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I.B.Khriplovich, E.V.Shuryak

CAN A PARTICLE COMING FROM CYGNUS X-3 BE A DIHYPERON H?

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НОВОСИБИРСК

Abstract

If the mass m_H of the dihyperon is in the range $2m_n$ to m_n+m_Λ it decays via second-order weak process in about 10^4 sec, which is too fast. The case $m_H<2m_n$ is excluded by stability of nuclei, unless m_H is in very narrow gap 1.87—1.88 GeV.

Recently two groups [1, 2] have reported observation of high energy muons, correlated in position and time with the pulsar Cygnus X-3, while a signal in air showers was reported earlier [3]. The striking feature of these data is that no known particle can carry this signal to the Earth. The data look as if the primary particle is a neutral hadron, but with a lifetime at least of the order of few years, or 10^8 sec.

In ref. [4] a hypothetical dihyperon bound state H, first discussed in ref. [5], was suggested as a candidate for this role. In particular, the possibility was considered that its mass is below m_n+m_Λ, so that only a second-order weak decay is possible. An alternative, emphasized as an open issue in [6], is that its mass is below $2m_n$, so that H is absolutely stable.

Let us start with estimates of second-order weak decay rate for the process $H\to 2n$. Consider the diagram 1 where the vertices are the phenomenological amplitudes of the $\Lambda\to n\pi^0$ decay:

$$M_1=iGm_\pi^2\,(A+B\gamma_5) \tag{1}$$

Here $G=10^{-5}m_p^{-2}$ is the Fermi constant, m_π and m_p are the pion and nucleon masses , and $A=1.07$, $B=7.14$. The amplitude of the transition $\Lambda\Lambda\to nn$ in the nonrelativistic approximation equals

$$M=(Gm_\pi^2)^2\left(\frac{A^2-B^2m_\pi^2/4m_p^2}{m_\pi^2+q^2}+\frac{B^2}{4m_p^2}\right) \tag{2}$$

We have taken into account here the spin-singlet nature of the initial and final states. Note, that the second term in (2) dominates numerically and is of local kind. So we approximate the decay rate for $H \to nn$ as follows:

$$W_H = |M|^2 |\psi(0)|^2 m_n k/\pi \tag{3}$$

where k is the neutron momentum. The wave function at the origin is assumed to be

$$|\psi(0)| = \left(\frac{3}{4\pi a^3}\right)^{1/2}, \qquad a = 1 \text{ fm} \tag{4}$$

So, the lifetime of H constitutes

$$\tau_H = 10^4 (ka)^{-1} \text{ sec} \tag{5}$$

With «typical» k about 100 MeV one finds a lifetime to be about 10^4 sec, several orders of magnitude less than needed for this particle to reach the Earth. The gap is so large, that it cannot be ascribed to uncertainties of our estimates and of experimental estimates for its energy.

A loophole in this statement is a possibility that k is very small, which means that m_H is very close to $2m_n$, with accuracy about an electronvolt. Note here, that for slow neutrons the decay rate is enhanced due to large singlet nn scattering length.

Another remark is that the contribution of small distances to the amplitude of the $\Lambda\Lambda \to nn$ transition, described by the quark diagram 2, turns out to be considerably smaller than that considered above.

Now we come to another possibility, that of the stable H with $m_H < 2m_n$. It can be excluded by the stability of usual nuclei, unless m_H lies within about 10 MeV (the minimal binding energy of two neutrons in stable nuclei) below $2m_n$. Indeed, for stable H the nuclear decay

$$(Z, A) \to (Z, A-2) + H \tag{6}$$

becomes possible. Again assuming the local nature of the interaction, we consider the quantity $|M||\psi(0)|$ as an effective Hnn coupling constant. Then, if the decay is not suppressed by specific nuclear selection rules, its order-of-magnitude estimate is

$$W \sim |M|^2 |\psi(0)|^2 m_H k_H/\pi \sim 3\cdot 10^{-4}(k_H a) \quad \text{sec}^{-1} \tag{7}$$

where k_H is the momentum of the outgoing H. Therefore, the stability of usual matter excludes the existence of the bound state $\Lambda\Lambda$ with mass less than 1.87 GeV.

Summarising our discussion of the dihyperon H, we state that it cannot be a particle coming from Cygnus X-3, unless its mass lies within the range 1.87—1.88 GeV.

Concluding this Letter, we may say, that if the discussed experimental results be confirmed and the hadronic nature of the events established, the possibility that the particle coming from this pulsar is a neutral strange quark cluster with $A > 2$ should be considered. Our estimates show that third-order weak processes have the time scale comparable to the age of the universe. Thus we do not make any conclusions on the case $A > 2$.

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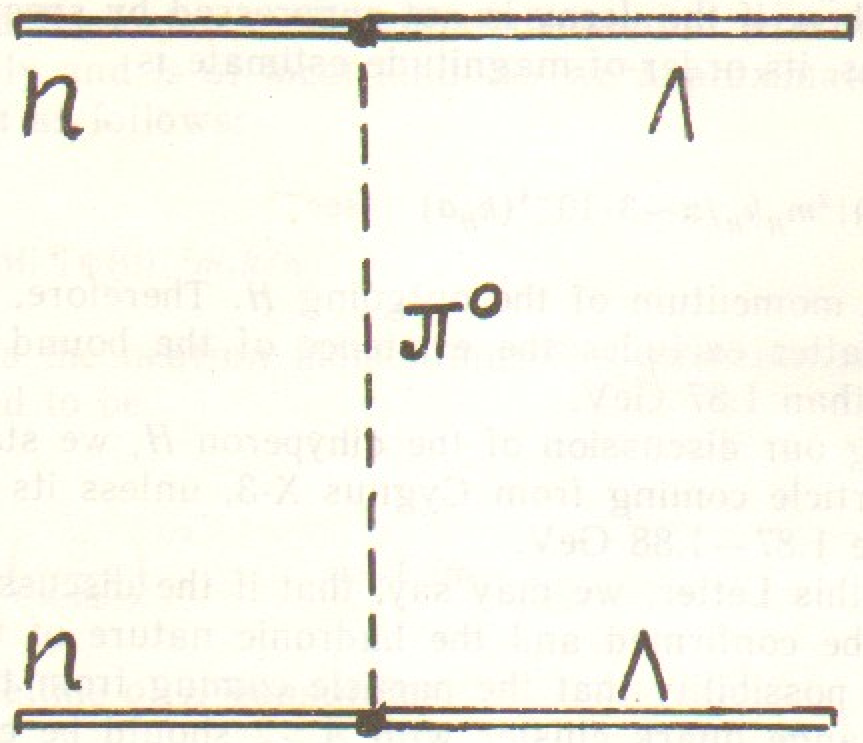

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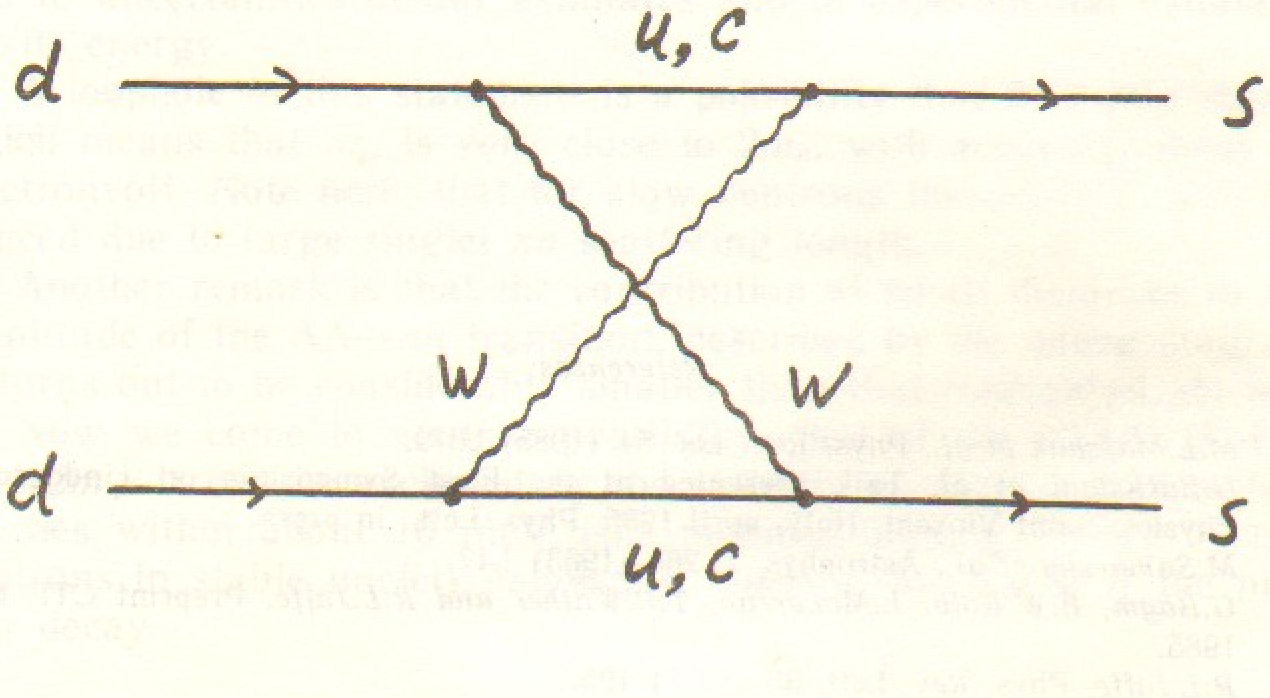

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I.B.Khriplovich, E.V.Shuryak

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