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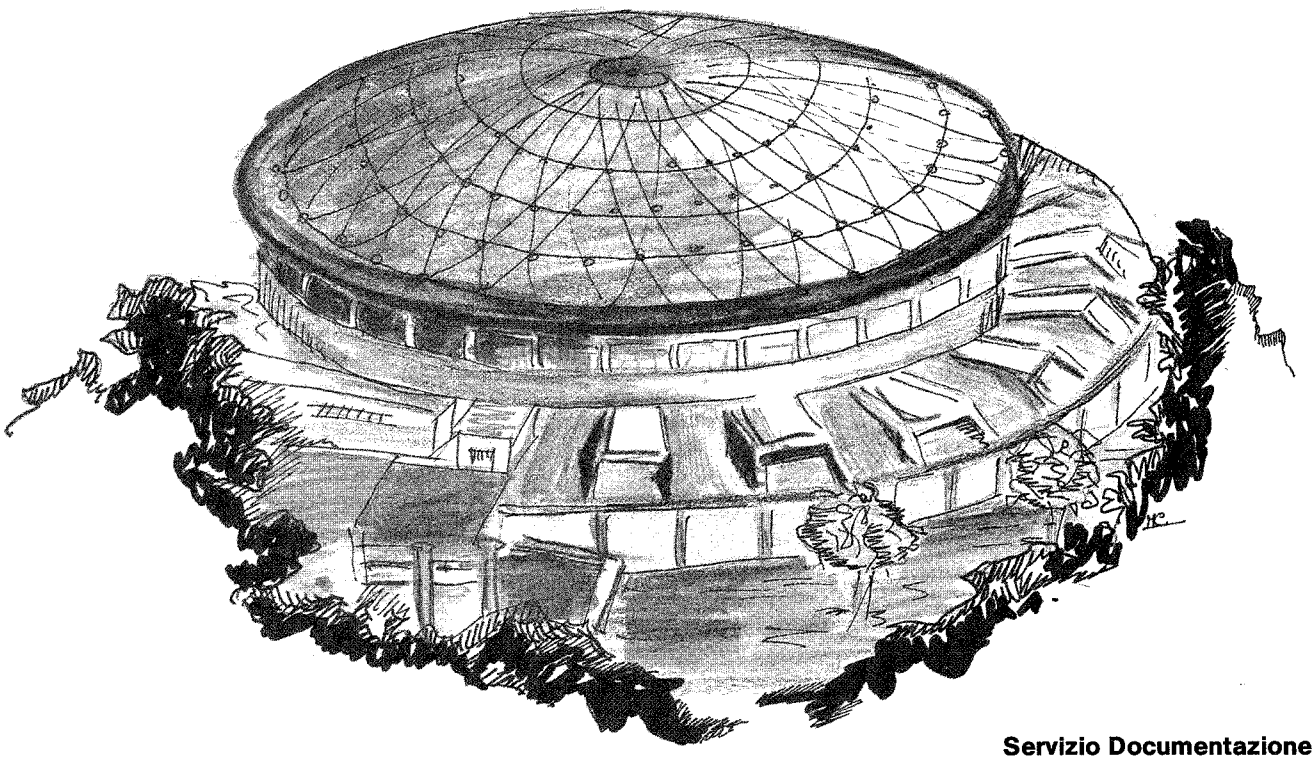

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SEMI-PONTECORVO REACTION $\bar{p}\,^3He \to \pi^- pp$ AND MULTIQUARK STATES IN HELIUM-3

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ABSTRACT

We discuss the probability of the semi Pontecorvo reaction $\bar{p}\,^3He \to \pi^- pp$ at rest and relate it to the admixture of 6q–bag in ^3He. According to our estimation, we find a branching ratio $B(\bar{p}\,^3He \to \pi^- pp) \approx (1 \div 4) \cdot 10^{-5}$, for stopped antiprotons.

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It was foreseen that some part of its operating time the OBELIX detector at LEAR [1] will use nuclear targets. Among the most non trivial channels of $\bar{p}$ A annihilations there are reactions with one or zero mesons in the final states. These Pontecorvo reactions [2] can not be realized on a single nucleon and two or more nucleons of a nucleus should be involved into annihilation process.

The reactions of two–body antiproton annihilation in deuterium were discussed in different approaches in refs. [3 ÷ 5]. As it was stressed in [3], Pontecorvo reactions are sensitive to the small internucleon separations in nuclei, where the quark degrees of freedom may play an important role.

In our recent paper [6] we discussed the probabilities of the Pontecorvo reactions

$$\bar{p}d \to \pi^- p \qquad (1)$$

$$\bar{p}\,{}^3\mathrm{He} \to pn \qquad (2)$$

at rest and related them to the admixtures of multiquark states in deuterium and helium –3. As the amplitudes of reactions (1) and (2) are sensitive to the small internucleon separation, the approach of the reduced QCD amplitude [7] was used for their analysis (see also ref.[8]). We have found rather small ratio of the probabilities of reactions (2) and (1): $R = \sigma_2/\sigma_1 \lesssim 10^{-3}$. This prediction means that, taking into account the experimental value for reactions (1) $(1.4\pm0.7)\cdot10^{-5}$ (ref. [9]) at rest, the branching ratio of the reaction (2) is very small, $B_2 \approx 10^{-8}$, and it cannot apparently be detected using the $\bar{p}$ beams available now. Such a small value of B_2 can be explained by the fact that the reaction (2) can proceed only when all three nucleons in ^{3}He are overlapped forming a 9q–bag.Therefore the probability of the reaction (2) is proportional to the admixture of 9q state in ^{3}He.

In this paper we consider the semi Pontecorvo reaction

$$\bar{p}\,{}^3\mathrm{He} \to \pi^- pp \qquad (3)$$

at rest, which involves at least two nucleons in ^{3}He.

Let us consider the Pontecorvo reaction

$$\bar{p}\text{„}d\text{"} \to \pi^- p \qquad (4)$$

where antiproton annihilates on a correlated (pn) pair in ^{3}He, which we call as quasideuteron „d" (see Fig. 1a).

According to refs.[6,8] the amplitude of reaction (4) is proportional to

$$\psi^{"d"}_{eff}(0) = \int d^3k \sqrt{\frac{m}{\varepsilon_k}} \psi^{"d"}(k) \qquad (5)$$

where $\psi^{"d"}(k)$ is the wave function of the (pn) pair in the momentum representation, m is the nucleon mass, $\varepsilon_k = (m^2+\mathbf{k}^2)^{1/2}$. The factor $\sqrt{\frac{m}{\varepsilon_k}}$ is due to relativistic corrections and will be ignored in our estimations.

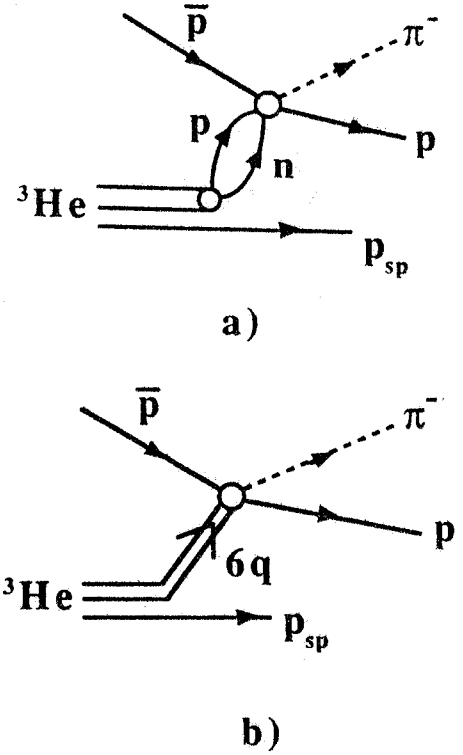

FIG. 1 - The graphs describing the semi–Pontecorvo reaction $\bar{p}\,{}^3He \to \pi^- pp$: annihilation of antiproton on two nucleons (a) and on the 6q–bag (b).

Let us consider the ratio of the probabilities of reactions (4) and (1)

$$\frac{\sigma_4}{\sigma_1} = \frac{|\psi^{"d"}_{eff}(0)|^2}{|\psi^{d}_{eff}(0)|^2} \qquad (6)$$

The value of $|\psi^{d,eff}(0)|^2$ which was found in ref. [6] using the experimental data [9] on the branching ratio $B(\bar{p}\,d \to \pi^- p)$ at rest is equal to:

$$|\psi^{d}_{eff}(0)|^2 = (1 \div 3)\cdot 10^{-5}\ GeV^3 \qquad (7)$$

This value agrees fairly well with the prediction of the hybrid model of deuteron (see e.g. ref. [10] where the nucleons inside deuteron fuse into 6q–bag when they are at the distance $r \le r_0$

$$|\psi_d^{eff}(0)|^2 = P_B\,|\psi_B(0)|^2 = (2.6\div 6)\cdot 10^{-5}\ \mathrm{GeV}^3 \qquad (8)$$

for $r_o = (0.7 \div 1.06)$ fm.

The quantity (8) was found considering the Gaussian parametrization of two-baryon component of the 6q-bag :

$$\psi_B(r) = (\sqrt{\pi}\,b)^{-3/2} \exp(-r^2/2b^2)$$

$$b = \sqrt{\frac{8}{3}}\,R_{6q}^{rms} \qquad (9)$$

To find the ratio σ_3/σ_1 between the probabilites of reactions (3) and (1) we shall use the hybrid model of ^{3}He considered in refs. [11,12]. When the critical distance between two nucleons in ^{3}He is equal to r_o=1fm, the 6q-bag admixture in ^{3}He was found to be

$$P_{6q} = (6\div 8)\%. \qquad (10)$$

The differential cross section of the reaction (3) can be written as

$$\frac{d^5\sigma}{d\Omega_\pi d^3p_{sp}} = 2\,P_{6q}\,\frac{d\sigma_{,p"d_{..}}}{d\Omega_\pi}\,|\psi(\mathbf{p}_{sp})|^2 \qquad (11)$$

where $|\psi(\mathbf{p}_{sp})|^2$ describes the relative motion of 6q-bag (dinucleon) and a spectator, and the factor 2 counts the number of (pn)–pairs in ^{3}He.

The reaction (3) will have a rather distinctive momentum distribution of the 3 charged particles in the final state: a fast proton and a π^- with momenta about 1.2 ÷ 1.25 GeV/c, flying almost back to back and a slow proton spectator. Integrating over the spectator momenta we find for the ratio of the cross-section σ_3 and σ_1:

$$\frac{\sigma_3}{\sigma_1} = 2\,\frac{P_{6q}}{P_B}\left(\frac{r_O^d}{r_O^{^3He}}\right)^3 = 2\div 3. \qquad (12)$$

At rest $B_2 = (1.4 \pm 0.7)\cdot 10^{-5}$ (ref.[9])
Therefore we get

$$B_3 = (1.5 \div 6)\cdot 10^{-5}\,\frac{\sigma_{inel}(\bar{p}d)}{\sigma_{inel}(\bar{p}\,^3He)} \qquad (13)$$

where $\sigma_{inel}(\bar{p}d)$ and $\sigma_{inel}(\bar{p}\,^3He)$ should be taken at the same $\bar{p}$ lab momentum.
Taking $\sigma_{inel}(\bar{p}d)\ /\ \sigma_{inel}(\bar{p}\,^3He) = 2/3$, we find the value

$$B_3 \approx (1 \div 4) \cdot 10^{-5} \qquad (14)$$

which is quite feasible to be measured at OBELIX.

The measurement of the probability of semi-Pontecorvo reaction (3) would give new interesting information on short range structure of ^{3}He and in particular on the probability to find 6 quarks in ^{3}He overlapping in a volume comparable with the confinement radius. Note that the reaction $\bar{p}$ „d" $\rightarrow \pi^- p$ is essentially different from the pion absorption by a pair of nucleons at rest. Firstly, the energy which is released after annihilation is much larger and, secondly, QCD dynamics of those reactions are expected to be very different, as the pion is a Goldstone particle. Among the next steps, it would be very interesting to study semi-Pontecorvo reactions with strange particles:

$$\bar{p}\,{}^3\mathrm{He} \rightarrow \quad K^0 \Lambda p \qquad (15)$$

$$\bar{p}\,{}^3\mathrm{He} \rightarrow \quad K^+ \Sigma^- p \qquad (16)$$

as well as energy and angular dependence of the Pontecorvo amplitudes. One can think that this investigation might reveal new interesting phenomena important for better understanding of QCD dynamics of multiquark systems.

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