Possible improvements on the mass of $\nu_\tau$ using leptonic $D^\pm_s$ decays

S. Pakvasa and K. Zuber

Department of Physics and Astronomy, University of Hawaii, Honolulu, HI
Denys Wilkinson Laboratory, University of Oxford, Keble Road, Oxford, OX1 3RH

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 $\nu_\tau$ which is known from ALEPH to be smaller than 18.2 MeV [4]. In this paper we explore leptonic $D^\pm_s$ decays for improving on the bound of $\nu_\tau$.

2 Leptonic $D^\pm_s$ decays

In the standard model the leptonic branching ratios of $D^\pm_s$ are given as

$$BR(D^\pm_s \to l\bar{\nu}_l) = \frac{G_F^2}{8\pi} | V_{cs} |^2 f_{D^\pm_s}^2 \tau_{D^0_s} m_{D^0_s} m^2_l F(1 - \frac{m^2_l}{m^2_{D^0_s}})^2$$ (1)
with $V_{cs}$ is the corresponding CKM matrix element, $\tau_{D_s}$ 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 $\nu_\tau$ mass [5]. Neglecting the muon neutrino mass to first approximation, the ratio between muonic and tauonic decays can be parametrised as a function of $\nu_\tau$ mass to first order in $m_{\nu_\tau}$

$$R = \frac{(D_{S}^{\pm} \rightarrow \tau \nu_\tau)}{(D_{S}^{\pm} \rightarrow \mu \nu_\mu)} = R_0(m_\nu = 0) \times \left(1 - C\frac{(m_{\nu_\tau})^2}{m_\tau} \right)$$

(2)

$R_0$ is obtained as

$$R_0(m_\nu = 0) = \frac{m_\tau^2}{m_\mu^2} \frac{\left(1 - \frac{m_\tau^2}{m_{D_{S}^{\pm}}} \right)^2}{\left(1 - \frac{m_\mu^2}{m_{D_{S}^{\pm}}} \right)^2} = 9.79$$

(3)

$C$ is given by

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

(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 $m_{\nu_\tau}$ is plotted in Fig.1. As expected, the figure shows that the ratio decreases as the mass of $\nu_\tau$ is increased. Furthermore, it follows from Eq. 4 that to improve the bound on $m_{\nu_\tau}$ 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 $\pi$ decays these have been carefully cal-
Fig. 1. The ratio $R$ defined in Eq.(2) as a function of the mass of $\nu_\tau$. The existing upper bound on $m_{\nu_\tau}$ obtained by ALEPH is 18.2 MeV. No radiative corrections are included. For details see text.

culated 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 $\nu_\tau$ mass. To extract a meaningful limit on the mass of $\nu_\tau$ 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

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

(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 makes $D^+$ unsuited for extracting mass limits on the tau neutrino.

3 Experimental status

The current status of leptonic branching ratios of interest are compiled in Tab. 1. As can be seen, all measurements still have large errors. Taking the PDG values [11] implies $R = 12.5 \pm 5.5$, clearly not allowing any conclusions on $m_{\nu_{\tau}}$. 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 $\nu_{\tau}$ 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 $m_{\nu_{\tau}}$ 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
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]   | $D_s \rightarrow \mu$ | $0.4^{+0.18+0.20}_{-0.14-0.19}$ |
| BEATRICE[13]| $D_s \rightarrow \mu$ | $0.83 \pm 23 \pm 0.06 \pm 0.18$ |
| BES[14]    | $D_s \rightarrow \mu$ | $1.5^{+1.3+0.3}_{-0.6-0.3}$ |
| ALEPH[15]  | $D_s \rightarrow \mu$ | $0.68 \pm 0.11 \pm 0.18$ |
| L3[16]     | $D_s \rightarrow \tau$ | $7.4 \pm 2.8 \pm 2.4$ |
| ALEPH[15]  | $D_s \rightarrow \tau$ | $5.79 \pm 0.76 \pm 1.78$ |
| OPAL[17]   | $D_s \rightarrow \tau$ | $7.0 \pm 2.1 \pm 2.0$ |

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.

Acknowledgements

We are thankful to J. Link, W. Marciano and the referee for useful discussions and critical comments. K. Zuber is supported by a Heisenberg Fellowship of the Deutsche Forschungsgemeinschaft.

References

[1] K. Zuber, Phys. Rep. 305, 295 (1998); S. M. Bilenky, C. Giunti, W. Grimus, Prog. Nucl. Part. Phys. 43, 1 (1999).
[2] C. Weinheimer, Talk presented at Neutrino 2002, Munich, to appear in the Proc.
[3] K. Assamagan et al., Phys. Rev. D 53, 6065 (1996).
[4] R. Barate et al., Eur. Phys. J. C 2, 395 (1998).
[5] M. P. Rekalo, JETP Lett. 27, 555 (1978).
[6] A. Halprin, S. T. Petcov, S. P. Rosen, Phys. Lett. B 125, 335 (1983).
[7] K. Zuber, *Phys. Rev.* D 56, 1816 (1997).

[8] S. M. Berman, *Phys. Rev. Lett.* 1, 468 (1958); T. Kinoshita, *Phys. Rev. Lett.* 2, 477 (1959).

[9] R.E. Marshak, Riazuddin, C.P. Ryan *Theory of weak interactions in particle physics*, J. Wiley and Sons, 1969.

[10] W. J. Marciano and A. Sirlin, *Phys. Rev. Lett.* 71, 3629 (1993).

[11] K. Hagiwara et al. *Phys. Rev.* D 66, 010001 (2002).

[12] S. Aoki et al., *Prog. Theo. Phys.* 89, 131 (1993).

[13] Y. Alexandrov et al., *Phys. Lett.* B 478, 31 (2000).

[14] J.Z. Bai et al., *Phys. Rev. Lett.* 74, 4599 (1995).

[15] A. Heister et al., *Phys. Lett.* B 528, 1 (2002).

[16] M. Acciari et al., *Phys. Lett.* B 396, 327 (1997).

[17] G. Abbiendi et al., *Phys. Lett.* B 516, 236 (2001).

[18] G. De Lellis, P. Migliozzi, P. Zucchelli, *Phys. Lett.* B 507, 7 (2001).

[19] R. A. Briere et al., CLNS-01-1742, 2001.