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Possible improvements on the mass of ν_τ using leptonic $D_s^\pm$ decays

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Abstract

We show how a very accurate measurement of the branching ratios of the leptonic decay modes of the $D_S^\pm$ mesons can lead to an improvement in the mass limit for the tau neutrino.

1. Introduction

The last few years have seen growing evidence for non-vanishing neutrino rest masses in the results from neutrino oscillation experiments [1]. However, the direct bounds on neutrino masses remain rather weak. While the electron neutrino mass is known to be smaller than about 2.2 eV [2], the muon neutrino mass has to be smaller than 170 keV [3], a bound about 5 orders of magnitude worse and still as high as 30% of the electron mass. The situation is even worse by another two orders of magnitude for ν_τ which is known from ALEPH to be smaller than 18.2 MeV [4]. In this Letter we explore leptonic $D_S^\pm$ decays for improving on the bound of ν_τ.

2. Leptonic $D_S^\pm$ decays

In the standard model the leptonic branching ratios of $D_S^\pm$ are given as

$$\mathrm{BR}\big(D_S^\pm \to l\bar{\nu}_l\big) = \frac{G_F^2}{8\pi}|V_{cs}|^2 f_{D_S}^2 \tau_{D_S} m_{D_S} m_l^2 F\left(1-\frac{m_l^2}{m_{D_S}^2}\right)^2 \qquad (1)$$

with V_{cs} is the corresponding CKM matrix element, τ_{D_S} the $D_S^\pm$ life-time, m_{D_S} the mass of the $D_S^\pm$, f_{D_S} the decay constant and m_l the lepton mass, and F is a phase-space factor which depends on the neutrino mass ($F=1$ when neutrino mass is zero). Several quantities cancel when the ratio of two leptonic branching ratios is taken and furthermore this ratio is quite sensitive to the ν_τ mass [5]. Neglecting the muon

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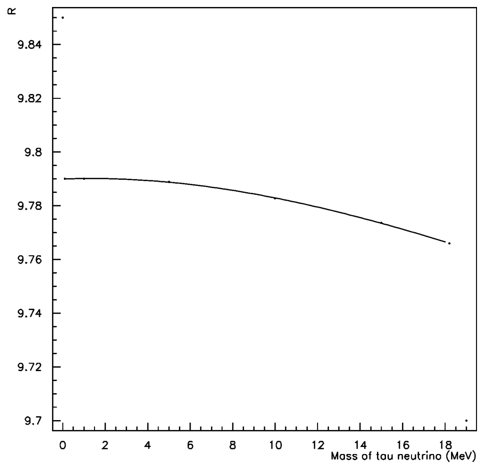

Fig. 1. The ratio R defined in Eq. (2) as a function of the mass of ν_τ. The existing upper bound on m_{ν_τ} obtained by ALEPH is 18.2 MeV. No radiative corrections are included. For details see text.

neutrino mass to first approximation, the ratio between muonic and tauonic decays can be parametrized as a function of ν_τ mass to first order in m_{ν_τ}

$$R = \frac{(D_S^\pm \to \tau\nu_\tau)}{(D_S^\pm \to \mu\nu_\mu)} = R_0(m_\nu = 0) \times \left(1 - C\left(\frac{m_{\nu_\tau}}{m_\tau}\right)^2\right), \tag{2}$$

R_0 is obtained as

$$R_0(m_\nu = 0) = \frac{m_\tau^2}{m_\mu^2}\,\frac{(1 - m_\tau^2/m_{D_S^\pm}^2)^2}{(1 - m_\mu^2/m_{D_S^\pm}^2)^2} = 9.79, \tag{3}$$

C is given by

$$C = \frac{3(m_\tau/m_{D_S^\pm})^4 - 1}{(1 - (m_\tau/m_{D_S^\pm})^2)^2} = 28.77. \tag{4}$$

The values were obtained using $m_\tau = 1777$ MeV and $m_{D_S^\pm} = 1969$ MeV [11]. The ratio R as a function of m_{ν_τ} is plotted in Fig. 1. As expected, the figure shows that the ratio decreases as the mass of ν_τ is increased. Furthermore, it follows from Eq. (4) that to improve the bound on m_{ν_τ} down to 10 MeV would correspond to a 0.1% effect on R only. To achieve the latter bound would be especially interesting, because it would close the window for observation of a MeV Majorana neutrino in double beta decay via atomic mass dependent effects [6,7].

We have not yet discussed the role of radiative corrections to the ratio R_0. For the case of π decays these have been carefully calculated and are well known [8,9]. A complete calculation of analogous radiative corrections for $D_S^\pm$ decays is yet to be done. It is expected that these corrections would be in the range of 2 to 4%. This will modify the bound on ν_τ mass. To extract a meaningful limit on the mass of ν_τ it will be necessary to have the radiative corrections to the value of R available.

One can also compare inclusive decay rates, rather than the exclusive modes above. The ratio

$$R_{\mu,\tau} = \frac{\Gamma(D_S^\pm \to \tau\nu_\tau + D_S^\pm \to \tau\nu_\tau\gamma)}{\Gamma(D_S^\pm \to \mu\nu_\mu + D_S^\pm \to \mu\nu_\mu\gamma)} \tag{5}$$

is free from any dependence on energy resolution and for a point-like $D_S^\pm$ the expression is as given in [10]. This gives a correction of 2.4% in the direction of increasing the tau branching ratio. In both cases, it would be desirable to have an estimate of the remaining structure dependent corrections, although we believe that they would not be larger than the effects already included here.

Similar considerations can be applied to the decays of D^+ as well. However, the rates in that case are suppressed by the CKM suppression as well as phase-space, and the branching ratios are smaller than for D_S decays by an order of magnitude or more. This make D^+ unsuited for extracting mass limits on the tau neutrino.

3. Experimental status

The current status of leptonic branching ratios of interest are compiled in Table 1. As can be seen, all

Table 1
Summary of the available experimental leptonic branching ratios of $D_S^\pm$. Branching ratios are given in per cent

Experiment	Channel	BR
WA75 [12]	$D_S \to \mu$	$0.4^{+0.18+0.20}_{-0.14-0.19}$
BEATRICE [13]	$D_S \to \mu$	$0.83 \pm 23 \pm 0.06 \pm 0.18$
BES [14]	$D_S \to \mu$	$1.5^{+1.3+0.3}_{-0.6-0.3}$
ALEPH [15]	$D_S \to \mu$	$0.68 \pm 0.11 \pm 0.18$
L3 [16]	$D_S \to \tau$	$7.4 \pm 2.8 \pm 2.4$
ALEPH [15]	$D_S \to \tau$	$5.79 \pm 0.76 \pm 1.78$
OPAL [17]	$D_S \to \tau$	$7.0 \pm 2.1 \pm 2.0$

measurements still have large errors. Taking the PDG values [11] implies $R = 12.5 \pm 5.5$, clearly not allowing any conclusions on m_{ν_τ}. However, recently there have been improvements in investigations of $D_S^\pm$ decays at LEP. Using the branching ratio values of ALEPH [15] a ratio of $R = 8.5 \pm 5.2$ can be obtained, unfortunately still having a much too large an error for the purpose at hand. The situation might be improved by producing a clean and statistically large sample by looking at diffractive $D_S^\pm$ production in antineutrino–nucleon scattering at a neutrino factory [18] or accurate measurements at the planned CLEO-c charm factory [19]. For the latter an accuracy on both branching ratios of 4% is predicted. If we assume that the central values remain the same as obtained by ALEPH this would imply a value of $R = 8.5 \pm 0.5$, which is significantly away from R_0. The accuracy in R, of about 6%, would be a great improvement over the current one, but still not quite at the level needed to get improved bounds on the ν_τ mass, which calls for a level of less than 1%.

4. Summary

We discuss the possibility of gaining information on the mass of the tau neutrino by investigating leptonic $D_S^\pm$ decays. An improvement on the m_{ν_τ} down to 10 MeV is possible if the ratio of muonic and tauonic $D_S^\pm$ decays can be measured with an accuracy of 0.1%. While current data do not allow to draw any conclusions, this might change in future experiments especially by using a charm factory. We emphasize the importance of having a calculation of the radiative corrections available in anticipation of a future improvement in the measurement of these branching ratios.

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