ISSN 0029-3865

CBPF-NF-036/91

ON THE DECAY $D_s^+ \to p\bar{n}$

by

Ignacio BEDIAGA[1] and Enrico PREDAZZI[2,3]

[1]Centro Brasileiro de Pesquisas Físicas - CBPF/CNPq
Rua Dr. Xavier Sigaud, 150
22290 - Rio de Janeiro, RJ - Brasil

[2]Dipartimento di Fisica Teorica
Universita di Torino
Italy

[3]Istituto Nazionale di Fisica Nucleare (INFN)
Sezione di Torino
Italy

Summary Classical arguments are used to show that the decay $D_s^+ \rightarrow p\bar{n}$ could be an indicator of whether or not the axial current is conserved at large q^2. Keeping the $\pi(1300)$ as the most relevant contribution to the form factor associated to the fourdivergence of the axial constant we find indications that the decay $BR(D_s^+ \rightarrow p\bar{n})$ could be as large as $\sim 1\%$.

Key-words: Charm decay; Axial current conservation.

As it is by now well recognized, the discrepancy between the data and the theoretical expectations of the naive (spectator) model for the non-leptonic decays of pseudoscalar charmed mesons is the direct consequence of strong interaction effects.

In this paper we suggest that the decay $D_s^+ \longrightarrow p\bar{n}$ could be measurable and could provide additional direct evidence of these non leptonic decays.

The matrix element for the above decay can be expressed in terms of the usual form factors associated with the (first class) currents of β decay and to the D_s decay constant $f_{D_s^+}$ as [1]

$$\begin{aligned} \mathcal{M} \;=\; & -\frac{G}{\sqrt{2}} i\, f_{D_s} \cos^2\theta_C\, q_\alpha\; f_1(q^2)\bar{u}_p\gamma^\alpha v_n \,+ \\ & +\; i\; f_2(q^2)\bar{u}_p\sigma^{\alpha\beta}q_\beta v_n \;-\; g_1(q^2)\bar{u}_p\gamma^\alpha\gamma^5 v_n \\ & -\, g_2(q^2)q^\alpha\bar{u}_p\gamma^5 v_n \end{aligned} \tag{1}$$

CVC (i.e. the neglect of the neutron-proton mass difference) makes the contributions of the vector currents totally negligible. By contrast, the axial vector current is not conserved at small q^2 values. The fourdivergence of the axial current vector is given by

$$< p\bar{n}|\partial_\mu A_\mu|0 >= G_A(q^2)\bar{u}_p\gamma^5 v_n \tag{2}$$

where $G_A(q^2)$ is given by

$$G_A(q^2) = 2m_N g_1(q^2) + q^2 g_2(q^2) \tag{3}$$

in which $g_1(q^2)$ is known as the axial form factor and $g_2(q^2)$ as the induced pseudoscalar form factor.

In general it is supposed that $G_A(q^2)$ tends to zero as $|q|^2 \rightarrow \infty$ or, more generally, that it obeys an unsubtracted dispersion relation [2]

$$G_A(q^2) = \frac{1}{\pi}\int_{-\infty}^{0} d\,q'^2\,\frac{Im G_A(q'^2)}{q'^2 - q^2}. \tag{4}$$

The latter requirement is highly non trivial; it implies [3] a complete cancellation between $2m_N g_1$ and $q^2 g_2$ when $|q|^2 \to \infty$. This need not be the case at the finite q^2 values we are considering.

The poles that can contribute to this form factor have quantum numbers $(I^G, J^P) = (1^-, 0^-)$. Thus, we can expect contributions from the π meson and from the $\pi(1300)$ (which we will refer to as π' in what follows) i.e. we shall write

$$G_A(q^2) = \frac{\sqrt{2}m_\pi^2 f_\pi g_{\pi NN}}{q^2 - m_\pi^2} + \frac{\sqrt{2}m_{\pi'}^2 f_{\pi'} g_{\pi' NN}}{q^2 - m_{\pi'}^2}. \tag{5}$$

For $q^2 << m_{\pi'}^2$ the first term dominates and the second can be replaced by a constant as anticipated [4]. In our case, $q^2 = m_{D_s}^2$ the first term is negligible and G_A is dominated by the π' pole.

For the Goldberger Treiman relation not to be violated, in eq. (5) we must have $f_{\pi'} g_{\pi' NN} << f_\pi g_{\pi NN}$ or, rather, it must be less than the difference between the experimental value and the value obtained theoretically from this relation. Using eq. (1), the width for $D_s^+ \to p\bar{n}$ is given by

$$\Gamma(D_s^+ \to p\bar{n}) = \frac{G^2}{16\pi} f_{D_s}^2 \cos^4\theta_c 2m_N g_1(m_{D_s}^2) \ + \ m_{D_s}^2 g_2(m_{D_s}^2)^2 m_{D_s} \sqrt{1 - \frac{4m_N^2}{m_{D_s}^2}} \tag{6}$$

The above can be compared with the decay

$$D_s^+ \to \tau^+ \nu_\tau \tag{7}$$

which we read off from

$$\Gamma(D_s^+ \to l^+ \nu_l) \ = \ \frac{G^2}{8\pi} f_{D_s}^2 \cos^2\theta_C m_l^2 m_{D_s} \left(1 - \frac{m_l^2}{m_{D_s}^2}\right)^2 \tag{8}$$

(where l is any lepton) so as to eliminate the factor f_{D_s} to which a large undetermination is attached. We find, for $l = \tau$

$$\frac{\mathrm{BR}(D_s^+ \to p\bar{n})}{\mathrm{BR}(D_s^+ \to \tau^+\nu_\tau)} \ = \frac{\cos^2\theta_c}{2m_\tau^2}\left(1 - \frac{4m_N^2}{m_{D_s}^2}\right)^{\frac{1}{2}} G_A^2(m_{D_s}^2)\,(1 - m_\tau^2/m_{D_s}^2)^{-2} \tag{9}$$

which, using $cos\theta_C \approx 0.97$ for the cosine of the Cabibbo angle, gives us the fundamental relation

$$r \equiv \frac{\mathrm{BR}(D_s^+ \to p\bar{n})}{\mathrm{BR}(D_s^+ \to \tau^+\nu_\tau)} \simeq 5G_A^2(m_{D_s}^2). \tag{10}$$

Measurements of the D_s^+ decays can, in principle, give a direct estimate of $G_A(q^2)$ via eq. (10). Here, however, we wish to turn things around and give an evaluation of the decay $D_s^+ \to p\bar{n}$ using what is known about $G_A(q^2)$. For this we need some estimate of $f_{\pi'}g_{\pi' NN}$. We shall try to get the latter from the knowledge of the form factors g_1 and g_2 of eq. (3).

$g_1(q^2)$ is phenomenologically fairly well known up to rather large (spacelike)$|q|^2$ values from $\nu N \to \mu N$ scattering and is parametrized as $g_1(q^2) \approx 1.26/(1+q^2/m^2)^2$ where, from fitting the data (see ref. [1] p. 296), one finds $m \sim 0.95 GeV/c^2$. As customary [5] we assume that we can continue this form from spacelike to timelike q^2 values.

The only measurement of g_2, by contrast, goes back to an old suggestion of measuring it in muon capture [6]. Thus, our knowledge of g_2 is confined to $q^2 \approx m_\pi^2$ i.e. much smaller than we need it. In order to overcome this difficulty, we can proceed in two alternative but basically equivalent ways. Firstly, we may, for instance, use for g_2 an unsubtracted dispersion relation and retain for it just the π' contribution (since the π term is here negligible and we neglect also the A_1 contribution) i.e.

$$g_2(q^2) \approx \frac{\sqrt{2} f_{\pi'} g_{\pi' NN}}{m_{\pi'}^2 - q^2}. \tag{11}$$

Using eqs.(3,5,11) and the value of $g_1(q^2)$ at $q^2 = m_{D_s}^2$, one finds

$$f_{\pi'} g_{\pi' NN} \approx 0.2 GeV. \tag{12}$$

One could object at assuming an unsubtracted dispersion relation for g_2 dominated by the π' pole. In this case, one could resort to demanding that the Goldberger Treiman be not violated by more than allowed by the data. This leads to exactly the same estimate as in eq. (12). Using the above estimate in eq.(5), from eq.(10) we have

$$r \approx 0.2. \tag{13}$$

From the above result we are led to conclude that the branching ratio for $D_s^+ \to p\bar{n}$ could be as large as $\approx 1\%$ (this estimate assumes also $f_{D_s} \approx 0.2GeV$ as suggested by theoretical considerations and depends also on the $\pi'(1300)$ width which is only quite poorly known [7]).

If our estimate is correct, this decay seems in principle not outside the possibility of detection at existing apparatus and could certainly be measured in future experiments.

In conclusion, we believe that the experimental observation of the D_s^+ decay mode into $p\bar{n}$ could be interesting on several counts: i) it would provide a direct evaluation of the extent to which the axial current is not conserved (at this values of q^2), ii) it would provide a value of the induced pseudoscalar form factor and, finally, iii) it would provide a direct information on its microscopic structure, since such a decay can only occur because of non spectator diagrams (e.g. to the so-called W-annihilation diagrams). As in the case of another rare decay mode suggested earlier [8] and dutifully found, the detection of such a decay would be very useful in discriminating among models striving to explain the differences between the lifetimes of the pseudoscalar charmed mesons D^+, D^0 and D_s^+.

Acknowledgements. We would like to thank M. Anselmino, R. Covolan and E. Menichetti for useful discussions. One of us (I. B.) would like to thank for its hospitality the Dipartimento di Fisica Teorica of the University of Torino where this work was completed.

References.

[1] See, e. g., E. D. Commins and P. H. Bucksbaum: *Weak interactions of leptons and quarks*, Cambridge Press Univ., New York (1983).

[2] J. Bernstein: *Elementary Particles and their Currents*, W. H. Freeman and Co., S. Francisco (1968).

[3] V. de Alfaro et al. *Currents in Hadron Physics*, North Holland, Amsterdam (1973).

[4] R. E. Marshak et al.: *Theory of Weak Interactions in Particle Physics*, Wiley Interscience, New York (1969).

[5] G. E. Brown et al.: Nuc. Phys. **454** A(1986) 669.

[6] J. Leite Lopes: Phys. Rev. **109** (1958) 509; L. Wolfenstein, N. Cimento **8** (1958) 882; A. Fujii and H. Primakoff, N. Cimento **12** (1959) 327.

[7] Particle Properties Data Group; Phys. Lett. **239** B (1990), 1.

[8] I. Bediaga and E. Predazzi; Phys. Lett. **199** B(1987) 131.