hadrons (the multiquark ones including) cannot exceed unity $Y < 1$". Here $Y = B + s + c + b$. Because the exotic resonances as a rule are narrow and satisfy this rule, one can probably expect that the stability of a system should increase with the decrease of its hypercharge up to the formation of bound multiquark states. Experimentally this effect can be achieved if one expands the flavour assortment n_f by including s ($Y = -2/3$)-, c ($Y = -2/3$)-, b ($Y = -2/3$)-quarks (remind that $Y_u = Y_d = +1/3$) as well as by enriching the contents of a system with quarks of a particular sort of $Y = -2/3$, e.g.,with s-quarks. The latter method is especially appropriate at energies up to 10 GeV.

Thus, it is reasonable to look for stable multiquark hadrons even in systems of mixed u-, d-, s-quark contents.

Recently theoretical ideas have been siggested of the existence of $I = 0$, $Y = 0$, $S = -2$, $J = 0^+$, flavour- and color-singlet dibaryon-H-dihyperon, which should be stable against strong decays ($M = 2150$ MeV/$c^2 < 2M_\Lambda$ /2/, $M = 2164$ MeV/$c^2 < 2M_\Lambda$ /3/). If the number of flavours is

$n_f = 4$, twenty-six stable dibaryons are possible /4/, providing as mentioned by the authors, the bag model is applicable in the charmed sector of multiquark states. These suggestions come from the following theoretical considerations /5,6/: The more flavour antisymmetric the N quark wave function the stronger the color magnetic attraction. Perhaps, this is another formulation of the empirical hypercharge selection rule.

The conjectured properties of the SD /2/ suggest appropriate detection technique. The SD is permitted to decay weakly into a hyperon and a nucleon. If indeed its lifetime is only somewhat longer than the hyperonic one /2/, the detection of its decay mode SD $\to \Sigma^- + p$ is feasible by means of the bubble chamber technique.

Nothing is known about the H-production mechanism. One of possible causes of the failure of its detection in pp interactions /7/ could be the low energy, near the SD production threshold, at which the experiment was performed. This circumstance can be got over by (i) increasing incident proton momentum and (ii) using nuclear targets. Both measures inspire hopes to increase chances to produce SD (i) in direct interactions of all sorts of negative strangeness secondaries with bound nucleons, di- and multibaryon fluctuons. The yields of these secondaries are increased with the use both of nuclear targets and higher momenta incident protons (ii) in interactions of incident protons with nuclear fluctuons.

These problems were hoped to be solved, at least partly, by exposing the JINR 2m propane bubble chamber to a proton beam of a maximal momentum of 11 GeV/c at the Dubna Synchrophasotron. 330K photographs were taken up to now. They were scanned for V°-decays associated with the interactions of either incident protons or charged and neutral secondaries with hydrogen, carbon and tantalum nuclei (a target made of one to three, depending on the exposure run, metallic ^{183}Ta plates was placed in the initial part of the chamber).

All tracks of a star, the associated V°-particle and e^+e^--pairs of the converted γ-quanta, if any, were measured. The methods of identification of V°- and charged particles were given elsewhere /8/. Here it should be mentioned that each V°-decay was tested for K°-, Λ-, $\bar{\Lambda}$-, SD-hypotheses. A preliminary upper limit for good K-, Λ-, $\bar{\Lambda}$-, SD-hypotheses was set up at X (lim) = 20.0.

The summary experimental X^2-distribution for good Λ- and K-hypotheses (fig.1, solid-line histogram) was treated in the following way. First the scaling factor was fixed at $a = 1$, and the theoretical distribution was

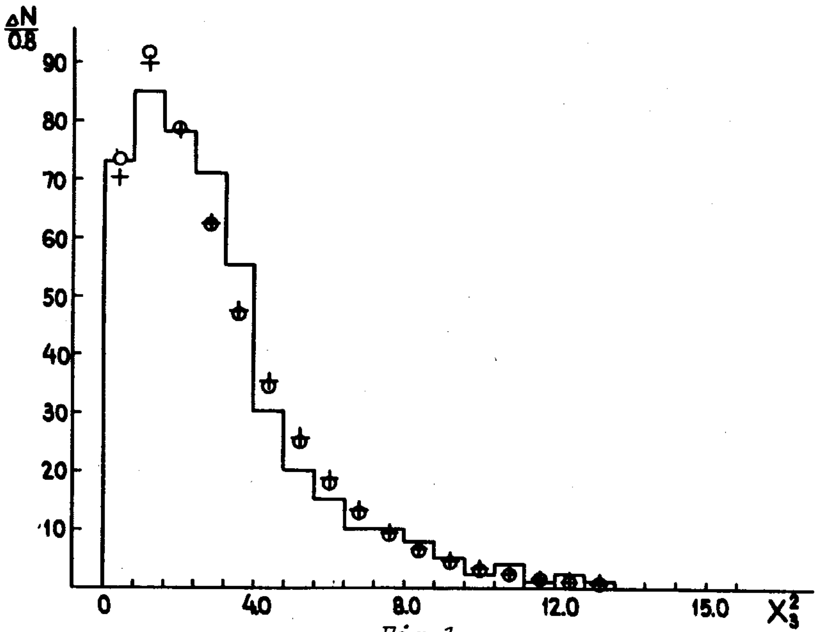

Fig.1

assumed to be X_3^2, i.e., the number of degrees of freedom was fixed at $n_D = 3$. The best fit histogram shown by crosses in fig.1 leads to $X_{12}^2 = 7.198$. Then another fit, with a and n_D as free parameters, was performed. The best fit parameters $a = 1.0109 \pm 0.0960$ and $n_D = 2.9648 \pm 0.2345$ were obtained in this case at $X_9^2 = 6.838$. The corresponding histogram is shown in fig.1 by circles. Thus, in this experiment, when estimating the probabilities of two-body decays, one can use the theoretical X_3^2 - distribution without inserting any correction.

The average values of the measured good K°- and Λ-particle masses are $M_k = (498.34 \pm 5.47)$ MeV/c^2 and $M_\Lambda = (1115.4 \pm 1.8)$ MeV/c^2 with standard deviations $S_k = 21.86$ and $S_\Lambda = 8.28$ MeV/c^2, respectively, in fair agreement with the tabular values.

Because the strict mass of the H-dihyperon presently is not yet known, we had to investigate the whole mass interval $\{(M_{\Sigma^-} + M_p), 2M_\Lambda\}$. For this purpose the H-hypothesis was tried, and the fit was performed at seven mass values distant from each other by 16 MeV/c^2, starting with $(M_{\Sigma^-} + M_p)$ and terminating at $2M_\Lambda$. If the K°-, Λ-, $\bar{\Lambda}$-hypothesis failed and one had $X_3^2(SD, M_{SD}) < 20.0$ at a particular M_{SD}, the V° -event was once more thoroughly investigated, remeasured, etc.

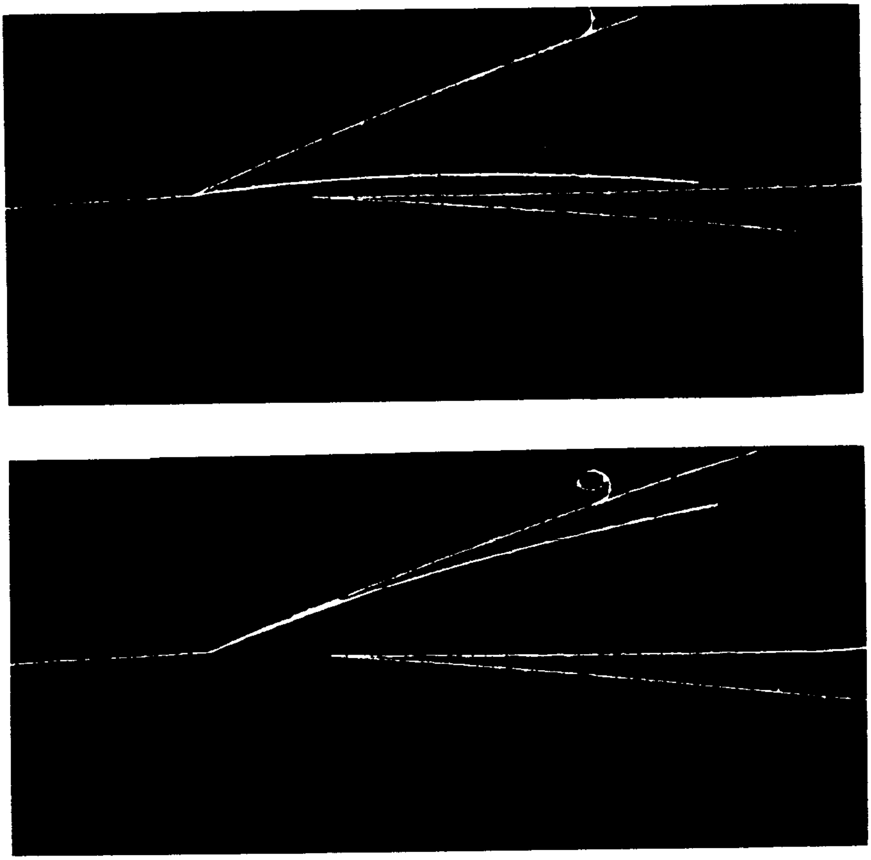

Fig.2

The systematic identification of V^{o}-events was started in May 1983. Since then possible candidates for SD were selected and processed. One of them, picked over 40K photographs in September 1983, is presented here. The photographs of two stereoviews of the event are shown in fig.2. At a point, situated at about 3/4 of the bubble chamber length, an incident proton produces a V^{o}-particle pointing to a two-prong star. Both prongs of the star are due to positively charged particles, the heavily ionizing one being a proton.

Already the first measurement and processing of this event clearly have shown the failure of K^{o}-, Λ-, $\bar{\Lambda}$-hypotheses and the success of the SD-hypothesis. In order to exclude possible accidental mistakes, the event was first measured by three operators using three different measuring devices,once measuring the corresponding end-

Table 1

Angles $\mu(\vec{L}, \vec{P}_{V^\circ})$, $\phi(\vec{L}, \vec{S})$, transversal momenta $P^{\perp}_{\Sigma^-}$ and $P^{\perp}_{p}$ (MeV/c), opening angle ψ, the distance L (cm) between the V° production and decay vertices, averaged over fifteen measurements. σ - is the error of the mean S - is the standard deviation

	$\langle\mu\rangle$	$\langle\varphi\rangle$	$\langle P^{\perp}_{\Sigma^-}\rangle$	$\langle P^{\perp}_{p}\rangle$	$\langle\psi\rangle$	$\langle L\rangle$
	04'50''	04'49''	114.0	113.0	03°27'44''	7.281
σ	06'55''	06'46''	3.0	1.0	49''	0.009
S	26'49''	26'13''	13.0	5.0	03'08''	0.034

points of tracks and for the second time the tracks were measured on each projection on their full lengths. Then the same three operators performed measurements using one and the same device in the same way. Thus, the event was measured fifteen times altogether. Several parameters averaged over fifteen measurements are shown in Table 1. Important conclusions follow from these results. Let us define the unit vector $\vec{L}$ along the direction connecting the interaction and decay vertices and the unit vector $\vec{S}$ along the projection of the summary momentum $\vec{P}_{V^\circ} = \vec{P}_- + \vec{P}_+$ on the V°-decay plane. Signs (+) and (-) correspond to the respective charge signs. From Table 1 it follows that both $\mu = (\vec{L}, \vec{P}_{V^\circ})$ and $\phi = (\vec{L}, \vec{S})$ angles are consistent with zero. The difference of the transverse momenta $\Delta = P^-_{\perp} - P^+_{\perp}$ in eight measurements occured to be positive and in seven ones - negative. Note also the proximity of $\langle P^-_{\perp}\rangle$ and $\langle P^-_{\perp}\rangle$ and smallness of the standard deviations $S(P^-_{\perp})$ and $S(P^+_{\perp})$.

All these factors suggest that the observed V° -particle either suffers two body decay or, in the case of three-or more-body decays, the summary momentum vector of all neutral decay particles has to be either collinear with $\vec{P}_{V^\circ}$ vector or has to be zero in the rest frame of the V°, within the limits of the experimental errors.

The possibility of imitation of the observed event by background processes was checked for a series of chains of strong reactions and for weak decays.

Strong Reactions

First of all, chains of trivial reactions $pp \to p\pi^+ n(m\pi^\circ)$, $m = 0, 1$, followed by $nn \to p\pi^- n$ or $n\,^{12}C \to p\pi^-\,^{12}C$ (coherently) were tried. The momentum vector of the neutron was assumed to be equal to the summary measured momentum of V° : $\vec{P}_n \equiv \vec{P}_{V^\circ}$. One-constraint kinematical fits to the reactions of the first link-failed with $X_1^2 = 142$ and $X_1^2 = 54$ for $m = 0$ and $m = 1$, respectively. A fit to the reaction $pp_F \to p\pi^+$ with the Fermi-moving target proton is also insignificant with $X_1^2 = 8.56$, C.L. = $3.7 \cdot 10^{-3}$. Nevertheless, we have estimated the expected summary yield of such events in a number of reaction chains with one and the same first-link reaction $pp_F \to p\pi^+n$ and the subsequent possible links $nn \to p\pi^-n$, $np \to pp\pi^-$, where one of the final state protons is slow and thereby unseen in the chamber and the coherent production of a $p\pi^-$-pair. For this purpose the data from papers /8-13/ were used. An independent estimate was made in the frame of the OPEM /14/ for the proton and neutron targets in both links. In the papers /8-13/ it was shown that at certain conditions the OPEM correctly describes the data at energies up to 10 GeV. As a final result of all these estimates, the summary yield of events with parameters, similar to the ones of the observed event, via the mentioned chains is less than $4 \cdot 10^{-5}$ on 40K photographs.

The fit to the next reaction chains with the first link $pp \to K^+p\pi^\circ\Lambda_1$ ($X_1^2 = 3.38$, C.L. = 6.9%) followed by $\Lambda_1 n \to p\pi^- \Lambda_2$ ($X_3^2 = 0.37$, C.L. = 94.5%) with the final state Λ_2 decaying via only the neutral mode $\Lambda_2 \to n\pi^\circ$, or $\Lambda_1{}^{12}C \to \Sigma^-\pi^+{}^{12}C$ ($X_1^2 = 0.035$, C.L. = 86.0%) with a very slow recoil ^{12}C nucleus, which is unable to form a seen track, was more successfull, though the expected yield is estimated to be less than 10^{-6} on 40 K photographs.

A second-link reaction $\Lambda_1 n \to \Sigma^- p$ is excluded by the energy-momentum conservation law.

Five other first-link reactions with the known strange particles in final states failed to fit the event ($X_1^2 \gg 10$).

Finally the hypothesis of SD-production on a deuteron-mass fluctuon, which is at rest inside a carbon nucleus, via the reaction $pd \to SDK^+K^\circ p$ was tried and proved to be successful ($X_1^2 = 1.71$, C.L. = 20.4%), with the final state K° decaying either via $K_S^\circ \to \pi^\circ\pi^\circ$ or via one of the K_L decay modes. Unfortunately, the yield of the SD is unknown but it is expected to be certainly very small.

It should be noted that both the SD-production and the excitation of background processes are also possible on heavier targets: tribaryon, tetrabaryon, etc.,fluctuons. But, unfortunately, the kinematical fit to these hypitheses is impossible. Therefore we limit ourselves only by pointing out this supplementary source of both the effect and the background.

Hypotheses of all known and possible two-body weak decay modes of all known neutral particles were tried and turned out to be insignificant (Table 2). The hypotheses of $K^{\circ}_{s} \to e^{+}e^{-}$ and $\mu^{+}\mu^{-}$ decay modes were not even tried because of inequalities $M_{e^{+}e^{-}} < M_{\mu^{+}\mu^{-}} < M_{\pi^{+}\pi^{-}} < M_{K^{\circ}}$ and the unsuccessful fit to the $K^{\circ}_{s} \to \pi^{+}\pi^{-}$ hypothesis.

Table 2

Invariant masses of V°*-particles and* X^{2}_{3} *for various two-body decay modes, averaged over fifteen measurements.* σ *- is the error of the mean,* S *- is the standard deviation*

	$\langle M_{\pi^+\pi^-}\rangle$	$\langle \Delta_{\pi^+\pi^-}\rangle$	$\chi^2_{K^\circ}$	$\langle M_{p\pi^-}\rangle$	$\langle \Delta_{p\pi^-}\rangle$	$\langle \chi^2_{\Lambda}\rangle$	$\langle \chi^2_{\Xi^\circ}\rangle$	$\langle M_{\bar{p}\pi^+}\rangle$	$\langle \Delta_{\bar{p}\pi^+}\rangle$	$\langle \chi^2_{\bar{\Lambda}}\rangle$	$\langle \chi^2_{\bar{\Xi}^\circ}\rangle$
	368.2	11.2	143.3	1557.0	49.1	312.6	51.5	1225.2	20.3	62.8	23.7
σ	1.6	0.2	6.9	5.8	0.7	21.6	0.9	2.2	0.3	1.1	0.5
S	6.2	0.8	26.6	22.4	2.7	83.5	2.9	8.6	1.0	4.3	1.8

Next the three-body decay hypotheses had to be tried. This test is a meaningful one if the two-body effective mass is lower than the mass of known particle. Thus, the hypotheses of all semileptonic decays of Λ, Ξ°, $\bar{\Lambda}$, $\bar{\Xi}^{\circ}$, assuming $P_{\nu}=0$ in the respective rest frames, led to B1- or $\bar{B1}$-effective masses which were significantly higher than the masses of the particles tried and had to be rejected. (For example, $M_{pe^-} = 1546 \pm 48$, $M_{\bar{p}e^+} = 1202 \pm 18$, $M_{\Sigma^- e^+} = 1965 \pm 50$, $M_{\bar{\Sigma}^+ e^-} = (1943 \pm 45)$ MeV/c^2, etc.).

From Table 2 it follows that only for the $V^{\circ} \to \pi^{+}\pi^{-}$ hypothesis one has $M_{V^{\circ}} < M_{K^{\circ}_{s}}$. Thus, one has to try the hypothesis $K^{\circ}_{s} \to \pi^{+}\pi^{-}\gamma$ assuming that the momentum vector of the γ-quantum is collinear with the $\vec{P}_{V^{\circ}}$ vector.

The radiative decay process $K^{\circ}_{s} \to \pi^{+}\pi^{-}\gamma$ was thoroughly studied in a number of experiments, particularly in [15,16]. It was shown that the measured spectrum agrees well with the internal bremsstrahlung spectrum.

Inserting the measured quantities and their errors into the formula for the differential branching ratio of the kaon radiative decay with the γ-quantum, emitted at solid angle around the $\vec{P}_{K^{\circ}}$-vector, defined by uncertainties of this experiment, one obtains

$$\left.\frac{d\Gamma(K_s^o \to \pi^+\pi^-\gamma)}{\Gamma(K_s^o \to \pi^+\pi^-)}\right|_{\vec{P}_\gamma || \vec{P}_{K^o}} = 1.7 \cdot 10^{-8} .$$

The yield of $K_s^o \to \pi^+\pi^-\gamma$ events on 40 K photographs is less than 10^{-5}.

The kinematical fit to this radiative decay hypothesis turned out to be successful (χ_2^2 = 9.3, C.L. = 1%).

Let us finally turn to the hypothesis of two-body $SD \to \Sigma^- + p$ decay. The measured and fitted momenta for this hypothesis, averaged over fifteen independent measurements, are given in Table 3. The decay $\Sigma^- \to n\pi^-$ is not seen on the photograph (fig.1). However, the probability of 4.95 GeV/c Σ^- to survive on a 40.92 cm track length is 10.1%.

Table 3

Measured and fitted momenta (MeV/c) for the hypothesis $SD \to \Sigma^- + p$, *averaged over fifteen independent measurements.* σ *- is the error of the mean,* S *- is the standard deviation*

	Measured		Fitted		Measured		Fitted		Measured		Fitted	
	$\langle P_{\Sigma^-}\rangle$	$\langle \Delta P_{\Sigma^-}\rangle$	$\langle P_{\Sigma^-}\rangle$	$\langle \Delta P_{\Sigma^-}\rangle$	$\langle P_p\rangle$	$\langle \Delta P_p\rangle$	$\langle P_p\rangle$	$\langle \Delta P_p\rangle$	$\langle P_{SD}\rangle$	$\langle \Delta P_{SD}\rangle$	$\langle P_{SD}\rangle$	$\langle \Delta P_{SD}\rangle$
$\langle P\rangle$	4921	413	4950	218	2900	196	2860	153	7818	459	7794	266
σ	56	8	5	3	17	2	18	2	59	8	60	3
S	216	30	188	11	65	8	70	7	227	30	231	11

The average best-fit mass M_{SD} = (2170.0±1.3) MeV/c^2 at an average minimum of χ_2^2 = 1.1±0.3, C.L. = 0.58, which is in agreement with a measured mass of (2167.9±15.3)MeV/c^2 as well as those predicted for the H-dihyperon ones: 2150 /2/ and 2164 MeV/c^2 /3/. The life-time of the event is $0.676 \cdot 10^{-10}$ sec, i.e., of the order of the hyperonic ones. This also does not contradict the conjectured life-time of the hypothetical H-dihyperon /2/.

If one identifies the observed event with the H-dihyperon, adopting thereby the branching ratio for the $H \to \Sigma^- + p$ decay mode /2/ as well as taking into account the scanning, measuring and detection efficiencies, the upper limit for the H-production effective cross section is estimated as 83 nb.

Table 4

Measured and fitted masses (MeV/c^2) and χ_3^2 averaged over fifteen independent measurements. σ - is the error of the mean, S - is the standard deviation

	Measured		Fitted	
	$<M_{SD}>$	$<\Delta M_{SD}>$	$<M_{SD}>$	$<\chi^2_{SD}>$
	2167.9	15.3	2170.0	1.1
σ	1.9	0.7	1.3	0.3
S	7.3	2.8	5.2	1.3

Resumé

Resuming this paper, one can say that the observed event fairly well fits the kinematics of the weak two-body decay of the hypothetical Stable Dibaryon, $SD \to \Sigma^- + p$ with a best-fit mass of (2170.0 ± 1.3) MeV/c^2.

It can be produced in the collision of 11 GeV/c proton with deuteron-mass fluctuon which is at rest inside a carbon nucleus.

The best-fit mass and the life-time of the SD agree well with the conjectured ones of the H-dihyperon /2,3/. Perhaps, this event can be considered as a first evidence for a six-quark bound state - H-dihyperon.

But it can be well imitated by two two-link reaction chains: with the common first-link reaction $pp \to pK^+\pi^o\Lambda_1$, and two different second-link reactions, $\Lambda_1 n \to p\pi^-\Lambda_2$ with $\Lambda_2 \to n\pi^o$ or $\Lambda_1{}^{12}C \to \pi^+\Sigma^-{}^{12}C$ with such a slow ^{12}C recoil nucleus that it cannot form a seen track.

It is appropriate to mention here that any V^o fitting the $SD \to \Sigma^- + p$ hypothesis even with a seen and proved decay $\Sigma^- \to n\pi^-$ has to be tried for the imitation by the second of the above reaction chains.

Of all two-body weak decays tried for this event, only the $SD \to \Sigma^- + p$ turned out successful. However, the hypothesis of radiative decay $K^o_s \to \pi^+\pi^-\gamma$, with $\vec{P}_\gamma \parallel \vec{P}_{K^o_s}$ also cannot be ruled out (χ^2_2 = 9.3, C.L. = 1%).

Thus, a definite conclusion of the existence of the Stable Dibaryon-H-dihyperon can be drawn on a more rich statistics of events even if of the same informativeness but with one and the same mass.

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